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Exploring transparent approaches to the authentication of signatures on artwork

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to my parents,

Glossary

ACE-V	Analysis, Comparison, Evaluation - Verification
ASTM	American Society for Testing and Materials
GC/MS	Gas Chromatography Mass Spectrometry
CICP	Complex Inorganic Color Pigments
CO	Code des Obligations
FDE	Forensic Document Examiner
FHE	Forensic Handwriting Examiner
FTIR	Fourier Transform Infrared Spectroscopy
ICAI	International Center for Art Intelligence
ICOM	International Council of Museums
IFAR	International Foundation of Art Research
LC/MS	Liquid Chromatography Mass Spectrometry
LD/MS	Laser Desorption Mass Spectrometer
LR	Likelihood ratio
PT	Proficiency Testing
Pyrolysis-GC/MS	Pyrolysis - Gas Chromatography Mass Spectrometry
SEM	Scanning Electron Microscopy
UV	Ultraviolet
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

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Aims of this thesis

This thesis is composed of three main parts. The first consists of a state of the art of the different notions that are significant to understand the elements surrounding art authentication in general, and of signatures in particular, and that the author deemed them necessary to fully grasp the microcosm that makes up this particular market. Individuals with a solid knowledge of the art and expertise area, and that are particularly interested in the present study are advised to advance directly to the fourth Chapter. The expertise of the signature, it's reliability, and the factors impacting the expert's conclusions are brought forward. The final aim of the state of the art is to offer a general list of recommendations based on an exhaustive review of the current literature and given in light of all of the exposed issues. These guidelines are specifically formulated for the expertise of signatures on paintings, but can also be applied to wider themes in the area of signature examination.

The second part of this thesis covers the experimental stages of the research. It consists of the method developed to authenticate painted signatures on works of art. This method is articulated around several main objectives: defining measurable features on painted signatures and defining their relevance in order to establish the separation capacities between groups of authentic and simulated signatures. For the first time, numerical analyses of painted signatures have been obtained and are used to attribute their authorship to given artists.

An in-depth discussion of the developed method constitutes the third and final part of this study. It evaluates the opportunities and constraints when applied by signature and handwriting experts in forensic science.

A brief summary covering each chapter allows a rapid overview of the study and summarizes the aims and main themes of each chapter. These outlines presented below summarize the aims and main themes addressed in each chapter.[1]

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1 Each chapter comprising the state of the art is presented to the reader with the key elements necessary for the understanding of the given chapter and its relationship with the thesis. In this sense, the reader can, depending on his background, jump chapters without losing the common theme of the work.

Part I - Theory

Chapter 1 exposes legal aspects surrounding the authentication of works of art by art experts. The definition of what is legally authentic, the quality and types of the experts that can express an opinion concerning the authorship of a specific painting, and standard deontological rules are addressed. The practices applied in Switzerland will be specifically dealt with.

Chapter 2 presents an overview of the different scientific analyses that can be carried out on paintings (from the canvas to the top coat). Scientific examinations of works of art have become more common, as more and more museums equip themselves with laboratories, thus an understanding of their role in the art authentication process is vital. The added value that a signature expertise can have in comparison to other scientific techniques is also addressed.

Chapter 3 provides a historical overview of the signature on paintings throughout the ages, in order to offer the reader an understanding of the origin of the signature on works of art and its evolution through time. An explanation is given on the transitions that the signature went through from the 15th century on and how it progressively took on its widely known modern form. Both this chapter and chapter 2 are presented to show the reader the rich sources of information that can be provided to describe a painting, and how the signature is one of these sources.

Chapter 4 focuses on the different hypotheses the FHE must keep in mind when examining a painted signature, since a number of scenarios can be encountered when dealing with signatures on works of art. The different forms of signatures, as well as the variables that may have an influence on the painted signatures, are also presented. Finally, the current state of knowledge of the examination procedure of signatures in forensic science in general, and in particular for painted signatures, is exposed. The state of the art of the assessment of the authorship of signatures on paintings is established and discussed in light of the theoretical facets mentioned previously.

Chapter 5 considers key elements that can have an impact on the FHE during his or her[2] examinations. This includes a discussion on elements such as the skill, confidence and competence of an expert, as well as the potential bias effects he might encounter. A better understanding of elements surrounding handwriting examinations, to, in turn, better communicate results and conclusions to an audience, is also undertaken.

Chapter 6 reviews the judicial acceptance of signature analysis in Courts and closes the state of the art section of this thesis. This chapter brings forward the current issues pertaining to the appreciation of this expertise by the non-forensic community, and will discuss the increasing number of claims of the unscientific nature of signature authentication. The necessity to aim for more scientific, comprehensive and transparent authentication methods will be discussed.

The theoretical part of this thesis is concluded by a series of general recommendations for forensic handwriting examiners in forensic science, specifically for the expertise of signatures on paintings. These recommendations stem from the exhaustive review of the literature and the issues exposed from this review and can also be applied to the traditional examination of signatures (on paper).

Part II - Experimental part

Chapter 7 describes and defines the sampling, extraction and analysis phases of the research. The sampling stage of artists' signatures and their respective simulations are presented, followed by the steps that were undertaken to extract and determine sets of characteristics, specific to each artist, that describe their signatures. The method is based on a study of five artists and a group of individuals acting as forgers for the sake of this study. Finally, the analysis procedure of these characteristics to assess of the strength of evidence, and based on a Bayesian reasoning process, is presented.

Chapter 8 outlines the results concerning both the artist and simulation corpuses after their optical observation, followed by the results of the analysis phase of the research. The feature selection process and the likelihood ratio evaluation are the main themes that are addressed. The discrimination power between both corpuses is illustrated through multivariate analysis.

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[2] Masculine gender is used throughout this thesis for purposes of clarity and readability, and refers to both men and women.

Part III - Discussion

Chapter 9 discusses the materials, the methods, and the obtained results of the research. The opportunities, but also constraints and limits, of the developed method are exposed. Future works that can be carried out subsequent to the results of the study are also presented.

Chapter 10, the last chapter of this thesis, proposes a strategy to incorporate the model developed in the last chapters into the traditional signature expertise procedures. Thus, the strength of this expertise is discussed in conjunction with the traditional conclusions reached by forensic handwriting examiners in forensic science. Finally, this chapter summarizes and advocates a list of formal recommendations for good practices for handwriting examiners.

In conclusion, the research highlights the interdisciplinary aspect of signature examination of signatures on paintings. The current state of knowledge of the judicial quality of art experts, along with the scientific and historical analysis of paintings and signatures, are overviewed to give the reader a feel of the different factors that have an impact on this particular subject. The temperamental acceptance of forensic signature analysis in court, also presented in the state of the art, explicitly demonstrates the necessity of a better recognition of signature expertise by courts of law. This general acceptance, however, can only be achieved by producing high quality results through a well-defined examination process.

This research offers an original approach to attribute a painted signature to a certain artist: for the first time, a probabilistic model used to measure the discriminative potential between authentic and simulated painted signatures is studied. The opportunities and limits that lie within this method of scientifically establishing the authorship of signatures on works of art are thus presented. In addition, the second key contribution of this work proposes a procedure to combine the developed method into that used traditionally signature experts in forensic science. Such an implementation into the holistic traditional signature examination casework is a large step providing the forensic, judicial and art communities with a solid-based reasoning framework for the examination of signatures on paintings. The framework and preliminary results associated with this research have been published (Montani, 2009a) and presented at international forensic science conferences (Montani, 2009b; Montani, 2012).

PART I - THEORY

Introduction

The domain of art authentication and the determination of authorship is extremely vast, requiring solid notions in art history and culture, analytical chemistry, and languages. One must be a connoisseur of the artist, of his techniques and his lifestyle, but must also possess an extensive knowledge of specific art periods and therefore of the material at the artist's disposal. The aim of this section is to help the reader understand why a forensic expert could be concerned by a work of art, his role and possible contributions in the authentication process. Before these issues can be addressed, the author wishes to define the different terms in relation to paintings from a forensic science perspective.

The different aspects pertaining to the authentication of paintings will be exposed and discussed. The first aspect is the quality of the experts that can rightfully and judicially express an opinion concerning the authorship of a specific painting. The second aspect that will be discussed is an overview of the different scientific analyses that can be carried out on paintings, and the added value that a signature expertise can have in comparison to other scientific techniques. A historical overview of the signature on paintings is given, in order to offer the reader an understanding of the origin of the signature on works of art and its evolution through time. The state of the art of the assessment of the authorship of signatures on paintings will then be established and discussed in light of the theoretical facets mentioned previously. A review of the acceptance of signature analysis in common law Courts is then presented. This chapter will bring forward the current issues pertaining to the appreciation of this expertise by the non-forensic community, and will discuss the increasing number of claims regarding the unscientific nature of signature authentication.

The theoretical chapters of this thesis will give the reader an understanding of the role the signature plays or can play in the authentication of a work of art, a testament of an artwork's originality and its authenticity. The rationale surrounding this inscription is manifold, and will be thoroughly discussed in these following chapters. Undeniably, art does not only interest artists, but also, and even more importantly, the people that revolve around the artist: art merchants, experts, collectors and buyers (Chatelain, 1982). These protagonists, their interests and the stakes involved will also be exposed in the following chapters.

The final aim of the state of the art is to offer the reader with a number of recommendations regarding the forensic expertise of signatures on paintings, but also the expertise of signatures in general. These guidelines stem from the disparities observed throughout the exhaustive literature review in the field of forensic examination of signatures on paintings, and aim at addressing these shortcomings through logical and easily implementable recommendations.

1 Legal aspects concerning art experts

This chapter aims to explain the different actors of the authentication process of works of art. Indeed, there is no single individual responsible for this task, but a range of people that emanate from different fields, all working towards the same common goal: to authenticate the works of an artist, or, on the contrary, to bring to light possible fakes.[3] The role of these different persons will be reviewed, followed by a summary of their legal rights and implications. Before looking at the types of experts that exist the concept of authenticity will be discussed, as it forms the basis of the expert examination.

1.1 Authenticity

These questions are inscribed in the general attribution effort that started in the 19th century in the art history discipline. From the moment the artists asserted the authorship of their paintings,[4] the quest to determine the said authorship has been continuous. Since, there has been an increasing societal tendency to put a label on and authenticate works of art, according to some in order to better protect works in the name of artist protection laws (Noce, 2003). Of course, the monetary implications in this area are enormous, and play a great role in the increasing need to authenticate items of art.

Before diving into the notions surrounding the authenticity of a work of art, a definition of this concept is necessary. By definition, authenticity is "what is genuinely of the author to whom we attribute it"[5] (Jornod, 2007b, p. 8). If the contents of this citation are broken down, two key elements can be highlighted. The first is the genuineness of the author, which at first glance seems obvious, but in fact can be quite subtle. Indeed, a painting can have several authors who could rightly claim paternity. It is well known that

3 The term "fake" is preferred to "forgery", because the latter does not imply a will to deceive. Fakes consist of art objects carried out in the style or manner of a certain artist that are passed off deliberately as being from the hand of the said artist. Forgeries, on the other hand, are "replicas of genuine pieces, which are either deliberately created to deceive or else innocently created but later passed off as original works of the famous artists" (Karlen, 1988, p. 220).

4 Generally since the Romantic period - see Chapter 3. During the 18th century, the art merchants carried out the expert role (Moulin, 2009).

5 Free translation from Jornod (2007b, p. 8): "Par définition, l'authenticité est ce qui est véritablement de l'auteur auquel on l'attribue".

certain Masters used apprentices and disciples to prepare the canvases, the base layers, or even paint most of the painting, to only add the final touches themselves.[6] Likewise, some artists claimed paternity of works that were not of their hand, as favours to friends or as a method of payment. Per contra, as mentioned by Lequette-de Kervenoaël (2006), artists also hid or disclaimed the paternity of their work, either because they were exclusively linked to a gallery or as a method of vengeance or retaliation towards the owner of the work of art whom they disliked.

The second definitional element to be specified is this "we" that detains the authority to "attribute" the authorship of a painting. This is, in principle, the expert's task. Indeed, a work of art is not by nature authentic, it only takes on this attribute once an expert has certified that it indeed possesses the expected qualities. The qualities thus linked to the question of authenticity of an item of art must be selected, and the person carrying out this selection defined.

Taking into account the subtleties presented above, a broader definition of the notion of authenticity can be proposed at this stage. Duret-Robert (2013), in his extremely complete volume on Art Market Law, proposes the following definition of authenticity: "a work of art is authentic when it indeed possesses the qualities, taking the attributes presented into account, that are considered by the experts to be essential in this type of work".[7]

The Courts consider the authenticity of a painting to be associated with the attributed author. And not having this authorship, or if there is a change in the attributed author, the sale, for one, can be cancelled. The art collector is, of all types of collectors, the one that is most confronted with problems pertaining to fakes and forgeries, because of the "sheer number of inauthentic art objects in the marketplace" (Karlen, 1988, p. 220). The lack of authenticity is also the main reason, and by far, that leads buyers to cancel the sale of an item of art in France (Duret-Robert, 2013), although the case is very likely to be true worldwide as well.

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6 The concept of authenticity as understood today was practically insignificant for works of art carried out in certain periods. The explanation as to why paintings are not signed is explained in Chapter 2.

7 Free translation of Duret-Robert (2013, p. 309): "une œuvre d'art est authentique lorsqu'elle possède effectivement les qualités qui, compte tenu de la présentation qui en est faite, sont considérées par les connaisseurs comme essentielles dans ce type d'œuvres".

The expert can use different methods to establish the authenticity of a work of art, and determine its value.[8] Lemoine (1992) summarizes the role of the experts and the types of analysis that can be carried out on a piece of art, which can be of a technical, stylistic, historical or scientific nature. The first type of analysis examines the work in general. The type of support and material that was used, as well as the state of conservation of the work is determined. The second analysis consists in examining the style and manner of painting of a certain artist, and comparing these aspects with the complete (or most complete possible) known corpus of the artist. In principle, this task can only be carried out by an experienced "eye", who examines different elements such as the composition, the technique, the style, the colors, and drawings, whose characteristics can be signs of authenticity or inauthenticity of a work. The historical analysis retraces the history of the work, which hands it touched, and if there is an interruption in its "line of custody". The final aspect is the scientific one, which analyses the different components of a work of art, from the support to the top varnish layer. This type of analysis has the advantage, contrary to the other three cited above, of being measurable (Lemoine, 1992). As Buquet and Hellebranth stated (1986, p. 247), "often, the expertise of paintings is based only on a partly subjective appreciation, without a scientific test".[9] Chapter 2 is devoted to this aspect.

The legal residence of an artist usually determines the law of his rights and those of his heirs and legatees. Since so many artists lived in France in the 19th and 20th centuries, French law has a great influence over international art law (Reeves, 2006). Likewise, Switzerland had held a leading role in the sales of art in the past fifty years, pushing the country to legislate in art law.[10] The first office that Christie's inaugurated outside Great Britain was in Geneva in 1968, followed shortly by Sotheby’s in Zürich in 1969 (Clerc, 2011).

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[8] The notion of authenticity and value are indissociable, since the authenticity of the work gives it its value. A painting that is re-attributed to a less famous author can lose up to most of its value. The famous statement made my H.E. Huntington in 1913 on a painting by Romney represents the "quasi absolute principle" found in the art market today: "If it's a Romney, I wouldn't give it up for all the gold in the world. If it's not a Romney, I don't want it at any price" (Duret-Robert, 1975, p. 4).

[9] Free translation of Buquet and Hellebranth (1986, p. 247): "Bien souvent, l’expertise des tableaux repose uniquement sur une appréciation en partie subjective, sans contrôle scientifique".

[10] The start was rather slow in this matter according to Ruoss (1988, p. 284) who stated in 1988 that "the legal aspects of art auctions have been virtually neglected by Swiss layers".

Switzerland's history in auction sales is quite young in comparison to other countries such as France and England. The country has nonetheless become a popular site for auction for numerous reasons: the location in the heart of Europe, political stability, and the strong financial marketplace (Ruoss, 1988). Switzerland also offers fiscal advantages, including the presence of port francs in Geneva and Basel, which have greatly contributed in Switzerland's popularity. Moreover, the traditionally French Artist Resale Right [11] concerning original works of art was generalized to the European Union on December 31st 2011 (Adam, 2012). Switzerland, having not ruled on this law, has increased its attractiveness as a selling venue, on top of fiscal differences advantages (Guex, 2002). See Stankiewicz (2012) for a comparative chart of the different taxation laws in effect in the main countries established in art sales. Because of the large amount of sales,[12] Switzerland has become a central point in the global market where questions regarding authenticity of items of art is frequent.

1.2 Types of experts

The definition of an expert is not univocal. Rather provokingly, Ferré, in his *Lettre ouverte à un amateur d'art pour lui vendre la mèche* stated that "All those who settle, decide, decree, deem, stop, order or forbid in art, call them an expert".[13] Although some may still feel that this is an accurate description of the reality of the art world,[14] a more precise definition can be proposed.

From a legal point of view, the expert can be classified in a number of different groups, according either to their fields of activities, their expert mission, their education, or if they work in the private or public area. Each facets of the expert will be presented here in a general perspective,[15] all while

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11 The "droit de suite" right was created in France in 1920, and is henceforth applicable to living artists and artists deceased under 70 years ago.

12 Switzerland ranks in the top five countries for art exports and imports (Guex, 2011).

13 Free translation of Ferré (1975, p. 35): "Tous ceux qui tranchent, décident, décrètent, jugent, arrêtent, ordonnent ou interdisent en art, qualifiez-les d'experts".

14 Chatelain and his colleagues state that the expert profession is characterized in France by an absence of status. Anyone can legally auto-proclaim oneself expert of art (Chatelain *et al.*, 1997). See Chapter 1.4 for more information on this subject.

15 The expert-appraiser, whose task is to determine the value of a work of art, will not be broached in the frame of this work.

noting, when possible, the specificities that can be found in different countries. The different expert groups are presented in the following sub-chapters.

1.2.1 Classification according to the fields of activity

The expert generally has another job occupation, usually in the art field, which has led him to gather the necessary knowledge, experience and artistic culture to conduct this duty. His expertise and competence is linked to the recognition held by his peers (Lequette-de Kervenoaël, 2006).

Duret-Robert (2007, pp. 32-33) classifies the different types of experts according to their 'respective fields of activities':

- The generalist, being a specialist of a period or artistic movement rather that of a specific artist, has a wide area of competence. According to Duret-Robert, these are the experts that should be contacted when trying to authenticate a work of art because they assess and value them on a regular basis. These could be, for example, auctioneers or experts of auction houses, customs and insurance companies experts,[16] court experts specialized in art law, etc.
- The specialists, who are principally authors of 'catalogues raisonnés', museum curators[17] and merchants, are experts of a limited number of artists. Museum curators are highly recognized in France as art experts, since their function is regulated by entrance examinations: "Expertise led by a curator offers therefore a very important guarantee of authenticity when it relates to an object directly under his specialty". [18] Art merchants, on top of delivering certificates of authenticity for works of art that they are selling (sometimes as private requests) also estimate the monetary value of the work of art. Chatelain *et al.* (1997) mention the academician as a resourceful

16 These types of experts usually evaluate the value of the objects but do not deliver a judgment on its authenticity (Jornod, 2007a, p. 13).

17 For countries that are members of the International Council of Museums (ICOM), such as Switzerland, museum curators are not allowed to expertise (or acquire) works of art (regulated by the ICOM Code of Ethics).

18 Free translation of Lequette-de Kervanoaël (2006, p. 169): "L'expertise menée par un conservateur présente donc une garantie d'authenticité très importante lorsqu'elle porte sur un objet relevant directement de sa spécialité".

expert. They are usually called on to help in judicial cases, as they constitute, in principle, a neutral reference. Likewise, they rarely offer an opinion for private or public sales, contrarily to the Anglo-Saxon customs (Lequette-de Kervenoaël, 2006). Authors of 'catalogues raisonnés' do not have or necessitate a specific background; they gain their status of an expert by peers, who review and validate their work and knowledge (Malvoisin, 2011).

- The heirs of an artist claim to detain the right to "rule on the authenticity of a piece without appeal".[19] Duret-Robert raises an objection against these types of experts, who, as bearers of only a moral right[20] of the works of an artist,[21] do not legally possess the power to authenticate them.[22] In French law, however, they do have the prerogative to launch legal proceedings to determine the authenticity of a work, known as a "saisie-contrefaçon" (Lucas and Lucas, 2001; Reeves, 2007).[23] These legal proceedings originate from the 1957 French Law,[24] which guarantees the heirs of the moral and patrimonial rights of the artist to be able to force the police to seize questionable works of art. This seizure can be carried out without any proof of inauthenticity, and its only aim is to launch a judicial procedure that designates qualified experts to judge the work's authenticity (Duret-Robert, 1990). The practice, however, has taken a turn from the theory. Heirs have diverted this prerogative into a right to authenticate works of art of their ancestors. This transformation of the moral rights of the heirs is logical: imagine an art merchant that discovers a work of art from a certain artist, and believes that it is authentic. By having the legal heir certify that the work of art is actually by the artist, for example his grandfather, the art merchant understands this

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19 Free translation of "le droit de décider souverainement de l'authenticité de ces œuvres".

20 The moral rights comprise the five following rights: (1) the right to create (2) the right of disclosure and completeness (3) the right to withdraw (4) the right of paternity (5) the right of integrity (Reeves, 2006).

21 In theory, the moral right of an artist is perpetual. But, after the death of an artist, only the rightful heirs can exercise this right. Likewise, an artist can exercise these rights, even in the absence of ownership of his work.

22 In French law, a professional (for example an art merchant) can even be considered to be at fault if he regards an authenticity certificate from an heir as sufficient evidence of authenticity (Lequette-de Kervenoaël, 2006).

23 The heir of the moral right of an artist possesses the right to launch a "saisie-contrefaçon", literally an counterfeit-seizure.

24 Loi du 11 mars 1957, Article 19.

certification as a guarantee that the heir will not seize the work of art and "acts as a insurance contract against the seizure risk" (Duret-Robert, 1990, p. 125). One can only imagine the effects of such a law, particularly since the need for justification is not necessary. Contrarily to an expert, who must support his conclusions, an heir need only hint at the idea that a work of art is inauthentic to cause drastic consequences in the art market (bearing in mind that these hints have absolutely no judicial impact, and for example are not enough to invalidate a sale).[25] As Duret-Robert states (1990, p. 133), "Judges are here to limit damages. They do not recognize the verdict right of the heirs, a limitless decision-making power. [...] they actually do not recognize any decision-making power [on their part]".[26] Indeed, judges consider it as a professional fault to think that an heir's certificate is a sufficient guarantee of a work's authenticity. Unfortunately, even if judges will give more weight to an expert testimony than to an heir's testimony, the damage is usually done by the time the case reaches Court. Recently though, French jurisprudence has given less and less weight to the heirs of artist in the authentication process (Duret-Robert, 2013).

- Chatelain *et al.* (1997) propose another category of experts: The "connoisseurs", who are essentially persons that gravitate around the art market (as a hobby, an occupation or by passion for an artist), but are not directly employed in one way or another by it. They are the persons who cannot be put into another category.

1.2.2 Classification according to the expert mission

Jornod (2007a, p. 13) states that the duty of an expert varies accordingly to the expert mission[27] that is given to him. This definition of the expert is linked more accordingly to the market. Jornod is one of the few authors who cited

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[25] For example the dispute between Mrs Léger, and E. David, an art merchant: the first had two gouaches in David's possession declared as inauthentic, and had the works seized by the police (publically). Experts and counter-experts were called on, and they all declared the works as authentic Léger (Duret-Robert, 1990).

[26] Free translation of "les juges sont là pour limiter les dégâts. Car, aux héritiers, ils ne reconnaissent pas un droit de verdict sans appel, un pouvoir de décision sans limites. [...] ils ne leur reconnaissent aucun pouvoir de décision".

[27] An "expert mission" is seen here as a commission by which a party is entrusted to perform a service and give its views or opinions. This term will be used throughout the rest of this study.

scientists, who carry out chemical and spectroscopic analyses on the different materials of the work, as a type of art expert.

Certain experts are indexed in pre-approved lists, and are called on depending on the nature of the expertise. For example judicial or custom officials can be requested to establish either the author of a work or its monetary value. The same can be said for insurance experts.

The expert mission can also be differentiated according to the payment that the expert receives. Experts appointed to judicial cases usually work for a fee.[28] In this case, the expert report must be motivated and based on extensive research. However, experts working outside the judiciary system either work for a fee or at no cost. In the first case, the amount of the fees is to the discretion of the expert. They either calculate their fee as a percentage of the total value of the work, or practice a fixed fee. Although one could question the independence of an expert that is remunerated in this manner, this practice is still current in the art community (Thévenoz, 1992; Lequette-de Kervenoaël, 2006). An even more questionable practice is when the expert is also an art merchant, and thus directly profits from his attributions. This contentious practice is brought up by a number of authors (Byrne-Sutton and Renold, 1992; Assouline, 1999; Lequette-de Kervenoaël, 2006).

1.2.3 Classification according to private versus public origin

Lemoine (1992) distinguishes experts according to a third characteristic: whether they are private or public experts. The first (who can be generalists, specialists or heirs) deliver certificates of value and authenticity of works of art to anyone needing their expertise (such as a private owner, auction houses or merchants).

On the other hand, museum curators and professionals of the educational system (such as university professors) are experts active in the public domain. Their activity is more oriented towards the authentication of works belonging to a museum or works a museum wishes to acquire, and furthermore to "study the works of public collections, establish their catalogue, verify their attributions and determine their authenticity".[29] In France, for example,

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[28] The amount of the fees is either set by the magistrates, as it is the case in France, or by the expert himself.

[29] Free translation from Lemoine (1992, p. 69): "Le travail [...] consiste à étudier les œuvres des collections publiques, à dresser leur catalogue, à vérifier leurs attributions et à déterminer leur authenticité".

museums curators are forbidden from carrying out private authentications or appraisals (Schmitt, 1996); their task consisting more of an academic function that defines a hierarchical order of the arts (Moulin, 2009).

The difference between private and public experts resides in the nature of the client and in the type of expert mission that is given. The first is commerce-orientated, while the second is carried out for the sake of advancing science and knowledge and bringing forth a historical contribution.[30]

1.2.4 Classification according to expert committees

The existence of this great variety of sources that can legitimately comment on the authenticity of a work of art has the obvious possible consequence of leading to conflicting opinions of the different commissioned experts (de Werra, 2007). Even though lists of possible experts exist, "for certain artists, there is in reality only one person (physical or moral) that is appointed by the market (and not the law) to decide on the authenticity of that artist's work with absolute power".[31] Committees of specialized institutions, which have either acquired the reputation and power to be the sole detainees of this right (by a positive recognition by fellow members or by auto-proclamation) or have been appointed by the artist himself, are known as "authentication boards". These boards are responsible for delivering certificates of authenticity and bringing to light existing fakes, and they often rely on their moral rights as a legitimization of this practice. It is important to highlight the fact that no one detains the judicial power to discretionarily rule on the authenticity of a work. The artist himself is no exception (de Werra, 2007).

The presence of these specialized boards and institutes has the disadvantage of creating monopoles, of which Jurnod (2007a) warns readers of.[32] These

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30 One might argue that the museum conservators do play a role in the art market, even though indirect: by opening up to new intellectual interests, the conservators also opens new interests of the market (Moulin, 2009).

31 Free translation from de Werra (2007, p. 105): "Les pratiques du marché de l'art démontrent toutefois que, pour certains artistes, il n'existe en réalité qu'une seule personne (physique ou morale) qui se voit reconnaître par le marché (et non par la loi) un pouvoir absolu pour se prononcer sur l'authenticité des œuvres".

32 Naturally, one might also argue that a number of specialized institutions are the most competent for a specific artist, having a panel of specialists working within the institution. One must also keep in mind and distinguish the quality of the different types of boards that exist (for example, a board of heirs versus a board of specialists).

institutions do not hesitate to apply and enforce their monopoly, and in reaction, Junod therefore proposes that, when debating on the authenticity of a work of art, a joint decision be made between an art historian, a law specialist, the beneficiaries, a scientist and a market specialist in order to avoid hegemony. Friedlaender (1944, p. 282) already stated the perverse effects of such a specialization: "Connoisseurship becomes more and more specialized, takes on the character of a mystery, so that even a highly regarded and experienced dealer can no longer say to his customers: 'I regard the picture as a work by Titian and assume the guarantee; there is no need for an expert opinion'. All these are circumstances which contribute to an increase in the power of the expert, and to the danger of misusing this power".

The art market is so febrile that if a renowned expert who detains the authority of the authenticity of a certain artist's works casts a doubt on a piece, it can immediately lose its value and even lead to the renunciation of its sale. These institutionalized boards do not even have to go so far as to cast a doubt on the authenticity of a work; a simple refusal to authenticate it can have just as disastrous consequences. The enforcement of a panel of experts would diminish such effects. Lemoine shares this view (1992), and rightly states: "The expert opinion has no value in itself. The work of the expert implies an expert consensus".[33] Even though it is the expert consensus that validates the expert opinion, one must keep in mind that this opinion is "fragile and temporary" (Moulin, 2009, p.23).

Likewise, since a certain stage of monopolization is or can be exerted by these institutionalized boards, a refusal to examine a work can be considered as unfair competition. Ringe (2007) enumerates the three types of experts that can usurp this monopoly: the first are authentication boards, described above, the second are non institutionalized expert groups, namely authors of catalogues raisonnés, and the third group are particular experts.

1.2.5 Classification according to professional organisations of art experts

In order to regulate and validate the knowledge and seriousness of their competencies, the experts of certain areas have grouped into professional organisations. Of course, each organisation, having a different aura, does not

[33] Free translation from Lemoine (1992, p. 71): "L'avis des experts n'a pas de valeur en soi. Le travail de l'expert suppose un consensus".

have the same criteria for being allowed into the initiated circle. In France, there are three major ones: the Syndicat français des experts professionnels, the Compagnie nationale des experts, and the Chambre nationale des experts spécialisés.[34] These three organisations, along with the Chambre belge des experts en œuvres d'art, make up the European Confederation of Art Experts (Duret-Robert, 1995). Membership is principally accepted by co-optation and based on past experience. To belong to one of these organisations gives the member the social recognition necessary to practice his profession, and is considered as a guarantee of the expert's competence. Likewise, in France an expert can be officially qualified to a Court.

1.3 Expert status

In the Swiss and French legal system, the status of an expert is neither protected nor controlled, and as a consequence, practically anyone can declare himself or herself an "art expert" (Chatelain *et al.*, 1997; de Werra, 2007). Numerous authors in Switzerland (Jornod, 2007a), France (Buquet *et al.*, 1992; Duret-Robert, 2007) and the United States (Byrne-Sutton and Renold, 1992) regret the fact that the title of art expert lacks legal regulation. Even if the title is not protected, once an expert, of whatever type he might be, "delivers a certificate of authenticity or describes a work in the catalogue of a public sale, he engages his own responsibility".[35] This is perfectly understandable: once someone delivers an opinion, he contractually implies that he is in the capacity to do so and therefore engages his responsibility with his opinion. To what extent this legal responsibility stretches is however somewhat imprecise. An inexhaustive list of possibilities where a party could ask for compensation for a wrongly assessed work of art are discussed by Chappuis (2007), who also addresses the legal aspects in reference to the responsibility of the expert towards his client, under Swiss law.[36]

The contract between a client and an expert falls in the domain of private law (Renold, 2010). This contract is referred to as a commission, and is defined by

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[34] None of these three organisations are officially recognized by public authorities (Moulin and Quemin, 1993). In 2013, these three organisations counted approximately 550 members (Duret-Robert, 2013).

[35] Free translation from Duret-Robert (2007, p. 34): "[...] lorsque l'expert délivre un certificat d'authenticité ou qu'il décrit une œuvre dans le catalogue d'une vente publique [...] il engage sa responsabilité".

[36] See also Thévenoz on this subject (1992).

the Code of Obligations (CO) as: "a contract where the commissioned person obliges himself, in the terms of the conventions, to handle the affairs for which he is hired or to render the services he promised".[37] This contract implies three characteristics (Thévenoz, 1992): a service to be accomplished, the independence (absence of subordination) of the expert, and the promise of a good and faithful execution of the commission. This last point is explicitly stated in Article 398 al. 2 of the CO.[38] Since the article does not specifically define what a good and faithful execution consists of, existing literature and jurisprudence have defined it as what can be reasonably expected by a client from a competent professional in the same situation (Thévenoz, 1992). For example, the Swiss Courts[39] held the expert of an auction house responsible for falsely estimating the price of a Gallé lamp on the basis of a description given over the phone and without giving any reserves. The estimation was given for a series article, when in fact the lamp was an original, and thus worth a great deal more (Renold, 2010).

Furthermore, the expert, exercising his competencies professionally, is doing so for a monetary counterpart (his responsibility diminishing if no remuneration is given). As such, the expert is obligated by the method and form of the expertise and cannot draw conclusions lightly. The responsibility of an expert (for example in the case of a mistaken conclusion) is also evaluated in accordance to his degree of specialization: his competencies (and thus the reason why he is hired) must measure up to his qualifications (Renold, 2010).

1.4 Deontological rules

As stated beforehand, the expert title is not protected, and many countries (except Germany) have avoided its regulation (Renold, 2010). Because of this absence of regulations of the expert title, the professional responsibility of the expert is not always clear (Ghestin, 1988). For these reasons, expert groups

[37] Article 394, al. 1 from the Swiss Code of Obligations. Free translation of "Le mandat est un contrat par lequel le mandataire s'oblige, dans les termes de la convention, à gérer l'affaire dont il s'est chargé ou à rendre les services qu'il a promis".

[38] Article 398, al. 2 from the Swiss Code of Obligations. Free translation of "Le mandataire est responsable envers le mandant de la bonne et fidèle exécution du mandat".

[39] ATF 112 II 347 = JdT 1987 128.

have proposed deontological rules. These rules ensure credibility on their parts, towards their peers as well as towards their clients and the general public.

The European Confederation of Art Experts states several essential rules to be followed by experts. It is applicable to all types of experts, independently of their area of expertise (Duret-Robert, 1995):

- Honesty rule: the expert must exercise his function in all honesty.
- Efficiency rule: the expert has the duty to stay up-to-date in his area.
- Fraternity rule: a fraternal relationship must be respected between all members of the same profession. They have the duty not to question the work of a colleague in front of a common client, etc.

As the title of expert is not legally protected, so are his fees. An expert, in the limits of market offer and demand, can freely define his rates. However, in France, some experts have kept the tradition[40] in which the fees of the expertise of an item of art are established according to fixed percentages. For example, the expertise of paintings and furniture dating from the 17th to 18th century cost 3% of the auction sale price, for stamps it cost 6 %, et cetera (Duret-Robert, 2013). Such practices are also found in other countries with a long tradition of auction sales. The deontological implications of this fee system can obviously lead to hasty conclusions given by an expert, who will be quicker at authenticating a work supposedly from a well-known artist rather than discarding it. Some authors (Okil, 2000) have also pointed out the contradictory notion of an art expert acting simultaneously as an art merchant (although on the decline), and the possible conflict of interest that can result from this double job.

Deontological guidelines have also been decreed on the manner in which an expert carries out the expert mission from a material point of view. The most common is working on original pieces and not on reproductions such as picture photographs (Stebbins, 2004; Endicott Barnett, 2006; Faunce, 2006; Ringe, 2007), following accepted methodological procedure of analysis that are accepted by the community of interest. Physical examination of a work of art also protects the expert against potential liability claims (Stern, 2006).[41]

[40] Until the 29th of March 1985, expert's fees were imposed by the "Chambre nationale des commissaires-priseurs".

[41] An interesting case cited by this author is Arheh v. Christie's International (Arheh v. Christie’s International, Index No 1030/86 (Supreme Court of the State of New York, 1986).

Unfortunately, many experts (and heirs) still issue certificates of authenticity based on photographs of the works of art.[42]

An interesting case on this subject is presented by Bresler (2007). She reports the case of Robert S. Fastov versus Christie's, Inc., a case that stretched over 15 years, and basically had stemmed from an expert opinion based on a photograph of a work. Fastov sued Christie's because it would not sell a Schindler painting without the certificate of authenticity from Dr. Frodl, the Schindler expert. Dr. Frodl however, would not deliver such certificate without having examined the original painting, and his decision was adamant. The transfer of the painting was at Fastov's expense, and he refused to pay, stating in the lawsuit that he had offered another valid expert to Christie's.[43]

Stebbins (2004, p. 139) insists on examining the original work, and "in difficult cases, to examine the object with a team". Spencer (2004) proposes guidelines and recommended procedures, based on court decisions, for experts authenticating works of art. He covers credibility issues, consensus of experts, and recommends careful visual inspection, particularly when determining authentication.

1.5 Expert Conclusions

Many expert conclusions are categorical in the sense that they state that a work of art is from the hand of a certain artist. The expert, however, should exercise caution when giving such conclusions, particularly when no reserves are given with the conclusion, because he could be held liable for any wrongful statements[44].

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[42] IFAR's catalogue raisonné survey (Flescher, 2006), answered by 90 respondents who had written or were in the process of preparing a catalogue raisonné, showed that for the question - Do you view/examine each work in person? - 22 of 86 respondents answered no (the other 64 yes). IFAR specifies out that this question was understood without the qualifying word "each".

[43] Auction houses, such as Christie's and Sotherby's, have their own experts that they have recourse for each artist (Sutton, 2006). According to Tancock (2006, p.41), there is literally "an 'expert' for nearly every artist".

[44] A example of expert liability in French Law is reported in the case of the Cour de cassations, 1ère civ., of April 3rd 2007, that states that an expert that attests of the authenticity of a work of art without giving reserve in his conclusions engages

Of course, the conclusions of the different experts do not have to be categorical (authenticated or not), but can be given with shades of grey. Experts often use the terminology proposed by the French decree n°81-255, dated the 3rd of March 1981,[45] which defines the formulations that can be used to define the link between a work of art and its author. This degree was created to clarify the rather unclear terminology used in the art market and thus protect buyers against tendentious terms used by unscrupulous sellers.

- The term: "from..." or "by...", followed by the name of the artist guarantees that the work is effectively from said artist. The formulation "signature of" also implies the same guaranty of authenticity. This article makes official a commonly adopted on principle (since the 19th century) that the presence of a signature implied that the author of the work was of the person that signed it (Lequette-de Kervenoaël, 2006).
- "Attributed to..." gives a certain doubt as to whether the artist in question is effectively the author of the painting. This term guarantees that the work was carried out during the period of production of the artist, and that he is, supposedly, the author.
- "From the workshop of..." means that the work effectively comes from the workshop of the artist in question or was done under his supervision.
- "From the school of..." implies that the author of the work of art was a student or disciple of the artist responsible of the school.
- Finally, the terms "in the style of...", "manner of...", "genre of...", etc. are all synonyms and confer no guarantee as the link between the author of the work and the mentioned artist or school.

The terminology employed in the authentication process can have consequential implication in the judicial system, as shown by the following case. The Prado brothers bought a painting at an auction sale labeled "from the workshop of Poussin" in 1984. When the painting was however recognized 10 years later as being an original Poussin, and not only from his workshop,

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his responsibility if at the time his conclusions seem misguided with the data at hand.

45 Décret n°81-255 du 3 mars 1981 sur la répression des fraudes en matière de transactions d'œuvres d'art et d'objets de collection, version consolidée au 1er octobre 2001 (www.legifrance.gouv.fr - Last consulted Oct. 2014).

the Prado brothers were ordered by the courts to return the painting to the older proprietor. This case illustrates how items of the art market are often considered as common consumer goods (Schmitt, 2003), and in particular how the label "authentic" or "fake" on a work can push the market price down by 99% (Duret-Robert, 1975), even though the work in itself remains unchanged. Indeed, as stated by Lequette-de-Kaervanoel, "there is no other good of such a strong economic value which is subject to fluctuations of this magnitude, because of one criterion that is uncertain and volatile".[46]

Even though an expert cannot always render categorical conclusions, it nonetheless lies upon the buyer to take all necessary steps and consult with experts on the authenticity of a work before buying it. The buyer must in this sense prove his good faith in his purchases. The fairly recent Swiss case[47] concerning a stolen Desportes painting illustrates this jurisprudence (Schmitt, 1997).

1.6 Conclusions

In conclusion, the role that an expert or a group of experts plays on the outcome of a work of art is primordial. An expert opinion can have a drastic influence on the position of a work on the art market and on the possibilities of its sale, according to Ringe (2007). This author summarizes the general situation extremely well by stating: "The art market is an extremely sensitive market, where the risk of a default of authenticity weights heavily and it is thus easy to understand the immense influence that an expert can have".[48] This issue raises the problem that one must turn to scientific data. Such data has the advantage of being independent from these experts, as well as overcoming their partial and possibly biased power. The next chapter will address the technical and scientific examinations that can be carried out on paintings.

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46 Free translation of "Il n'existe aucun autre bien qui, incluant en lui une valeur économique aussi forte, est soumis à des fluctuations d'une pareille ampleur en vertu d'un critère aussi incertain et volatile" (Lequette-de Kervenoaël, 2006, p. 259).

47 ATF 123 II 134 (dated April 29th 1997).

48 Free translation from Ringe (2007, p. 136) : "Le marché de l’art est un marché très sensible, le risque de défaut d’authenticité pèse lourd et l’on comprend ainsi aisément l’immense influence que peut avoir un expert".

2 Scientific examination of paintings

2.1 Introduction

Ever since the Romantic period, the quest to determine the author of a work of art has been a focus of art historians. This has been particularly difficult since up to that time, the author of the work was secondary, the artistic technique deemed most important. The object of the value has since shifted to the creative faculty of the author, as proved by the enormous price difference between a work of art from a Master and one from his workshop (Lequette-de Kervenoaël, 2006). The process of authenticating a work of art concerns a myriad of domains and facets. They can be carried out in accordance to historical references (iconography), by studying the stylistic nature of the work or it's technical aspects. All in all, the means to describe a painting are made up of rich sources of information, the signature being one of these many sources.

These practices, developed for establishing the authenticity of a piece, have been addressed by art specialists, experts and merchants for many years, and are largely referenced in the literature (Nobili, 1922; Friedländer, 1944; Jones, 1990). Chatelain *et al.* (1997) goes as far as to speak of types of proof. Again, the question if an expert can carry out this line of work is debated among authors (Chatelain *et al.*, 1997) and is an open question.[49] Since the stylistic authentication method requires a trained and experienced eye, how much of this said experience is necessary to gain sufficient knowledge on the painter and his execution style to authenticate his work? How can one deem to have a sufficient representation of the corpuses of an artist? And seeing as two works of art are rarely exactly the same, how can the expert be sure that the comparison between a given painting and a known body of genuine works is adequate? These issues have pushed the art community to take the conclusions of stylistic experts with a pinch of salt, notably since recent cases have shown the difficulty experts had in achieving unanimous conclusions regarding the authorship of certain Rembrandt painting in the Rembrandt Research Project (Sutton, 2006), and develop parallel methods to help in the decision making of the authenticity of a painting. The increasing number of articles in art journals (Milgrom, 2005; Martin, 2008; Newman, 2008) attests

[49] For information as to who qualifies for this type of expertise, see Chapter 1.

of the art community's inclination towards a more scientific approach in the field of art authentication.

The scientific examination of art was developed much later than these historical techniques, among other reasons because of its difficulty to penetrate the art market due to the reluctance of art historians: "The laboratory is often insufficient to carry out the expertise of works of art alone. [...] the combination of a scientist familiar with very specific technical examinations of works of art, and specialists experienced in art history and in the practices of the artist are necessary".[50] Microscopic observations of craquelures were one of the first few techniques proposed to study the veracity of a work, followed by destructive micro-chemical tests, to finally blossom in the 20th century, on account of the development of analytical chemistry. Even though contemporary authors undoubtedly agree that a scientific examination is necessary for the authentication process[51] (Buquet and Hellebranth, 1986; Stebbins, 2004), it took a great deal of time for this to be accepted by the art community, and for some is unfortunately still the case today: "There is a great need for the integration of a scientific approach to the authentication of works of art" (Chartier and Notehelfer, 1998, p. 74).

2.2 Rise and development

This need for a more scientific conceptualization in the domain of art expertise began in the 19th century. One of the first known cases when a scientific examination was used to discredit the opinion of art experts and raise awareness of the necessary contribution of scientific analysis was the painting the "Jolly Rider", supposedly by Frans Hals (Kurz, 1983). The scientific examination of the pigments proved that the painting was a fake, even though the art experts had certified it as being an authentic Hals. The first museum to become equipped with a laboratory was the Staatliches

[50] Free translation from Sannié (1953, p. 201): "Le laboratoire seul est donc souvent insuffisant dans l'expertise des œuvres. [...] Il faut la conjugaison d'un scientifique très au courant des techniques particulières de l'examen des œuvres d'art, et de spécialistes connaissant parfaitement l'histoire de l'art et les procédés de l'artiste".

[51] Art historians, often seen as the last recalcitrant entity for an scientific integration in art authentication, are realizing its necessity (Stebbins, 2004, p. 139): "I believe that art historians in the future will regard collaboration with conservators and scientists to be absolutely necessary in the most difficult cases of questioned authenticity".

Museum of Berlin, which opened in 1888. Other museums followed in the beginning of the 20^{th} century: the British Museum Research Laboratory of London, the Museum of Fine Art of Boston and the Louvre of Paris in 1931 (Mohen, 1998), to finally generalize themselves to basically every important museum of the world today.

These young scientific laboratories were opened with the goal of conserving and restoring artwork,[52] not determining their authenticity or inauthenticity (Chatelain *et al.*, 1997). It was after the discovery of the inauthenticity of what were thought to be "sure" works of art that the largeness of their workload broadened. "A correct assessment of the current chemical and physical state is crucial for responsible decisions on the state of conservation and restoration treatments" (van der Weerd, 2002, p. 2). On the other hand, works of art thought to be of low value can be worth a lot more after a restoration process unveils a more prestigious authorship than originally thought.[53] For these reasons, the study of the authenticity of a work of art and the restoration process are closely knitted notions. Even so, the main mission of most official laboratories today is still to ensure the conservation and restoration[54] of the works (Chatelain *et al.*, 1997).

An overview of the main techniques found and routinely carried out by the major existing laboratories, as well as their frequency of use is listed by Boutaine (2006). The hopeful outcome of these procedures is to prove an anachronism of the materials used to confection a work, and thus bring to light its disputed nature. On the other hand, the absence of these anachronisms will not prove the authenticity of the work of art: "Scientific testing cannot prove authenticity. At best, it may disprove authenticity, or may uncover restoration or overpainting which hides significant information about the author of the work" (Spencer, 2004, p. 202). Since proving chronological inconsistencies does not help in determining authorship, only disproving it, scientific analyses have remained complementary to other types of art expertise in the art market (Azimi, 2005).

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52 A sort of "medical check-up" of the artwork.

53 A Sandro Botticelli painting was recently discovered by the National Gallery of London after its restoration, after having spent over 150 years in the secondary exposition rooms (Paul, 2003).

54 In France, the national and conservation research laboratories (Laboratoires de recherche des Musées de France et des monuments historiques) are not permitted to expertise private works of art (Azimi, 2005).

The type of materials and techniques that should be expected from a work of art of a certain time period and school are set by reference novels, the pillar being *Il libro dell'arte*, written in the 15th century by Cennino Cennini. His manuscript portrays the strict painting techniques of artists of the Quattrocento and is used today to verify the coherence of the different components of a painting. His manuscript was rediscovered and published in 1821 and quickly translated into several languages (Cennini *et al.*, 1844). These publications were interestingly accompanied by a new era of high quality forgeries executed according to traditional materials and techniques (Hours, 1980). A more recent novel by Max Doerner (1935) is considered as the authority on questions of materials and painting techniques, all schools considered. Many have followed: (Feller, 1986; Roy, 1993; FitzHugh, 1997; Berrie, 2007). Other authors have given the tricks used by forgers. Another interesting and sizeable source of information is from a forger's point of view. Eric Hebborn, a well-known forger, gives artifices and secrets on how to forge artwork (Hebborn, 1997).

There are also a great number of books and articles giving impressive examples where science was able to establish inconsistencies and anachronisms with supposedly certified attributions (Hours, 1980; Kurz, 1983; Natale and Ritschard, 1997; Mohen, 1998; Pinna *et al.*, 2009). By studying the different materials at hand, an indication of the localization and date is possible. Highlighting the presence of materials that did not exist at the presumed date of production of a painting are evident signs of falsification (Rinuy, 1997).

For private requests of authentication there are several organisations regrouping a number of specialists from different areas of expertise that can be consulted. The International Foundation of Art Research (IFAR)[55] catalogues art theft and fraud, forgeries and research papers. They also possess an authentication research service. The International Center for Art Intelligence[56] also proposes a series of scientific examination techniques that can be carried out for art authentication, which includes stylistic analyses, different illumination techniques, and spectroscopic and chromatographic techniques. It was created in 1998 by SPIE - The International Society for

55 International Foundation of Art Research: www.ifar.org - Last consulted Oct. 2014.

56 International Center for Art Intelligence: www.authentica.org - Last consulted Oct. 2014.

Optical Engineering during the conference Scientific Detection of Fakery in Art. Both of these organisations are non-profit groups, promoting art authentication.

Before exposing the different techniques that can be performed on a painting, an overview of the components of a painting is necessary. Paintings often share the same characteristic: they are multi-layered. Therefore, they can be studied on a number of levels such as the support used for the work (wood, canvas, etc.), the preparatory ground and priming layers, the underdrawings, the paint layer(s) and the different varnishes, finishes or glazes (van der Weerd, 2002; Pinna *et al.*, 2009). One must keep in mind though that the most often encountered painting forgeries are not made from scratch, but are based on an existing (and likely low value) painting that serves as a basis (Kurz, 1983), to give the illusion that the painting is of a certain age. For these reasons, it is important to examine all of the components of the painting, from the canvas to the varnish.

The different layers that make up a painting, as well as the techniques used to analyse them, are presented in the following sections. A schematic view of the layers that can be found on a traditional oil paint is proposed in Figure 1.

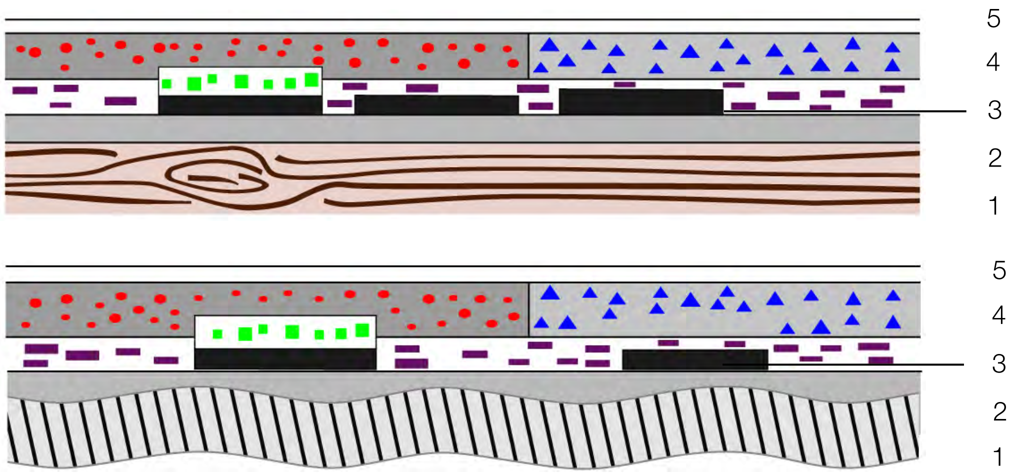

Figure 1 - Schematic view of a traditional oil paint, on a wooden (top) and canvas (bottom) support. The different layers are: 1.Support 2.Preparatory ground and priming layers 3.Underdrawings 4.Different colored paint layers (purple, green, red, blue) 5.Varnish.

2.3 Supports

The two main supports that can be encountered are either of wood or canvas. The wood supports were used for panel painting, common in Europe from the 13th century on. The use of canvases became common only in the 15th century, but was quickly popularized because of their convenience, weight and ease of transport. In the 16th century, supports made of copper were also used, although less common (Levenson, 2004; Matteini and Mazzeo, 2009). The study of these materials with known pieces of various artists can provide information as to the area in which they were produced and their approximate date of confection. Information on whether or not "composition has (or has not) been reduced, enlarged, or otherwise altered" can also be established (Levenson, 2004, p. 112).

The type of wood that was used for the wooden panels is a good indication of where it was manufactured. As Matteini and Mazzeo state (2009, p. 11) "[...] the general rule was that the type of timber chosen for the support was usually native to the area" and that, except for small exceptions in Spain, most painters used wood obtained locally (Marette, 1961). Therefore, once the type of species of wood is identified, indications pertaining to the geographical localization of the painting can be deduced; for example, oak was commonly used in northern Europe, whereas chestnut was more common in Italy. The species can be identified by observing the wood, first in it's natural condition under small magnification, and afterwards microscopically, with thin sections. X-Radiography as well as Scanning Electron Microscopy (SEM), can be used for the identification of the wood species. The manner in which the planks were assembled and held together is also an important indication of the time era and location of production. Finally, the wood can be dated with the use of dendochronological and/or radiocarbon dating techniques (Pinna *et al.*, 2009).

Little by little, canvases replaced the heavy and cumbersome wooden supports. Like wooden supports, the types of fibers used to make the canvas, as well as the manufacturing style and quality of the canvas, are elements that can give an indication of the time era and geographical localization of the production. The four principal fibers that can be found are flax, hemp, cotton and silk. They can all be easily identified with microscopic observations and/or Fourier Transform Infrared Spectroscopy (FTIR) (Pinna *et al.*, 2009). The presence or absence of seams, the tacking margins and the types of nails are also elements that should be studied. Inscriptions or stamps on the backside of the canvas, useful for historical and identification reasons, can be enhanced with transillumination, Ultraviolet Fluorescence Imaging or Infrared Reflectography. Finally, a radiocarbon dating of the canvas can give an approximate date of production (Watchman, 2007), and thus be sufficient to refute an attribution on the basis of a material anachronism.

2.4 Ground and priming layers

Paint layers could not be directly applied on the surface of the canvas or the wood. Ground layers, composed of gypsum (hydrated calcium sulphate, $CaSO_4{\bullet}2H_20$) or chalk (calcium carbonate, $CaCO_3$) and a glue-based binding medium (a protein-based material such as animal glue), were spread on the whole support in order to eliminate surface irregularities (especially on wooden supports) and give the painter a smooth and homogeneously coloured surface to draw and paint on. These ground layers were also used as a barrier between the paint mixture and supports, since the latter tended to absorb the binding medium of the paint. As a consequence, "the drying of the paint resulted from an evaporation process rather than an absorption one" (Matteini and Mazzeo, 2009, p. 13), giving the painting a shiny appearance. The number of ground layers used depended on "the type of support, the execution period and the artist's workshop" (Matteini and Mazzeo, 2009, p. 13).

Once the ground layers were in place, priming layers were added. These priming layers, whose principal goal was to give a coloured base to the paint layers, were composed of pigments[57] such as lead white, mixed with a binding medium, usually egg tempura (Vandenabeele and Moens, 2005). The ground and priming layers are in principle not visible on a painting, except for on the margins of the painting, or in areas where there is paint loss (lacuna).

The organic compounds of the ground layer can be easily identified with either Raman micro-Spectrometry or FTIR. Thus, the calcium sulphate can be differentiated from the calcium carbonate by comparing the obtained spectra with a known spectrum from a database. The pigments in the ground and priming layers can be easily spotted with optical microscopy and ultraviolet

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57 A distinction can be made at this point between a pigment and a dye, both used as coloring matter. The first consists of insoluble particles in suspension in a medium, while the second are soluble in their medium.

fluorescence, which help differentiate them from their surface (Pinna *et al.*, 2009). Carbon black and ochre are common in the ground layers, whereas principally lead white, but also red ochre and red lead, compose the priming layers. An extremely good knowledge of the artist's material and artistic habits is required: for example Rembrandt is the only person known to have used a type of limestone instead of the lead white pigment in his paintings (Mohen, 1998).

The binding media of the ground and priming layers are composed of organic material, principally animal glue and egg tempura respectively. Their detection and identification follows the same technique as for the binding media in the paint layers, therefore their analysis methods are exposed in sub-section 2.6.2.

2.5 Underdrawings

The artist frequently sketched his drawing on the prepared support before applying the paint layer(s). These could be either drawn with a carbon-based instrument (e.g. a graphite pencil, pure graphite, charcoal, black chalk), with ink, or could be engraved with a sharp instrument directly on the underpaint or gesso (Pinna *et al.*, 2009). Both can be revealed with the help of infrared reflectography and X-ray radiography. The first technique detects the underdrawings or erased writings hidden under the paint layers, provided the paint layers are transparent to infrared light and that the material used for the drawing (e.g. carbon black pigment) absorbs them (Rinuy, 1997). X-Radiography can be useful to uncover an underdrawing if the drawing was incised on the gesso, and a high X-ray absorbing pigment was used for the underpaint. As a result, the absorbing pigment is found in higher concentrations in the incisions, thus revealing the drawing (Pinna *et al.*, 2009).

Naturally, the drawing and copying styles varied according to the artists that used them and are therefore an important source of information on the painting technique of an artist. The changes between the original drawing and the finished painting can be radical. In the case of a lacuna, Raman Spectrometry can be performed on the underdrawing to identify the type of carbon material used to produce the drawings, whereas Scanning Electron Microscopy with an Energy Dispersive X-Ray Spectroscopy can be used to identify the type of ink (for example, iron gall ink). Once again, knowledge of the type of material on a found on a painting are extremely useful: "The physical evidence of a particular artist's preparation and planning process can be decisive in the process of authentication and attribution" (Levenson, 2004, p. 115).

2.6 Paint layers

There are a number of parameters concerning the paint layers that have varied through time. The type of pigments used went from easily available and simple elements such as carbon black (charcoal), red and yellow ochre and hearth, to treated minerals and vegetable dyes, obtained naturally or synthetically. In the 19th century, synthesized compounds obtained from elements such as cobalt, cadmium or selenium were commonly used (Matteini and Mazzeo, 2009). With the chemical investigations of pigments, scientists are able to conclude to a relative date of a painting. Indeed, the historical discovery and emergence of pigments is known and documented (Feller, 1986; Roy, 1993; FitzHugh, 1997; Berrie, 2007).

2.6.1 Pigments

The pigments used in paintings were traditionally inorganic ones of a mineral origin (e.g. lapis lazuli, cinnabar, azurite, etc.) or prepared by chemical synthesis (e.g. egyptian and prussian blue, lead-tin yellow, etc.). Pigments from an organic nature, extracted from plants or animals, also existed, but were less commonly used in paintings. They can be divided into three groups: indigoids (blue), flavonoids (yellow) and anthraquinones (red). The first can be used without any preparation, but the latter two have to be transformed into an organic substance, called a lake, by precipitating the dye with an inert inorganic substrate such as alum (Wyplosz, 2003; Vandenabeele and Moens, 2005). This type of pigments was often also used in the glazes or varnishes.

Light microspectroscopy, a non-invasive technique, can be used to localize and characterize the different types of pigments present in the pictorial layers by recording their reflectance spectra (van der Weerd, 2002). Multispectral scanning and imaging techniques can be used in the same aim (Elias and Cotte, 2008). Other analytical techniques, described below, are necessary for the identification of the detected pigments. The pigments can be identified with the help of non-destructive or micro-destructive techniques. X-Ray Fluorescence (XRF), by identifying the different metal elements in a matrix, indicates which type of inorganic pigment was used in the paint. For example, a blue area of a painting, with strong copper peaks indicate that the blue pigment is azurite. FTIR by fibers optics, also non-destructive, can be used to identify inorganic compounds such as silicates, carbonates or sulphates. It can also be used to determine if a pigment is of natural or synthetic origin.[58] X-Ray Diffraction (XRD), by revealing the presence of lighter inorganic pigments, can be used complementarily with XRF (Rinuy, 1997).

The two main micro-destructive techniques used to identify pigments are FTIR and Raman Micro-Spectrometry. The first possesses the advantage of being able to characterize the pigments and the binding media on a stratigraphic cross section. Raman can be used to identify organic and inorganic pigments (Edwards and Chalmers, 2005) and for *in situ* analysis with the development of portable systems (Lauwers *et al.*, 2014). Raman can however have the disadvantage of presenting an overwhelming fluorescence caused by the pigment or the binding media, hindering identification. Other techniques such as laser desorption mass spectrometer (LD/MS) have also been proposed for the study of organic pigments (Wyplosz, 2003), in order to overcome the problem due to the strong interferences of paint materials sometimes encountered in traditional spectrometric analysis. Finally, SEM coupled with EDX can be used to characterize Complex Inorganic Color Pigments (CICPs), which are synthesized pigments, the most known being rutile (TiO_2) and spinel ($MgAl_2O_4$).

2.6.2 Binding medium

Just like the ground and priming layers, a binding medium was mixed with the powdered pigments in order to fix them. The different types of binding medium of the paint layers were of diverse nature, which were generally contingent on an era and a provenance. They were used as a matrix for the colouring pigments and were "responsible for the adhesion of the colorant onto the support" (Vandenabeele and Moens, 2005). In primitive art, the binding medium came essentially from vegetable origins (fish, casein, animal glue), whereas egg tempura was "one of the most used binding media from Roman times and throughout the Middle Ages" (Pinna *et al.*, 2009, p. 93) because it

58 For example by distinguishing ultramarine, a synthetic pigment, from lapis lazuli, its mineral form.

allowed the artist to apply several layers of paint on top of each other. It was only in the early Renaissance (during the 15th century) that siccative oils (mainly linseed oil) were first added to the egg yolk and used together in a complex layering technique. In the 17th century, oil slowly substituted the mixture completely, but egg tempura was still used for the painting of flesh (Johnson and Packard, 1971). This technique, known as oil painting, was predominantly used until the arrival of synthesized chemical products (e.g. acrylics) in the 1950s.

The identification of these binding agents is difficult because "the organic matter that make up these complex mixture have undergone important changes by oxidation and polymerization through time"[59] (Hours, 1980, p. 63), the small sample size, and their low purity. The organic materials are thus complicated mixtures of natural origins and can be classified into four main groups:

- Proteinaceous: animal glue, egg white and yolk, and milk (casein)
- Lipids: drying oils (e.g. walnut or linseed oil), and waxes
- Terpenoids: resins and essential oils
- Polysaccharides: gums

The analysis of the binding media, although more complicated than the almost routine analysis of organic elements, is vital because "the techniques the artists used through the centuries differ more in the binding media than in the pigments" (Casoli *et al.*, 1998, p. 150). A larger variety of binding techniques used by artists imply more criteria that can be used for differentiation means. Unfortunately, the identification of the binding medium has not yet been proven possible by non-destructive techniques apart from the use of FTIR by fiber optics in the case of a lacuna (Pinna *et al.*, 2009). Spot tests can be performed on micro samples or cross sections to give an indication of the nature of the organic material.

The organic binders can be characterized with the help of chromatographic methods, which separate the organic components of these complex mixtures. Gas Chromatography coupled with Mass Spectrometry (GC/MS), which is the

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[59] Free translation from Hours (1980, p. 63): "[...] leur identification est difficile car les matières organiques qui les composent sont des mélanges complexes qui ont subi au cours des temps des changements importants par oxydation et polymérisation".

most common analytical technique used for the identification of organic binders, can be used to formally identify the protein-based binding media used for the ground layers. A GC/MS amino acid analysis (after hydrolysis and derivatization) can be used to separate and identify the amino acid composition of the sample (Pinna *et al.*, 2009), in order to determine if the protein originates from eggs, casein or animal glue. It is also possible, by using the same simultaneous method, to analyze the fatty acids, in order to determine the type of oil present in the binding media (Casoli *et al.*, 1996), as well as polysaccharides and natural resins. Liquid Chromatography Mass Spectrometry (LC/MS) can also be used in the same optic (Doménech-Carbó, 2008). Pyrolysis-GC/MS can be complementary to the above-cited techniques, which can be limited when faced with polymeric compounds of high molecular weight. The advantage of this technique is that it breaks the molecules down into smaller and volatile fragments (Doménech-Carbó, 2008).

2.7 Varnish

The varnish is added as a final layer to a painting for aesthetic and protective reasons. It has a saturation effect on the colors of the painting, conferring them a rich and wet aspect. The painting takes on, as a consequence, a glossy appearance. The first types of varnishes were made by boiling resins with drying oils and are known as oil varnishes (Matteini and Mazzeo, 2009). The most frequently encountered organic products are lipids (drying oils) and terpenoids (Doménech-Carbó, 2008). Since the development of synthetic components, modern varnishes are principally made of synthetic polymers.

FTIR by fiber optics and FTIR can be carried out respectively on the surface of the painting, or on a micro-sample, to characterize the resins and oils (Doménech Carbó *et al.*, 1996). The organic terpenoid and diterpenoid resins can also be detected and identified by GC/MS, by following the same procedure as the analysis of the organic compounds of the binding media exposed in section 2.6.2.

2.8 Observation of the signature

Different techniques have been refined for the observation of signatures present on paintings. These consist of observing the signature under different lighting conditions, as well as macro examination with the study of inconsistencies and craquelures. These points are discussed in the following sub-chapters.

2.8.1 Illumination techniques

The signature of a painting can be observed with the naked eye and with small magnification, with different illumination techniques. This should be done with white, ultra-violet and infrared light, with different illumination angles and with the use of filters. The purpose of using different light sources is to see if the signature was altered in anyway (signs of scraping or repaints). A simple illumination of works of art with direct or raking light can give indications on its general state, but can also highlight hidden signatures, dates and images (Blum, 1948). This technique, along with ultraviolet and infrared illumination, and X-ray radiography, was among the first to equip museum laboratories, and can be considered as the standard techniques, commonly carried out (along with pigment analysis) (Fleming, 1986).

Ultraviolet illumination of the support gives an indication of the state of the surface, such as touch ups and repainted areas (Vigears, 2000). Ultraviolet (UV) light can be used to see if the signature is contemporary with the painting. If the signature dates from a different period then the rest of painting, a contrast can be observed between the two. This type of lighting can also render information as to whether the varnish was altered or applied at different dates, which can generate fluorescence differences. Touch-ups, tampering, and the removal and replacement of varnishes can also be easily revealed with UV light (Widla, 1985; Lines, 2006). This type of illumination has also been documented to help decipher illegible signatures (Kurz, 1983). Infrared observation can be used to detect a hidden signature and inscriptions, or a pre-existing signature under the paint layer (Buquet and Hellebranth, 1986; Alexander, 1998; Calligaro *et al.*, 2003). X-ray radiography allows the scientist to study the internal structure of the painting and the painting technique (Rinuy, 1997).

2.8.2 The study of craquelures

The craquelures were often faked and imitated, because they were conceived for a long time as being a guarantee of the authenticity of a work. Craquelures can be artificially added by using different techniques (Nobili, 1922). Forgers also resulted to damaging their works, only to restore them right after. Just as it was once the case for craquelures, restorations are accepted as "certificates" of authenticity (Kurz, 1983). Bucklow (1997) studied the different types of craquelures networks and categorized them with precise descriptors. He was able to associate distinct variations of the craquelures within different eras of art history, to finally conclude: "...chronological and geographical variations across relatively homogenous technical traditions were evident" (p. 137). The craquelures can also be stained, which shows that the painting was cleaned or varnished after it had aged and cracked, and the liquefied resin having seeped into the existing cracks (Levenson, 2004). If the network is continuous between the signature and the paint background, and is thus not stopped by the signature, then they are contemporary (Hours, 1976). The craquelures on the signature should also be homogenous and correspond with the pattern on the painting (Widla, 1985). Naturally, the fact that the network is homogenous does not prove that the painting is of the hand of the artist. On the other hand, inconsistencies are elements that can shed doubt on the authenticity of the painting and can call for a further examination.

2.9 Summary of painting components

The different configurations of components and materials that can be encountered on a painting can be summarized graphically. The choice of which configuration was chosen depends on the date of execution of the painting, the geographical location of the artist, the material that the artist had at hand, as well as many other factors. Of course, in the case of fake paintings, a number of inconsistences may arise, and for this reason all of the possible configurations are presented in Figure 2.

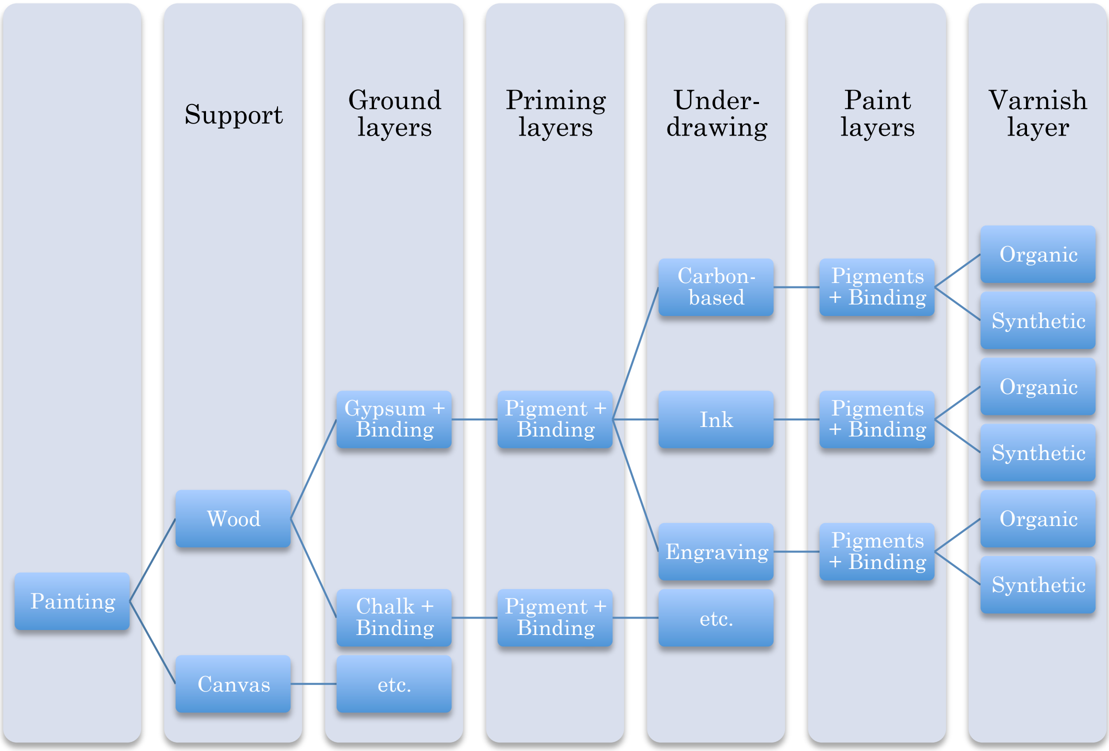

Figure 2 - Summary of components found in layers of a painting. For means of simplification, the pigments that can be found in the priming layers and/or the paint layers can be of inorganic, organic or synthetic origin. The binding medium of every stage can be of organic (vegetable, egg, oil) or synthetic origin.

The different scientific techniques exposed in this chapter are used more and more in the art community today, even though their systematic recourse is still scarce in comparison to the total number of works of art sold on the market. Of course, all of these scientific examinations are carried out with the prospect of detecting inconsistencies with the alleged date of execution of the work. If anachronistic details are discovered, for example, a certain type of pigment was invented after the time of death of the alleged artist, the attribution is obviously incorrect. On the other hand, if none of the analyzed materials present an anachronism, this is not enough to confirm the authenticity of the work. Indeed, in terms of attribution, and in the case where no inconsistencies are observed, the outcome of these techniques is at best the confirmation of an era in which the work was produced. It is not the laboratory's main focus to establish the authenticity, but more to discover material inconsistencies.

The use and limitations of these techniques also depends on the alleged date of the work: since anachronisms are rare on contemporary works, for example, the stylistic examination of the painting, as well of its signature, might be more conclusive. Indeed, unless an artist is known to have used a specific palette of materials when creating his work, an absence or presence of these materials could provide useful information for the authentication process.

The attribution of a signature on a painting, which is one of the aims of this research, would be the only scientific method that would allow one to attribute a work of art to an artist. A detailed description, methods and qualifications needed for analyses of painters' signatures is presented in Chapter 4. Before this subject is tackled, a historical overview of the use, development and metamorphosis of signatures on paintings is presented in the next chapter. This overview is essential for an understanding of the signature's purpose, which in turn is needed to fully grasp its expertise.

3 Historical aspect of signatures on art

3.1 Introduction

When an artist signs a work of art, he is trying to show two things: the first is that the work is of his hand, and the second that the work is completed. The signature represents in itself the whole artistic process of the artist, a visual entity left by the artist of the painting, and representing his person.

The signature as we know it has however not always been present on works of art, and has taken on various forms defined by the common practice of both the era and the geographical location in question (Sala, 1987). In civilizations preceding Christianity, such as the Greeks and the Romans, the practice of signing works of art, such as paintings and potteries, was commonly encountered. However, during the Byzantine era (4th to 15th century) and the Middle age (5th to 15th century), this custom disappeared and artists' signatures are practically absent: "The function of the sacred image leaves no space to the terrestrial middleman, relegated to the role of an anonymous transcriber of a transcendental image".[60] Anonymity is the general rule in the Occident in the High Middle Ages, the artistic individualism practically inexistent. Indeed, the "artist" of this period is more an artisan, whose occupation or trade is encompassed in a savoir-faire or skill (Moulin, 1995a). This skill is taught and regulated by corporations, who impose strict steps to achieve the profession.[61] The artisan is seen as a supplier, who anonymously carries out an order for a rich client (Lequette-de Kervenoaël, 2006).

The first appearance of the signature is in the 12th century, but only in precious arts, illumination and decorative sculpturing. These are all arts representing images not "susceptible of miracles" (1974, p. 15), as theorised by Lecoq, since religion and religious figures were not directly represented by these types of artwork.

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60 Free translation from Sala (1987, p.119): "La fonction même de l'image sacrée ne laisse aucun espace à l'intermédiaire terrestre, relégué au rôle de transcripteur anonyme d'une image transcendantale autrement significative".

61 The steps to achieve the status of crowned master in the Corporation of painters and confectioners of pictures (literal translation of "tailleurs d'images"), founded in 1391 were five years of apprenticeship, followed by four years of a companion internship, and the confection of a masterpiece (Moulin, 1995a).

3.2 Emergence of an identity

The first manifestation of the signature on paintings occurred in Italy between the end of the 13th and the beginning of the 14th century (Lecoq, 1974; Sala, 1987; Fraenkel, 1992), where it was found on the frames of the paintings, and only in special forms. Indeed, the transition between the sacred image, theoretically anonymous, and the claim of authorship is subtle. At first, the artist's names were followed by the Latin forms "me pixit" or "me fecit", in the first person, as if it were the paintings that were speaking: "so and so painted (or made) me" (Juren, 1974; Lecoq, 1974). The signature was placed on a sculpted banner, which represented the parapet of the loggia surrounding the sacred figures. In the case of polyptychs,[62] the inscription was always placed under the central panel. These Latin signature formulas were inspired from the goldsmith community, just as will be the case of monograms from the 15th century on (Chastel, 1974). From this point, the signature eased its way into the iconic field of the paintings. The parapet went from being an external element of the painting (the physical frame), to being part of the painted picture, by painting a fake frame in trompe-l'oeil as the support for the inscriptions (Figure 3). With this transition, dating from the beginning of the 15th century, the signature finally became part of the painting, even if it's presence was still very discrete and modest (Lecoq, 1974). This crucial change was nonetheless at the origin of the modern signature.

Figure 3 - Petrus Christus, Portrait of a Carthusian, Detail of the painted inscription « Petrus me fecit », 1446 , New York, The Metropolitain Museum of Art[63]

[62] Polyptyches are paintings that are divided into two (diptych), three (triptych) or more panels or sections.

[63] "Petrus Christus: Portrait of a Carthusian (49.7.19)". In Heilbrunn Timeline of Art History. New York: The Metropolitan Museum of Art.

These cautiously painted parapets, which still marked a distance between the inscriptions and the paintings, slowly took on other forms, and were in turn directly incorporated, among the sacred figures, into the paintings on different types of objects. These styles of signatures, known as epigraphic signatures, all abided by the same principle: like the parapet, they were painted in the trompe-l'oeil technique. The following forms were used as supports for signatures: the cartellino (folded paper), ex-voto, tabula (tablet), titulus suspensus (suspended placard or sign) (see Figure 4), monogram (see Figure 4) and stele (stone slab or pillar) (see Figure 5).

Figure 4 - Albrecht Dürer, Eve, detail of the titulus suspensus, with the signature and monogram of the artist. 1507, Madrid, Prado Museum.[64]

Figure 5 - Giovanni Bellini, Madonna col Bambino, detail of a stele, with the signature of the artist. 1510, Milan, Pinacoteca di Brera.[65]

These inscriptions and signatures were used to glorify the painter and reveal the name of the subscriber of the painting to the clergy so that his acts of generosity would not go unnoticed. These inscriptions therefore had to be obvious to the public eye, and in doing so, the artist's status slowly changed:

http://www.metmuseum.org/toah/hd/optg/ho_49.7.19.htm; Last consulted Oct. 2014.

64 http://www.museodelprado.es/en/the-collection/online-gallery/on-line-gallery/obra/eve/ - Last consulted Oct. 2014.

65 http://www.wga.hu/html/b/bellini/giovanni/1510-/194madon.html - Last consulted Oct. 2014.

from a craftsman or copyist, he became an artist. The artist underwent an empowerment process; he went from made-to-order works to working on his own themes. The icon thus became a work of art, conferring an economic value to it (Lecoq, 1974). Chastel remarks (1974, p.11) that, around the 15th century, the signature "appears as practically the only writing that is tolerated in a painting, where all is done to preserve the visual uniformity of the spectacle, the only [writing] precisely because it is not part of the painting and it can not be confused with it".[66] This custom takes place initially in the North of Europe, specifically in the Germanic regions, where it can be seen to a certain degree as the development of the self-consciousness and assertiveness of the artists[67]. This is confirmed by the fact that auto-portraits appear around the same time in these same regions (Ibid.). The practice quickly generalized itself in Italy, but only in the 16th century. The signature at this point can be interpreted as a stamp an item of art receives once it leaves the workshop (Butor, 1969).

3.3 Development of signatures on paintings

Little by little, the Latin suffixes were dropped, and the signature was partially integrated in the pictorial field of the paintings, appearing on walls or tables. The final transition could already be observed with certain artists in the second half of the 16th century. The signature was detached from the supports used up to this point and gave the impression to float in the painting. The signature became important because it represented the full assertiveness of the status of the artist. Bruegel the Elder was one of the first to adopt this style, in parallel with Titien. As justly pointed out by Lebensztejn (1974, p. 50), the painters "vividly reveal the semiotic heterogeneity of the image and the inscription".[68] The signature has taken on the form of a superimposed element, where the name, placed on the painting,

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66 Free translation from Chastel (1974, p. 11): “[La signature] apparaît pratiquement comme le seul écrit toléré dans la peinture, dont tout tend à sauvegarder l'homogénéité visuelle de spectacle, le seul précisément parce qu'elle n'en fait pas partie et ne peut se confondre avec lui".

67 The status of the artist if not fully asserted at this point, as shown by the continuous use of the latin suffixes after the signatures, which remind the artist of his craftsman heritage.

68 Free translation from Lebensztejn (1974, p. 50) "[Les peintres] ont laissé apparaître à vif à l’hétérogénéité sémiotique de l’image et de l’inscription".

is exterior to the composition. In this case, the signature encompasses a distinct feature or quality of the painting.

Parallel to this phenomenon, the artist slowly liberated himself from the yoke of the corporations by making himself indispensable of commissioners in courts, royal families and religious orders. A famous example of this new class of art commissioners was the Medici family, who ordered and collected a great number of works of art from a large number of artists (Moulin, 2009). The artist was considered as a person, and not as a representative of an institution or corporation: a first step out of anonymity. As such, his social and intellectual position reached a higher level, which was re-enforced by a constant increase in the number of orders.

The artists wished to add the skill dimension to the pre-existing technique, and founded Academies, such as the *Accademia del disengo* in 1563 in Florence, or the *Académie royale de peinture et de sculpture* in 1648 in Paris. The Academies "accredits indefinitely painting and sculpture as a 'liberal' art, distinct of arts and crafts and commerce".[69] The artisan has thus become officially an artist. This movement provoked the decline of the corporations, and the beginning of a new era of the artist: a person of knowledge. Academies were created throughout Europe, and were strictly hierarchized (Moulin, 2009). They inherited the collective aspect linked to working in corporation: most artists worked in workshops.

Academies are worth mentioning for another reason: they believed that it is not the originality or conception of the work of art that is of most importance, but the skill and the quality of the final work of art. This vision had two main consequences, both of which are significant today: sketches and drafts were considered insignificant, since they were not considered as the finished work, answering to the strict norms of beauty imposed by the academies (Lequette-de Kervenoaël, 2006). For these reasons, signatures were naturally never added onto sketches, since they were not considered as finished works of art, but rather as imperfect forms of the process. The second consequence is that artists tended to copy works of art considered to have achieved perfection in

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[69] Free translation from (Moulin, 1995a): "[…] l'Académie de Louis XIV accrédite définitivement la peinture et la sculpture comme arts 'libéraux' distincts de l'artisanat et du commerce".

terms of beauty and master of skill.[70] Reproductions were not seen as illegal copies, but rather as equivalents of the original work.

In parallel to the written signatures described above, emblematic signatures, which are signatures that can only be understood through a symbol, appeared on paintings. They were either alone, or used in conjunction with the artist's monogram (1974). Other artists, such as Filippo Lippi or Botticelli, preferred to paint their faces in their paintings rather than sign them (Chastel, 1974).

3.4 The Romantic period – the emancipated artist

After the French revolution, a number of academies were dissolved. The artist lost his submissiveness: he was able to create his art, and did not depend on orders. The aesthetic of the work overcame its perfection, and the artist inherited a new faculty: that of a creator. His art bestowed a new characteristic, that of originality: "Since the artist is giving the gift of creation, as a consequence, it is the innovative nature that will increasingly characterize the work of art. The genuine work of art is one that has never been done: the original work in one word".[71]

The Romantic period is considered as the turning point for the status of the artist. Towards the end of the 18th century, this practice of the modern signature was widespread and finally stabilized itself around 1880 (Chastel, 1974; Widla, 1985). A distinction was made between the manual artisan, and the artist, the creator. His art became and was, as the artist himself, unique and irreplaceable (Moulin, 1995b). By signing his work, the artist completely emerged out of the anonymity.

Sketches and drafts, once considered void of purpose, became suddenly an important step in the artistic process: they were the essence of the work, representing its creation and the incarnating the spontaneity of the artist. "All works [of art], drafted or completed, inedited or altered, that leaves the hand of the artist henceforth an original work. The notion of originality

70 These copies were either produced by the artist himself, or by his students who would copy the work under his supervision (Chatelain, 1982).

71 Free translation from Chatelain (Chatelain, 1982), p. 26: "Puisque c'est le don de creation qui fait l'artiste, c'est par voie de conséquence le caractère d'innovation qui va de plus en plus caractériser l'œuvre d'art. La veritable œuvre d'art est celle qui n'a jamais encore été faite: l'œuvre originale en un mot".

coincides with that of authenticity".[72] Coincidently, copies of works of art also became unwanted and lost their value, interrelated to the notion of rarity of the work. As Marcel Duchamp puts it: "Rarity gives the artistic certificate".[73]

Throughout the 20th century, variations of the traditional signature appeared (Gottlieb, 1976). Traditional is to be understood as the modern "superimposed" signature, dating from the end of the 18th century on. These variations include the signature on the back cover of the canvas, carried out for aesthetic reasons as well as a mean to guarantee the authenticity of the work of art. Other variations include the use of finger, hand and face marks or prints as a type of signature, as well as auto-portraits, which can be seen as "the intellectual equivalence of the signature" (Ibid., p. 71).

3.5 Contemporary period

The classical view of art is put to the test, already at the beginning of the 20th century, but more particularity since the 1970s. Artists have a goal of auto-destruction of art and of protest of the market. This branch of artists stems from the dual vision of the artist around 1870-1880: the academic artists, and the independent artists.[74] The consequence is that the artist replaces the work of art. The work becomes the materialization of their thoughts. The act of creation is overcome by the action of the artist (Moulin, 1995a).

The signature still plays a central role as a visual concretization that a work of art is completed, and can be an element, along with the date, that indicates that an artist had not completed a work or considered it as a studio work. A recent example in the French courts ruled in a favor of the heirs of the painter Simon Hantaï, who were opposed to having a painting of their father sold, citing notably the fact that the signature was not present, and the that the painting was therefore not finished (Brunel, 2012). The signature can be considered as a sign that a work has been completed: "When a painter refuses to declare that his work is done, it is because he does not consider that his

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72 Free translation from Chatelain (1982, p. 27): "Tout œuvre, ébauchée ou achevée, inédite ou reprise, qui sort de la main de l'artiste est désormais une œuvre originale. La notion d'originalité se confont avec celle d'authenticité".

73 Free translation of Marcel Duchamp, cited in Moulin (1982, p. 31): "C'est la rareté qui donne le certificat artistique".

74 Moulin goes as far to speak of a bipolarity of the artistic life (Moulin, 1995a, p. 94).

canvas exists as a finished work. It cannot, as a consequence, constitute a possession that can be appropriated and that is transferable".[75]

Finally, the "verdict signature", as proposed by Gottlieb (1976), is when the artist recognizes an aesthetic value of an object, and validates this recognition by his signature. In this case, "it is the name, the apposition of the signature, that defines the work of art [...]".[76] The signature in this case has a predominant influence on the work of art. Without it (literally and figuratively speaking), nor the artistic reasoning, nor the object, has its irreplaceable value. Moulin summarizes this process: "The devaluation of the work calls for the enhancement of the author in its irreplaceable uniqueness. When the artistic product evolves into "anything", the recovery of the uniqueness requires that this "anything" is not done by anyone. The transfer of rarity occurs between the work of art to the author [...]. The focus has shifted from the uniqueness of the work to the uniqueness of the artist [...]".[77]

3.6 Conclusions

With the changes of the signature in contemporary art, the circle is closed: today, the signature is rarely visible (just as it once was the case in the Middle Ages). The difference is that today, the signature is necessary to guarantee the quality of the work as a work of art linked to an individual. The signature as it is known has not always existed, but underwent a series of transitions, dictated by changes of the sense of religious art, schools of thought and geographical locations. The passage from a group or workshop to an individual brought forward the intellectual and artistic quality of the artist. By signing his work, its originality is recognized by the artist and by the public. The signature becomes also a symbol of the valorization of the artist,

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75 Free translation from Brunel (2012): "Lorsqu'un peintre refuse de déclarer son travail abouti, c'est qu'il considère que sa toile n'existe pas encore en tant qu'œuvre finie. Celle-ci ne peut, par conséquent, constituer un bien appropriable et aliénable".

76 Free translation from Chastel (1974, p. 13): "C'est le nom, l'apposition de la signature, qui définit l'œuvre d'art [...]".

77 Free translation from Moulin (1995b, p. 176): "La dévalorisation de l'œuvre appelle à la valorisation de l'auteur, dans son irremplaçable singularité. Au moment où le produit artistique évolue vers 'n'importe quoi', la récupération de l'unicité exige que le 'n'importe quoi' ne soit pas fait par n'importe qui. Un transfert de rareté s'opère de l'œuvre à l'auteur […]. L'accent est déplacé du caractère unique de l'œuvre au caractère unique de l'artiste […]".

and helps him acquire his fame. The artist's signature was able to extract itself from the pictorial elements of the painting and become an element on its own, taking on its modern form as it is know today. The signature is now accepted as being the trace of the artist, almost a certification of the artist's hand and proof of the painting's authenticity. Thus, when signing a work of art, the artist validates the work as being from his hand, and that it is completed. Sala (1987) justly sums up its importance: "The signature is, for any art enthusiast, the visible and definitive 'truth' of the origin and of the authenticity of the painted work".[78]

[78] Free translation from Sala (1987, p. 119): "La signature est, pour tout amateur d'art, la 'preuve' visible et définitive de l'origine et de l'authenticité de l'œuvre peinte".

4 The expertise of the signature

4.1 Introduction

Friedlaender (1944), an art expert and art historian, proposes three objective criteria for establishing the authorship of a painting. The first are signatures and monograms, the second documentary information, and the third the study of similar forms. Signatures and monograms will be thoroughly discussed throughout this chapter, the documentary information having already been mentioned in Chapter 2. The third method, developed by Giovanni Morelli (Morelli and Anderson, 1991) in the end of the 19th century, is widely known as the attribution theory (Willheim, 1974; Zerner, 1978; Ginzburg, 1989; Guédron, 1998). Morelli identified the characteristic 'brush' of a painter by examining the forms of minor details such as ears or hands, and comparing them with known and authenticated works of art.

Unfortunately, this method is not applicable for the detection of fakes, as pointed out by Friedlaender (p. 167): "The criterion of similarity of form is completely unavailing, once we are faced with the task of differentiation original from copy-thus to answer a question which, in the practice of connoisseurship, is a particularly frequent and burning one". It is for this reason that the Morelli attribution theory was gently put aside.[79] Another reason, as Friedlaender remarks, was that the art critic creates a mental model of what a work of a certain period from a certain artist must look like, based on the solid knowledge that the critic has of the artist and on the evolution of his style, and does not, as Morelli suggests, base himself only on what he has seen. The attribution theory, just like the scientific methods that were starting to emerge at the same time, were reluctantly accepted by the art community of that time because they were deemed less efficient, and also because they were very likely perceived as competition to the traditional methods in place.

79 The Morelli technique might perhaps be making a slow comeback. Indeed, the Rembrandt Research Project (RRP) cited that their system of connoisseurship was based on that of Morelli's. The RRP selected details of the collars and lace cuffs in Rembrandt's portraits as indicators of Rembrandt's paternity, which resulted in the disattribution of several works attributed as of Rembrandt's (Sutton, 2006).

4.2 Fake and authentic signatures on paintings

It has already been noted how the presence of the signature significantly changed the perception that one had of a work of art and how it held a central role in the art market. The signature has a psychological impact on the work, as it is amusingly portrayed by Hebborn (p. 61): "How often have we watched an art lover peering at the corner of a picture, anxiously searching for the signature that will tell them whether or not to be spellbound, [...] for a work with the name of a famous artist attached to it has had a spell cast over it, [...] [which] greatly increases its price". Since the value of a signed painting compared to a non-signed painting is generally much higher, forged paintings usually have a signature on them (Ionescu, 1985).

Therefore, it naturally comes as no surprise that the signature is the most often faked element of a painting. Bensimon (1996) points out that a fake signature is more often added on an already existent painting, rather than on an entirely fake painting. Compared to producing a work of art from scratch, it is much easier and economical to simply add a signature on a work of art dating from the same approximate era of interest, and in what could be considered in the artistic domain of the artist (one could argue that even the best artists had their bad days). The addition or transformation of a signature is therefore one of the simplest transformations that can be done on a painting. This practice started with the Hollander painters, who as mentioned in Chapter 3, were among the first to sign their paintings regularly, and as a consequence, collectors sought out signed paintings. Signatures were also often added on perfectly original and authentic pieces, in order to enhance their authenticity. It was not uncommon for art merchants to scrape off the "useless" signatures of obscure masters, clean them off and replace them with more convenient, but false, names (Friedländer, 1944; Kurz, 1983).

In French law, if an artist imitates the style of another to create a pastiche (or uses the artist's work as an inspiration), the artwork cannot be considered a fake unless the similitudes are obvious. However, if a fraudulent signature is added to pass the work off as coming from the copied artist, the moral rights of the artist are affected, and the work is considered as a fake (Lequette-de Kervenoaël, 2006). The same can be stated for an item of art that isn't even inspired from the said artist.

However, reproductions of works of art that have fallen in the public domain (theoretically 70 years after the death of the artist) can be carried out, as long as there is not a will to deceive (this can be clearly stated by printing the word "Copy" or "Reproduction" on the back of the canvas and by using a different canvas format). In French law, even the simulation of the signature is authorized, as shown by the ruling given by the cour d'appel of Paris: "When copies sold may in no way be confused with the originals, given the different size of the paintings and of their different media, there was no violation of the moral rights in the reproduction of the signature, which is indisputably part of the work itself. It should be added that no dispositions with penal sanctions forbids the reproduction by any technique the signature of an artist whose work has fallen the public domain".[80] The Cour de cassation confirmed this hearing one year later.

The forger can sign an unsigned painting or can modify an already existing signature in order to raise the prestige of the painting with the name of a famous artist. He can proceed in the following manners (Ionescu, 1985; Bensimon, 1996):

- By modifying the existing signature by adding lines or letters;
- By scraping the existent signature and painting a new one in it's place;
- By painting over the existing signature, and painting a new signature over it.
- By integrating the existing signature into an object of the painting (ex: a leaf or fold of a clothing) so it becomes hidden, and painting a new signature at another place.

Several authors have described the signature simulation techniques used by forgers: "Usually a forger will concentrate on the general appearance of the letter forms themselves, but it is difficult to suppress one's own habits while trying to adopt someone else's pattern. Therefore some stylistic similarity to an artist's known signatures may be achieved, but subtleties usually escape a forger's awareness or ability to duplicate" (Siegel, 2004, p. 92). The beginning

[80] Free translation of the hearing in case Paris, 13e ch. sect. B, 12 avr. 1996, RG n°95-04324: "dès lors que les copies vendues ne peuvent en aucun cas être confondues avec les originaux, compte tenu des dimensions différentes des toiles, de leurs matières de supports différents, il n'y avait aucune violation du droit moral dans la reproduction de la signature qui fait incontestablement partie de l'œuvre elle-même. Il convient d'ajouter qu'aucune disposition assortie de sanction pénales n'interdit de reproduire par quelque technique que ce soit la signature d'un artiste dont l'œuvre est tombée dans le domaine public".

of a signature is the part that the forger will have the best luck copying. He will apply himself at the beginning and little by little as he progresses in the signature, unconscious liberties will take over, generally simplifying the signature, but without changing its general appearance. These 'liberties' will in turn allow the expert to detect the fakery (Ionescu, 1985). This could be because the forger will be extremely concentrated at the beginning, when he starts to copy the signature, and notices that the copy greatly resembles the original, gains confidence in his forging capacities, and 'relaxes' his hand. It is at this point that the small inadvertences or deviations will appear.

The well-known forger Hebborn, with his recommendations on how to imitate a signature, can be anecdotally mentioned (Hebborn, 1997, p. 64): "one should ideally have the same kind of pen as the one with which the original was written [...]"; followed by his copying techniques: "[...] the penman should not view the signature he is copying as a series of letters but rather as an abstract line or series of lines". In order to do so, he suggests turning the signature upside down when producing the copy, and to practice until a natural flow is obtained. Of course, this simulation method would be easily discovered and the forgery uncovered by any forensic document examiner (FDE) carrying out a traditional signature examination. The construction modes of the letters as well as their line crossings would reveal inconsistencies when observed with magnification. These simulation recommendations show that forgers feel concerned by the signature and are aware that an ulterior signature examination could be carried out. They take care, or at least try, to reproduce at best the visual aspect of the signature and its characteristics.

Sometimes, signatures are added by merchants or collectors on facsimiles thought to be authentic, without the necessary intent to deceive by trickery. These painting simulations can take on a number of forms: they can be slavish copies, showing no originality and blindly imitative. They can be pastiches, which consist of reproducing parts of original works and patching them together on one painting, or can be completely fabricated fakes, without being based on a specific painting (Bazin, 2010). Sketches of an artist that were never turned into a painting can be used as a base of a painting simulation (Bensimon, 1995). Simulations can also be masqueraded as preparatory works, passing themselves off as work of the artist in his early, inexperienced years (Buquet *et al.*, 1992). In any case, signatures are almost systematically added to these painting simulations, because "[...] the simulation is incomplete if the artist's signature is not included" (Hanna, 1992, p. 1112). In all of these possible scenarios, the signature remains a simulation (or forged signature)[81] that is affixed on an authentic (or unauthentic) piece.

On the other hand, there are three main scenarios where the signature of the artist is perfectly authentic, but the work of art on which they figure is not of his hand. This is the case of apprentices in master workshops that usually painted under their Master's supervision, and who in turn often signed the paintings once they were finished.[82] In this example, the signature is more a stamp of the workshop, and indeed works of art such as this often bear the note 'from the workshop of...'.

The second case scenario (of an authentic signature found on a work or another person), is where some popular artists have been known to sign works of less fortunate, unknown artists, as a favor (Buquet *et al.*, 1992). These are commonly known as charity signatures ('signature de complaisance' in French). The artists Corot, Modigliani and Dali were well known for signing paintings made by friends or admirers, either as acts of kindness or out of pure indifference (Lequette-de Kervenoaël, 2006).

The last of the three situations when an authentic signature can be found on a work of another artist's hand is when a person with an intent to deceive can present paintings as long-lost pieces to artists, who either naively or simply from a faulty memory willingly affix their signature.[83] This category is close to that of the charity signatures, but can be differentiated with the intent to pass

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81 It seems indispensable at this point differentiate a simulated signature from a forged signature. The forged signature can be concisely defined as a simulation of something, with the intent to deceive. The conditions as requisite to forgery in art are discussed by Kennick (1985). When possible, the term 'simulation' or 'imitation' will be used instead of the more charged 'forgery'.

82 A more contemporary example is Renoir, who, from 1913 to 1917 was not able to work. He relied on the sculptor Richard Guino to carry out his work, according to his specifications. Renoir then signed the sculptures. After a lengthy judicial procedure, the French Courts decided to grant Guino co-authorship of these works (Edelman, 2008).

83 Lessard gives an example of this scenario in his autobiographic novel (Lessard, 1988): In 1960, the Lessard-Legros duo showed Van Dongen a painting that he had supposedly painted at the turn of the century. Van Dongen signed the painting, dated it back to 1910, and delivered a certificate of authenticity. According to Lessard, it was himself that had actually painted it two years earlier. Even more troublesome, the painting was later authenticated by Paul Ebstein, a Van Dongen expert.

off the painting as an authentic painting of the person who signed it. Thus, in these three cases, the 'forged' painting will adorn an authentic signature.

Finally, and in parallel to the situations presented beforehand, the signature may also have been painted some time after the work was completed, either genuinely (bona fide) by the actual author of the painting, or insincerely (mala fide) by someone else.

A subset of authentic signatures, although mostly applicable to the case of reproductions and multiple prints, is the case when, after an artist's death, his heir signs works of art in his name, because they (his signatures) were included in the artist's contract.[84] Deontological recommendations state that sculptors must, for every proof, add a signature, the year of production, and the founder or caster. Authors of engravings, lithographs, embossments, etc., also follow the same codes of conduct. These works are numbered and signed, in order to guarantee their pseudo "uniqueness". Likewise, an authentic signature (in the sense that its from the hand of the author), could be ruled inauthentic if the artist signed supplementary proofs,[85] not agreed on in the initial contract and/or did not state them as being "reproductions" (Lequette-de Kervenoaël, 2006).

Finally, a case of an authentic signature on an authentic work of art from the viewpoint of its artistic value, but not from the view of the courts, is worth mentioning. The authenticity of a work can be considered partial or totally lacking, such as Van Dongen who was sentenced to pay damages to art collectors and merchants for having signed and anti-dated some of his paintings to increase their value before the sale. Indeed, the market value for paintings dating from 1905 to 1910 was much higher than those of a later date (Lessard, 1988).

These many situations show that the problems concerning the apposition of a signature are numerous in terms of authenticity of paintings and of signatures. The signature is thus to be considered as a sign, among many others, that can help determine the authorship of a work of art. These issues

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84 The French Court ruled in the case of the original painting reproductions of the artist Takanori Oguiss. He passed away before he could sign the reproductions of his work, so his wife, who had co-signed the contract, was legally obligated to sign the works. Her signatures were in this sense considered as authentic.

85 In this case they could not be considered as original.

should be keep in mind by the FHE if he is confronted with a case of signature examination.

4.3 Examination of the signature

Friedländer recommends exercising caution and critique for the use of the signature as an objective criterion of authorship (Friedländer, 1944). He acknowledges the existence of graphological tests as he puts it (to be understood here as forensic signature analyses) that support chemical ones. But he warns the reader that even a 'genuine' inscription of the hand of the master must not be considered legitimate and that "a copyist may have taken it over from the archetype" (p.164). His conclusion is inevitable: "the signature is at it's best a clue of authorship and its objectiveness questionable". On the other hand, other, more recent authors defend the contrary: "The signature ensures the authenticity of the work".[86]

Signature identification has gained an important role in the authentication of paintings from a court's point of view. It is considered as an element among, and along with, others that can assist the judge in determining the authorship of a work of art. Judges, who are already used to dealing with signatures on legal documents, give a great amount of credit to the expertise of painter's signature as a mean to authenticate a painting (Siegel, 2004). According to Spencer (2004, p. 195), "courts have relied, to a much greater extent than the art world,[87] on signature evidence", which he demonstrates by presenting two cases, a Cadler and a Schiele, where the signatures played a central role for the determination of the authenticity of the works in the court. Lequette-de Kervenoaël (2006, p. 190-191) also gives an account of numerous French cases where the signature was taken into account by the Courts to determine a work's authenticity. For example the sale of an Utrillo painting was cancelled because of abnormalities regarding his signature, or a Fantin-Latour signature considered inauthentic because of its abnormal size.

[86] Free translation of Buquet and Hellebranth (1986, p. 242): "La signature garanti[t] l'authenticité de l'œuvre [...]".

[87] Interestingly, catalogue raisonnés, used by this same 'art world', often reproduce details of examples of signatures of artists. This attests that the signature carries an importance to the eyes of these experts.

4.3.1 Forms of the signature

Signatures on a work of art exist in a number of forms, and as such, FDE do not unanimously agree on which types fall within their competencies. For example, drawings or prints are usually signed with a standard writing instrument, such as a pen or graphite pencil, and these types of signatures "fall within the sphere of forensic document examination" (Hanna, 1992, p. 1096). Signatures on a painting or on a sculpture differ drastically with the traditional signature of ink on paper: on sculptures, the signature is usually carved out of the matrix of the work with a thin sharp object. This type of signature can also be found on paintings, but is quite rare. The most common signature found on paintings is the painted one, where the writing instrument is a paintbrush. It is precisely this type of instrument that gives rise to the difficulty of the signature examination: "[...] the signatures of master's paintings are a very special field of exploration, given the nature of the instrument".[88]

Most authors agree that the traditional FDE does not possess the adequate qualifications to carry out casework of this type (Widla, 1985; Goetschel, 1987; Hanna, 1992; Bensimon, 1996); although several others have carried out painters' signature identification and published their casework (Ionescu, 1985; Siegel, 2004; Lines, 2006)[89]. Hanna (1992) warns FDE about the complexity of document examinations on art. She clarifies the situations that fall within her capacity when determining art fraud or forgery, and sets standards to determine in what cases such types of casework can be undertaken. Three main guidelines are articulated: the first is to determine the type of art and if the signature examination is possible, depending on the type of art (as some mediums will possess too many variables). The second is to ensure that reference signatures are easily obtainable, and the third to make sure that the expert has enough time to collect information on the subject, collect the standards, and carry out the signature examination.

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[88] Free translation Buquet and Hellebranth (1986, p. 243): "Les signatures des tableaux de maître constituent un champ d'exploration tout à fait spécial, étant donné la nature même de l'instrument utilisé".

[89] Few mentions of the use of the signature by the art restorer as a mean to authenticate or pronounce a work as a forgery exist. The only mention found by the author was that of Simon Parker, a restorer for Sotherby's, who stated for an alleged Benson painting "[...] I am sure that the signature is not of period, and it seems to be on top of a lot more varnish and repaint". (Johannes R. Kramer and Betty P. Krahmer v. Christie's, Inc., cited by (Bresler, 2007)).

The authentication of signatures on paintings does not fall within this said competency according to Hanna (1992, p. 1097), because "conventional writing instruments such as a pen or pencil" do not sign the works. Therefore, a "broader base of knowledge than is afforded by the traditional training of forensic document examiners" is required (Hanna, 1992, p. 1097). Unfortunately, what the 'broader base of knowledge' consists of is not specified. The methodology or procedure that can be undertaken by a forensic document expert for the authentication of a painted signature is incomprehensive and fraught with gaps, for a good reason: "up till now, little importance has been attached to the problem of the expertise of signatures. Attention has been focused on technical exams with total disregard of handwriting examination" (Widla, 1985, p. 3).

4.3.2 Variables involved

The complexity behind the signature examination is imputable to the emergence of the many new variables involved in comparison to signatures on paper. The different elements that will have an influence on the variation of the signature on a painting and that differ from those of a traditional signature (Widla, 1985; Goetschel, 1987; Ionescu, 1990) are the following:

- The paintbrush can have a number of variable factors, such as thickness, hardness, size, form and composition (i.e. the type of fibers); The fluency of the lines will also depend on the manner in which the paintbrush is held (for example, at the base, middle or end).
- The paint characteristics can vary depending on the type of paint (for example oil versus acrylic), its fluidity and dryness (both due to the amount of pigments, binders and diluents). The consistency of the paint can change throughout the day.
- The support of the painting can differ (canvas, wood, stone), as well as the number and type of preparatory and paint layers: "An even surface allows light, continuous brush strokes whereas a rugged one produces ridges and interruptions when 'jumping over obstacles'".[90] These non-conventional supports will have an outcome on the signatures.[91]

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[90] (Ionescu, 1990, p. 33)

[91] Certain authors (Sciacca, 2010) have developed theories stating that the graphical movements, in particular that of the signature, remain constant independently of the support or the hand/body position (i. e. the writing conditions). They suggest

A fourth difference between the painted and traditional signature which is only mentioned by Ionescu (1990) is the hand position of the signer. When signing a painting, the artist will not necessarily have a support on which to rest his palm, wrist or forearm, which can have an effect on the line quality of the signature.

Nevertheless, these variables do not prevent some specialized FDE to carry out an expertise of painters' signatures: "Whether by pen stroke or brush stroke, it is this individuality of repeated movements and overlapping motifs which provides the foundation for comparison. It allows the handwriting expert to differentiate one person's writing from another's and, ultimately, to determine if a signature is genuine" (Siegel, 2004, p. 89).

4.3.3 Examination process

The examination process of a questioned signature is divided into steps that are the analysis, the comparison and the evaluation process, as presented by Huber and Headrick (1999). The verification step was subsequently added by Ashbaugh (1991), in the domain of fingerprint examination. This process is commonly referred to as the ACE-V,[92] of which an overview is presented in Figure 6 below. The ACE-V is not a method per se, but a stepwise approach to guide examiners throughout their examination process (Champod, 2008). The first steps of the examination process, i.e. examination of the questioned and reference signatures, and comparison of both sets will be presented in the following paragraphs. An overview of the evaluation stage is presented in Section 4.4.

that the production of the signature will be more influenced by a certain number of neuropsychological parameters, such as the training of the hand to produce the graphical movement. For this research, the understanding of such theoretical models will not be addressed, as the aim of this research is to study the variability of painted signatures with the appropriate tools, and not from the writing conditions point of view. The results obtained are considered more crucial than the writing conditions.

92 The ACE protocol (without the verification stage) was first proposed by the forensic document examiner Roy Huber in 1959 (Huber, 1959). Since, the approach has been implemented and is widely used in many areas of forensic science where an individualization process exists, from shoemarks to fingerprints (Langenburg, 2012).

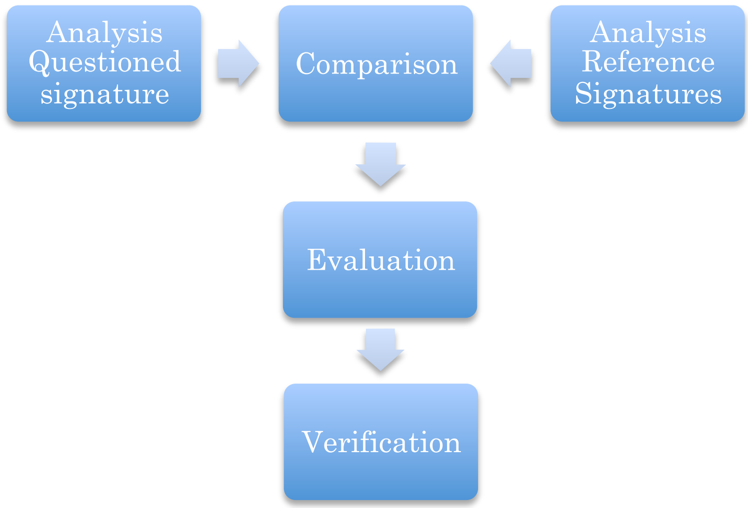

Figure 6 - The ACE-V signature examination procedure comprising the analysis of the questioned and reference signatures, their comparison, the evaluation and verification stages.

a) Analysis of the questioned signature

In the case of forensic examinations of handwriting, the analysis phase includes a number of elements the forensic handwriting examiner must assess. Huber and Headricks (1999) present a number of these elements (they put forward 21 in total). They recommend observing the elements of style of the handwriting or signature (from this point referred to as general graphical aspects), which consist of the style (cursive or manuscript, or a mix of both), the connections, the slant or slope of the writing (or signature) in general and of the letters, dimensions of words and letters (proportions, relative heights, absolute size, relative size, lateral expansion) and intraword spacings.

The second class of elements to observe is the elements of execution, which consist of the alignment of the signature to an imaginary baseline, the pressure, the beginnings and the terminations of lines, presence and form of diacritics and punctuation, embellishments, legibility and writing quality, line continuity, line quality and writing movement. The authors note these elements as being "the personal idiosyncracies of writing in which we find the subtle dissimilarities between the writing of one individual and the next" (p. 91).

A signature, by definition, will not possess a number of these elements that can be found in handwriting. Thus, the examination of a questioned signature involves an emphasis on the analysis of the dynamism of the signature, its dimensions and proportions, and the letter formation manner.

The authors that discussed the authentication of painters' signatures all agree that the first step of the examination consists of observing the signature with a naked eye and with small magnification (Ionescu, 1985). The different types of illumination techniques as well as their possible outcomes and goals are thoroughly explained in Chapter 3. This stage may be sufficient to conclude on the inauthenticity of a signature, for example as in the case cited by Ringe (2007), where the authenticity of a painting by Pollock was declared as false because of a misspelled signature.

In order to see if the signature coincides with the date of the painting, several macroscopic observations can be carried out (Ionescu, 1985; Lines, 2006):

- If the signature was added with a dry paintbrush onto paint that was not dry, the brush will have left groves or parallel striation marks.
- If the signature was added with a sharp object (such as a opposite end of the paintbrush), the same groove can be observed. The sides of the signature will be smooth. If the signature is added in a completely dry base, the sharp instrument will scrape bits of paint away, and the sides of the signature will be chipped.
- If the signature was painted with a paintbrush onto fresh paint, the brush stokes will carve into the painted media and the paint of the signature will seep into the paint base and both colors will be mixed. On the other hand, if the paint is already dry, the brush strokes will not leave an indentation, both paints are separated with sharp borders and compose two distinct layers.
- The craquelure network (described in Chapter 3) can also be observed: if the network is continuous between the signature and the paint background, and is thus not stopped by the signature, then "the material of the signature is contemporary to the painting" (Hours, 1976, p. 40). This does not prove that the painting is of the hand of the artist.

b) Analysis of the reference signatures

The questioned signature, once thoroughly examined, can be compared with a sample of known authentic signatures. It is noted by several authors (Ionescu, 1985; Goetschel, 1987; Hanna, 1992) that this collection stage of authentic signatures is much more complicated than his paper counterpart: "Obtaining and establishing known standards is the single most difficult factor in the examination of art".[93] The expert faces the challenge of gathering a sufficient amount of comparison material, which should be of the same painting technique and near the assumed date of the questioned signature (Ionescu, 1985; Widla, 1985). This can be quite difficult because this material is not likely to be accessible on one site, but is more likely than not to be spread among a number of museums, which thus forces the experts to work from photographs, probably not even taken by them.

On top of these technical difficulties, the expert can also be confronted with the reluctance of a museum to collaborate. Wilda (1985) suggests to work with several photographs of each signature, taken with diffuse and oblique lighting, in order to respectively determine the configuration and enhance the structural details of the signature. Unfortunately, none of the cases reported in the literature specify if the experts were able to examine the original comparison signatures or if they only worked from their photographic copies (Ionescu, 1985; Siegel, 2004; Lines, 2006). The number of authentic signatures used for comparison can range from four to fourteen. The same authors also specify that the authenticity of the comparison material should be questioned because the fact that a painting hangs in a museum is not sufficient to guarantee his authenticity.[94]

It is up to the expert to evaluate whether or not the reference material is valid. In any case, the number and type of signatures must be sufficient and representative in order to evaluate the natural variation of an artist, and bring out the constancies and variants (Ionescu, 1985; Buquet and Hellebranth, 1986): "it is necessary to follow the evolution of features of the signature on the entire career of the artist, in order to form a range of comparison that is truly representative".[95] As good as this seems on paper, the

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[93] (Hanna, 1992, p. 1105-1106)

[94] "Just because a work is in a museum or in a famous collection does not mean that the signature is established as authentic" (Hanna, 1992, p. 1111).

[95] Free translation of Buquet and Hellebranth (1986, p. 242): "La signature garantissant l'authenticité de l'œuvre, son examen graphique requiert

reality of signature expertise dictate that this goal is virtually impossible to achieve. These recommendations are, from a practical view, difficultly applicable.[96] As a matter of fact, for the experts that published casework, the number of authentic signatures used for comparison ranged from four to five (Ionescu, 1985; Siegel, 2004; Lines, 2006). According again to the authors, the known signatures must first be compared between themselves to determine if significant differences are observed. Let us note that none of these same authors specify what these "significant differences" consist of. Only one author, Wilda (1985), suggests examining signatures written in several different materials in order to estimate the intra-individual variability imputable to the writing conditions.

c) Comparison

For the comparison process, the authors cited above acknowledge that this type of signature examination represents a specific phenomenon, but at the same time they suggest using the same principles used in traditional handwriting casework. They propose to "take into account the particularities caused by the execution of the signature with a paintbrush, since it is different than the usual writing instrument, as well as the size and the model of the paintbrush".[97] A systematic list of the characteristics each author suggests to examine (as well as the ones they effectively examine is the casework examples) is presented below, along with their conclusions.

Lines (2006) observes the approach and ending strokes, the accent mark, and the form of the letters (wide, narrow, rounded or flat), and notes that these features present significant differences between the questioned and known signatures, comes to the following conclusion (p. 931-932): "The differences [...] support the finding that J.M.V. very probably did not sign this painting.

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obligatoirement une documentation de comparaison. Pour cela, il est nécessaire de suivre l'évolution du faciès de la signature pendant toute la carrière de l'artiste, de manière à constituer une gamme de comparaison qui soit vraiment représentative".

96 The authors imply, however, by stating such recommendations, that they have indeed reached them (even though they are, as stated, virtually impossible to reach). Furthermore, technical elements such as this are difficult to evaluate.

97 Free translation of Ionescu (1985, p. 352): "[...] on tiendra compte des particularités engendrées par l'exécution de la signature au moyen du pinceau, différente de l'instrument scripturant habituelle, ainsi que de la dimension et du modèle du pinceau".

In addition, the limited amount of known signatures [i.e. four] prevented a more conclusive finding".[98]

Ionescu (1985) proposes to observe the following features when examining the signatures. The last two being, according to the author, the hardest to correctly simulate:[99]

- Literal morphology
- Base line orientation
- Slant
- Dimension (without any specifications)
- Natural execution
- Accordance of the movement with the style of the painter

But in the case he presents in this same article, he examines the following characteristics, on top of the characteristics listed above, for the examination of the painter's questioned signatures (in the number of two):

- Emplacement
- Construction of the letters
- Spontaneity and continuity, as Ionescu states: "the features of the painting's questioned signature are spontaneous and continuous, proving a great dynamism and an ease in the handling of the brush".[100]
- Caesurae: This last element is decisive, because it is the presence of several unjustified caesurae that push him to conclude to the inauthenticity of the questioned signature.

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98 Although not the point of this chapter, the author would like to point out that she does not support this type of conclusions. Readers who would care to have more information on how to conclude according to probabilistic reasoning are referred to the section 4.4.

99 Strictly speaking, these last two elements are not features, but are rather inferences based on one or several observations.

100 Free translation from Ionescu (1985, p. 353-354): "[...] les traits de la signature du tableau expertisé sont spontanés et continus, prouvant un dynamisme et une grande désinvolture dans le maniement du pinceau".

Ionescu (1985) finally concludes that an expert can only consider himself the specialist of a very limited number of artists, because he has to develop an expert eye, and can only do so by observing a large number of signatures under different lighting conditions. To work as a traditional signature expert does, by "simply comparing signatures based only on a few original signatures, randomly-collected, exposes the expert to large risks of error".[101]

Siegel (2004), observed the following characteristics between a questioned and fourteen known Pollock signatures:

- Line/stroke quality
- Pressure
- Space between the letters
- Line continuity (caesurae)
- Form of the letters
- Size/height

She ends by stating (2004, p. 90): "Although the superficial appearance of the questioned signature is similar to Pollock's known signatures, a close, methodical examination reveals significant contrasting elements. These led me to conclude that the questioned signature is not genuine".

Even though experts generally agree that the basic principles of signature examination can be adapted to the authentication of painters' signatures, they are far from reaching a unanimous consensus on the analysis and comparison process, the possible conclusions and limitations that can be rendered, and the competencies required for such an examination. The general impression one can take how when reading these last paragraphs, it seems, is that every expert is following his own comparison procedure, all the while fixing unobtainable conditions for real case-work.

In the cases presented in the literature, none of the experts followed a strict declared methodological procedure; the characteristics observed by the

[101] Free translation from Ionescu (1985, p. 353): "[...] par la simple comparaison des signatures en discussion se basant seulement sur quelques signatures originales, rassemblées au hasard, expose celui qui s'y hasarde à de grands risques d'erreur".

different experts, and that allowed them to conclude, were never the same. It reveals the existing inherent gaps of this area of forensic document examination. The second section of this thesis proposal project aims to fill in these deficiencies, and in the end, allow the forensic document examiner to conduct such analyses.

4.4 Overview of the signature individualization rationale

The set of similarities and differences which are observed on the questioned and reference signature, which can be defined as the forensic findings in a case, must be assessed to determine whether they are more likely under the hypothesis of authenticity or the hypothesis of simulation. The expert, by estimating the probabilities of the observations under both hypotheses, will be able to support to a certain degree one of the two hypotheses. This level of support is expressed by the likelihood ratio, and is part of a Bayesian reasoning logic in the face of uncertainty.

4.4.1 Likelihood ratio

The comparison and evaluation of evidence is assessed in forensic science through the assignment of a likelihood ratio (LR), a component of the Bayesian theory (Aitken and Taroni, 2004, pp. 95-97). The use of the likelihood ratio to logically assess forensic findings is well established in some aspects of forensic science, and is emerging in the field of handwriting examination (Marquis *et al.*, 2011; Taroni *et al.*, 2012; Taroni *et al.*, 2014), being applied in some European laboratories. The likelihood ratio gives an estimation of the degree to which observations support one of a pair of competing hypotheses. The hypotheses can be formulated as "the signature is authentic, it was signed by the presumed writer (or artist)" (H_1), and "the signature is a simulation, produced by a third writer (or forger)" (H_2). The likelihood ratio will be given by the probability of the forensic findings given the first proposition is true divided by the probability of the forensic findings given that the second proposition is true.

The likelihood ratio can be formally expressed as follows:

$$LR = \frac{\Pr(E \mid H_1, I)}{\Pr(E \mid H_2, I)}$$

where: H_1 = The signature is authentic, it was signed by the presumed writer (or artist)

H_2 = The signature is a simulation, produced by a third writer (or forger)

E = The forensic findings made on the signature

I = Background Information, which is contextual information of the case.

The forensic findings traditionally consists of a list of similarities and differences found following a systematic comparison of each characteristic. The notion of characteristic is extensive and can range from the general aspect of the signature such as the base line to particularities of character construction (for example the form of a letter). The findings consists of a set of observed features or characteristics: x_1, x_2, x_3, …, x_n.[102] Extensive lists of the features that will be studied are presented in Chapter 7. Each one of these characteristics will be evaluated under the pair of competing hypothesis to assign the likelihood ratio. The features may also be potentially evaluated collectively: the FHE will observe each characteristic individually and ultimately be able to integrate, somewhat holistically, its value into the establishment of its overall likelihood ratio.

The numerator can be translated as the probability to observe the characteristic x_i, knowing that the artist signed the questioned signature. This can also be linked to the reproducibility of the characteristic x_i of the authentic signatures. This value may be assigned to it's maximum, which is one. If the features are perfectly reproducible, all of the features on the questioned signature are present in this case (i.e. H_1 is true) in all of the reference signatures.

The denominator represents the probability of observing the forensic findings if the alternative hypothesis H_2 is true, or specifically in this case, as the probability to observe the characteristic x_i, knowing that someone other than the artist (i.e. a forger) wrote the questioned signature. This represents the

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[102] These features are observed on both the questioned and the known signatures.

forger's capacity to observe and correctly reproduce the characteristics of the authentic signature. The characteristics that are the hardest to reproduce (in other words, the characteristics which the forgers have a hard time imitating) will minimize the value of the denominator. The background information I is useful here because it will dictate that either one forger or a pool of forgers are to be considered as potential authors of the simulated signature. In this sense, the background information I can dictate two alternative hypotheses H_2: the signature is a simulation, but that the forger is unknown, or the signature is a simulation, and the forger is known.

4.4.2 Relevance of a characteristic

A characteristic can be judged as relevant[103] if the examination of the characteristic leads to a likelihood ratio higher or lower than one. In other terms, the relevance can be visualized as the average weight a feature will have in the decision balance. Of course, not all characteristics are of equal significance, and they will therefore not have the same weight in the evaluation. For example, Hilton stated "a single significant difference[104] between the (known and unknown) specimens is a strong indication of two writers, unless the divergences can be logically accounted for by the facts surrounding the preparation of the specimens". For this author, just this one characteristic in question is enough to make the LR balance towards zero, because of a low numerator. Even with the presence of similarities, a single difference can outweigh the similarities and be ground for an exclusion, one must 'only' be able to tell if this difference is significant or not (by gauging its weight).

Huber and Headricks (1999) define the two differences that one can encounter in writing: lucid differences, which are obvious and include differences in the style, dimensions, and letter construction for example. Elusive differences are subtle and discrete (commencements and terminations, line continuity and

[103] The relevance can be seen as the ability of the feature to have an effect on the LR, depending on whether it applies to the numerator or the denominator.

[104] The definition of expressions such as 'significant difference', used by some FDE, has been subject to debate. Whiting (1996) put forward the vagueness found in the literature of what consists of basic differences, significant unique differences and fundamental differences. He found the terminology to vary according to the authors using it, and proposes several classifications. For these reasons, the term 'relevant' will be used in place of 'significant difference' since a proper definition of this expression is lacking in literature, and is differently used according to the authors.

quality). In the same manner, disparities, such as defined by the same authors can be perceived as lucid differences, while divergences are elusive differences. According to the authors, disparities occur in elements of style, while divergences pertain to elements of execution, which correspond to more "personal aspects of the writing" (Huber and Headrick, 1999, p. 48).

The characteristics that present the highest or lowest likelihood ratios will be preferably chosen since they possess the best relevance and will thus have more weight in the final decision process. The combination of the studied characteristics will consequently allow the expert to evaluate the authenticity of the questioned signature.

Unfortunately, at the present state, no tools exist to evaluate the weight of observable findings on signatures on paintings. The existence of a list of characteristics that should be considered when authenticating signatures on works of art is inexistent, contrary to the expertise of traditional signatures of pen on paper (see subsection 4.3.3 on the examination process for a reminder of these features). This ensues the absence of the proper tools that could be used for a signature expertise.

It has been shown in these last sections that painted signatures consist of a specific sub-field of signature examinations. First, a number of features that are normally used to characterize a written signature cannot be (or are difficultly) assessed on a painted signature. These features are, namely, the:

- Pressure of the line stroke. Studies on the difference in diameter of the line stroke could be an indication of the pressure applied on a paintbrush. The pressure of a line stroke is particularly important to help assess the dynamism of a signature.
- Retouching (or touch-ups) of the line. Retouches can be extremely difficult to determine if a line stoke is painted over an initial stroke made with fresh paint. In this case, since both the original and touch-up lines melt together to form one visible line, it is extremely difficult to tell if there is only one initial line stoke, or if second or third strokes were painted over the initial stoke.
- Hesitations. Line trembles and hesitations in the line stroke can be "masked" in the line stroke since the line is not as defined as a line made with a traditional writing instrument. The use of a large amount of paint charged onto the paintbrush can also produce a larger and

irregular thickness of the line at the beginning of the paint deposition, when, by capillarity, the paint on the paintbrush coming into contact with the canvas surface transfers in large amounts. Hesitations can also be painted over to hide or diminish their presence and make the line stroke appear with constant boarders.

- Fluidity. The impression of a fluid signature line stoke can be falsely given, even with a slowly painted line stoke, because of the nature of the writing instrument. A paintbrush will easily produce line strokes with smooth boarders, even though the line is slowly drawn. Moreover, signs of absence of fluidity can be masked by retouches.

These deficiencies, along with the existing subjectivity of the observed characteristics will be resolved by developing a method that focuses on a set of observable features that defines the signature. In this manner, the expert will be able to assess the authenticity of a questioned painted signature through a transparent reasoning process.

5 Discussion on expert conclusions

The search for a more science-based examination requires the discussion of a certain number of parameters gravitating around this notion. Does the expert possess a golden eye, unknown to non-initiated members of the forensic community? How well, and with what tools, can the expert assess his knowledge and competence? Or is there an illusion of objectivity? How can the expert express his uncertainty without losing credibility in front of his audience? Different factors have been documented to have an effect on the conclusions of an expert, as well as the possible biases that he can encounter. These are just a few of the many issues that forensic scientists are facing today, and in the context of this research, will have implications on how the signature expertise is carried out and how it is viewed as by the forensic, judicial, and laymen community. These issues will be addressed in the following sections.

5.1 Skills, confidence and competence of the expert

The present day expert is being pushed by different stakeholders and protagonists to appear anything but confident, and conveying an image of an expert possessing an infallible eye. As articulated by Charlton (2013, p. 71), "Fingerprint examiners are discouraged from displaying uncertainty or self doubt. It is a sign of weakness within the fingerprint profession to display anything other than absolute certainty". There are two key aspects that can be taken from this citation and that are completely transferable to the field of handwriting and signature examinations. The first is that experts must (or are expected to) be confident in their findings and associated conclusions. The second is the notion of absolute certainty that the expert must convey.

There is a simple reason why experts cannot display self doubt: confidence is often mistaken for competence (Evans, 2012). A study conducted by Tetlock (2005), and cited by Evans (Ibid.), found that when predicting an outcome, individuals who were well-confirmed experts in political science were more overconfident than their colleagues and provided less correct outcomes of their predictions. Evans defines overconfidence as one having an "unwarranted belief in the correctness of one's statement. [...] it means in believing in something more strongly than is justified by the evidence, and thinking you know more than you really do". (Evans, 2012, p. 24). This can also be defined as a low level of metacognition, which is basically how much someone knows he knows of something, or knowing about knowing.

Studies comparing FHEs with laypersons have confirmed that document experts do possess a skill of expertise when examining questioned signatures (Found *et al.*, 1999; Kam *et al.*, 2001; Sita *et al.*, 2002; Dyer *et al.*, 2006; Dyer *et al.*). Experts are therefore more competent than laypersons, and this concept has been adopted by the judicial system: "[...] the law has accepted that, as to the defined area of specialized knowledge or skill, the products of their practice are better than the jury could do alone" (Saks *et al.*, 2003, p. 83).

There are several ways [105] in which an expert can address his level of competence (Huber and Headrick, 1999). First, the academic qualifications of an expert can attest of his general knowledge, and that he is capable of understanding and applying scientific methods. This solid academic experience should be coupled with the training program he completed in the field of document and handwriting examination, a second element to attest of the competence of the FHE. There are very few existing training programs, most FHE's (of usually a two-year period) taking the form of an apprenticeship with more experienced colleagues, or tutors, and by direct immersion in casework. Third, the quality of the expert's research publications (books, peer-reviewed articles, etc.) can also be taken as an indicator of the competence of an expert. Fourth, participation in continuous education, in workshops, and in meetings, and keeping up to date with the latest advancements and publications are necessary for experts to maintain their knowledge. This maintenance in proficiency is also achieved through the regular participation in proficiency testing, [106] and of course (most importantly) by obtaining correct results. Successful participation in such tests is also an element that could attest of the reliability of an expert.

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[105] The author is assuming that the expert possesses the proper facilities and equipment to undertake full document examinations. Although this may seem to be a given, many FHE who work privately possess only limited laboratory materiel.

[106] Two annual proficiency tests are usually carried out by European FHE, one distributed by the European Network of Forensic Handwriting Experts (an Expert Working Group of the European Network of Forensic Science Institutes), and one by the Collaborative Testing Services (CTS, USA). Other tests, such as the Skill-Task, Training, Assessment and Research (ST^{2}AR, USA), and the Forensic Profiling Laboratory (La Trobe University - Australia) are also employed (Found and Ganas, 2013).

Courts have a tendency to use the number of years of experience an expert has to gauge his competence, but this criteria is not precise and should not be used as a golden standard, as one can only handle one or two cases a year.[107] If experience is deemed important, one should therefore speak in absolute number of cases he handles personally, and the number of cases for which he stood in as a controller (verification stage). If the numerous studies concerning the error rate of FHE is representative of the actual casework, then experts can produce erroneous conclusions. Kam (Kam *et al.*, 2001) showed that signature examination experts produced approximately 0.5% Type I errors (false positive) and 7% type II errors (false negative). Sita *et al.* (2002) also found that FHEs produced erroneous conclusions: an average error rate of 3.4% (including both false positives and false negatives) in signature examinations. In order to attest the quality of their work, experts could thus more often make the Court aware of such studies, but also of their personal results of the last proficiency tests taken in their domain.[108]

The last decades have witnessed the emergence of an array of different programs and associations that offer membership to FDE and FHE (Huber and Headrick, 1999). These programs are based in the United States and are limited to Americans or residents of non-European Anglo-Saxon countries. The five most important (listed by ascending foundation dates) are the American Society of Questioned Document Examiners (ASQDE-1942), the American Board of Forensic Document Examiners (ABFDE-1977), the National Association of Document Examiners (NADE-1979), the Association of Forensic Document Examiners (AFDE-1986), and the more recent Board of Forensic Document Examiners (BFDE - date of foundation unknown).

Membership in these programs can also be perceived as a measure of an expert's competence, since certain criteria must be met to be able to join. All of these associations offer some form of membership and certification programs, each with different and specific requirements and standards. Most require a minimum education of a Bachelor degree (except the NADE), a two-year training in questioned documents, and having undergone a form of written, and/or oral, and/or practical examinations (except the AFDE). Continuous

[107] Even here, one could argue that an expert only works on a few cases a year, but correctly (with a correct work methodology and with correct results), as opposed to someone with a large caseload, but who makes repeated mistakes.

[108] The author places emphasis on the fact that the type of proficiency test must be given; some tests are known to be either too easy, or too far-fetched to represent day-to-day casework.

certification must also be achieved through (limited) proficiency testing (ABFDE, ASQDE, and BFDE), participation in meetings, and publications.[109] There are therefore a number of different sources of testing of the competence and qualification of FDE, each with different criteria for obtaining membership, which makes it practically impossible to compare or rank them. This somewhat confusing collection of programs makes it even more complicated to clearly communicate one's competence, and for a layperson to comprehend one's capabilities and limits an expert can offer.

The second point in Charlton's citation (op. cit.) is the need not to "display anything other than absolute certainty". Uncertainty is a notion that most people are uncomfortable with. Individuals prefer a reassuring 100% sure answer, rather than a closer to the truth 80% certainly answer. The problem with the remaining 20% is that it instills doubts in people's minds. Doubt is a particularly touchy subject in the justice system, and people have a hard time coping with this type of uncertainty. However, with science, comes doubt: the two are intrinsically linked. As stated by Margot (2011, p. 95), "Serious forensic scientists do not contest uncertainty. They promote methods for presenting evidence with their uncertainties [...]. As a consequence, experts must become comfortable with the notion of uncertainty, and must convey this message to the stakeholders that are on the receiving end of their conclusions."

The notion of dealing with uncertainty in forensic science is not novel. Reiss (1906, pp. 868-869) supported this argument over a hundred years ago when he referred to[110] handwriting examinations: "In many cases, it is not possible for us to bring compelling and tangible evidence to the investigation [...], and we must then say to the judges: 'The careful and thorough study of the handwriting convinced us that the incriminated documents are from a particular individual, but we can not bring you irrefutable proof of this fact'."

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109 For a precise list of the qualifications and requirements for certification, the author refers the reader to the Internet pages of each of these associations: www.asqde.org - www.abfde.org - www.documentexaminers.org - www.afde.org - www.bfde.org - Last consulted Oct. 2014.

110 Free translation of "Dans maintes cas, il ne nous est pas possible d'apporter à l'enquête des preuves irréfutables et tangibles [...], et nous devons dire alors aux juges: 'L'étude méthodique et approfondie des écritures à examiner nous a convaincu que les documents incriminés proviennent de tel ou tel individu, mais nous ne pouvons pas vous apporter la preuve irréfutable de ce fait'."

Dissenting Circuit Judge Michaels argued over a decade ago that "Professions of absolute certainty by an expert witness, however, seem out of place in today's courtroom".[111] Likewise, a study conducted in 1971 and reported by Evans (2012) showed how differently the phrase "beyond a reasonable doubt" could be interpreted (Ibid., p. 122). The study found notable differences in the interpretation of the phrase, going from 83% degree of belief for jurors, to 89% for judges.

So why are courtrooms still finding it hard to accept uncertain conclusions, even though they "only" need an 83 percent degree of belief to convict someone? Why are the majority of Courts asking experts to give their conclusions categorically? Ligertwood and Edmond (2012) offer a response to this question by observing that juries have been taught to convict a person as guilty only if they are satisfied with the elements presented to them, and have brushed away any possible innocent explanations of their implication with the evidence. They state (p. 290) that "this approach to criminal proof, firmly entrenched in the presumption of innocence, seeks not mathematical probability but apparent certainty [...]".

Likewise, the stakeholders (the legal community, jurors, etc.) on the receiving end must correctly interpret the message the expert is giving. They must understand the inherent risk of the judgment procedure: "In this sense, we just have to accept that there is a risk, just as there is a risk in a process of judgment. Justice failures happen and it is an easy way out of responsibility to make forensic science accountable for mistakes rather than face uncertainties and their associated risk" (Margot, 2011, pp. 95-96). One must also keep in mind that the terminology *beyond a reasonable doubt* refers to moral certainty. Someone is convicted as being guilty with the moral certainty that he is guilty. Again, the forensic scientist must convey his message with the most transparency possible in order to assist at best the justice system so it clearly understands the limits of the forensic findings.

Several elements prevent individuals from being comfortable with uncertainty, one of which is the "ambiguity intolerance". This intolerance emerges because "ambiguity or uncertainty is perceived as a threat or a source of discomfort and anxiety" (Evans, p. 54). People feel more comfortable when they know, or do not know, something for certain. The need for closure (overconfidence), or on the contrary, the need to avoid closure

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111 United States v. Crisp, 324 F.3d 261 (4th Cir. 2003), paragraph 53.

(underconfidence), are two opposing forces that are extremely important in the decision-making process. "In a person with high risk intelligence, these two opposing forces are so evenly matched as to cancel each other out, leaving the work of judgment to proceed entirely on the basis of rational calculation. For most people, however, one force will typically be stronger than the other, and as a result their probability estimates will be systematically biased in one direction or another" (Ibid., p. 54).

Our ability to judge between different probabilities also depends on where the probabilities are set on the scale. Intermediate probabilities are harder to juggle with than extreme probabilities: going from 89 to 90% occurrence is not the same as going from 99 to 100%, even though both incur a 1% probability change. As soon as we reach the extremes of the probability scale, we are more at ease in comprehending slight differences (Allais, 1953).

A second element that diminishes a person's capacity to deal with uncertainty is the all-or-nothing fallacy: there is a "tendency to think of proof, knowledge, belief, and other related concepts in binary terms; either you prove/know/believe something or you don't, and there are not shades of grey in between." (Evans, p. 61). The all-or-nothing fallacy pushes probability estimates towards the extremes of 0 or 100%. This "sets the threshold (for proof [..]) as high as possible, at the level of absolute certainty. Certainty, of course, is very difficult to achieve [...]". This all-or-nothing fallacy encourages the idea that something is false, just because it can't be proven with certainty. Fortunately, the judicial systems that have embraced the Bayesian reasoning approach now better understand the implications and limitations linked to such a process, whereas systems that have not still look for certainty from the expert; they even expect it.

The best way to convey uncertainty is to begin by understanding our own personal limits of uncertainty. The more a person gains knowledge in his domain, the more he will be conscious of the limits of his expertise (Evans, 2012). A good handwriting or signature expert would therefore be a person who is aware of the limits of his conclusions in a case. He would have identified and converted all of the "unknown unknowns" into "known unknowns", whereas the less competent expert would have just left them at the "unknown unknowns" stage.[112] The way to leave the latter stage is to gain

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112 Evans states that knowledge can be classified into four divisions: the known knowns (things we know we know), the known unknowns (things we know we

more knowledge and become more competent. This can be achieved by continuous training programs, proficiency testing, and, as exposed in the next section, an acknowledgement of the possible biases an expert can be subjected to.

There are several ways to help people assess what they know they know, and how well they know it. Evans (2012) reports the use of highly effective training problems in companies to help experts assess their metacognition of their subject area. Training involving different case scenarios with specific feedback helps experts adjust their levels of under or overconfidence, a key element in increasing one's grasp on uncertainty (or risk intelligence).

The recent response to the R v. T ruling,[113] for which a list of forensic scientists responded in an open response in the journal Science and Justice (Guest editorial, 2011, p. 1), states, in its seventh point, that "Probabilities should be informed by data, knowledge, and experience", and that "all data collections are imperfect", so in turn, "different experts might assign different probabilities to the same set of observations". Indeed, probabilities are personal, or in other words, subjective. Because during this frenzy to reach objective standards, quite a few have forgotten that probabilities are by definition uncertain. They are not estimated by one person, but are assigned by him. Each person, therefore, will have his own probability: there is not only one probability for one event.

The skills, confidence and competence of the expert have thus been shown as important factors defining the expert's expertise. Other factors can also have an impact on his expertise and conclusions, and are presented in the three following sub-sections.

5.2 Opinions and context bias

All individuals are biased in one way or another in their judgments. A great number of biases and their effects having been documented in the field of decision-making (also referred to as cognitive bias). Context bias, or

don't know), the unknown knowns (things we don't know we know, more specifically, things we know but fail to use when we need them because we fail to see their relevance), and the unknown unknowns (things we don't even know that we don't know).

113 R v. T, Court of Appeal - EWCA Crim 2439, 2010.

confirmation bias, is the bias which is the most frequently brought up in the forensic practice. However, a number of other biases also exist. Tversky and Kahneman, known as the fathers of cognitive bias, documented heuristics and their biases over 40 years ago. The aim of this section is to present an overview of biases than can potentially effect the FHE during his casework. By acknowledging the possible sources of the bias, one is open to finding ways to diminish or eliminate them. Several specific solutions for FHEs will also be proposed towards this aim.

The consideration of potential bias effects in forensic science is rather recent. The first study in forensic science was actually conducted in the area of handwriting examination already several decades ago (Miller, 1984). Miller led a study on the potential confirmation biases FHEs could be subjected to by testing the influence of contextual information on two small groups of examiners. The results of the study supported the hypothesis that the group, which was provided with contextual information, concluded in a biased manner. Miller conducted another test of this nature, but in the area of hair examination, and reached similar conclusions (Miller, 1987). Studies on forensic bias disappeared for years following these two analyses. It was not until the Daubert trilogies, which required studies on conclusion error rates, that the question of inherent bias effects emerged once again (Saks *et al.*, 2003; Dror *et al.*, 2006). Since then, the potential bias of the forensic scientist has become an important research topic.

The availability heuristic is defined as follows: In order to estimate a probability of the occurrence of an event, our brain will try to recall if such an event has ever taken place. If it has, we will estimate the probability as "likely". If not, we will estimate it as "unlikely". The difficulty with this heuristic is that it is affected by several biases during the estimation process, three of which are developed below: the bias of the ease of retrievability, the bias of imaginability, and the bias of illusory correlation. These three associated biases of the availability heuristics (more associated biases exist), leads us to produce systematic errors when estimating the probability of occurrence of an event (Tversky and Kahneman, 1974; Evans, 2012).

The first bias of the availability heuristic is linked to the ease of retrievability of an instance (Tversky and Kahneman, 1974). The easier it is to retrieve the recollection of an event, the higher we will estimate its occurrence. In other words, if images of an event can be easily remembered, or if an event is often (over)-publicized by the media, we will have a tendency to overestimate the likelihood of occurrence of an event that is known to us (and underestimate the likelihood of a situation that is difficult to imagine).

In fact, just picturing an event happening is enough to have our mind overestimate its occurrence due to the bias of imaginability, the second bias of the availability heuristic. False memories can even be created and bias a person into giving a sense of confidence for something that never happened (Evans, 2012). The power of suggesting events that took place is plausible and should be kept in mind when discussing witness events.

The bias of illusory correlation is also documented by Tversky and Kahnemann (1974) as a bias of the availability heuristic. It consists of finding or overestimating correlations in between two entities (such as suspiciousness and peculiar eyes in the example cited by the authors) although they are inexistent. This bias even pushes us to exclude contradictory data once our minds are made up. The authors even documented the fact that the effect "[...] persisted even when the correlation between symptom and diagnosis was actually negative, and it prevented the judges from detecting relationships that were in fact present" (Ibid., p. 1128). Likewise, if we recall two events as being strongly correlated, then we will overestimate the frequency of their co-occurrence: "when the association is strong, one is likely to conclude that the events have been frequently paired" (Ibid., p. 1128).

The FHE should remain aware of these three possible biases when working on cases. This awareness will of course not make the expert immune to bias, but does constitute a cornerstone in minimizing bias risks. The first bias, linked to the ease of retrievability, could have an effect on the expert in the choice of his hypotheses. He may more easily pick hypotheses by pairing his case with past casework presenting the same types of observation and may unconsciously push aside working hypotheses that should also be addressed (and likewise ignore a hypothesis that is rarely encountered in cases). The bias of illusory correlation might also influence the expert by making him overestimate the correlation of one type of observation with a given hypothesis. For all of these issues, the expert must maintain an open and critical mind when setting his hypotheses.

Another considerable bias that can have important consequences on a conclusion is the confirmation bias, which states that people will tend to choose elements that confirm their beliefs, rather than look for elements that go against or contradict them (Evans, 2012). For example, an expert may have a initial "good impression" and stick with it by only looking for elements during the examination that confirm this first impression. The instilled ACE-V approach, if properly carried out, aims to diminish to a maximum the risk of confirmation bias. Indeed, if an expert jumps directly to the comparison phase before completing the first analysis phase, he puts himself at risk to this bias. This scenario can unfortunately be the case, where poor practices and time constraints have forged this type of shortcut.

However, if the expert carefully examines and analyses the questioned signature before moving on to the analysis of the reference signatures, any additional elements noticed during the comparison phase will need to be extremely well justified by the expert if taken into account during the evaluative phase.

Also, an additional solution to downplaying confirmation bias is to look ourselves for elements that are for, and particularly against, our opinions during the evaluative phase. Normally, the FHE already incorporates this reasoning process in the Bayesian approach, where the observations (similitudes and differences) are discussed under each of the alternative hypothesis. In the specific case of this study, if both the holistic signature expertise and the developed model are used, a possible confirmation bias might be developed between the two. If the results of the model are taken at face value, the expert might want to adapt the results of the casework to confirm those obtained by the model (an extensive discussion of these issues is presented in Chapter 10).

Probability outcome independence is also an important rule to follow when assigning a probability of occurrence to an event. By following this rule, a person is not influenced by the outcome he wishes (or does not wish) to obtain. One would think that the FHE follows the rule of probability outcome independence since he does not (theoretically) have an apparent reason to conclude one way or another. Indeed, he will not be richer or poorer if he concludes that a signature is authentic or a simulation. In other words, no personal profit is to be gained,[114] so wishful thinking should not influence the expert's conclusions. However, in the case of private cases of authentication of artwork, and particularly in the case where the expert receives a percentage

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[114] Unless, perhaps, the expert finds more satisfaction in concluding that a signature is authentic, or vice versa. Although this is extremely unlikely, it cannot be excluded, particularly in the domain of art authentication.

value of the sales price of the item, wishful thinking of a positive outcome is more than possible, even though the expert might unconsciously do it.

A final bias worth mentioning is the hindsight bias, which consists in overestimating the correctness of our projections once the event has occurred. For example, if someone tells us after the fact that someone confessed to having simulated a signature, we'll have a tendency to say "I knew it!", even though at the time we would have concluded less conclusively. In other words, if we had assigned a falsely high probability of an event, we will lower it, and if we had assigned a too low probability, we will increase it (Evans, 2012). The important message of hindsight bias is that we overcome it in order to learn from our mistakes. Of course, someone with hindsight bias will not be able to learn from his mistakes, because he assumes that he has always given the correct projections of an event. Indeed, as Evans (ibid., p. 94) rightly suggests "By minimizing our errors or distancing ourselves from them, we rob them of their teaching potential".

The danger of hindsight bias, particularly with a combined use of holistic signature expertise and the developed model, is that the expert takes the model's results at face value, and actually adapts his conclusions accordingly. A solution to reduce the possibilities of hindsight bias is the regular participation in proficiency tests. If the expert records his results and reviews them in light of the test results (ground truth), he can learn from possible mistakes in judgment for future casework. The importance of these proficiency tests is paramount for forensic scientists, the ground truth being very rarely obtainable. The experts thus have very few possibilities, in comparison with the amount of caseload carried out, to establish or confirm the veracity of their results and diminish the effect of hindsight bias.

Another possible effort to help diminish the effects of hindsight bias is to extensively document each step of the examination process, before obtaining the model's results. Therefore, the results of the holistic expertise are not influenced in one manner or another by the model, since they would be put in relation at the very least at a post-analysis phase. The resulting benefit, which is linked to the feasibility of such a practice, will be discussed in the last section of this chapter.

On top of the biases presented beforehand, there are also several uncomfortable social forces that can modify our beliefs. One of these is the inclination we have to conform our opinion to that of the crowd. The need for social conformity is well established, and it could very possibly be encountered in a smaller microcosm of expert pools. A younger expert might line up with the conclusions of a more experienced and confident older peer (but who, as seen earlier, is not necessarily more competent).

As these last paragraphs have shown, a number of different biases may have an effect on the expert during his examination. The awareness of their existence is a great first step, but the acknowledgement of the role they may play is vital to be able to diminish their effects.

A number of elements can be carried out to reach this goal, but the underlying key lies in transmitting only the relevant information to the document examiner. Such information can be considered as the information necessary for the FHE to lay down his working hypotheses. It comes down to a just measure: knowing what is sufficiently necessary, but not knowing too much to cross over the line of the unnecessary (and potentially biasing). Put simply, it is the distinction between the relevant and the irrelevant context. In the case of the expertise of signatures on paintings, the unnecessary information might be, for example, the conclusions of the historical, stylistic and analytical examinations. However, information concerning the habits of the painter are useful for the examiner. For example, did the artist have a tendency to sign his paintings as soon as they were done? What brushes and paint did he usually use? The difference between both groups is indeed a fine one, for that reason, the supervision by a third party that filters (or confirms) what should or should not be brought to the attention of the examiner, a sort of an intelligent filter. Indeed, Miller (1984) already advised to implement procedures to limit bias (in particular, police forces or attorney should not state their beliefs of guilt to the FHE before he performs the casework). Found and Ganas (Found and Ganas, 2013) recently proposed the management of context by competent services to reduce potential bias effects. In this case, a third party (the context manager) oversees the input (from the client) and the output (to the document examiner) of contextual information. This context manager procedure has been documented to have numerous advantages.

On top of structural and procedural improvements proposed, the FHE may also diminish possible bias effect keeping in mind several considerations. The first is the acceptance that initial judgments are sometimes incorrect and revision of conclusions may be necessary. He must also keep a critical mind when working cases and evaluating the information at hand, at all stages of the examination procedure. Finally, he must be aware of the elements and observations that support, but also go against, both of his working case hypotheses. The forensic document examiner carries out a reflective practice, and an open mind must be maintained at all times.[115] A procedural structure is indeed one way to diminish bias, but one must not forget that other solutions lie in the training and education of the FHE (where risks of bias are rarely addressed), the reinforcement of continual training programs, implementation of certification programs and better conceptualization of proficiency testing.

It is absolutely necessary to understand the inherent mechanisms of the evaluation process. Research in this area has become a central preoccupation in the last few years, increasing greatly after the Daubert hearing (Risinger *et al.*, 2002), and after the individualization of the wrong fingerprint in the Madrid bombing in 2004 (Dror *et al.*, 2006). Studies in this area have shown the existence of a number of potential biases that can affect the FHE during his expertise, and have even been coined by Risinger as a "peculiar vulnerability of forensic practice" (Risinger, 2009, p. 24). Solutions to diminish these bias effects have been proposed (Found and Ganas, 2013; Kassin *et al.*, 2013) and are already implemented in some laboratories.

However, the continual on-going research in this area have reached a point where a rock is thrown in the direction of any examination where hints of bias are suspected, demanding a reasoning process exempt of subjective reasoning. These studies are reaching for an objective forensic science, as the remarks made in the recent National Academy of Science report on strengthening forensic science attest: "All of these sources of bias are well known in science, and a large amount of effort has been devoted to understanding and mitigating them. The goal is to make scientific investigations as objective as possible so the results do not depend on the investigator" (National Research Council, 2009, p. 124).

5.3 The quest for an objective science

Objectiveness is perceived as being scientific, whereas subjectivism is seen as something unscientific. The recent R v. T judgment[116] clearly depicts the general perception of subjectivism in the judiciary: "It is essential, if the

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115 But not so open that his brain falls out, as the common saying goes.
116 R v. T, Court of Appeal - EWCA Crim 2439, 2010 (point n°96).

expert examiner of footwear expresses a view which goes beyond saying that the footwear could or could not have made the mark, that the report makes clear that this is a view which is subjective and based on his experience. For that reason we do not consider that the word "scientific" should be used, as, if that phrase is put before the jury, it is likely to give an impression to the jury of a degree of precision and objectivity that is not present given the current state of this area of expertise".[117]

Likewise, the recent NAS report (National Research Council, 2009) also leans towards this objective reasoning by stating that (p. 125): "The premium that science places on precision, objectivity, critical thinking, careful observation and practice, repeatability, uncertainty management, and peer review enables the reliable collection, measurement, and interpretation of clues in order to produce knowledge." This statement depicts the unrecognized conflicting definitions of uncertainty and objectivity, since they are presented here in the same sentence.

These recent statements show the judiciary's need for an objective forensic science. It's what the people want, just as they want certainty for the natural reason that we are uncomfortable with uncertainty. Objectiveness is also an easy word to toss around to increase the attractiveness of a procedure or method. We want an objective science with objective methods and tools. In short... we want to be sure? Who wouldn't? But is this certainty possible? Or is an illusion we use to reassure ourselves in our conclusions? The quest for objectiveness is closely associated with that of certainty.

This increasing desire to reach absolute objectivity in forensic science goes hand in hand with the increasing tyranny of numbers and the need to absolutely quantify results in order to increase their "objectivity", exempt of any potential bias. This need to quantify every observation does not necessarily imply a more sound science-based discipline, and shuns the forensic reasoning process completely, which is based on a discussed methodology, a transparent reasoning process, and a probabilistic evaluation of observations.

Authors such as Berger and Berry (Berger and Berry, 1988, p. 159) have raised awareness against precisely what is stated in R v. T: the illusion of

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117 See the discussion of the scientific nature of forensic science and of handwriting examination, which is addressed in Chapter 4.

objectivity in science. They affirm that "[...] this general perception of the objectivity of statistics, and perhaps of science in general, may be misguided. [...] objectivity is a loaded word, and the next worst thing to being a fraud is to be 'nonobjective'." Being perceived as a fraud is a perception that a forensic scientist can ill afford, particularly in the current state of hostility towards forensic science.

Studies in the field of handwriting and signature analysis, under fire since the Daubert hearings, have sought to develop objectiveness in historical subjectivity. Recent years have seen the emergence of a number of studies that aim to objectify the aspects studied by the FHE (Rogers and Found, 1996; Rogers *et al.*, 2003). The present study also aims to objectify the examination process and hence increase its attractiveness in Court. These turns of events in Courts has also triggered an auto-questioning, and reinforcement, of scientific basis of forensic science within the forensic science community (Crispino *et al.*, 2011; Margot, 2011). The authors conclude that two of the founding laws of forensic science, Kirk's law and Locard's law, are both scientific laws as "they add knowledge that can be measured and used in logic for the sake of the law" (Crispino *et al.*, 2011, p. 170). However, an aim to objectify procedures is different than having an expert perform his expertise as a machine (or only with machines), with no contextual information at hand (we would not want him to be biased), and with objective results. The first is attainable, but the latter is unrealistic. One must not confuse "science" with "objectivity", since as discussed before, the two are not mutually exclusive.

The recent paper by Biedermann and Taroni (2013), offers responses to these recent advocates of objectivity. The authors specify the different perceptions of the notion of objectivity in forensic science today, as well as their perception by the main stakeholders of the receiving end of the expert's conclusions. The quest for an "objective" forensic science, carried out for example without contextual information, is unachievable. For one, the FHE must be aware of the context in which he is evolving. Knowing the contextual information of a case is not necessarily negative. Actually, it is vital, particularly in the examination of handwritings and signatures. The expert must however be transparent in his report of what contextual information was given to him to establish his hypotheses, as suggested by Found and Edmond (Found and Edmond, 2012).

Margot (2011, p. 93) highlights the importance of knowing the contextual information of a case: "Knowing what is out of place, extra-ordinary, means, again, that case information is at hand for the scientist to use to test the best possible source of information that may be present to understand a potential value of observations made. Otherwise, the scientist may focus on elements that appear strange but that are quite natural in a given environment". This observation is particularly relevant in the area of questioned documents: the hypotheses of a given case can change drastically depending on the context of the case. Indeed, observations made throughout a case may have a number of potential causes. The context allows the forensic scientist to eliminate causes that can be explained in a given environment (Margot, 2011).

5.4 Science defined by transparency

The quest for an objective forensic science is, as discussed beforehand, an insatiable quest. This opinion is not shared by everyone, and a number of different stakeholders expect this objectiveness when dealing with forensic findings. However, what they should expect is forensic science defined by transparency.

A first step in this direction can be reached by communicating the illusion of objectiveness to these different stakeholders. One word is crucial here: transparency. Courts are demanding objectivity because a number of experts have been giving it to them, without explaining their conclusions, but rather by basing them on experience. If the expert explains his examination procedure, his assessment process, and how he reached his conclusions, all in the most transparent manner possible, the audience can have a better understanding of the process and its limits. Findings naturally have a receiving end: they are intended for a specific population of listeners. Ideally, the output of expertise should correspond to the input of these stakeholders: Both sides must understand the results and their inherent uncertainty (Budescu *et al.*, 2009).

Champod (Champod, 2008) advocates a move towards more transparency in forensic science activities and procedures in the wake of the "objective mania". He states (p. 114) that the evaluation phase of the ACE-V approach for fingerprint examination is obscure and "is rarely described in the literature in a logical and transparent manner". This same assessment can be made for handwriting and signature analysis. Logically, this would be the first step in documenting transparent methods, the next step being their communication in courts.

Again, Reiss (Reiss, 1906, p. 876), ahead of his time, highlighted the necessity of clearly communicating the steps used by the expert to reach his conclusions, in order for the judicial crowd to fully understand his findings: "By reporting [by the expert], for example, the different ways to discover handwriting forgeries, etc., the judge or the investigating magistrate will be able to control the report of the expert, who he instructed to discover the truth. He will thus know what value can be attributed to this report".[118]

The ACE-V approach, although argued as being "objective" by some, remains a subjective procedure in the author's opinion, as is the interpretation of forensic findings. This opinion is shared by a number of authors (Biedermann *et al.*, 2008; Biedermann and Taroni, 2013), even in areas of forensic science that have traditionally been classified as the objective branches, such as fingerprint examination (Langenburg, 2012). However, the notion of "subjectivity" does not imply that an assessment is arbitrarily carried out, but rather that it is carried out by one specific person (Biedermann *et al.*, 2008), with his own personal life experience.[119] This concept implies that each expert, being a different individual, will have his own individual (and thus subjective) vision, shaped by a number of factors such as training, experience, beliefs, etc. (Langenburg, 2012). Even though the expert's assessment is subjective, it followed the structured ACE-V approach and is given through an informed and sensible judgment.

Found and Edmond (Found and Edmond, 2012) observe that the different branches of pattern evidence lacked in standardization for the presentation of their results. They propose several recommendations to improve the transparency of the communicated results that should figure in every forensic report.[120] They also suggest that the expert states any contextual information to which he may have been privy during the case, as well as personal validation and blind testing results.

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118 Free translation of "En leur signalant, par exemple, les différentes méthodes pour découvrir les faux en écritures, etc., le juge ou magistrat enquêteur sera en état de contrôler le rapport de l'expert, chargé, par lui, de découvrir la vérité. Il saura ainsi quelle valeur il peut attribuer à ce rapport".

119 An absence of disclosure of the interpretation mechanism, often encountered, does not fall under these subjective tent.

120 These are (Found and Edmond, 2012, p. 194): "the agency from which the report was issued, a list of exhibits, chain of custody information in relation to the exhibits, a statement of the proposition(s) under consideration and any limitations or uncertainties associated with the methodologies adopted".

The use of the model of the present study must go hand in hand with one key element: transparency. An opaque model can only have downsides in assisting an expert in reaching a conclusion. Emphasis is put here on the word assist. An expert can join his expertise to the conclusions of the model only through clear definitions of the model, whose limitations are defined and understood. The expert must be able to use a number of tools. He must understand them and be capable of justifying their use and results. He must also be capable of explaining the different steps of this reasoning process. The method developed in this study reasoning process allows to do just that. The expert must have information on which characteristics had a weight in the reasoning balance and the degree of their weight.

The developed model can be put into comparison with classification techniques based on pattern recognition, potentially more discriminant, but put under the umbrella of complex classification techniques. The use of a complex computer models has many advantages, but is also a risky business. For one, it's a move in the other direction of the much-needed transparency. The method and obtained results cannot be transparently analyzed by the average FHE, and thus fully comprehended by him. Moreover, computer models have a common downside, which is to infantilize their user, then drive their users to restrain themselves from using their own judgment, and instead rely on an instrument misconstrued as foolproof. An expert must understand the tool he is using so he can incorporate its findings into his own, in order to reach the most transparent conclusions possible.

For issues concerning transparency, and the best understanding of results, the forensic scientist must maximize the communication potential of his conclusions. He must communicate the notions surrounding probabilities, as well as the reason they are used in the framework. He should specify that probabilities are personal, conditional and change in the light of new information.[121]

The results should also be communicated in a certain manner, due to the problem that lies in the misunderstanding conveyed by the verbal communication of risks (or in this case, in the strength of the evidence given the alternative hypotheses). Forensic scientists adopting a probabilistic

121 Notions stated by Ian Evett during the presentation "The Hunting of the Snark: A Search for the "Real LR" in Forensic Science" (May 23th 2013 - School of Criminal Justice, University of Lausanne).

reasoning process habitually use a verbal scale to communicate their results. This scale is used to translate either quantitative results, or qualitative results (such is the case for handwriting examinations). Evett (Evett, 1987; Evett, 1990; Evett *et al.*, 2000) was the first to propose a verbal scale for communicating results. Verbal scales were introduced, among other reasons, to help communicate results between forensic scientists and their audience (mainly lawyers, judges, juries, etc.). According to the fifth point of the abovementioned response (Guest editorial, 2011), the use of a verbal scale is still advocated in forensic sciences for communicating results.

Areas such as weather forecasting, climate change and medical diagnostics[122] also proposed to communicate results with verbal scales due to the general population's misunderstanding of numerical probabilities. Even though verbal scales have many positive aspects, they have the disadvantage of being approximate and vague, and in turn induce an "illusion of communication" (Budescu and Wallsten, 1985). Stakeholders think they are agreeing on the probability of occurrence, but in fact, the actual numerical translations of their beliefs are quite different.

However, studies in these areas have shown that the interpretation of communicated data in the form of a verbal scale can also be prone to misunderstanding by the receiving end. Karelitz and Budescu (Karelitz and Budescu, 2004) identified three reasons for communication errors between individuals using verbal probabilities: (a) people favor verbal rather than numerical terminologies; (b) people use different terms to describe uncertainty;[123] (c) people have different numerical interpretations of verbal terms. Indeed, "most people perceive the meanings of verbal probabilities consistently and reliably, but differently from each other" (p. 27).

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122 The author notes that the results communicated in forensic science are not of the same nature as results of other sciences. Indeed, these domains usually convey the probability (likelihood) of occurrence of an action in the future, for example (taken from (Budescu *et al.*, 2009, p.306)), "Temperatures of the most extreme hot nights, cold nights and cold days are likely (80-90%) to have increased because of anthropogenic forcing", they concern the probability of a proposition given the observations (transposed conditional). However, the forensic scientist communicates the probability of occurrence of his observations based on alternative hypotheses: the likelihood of something in comparison to something else.

123 The authors of this study showed that subjects produced more than 70 ways to verbally describe a probabilistic occurrence of an event (for example, a chance, a possibility, likely, fairly certain, etc.), some of course more popular than others.

Budescu and his colleagues (Budescu *et al.*, 2009) documented this last point by highlighting the discrepancies between a scale of five verbal terms[124] their numerical likelihood of occurrence. The term "very likely" was interpreted by 25% of the persons tested as lower than 70% probability of occurrence (even though they were given guidelines on how to interpret the verbal scales). Even the term "more likely than not" was interpreted by 9% of the subjects as having less than a 50% probability of occurrence of an event. Of course, it did not concern forensic sciences specifically, but it does show the grasp the general population has on verbal scales.

This "illusion of communication" does raise the question as to whether a verbal scale is appropriate for communicating results to a forum that will be making life-altering decisions.

Budescu and his collegues (Budescu *et al.*, 2009) found that, when giving both the verbal scale and its corresponding numerical boundaries, the communication between the giver and the receiver improved. For these reasons, they suggest giving both elements when communicating uncertainty. They also recommend, when giving both elements, to adjust the numerical range according to the uncertainty of the event (for example, likely (65-85%), or very likely (80-90%)). This specific recommendation is opportune, since the same verbal scale is interpreted differently according to the severity of an event, for example a disease. Bonnefon and Villejoubert (Bonnefon and Villejoubert, 2006) found that subjects interpreted the term probable of having a certain disease with a higher probability, the graver the disease. The same proposition of implementing a dual verbal-numerical scale has also been proposed in the framework of forensic science (Martire *et al.*, 2013).

The point of the verbal scale resides in the difficulty in linking a result given with a verbal scale, and a result given with a numerical scale, such as would be the case here, with a verbal conclusion of the holistic examination, and a numerical output of the model. In this chapter, a number of different factors have been shown to have an impact on the expert, on his conclusions, and on the communicated interpretation of these conclusions. However, once the expert becomes aware of these factors, and uses the different techniques and skills to overcome them, a step towards a transparent examination procedure is established.

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124 The terms ranged from: very unlikely, unlikely, more likely than not, likely, very likely.

6 Reliability of signature identification

6.1 Introduction

Generally, for all signatures, whatever their types, the forensic document examiner (FDE) uses the traditional procedure applied in forensic science for signature comparisons (Found, 2009, pp. 1438-1439). The questioned signature is analysed at the level of its general appearance, then at the level of the detailed features of construction and shape. Next, reference signatures (i.e. assumed to be signed by the true writer) are compared between each other in order to establish their variation range. This consists of evaluating the extent of the variability of the reference signatures, which corresponds to the within-writer variability. Finally, the questioned signature is compared to the reference group to determine if the features of the first fall into the variation range of the latter. In simpler terms, similarities are features that fall into this variation range, whereas differences are features that fall outside of the observed variation range. The set of similarities and differences, which can be defined as the forensic findings in a case, must be assessed to determine whether they are more likely under the hypothesis of authenticity or the hypothesis of simulation.[125] The expert, by assigning the probabilities of the observations under both hypotheses, will be able to support to a certain degree one of the two hypotheses.

Nevertheless, the interpretation of the weight that each of these similarities or differences will carry in the comparison process is often subjectively assigned by the experts. Indeed, the interpretation of their observations is often based on their own personal experience. It is not surprising that a training period of two years is recommended by the American Society for Testing and Materials (ASTM, E2388-05, 2005), a period that allows the trainee to fully comprehend the weight that can be given to his/her observations. As stated by Day (2009, p. 1457) "[…] the signature comparison draws more heavily on the skill and experience of an examiner than handwriting comparison, but the principles for comparison and evaluation are the same". The interpretation of the FDEs' results, as well, is a "holistic assessment based on the examiner's training and experience" (2009, p. 1453).

[125] The term simulation stems from the terminology 'simulation behaviour', which is the process of copying a signature (Found, 2009).

These recent writings demonstrate the present-day state of affairs found in the handwriting community: experience is an important and indispensable pre-requisite for any signature expert. This implies that very few experts could reasonably carry out a comparison of signatures on paintings, and let alone justify their conclusions, given that very few have the above-spoken experience to do so.

In order to understand the position handwriting identification holds in the courts today, a brief summary of the development of this branch of forensic science is helpful. The aim of the following sections is to present the (still ongoing) shifts in the reliability of signature examinations, and the implications that these have on the research conducted in the field of handwriting and signature analysis.

6.2 Beginning of handwriting identification

6.2.1 The rise of a discipline

Handwriting identification, which emerged in Italy and France in the 17th century, is the oldest documented forensic expertise allowed into the courtroom (Risinger, 2007), and can thus be seen as the oldest "forensic science". Despite this head start as a forensic discipline, handwriting identification expertise underwent years of judicial hostility. Doubts towards handwriting examination were also expressed by forensic scientists.[126]

The turning point in its acceptance can be imputed to several factors, the first being the publication in 1871 of Charles Chabot's book, *The Handwriting of Junius, Professionally Investigated*. This was the first book in English to "claim that a science of handwriting identification existed and to explicate the claimed discipline" (Risinger *et al.*, 1989, p. 758). Second, John H. Wigmore

[126] For example, when Reiss stated that the results of the handwriting examination were insufficient evidence on its own to sentence someone: "So if you have, in addition to our [handwriting] expertise, other proof or very strong evidence against the person charged, sentence him. If, however, our [handwriting] expertise is the only charge against him, you cannot sentence him". (Free translation from Reiss (1906, p.869): "Si donc vous avez, à côté de notre expertise [en écritures], d'autres preuves ou de très forts indices contre l'individu inculpé, condamnez-le. Si, par contre, notre expertise est la seule à charge contre lui, vous ne pouvez pas le condamner.").

and Albert Osborn went on a 'crusade' to "eliminat[e] the judicial attitude of contempt and treat [...] handwriting identification expertise by rules appropriate to a valid scientific discipline" (Risinger *et al.*, 1989, p. 758). Osborn's textbook, published in 1910 and republished in 1929 (Osborn, 1929), is still considered by many as the "pivotal doctrine" of handwriting examination (Found, 2009, p. 1436).

The Wigmore-Osborn duo built public relations to sell their vision, which became universally accepted in 1936 when Osborn was called as chief witness in the Lindbergh kidnapping case.[127] He testified that B. Hauptmann had written the ransom notes found in the baby's crib and sent to the Lindbergh family. Osborn's conclusions in this highly publicized case turned him into a public hero, because people wanted Hauptmann to be guilty, and were grateful to Osborn for giving them a confirmation of his guilt. The conclusion given by Risinger *et al.* (1989, p. 771) sums up the state of mind after the trial: "This public anointment of handwriting expertise, however, (coupled with its judicial canonization in Hauptmann) seems to have stamped out virtually all manifestations of judicial skepticism". According to Risinger (2007, pp. 384-385), Osborn "never seemed to notice that most of the generalities upon which he built his own system lacked empirical verification".

6.2.2 The untouchable years

After this highly publicized episode, handwriting identification expertise, for many decades on, rode on the wave and the aura that Osborn and Wigmore built up. Several authors continued to publish textbooks in the area of forensic handwriting examination (Hilton, 1956; Harrison, 1958; Conway, 1959), and continued to re-enforce the academic references detailing the principles of forensic handwriting examination. This lasted up until the Courts, particularly in the United States, started to question the scientism of the expertise of handwriting examination. Since these doubts first mainly emerged in the United States, this country will be used as a backdrop to depict the different statutes forensic expertise, and in particular handwriting and signature examination, has undergone in the past two decades. Parallels of these shifts in the acceptance of signature expertise could be made with Switzerland and the future acceptance of signature examination in courts.

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[127] State v. Hauptmann, 115 N.J.L. 412, 180 A. 809 (1935)

6.3 Emergence of doubt of science-based signature examination

6.3.1 The trigger

The first signs of skepticism surfaced only half a century after the famous Lindbergh saga with two events, the publication of the article "Exorcism of Ignorance as a Proxy for Rational Knowledge: The Lessons of Handwriting Identification 'Expertise'" by Risinger, Denbeaux and Saks in 1989, and the US Supreme Court decision in Daubert vs Merrell Dow Pharmaceuticals[128] in 1993. Risinger, Denbeaux and Saks's article pointed out the importance of empirical testing of handwriting identification methods. They argue that for expert testimony to be admissible, it must have "demonstrated marginal efficacy for the asserted specialized knowledge above that of the average trier of fact" (Risinger *et al.*, 1989).[129] After a literature review on the empirical evaluation of handwriting, the authors conclude that extremely few empirical tests existed and that the few that did[130] omitted to study the impact of control groups of lay test takers, so there was no way to determine if experts actually helped the trier of fact with an above-average knowledge. The authors conclude that the claims on which handwriting identification expertise were based were invalidated by proper testing; they finally (and rather ironically) propose an "exorcism of ignorance model", for which the system, with no other alternative, "will invite the creation of a proxy for rational knowledge, a form with the appearance of evidence but no rational content, to be used in a ritual exorcism of an ignorance we cannot bear" (Ibid., p. 782).

128 Daubert v. Merrell Dow Pharm., Inc., 509 U.S. 579, (1993)

129 The authors cite the Federal Rule of Evidence 702, enacted in 1975: "If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise, if (1) the testimony is based upon sufficient facts or data, (2) the testimony is the product of reliable principles and methods, and (3) the witness has applied the principles and methods reliably to the facts of the case."

130 Forensic Science Foundation proficiency tests.

6.3.2 The end of the Frye rule for admissibility

The Daubert U.S. Supreme Court decision confirmed the remarks of these authors just four years later.[131] The Daubert decision turned out to be the beginning of a whole process of questioning of standard practices of forensic science that had gone practically unchallenged since the Frye ruling in 1923, still widely used by a number of American courts, even though it was contrary to the Federal Rule of Evidence (FED. R. EVID.) 702 that had been enacted in 1975 (Sanders, 2001). The Frye rule, also known as the general acceptance rule, deemed that a proffered expertise was admissible in court only if it had "gained general acceptance in the particular field in which it belongs".[132] The FED. R. EVID. 702 requires evidence to be reliable as well as relevant to be admissible (Champod and Vuille, 2011). In Daubert, the Supreme Court rejected the Frye admissibility criteria used by the courts, and held that the FED. R. EVID. 702 superseded Frye as the standard for admissibility. The court questioned the validity of certain scientific claims under the FED. R. EVID. 702 and concluded that expert evidence must be reliable, and proposes five factors to assess its scientific validity:

1/ Falsifiable (and tested) technique

2/ Reliability of procedure and known error rates

3/ Technique submitted to peer review and publication

4/ Maintenance of standards

5/ General acceptance in relevant scientific community

The court also stated that the judge would have a gatekeeping role. He would thus filter invalid scientific testimonies before their potential further submission to juries. The obvious question that comes to mind is: How is a judge to decide what is and is not scientific, particularly when people inside this said area of competence are not unanimously in agreement? The Daubert decision pulled the rug under the feet of handwriting examiners, and took back a century of undisputed "science-based" testimonies.

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[131] The Daubert decision, although not dealing directly with handwriting, is mentioned because of the extreme impact it had on the acceptance of virtually all forensic findings in the court.

[132] Frye v. United States, 293 F. 1013 (D.C. Cir. 1923)

6.4 Is handwriting identification not a science?

6.4.1 The Starzecpyzel hearing

The Starzecpyzel hearing in 1995 is the one of the first post-Daubert forensic cases[133] for which the Court concluded: "the Daubert hearing established that forensic document examination, which clothes itself with the trappings of science, does not rest on carefully articulated postulates, does not employ rigorous methodology, and has not convincingly documented the accuracy of its determinations", and states that "forensic document examination does involve true expertise, [...], [and that] FDEs gradually acquire the skill of identifying similarities and differences between groups of handwriting exemplars". However, Judge McKenna insists on the fact that "FDE are not scientists – they are more like artisans", using practical skills rather than scientific methods. "[T]he testimony at the Daubert hearing firmly established that forensic document examination, despite the existence of a certification program, professional journals and other trappings of science, cannot, after Daubert, be regarded as 'scientific [...] knowledge'". In Starzecpyzel, the court concluded that Daubert standards did not apply to handwriting identification, simply because it did not consist of scientific evidence, and Daubert standards were intended for scientific evidence only (Saks and Koehler, 2005). They also ironically (and justly) note: "[...] fields that initially gained entry to the courts by declaring themselves to be 'sciences' now sought to remain in court by denying any connection with scientific methods, data, or principles" (p. 894).

6.4.2 The post-Starzecpyzel era

In handwriting cases following Starzecpyzel, the court questioned the validity of handwriting identification expertise, particularity the experts' ability to attribute the authorship of a forged signature to a person, basing their comparisons and conclusions on samples of the supposed author's true writing, often with very small samples of questioned and/or reference signatures. This exact scenario is portrayed in U.S. v. Ruth (Ruth I),[134] U.S. v. Jones,[135] and U.S. v. Battle,[136] where the courts all adopt a Starzecpyzel

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133 United States v. Starzecpyzel, 880 F. Supp. 1027 (S.D.N.Y. 1995)

134 Arheh v. Christie's International, Index No 1030/86 (Supreme Court of the State of New York) 42 M.J 730 (A.C.C.A. 1995)

135 United States v. Jones, 107 F.3d 1147, 46 Fed. R. Evid. Serv. 885, 1997 FED App. 0082) (6th Cir. 1997)

approach for the reliability of the expert testimony, even though in Starzecpyzel, the handwriting expert was asked to determine if a signature was genuine, not if he could authenticate the author of a forged signature. Indeed, it is the reliability of a subsection of handwriting analysis that is questioned in these three cases. A fourth decision worth mentioning is that of Judge Matsch's in U.S. v. McVeigh.[137] "Unless document examiners could satisfy the requirements of Daubert, their testimony would be limited to pointing out similarities between the questioned document and the known exemplars, but not to give a conclusion about the authorship of the questioned document" (Risinger, 2007, p. 387). Unfortunately though, he does not specifically indicate which task is at hand in this case.[138]

6.5 Third time's a charm: the Kumho Tire hearing

The Supreme Court's decision in Kumho Tire in 1999[139] sealed the Daubert triology[140] (and the questions raised by Starzecpyzel thereafter) by extending Daubert to non-scientific expertise as well. The court provided four reasons why the Daubert requirements of validity applied not only to scientific expert testimony, but to non scientific (skill and experience-based) expert testimony as well (Sanders, 2001):

- Daubert was only limited to scientific expertise because of the nature of the case;
- The line between scientific and non scientific experts is difficult to distinguish;
- FED. R. EVID. 702 makes no distinction between scientific and technical knowledge;

136 United States v. Battle, 188 F.3d 519 (10th Cir. 1999)
137 United States v. McVeigh, 1997 WL 47724 (D. Colo., Transcript, 1997)
138 It is a requirement under Kumho Tire to evaluate the reliability of expert testimony in regard to the nature of the case.
139 Kumho Tire v. Carmichael 526 U.S. 137 (1999)
140 Together with Daubert and Joiner (General Electric Co. v. Joiner 522 U.S. 136 (1997)), Kumho Tire is considered the third pillar of the Daubert triology.

- Even though the FED. R. EVID. 702 and 703 give wide latitude to all experts, it is because it is assumed "that the expert's opinion will have a reliable basis in the knowledge and experience of his discipline".[141]

Thus, the court ruled that the judge would keep his gatekeeping role, for all types of expert testimony, whether scientific or skill-experience based. As summarized by Jackson (2006, p. 38), the "courts emphasized that trial courts had great latitude not only in determining the reliability of an expertise, but also in whether to apply the Daubert criteria at all".

6.5.1 The first consequence: Exclusion or limitation of handwriting identification

Since Kumho Tire, the doctrine adopted by American courts has been divergent. For example, four cases regarding handwriting identification (U.S. v. Hines,[142] U.S. v Santillan,[143] U.S. v. Hernandez,[144] Wolf v. Ramsey[145]) have followed the McVeigh approach. The courts stated that the handwriting expertise had failed to reach the reliability standards and in consequence the experts were only allowed to state their observations, and were barred from expressing inferences on the authorship or probability of authorship drawn from their observations. Two cases (U.S. v. Rutherford[146] and U.S. v. Brown[147]) concerning signatures (more specifically the attribution of authorship of a forged signature) followed the same approach. The courts' choice to opt for such expert testimonies is hopefully only a temporary course of action, adopted as long as handwriting expert testimonies cannot fulfil the Daubert standard. Indeed, what would seem to be a sound decision could spawn the devious consequence of an expert bluffing his public with hi-tech material and well-rounded presentations in order to push their conclusions in a desired direction. This may be one of the reasons why the courts had a more

141 Kumho Tire v. Carmichael 526 U.S. 137 (1999), quoting Daubert v. Merrell Dow Pharm., Inc., 509 U.S. 579, 592 (1993)

142 United States v. Hines, 55 F. Supp 2d 62, 52, Fed. R. Evid Serv. 257 (D. Mass. 1999)

143 United States v. Santillan, 199 WL 1201765 (N.D. Cal. 1999)

144 United States v. Hernandez, 42 Fed. Appx. 173, 89 A.F.T.R2d 2002-3049 (10th Circuit)

145 Wolf v. Ramsey, 253 F. Supp. 2d 1323, 61 Fed. R. Evid. Serv. 1715 (N.D. Ga 2003)

146 United States v. Rutherford, 104 F. Supp. 2d 1190, 55 Fed. R. Evid Serv. 201 (D. Neb. 2000)

147 United States v. Brown, No. CR 99-184 ABC (C.D. Cal., Dec. 1, 1999)

radically approach with three other handwriting cases (U.S. v. Fujii,[148] U.S. v. Saelee,[149] U.S. v. Lewis[150]) and one signature case (U.S. v. Brewer[151]): the lack of reliability in the proffered expert testimony resulted in its complete exclusion.

6.5.2 The second consequence: Handwriting identification IS a science

In a complete opposite of these last cases (and an attestation of the controversy regarding handwriting expertise validity), the court rejected the defense motion to exclude handwriting expert testimonies in U.S. v. Elmore[152] (involving the authorship of a forged signature), and in U. S. v. Johnson, where the court goes as far to state: "it is undisputed that handwriting analysis is a science in which expert testimony assists a jury",[153] practically ignoring all judicial decisions since Daubert. In the federal cases U.S. v Ruth II,[154] U.S. v. Paul,[155] and U.S. v. Velasquez,[156] the defense called Prof. Mark Denbeaux to testify to the weakness of handwriting expertise proposed by the prosecution. The decisions pronounced by the courts were contradictory: in Velasquez, the defense was allowed to call Prof. Denbeaux to testify; the court noted that the fact that he was not a FDE did not imply that he was incompetent to criticize the standards employed in the FDE field. Ruth II followed the same approach. However, in Paul, and in complete polar opposite of Ruth II and Velasquez, Denbeaux's academic research, as well as his testimony, was dismissed. He was unqualified to be a FDE, and could therefore not criticize the reliability of the field. Risinger (2007, p. 445) cites

148 United States v. Fujii, 152 F. Supp. 2d 939, 56 Fed. R. Evid. Serv. 1029 (N.D. Ill. 2000)

149 United States v. Saelee, 162 F. Supp. 2d 1097, 57, Fed. R. Evid. Serv. 916 (D. Alaska 2001)

150 United States v. Lewis, 220 F. Supp. 2d 548 (S.D. W. Va. 2002)

151 United States v. Brewer, 2002 WL 596365 (N.D. Ill. 2002)

152 United States v. Elmore, 56 M.J. 533 (N.M.C.C.A 2001), review denied, 57 M.J. 99 (C.A.A.F. 2002)

153 United States v. Johnson, 30 Fed. Appx. 685 (9th Cir. 2002), cert. denied, 537 United States 1241, 123 S. Ct. 1374, 155, L. Ed. 2d 213 (2003)

154 Arheh v. Christie's International, Index No 1030/86 (Supreme Court of the State of New York) M.J. 1 (C.A.A.F. 1997)

155 Arheh v. Christie's International, Index No 1030/86 (Supreme Court of the State of New York) 175 F.3d 906, 51 Fed. R. Evid. Serv. 1464, 183 A.L.R. Fed. 773 (11th Cir. 1999)

156 United States v. Velasquez, 64 F.3d 844, 42 Fed. R. Evid. Serv. 1175 (3rd Cir. 1995)

this decision as being an extreme guild test and cautions "The result of Paul, if followed, is not only that handwriting experts may testify, but that they are virtually unchallengeable [...]". Finally, in U.S. v. Prime,[157] the judge stated "decisions were intended to exclude unreliable novel evidence, not established, time-honored techniques, such as forensic handwriting examination. In his final analysis, the judge concluded that the expertise satisfied all of the Daubert factors and, therefore, was reliable and admissible".[158] Recently, the D.C. Court of Appeals rejected Pettus's appeal on the inadmissibility of handwriting expert testimony, made in the light of the National Research Council Committee Report findings.[159] The Court ruled that "forensic handwriting comparison and expert opinions based thereon satisfy the bedrock admissibility standard of Frye and Ibn–Tamas and may be put before a jury." The Court also states that "remaining issues of reliability may be argued, after cross-examination and any counter-expert testimony, as affecting the weight of the opinions", leaving the door open for further discussions on expert admissibility.

6.6 Towards a more science-based expertise

Several authors, before and after the Daubert trilogy, questioned the lack of scientific basis in handwriting identification and expressed the need to adapt Daubert standards to reach a science of handwriting identification, from the point of view of both FDE (Huber and Headrick, 1990), and the law community (Risinger *et al.*, 1989; Saks and Risinger, 1996; Mnookin, 2001). In a response to the Starzecpyzel case, Found *et al.* (1998) proposed a quantification of the complexity feature of signatures with the help of predictors. The most powerful predictors were found to be the number of turning points, the number of feathering points and the number of intersections and retraces. Other authors (Alewijnse *et al.*, 2009) have recently proposed to quantify additional features present on a signature, which shows that the need and will to turn towards scientific quantification of signatures is on-going. But even now, some authors still argue that the FDE is an 'experience'-based scientific technique: a "likelihood is always qualitative and is based on the experience of the examiner" (Day, 2009, p. 1457).

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[157] United States v. Prime, 363 F. 3d 1028 (9th Cir. 2004)
[158] (Jackson, 2006, p. 40)
[159] United States v. Pettus, 37 A.3d 213, 217 (D.C.2012)

One of the goals of this research project is to surpass this 'experience' and 'skill' pre-requisite and issue standards, clear guidelines, and a transparent comparison and evaluation process, that could be applicable by a signature expert conducting an examination of a signature on a painting. Indeed, an 'art' of signature expertise has clearly become at the least questionable, if not unacceptable, in courts in the last two decades. Thus, proposing a research that rests solely on a skill approach would not only be counterproductive, it would go against everything the law (and forensic) community has been trying to change. The recent National Research Council (2009) report, which is awaited to have an impact on the doctrine regarding the admissibility of expert testimony, emitted a list of recommendations (such as funding, use of standardized terminology and reporting, research to validate basic premises and techniques, improvement of the scientific basis of forensic science examinations, evaluation of human error, development of standards and quality control, education and training, etc.) to push forensic science in this same direction.

The task is arduous, for handwriting examination, one of the oldest forensic expertise, is also ironically one of the areas whose methods have the least evolved in its over 100 years practice. Indeed, the methods used today have remained quite unchanged, or have even regressed in terms of scientific analysis: Fraser, in 1899, was already advocating the use of measurements in handwriting examination, but his views were quickly discarded, and "actual measurement appears to play no greater role in standard practice today than in 1935".[160]

Few methods of features extracted from handwriting, and based on features used by FDE, exist. The study conducted by Pervouchine and his team (Pervouchine and Leedham, 2007) proposes the extraction of features from the letters -d-, -y- and -f-, and from the grapheme -th-, to discriminate genuine handwriting samples from forged ones. The results showed that the features with the strongest relevance varied between the letters, being either the height, width, height to width ratio, and for the -th- grapheme, mainly distances within the two letters an the slant of their stems. The final stroke angle and the fissure angle were found to be two irrelevant features for writer discrimination.

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[160] Risinger, 2007, p. 455

Al Haddad and his colleagues (Al Haddad *et al.*, 2011) investigated the use of Principal Component Analysis on measurable and classifiable variables on signatures in order to classify the description weight of each of the studied variables. The logic behind the choice of variables was not specified, but included the total height and lengths of the signatures, as well a distances between words, points, and loops (13 and 16 variables for both sets of studied signatures). Although the use this method to discriminate with forged signatures is limited in their research,[161] several interesting conclusions were reached by the authors, such as classified variables should not be used because they do not present a discriminating power. They also found that a sample size of 25 signature to be adequate to fully describe each of the signature sets they collected. The authors also concluded by pointing out that other factors, besides the measured variables, should be used by FDE to alert of possible forgeries. They cite for example the observation of the fluidity of the line stroke.

This research project will orientate handwriting examination towards a same thought process as one designed by Fraser (1899): a quantification of observable characteristics, which will enable a concrete, objective and transparent evaluation of the questioned and reference signatures in order to help determine the authorship of a signature. Factors, such as the fluidity of the line stroke cited above, but also hesitations, the pressure, and the absence or presence of touch-ups,[162] cannot easily be observed on painted signatures. Thus, the absence of observation of these factors warrants even more the use of observable measurable features such as ones used in the two above cited research papers.

Hopefully, statements such as the following will become a thing of the past: "the crux of the examination becomes whether or not someone would have the skill to be able to simulate the signature in question. To answer this, the examiner then has to draw on their experience as to the complexity of the signature and the ability of people to simulate this complexity of signature this well" (Day, 2009, p. 1457).

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[161] Only three forgeries were compared with each of the two sets of signatures. Moreover, the resulting values measured on the forgeries were compared in a basic manner with the two sets of authentic signatures (if they entered or not the minima and maximal values of the authentic sets).

[162] These different factors are discussed in Sub-section 4.4.2.

Recommendations for forensic handwriting examiners stemming from the state of the art

The introductory chapters and state of the art of this thesis have shown many existing disparities in the field of forensic examination of signatures on paintings. As such, the need for a number of guidelines and general recommendations for forensic handwriting examiners is deemed necessary. The aim of this section is thus to offer logical and easily implementable recommendations through a holistic view of signature examination, to aid FHE in the examination processes. These recommendations stem notably from the state of the art of this present research, but also from the personal experience of the author and from discussions through colleagues and peers of the field. A number of recommendations come from literature in the field of handwriting examination (Huber and Headrick, 1999) but from other forensic domains where research in the examination procedure has been addressed (Langenburg, 2012). These points should be viewed as recommendations for the examinations of signatures in general, and for the examination of signatures on paintings specifically. For these reasons, distinctions between the two will not always be specifically made, but are to be understood by the reader from a holistic view when nothing is specified.

The strength given to each recommendation is at the discretion of the expert. Of course, not every single one must be fulfilled to correctly carry out the examination of a painted signature. Indeed, these recommendations have not all necessarily been tested and proven, but they do offer a sound basis to improve current practices, not only in the field of painted signatures on works of art, but for signatures examinations altogether. The author believes that these recommendations must be met in order to carry out the expertise in the best possible conditions.

1. The examination of painted signatures is to be carried out by skilled and sufficiently qualified experts.

As exposed in the beginning of this thesis, a preamble for painted signature examination is a solid education in forensic science, with a specialization in handwriting and signature examination. Domains such as material examination (paper, wood, fabrics, etc.), analytical chemistry (paint pigments, varnishes, binders, etc.), document examination (certificates of authenticity, stamps, etc.) and photography are intrinsically linked to the examination of the signature, and as such, should be mastered by the expert. The expert must also have followed continuing education in the area of handwriting and signature examination, when possible. Indeed, training courses in this field are scarce, continuous training is often brought by novel cases encountered in casework by the expert himself or by his colleagues or peers. The examination of signatures on paintings necessitates these prerequisites, and additional experience in the specific field of signatures on art. Naturally, it would be unrealistic at this stage to require a training course in this area, since such courses are inexistent at the time of the writing of this study.

Research comparing the performances of FHEs with laypersons for the examination of signatures has shown that expert possess a superior performance rate. The studies in this area, although limited, do show that experts indeed possess a skill. However, the skilled expert must not use this skill as an excuse to go though casework that does not follow a transparent procedural model. The expert cannot call upon this golden eye status to convince the receiving end of the examination (judicial system), he must do so in a transparent and justifiable manner.

2. The necessary time and equipment should be available to the expert to see the examination successfully through.

A sufficient amount of time should be allotted for the expert to carry out the signature examination. The expert cannot be stressed into giving a result without having had a proper time frame to go through each of the examination phases (analysis, comparison, and evaluation). Indeed, Langenburg (2012) found that the time factor had an influence on the reported results.

Although the expert might have a sufficient time frame, the same sufficient time frame must also be allotted to the verifying expert, who cannot be rushed into giving a quick response that corroborates the conclusions of the first expert (which the second expert should incidentally not even be aware - see Section 5.2 on opinions and context bias). The expert consensus protocol developed in Section 10.2 should provide the necessary structure for both experts and prevent them from (inadvertently) jumping corners in the examination procedure for pressing schedule reasons.

The expert must have at his disposal the necessary equipment to successfully complete the examination. Failure to provide this equipment might force the expert to overlook a certain number of the examination phases (for example the examination under different lighting conditions). Illumination techniques must be carried out on the painted signature, as well as on the painted surface to highlight the homogeneity or inconsistencies of the surface (see Section 2.8.1). Macroscopic examination should also be carried out these surfaces to study the craquelures network (see Section 2.8.2).

3. Experts must carry out the signature examinations on the original questioned and reference materials (not on reproductions).

Although photographic recordings are necessary for the model to put down the points and conduct measurements, the expert conducting the signature examination should do so exclusively on original material. The photographic recordings can constitute an aid for the expert for illustrating his findings, but should not be used as a basis for the examination procedure.

If the expert must however use reproductions for the reference material, extreme caution should be emitted, particularly if the expert was not able to observe the signature in person. Also, the expert should verify the quality of the reproductions (correct scaling, parallel plans, etc.). This could be the case for example if a available painting is geographically distant, and the expert must rely on a photographic recording from a museum. The expert must also stress when he was working from reproductions in his report.

4. Special attention should be given for the collection of the reference material.

The reference material should be of the same type and quality of the questioned. The sizes of the paintings with the reference signatures should be of roughly the same size as the painting with the questioned signature. If however, the number of reference signatures is limited and the expert must use larger or smaller paintings, he must specify these limitations in his report (the influence of the size of the canvas on the artist's signature being unknown). Likewise, the expert must search for reference material of the same nature as the questioned material. For example if the questioned signature was signed with oil paint, reference material using the same type of material should be sought out. Again, if the expert is limited in his choice and only reference materials of a different type are available, the expert must specify these limitations in his report.

The expert should be extremely cautious in the reference material sampling stage. Unfortunately, a number of authors (see Section 4.2) have emitted the risk of finding even inauthentic works of art in museums and collections. The risk of being confronted with inauthentic material should be considered at all times by the expert. If possible, the expert should use reference material from museums that acquired the work of art while the artist was still alive.

Reservations should also be emitted when the date of the signing of the painting is unknown. The date of a painting is not necessarily the same as date of signature on the painting. Knowledge of the artist is useful in determining what was customary according to his habits. For example, some artists have been known to anti-date a painting years after it's execution following requests from the proprietors (usually with the aim to increase it's market value). For the full list of possibilities, the reader is instructed to see Section 4.2.

5. Experts are to follow the ACE procedure for the examination of the signatures. The three steps of this procedure must be sufficiently documented by the expert, as well as the manner in which he obtained his (Intermediate) Confidence Level 1 (See Section 10.2).

The use of the ACE procedure for signature examination was first proposed by Huber in 1959 (Huber, 1959). Since, this protocol has proven its many strengths and has been implemented as the examination procedure of many areas of forensic science. A correct use of the ACE procedure diminishes the risks of bias for and between experts. The conflict resolution protocol (Chpater 10) was also developed for experts using exclusively this type of examination procedure.

The protocol and the elements used to reach the conclusion level should be documented. The second verifying expert, but also for the recipients of the report should be fully aware of the features that the expert used to reach his confidence level. As stated by Langenburg (2012, p. 234) "understanding how someone reached a decision can be more important than the reported conclusion itself" and is as true in the area of fingerprint examination as in the area of signature examination.

If the steps used by the first expert to reach his confidence level are unclear, he himself will not be able to clearly use the protocol developed in this study to reach a final consensual conclusion. He will find himself unable to confront his analysis, comparison and evaluation stages with a second verifying expert, or with the results obtained by the model.

6. Experts should follow the protocol developed for the integration of the model into the expert examination.

The model developed in this study is not intended to be used alone, but to be integrated into the holistic signature examination procedure. As such, a protocol was developed to adequately integrate this tool into the expert's conclusion. This structure was also developed to provide a structured and transparent manner for experts encountering conflicting results between their traditional holistic expertise and the model to reach a consensual conclusion. The structure has the form of a discussion-based canvas that breaks down the different thought processes that one goes through before reaching a conclusion.

The structured protocol for the juxtaposition of an expert and the model's conclusions forces the expert to proceed in a fixed manner (without jumping to unwarranted conclusions), and thus drastically diminishes risks of bias. The expert must follow the fixed steps of the protocol and is shielded from unnecessary information that can potentially influence his examination process. Having an expert adhere to the develop protocol also forces him to present his findings in a clear and documented manner.

Likewise, in the case where a second expert is implicated, the two-expert consensual conclusion protocol should be used. The choice of having a second (or third) expert should be predetermined by the pool of working experts for all of their cases. The experts cannot choose to resort to second expert for one case, but then not for another: the protocol in effect must stay coherent for all cases. The same goes for the threshold permitted on the conclusion scale in case of diverging conclusions (between the model and the expert or between two experts). The threshold cannot be adapted from case to case, but must be fixed. However, the protocol and the thresholds can be adapted after a set of cases, if considered necessary by the whole pool of experts.

7. The extrapolation of the model's results are to be carried out and documented by another expert than the one performing the signature examination.

A different expert than the one carrying out the holistic examination should carry out the points sampling stage. Having two independent experts working on the signature examination from two different angles constitutes a great-added value to the developed signature examination procedure. The inherent bias risks are also drastically diminished.

The choice of the points, measurements and characteristics the model should analyze are somewhat contingent on the choices of the operator of the model. The list of recommended characteristics is the same for all types of signatures, but as signatures are extremely variable the expert may have to adapt the list of features to the signature at hand. In any case, the list of points and measurements must be documented in detail to allow a possible verification by another expert.

8. An expert should be aware of risks of bias, and should take several measures to diminish these risks.

Everyone is at the risk of being influenced by different factors. Even though studies have shown that an expert (with a working experience of several years) is less affected by bias than a novice (Miller, 1984; Langenburg, 2012), a number of factors have been shown to have an influence on forensic scientists, many of which are not known. These risks should be taken seriously, and experts should take different steps to ensure their (partial, if not complete) eradication.

A procedural structure such as the one developed in this study is indeed one way to diminish bias, but one must not forget that other solutions lie in the training and education of the FHE, where risks of bias are rarely addressed. Working experts should be aware of the different types of bias they might encounter, and of the possible means to diminish these risks. The reinforcement of continual training programs, implementation of certification programs and better conceptualization of proficiency testing could constitute steps that better educate the experts of these bias risks, and gives him keys to overcome them.

9. An expert should participate in regular proficiency testing programs

The participating in proficiency testing programs (PT) for handwriting and signatures analyses is highly recommended. The involvement in regular proficiency testing is paramount for the expert himself, but also for his clients. The first, and most straightforward reason to participate in PT is to validate one's competence in the examination process. In an area where the ground truth is very rarely know, the occasions where the expert can test his capacities are scarce and must be taken extremely seriously. A second and evident reasons to participate in PT is to offer the expert an opportunity to improve possible bias effects he might work under. Two specific biases are targeted: bias linked to context knowledge (which leads to confirmation bias) and hindsight bias.[163] By learning from errors made, there exists a potential for improvement.

A third reason for experts to participate in PT is that by fulfilling this task, the experts offers an indirect accreditation for Courts, even "demonstrable proof of expert performance" (Langenburg, 2012, p. 231). Indeed, experts often cite years of experience as an attestation of competence, but as mentioned before, since the ground truth is never know, an expert may be concluding falsely over his career. However, and has been suggested by recent literature (Found and Ganas, 2013), and for a number of reasons, PT should be directly incorporated into the casework of the expert, and not distributed and specifically labeled as a proficiency test. In other words, the expert should not be aware that he is under PT. They should also cover a spectrum of cases that can be encountered in regular casework by FHE.

10. Communication of results

The communication of the final consensual results is the last mountain to overcome, but is far from being the easiest. The presentation of conclusions in a probabilistic approach is widespread and has come to be accepted by the forensic handwriting community. The form of the conclusions is usually straightforward, and given in accordance with a verbal scale. However, acceptance of quantitative information as means to communicate results in the courtroom has received recent criticism, particularly since the R v. T judgment that stated that "[...] no likelihood ratios or other mathematical formula should be used in reaching that judgment for the reasons we have given".[164]

Communication of results in the form of a quantitative likelihood ratio alone seems rather inadequate in regard to the widespread innumeracy in the general population (Garner, 2012) and by extension in the potential juries or laypersons in the judicial system. Furthermore, the use of quantitative results seems unsatisfactory in response to recent criticism the forensic community

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[163] See Section 5.2 for more information on how PT can help experts be aware and overcome these biases.

[164] R v. T, Court of Appeal - EWCA Crim 2439, 2010 (point n°95).

has received and studies showing the confusion regarding their understanding.

However, as presented in section 5.4, verbal results alone seem insufficient as well as the optimal mean to communicate results. Indeed, the understanding of the actual numerical translations of verbal scales is also quite different between individuals. Research in these areas show the interpretation of communicated data in this form is often misunderstood by the receiving end (Budescu and Wallsten, 1985; Karelitz and Budescu, 2004; Budescu *et al.*, 2009).

In her recent presentation at the National Institute of Standards and Technology (NIST) conference on The Measurement Science and Standards in Forensic Handwriting Analysis Conference (June 2013), Taylor enumerates several non-exclusive options to present obtained results. One can either present the features, the qualitative data (strength of evidence), the quantitative data (posterior probabilities), and the errors (discussed through proficiency tests). Thus, results should be communicated with one, or a combination of several of these options. One thing that is however certain is that research studying how communicated forensic results are interpreted by laypersons should be developed. This would help develop the best communication strategy to convey results, to prevent confusion and lessen (and ideally, close) the gap discussed beforehand between the giving and receiving ends of uncertainty information.

With regard to the different studies in this field, results communicated in a verbal and numerical fashion (with predefined and existing scales) appears to be the best course of action for presenting results to laypersons. The inevitable uncertainty can thus be communicated in the best manner possible, so the public understands the limits of the forensic signature examination. By doing so, the process becomes more transparent for the recipient of the information (justice workers, juries, etc.), who in turn will likely place more trust in forensic expertise. If a verbal scale alone must be given (in accordance with recent recommendations (Guest editorial, 2011)), then the range of the scale must be made explicit, as well as the range in which the verbal results are situated (Langenburg, 2012). By doing so, the "audience" can easily locate where the conclusions are on the whole scale and be able to focus on the relative strength of the conclusions. The conclusion must be presented in a transparent and consistent frame.

Conclusions before moving on

The need to step towards a more regularized procedure of attribution of artwork can be felt throughout the art community. Indeed, numerous authors have questioned the reliability of traditional authentication methods, particularly if the experts do not have an art history education, which is usually the case with heirs. The excuse of a sixth sense is difficult to test and verify, just as it is hard to prove false attributions carried out in this manner. Scientific examinations of works of art have become more sought after, as more and more museums equip themselves with laboratories.

This overview has shown that the art market functions in a particular operation that follows no logical rule of customary trade, but is rather the result of years of sales on a volatile and intricate market. No simple relationship between the law and practice can be deduced. The market value of a work can be destroyed at the drop of a hat with the testimony of the heir of an artist, a testimony that would oddly never be acceptable if given by an expert, albeit more qualified.

The courts in the United States have established that a scientific method of expert examination of signatures is necessary to guarantee a fruitful collaboration between the judicial system and the forensic handwriting community in the future years to come. Reinstating the faith that was once instilled in this forensic community is possible, but only if this said community takes a step in their direction: by aiming towards a more scientific and comprehensive authentication method. The list of recommendations developed at the end of the first part of this thesis aims at addressing the reproaches, but must be completed by analyses that can bring forward the opportunities and limits of an authentication method.

This scientific approach can be achieved by embracing a probabilistic reasoning process. The comparison and evaluation of evidence is assessed in forensic science through the assignment of a likelihood ratio (LR). This approach allows the expert to weight his observations in light of two competing hypotheses. The likelihood evaluates the degree to which the observations support one of a pair of competing hypotheses.

The experimental part of this thesis will address the shortcomings identified in the theoretical chapters of this research. We will thus be able to see if authentic signatures can effectively be separated with a proposed method from a population of forgeries of his signature. Positive outcomes of this research will have a double impact on a forensic signature expert: he will have the knowledge to what extend a painted signature can successfully be individualized, and, with the help of the developed method, possess a transparent and scientific expertise procedure.

PART II - EXPERIMENTAL

Introduction

The second part of this thesis covers the experimental stages of the research and has three main objectives. The first objective is to develop a model that can be used to appreciate the authorship of painted signatures on works of art. This method is articulated and reached through several sub-objectives that include collecting raw data of artists' signatures and their respective simulations, defining measurable features on painted signatures, defining their relevance, and establishing the separation capacities between groups of authentic and simulated signatures, all with the help of numerical analysis of the sampled authentic and simulated signatures. A transparent system for authenticating signatures on paintings can be proposed with this developed model, which can contribute to bringing a scientifically-based system to a complex discipline that is crucially lacking (all the while longing for) scientific basis.

The second objective is to bring forward the current concrete limitations of the existing system. Indeed, the developed tool highlights constraints which allow us to understand its limits, and in turn show, with the results of this study, to support the affirmations that one cannot be as categorical and positive as some expert would like to say in the field of attributing signatures on works of art. These results should help the different stakeholders understand that the forensic signature examination of painted signature is extremely complex, unsurprisingly as it has been shown to be the case in the domain of art authentication.

The final aim of this experimental stage is to provide the expert with a future tool that can help him take transparent and weighted decisions in the signature examination expertise, and at the same time understand the limits of his evaluation. This tool, whose concrete articulation can be developed after this thesis research, can be implemented into his current reasoning process, but also used to blind testing and continuing education. This tool will bring transparency in a system lacking it, as was highlighted in the review of the literature beforehand.

7 Data sampling, extraction and analysis

The data collection process includes the preparation of the collection supports, the sampling of the authentic signatures and the sampling of the inauthentic, simulated signatures. The extraction process consists of the extraction of features in both signature corpuses. Finally, the analysis stage presents the statistical tests that are applied to the extracted features. The whole sampling, extraction and analysis process is summarized in Figure 7.

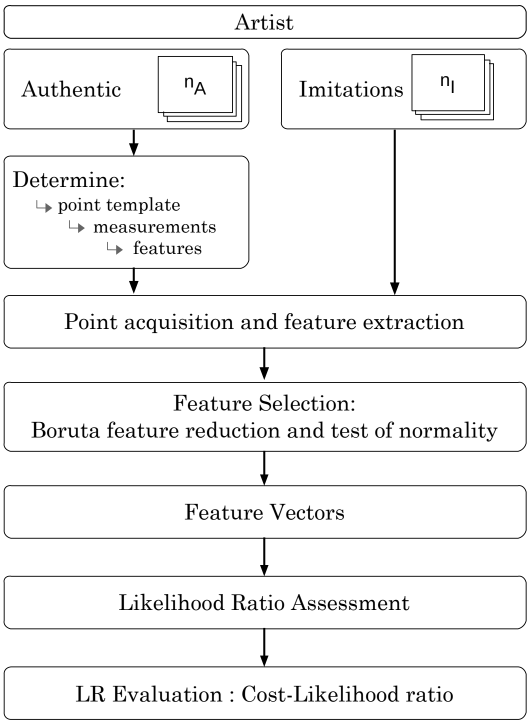

Figure 7 - Summary of the overall sampling, extraction and analysis process used for the study

7.1 Data sampling: Sampling of authentic signatures

7.1.1 Artist selection criteria and number of signatures

The artist selection stage is the first stage of the sampling process. The number of artists chosen to produce the signature samples is set at five. The choice of the type of artists selected for the research is set according to a certain number of criteria:

- First, the artists have to meet the prerequisite of being professional artists: they must be educated in the fine arts and must practice their art as their main professional activity. By fulfilling these qualifications, the artists therefore distinguish themselves from a layperson and/or an amateur artist who do not manipulate a paintbrush on a day-to-day basis.
- Second, the artists are chosen according to the signing technique of their own painted signature. Their habitual signing technique must be carried out by adding paint on paint, and not by scratching the signature in the matrix for example.[165]
- Third, the artists are chosen according to the material they are used to painting with. Artists using oil and/or acrylic paint as their usual painting medium are selected, since oil paint is used in the present study as the painting medium.[166]
- Fourth and finally, the artists are selected to obtain signatures covering different styles and lengths. Ideally, the signatures styles should cover the following style possibilities: lowercase or capitals, cursive or script, or a mix of each. The signatures are also targeted according to their lengths (in terms of the number of letters composing the signature): short, medium or long.

The number of signatures selected for each artist's corpus is set at 24. During each signature session, four signatures are sampled. Six sessions are held, giving a total of 24 signatures per artist. A minimum one-week period between each acquisition session is maintained. Each artist participating in the study is compensated with a copy of the book *Le théâtre du crime*, as an incentive for their cooperation and their diligence.

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[165] By "scratched signature" the author is referring to when an artist signs a painting with a sharp instrument, thus removing a portion of the painted surface and leaving his signature in negative.

[166] Artists using acrylic paint are not discarded as acrylic paint is often associated with oil paint in terms of consistency and application.

7.1.2 Signature acquisition (data collection)

a) Signature sampling material

Each signing support is a 40 x 40 cm pre-stretched mixed cotton profile canvas with back stapling (350 g/m^2 with a lightly absorbent white universal primer), prepped with a base of oil priming layers. Cotton is preferred to the traditional linen canvas for cost and polyvalence reasons. The canvases are prepared beforehand with two layers of white primer (Guardi) and two layers of oil paint (Schmincke Norma professional titanium white oil paint). The oil preparations are diluted (approximately 2:1 v/v) with oil thinner (Schmincke Mussini Medium 3 drying accelerant) to insure a smooth application process. A 24-hour drying period is respected after each of the gesso priming layers is painted, and a one-week drying period is respected after each layer of oil paint is added.

The oil paint given to each artist to sign with is black oil paint (Schmincke Norma professional ivory black oil paint) diluted (1:1.8 v/v) with common turpentine paint thinner (Talens rectified turpentine for oil colour). The dilution level is adapted to obtain a paint consistency close to that of a rich cream, allowing for an easy application by the subjects. The type of paintbrush used by the artists is also imposed, and consists of a Boesner longhaired size 2 pure sable hair paintbrush. One of the artists encountered difficulties with this paintbrush and used a Pébéo Aqua size 6 synthetic hair paintbrush instead. A detailed list of the materials used for the sampling process (canvases, priming layers, paint and paintbrushes) is given in Appendix I.

b) Acquisition process

The sampling stage of the artists' signatures is carried out in the following manner. During each of the six sampling sessions, each artist is asked to sign his/her signature four times on a blank oil canvas, however they deem fit, and in a location of their chosing. Nor the size nor the emplacement of their signatures is controlled. They are also informed that the canvas can be set up however they are the most comfortable, for example vertically, horizontally, or on an easel. They are also told that the positions of their forearm, elbow and hand are free.

General information concerning the education, the language, the day-to-day painting and signing habits of each artist are obtained at the beginning of the sampling process. In addition to this general information, the artists are asked to fill out an information sheet at the end of each sampling session with specific information regarding the session. Four signatures are collected on the information sheet at this point with a standard black ink Bic® ballpoint pen (in a predefined printed rectangle). An example of this information sheet is presented in Appendix II.

7.1.3 Data recording

A high-resolution camera with a digital sensor of 5616 x 3744 pixels (Canon EOS 5D Mark II), mounted on a stereomicroscope (Leica M420), is used to record the signatures. The canvas is placed on a horizontal plane, mobile in the x and y axes. The baseline of the signature is fixed by placing the edge of the canvas parallel to the base of the capture zone of the camera. Once the edge of the canvas is established, the horizontal plane underneath is shifted to change the position of the capture zone. Each signature is recorded sequentially, all the while observing an overlap of at least 15% on each side of each image with the adjacent images (see Figure 8). The overlapping areas are recorded to ease the ulterior automatic assembly of the photographs. Each zone is recorded with two white-light flashes (Elinchrom 1000, 1200 W/s, F-stop 128, reflector 50°) in a reproduction mode with both flashes oriented at 45° (to minimize parasite reflections). The images are then automatically assembled with the image processing software Adobe Photoshop CS5®, and its Photomerge function to produce one final image per signature. The resolution of the final images is approximately 3650 ppi.[167]

[167] More specifically, the resolution for the signatures of the first artist is 3648, the second 3648 ppi, the third 3656 ppi, the fourth 7200 and the fifth 3640 ppi.

Figure 8 - Sequential recording of a signature

Such a high resolution is not considered absolutely essential for the feature extraction step, but is nonetheless judged necessary for an optimal visualization of the signatures' constitution and an optimal reproduction of the line quality of the signatures, thus maximizing the reproduction quality for the copyists. Thus, the copyists will only have reproductions of the original painted signatures as models for the production of the simulated signatures.

It is not judged necessary to dynamically collect the signatures on an on-line graphical tablet since an expert only has off-line static signatures at his disposal when he compares signatures. Even so, feature extraction on these types of signatures can be carried out (Srihari, 2006). However, in this case, the disadvantages linked to the development of such a collection system outweigh the possible benefits.

7.2 Data sampling: Sampling of simulated signatures

7.2.1 Copyist selection criteria and number of signatures

The goal of this simulation step is to obtain reliable signature reproductions, which simulate at best the graphical characteristics of the artist's signatures. In order to reach this aim, simulators (or copyists, or imitators)[168] acting as forgers are sought out and asked to copy the signatures of the five artists. The simulators are chosen according to their affiliation to three distinct, but possibly overlapping groups.

The persons in each of these three groups distinguish themselves from laypersons. Indeed, in order to obtain simulations of the highest quality, persons who are either extremely familiar with the use of paintbrushes, or persons with a trained eye, are copyists of potentially high quality. Furthermore, as pointed out by Buquet *et al.* (1992, p. 38), "the pictorial fake is rarely carried out by real amateurs". In this aspect, it is especially important to have simulators that are used to manipulating a paintbrush and used to observing and copying a painting style. In this sense, even the amateur artist who does not regularly manipulate a paintbrush is not included in the list of copyists.

The first group of simulators is composed of art restorers and/or conservators. This group possesses what would appear to be the skills necessary to produce proficient simulations: observation, analysis, and dexterity and control in reproduction. Indeed, they are brought to observe and copy a painting style when restoring works of art. These skills could prove beneficial to produce high quality simulated signatures.

The second group of simulators includes painters or persons educated in the fine arts or graphic arts. These individuals have developed an ease of use in terms of manipulation of paintbrushes, either through their studies, or through their artistic activity (painting on a weekly basis). This pool, like the first group, possesses skills in observation and dexterity. The proposition that artists may be capable of producing higher quality simulations (pen on paper) than laypersons has been emitted by Dewhurst (Dewhurst *et al.*, 2008). The

[168] The terms simulators, copyists and imitators are used synonymously in this context. However, the terminology of simulator is preferred, since participants in this thesis did not have an intention to deceive.

authors of this study notably found that calligraphers are more skilled than laypeople at producing simulations.

The third group of simulators composed of forensic handwriting examiners (FHE). The professional activity of this group has led them to master the deconstruction of line tracings and to develop an acute sense of observation. The choice of this group as a copyist group stems from the observation that studies (Found *et al.*, 1999; Kam *et al.*, 2001; Sita *et al.*, 2002) have proven FHE to be more skilled than laypersons for signature analyses.[169] FHE could, in the same sense, have an advantage over a layperson when it comes to the simulation of a person's signature.

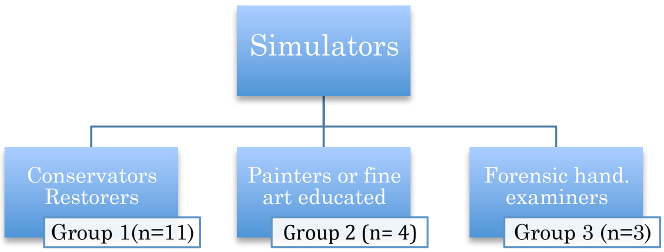


Figure 9 - The three groups of simulators (or copyists).

A total of eighteen simulators are chosen to simulate the signature of each artist. They are distributed in the following manner: eleven in Group 1, four in Group 2, and three in Group 3 (see Figure 9).

As with the artists, this number of potential simulators is set in order to correctly represent the variation, and as a maximum that could be readily obtained for the study. Each copyist will thus simulate each of the five artists, based on high quality photographs and enlargements of the reference corpus of 24 signatures. The number of simulated signatures is set at five signatures per artist per copyist, which will tally up to a total of 90 simulated signatures for every artist. This number is considered to represent the maximum number that could reasonably be requested from copyists for a research project, but the minimum necessary in order to obtain representative data. By using 18 forgers simulating the five artists, a total of 450 simulated signatures will theoretically be obtained.

[169] Found does note, however, that these studies are "limited in their number and scope" (Found, , p.1437).

7.2.2 Signature acquisition (data collection)

Each copyist is given a kit containing instructions as well as the necessary material to carry out the simulations. The instructions explain the aim of the research, contain several questions for the copyist on his background and skill, and indicate the procedure that he or she had to follow. A copy of these instructions and questions is presented in Appendix III.

Each kit contains reproductions of all of the artists' signatures in their actual size. They are printed on A3 size photography paper in order to have an overview of their signatures. Depending on their size, the artists' signatures are presented on one to four A3 sized-sheets. The signatures are also enlarged (2 to 3 times, depending on the initial size of the signature) in order for each of them to fit on one sheet of A4 paper. These enlargements consist of an aid for the copyist to evaluate the details of each signature. The same material as the one used by the artists is given for the sampling process: six numbered 40 x 40 cm oil canvases (one per artist and one for training/practice), black oil paint in the same dilution, and paintbrushes of the same brand and model as the ones used by the artists. Four additional paintbrushes - Pébéo, model 9960, size 3 and Artist synthetic real Zenia Acryl hair, model 74, sizes 2, 4 and 6 - are added into each kit (see Appendix I). The order in which the artists are presented in the kits is varied in order to avoid a bias of results due to either a training process or fatigue of the copyists.

The simulation procedure follows two steps: the first is a training step during which the copyists are asked to choose the paintbrushes that feel the most comfortable and reproduce at best the signature of each artist. The copyists are then asked to train their reproduction skills during a minimum of one training session. The practice canvas is provided for this purpose, but paper or cardboards are also available. Once the copyists have the impression that they can optimally reproduce the signature of each artist,[170] they can proceed to the second stage. During this stage, they are asked to simulate the signature of each artist five times.[171] The acquisition of the five simulated signatures of each artist can be carried out in the same session. The copyists are also asked

[170] The sample signatures produced in this first practice stage are not retained.

[171] The number five was set as the minimum - several copyists produced more than this amount. When more than five signatures were painted, the author, in concurrence with the copyist, picked out five signatures that seemed to best reproduce the original signatures, with a particular attention given to the construction mode of the signatures.

to indicate which of the artists' signatures they base their simulations on if a specific signature is used as a model.

7.2.3 Data recording

The signatures resulting from the simulation stage are digitalized in the same manner as the artists' signatures. The only difference resides in the use of a Phase One 645 DF digital camera (Phase One P65^{+} captor of 65 million pixels image resolution), equipped with a Phase One MF 120 mm 1:4 Macro lens. This type of camera is used instead of the stereomicroscope because the resolution is deemed sufficient for the submission of the images in the analysis process of the study. The final resolution of the images is approximately 3650 ppi. Such material does not necessitate an assembly of the signatures, since each signature is captured in principle with one photograph.[172]

7.3 Data extraction

7.3.1 Initial analysis and comparisons of authentic and simulated signatures

When a forensic handwriting expert faces a questioned signature, he approaches the question of whether the signature is authentic or simulated by using an ACE-V stepwise approach (presented in Chapter 4). In the analysis stage, both the authentic and simulated signatures are observed and described in terms of general aspects (elements of style, dimensions, overall proportions, spacing, quality and regularity of the line, pressure, etc.) and particular aspects. The latter are linked to the construction mode of the signature: namely the number of lines, starting and ending strokes, position of line crossings, position of points and accents, direction of lines, and types of links (Huber and Headrick, 1999).

In the present study, the general and particular aspects of the authentic signature corpus of each artist are described. Signatures that present abnormalities in terms of the construction mode are ejected from the signature set of the artist. These abnormalities can be for example a letter (or

[172] Certain signatures of larger size are captured with two photographs. These are subsequently assembled in the same manner as the authentic signatures.

a portion of the letter) missing from the signature, or can be an added letter or portion of a letter into the signature. Only extreme cases of irregularities are taken into account at this stage in order to avoid a premature removal of a signature from the set. This stage is also only carried out once all of the signature of each set have been properly analyzed and compared with one-another.

The same description process is then carried out on the simulated corpuses. Before the collected simulated signatures can be implemented into the developed database, an overall comparison is made between both corpuses, and an initial sort is performed. Inauthentic signatures that did not follow the same construction mode as those found in the authentic corpuses are discarded. All of the five simulated signatures, carried out by each copyist of each artist, must fulfill this stage to be kept. If this is not the case, these signatures are discarded (for example, if only one of the five signatures does not present the same construction mode as the authentic signatures, all of the copyist's simulated signatures are discarded).[173]

Before discussing the designation of measurements and characteristics that can describe a painted signature, a few general terminologies and prerequisites should be addressed. Careful considerations are necessary regarding the designation aspect, because the characteristics chosen at this stage will represent and define the bases of the project. A badly attributed terminology can lead to important problems during the comparison process between different signature specimens. The author advocates the use of the definitions emitted by the ASTM (ASTM, E2290-07a, 2007). Indeed, these definitions are put forward by working groups representing the forensic signature expert community and are widely recognized as a basis for signature identification:

- Known: "of established origin".
- Questioned: "associated with the matter under investigation about which there is some question, including, but not limited to, whether the questioned and known items have a common origin".
- Character: "any language symbol, other symbol or ornament".
- Characteristic: "a feature, quality, attribute, or property of writing".

[173] This sample selection stage is necessary to possess realistic data for the data sampling stage.

- Comparable: "pertaining to handwritten items that contain the same type(s) of writing and similar characters, words, and combinations. Contemporaneousness and writing instruments may also be factors". This definition raises the problem encountered by FDE concerning the expertise of signatures on paintings. The nature of the writing instrument can have a substantial impact on the evaluation of the observations made by a FDE on signature comparisons. For example, a signature signed with a ballpoint pen will not present the same number and quality of characteristics as a signature signed with a thick paintbrush.
- Distorted writing: "writing that does not appear to be, but may be natural. This appearance can be due to either voluntary factors (for example, disguise, simulation) or involuntary factors (for example, physical condition of the writer, writing conditions)".
- Natural writing: "any specimen of writing executed without an attempt to control or alter its usual quality of execution".
- Range of variation: "the accumulation of deviations among repetitions of respective handwriting characteristics that are demonstrated in the writing habits of an individual".
- Variation: "those deviations among repetitions of the same handwriting characteristic(s) that are normally demonstrated in the habits of each writer". In order to adequately assess a writer's variation, a sufficient quantity and quality of known signatures must be at the FHE's disposal.

7.3.2 Pre-processing of signatures

The image processing softwares Adobe Photoshop CS5® and CS6® are used to pre-process the set of authentic and simulated signatures of each artist. The pre-processing phase is carried out semi-automatically with a script that contained the following steps:

- Transformation of the RGB pixels into grey scale pixels;
- For areas of the signature that have a thin or diluted layer of paint, a progressive circular filter is applied on a layer. These areas are darkened to reach approximately the same level of grey scale as the rest of the signature (and for the background as well).

- A second curves layer is added. The grey pixels of the signature are pulled towards black, and the background is pulled towards white. The background pixels are erased. The background is selected (including the inside of the closed loops), the selection is inverted, and the holes inside the black line tracing are filled (see Figure 10); This filling process was a necessary decision to be able to carry out efficient measurements on the sample, but can effectively lead to a diminution of the information.
- Smears are erased manually;
- A visual control of the transformed signature is carried out using the "before" and "after" layers;
- The resulting image is reduced (bilinear, more focused) into a 240 dpi resolution with the correct size (by using a control ruler); this step also reduces the bit size from 16 to 8;
- All of the new layers are fused together to make up one image and the signature is cropped;
- Binarization of grey scale pixels with a 50% threshold to transform of the grey scale pixels into black pixels;

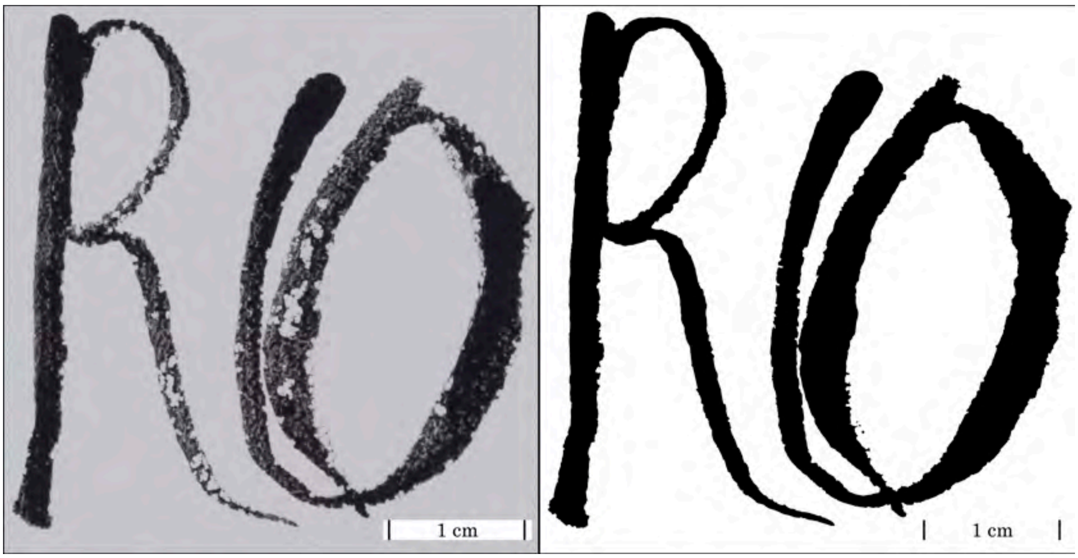


Figure 10 - Example of line tracing, before (left) and after (right) filling.

A 1 cm scale is kept for size verification purposes on each image. The full script of the image pre-processing is presented in Appendix IV.

7.3.3 SoDE Extraction software

A software (named SoDE) especially developed by the School of Criminal Justice of the University of Lausanne is used to analyze the sampled authentic and simulated signatures. The SoDE software is managed by pgAdmin (v1.16.1), and is linked to the PostgreSQL open source database. The software is designed to analyze each signature individually and to export the recorded data for subsequent statistical analysis.

Each binarized signature image is individually loaded - in tiff format - into the software and linked simultaneously to the name of the person having signed or produced the signature (the writer being either one of the five artists or one of the 20 copyists/imitators) and to the artist's signature template (that is, for each of the five artists). This procedure is schematized in Figure 11.

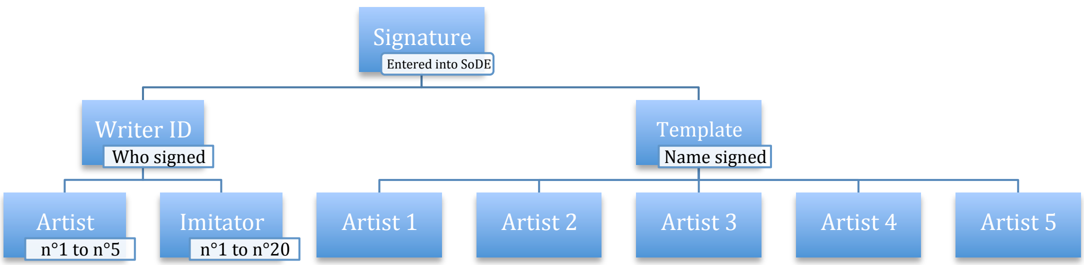


Figure 11 - Link of signatures in the SoDE software.

Thus, when each signature is added, three elements must be specified: the writer, the signature number, and the signature point template. Figure 12 shows the example of how the first Bacsay simulation (signature n°1 of artist named Bacsay) painted by the Imitator (or copyist) 1 is loaded into the database.

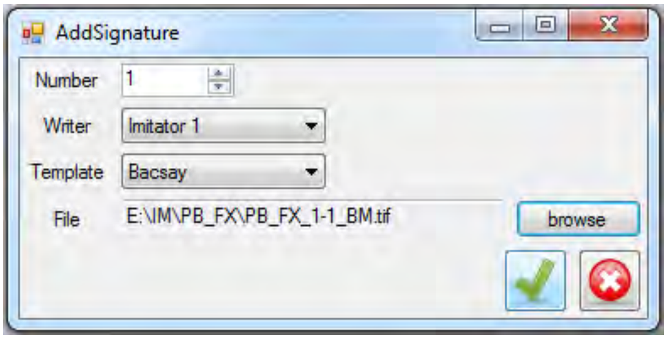


Figure 12 - Illustration showing how a signature is added into the SoDE software.

7.3.4 Selection and definition of the point template for each artist

Each artist's name is linked to a template that is needed to analyze his signature. The template is initially specified by the user, and consists of a list of x and y Cartesian coordinates that are manually assigned to each signature by the operator. The same set of points is used for each signature type (an authentic signature signed by the artist in question, or a simulation in his name), and varies according to the characteristics of the signature (i.e. length, accents, ornamentations).

The selection of the series of points for each artist is carried out in accordance with three elements:

1/ The construction mode of each signature component. The points are placed in a manner that they can be placed in every signature present in the authentic corpus.

2/ Measurements of the signature, and of the letters and elements composing it.

3/ Features (or characteristics) that will be analyzed for each signature type in the later stage.

The first aspect is developed in this sub-chapter; the last two aspects are extensively presented in the next two sub-chapters.

The numbers of points are taken in order to record the measurements that best define and characterize each signature type. The set of points is defined for each set of an artist's authentic signatures: the corpuses of the authentic signatures of each artist are studied, and a series of points are defined in a manner that they can be placed on each signature found in his corpus. Indeed, if an artist never closes the loops of his -e-, the intersection point of this unclosed loop cannot be designated. In this manner, every signature corpus is unique, and certain adaptations had to be carried out to define each corpus the best possible.

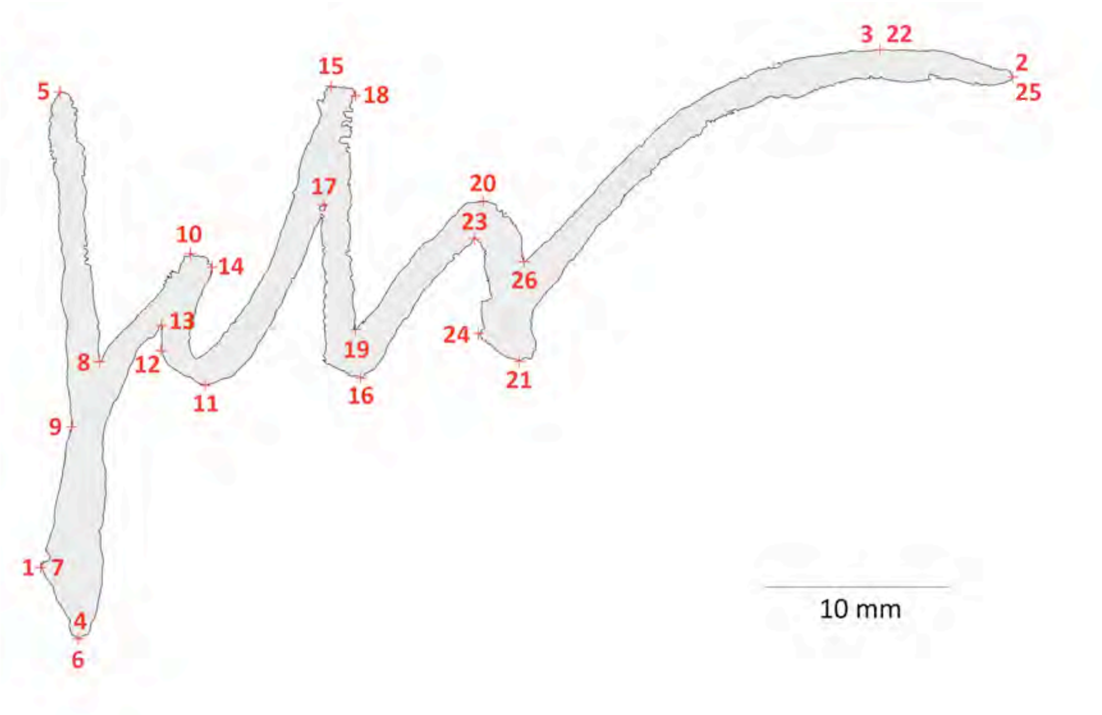


Figure 13 - Illustration of the Cartesian coordinates recorded on each of the authentic signatures of artist n°1: JC Schauenberg.

Each point of each specific signature is codified in such manner to render their selection in principle invariable of the operator selecting them. Guidelines are defined and are specific for each signature in the study, but the general view is to enclose the maxima and minima of the signature, of each letter composing the signature, as well as of each component (for example the stem) of the letter. For example, for the signature in the name of Schauenberg (artist n°1), a total of 26 points are recorded for each signature (see Figure 13).

In case the extremities of the letter or signature (in terms of height and length) are found to vary, a specific set of points is assigned to these maximum points (for example the points n°1, 2, 3 and 4 for the maximum length and height respectively of the signature of artist n°1 (Schauenberg), presented in Figure 13). In this case, the highest point of the signature varies from the tip of the stem of the letter -J-, the tip of the stem of the letter -l-, and the top of the endstroke of the letter -s-.

The general guidelines for determining the points follows the following rule: If a line tracing overlaps another line tracing (and terminates it's stroke within the thickness of the second line tracing), the point for determining the initial (or terminal) point of this first line is taken as the last visible point of the line (furthest point on either the x or y axis - depending on the nature of the point). By doing so, any interpretation as to which extent a line overlaps another is excluded (see Figure 14).

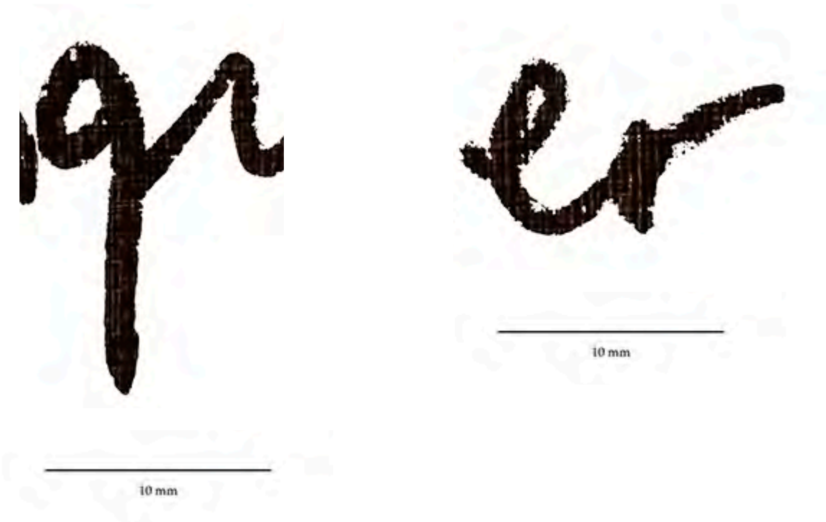


Figure 14 - (Left) Visual example of an initial stroke (letter -u-) overlapping a line tracing (letter -q-); (Right) of a terminal stroke (letter -e-) overlapping a line tracing (stem of letter -r-).

The template for each signature type is defined in the SoDE software, and can be changed at any time. Figure 15 shows how the coordinates template is defined for each signature type. Each point is recorded in a Cartesian coordinate plane, where each coordinate designates one specific pixel of the signatures image.

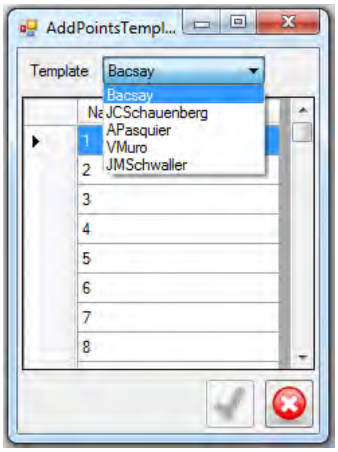


Figure 15 - Window illustrating the choice of possible point templates.

The coordinates designated for each signature corpus in the SoDE software are recorded in the PostgreSQL database. The data are then exported from this database and transformed in R,[174] the x-y coordinates of each point are integrated into a matrix. The ensuing data analyses are also performed with R software.

7.3.5 Measurements carried out on the signatures

For each artist, the coordinate selection (set of points) is intrinsically linked to the different measurements that can be subsequently carried out on each signature. There are two types of measurements taken from each signature corpus (authentic and simulated): either linear distances or angles.

The distances of each signature are obtained by calculating the difference between either the y-coordinates of two coordinates, or the x-coordinates of two coordinates. In this manner, a large amount of distances can be calculated, and the list can be revised at any moment. The distances measurements (given in pixels) are determined by calculating the linear distance between two coordinates $(\boldsymbol{x1}, \boldsymbol{y1})$ and $(\boldsymbol{x2}, \boldsymbol{y2})$, either on the horizontal ($\boldsymbol{x.distance}$) or the vertical axis ($\boldsymbol{y.distance}$):

$$\boldsymbol{x.distance} = \boldsymbol{x2} - \boldsymbol{x1} \quad \text{and} \quad \boldsymbol{y.distance} = \boldsymbol{y2} - \boldsymbol{y1}$$

[174] R 2.15.2 GUI 1.53 Leopard build 64-bit

Figure 16 illustrates an example of distance measurements between two coordinates. In this example, the numbers 18 and 19 correspond to the measurements 18th and 19th carried out on this signature.

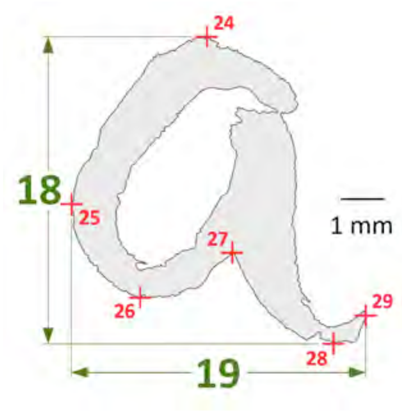


Figure 16 - Example of distance measurements (distances 18 and 19) between two coordinates.

The proposed set of measurements to be determined on each signature is based on studies and references on the analysis and comparison of signatures on paper. The first author to propose measures of features for signature examinations is Frazer (1899). According to the author, the most important features to observe and measure are the height, width, distances, spaces, and angles of a signature's components. Bertillon (1898) also proposes several features, and highlights the importance of translating them into numerical data. Locard (1934; 1936) offers a very detailed description of the different features that can be measured on handwriting, with examples of calculations and their significance. Osborn (1929, pp. 288-293) suggests a complete list of features that the handwriting expert should study when conducting a signature comparison. An abundance of more recent literature describing features that can be studied by forensic document examiners exists (Hilton (1982), Huber and Headrick (1999) and Morris (2000)). In the case of a questioned painted signature present on a work of art (see Section 4.3.3), a number of these are also reported as being used by FDE for this type of examination. The findings of these authors are also used as references for determining potential features.

These references offer numerous features for handwriting and signature comparison and are used as a starting point for establishing which measurements and characteristics will be considered for the study of signatures on paintings. Thus, the distances that can be potentially extracted from signatures can be classified into one of the five following groups, each presented below with the help of an illustrated example:

1. Signature (considered as a whole element): height and length. The accents, if any, are not taken into account for the total height of a signature.

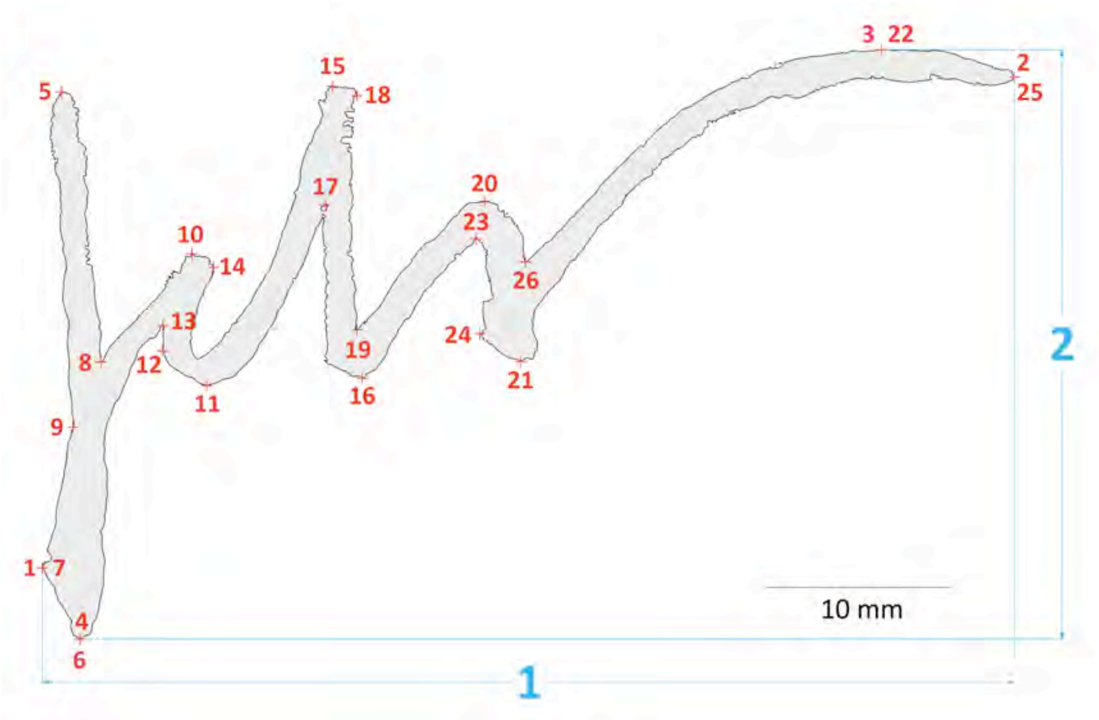


Figure 17 - Signature in the name of JC Schauenberg. The total length (n° 1) and height (n° 2) of the signature are presented in blue. The numbers is red correspond to the points (points n°1 to 26) recorded on this artist's corpus.

2. Letters (considered as a whole): height and length. In the case of beginning or terminal hooks that are intermittently present, the total length of a letter does not include these portions of the letter. Likewise, if some letters can be deconstructed into smaller elements (for example, in the presence of a dot or acute over a letter, this element is used as an entity in itself, and is not considered for the total height of the letter to which it's attached to).

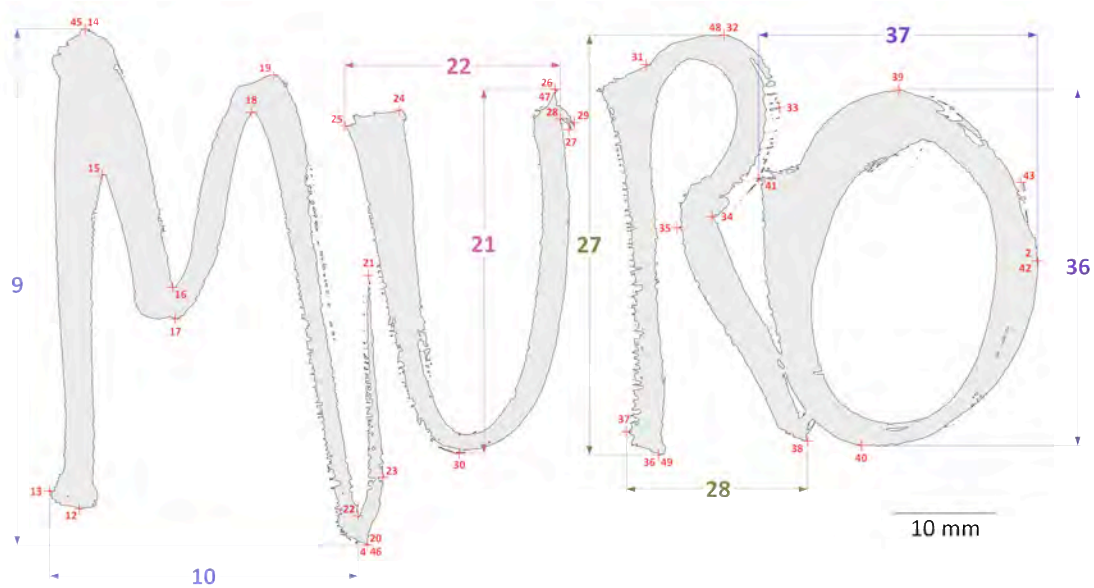


Figure 18 - Signature in the name of V Muro. The total lengths (n° 10, 22, 28, and 37) and heights (n° 9, 21, 27, and 36) of each letter of the signature are presented.

3. Spaces (between words, letters, and accents or diacritic marks and closest letter).

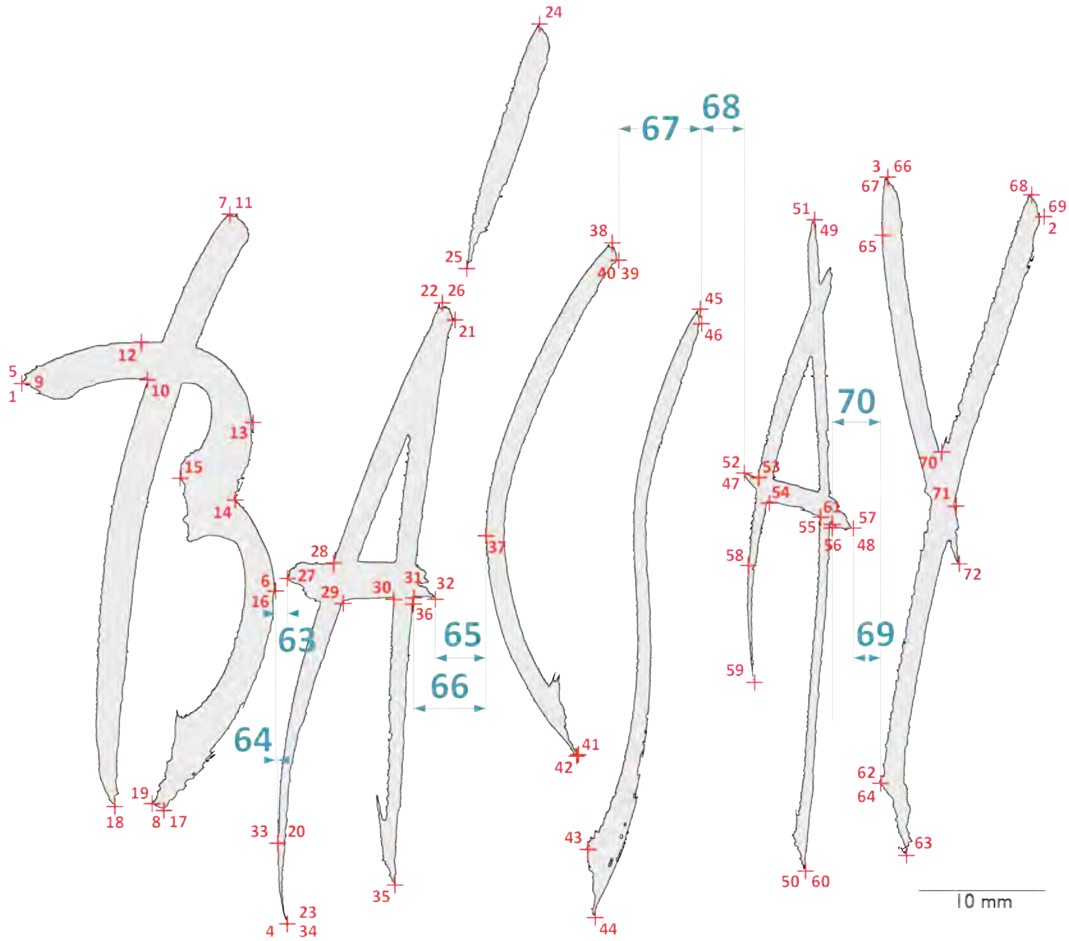


Figure 19 - Signature in the name of Bacsay. The spaces between each letter of the signature, and between the accent and the closest letter (here, an A), are presented.

4. Height differences between two letters (upper ascending and lower descending).

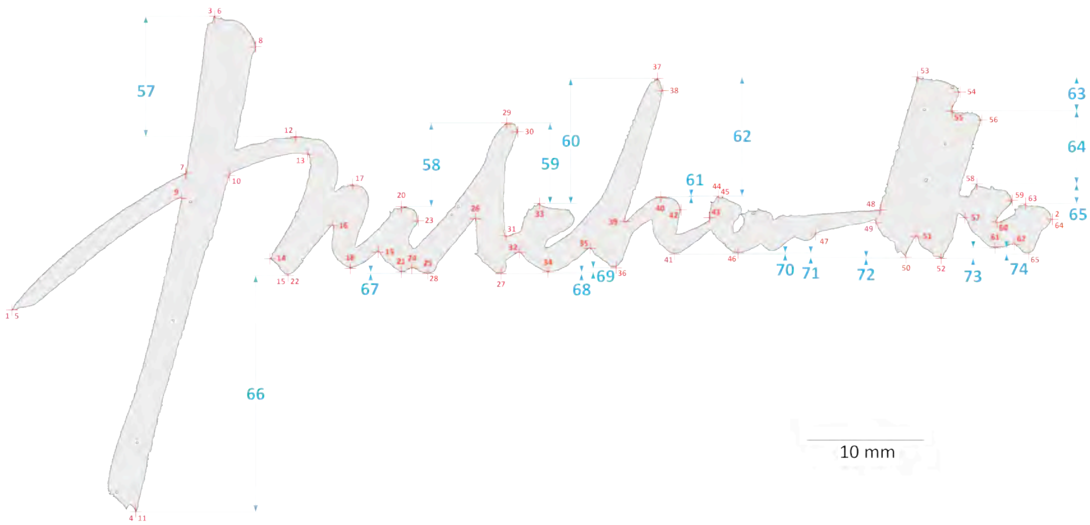


Figure 20 - Signature in the name of JM Schwaller. The height differences between the upper ascending letters (for example n° 60 corresponds to the upper height difference between the letter c and h), and the lower descending letters (for example n°66 is the difference between stem of J and first foot of m) of the signature are presented.

5. Intra-letter distances.

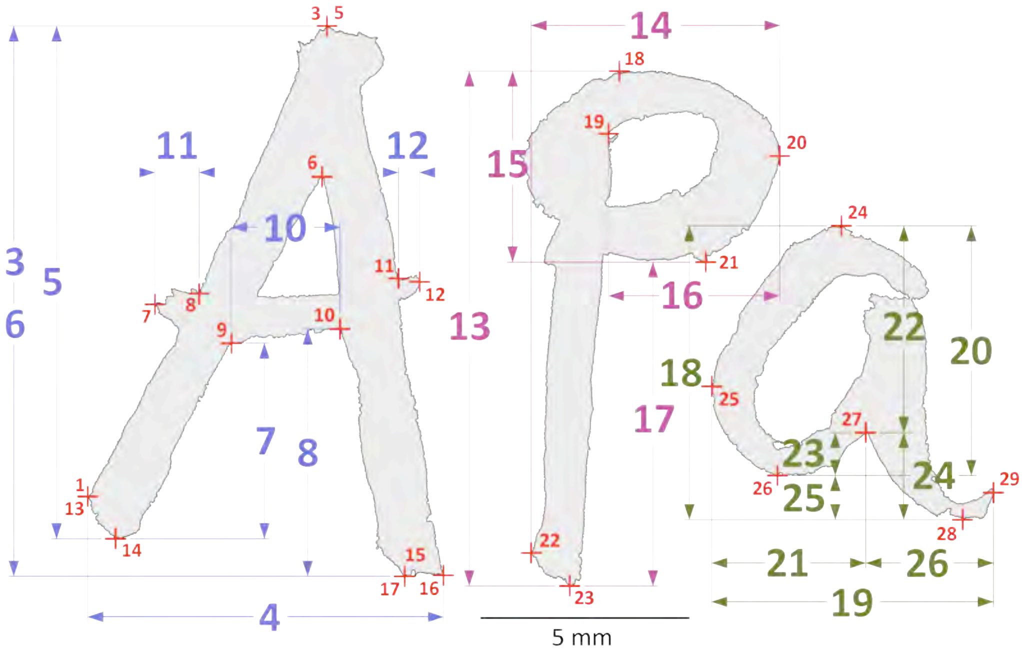


Figure 21 - Signature in the name of A Pasquier. The different intra-letter distances of the letters A (measurement in blue), P (measurements in purple) and a (measurements in green) in the signature are presented. The color code is simply used for esthetic reasons.

The angle measurements (given in degrees) are determined by calculating the angle between two coordinates $(\boldsymbol{x1}, \boldsymbol{y1})$ and $(\boldsymbol{x2}, \boldsymbol{y2})$ and the horizontal axis (0°), according to the following equation:

$$\boldsymbol{\alpha} = \boldsymbol{arctan}\left(\frac{\boldsymbol{y2} - \boldsymbol{y1}}{\boldsymbol{x2} - \boldsymbol{x1}}\right) * \frac{\mathbf{180}}{\boldsymbol{\pi}}$$

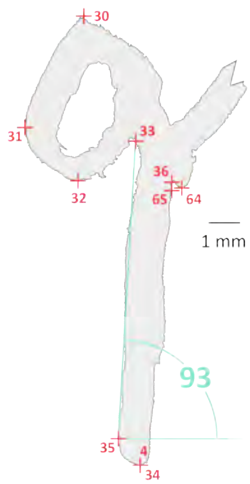


Figure 22 - Example of angle measurement (n°93) between two coordinates.

As for the linear distances measured on the signatures, the measured angles are also based on literature exposed above, which suggests to measure:

1. Slant or slope of elements of the signature. A precise measurement of the slant of the signature will be carried out on the letters containing 'staffs', namely the lowercase letters 'b', 'd', 'f', 'g', 'h', 'i', 'j', 'k', 'l', 'm', 'n', 'p', 'q', and 't', on letters with a closed loop, or on uppercase letters containing 'staffs'[175]. Frazer (1899) considers this feature to be important for the authentication process because forger usually focus their attention on the simulation of the forms and relative distances of the signature's components. Morris (2000) points out that "[…] relative slant within and between individual letters is hardest to duplicate when someone is trying to simulate another person’s writing. […] relative slant is more significant than overall slant when the forensic document examiner is comparing writings for common authorship."

[175] 'Staffs', which are also referenced as 'stems' in literature, correspond to the backbone, or main component of a letter.

2. For letters with horizontal crossings, i.e. the letters 'A', 'f', 't', and 'z', the angle (slant) will be measured.

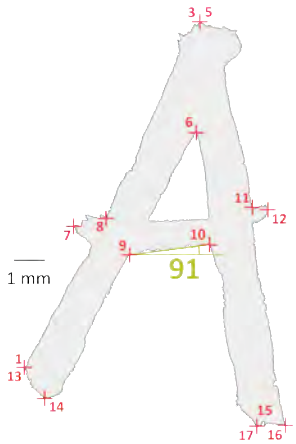


Figure 23 - Example of angle measurement of the crossing bar of letter -A-.

The distance and angle calculation R scripts can be found in Appendix XI.

7.3.6 Definition of relative measurements

Once the set of measures are defined for each artist's signature, a set of metric characteristics (or features) is determined based on the artist's signatures, and extracted for both signature corpuses (authentic and simulated) of each artist. During the authentication process, a number of similarities and dissimilarities are highlighted at the end of the comparison process between the questioned signature and the known reference signatures. These similarities and dissimilarities consist of the different characteristics or features that can be observed on a signature.

In order to define which characteristics could be used to best put forward the differences between signatures on paintings, research has been carried out on the characteristics that can be found in literature recommendations for standard handwriting and signatures comparisons (i.e. carried out with standard writing material, such as a pen or pencil on paper). These references include essential handwriting literature, for example Osborn (1929), Hilton (1982) and Huber and Headrick (1999). They also include international standards such as the European Network of Forensic Handwriting Experts (ENFHEX), which is part of the European Network of Forensic Science Institutes (ENFSI), which also proposes, in the Overview Procedure for

Signature Comparisons, a list of features to assess during the course of the examinations. These concern general characteristics such as style and legibility ("roundness or angularity of the signature"), size, proportions, spacing, slope and layout (ENFHEX, 2009). The ENFEX also suggests examining the detail features of the signature, such as the shape of the individual parts of the signature, the individual character proportions, the construction of the signature, and the degree of connections between the individual parts of the signature.

The defined set of characteristics is based on these literature references[176] and adapted to the nature of a painted signature. Each measurement is put in relation with another measurement, and is considered to be a normalization step of the data. This process enables a comparison of results between the signatures of an artist, and the simulations:

1. Relative size of the signature. This consists in calculating the length versus height ratio, for the whole signature, for the elements (first name and surname) of the signature.
2. Relative size of a letter:
   - With the signature. The height and length of each letter is put in relation with both the height and length of the signature.
   - With itself. This feature is the height to width ratio of each letter.
3. Relative height of a letter with the length of another letter, for example the letter following it.
4. Relative length of a letter with the height of another letter, for example the letter following it.
5. Spaces, that can either be:
   - Between words. Spacing of the first name(s)/initials(s) and last name (interword spacing): The spacing in between each name or initial will be calculated in relation to the overall length of the signature.
   - Between letters. If 'pen lifts' are present, the length of each of these interletter spaces are put in relation to the length of the letter after

[176] It is reasonable to assume that these features already have a signature discrimination potential established by the forensic community.

the space. In the case that there is no ‘pen lift’ in between two letters, spaces are not necessarily calculated.

6. Intraletter features (or proportion of elements found within letters). The list of the different proportions that can be observed are extensively listed by (Huber and Headrick, 1999): “proportion of bowls to staff, of bodies to loops, of upper loops to lower loops, of bowls to loops, of arches to loops, of troughs to loops, of bowls to bowls, of staffs to arms or legs, of upper loops to base elements, of upper curve to lower curve”. These proportions depend on the letters found in the signature.
7. The angle measurements obtained beforehand are not put in relation with any other angles or measurements; they are used as characteristics.

Once the set of points, of measurements, and of features to be extracted are defined for each signature type, the authentic and simulated signatures of each artist are entered in the SoDe software and the set of points are manually defined by the user. Once all of the points are acquired, the Cartesian coordinates are extracted, and the set of measurements and features are calculated.

This acquisition step will bring forth a set of characteristics (or features) that can be potentially observed and measured on an authentic and simulated set of an artist's painted signatures.

The following stages of the study will be based on the characteristics extracted on the sets of authentic and simulated signatures. The author will effectively aim to measure the variability of these characteristics on the authentic and simulated signatures of each artist, reduce their number, and assess their probative weight.

7.4 Data analysis

Once all three stages of the data sampling, i.e. point assignment, measurements and characteristics extraction, have been carried out on both the authentic and simulated signature corpuses of each of the five artists, the resulting characteristics or features can be analyzed to assess their relevance.

All of the following analysis are carried out with the R software; the specific scripts used are presented in Appendix XI.

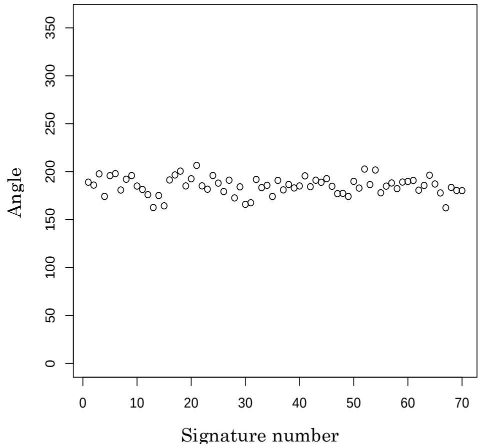
7.4.1 General assessment of measurements and characteristics

In order to have a general assessment of the measurements extracted on each signature set, visual plots are generated. Potential outliers and/or errors in the attribution of the points are thus easily highlighted, double-checked, and corrected if their origin is due to a false manipulation or mistake in the sampling stage.[177] If the extreme point is actually correctly attributed and not due to a mistake in the sampling procedure, then the origin of the outlying value can be understood by examining the signature images.

The same procedure is carried out for the resulting characteristics. An overview of the outliers detected in each authentic and simulated set is carried out. This allows one to become aware of the variation than can be expected with each signature, when considered individually. For each detected outlier, the origin of the outlying feature is given. Only the outliers detected in the authentic sets are presented in the results section, as their aim is to give the reader an understanding of the extreme variation that can be found for a given artist, and that can thus be an inspiration for the simulators (the simulators being able to base their produced signatures on one of these extreme values).

Plots are also generated for the characteristics of each signature set, again to highlight potential outliers in the data sets. Each extreme value is once again verified and appreciated by examining the signature images. The plots of the angle characteristics pointed out the need to carry out adjustments for a small number of the angle calculations. For example, for the characteristics C143 of the artist n°4 (Pasquier), the angle measurements were situated between the degrees 330° and 30°. Thus, 180 degrees are added to the all of the values making up this characteristic (see Figure 24). The different angle characteristics that must be adapted in each signature set are thus determined and modified (see Appendix XI).

[177] These outliers are, in this case, errors. If no error in the sampling stage is brought forward, the extreme values are considered outliers and are conserved.



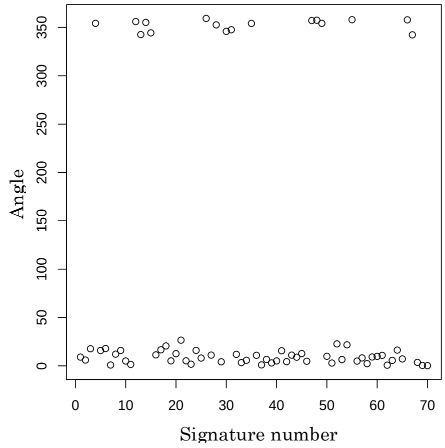


Figure 24 - Plot of values of C143 of artist n°4 (authentic and simulated sets), before (left image), and after (right image) the adjustment of the angle values.

Boxplot representations of the authentic and simulated signature sets are also generated to observe the degree of dispersion of both data sets, the skewness of the data sets, and also to confirm the presence of outliers. The resulting outliers are visually identified on the boxplots when situated lower than: Q1-4.5*IQR, or higher than Q3 + 4.5*IQR (Q1 and Q3 being the first and third quartile, IQR being the interquartile range).

7.4.2 Principal component analysis

In order to obtain global visualizations of the multivariate data, principal component analyses (PCA) are initially carried out on each data set. The aim of Principal Component Analysis is to "reduce the dimensionality of a data set consisting of a large number of interrelated variables, while retaining as much as possible of the variation present in the data set. This is achieved by transforming to a new set of variables, the principal components (PCs), which are uncorrelated, and which are ordered so that the first few retain most of the variation present in all of the original variables".[178]

PCA permits a simultaneous vision of all of the characteristics (n_c) defining both data sets. PCA rotates the data sets in order to visualize the maximum variability of these sets (the PCA aiming to maximize the two sets of authentic and simulated signatures). In this manner, the n_c characteristics (or

[178] (Jolliffe, 2002, p.1)

features) are reduced drastically to a pre-defined number of components (but of a maximum of number of n_c-1). The variables are reduced and centered since the variables do not all have the same order of magnitude.[179]

The PCA analysis is carried out once again, once each feature vector has been selected for each artist. This second analysis can allow a comparison with the initial PCA results, in order to visual determine the impact that the selected feature vector has in terms of separation potential between the authentic and simulated sets of signatures for each artist.

7.4.3 Feature Selection

a) Boruta feature selection

The data set describing each artists' signatures contains a large number of features. As is the case for most data sets, these features do not all possess the same weight when it comes to their classification power between the authentic and simulated classes: some are more relevant than others. The feature sets must be analyzed to assess the impact of each feature on the separation power between the two classes. The more relevant the feature, the better this feature is able to correctly distinguish both classes.

The selection of a small, and possibly optimal, feature set that renders the best possible classification results has the advantage of presenting manageable-sized data. Also, large data sets have been shown to produce a decrease of accuracy then dealing with larger than optimal feature sets (Kursa and Rudnicki, 2010). This selection step is carried out on all of the features characterizing each artist, and in parallel to the normality testing.

The selection stage is carried out with the Boruta selection process. The Boruta algorithm consists of a feature selection algorithm for finding all relevant variables. This algorithm, implemented in an R package,[180] uses a wrapper approach built around a random forest classification algorithm. Random forest is based on a method developed by Breiman (2001), and has also been implemented into R.[181] Random forest classification has proven to be

179 The PCA analyses are carried out with the function dudi.pca() of the ade4 package.
180 Package Boruta, version 1.3.
181 Package randomForest, version 4.6-10 (Liaw and Wiener, 2002).

a popular technique, notably because of its low misclassification error rates (Hastie *et al.*, 2009).

The general principle of a random forest classification is the following: From the total number of features used to define the data set (p), a random sample of (m) features are chosen to define a subset, which will be used to construct a tree. Each tree is thus constructed on a different subset of m features according to the bagging technique, where a random subset of data is selected from the training set. For random forest classification, the value of m is typically $\sqrt{p}$. Each tree is then grown by selecting the best variable/split-point among the m features, and is then separated into two sub-nodes (Hastie *et al.*, 2009). Also, an initial bootstrapped data set can be randomly drawn before the construction of the trees.

One tree will not constitute an overall suitable classifier. This one tree may be correct, but will however only represent a subset of the data. Therefore, a number of trees are constructed according to the random subset selection of data explained above. Each tree is trained independently and in parallel, and represents a different subset of the data.

All of these given trees together constitute the forest. The outcome of all the trees are averaged when using random tree regressions, and are classified using a majority vote when using random tree classification (as is the case here). Therefore, a higher number of trees will consequently give a lower rate of misclassification.

The Boruta algorithm, as presented beforehand, is based on a random forest type classification. The aim of this algorithm is to discover all of the features for which their "correlation with the decision is higher than that of random attributes" (Kursa and Rudnicki, 2010, p. 4).

The Boruta algorithm consists of following steps (Kursa and Rudnicki, 2010, pp. 3-4):

- "Extend the information system by adding copies of all variables (the information is always extended by at least 5 shadow attributes, even if the number of attributes the original set is lower than 5).
- Shuffle the added attributes to remove their correlations with the response.

- Run a random forest classifier on the extended information system and gather the Z scores computed.
- Find the maximum Z score among shadow attributes (MZSA), and then assign a hit to every attribute that scored better than MZSA.
- For each attribute with undetermined importance perform a two-sided test of equality with the MZSA.
- Deem the attributes which have importance significantly lower than MZSA as 'unimportant' and permanently remove them from the information system.
- Deem the attributes which have importance significantly higher than MZSA as 'important' [i.e. 'Confirmed'].
- Remove all shadow attributes.
- Repeat the procedure until the importance is assigned for all the attributes, or the algorithm has reached the previously set limit of the random forest runs."

The Algorithm will stop when either two of the steps are reached: either only 'Confirmed' attributes are left, or when the maxRuns of runs are reached in the last round. The maxRuns parameter can be increased to try to resolve the state of the tentative attributes. The higher the number of runs, the more the nature of the Tentative features are resolved, and either placed in the 'Confirmed', or the 'Unimportant' sets. However "there may be attributes with importance so close to MZSA that Boruta won't be able to make a decision with the desired confidence in realistic number of random forest runs" (Kursa and Rudnicki, 2010, p. 7).

For this study, the number of of trees (ntree) used to construct the forest are varied in order to assess their influence on the selection set. The ntree parameters is a randomForest parameter, and is varied here from 1000 to 100000.[182]

The different outcome of selected features, according to the given parameters, are compared with one another. The feature vector containing the highest number of features attributed as 'Important' and 'Tentative' is retained for

[182] The parameter of maxRuns, which corresponds to the maximum number of runs that are accomplished during the analysis, is tested at a preliminary stage from 1000 to 200. The number of maxRuns of 1000 is selected.

each given artist. The 'Tentative' features are retained in order to keep a broader spectra of relevant features, rather than preciously eject a feature that might be relevant, but only ejected because of a too low number of maxRuns.

b) Normality testing

The normality of the distribution of each characteristic describing the authentic and simulation set for each artist is necessary for the sub-sequent analysis of the data with the likelihood ratio assessment. The normality is tested with a Shapiro-Wilks test,[183] with $\alpha = 0.05$ and 0.01 threshold of p-values to not reject the hypothesis that the data has a normal distribution. The results are studied in regard to the authentic and simulation set. After comparing different normality tests, (Yazici and Yolacan, 2007, p. 182) found Shapiro-Wilks statistics "provides a superior omnibus indicator of non-normality judges over the various symmetric, asymmetric, short- and long-tailed alternatives and over all the sample sizes used".

A sub-step of pre-processing of the data is initially carried out, and consists of transforming each data set into a logarithmic scale.[184] Thus the pre-processing stage was rejected and a final value of $\alpha = 0.01$ was retained.

Only features that present non significant p-value for both the authentic and simulation sets are retained for the feature selection stage. However, no feature selection step is preformed at this stage of the analysis, all of the features are retained, whether they pass the normality testing or not. Only once the feature selection stage has been carried out, will the results of the normality testing be combined to give the final selected features.

The results of the Boruta feature selection stage is finally combined with the results of the normality testing stage. Features that pass both of these requirements are retained (k), and make up the final feature vector. This final feature vector has a minimal length of two characteristics, and a maximal

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183 Carried out with the function shapiro.test in R.

184 Since a number of the characteristics are present in a negative scale, an addition of +10 is added to each characteristic value in order to obtain only positive values. This pre-processing step was carried out on both the authentic and simulated sets of each artist. The pre-processing stage carried out did not, on a whole, improve the percentage of characteristics presenting normality, in regard to a $\alpha = 0.05$ threshold. Indeed, an improvement was only noted for the authentic and simulated sets of the artist n°2 (Bacsay).

length of the number of features that are retained (k). Thus the feature vector can be represented in the following manner:

$$\upsilon = (\upsilon_1 - \upsilon_n)^T \text{ with n = 2 to } k$$

The length of the feature vector (i.e. the number of features) is not limited, and may vary according to the sampled data. Thus, for each of the five artist, a feature vector is defined and used for the last stage of the analysis: the likelihood ratio calculations. The final aim being to obtain the optimal feature vector υ.

7.4.4 Likelihood ratio evaluation

The likelihood ratio evaluation principles are presented in Section 4.4.1. If we come back to what was presented beforehand, we have the following equation:

$$LR = \frac{\Pr(E \mid H_1, I)}{\Pr(E \mid H_2, I)}$$

where:

- H_1 = The signature is authentic, it was signed by the presumed writer (or artist)
- H_2 = The signature is a simulation, produced by a third writer (or forger)
- E = The forensic findings made on the signature
- I = Background Information, which is contextual information of the case

The forensic findings correspond to the feature set describing the authentic and simulated signatures of each artist. The feature set υ is composed of 2 to k features, depending on which features were retained in the feature selection process for each particular artist.

If taken individually, each feature of the selected feature vector follows a univariate Normal distribution, $X_i \sim N(\mu_i, \sigma^2)$, of known mean μ, and variance σ^2 (with i = 1, 2, .., k). In the present case, the data consists of multivariate continuous data: each artist's signature set is described by the feature set of length k. Therefore, each population of authentic and simulated signature sets consist of two multivariate Normal populations: $N(\mu_W, \Sigma_W)$ for the authentic population, and $N(\mu_B, \Sigma_B)$, for the simulated population, where μ denotes these vector of means of the k features, and Σ the matrix of variances and covariances.[185] The simulated set is constructed using all of the simulated signatures of each artist (not only one specific simulator). Each recovered signature can be classified in either of these two multivariate Normal populations. The probability to observe the characteristics of a recovered signature y (where $y = y_1,...., y_k$) given an origin from the authentic set is assessed. Likewise the probability to observe the characteristics of this same recovered signature y, given an origin from the simulated set, is also assessed. The ratio of these two probabilities produces the value of the evidence. Since the distributions of both the authentic and simulated populations are known (with both known means and known covariance matrixes), the value of the evidence can be assessed with the following (Bozza *et al.*, 2008; Taroni *et al.*, 2010):

$$V = \frac{P(E|H_1,I)}{P(E|H_2,I)} = \frac{f(y \mid \mu_W,\Sigma_W)}{f(y \mid \mu_B,\Sigma_B)} = \frac{exp\left[-\frac{1}{2}(y-\mu_W)\,\Sigma^{-1}(y-\mu_W)\right]}{exp\left[-\frac{1}{2}(y-\mu_B)\,\Sigma^{-1}(y-\mu_B)\right]}$$

This type of evaluation of forensic findings has proven to be pertinent for the multivariate analysis of continuous handwritings data (Taroni *et al.*, 2012). In the present case, there are no recovered signatures, thus the value of the evidence is calculated with the "leave one out" technique. Each signature, whether authentic or simulated, is taken out of its original set and used as the tested signature y. The signature is considered as recovered data of unknown origin. The resulting sets of the authentic and simulated signatures are used to calculate the background data sets. The mean (μ) and the matrix of variances and covariances (Σ) of both the authentic and simulated sets are then calculated: μ_W and Σ_W represent the mean and the matrix of variances and covariances of the authentic set and represent the within variation. Likewise, μ_B and Σ_B represent the mean and the matrix of variances and covariances of the simulated set, and represent the between variation.

Once the value of evidence is calculated with the tested y signature, the signature is then thrown back into its original population. The procedure is repeated with all n_A authentic signatures, and with all n_I simulated

[185] The subscript W denotes the word "within", as in within population, and B, the between.

signatures. A total of n_A likelihood ratios in favor of the prosecution (under H_p), and n_I likelihood ratios in favor of the defense (under H_d) result of the whole procedure. Figure 25 presents a schematic illustration of this process.

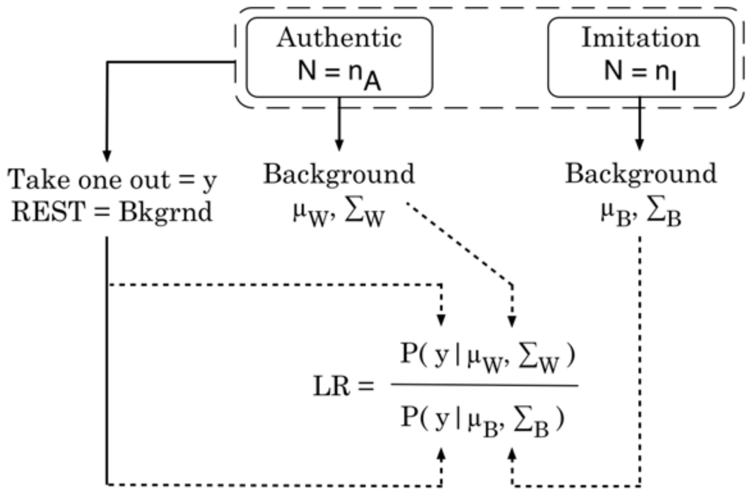

Figure 25 - Illustration of the likelihood ratio assessment procedure for each signature.

Since each authentic and simulated signature of a given artist is described by the *v* feature vector, up to *k* features are used together to describe each signature, giving a total of *k-1* feature vectors to test. The value of the evidence, as described in Figure 25 is repeated for each feature vector of each artist (i.e. with a feature vector containing the first two features, first three features, ... up to the k features).

The error rates in terms of false positive results and false negative results are calculated to assess the reliability of the developed method. A false positive is found when a simulated signature (different sources) obtains a log(LR) over zero, and a false negative is found when an authentic signature (same source) obtains a log(LR) below zero.

7.4.5 Log-likelihood-ratio cost evaluation

The final stage of the signature analysis consists of measuring the validity of each feature vector with the log-likelihood-ratio cost metric (Morrison, 2011). This type of metric, developed in the speaker recognition field, offers an output based on likelihood ratios results. Thus, if this measure is applied to all likelihood ratios obtained for each feature vector, the optimal number of features to discriminate the authentic signature sets from the simulated signatures sets can be extrapolated for each artist.

The log-likelihood-ratio cost (C_{llr}) is obtained using the following equation (Morrison, 2011):

$$C_{llr} = \frac{1}{2}\left(\frac{1}{N_{ss}}\sum_{i=1}^{Nss}\log_2\left(1 + \frac{1}{LR_{ss_i}}\right) + \frac{1}{N_{ds}}\sum_{i=1}^{Nss}\log_2\left(1 + \frac{1}{LR_{ds_j}}\right)\right)$$

The LR_{ss} are the likelihood ratios obtained from comparisons of test pairs of signatures of the same-source (ss), whereas LR_{ds} consist of the likelihood ratios obtained with comparisons of tests pairs of the simulated signatures, of different-sources (ds). N_{ss} and N_{ds} are the number of these same-source (and respectively different source) comparisons. Note that the likelihood ratios are in base 2, therefore a transformation from the natural logarithmic must be carried out. The log-likelihood-cost function is the mean of two means: the mean of a function derived from likelihood ratios obtained from same-source comparisons, and the mean of a function derived from the likelihood ratios obtained from the different-source comparisons. Thus, if the same-source comparisons gave a high LRs, the first mean will be low, and contribute little to the C_{llr}, however, a if the same-source comparisons gave low LRs, the first mean will be higher and give a higher final C_{llr}. Naturally, the aim for this type of measure is to obtain a value as low as possible: the lower the value, the better the validity.

8 Results

8.1 Observations made on the artists' signatures

As exposed in Section 6.1.1, the selection of the artists for this study was carried out according to four criteria:

- The artists have to meet the prerequisite of being professional artists.
- The artists are chosen according to the signing technique of their own painted signature.
- The artists are chosen according to the material they are used to painting with.
- The artists are selected for signatures covering different styles and lengths.

The five artist selected fulfill these criteria. Only artist n°1 (Schauenberg) uses different media for his compositions, namely charcoal, crayon, and acrylic. His signatures were however kept because of their short length and their cursive style. An overview of the artists and their personal backgrounds is presented in Appendix V. The artist all maintained a minimal one-week interval between each signing session. The exact time frame between each sampling session as well as the position of the canvas and if a support was used to sign, are also presented in Appendix V.

Different types of signature styles were represented: the artists' signatures were composed of lowercase and/or capital letters, and covered the cursive or script style, or were a mix of both. Varying signature lengths were also obtained. The signatures present a variable degree in their complexity level (number of line crossings, pen lifts, number of letters). An overview of these characteristics is given, for each artist, in Table 1.

	Artist n°1 Sch.	Artist n°2 Bacsay	Artist n°3 Muro	Artist n°4 Pasquier	Artist n°5 Schwaller
Composition of signature	Jcls (4 letters)	BACSAY (6 letters)	V. MURO (5 letters)	A Pasquier (9 letters)	Jmschwller (10 letters)
Signature style	Cursive	Script	Script	Cursive and script	Cursive
Letter style	Lowercase	Capital	Capital	Lowercase and capital	Lowercase and capital

Table 1 - Overview of signature composition, signature style, and letter style for each of the five artists.

A more detailed description of the general graphic elements of the different signatures, as well as a description of particular aspects and their construction modes, are presented, individually for each artist, in the following sub-sections. For visual references of these signatures corpuses, see Appendix VI, and for documentation on the terminology used for the different letter formations of each signature type, see Appendix VII.

8.1.1 Description of signatures of artist n°1 - Schauenberg

When signing, the artist placed each signature on the bottom right hand corner of every side of each canvas. The artist placed the canvas on a flat surface for each signature sampling, and used either the canvas, or an object of the same thickness of the canvas, as a support to sign.

The artist also mentioned that the signature is (or can be considered) as a painted graphical sign, rather than a spontaneous signature. The artist notably stated that the "signature is 'drawn'" in the information sheet.

The 24 signatures of the artist are of the same composition: the letters -J-, -c-, -l-, and -s-, and are written in a cursive style and in lowercase letters (see Appendix VI). The construction mode of the signatures is consistent throughout the corpus, with the exception of signature JCS-05, where the letter -s- is constructed with an additional descending loop. The stroke line is continuous in some signatures, and consisting of conjoined strokes in others.

However, a clear interruption of the stroke line is not observed. Some additional small variations in the construction modes are visible (see Appendix VII for the name reference of the different components of the signature):

- The lower loop of the letter -J- is most often blind, but on a few occasions the counter of the loop is visible (JCS-05).
- The inner curvature of the bow of the letter -c- is more (for example on JCS-01), or less (JCS-11 or JCS-12) pronounced. In the latter case, the curvature is inexistent, consisting in a vertical line or even an inversed curvature.
- The final loop between the descending stroke of the letter -s- and the endstroke is most often blind, but is occasionally an open loop (JCS-19).

In light of the analysis of the signatures produced by artist n°1, the totality of his corpus is retained, with exception of signature JCS-05. This signature is ejected from the set due to its exceptional construction mode of the letter -s-, leaving a corpus of 23 signatures for this artist.

8.1.2 Description of signatures of artist n°2 - Bacsay

When signing, the artist placed each signature on the bottom right hand corner of every side of each canvas. The conditions used in the sampling stage were not given by the artist, however, he did state for the first sampling stage that no support was used to rest his hand or forearm for the signing of the signatures.

The 24 signatures of the artist are of the same general aspect (see Appendix VI). They are composed of the letters -B-, -A-, -C-, -S-, -A-, and -Y-, and are written in a script style and in capital letters. All of the 24 authentic signatures signed by this artist show a similar construction mode. Some general remarks can however be made (see Appendix VII for the name reference of the different components of the signature):

- On several occasions, the line strokes of the letter -B- that are habitually made with one stroke are clearly made with two strokes (i.e. -S- of PB-01, stem of -B- of PB-05 and PB-24).
- The top portion of the stem of the letter -B- either overlaps the top bow of the letter or is either terminated within the stroke of the bow (PB-

17). Likewise, the buckle of the letter is either situated on the right of the stem (PB-05), either terminates within the stroke of the stem (PB-07), or either overlaps the stem (PB-01).

- The stems of the letters -A- are occasionally not joined at their summit, or their intersection is overlapping in a "teepee" type formation. Rarely, the line stroke is partially missing (for example, upper component of left stem of first -A- of PB-06 and PB-18, or bows of -B- on PB-06). Terminal hooks are occasionally present on stems of both letters -A- (for example on PB-01, PB-03, and PB-07).
- On one occasion (PB-23), the left stem of the -Y- does not overlap the right stem.

8.1.3 Description of signatures of artist n°3 - Muro

When signing, the artist placed one signature above the other, horizontally. The artist placed the canvas on a flat surface for each signature sampling, and used her hand as a support for signing for the first and last sampling sessions, but did not use any support for the sessions in between.

In the information sheet, Muro states that her signing techniques depended on the support to be signed: paintings were signed in capital letters, however drawings on paper are signed with lowercase letters.

The 24 signatures of the artist are varying in their general aspect:

- Fourteen are composed of the capital letters -V-, -M-, -U-, -R-, and -O, written in a script style. The letters -M- and -U-, and -R- and -O- are occasionally conjoined.
- Six are composed of the letters -V-, -i-, -r-, -g-, -i-, -n-, -i-, -a, -M-, -u-, -r-, and -o-, written in a mix of capital and lowercase letters, and in a cursive style.
- Four are composed of the letters -V-, -I-, -R-, -G-, -I-, -N-, -I-, -A-, -M-, -U-, -R- and -O-, written in a capital letters and in a script style.

Interestingly, the artist even once used the three different signature styles in the same session. In light of these three different signature styles, the author chose the first signature style as a basis for analysis (since it was used in the highest number of signatures) and asked the artist to produce an additional 12 signatures, using the first signature style and composition. These additional signatures were once again carried out with a one-week time interval between each session, and with the same material as for the first six sessions. Thus, the artist participated in a total of 9 signature sampling sessions.

A total of 26 signatures, signed with the letters capital letters -V-, -M-, -U-, -R-, and -O in a script style, are used as the artist's corpus for the study (see Appendix VI). The construction mode of these 26 signatures vary in the sense that strokes were sometimes overlapping or linked, and sometimes clearly distinguishable as two separate strokes. Also, the presence of initial or terminal hooks varies throughout the corpus. Specifically, for each letter, the following observations are made (see Appendix VII for the name reference of the different components of the signature):

- The letter -V- includes a terminal hook, which is more or less pronounced, on 18 of the 26 signatures. The angularity of the apex of the letter is also more or less pronounced.
- The point between the letter -V- and -M- is present on four of the signatures.
- The letter -M- presents several formation modes. The left stem is generally composed of one stroke, however, on a few signatures (for example VM-13, VM-15, VM-16, VM-18, VM-21), two strokes are clearly visible (downward and upward stroke). The left stem and the left median stem are sometimes made with one continuous stroke, and sometimes are composed of two distinct strokes. The same remark can be made for the conjunction of the two median stems, and the right median stem with the right stem. Finally, the right stem of the letter is either straight with an abrupt finish, or is linked with the letter -U- with a connecting stroke. This connection stroke is either a conjoined continuation of the letter -M-, or is made of an overlapping stroke.

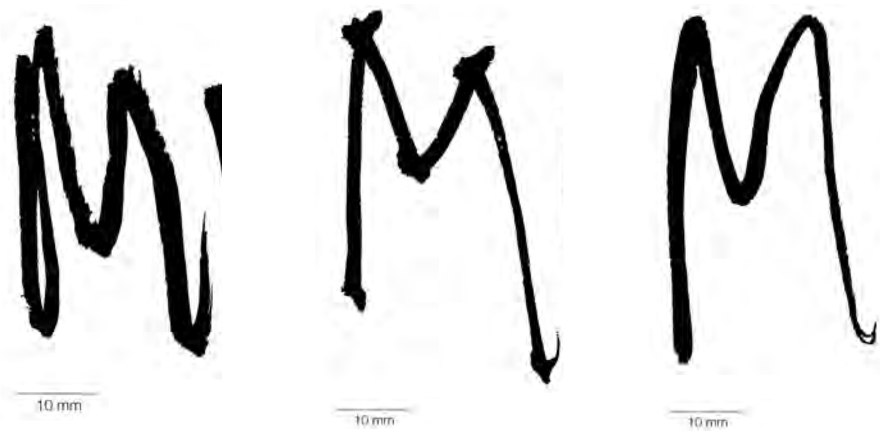

Figure 26 - Illustrated examples of the three formation modes of the letter -M-

- The letter -U- includes a terminal hook that is more or less pronounced, on 11 of the 26 signatures.
- The letter -R- presents several formation modes. The stem is generally composed of one stroke, however, on a few signatures (for example VM-01, VM-08, VM-09, VM-15, VM-24, VM-26), two strokes are clearly visible (downward and upward stroke). These two strokes form either an open or a closed loop. The beginning of the modified bowl is either overlapping the top of the stem, is either a continuation of the ascending stroke of the stem, or is either completely visible (and is thus not overlapping with the stem). The buckle is either overlapping the stem, or is either completely visible. Its form is sometimes rounded, but frequently angular. Rarely, the modified bowl and the leg of the letter are formed of two distinct strokes. The leg is either abruptly terminated, with or without the presence of an ascending terminal hook, or is either conjoined with the initial stroke of the letter -O-.
- The number of encircling's of the letter -O- varies from one full circle, to approximately 2 and a half circles.

8.1.4 Description of signatures of artist n°4 - Pasquier

When signing, the artist placed each signature on the bottom right hand corner of every side of each canvas. The artist placed the canvas vertically on an easel for each signature sampling, and used his hand as a support to sign his signatures.

For the artist Pasquier, the signature is adapted to the size of the painting. For small canvas formats, only the initials, followed by the 2 last numbers of the year are signed ("AP 10"). Medium formats are signed with the full name in lower-case letters, and optionally followed by the year (A Pasquier 2010, or Augustin Pasquier). Finally, large formats are signed with the full name in capital letters, followed by the year (AUGUSTIN PASQUIER).

He states as general commentaries that "My signature can vary, because I do not consider it as a mark of authenticity, but rather as an information with the name, but also the date which is important. On small formats, the signature, with the date, and sometimes the title [of the painting], can be inscribed on the back of the work. The paintbrushes and the consistency of the paint are not the same for one painting and another." This artist mentioned, as had Schauenberg, that the signature is (or can be considered) as a painted graphical sign, rather than a signature emanating from a repeated and natural gesture. He states for example:

"The signature is sometimes a graphical game."

Finally, this artists specifies that the signature must not interfere with the reading of the painting.

The signatures of this artist are composed of the letters -A-, -P-, -a-, -s-, -q-, -u-, -i-, -e-, and -r-. The signatures are written in a mix of a script and cursive style and with a capital -A- and -P-, and otherwise lowercase letters (see Appendix VI). The 24 authentic signatures signed by the artist show a similar construction mode in general, but 2 letters are formed using different styles. The last signature (AP-24) is rejected from the artist's corpus because the letter -e- is absent. Some general remarks can however be made (see Appendix VII for the name reference of the different components of the signature):

- The crossbar of the letter -A- is either started and terminated in the width of the left and right stem (AP-10), or either overlaps one or both of the stems.
- In the case of a cursive style, the letters -a- and -s- are conjoined with a connecting stroke.
- The letter -s- presents two construction modes, either in a script (six times), either in a cursive style (18 times). Because of this major

difference between both construction modes, the letter -s- is ejected from the signature. Therefore, neither the point, measurements or characteristics are studied for the letter -s-.

- For the letters -P-, -a-, and -q-, the modified bowl is open, sometimes closed.
- The letter -i- occasionally presents a terminal ascending hook (AP-02).
- As observed for the letter -s-, the letter -r- also presents two different construction modes, in a script capital style (one time, in AP-01) and in a script lowercase style (23 times).

8.1.5 Description of signatures of artist n°5 - Schwaller

When signing, the artist placed one signature above the other, horizontally. The artist placed the canvas on a flat surface for each signature sampling, and placed hand on canvas or on a support of same thickness for support when signing.

The signatures of artist n°5 are composed of the letters -J-, -m-, -s-, -c-, -h-, -w-, -l-, -l-, -e-, and -r-. The signatures are written in a cursive style and with a lowercase letters, except the letter -J-, which is always written in a capital style (see Appendix VI). All of the 24 authentic signatures signed by the artist n°5 show a similar construction mode. Some general remarks can however be made (see Appendix VII for the name reference of the different components of the signature):

- On one signature (JMS-07), the initial stroke of the crossbar of the letter -J- contains an hook.
- Occasionally, a hiatus is observed between two of the arches of the letter -m-, due to a paintbrush lift in the stroke (JMS-05, JMS-07, JMS-11, JMS-15).
- An occasional interruption of the line stoke between the letters -m- and -s- are observed. This interruption is either clearly separated by a space between the two letters (for 16 signatures), either by a splicing (slight overlapping) of the two strokes (for seven signatures). In one case (JMS-04), the two letters are linked by a continuous stroke.
- An occasional hiatus in the continuation of the line stroke is observed between the ascending and descending strokes composing the letter -s-

(JMS-05, JMS-13, JMS-17, JMS-21, JMS-22). The blind loop connecting the descending endstroke of the letter -s- with the letter -c- is more or less pronounced.

- The bow of letter -c- is often closed (with the top and bottom curve that are connected).
- The letters -c- and -h- are linked by a continuous line stroke in all signatures but one (JMS-13).
- The line defining the arch of the letter -h- is absent in one signature (JMS-07) and is partially absent in another (JMS-11).
- The connection between the letters -h- and -w- are either composed of a continuous line (in 19 signatures), or of an interruption in the line (either distinctly separated, either presence of splicing).
- The letter -w- is the letter of the signature with the most variation, possibly because the letter -a- is included in the letter formation. The letter varies from containing two vertical and separated stems up to a fully formed -w- with three stems, and with a more or less pronounced presence of terminal closed loops. The terminal spur of the letter is more or less pronounced among the signature corpus.
- The spur of the letter -w- is not connected with the following letter -l-. However, the strokes are occasionally overlapping.
- The letters -l- are mainly connected with a hairline stroke. However, occasionally both stems are completely overlapping each other.
- The second letter -l- either abruptly terminates at the bottom of the stem (JMS-01, JMS-20, and JMS-22), or is either connected with following letter -e-. This connection is most often shown with a continuation in the line stroke, but is occasionally interrupted (JMS-04 and JMS-15).
- The final letter -r- is sometimes simplified in the form of a small arch (for example in JMS-10).

In light of the analysis of the signatures produced by artist n°5, signature JMS-07 is ejected from his corpus, leaving a corpus of 23 signatures for this artist. This signature is ejected from the set mainly because of the construction mode of the letter -h-. Indeed, half of the letter is absent (only the stem of the letter -h- is present, the arch is lacking).

8.2 Observations made on the simulated signatures

An overview of the 18 simulators that participated in the study are presented in Appendix V. As presented in section 6.2, the simulators were taken form three classes: eleven in Group 1, four in Group 2, and three in Group 3 (see Figure 9).

In theory, a total of 90 simulated signatures should have been obtained per artist. However, 3 simulators (n°6, n°12 and n°18) were not able to complete the exercice. The first two (n°6 and n°12, who are conservator-restaurateurs) produced an incomplete number of signatures. The third (n°18), who is an artist and drawer, was unable, notably for moral reasons, to produce simulated signatures. The ejection of these three simulators from the sample set left a total of 75 simulated signatures per artist. Simulator n°3 did not complete the signature simulations of artist n°4 (Pasquier). The other simulated signatures of the four other artists of his set were retained.

Simulator	Group	Artist n°1 Schauenberg	Artist n°2 Bacsay	Artist n°3 Muro	Artist n°4 Pasquier	Artist n°5 Schwaller
1	1	✓	✓	✓	✓	✓
2	1	✓	✓	✓	✓	✓
3	1	✓	✓	✓	✕	✓
4	2	✓	✓	✓	✓	✓
5	1	✓	✓	✓	✓	✓
6	1	✕	✕	✕	✕	✕
7	1	✓	✓	✓	✓	✓
8	1	✓	✓	✓	✓	✓
9	1	✓	✓	✓	✓	✓
10	1	✓	✓	✓	✓	✓
11	1	✓	✓	✓	✓	✓
12	1	✕	✕	✕	✕	✕
13	2	✓	✓	✓	✓	✓
14	2	✓	✓	✓	✓	✓
15	3	✓	✓	✓	✓	✓
16	3	✓	✓	✓	✓	✓
17	3	✓	✓	✓	✓	✓
18	2	✕	✕	✕	✕	✕

Table 2 - Overview of the sampled simulated signature sets from the three different groups of simulators

A description of the simulation signatures sets of each simulator is presented, in the following sub-sections, for each artist. A detailed description of the general graphic elements of the different signatures, as well as a description of particular aspects and their construction modes is carried out. Repeated observation of signatures of each simulation set that do not follow the general graphic elements and the basic construction mode of the authentic signatures are discarded after this filtering stage. For visual references of these signatures corpuses, see Appendix VI, and for documentation on the terminology used for the different letter formations of each signature type, see Appendix VII.

Readers wishing to directly obtain an overall view of the results of the observation phase, obtained for all of the simulated signatures are directed to sub-section 8.2.6.

8.2.1 Description of simulated signatures of artist n°1 - Schauenberg

As shown in Table 2, a total of 15 persons simulated the signature of artist n°2, giving a simulation sampling set of 75 signatures. The simulation set produced by simulator n°1 presented two interruptions in the line stroke, on signature JCS_SIM_1-03[186] and JCS_SIM_1-05. The formation of the letter -s- is horizontal and descending for signature JCS_SIM_1-04. These inconsistencies in the line formation and construction mode led the author to reject the signature set produced by simulator n°1.

The signature JCS_SIM_4-03 presents an interruption in the connecting stroke between letters -c- and -l-. As this is the only inconsistency in the line construction of the signatures of this simulator, the set is retained.

All of the signatures produced by simulator n°10 present many line retracings (continual overlapping of line constructions). Such interruptions in the line stroke are also observed, albeit in a lesser extent, in the authentic set, and therefore do not justify a rejection of this signature set.

8.2.2 Description of simulated signatures of artist n°2 - Bacsay

A total of 15 persons simulated the signature of artist n°2, giving a simulation sampling set of 75 signatures (see Table 2). Simulator n°3 is ejected from the simulation population because several components of the signature are missing (namely crossbar of -A- on PB_SIM_3-01 and PB_SIM_3-03, acute of -A- on PB_SIM_3-05).

The simulations PB_SIM_5-04 and PB_SIM_8-02 both include a hook at the terminal stoke of the -Y- stem. Since this element is not considered as a fault

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[186] The notation JCS_SIM_1-03 should be understood as the third simulated signature produced by simulator n°1, of the artist JCS.

in the construction mode, the simulations of simulators 5 and 8 are retained in the simulation population.

8.2.3 Description of simulated signatures of artist n°3 - Muro

As shown in Table 2, a total of 15 persons simulated the signature of artist n°3, giving a simulation sampling set of 75 signatures. For simulator n°1, several components of the signature are missing (right stem of letter -M- and top of modified bowl of letter -R- of VM_SIM_1-01; left stem of letter -U- of VM_SIM_1-02 and VM_SIM_1-03; left right median stroke of letter -M- of VM_SIM_1-03; bowl of letter -O- of VM_SIM_1-04). An interruption in the line continuity between the stem of the letter -M- with it's median strokes is slightly visible in one of the authentic signatures of Muro (VM-21), however, the other line interruptions observed in the signature set of simulator n°1 are not present, and therefore this set is ejected from the simulation population.

The simulations VM_SIM_2-03 and VM_SIM-4-05 also present an interruption in the line stroke between the left stem of the letter -M- and its left median stroke. However, since this element is present in one of the authentic signatures, the sampling set of simulator n°2 is retained.

A terminal ascending hook on the letter -U- is observed on the simulation VM_SIM_3-03. This is the only inconsistency found in this simulated signature set, therefore the author decided to retain the set.

The two strokes constructing the left stem of the letter -M- are clearly visible on several signatures of both the signature sets of simulators n°7 and n°8. The overlapping of these two strokes is however less pronounced in the simulation signatures than in the authentic signatures. This difference does not justify a rejection of these signature sets.

8.2.4 Description of simulated signatures of artist n°4 - Pasquier

A total of 15 persons simulated the signature of artist n°3, giving a simulation sampling set of 75 signatures (see Table 2).

The simulation set produced by simulator n°1 shows an interruption in the line tracing between the letters -u- and -i- on signatures AP_SIM_1_03 and AP_SIM_1-04. This being only a minor difference in the construction mode of the signature, the simulation set produced by simulator n°1 is retained.

Four of the signatures produced by simulator n°10 present many line retracings (continual overlapping of line constructions). Such interruptions in the line stroke are also observed, albeit in a lesser extent, in the authentic set, and therefore do not justify a rejection of this signature set.

8.2.5 Description of simulated signatures of artist n°5 - Schwaller

A total of 15 persons simulated the signature of artist n°3, giving a simulation sampling set of 75 signatures (see Table 2). For simulator n°1, several components of the signature are missing, for example the connecting strokes between the arches (JMS_SIM_1-05) or the second arch of the letter -m- (JMS_SIM_1-02). The letter -s- is composed of a supplementary crossbar on three signatures (JMS_SIM_1-02, JMS_SIM_1-04 and JMS_SIM_1-05). For these reasons, the signature set of simulator n°1 is discarded from the simulation set.

Several elements of the signatures produced by simulator n°2 are also absent: the second arch of the letter -m- is four of the five signatures (JMS_SIM_2-01, JMS_SIM_2-02, JMS_SIM_2-03, and JMS_SIM_2-05). The arch of the letter -h- is also absent in JMS_SIM_2-01. The signature set of simulator n°2 is thus also discarded from the simulation set.

The fourth signature produced by simulator n°10 (JMS_SIM_10-4) is missing the letter -h- in the construction, therefore the simulation set produced by this simulator are discarded.

The third signature produced by the simulator n°14 (JMS_SIM_14-3) contains a fourth arch composing the letter -m-. However, as this is the only inconsistency observed, the simulation set is retained.

8.2.6 Summary of observations made on the simulated signatures

An overview of the simulated signature sets that are retained as the simulation corpus for each artist is presented in Table 3. The three simulators n°6, n°12 and n°18 were directly discarded due to an insufficient number of signature samples. The reasons of this insufficient number is presumably due to time constraints and/or difficultly in producing the samples for the first for simulators, and for moral reasons for simulator n°18. Likewise, simulator n°3 did not carry out the simulations of artist n°3 (Pasquier) for limited time reasons.

These observations also establish that a difference regarding the competencies of the simulators to simulate a correct construction mode of the given authentic signatures can already be observed. For example, for simulator n°1, three of the five sets of signatures produced by this simulator were discarded, showing very poor simulation skills for this person.

Simulator	Artist n°1 Schauenberg	Artist n°2 Bacsay	Artist n°3 Muro	Artist n°4 Pasquier	Artist n°5 Schwaller
1	✗ (red)	✓	✗ (red)	✓	✗ (red)
2	✓	✓	✓	✓	✗ (red)
3	✓	✗ (red)	✓	✗	✓
4	✓	✓	✓	✓	✓
5	✓	✓	✓	✓	✓
6	✗	✗	✗	✗	✗
7	✓	✓	✓	✓	✓
8	✓	✓	✓	✓	✓
9	✓	✓	✓	✓	✓
10	✓	✓	✓	✓	✗ (red)
11	✓	✓	✓	✓	✓
12	✗	✗	✗	✗	✗
13	✓	✓	✓	✓	✓
14	✓	✓	✓	✓	✓
15	✓	✓	✓	✓	✓
16	✓	✓	✓	✓	✓
17	✓	✓	✓	✓	✓
18	✗	✗	✗	✗	✗

Table 3 - Overview of the simulated signatures that are either rejected or accepted as for the simulation corpus of each artist. The signature sets that are discarded after an examination of the sampled signatures are noted with a red x mark.

Table 4 summarizes the number of simulated signatures for each artist, before and after their observation. All of simulator's sets were retained for the artist n°4, one was rejected for artists n°1, 2 and 3, and three were rejected for artist n°5.

	Artist n°1 Schauenberg	Artist n°2 Bacsay	Artist n°3 Muro	Artist n°4 Pasquier	Artist n°5 Schwaller
Initial number of simulations	75	75	75	70	75
Final number of simulations	70	70	70	70	60

Table 4 - Recapitulation of number of sampled simulations, and the final number of simulations that were retained after the filtering process of the general and particular aspects.

8.3 Definition of points templates, of measurements, and of characteristics for each artist and his simulation corpus

8.3.1 Definition of points templates

As presented in Section 7.3.4, in order to determine the possible points of each corpus of each artist, the signatures are examined one by one, and the construction mode of each signature component analyzed. The points are then placed in a manner that they cover every signature in the authentic corpus. Generally, the more variation present in the construction modes of each authentic set of signatures, the more the points are adapted, in order to cover each possible mode. This adaptation inevitably leads to a simplification in the possible point determinations. For example, for the letter -M- of artist n°3 (Muro), the points were selected to cover each and every formation mode: the position of the attack of the left median stem of the letter -M-, clearly present (and distinct of the left stem) in eight of the 26 signatures of this artist, is not chosen to be analyzed because it is not a representative feature of the whole corpus. The points are also determined by keeping in mind the ulterior measurements that will be carried out on the signatures.

For the artist n°1 (Schauenberg), two of the 26 points were rejected during the process: points 14 and 18 were found to be difficult to place in a reproducible manner on both the authentic and inauthentic corpuses, because of the large variation in the angle of the cusp of the letter -c- and in the main stem of the letter -l-.

For artist n°2 (Bacsay), a set of 72 points are determined and measured on the authentic and simulated sets. The letters -B- and both -A-s of the signature presented a variation in the authentic set: the part section of the stem varied in its overlapping of the top bow of the letter -B-. Likewise, the buckle of the letter was sometimes overlapping the stem, sometimes distinctive of the stem. These two variations led the author to place the points in order that they could be adapted depending on the encountered construction mode. The points describing the apex of the letters -A- are also simplified to describe the highest point of the letters (instead the highest point of the left and of the right stem, occasionally, but not always, visible).

For artist n°3 (Muro), a set of 48 points are determined and measured on the authentic and simulated sets. The terminal hooks present on the letters -V-, -M- and -U- of most of the authentic signatures are taken into account in the point sets. As detailed in sub-section 6.3.5, the hooks are not taken into account for the determination of the total lengths of these letters. Since the letter -O- has several different construction modes, only the four extremities of the letter are recorded, as well as the position of the final endstroke.

For artist n°4 (Pasquier), no coordinates are measured for the letter -s- because of its two different construction modes. However, the letter -r- is measured in the same manner for both of its construction modes (-r- in both a capital and lowercase script). The capital script mode is only present in the first signature of the authentic corpus, and on the first signature produced by the simulator n°5. Point 6 is discarded from the set of points measured because its added-value is deemed small since the apex of the letter -A- could be easily determined on all of the signatures of the authentic signature set.

For artist n°5 (Schwaller), the hook at the beginning of the crossbar of the letter -J- is not taken into account, since it is only present on one of the signatures. The letter -w- is the letter presenting the most variation in its construction mode. Thus, only the extremities of the letter as well as the height of the first stem (visible on each signature of the authentic set) and the terminal spur are taken into account.

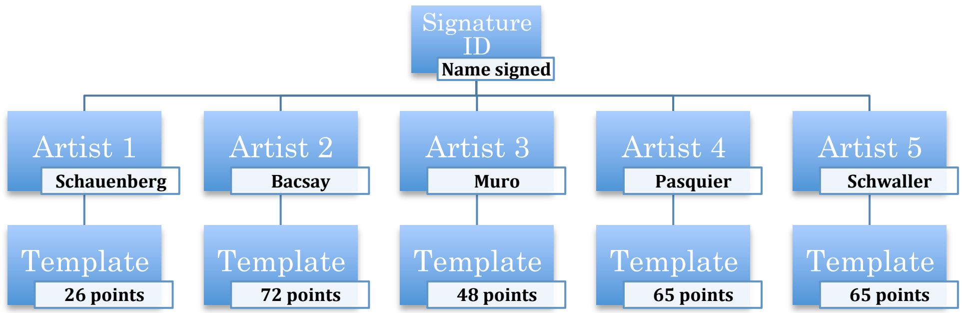


Figure 27 - List of points templates of each artist.

For each artist's signature corpus, a list of points templates is defined, with clear instructions of how each point should be placed by the operator. For the simulation corpuses, the definition of the point template follows the same guidelines as for it's corresponding artist. However, occasionally, if a slight difference in the formation mode hindered the acquisition of a point, an alternative point is proposed and defined in the guidelines of the point template. Appendix VIII describes the point template defined for each artist's corpus, and for his simulation corpus. An illustrated example of the emplacement of the point set for each signature type is given in Appendix VIII.

8.3.2 Definition of measurements of each artist's corpus

Appendix IX describes the set of measurements defined for each artist's corpus, and for his simulation corpus, according to the method described in sub-section 7.3.5. An illustrated example of the measurement set is also presented in Appendix IX, for one signature of each artist.

8.3.3 Definition of characteristics of each artist's corpus

Appendix X describes the characteristics defined for each artist's corpus, and for his simulation corpus, according to the method described in sub-section 7.3.6.

8.4 Statistical analysis of authentic and simulated signatures

As was the case for the presentation of the results of the observation phase, the results obtained are presented for each artist following the same analysis procedure, but all the while highlighting specifics observed for each artist. Readers wishing to directly obtain an overall view of the results obtained for all of the artists are directed to sub-section 8.4.6.

8.4.1 Artist n°1 - Schauenberg

General assessment of measurements and characteristics

The plots of the measurements of artist n°1 highlight some extreme values in both the authentic and simulated signature sets. The corresponding points of these measurements have been all verified and acknowledged as correct.

The examination of the plots and boxplots of the 85 characteristics/features defining the signature of artist n°1 are also verified. The authentic signatures presenting extreme values are visually identified and are reported in Table 5. The origin of the extreme values are explained (see Illustration of signatures in Appendix VI). For the sake of brevity of the text, the outliers of the simulated signatures are not presented.

Eight signatures of the authentic set present outlying feature values, with each signature presenting a range of one to seven outliers. The study of the outlying features shows that their origin comes from one or two elements of each signature, even if several outliers are observed.

Sig. n°	Outlying feature	Feature specification	Origin of outlying value[187]
7	C39	Inf. height difference -l- and -s- / Height -l-	Letter -s- positioned higher than on other signatures
	C45	Length -s- / Height -s-	Letter -s- positioned higher than on other signatures
	C64	-s- : Height of ascending stroke, from intersection with letter -l- /	Letter -s- positioned higher than on other signatures

[187] The origins of the outlying values are given in comparison with the other signatures of the set.

		Height of loop	
	C68	-s- : Total height of ascending stroke / Height of loop	Letter -s- positioned higher than on other signatures
8	C2	Length -J- / Length signature	Signature longer than other references
9	C22	Length -J- / Length -c-	Curvature of letter -c- pronounced (giving a longer length)
	C49	-c- : Height of ascending stroke / Height letter	Curvature of letter -c- pronounced (giving a longer length)
	C50	-c- : Height of ascending stroke / Length letter	Curvature of letter -c- pronounced (giving a longer length)
	C55	-c- : Length distance between beginning of ascending stroke and its intersection with the loop / Length letter	Curvature of letter -c- pronounced (giving a longer length)
	C79	-c- :Angle of ascending stroke	-
11	C45	Length -s- / Height -s-	Pronounced terminal stroke of -s-
	C62	-l- : Height of stem between bottom of loop and intersection with letter -s- / Total height of letter (height of main stem)	Eyelet of loop of -l- open, producing a thin height of tip
	C64	-s- : Height of ascending stroke, from intersection with letter -l- / Height of loop	Long ascending stroke of letter -s-
	C81	-s- : Angle of stem	-
13	C72	-s- : Height of ascending stroke, from intersection with letter -l-, up to the inner cusp / Length of loop	Pronounced curvature of cusp of letter -s-
19	C45	Length -s- / Height -s-	Pronounced length of terminal stroke
21	C4	Length -l- / Length signature	Short terminal stroke of letter -s-, giving a small signature length
	C6	Length -s- / Length signature	Short terminal stroke of letter -s-, giving a small signature length
	C11	Length -s- / Height signature	Short terminal stroke of letter -s-, giving a small signature length

	C25	Length -s- / Length -s-	Short terminal stroke of letter -s-
	C70	-s- : Length of endstroke, from intersection with loop / Total length of letter (both segments)	Short terminal stroke of letter -s-
	C75	-s- : Length of endstroke / Total length of letter (both segments)	Short terminal stroke of letter -s-
	C80	-l- : Angle of ascending stroke	-
23	C62	-l- : Height of stem between bottom of loop and intersection with letter -s- / Total height of letter (height of main stem)	Eyelet of loop of -l- open, producing a thin height of tip
	C81	-s- : Angle of stem	-

Table 5 - Outliers detected in the authentic signature set of artist n°1

Generally speaking, the boxplots of the characteristics of the authentic signature set present less dispersion than the simulated sets, with an exception for characteristics C39 and C68. None of the boxplots depicting the values of the authentic set are fully separated from the simulated sets, a partial or full overlapping is always present between the interquartile ranges, and between the first and last quartiles. Figure 28 illustrates as an example the boxplots of the angles defining the authentic and simulated signature sets.

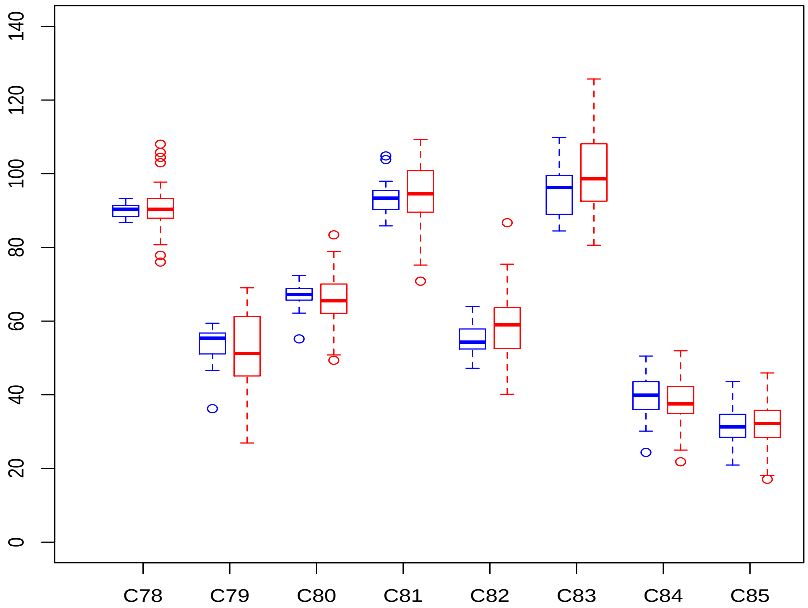


Figure 28 - Boxplot representation of authentic (blue) and simulated (red) signatures of characteristics C78 to C85 (angles) of artist n°1.

Principal component analysis

The data set collected is initially visualized through a Principal Component Analysis in order to obtain a global view of the multivariate data of both classes (authentic and simulations). As exposed before, this technique aims to reduce the number of original variables (our characteristics) into principal components (PCs), all the while retaining (as much as possible) the variation of the original variables (Jolliffe, 2002). In this example, the first three PCs of this data set account for approximately 20%, 12%, and 10% of the total variation (80 % of the variance is explained by the first 10 variables). Thus a three-dimension plot of the first three PCs will give a general, although not exhaustive, account of the relative position of the observations in their original 85-dimensional space.

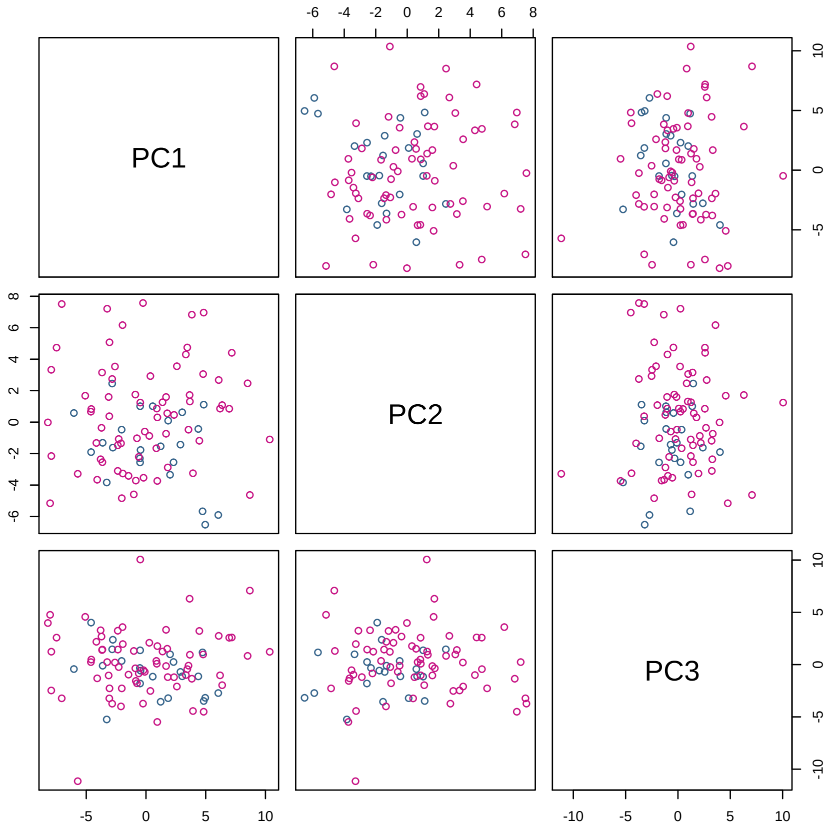


Figure 29 - Representation of first three PCs plotted against each other. Each dark blue point represents an authentic signature, and each dark pink point represents a signature of the simulated set.

The 2-axis representation of the first three principal components (PCs) in Figure 29 shows a limited potential of separation between both classes. The authentic set of signatures shows greater variation in the direction of the second PC axis, whereas the simulated sets presents variation in the direction of both PC1 and PC2. Both sets show less variation in the direction of the third PC.

If the set of simulated signatures is broken down and represented according to the different groups of simulators, the three groups are discernable: the Conservators-restorers, the Artists, and the FHEs (see Figure 30). With such a distinction, the influence on the type of group that the simulator comes from has an influence on his simulation capacities. As illustrated in Figure 30, the group of Conservators-restorers produced data more spread out across PC1 and PC2. The signatures from this group are the most distant from the group of authentic signatures. Indeed, the signature sets produced by the Artists and by the FHEs overlap the authentic signature set.

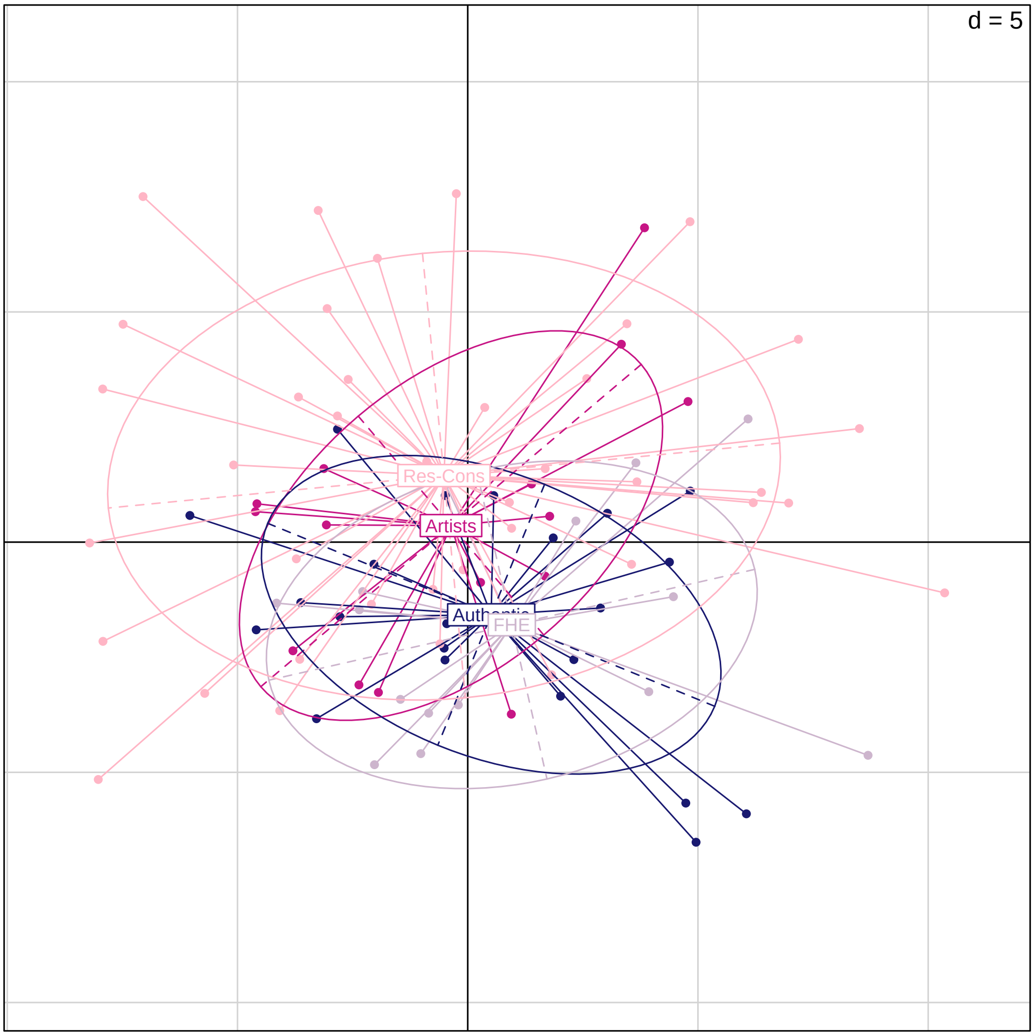


Figure 30 - Representation of the first two PCs (PC1 on x-axis and PC2 on y-axis) obtained of the PCA analysis of the authentic set and the three simulated set of signatures of artist n°1 (Schauenberg).

Figure 31 illustrates the differences in the simulation capacities of each simulator. These results tend to display a simulation capacity that is linked to the personal abilities of the person, as well as to their group affiliation. The first group of Conservators-restorers are separated from the authentic group for individuals 2, 9, and 10; individuals 3, 8 and 11 are partly separated, whereas individuals 5 and 7 are contained in the repartition of the authentic signature set, and thus produced the best simulations of their group. For the second group of simulators (Artists), two of the three simulators are contained within the authentic set; only simulator 14 is partially separated. Finally, for the third group (FHEs), the same observations as for the Artist group can be made.

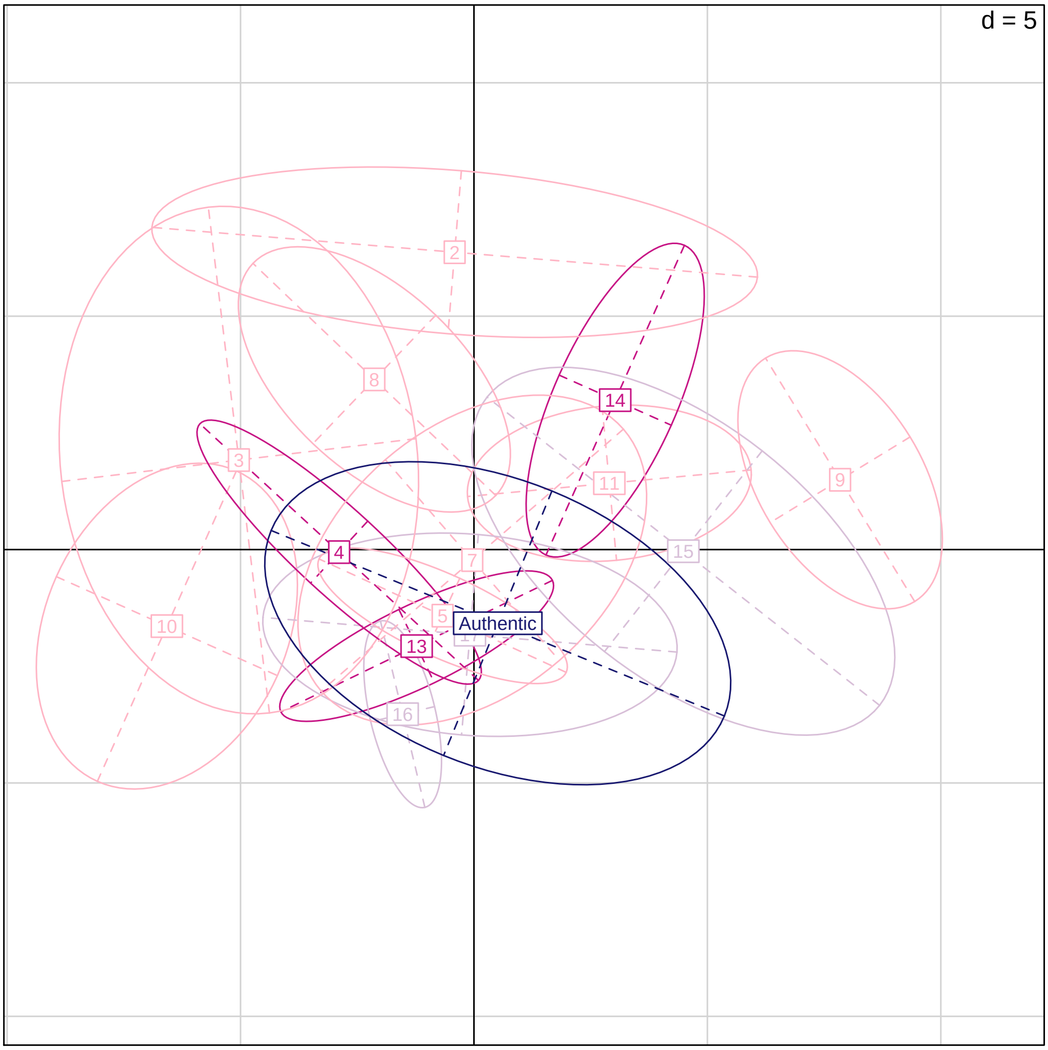


Figure 31 - Illustration of PCA analysis (PC1 on x-axis and PC2 on y-axis) of the authentic set and the each simulated set (n=14) of signatures of artist n°1 (Schauenberg). The simulators from the Res-Con group are represented in pink, the Artist group in dark pink, and the FHEs in mauve.

The dispersion of the each of the simulated signatures varies according to the simulator, and does appear to be linked to the group affiliation: simulators of the first group generally presented more dispersed signature sets than the other two groups (with an exception of simulator 15 who produced a dispersed set). Thus, three groups of simulators can be deduced: very skilled simulators (5, 7, 4, 13, 17), moderately skilled simulators (8, 11, 16), and poorly skilled simulators (2, 3, 9, 10, 14, 15).

Feature selection

a) Boruta feature reduction

The Boruta feature reduction testing was carried out with the different pre-defined parameter and the best results were obtained with ntree=100000. In this case, the highest number of both confirmed (14) and tentative (1) variables were given. In total, 15 of the 85 initial characteristics (17.6%) were retained and are listed in Table 6 with their corresponding feature classes and feature specifications. Each letter is represented at least once within the selected features. The importance values of each characteristic with the Boruta analysis are reported in Appendix XIII.

The results display the importance of the Height of the letter/Height of the signature class in the feature selection. Indeed, of the first four selected features, two emanate from this class.

Feature	Feature class		Feature specification
C14	4	Height letter / Height signature	H -l- / H tot
C24	6	Length letter / Length letter after	L -l- / L -s-
C82	13	Angle	-J- : Angle of ascending stroke
C13	4	Height letter / Height signature	H -c- / H tot
C74	12	Intraletter	-s- : Height distance between top of endstroke and tip of endstroke / Height of endstroke
C78	13	Angle	-J- : Angle of stem
C38	9	Height difference (inf.) / Height letter before	H -c- and -l- / H -c-
C79	13	Angle	-c- : Angle of ascending stroke
C37	9	Height difference (inf.) / Height letter before	H -J- and -c- / H -J-
C61	12	Intraletter	-l- : Length distance of ascending stroke / Height of ascending stroke
C58	12	Intraletter	-l- : Height of ascending stroke / Total height of letter (height of main stem)
C5	2	Length letter / Length signature	L -s- / L tot
C36	8	Height difference (sup.) / Height letter before	H -s- and -s- / H -s-
C9	3	Length letter / Height signature	L -l- / H tot
C4	2	Length letter / Length signature	L -l- / L tot

Table 6 - List of features retained after Boruta feature selection step, listed by their order of importance.

b) Normality testing

The results obtained after the Shapiro-Wilk normality test on the 85 characteristics describing the signature of artist n°1 are presented according to their class affiliation in Table 7. The detailed results of the tests (for each characteristic) are presented in Appendix XII.

For the authentic set of signatures, the normality of the data is on the whole respected. Only the second class of features (Length of each letter/Length of the signature) possesses a higher number (three out of five) of significant p-values. The simulated signature set however possesses a greater number of variables that do not come from normally distributed populations, particularly in the class 9 (Inferior height difference between two letters / Height of the letter before) and 11 (Length of a letter / Height of the same letter).

The normality results of both the authentic and simulated sets considered together show that four classes (2, 6, 9, and 11) each have less than 50% of their variables that are normally distributed.

Class	Authentic		Simulated		Both sets (Auth. and Sim.)		
	Normal #	Total #	Normal #	Total #	Normal #	Total #	(%)
1	1 /	1	1 /	1	1 /	1	100 %
2	2 /	5	4 /	5	2 /	5	40 %
3	5 /	5	3 /	5	3 /	5	60 %
4	5 /	5	5 /	5	5 /	5	100 %
5	5 /	5	5 /	5	5 /	5	100 %
6	4 /	5	3 /	5	2 /	5	40 %
7	5 /	5	3 /	5	3 /	5	60 %
8	5 /	5	3 /	5	3 /	5	60 %
9	5 /	5	2 /	5	2 /	5	40 %
10	- /	Ø	- /	Ø	- /	Ø	Ø
11	4 /	5	2 /	5	2 /	5	40 %
12	30 /	31	23 /	31	22 /	31	71 %
13	7 /	8	7 /	8	6 /	8	75 %

Table 7 - Results of Shapiro-Wilk normality test, given for each class composing the authentic set, the simulated set, and both sets together.

The affiliation of each selected characteristics after the Boruta selection step to his respective feature class is noted in the third column of Table 8, with the relative percentage in parentheses. Classes 1, 5, 7 and 11 are not represented by a selected feature. The classes that have the highest percentages of selected features are classes 2 (Length letter/Length signature), 4 (Height letter/Height signature), 9 (Height difference (inferior) between two letters/Height letter before), and 13 (Angles).

Once the results of the normality testing are applied on the Boruta feature selection results, a final number of 11 features are retained (see Table 8), which corresponds to a 87.1% reduction from the initial 85 features. The same classes are represented, however, only one feature is retained in classes 2, 12 and 13.

Class		Number of features in each class (and corresponding %)	
N°	# of Features in Class	... after Feature selection	... after Feature selection *and* normality testing
1	1	0 (0 %)	0 (0 %)
2	5	2 (40 %)	1 (20 %)
3	5	1 (20 %)	1 (20 %)
4	5	2 (40 %)	2 (40 %)
5	5	0 (0 %)	0 (0 %)
6	5	1 (20 %)	1 (20 %)
7	5	0 (0 %)	0 (0 %)
8	5	1 (20 %)	1 (20 %)
9	5	2 (40 %)	2 (40 %)
10	∅	∅	∅
11	5	0 (0 %)	0 (0 %)
12	31	3 (9.6 %)	2 (6.5 %)
13	8	3 (37.5 %)	1 (12.5 %)
Total	**85**	**15 (17.6 %)**	**11 (12.9 %)**

Table 8 - List of features of each class retained after Boruta feature selection and normality testing

The final list of features retained after the Boruta feature selection and normality testing is presented in Table 9, with their corresponding class and letter specifications. Each of the four letters are represented as least once.

Feature	Feature class		Letter specification
C14	4	Height letter / Height signature	H -l- / H tot
C24	6	Length letter / Length letter after	L -l- / L -s-
C82	13	Angle	-J- : Angle of ascending stroke
C13	4	Height letter / Height signature	H -c- / H tot
C38	9	Height difference (inf.) / Height letter before	H -c- and -l- / H -c-
C37	9	Height difference (inf.) / Height letter before	H -J- and -c- / H -J-
C61	12	Intraletter	-l- : Length distance of ascending stroke / Height of ascending stroke
C58	12	Intraletter	-l- : Height of ascending stroke / Total height of letter (height of main stem)
C5	2	Length letter / Length signature	L -s- / L tot
C36	8	Height difference (sup.) / Height letter before	H -s- and -s- / H -s-
C9	3	Length letter / Height signature	L -l- / H tot

Table 9 - List of features retained after Boruta feature selection and normality testing.

The list of features presented in Table 9 make up the final feature vector v for artist n°1 (Schauenberg) used for the likelihood ratio assessment: v_{10} (containing the first 11 selected features).

As a reminder, the feature vector may be decomposed into a number of sub-vectors, their composition can be schematized in the following . Thus the 10th feature vector for the artist n°1 contains the first 11 selected features.

v	Characteristics retained (according to order of importance given with Boruta)				
v_1	1	2			
v_2	1	2	3		
v_3	1	2	3	4	
v_4	1	2	3	4	5

Table 10 - Example of the feature vectors and their construction.

Likelihood ratio assessment

The strength of the set of selected features are finally assessed with a likelihood ratio examination. The feature vector v_{10} containing the selected features C14, C24, C82, C13, C38, C37, C61, C58, C5, C36 and C9 are used compute a multivariate likelihood ratio for each authentic and simulated signature, as explained in sub-section 7.4.4. The results of the likelihood ratio assessment carried out with the 11 feature long vector v_{10} of artist n°1 are presented in Table 11 below.

Authentic		Simulated			
Sig n°	**log(LR)**	**Sig n°**	**log(LR)**	**Sig n°**	**log(LR)**
1	5.2	1	-2.9	36	-8.1
2	**-0.2**	2	-58.2	37	-17.5
3	1.9	3	-43.2	38	-16.6
4	3.1	4	-25.2	39	-17.2
5	**-8.4**	5	-30.8	40	-13.4
6	9.7	6	-13.6	41	-2.3
7	**-8.0**	7	-19.4	42	-11.9
8	**-49.3**	8	-23.2	43	-17.9
9	1.5	9	-66.0	44	-5.8
10	**-9.0**	10	-3.2	45	-7.4
11	**-11.4**	11	-10.4	46	-3.2
12	1.2	12	**2.0**	47	-11.3
13	1.7	13	**4.9**	48	-20.0
14	0.1	14	**5.7**	49	-4.0
15	1.9	15	-28.3	50	-11.8
16	**-2.0**	16	-13.8	51	-16.5
17	0.8	17	-18.7	52	-46.8
18	6.7	18	-8.8	53	-8.0
19	**-19.8**	19	-17.2	54	-14.5
20	**-85.2**	20	**8.4**	55	-29.8
21	4.5	21	-2.9	56	-16.5
22	**-31.6**	22	-23.9	57	-21.4
23	4.3	23	-10.9	58	-25.8
		24	-16.5	59	-30.2
		25	**0.8**	60	-67.4
		26	-11.4	61	-1.1
		27	-7.3	62	**1.9**
		28	-12.6	63	-0.5
		29	-25.2	64	**0.2**
		30	-11.8	65	-4.4
		31	-13.4	66	**5.2**
		32	-33.1	67	-7.0
		33	-35.2	68	-17.9
		34	-2.7	69	**2.8**
		35	-29.5	70	-0.7

Table 11 - Log(Likelihood) results obtained for each signature in the authentic and simulated signature sets with the feature vector υ_{10}. Negative results under H_1, and positive results under H_2, are highlighted in bold.

The obtained log(LR) results are presented graphically for the authentic signatures in Figure 32, and for the simulated signatures in Figure 33. For the authentic signatures, the plot clearly depicts four signatures with very low log(LR) values, these correspond to signatures 8, 19, 20 and 22.

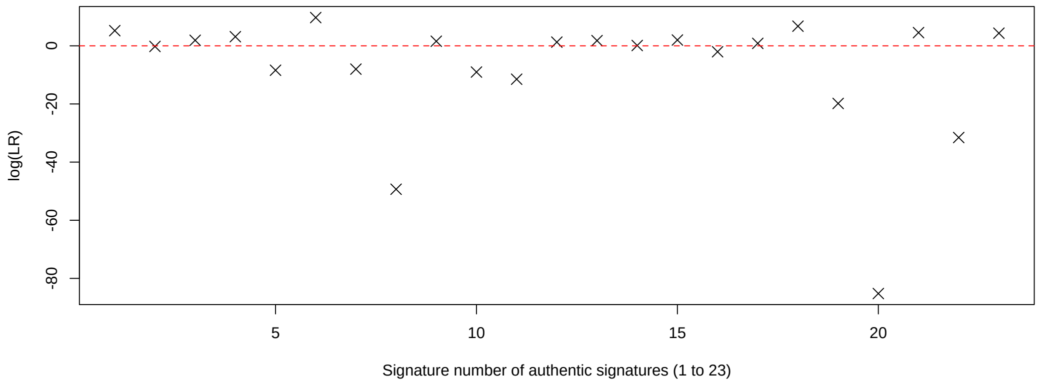


Figure 32 - Visual representation of the log(likelihood ratio) obtained for the authentic signatures of artist n°1.

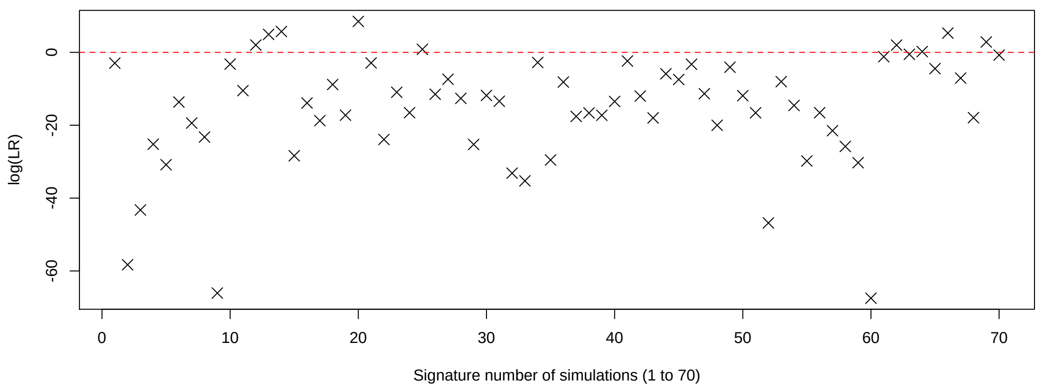


Figure 33 - Visual representation of the log(likelihood ratio) obtained for the simulated signatures of artist n°1.

Of the 23 authentic signatures, 13 possess a log(LR) above zero (true positives), leaving the remaining 10 with a log(LR) below zero (false negatives). These results are illustrated in Figure 34: the values in the top left rectangle represent the true positives and those in the bottom left rectangle the false negatives.

Likewise, for the 70 simulated signatures, 61 possess a log(LR) below zero (true negatives) and are represented in the bottom right rectangle. The remaining 9 signature, situated in the top right rectangle, possess a log(LR) above zero, and are thus false positives. The sensitivity (true positive rate) amounts to 56.52%, and the specificity (true negative rate) to 87.14%.

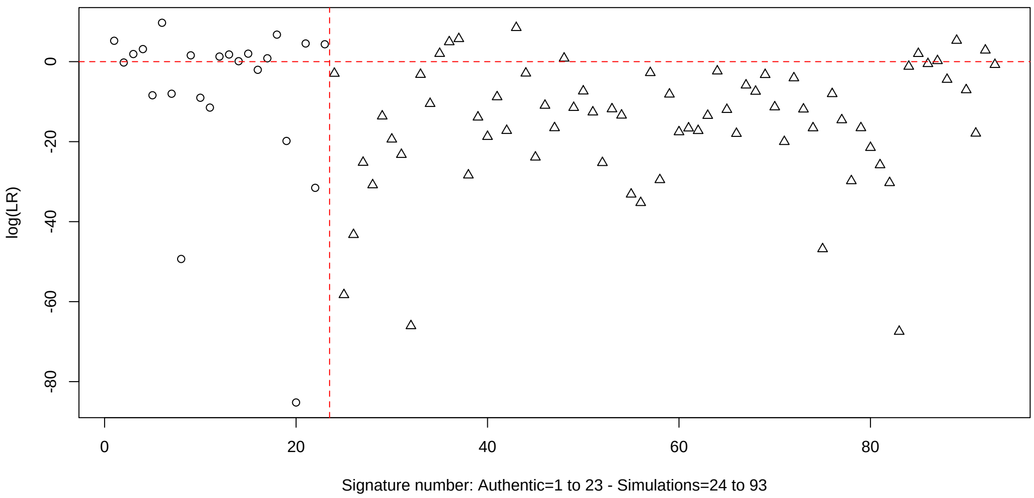


Figure 34 - Visual representation of the log(likelihood ratio) obtained for all of the signatures of artist n°1 (authentic signatures are represented by a circle, simulations by a triangle).

A closer look of the results obtained for the simulated set depicts the same range of results as the PCA analysis as a means to characterize the simulation capacity of a person. For example, simulators 16 (signatures 61-65) and 17 (signature 66-70) both have two of their signatures that present a log(LR) above zero, and with the three remaining signatures with log(LR) values just below zero. Likewise, simulator 5 possesses three signatures with a log(LR) above zero, attesting of their superior simulation skill.

The dispersion of the results obtained with the 10th feature vector v_{10} are represented in Figure 35 through a histogram of the number of occurrences obtained for each range of log(LR) with the authentic and simulated signature populations.

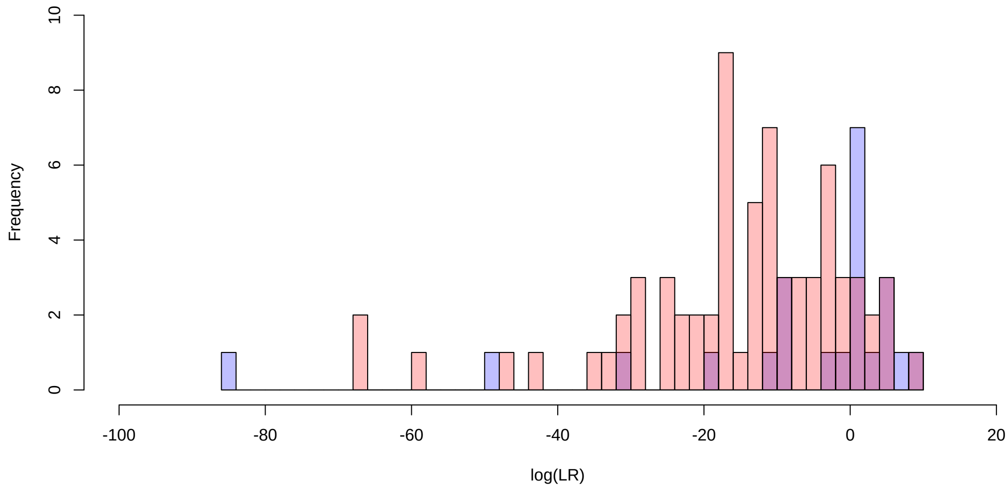


Figure 35 - Likelihood ratios (in a logarithmic form) obtained for the authentic and the simulated signatures of artist n°1 with feature vector v_{10}, represented in the form of a histogram and according to the number of occurrences (y-axis). The authentic signatures are shown in blue, the simulated signatures in red.

The results of the log(LR) depict a clear overlapping between the authentic and simulated signature sets. The authentic signatures are grouped around the value zero, but a certain number of signatures are spread along the negative end of the x-axis, even further than the simulated set. The simulated set is predominately situated with log(LR) values lower than zero, but does overlap onto the positive side of the axis. The overlapping is less stretched out along the positive end of the axis than the authentic signatures are on the negative end.

The log(LR) results obtained for all of the 10 feature vectors (v_1-v_{10}), for each of the authentic signatures is represented in the following boxplot (Figure 36) - the exact values obtained for each signature and for each feature vector are reported in Appendix XIV. Except for signature 19, all of the signatures presenting a negative log(LR) with the feature vector v_{10}, i.e. signatures 2, 5, 7, 8, 10, 11, 16, 19, 20 and 22, present log(LR)s that are at one point higher than the value of zero. Moreover, signatures with lower log(LR) values tend to present a higher variation in their results (see signatures 5, 8, 10, 11, 19, 20, 22), whereas signatures presenting positive log(LR) results produce less variation with the different feature vectors used.

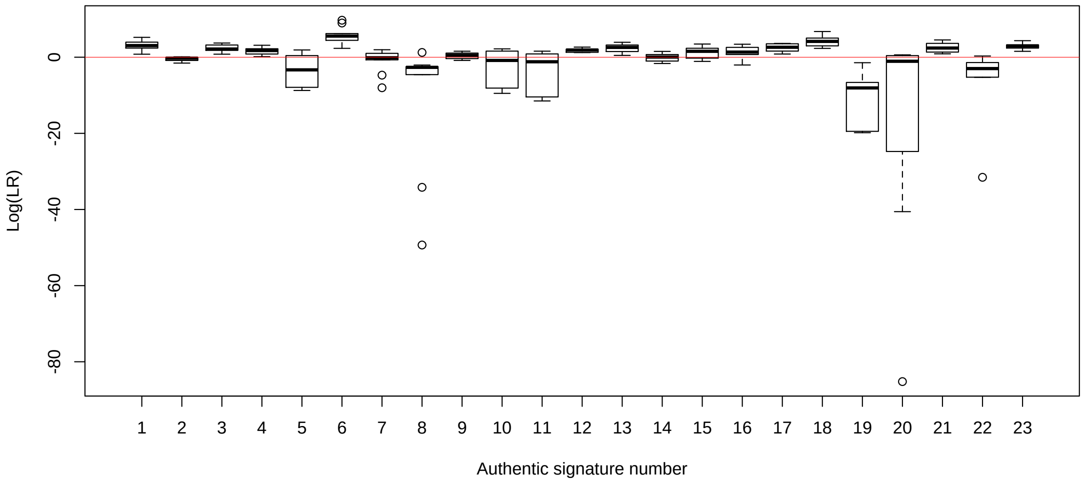


Figure 36 - Likelihood ratios (in a logarithmic form) results obtained for all of the feature vectors v_1 - v_{10} for the authentic signatures of artist n°1, represented in the form of a boxplot.

The log(LR) results obtained for all of the 10 feature vectors (v_1-v_{10}), for each of the simulated signatures is represented in the same manner in the following boxplot (Figure 37). The signatures 12, 13, 14, 20, 25, 62, 64, 66 and 69 gave positive log(LR) with the final feature vector v_{10}, and signatures 11, 12, 13, 14, 20, 25, 66, 69 gave a positive median log(LR) value for feature vectors v_1-v_{10}. However, only two of these signatures, 12 and 14, present a positive log(LR) for all of the 10 feature vectors.

Both of these signatures were made by simulator 5, attesting of this person's high simulation capacity. Simulators 16 and 17 also produced signatures which gave little variation in the log(LR) results which were also partly positive, for the 10 different features vectors.

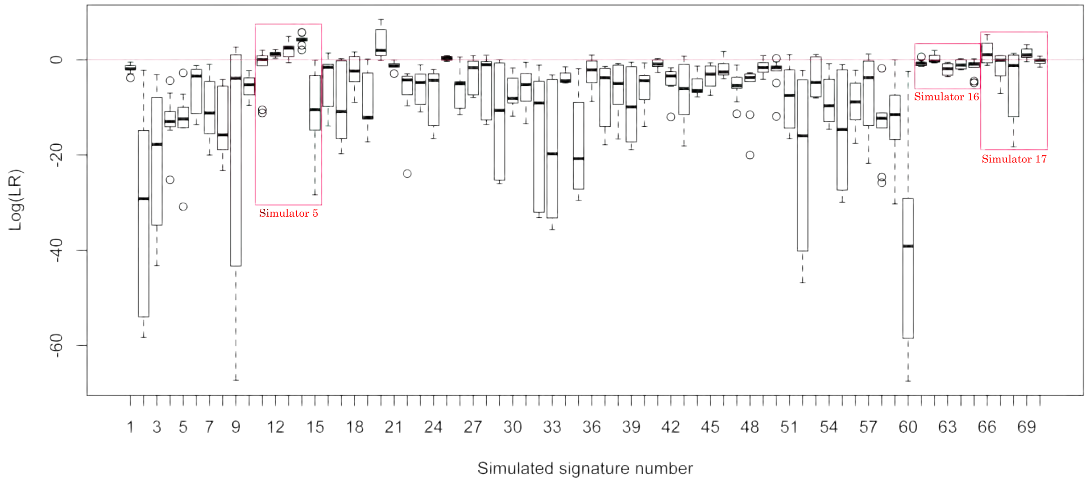


Figure 37 - Likelihood ratios (in a logarithmic form) results obtained for all of the feature vectors for the simulated signatures of artist n°1, represented in the form of a boxplot. Signatures produced by simulators 5, 16 and 17 are highlighted in red.

Given the large variation obtained in the log(LR) with the different feature vectors, the log(LR) results are plotted in Figure 35 - Figure 41 for each of the 10 different feature vectors for the authentic signature set. The influence of the length of the feature vector on the log(LR) results for each of the authentic signatures can be divided into four distinct categories according to the general tendencies observed:

- The log(LR) results increase as the length of the feature vector increases (Figure 38);
- The log(LR) decreases as the length increases (Figure 39);
- An increase, followed by a sharp decrease of the log(LR) is observed as the length of the feature vector increases (Figure 40);
- or finally, no simple behavior can be drawn (Figure 41).

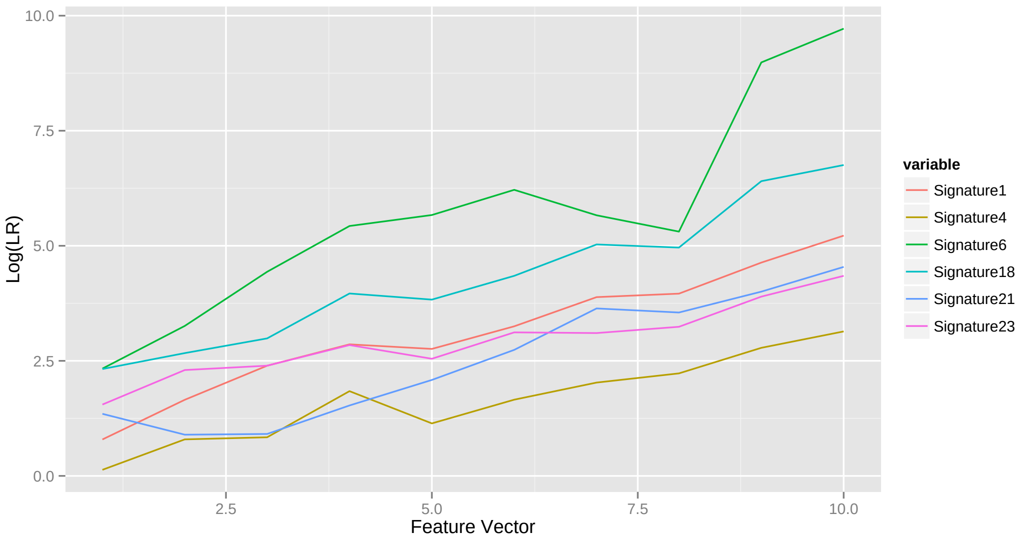


Figure 38 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures, for each feature vector.

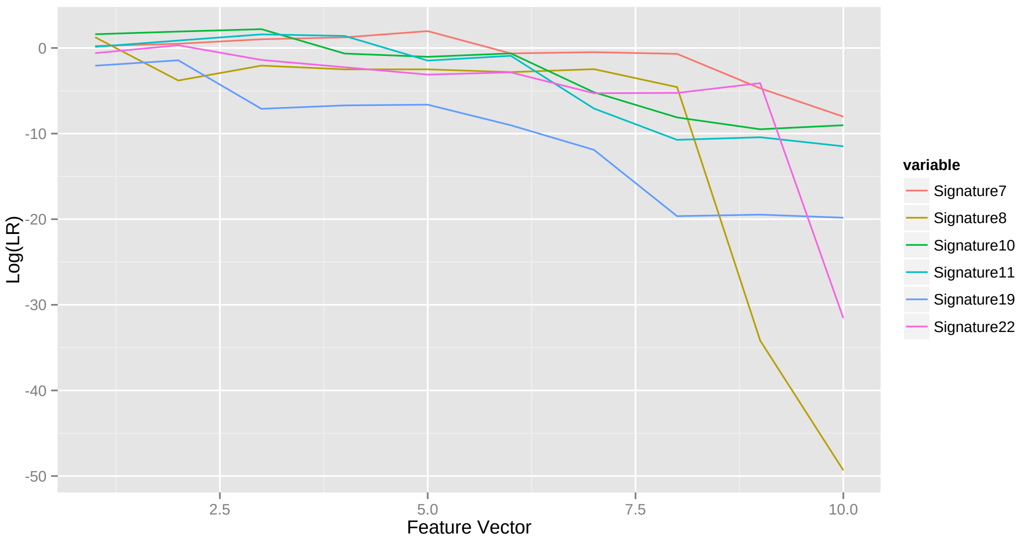


Figure 39 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

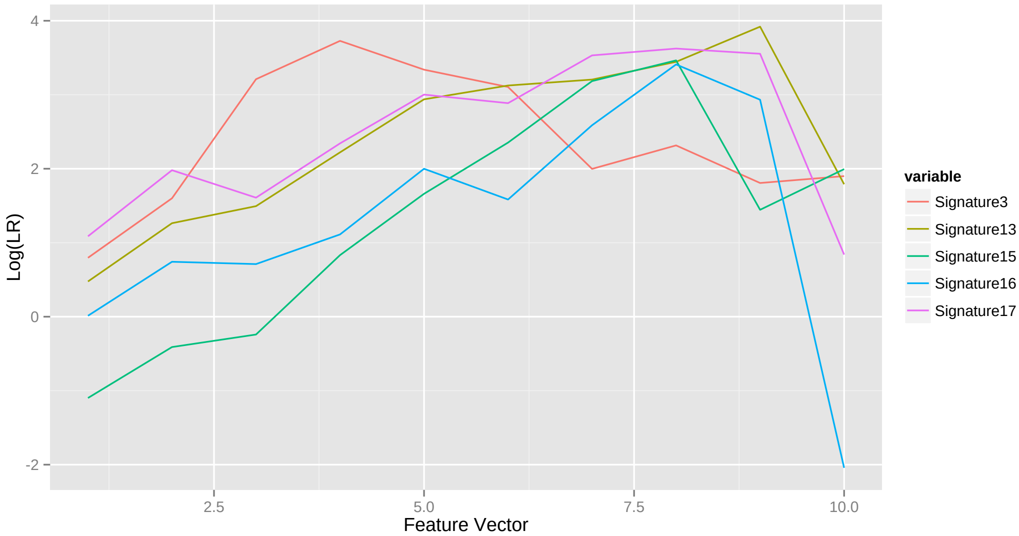


Figure 40 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

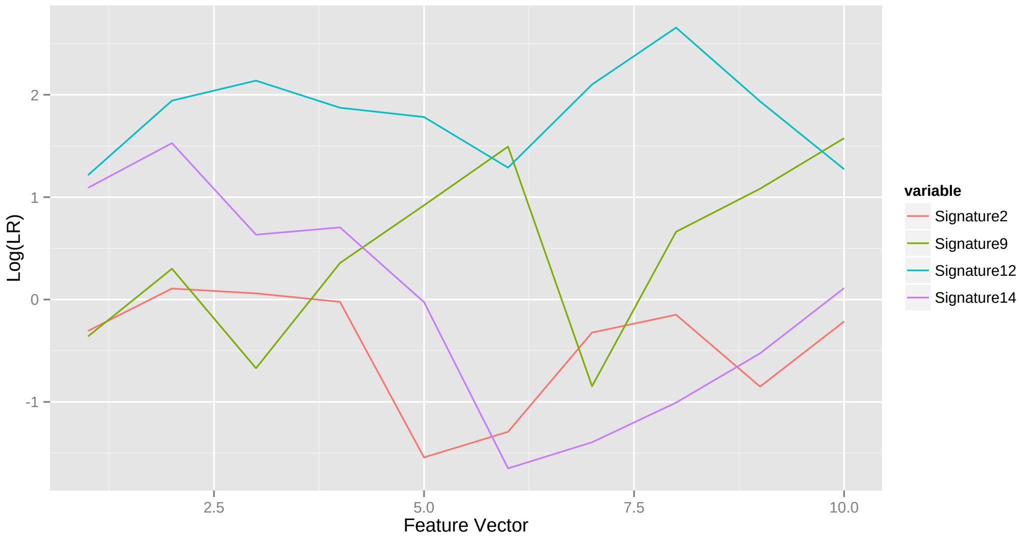
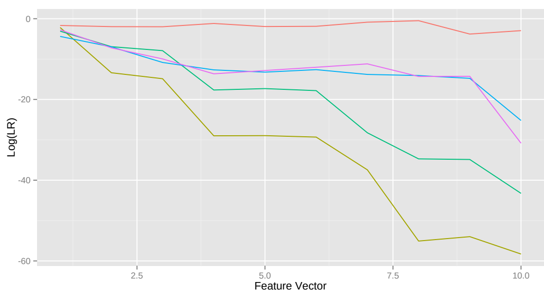


Figure 41 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

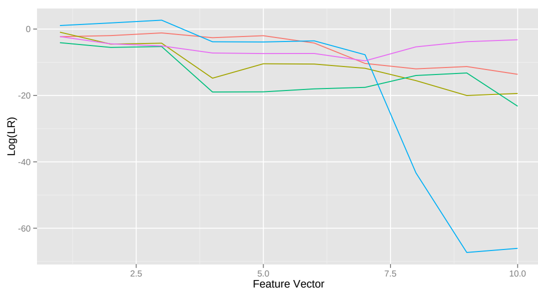
The simulated signature sets are presented, for each simulator, in Figure 42, where the influence on the feature vector employed and the resulting log(LR) results are depicted. All of the simulators produced at least one signature whose log(LR) results decreased as the length of the feature vector increased.

This was the case for all five signatures produced by simulators 3, 9, 11, 13, 14, and 15. For a number of these signatures, the first feature vectors gave results gravitating around (just below and above) the value of log(LR) of zero.

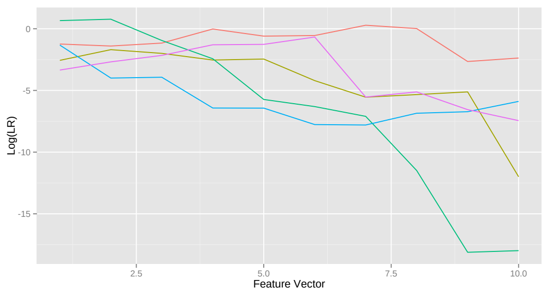
Several signatures produced results that varied little as the feature vector changed (for example: the first signature of Simulator 1, the first and fifth signatures of Simulator 8, the fourth signature of Simulator 10). Finally, several signatures within the sets produced by simulators 5, 7, 16 and 17, produced higher log(LR) results as the length of the feature vector increased, All but one of these signatures terminated in positive log(LR) values with the feature vector v_{10}, attesting of the superior simulation skill of these subjects. However, none of these simulation sets contained only signatures with this behavior. At least two signatures of each of these sets followed the tendency of the majority of the simulators: the log(LR) results decreased as the feature vector increased.



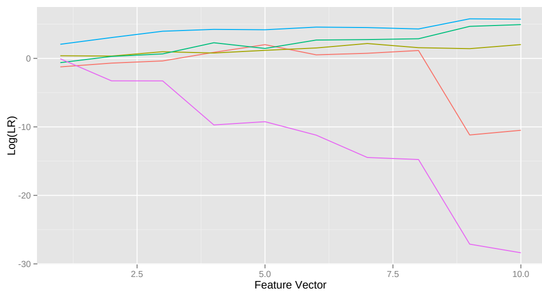
Simulator 2



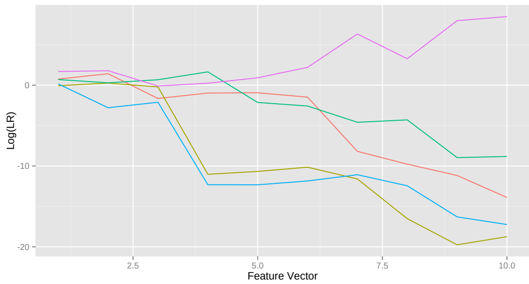
Simulator 3



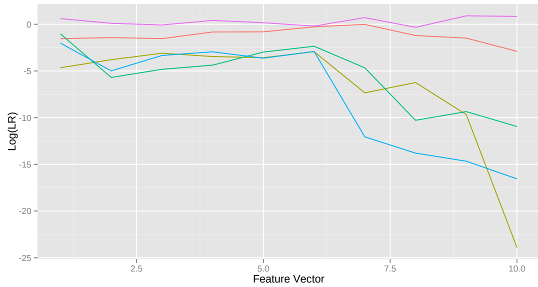
Simulator 4



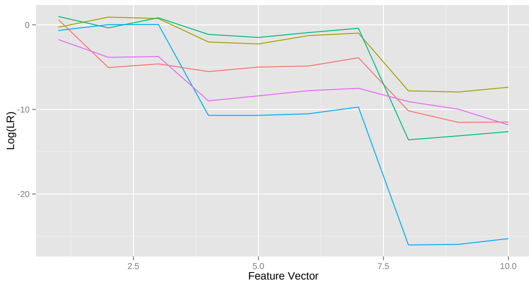
Simulator 5



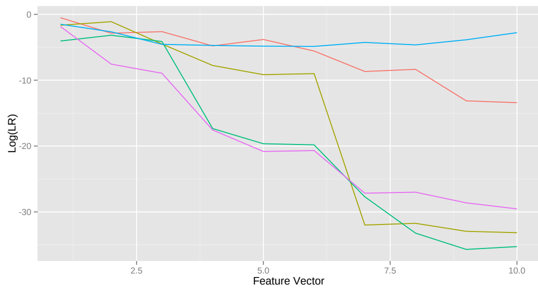
Simulator 7



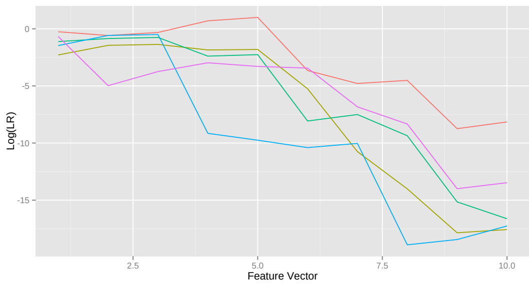
Simulator 8



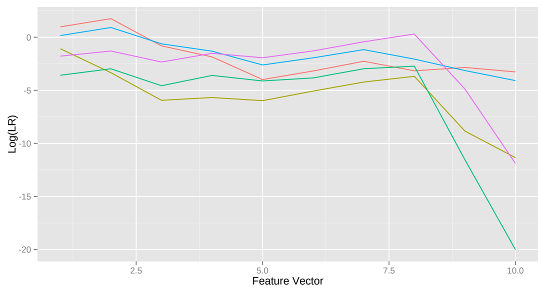
Simulator 9



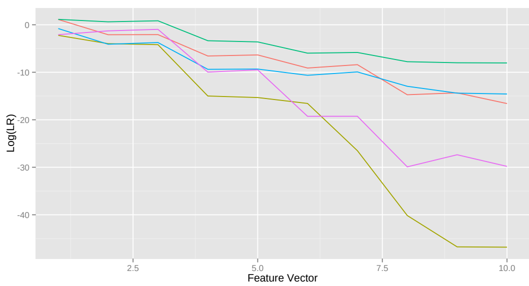
Simulator 10



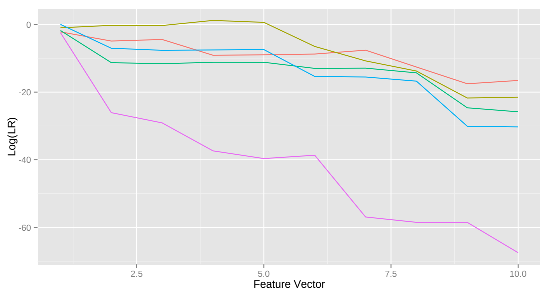
Simulator 11



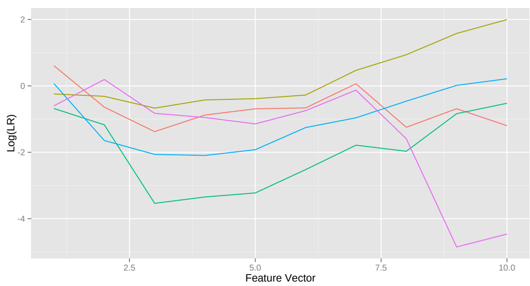
Simulator 13



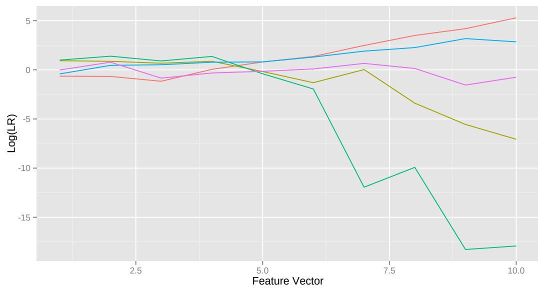
Simulator 14



Simulator 15



Simulator 16



Simulator 17

Figure 42 - Log(LR) results, plotted for the each of the 10 feature vectors, obtained for the 5 signatures samples of each of the simulators of artist n°1. The legend for each signature is as follows: Signature1 Signature2 Signature3 Signature4 Signature5

The calculation of the log-likelihood-ratio cost (C_{llr}) gives weighted results in light of the different behaviors of the authentic and simulated signatures according to the length of the feature vector used. A look at the impact of the feature vector used to calculate the log(LR) for both signature sets show C_{llr} results under the value of one for only the first five feature vectors (containing the first two to the first six features).

Feature vector	Feature combination	CCLR
1	2 features	0.787
2	3 features	**0.731**
3	4 features	0.824
4	5 features	0.829
5	6 features	0.921
6	7 features	1.157
7	8 features	1.712
8	9 features	2.961
9	10 features	4.542
10	11 features	7.504

Figure 43 - C_{llr} results obtained for artist n°1. The lowest value is highlighted in bold.

The C_{llr} results, illustrated in the two plots below (Figure 44), follow an exponential increase curve as the length of the feature vector rises.

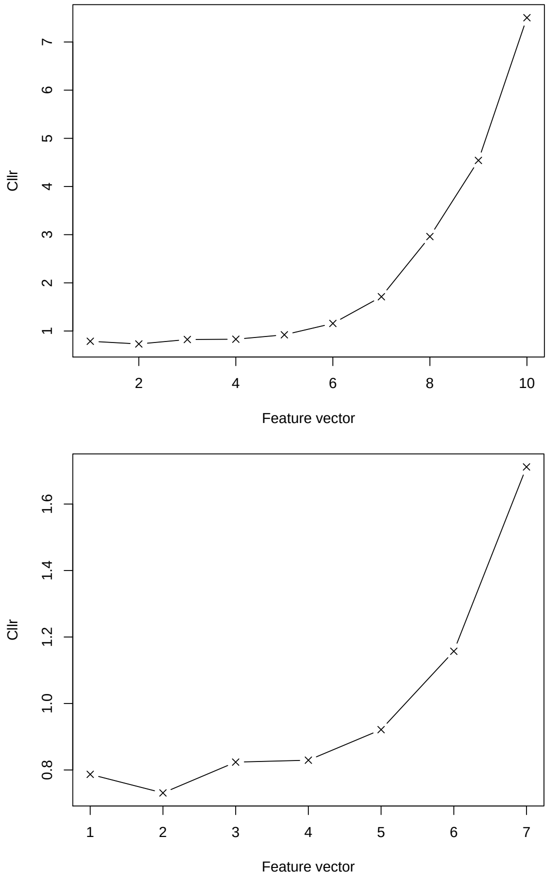


Figure 44 - C_{llr} results obtained for artist n°1, plotted for each feature vector (v_1 to v_{10}) combination composed of two to 11 features (above). A zoom on the first 7 feature vectors (v_1 to v_7) is presented below.

The feature vector v_2 (containing the first 3 features) presents the lowest C_{llr} value (C_{llr} = 0.731), and is thus selected for subsequent log(LR) calculations. This feature vector v_2 contains the features:

C14	Height letter of the letter -l- / Height of the signature
C24	Length of the letter -l- / Length of the letter after (letter -s-)
C82	Angle: Angle of the ascending stroke of letter -J-

The resulting TP rate of 86.95% and TN Rate of 71.42% are found. The distribution of the log(LR) results of the authentic and simulated signatures is presented in Figure 45. The distribution of the authentic signatures is clearly pushed towards the positive side of the axis. The same observation can be made, but to a lesser extent, with the population of simulated signatures.

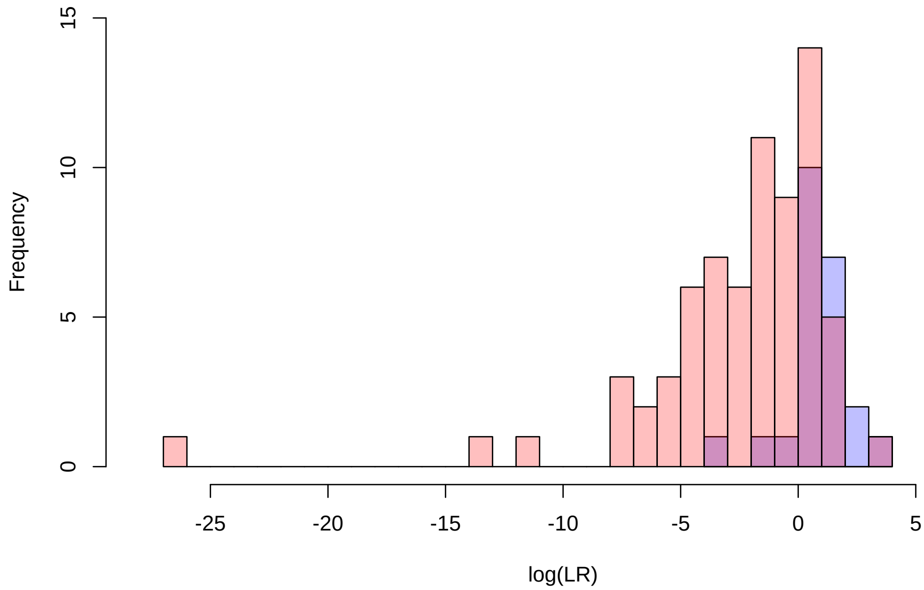


Figure 45 - Likelihood ratios (in a logarithmic form) obtained for the authentic and the simulated signatures of artist n°1 with the feature vector v_2, represented by the number of occurrences of each results. The authentic signatures are represented in red, the simulated signatures in blue.

8.4.2 Artist n°2 - Bacsay

General assessment of measurements and characteristics

The plots of the measurements of artist n°2 highlight some extreme values in both the authentic and simulated signature sets. The corresponding points of these measurements have been all verified and acknowledged as correct.

The examination of the plots and boxplots of the 112 characteristics/features defining the signature of artist n°2 are also verified. Angle adjustments are necessary for characteristics C106 and C110, which correspond to the angle of the crossbar of both -A-s of the signature.

The authentic signatures presenting extreme values are visually identified through the plots and boxplots of the characteristics, and are reported in Table 12. The origins of the extreme values are explained (see Illustration of signatures in Appendix VI). For the sake of brevity of the text, the outliers of the simulated signatures are not presented.

Sig. n°	Outlying feature	Feature specification	Origin of outlying value[188]
1	C16	Height -C- / Height signature	Letter -C- is vertically prolonged (large height)
	C33	Height letter -A- / Height letter -C-	Letter -C- is vertically prolonged (large height)
4	C12	Length -A- / Height signature	Letter -A- less vertically prolonged than on other signatures
	C54	Space between -C- and -S- / Length -S-	Letters -C- and -S- clearly separated and not overlapping
	C62	Length -A- / Height -A-	Letter -A- less vertically prolonged than on other signatures
8	C64	-B- : Height of stem / Height letter	-
9	C32	Height -B- / Height -A-	Letter -B- has a pronounced vertical elongation
14	C106	1st -A- : Angle of crossbar	Crossbar presents a pronounced downward slope
15	C55	Space between -S- and -A- / Length -A-	Letters -S- and -A- clearly separated, letters present no overlapping
	C73	-B- : Length of top bow / Length of top bow, taken from buckle	Curvature of top bow very sharp, long initial stroke of top bow
16	C82	1st -A- : Height of left stem under crossbar / Height of left stem	Crossbar situated higher than on other signatures
17	C41	Superior height difference between -S- and -A- / Height -S-	Letter -S- vertically compact
19	C12	Length -A- / Height signature	-
	C45	Superior height difference between -A- and -C- / Height -A-	Letter -C- is vertically compact, and beginning stroke is situated lower than letter -A-
	C51	Space between -B- and -A- / Length -A-	Letters -A-, -C- and -S- clearly separated
	C52	Space between -A- and -C- / Length -C-	
	C53	Space between -A- and -C- / Length -C-	
22	C48	Inferior height difference between -A- and -Y- / Height -Y-	Right stem of -A- prolonged vertically

[188] The origins of the outlying values are given in comparison with the other signatures of the set.

24	C33	Height -A- / Height -C-	Letter -C- vertically compact
	C64	-B- : Height of stem / Height of letter	-
	C110	2nd -A- : Angle of crossbar	Crossbar presents a pronounced upwards slope

Table 12 - Outliers detected in the authentic signature set of artist n°2

Eleven signatures of the authentic set present outlying feature values, with each signature presenting a range of one to five outliers. The study of these outlying features shows that their origin comes from one or two elements of each signature, even if several outliers are observed. Only signature n°24 possessed three outliers with three different origins.

The boxplots of the characteristics of the authentic signatures present more dispersion than the simulated sets for a number of the features, listed here by their class affiliation: Class 3 (C8 and C12), Class 4 (C17), all of Class 5 (C20 to C25), Class 7 (C35), Class 8 (C39, C40 and C42), C47, all of Class 11 (C58 to C63), Class 12 (C81, C83, C88, C89, C90, C92, C97, and C98). The reason behind the large dispersion of the authentic signatures is the great variation in the signatures signed by the artist. Indeed, artist n°2 depicted a signature "style" linked to every session, and the results of such a variation are translated into the characteristics. A plot of the characteristics C25, which corresponds to the ratio of the height of the letter -Y- to the length of the signature shows the style difference in-between each of the 6 sessions (see Figure 46).

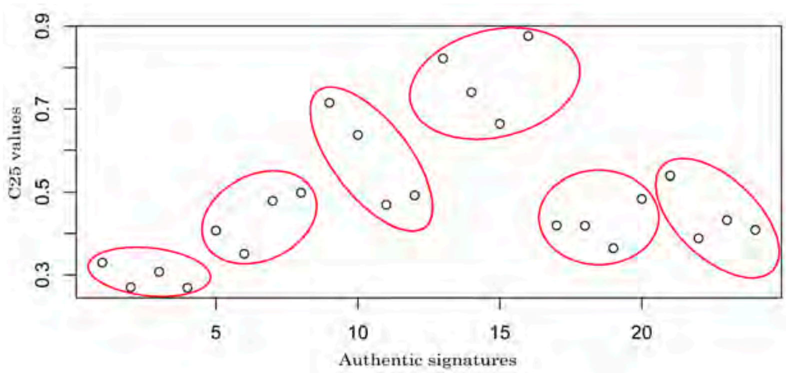


Figure 46 - Plot of characteristic C25 values of the authentic signature set. The signatures are grouped by their sampling session (1 to 6).

None of the boxplots depicting the values of the characteristics of the authentic signatures are fully separated from their simulated counterpart, a partial or full overlapping is always present from the range from the first up to the last quartile. However, the interquartile ranges between the authentic and simulated sets are separated for characteristics C80 and C103.

Principal component analysis

As for the first artist, a PCA is carried out on the data set obtained from the authentic and simulated signatures. The first three PCs of this data set account for approximately 20%, 11%, and 7% of the total variation (80 % of the variance is explained by the first 16 variables). Thus a three-dimension plot of the first three PCs will give a general, although not exhaustive, account of the relative position of the observations in their original 112-dimensional space.

The PCA representation of the first three PCs plotted against each other (see Figure 47) demonstrate a partial separation of both sets (particularly with PC1 plotted against PC2). The illustration also highlights the directionality of the authentic signature set towards the positive axes of PC1 and PC2. This large dispersion of the signature set was already observed during the general assessment of the characteristics with the large dispersion of the boxplot of the data describing the authentic signature set.

The simulated set of signatures shows greater variation in the direction of the first PC (and are concentrated along its positive axis), but also varies in the direction of the second PC. Both sets show less variation in the direction of the third PC.

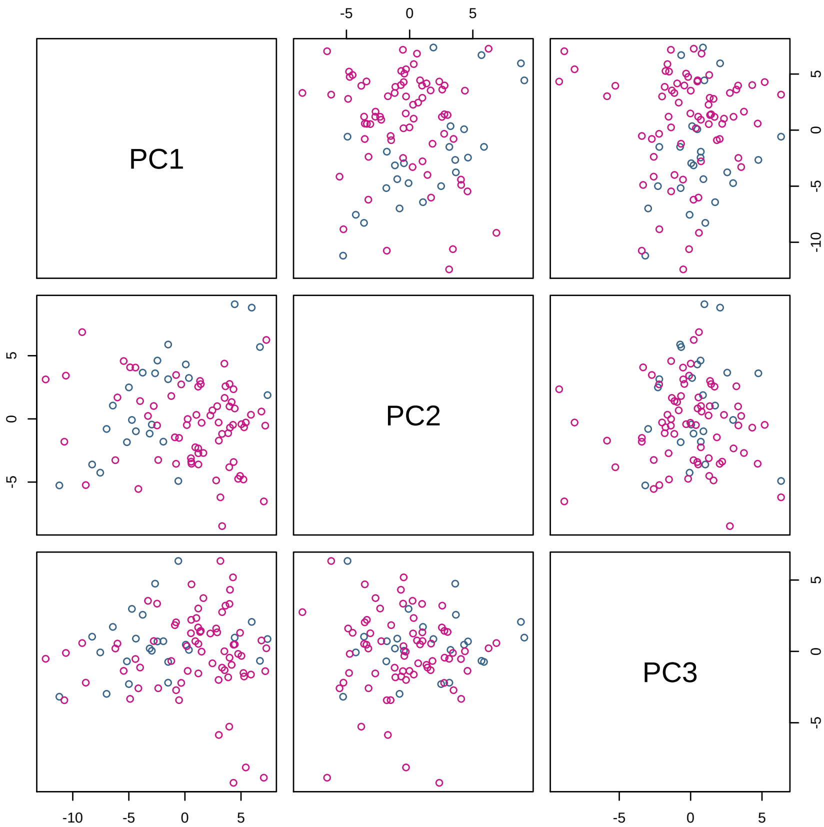


Figure 47 - Representation of first three PCs plotted against each other. Each blue point represents an authentic signature, and each pink point represents a signature of the simulated set.

The set of simulated signatures are broken down and represented according to the different groups of simulators (see Figure 48): the Conservators-restorers, the Artists, and the FHEs. The group of Conservators-restorers produced data showing variation across the first PC, and partially overlapping the set of authentic signatures. The signature set produced by the Artists partially overlap the authentic set, and show the most variation along the positive axis of PC1 and negative axis of PC2. The last group of simulators, the FHEs, is separated from the authentic set, and shows more variation across the second PC axis.

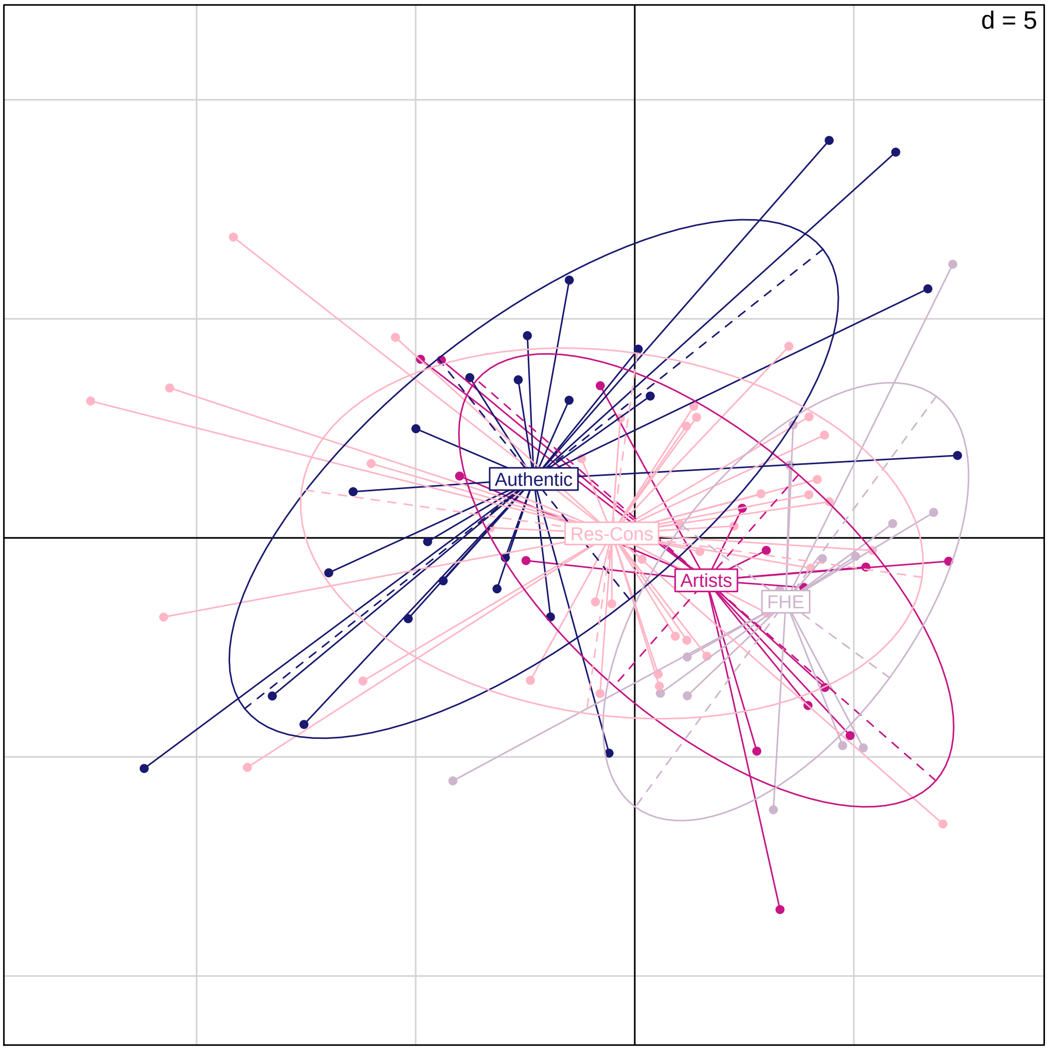


Figure 48 - Representation of the first two PCs (PC1 on x-axis and PC2 on y-axis) obtained of the PCA analysis of the authentic set and the three simulated set of signatures of artist n°2 (Bacsay).

Figure 49 illustrates the differences in the simulation capacities of each simulator. These results display a simulation capacity that is linked to both the personal abilities of the person as well as to their group affiliation. For the first group of Conservators-restorers, simulators 1, 2 and 10 are essentially separated from the authentic group, simulators 5, 7, and 9 are partly separated, whereas simulators 8 and 11 are contained in the distribution of the authentic signature set. For the second group of simulators (Artists), only one of the three simulators is contained within the authentic set (simulator 4); whereas simulators 13 and 14 are completely separated from the authentic set. Finally, for the third group (FHEs), the three simulators (15, 16 and 17) are completely separated from the authentic set.

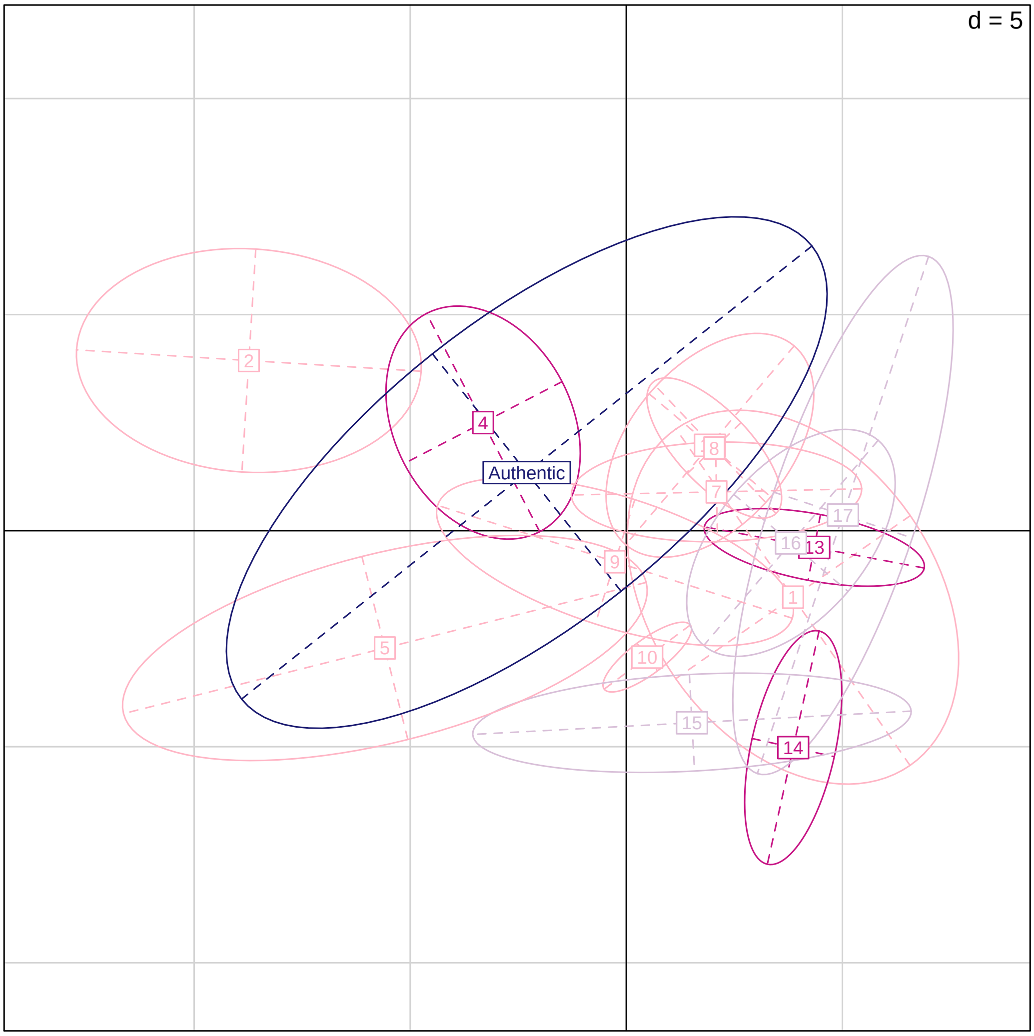


Figure 49 - Illustration of PCA analysis (PC1 on x-axis and PC2 on y-axis) of the authentic set and the each simulated set (n=14) of signatures of artist n°2 (Bacsay). The simulators from the Res-Con group are represented in pink, the Artist group in dark pink, and the FHEs in mauve.

The dispersion of the each of the simulated signatures varies according to the simulator, and only appears to be linked to the group affiliation for the FHEs. Thus, three groups of simulators can be deduced: very skilled simulators (8, 11 (hidden behind number 8 in Figure 49, and 4), moderately skilled simulators (5, 7, and 9), and poorly skilled simulators (1, 2, 10, 13, 14, 15, 16, and 17). The simulators of the first group generally presented more dispersed signature sets (varying more along PC1 or PC2) than the other two groups (with an exception of simulator 17 who produced a set varying along PC2).

Feature reduction

a) Boruta feature reduction

The Boruta feature reduction testing was carried out with the different pre-defined parameter and the best results were obtained with the parameter ntree=10000. In this case, the highest number confirmed (26) and tentative (2) characteristics were given. Thus a total of 28 of the initial 112 characteristics were selected (25%) and are listed in Table 13 with their corresponding feature classes and feature specifications. The importance values of each characteristic with the Boruta analysis are reported in Appendix XIII.

Each letter is represented at least once within the selected features. However, some letters are over-represented than others, in comparison with their initial number of corresponding characteristics. The last letter -Y- is present in approximately a third of the selected features (22% for characteristics concerning the letter -Y- alone, and 36% when considering the letter -Y- in combination with another letter).

Feature	Feature class		Letter specification
C103	13	Angle	-B- : Angle of stem
C80	12	Intraletter	-B- : Length of initial stroke left of stem / Length letter
C99	12	Intraletter	-Y- : Length of spreading between outer extremities of stems / Length letter
C109	13	Angle	1st -A- : Angle of right stem
C105	13	Angle	2nd -A- : Angle of right stem
C20	5	Height letter / Length signature	H -B- / L tot
C112	13	Angle	-Y- : Angle of right stem
C87	12	Intraletter	1st -A- : Length of spreading between outer extremities of stems / Length letter
C42	8	Height difference (sup.) / Height letter before	H -A- and -Y- / H -A-
C39	8	Height difference (sup.) / Height letter before	H -A- and -C- / H -A-

C75	12	Intraletter	-B- : Length of bottom bow, taken from buckle / Length of bottom bow
C102	12	Intraletter	-Y- : Height of left stem overlapping right stem / Height of left stem, up to intersection of stems
C111	13	Angle	-Y- : Angle of left stem
C4	2	Length letter / Length signature	L -C- / L tot
C108	13	Angle	2nd -A- : Angle of left stem
C43	8	Height difference (sup.) / Height letter before	H -Y- and -B- / H -Y-
C49	9	Height difference (inf.) / Height letter before	H -Y- and -B- / H -Y-
C13	3	Length letter / Height signature	L -Y- / H tot
C56	10	Space / Length letter after	-A- and -Y- / L -Y- : Space between right overlapping crossbar of -A- and -Y-
C90	12	Intraletter	-C- : Length of upper curve / Length of lower curve
C107	13	Angle	-S- : Angle (general orientation)
C97	12	Intraletter	2nd -A- : Length of spreading between outer extremities of stems / Length letter
C7	2	Length letter / Length signature	L -Y- / L tot
C41	8	Height difference (sup.) / Height letter before	H -S- and -A- / H -S-
C38	8	Height difference (sup.) / Height letter before	H -B- and -A- / H -B-
C45	9	Height difference (inf.) / Height letter before	H -A- and -C- / H -A-
C1	1	Length signature / Height signature	Signature
C10	3	Length letter / Height signature	L -C- / H tot

Table 13 - List of features retained after Boruta feature selection step, listed by their order of importance.

The results display the importance of the angle class in the feature selection. Indeed, of the first seven selected features, four are angles of the stems of letters. Interestingly though, the angle of the right stem of both -A-s come out at the beginning of the list of selected features, however their corresponding left stem appears further down in the list for the second -A-, and is not even selected for the first -A-.

The intraletter class is also well represented in the feature list: three of the first eight features come from this class. The high number of angles selected can be explained by looking back at the boxplots of the characteristics. It is a confirmation of what was visually observed through the boxplots of the characteristics: the angle class is the only class that presented no characteristics where the dispersion of the authentic set was greater than that of the simulated set.

b) Normality testing

The results obtained after the Shapiro-Wilk normality test on the 112 characteristics describing the signature of artist n°2 are presented according to their class affiliation in Table 14. The detailed results of the tests (for each characteristic) are presented in Appendix XII.

For the authentic set of signatures, the normality of the data is on the whole respected. Only the intraletter class of features (class 12) possesses five (out of 39) features with significant p-values, as well as class 13 that presents two (out of 10) features with a significant p-value. The simulated signature set however possesses a greater number of variables that do not come from normally distributed populations, particularly in the classes 3 (Length of a letter/Height of the signature), 6 (Length of a letter/Length of the letter after), 11 (Length of a letter/Height of the same letter) and 13 (Angles).

The normality results of both the authentic and simulated sets considered together show that six classes (1, 3, 6, 11, 12, and 13) each have less than 50% of their variables that are normally distributed.

Class	Authentic			Simulated			Both sets (Auth. and Sim.)			
	Normal #		Total #	Normal #		Total #	Normal #		Total #	(%)
1	1	/	1	0	/	1	0	/	1	0 %
2	6	/	6	4	/	6	4	/	6	66.7 %
3	6	/	6	1	/	6	1	/	6	16.7 %
4	6	/	6	4	/	6	4	/	6	66.7 %
5	6	/	6	5	/	6	5	/	6	83.3 %
6	6	/	6	2	/	6	2	/	6	33.3 %
7	6	/	6	5	/	6	5	/	6	83.3 %
8	6	/	6	4	/	6	4	/	6	66.7 %
9	6	/	6	6	/	6	6	/	6	100 %
10	6	/	8	4	/	8	4	/	8	50 %
11	6	/	6	1	/	6	1	/	6	16.7 %
12	34	/	39	20	/	39	19	/	39	48.7 %
13	8	/	10	4	/	10	2	/	10	20 %

Table 14- Results of Shapiro-Wilk normality test, given for each class composing the authentic set, the simulated set, and both sets together.

The affiliation of each selected characteristics to his respective feature class after the Boruta selection step is noted in the third column of Table 15, with the relative percentage in parentheses. Classes 4, 6, 7 and 11 are not represented by a selected feature. The classes that have the highest percentages of selected features are classes 1 (Length signature/Height signature), 2 (Length letter/Length signature), 3 (Length letter/Height signature), 8 (Height difference (superior) between two letters/Height letter before), 9 (Height difference (inferior) between two letters/Height letter before), and 13 (Angles). Thus, if simplified, three general tendencies can be drawn in the selected feature classes: Lengths of letters, Height difference between letters, and angles.

Once the results of the normality testing are applied on the Boruta feature selection results, a final number of 12 features are retained (see Table 15), which corresponds to a 89.3% reduction from the initial 112 features. Classes 1 and 3 are no longer represented. The two most drastic drops in class representations are in classes 12 and 13, where respectively only one and two features are retained. The classes of Height difference between letters (classes 8 and 9) represent 50% of the final selected features.

Class		Number of features in each class (and corresponding %)	
N°	# of Features in Class	... after Feature selection	... after Feature selection *and* normality testing
1	1	1 (100 %)	0 (0 %)
2	6	2 (33.3 %)	1 (16.6 %)
3	6	2 (33.3 %)	0 (0 %)
4	6	0 (0 %)	0 (0 %)
5	6	1 (16.6 %)	1 (16.6 %)
6	6	0 (0 %)	0 (0 %)
7	6	0 (0 %)	0 (0 %)
8	6	5 (83 %)	4 (66.6 %)
9	6	2 (33.3 %)	2 (33.3 %)
10	8	1 (12.5 %)	1 (12.5 %)
11	6	0 (0 %)	0 (0 %)
12	39	7 (17.9 %)	1 (2.6 %)
13	10	7 (70 %)	2 (20 %)
Total	**112**	**28 (25 %)**	**12 (10.7 %)**

Table 15 - List of features of each class retained after Boruta feature selection and normality testing

The final list of features retained after the Boruta feature selection and normality testing is given in Table 16, with their corresponding class and letter specifications. Each of the six letters are represented either directly, or in relation with another letter. However, no features representing solely the two -A-s of the signature are retained.

Feature	Feature class		Letter specification
C20	5	Height letter / Length signature	H -B- / L tot
C39	8	Height difference (sup.) / Height letter before	H -A- and -C- / H -A-
C75	12	Intraletter	-B- : Length of bottom bow, taken from buckle / Length of bottom bow
C111	13	Angle	-Y- : Angle of left stem
C43	8	Height difference (sup.) / Height letter before	H -Y- and -B- / H -Y-
C49	9	Height difference (inf.) / Height letter before	H -Y- and -B- / H -Y-
C56	10	Space / Length letter after	-A- and -Y- / L -Y- : Space between right overlapping crossbar of -A- and -Y-
C107	13	Angle	-S- : Angle (general orientation)
C7	2	Length letter / Length signature	L -Y- / L tot
C41	8	Height difference (sup.) / Height letter before	H -S- and -A- / H -S-
C38	8	Height difference (sup.) / Height letter before	H -B- and -A- / H -B-
C45	9	Height difference (inf.) / Height letter before	H -A- and -C- / H -A-

Table 16 - List of features retained after Boruta feature selection and normality testing.

Likelihood ratio assessment

The strength of the set of selected features are finally assessed with a likelihood ratio examination. The feature vector v_{11} containing the selected features C20, C39, C75, C111, C43, C49, C56, C107, C7, C41, C38 and C45 are used altogether to compute a multivariate likelihood ratio for each authentic and simulated signature, as explained in sub-section 7.4.4. The results of the likelihood ratio assessment carried out with the 12 feature long vector v_{11} of artist n°2 are presented in Table 17 below.

Authentic		Simulated			
Sig n°	log(LR)	Sig n°	log(LR)	Sig n°	log(LR)
1	**-12.1**	1	-1.3	36	**1.8**
2	**-3.1**	2	-40.2	37	-18.3
3	2.2	3	-29.3	38	-10.3
4	8.8	4	-34.2	39	**3.2**
5	**-1.4**	5	-11.5	40	-10.7
6	**-5.8**	6	-6.0	41	-3.3
7	4.3	7	-31.6	42	**0.3**
8	**-0.5**	8	-20.4	43	-12.8
9	8.8	9	-15.2	44	-14.6
10	5.4	10	-22.4	45	-8.1
11	1.1	11	-6.2	46	-8.0
12	1.0	12	-4.2	47	-8.5
13	7.9	13	-1.4	48	-13.5
14	10.4	14	-17.7	49	-8.4
15	**-8.0**	15	-1.8	50	-12.2
16	**-8.3**	16	-11.7	51	-19.8
17	0.3	17	**3.8**	52	-12.4
18	**-8.0**	18	**2.2**	53	-23.1
19	**-4.6**	19	-12.7	54	-19.4
20	**-1.9**	20	-23.9	55	-15.5
21	**-1.1**	21	-6.2	56	-12.1
22	**-8.1**	22	-7.0	57	-21.9
23	3.4	23	-9.7	58	-25.8
24	**-5.7**	24	-11.8	59	-19.3
		25	-14.9	60	-33.1
		26	-5.3	61	**0.2**
		27	-4.8	62	-6.8
		28	**0.2**	63	-13.9
		29	-2.3	64	-13.0
		30	**1.3**	65	-12.7
		31	-5.4	66	-5.0
		32	-9.5	67	-0.6
		33	-8.2	68	-0.03
		34	-5.5	69	-10.3
		35	-7.0	70	-10.3

Table 17 - Log(Likelihood) results obtained for each signature in the authentic and simulated signature sets with sets with the feature vector υ_{11}. Negative results under H_1, and positive results under H_2, are highlighted in bold.

Of the 24 authentic signatures, 11 possess a log(LR) above zero (true positives), leaving the remaining 13 with a log(LR) below zero (false negatives). The obtained log(LR) results are presented graphically for the authentic signatures in Figure 50: The values in the top left rectangle represent the true positives and those in the bottom left rectangle the false negatives.

Of the 70 simulated signatures, 62 possess a log(LR) below zero (true negatives) which are represented in the bottom right rectangle. The remaining 8 signatures, situated in the top right rectangle possess a log(LR) above zero, and are thus false positives. The sensitivity (true positive rate) amounts to 45.83%, and the specificity (true negative rate) to 88.57%.

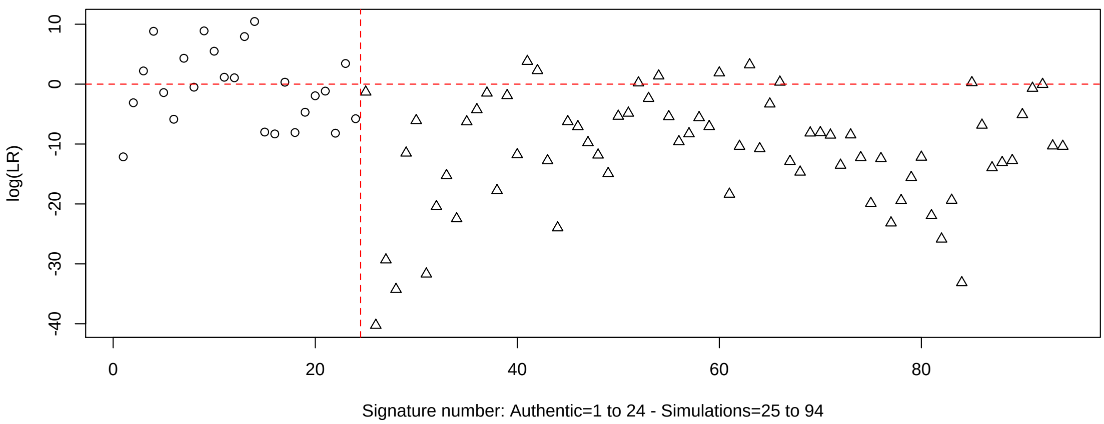


Figure 50 - Visual representation of the log(likelihood ratio) obtained for all of the signatures of artist n°2 (authentic signatures are represented by a circle, simulations by a triangle).

A closer look of the results obtained for the simulated set depicts the same range of results as the PCA analysis as a means to characterize the simulation capacity of a person. For example, simulators 7 (signatures 16-20), 9 (signatures 26-30) and 11 (signature 36-40) both have two of their signatures that present a log(LR) above zero. Likewise, simulator 5 possesses three signatures with a log(LR) above zero.

The dispersion of the results are represented in Figure 51 through a histogram of the number of occurrences obtained for each range of log(LR) with the authentic and simulated signature populations.

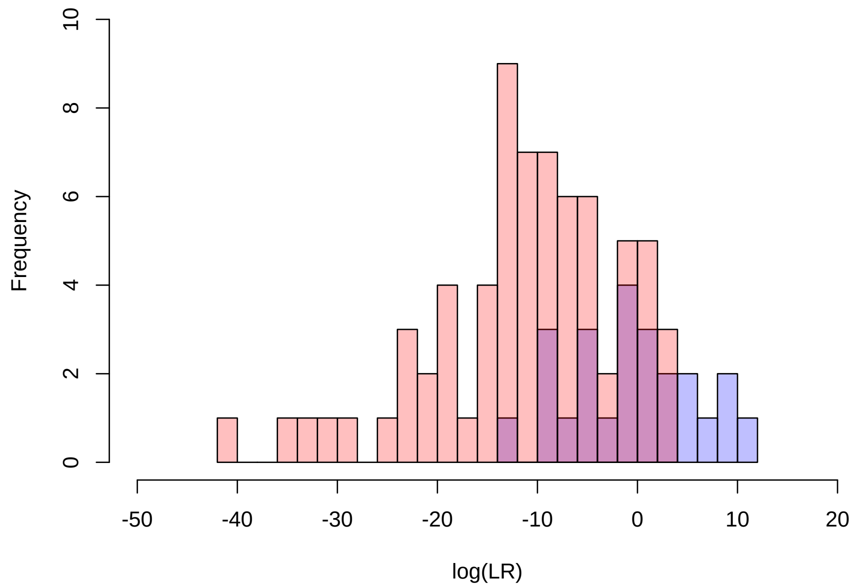


Figure 51 - Likelihood ratios (in a logarithmic form) obtained for the authentic and the simulated signatures of artist n°2 with the feature vector v_{11}, represented in the form of a histogram and according to the number of occurrences (y-axis). The authentic signatures are shown in blue, the simulated signatures in red.

The results of the log(LR) depict an overlapping between the authentic and simulated signature sets. The authentic signatures are grouped around the value zero, but with however 13 signatures spread along the negative end of the x-axis. The simulated set is predominately situated with log(LR) lower than zero, but does overlap onto the positive side of the axis (for 8 signatures). The overlapping is less stretched out along the positive end of the axis than the authentic signatures are on the negative end.

The log(LR) values obtained with all of the 11 feature vectors (v_1-v_{11}), for each of the authentic signatures, are shown in Figure 52 through boxplot illustrations - the exact values obtained for each signature and for each feature vector are reported in Appendix XIV. As highlighted in Figure 46, this artist's signatures can be visually grouped by fours, and corresponds to the time they were signed (since the artist signed four signatures during each sampling session). This observation attests of the large variation within the authentic signature set, already observed with the results after the observation phase.

The signatures presenting a negative log(LR) with the feature vector v_{11}, i.e. signatures 1, 2, 5, 6, 8, 15, 16, 18, 19, 20, 21, 22, and 24 all (except for signature 24) present log(LR)s that are at one point higher than the value of zero. This indicates that the feature vector v_{11} is not the optimal feature vector choice in terms of false negatives.

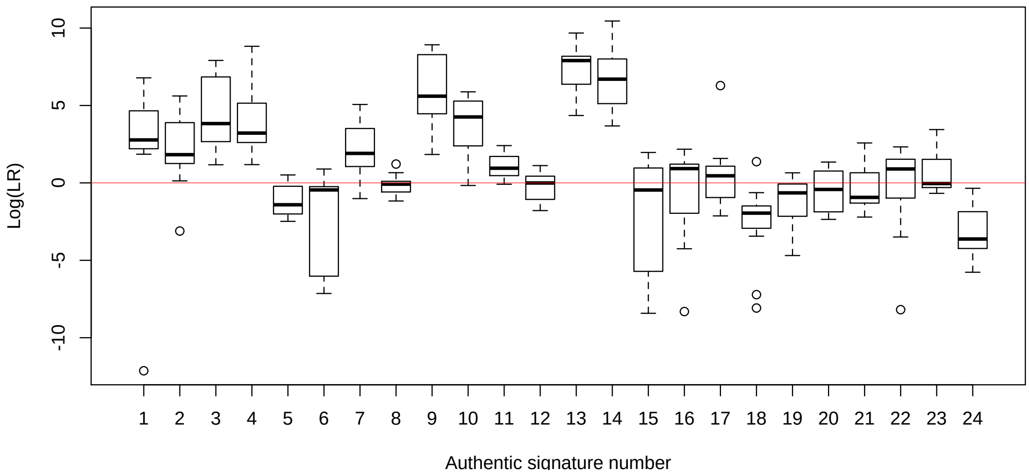


Figure 52 - Likelihood ratios (in a logarithmic form) results obtained for all of the feature vectors v_1-v_{11} for the authentic signatures of artist n°2, represented in the form of a boxplot.

The log(LR) results obtained for all of the 11 feature vectors (v_1-v_{11}) for each of the simulated signatures is represented in the same manner in the following boxplot (Figure 52). The signatures 17, 18, 28, 30, 36, 39, 42 and 61 gave positive log(LR) with the final feature vector v_{11}. However, only two of these signatures, 36 and 39 present positive log(LR) values for all of the 11 feature vectors. Both of these signatures were made by simulator 11, attesting of this person's high simulation capacity.

Simulators 4, 5 7, 9, and 17 also produced at least one signature whose median log(LR) value obtained for all feature vectors is positive. Except for signature 12 (made by simulator 5), these signatures gave low variation in the log(LR) values (see Figure 53).

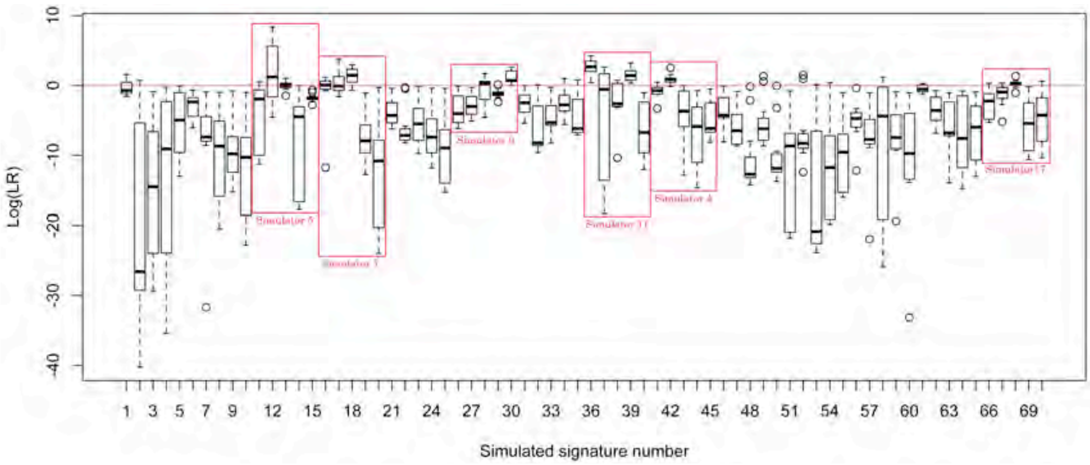


Figure 53 - Likelihood ratios (in a logarithmic form) results obtained for all of the feature vectors for the simulated signatures of artist n°2, represented in the form of a boxplot. Signatures produced by simulators 4, 5, 7, 9, 11 and 17 are highlighted in red.

The log(LR) results obtained for each authentic signature for each of the 11 different feature vectors are plotted in Figure 54 - Figure 57. As was the case for artist n°1, the influence of the length of the feature vector on the log(LR) results for each of the authentic signatures can be divided into four distinct categories, according to the general tendencies observed:

- The log(LR) results increase as the length of the feature vector increases (Figure 54);
- The log(LR) decreases as the length increases (Figure 55);
- An increase, followed by a sharp decrease of the log(LR) is observed as the length of the feature vector increases (Figure 56);
- or finally, no simple behavior can be drawn (Figure 57).

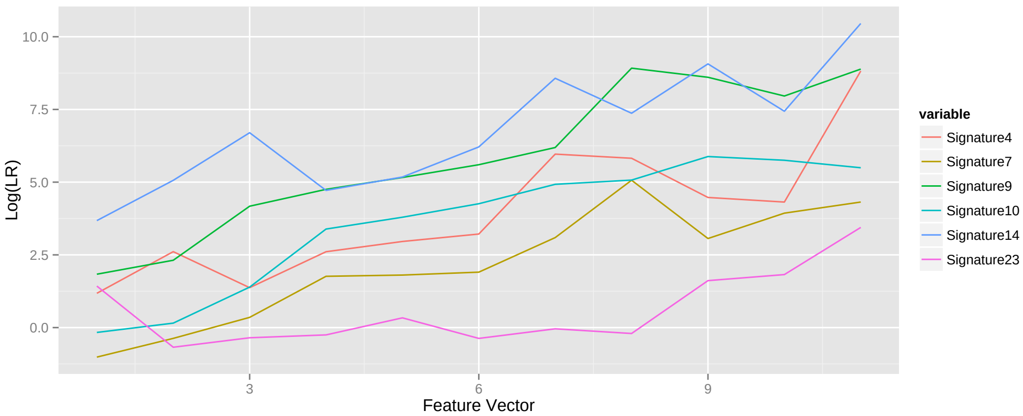


Figure 54 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

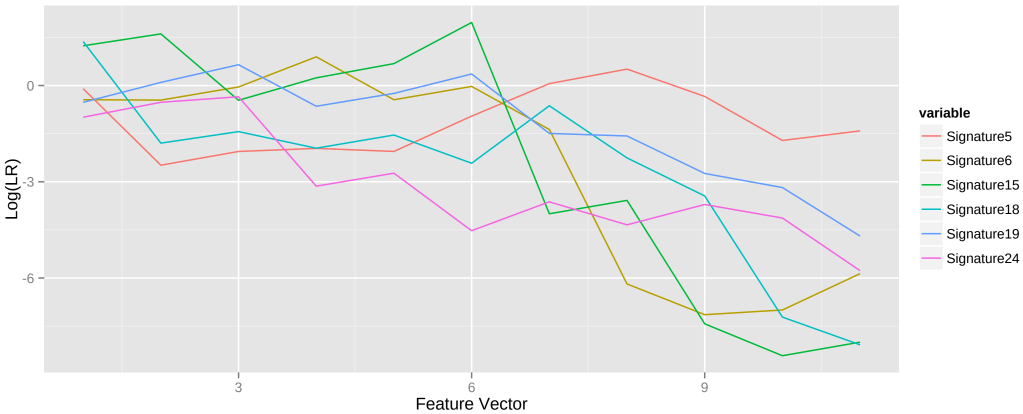


Figure 55 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

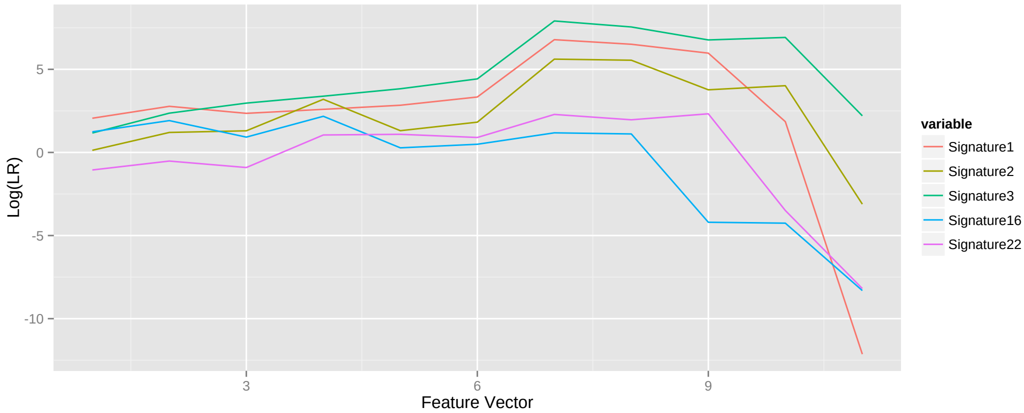


Figure 56 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

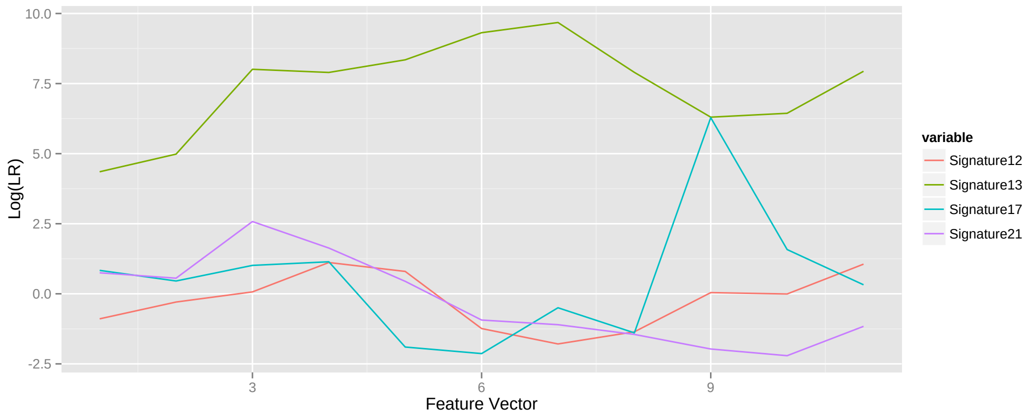
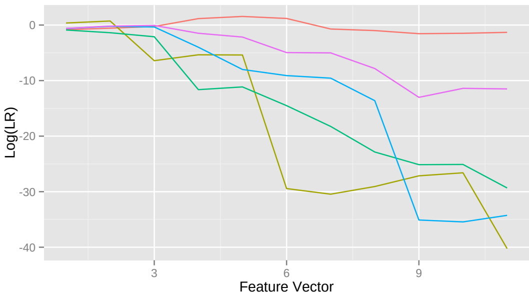


Figure 57 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

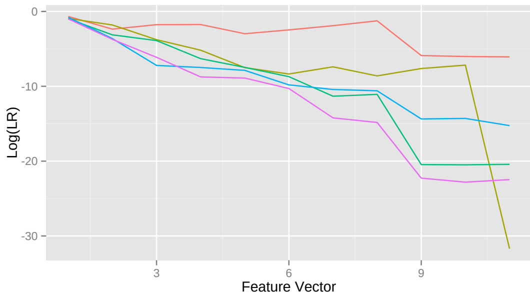
The simulated signature sets are presented, for each simulator, in Figure 58, where the influence on the feature vector, and the resulting log(LR) results, are depicted. All of the simulators produced at least two signatures whose log(LR) results decreased as the length of the feature vector increased. This was the case for all five signatures produced by simulators 2, 8, 10, 13, 14, and 15. For a number of these signatures, the first feature vectors gave results gravitating around (just below and above) the value of log(LR) of zero.

Several signatures produced results which varied little as the feature vector changed, for example: the first signature of Simulator 1, the first and fifth signatures of Simulator 8, the first signature of Simulator 4, the third and fifth signature of Simulator 5, the second signature of Simulator 7, the first signature of Simulator 16 and the third signature of Simulator 17).

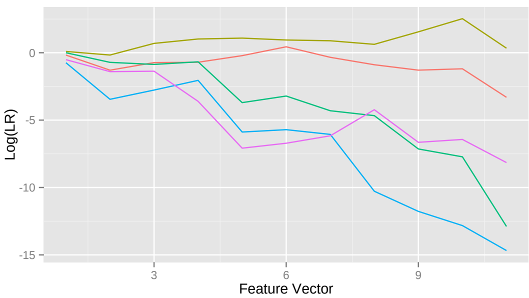
Finally, several signatures within the sets produced by simulators 4, 7, 9 and 11, produced higher log(LR) results as the length of the feature vector increased. However, none of these simulation sets contained only signatures presenting this behavior. At least three signatures of each of these sets followed the tendency of the majority of the simulators: the log(LR) results decreased as the feature vector increased. Finally, the third signature of simulator 5 produced high log(LR) results that increased with the length of the feature vector, but then drastically dropped below zero after the feature vector v_6.



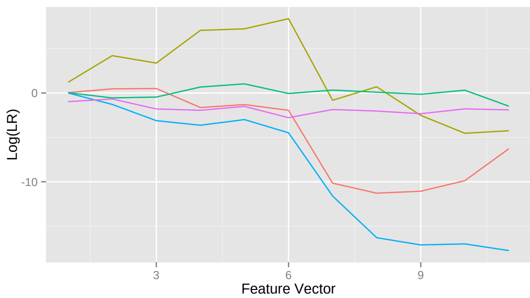
Simulator 1



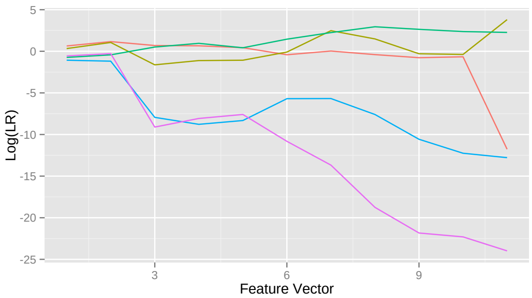
Simulator 2



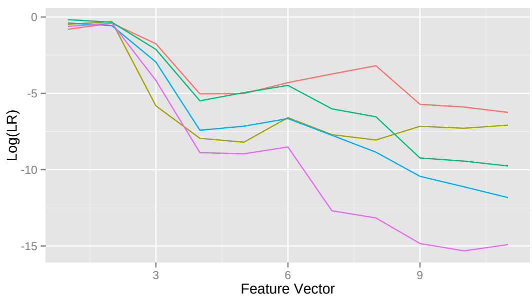
Simulator 4



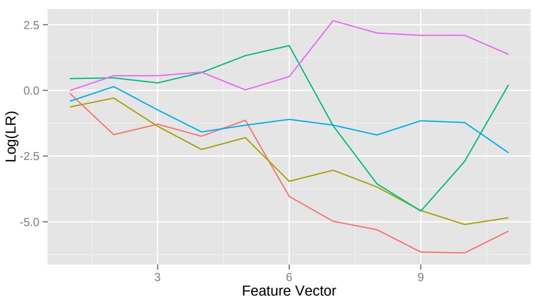
Simulator 5



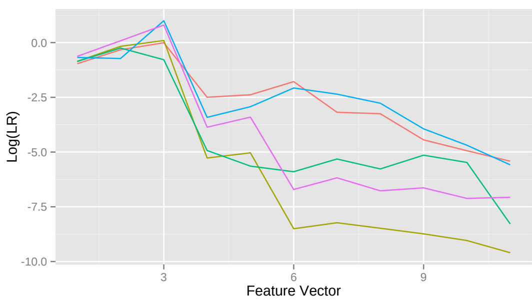
Simulator 7



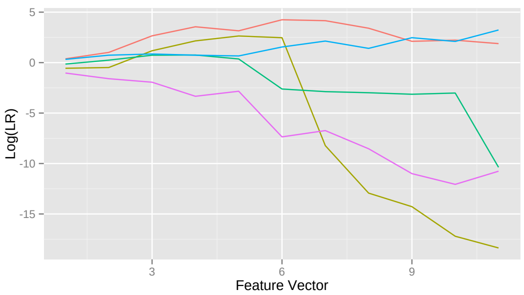
Simulator 8



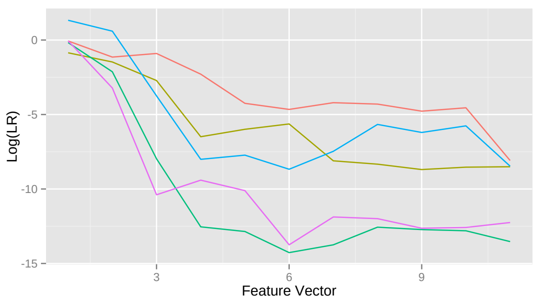
Simulator 9



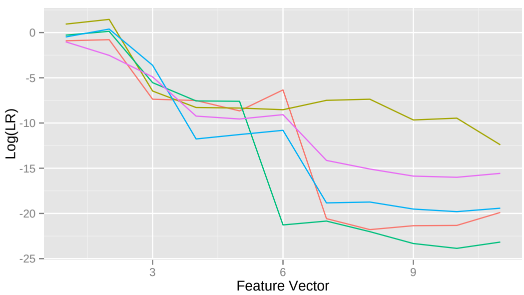
Simulator 10



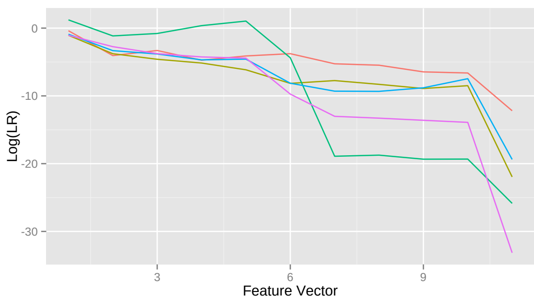
Simulator 11



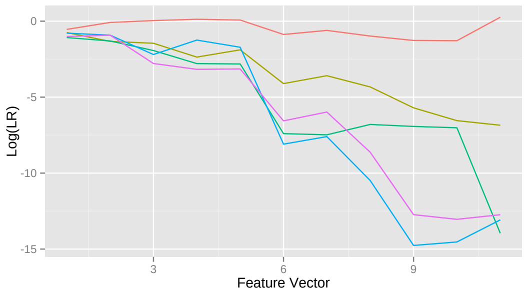
Simulator 13



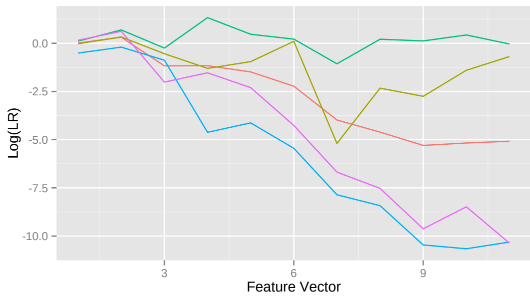
Simulator 14



Simulator 15



Simulator 16



Simulator 17

Figure 58 - Log(LR) results, plotted for the each of the 10 feature vectors, obtained for the 5 signatures samples of each of the simulators of artist n°2. The legend for each signature is as follows: Signature1 Signature2 Signature3 Signature4 Signature5

The calculation of the log-likelihood-ratio cost (C_{llr}) gives weighted results in light of the different behaviors of the authentic and simulated signatures according to the length of the feature vector used. The feature vector used to calculate the log(LR) for both signature sets show C_{llr} results under the value of one for only the first eight feature vectors (containing the first two to the first six features).

Feature vector	Feature combination	CCLR
1	2 features	0.848
2	3 features	0.890
3	4 features	**0.706**
4	5 features	0.709
5	6 features	0.760
6	7 features	0.851
7	8 features	0.841
8	9 features	0.982
9	10 features	1.231
10	11 features	1.589
11	12 features	2.332

Figure 59 - C_{llr} results obtained for artist n°2. The lowest value is highlighted in bold.

The C_{llr} results, illustrated in the two plots below (Figure 60), follow an exponential increase curve as the number of features in the feature vector rises.

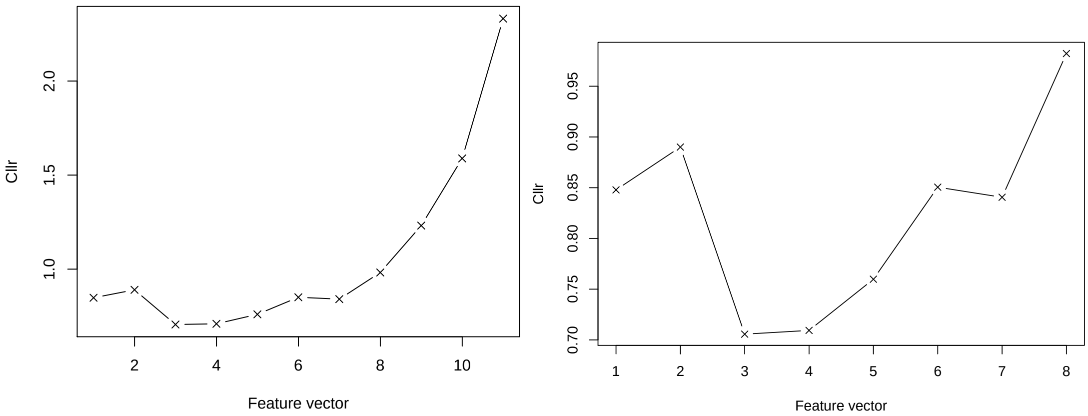


Figure 60 - C_{llr} results obtained for artist n°2, plotted for each feature vector (v_1 to v_{11}) combination composed of two to 12 features (left). A zoom on the first 8 feature vectors (v_1 to v_8) is presented on the right.

The feature vector v_3 (containing the first four features) presents the lowest C_{llr} value (C_{llr} = 0.706), and is thus selected for subsequent log(LR) calculations. This feature vector contains the features:

C103	Angle of the stem of letter -B-
C80	Length of initial stroke left of stem of letter -B- / Length of letter -B-
C99	Length of spreading between outer extremities of stems of letter -Y- / Length of letter -Y-
C109	Angle of right stem of 1st -A-

The resulting TP Rate of 66.66% and TN Rate of 78.57% are drawn. The distribution of the authentic and signatures is presented in Figure 61. The distribution of the authentic signatures is clearly pushed towards the positive side of the axis, with only 8 signatures giving negative log(LR). The same observation can be made to a lesser extent to the population of simulated signatures, whose distribution is less spread out across the negative end of the axis.

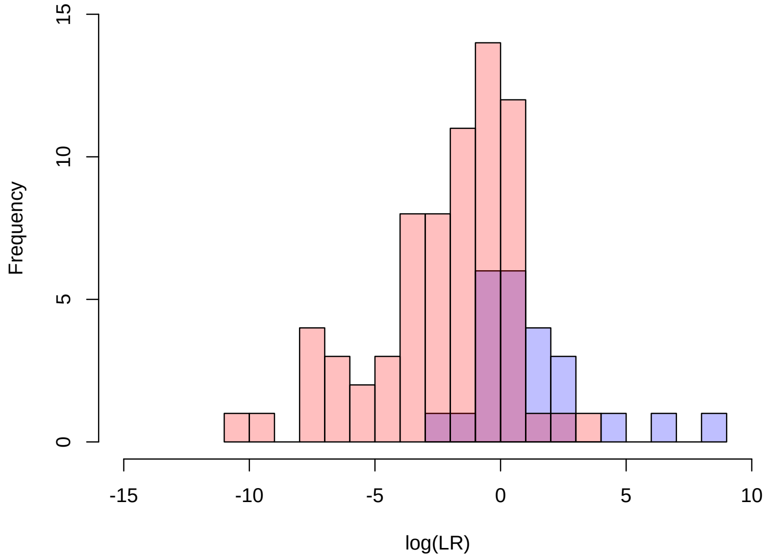


Figure 61 - Likelihood ratios (in a logarithmic form) obtained for the authentic and the simulated signatures of artist n°2 with feature vector v_3, represented by the number of occurrences of each results. The authentic signatures are represented in red, the simulated signatures in blue.

8.4.3 Artist n°3 - Muro

General assessment of measurements and characteristics

The plots of the measurements of artist n°3 highlight some extreme values in both the authentic and simulated signature sets. The corresponding points of these measurements have been all verified and acknowledged as correct.

The authentic signatures presenting extreme outlying values are visually identified through the plots and boxplots of the characteristics, and are reported in Table 18. The origins of the extreme values are explained (see Illustration of signatures in Appendix VI). For the sake of brevity of the text, the outliers of the simulated signatures are not presented.

Sig. n°	Outlying feature	Feature specification	Origin of outlying value[189]
1	C66	-M- : Length of hook / Length of letter	Long terminal hook
2	C16	Height -O- / Height signature	Letter -V- higher than other letters; Small letter -O-
	C30	Height -R- / Height -O-	Small letter -O-
	C36	Superior height difference between -O- and -V- / Height of -O-	Letter -V- higher than other letters; Small letter -O-
3	C6	Length -O- / Length signature	Letter -O- wide
6	C7	Length -V- / Height signature	Letter -V- prolonged horizontally
	C8	Length -M- / Height signature	Letter -M- prolonged horizontally
	C47	Length -M- / Height -M-	Letter -M- prolonged horizontally
8	C53	-V- : Height hook / Height letter	Prolonged hook
	C61	-M- : Length left median stroke / Length right median stroke	Letter -M- asymmetrical; right median stroke practically vertical
	C68	-U- : Height hook / Length hook	-
9	C20	Height -R- / Length signature	Letter -R- is prolonged vertically
	C49	Length -R- / Height -R-	Letter -R- is prolonged vertically
	C66	-M- : Length of hook / Length of letter	Long terminal hook
11	C14	Height -U- / Height signature	Letter -U- prolonged vertically
	C66	-M- : Length of hook / Length of letter	Long terminal hook
12	C61	-M- : Length left median stroke / Length right median stroke	Letter -M- asymmetrical; right median stroke prolonged horizontally
13	C16	Height -O- / Height signature	Large letter -O-

[189] The origins of the outlying values are given in comparison with the other signatures of the set.

	C61	-M- : Length left median stroke / Length right median stroke	Letter -M- asymmetrical; right median stroke practically vertical
14	C68	-U- : Height hook / Length hook	Length of hook short
20	C54	-V- : Length hook / Length letter	Prolonged hook vertically
22	C75	-R- : Height leg / Length leg	Leg compact horizontally

Table 18 - Outliers detected in the authentic signature set of artist n°3.

Twelve signatures of the authentic set present outlying feature values, with each signature presenting a range of one to three outliers (for signatures n°2, 6, 8 and 9). For these signatures, the three outliers are explained by two elements, with an exception from signature n°8, where the three outliers have as an origin three elements of the signature.

The boxplots of the characteristics of the authentic signatures present, for most parts, less dispersion than the characteristics of the simulated signatures. Several exceptions are however noted and are: C27, C54, C58, C64, C67, C68, C79, C80, and C90.

For several characteristics, the effort made by the simulator to correctly reproduce graphical particularities of the authentic signatures can be assessed. Indeed, the plots and boxplots (see Figure 62) of hooks of the letters -V-, -M-, and -U- indicate that the majority of simulators chose to eliminate the hooks of these letters, even though they were present on the majority of the authentic signatures.

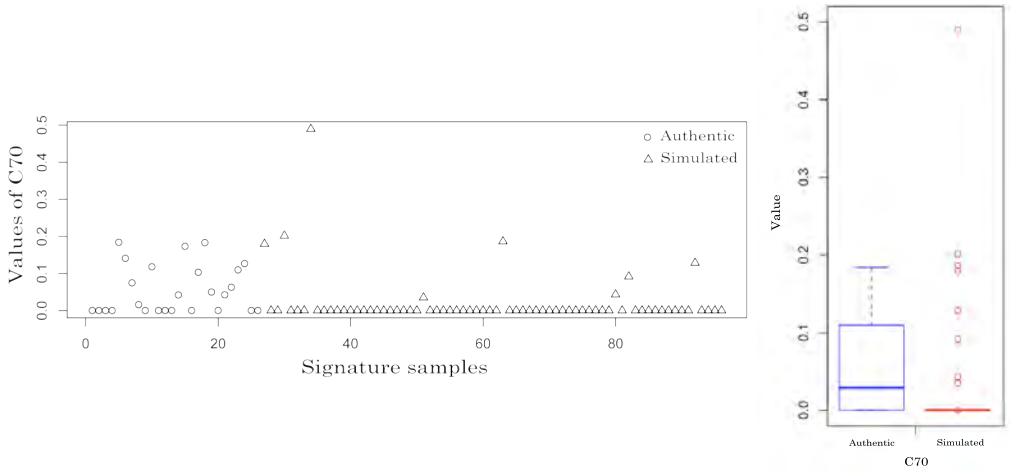


Figure 62 - Plot (left) and boxplot (right) of characteristic C70.

None of the boxplots depicting the values of the characteristics of the authentic signatures are fully separated from their simulated counterpart, a partial or full overlapping is always present between either the interquartile ranges, or between the first and last quartiles.

Principal component analysis

A PCA is carried out on the data set obtained from the authentic and simulated signatures. The first three PCs of this data set account for approximately 12%, 9.5%, and 9% of the total variation (80 % of the variance is explained by the first 17 variables). Thus a three-dimension plot of the first three PCs will give a general, although not exhaustive, account of the relative position of the observations in their original 90-dimensional space.

The PCA representation of the first three PCs plotted against each other (see Figure 63) shows a partial separation of both signature sets. The illustration also demonstrates that the authentic set of signatures shows greater variation in the direction of the first PC, but also varies, in a smaller extent, in the direction of the positive axis of the second PC. The plots of the first and second PC against the third PC show a greater variation in the direction of the third PC. The simulated set demonstrates a variation along both PC1 and PC2.

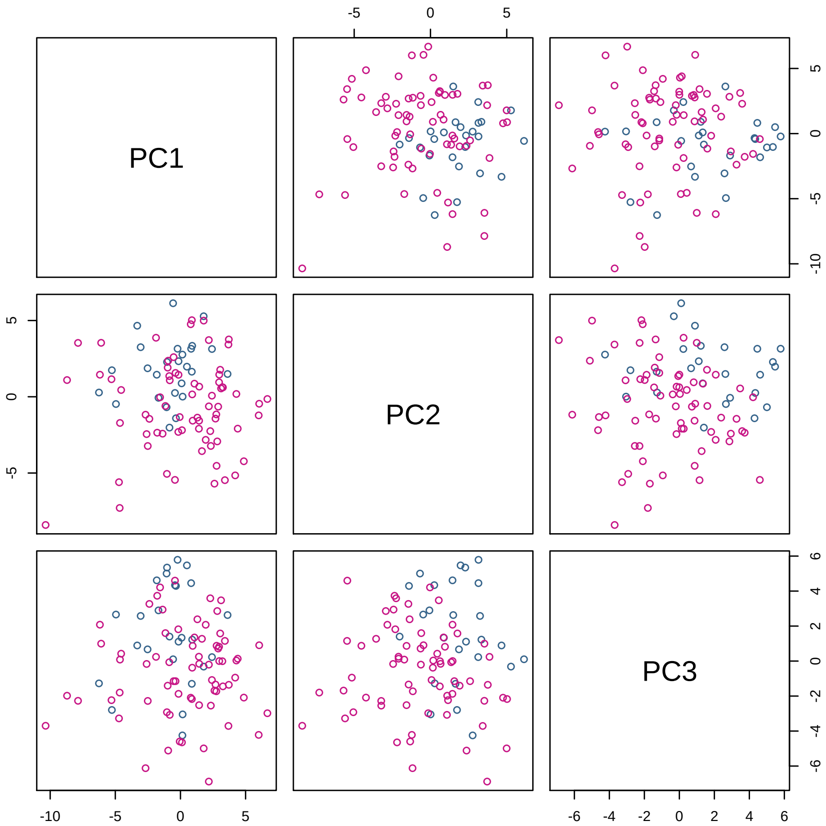


Figure 63 - Representation of first three PCs plotted against each other. Each blue point represents an authentic signature, and each pink point represents a signature of the simulated set.

The set of simulated signatures is broken down and represented according to the different groups of simulators: the Conservators-restorers, the Artists, and the FHEs (see Figure 64). The group of Conservators-restorers produced data showing more variation across the first PC, and partially overlapping the set of authentic signatures. The signature set produced by the artists partially overlaps the authentic set, and show the most variation along PC2. The last group of simulators, the FHEs, also partially overlaps the authentic set. The dispersion of this third group presents, like as for the second group, the most variation along PC2, however in a smaller extent (the group point is more confined).

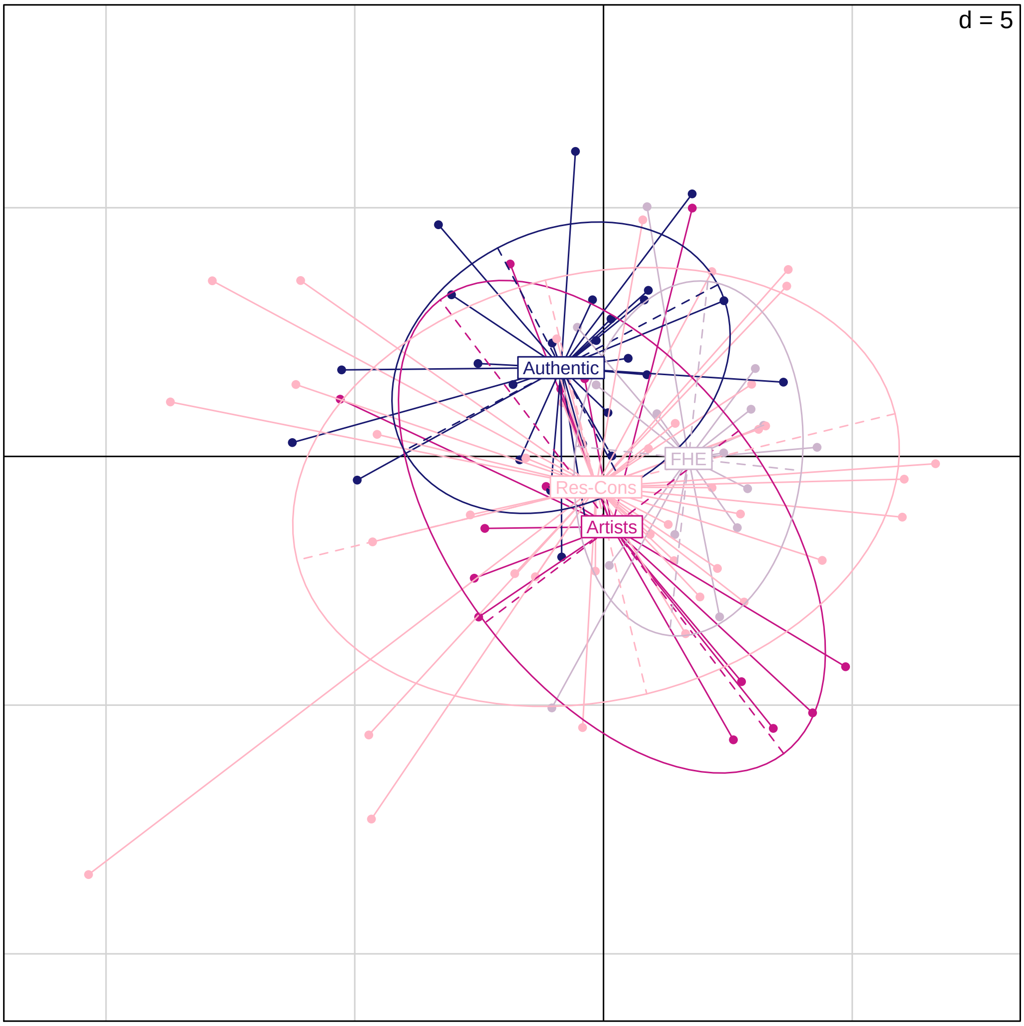


Figure 64 - Representation of the first two PCs (PC1 on x-axis and PC2 on y-axis) obtained of the PCA analysis of the authentic set and the three simulated set of signatures of artist n°3 (Muro).

Figure 65 illustrates the differences in the simulation capacities of each of the 14 simulators. These results display a simulation capacity that is linked to both the personal abilities of the person, and to a lesser extent, to their group affiliation. For the first group of Conservators-restorers, simulators 2, 8, 10 and 11 are essentially separated from the authentic group, and simulators 3, 5, 7, and 9 are partly separated. For the second group of simulators (Artists), simulator 4 is completely separated from the authentic set, simulator 13 is partially separated, whereas as simulator 14 is completely overlapping the authentic signature set, and moreover producing the same variation over PC1 and PC2. Finally, for the third group (FHEs), the simulators 15 and 16 are separated from the authentic set, whereas simulator 17 is essentially overlapping the authentic set.

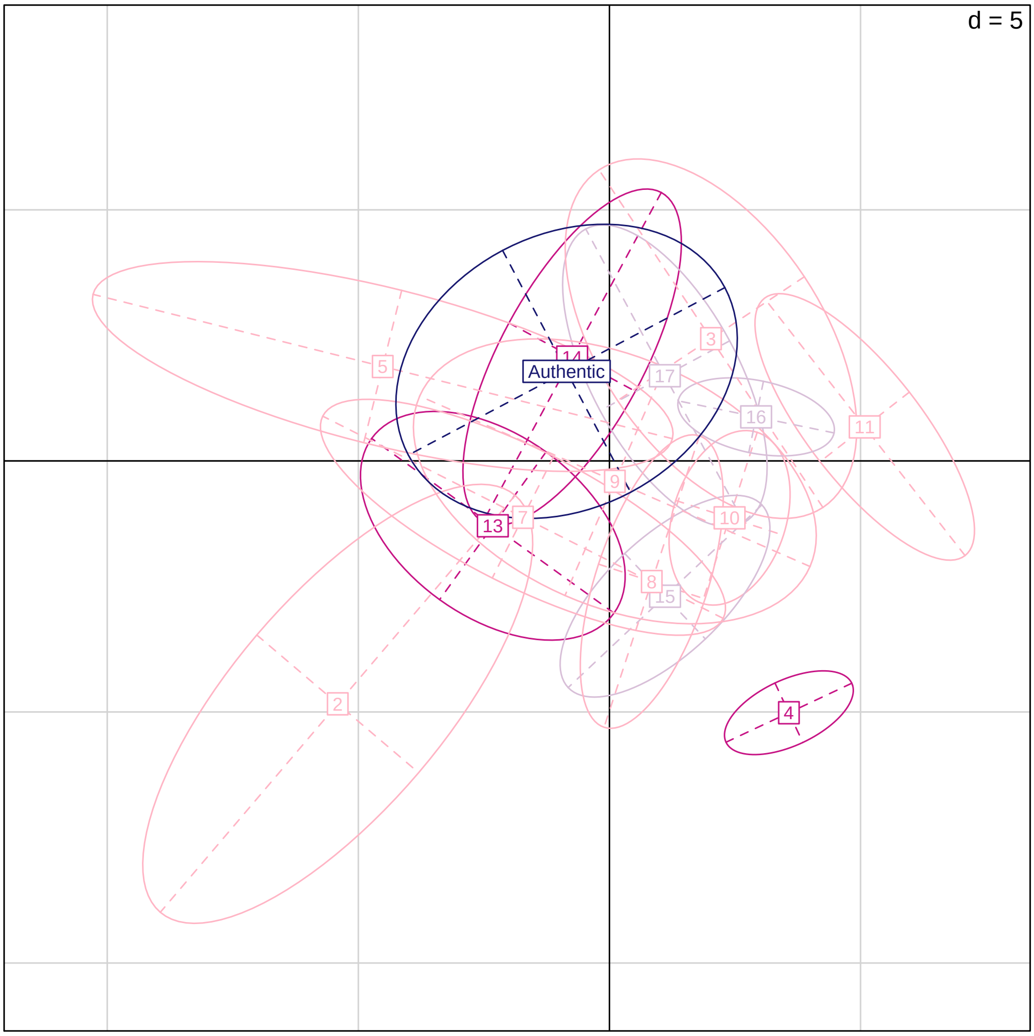


Figure 65 - Illustration of PCA analysis (PC1 on x-axis and PC2 on y-axis) of the authentic set and the each simulated set (n=14) of signatures of artist n°3 (Muro). The simulators from the Res-Con group are represented in pink, the Artist group in dark pink, and the FHEs in mauve.

The dispersion of the each of the simulated signatures varies according to the simulator. Thus, three groups of simulators can be visually deduced: very skilled simulators (14 and 17), moderately skilled simulators (3, 5, 7, 9, and 13), and poorly skilled simulators (2, 8, 10, 11, 4, 15, and 16). The simulators of the first group generally presented more dispersed signature sets (showing more variation along PC1 or PC2) than the other two groups (with an exception of simulator 10 and 11 who produced signature sets with small variation along both PCs).

Feature reduction

a) Boruta feature reduction

The Boruta feature reduction testing was carried out with the different pre-defined parameter and the best results were obtained with the parameter ntree=10000. In this case, the highest number of confirmed (22) and tentative (4) characteristics were given. Thus a total of 26 of the initial 90 characteristics were selected (28.9%) and are listed in Table 19 with their corresponding feature classes and feature specifications. The importance values of each characteristic with the Boruta analysis are reported in Appendix XIII.

Feature	**Feature class**		**Letter specification**
C64	12	Intraletter	-M- : Height hook / Length hook
C85	13	Angle	-M- : Angle of left median stroke
C68	12	Intraletter	-U- : Height hook / Length hook
C43	10	Space / Length letter after	-M- and -U- / L -U-
C69	12	Intraletter	-U- : Height hook / Height letter
C83	13	Angle	-V- : Angle of right stem
C42	10	Space / Length letter after	-V- and -M- / L -M-
C46	11	Length letter / Height letter	L -V- / H -V-
C54	12	Intraletter	-V- : Length hook / Length letter
C66	12	Intraletter	-M- : Length hook / Length letter
C7	3	Length letter / Height signature	L -V- / H tot
C87	13	Angle	-M- : Angle of left stem
C71	12	Intraletter	-R- : Height of modified bowl / Length of modified bowl
C63	12	Intraletter	-M- : Length of right median stroke / Length letter
C16	4	Height letter /	H -O- / H tot

		Height signature	
C35	8	Height difference (sup.) / Height letter before	H -R- and -O- / H -R-
C36	8	Height difference (sup.) / Height letter before	H -O- and -V- / H -O-
C70	12	Intraletter	-U- : Length hook / Length letter
C44	10	Space / Length letter after	-U- and -R- / L -R-
C18	5	Height letter / Length signature	H -M- / L tot
C88	13	Angle	-R- : Angle of stem
C59	12	Intraletter	-M- : Height difference between apexes of both stems / Height left stem
C1	1	Length signature / Height signature	Signature
C22	6	Length letter / Length letter after	L -V- / L -M-
C40	9	Height difference (inf.) / Height letter before	H -R- and -O- / H -R-
C65	12	Intraletter	-M- : Height hook / Height letter

Table 19 - List of features retained after Boruta feature selection step, listed by their order of importance.

The results display the importance of the intraletter class in the feature selection, particularly the hooks present. Five of the first 10 features concern the hook of the letters -V-, -M- or -U-. The space (10) and angles (13) classes are both represented twice in the first seven features.

b) Normality testing

The results obtained after the Shapiro-Wilk normality test on the 90 characteristics describing the signature of artist n°3 are presented according to their class affiliation in Table 20. The detailed results of the tests (for each characteristic) are presented in Appendix XII.

For the authentic set of signatures, the normality of the data is on the whole respected. Only the intraletter class of features (class 12) possesses seven (out of 31) features with significant p-values. The simulated signature set however possesses a greater number of variables that do not come from normally distributed populations, particularly in classes 8 (Height difference (superior)/Height letter before), 9 (Height difference (inferior)/Height letter before), 11 (Length of a letter/Height of the same letter) and 12 (Intraletter).

The normality results of both the authentic and simulated sets considered together show that four classes (8, 9, 11 and 12) each have less than 50% of their variables that are normally distributed.

Class	Authentic		Simulated		Both sets (Auth. and Sim.)		
	Normal #	Total #	Normal #	Total #	Normal #	Total #	(%)
1	1 /	1	1 /	1	1 /	1	100 %
2	5 /	5	5 /	5	5 /	5	100 %
3	3 /	5	5 /	5	3 /	5	60 %
4	5 /	5	4 /	5	4 /	5	80 %
5	4 /	5	3 /	5	3 /	5	60 %
6	5 /	5	3 /	5	3 /	5	60 %
7	5 /	5	3 /	5	3 /	5	60 %
8	5 /	5	2 /	5	2 /	5	40 %
9	5 /	5	2 /	5	2 /	5	40 %
10	4 /	4	4 /	4	4 /	4	100 %
11	5 /	5	2 /	5	2 /	5	40 %
12	24 /	31	15 /	31	15 /	31	48.4 %
13	9 /	9	7 /	9	7 /	9	77.8 %

Table 20 - Results of Shapiro-Wilk normality test, given for each class composing the authentic set, the simulated set, and both sets together.

The affiliation of each selected characteristics to his respective feature class after the Boruta selection step is noted in the third column of Table 21, with the relative percentage in parentheses. Classes 2 and 7 are not represented by a selected feature. The classes that have the highest percentages of selected features are classes 1 (Length signature/Height signature), 8 (Height difference (superior) between two letters/Height letter before), 10 (Space/Length letter after), 12 (Intraletter) and 13 (Angles).

Once the results of the normality testing are applied on the Boruta feature selection results, a final number of 16 features are retained (see Table 21), which corresponds to a 82.2% reduction from the initial 90 features. Class 3 is no longer represented. The most drastic drops in class representations is in classes 12, where respectively only two of the 10 features are retained.

Class		Number of features in each class (and corresponding %)			
N°	# of Features in Class	... after Feature selection		... after Feature selection *and* normality testing	
1	1	1	(100 %)	1	(100 %)
2	5	0	(0 %)	0	(0 %)
3	5	1	(20 %)	0	(0 %)
4	5	1	(20 %)	1	(20 %)
5	5	1	(20 %)	1	(20 %)
6	5	1	(20 %)	1	(20 %)
7	5	0	(0 %)	0	(0 %)
8	5	2	(40 %)	2	(40 %)
9	5	1	(20 %)	1	(20 %)
10	4	3	(75 %)	3	(75 %)
11	5	1	(20 %)	1	(20 %)
12	31	10	(32.3 %)	2	(6.5 %)
13	9	4	(44.4 %)	3	(33.3 %)
Total	**90**	**26**	**(28.9 %)**	**16**	**(17.8 %)**

Table 21 - List of features of each class retained after Boruta feature selection and normality testing.

The final list of features retained after the Boruta feature selection and normality testing is given in Table 22, with their corresponding class and letter specifications. Each of the five letters composing the artist's signature are represented either directly, or in relation with another letter.

Feature	Feature class		Letter specification
C43	10	Space / Length letter after	-M- and -U- / L -U-
C83	13	Angle	-V- : Angle of right stem
C42	10	Space / Length letter after	-V- and -M- / L -M-
C46	11	Length letter / Height letter	L -V- / H -V-
C87	13	Angle	-M- : Angle of left stem
C71	12	Intraletter	-R- : Height of modified bowl / Length of modified bowl
C16	4	Height letter / Height signature	H -O- / H tot
C35	8	Height difference (sup.) / Height letter before	H -R- and -O- / H -R-
C36	8	Height difference (sup.) / Height letter before	H -O- and -V- / H -O-
C44	10	Space / Length letter after	-U- and -R- / L -R-
C18	5	Height letter / Length signature	H -M- / L tot
C88	13	Angle	-R- : Angle of stem
C59	12	Intraletter	-M- : Height difference between apexes of both stems / Height left stem
C1	1	Length signature / Height signature	Signature
C22	6	Length letter / Length letter after	L -V- / L -M-
C40	9	Height difference (inf.) / Height letter before	H -R- and -O- / H -R-

Table 22 - List of the 16 features retained after Boruta feature selection and normality testing

Likelihood ratio assessment

The strength of the set of selected features are finally assessed with a likelihood ratio examination. The feature vector υ_{15} containing the selected features C43, C83, C42, C46, C87, C71, C16, C35, C36, C44, C18, C88, C59, C1, C22, and C40 is taken to compute a multivariate likelihood ratio for each authentic and simulated signature, as explained in sub-section 7.4.4. The results of the likelihood ratio assessment carried out with the 16 feature long vector υ_{15} of artist n°3 are presented in Table 23 below.

Authentic		Simulated			
Sig n°	**log(LR)**	**Sig n°**	**log(LR)**	**Sig n°**	**log(LR)**
1	**-1.9**	**1**	-57.3	**36**	-104.9
2	6.1	**2**	-58.0	**37**	-59.2
3	**-23.8**	**3**	-133.8	**38**	-56.4
4	**-4.4**	**4**	-100.9	**39**	-102.3
5	**-61.7**	**5**	-124.9	**40**	-76.6
6	**-30.5**	**6**	-22.4	**41**	-87.8
7	**-2.0**	**7**	-19.7	**42**	-42.5
8	**-1.2**	**8**	-37.7	**43**	-38.2
9	**-7.5**	**9**	-34.0	**44**	-140.9
10	**-20.5**	**10**	-60.7	**45**	-82.0
11	**-15.1**	**11**	-58.3	**46**	-30.5
12	**-9.2**	**12**	-70.7	**47**	-26.1
13	**-20.5**	**13**	-24.1	**48**	-40.9
14	5.7	**14**	-32.5	**49**	-36.8
15	6.5	**15**	-28.9	**50**	-49.8
16	**-15.8**	**16**	-22.5	**51**	-19.7
17	24.1	**17**	-68.2	**52**	-24.8
18	12.0	**18**	-59.5	**53**	-23.4
19	**-18.5**	**19**	-10.9	**54**	-24.6
20	**-6.5**	**20**	-76.8	**55**	-21.4
21	**-9.3**	**21**	-80.5	**56**	-97.7
22	6.8	**22**	-63.6	**57**	-137.1
23	14.5	**23**	-35.0	**58**	-179.7
24	2.6	**24**	-47.9	**59**	-201.1
25	**-56.9**	**25**	-26.3	**60**	-206.4
26	8.1	**26**	-102.0	**61**	-18.1
		27	-22.3	**62**	-36.9
		28	-60.5	**63**	-14.0
		29	-1.6	**64**	-38.7
		30	-49.3	**65**	-50.2
		31	-126.4	**66**	-14.2
		32	-43.4	**67**	-4.6
		33	-59.0	**68**	-6.8
		34	-13.4	**69**	-15.1
		35	-104.3	**70**	-17.8

Table 23 - Log(Likelihood) results obtained for each signature in the authentic and simulated signature sets with the feature vector v_{15}. Negative results under H_1, and positive results under H_2, are highlighted in bold.

Of the 26 authentic signatures, only 9 possess a log(LR) above zero (true positives), leaving the remaining 17 with a log(LR) below zero (false negatives). The obtained log(LR) results are presented graphically for the authentic signatures in Figure 66: The values in the top left rectangle represent the true positives and those in the bottom left rectangle the false negatives. Likewise, for the 70 simulated signatures, 70 possessed a log(LR) below zero (true negatives) and are represented in the bottom right rectangle. Thus, the whole set of simulated signatures was correctly classified into the correct population. The sensitivity (true positive rate) amounts to 34.61%, and the specificity (true negative rate) to 100%.

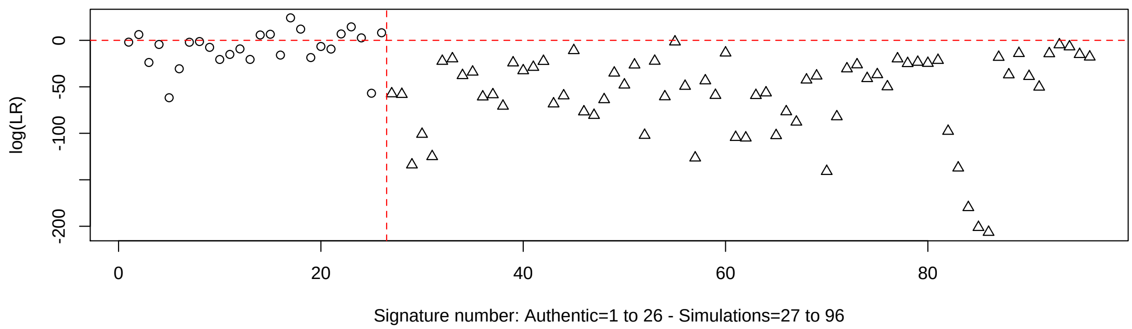


Figure 66 - Visual representation of the log(likelihood ratio) obtained for all of the signatures of artist n°3 (authentic signatures are represented by a circle, simulations by a triangle).

A plot of the results obtained for the simulated set depicts the simulation capacity of a person. For example, simulators 13 (signatures 72-76), 14 (signatures 77-81), 16 (signature 87-91) and 17 (signatures 92-96) produced signatures that are grouped and with log(LR) higher than the other simulators, showing their superiority in their simulation skills.

The dispersion of the results are represented in Figure 67 through a histogram of the number of occurrences obtained for each range of log(LR) with the authentic and simulated signature populations.

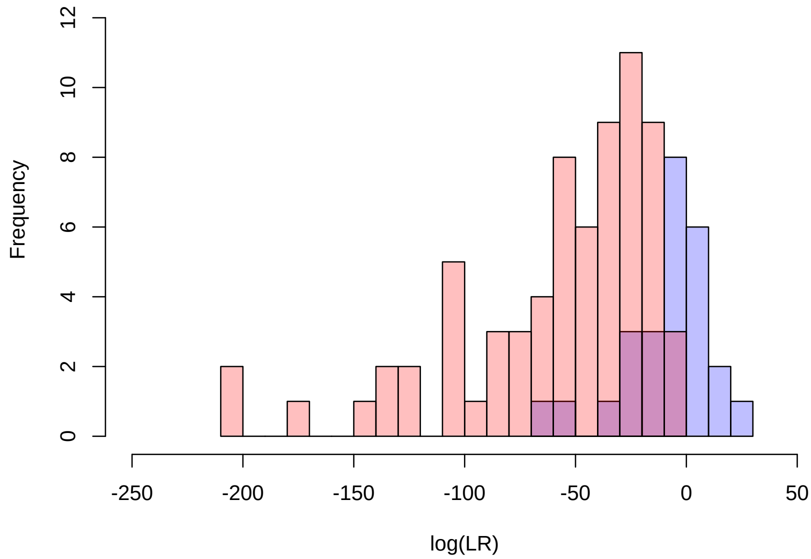


Figure 67 - Likelihood ratios (in a logarithmic form) obtained for the authentic and the simulated signatures of artist n°3 with the feature vector v_{15}, represented in the form of a histogram and according to the number of occurrences (y-axis). The authentic signatures are shown in blue, the simulated signatures in red.

The results of the log(LR) depict a clear overlapping between the authentic and simulated signature sets. The authentic signatures are grouped around the value zero, but with however 17 signatures spread along the negative end of the x-axis, and overlapping the simulated population. The simulated set does not overlap onto the positive side of the axis, but is less stretched out along its negative end.

The log(LR) values obtained with all of the 15 feature vectors (v_1-v_{15}), for each of the authentic signatures, are shown in Figure 68 through boxplots illustrations. Fifteen of the 17 signatures presenting a negative log(LR) with the feature vector v_{15} present log(LR)s that are at one point higher than the value of zero; only signatures 6 and 9 have negative log(LR) values for all of the feature vectors. This clearly shows that the feature vector v_{15} is not the optimal feature vector choice in terms of false negatives.

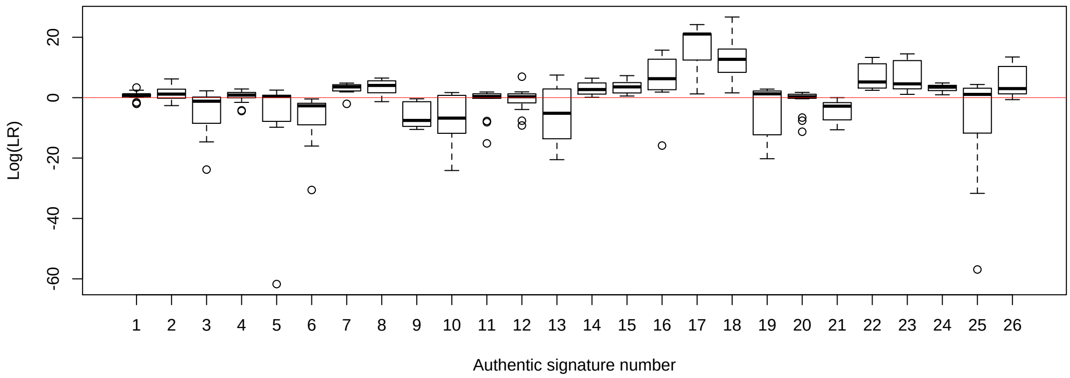


Figure 68 - Likelihood ratios (in a logarithmic form) results obtained for all of the feature vectors for the authentic signatures of artist n°3, represented in the form of a boxplot.

The log(LR) results obtained for all of the 15 feature vectors (v_1-v_{15}) for each of the simulated signatures is represented in the same manner in the following boxplot (Figure 69) - the exact values obtained for each signature and for each feature vector are reported in Appendix XIV. As shown in Table 23, there are no positive log(LR) values with the final feature vector v_{15}, thus no simulator was able to produce a simulation of sufficient quality. However, when a shorter feature vector (v_{14}) is used, one signature (the fourth signature of simulator 9) produces a positive log(LR) result, and as the length of the feature vector decreases, the number of positive log(LR) results increases.

Simulators 3, 5, 7, 9, 14 and 17 also produced at least one signature whose median log(LR) value obtained for all feature vectors is positive. The variation in the log(LR) values between the five signatures of the sets of simulators 3, 4, 7 and 9 varied depending on the signatures: some of the signatures showed very little variation, whereas others showed a consistently larger variation in the values according to the feature vector used.

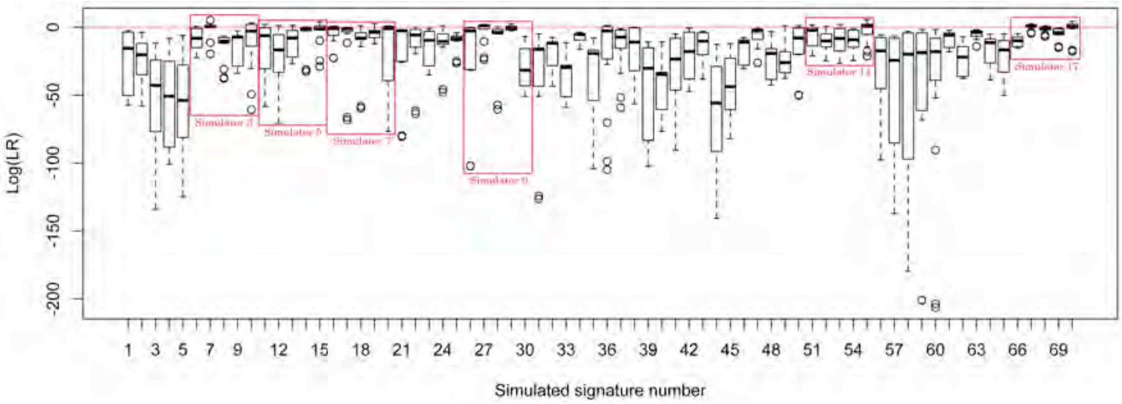


Figure 69 - Likelihood ratios (in a logarithmic form) results obtained for all of the feature vectors for the simulated signatures of artist n°3, represented in the form of a boxplot. Signatures produced by simulators 3, 5, 7, 9, 14 and 17 are highlighted in red.

The log(LR) results obtained for each authentic signature, for each of the 16 different feature vectors, are plotted in Figure 70 - Figure 73. As was the case for artist n°1 and n°2, the influence of the length of the feature vector on the log(LR) results for each of the authentic signatures can be divided into four distinct categories:

- The log(LR) results increase as the length of the feature vector increases (Figure 70);
- The log(LR) decreases as the length increases (Figure 71), this is the case for 12 of the 26 signatures;
- An increase, followed by a more or less sharp decrease of the log(LR) is observed as the length of the feature vector increases (Figure 72);
- or finally, no simple behavior can be drawn (Figure 73).

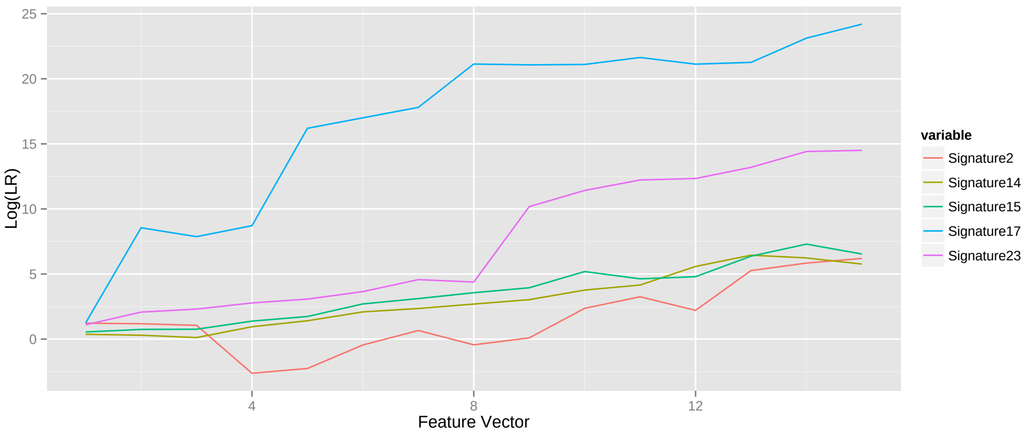


Figure 70 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

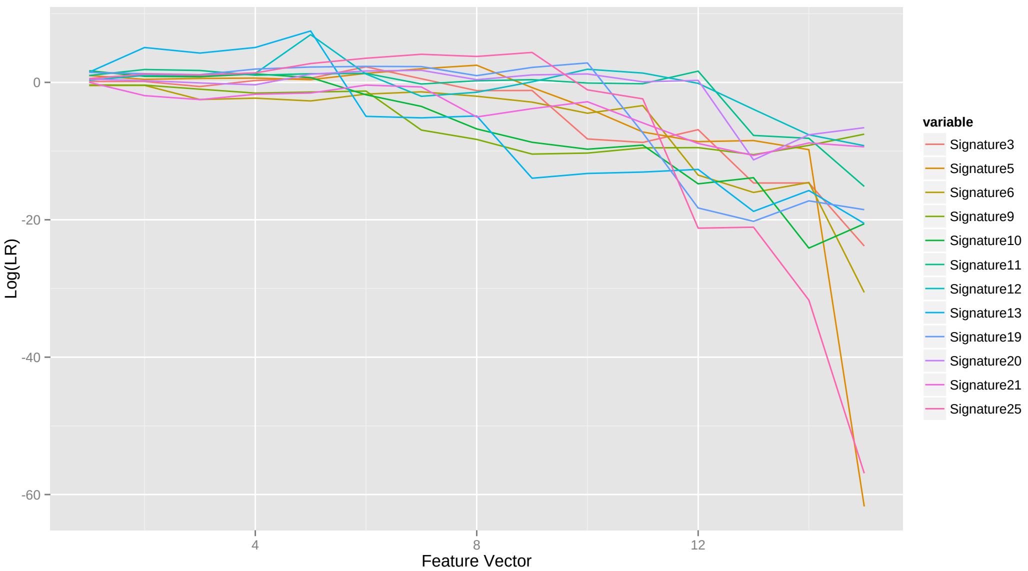


Figure 71 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

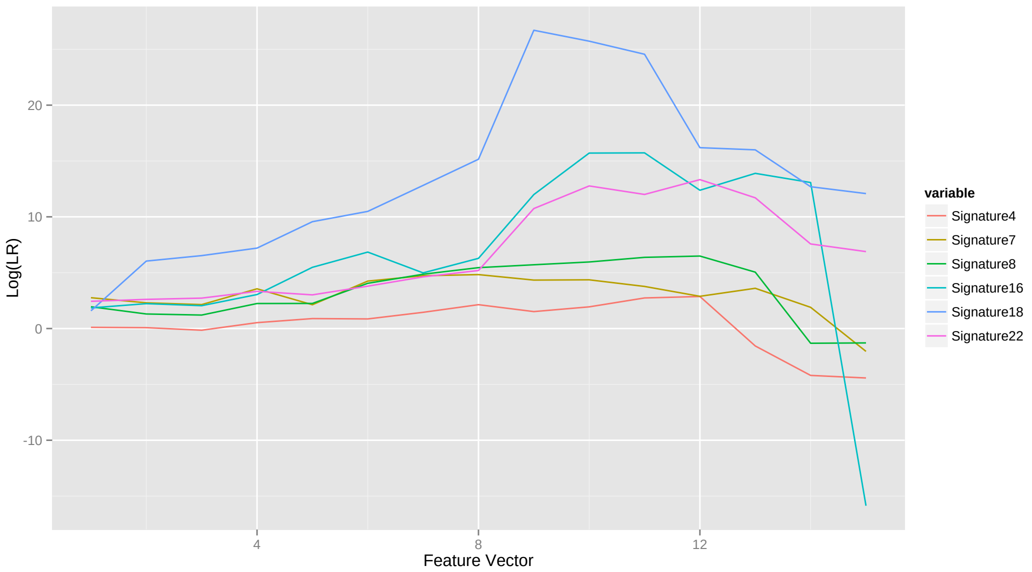


Figure 72 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

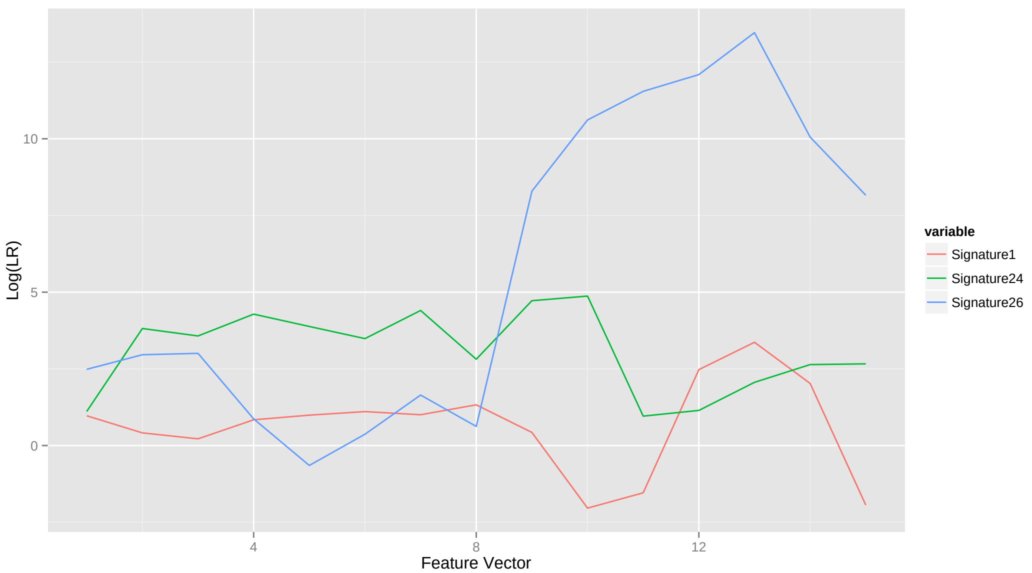
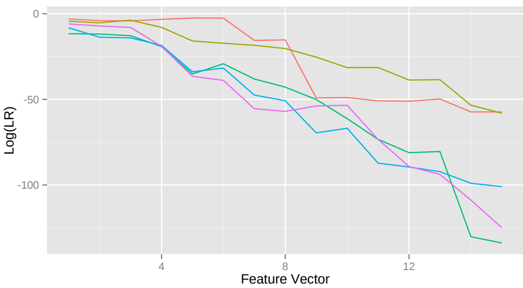


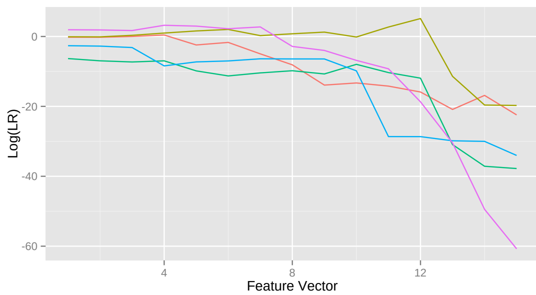
Figure 73 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

The simulated signature sets are presented, for each simulator, in Figure 74, where the influence on the feature vector and the resulting log(LR) results, are depicted. Most of the simulators produced signatures where the log(LR) results decreased as the length of the feature vector increased.

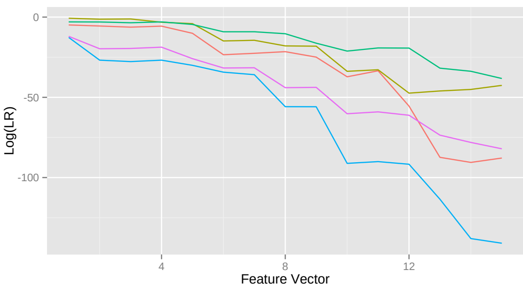
No signatures produced higher log(LR) results as the length of the feature vector increased. However, the fourth signature of simulator 10 produced results that varied little depending on the feature vector. This was also the case for the fourth signature of simulator 9. Two other signatures of this simulator as well as three signatures of simulator 17 produced results which varied little, up until the 13th feature vector, moment where the log(LR) values dropped drastically.



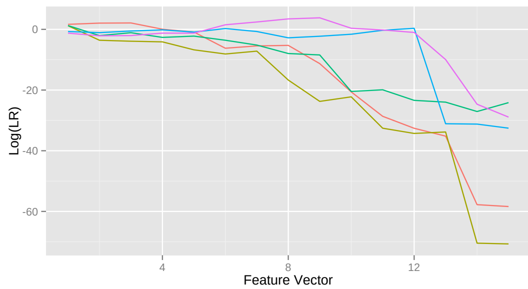
Simulator 2



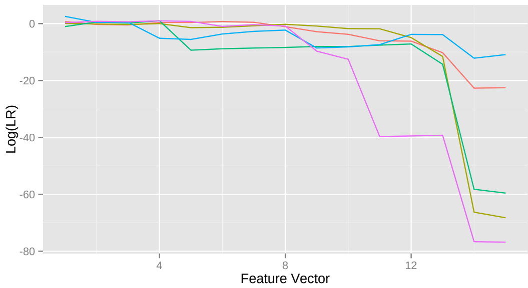
Simulator 3



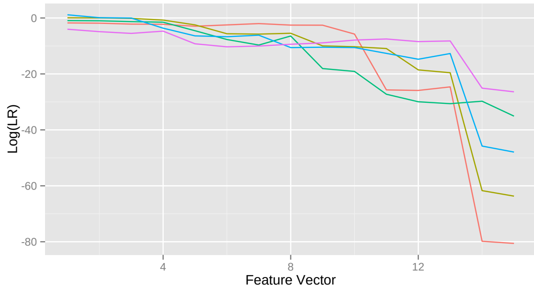
Simulator 4



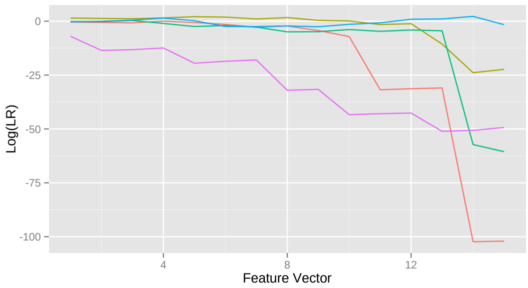
Simulator 5



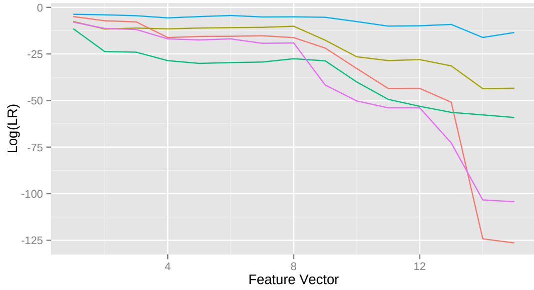
Simulator 7



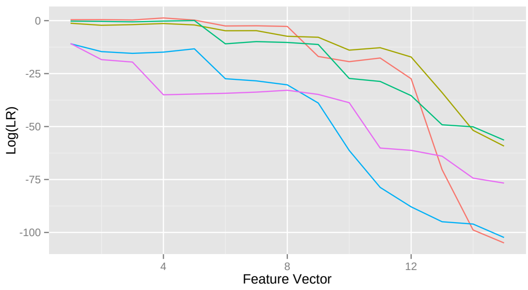
Simulator 8



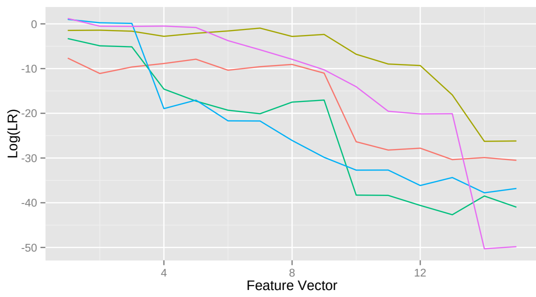
Simulator 9



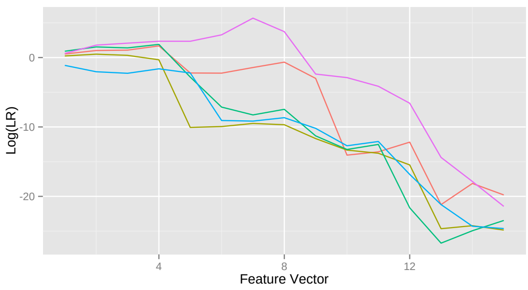
Simulator 10



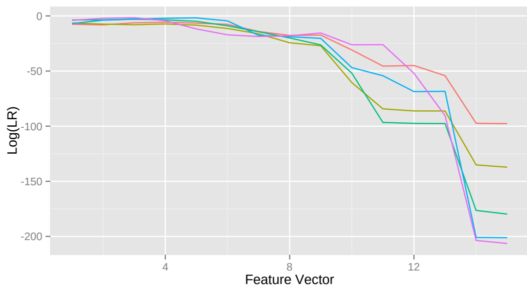
Simulator 11



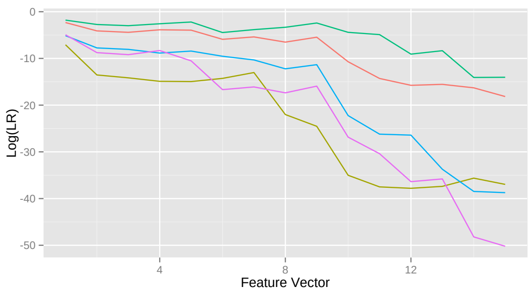
Simulator 13



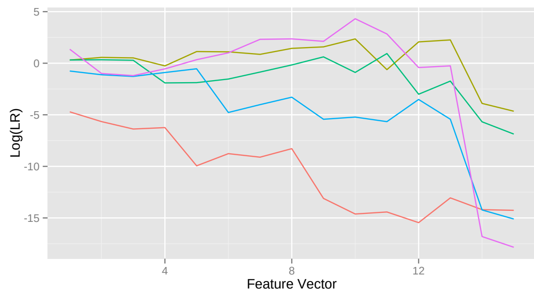
Simulator 14



Simulator 15



Simulator 16



Simulator 17

Figure 74 - Log(LR) results, plotted for the each of the 15 feature vectors obtained for the 5 signatures samples of each of the simulators of artist n°3. The legend for each signature is as follows: Signature1 Signature2 Signature3 Signature4 Signature5

The calculation of the log-likelihood-ratio cost (C_{llr}) gives weighted results in light of the different behaviors of the authentic and simulated signatures according to the length of the feature vector used. The impact of the feature vector used to calculate the log(LR) for both signature sets show C_{llr} results under the value of one for only the first seven feature vectors (containing the first two to the first eight features).

Feature vector	Feature combination	CCLR
1	2 features	0.619
2	3 features	**0.564**
3	4 features	0.661
4	5 features	0.674
5	6 features	**0.566**
6	7 features	0.596
7	8 features	0.862
8	9 features	1.113
9	10 features	1.389
10	11 features	1.704
11	12 features	2.058
13	13 features	3.340
14	14 features	4.462
15	15 features	4.888
16	16 features	8.511

Figure 75 - C_{llr} results obtained for artist n°3. The lowest values are highlighted in bold.

The C_{llr} results are illustrated in the two plots below (Figure 76). The C_{llr} results follow an exponential increase curve as the number of features in the feature vector rises.

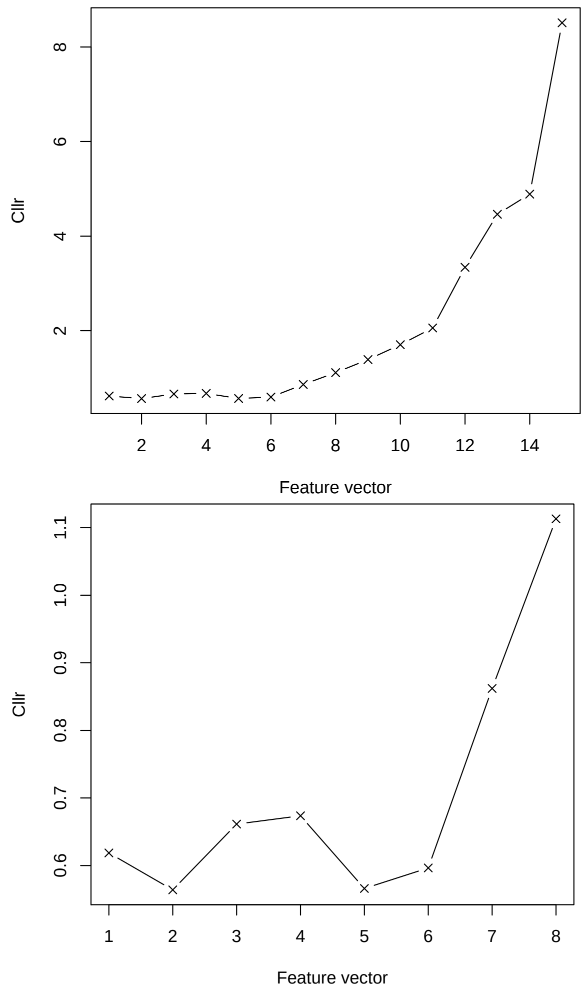


Figure 76 - C_{llr} results obtained for artist n°3, plotted for each feature vector (v_1 to v_{15}) combination composed of two to 16 features (above). A zoom on the first 8 feature vectors (v_1 to v_8) is presented below.

The feature vector v_2 (containing the first three features) presents the lowest C_{llr} value (C_{llr} = 0.564), and is thus selected for subsequent log(LR) calculations. This feature vector contains the features:

C43	Space between letters -M- and -U- / Length of letter -U-
C83	Angle of right stem of letter -V-
C42	Space between letters -V- and -M- / Length of letter -M-

The resulting TP Rate of 88.46% and TN Rate of 77.14% are found with the feature vector v_2. The distribution of the authentic and simulated signatures is presented in Figure 77. The distribution of the authentic signatures is pushed towards the positive side of the axis, with only 8 signatures giving negative log(LR). The same observation can be made to a lesser extent to the population of simulated signatures, whose distribution is less spread out across the axis.

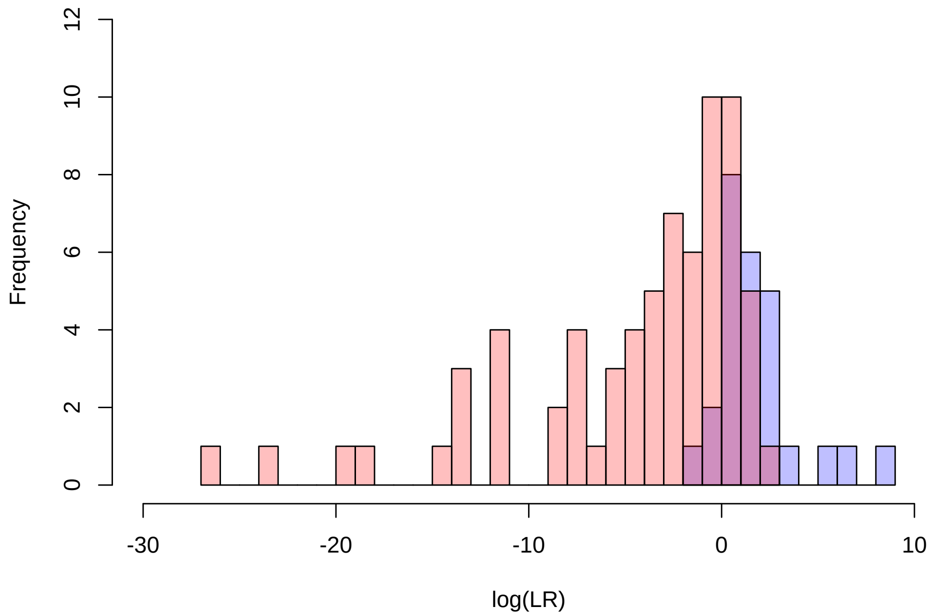


Figure 77 - Likelihood ratios (in a logarithmic form) obtained for the authentic and the simulated signatures of artist n°3 with the feature vector v_2, represented by the number of occurrences of each results. The authentic signatures are represented in red, the simulated signatures in blue.

The feature vector v_5 containing the first 6 features presents a C_{llr} value (C_{llr} = 0.566) closely following that of the second feature vector. With this feature vector, the number of true positives more than doubles, but as a consequence the number of false positives increases from zero to 11. The TP Rate slightly decreases to 80.76%, and the TN Rate increases to 84.28%. The three additional feature considered here are:

C46	Length of letter -V- / Height of letter -V-
C87	Angle of left stem of letter -M-
C71	Height of modified bowl of letter -R- / Length of modified bowl of letter -R-

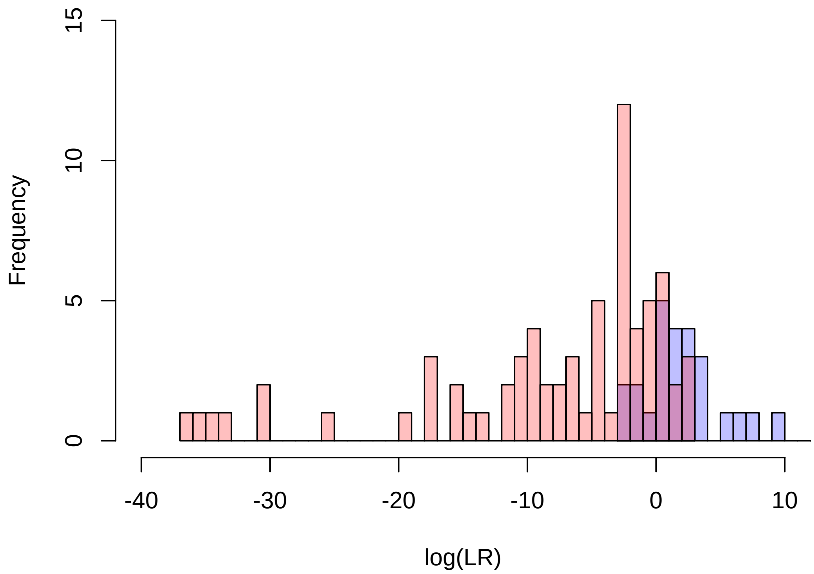


Figure 78 - Likelihood ratios (in a logarithmic form) obtained for the authentic and the simulated signatures of artist n°3 with the feature vector v_5, represented by the number of occurrences of each results. The authentic signatures are represented in red, the simulated signatures in blue.

8.4.4 Artist n°4 - Pasquier

General assessment of measurements and characteristics

The plots of the measurements of artist n°4 highlight some extreme values in both the authentic and simulated signature sets. The corresponding points of these measurements have been all verified and acknowledged as correct.

The examination of the plots and boxplots of the 146 characteristics/features defining the signature of artist n°4 are also verified. Angle adjustments are necessary for characteristic C143, which corresponds to the angle of the crossbar of the -A- of the signature.

The authentic signatures presenting extreme values are visually identified through the plots and boxplots of the characteristics, and are reported in Table 24. The origin of the extreme values are explained (see Illustration of signatures in Appendix VI). For the sake of brevity of the text, the outliers of the simulated signatures are not presented.

Sig. n°	Outlying feature	Feature specification	Origin of outlying value[190]
1	C32	Height -e- / Length signature	Letter -e- large
	C91	-P- : Height of modified bowl / Length of modified bowl	Modified bowl rounded, and not elongated horizontally
2	C65	Inferior height difference -r- and -A- / Height -r-	Letter -r- compact vertically
4	C63	Inferior height difference -i- and -e- / Height -e-	Letter -e- lower than letter -i-
5	C106	-q- : Length of bowl / Length -q-	Upper hook in stem, prolonging the length of stem
	C107	-q- : Length of stem, taken from intersection of bowl with stem / Length -q-	Upper hook in stem, prolonging the length of stem
6	C103	-q- : Height of inferior section of bowl / Height -q-	Stem of -q- is short
7	C1	Length signature / Height signature	Signature elongated horizontally due to space between letters -i- and -e-
	C20	Height -a- / Height signature	Letter -a- larger in size, compared to letters -A- and -P-
8	C38	Length -u- / Length -i-	Letter -i- without terminal stroke, giving a short length
	C136	-e- : Height of eyelet / Length of eyelet	Eyelet prolonged vertically
	C139	-r- : Height of stem / Height of arch, taken from lowest point of stem	Stem of letter -r- higher than arch
	C143	-A- : Angle of crossbar	-
9	C56	Superior height difference -e- and -r- / Height -e-	Letter -e- prolonged vertically
	C136	-e- : Height of eyelet / Length of eyelet	Eyelet prolonged vertically

190 The origins of the outlying values are given in comparison with the other signatures of the set.

10	C91	P- : Height of modified bowl / Length of modified bowl	Modified bowl rounded, and not elongated horizontally
12	C143	-A- : Angle of crossbar	-
14	C121	-u- : Length of initial stroke / Height of initial stroke	Letter -u- compact vertically, producing a small height of initial stroke
15	C6	Length -u- / Length signature	Signature horizontally compact
	C35	Length -P- / Length -a-	Letter -P- larger in overall size
	C106	-q- : Length of bowl / Length -q-	Short length of bowl
	C107	-q- : Length of stem, taken from intersection of bowl with stem / Length -q-	Thickness of line stroke, producing larger length of stem
	C108	-q- : Length stem / Length -q-	Thickness of line stroke, producing larger length of stem
	C121	-u- : Length of initial stoke / Height of initial stroke	Short length of initial stroke

Table 24 - Outliers detected in the authentic signature set of artist n°4

Twelve signatures of the authentic set presented outlying feature values, with each signature presenting a range of one to six outliers. The study of these outlying features shows, that for the signatures with more than 2 outliers, their origin comes from either one element of the signature (signature n°9), or from up to four (see signature n°15). A tendency to observe correlated outlying features (linked to the same one or two elements of a signature) is however observed.

The boxplots of the characteristics of the authentic signatures present, for most parts, less dispersion than the characteristics of the simulated signatures. Several exceptions (without taking outliers into account) are however noted and are: C3, C11, C60, C83, C101, C105, C118, and C122.

None of the boxplots depicting the values of the characteristics of the authentic signatures are fully separated from their simulated counterpart, a partial or full overlapping is always present from the range from the first up to the last quartile. However, the interquartile ranges between the authentic and simulated sets are separated for characteristics C51 and C62.

Principal component analysis

The PCA is carried out on the data set obtained from the authentic and simulated signatures. The first three PCs of this data set account for approximately 11%, 10%, and 9% of the total variation (80 % of the variance is explained by the first 18 variables). Therefore, a three-dimension plot of the first three PCs will give a general, although not exhaustive, account of the relative position of the observations in their original 146-dimensional space.

The PCA representation of the first three PCs plotted against each other (see Figure 79) shows a partial separation of both signature sets. The authentic set produces more variation along the positive axis of PC1. The general variation is quite confined for the authentic set, apart from signature n°7 of the artist that varies more that the other signatures in the direction of positive axis of the first PC. The simulated set varies along both PC1 and PC2, particularly in the direction of their positive axes. The plots of the first and second PC against the third PC show a smaller variation in the direction of the third PC.

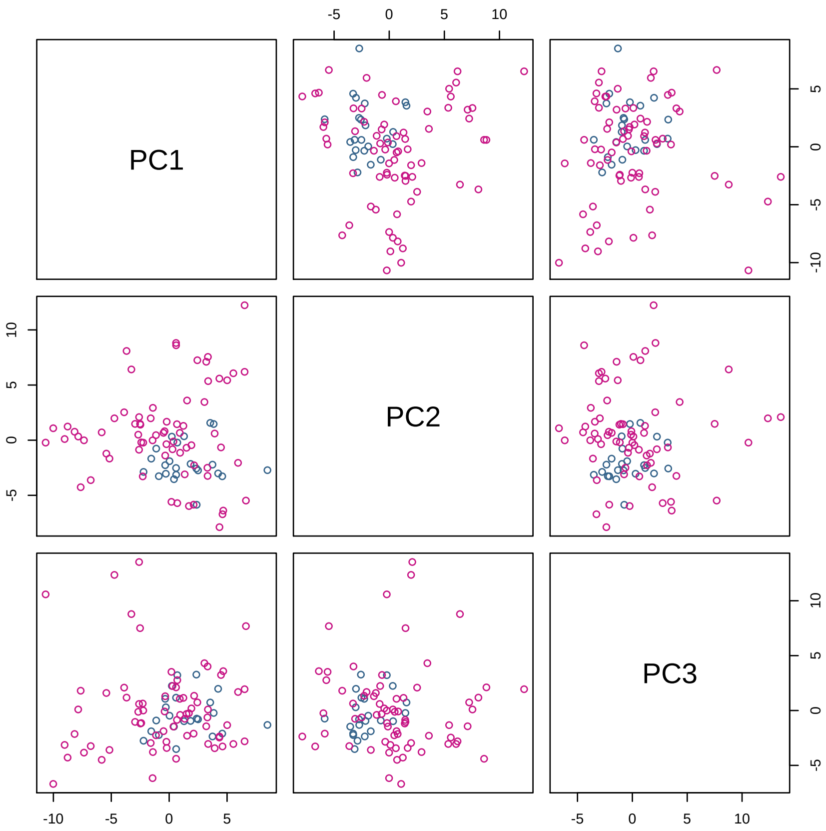


Figure 79 - Representation of first three PCs plotted against each other. Each blue point represents an authentic signature, and each pink point represents a signature of the simulated set.

When the set of simulated signatures is broken down and represented according to the different groups of simulators (see Figure 80): the Conservators-restorers, the Artists, and the FHEs, a different behavior is seen according to the group. The conservators-restorers vary equally across PC1 and PC2. The second group, the Artists, show more variation on PC1, than on PC2, but with a small variation along the negative axis of PC2. The third group, on the complete contrary, varies along the positive axis of PC1 and PC2. All three simulation sets partially overlap the authentic set.

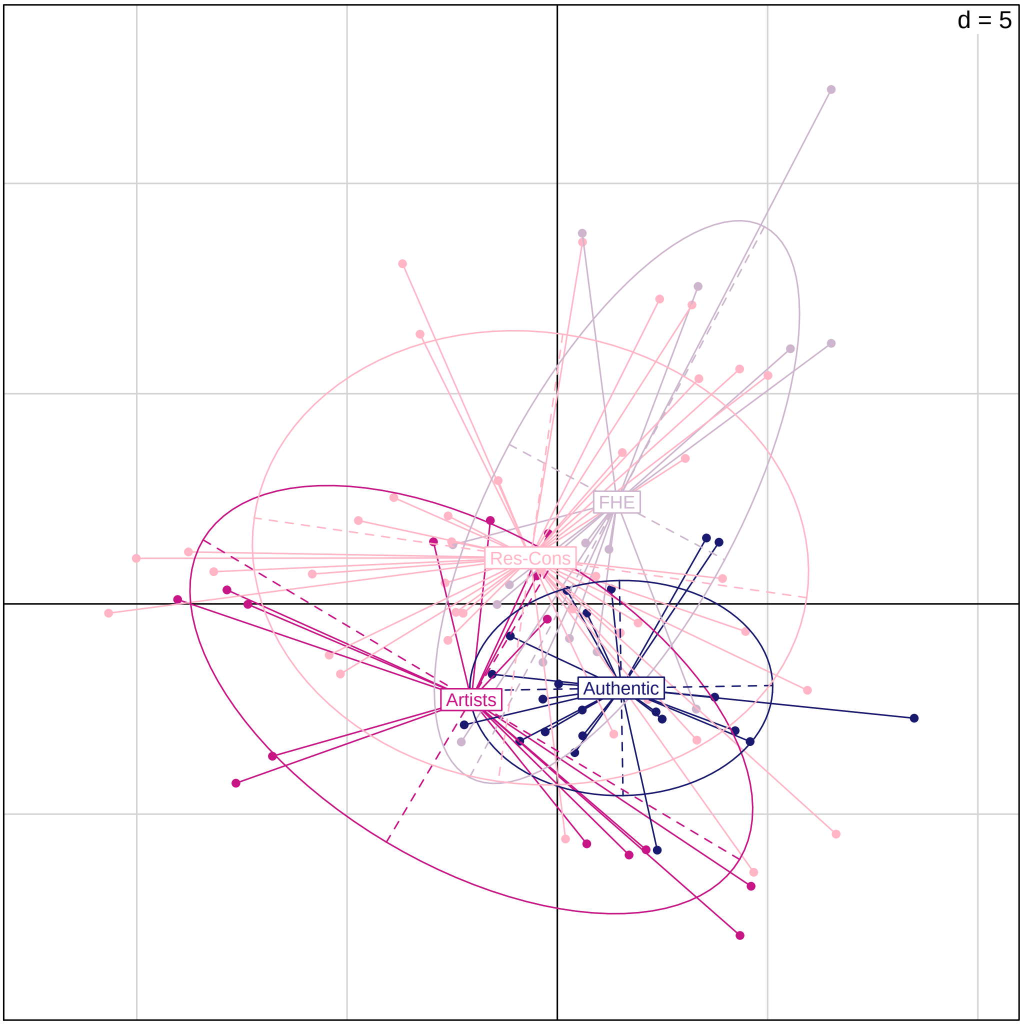


Figure 80 - Representation of the first two PCs (PC1 on x-axis and PC2 on y-axis) obtained of the PCA analysis of the authentic set and the three simulated set of signatures of artist n°4 (Pasquier).

A closer look into the composition of the simulators group representations of Figure 80 shows that the spread-out group of Artists, when taken individually, are distinctly separated into three confined simulators composing the group (see Figure 81). Thus, their partial overlapping with the authentic set is due to one simulator (13) of the group, that produced simulations of higher quality than the other two of his group. The same observation can be made for the third group of FHEs. Initially spread out across PC2, the simulators taken individually are in fact well confined in their simulator group. Thus simulators 16 and 17 produced sets that are not separated from the authentic set, whereas simulator 15 produced a signature set that is the most separated, of all simulation sets, from the authentic signatures. As for the first group of Conservators-Restorers, simulators 2, 7 and 11 produced sets that are not separated from the original set. However, all of the other simulators of this group (1, 5, 8, 9, and 10) produced signatures that are distinctly separated from the authentic set. These results display a simulation capacity that is linked more to the personal abilities of the person rather than to their group affiliation.

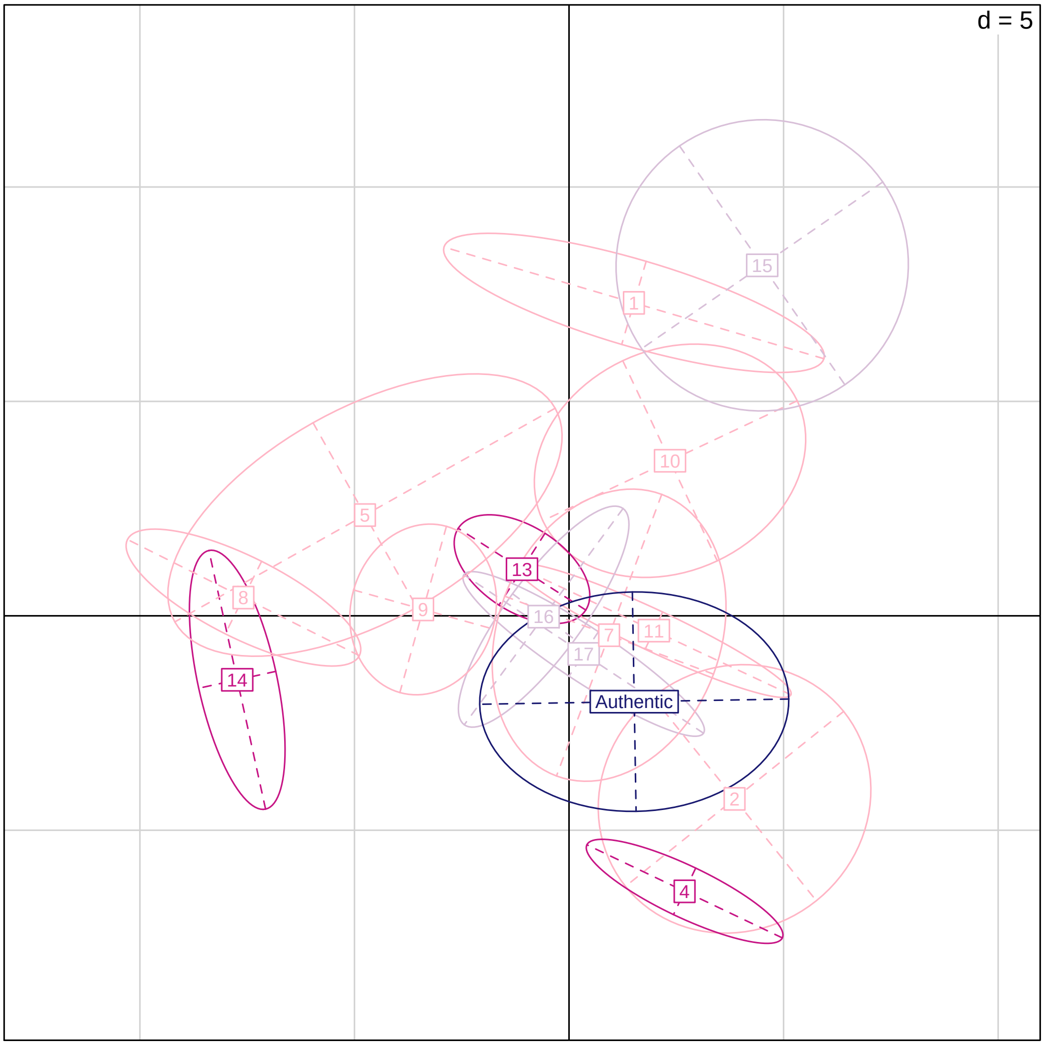


Figure 81 - Illustration of PCA analysis (PC1 on x-axis and PC2 on y-axis) of the authentic set and the each simulated set (n=14) of signatures of artist n°4 (Pasquier). The simulators from the Res-Con group are

represented in pink, the Artist group in dark pink, and the FHEs in mauve.

Thus, three groups of simulators can be deduced : very skilled simulators (11 and 17), moderately skilled simulators (2, 7, 13 and 16), and poorly skilled simulators (1, 5, 8, 9, 10, 4, 14, and 15).

Feature reduction

a) Boruta feature reduction

The Boruta feature reduction testing was carried out with the different pre-defined parameter and the best results were obtained with the parameter ntree=10000. In this case, the highest number of confirmed (42) and tentative (6) characteristics were given. Thus a total of 48 of the initial 146 characteristics were selected (25%) and are listed in Table 25 with their corresponding feature classes and feature specifications. Each letter composing the signature is represented at least once within the selected features. The importance values of each characteristic with the Boruta analysis are reported in Appendix XIII.

Feature	**Feature class**		**Letter specification**
C51	8	Height difference (sup.) / Height letter before	-P- and -a- / H -P-
C62	9	Height difference (inf.) / Height letter before	-u- and -i- / H -u-
C124	12	Intraletter	-i- : Height of initial stroke / Height letter
C59	9	Height difference (inf.) / Height letter before	-P- and -a- / H -P-
C39	6	Length letter / Length letter after	L -i- / L -e-
C88	12	Intraletter	-P- : Height of modified bowl / Height letter
C89	12	Intraletter	-P- : Height of stem under lowest point of modified bowl / Height letter
C100	12	Intraletter	-a- : Height of stem / Length of stem
C106	12	Intraletter	-q- : Length of bowl / Length letter
C107	12	Intraletter	-q- : Length of stem, taken from intersection of bowl with stem / Length letter

C52	8	Height difference (sup.) / Height letter before	-a- and -q- / H -a-
C7	2	Length letter / Length signature	L -i- / L tot
C24	4	Height letter / Height signature	H -e- / H tot
C81	11	Length letter / Height letter	L -r- / H -r-
C129	12	Intraletter	-i- : Length of stem / Height letter
C95	12	Intraletter	-a- : Height of stem / Height letter
C136	12	Intraletter	-e- : Height of eyelet / Length of eyelet
C93	12	Intraletter	-a- : Height of superior section of bowl / Height letter
C103	12	Intraletter	-q- : Height of inferior section of bowl / Height letter
C45	7	Height letter / Height letter after	H -q- / H -u-
C110	12	Intraletter	-q- : Height of stem / Length of stem, taken from intersection of bowl with stem
C38	6	Length letter / Length letter after	L -u- / L -i-
C108	12	Intraletter	-q- : Length of stem / Length letter
C118	12	Intraletter	- u- : Height of left stem / Height of right stem
C71	10	Space / Length letter after	-u- and -i- / L -i-
C48	7	Height letter / Height letter after	H -e- / H -r-
C85	12	Intraletter	-A- : Length of inner crossbar / Length letter
C1	1	Length signature / Height signature	Signature
C14	3	Length letter / Height signature	L -u- / H tot
C92	12	Intraletter	-a- : Height of bowl / Height letter
C96	12	Intraletter	-a- : Height of stem under lowest point of bowl / Height letter
C10	3	Length letter / Height signature	L -A- / H tot
C79	11	Length letter / Height letter	L -i- / H -i-
C113	12	Intraletter	-u- : Height of right stem / Height letter
C19	4	Height letter / Height signature	H -P- / H tot
C64	9	Height difference (inf.) /	-e- and -r- / H -e-

		Height letter before	
C16	3	Length letter / Height signature	L -e- / H tot
C125	12	Intraletter	-i- : Length of initial stroke / Length letter
C126	12	Intraletter	-i- : Length of stem / Length letter
C127	12	Intraletter	-i- : Length of stem / Length of initial stroke
C84	12	Intraletter	-A- : Height of right stem under crossbar / Height right stem
C22	4	Height letter / Height signature	H -u- / H tot
C119	12	Intraletter	-u- : Height of right stem / Height of endstroke (connecting with letter -i-)
C32	5	Height letter / Length signature	H -e- / L tot
C31	5	Height letter / Length signature	H -i- / L tot
C109	12	Intraletter	-q- : Height of bowl / Length of bowl
C20	4	Height letter / Height signature	H -a- / H tot
C15	3	Length letter / Height signature	L -i- / H tot

Table 25 - List of features retained after Boruta feature selection step, listed by their order of importance.

The results display the importance of the Height difference between letters classes (classes 8 and 9) in the feature selection. Indeed, of the first four selected features, three are from these classes. The intraletter class is also well represented in the feature list: six of the first ten features come from this class.

b) Normality testing

The results obtained after the Shapiro-Wilk normality test on the 146 characteristics describing the signature of artist n°4 are presented according to their class affiliation in Table 26. The detailed results of the tests (for each characteristic) are presented in Appendix XII.

For the authentic set of signatures, the normality of the data is on the whole respected. Only the intraletter class of features (class 12) possesses seven (out of 31) features with significant p-values. The simulated signature set however possesses a greater number of variables that do not come from normally distributed populations, particularly in classes 8 (Height difference (superior)/Height letter before), 9 (Height difference (inferior)/Height letter before), 11 (Length of a letter/Height of the same letter) and 12 (Intraletter).

The normality results of both the authentic and simulated sets considered together show that two classes (1 and 6) each have less than 50% of their variables that are normally distributed.

Class	Authentic			Simulated			Both sets (Auth. and Sim.)			
	Normal #		Total #	Normal #		Total #	Normal #		Total #	(%)
1	1	/	1	-	/	1	-	/	1	0 %
2	7	/	8	7	/	8	6	/	8	75 %
3	8	/	8	5	/	8	5	/	8	62.5 %
4	7	/	8	7	/	8	6	/	8	75 %
5	8	/	8	7	/	8	7	/	8	87.5 %
6	8	/	8	1	/	8	1	/	8	12.5 %
7	8	/	8	6	/	8	6	/	8	75 %
8	8	/	8	5	/	8	5	/	8	62.5 %
9	8	/	8	6	/	8	6	/	8	75 %
10	8	/	8	4	/	8	4	/	8	50 %
11	7	/	8	8	/	8	7	/	8	87.5 %
12	54	/	59	34	/	59	31	/	59	52.5 %
13	6	/	6	5	/	6	5	/	6	83.3 %

Table 26- Results of Shapiro-Wilk normality test, given for each class composing the authentic set, the simulated set, and both sets together.

The affiliation of each selected characteristics after the Boruta selection step to his respective feature class is noted in the third column of Table 27, with the relative percentage in parentheses. The selected features are spread out across the different classes, however, only class 13 (angles) is not represented by a selected feature. The classes that have the highest percentages of selected features are classes 1 (Length signature/Height signature), 3 (Length letter/Height signature), 4 (Height letter/Height signature) and 9 (Height difference (inferior) between two letters/Height letter before).

Once the results of the normality testing are applied on the Boruta feature selection results, a final number of 24 features are retained (see Table 27), which corresponds to a 85.6% reduction from the initial 146 features. Classes

1 and 6 are no longer represented. Aside from class 12 where the number of selected features drops from 24 to 11, no other drastic drops are observed.

Class		Number of features in each class (and corresponding %)			
N°	# of Features in Class	... after Feature selection		... after Feature selection *and* normality testing	
1	1	1	(100 %)	0	(0 %)
2	8	1	(12.5 %)	1	(12.5 %)
3	8	4	(50 %)	2	(25%)
4	8	4	(50 %)	2	(25 %)
5	8	2	(25 %)	2	(25 %)
6	8	2	(25 %)	0	(0 %)
7	8	2	(25 %)	2	(25 %)
8	8	2	(25 %)	1	(12.5 %)
9	8	3	(37.5 %)	1	(12.5 %)
10	8	1	(12.5 %)	1	(12.5 %)
11	8	2	(25 %)	1	(12.5 %)
12	59	24	(40.7 %)	11	(18.6 %)
13	6	0	(0 %)	0	(0 %)
Total	**146**	**48**	**(32.9 %)**	**24**	**(16.4 %)**

Table 27 - List of features of each class retained after Boruta feature selection and normality testing.

The list of features retained after the Boruta feature selection and normality testing is given in Table 28, with their corresponding class and letter specifications. Each of the eight letters are represented either directly, or in relation with another letter.

Feature	**Feature class**		**Letter specification**
C124	12	Intraletter	-i- : Height of initial stroke / Height letter
C52	8	Height difference (sup.) / Height letter before	-a- and -q- / H -a-
C7	2	Length letter / Length signature	L -i- / L tot
C24	4	Height letter / Height signature	H -e- / H tot
C95	12	Intraletter	-a- : Height of stem / Height letter
C93	12	Intraletter	-a- : Height of superior section of bowl /

			Height letter
C45	7	Height letter / Height letter after	H -q- / H -u-
C110	12	Intraletter	-q- : Height of stem / Length of stem, taken from intersection of bowl with stem
C71	10	Space / Length letter after	-u- and -i- / L -i-
C48	7	Height letter / Height letter after	H -e- / H -r-
C85	12	Intraletter	-A- : Length of inner crossbar / Length letter
C92	12	Intraletter	-a- : Height of bowl / Height letter
C96	12	Intraletter	-a- : Height of stem under lowest point of bowl / Height letter
C10	3	Length letter / Height signature	L -A- / H tot
C79	11	Length letter / Height letter	L -i- / H -i-
C19	4	Height letter / Height signature	H -P- / H tot
C64	9	Height difference (inf.) / Height letter before	-e- and -r- / H -e-
C16	3	Length letter / Height signature	L -e- / H tot
C125	12	Intraletter	-i- : Length of initial stroke / Length letter
C126	12	Intraletter	-i- : Length of stem / Length letter
C84	12	Intraletter	-A- : Height of right stem under crossbar / Height right stem
C32	5	Height letter / Length signature	H -e- / L tot
C31	5	Height letter / Length signature	H -i- / L tot
C109	12	Intraletter	-q- : Height of bowl / Length of bowl

Table 28 - List of features retained after Boruta feature selection and normality testing.

Finally, the creation of the covariance matrix of the selected 24 features indicates that three pairs of features present a negative covariance. These are the features pairs C95 - C93, C92 - C96, and C125 - C126. These three pairs of features each present a perfectly linear relationship between each other, and as a result, features C93, C96 and C126 are not retained in the final feature vector.

Likelihood ratio assessment

The strength of the set of selected features are finally assessed with a likelihood ratio examination. The feature vector v_{20} containing the selected features C124, C52, C7, C24, C95, C45, C110, C71, C48, C85, C92, C10, C79, C19, C64, C16, C125, C84, C32, C31, C109 are used to compute a multivariate likelihood ratio for each authentic and simulated signature, as explained in sub-section 7.4.4. The results of the likelihood ratio assessment carried out with the 21 feature long vector v_{20} of artist n°4 are presented in Table 29.

Authentic		Simulated			
Sig n°	**log(LR)**	**Sig n°**	**log(LR)**	**Sig n°**	**log(LR)**
1	**-5702.2**	**1**	-1418.3	**36**	-64.5
2	**-128.7**	**2**	-8587.6	**37**	-1482.9
3	**-1016.6**	**3**	-2277.0	**38**	-871.8
4	**-59.7**	**4**	-809.7	**39**	-539.4
5	**-12112.2**	**5**	-105.9	**40**	-118.7
6	**-1347.7**	**6**	-215.4	**41**	-1407.2
7	**-430.0**	**7**	-2838.5	**42**	-3207.0
8	**-75.8**	**8**	-1503.4	**43**	-1044.2
9	**-202.7**	**9**	-505.9	**44**	-1466.4
10	**-815.0**	**10**	-469.3	**45**	-502.8
11	**-495.5**	**11**	-3430.0	**46**	-438.0
12	**-730.8**	**12**	-457.1	**47**	-1018.4
13	**-46.1**	**13**	-535.2	**48**	-15.6
14	**-72.8**	**14**	-1130.4	**49**	-545.0
15	**-61.8**	**15**	-2808.5	**50**	-534.6
16	**-4373.8**	**16**	-323.0	**51**	-1785.8
17	**-261.0**	**17**	-396.2	**52**	-1395.6
18	**-503.6**	**18**	-412.0	**53**	-652.7
19	**-1888.1**	**19**	-1371.1	**54**	-465.9
20	**-500.2**	**20**	-1295.0	**55**	-494.1
21	0.8	**21**	-608.9	**56**	-85.1
22	**-518.9**	**22**	-757.9	**57**	-1106.7
23	**-194.9**	**23**	-2038.6	**58**	-2407.2
		24	-1574.7	**59**	-319.6
		25	-382.0	**60**	-5059.1
		26	-292.0	**61**	-197.1
		27	-671.5	**62**	-4416.5
		28	-3404.9	**63**	-932.5
		29	-2658.3	**64**	-437.2
		30	-1162.1	**65**	-1708.2
		31	-1418.1	**66**	-290.9
		32	-1469.9	**67**	-98.1
		33	-291.7	**68**	-226.2
		34	-10265.1	**69**	-278.9
		35	-82.1	**70**	-583.1

Table 29 - Log(Likelihood) results obtained for each signature in the authentic and simulated signature with sets with the feature vector υ_{20}. Negative results under H_1, and positive results under H_2, are highlighted in bold.

Of the 23 authentic signatures, only one possesses a log(LR) above zero (true positives), leaving the remaining 22 with a log(LR) below zero (false negatives). The obtained log(LR) results are presented graphically for the authentic and simulated signatures in Figure 82. All of the 70 simulated signatures possess a log(LR) below zero (true negatives) and are represented in the bottom right rectangle. Thus, the whole set of simulated signatures was correctly classified into the correct population.

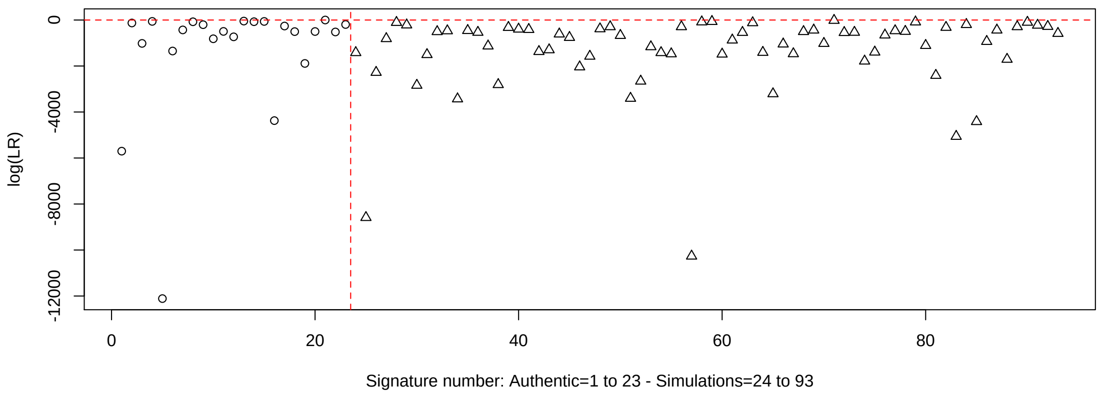


Figure 82 - Visual representation of the log(likelihood ratio) obtained for all of the signatures of artist n°3 (authentic signatures are represented by a circle, simulations by a triangle).

The sensitivity (true positive rate) can be calculated with these results and amounts to 4.34%, and the specificity (true negative rate) to 100%. Four signatures of the authentic set, signatures 1, 5, 16 and 18, present particularly low log(LR) values.

The plot of the results obtained for the simulated set visually depicts the simulation capacity of a person. For example, simulators 7 (signatures 39-43), 13 (signatures 69-73), 14 (signatures 74-78), and 17 (signatures 89-93) produced signatures that are grouped and with log(LR) higher than the other simulators, showing their superiority in their simulation skills.

The dispersion of the results are represented in Figure 83 through a histogram of the number of occurrences obtained for each range of log(LR) with the authentic and simulated signature populations.

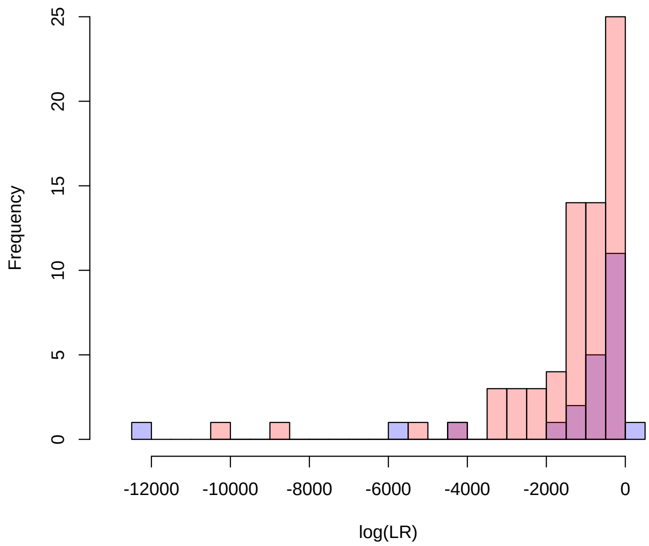


Figure 83 - Likelihood ratios (in a logarithmic form) obtained for the authentic and the simulated signatures of artist n°4 with the feature vector v_{20}, represented in the form of a histogram and according to the number of occurrences (y-axis). The authentic signatures are shown in blue, the simulated signatures in red.

The results of the log(LR) depict a clear overlapping between the authentic and simulated signature sets. The authentic signatures are grouped around the value zero, but with however 22 signatures spread along the negative end of the x-axis, and overlapping the simulated population. The simulated set does not overlap onto the positive side of the axis, but is less stretched out along the negative end of the axis than are the authentic signatures.

The log(LR) values obtained with all of the 20 feature vectors (v_1-v_{20}), for each of the authentic signatures, are shown in Figure 84 through boxplot illustrations. The exact values obtained for each signature and for each feature vector are reported in Appendix XIV. All of the signatures of the authentic set present a negative log(LR) with the feature vector v_{20}, but present log(LR)s that are at one point higher than the value of zero, clearly with the lower feature vectors. Thus, feature vector v_{20} is not the optimal feature vector choice in terms of rendering the highest amount of true positives.

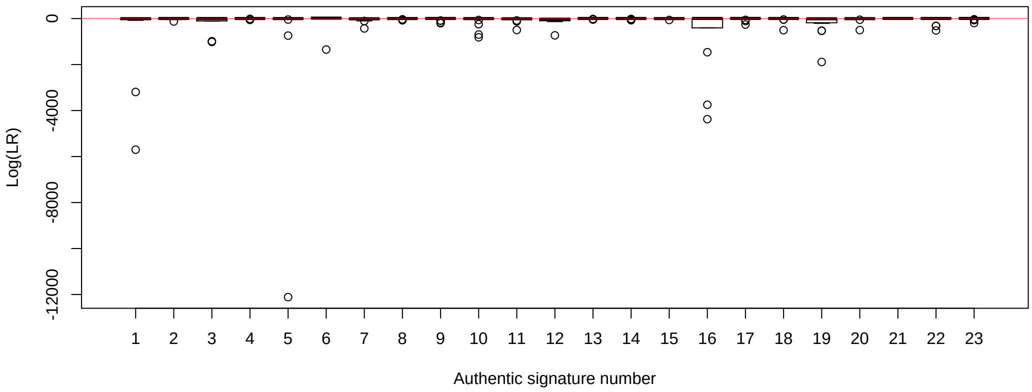


Figure 84 - Likelihood ratios (in a logarithmic form) results obtained for all of the feature vectors v_1-v_{20} for the authentic signatures of artist n°4, represented in the form of a boxplot.

A reduction of the feature vector to the first 18 features (v_1-v_{17}) produces less extreme negative log(LR) values. However, a number of these signatures, even with the smaller feature vectors, are leaning towards the negative end of possible log(LR) values (see Figure 85).

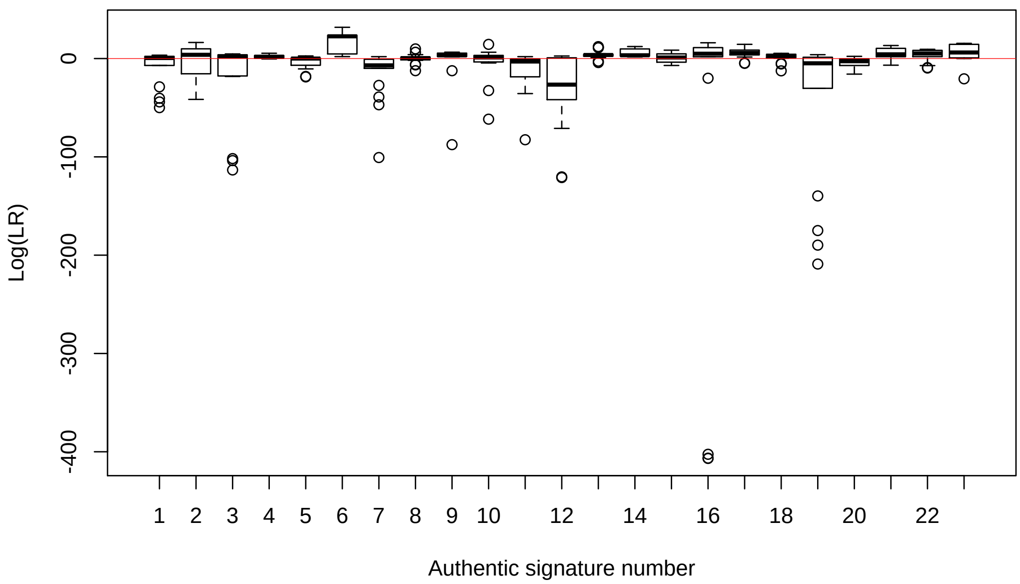


Figure 85 - Likelihood ratios (in a logarithmic form) results obtained with the feature vectors v_1-v_{17} for the authentic signatures of artist n°4, represented in the form of a boxplot.

The log(LR) results obtained for all of the 20 feature vectors (v_1-v_{20}) for each of the simulated signatures also gave results that reached very low log(LR) values, up to -10000 (Figure 86). A representation of log(LR) values obtained with the first 18 features (v_1-v_{17}) facilitates the observation of the results (Figure 87). Simulators 11, 13, and 17 produced at least one signature whose median log(LR) value obtained for all feature vectors is positive. Simulators 13 and 17 produced signature with low variation in the log(LR) values.

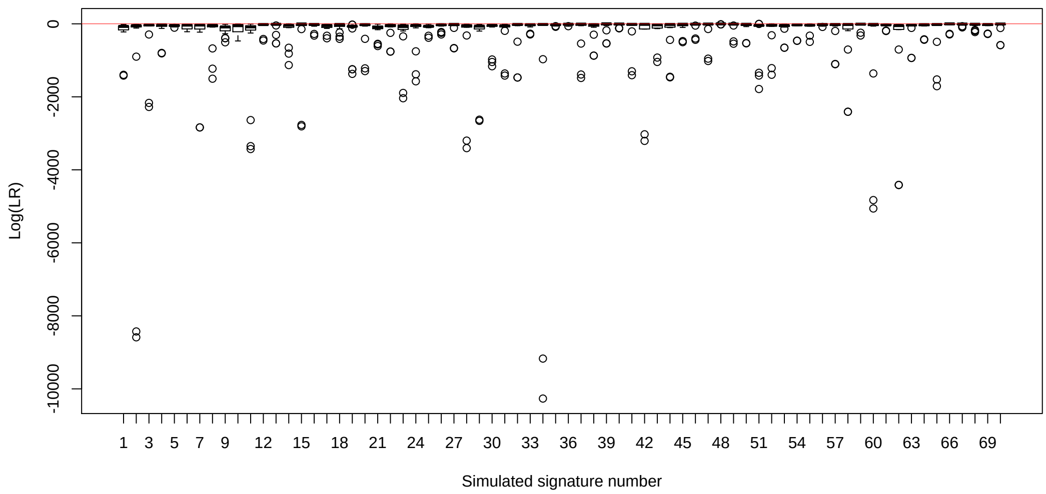


Figure 86 - Likelihood ratios (in a logarithmic form) results obtained for all of the feature vectors v_1-v_{20} for the simulated signatures of artist n°4, represented in the form of a boxplot.

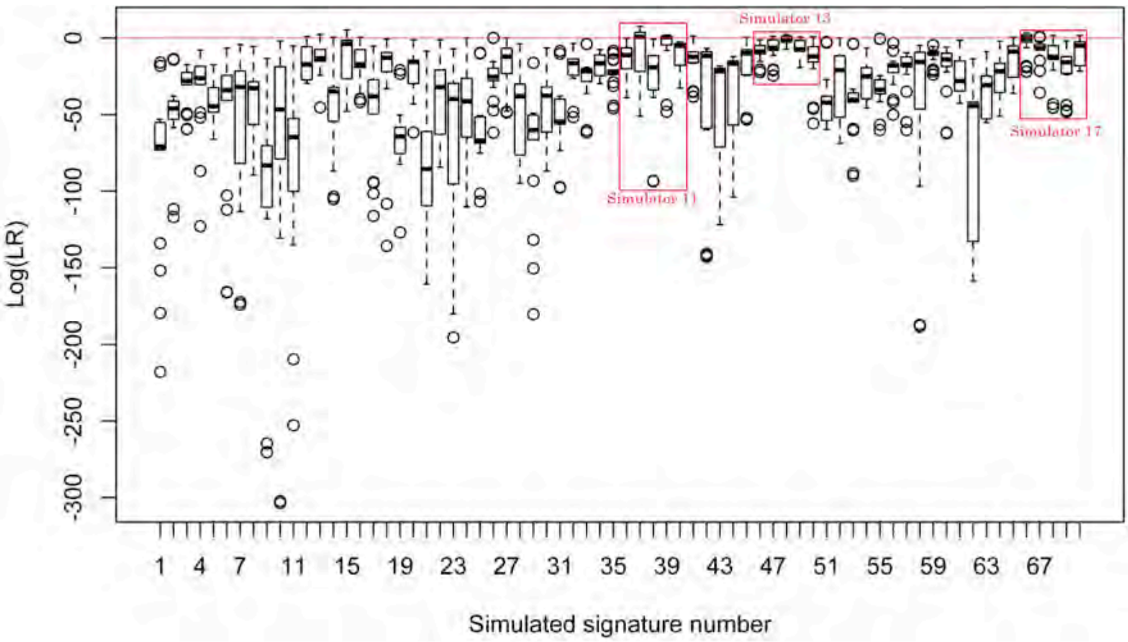


Figure 87 - Likelihood ratios (in a logarithmic form) results obtained for all of the feature vectors v_1-v_{17} for the simulated signatures of artist n°4, represented in the form of a boxplot.

The log(LR) results obtained for each authentic signature, for each of the 17 different feature vectors are plotted in Figure 88 - Figure 91. The values obtained with the last three feature vectors are not included due to the extreme results obtained (which impedes a useful visual illustration). As was the case for the other artists, the influence of the length of the feature vector on the log(LR) results for each of the authentic signatures can be divided into four distinct categories:

- The log(LR) results increase as the length of the feature vector increases (Figure 88);
- The log(LR) results decreases as the length increases (Figure 89);
- An increase, followed by a more or less sharp decrease of the log(LR) is observed as the length of the feature vector increases (Figure 90);
- or finally, no simple behavior can be drawn (Figure 91).

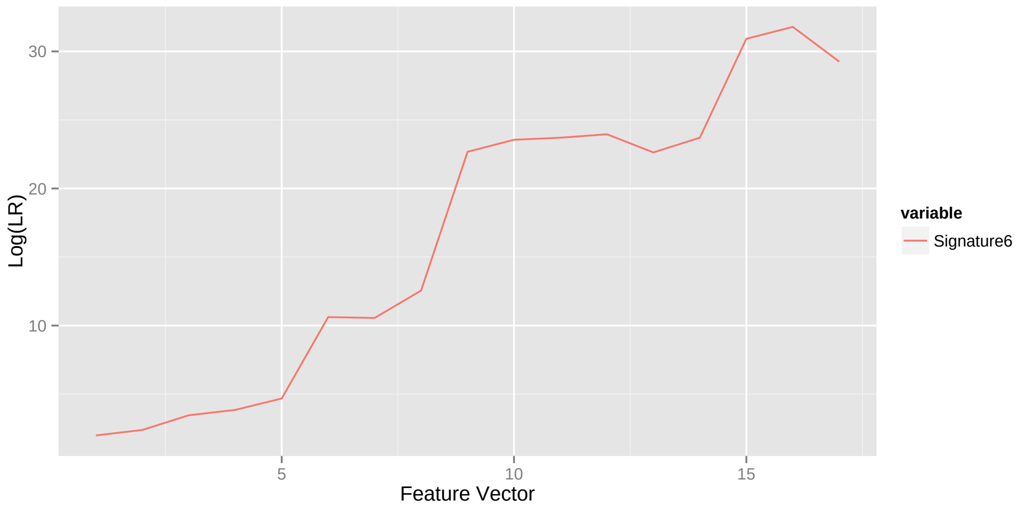


Figure 88 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

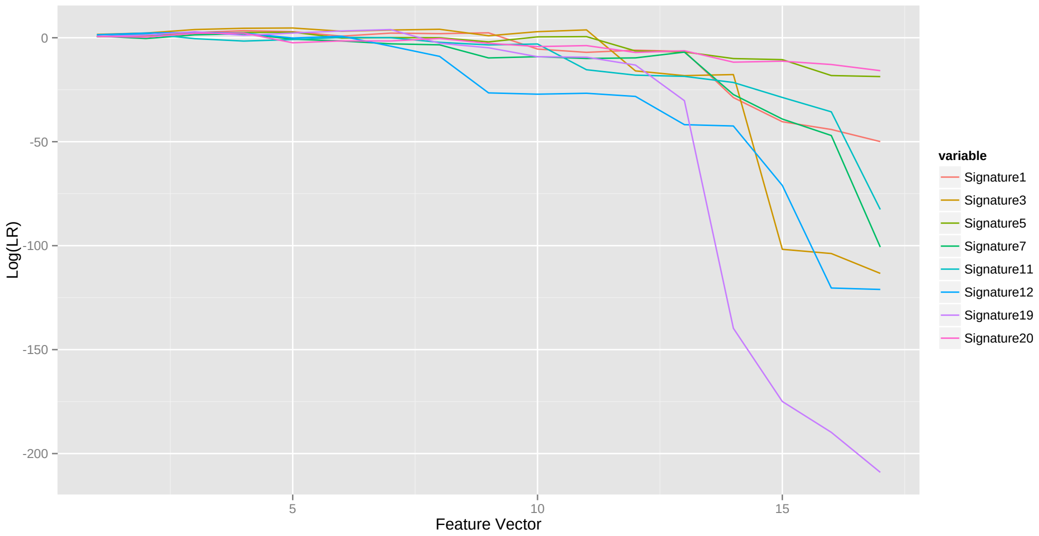


Figure 89 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

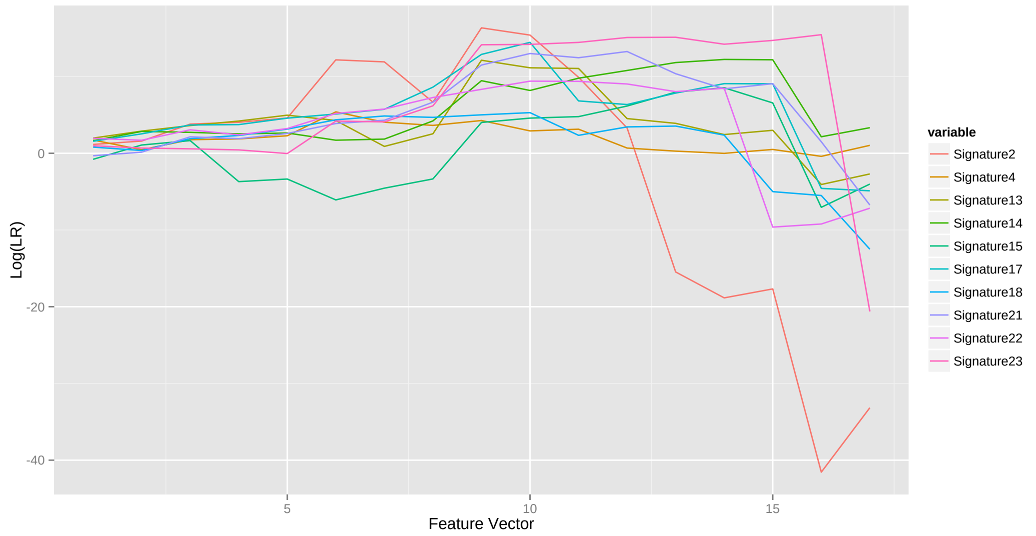


Figure 90 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

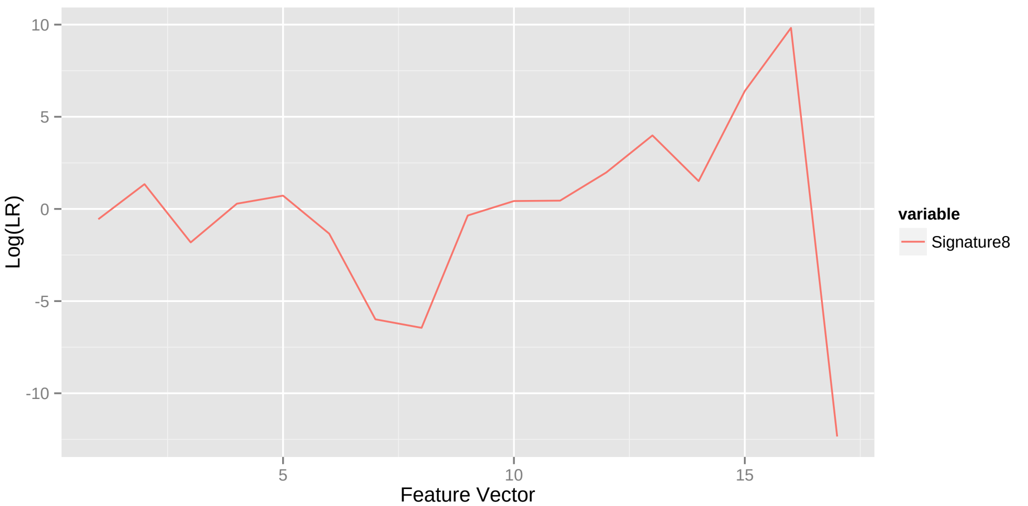
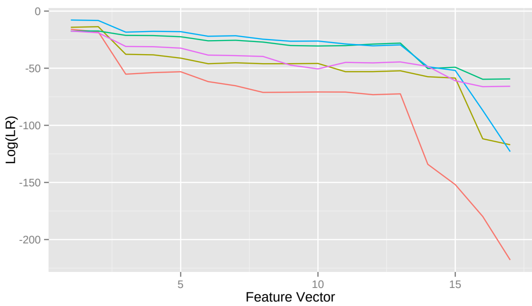


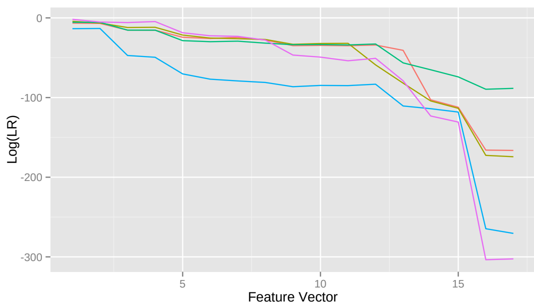
Figure 91 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

The simulated signature sets are presented for each simulator in Figure 92, where the influence on the feature vector and the resulting log(LR) results are depicted. For most of the simulators, each of their five signatures gave log(LR) results that decreased as the length of the feature vector increased. Several simulators, 5, 11, 13 and 17, presented at least one signature where the results varied little as the feature vector increased, sometimes even increasing. This was the case for all five signatures produced by simulators 2, 8, 10, 13, 14, and 15. For a number of these signatures, the first feature vectors gave results gravitating around (just below and above) the value of log(LR) of zero.

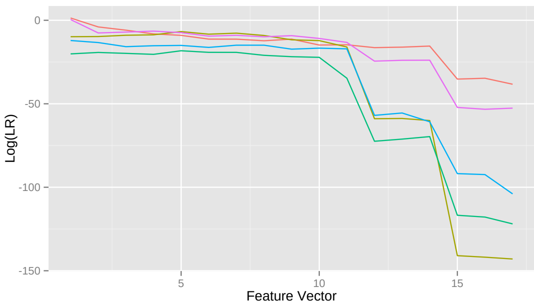
Finally, no signatures produced higher log(LR) results as the length of the feature vector increased.



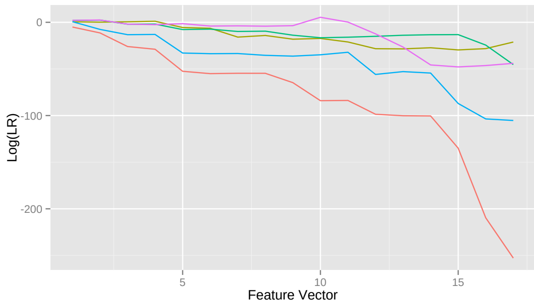
Simulator 1



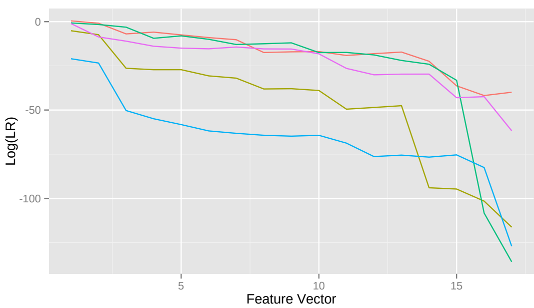
Simulator 2



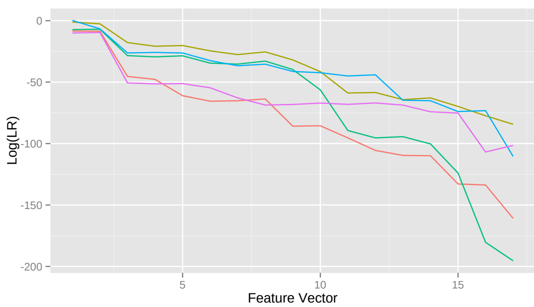
Simulator 4



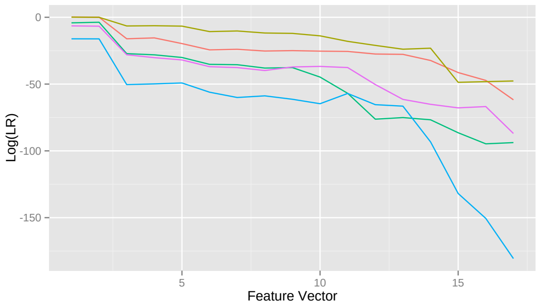
Simulator 5



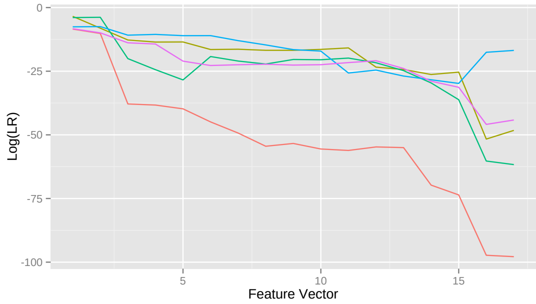
Simulator 7



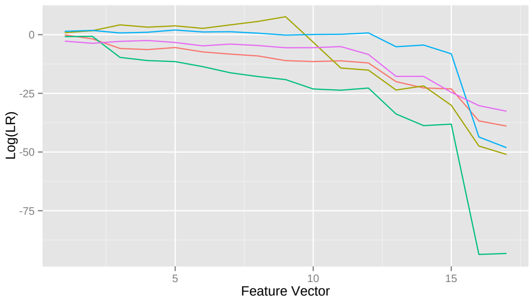
Simulator 8



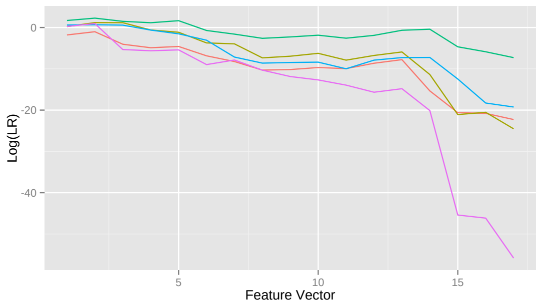
Simulator 9



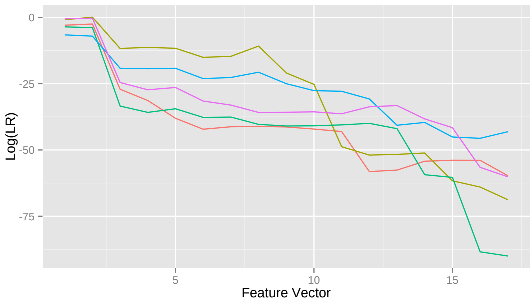
Simulator 10



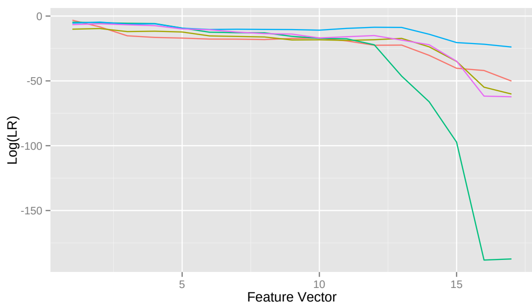
Simulator 11



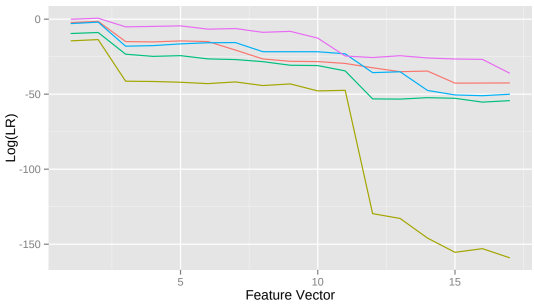
Simulator 13



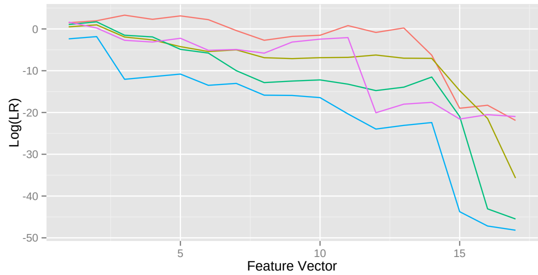
Simulator 14



Simulator 15



Simulator 16



Simulator 17

Figure 92 - Log(LR) results, plotted for the each of the 17 feature vectors, obtained for the 5 signatures samples of each of the simulators of artist n°4. The legend for each signature is as follows : Signature1 Signature2 Signature3 Signature4 Signature5

The calculation of the log-likelihood-ratio cost (C_{llr}) gives weighted results in light of the different behaviors of the authentic and simulated signatures according to the length of the feature vector used. The impact of the feature vector used to calculate the log(LR) for both signature sets show C_{llr} results under the value of one for only the first eight feature vectors (containing the first two to the first nine features).

Feature vector number	Feature combination	CCLR
1	2 features	0.574
2	3 features	0.481
3	4 features	**0.305**
4	5 features	0.366
5	6 features	0.458
6	7 features	0.500
7	8 features	0.739
8	9 features	0.986
9	10 features	1.681
10	11 features	2.037
11	12 features	2.410
12	13 features	3.440
13	14 features	4.803
14	15 features	10.788
15	16 features	28.723
16	17 features	34.397
17	18 features	43.013
18	19 features	Inf
19	20 features	Inf
20	21 features	Inf

Figure 93 - C_{llr} results obtained for artist n°4. The lowest value is highlighted in bold.

The C_{llr} results are illustrated in the two plots below (Figure 94). The C_{llr} results follow an exponential increase curve as the number of features in the feature vector rises.

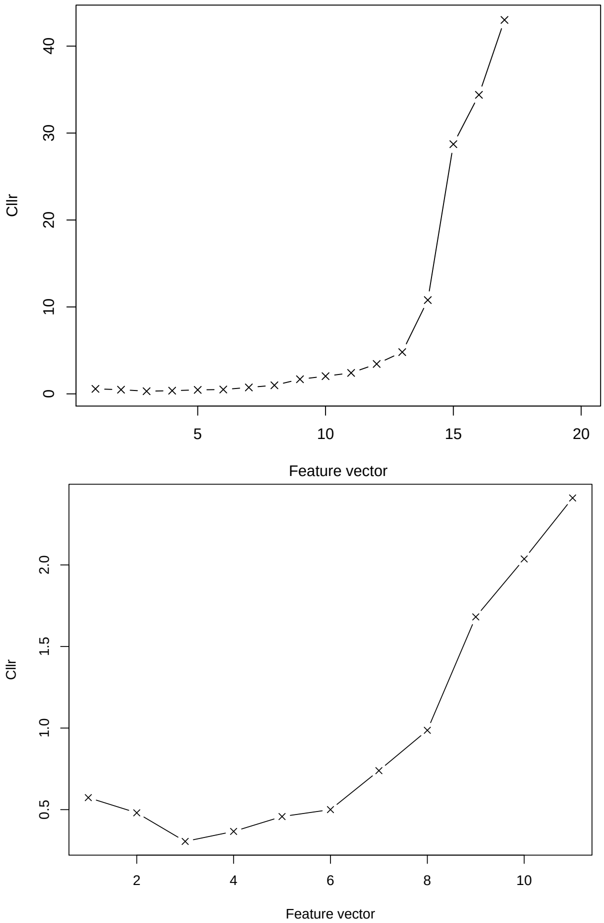


Figure 94 - C_{llr} results obtained for artist n°4, plotted for each feature vector (v_1 to v_{18}) combination composed of two to 18 features (above); C_{llr} values of feature vectors 19 to 21 are not shown due to their infinitive values. A zoom on the first 11 feature vectors (v_1 to v_{11}) is presented below.

The feature vector v_3 (containing the first four features) presents the lowest C_{llr} value (C_{llr} = 0.305), and is thus selected for subsequent log(LR) calculations. This feature vector contains the features:

C51	Superior height difference between letters -P- and -a- / Height of the letter -P-
C62	Inferior height difference between letters -u- and -i- / Height of the letter -u-
C124	Height of initial stroke of letter -i- / Height of letter -i-
C59	Inferior height difference between letters -P- and -a- / Height of letter -P-

The resulting TP Rate of 91.30% and TN Rate of 90% are found with the third feature vector v_3. The distribution of the authentic and simulated signatures is presented in Figure 95. The distribution of the authentic signatures is clearly pushed towards the positive side of the axis, with only 2 signatures giving negative log(LR) values. The same observation can be made to a lesser extent to the population of simulated signatures, whose distribution is less spread out across the negative axis than with the previous feature vector v_{20}.

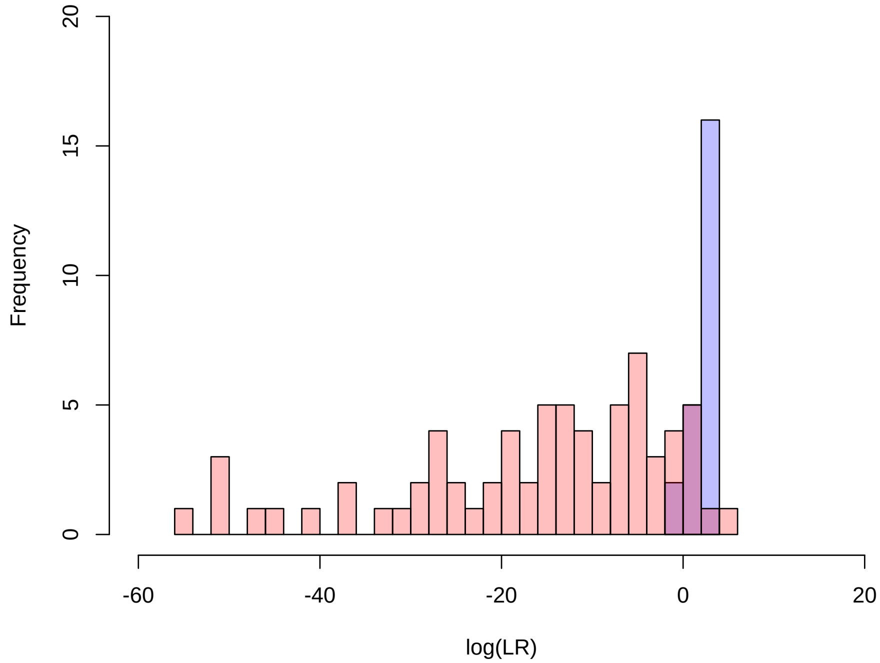


Figure 95 - Likelihood ratios (in a logarithmic form) obtained for the authentic and the simulated signatures of artist n°4 with the third feature vector v_3, represented by the number of occurrences of each results. The authentic signatures are represented in red, the simulated signatures in blue.

8.4.5 Artist n°5 - Schwaller

General assessment of measurements and characteristics

The plots of the measurements of artist n°5 highlight some extreme values in both the authentic and simulated signature sets. The corresponding points of these measurements have been all verified and acknowledged as correct.

The examination of the plots and boxplots of the 152 characteristics/features defining the signature of artist n°5 are also verified. The authentic signatures presenting extreme values are visually identified through the plots and boxplots of the characteristics, and are reported in Table 30. The origins of the extreme values are explained (see Illustration of signatures in Appendix VI). For the sake of brevity of the text, the outliers of the simulated signatures are not presented.

Sig. n°	Outlying feature	Feature specification	Origin of outlying value[191]
1	C43	Length -m- / Length -s-	Length of -s- short due to short initial stroke
2	C43	Length -m- / Length -s-	Length of -s- short due to short initial stroke
4	C76	Inferior height difference between -w- and -l- / Height -w-	Bottom of letter -l- is prolonged vertically
5	C85	Space between -w- and -l- / Length -l-	Short terminal spur of -w-, giving a larger space between letters -w- and -l-
	C97	Length -e- / Height -e-	Longer terminal stoke of -e-
	C124	-s- : Height of descending stroke, taken from intersection of initial stroke and descending stroke / Height of descending stroke	Interruption in line stroke between initial stroke and descending stroke giving a longer height of initial stroke
6	C85	Space between -w- and -l- / Length -l-	Short terminal spur of -w-, giving a larger space between letters -w- and -l-
	C145	-s-: Angle of initial stroke	-
8	C116	-m- : Length of second stem / Length of third stem	Third stem compact horizontally
9	C85	Space between -w- and -l- / Length -l-	Short terminal spur of -w-, giving a larger space between letters -w- and -l- and large space between both letters
	C116	-m- : Length of second stem / Length of third stem	Third stem compact horizontally
10	C85	Space between -w- and -l- / Length -l-	Short terminal spur of -w-, giving a larger space between

[191] The origins of the outlying values are given in comparison with the other signatures of the set.

			letters -w- and -l- and large space between both letters
12	C98	Length -r- / Height -r-	Arch of -r- compact, giving small length of letter
	C142	-e- : Height of eyelet / Length of eyelet	Eyelet prolonged horizontally
13	C129	-h- : Height of stem, taken from intersection with terminal stroke of -c- / Height of -h-	Interruption in line stroke between -c- and -h- resulting in longer height of stem, taken from intersection with -c-
16	C54	Height -s- / Height -c-	Letter -s- compact vertically
17	C24	Height -s- / Height signature	Letter -s- prolonged vertically
18	C129	-h- : Height of stem, taken from intersection with terminal stroke of -c- / Height of -h-	Terminal stroke of -c- intersects at a higher point on stem of letter -h-
21	C132	-h- : Height of arch / Height of letter	Arch is pronounced vertically
24	C142	-e- : Height of eyelet / Length of eyelet	Small height of eyelet

Table 30 - Outliers detected in the authentic signature set of artist n°5

Fifteen signatures of the authentic set present outlying feature values, with each signature presenting for the most only one outlier. Only signature n°5 possesses three outliers, and with each outlier coming from a different element or portion of the signature.

The boxplots of the characteristics of the authentic signatures present in general less dispersion than the characteristics of the simulated signatures. Several exceptions (without taking outliers into account) are however noted and are: C50, C59, C65, C72, C88, C92, C108, C133, C135.

None of the boxplots depicting the values of the characteristics of the authentic signatures are fully separated from their simulated counterpart, a partial or full overlapping is always present from the range from the first up to the last quartile. However, the interquartile ranges between the authentic and simulated sets are separated for characteristics C21 and C134.

Principal component analysis

The PCA is carried out on the data set obtained from the authentic and simulated signatures. The first three PCs of this data set account for approximately 12%, 11%, and 8% of the total variation (80 % of the variance is explained by the first 18 variables). Thus, as was the case with the last four artists, a three-dimension plot of the first three PCs will give a general, although not exhaustive, account (an explanation of only 31% of the variation) of the relative position of the observations in their original 152-dimensional space.

The PCA representation of the first three PCs plotted against each other (see Figure 96) shows a partial separation of both signature sets. The authentic set produces more variation along the negative axis of PC1, than on PC2. The general variation is quite confined for the authentic set, apart from signatures n°5 and n°9 of the artist that vary more in the negative direction of PC1 than any of the other signatures of the set. The simulated set varies along both PC1 and PC2, particularly in the direction of their positive axes. For this set, the plots of the first and second PC against the third PC show a large variation in the direction of the third PC, particularly when PC2 is plotted against PC3.

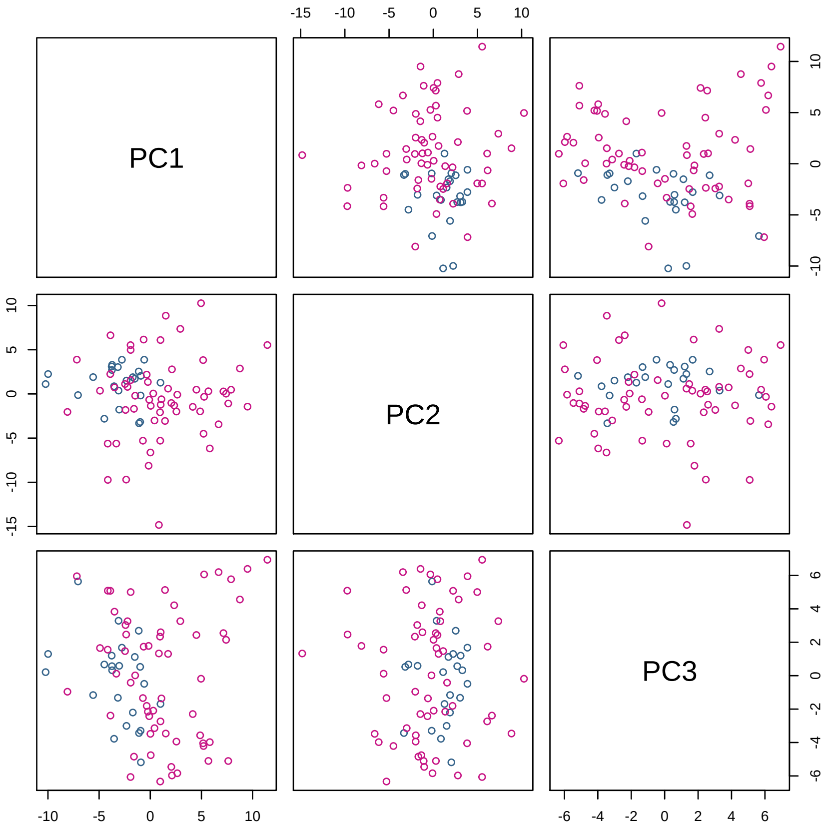


Figure 96 - Representation of first three PCs plotted against each other. Each dark blue point represents an authentic signature, and each dark pink point represents a signature of the simulated set.

The set of simulated signatures is broken down and represented in Figure 97 according to the different groups of simulators: the Conservators-restorers, the Artists, and the FHEs. With such a distinction, the type of group that the simulator comes from has an influence on his simulation capacities. The group of Conservators-restorers produced data that is more spread out across PC2 than PC1, and that partly overlaps the authentic set. The signatures from the second group of simulators (Artists) are the most distant from the group of authentic signatures, and vary along the positive axis of PC1. The third group of FHEs vary along PC1, and are partly separated from the authentic set.

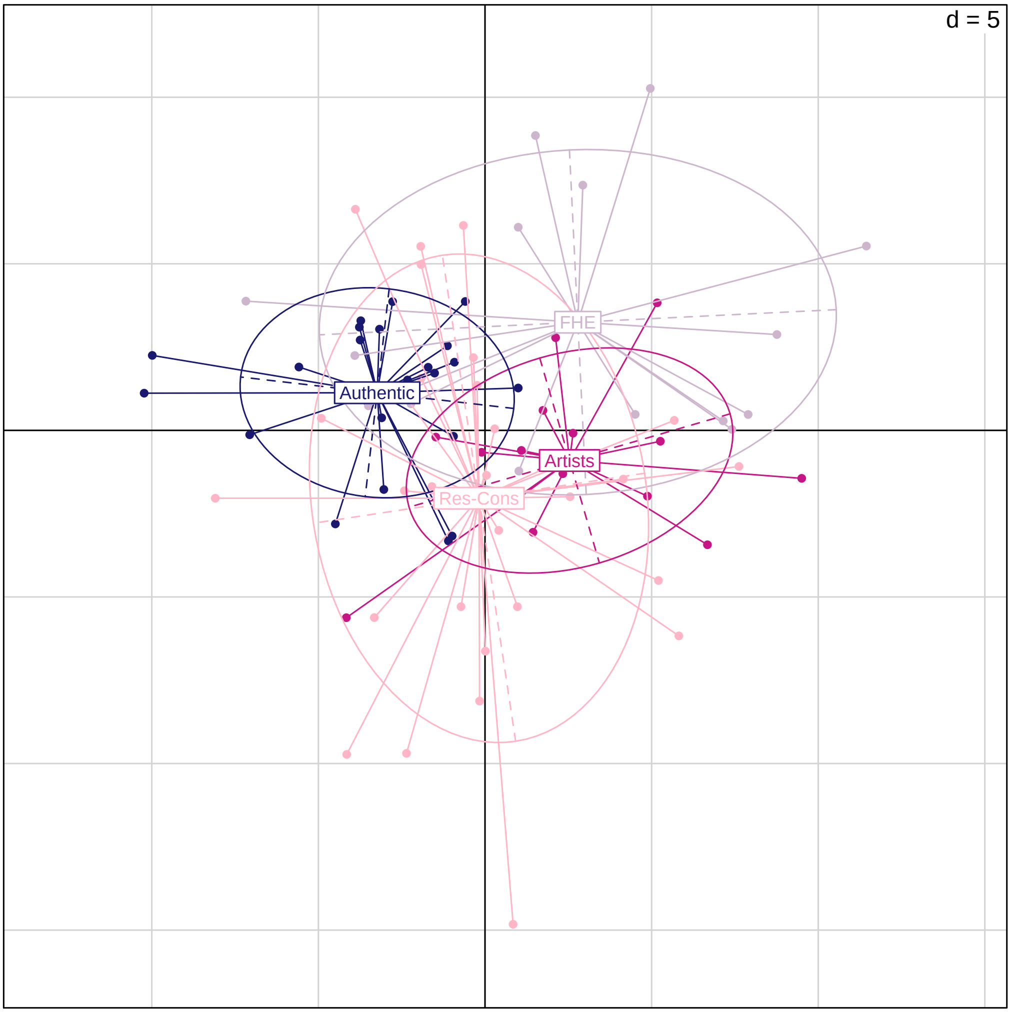


Figure 97 - Representation of the first two PCs (PC1 on x-axis and PC2 on y-axis) obtained of the PCA analysis of the authentic set and the three simulated set of signatures of artist n°5 (Schwaller).

Figure 98 illustrates the differences in the simulation capacities of each specific simulator. These results tend to show that the simulation capacity is more linked to the personal abilities of the person than to their group affiliation. For the first group of Conservators-restorers, only one simulator (11) produced signatures that are overlapping the group of authentic signatures. The rest of the simulators of this group produced signatures that varied across PC2.

The second group of simulators (Artists) are grouped together along the positive axis of PC1, and are all separated from the authentic set. The third group of simulators, taken together, are spread out across PC2 (as seen in Figure 97). However, once taken individually, the simulators are in fact well confined in their own sub-group. Thus, simulators 15 and 16 produced sets that are well separated from the authentic set, whereas simulator 17 produced a signature set that overlaps the most the authentic set (see Figure 98).

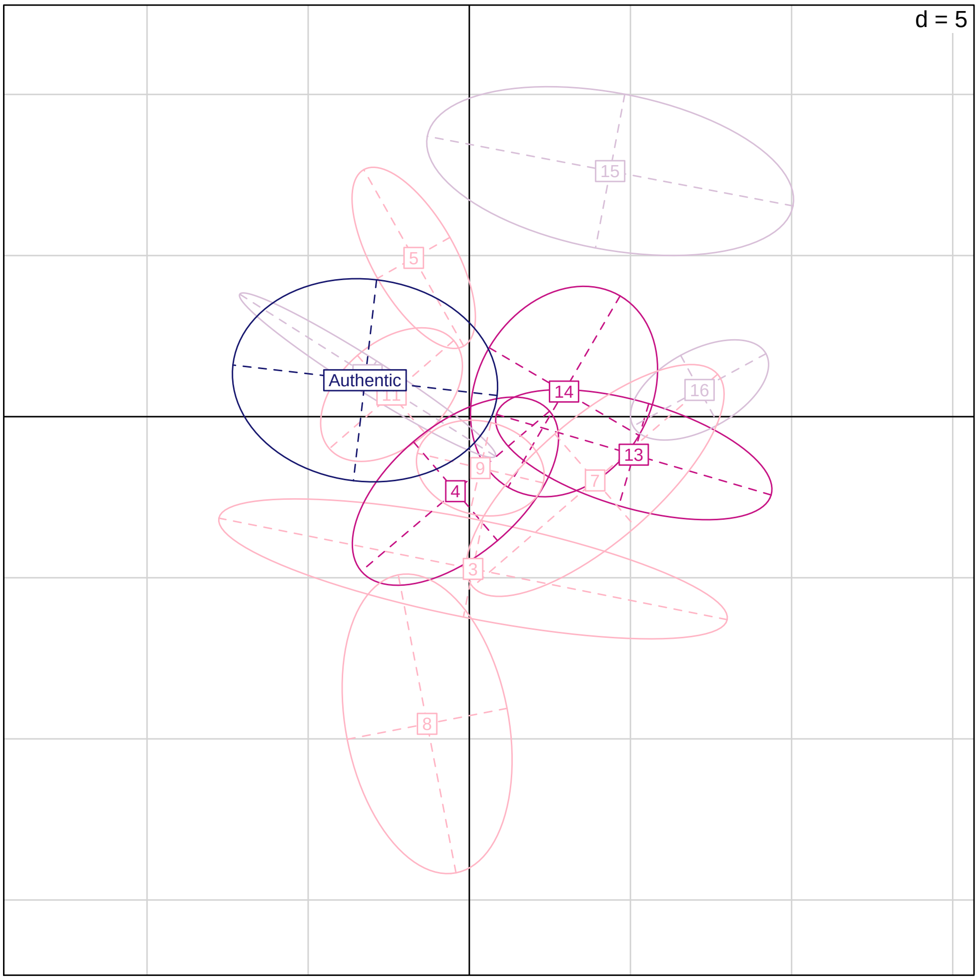


Figure 98 - Illustration of PCA analysis (PC1 on x-axis and PC2 on y-axis) of the authentic set and the each simulated set (n=14) of signatures of artist n°5 (Schwaller). The simulators from the Res-Con group are represented in pink, the Artist group in dark pink, and the FHEs in mauve.

The dispersion of the each of the simulated signatures varies according to the simulator, but does not appear to be linked to the group affiliation. From these visual results, three groups of simulators can be deduced: very skilled simulators (11 and 17), moderately skilled simulators (5, 9, 4 and 14), and poorly skilled simulators (3, 7, 8, 13, 15, and 16).

Feature reduction

a) Boruta feature reduction

The Boruta feature reduction testing was carried out with the pre-defined parameter, and the best results were obtained with the parameter ntree=100000. In this case, the highest number confirmed (43) and tentative (1) characteristics were given. Thus a total of 44 of the initial 152 characteristics were selected (28.9%) and are listed in Table 31 with their corresponding feature classes and feature specifications. Each letter is represented at least once within the selected features. The importance values of each characteristic with the Boruta analysis are reported in Appendix XIII.

Feature	Feature class		Letter specification
C21	3	Length letter / Height signature	L -r- / H tot
C135	12	Intraletter	-h- : Height of arch, taken from intersection of stem with arch / Height of second foot of arch (right stem)
C56	7	Height letter / Height letter after	H -h- / H -w-
C134	12	Intraletter	-h- : Height of arch / Height of second foot of arch (right stem)
C11	2	Length letter / Length signature	L -r- / L tot
C72	9	Height difference (inf.) / Height letter before	-m- and -s- / H -m-
C71	9	Height difference (inf.) / Height letter before	-J- and -m- / H -J-
C82	10	Space / Length letter after	-s- and -c- / H -c-
C93	11	Length letter / Height letter	L -h- / H -h-
C133	12	Intraletter	-h- : Height of left foot / Height of arch
C141	12	Intraletter	-e- : Height difference between final ascending curve and lowest point of letter / Height letter
C60	7	Height letter /	H -e- / H -r-

		Height letter after	
C51	6	Length letter / Length letter after	L -r- / H -J-
C70	8	Height difference (sup.) / Height letter before	-e- and -r- / H -e-
C33	5	Height letter / Length signature	H -m- / L tot
C100	12	Intraletter	-J- : Height of lower stem (below crossbar) / Height letter
C125	12	Intraletter	-c- : Length of connecting stroke / Length letter
C99	12	Intraletter	-J- : Height of upper stem (above crossbar) / Height letter
C127	12	Intraletter	-c- : Length of bow / Length letter
C101	12	Intraletter	-J- : Length of initial stroke left of stem / Length letter
C67	8	Height difference (sup.) / Height letter before	-w- and -l- / H -w-
C84	10	Space / Length letter after	-h- and -w- / H -w-
C37	5	Height letter / Length signature	H -w- / L tot
C148	13	Angle	-h- : Angle of stem, taken from point furthest right of stem
C63	8	Height difference (sup.) / Height letter before	-m- and -s- / H -m-
C94	11	Length letter / Height letter	L -w- / H -w-
C62	8	Height difference (sup.) / Height letter before	-J- and -m- / H -J-
C52	7	Height letter / Height letter after	H -J- / H -m-
C146	13	Angle	-s- : Angle of descending stroke
C23	4	Height letter / Height signature	H -m- / H tot
C76	9	Height difference (inf.) / Height letter before	-w- and -l- / H -w-
C41	5	Height letter / Length signature	H -r- / L tot
C53	7	Height letter / Height letter after	H -m- / H -s-
C115	12	Intraletter	-m- : Length of first stem / Length of second stem
C73	9	Height difference (inf.) / Height letter before	-s- and -c- / H -s-
C39	5	Height letter /	H -l- / L tot

		Length signature	
C4	2	Length letter / Length signature	L -s- / L tot
C109	12	Intraletter	-m- : Length of second stem / Length letter
C130	12	Intraletter	-h- : Length of arch, taken from intersection of stem with arch (buckle) / Height letter
C55	7	Height letter / Height letter after	H -c- / H -h-
C65	8	Height difference (sup.) / Height letter before	-c- and -h- / H -c-
C137	12	Intraletter	-w- : Length of spur / Length letter
C136	12	Intraletter	-w- : Length of three stems / Length letter
C81	10	Space / Length letter after	-m- and -s- / H -s-

Table 31 - List of features retained after Boruta feature selection step, listed by their order of importance.

b) Normality testing

The results obtained after the Shapiro-Wilk normality test on the 152 characteristics describing the signature of artist n°5 are presented according to their class affiliation in Table 32. The detailed results of the tests (for each characteristic) are presented in Appendix XII.

For the authentic set of signatures, the normality of the data is on the whole respected. Only the intraletter class of features (class 12) possesses four (out of 45) features with significant p-values. The simulated signature set however possesses a greater number of variables that do not come from normally distributed populations, particularly in classes 4 (Height letter/Height signature), 6 (Length letter/Length letter after), 7 (Height letter/Height letter after), 8 (Height difference (superior)/Height letter before), 10 (Space between two letters/Length of the letter after), 11 (Length of a letter/Height of the same letter) and 12 (intraletter).

The normality results of both the authentic and simulated sets considered together show that four classes (4, 6, 7 and 10) each have less than 50% of their variables that are normally distributed.

Class	Authentic			Simulated			Both sets (Auth. and Sim.)			
	Normal #		Total #	Normal #		Total #	Normal #		Total #	(%)
1	1	/	1	1	/	1	1	/	1	100 %
2	10	/	10	8	/	10	8	/	10	80 %
3	10	/	10	7	/	10	7	/	10	70 %
4	9	/	10	5	/	10	4	/	10	40 %
5	10	/	10	9	/	10	9	/	10	90 %
6	9	/	10	3	/	10	3	/	10	30 %
7	8	/	10	5	/	10	4	/	10	40 %
8	9	/	9	5	/	9	5	/	9	55.6 %
9	9	/	9	6	/	9	6	/	9	66.7 %
10	8	/	9	4	/	9	3	/	9	33.3 %
11	10	/	10	5	/	10	5	/	10	50 %
12	41	/	45	27	/	45	27	/	45	60 %
13	9	/	9	7	/	9	7	/	9	77.8 %

Table 32 - Results of Shapiro-Wilk normality test, given for each class composing the authentic set, the simulated set, and both sets together.

The affiliation of each selected characteristics after the Boruta selection step to his respective feature class is noted in the third column of Table 33, with the relative percentage in parentheses. Class 1 is not represented by a selected feature. The classes that have the highest percentages of selected features are classes 7 (Height letter/Height letter after), 8 (Height difference (superior) between two letters/Height letter before), 9 (Height difference (inferior) between two letters/Height letter before). Thus, if simplified, three general tendencies can be drawn in the selected feature classes: Height of letters and Height difference between letters.

Once the results of the normality testing are applied on the Boruta feature selection results, a final number of 25 features are retained (see Table 33), which corresponds to a 83.6% reduction from the initial 152 features. Classes 3, 4 and 6, which only contained one feature, are no longer represented. No drastic drops in the number of features is observed apart from class 12, which declined from 14 to 8 features.

Class		Number of features in each class (and corresponding %)	
N°	# of Features in Class	... after Feature selection	... after Feature selection *and* normality testing
1	1	0 (0 %)	0 (0 %)
2	10	2 (20 %)	1 (10 %)
3	10	1 (10 %)	0 (0 %)
4	10	1 (10 %)	0 (0 %)
5	10	4 (40 %)	3 (30 %)
6	10	1 (10 %)	0 (0 %)
7	10	5 (50 %)	4 (40 %)
8	9	5 (55.5 %)	3 (33.3 %)
9	9	4 (44.4 %)	3 (33.3 %)
10	9	3 (33.3 %)	1 (11.1 %)
11	10	2 (20 %)	1 (10%)
12	45	14 (31.1 %)	8 (17.8 %)
13	9	2 (22.2 %)	1 (11.1 %)
Total	**152**	**44 (28.9 %)**	**25 (16.4 %)**

Table 33 - List of features of each class retained after Boruta feature selection and normality testing

The list of features retained after the Boruta feature selection and normality testing is given in Table 34 with their corresponding class and letter specifications. Each of the ten letters are represented either directly, or in relation with another letter.

Feature	**Feature class**		**Letter specification**
C56	7	Height letter / Height letter after	H -h- / H -w-
C71	9	Height difference (inf.) / Height letter before	-J- and -m- / H -J-
C93	11	Length letter / Height letter	L -h- / H -h-
C141	12	Intraletter	-e- : Height difference between final ascending curve and lowest point of letter / Height letter
C70	8	Height difference (sup.) / Height letter before	-e- and -r- / H -e-
C33	5	Height letter / Length signature	H -m- / L tot

C100	12	Intraletter	-J- : Height of lower stem (below crossbar) / Height letter
C99	12	Intraletter	-J- : Height of upper stem (above crossbar) / Height letter
C101	12	Intraletter	-J- : Length of initial stroke left of stem / Length letter
C67	8	Height difference (sup.) / Height letter before	-w- and -l- / H -w-
C62	8	Height difference (sup.) / Height letter before	-J- and -m- / H -J-
C52	7	Height letter / Height letter after	H -J- / H -m-
C146	13	Angle	-s- : Angle of descending stroke
C76	9	Height difference (inf.) / Height letter before	-w- and -l- / H -w-
C41	5	Height letter / Length signature	H -r- / L tot
C53	7	Height letter / Height letter after	H -m- / H -s-
C115	12	Intraletter	-m- : Length of first stem / Length of second stem
C73	9	Height difference (inf.) / Height letter before	-s- and -c- / H -s-
C39	5	Height letter / Length signature	H -l- / L tot
C4	2	Length letter / Length signature	L -s- / L tot
C109	12	Intraletter	-m- : Length of second stem / Length letter
C130	12	Intraletter	-h- : Length of arch, taken from intersection of stem with arch (buckle) / Height letter
C55	7	Height letter / Height letter after	H -c- / H -h-
C65	8	Height difference (sup.) / Height letter before	-c- and -h- / H -c-
C137	12	Intraletter	-w- : Length of spur / Length letter
C136	12	Intraletter	-w- : Length of three stems / Length letter
C81	10	Space / Length letter after	-m- and -s- / H -s-

Table 34 - List of features retained after Boruta feature selection and normality testing.

Finally, the establishment of the covariance matrix of the selected 25 features indicates that one pair of features present a negative covariance: the feature pair C137 - C136. This pair of features thus presents a perfectly linear relationship between each other. As a result, feature C136 is not retained in the final feature vector.

Likelihood ratio assessment

The strength of the set of selected features are finally assessed with a likelihood ratio examination. The feature vector containing the selected features C56, C71, C93, C141, C70, C33, C100, C99, C101, C67, C62, C52, C146, C76, C41, C53, C73, C39, C4, C109, C130, C55, C137, and C81 are used to compute a multivariate likelihood ratio for each authentic and simulated signature, as explained in sub-section 7.4.4. The feature vector containing the 24 features presented proved to be too long for analysis and produced covariance matrixes that were too complex to manage. Thus, the last three features of the feature list were discarded, giving the feature vectors: v_2 to v_{20}. The results of the likelihood ratio assessment carried out with the 21 feature long vector v_{20} of artist n°5 are presented in Table 35 below.

Authentic		Simulated			
Sig n°	**log(LR)**	**Sig n°**	**log(LR)**	**Sig n°**	**log(LR)**
1	**-3582.32**	1	-325.22	31	-127.18
2	**-37.00**	2	-81.50	32	-96.33
3	**-17.00**	3	-67.58	33	-401.79
4	**-156.36**	4	-238.60	34	-127.61
5	**-726.65**	5	-83.76	35	-70.07
6	**-1292.53**	6	-562.26	36	-71.45
7	**-71.55**	7	-651.45	37	-355.12
8	**-304.52**	8	-399.30	38	-779.95
9	**-415.66**	9	-179.55	39	-708.97
10	**-66.60**	10	-104.78	40	-217.08
11	**-33798.64**	11	-1045.00	41	-157.94
12	**-153.06**	12	-186.76	42	-163.64
13	**-944.06**	13	-377.44	43	-194.96
14	**-193.27**	14	-254.34	44	-232.71
15	**-3431.56**	15	-185.36	45	-222.02
16	**-494.01**	16	-245.70	46	-1056.59
17	**-1726721.14**	17	-207.88	47	-466.36
18	**-2937.04**	18	-183.24	48	-329.27
19	**-261.11**	19	-203.26	49	-706.36
20	**-127184.08**	20	-322.78	50	-207.52
21	**-2264.19**	21	-187.70	51	-931.77
22	**-23.77**	22	-113.87	52	-1090.30
23	**-466.49**	23	-158.63	53	-864.69
		24	-129.48	54	-148.45
		25	-116.73	55	-268.82
		26	-294.09	56	-182.50
		27	-126.81	57	-388.12
		28	-124.66	58	-108.87
		29	-66.13	59	-62.86
		30	-187.97	60	-137.83

Table 35 - Log(Likelihood) results obtained for each signature in the authentic and simulated signature sets with the feature vector υ_{20}. Negative results under H_1, and positive results under H_2, are highlighted in bold.

All of the 23 authentic signatures possess a log(LR) below zero (false negatives), when using the twentieth and final feature vector υ_{20}. With this same feature vector, all of the 60 simulated signatures possess a log(LR) below zero (true negatives). However, the values obtained with the simulated population are less negative than those obtained with the authentic population, giving rather extreme values of 0% for the sensitivity (true positive rate), and 100% for the specificity (true negative rate). For these reasons, and so more discernable results can be drawn, the feature vector is directly shortened down by 2 features, up to the 18th feature vector. The dispersion of the results obtained with the feature vector v_{18} are represented in Figure 99 through a histogram of the number of occurrences obtained for each range of log(LR) with the authentic and simulated signature populations.

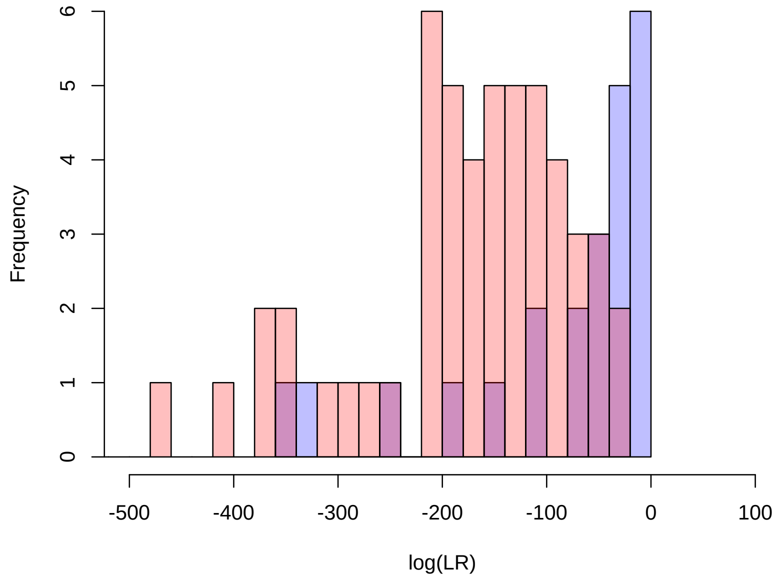


Figure 99 - Likelihood ratios (in a logarithmic form) obtained for the authentic and the simulated signatures of artist n°5 with the feature vector v_{18}, represented in the form of a histogram and according to the number of occurrences (y-axis). The authentic signatures are shown in blue, the simulated signatures in red.

The log(LR) results depict a clear overlapping between the authentic and simulated signature sets. The authentic signatures are grouped entirely below the value of zero, and stretch out into the negative log(LR) values, up to negative 360. The simulated set is situated on the negative end of the axis, and predominately between log(LR) values of -20 and -200. Both populations are overlapping along the negative axis.

The log(LR) values obtained with all of the 18 feature vectors (v_1-v_{18}), for each of the authentic signatures, are shown in Figure 100 through boxplots illustrations. The exact values obtained for each signature and for each feature vector are reported in Appendix XIV. All of the signatures produced by this artist present a negative log(LR) with the feature vector v_{18} (as shown in Figure 99), but present log(LR)s that are at one point higher than the value of zero. This confirms that the feature vector v_{18} is not the optimal feature vector choice in terms of false negatives.

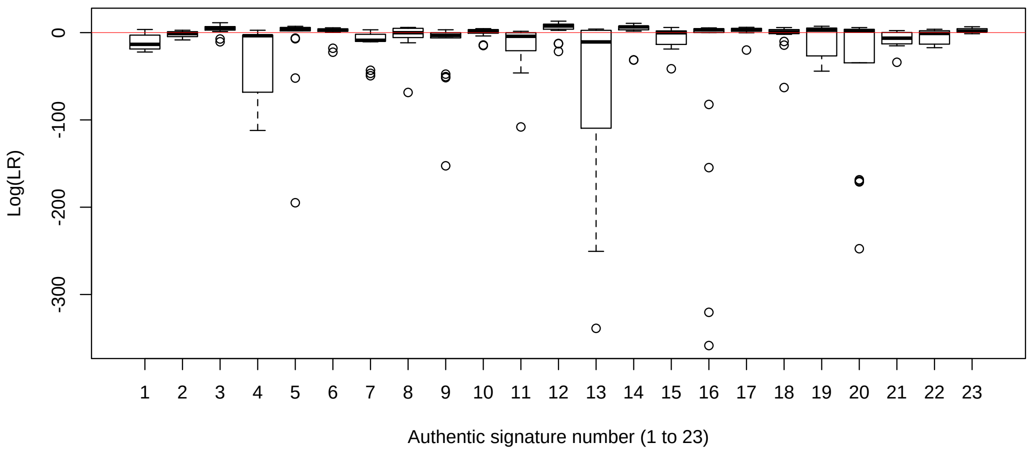


Figure 100 - Likelihood ratios (in a logarithmic form) results obtained for all of the feature vectors v_1-v_{18} for the authentic signatures of artist n°5, represented in the form of a boxplot.

The log(LR) results obtained for all of the 18 feature vectors (v_1-v_{18}) for each of the simulated signatures is represented in the same manner in the following boxplot (Figure 101). There are no positive log(LR) values with the final feature vector v_{18}, thus no simulator was able to produce a simulation of sufficient quality with these characteristics taken into account. However, when a shorter feature vector (starting at v_{12}) is used, two signatures (the second signature of simulator 4 and the first signature of simulator 9) produce a positive log(LR) result, and as the length of the feature vector decreases, the number of positive log(LR) result increases.

Simulators 3, 4, 5, 9, 11, 14 and 17 also produced at least one signature with at least one positive log(LR) value over all 18 possible feature vectors (v_1-v_{18}). However, only one of these signatures, the second signature produced by simulator 4, gave a positive median log(LR) value for all these feature vectors up to v_{12}. The variation in the log(LR) values between the five signatures of the sets of simulators 3, 4, 9, 11 and 17 varied depending on the signatures: some of the signature showed very little variation, whereas others showed a consistently larger variation in the values according to the feature vector used.

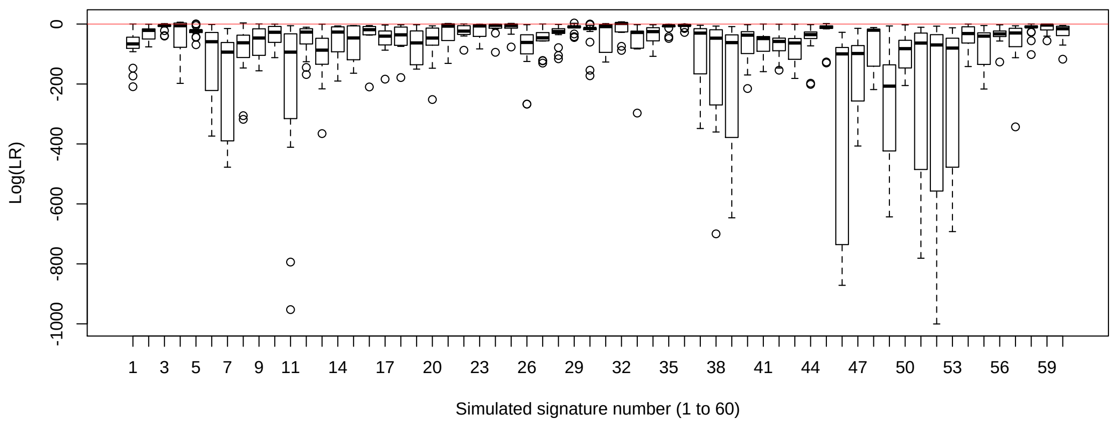


Figure 101 - Likelihood ratios (in a logarithmic form) results obtained for all of the feature vectors υ_1-υ_{18} for the simulated signatures of artist n°5, represented in the form of a boxplot.

The log(LR) results obtained for each authentic signature, for each of the 18 different feature vectors are plotted in Figure 102 - Figure 105. The influence of the length of the feature vector on the log(LR) results for each of the authentic signatures can be divided into four distinct categories according to the general tendencies observed:

- The log(LR) results increase as the length of the feature vector increases (Figure 102): In line with the results shown in Table 35, and the results shown with a shorter feature vector, this category was not observed for any of the authentic signatures. However, several signatures presented this behavior up to the 15th feature vector (signatures 3, 12, and 14), or 16th feature vector (signature 23), but at higher feature vectors their log(LR) values dropped. They are however presented separately from the third group (Figure 104) because the increase in the log(LR) values carries on longer throughout the feature vectors.
- The log(LR) decreases as the length increases (Figure 103): For signatures 4, 7 and 11, after an initial drop, a slight increase in the log(LR) values are observed from the 13th to 15th feature vector, before dropping again altogether.
- An increase, followed by a sharp decrease of the log(LR) is observed as the length of the feature vector increases (Figure 104); As signatures 5, 9, 13, 16 and 20 presented very low log(LR) results starting with the

14th feature vectors, they are omitted in a second representation of signatures of this group (for illustration reasons) in Figure 105.

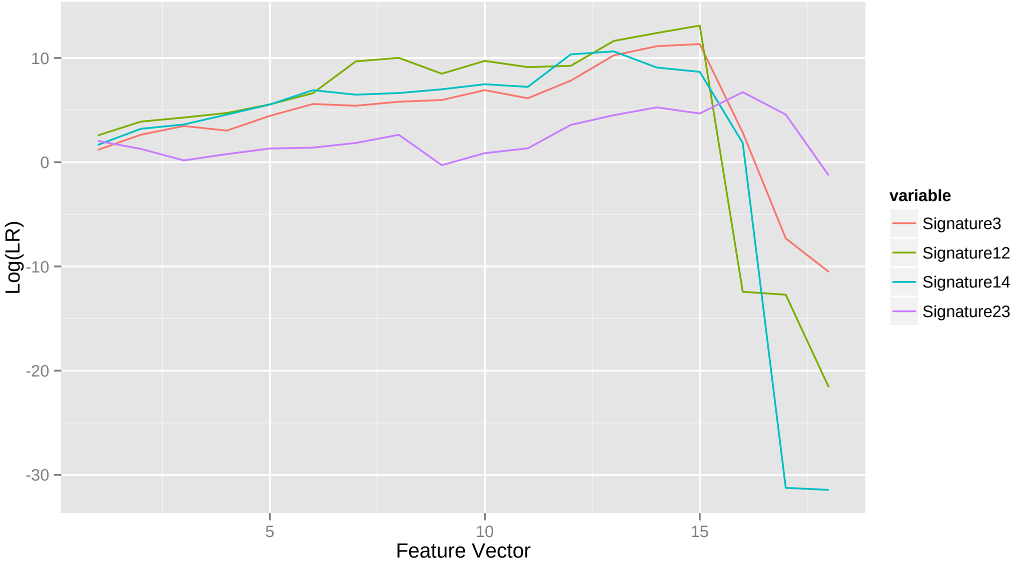


Figure 102 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

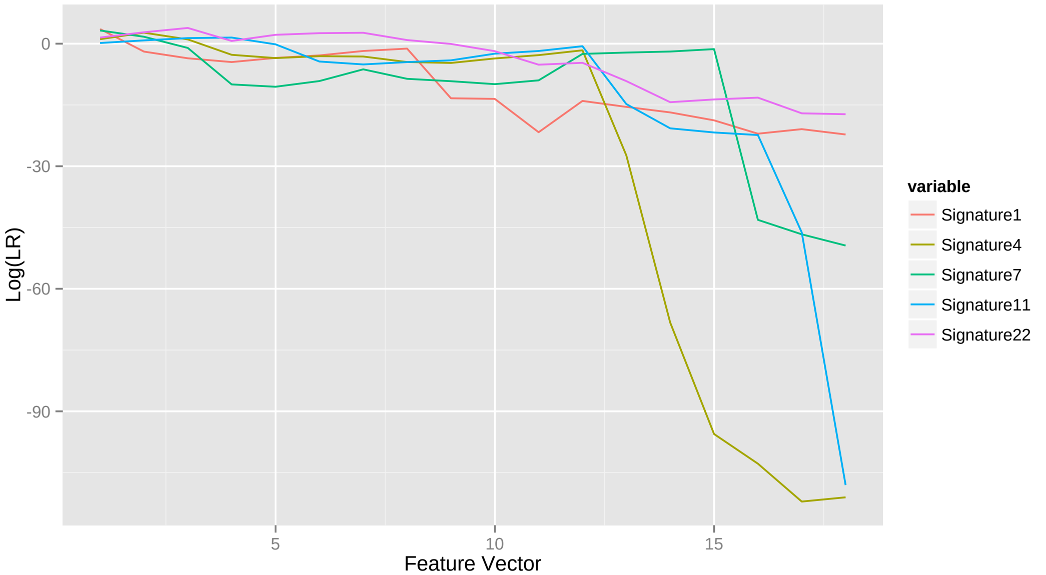


Figure 103 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

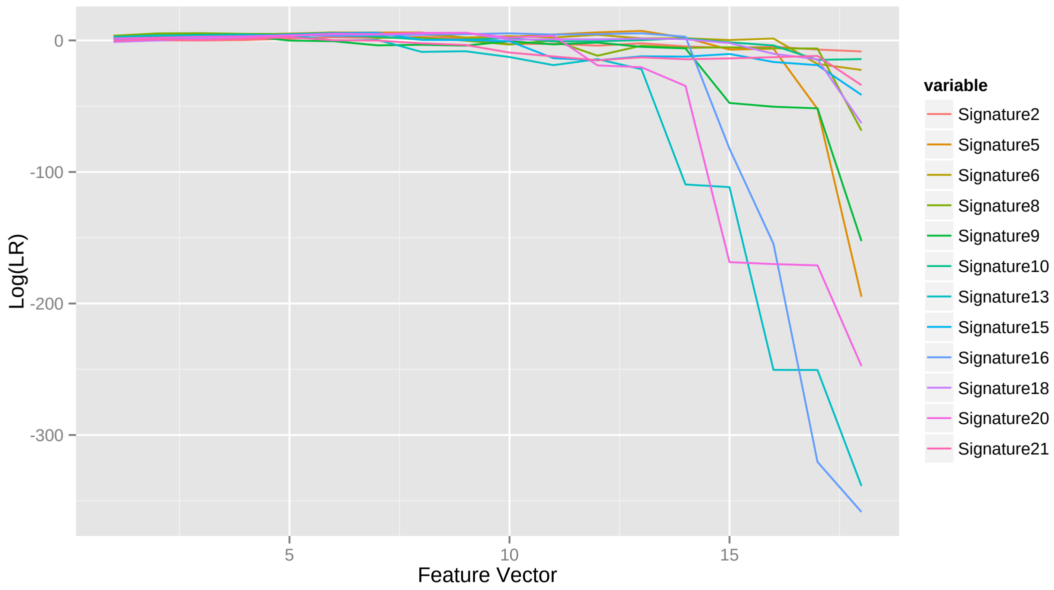


Figure 104 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

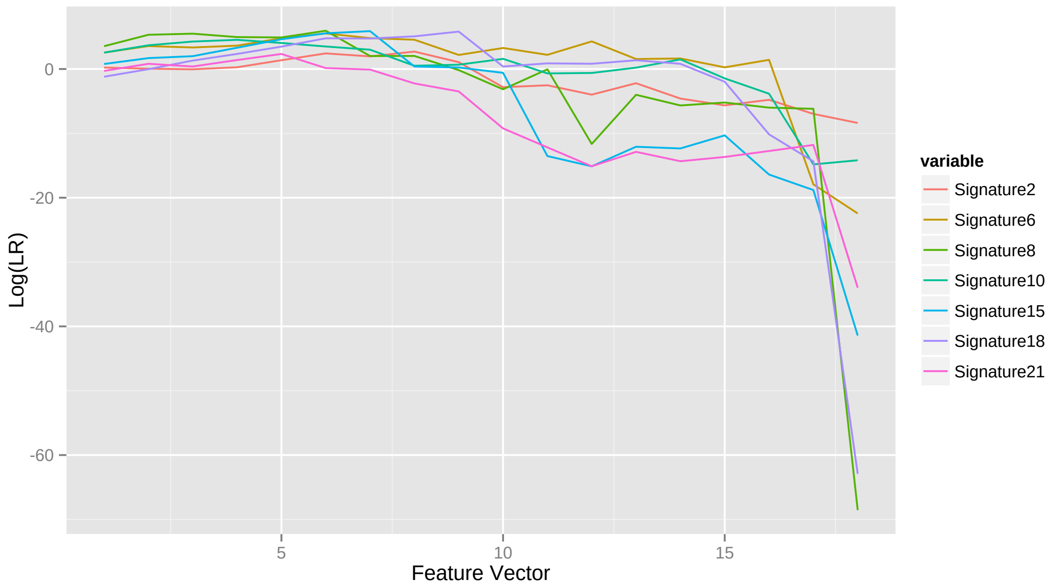
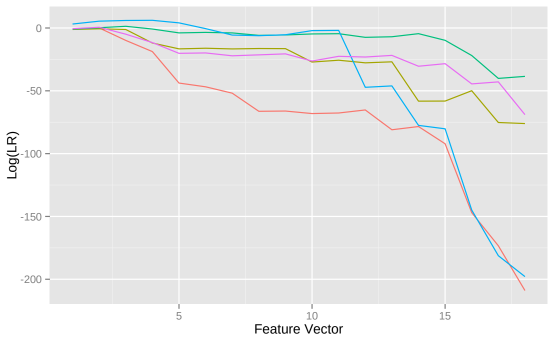


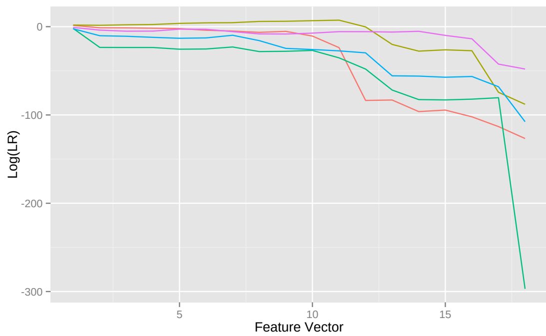
Figure 105 - Likelihood ratios (in a logarithmic form) obtained for the authentic signatures (under H_1), for each feature vector.

The illustration of the evolution of the log(LR) of the simulated signature sets with the length of the feature vector is given in Figure 106. The totality of their signatures gave lower log(LR) values results as the length of the feature vector increased. However, a number of simulators had at least one of their signatures that gave positive log(LR) values within the first 5 feature vectors: these are simulators 3, 5, 9, 11, 14 and 17. Simulator 4 possessed one signature (his second) which presented positive values up to the 12th feature vector.

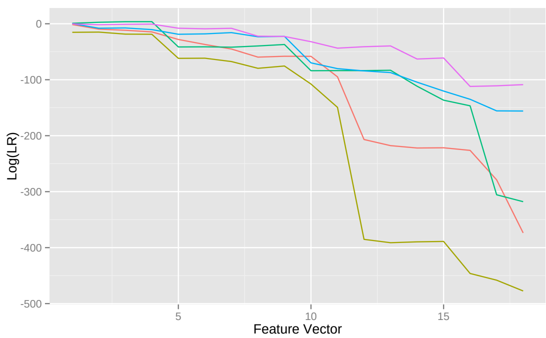
Differences in the behavior of the five signatures of one simulator were highlighted with simulator 13 and 16. For simulator 13, his first signature gravitated below the value of zero, while the other signatures of his set produced low log(LR) after the tenth feature vector. For simulator 16, two behavior groups are observed: two signatures produced results that decrease gradually as the feature vector increases, however the other three show a drastic drop in the log(LR) results after the tenth feature vector.



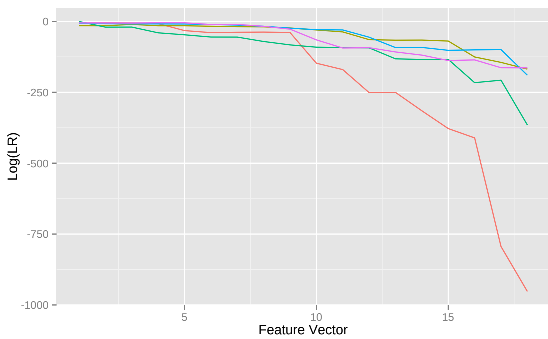
Simulator 3



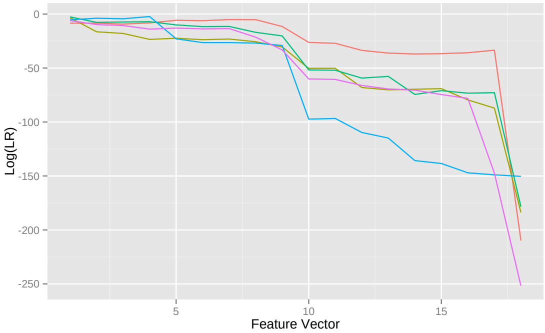
Simulator 4



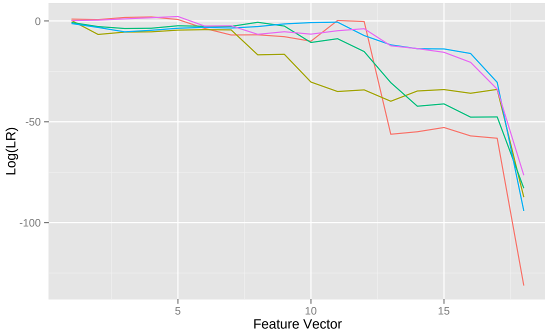
Simulator 5



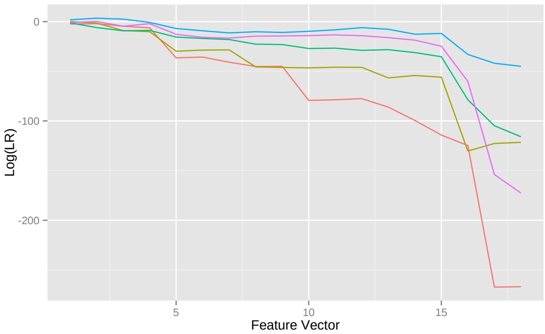
Simulator 7



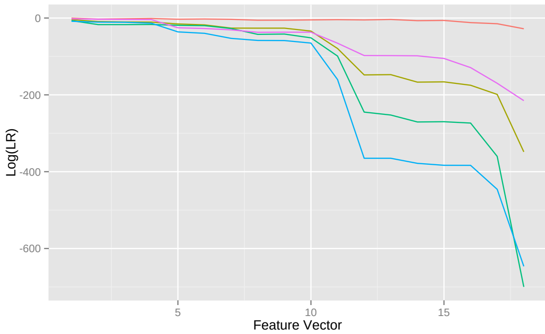
Simulator 8



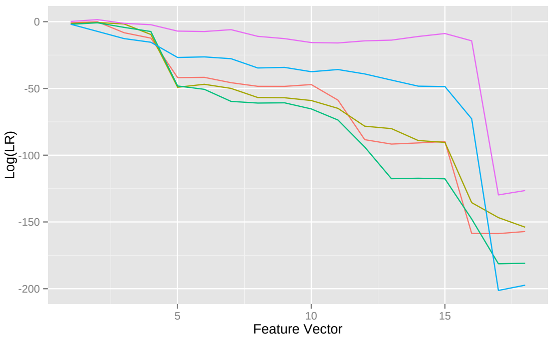
Simulator 9



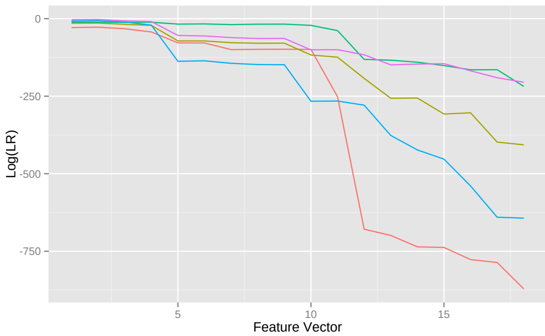
Simulator 11



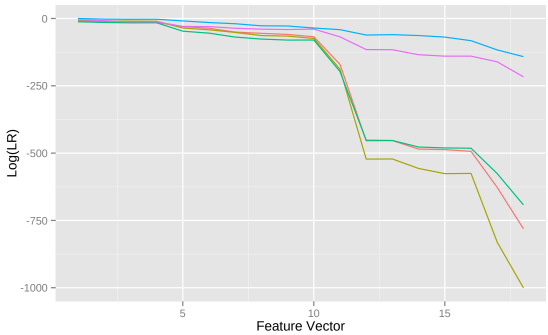
Simulator 13



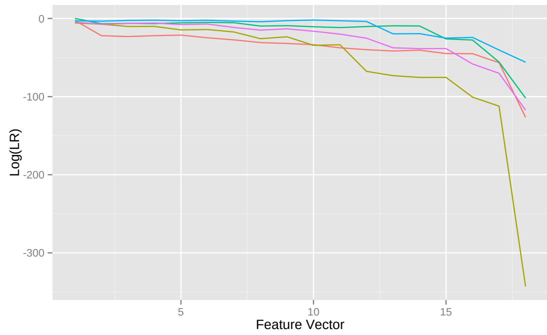
Simulator 14



Simulator 15



Simulator 16



Simulator 17

Figure 106 - Log(LR) results, plotted for the each of the 18 feature vectors, obtained for the 5 signatures samples of each of the simulators of artist n°5. The legend for each signature is as follows: Signature1 Signature2 Signature3 Signature4 Signature5

The calculation of the log-likelihood-ratio cost (C_{llr}) gives weighted results in light of the different behaviors of the authentic and simulated signatures according to the length of the feature vector used. A look of each the impact of the feature vector used to calculate the log(LR) for both signature sets show C_{llr} results under the value of one for only the first seven feature vectors (containing the first two to the first eight features).

Feature vector	Feature vector combination	CCLR
1	2 features	0.522
2	3 features	**0.473**
3	4 features	0.516
4	5 features	0.837
5	6 features	0.768
6	7 features	0.769
7	8 features	0.751
8	9 features	1.179
9	10 features	1.677
10	11 features	2.060
11	12 features	3.033
12	13 features	3.361
13	14 features	4.663
14	15 features	10.580
15	16 features	19.894
16	17 features	29.410
17	18 features	39.961
18	19 features	62.142
19	20 features	Inf
20	21 features	Inf

Figure 107 - C_{llr} results obtained for artist n°5. The lowest value is highlighted in bold.

The C_{llr} results are illustrated in the two plots below (Figure 108). The C_{llr} results follow an exponential increase curve as the length of the feature vector rises.

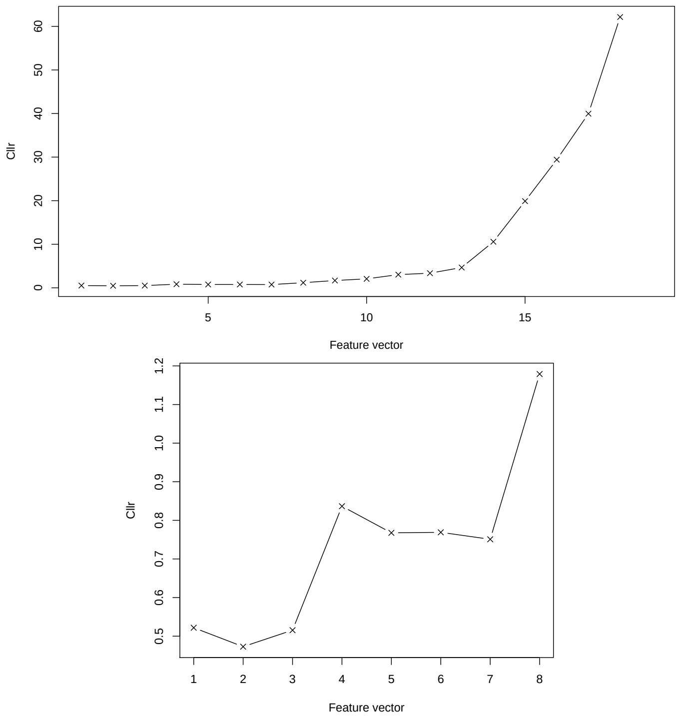


Figure 108 - C_{llr} results obtained for artist n°5, plotted for each feature vector (v_1 to v_{18}) combination composed of two to 19 features (left); C_{llr} values of feature vectors 19 to 20 are not shown due to their infinitive values. A zoom on the first 8 feature vectors (v_1 to v_8) is presented on the right.

The feature vector v_2 (containing the first 3 features) presents the lowest C_{llr} value (C_{llr} = 0.473), and is thus selected for subsequent log(LR) calculations. This feature vector contains the features:

C56	Height of letter -h- / Height of letter -w-
C71	Inferior height difference between letters -J- and -m- / Height of letter -J-
C93	Length of letter -h- / Height of letter -h-

The resulting TP Rate of 91.30% and TN Rate of 81.66% are found. The distribution of the authentic and signatures is presented in Figure 109. The distribution of the authentic signatures is clearly pushed towards the positive side of the axis. The same observation can be made to a lesser extent to the population of simulated signatures.

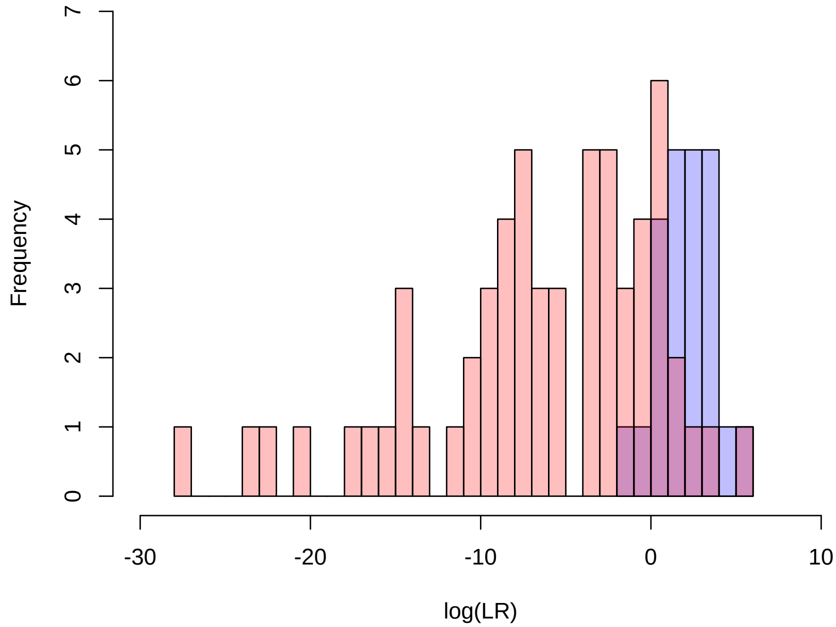


Figure 109 - Likelihood ratios (in a logarithmic form) obtained for the authentic and the simulated signatures of artist n°5 with the feature vector v_2, represented by the number of occurrences of each results. The authentic signatures are represented in red, the simulated signatures in blue.

8.4.6 Synthesis - a comparison between the studied artists

General assessment of measurements and characteristics

Generally speaking, for four of the five artists, the boxplots of the characteristics of the authentic signature set present less dispersion than the simulated sets. For artist n°2 (Bacsay) however, approximately 20% of the characteristics defining his signature present more dispersion than the simulated counterparts.

None of the boxplots depicting the values of the authentic sets are fully separated from the simulated sets, and this for all of the five artists. However, three of the artists (n°2, n°4, and n°5) each possess two characteristics for which the interquartile ranges between the authentic and simulated sets are separated.

For the general assessment of the outliers, visually identified from the produced boxplots, no general tendencies between the five artists can be drawn in regard of the origin of the outlying features (one specific feature class for example). A considerable number of outliers are observed, but they are spread out across approximately one-third to half of each of the signatures sets. Each signature presents at least one outlying feature. However, the outlying features linked to each signature are rarely linked to more than two different features of the signature, even in the case where a greater number of outlying features are observed for the signature in question.

For artist n°1 (Schauenberg), the signature presenting outlying values rarely presented only a single outlier, but rather several which originated from different elements of the signature. However, for artists n°2, 3, 4 and 5, many signatures identified with an outlier presented only a single (or two) outlying feature(s), and often linked to the same element of the signature (for example a unusually large letter), or two elements of the signature. A few signatures did present a larger number of outliers. This is the case for signature AP_15 (artist n°4 - Pasquier), which presented a total of seven outliers, and signature PB_19 (artist n°2 - Bacsay), which presented five outliers.

Principal component analysis

The principal component analysis results can be considered as a measure for evaluating, from a general visual point of view, the authentication method developed. For all five artists, the first three PCs explained from roughly 42%

(for artist n°1) to 30% (for artist n°4) of the total variation. Thus these preliminary visual results are only a partial representation of the data-reduction.

The results obtained from the PCA present differences according to the artist. Generally, the better separations observed between both the authentic and simulation groups (and thus the poorer the quality of execution of the simulations) were done so on the signatures of artists that are of longer length (namely artists n°4 and n°5). For the shortest signature of the study (artist n°1 who signed with his initials), the simulations were of higher quality (a higher amount of signature sets that partially or totally overlap the authentic signature set). The simulations capabilities of each simulator are summarized in Figure 110.

The simulation capabilities seem to be, in light of these results, linked to the personal simulation capabilities of the person, and less to their education or occupation. Indeed, for the first group of nine Conservator-Restorers, simulators ranged from very poor (1, 2, 3 and 10), to moderate (8 and 9) to skilled (5, 7, and 11).[192] For the last group of FHEs, the three simulators fell into the three groups: poor (15), moderate (16), and skilled (17). Only the second group of Artists all produced simulations of good quality: one simulator produced moderate simulations (14), and the other two skilled simulations (4 and 13). This is the only group that showed a global superior skill in producing simulations.

Interestingly, the simulators were not all altogether consistent in their own simulation capabilities. For the simulators 1, 2, 3, and 10 (who already each had one to three signature sets ejected due to false construction modes) and simulator 15, the simulations produced were of either poor or moderate quality. Other simulator's signatures ranged from very poor to very skilled (for example for simulators 8, 4, 13 and 14). Even for the four other simulators that were classified as very skilled (5, 7, 11 and 17), each produced at least one signature set that was of poor simulation quality.

[192] The attribution of the skill of the simulation set is carried out according to the visual results of the PCA analysis and an overall evaluation of these results.

Sim. n°	Group	Artist n°1 Schauen.	Artist n°2 Bacsay	Artist n°3 Muro	Artist n°4 Pasquier	Artist n°5 Schwaller
1	Cons-Res	na	*	na	*	na
2	Cons-Res	*	*	*	**	na
3	Cons-Res	*	na	**	na	*
5	Cons-Res	***	**	**	*	**
7	Cons-Res	***	**	**	**	*
8	Cons-Res	**	***	*	*	*
9	Cons-Res	*	**	**	*	**
10	Cons-Res	*	*	*	*	na
11	Cons-Res	**	***	*	***	***
4	Artists	***	***	*	*	**
13	Artists	***	*	**	**	*
14	Artists	*	*	***	*	*
15	FHEs	*	*	*	*	*
16	FHEs	**	*	*	**	*
17	FHEs	***	*	***	***	***

Figure 110 - Summary chart of the different simulators and their simulation capacity (* poor; ** moderate; *** skilled) in respect to PCA results.

Feature selection

a) Boruta feature selection

A comparison of the class affiliations of the selected features for the five different artists is carried out to detect general tendencies concerning their selected features. The percentages of features that are retained in each class after the feature selection step are reported in Table 36.

The first class contained only one feature, the height on length ratio of the whole signature. This feature was retained for three of the five artists. Generally speaking, classes 2 to 7, which covered the length and height of the letters on either the length and height of the signature, or on the length and height of the letter following the letter in question, produced low results in terms of feature selection. However, classes 8 and 9, which covered the superior and inferior height difference between two letters on the height of the letter before, contained a high number of features that proved to be valuable for the discrimination of both the authentic and simulated classes. The lowest number of retained features was 20%, and the highest climbed up to 83%. Likewise, the class covering the spaces between the letters also produced a high number of retained features, going from 12.5% to 75%. Unsurprisingly, after the results observed for classes 2 to 7, class 11 (which consists of the ratio of the length of a letter on the height of the same letter) also produced low results. Class 12, the intraletter class, produced acceptable results (approximately 10% to 30%). Finally, the last class covering the different measurable angles in the signature produced extremely variable results, from 0% to 70%. Naturally, the angle measurements within each signature are not comparable as they describe different letters, however, the overall discrimination power of this type of feature remains high.

Class	**Percentage of features of each class retained after the Boruta feature selection step**				
N°	Artist 1	Artist 2	Artist 3	Artist 4	Artist 5
1	0 %	100 %	100 %	100 %	0 %
2	40 %	33.3 %	0 %	12.5 %	20 %
3	20 %	33.3 %	20 %	50 %	10 %
4	40 %	0 %	20 %	50 %	10 %
5	0 %	16.6 %	20 %	25 %	40 %
6	20 %	0 %	20 %	25 %	10 %
7	0 %	0 %	0 %	25 %	50 %
8	20 %	83 %	40 %	25 %	55.5 %
9	40 %	33.3 %	20 %	37.5 %	44.4 %
10	∅	12.5 %	75 %	12.5 %	33.3 %
11	0 %	0 %	20 %	25 %	20 %
12	9.6 %	17.9 %	32.3 %	14.6 %	31.1 %
13	37.5 %	70 %	44.4 %	0 %	22.2 %
Total	**15 (on 85) 17.6 %**	**28 (on 112) 25 %**	**26 (on 90) 28.9 %**	**48 (on 146) 32.9 %**	**44 (on 152) 28.9 %**

Table 36 - Summary of percentages of features of each class retained after the features selection step, given per artist.

An overall representation of the weight of the classes 2 to 12 of each artist, in comparison to the corresponding class of the other artists, is illustrated in

Figure 111. One can discern the high weight of class 2 for artists 2 and 3 in comparison with the other artists. Likewise, the 70% of selected features in class 13 of artist n°2 are clearly highlighted in comparison to the corresponding class of the artist n°4 (0%) for example.

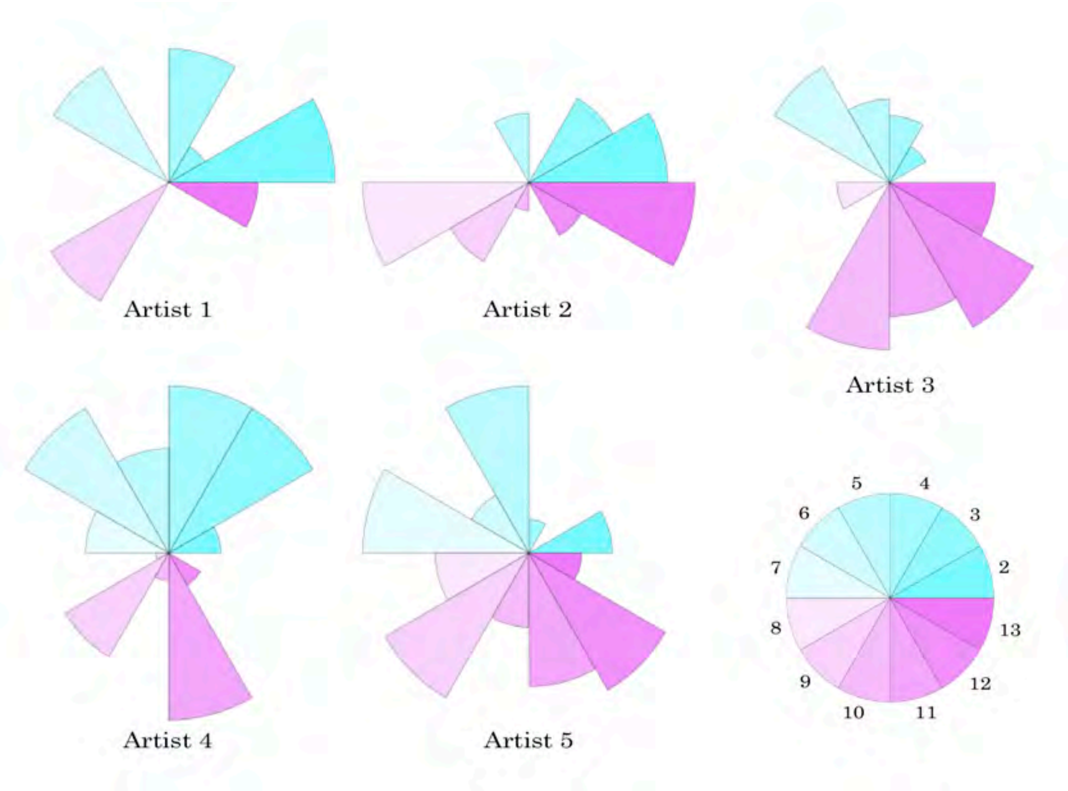


Figure 111 - Graphical representation of the weight of classes 2 to 12 of each artist (after Boruta feature selection), compared to the corresponding classes of the other artists. Bigger pie charts indicate relatively higher percentages in the corresponding class, compared to the other artists.

b) Normality testing

For each set of authentic and simulated signatures of each artist, a test of the normality of each data distribution is carried out to test their subsequent use in the likelihood ratio analysis. For all five artists, the characteristics of the authentic sets produced by the artists are overall normally distributed (ranging from 89% to 95% of normally distributed characteristics for the five artists). A few characteristics show a significant p-value, but they are distributed among the different classes, thus no general tendency regarding the normality of the different classes can be drawn.

However, the simulation sets proved to be drastically less normally distributed. Indeed, percentages of characteristics defined by normally distributed data ranged from 56% (for artist n°2), up to 72% (for artist n°1). A few tendency can be drawn in regard to classes presenting the highest numbers of significant p-values: class 11 (Length of a letter/Height of the same letter) was found to fall in this category for all of the five artist, followed by class 8 (Height difference (superior)/Height letter before), class 9 (Height difference (inferior)/Height letter before), and class 12 (Intraletter) for artists n°3, n°4 and n°5. Finally, class 6 (Length of a letter/Length of the letter after) was highlighted in the same manner for artists n°2 and n°5.

The normality results of both the authentic and simulated sets considered together show that, for at least three of the artists, three classes (6, 9, and 11) each have less than 50% of their variables that are normally distributed. Likewise, for at least two artists, the classes 1 and 12 also each have less than 50% of their variables that are normally distributed.

c) Feature selection (Boruta selection and normality testing)

After the application of results of the normality testing, the disparity between the different classes is even more visible (see Table 37). Only classes 8 and 9 show an overall high retention of features in their classes.

Class	Percentage of features of each class retained after Boruta feature selection *and* Normality testing				
N°	Artist 1	Artist 2	Artist 3	Artist 4	Artist 5
1	0 %	0 %	100 %	0 %	0 %
2	20 %	16.6 %	0 %	12.5 %	10 %
3	20 %	0	0 %	25%	0 %
4	40 %	0 %	20 %	25 %	0 %
5	0 %	16.6 %	20 %	25 %	30 %
6	20 %	0 %	20 %	0 %	0 %
7	0 %	0 %	0 %	25 %	40 %
8	20 %	66.6 %	40 %	12.5 %	33.3 %
9	40 %	33.3 %	20 %	12.5 %	33.3 %
10	∅	12.5 %	75 %	12.5 %	11.1 %
11	0 %	0 %	20 %	12.5 %	10%
12	6.5 %	2.6 %	6.5 %	18.6 %	17.8 %
13	12.5 %	20 %	33.3 %	0 %	11.1 %
Total	**11 (on 85) 12.9 %**	**12 (on 112) 10.7 %**	**16 (on 90) 17.8 %**	**24 (on 146) 16.4 %**	**25 (on 152) 16.4 %**

Table 37 - Summary of percentages of features of each class retained after the features selection step and normality testing, given per artist.

The high difference of feature retention for the classes between the different artists is easily visible in the illustration of Figure 112. For example, for class 4 of artist n°1, the 40% of feature retention in comparison to the other artists stands out. Likewise for class 7 of artist n°5 (40% retention), and class 10 of artist n°3 (75%). Finally, the higher percentage of retention of features of class 13 is visible for artist n°3 in comparison to the other artists.

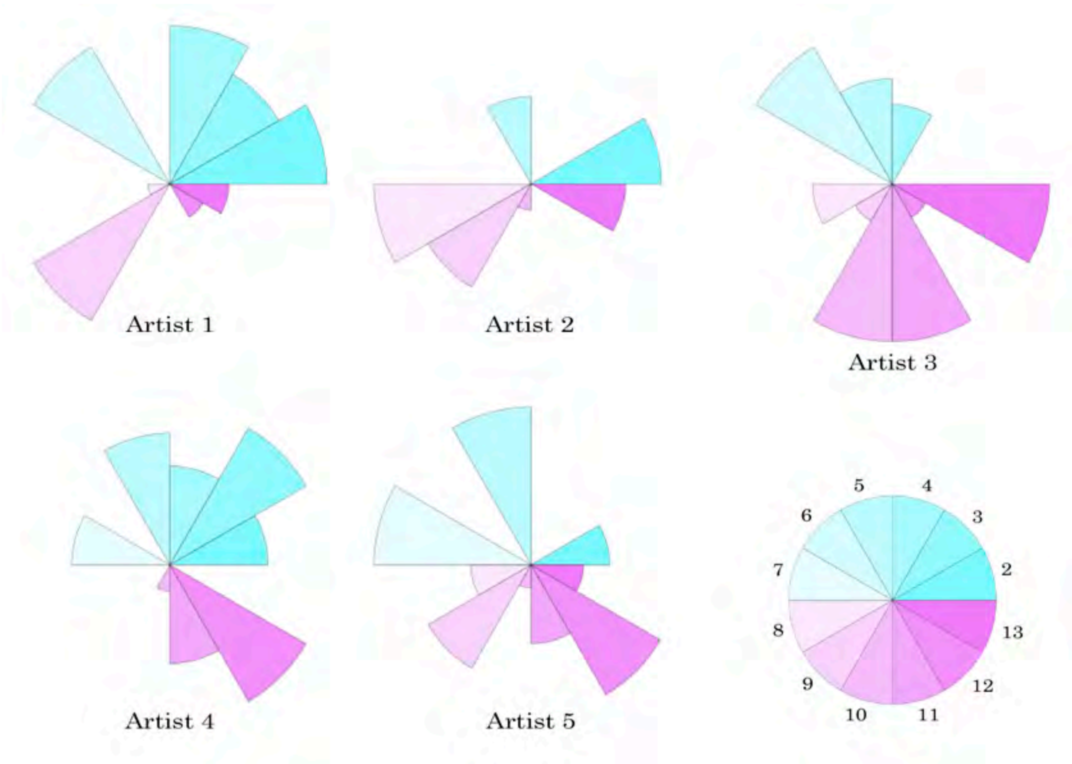


Figure 112 - Graphical representation of the weight of classes 2 to 12 of each artist (after final feature selection, with both Boruta feature selection and normality testing), compared to the corresponding classes of the other artists. Bigger pie charts indicate relatively higher percentages in the corresponding class, compared to the other artists.

Likelihood ratio assessment

All of the five artists presented a signature population whose behavior varied according to the feature vector used:

1. The log(LR) results increased as the length of the feature vector increased;
2. The log(LR) results decreased as the length of the feature vector increased;
3. An increase, followed by a more or less sharp decrease of the log(LR) was observed as the length of the feature vector increased;
4. No simple behavior can be drawn. This group covered signatures that increased and decreased successively, and in no particular order.

Each artist possessed signatures that fell into one of these four groups, except for artist n°5 which presented no signatures that could be classified into the first group. However, the number of signatures in each group did vary:

1. For the first group: as mentioned above, artist n°5 did not have any signatures with this behavior, and artist n°4 only presented one signature following this trend. Artists n°1, 2, 3 each presented between 5 and 6 signatures in this group. Since the artists n°4 and 5 both had longer feature vectors to work with (20 feature long) than the other three artists, the absence of signatures in this class could be due to their classification into the third group (increase followed by a decrease).
2. The second group covered approximately a fourth of the signatures within each artist's corpus. For artist n°3, this group accounted for 12 of his 26 signatures. The slope of the curve changed between the artists: for artist n°2, the slope presented a gradual and constant decrease in the slope, the other four artists however presented curves that lingered around the zero value and proceeded to a sharper decrease after higher feature vectors were reached (v_8 for artist n°1, v_{11} for artist n°3, v_{12} for artist n°4, v_{11} for artist n°5).
3. The third group contained 5 to 6 signatures for the artists n°1, 2 and 3, and 7 and 10 signatures for artists n°5 and 4. The higher representation of signatures from the last two artists is simply due to their non-classification in the first group, in particular for the fourth artist. Indeed, a number of his signatures presented a positive curve up to the fifteenth feature vector.
4. The last possible classification group grouped the signature behaviors that could not be put in the three other groups. Most signatures put into this class concerned signatures whose values gravitated around zero.

The simulators presented noticeable differences between one another in terms of their simulation capacity. An overview of the log(LR) values obtained for all simulators for the totality of feature vectors considered for each artist presented varying results. A few tendencies can however be drawn (see Figure 113):

- Three classes of simulators, in regard to their **overall** simulation capacities, can be drawn: poor[193] (1, 2, 8 and 15), moderate (3, 4, 9, 10, 13, 14, 16), and skilled (5, 7, 11 and 17);
- No simulator was able to produce satisfying results for all five artists;
- Simulation capacities of each simulator varied between the artists: some simulators produced high results for one artist they were simulating, but poor results for another. This was the case for virtually all simulators (the differences were however more or less pronounced between the simulators).
- Variation within the set produced by each simulators also varied: for example simulators 5 and 11, who each produced 2 signatures (for artists n°1 and 2 respectively) with positive log(LR) values for all the feature vectors, were however unable to produce a fifth signature with at least one positive value.
- For artist n° 5, there are not as many signatures within each simulation set that presented a large number of positive log(LR) values for all features vectors, in comparison with the other four artists. This artist thus appears to be more difficult to correctly simulate.

[193] Is understood by poor: two or less signatures with as least one positive log(LR) result are obtained for all five artists. By skilled is understood: at least 4 signatures for two of the artists present positive log(LR) regardless of the feature vector.

Sim. n°	Group	Artist n°1 Schauen.	Artist n°2 Bacsay	Artist n°3 Muro	Artist n°4 Pasquier	Artist n°5 Schwaller
1	Cons-Res	na	2	na	0	na
2	Cons-Res	0	0	0	0	na
3	Cons-Res	1	na	3	na	4
5	Cons-Res	4*	3	5	4	2
7	Cons-Res	5	3	5	1	0
8	Cons-Res	1	0	2	1	0
9	Cons-Res	4	1	4	2	3
10	Cons-Res	0	3	0	0	na
11	Cons-Res	1	4*	2	2	3
4	Artists	2	3	0	2	2
13	Artists	3	1	2	4	0
14	Artists	2	3	4	1	1
15	FHEs	2	1	0	0	0
16	FHEs	4	1	0	1	0
17	FHEs	**5**	4	3	4	1

Figure 113 - Summary chart of the different simulators and the number of signatures produced containing at least one positive log(LR) value, for all considered feature vectors. Simulators 5 and 11 each produced 2 signatures within their set, for artists n°1 and 2 respectively, which produced positive log(LR) values for all the feature vectors (marked by an asterisk).

An overview of the behavior of the log(LR) results obtained for the different feature vectors also showed differences between the five artists. For artist n°1, 6 simulators produced at least one signature whose log(LR) results increased as the length of the feature vector increased (simulators 5, 7, 8, 10, 16 and 17). For artist n°2 this was only the case for 4 simulations (simulators 4, 7, 9 and 11), and for artist n°3 for only 1 simulation (simulator 9). Finally, no simulations of artists n°4 and 5 produced these type of behaviors.

The true positive and true negative results obtained for all five artists for the feature vector after the feature selection step and after the C_{llr} selection step are given in Table 38. The same tendencies are observed for all five artists: the feature vector obtained after the feature selection step (containing between 11 and 21 features) presented substantially higher true negative results than true positive results. As the length of the feature vector decreased, the true positive rate increased, but as a counterpart, the percentage of true negatives decreased (but always in a lesser extent than the true positive increase).

	Artist 1		**Artist 2**		**Artist 3**		**Artist 4**		**Artist 5**	
Feature vector	v_{10}	v_2	v_{11}	v_3	v_{15}	v_2	v_{20}	v_3	v_{20}	v_2
True positive %	56.52	86.95	45.83	66.66	34.61	88.46	4.34	91.30	0	91.30
True negative %	87.14	71.42	88.57	78.57	100	77.14	100	90.00	100	81.66

Table 38 - Summary of the true positive and true negative results obtained for all five artists for the feature vector after the feature selection step and after the C_{llr} selection step.

Even though the feature vectors obtained after the feature selection step were of variable length (from 11 features for artist n°1 to 21 features for artists n°4 and 5), the final and optimal feature vector obtained after the C_{llr} calculations contained either 3 (artists n°1, 3 and 5) or 4 features (artists 2 and 4).

All five artists presented an exponential behavior in the C_{llr} results as their feature vector increased. An inflexion point in the resulting curve was observed for artists n°1, 2, 3, and 5 but these sections never presented lower C_{llr} results than the ones obtained with the first 3 or 4 features and were thus not considered. C_{llr} results above the cut-off of one were reached after the fifth feature vector for artist n°1, the eighth feature vector for artist n°2, the seventh feature vector for artist n°3, the eighth feature vector for artist n°4, and the seventh feature vector for artist n°5.

The lowest C_{llr} results varied between the different artists. The lowest value was obtained with artist n°4 (Pasquier) with C_{llr} = 0.305, followed by the artist n°5 (Schwaller) with C_{llr} = 0.473, artist n°3 (Muro) with C_{llr} = 0.564, artist n°2 (Bacsay) with C_{llr} = 0.706, and finally artist n°1 (Schauenberg) with C_{llr} = 0.731. The features composing each optimal feature vector are presented in Figure 114.

	Feature	Feature class		Letter specification
Artist 1	C14	4	Height letter / Height signature	H -l- / H tot
	C24	6	Length letter / Length letter after	L -l- / L -s-
	C82	13	Angle	-J- : Angle of ascending stroke
Artist 2	C20	5	Height letter / Length signature	H -B- / L tot
	C39	8	Height difference (sup.) / Height letter before	H -A- and -C- / H -A-
	C75	12	Intraletter	-B- : Length of bottom bow, taken from buckle / Length of bottom bow
	C111	13	Angle	-Y- : Angle of left stem
Artist 3	C43	10	Space / Length letter after	-M- and -U- / L -U-
	C83	13	Angle	-V- : Angle of right stem
	C42	10	Space / Length letter after	-V- and -M- / L -M-
Artist 4	C124	12	Intraletter	-i- : Height of initial stroke / Height letter
	C52	8	Height difference (sup.) / Height letter before	-a- and -q- / H -a-
	C7	2	Length letter / Length signature	L -i- / L tot
	C24	4	Height letter / Height signature	H -e- / H tot
Artist 5	C56	7	Height letter / Height letter after	H -h- / H -w-
	C71	9	Height difference (inf.) / Height letter before	-J- and -m- / H -J-
	C93	11	Length letter / Height letter	L -h- / H -h-

Figure 114 - Features composing the optimal feature vector for each artist

Each feature is represented only once (for classes 2, 3, 5, 6, 7, 9, 11) or twice (4, 8, 10, 12, 13) by the different feature classes (ranging from 2 to 13), showing that one feature class alone does not have a more significant weight than then others for the separation of both populations.

Conclusions before moving on

The second part of this thesis presented the results of the experimental stages of the research. A model that can be used to authenticate painted signatures on works of art was developed, and brought forward several contributions to the domain of authentication of signatures on art. The first contribution shows the opportunities and constraints of such a model. The generalization of the obtained results is shown to be extremely difficult, and as a consequence, the use of the results in actual cases difficult as well. These issues will be addressed in the next and final part of this thesis: the discussion of the results and of the model.

The model developed, albeit limited is nonetheless a promising tool, and must be implemented correctly in the expert examination process to be profitable. Thus, a strategy to incorporate the model into the traditional signature expertise procedures must be proposed. The strength of this type of finding must be discussed in conjuncture with the traditional conclusions reached by forensic handwriting examiners, to finally offer a viable solution for the courts.

PART III - DISCUSSION

Introduction

The following two chapters incorporate the discussions that emanate from the results of this research, and make up the third and final part of this thesis. After a discussion of the materials, the methods, and the obtained results of the research, the added-value, the opportunities and the limits of the model will be addressed. The future works that can be carried out subsequent to the results of the study are also presented.

The last chapter of this thesis proposes a strategy to incorporate the model developed in the last chapters into the traditional signature expertise procedures. Thus, the strength of this type of forensic finding developed in the research is discussed in conjuncture with the traditional conclusions reached by forensic handwriting examiners. Consequently, one of the final main aims of obtaining a better acceptance of the signature expertise by courts of law can be reached.

9 Discussion of developed method

9.1 Material and methods

As a reminder, the sampling stage of the artists' signatures was carried out according to the following procedure: At each signature sampling session, each artist was asked to sign his/her signature four times on a 40 x 40 cm oil canvas, however they deemed fit. In this manner, nor the size nor the emplacement of their signatures was controlled. They were also informed that the canvas could be set up however they were the most comfortable (vertically, on a table or easel, etc.).

The artists were asked to maintain a minimum one-week period between each acquisition session. The sampling sessions were repeated 6 times, giving a total of 24 signatures per artist. The sampling over a period of time was chosen following the results of the study conducted by Thiéry *et al.* (2013) which demonstrated the importance of a signature collection procedure covering an adequate number of sampling sessions, with a sufficient number of samples per session.

General information concerning the education, language, the day-to-day painting and signing habits of each artist were acquired at the beginning of the sampling process, and at the end of each sampling session (See Appendix II). Five signatures were also collected with a standard black ink Bic® ballpoint pen at each session.

The best possible conditions were thus given to the copyists to enable them to produce the best possible simulations: the reproductions of the authentic signatures were of high quality, and given in their actual size and in enlargements. The canvases were prepared with smooth layers to reduce to a maximum possible roughness in the support surface, which would affect the line quality and fluidity. The same paint and brushes used by the artists were given to the simulators.

The number of chosen artists to produce the signatures was set at five. This amount is taking into consideration the difficulty of finding numerous artists that fulfill the required conditions, as well as the feasibility of the research planning. Furthermore, the corpus of five artists are deemed as sufficient indicators of the generalization capabilities of the results; the signatures of the chosen artist covering several levels of complexity of signatures. Indeed, the use of a larger amount of artists will only extend the project without bringing in a surplus value. If the generalization capabilities of the results are only partially or totally unachieved, this would point to the fact that each signature examination should be carried out on a case by case basis.

Concerning the signature corpus size sampled for each artist, the choice of 24 signatures per artist was considered as the maximum amount that could be reasonably asked for a research project. This amount is also justified by what could be found in actual casework, since a questioned document examiner can rarely ask and obtain more than this number of samples, even less if the paintings are to be transferred from museums or private collections. Conversely, this amount was considered to be a necessary minimum in order to obtain representative data, while taking into consideration the possibility that certain characteristics may not be present on each signature of each artist. Even so, it is rarely deemed necessary by the forensic document examiner to obtain a higher quantity of comparison material.

The number of chosen authentic signatures is comforted by results obtained from a research conducted by the author (Thiéry *et al.*, 2013) that reveals the importance of a signature collection procedure covering an sufficient number of sampling sessions (12 were chosen in the study), and with a satisfactory number of samples per session, as opposed to signatures collected in a one or two signature sampling sessions.

Concerning the frequency of the sample collection, each sample was obtained by means of four at a time, with an interval of one week between each collection. A minimum one-week period between each acquisition session was maintained in order to cover the natural variation of signature. A period of several months can be judged to sufficiently represent the variation that could be observed on a painting.

The artist signed each canvas four times: either once on each side, or one after each other (horizontally). This type of sampling was preferred to using a small canvas for sampling (with only one signature) because it approaches more realistic conditions in term of spatial dimensions. Indeed, a 40 x 40 cm canvas size was chosen to reproduce a frequently encountered canvas size, and gave the artist enough space to sign without restraint and thus avoid constricted signatures. Practical and economical reasons also dictated the choice of four signatures per canvas, as opposed to just one per canvas.

The parameters for the fabrication of the samples were chosen in accordance with the materials that are commonly found in works of traditional paintings: a standard size brush as well as paint of oil and acrylic type. The author also had to make sure that from the angle of the material, the sampling was feasible. Each canvas was prepared with two layers preparation layers, followed by two layers oil paint. These layers produced a smooth and uniform surface area, thus minimizing line tremors or interruptions that could be due to a rough or irregular support. The artists signed their signatures with the given materials (as presented in Section 6.1.2, one of the artists encountered difficulties with the given paintbrush and used a Pébéo Aqua size 6 synthetic hair paintbrush).

The simulators in this study were chosen because of their affiliation to three distinct, but possibly overlapping groups. The first group of simulators was composed of art restorers and/or conservators. This group was chosen because it appeared to possess the skills necessary to produce proficient simulations: observation, analysis, and dexterity and control in reproduction. The second group of copyists included painters or persons educated in the fine arts or graphic arts. These individuals were chosen because they developed an ease of use in terms of manipulation of paintbrushes, either through their studies, or through their artistic activity (painting on a weekly basis). This pool, like the first group, possesses skills in observation and dexterity. The third group of copyists was composed of forensic handwriting examiners, and was chosen because the professional activity of this group has led them to master the deconstruction of line tracings and to develop an acute sense of observation.

As with the artists, this number of sampled signatures (set at five) was fixed in order to correctly represent the variation in different signature simulations, but was also a maximum that could be readily obtained for the study. For the imitators, the apposition of the five simulated signatures of each artist could be carried out in the one and the same sampling session. Indeed, the variation of the simulations over a time span was unnecessary, seeing as a questioned signature is created at a specific determined time. The author worked under the assumption that the simulators represent a general population of simulators.

The software created for this study was done so that each signature could be easily and quickly loaded into the software, and linked to their appropriate source (artist or simulator). The attribution of the sets of points on each signature could be carried out on full screen representations of the signature, but also on enlargements. The power of the enlargements depended on the initial image size, but for most signatures amounted, at a minimum, to the enlargements of approximately the letter, and at a maximum, to the observation of the pixels composing the line stroke. Being able to access high quality enlargements of the signatures ensured a correct and precise placement of each point on the signatures. The software was also designed to be able to easily change the placement of falsely attributed points in a point set, and to export the obtained results according to the writer and the signature type.

9.2 Results

9.2.1 Results of the observation phase

For this study, different types of signature styles were represented. The artists' signatures were composed of lowercase and/or capital letters, and covered the cursive or script style, or were a mix of both. Varying signature lengths were also obtained. The signatures present a variable degree in their complexity level (number of line crossings, pen lifts, number of letters).

Before the collected simulated signatures could be implemented into the developed database, the general and particular aspects of the authentic signature corpus of each artist were described to assess the variation present in each authentic signature set. A particular attention was given to the construction modes of the signatures of each artist, since they will determine the set of points and measurements carried out at a latter stage. Indeed, the limitations in the attribution of the point sets depended on the variation of the authentic signatures of each artist. If a certain letter or element of the signature was formed in several different manners, it became difficult to place the points. For example, the artist JC Schwaller's letter -w- was formed with either 2, 3 or 4 strokes, only the minimum and maximum height and length of the letter was recorded.

The same general description process was then carried out on the simulated corpuses. Inauthentic signatures that do not follow the same construction mode as those found in the authentic corpuses have been discarded, and already exhibited differences in simulation competencies between the different simulators. Indeed, simulator n°1, having three of his five signatures discarded, showed very poor simulation skills for this person. This filter stage was however implemented because of the method used to characterize each signature, and the necessity in having comparable construction modes between all the signature samples to be measured.

The choice of the characteristics was derived from existing literature in the document domain, for both general aspects of the signature as well as particular features. This literature consisted of fundamental pillars that are well known and have gained general acceptance in the questioned document community. Painting signatures being a sub-field of signature examination, a number of features normally used to characterize a written signature cannot be (or are difficultly) assessed on a painted signature. These features are, namely, the pressure of the line stroke, retouching (or touch-ups) of the line, hesitations, and fluidity. Thus, the usefulness of the analysis method developed in this study is put forward, since one cannot rely on features normally found on signatures made by a traditional writing instrument on paper.

However, other factors may be introduced by the paint element, for example the variation in the thickness of the painted line (for example if excess pressure is produced by the artist) might induce unwarranted variations in the different measurements. These variations in the line thickness might thus be a possible source of the differences in the measurements carried out on the signatures. These variations in the line thickness are not found, or in a lesser extent, on signatures on paper carried out with a traditional writing instrument.

The use of computed characteristics with the ratio of the two measurements instead of a normalized set of the measurements[194] as a basis for describing the data is carried out for two reasons. The first is that experts use ratios of measurements when analyzing and comparing a questioned and reference signatures, rather than absolute distance measurements alone. The second reason for not using normalized measurements is that the size of signatures found on a painting can change drastically according to the size of the canvas. The use of measurements alone in this case could be biased by a small number of large signatures.

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194 For example a min-max or z-score normalization.

Practically, the method developed has the disadvantage of potentially containing errors in the working templates, due to the number of steps the user has to complete for a full analysis. These errors can stem from one of the three main stages the user has to work through for each signature type analysis:

- the points can be badly assigned by the user
- the worksheet containing the measurements (reporting error)
- the worksheet containing the characteristics (reporting error)

These three risks were not assessed with another user in the thesis, since they were assessed in initial analysis with the search of outliers. Since the amount of badly assigned point or reporting errors remain anecdotal, a more thorough assessment was not deemed necessary at this stage of the research.

Of course, these disadvantages are countered by the advantage of the flexibility of use of the analysis method. Indeed, the user can simply and easily modify any three of the above-mentioned steps if he wishes to alter the characteristics that he wishes to analyze.

9.2.2 General assessment of measurements and characteristics

The general assessment of the measurements and characteristics explaining the authentic and simulated signature sets of the five artists was carried out with plots and boxplots of the data sets. The observed outliers are visually identified from the boxplots of the characteristics of the authentic signature sets. Each outlying values is then confirmed as an outlier or an error by observing the signature in question, and by identifying the origin of the outlying value (since its origin can come from either of the two measurements making up the ratio value characterizing the characteristic).

Approximately one-third up to a half of each of the signatures sets present at least one outlying feature. The outlying features linked to each signature are rarely linked to more than two different elements of the signature, even in the case where a greater number of outlying features are observed for the signatures in question. This tendency shows that the artists keep an overall consistency within each of their signature sets. The outliers are spread out across their signature sets, and they rarely produce a signature with a large number of outlying elements. Thus, the presence of a signature where a large number of outlying features, each themselves coming from different and somewhat independent regions of the signature, is unlikely given the present results. The simulators were thus given, in this case, generally homogenous sets of authentic signature sets to inspire themselves from.

9.2.3 Principal component analysis

The conclusions that could be drawn from the PCA results were three-fold in regard to the simulation capacities of the simulators:

- The simulation capacities do not appear to be linked to the group affiliation of the simulator (Conservators-restorers, artists, FHE), but is rather linked to the person's own simulation skill.
- The simulation capacities were highly variable between each simulator. Simulations varied from extremely poor to very skilled.
- However, from the class of skilled simulators, not one simulator produced exclusively high quality simulations; a poor or medium quality simulations was included with the simulation sets for these simulators.

The different simulation skills of observed between the different simulators can be extrapolated from different factors, such as the observation skill of the person, his personal capacity in producing reproductions and his ease of use of a paintbrush. Interestingly, the use of the paintbrush does not appear to a main factor, since simulators 16 and 17 (both FHE) both produced simulations of moderate and skilled levels, although neither regularly use paintbrushes. Likewise, the first three simulators (Cons-Res), use a paintbrush on more regular bases, but their simulations were generally of poor quality.

The reason of the variation of the simulator's skill to reproduce the signatures of the five artists may be linked to the affinity of the simulator with the graphical construction of the signatures. Specifically, a signature written in a script style, for example as is the case with the signature of the artist n°2 (Bacsay), may be easier to reproduce for someone who habitually uses this type of writing style.

For both of these elements, it remains difficult as this point to determine the key factors that explain what makes up a skilled simulator. Indeed, the results do not point towards one specific factor, but rather towards a conjecture of identifiable elements (education, regular use of paintbrush), and unidentifiable [195] elements (personal skill of the simulator, affinity to a signature style, etc.).

9.2.4 Feature selection

The aim of this step of the procedure was to reduce, and minimize the numbers of features that bring out the best separation capacities between both sets of authentic and simulated signature sets. The feature selection step was carried out with two sub-steps: normality testing of features and Boruta feature reduction.

a) Normality testing of data

Only features whose normality could not be rejected for both the authentic and the simulated sets were retained for the further analysis in the study. The choice of the statistical method used in this study imposed the normality of the distribution of the data (Taroni *et al.*, 2012). Depending on the artist, a number of potentially discriminating characteristics were however ejected because of their non normal distribution and by doing so, theoretically weakened the overall separation capacity of the model. In this sense, a higher number of signatures, particularly for the simulated signature set, would prove helpful to obtain more data following normal distributions and being able to continue with the developed method. These characteristics could be re-integrated so the model renders a better output.

Even though some features were ejected due to a non-normal distribution within the authentic signatures sets, most features were thus ejected because of the non-normal distributions of characteristics emanating from the simulation population. The choice of only retaining features that fulfilled this double condition was made according to the further analysis that were to be carried out and that required normally distributed data in both populations. Indeed, to only study one population would be counter productive and put limitations on the likelihood ratio evaluations. A large discrepancy concerning the normality of the characteristics was observed between the authentic and simulated sets. For all five artists, the characteristics of the authentic sets

[195] The author does not imply that these factors are unidentifiable on an absolute basis, but that they are in the case of this research.

produced by the artists were overall normally distributed[196] (ranging from 89% to 95% of normally distributed characteristics for the five artists according to the chosen test). However, for the simulation sets, the percentages of characteristics defined by normally distributed data ranged from 56% (for artist n°2), up to 72% (for artist n°1). This difference is linked to the origin of the simulated population: up to 15 different persons produced each simulated signature set, creating multimodal distributions in the data, resulting in non-normal distributions. A larger set of simulated signatures (more specifically a larger number of simulators) would diminish the occurrence of non normal distributions of the simulated population.

This tendency could reflect the difficulty encountered by the simulators in reproducing these features: a non-normal (and thus multi-modal) distribution a consequence of an incorrect and scattered reproduction of features that are originally taken from a normal population. In other words, the artists produced sufficiently homogeneous (normally distributed) signatures that should have allowed, in theory, the simulators to also reproduced them homogeneously in turn. This was obviously not the case, and aside from the fact that a larger number of persons were at the origin of the simulated sets, one can only conclude that the non-normality is linked to an improper reproduction of these features. Finally, one cannot exclude the notion that the non-normal distribution in the simulation sets could arise from a few number of the (less skilled) simulators within the set.

Regarding the normality of the features within the specific feature classes, for the authentic sets, no general tendency could be observed. However, for the simulation sets, a few tendency could be drawn in regard to classes presenting the highest numbers of significant p-values: class 11 (Length of a letter/Height of the same letter) was found to fall in this category for all of the five artist, followed by classes 8 (Height difference (superior)/Height letter before), 9 (Height difference (inferior)/Height letter before), and 12 (Intraletter) for artists n°3, n°4 and n°5. Finally, class 6 (Length of a letter/Length of the letter after) was highlighted for artists n°2 and °5. In the same manner as the observation made above, one could assume that the increase in the non-normality distribution of these features is linked to the higher difficulty the simulators had in properly reproducing these features.

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[196] Strictly speaking, it should be specified that one cannot conclude that the data is normal, only that the hypothesis that the sample comes from a population which has a normal distribution cannot be rejected.

The normality results of both the authentic and simulated sets considered together[197] show that, for at least three of the artists, three classes (6, 9, and 11) each have less than 50% of their variables that are normally distributed, and for at least two artists, the classes 1 and 12 also each have less than 50% of their variables that are normally distributed. The observation on the difficultly of correct reproduction of the features can be given once again.

Concerning classes 1 and 12, class 1 contains only one feature, thus generalizations are difficult to produce. Class 12 consists of the intraletter features, making generalizations also difficult to produce since the features composing this class are extremely varied. For classes 6, 9 and 11, the highest feature rejection rate (since a non-normal distribution induced a rejection) was observed. This non-normality is, as mentioned above, possibly due to errors and inconsistencies in the reproduction of the line stroke, and could consequently be used as an important element to discriminate the two populations. Therefore, the rejection of the feature can be seen as counter-indicated in light of the ulterior information that it could bring. However, the author preferred to continue using the pre-defined guidelines for the feature selection process, and references to possible future works where a larger simulation population would drain this effect.

b) Boruta feature reduction

The Boruta parameter of ntree=100000 used for the feature selection step gave the highest number of both confirmed and tentative variables for artists n°1. For the other four artists, the parameters ntree=10000 produced, in comparison with the parameter ntree=100000, either the same or a lower number of Confirmed variables, but always a higher number of tentative variables. For example, for artist n°5, the lower number of ntrees gave 36 confirmed and 8 tentative variables. Once the ntree increased, 7 of these 8 tentative features received the confirmed status.

The lower ntree parameters were always rejected for the feature selection step. These results show that above a certain number of trees (approximately 10'000), the results vary little and the increase of number of trees has little impact. The variation in the number of maxRuns (for ntree=1000), confirmed that the higher number of runs made, the lower amount of tentative variables

[197] In other words, when a specific feature is normally distributed in both the authentic and the simulated sets.

were observed. Indeed, once the number of maxRuns increases, these tentative variables are resolved into either the Confirmed variable set, or are classified as unimportant.

As a reminder, the overall results of the feature reduction step (without considering the normality results) are as follows:

For artist n°1, 15 of the 85 initial characteristics were retained after the feature selection step. The classes where the highest percentage of variables were retained are classes 2, 4, 9 and 13. Of the first four selected features, two come the Height of the letter/Height of the signature class (class 2).

For artist n°2, 28 of the 112 characteristics were retained, and the classes where the highest percentage of variables were retained are classes 8 and 13 (without considering class 1). The five first selected features originate from class 12 or 13.

For artist n°3, 26 of the 90 characteristics were retained, and the classes where the highest percentage of variables were retained are classes 8, 10 and 13 (without considering class 1). The three of the first six selected features originate from class 12 and two from class 13.

For artist n°4, 48 of the 146 characteristics were retained, and the classes where the highest percentage of variables were retained are classes 3 and 4 (without considering class 1). The three of the first four selected features originate from class 8 or 9 (both concerning height differences between two letters).

For artist n°5, 44 of the 152 characteristics were retained, and the classes where the highest percentage of variables were retained are classes 3 and 4 (without considering class 1). The two of the first four originate from class 12.

The number of retained features shows great overall differences, going from 15 (artist n°1) to 48 features (artist n°4). However, when considered as percentages, the total percentage of retained features varies from 17.6% (artist n°1) to 25%-32.9% for the other artists (artist n°4 having the highest percentage at 32.9%). The difference observed between the different artists is partly due to the fact that only one tentative feature was retained for artist n°1, whereas for the other artists, this number was equal or higher (up to 6 features for artist n°4). Another origin of this difference could come from the fact that, since the signature of the artist n°1 was shorter than the other four (containing only 4 letters), and the last letter was deconstructed into two letter portions during the establishment of the measurements and characteristics, the additional created characteristics were more correlated between themselves, and therefore judged superfluous and were ejected.

9.2.5 Likelihood ratio assessment

For all artists, the first feature vector, chosen after the feature selection process, was not ideal. High false negative rates were recorded with calculations of the resulting likelihood ratios, rendering the separation capacities of the method of poor quality. However, for all artists, the initial true negative rates were extremely high, reaching 100% TN Rate for the artists n°3, 4 and 5.

The variation of the impact of the length of the feature vector was studied for each artist by analyzing the likelihood ratios given for each feature vector, from the first containing the first two characteristics, to the last feature vector containing the set of characteristics given after the feature selection step (normality testing and Boruta feature reduction).

As stated in sub-section 7.4.6, differences were observed between the behaviors of the feature vectors within and between the artists. Four general behaviors were outlined for each artist:

- The log(LR) results increased as the length of the feature vector increased. Artist n°5 presented no signatures in this group;
- The log(LR) results decreased as the length increased;
- An increase, followed by a more or less sharp decrease of the log(LR) was observed as the length of the feature vector increased;
- or no simple behavior can be drawn. In this group covered signatures that increased and decreased successively, and in no particular order.

The first group concerned principally artists n°1, 2 and 3, since artist n°4 only presented only one signature in this group and artist n°5 none. This behavior is the ideal behavior that is awaited of the authentic signatures: a higher the number of features used to describe the authentic population should yield more weight towards the hypothesis that the signatures were signed by the artist (H_1). However, as the length of the feature vector increased, a "maximal value" of the feature vector could be extricated. With a longer feature vector length, the multivariate analysis system is too poor to robustly manage the amount of data. For this reason, artists n°4 and 5, with longer initial feature vectors, produced only one (for artist n°4) or no (artist n°5) signatures in this first group. The signatures that could have been classified in this group were put into the third group (increase followed by a decrease), for which an increase was noted up to the feature vector 15 for both artists. For artists 1, 2 and 3, the initial feature vector was of a shorter length (respectively 10, 11 and 15).

The second group covered approximately a fourth of the signatures within each artist's corpus. For artist n°3, this group accounted for 12 of his 26 signatures. The decrease of the LR results with a longer feature vector length is either due to the fact that the multivariate analysis system is too poor to robustly manage the amount of data, or that the ideal feature vector for these signature contained the first two features.

The third group contained 5 to 6 signatures for the artists 1, 2 and 3, and 7 and 10 signatures for artists 5 and 4. The higher representation of signatures from the last two artists is simply due to their non-classification in the first group, in particular for the fourth artist. Indeed, a number of his signatures presented a positive curve up to the fifteenth feature vector.

The last possible classification group grouped the signature behaviors that could not be put in the three other groups. Most signatures put into this class concerned signatures whose values gravitated around the zero value. Thus, the features chosen to characterize these signatures were not the optimal features relevant to separate the authentic from the simulated classes. The importance of having a large sample set is highlighted here.

As stated in the results, none of the simulators were able to correctly reproduce the graphical features measured on the authentic corpuses for all five of their simulated signatures. However, some simulators were able produce at least one signature within his corpus that gave a positive log(LR) result, resulting in large differences within the simulator's corpus, and thus his simulation capacities. The difference in the simulation confirms the results found in the principal component analysis, each simulator is different and his capacities are not linked to his professional background. Thus, the generalization of the results of the population of simulators to another unknown simulation population remains problematic.

One of the reasons that can be imputed to the differences observed between the simulators is they did not base their simulations on one specific signature, but rather on at least two different signatures, if not more. Most of the simulators stated that they tried to reproduce simulations that were representative of the whole corpus of each artist. Only one simulator (17) stated that their simulations were based on one specific signature sample.

The C_{llr} results of all of the artists followed an exponential increase curve as the length of the feature vector rose. The minimal values of the C_{llr} results were chosen to compose the final feature vectors for each artist in order for the model to be the most calibrated possible. By choosing the lowest C_{llr} value, the system is best calibrated to diminish the costs of errors, but, is at the same time, less powerful and produces lower LR results in favor in one hypothesis or another. An example of the effect of the calibration can be given with artist n°5 (Figure 115).

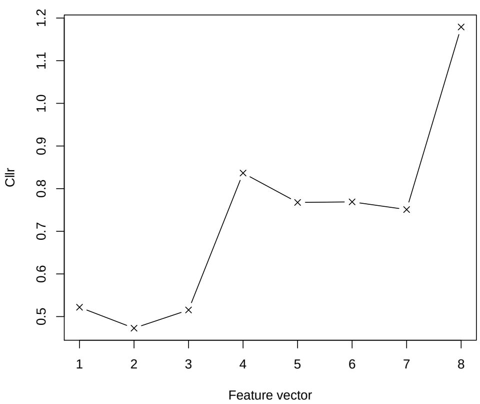

Figure 115 - C_{llr} results obtained for artist n°5, plotted for the first 8 feature vectors (v_1 to v_8).

For this artist, the feature vector v_2 (containing the first 3 features) presents the lowest C_{llr} value (C_{llr} = 0.473), and was thus selected for subsequent log(LR) calculations. The resulting TP Rate of 91.30% and TN Rate of 81.66% were found. By selecting the seventh feature vector v_7 (containing the first 8 features), which corresponded to the lowest C_{llr} value (C_{llr} = 0.751) after the inflexion point in the calibration curve, the rate of TP Rate decreases to 73.91% and TN Rate increases to 98.33%. The distribution of the authentic and signatures with feature vectors v_2 and v_7 are presented in Figure 116.

The increase in the feature vector length renders lower log(LR) obtained for the simulated signatures. By choosing the lowest C_{llr} value, and calibrating the system, we wish to minimize the costs that can be associated to a high (or low) log(LR) results. In Figure 116, the higher C_{llr}, taken with the longer feature vector, presents lower results for the simulated set (up to approximately log(LR) = -140), while this same signature is scaled down to log(LR)=-28 with the lowest C_{llr} results. This calibration step has however the disadvantage of rendering the system less powerful, since lower LR results are associated with each possible error (the LR associated to the errors have a greater importance). These notions can have an impact when presenting a case to the court. Finally, it is important to recall that one of the objectives of this thesis was to minimize the number of features, and this objective is also reached by applying the calibration step.

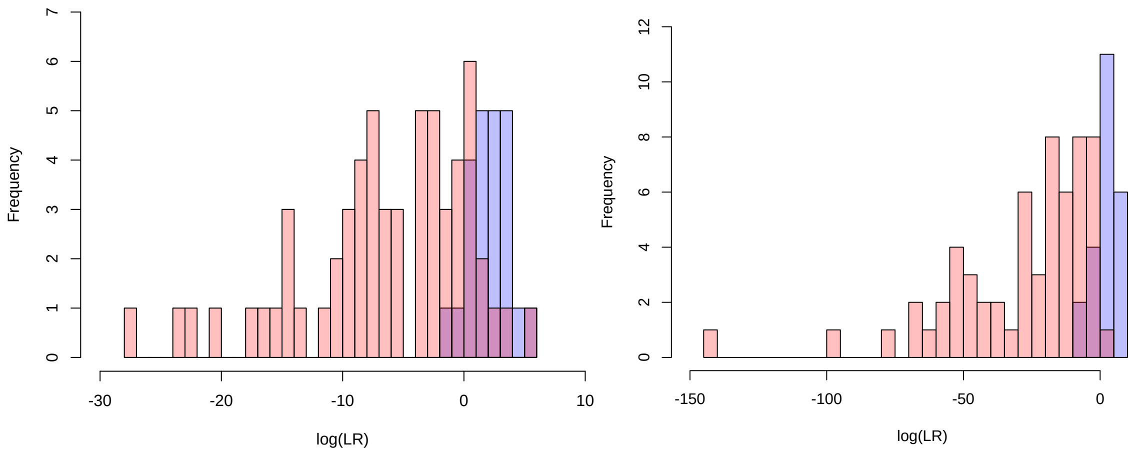

Figure 116 - Likelihood ratios (in a logarithmic form) obtained for the authentic and the simulated signatures of artist n°5 with the feature vector v_2 (left), with the feature vector v_7 (right) - both with a different scaling. The authentic signatures are represented in red, the simulated signatures in blue.

The final likelihood results, obtained for all of the artist with their lowest C_{llr} values, vary in the following range (see Table 39). The second artist had two signatures giving high LR, signature 13 (LR=3010.55) and 14 (LR= 812.06). The remaining 22 signatures of this artist's set did not exceed an LR of 64.91. The third artist also had only two signatures giving high LR, signature 17 (LR=2619.30) and 18 (LR= 684.04). The remaining 24 signatures of this artist's set did not exceed an LR of 35. These LR results thus provide only a very limited support in favor of either hypothesis H_1 or H_2.

Artist	Authentic set		Simulated set	
	LR min	LR max	LR min	LR max
1	0.02	26.01	0	20.87
2	0.12	3010.55	0	29.15
3	0.08	2619.30	0	20.17
4	0.16	54.50	0	64.57
5	0.14	205.36	0	229.32

Table 39 - Minimum and maximum likelihood ratios for both authentic and simulated sets of all five artist. Note: values lower 1*E-5 are noted as 0.

These low LR results do have the advantage of proving, with measures to support the affirmations, that the expertise of painted signatures on works of art only provides limited support in favor of either hypotheses, and does not allow us to be as positive in the attributing the authorship of a signature as some experts affirm.

The reduction of the number and types of the most relevant features best separating the authentic set from the simulated counterpart show that the final relevant feature vectors obtained varied between the five studied artists. The extrapolation capabilities of the method are thus limited, and the expert has a limited possibility to generalize these results to his own casework. In order to obtain the highest possible log(LR) results, the whole procedure must be carried out from the beginning of the process. A generalization of the results to other artists is, at this stage, not possible.

These recapped and discussed results, as well as the results shown in the summary (sub-section 8.4.6), show the extreme complexity that resides in the attribution of a painted signature: in the limited strength of the model and the limited capacities to extrapolate the obtained data to other cases. In the sense, we cannot expect strong evidence arising from this developed approach. An overall discussion of the proposed recommendations and of the developed method are necessary to weight its possible opportunities in strengthening the field of examination of painted signatures, but also the constraints and limits in its use and implementation.

9.3 Overall discussion of the proposed recommendations and developed method

The recommendations that stem from the exhaustive literature review offer, for the first time, a series of guidelines to be implemented by FHE confronted with the specific examination of painted signatures, and of signature analysis in general. The expert should follow these guidelines when establishing a within population of the studied artist (numerator of the likelihood ratio). These recommendations highlight the interdisciplinary nature of the examination of signatures on paintings, and how the signature is just but one of the many aspects that can and should be studied when determining the authorship of a work of art.

Some constraints were put forward by the limits of the model. The results of the study point towards a very limited possibility of generalization of the results, even if the number of the artists used in this study also remains limited. Indeed, even if only five artists were selected, any subsequent generalization of the results to other artists with a larger sample of studied artists remains extremely limited. The results obtained in the study (final likelihood ratios) can only be linked to, and depend on, the artist studied in question.

Since no generalization of the relevance of features extracted from signatures could be made, if this model were to be operationally implemented for FHE and deployed into a realistic casework situation, the expert would have to carry out the entire procedure from the beginning to the end, from the data collection, to the definition of the points, measurements and characteristics, to the analysis and comparison of both data sets. The expert would have to produce, with the help of a pool of simulators, the set of simulated signatures samples to constitute the between population. He could also use to this end known forgers of the artist's signature. For the modelling of this population (distribution linked to the denominator of the likelihood ratio), the expert must have a population of forgers at his disposal, and whose data will represent the distribution of the denominator of the likelihood ratio for each given artist, this distribution not being able to be postulated.

The collection of the population of simulated signatures for an actual case is an enormous operational constraint of the model and its implementation for actual use in casework. The limit of this model has ramifications larger than in the field of examination of painted signatures: these constraints can be translated as the constraints that are put on FHE when carrying out analyses of signatures. The constraints in which the system must operate highlight the constraints in which the expert should, in light of the present results, operate, if he wants to effectively measure the variability of the simulation population. As a consequence, the expert, who bases his examination and evaluation on his experience and on the generalization of his past observations must question the validity of his estimations of this population that make up the denominator of the likelihood ratio. In the signature examination procedure, one cannot settle for the appreciation of the expert to which extent a forger might have painted a signature, without the expert having been able to gather operational data. The ability to reproduce the signatures can indeed be estimated and appreciated in a holistic manner by the expert, but, without the effective data set, he cannot measure them.

However, what may seem as operational constraints can be pivoted into a strong point of the method: since a modelisation of the variability of the simulation population is known, the weight of the results are also therefore inevitably reinforced and can clearly be used in the court to show the transparent and evidence-based results of the signature examination.

Another limit of the method is that it is not developed to detect an element that may have been added on a simulated signature (for example a terminal hook in a letter), but that is not present on any signature within the authentic corpus. In this case, the added element is purely a particular element linked to the graphical style of the simulator. If these additional elements are present, the method is not able to adequately measure and characterize them (it may be counted in the length, or height, of a letter or of the signature), since the list of features is based solely on the authentic corpus. The assumption is nevertheless made that the simulator is sufficiently skilled to not add any personal additional elements: since the authentic corpus do not contain these features, the simulation set should theoretically be exempt of them as well.

Since the extrapolation capabilities of the method are limited, and that the expert has a practically no possibility to generalize these results to his own casework, he must carry out, if implemented, the whole procedure from the beginning of the process. This has the major disadvantage of being time-consuming for an expert, and, inevitably, a costly procedure.

Furthermore, if the expert were to carry out the whole procedure for an actual case, we cannot, based on the results of the study, expect strong evidence arising from this developed approach to either hypothesis of an authentic or simulated signature. Even lower results should be expected, since all operating conditions will reduce the LR.

However, a number of opportunities do arise from the study in general, and are worth highlighting. For the first time, cases that can be calibrated on actual data from authentic and simulated signatures are carried out. The study is based on concrete measures that allow for a transparent appreciation of the signature examination process.

As such, the study has shown the extreme complexity that resides in the attribution of a painted signature to an artist. This complexity is resides notably in the limited strength of the final results, which show that the expertise of painted signatures on works of art only provides limited support in favor of the competing hypotheses, and does not allow us to be as positive in the attributing the authorship of a signature as some experts affirm.

In conclusion, the method, does not appear, if left unchanged and in light of the exposed constraints and with respect to the investments, to be worth pursing. The overall added value of this model, if it were to be implemented for actual casework, is limited. An implementation of the developed system for practical cases does not seem viable for the time being.

However, the model has brought forward areas for improving the robustness in the examination of painted signatures, but also in the signature examination process in general. The expert process was meticulously analyzed by following the guidelines emitted and the steps of the model. This step by step examination process reinforces the work carried out by the expert and allows him to have a basis of common discussion with other experts and stakeholders. These areas will be developed in the last chapter of the thesis.

9.4 Future works

Four signatures are collected in the information sheet a with a standard black ink Bic® ballpoint pen (in a predefined printed rectangle). The data collected during the acquisition stage will enable a signature comparison between the painted signatures and the written signatures of each artist, using the same method developed in this research. The results will offer the possibility of verifying the hypothesis of motor function equivalence. Indeed, the gesture and muscles implicated in both of these signing processes are different, but perhaps no difference can be detected between the final products.

The technique developed in this study is based on continuous variables alone. The reason is linked to simplicity of use and development of a model at this early stage. An integration of discrete variables into the model could however be implemented. These variables could be for example be factual observations, such as the presence or absence of hooks, or of attacking and terminal stroke, or these variables could results more from impressions of the examiner, such as impressions of fluidity of the line and of tremors.

The model could also incorporate other elements of the signature that were not studied in the present thesis. The form of closed bowls could be analyzed and integrated as supplementary characteristics in the already existing set (Marquis, 2007). These characteristics have shown to have a discriminative power and could therefore, if present in the signature, reinforce the separation capacity of the global method.

A number of improvements could be conceived in regard to the software developed in this study. Indeed, the software was designed for a functional and efficient use in the frame of this research, but improvements could be carried out if the method is implemented on a larger scale. The interface of the software could be changed to help the user determine the points, and diminish the possibility of wrongly attributed points. The acquisitions of the points could also be carried out in a more or less automated mode.

The larger number of signatures in the simulated set would give a more realistic reflection of the actual state of possible variations in a simulated population. A larger sample set, either with a larger number of simulators, or a larger number of simulations per simulator (or a combination of both), could diminish the precocious ejection of features as mentioned in the normality study section, and theoretically increase the separation capacity of the two populations.

Other methods of the feature selection step, to arrive at the final likelihood ratios, could also be explored. This could be particularly beneficial to eject the normality testing stage that did show a drastic drop in the number of relevant features, and not warrant a higher number of simulated signature as stated in the preceding paragraph. Likewise, an optimization of some of the calculation methods (Boruta reduction for example) could also be undertaken.

The developed method could undergo tests of the repeatability and reproducibility, either from the beginning of the analysis stage (where different experts assign the points, the measurements and the characteristics of an artist's signature, followed by the point selection), or directly from the data collection stage (point selection). The robustness of the method with different users could be assessed. A comparison of results obtained with model with those obtained by FHEs could be step forward in the juxtaposition of the model's results with those of a FHE. Likewise, real cases carried out by a FHE in the field of painted signatures could be analyzed with the model and difference between the two studied in the same manner.

Blind testing between experts and results of the model can be carried out. The aim would be to see if a difference is obtained in the expert conclusions if a tool is given to help him during the authentication process. Langenburg and his colleagues (2012) found that tools given to a fingerprint examiner, such as other expert's opinions or LR assessment tools, help decrease the false positive and false negative rates. The tool in this case would be the LR results obtained with the model of this study. The expert conclusions given by experts that are given the tool, in comparison to experts without the tool, would be studied. The possible realization of the developed method as a tool for FHEs is considered in the last chapter of this research.

10 Juxtaposition of two-source results

10.1 Introduction[198]

The aim of this section is to discuss how the results obtained with the model developed in this study could be integrated or combined in the traditional signature examination process. The results obtained are of course limited as shown to the artists in question and have potential operational constraints and limits that may need to be overcome, but they do present an opportunity as an effective method to correctly aid the reasoning process. If such a model is developed to be ubiquitously used, and can effectively support the correct hypothesis, then the expert must possess a logical and documented strategy to integrate the model's findings into his own reasoning process. Indeed, without a clear structure explicating how to embed the two examinations, the addition of each taken individually is worth less for the expert than the two put in combination with each other. Thus, the prominent question that will be addressed in this section, and that constitutes the closing chapter of this thesis, is how to link both the traditional holistic signature examination expertise and the developed quantitative model.

Even if the model cannot be implemented at the present time within the framework of this research, this general discussion regarding the juxtaposition of results obtained from a model and a forensic expert can be generalized to a number of forensic domains, well beyond the scope of signature examination. Indeed, the use of more or less opaque models will inevitably be developed in the future and their co-existence will have to be addressed. The future expert will be assisted with technological systems that will help them appreciate the weight of their forensic findings.

Foremost, and before jumping into the subject, there are two main possibilities on how to integrate the results of this developed model and the results of the traditional signature expertise:

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198 This chapter is the fruit of numerous discussions carried out with colleagues of the School of Criminal Justice, Dr. Raymond Marquis in the field of signature and handwriting examination, and Dr. Nicole Egli Anthonioz in the field of fingerprint examination.

- The results of the model are used alone, and the conclusions of the traditional expertise put aside completely.
- Both the results of the model and of the traditional expertise are used together to arrive at a conclusion that takes advantage of both processes.

One could argue that the model, albeit limited, demonstrates sufficient value for the individualization process, and therefore to carry out the traditional expertise, tainted with the difficulties of the subjective approach to it, on top is a superfluous and non-necessary task. However, since the model only uses a metric view, a number of elements are left to the discretion of the FHE during his examination for analysis (for example, specific forms of letters or ornamentations). This clearly justifies the complementary use of both the traditional signature examination procedure with the developed model.

The complementary implementation however implies a perfect working situation of this system. Each possible outcome scenario should be discussed beforehand, in order to possess a transparent structure. Indeed, once the procedure of implementing the quantitative model into the traditional examination process is finalized, the option of picking and choosing, for example, cannot be an option. The expert cannot take into account the results of the model when they provide him with a supplementary weight in his conclusions, comforting him in his decision. Likewise, the expert cannot decide to discard the results of the model that do not please him, or that go against the results obtained with the holistic examination. Therefore, one of the aims of this chapter is to identify the possible conflicting scenarios. Once these conflicting results obtained from the model and from an expert have been defined, a procedure to resolve them will be addressed. The developed protocol will offer a coherent framework for FHEs to structure and communicate their views with one another.

10.2 Resolution of conflicting conclusions between two experts

Before comparing the results of an expert with that of a model, a few ideas on how to complement the two can be taken from a case that practically every expert has faced at one time or another of his career: when one expert reaches a conclusion that is contrary to the one reached by his colleague. For example the first expert arrives at an inconclusive conclusion, while the other may support the hypothesis that the signature is authentic rather than simulated. The two conclusions can be even more extreme, for example, if one expert is more inclined towards an authentic signature while the other is more inclined towards a simulation. One can easily imagine this case scenario, especially since FHE, who normally follows the ACE-V approach (as seen beforehand, the V standing for Verification by a peer), are bound to arrive at different conclusions at one point or another in their careers.

So, how are these cases with conflicting conclusions between the two experts resolved? One of the two experts can try to convince the other that his logic is better, that he has more experience, or that he spent more time on the case, and so on. But if we imagine the scenario where the two experts have similar training and experience, have spent the same amount of time on the case, and are more or less equal in other aspects relevant to the examination process, how can their conflicting conclusions be resolved?

As shown in the preceding chapters, recent literature suggests that the ACE-V approach is accepted for handwriting and signature examination. There are several reference books and articles that describe how the analysis and comparison stages should be carried out. However, and likewise as observed by Champod (2008) in the field of fingerprint examinations, elements pertaining to the evaluation and verification stages are not as developed. For example, literature on the weight a forensic examiner might give to different features observed in a signature examination is scarce. Likewise, the different elements (such as conflicting conclusions) that fall under this verification stage umbrella are also rarely addressed.

In practice, the verification phase of a signature analysis case could be carried out by the second expert by reading over the report of his colleague, and with a thorough discussion between both experts of the findings they made (see Figure 117). This situation does present the advantage of being time efficient for the second expert, all the while verifying the ACE procedure and findings of the working expert. It is however not recommended because of the possibility of bias effects on the second expert.[199]

[199] The author would like to highlight that this possible bias threat has yet to be demonstrated in the field of signature and handwriting examination at this present time. However, taking steps to minimize this possible bias seems like the logic consequent of elements developed in Chapter 5.

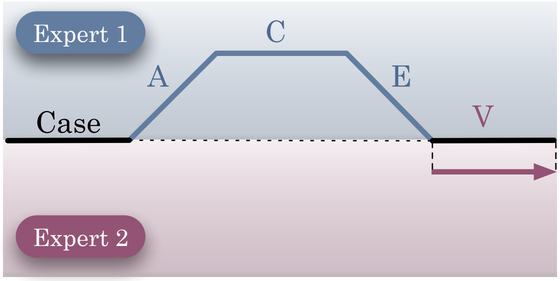

Figure 117 - Schematic representation of the ACE-V examination procedure

Ideally, the whole examination procedure should be carried out by both experts, thus guaranteeing independence between the outcomes with a realistic confrontation of both experts' results. The bias effects are also highly diminished by implementing this line of working. The ACE procedure would thus be carried out by both experts, either one after the other (see Figure 118), either simultaneously (see Figure 119).

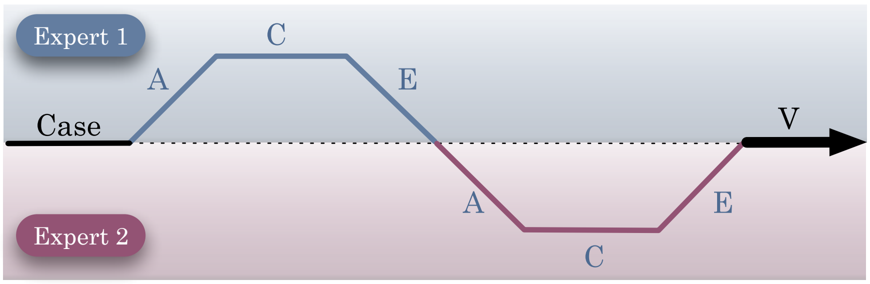

Figure 118 - Representation of ACE-V examination process carried out by first, then by second expert

The simultaneous two-expert ACE-V examination process has the advantage of minimizing the potential bias effects, since both procedures are carried out simultaneously, and the second expert will not have the temptation of obtaining the first experts' results.

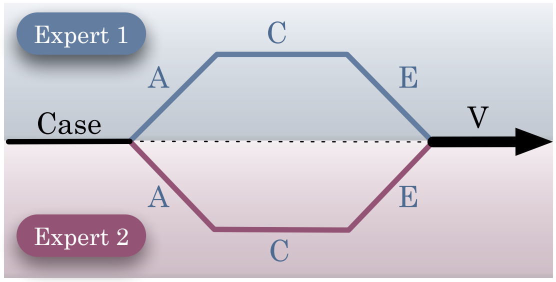

Figure 119 - Representation of ACE-V examination process carried out simultaneously by two experts.

However, if such a procedure is carried out, the evaluation and verification stages must be transparently dissected in order to coherently understand and propose a scheme for the joint implementation of both experts' conclusions. A proposal of an evaluation process enabling two experts to arrive at a consensual final conclusion, and taking into account the specifics of both the evaluation and verification stages, was elaborated and is schematically proposed in Figure 120. This figure summaries the different analyses, conclusions, confrontations, and discussion steps that should take place between two (or more) experts in their evaluation procedure, and proposes their logical arrangement.

Of course, this working procedure illustrated in Figure 120, is established in the context of a best-case scenario, where one expert has been mandated to work on a handwriting or signature case, and does so with the ACE-V approach. This canvas will be explained in the view of signature examination specifically. The second expert is within a same laboratory, and both of the experts are expected to give a final consensual conclusion on the signature case. For this general canvas, the working hypotheses are known and laid down by both experts. Both experts carry out the evaluation according to the same underpinning principle, and must provide a conclusion situated on a commonly used verbal scale (if used).

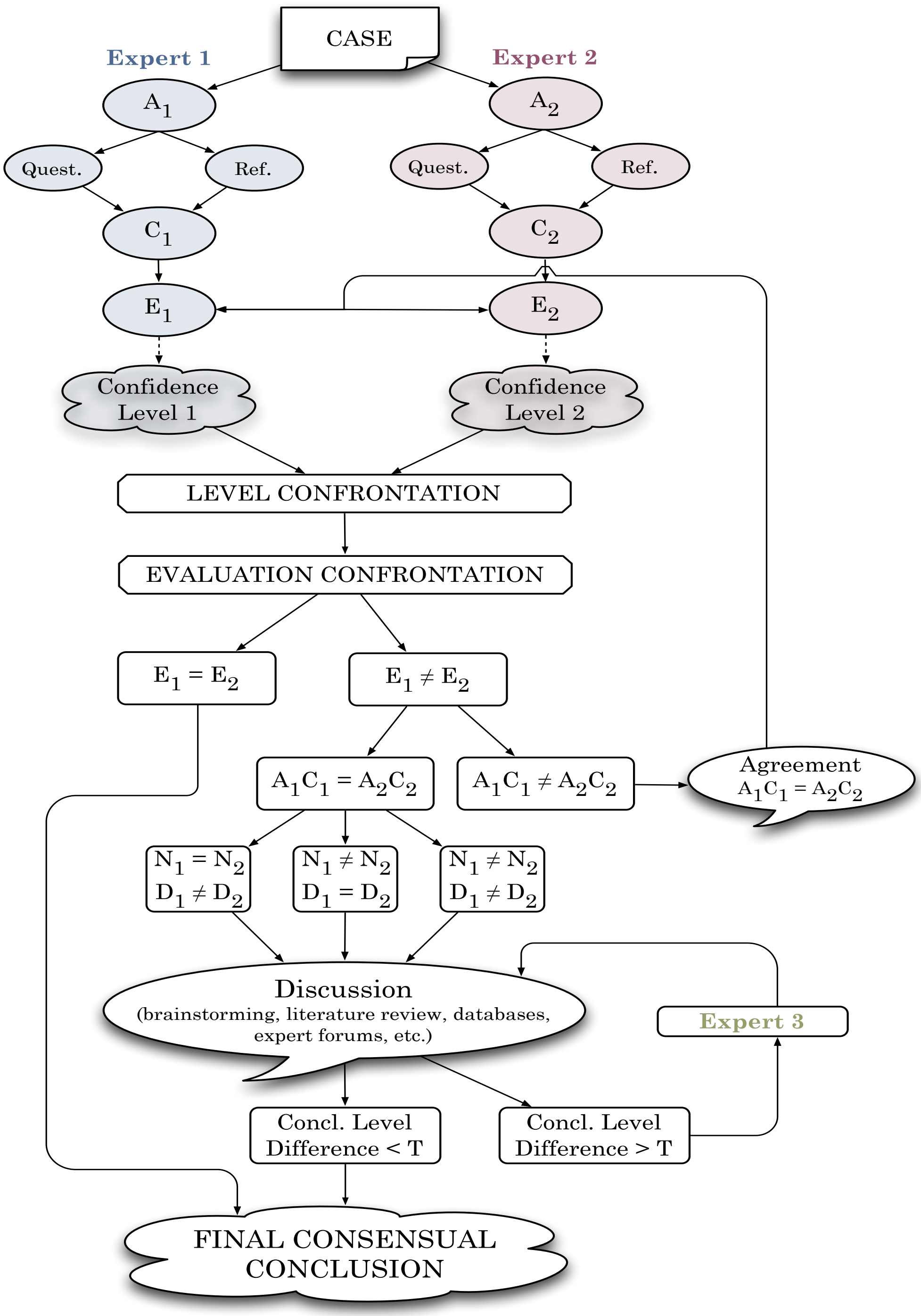

Figure 120 - Consensual signature evaluation procedure between two experts. Each activity is represented by a specific shape: the individual actions are represented by circles, the conclusions by clouds, expert

confrontations by hexagons, possible expert actions by rectangles, and discussions by discussion bubbles.

When an expert works on a signature examination case, he first conducts the analysis of the questioned and reference signatures. He then compares both of these analyses together in order to identify a number of findings that are evaluated in the light of two competing hypotheses. These steps consist of the A-C-E steps. These two phases are presented in Figure as the A_1, C_1 and E_1 nodules for the first expert. The second expert will theoretically follow the same evaluation process, represented by the nodules A_2, C_2 and E_2 in the figure. At the end of each expert's ACE procedure, each expert will have reached his own conclusion, given in the form of a confidence level (Confidence Level 1 for the first expert, and Confidence Level 2 for the second expert). This confidence level conclusion is intrinsically linked to the evaluation phase of each expert, but is graphically represented separately for the sake of clarity. These expert confidence levels should be understood here as the final conclusions of the experts, stating for example: "The findings observed on the questioned and reference signatures strongly support the hypothesis H_1, rather than the alternative hypothesis H_2".

Once each expert has completed their respective ACE phases, the experts confront their conclusions in the Level Confrontation nodule. Several different scenarios can be imagined at this point between both of the experts' conclusions (illustrated in Figure 121). For the sake of illustration, the verbal scale in use at Swedish National Laboratory of Forensic Sciences is used (Nordgaard *et al.*, 2012). It comprises a nine-step scale where the observations can give weak, moderate, strong, or very strong support for either of the hypotheses, or can be inconclusive (LR = 1).

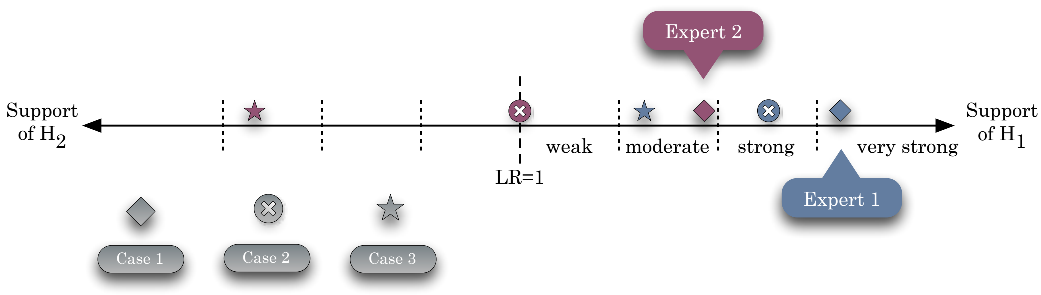

Figure 121 - Confidence level possibilities for two experts (illustrated with three cases).

The divergent conclusions of each of the experts depicted in Figure 121 can be classified according to three main case conclusions:

- In the first case, both experts will more or less support the same hypothesis, and are thus both situated on the right side of the graphic, but at different levels (with potentially different strengths, for example expert 1 may very strongly support H_1, whereas expert 2 would only moderately support H_1).
- The second possibility (Case 2) is if one expert supports more or less strongly one hypothesis (for example H_1 in this illustration), but the second expert arrives at the conclusion that the observations do not allow him to support one hypothesis more than the other (i.e. inconclusive).
- Finally, the third and most extreme possibility (Case 3) is to have both experts support a different hypothesis, more or less strongly (for example expert 1 strongly supports H_1, whereas expert 2 moderately supports H_2).

At this stage, the experts are able to assess their degree of agreement (or of disagreement). This stage enables the expert to assess the severity of the disagreement, if any. Once both experts have taken note of the confidence level of their colleague, they will continue to the next phase, entitled "Evaluation confrontation", even if their conclusions are both situated in the same conclusion level confidence interval. Indeed, for transparency reasons, the experts must verify that they are indeed basing their evaluations on the same observed elements.

This evaluation phase consists of a pooling of both of the experts' findings. Two main outcomes are possible: either the evaluations of the first expert are the same as the findings of the second expert ($E_1 = E_2$), or the evaluations of both experts are not the same.[200] In the first case, the same evaluations of both experts presuppose that the experts reached the same findings ($A_1C_1 = A_2C_2$), and that the findings were assigned the same weight. Therefore, the experts can directly head to the final consensual conclusion stage.

If however, the evaluations of both experts are different ($E_1 \neq E_2$), this can be because of one of two possibilities. Either the experts arrived at different

[200] This stage can be analogized with a comparison of both of the expert's discussion segment of their report.

findings ($A_1C_1 \neq A_2C_2$), either the findings are the same ($A_1C_1 = A_2C_2$), but a different weight was assigned to them (since $E_1 \neq E_2$). In the first case, where the findings differ between the two experts, both experts must initiate a discussion to arrive if feasible to an agreement concerning the observable characteristics and comparison findings ($A_1C_1 = A_2C_2$). Once an agreement is met, both experts must return to their respective Evaluation phases (E_1 for expert 1 and E_2 for expert 2), reach their personal confidence levels, and continue in the established protocol (level confrontation, etc.).

Once the experts have reached a consensus on the findings ($A_1C_1 = A_2C_2$), the they must determine the cause of their divergent evaluations. These can be of three origins:

- The numerators of the LR are similar ($N_1 = N_2$), but the divergence in the evaluation is due to divergent denominator estimations ($D_1 \neq D_2$).
- The denominators of the LR are similar ($D_1 = D_2$), but the divergence in the evaluation is due to divergent numerator estimations ($N_1 \neq N_2$).
- Both the numerators and denominators of the LRs are divergent ($N_1 \neq N_2$ and $D_1 \neq D_2$).

In the first case, there are several origins of a divergent denominator evaluation. The complexity of the questioned signature might be assessed differently by both experts. They might also assess the variation of the reference material differently. Or one of the experts might consider certain differences to be more significant under the alternative hypothesis. In the second case, divergent numerator evaluations can have as an origin divergent views on the quality and quantity of the reference material. They might also assess the individual weight of the observed features differently. The third case is naturally due to a mix of both of these possibilities.

The experts must at this stage discuss between themselves their respective evaluations of the numerator, denominator, or both, and in order to determine why they assessed their findings differently. This discussion can take the form of a brainstorming activity, by researching and consulting literature, conference proceedings, articles and books, by consulting databases or expert forums (for example ENFHEX). Each of the expert's evaluations (and therefore conclusions) can be moved along the scale of the support of the hypothesis. The global aim of finding a consensual conclusion between both experts is to have the experts slide along the scale (upwards or downwards) to a point where they are both content and satisfied with the final conclusions. This concept is illustrated in Figure 122.

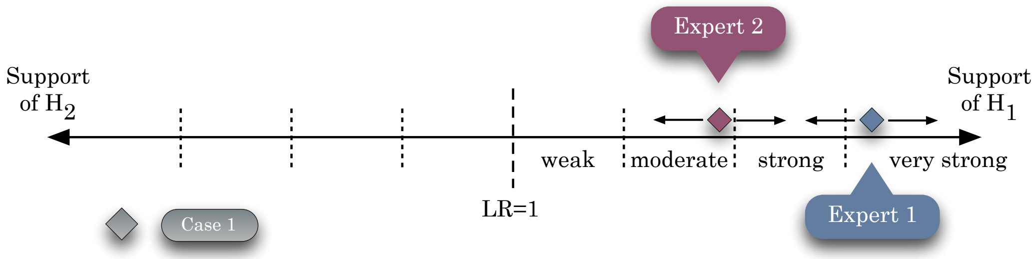

Figure 122 - Illustration of expert 1 and expert 2 conclusions on a scale.

This discussion stage is the milestone of the evaluation process. It also allows the experts to exceed their habits by sharing their view with another person, and correcting their possible errors. A certain threshold can be established to determine the jump in the level of confidence that is permitted before giving out the final conclusion. This threshold can be based on elements such as results of proficiency testing: proficiency tests allow a certain deviation in the expert's results with the results of the test, but still considers the results as correct. The same line of reasoning could be adapted here. The final question however lies in the allowable deviation between two experts' conclusions. Of course, the definition of the tolerated discrepancies must be discussed and enforced on a day-to-day working practice. If, after this discussion, the experts both reach conclusion levels that are situated beneath this predefined allowed threshold, they can provide a final consensual conclusion. In this sense, both experts are able to put forward a single and consensual feature set.

Finally, the expert that is mandated by name will have the final saying in which level (under the threshold) will be used in the final conclusion: for example, if the threshold in effect is one level of confidence (excluding the inconclusive level), and expert 1 strongly support H_1, and expert 2 moderately supports H_2, then expert 1, being the officially consulted expert of the case, may conclude by expressing strong support for H_1.

The third expert is consulted if, after the discussion stage, both experts 1 and 2 are unable to reach a consensus in the final conclusion that situated beneath the predefined threshold. In this case, the third expert (for example a colleague), will enter the discussion stage and will help experts 1 and 2 reach a consensual conclusion (i.e. have both experts reach a conclusion level difference beneath the threshold). This third expert is working from the evaluation phase, and does not have to redo the whole process from the beginning, seeing as both experts 1 and 2 have already reached a consensus regarding the analysis and comparison phases. The third expert must however help the expert assess the numerator and denominator of the likelihood ratio of the findings.

If the discussion with the third expert helps both experts reach respective conclusion levels beneath the threshold, the experts can continue to the final stage of providing a consensual final conclusion. However, if, even after this 3-way discussion, both experts keep conclusion levels exceeding the threshold, no final consensual conclusion can be given. The experts may however state their different options in the report, and motivate their diverging conclusions. The final conclusion is thus transparent for the receiving audience.

This working canvas fulfills three important parameters. It proposes a transparent and pragmatic approach to guide co-experts in their evaluation process and propose a procedure to follow in the case of conflict resolution. The examination process is thus a continual learning process where the verification of one's work by peers is necessary to guarantee a coherent and most independent system possible.

10.3 Integration of the developed model into holistic casework

The integration of the model into the traditional holistic casework is based on the two-expert conflict resolution procedure developed in the last section. The main difference with this last procedure resides in the point that the model cannot change or adapt its conclusions in the expert's direction, whereas with the two experts, one expert can change his evaluations after discussions with another expert (or vice versa).[201]

For the sake of the present discussion, this section will be presented from the viewpoint of an ideal case, without taking into account possible errors

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[201] For the sake of example, H1 is "the artist X signed the signature", H2 is "someone other than the artist signed the signature: it is an imitation". As a reminder, in the case of authentication of signatures on artworks, the hypothesis of a disguised signature can be reasonably put aside.

stemming from either the model or from the expert(s). The assumption is made that the model provides correct results (that are independent of the user), and with documented error rates. The expert must have confidence in the values of the model and in the significance of the results in regard to the verbal scale.

The first expert can either adapt his confidence level in the direction of the model's conclusions, he can completely reach the model's conclusions, or he can decide to keep his own confidence level conclusion. In this case, the results obtained from the model could be simply integrated in the FHE's report, taken "as is", without any justification or transparency. The expert's three possibilities are illustrated in Figure 123.

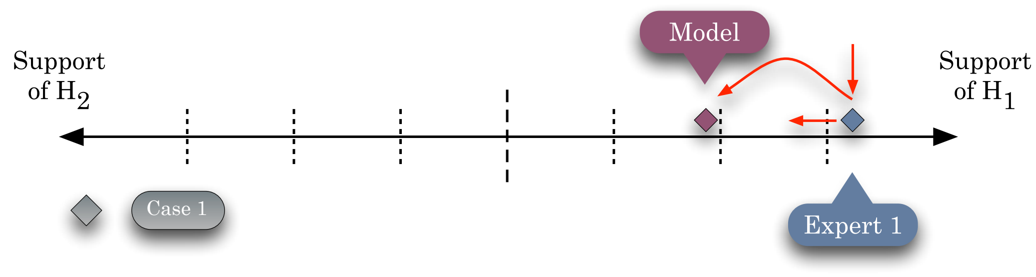

Figure 123 - Illustration of the three possibilities (red arrows) given to an expert facing a conclusion conflicting with the model's conclusion. The expert can either adapt his confidence level, he can completely reach the model's conclusions, or he can decide to keep his own confidence level conclusion.

The ideal situation is of course the first, where the expert will take advantage of the model and let it assist him in his examination. The difficulty lies in how to combine the conclusions of the model with those of the expert. The role the model will have in the expert's conclusions must also be specified: can it be considered as a verifier, or as a second expert?

The integration of the results obtained from the model into the reasoning process generates a number of questions, particularly pertaining to the different options available to the expert on how to react when confronted with contradicting results. From this juxtaposition of results, emerge questions such as:

- Are there elements that the expert observes also included in the model (and vice versa)?
- Are the expert and the model independent of one another?
- How will the expert handle the output given by the model?
- How will the expert adapt his results with those of the model? For example, if the expert finds inconclusive results, will the results of the model take over? Or if the expert supports one hypothesis very strongly, but the model only supports the hypothesis weakly, which conclusions should be used?
- How will the second expert take into account the conclusion of the first expert and of the model?

These many questions that may arise when trying to juxtapose the results of the model with those of an expert may be answered by developing a standardized working procedure. Such a procedure would adequately integrate the results of the model into the holistic expert examination. Based on the two-expert procedure developed in Section 10.2, this procedure includes a protocol for resolving conflicting conclusions between the expert and the model (presented below in Figure 124).

As for the two-expert procedure, the present procedure must be defined through a structured and coherent protocol.[202] Once this protocol is implemented, the expert may not stray from it, and find himself in the "pick and choose" situation where he only uses the model's conclusion when they are in his favor, but discards them when they contradict his own conclusions. The aim however, is not to put forward exclusively the expert or the model; they are not competing for the conclusion. In this sense, the model is not better than the expert, nor the expert better than the model. The expert must be able to fully comprehend the features analyzed by the model (it cannot be simply a blackbox) and understand how the output for each specific case is reached.

[202] Several suggestions of a simultaneous use of the model with the holistic examination have already been discussed in regard to potential bias effects (see Section 9.2).

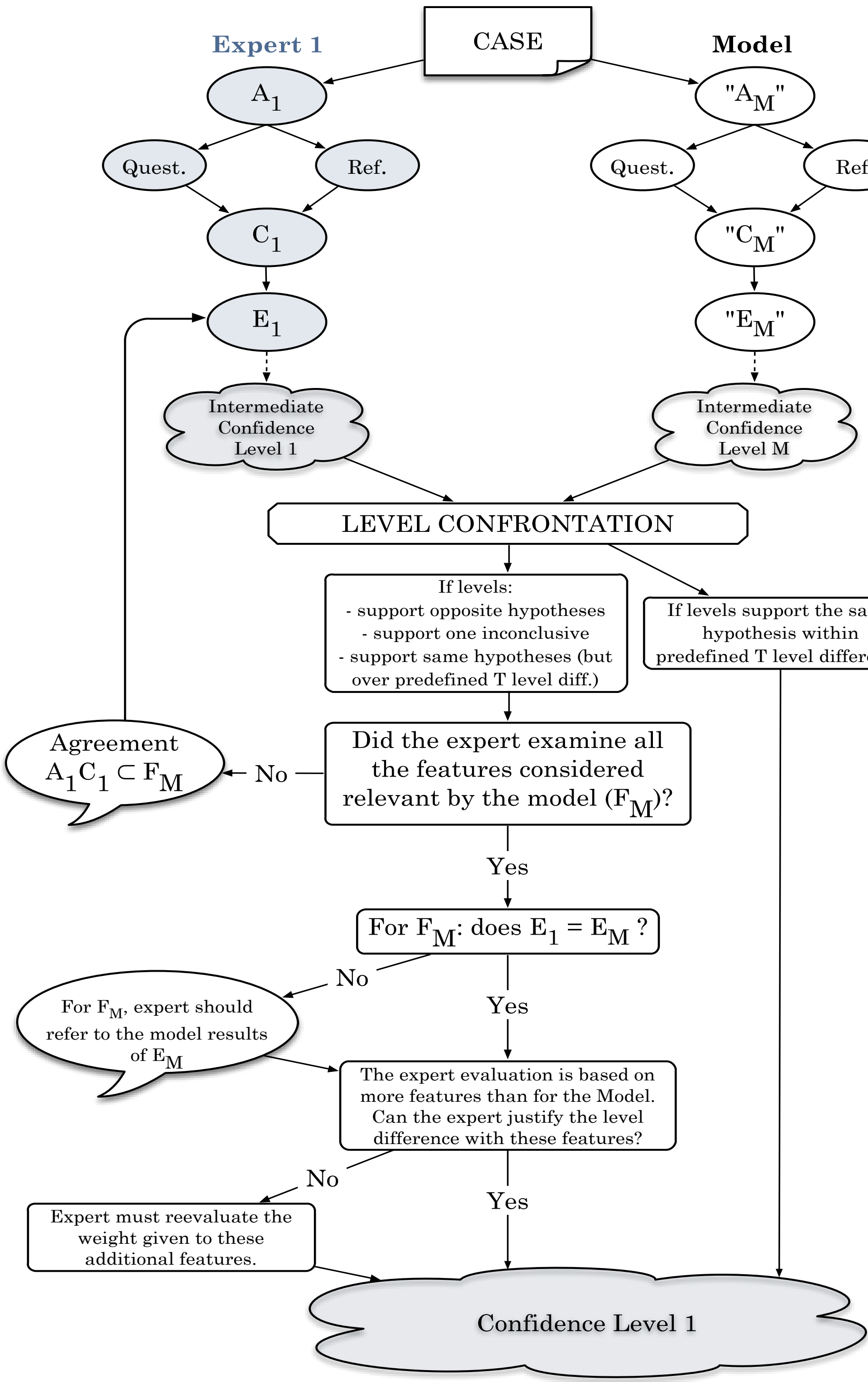

Figure 124 - Scheme depicting conflict resolution between an expert and the model. Each activity is represented by a specific shape: the individual actions

are represented by circles, the conclusions by clouds, expert confrontations by hexagons, possible expert actions by rectangles, and discussions by discussion bubbles.

The proposed procedure follows the same first step as the two-expert procedure. Both the expert 1 and the model will arrive at their respective Intermediate Confidence Levels 1 and M,[203] after having followed and ACE procedure (A_1, C_1, and E_1 for Expert 1, and "A_M", "C_M", and "E_M" for the Model). The model's ACE examination procedure is put in quotation marks because it does not follow an ACE examination process from a traditional point of view. Indeed, the analysis, comparison and evaluation levels are limited by the developed model. Once the intermediate confidence levels for both the expert and the model have been reached, the expert confronts his conclusions with those of the model at the Level Confrontation stage.

Three main possibilities, illustrated in Figure 125, can be imagined:

1. Case 1: The expert and the model support the same hypothesis, within the limit of a predefined threshold level difference, or they both arrive at inconclusive confidence levels.
2. Case 2: The expert and the model support the same hypothesis, but over the limit of a predefined threshold level difference, or the expert supports one hypothesis, and the model is inconclusive (or vice versa).
3. Case 3: The expert and the model support opposite hypotheses.

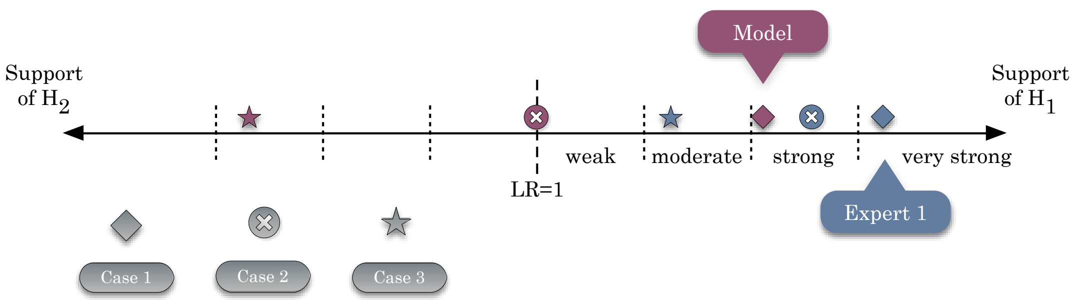

Figure 125 - Different level confrontation possibilities between an expert and the model.

[203] Note that in comparison with Figure 120, the expert arrives at an *Intermediate* Confidence Level, not a Confidence Level. The Expert 1 will only reach his own Confidence Level 1 after having integrated the conclusions of the model into his own conclusions.

In the Case 1 scenario when the expert and model support the same hypothesis within a predefined threshold level difference (for example both experts support H_1, but one moderately, and one strongly). The second Case 1 scenario arises when the expert and the model both arrive at an inconclusive confidence level. For both of these scenarios, the expert can directly continue to the end of the procedure and present his Confidence Level 1 (see Figure 124).[204]

In this case, even though the expert and the model support the same hypothesis within a predefined threshold level difference, both could theoretically have Intermediate Confidence Levels that are rather distant in terms of strength of support of the hypothesis, as depicted in Figure 126 below, where Expert 1 supports H_1 strongly and the Model only supports H_1 moderately,[205] but both being at the extremity of their levels. This difference in the strength of the support can be acknowledged by the expert, who has three possibilities for reporting the Confidence Level 1:

- He can chose to continue the conflict resolution procedure, instead of directly giving his Confidence Level 1.
- He can adapt his Confidence Level 1 in the direction of the model's (without going further in the procedure).
- He can keep his Intermediate Confidence Level 1, and directly communicate the Confidence Level 1.

Although the first course of action is not recommended since it defies the use of the developed model, it can be useful for cases such as the one illustrated in Figure 126, as well as for initiating reflections on the cause of such differences in the strength of support. The other two possibilities depend on the expert and his personal choices.

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[204] In this sense, efforts should be made *in priority* in cases where the model and the experts support the same hypothesis (above the threshold level), or support different hypotheses (i.e. case scenarios 2 and 3). However, the fact that different conclusions are not reached between the expert and the model does not imply that future efforts should not also be made in the combination of both of the expert's and the model's "same" conclusions, since a degree of opacity in their reasoning process subsides.

[205] Actually, the findings made by the Expert 1 strongly support the hypothesis (it is not the Expert that provides support). For simplification means, a shortcut is made in the language.

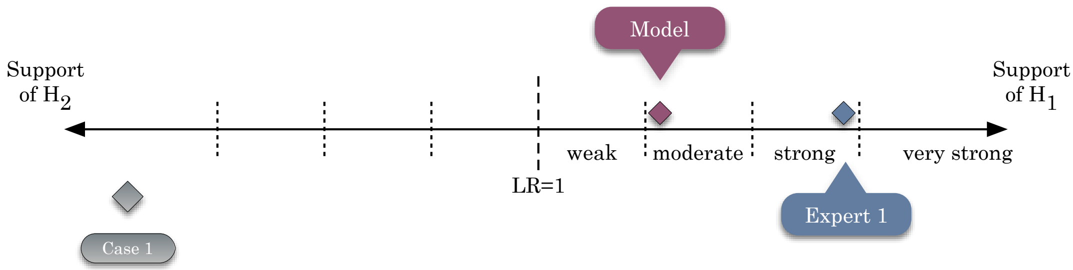

Figure 126 - Illustration of possible difference in support of H_1 given by the Expert 1 and the Model. In this example, Expert 1 supports H_1 very strongly, whereas the Model only supports H_1 weakly.

If, however, the expert supports the same hypothesis as the model, but with a strength above the predefined threshold level difference, or if the expert supports one hypothesis, and the model is inconclusive (case 2 of Figure 125), or finally if the expert and the model support opposite hypotheses (case 3 of Figure 125), the expert must continue in the resolution procedure proposed in Figure 124 and ask himself if he considered all the features that were considered relevant by the model (F_M) and used to calculate the model's output. By taking this further step, the expert is able to fully assess the features that were taken into account by the model to reach it's Intermediate Confidence Level M.

With this step lies one of the main advantages of the developed model in comparison to other complex classification models: with only an extremely transparent system can the expert dissect the inner workings of the model and establish which factors held a role in the conclusion process. If the expert realizes that he did not examine all the features considered relevant by the model (F_M), then he must arrive at an agreement for which the results of his own A_1C_1 stages include the model's relevant features (F_M are a subset of A_1C_1). He must then return to his E_1 stage and evaluate these "missed" features.

If the expert did however consider all the features that were considered relevant by the model (F_M), then he must establish, specifically for these common features, if the evaluation he gave equals the evaluation given by the model. If not, then the expert should refer to the model's results for the evaluation of these features. If yes, then other features (other than F_M) must be responsible for the global evaluation difference. The weight of these additional features must be justified to reach the Confidence Level 1. Thus, if the expert can justify the difference between his confidence level and the model's confidence level with these additional features, then he can proceed to the Confidence Level 1. However, if the expert cannot justify the level difference, then the he must reevaluate the weight he attributed to these additional features before emitting the Confidence Level 1. The expert therefore reassesses the features not taken into account in the model, to see if they only are enough to warrant the difference in the conclusion in comparison with the model. By doing so, the expert must be capable of decomposing his evaluation.

With this step, the author is thus considering the possibility that the expert can use a greater number of features than the model to reach his Intermediate Confidence Level 1. Indeed, the input analyzed by the model is by definition based on less wide range of features than the features that can be observed and analyzed by an expert. However, this stage in the protocol is vital because it does not allow the expert to express defensive views such as "I see more than the model, therefore my conclusion is better than the model's", because any difference in his observations and in his evaluations can be used, but must be reasonably justified. The expert must be capable of justifying why the additional features allow him to increase his evaluations for example by a factor of 100 (if for example a two level difference is preconized between his final evaluation and the model's). The arguments expressed by the expert in this case tend towards the transparency objective expressed in Chapter 5.

If, the expert is however unable to reasonable justify the gap in the confidence levels, a second expert can be called upon at this point, and a discussion initiated. If no consensus can be reached, an inconclusive conclusion can be given, even disclosing that a discord with the model's results was found (and eventually even giving the results of both the expert and the model).

The developed procedure thus allows the expert to keep his observations and evaluations, but within the defined and logical framework that works as a safeguard and prohibits unjustifiable actions on the expert's behalf. By having experts explicitly explain the observations that allow them to divert from the model forces them to transparently justify their conclusions. For example, if the expert only has two additional features in his evaluation, he must ask himself if these two features are sufficient enough to slide along the scale of support of H_1 and warrant going from weak support to very strong support (to take the example in Figure 126).

This Confidence Level 1 is considered as the first expert's confidence level, which, once determined, can be integrated into the two-expert procedure (see Figure 120) if a second verifier is warranted. The whole examination procedure is schematized in Figure 127.

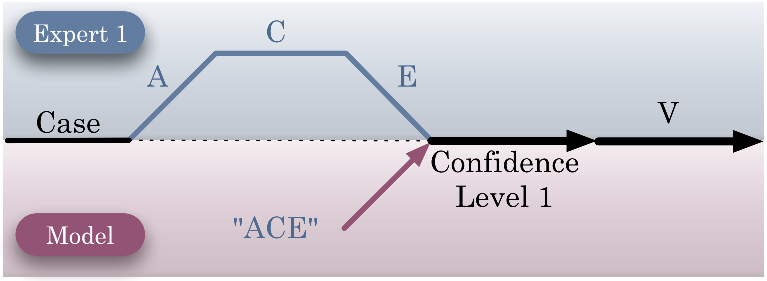

Figure 127 - Schematic view of the examination procedure between the expert and the model.

However, the Expert and Model procedure can be argued as being sufficient to guarantee the verification of the expert examination. If we continue in this line of reasoning, the model developed in this research could completely replace the expert responsible for the verification stage, and would act as the verification step as a whole. This could be a possible approach to integrate the model in the ACE-V approach. In this case, since the second expert is absent from the procedure, the Confidence Level 1 could be directly transformed into the Final Consensual Conclusion (see Figure 120).

The model could thus be used in conjunction with one, or with two experts. The decision of whether a second expert should be used could depend on the difference of the level confrontation between the first expert and the model: if both, right from the beginning, support the same hypothesis, one could argue that having a second expert is time-consuming and redundant. However, referring to a second expert could be justified for cases that pose more problems, and could offer reassurance to the first expert of his obtained confidence level.

In conclusion, the aim of this protocol is to offer general guidelines for best practices between an expert and the developed model. The protocol is to be understood as a common sense approach framework for testing propositions, and integrating results of different sources (expert conclusions versus model conclusions). The transparency of model allows for a juxtaposition of both the model and the expert's conclusions. With such a transparent system, any decision of a different conclusion than the one given by the model must, and more importantly can, be justified by the expert.

Both of the protocols developed in the case of juxtaposition two-experts or experts with the model, help the expert to better understand the parameters that have an impact on his conclusions and on the conclusions of his colleagues. The developed protocols thus offer coherent frameworks for FHEs to structure and communicate their views in the most transparent manner possible. At the present stage, however, the developed model cannot completely replace an expert. It is a quantitative tool used in the framework of signature examinations. Since the signature analysis tool is based on a quantitative approach, the different bias factors are also diminished. The contribution of the model in relation to the expert reassures the court that a quantitative tool was used to obtain the expert conclusions.

The model's greatest advantage is that it is based on a quantitative approach that can be comprehensively understood by a forensic examiner. Indeed, forensic examinations of this type are more and more solicited by the judicial system, who has clearly stated the need for quantitatively palpable results. The expert is thus able to integrate these results into his own examination, and provide the court with a holistic expertise. The model also offers the advantage of being time saving, in regard to a two-expert examination procedure. The third non negligible benefit is the continual education it provides for experts working with the model, who are able to benefit of the model's finding and adapt their personal beliefs.

General Conclusions

The domain of art authentication is extremely vast and complex, requiring solid notions in various subject matters, from art history, scientific and historical analysis of paintings and signatures, to the judicial quality of art experts. As a consequence, the forensic examination of questioned signatures on paintings requires knowledge of these fields, on top of the knowledge of forensic signature analysis. The theoretical part of this doctoral research offers an overview of these themes, highlighting the numerous and non exhaustive factors that have an impact on the authentication process of a work of art, and the interdisciplinary aspect of signature examination of signatures on paintings.

The validity of the foundations of signature analysis is the subject of ongoing debate and is increasingly challenged, not only judicially, but by scientific commentators. Its temperamental acceptance explicitly demonstrates the necessity of strengthening the underpinnings of signature analysis for a generalized acceptance of signature expertise by courts of law. The judicial acceptance is even more complicated for painted signatures, as very little research has been carried out on the subject up to this point. In this thesis, we are confronted with the specific issues of signatures on works of art, which have their own lot of specificities, and which have brought the author to formulate recommendations for this type of expertise. These recommendations have never been formulated in a structured manner, and they throw light on the recent debates on the scientific quality of the domain. The theoretical part is thus concluded by these guidelines that are crucially lacking in the field of art authentication, and that stem from the conducted literature review. They are specifically enunciated for the expertise of signatures on paintings, but can also be applied to wider field in the area of signature examination.

The need to step towards a more regularized procedure of attribution of artwork is also felt throughout the art community. Indeed, numerous authors have questioned the reliability of traditional authentication methods, particularly if the experts do not have an art history education. The excuse of a connoisseurship or of the "eye" of the expert is difficult to test and verify, just as it is hard to prove false attributions carried out in this manner. Scientific examinations of works of art have become more sought after, as more and more museums equip themselves with laboratories.

This scientific approach of authenticating a signature can be achieved by embracing a probabilistic reasoning process. The comparison and evaluation of evidence is assessed in forensic science through the assignment of a likelihood ratio (LR). This approach allows the expert to weight his observations in light of two competing hypotheses. The likelihood ratio (LR) evaluates the degree to which the observations support one of a pair of competing hypotheses (authentic versus simulated signature).

For the first time, cases that can be calibrated on actual data from authentic and simulated signatures were carried out in this research. The study is based on concrete measures that allow for a transparent appreciation of the signature examination process, based on the corpus of five contemporary artists. The developed method consisted of a succession of steps carried out on the authentic and simulated set of signatures, in order to maximize their separation potential. The selection and definition of a set of features defining the signature was carried out on the signature sets, followed by a feature reduction step, implemented to reduce the number of features describing each signature set. Finally, the reduced feature set was integrated into a multivariate probabilistic assessment of the strength of the forensic findings.

Several limits of the contribution of this type of analysis for the determination of the authenticity of a painted signature were brought forward with the results of the study. The obtained LR results provided only limited support in favor of either competing hypothesis. The reduction of the number and types of the most relevant features best separating the authentic set from the simulated counterparts also showed that the final relevant feature vectors obtained varied between the five studied artists, thus pointing towards a very limited possibility of generalization of the results. The results obtained in the study (final likelihood ratios) can only be linked to, and depend on, the artist, studied in question. Since the extrapolation capabilities of the method are limited, and that the expert has practically no possibility to generalize the results of this study to his own casework, he must carry out, if the model were to be implemented, the whole procedure from the beginning of the process, including the collection of the population of simulated signatures.

However, what may seem as operational constraints can be pivoted into a strong point of the method: since a modelisation of the variability of the simulation population is known, the weight of the results are also therefore inevitably reinforced, and can be clearly used in the court to show the transparent and evidence-based results of the signature examination. This limit of this model has ramifications larger than in the field of examination of painted signatures: the constraints in which the system must operate highlight the constraints in which the expert should operate, in light of the present results, if he wants to effectively measure the variability of the simulation population. As a consequence, the expert, who bases his examination and evaluation on his experience and on the generalization of his past observations must question the validity of his estimations of the relevant population that make up the denominator of the likelihood ratio. The ability to reproduce the signatures can indeed be estimated and appreciated in a holistic manner by the expert, but, without the effective data set, he cannot measure them.

In the case of signatures on paintings, even if the expert were to carry out the whole procedure for an actual case, we cannot, based on the results of the study, expect strong evidence arising from this developed approach to either hypothesis of an authentic or simulated signature. The low LR results do have the advantage of proving, with measures to support the affirmations, that the expertise of painted signatures on works of art only provides limited support in favor of the either hypotheses, and does not allow us to be as positive in the attributing the authorship of a signature as some experts affirm is possible.

At the present time, the method does not appear, if left unchanged and in light of the exposed constraints and with respect to the investments, to be worth pursuing. The overall added value of this model, if it were to be operationally implemented for actual casework, is limited. An implementation of the developed system for practical cases does not seem viable for the time being.

We are heading in the future more and more towards experts who will be assisted with models that will help them appreciate the rarity of different observed features and guide them to establish likelihood ratios. Our goal is not to arrive at a system where models dominate the expert, who is removed from the equation, but at a system where the advantages of both systems are combined.

For the first time, and in regard to these considerations, a strategy to incorporate the model into the traditional signature expertise procedures is proposed. The research shows that this combination is feasible. This issue of cohabitation is partially resolved in this thesis and a number of leads are proposed to open a new field of cohabitation/integration between a system based on a likelihood ratio with a traditional expert system. The largest lead to foster is the notion of transparency, which forces the expert to dissect his reasoning process.

This thesis showed that a certain methodology can be put in place with the developed model, and that it can be broken down into several key concepts. The expert/model combination allows the expert to dissect his reasoning process. This reinforces the value of his work and provides a recognized and acknowledged basis for common discussions. These steps should structure the expert's work, his evaluation of the forensic findings, and his exchanges with other peers. This approach brings forward the methodological issues that may be raised throughout the procedure carried out by the experts. The whole process will allow the specialist to strengthen his approach and his conclusions. Arriving at the court, the expert will possess a transparent process that greatly enhances the value of his expertise.

The limited strength of the final results reflects the extreme complexity that resides within the attribution process of a painted signature to an artist. However, the model has brought forward areas for improving the robustness in the examination of painted signatures, but also in the signature examination process in general. This step-by-step examination process reinforces the work carried out by the expert and allows him to have a basis of common discussion with his peers and stakeholders.

With the proposed recommendations and methodological approach, the conclusions drawn from this study finally show the importance of considering the examination of the authenticity of a painting in a holistic manner. The signature should be considered as an element that is intrinsically linked to the work of art in its' whole, not individually. The work of art should be considered as a source of additional relevant information, necessary and indispensable to arrive at a final decision of authenticity. Even though operational limitations have been identified, the proposed methodological approach can offer opportunities as a structured tool that can be used in the field of initial training, continuing education and proficiency testing. The forensic handwriting expert can use this tool to help structure and strengthen his reasoning process. Thus, the expert will be more aware of and accept the limitations of the interpretation of the forensic findings, and arm him with scientifically more reliable conclusions to present to the Court.

In conclusion, despite the identified limitations, this study has demonstrated that it is possible to provide, for the first time, a scientific approach to authenticate signatures on works of art.

Bibliography

ADAM, G. (2012), "Les marchands britanniques inquiets" Le Journal des Arts, 361, Online article: http://www.lejournaldesarts.fr/jda/archives/docs_article /96746/les-marchands-britanniques-inquiets.php: Last consulted: October 2014.

AITKEN, C. and TARONI, F. (2004), Statistics and the evaluation of evidence for forensic scientists, John Wiley and Sons, Ltd., Chichester.

AL HADDAD, A.A., WHITE, P.C. and COWELL, A.M. (2011), "The use of principal component analysis to provide objective methods for the examination of arabic signatures", Journal of the American Society of Questioned Document Examiners, 14: 3-18.

ALEWIJNSE, L.C., VAN DEN HEUVEL, C.E., STOEL, R.D. and FRANKE, K. (2009), Analysis of Signature Complexity, Proceedings of the 14th Conference of the International Graphonomics Society (IGS), Dijon, Annie Winter and Jean-Luc Velay, Eds., 6-17.

ALEXANDER, K. (1998), "Conservation in the Aid of Authentication: How a Painting 'signed' Jozef Isreals was Reattributed to J.H.S. Kever", International Foundation for Art Research Journal, 1: 15-16.

ALLAIS, M. (1953), "Le comportement de l'homme rationel devant le risque: critique des postulats et axiomes de l'école américaine", Econometrica, 21: 503-546.

ASHBAUGH, D.R. (1991), "Ridgeology", Journal of Forensic Identification, 41: 16-64.

ASSOULINE, P. (1999), L'homme de l'art : D.-H. Kahnweiler 1884-1979, Gallimard, Paris.

ASTM, E2290-07a (2007), Standard Guide for Examination of Handwritten Items, Annual ASTM Standards on Disc, vol. 14.02, 2007, American Society for Testing and Materials.

ASTM, E2388-05 (2005), Standard Guide for Minimum Training Requirements for Forensic Document Examiners, Annual ASTM Standards on Disc, vol. 14.02, 2007, American Society for Testing and Materials.

AZIMI, R. (2005), "Les experts relativisent l'analyse scientifique" Le Journal des Arts, 209, Online article: http://www.lejournaldesarts.fr/jda/archives /docs_article/24242/les-experts-relativisent-l-analyse-scientifique.php: Last consulted: October 2014.

BAZIN, G. (2010), Faux en art, Encyclopaedia Universalis, Paris.

BENSIMON, P. (1995), L'absence de mesures spécifiques face à un délit méconnu : les faux en peinture, Doctoral thesis, School of Criminology, University of Montreal, Éditions Cursus universitaire, Montreal.

BENSIMON, P. (1996), "L'expertise des signatures en matière de faux tableaux", Revue internationale de police criminelle, 457: 28-30.

BERGER, J.O. and BERRY, D.A. (1988), "Statistical analysis and the illusion of objectivity", American Scientist, 76: 159-165.

BERRIE, B.H., Ed. (2007), Artists' pigments: a handbook of their history and characteristics. Vol. 4, National Gallery of Art, Washington, D.C.

BERTILLON, A. (1898), "La comparaison des écritures et l'identification graphique", Revue scientifique, December 18th 1897 and January 1st 1898: 1-79.

BIEDERMANN, A., BOZZA, S. and TARONI, F. (2008), "Decision theoretic properties of forensic identification: Underlying logic and argumentative implications", Forensic Science International, 177: 120-132.

BIEDERMANN, A. and TARONI, F. (2013), "Réserves à propos de la notion d'objectivité en lien avec l'incertitude et les probabilités rencontrées dans le procès pénal", Revue Internationale de Criminologie et de Police Technique et Scientifique, 66: 47-55.

BLUM, A. (1948), "Un office de documentation international sur les faux artistiques", Revue Internationale de Criminologie et de Police Technique, 2: 174-180.

BONNEFON, J.-F. and VILLEJOUBERT, G. (2006), "Tactful or Doubtful?: Expectations of Politness Explain the Severity Bias in the Interpretation of Probability Phrases", Psychological Science, 17: 747-751.

BOUTAINE, J.L. (2006), The Modern Museum, in David Bradley and Dudley Creagh, Eds., Physical techniques in the study of art, archaeology and cultural heritage, Elsevier, Amsterdam, 1-39.

BOZZA, S., TARONI, F., MARQUIS, R. and M., S. (2008), "Probabilistic evaluation of handwriting evidence : Likelihood ratio for autorship", Applied statistics, 57: 1-13.

BREIMAN, L. (2001), "Random Forests", Machine Learning, 45: 5-32.

BRESLER, J. (2007), "Expert opinions and liabilities - an IRAR update", International Foundation for Art Research Journal, 9: 16-26.

BRUNEL, H. (2012), "Pas de commercialisation sans divulgation" Le Journal des Arts, 364, Online article: http://www.lejournaldesarts.fr/jda/archives/docs_article/98334/pas-de-commercialisation-sans-divulgation.php: Last consulted: October 2014.

BUCKLOW, S. (1997), "The Description of Craquelure Patterns", Studies in Conservation, 42: 129-140.

BUDESCU, D.V., BROOMELL, S. and POR, H.-H. (2009), "Improving Communication of Uncertainty in the Reports of the Intergovernmental Panel on Climate Change", Psychological Science, 20: 299-308.

BUDESCU, D.V. and WALLSTEN, T.S. (1985), "Consistency in interpretation of probabilistic phrases", Organizational Behavior and Human Decision Processes, 36: 391-405.

BUQUET, A., DUGAS, A. and HAUSTRATE, G. (1992), Le guide des faux et des faussaires, Philippe Lebaud, Paris.

BUQUET, A. and HELLEBRANTH, R. (1986), "Les investigations scientifiques minimales et indispensables dans l'expertise des toiles de maître", Revue internationale de police criminelle, 402: 239 - 247.

BUTOR, M. (1969), Les mots dans la peinture, Skira.

BYRNE-SUTTON, Q. and RENOLD, M.-A., Eds. (1992), L'expertise dans la vente d'objets d'art, Aspects juridiques et pratiques, Etudes en droit de l'art, Schulthess Polygraphischer Verlag, Zürich.

CALLIGARO, T., DRAN, J.C. and KLEIN, M. (2003), "Application of photodetection to art and archaeology at the C2RMF", Nuclear Instruments & Methods in Physics Research Section a-Accelerators Spectrometers Detectors and Associated Equipment, 504: 213-221.

CASOLI, A., MUSINI, P.C. and PALLA, G. (1996), "Gas chromatographic-mass spectometric approach to the problem of characterizing binding media in paintings", Journal of Chromatrography A, 731: 237-246.

CASOLI, A., PALLA, G. and TAVLARIDIS, J. (1998), "Gas-Chromatography/Mass-Spectrometry of Works of Art: Characterization of Binding Media in Post-Byzantine Icons", Studies in Conservation, 43: 150-158.

CENNINI, C., TAMBRONI, G. and MERRIFIELD, M.P. (1844), A treatise on painting, Edward Lumley, London.

CHAMPOD, C. (2008), "Fingerprint examination: towards more transparency", Law, Probability and Risk, 7: 111-118.

CHAMPOD, C. and VUILLE, J. (2011), "Scientific Evidence in Europe - Admissibility, Evaluation and Equality of Arms", International Commentary on Evidence, 9: 1554-4567.

CHAPPUIS, C. (2007), L'authentification d'oeuvres d'art: responsabilité de l'expert et qualification du contrat en droit suisse, in Marc-André Renold, Pierre Gabus and Jacques de Werra, Eds., L'expertise et l'authentification des oeuvres d'art, Schulthess, Genève, 47-74.

CHARTIER, D.R. and NOTEHELFER, F.G. (1998), Authentication: science and art at odds?, Scientific Detection of Fakery in Art, San Jose, CA, USA, SPIE, 74-86.

CHASTEL, A. (1974), "Signature et signe", Revue de l'art, Issue 26: 8-14.

CHATELAIN, F., CHRISTIAN, P. and CHATELAIN, J. (1997), Oeuvres d'art et objets de collection en droit français, Berger-Levrault, Paris.

CHATELAIN, J. (1982), La notion d'oeuvre d'art originale. L'oeuvre d'art vue par le juriste, in Michel Vanden Abeele, Ed. Le marché commun et le marché de l'art, Institut d'Etudes Européennes, Université Libre de Bruxelles, Bruxelles, 19-29.

CLERC, P. (2011), Christie's et Sotherby's en Suisse. Problématiques dans la première décennie du XXIe siècle, entre crises et concurrence, in Paul-André Jaccard and Sébastien Guex, Eds., Le marche de l'art en Suisse. Du XIXe siècе à nos jours., Institut suisse pour l'étude de l'art, 177-192.

CONWAY, J.V.P. (1959), Evidential documents, Thomas, Springfield, Ill.

CRISPINO, F., RIBAUX, O., HOUCK, M. and MARGOT, P. (2011), "Forensic science – A true science?", Australian Journal of Forensic Sciences, 43: 157 - 176.

DAY, S.P. (2009), Interpretation of Comparison of Handwriting and Signatures, in Allan Jamieson and Andre Moenssens, Eds., Wiley encyclopedia of forensic science, Wiley, Chichester, 1451-1458.

DE WERRA, J. (2007), L'authentification d'oeuvres d'art et le droit de la propriété intellectuelle, in Marc-André Renold, Pierre Gabus and Jacques de Werra, Eds., L'expertise et l'authentification des oeuvres d'art, Schulthess, Genève, 103-134.

DEWHURST, T., FOUND, B. and ROGERS, D. (2008), "Are expert penmen better than lay people at producing simulations of a model signature?", Forensic Science International, 180: 50-53.

DOERNER, M. (1935), The materials of the artist and their use in painting, with notes on the techniques of the old masters, G. G. Harrap, London.

DOMÉNECH CARBÓ, M.T., BOSCH REIG, F., GIMENO ADELANTADO, J.V. and PERIZ MARTÍNEZ, V. (1996), "Fourier transform infrared spectroscopy and the analytical study of works of art for purposes of diagnosis and conservation", Analytica Chimica Acta, 330: 207-215.

DOMÉNECH-CARBÓ, M.T. (2008), "Novel analytical methods for characterising binding media and protective coatings in artworks", Analytica Chimica Acta, 621: 109-139.

DROR, I.E., CHARLTON, D. and PÉRON, A.E. (2006), "Contextual information renders experts vulnerable to making erroneous identifications", Forensic Science International, 156: 74-78.

DURET-ROBERT, F. (1975), "Fictions de l'authenticité - Réalités de l'expertise", Connaissance des arts, 285: 106-138.

DURET-ROBERT, F. (1990), "Le règne des héritiers", Connaissance des arts, 457: 123-136.

DURET-ROBERT, F. (1995), "Les experts", Connaissance des arts, 517: 106-115.

DURET-ROBERT, F. (2007), L'authenticité des oeuvres d'art dans la pratique du marché de l'art, in Marc-André Renold, Pierre Gabus and Jacques de

Werra, Eds., L'expertise et l'authentification des oeuvres d'art, Schulthess, Genève, 29-37.

DURET-ROBERT, F. (2013), Droit du marché de l'art, Dalloz, Paris.

DYER, A.G., FOUND, B. and ROGERS, D. (2006), "Visual Attention and Expertise for Forensic Signature Analysis", Journal of Forensic Sciences, 51: 1397-1404.

DYER, A.G., FOUND, B. and ROGERS, D. (2008), "An Insight into Forensic Document Examiner Expertise for Discriminating Between Forged and Disguised Signatures", Journal of Forensic Sciences, 53: 1154-1159.

EDELMAN, B. (2008), La propriété littéraire et artistique, Presses universitaires de France, Paris.

EDWARDS, H.G.M. and CHALMERS, J.M. (2005), Raman spectroscopy in archaeology and art history, Royal Society of Chemistry, Cambridge.

ELIAS, M. and COTTE, P. (2008), "Multispectral camera and radiative transfer equation used to depict Leonardo's sfumato in Mona Lisa", Applied Optics, 47: 2146-2154.

ENDICOTT BARNETT, V. (2006), "The Kandinsky Catalogue Raisonné", International Foundation for Art Research Journal, 8: 21-23.

ENFHEX (2009), Overview Procedure for Signature Comparisons, 04 June 2009, European Network of Forensic Handwriting Experts [on file with the author].

EVANS, D. (2012), Risk Intelligence - How to Live with Uncertainty, Simon & Schuster, Inc., New York.

EVETT, I.W. (1987), "Bayesian inference and forensic science: problems and perspectives", The Statistician, 36: 99-105.

EVETT, I.W. (1990), "The Theory of Interpreting Scientific Transfer Evidence", Forensic Science in Progress, 4: 141-179.

EVETT, I.W., JACKSON, G., LAMBERT, J.A. and MCCROSSAN, S. (2000), "The impact of the principles of evidence interpretation on the structure and content of statements", Science & Justice, 40: 233-239.

FAUNCE, S. (2006), "Establishing Reliable Evidence", International Foundation for Art Research Journal, 8: 18-20.

FELLER, R.L., Ed. (1986), Artists' pigments: a handbook of their history and characteristics. Vol. 1, National Gallery of Art, Cambridge.

FERRÉ, J. (1975), Lettre ouverte à un amateur d'art pour lui vendre la mèche, Albin Michel, Paris.

FITZHUGH, E.W., Ed. (1997), Artists' pigments: a handbook of their history and characteristics. Vol. 3, National Gallery of Art, New York.

FLEMING, S. (1986), "Art Forgery: Some Scientific Defenses", Proceedings of the American Philosophy Society, 130: 175-195.

FLESCHER, S. (2006), "IFAR's Catalogue Raisonné Survey", International Foundation for Art Research Journal, 8: 110-116.

FOUND, B. (2009), Comparison of Handwriting and Signatures, in Allan Jamieson and Andre Moenssens, Eds., Wiley encyclopedia of forensic science, Wiley, Chichester, 1436-1451.

FOUND, B. and EDMOND, G. (2012), "Reporting on the comparison and interpretation of pattern evidence: recommendations for forensic specialists", Australian Journal of Forensic Sciences, 44: 193-196.

FOUND, B. and GANAS, J. (2013), "The management of domain irrelevant context information in forensic handwriting examination casework", Science and Justice, 53: 154-158.

FOUND, B., ROGERS, D., ROWE, V. and DICK, D. (1998), "Statistical modelling of experts' perceptions of the ease of signature simulation", Journal of Forensic Document Examination, 11: 73-79.

FOUND, B., SITA, J. and ROGERS, D. (1999), "The development of a program for characterising forensic handwriting examiners' expertise: signature examination pilot study", Journal of Forensic Document Examination, 12: 69-80.

FRAENKEL, B., Ed. (1992), La signature : genèse d'un signe, Bibliothèque des histoires, Gallimard, Paris.

FRAZER, P. (1899), Des faux en écriture et de l'écriture méthode scientifique nouvelle d'analyse et d'examen, Guillaumin, Paris.

FRIEDLÄNDER, M.J. (1944), On art and connoisseurship, Cassirer, London.

GARNER, R. (2012), Almost 50 per cent of adults can't do basic maths (that means half), March 2nd, The Independent, London.

GHESTIN, J. (1988), Le droit interne français de la vente d'objets d'art et de collection, International Sales of Works of Art - La vente internationale d'œuvres d'art, Institute of International Business Law and Practice - Faculté de Droit de Genève, 131-156.

GINZBURG, C. (1989), Mythes, emblèmes, traces, Flammarion, Paris.

GOETSCHEL, C. (1987), Problems of identifying disputed signatures on works of art, Questioned Document Article Database, Paper presented at the American Society of Questioned Documents Examiners at http://www.asqde.org [on file with the author].

GOTTLIEB, C. (1976), "Addendum to the Art of the Signature - Signature in the 20th-Century", Revue de l'art, Issue 34: 70-80.

GUÉDRON, M. (1998), Giovanni Morelli (1816-1891): description et identification, in Roland Recht, Ed. Le texte de l'oeuvre d'art : la description, Presses universitaires de Strasbourg, Strasbourg, 89-98.

GUEST EDITORIAL (2011), "Expressing evaluative opinions: A position statement", Science and Justice, 51: 1-2.

GUEX, S. (2002), "Le marché Suisse de l'art 1886-2000, Un survol chiffré", Traverse: Revue d'histoire, 1: 29-62.

GUEX, S. (2011), Le marché Suisse de l'art au XXe siècle (1886-2008) Survol chiffré et comparaison internationale, in Paul-André Jaccard and Sébastien Guex, Eds., Le marche de l'art en Suisse. Du XIXe siècle à nos jours., Institut suisse pour l'étude de l'art, 233-272.

HANNA, G.A. (1992), "Art Forgery - the Role of the Document Examiner", Journal of Forensic Sciences, 37: 1096-1114.

HARRISON, W.R. (1958), Suspect documents : their scientific examination, Praeger, New York.

HASTIE, T., TIBSHIRANI, R. and FRIEDMAN, J. (2009), The Elements of Statistical Learning - Data Mining, Inference, and Prediction.

HEBBORN, E. (1997), The art forger's handbook, Overlook Press, Woodstock, N.Y.

HILTON, O. (1956), Scientific examination of questioned documents, Callaghan, Chicago.

HILTON, O. (1982), Scientific examination of questioned documents, Elsevier, New York, N.Y.

HOURS, M. (1976), Analyse scientifique et conservation des peintures, Office du Livre, Fribourg.

HOURS, M. (1980), Peinture, in Ministère de la Culture et de la Communication, Ed. La vie mystérieuse des chefs-d'oeuvre: la science au service de l'art Editions de la Réunion des musées nationaux, Paris, 45-78.

HUBER, R.A. (1959), "Expert Witness", The Criminal Law Quarterly, 2: 276-295.

HUBER, R.A. and HEADRICK, A.M. (1990), "Let's do it by numbers", Forensic Science International, 46: 209-218.

HUBER, R.A. and HEADRICK, A.M. (1999), Handwriting identification facts and fundamentals, CRC Press, Boca Raton.

IONESCU, L. (1985), "Particularités de l'expertise des signatures des tableaux", Revue Internationale de Criminologie et de Police Technique, 40: 349-356.

IONESCU, L. (1990), "Authenticity Judgement with the Help of Paint-brush Traces", Forensic Science International, 46: 33-35.

JACKSON, K. (2006), The Daubert era, in Jan Seaman Kelly and Brian S. Lindblom, Eds., Scientific examination of questioned documents, CRC Press, Taylor and Francis Group, Boca Raton, FL, 37-42.

JOHNSON, M. and PACKARD, E. (1971), "Methods used for the Identification of Binding Media in Italian Paintings of the Fifteenth and Sixteenth Centuries", Studies in Conservation, 16: 145-164.

JOLLIFFE, I.T. (2002), Principal Component Analysis, Springer, New York.

JONES, M. (1990), Fake? the art of deception, British Museum Publications, London.

JORNOD, J.-P. (2007a), L'expert et son rôle, in Marc-André Renold, Pierre Gabus and Jacques de Werra, Eds., L'expertise et l'authentification des oeuvres d'art, Schulthess, Genève, 13-17.

JORNOD, N. (2007b), Le catalogue raisonné, in Marc-André Renold, Pierre Gabus and Jacques de Werra, Eds., L'expertise et l'authentification des oeuvres d'art, Schulthess, Genève, 19-27.

JUREN, V. (1974), "Fecit-faciebat", Revue de l'art, Issue 26: 27-30.

KAM, M., GUMMADIDALA, K., FIELDING, G. and CONN, R. (2001), "Signature authentication by forensic document examiners", Journal of Forensic Sciences, 46: 884-888.

KARELITZ, T.M. and BUDESCU, D.V. (2004), "You Say "Probable" and I Say "Likely": Improving Interpersonal Communication With Verbal Probability Phrases", Journal of Experimental Psychology: Applied, 10: 25-41.

KARLEN, P.H. (1988), Fakes, Forgeries and Expert Opinions, in Pierre Lalive, Ed. International Sales of Works of Art - La vente internationale d'oeuvres d'art, Institute of International Business Law and Practice - Faculté de Droit de Genève, 219-250.

KASSIN, S.M., DROR, I.E. and KUKUCKA, J. (2013), "The forensic confirmation bias: Problems, perpectives, and proposed solutions", Journal of Applied Research in Memory and Cognition, 2: 42-52.

KENNICK, W.E. (1985), "Art and Inauthenticity", The Journal of Aesthetics and Art Criticism, 44: 3-12.

KURSA, M.B. and RUDNICKI, W.R. (2010), "Feature Selection with the Boruta Package", Journal of Statistical Software, 36: 1-13.

KURZ, O. (1983), Faux et faussaires, Flammarion, Paris.

LANGENBURG, G.M. (2012), A Critical Analysis and Study of the ACE-V Process, Doctoral thesis, School of Criminal Justice, University of Lausanne, Lausanne.

LANGENBURG, G.M., CHAMPOD, C. and GENESSAY, T. (2012), "Informing the judgments of fingerprint analysts using quality metric and statistical assessment tools", Forensic Science International, 219: 183-198.

LAUWERS, D., GARCIA HUTADO, A., TANEVSKA, V., MOENS, L., BERSANI, D. and VANDENABEELE, P. (2014), "Characterisation of a portable Raman spectrometer for in situ analysis of art objects", Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 118: 294-301.

LEBENSZTEJN, J.-C. (1974), "Esquisse d'une typologie", Revue de l'art, Issue 26: 48-56.

LECOQ, A.-M. (1974), "Cadre et rebord", Revue de l'art, Issue 26: 15-20.

LEMOINE, S. (1992), Le rôle de l'expert dans la pratique, in Quentin Byrne-Sutton and Marc-André Renold, Eds., L'expertise dans la vente d'objets d'art, Aspects juridiques et pratiques, Schulthess Polygraphischer Verlag, Zürich, 1, 67-76.

LEQUETTE-DE KERVENOAËL, S. (2006), L'authenticité des œuvres d'art, Librairie générale de droit et de jurisprudence, Paris.

LESSARD, R. (1988), L'amour du faux, La vérité sur l'affaire Legros, Hachette, Paris.

LEVENSON, R.S. (2004), Examining the Techniques and Materials of Paintings, in Ronald D. Spencer, Ed. The expert versus the object - Judging fakes and false attributions in the visual arts, Oxford University Press, Oxford, 111-124.

LIAW, A. and WIENER, M. (2002), "Classification and Regression by randomForest", R News, 2: 18-22.

LIGERTWOOD, A. and EDMOND, G. (2012), "Expressing evaluative forensic science opinions in a court of law", Law, Probability and Risk, 11: 289-302.

LINES, S.R. (2006), "Examination of a "Velasco" signature on an oil painting", Journal of Forensic Sciences, 51: 929-933.

LOCARD, E. (1934), Manuel de technique policière, Payot, Paris.

LOCARD, E. (1936), L'espertise des documents écrits, les correspondances secrètes, les falsifications, Desvigne, Lyon.

LUCAS, A. and LUCAS, H.-J. (2001), Traité de la propriété littéraire et artistique, Litec, Paris.

MALVOISIN, A. (2011), "La sentence du catalogue raisonné" Le Journal des Arts, 357, Online article: http://www.lejournaldesarts.fr/jda/archives/docs_article/92227/la-sentence-du-catalogue-raisonne.php: Last consulted: October 2014.

MARETTE, J. (1961), Connaissance des Primitifs par l'étude du bois du XIIe au XVIe siècle, Picard, Paris.

MARGOT, P. (2011), "Forensic science on trial - What is the law of the land?", Australian Journal of Forensic Sciences, 43: 89-103.

MARQUIS, R. (2007), Etude de caractères manuscrits : de la caractérisation morphologique à l'individualisation du scripteur, Faculté de droit et des sciences criminelles, Université de Lausanne.

MARQUIS, R., BOZZA, S., SCHMITTBUHL, M. and TARONI, F. (2011), "Handwriting Evidence Evaluation Based on the Shape of Characters: Application of Multivariate Likelihood Ratios", Journal of Forensic Sciences, 56: 238-242.

MARTIN, J. (2008), "An Overview of the Scientific Analysis of the "Matter Paintings"", International Foundation for Art Research Journal, 10: 25-35.

MARTIRE, K.A., KEMP, R.I. and NEWELL, B.R. (2013), "The psychology of interpreting expert evaluative opinions", Australian Journal of Forensic Sciences, 45: 305-314.

MATTEINI, M. and MAZZEO, R. (2009), Structure of panel and canvas paintings, in Daniela Pinna, Monica Galeotti and Rocco Mazzeo, Eds., Scientific examination for the investigation of paintings a handbook for conservator-restorers, Centro Di, Firenze, 11-20.

MILGROM, E. (2005), "Vers un « profil ADN » des œuvres d'art" Le Journal des Arts, 209, Online article: http://www.lejournaldesarts.fr/jda/archives/docs_article/24243/vers-un---profil-adn---des-oeuvres-d-art.php: Last consulted: October 2014.

MILLER, L.S. (1984), "Bias among forensic document examiners: A need for procedural changes", Journal of Police Science and Administration, 12: 407-411.

MILLER, L.S. (1987), "Procedural bias in forensic examination of human hair", Law and Human Behavior, 11: 157-163.

MNOOKIN, J.L. (2001), "Scripting Expertise: The History of Handwriting Identification Evidence and the Judicial Construction of Reliability", Virginia Law Review, 87: 1723-1845.

MOHEN, J.-P., Ed. (1998), L'art et la science : l'esprit des chefs-d'oeuvre, Découvertes Gallimard 299. Sciences, Gallimard : Réunion des musées nationaux, Paris.

MONTANI, I. (2009a), "La contribution de l'expertise de la signature pour l'authentification des oeuvres d'art", Revue internationale de criminologie et de police technique et scientifique, 62: 52-53.

MONTANI, I. (2009b), A novel approach for the authentication of signatures on works of art, European Academy of Forensic Science Conference, Glasgow, Poster presentation.

MONTANI, I. (2012), An approach for the authentication of signatures on works of art, European Academy of Forensic Science Conference, The Hague, Poster presentation.

MORELLI, G. and ANDERSON, J. (1991), Della pittura italiana studii storico-critici le Gallerie Borghese e Doria-Pamphili in Roma, Adelphi Edizioni, Milano.

MORRIS, R. (2000), Forensic handwriting identification fundamental concepts and principles, Academic Press, San Diego, California.

MORRISON, G.S. (2011), "Measuring the validity and reliability of forensic likelihood-ratio systems", Science & Justice, 51: 91-98.

MOULIN, R. (1982), Remarques sur la définition sociologique de l'oeuvre d'art, in Michel Vanden Abeele, Ed. Le marché commun et le marché de l'art, Institut d'Etudes Européennes, Université Libre de Bruxelles, Bruxelles, 31-34.

MOULIN, R. (1995a), De l'artisan au professionnel: l'artiste, in Raymonde Moulin, Ed. De la valeur de l'art, Flammarion, Paris, 91-106.

MOULIN, R. (1995b), La genèse de la rareté artistique, in Raymonde Moulin, Ed. De la valeur de l'art, Flammarion, Paris, 161-191.

MOULIN, R. (2009), Le marché de l'art. Mondialisation et nouvelles technologies, Flammarion, Paris.

MOULIN, R. and QUEMIN, A. (1993), "La certification de la valeur de l'art. Experts et expertises ", Annales. Économies, Sociétés, Civilisations 48: 1421-1445

NATALE, M. and RITSCHARD, C., Eds. (1997), L'art d'imiter : images de la Renaissance italienne au Musée d'Art et d'Histoire, Musées d'art et d'histoire, Genève.

NATIONAL RESEARCH COUNCIL, N.R.C. (2009), Strengthening forensic science in the United States: A path forward, The National Academies Press, Washington D.C.

NEWMAN, R. (2008), "An Overview of the Scientific Analysis of the 'Matter Paintings'", International Foundation for Art Research Journal, 10: 18-24.

NOBILI, R. (1922), The gentle art of faking : a history of the methods of producing imitations and spurious works of art from the earliest times up to the present day, Seeley : Service, London.

NOCE, V. (2003), "Le droit d'auteur et ses abus" L'Oeil, 550, Online article: http://www.lejournaldesarts.fr/oeil/archives/docs_article/27260/le-droit-d-auteur-et-ses-abus.php: Last consulted: October 2014.

NORDGAARD, A., ANSELL, R., DROTZ, W. and JAEGER, L. (2012), "Scale of conclusions for the value of evidence", Law, Probability and Risk, 11: 1-24.

OKIL, E.N. (2000), How appraisers deal with authenticity, Scientific Detection of Fakery in Art II, Boston, MA, USA, SPIE, 75-79.

OSBORN, A.S. (1929), Questioned documents, Boyd Printing Company, Albany, N.Y.

PAUL, J. (2003), "Un Botticelli réattribué" Le Journal des Arts, 167, Online article: http://www.lejournaldesarts.fr/jda/archives/docs_article/28129/un-botticelli-reattribue.php: Last consulted: October 2014.

PERVOUCHINE, V. and LEEDHAM, G. (2007), "Extraction and analysis of forensic document examiner features used for writer identification", Pattern Recognition, 40: 1004-1013.

PINNA, D., GALEOTTI, M. and MAZZEO, R., Eds. (2009), Scientific examination for the investigation of paintings a handbook for conservator-restorers, Centro Di, Firenze.

REEVES, V.K. (2006), "Droit Moral and Authentication of Works in France", International Foundation for Art Research Journal, 8: 46-49.

REEVES, V.K. (2007), L'expertise devant les tribunaux: expériences en France et aux USA, in Marc-André Renold, Pierre Gabus and Jacques de Werra, Eds., L'expertise et l'authentification des oeuvres d'art, Schulthess, Genève, 39-44.

REISS, R.A. (1906), "Les méthodes scientifiques dans les enquêtes criminelles et policières", Archives d'anthropologie criminelle, de criminologie et de psychologie normale et pathologique, 21: 857-876.

RENOLD, M.-A. (2010), "Le droit de l'art et des biens culturels en Suisse : questions choisies", Revue de droit suisse, 129: 137-220

RINGE, F.J. (2007), Le pouvoir de l'expert face au droit de la concurrence, in Marc-André Renold, Pierre Gabus and Jacques de Werra, Eds., L'expertise et l'authentification des oeuvres d'art, Schulthess, Genève, 135-147.

RINUY, A. (1997), Les falsifications sous le microscope, in Mauro Natale and Claude Ritschard, Eds., L'art d'imiter, Images de la Renaissance italienne, Musée d'art et d'histoire, Genève, 293-301.

RISINGER, D.M., SAKS, M.J., THOMPSON, W.C. and ROSENTHAL, R. (2002), "The Daubert/Kumho Implications of Observer Effects in Forensic Science: Hidden Problems of Expectation and Suggestion", California Law Review, 90: 1-56.

RISINGER, M.D. (2007), Handwriting Identification, in D. L. Faigman, D. H. Kaye, M. J. Saks, J. Sanders and E. K. Cheng, Eds., Modern Scientific Evidence: The Law and Science of Expert Testimony, Thompson/West Eagan, MN, 4, 377-524.

RISINGER, M.D. (2009), "The NAS Report on Forensic Science: A Glass Nine-Tenths Full (This is About the Other Tenth)", Jurimetrics, 50: 21-34.

RISINGER, M.D., DENBEAUX, M.P. and SAKS, M.J. (1989), "Exorcism of Ignorance as a Proxy for Rational Knowledge: The Lessons of Handwriting Identification 'Expertise'", The University of Pennsylvania Law Review, 137: 731-792.

ROGERS, D. and FOUND, B. (1996), The objective measurement of spatial invariance in handwriting, in M.L Simner, C.G. Leedham and A.J.W.M. Thomassen, Eds., Handwriting and Drawing Research: Basic and Applied Issues, IOS Press, Amsterdam, 3-13.

ROGERS, D., FOUND, B. and GANAS, J. (2003), "An objective comparison of spatial characteristics between forged and genuine signatures using matrix analysis software", Forensic Science International, 136: 82-82.

ROY, A., Ed. (1993), Artists' pigments: a handbook of their history and characteristics. Vol. 2, National Gallery of Art, Cambridge.

RUOSS, R.T. (1988), The Constestation of Auction Sales under art. 230 CO, in Pierre Lalive, Ed. International Sales of Works of Art - La vente internationale d'oeuvres d'art, Institute of International Business Law and Practice - Faculté de Droit de Genève, 283-297.

SAKS, M.J. and KOEHLER, J.J. (2005), "The Coming Paradigm Shift in Forensic Identification Science", Science, 309: 892-895.

SAKS, M.J. and RISINGER, M.D. (1996), "Science and nonscience in the courts: Daubert meets handwriting identification expertise", Iowa Law Review, 82: 21-74.

SAKS, M.J., RISINGER, M.D., ROSENTHAL, R. and THOMPSON, W.C. (2003), "Context effects in forensic science: A review and application of the science of science to crime laboratory practice in the United States", Science and Justice, 43: 77-90.

SALA, C. (1987), "La signature à la lettre et au figuré", Poetique, Issue 69: 119-127.

SANDERS, J. (2001), "Kumho and How We Know", Law and Contemporary Problems, 64: 375-415.

SANNIÉ, C. (1953), "L'expertise des oeuvres d'art", Revue Internationale de Criminologie et de Police Technique, 7: 200 - 210.

SCHMITT, J.-M. (1996), "Expertise : histoire d'un surplace" Le Journal des Arts, 27, Online article: http://www.lejournaldesarts.fr/jda/archives /docs_article/70795/expertise--histoire-d-un-surplace.php: Last consulted: October 2014.

SCHMITT, J.-M. (1997), "Les juges suisses proclament un « ordre public international »" Le Journal des Arts, 44, Online article: http://www.lejournaldesarts.fr/jda/archives/docs_article/67868/les-juges-suisses-proclament-un---ordre-public-international--.php: Last consulted: October 2014.

SCHMITT, J.-M. (2003), "Le Poussin des frères Pardo : un regrettable épilogue" Le Journal des Arts, 180, Online article: http://www.lejournaldesarts.fr/jda/archives/docs_article/26699/le-poussin-des-freres-pardo--un-regrettable-epilogue.php: Last consulted: October 2014.

SCIACCA, E. (2010), Etude de mentions manuscrites apposées dans des conditions non conventionnelles, Philosophiae Doctor, Université Paul Cézanne and Université de Lausanne, Aix-Marseille and Lausanne.

SIEGEL, P. (2004), Signature Identification, in Ronald D. Spencer, Ed. The expert versus the object - Judging fakes and false attributions in the visual arts, Oxford University Press, Oxford, 89-93.

SITA, J., FOUND, B. and ROGERS, D. (2002), "Forensic handwriting examiners' expertise for signature comparison", Journal of Forensic Sciences, 47: 1117-1124.

SPENCER, R.D. (2004), Authentication in Court, in Ronald D. Spencer, Ed. The expert versus the object - Judging fakes and false attributions in the visual arts, Oxford University Press, Oxford, 189-215.

STANKIEWICZ, L. (2012), "L'amateur d'art, le marchand et le fisc" Le Journal des Arts, 366, Online article: http://www.lejournaldesarts.fr/jda/archives/docs_article/98988/l-amateur-d-art-le-marchand-et-le-fisc.php Last consulted: October 2014.

STEBBINS, T.E. (2004), The Art Expert, the Law, and Real Life, in Ronald D. Spencer, Ed. The expert versus the object - Judging fakes and false attributions in the visual arts, Oxford University Press, Oxford, 135-142.

STERN, P.R. (2006), "Insultating Yourself from Liability", International Foundation for Art Research Journal, 8: 74-76.

SUTTON, P.C. (2006), "Judging the Experts", International Foundation for Art Research Journal, 8: 34-39.

TANCOCK, J.L. (2006), "The View from the Auction House", International Foundation for Art Research Journal, 8: 40-45.

TARONI, F., BOZZA, S., BIEDERMANN, A., GARBOLINO, P. and AITKEN, C. (2010), Data analysis in forensic science - A Bayesian decision perspective, John Wiley and Sons, Ltd., Chichester.

TARONI, F., MARQUIS, R., SCHMITTBUHL, M., BIEDERMANN, A., THIÉRY, A. and BOZZA, S. (2012), "The use of the likelihood ratio for evaluative and investigative purposes in comparative forensic handwriting examination", Forensic Science International, 214: 189–194.

TARONI, F., MARQUIS, R., SCHMITTBUHL, M., BIEDERMANN, A., THIÉRY, A. and BOZZA, S. (2014), "Bayes factor for investigative assessment of selected handwriting features", Forensic Science International, 242: 266-273.

TETLOCK, P. (2005), Expert Political Judgment: How Good Is It? How Can We Know?, Princeton University Press, Princeton, N. J.

THÉVENOZ, L. (1992), Le responsabilité de l'expert en objets d'art selon le droit suisse, in Quentin Byrne-Sutton and Marc-André Renold, Eds., L'expertise dans la vente d'objets d'art, Aspects juridiques et pratiques, Schulthess Polygraphischer Verlag, Zürich, 1, 67-76.

THIÉRY, A., MARQUIS, R. and MONTANI, I. (2013), "Statistical evaluation of the influence of writing postures on on-line signatures. Study of the impact of time", Forensic Science International, 230: 107-116.

TVERSKY, A. and KAHNEMAN, D. (1974), "Judgment under Uncertainty: Heuristics and Biases", Science, 185: 1124-1131.

UNKNOWN (1974), "La signature emblématique", Revue de l'art, Issue 26: 31-32.

VAN DER WEERD, J. (2002), Microspectroscopic Analysis of Traditional Oil Paint, Doctoral thesis, Faculteit der Natuurwetenschappen, Wiskunde en Informatica, Universiteit van Amsterdam, Amsterdam.

VANDENABEELE, P. and MOENS, L. (2005), Overview: Raman Spectroscopy of Pigments and Dyes, in Howell G. M. Edwards and John M. Chalmers, Eds., Raman spectroscopy in archaeology and art history, Royal Society of Chemistry, Cambridge, 71-83.

VIGEARS, D. (2000), "Eclairage et photographie scientifique", Technè, 12: 50-55.

WATCHMAN, A.L. (2007), "Parmigiani Amica: analysis and radiocarbon dating of an Il Parmigianino oil painting", Technè, 25: 12-19.

WHITING, F.I. (1996), "The Application of Reasoning to the Evaluation of Fundamental Differences in Handwriting Comparisons", Journal of Forensic Sciences, 41: 634-640.

WIDLA, T. (1985), Forgery of Artists' Signatures, Experiencing Graphology, [on file with the author].

WILLHEIM, R. (1974), Giovanni Morelli and the Origins of Scientific Connoisseurship, On Art and the Mind, Cambridge, 175 - 201.

WYPLOSZ, N. (2003), Laser Desoption Mass Spectrometric Studies of Artists' Organic Pigments, AMOLF (FOM Institute for Atomic and Molecular Physics), University of Amsterdam, Amsterdam.

YAZICI, B. and YOLACAN, S. (2007), "A comparison of various tests of normality", Journal of Statistical Computation and Simulation, 77: 175-183.

ZERNER, H. (1978), "Giovanni Morelli et la science de l'art", Revue de l'art, Issue 40: 209-215.

Judicial references - listed by order of appearance

ATF 112 II 347 (June 3rd 1986)

Cour de cassations, 1ère civ. (April 3rd 2007)

ATF 123 II 134 (April 29th 1997)

State v. Hauptmann, 115 N.J.L. 412, 180 A. 809 (1935)

Daubert v. Merrell Dow Pharm., Inc., 509 U.S. 579, (1993)

Frye v. United States, 293 F. 1013 (D.C. Cir. 1923)

United States v. Starzecpyzel, 880 F. Supp. 1027 (S.D.N.Y. 1995)

Arheh v. Christie's International, Index No 1030/86 (Supreme Court of the State of New York) (1986),42 M.J 730 (A.C.C.A. 1995)

United States v. Jones, 107 F.3d 1147, 46 Fed. R. Evid. Serv. 885, 1997 FED App. 0082 (6th Cir. 1997)

United States v. Battle, 188 F.3d 519 (10th Cir. 1999)

United States v. McVeigh, 1997 WL 47724 (D. Colo., Transcript, 1997)

Kumho Tire v. Carmichael 526 U.S. 137 (1999)

General Electric Co. v. Joiner 522 U.S. 136 (1997)

Kumho Tire v. Carmichael 526 U.S. 137 (1999), quoting Daubert v. Merrell Dow Pharm., Inc., 509 U.S. 579, 592 (1993)

United States v. Hines, 55 F. Supp 2d 62, 52, Fed. R. Evid Serv. 257 (D. Mass. 1999)

United States v. Santillan, 199 WL 1201765 (N.D. Cal. 1999)

United States v. Hernandez, 42 Fed. Appx. 173, 89 A.F.T.R2d 2002-3049 (10th Circuit)

Wolf v. Ramsey, 253 F. Supp. 2d 1323, 61 Fed. R. Evid. Serv. 1715 (N.D. Ga 2003)

United States v. Rutherford, 104 F. Supp. 2d 1190, 55 Fed. R. Evid Serv. 201 (D. Neb. 2000)

United States v. Brown, No. CR 99-184 ABC (C.D. Cal., Dec. 1, 1999)

United States v. Fujii, 152 F. Supp. 2d 939, 56 Fed. R. Evid. Serv. 1029 (N.D. Ill. 2000)

United States v. Saelee, 162 F. Supp. 2d 1097, 57, Fed. R. Evid. Serv. 916 (D. Alaska 2001)

United States v. Lewis, 220 F. Supp. 2d 548 (S.D. W. Va. 2002)

United States v. Brewer, 2002 WL 596365 (N.D. Ill. 2002)

United States v. Elmore, 56 M.J. 533 (N.M.C.C.A 2001), review denied, 57 M.J. 99 (C.A.A.F. 2002)

United States v. Johnson, 30 Fed. Appx. 685 (9th Cir. 2002), cert. denied, 537 United States 1241, 123 S. Ct. 1374, 155, L. Ed. 2d 213 (2003)

Arheh v. Christie's International, Index No 1030/86 (Supreme Court of the State of New York) (1986). M.J. 1 (C.A.A.F. 1997)

Arheh v. Christie's International, Index No 1030/86 (Supreme Court of the State of New York) (1986). 175 F.3d 906, 51 Fed. R. Evid. Serv. 1464, 183 A.L.R. Fed. 773 (11th Cir. 1999)

United States v. Velasquez, 64 F.3d 844, 42 Fed. R. Evid. Serv. 1175 (3rd Cir. 1995)

United States v. Prime, 363 F. 3d 1028 (9th Cir. 2004)

United States v. Pettus, 37 A.3d 213, 217 (D.C.2012)

Paris, 13e ch. sect. B, April 12th 1996, RG n°95-04324

R v. T, Court of Appeal - EWCA Crim 2439 (2010)

United States v. Crisp, 324 F.3c d d 261 (4th Cir. 2003)

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Exploring transparent approaches to the authentication of signatures on artwork

Appendixes

Isabelle Montani

Lausanne, 2015

Appendix I

List of sampling material

Painting material

Canvas	Henri 40x40 pre-stretched mixed 350 g/m^2 cotton profile with lightly absorbent white universal primer and with back stapling
Primer	Guardi white primer
Oil paint	Schmicke Norma professional titanium white, n°114 Schmincke Norma professional ivory black, n°704
Oil thinner for canvas preparation	Schmincke Mussini Medium 3 drying accelerant, series 50 040
Oil thinner	Talens rectified turpentine for oil colour, series 2, model 032
Paintbrushes	Boesner longhaired mohair size 2 Pébéo Aqua synthetic hair size 6 Pébéo model 9960 size 3 Artist synthetic real Zenia Acryl hair model 74 size 2 Artist synthetic real Zenia Acryl hair model 74 size 4 Artist synthetic real Zenia Acryl hair model 74 size 6

Appendix II

Information sheet submitted to each artist for the authentic signatures acquisition stage

UNIL | Université de Lausanne
Institut de police scientifique
bâtiment Batochime
CH-1015 Lausanne

INSTRUCTIONS

You have received:

- Six canvases, prepared with base oil layers, and numbered on the back
- A paintbrush (Boesner, pure red sable hair, size 2) and standard Bic black ballpoint pen
- Diluted black paint (Schmincke Norma Professional ivory black - 704)
- Sticks to mix the oil paint and parafilm to seal the paint jar.

The experiment is conducted on a minimum of 6 weeks. There are 6 sampling sessions, one per week. For each sampling session, you must sign your signature FOUR times with the given paintbrush and paint. You can test the brush and oil on canvas, either by signing or painting, so you are comfortable with the brush and oil. If you have questions or comments, please contact me.

General Information

Left-handed / Right-handed

First learned written language:

Education:

Since when do you practice oil painting?

Do you practice on a regular basis?

Did you sign your work? If so, since when do you sign them? If not, is there a particular reason why?

Do you use different signatures when signing your works? If yes, why do you change your signature?

Other information or comments:

SAMPLING N°1 - Canvas n°1

Date:

Support the canvas is placed on and its inclination (for example, flat on a table, with approximately 30°, etc.):

Did you use your hand, forearm or elbow to rest on? If yes, what did you use as a hold and what was it rested on?

Other comments or observation made during the sampling of the signature (for example on the paint consistency, etc.)

Please sign your habitual signature four times below (with the ballpoint pen):

SAMPLING N°2 - Canvas n°2

Date:

Support the canvas is placed on and its inclination (for example, flat on a table, with approximately 30°, etc.):

Did you use your hand, forearm or elbow to rest on? If yes, what did you use as a hold and what was it rested on?

Other comments or observation made during the sampling of the signature (for example on the paint consistency, etc.)

Please sign your habitual signature four times below (with the ballpoint pen):

SAMPLING N°3 - Canvas n°3

Date:

Support the canvas is placed on and its inclination (for example, flat on a table, with approximately 30°, etc.):

Did you use your hand, forearm or elbow to rest on? If yes, what did you use as a hold and what was it rested on?

Other comments or observation made during the sampling of the signature (for example on the paint consistency, etc.)

Please sign your habitual signature four times below (with the ballpoint pen):

SAMPLING N°4 - Canvas n°4

Date:

Support the canvas is placed on and its inclination (for example, flat on a table, with approximately 30°, etc.):

Did you use your hand, forearm or elbow to rest on? If yes, what did you use as a hold and what was it rested on?

Other comments or observation made during the sampling of the signature (for example on the paint consistency, etc.)

Please sign your habitual signature four times below (with the ballpoint pen):

SAMPLING N°5 - Canvas n°5

Date:

Support the canvas is placed on and its inclination (for example, flat on a table, with approximately 30°, etc.):

Did you use your hand, forearm or elbow to rest on? If yes, what did you use as a hold and what was it rested on?

Other comments or observation made during the sampling of the signature (for example on the paint consistency, etc.)

Please sign your habitual signature four times below (with the ballpoint pen):

SAMPLING N°6 - Canvas n°6

Date:

Support the canvas is placed on and its inclination (for example, flat on a table, with approximately 30°, etc.):

Did you use your hand, forearm or elbow to rest on? If yes, what did you use as a hold and what was it rested on?

Other comments or observation made during the sampling of the signature (for example on the paint consistency, etc.)

Please sign your habitual signature four times below (with the ballpoint pen):

Appendix III

Information and instruction sheet submitted to simulators for the simulated signatures acquisition stage

Unil
UNIL | Université de Lausanne
Institut de police scientifique
bâtiment Batochime
CH-1015 Lausanne

IDENTIFICATION NUMBER 1

INSTRUCTIONS

Approximate age : Left / right-handed :

Highest studies followed :

Do you regularly use a paintbrush (for work or artistic reasons) ?

If yes, please detail the exact use and frequency :

How would you consider your signature imitation skills?

Aim of this research and why I need your help:

I am currently a PhD student at the Institute of Forensic Science (Kriminaltechnik Wissenschaft) of the University of Lausanne (www.unil.ch/esc) and I am conducting a research on the possibility of authenticating signatures on paintings.

Five artists have participated in my research and have produced approximately 25 signatures on oil canvases. To assess the signature authentication method I have developed, I am looking for persons who are willing to play the role of imitators, and would try to imitate the signature of these five artists.

Your participation in this study is anonymous. The Identification number (ID) is used to identify you from this point on. All of the signatures produced will be strictly treated in the framework of this study.

I can be reached by email (isabelle.montani@unil.ch) or phone (021/692.46.47) for any questions or comments.

Thank you again for your participation, it is greatly appreciated ! I. Montani

---

Each kit is numbered and contains:

- A3 size dossier containing the signatures of the five artists, in their actual size.
- A4 size dossier containing enlargements of the signatures of the five artists.
- 5 oil canvases - Your **ID kit number** (see top-right corner of this page) is printed on the back of the canvas
- 1 oil canvas for practice (**practice** is written on the back of the canvas)
- different types of paintbrushes; two of these paintbrushes are marked A and B
- black oil paint, diluted (Ms. Soppa has a tube of paint and turpentine if need to thicken or dilute the paint)

The imitation process is done in two stages:

1st stage : Choice of paintbrush and practice

Choose the brush with which you feel most comfortable and reproduces best the signature of the artist.

Note: artists A.Pasquier, J.C.Schauenberg, V.Muro and P.Bacsay used the paintbrush **A** - artist J.M.Schwaller used the paintbrush **B**. Other information on the artists is available in the table below.

Please practice the signature of each artist until you feel you have reached the **best imitation possible**. This stage should ideally be carried out at least two times (on two different days). You can use the **practice** canvas for this purpose.

2nd stage : Imitation stage

Take one of the canvases - make sure it has your correct **ID number** on the back.

Imitate the artist's signature a minimum of **five** times on this canvas. Take a new canvas for every one of the artists.

Feel free to remove excess paint on the brush before starting the signature (you can doodle/scribble on the canvas).

If you think a signature has not been ideally imitated, please redo another signature (no need to cross out the signature you “missed”).

If you based your imitations on one particular signature, please indicate which one in the table below.

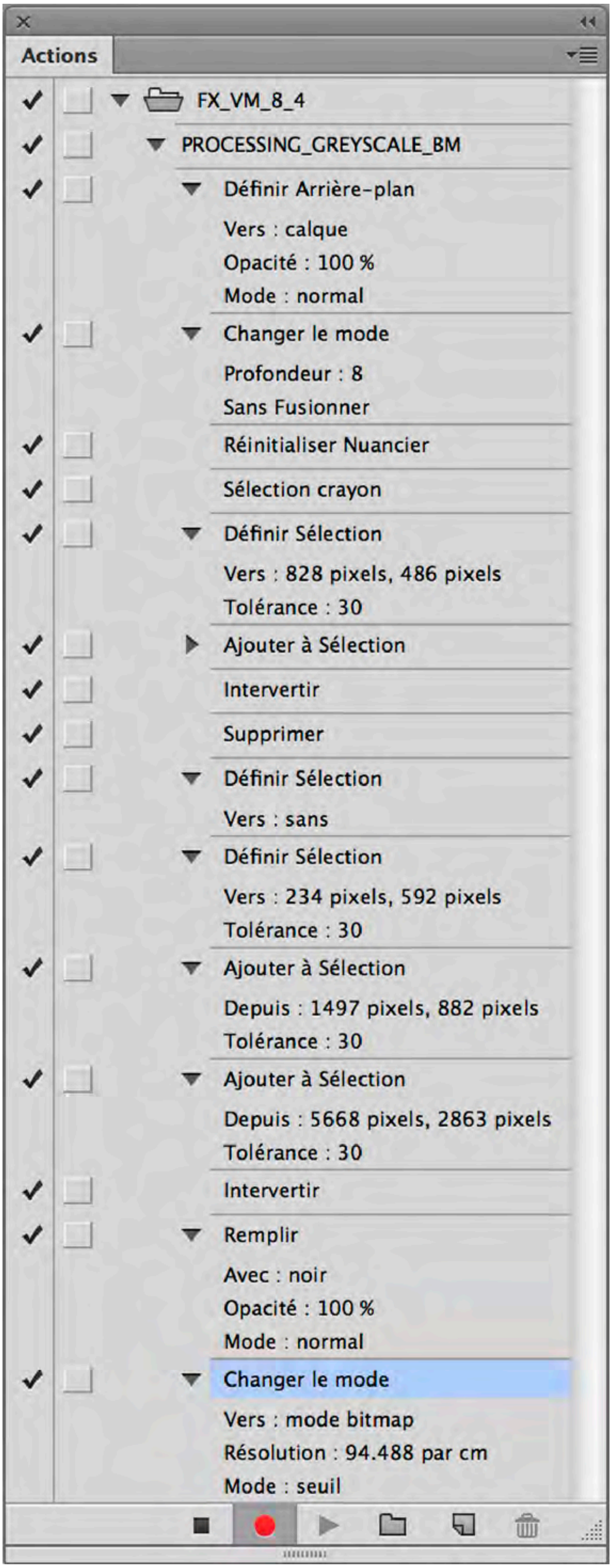
Information on the artists:

GENERAL INFORMATION ON ARTISTS					
ARTISTS	**A. Pasquier**	**V. Muro**	**JC Schauenberg**	**P. Bacsay**	**J-M Schwaller**
Writing language	French	Spanish - French	French	Hungarian - French	French
Left / right handed	right-handed	right-handed	right-handed	right-handed	right-handed
Paintbrush used	A	A	A	A	B
IMITATIONS	Which signature(s) did you base your imitations on ?				
Imitated signatures					

Additional comments:

Appendix IV

Photoshop script for image pre-processing


Actions
FX_VM_8_4
PROCESSING_GREYSCALE_BM
Définir Arrière-plan
Vers : calque
Opacité : 100 %
Mode : normal
Changer le mode
Profondeur : 8
Sans Fusionner
Réinitialiser Nuancier
Sélection crayon
Définir Sélection
Vers : 828 pixels, 486 pixels
Tolérance : 30
Ajouter à Sélection
Intervertir
Supprimer
Définir Sélection
Vers : sans
Définir Sélection
Vers : 234 pixels, 592 pixels
Tolérance : 30
Ajouter à Sélection
Depuis : 1497 pixels, 882 pixels
Tolérance : 30
Ajouter à Sélection
Depuis : 5668 pixels, 2863 pixels
Tolérance : 30
Intervertir
Remplir
Avec : noir
Opacité : 100 %
Mode : normal
Changer le mode
Vers : mode bitmap
Résolution : 94.488 par cm
Mode : seuil

Appendix V

Information on participating artists and simulators

Information on participating artists

GENERAL INFORMATION					
Name Artist	**1/ Schauenberg**	**2/ Bacsay**	**3/ Muro**	**4/ Pasquier**	**5/ Schwaller**
Language	French	Hungarian/French	Spanish/French	French	French
Left / right-handed	L ☐ R ☑	L ☐ R ☑	L ☐ R ☑	L ☐ R ☑	L ☐ R ☑
Studies	Fine-Arts, Lausanne	Fine-Arts, Budapest	Fine-Arts, Argentina	Fine-Arts, Geneva	Drawing Master, University of Berne
Regular use of oil	no	yes	yes	yes	yes
Since when?	-	1974	1970	1987	1970
Signs since when?	1960	1974	1975	1990	1970
Date 1	28/03/2011	02/03/2011	18/12/2010	13/09/10	14/05/2011
Position of canvas	Flat (table)	-	Flat (table)	Vertical (easel)	Flat (table)
Support/rest	Hand on a support of same thickness	no	Hand	Hand	Hand on canvas or on a support of same thickness
Date 2	04/04/2011	11/03/2011	25/12/2010	10/9/2010	19/05/2011
Position of canvas	Flat (table)	-	Flat (table)	Vertical (easel)	Flat (table)
Support/rest	Hand on a support of same thickness	-	No support	Hand	Hand on canvas or on a support of same thickness
Date 3	11/04/2011	20/03/2011	02/01/2011	30/09/10	24/05/2011
Position of canvas	Flat (table)	-	Flat (table)	Vertical (easel)	Flat (table)
Support/rest	Hand on a support of same thickness	-	No support	Hand	Hand on canvas or on a support of same thickness
Date 4	30/05/2011	29/03/2011	12/01/2011	11/10/10	30/05/2011
Position of canvas	Flat (table)	-	Flat (table)	Vertical (easel)	Flat (table)
Support/rest	Hand on canvas	-	No support	Hand	Hand on canvas or on a support of same thickness
Date 5	09/06/2011	08/04/2011	19/01/2011	19/10/10	10/06/2011
Position of canvas	Flat (table)	-	Flat (table)	Vertical (easel)	Flat (table)
Support/rest	Hand on a support of same thickness	-	No support	Hand	Hand on canvas or on a support of same thickness
Date 6	13/06/2011	22/04/2011	27/01/2011	28/10/10	20/06/2011
Position of canvas	Flat (table)	-	Flat (table)	Vertical (easel)	Flat (table)
Support/rest	Hand on a support of same thickness	-	Hand	Hand	Hand on canvas or on a support of same thickness
Date 7	-		19/03/2011	-	
Position of canvas			Hand		
Support/rest			Hand		
Date 8			19/03/2011		
Position of canvas			Flat		
Support/rest			Hand		
Date 9			26/03/2011		
Position of canvas			Flat		
Support/rest			Hand		

Information on participating simulators

GENERAL INFORMATION						
Identification number	**1 (HKB)**	**2 (HKB)**	**3 (HKB)**	**4 (HKB)**	**5 (HKB)**	**6 (HKB)**
GROUP	1 (conservateur-restorateur)	1 (conservateur-restorateur)	1 (conservateur-restorateur)	2 (painter - graphist)	1 (conservateur-restorateur)	1 (conservateur-restorateur)
Language	German	German (55 yo)	German	German (43 yo)	German (34 yo)	German (51 yo)
Left / right-handed	L ☐ R ☑	L ☐ R ☑	L ☐ R ☐	L ☐ R ☑	L ☐ R ☑	L ☐ R ☑
Highest studies followed	Unknown	HES	Bachelor of art (Studying Master in Conservation)	Graphic design HES	Art acadamy Stuttgart in Conservation	
Regularly uses paintbrush	☐	☑	☑	☑	☑	☐
Paintbrush use	na	Painting on fibers		Illustrations and watercolors	Conservation	
Frequency	na	na		5 times a year	na	
Imitation skill	na	low		good - never tried	low	
Sufficient number of signatures	☑	☑	☐	☑	☑	☐
DECISION			Pasquier signatures missing			DISCARDED insufficient data
PAINTER	Schauenberg	Schauenberg	Schauenberg	Schauenberg	Schauenberg	Schauenberg
Total N° of signatures	19	10	15	5	5	5
Based on specific signature?						
N° Photo: JCS_SIM_X	JCS_SIM_1-01 to 05	JCS_SIM_2-01 to 05	JCS_SIM_3-01 to 05	JCS_SIM_4-01 to 05	JCS_SIM_5-01 to 05	JCS_SIM_6-01 to 05
Other						
PAINTER	Bacsay	Bacsay	Bacsay	Bacsay	Bacsay	Bacsay
Total N° of signatures	11	9	5	5	5	3
Based on specific signature?						
N° Photo: PB_SIM_X	PB_SIM_1-01 to 05	PB_SIM_2-01 to 05	PB_SIM_3-01 to 05	PB_SIM_4-01 to 05	PB_SIM_5-01 to 05	PB_SIM_6-01 to 05
Other	-	-	-	-	-	-
PAINTER	Muro	Muro	Muro	Muro	Muro	Muro
Total N° of signatures	13	6	8	5	5	3
Based on specific signature?						
N° Photo: VM_SIM_0X	VM_SIM_1-01 to 05	VM_SIM_2-01 to 05	VM_SIM_3-01 to 05	VM_SIM_4-01 to 05	VM_SIM_5-01 to 05	VM_SIM_6-01 to 05
Other	-	-	-	-	-	-
PAINTER	Pasquier	Pasquier	Pasquier	Pasquier	Pasquier	Pasquier
Total N° of signatures	13	9	Uncompleted	5	5	0
Based on specific signature?			-			
N° Photo: AP_SIM_0X	AP_SIM_1-01 to 05	AP_SIM_2-01 to 05	-	AP_SIM_4-01 to 05	AP_SIM_5-01 to 05	AP_SIM_6-01 to 05
Other	-	-	-	-	-	-
PAINTER	Schwaller	Schwaller	Schwaller	Schwaller	Schwaller	Schwaller
Total N° of signatures	11	8	8	5	5	3
Based on specific signature?						
N° Photo: JMS_SIM_0X	JMS_SIM_1-01 to 05	JMS_SIM_2-01 to 05	JMS_SIM_3-01 to 05	JMS_SIM_4-01 to 05	JMS_SIM_5-01 to 05	JMS_SIM_6-01 to 05
Other	-	-	-	-	-	-

GENERAL INFORMATION

Identification number	7 (HKB)	8 (HKB)	9 (HKB)	10 (HKB)	11 (HKB)	12 (HKB)
GROUP	1 (conservateur-restorateur)	1 (conservateur-restorateur)	1 (conservateur-restorateur)	1 (conservateur-restorateur)	1 (conservateur-restorateur)	1 (conservateur-restorateur)
Language	German (50 yo)	German (50 yo)	German (29 yo)	German (30 yo)	German (30)	German
Left / right-handed	L ☐ R ☑	L ☐ R ☑	L ☐ R ☑	L ☑ R ☐	L ☐ R ☑	L ☐ R ☑
Highest studies followed	Art acadamy Vienna in Conservation - restoration	Art acadamy in Restoration	Bachelor of art (Studying Master in Conservation)	Bachelor of art (Studying Master in Conservation)	Bachelor of art (Studying Master in Conservation)	Kit not returned
Regularly uses paintbrush	☑	☑	☑	☑	☑	☐
Paintbrush use	Mix (gold inscription on metal plates with oil mixtion)	Paper conservation and restoration	Retouching and restoration of paintings	Retouching of paintings	Consolidation of paint layers and retouching	
Frequency	Several times a week	2-4 times a month	several weeks a year		every third week (monthly)	
Imitation skill	na	low	medium	medium - low	low	
Sufficient number of signatures	☑	☑	☑	☑	☑	☐
DECISION						DISCARDED - NO DATA
PAINTER	Schauenberg	Schauenberg	Schauenberg	Schauenberg	Schauenberg	Schauenberg
Total N° of signatures	6	6	9	6	13	-
Based on specific signature?						-
N° Photo: JCS_SIM_X	JCS_SIM_7-01 to 05	JCS_SIM_8-01 to 05	JCS_SIM_9-01 to 05	JCS_SIM_10-01 to 05	JCS_SIM_11-01 to 05	-
Other						-
PAINTER	Bacsay	Bacsay	Bacsay	Bacsay	Bacsay	Bacsay
Total N° of signatures	7	5	8	5	9	-
Based on specific signature?						
N° Photo: PB_SIM_X	PB_SIM_7-01 to 05	PB_SIM_8-01 to 05	PB_SIM_9-01 to 05	PB_SIM_10-01 to 05	PB_SIM_11-01 to 05	-
Other	-	-	-	-	-	-
PAINTER	Muro	Muro	Muro	Muro	Muro	Muro
Total N° of signatures	8	6	6	5	9	-
Based on specific signature?						-
N° Photo: VM_SIM_0X	VM_SIM_7-01 to 05	VM_SIM_8-01 to 05	VM_SIM_9-01 to 05	VM_SIM_10-01 to 05	VM_SIM_11-01 to 05	-
Other	-	-	-	-	-	-
PAINTER	Pasquier	Pasquier	Pasquier	Pasquier	Pasquier	Pasquier
Total N° of signatures	5	6	10	6	15	-
Based on specific signature?						-
N° Photo: AP_SIM_0X	AP_SIM_7-01 to 05	AP_SIM_8-01 to 05	AP_SIM_9-01 to 05	AP_SIM_10-01 to 05	AP_SIM_11-01 to 05	-
Other	-	-	-	-	-	-
PAINTER	Schwaller	Schwaller	Schwaller	Schwaller	Schwaller	Schwaller
Total N° of signatures	6	6	6	5	9	-
Based on specific signature?						-
N° Photo: JMS_SIM_0X	JMS_SIM_7-01 to 05	JMS_SIM_8-01 to 05	JMS_SIM_9-01 to 05	JMS_SIM_10-01 to 05	JMS_SIM_11-01 to 05	-
Other	-	-	-	-	-	-

GENERAL INFORMATION

Identification number	13 (MM)	14 (MG)	15 (LC)	16 (IM)	17 (RM)	18 (ML)
GROUP	2 (painter - graphist)	2 (painter - graphist)	Forensic handwriting examiner	Forensic handwriting examiner	Forensic handwriting examiner	2 (painter - graphist)
Language	French	French	Italian - French	French	French	French
Left / right-handed	L ☐ R ☑	L ☐ R ☑	L ☐ R ☑	L ☐ R ☑	L ☐ R ☑	L ☐ R ☑
Highest studies followed	unknown	achitecture de paysage - peinture ESAJ Paris, formation peinture J. Walther.	IPS, 20012	IPS, 2006	IPS, 2007	
Regularily uses paintbrush	☑	☑	☐	☐	☐	☑
Paintbrush use	-	acrylic, ink, professional	-	rare	-	-
Frequency		1-2 week	-	-	-	
Imitation skill	medium - good	medium	medium - low	medium		good
Sufficient number of signatures	☑	☑	☑	☑	☑	☐
DECISION	-	-		-	-	DISCARDED - NO DATA
PAINTER	Schauenberg	Schauenberg	Schauenberg	Schauenberg	Schauenberg	Schauenberg
Total N° of signatures	5	12	5	5	7	-
Based on specific signature?					5 and 8	-
N° Photo: JCS_SIM_X	JCS_SIM_13-01 to 05	JCS_SIM_14-01 to 05	JCS_SIM_15-01 to 05	JCS_SIM_16-01 to 05	JCS_SIM_17-01 to 05	-
Other						-
PAINTER	Bacsay	Bacsay	Bacsay	Bacsay	Bacsay	Bacsay
Total N° of signatures	10	9	5	5	7	-
Based on specific signature?					5	
N° Photo: PB_SIM_X	PB_SIM_13-01 to 05	PB_SIM_14-01 to 05	PB_SIM_15-01 to 05	PB_SIM_16-01 to 05	PB_SIM_17-01 to 05	-
Other	-	-	-	-	-	-
PAINTER	Muro	Muro	Muro	Muro	Muro	Muro
Total N° of signatures	18	7	5	5	5	-
Based on specific signature?					7	-
N° Photo: VM_SIM_0X	VM_SIM_13-01 to 05	VM_SIM_14-01 to 05	VM_SIM_15-01 to 05	VM_SIM_16-01 to 05	VM_SIM_17-01 to 05	-
Other	-	-	-	-	-	-
PAINTER	Pasquier	Pasquier	Pasquier	Pasquier	Pasquier	Pasquier
Total N° of signatures	5	12	5	5	7	-
Based on specific signature?					1, 4 and 9	-
N° Photo: AP_SIM_0X	AP_SIM_13-01 to 05	AP_SIM_14-01 to 05	AP_SIM_15-01 to 05	AP_SIM_16-01 to 05	AP_SIM_17-01 to 05	-
Other	-	-	-	-	-	-
PAINTER	Schwaller	Schwaller	Schwaller	Schwaller	Schwaller	Schwaller
Total N° of signatures	11	14	5	9	6	-
Based on specific signature?					4	-
N° Photo: JMS_SIM_0X	JMS_SIM_13-01 to 05	JMS_SIM_14-01 to 05	JMS_SIM_15-01 to 05	JMS_SIM_16-01 to 05	JMS_SIM_17-01 to 05	-
Other	-	-	Same brush as artists used;	-	-	-

Appendix VI

Illustrations of authentic and simulated signatures (presented by artist and by simulator)

[on file with author ; isabelle.montani@alumnil.unil.ch]

Appendix VII

Terminology employed to designate the encountered signature components

Appendix VII – Name reference of the different components of the signature

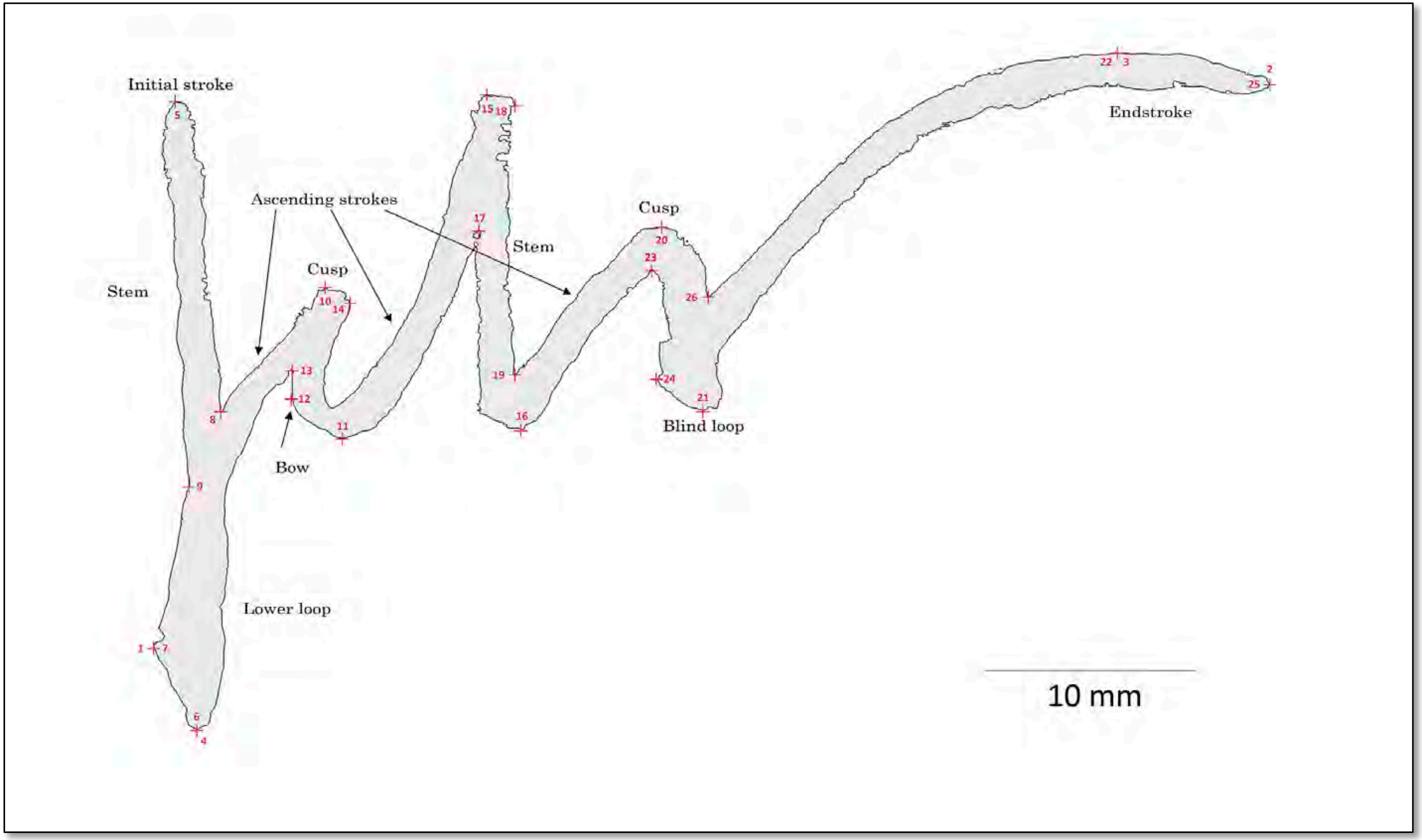


Illustration 1 - Name reference of the different components of the signature of artist n°1 - Schauenberg

Appendix VII – Name reference of the different components of the signature

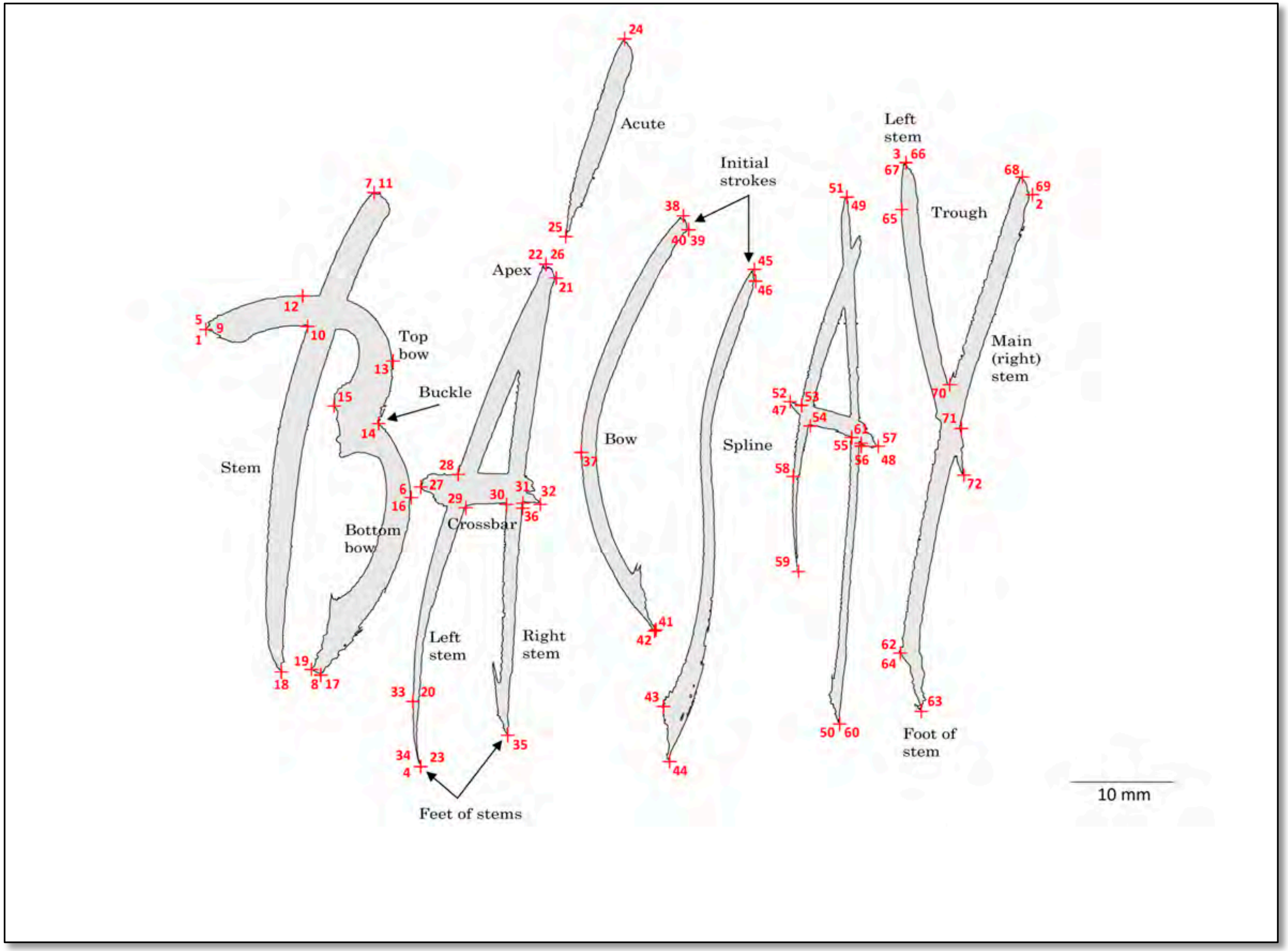


Illustration 2 - Name reference of the different components of the signature of artist n°2: Bacsay

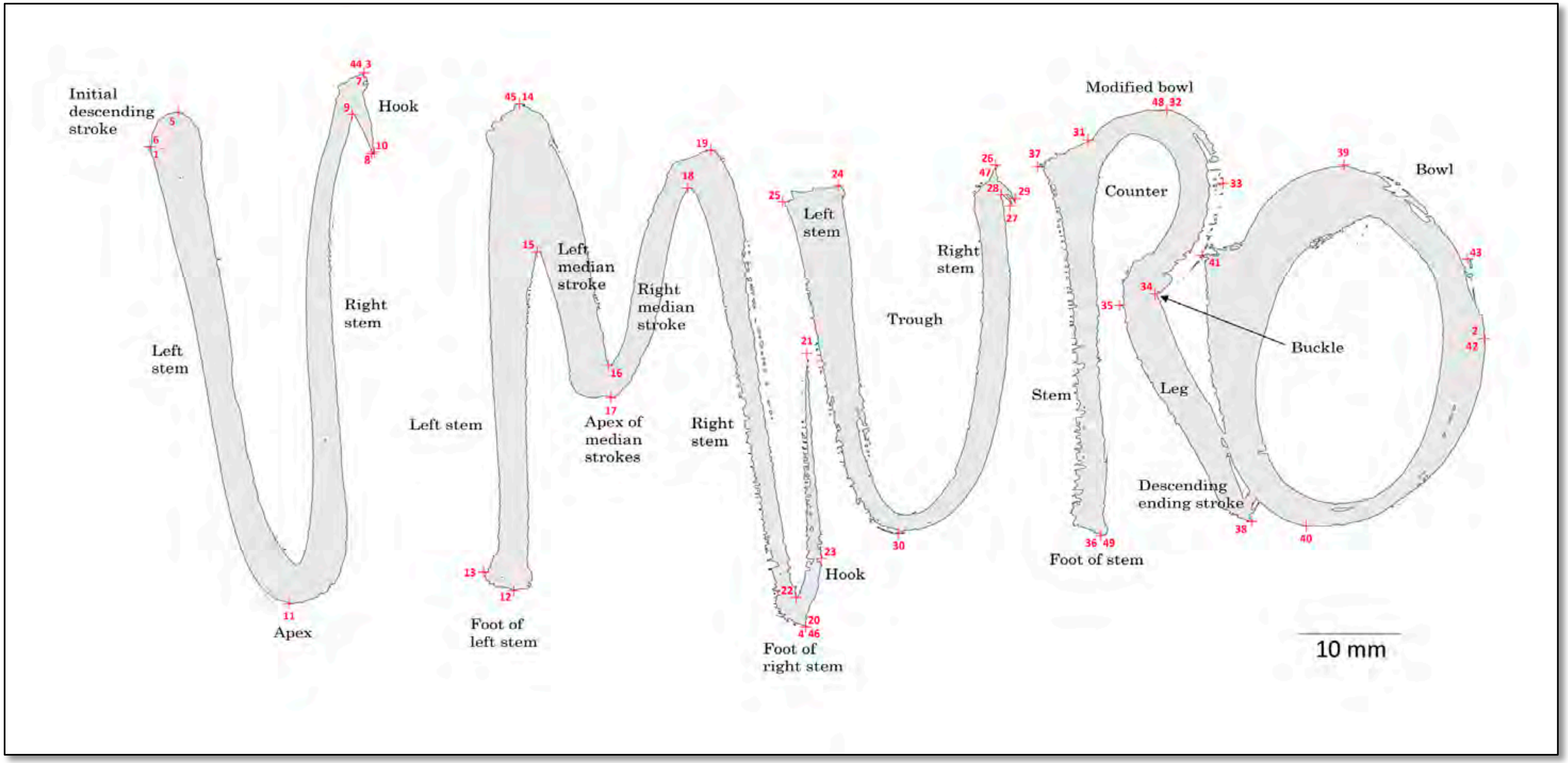


Illustration 3 - Name reference of the different components of the signature of artist n°3: Muro

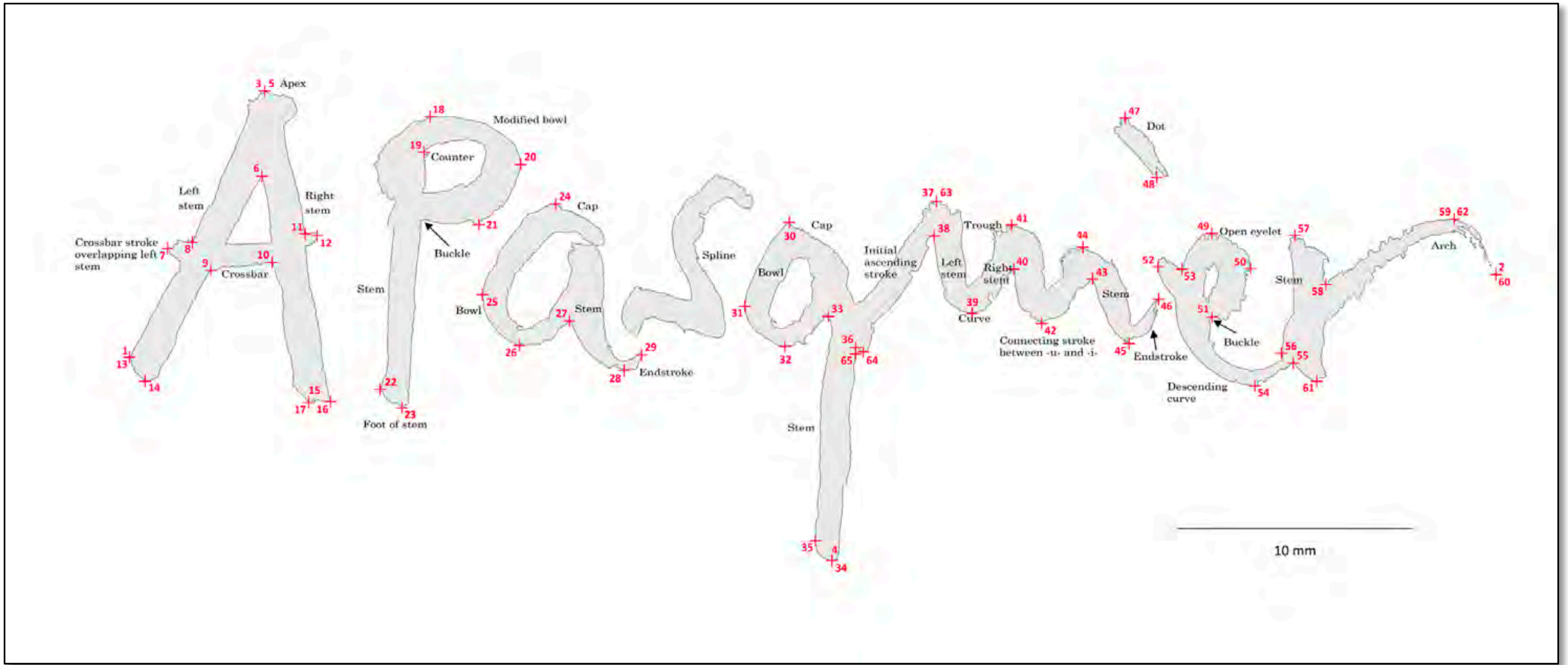


Illustration 4 - Name reference of the different components of the signature of artist n°4: Pasquier

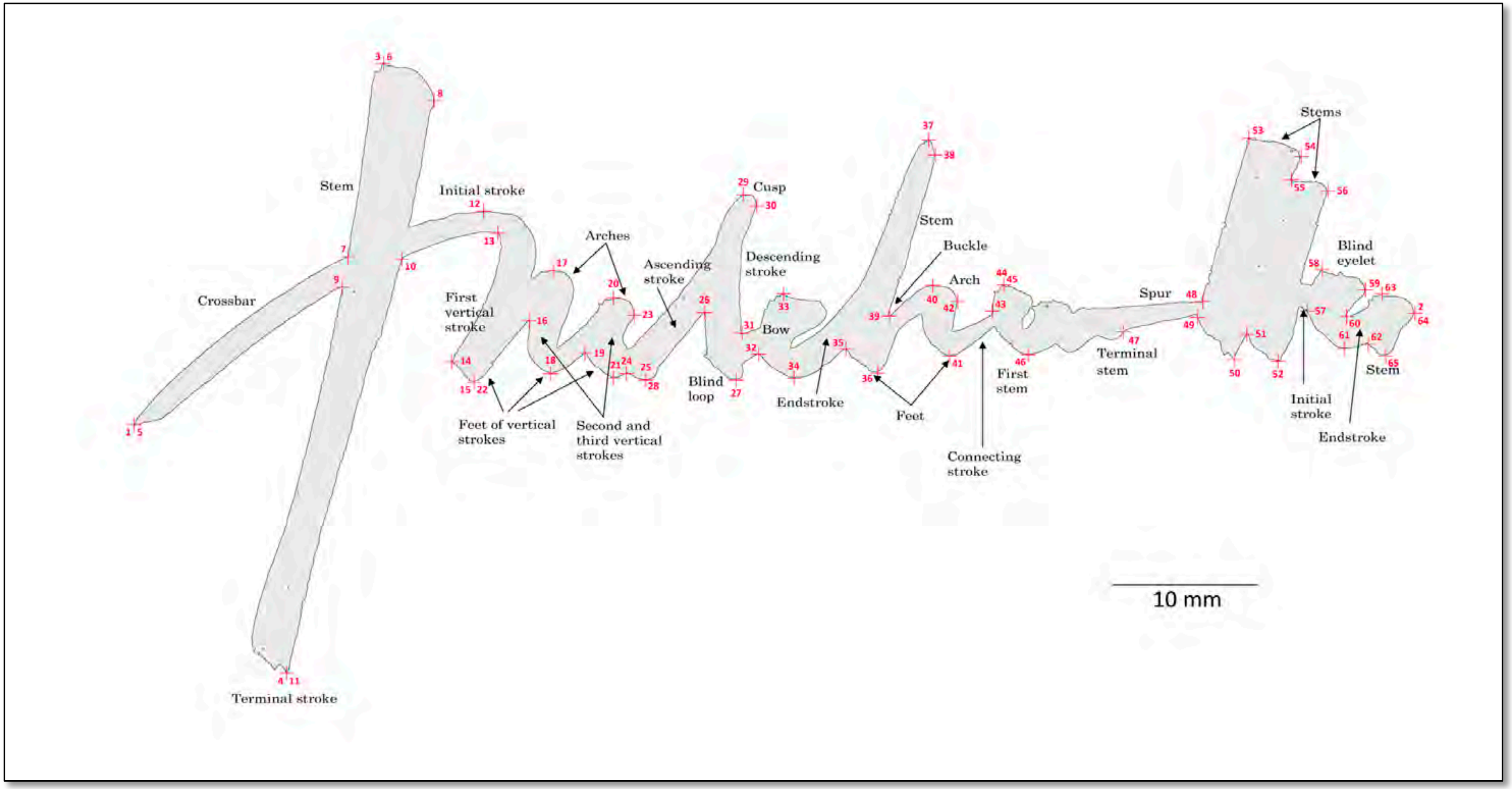


Illustration 5 - Name reference of the different components of the signature of artist n°5: Schwaller

Appendix VIII

Point sets and guidelines for point affixing

Illustrated example of point sets for each signature type

Artist n°1 - Schauenberg - table width 16 cm, size 10, centered

N°	Letter	Point description
1	Signature	Furthest point on left of signature
2	Signature	Furthest point on right of signature
3	Signature	Furthest point on top of signature
4	Signature	Furthest point on bottom of signature
5	-J-	Highest point of the letter
6	-J-	Lowest point of the letter
7	-J-	Point furthest left on the bottom loop of the letter
8	-J- / -c-	Intersection between the stem of the letter -J- and the beginning of the letter -c-
9	-J-	Intersection between the stem of the letter and its bottom loop
10	-c-	Highest point of letter (cusp's summit)
11	-c-	Lowest point of letter
12	-c-	Point furthest on the left of the loop of the letter (bow of -c-)
13	-c-	Intersection between the ascending stroke of the letter and its loop
14	-c-	Point furthest on the right of the top of the loop
15	-l-	Highest point of the letter
16	-l-	Lowest point of the letter
17	-l-	Intersection between the two stems | ! In case of a line interruption: point 17 = highest point of left stem
18	-l-	Point furthest on the right of the main stem
19	-l- / -s-	Intersection between the main stem of the letter -l- and the beginning stroke of the letter -s-
20	-s-	Highest point of the cusp
21	-s-	Lowest point of the loop
22	-s-	Highest point of the end stroke
23	-s-	Highest point inside the loop of the letter (inner cusp)
24	-s-	Point furthest on the left of the blind loop between the descending stroke and the end stroke
25	-s-	Point furthest to the right of the end stroke
26	-s-	Intersection between the descending stroke and the end stroke

Artist n°2: Bacsay

N°	Letter	Point description	Specifications
1	Signature	Point furthest left of signature	
2	Signature	Point furthest right of signature	
3	Signature	Highest point of signature	
4	Signature	Lowest point of signature	
5	-B-	Point furthest left of letter	
6	-B-	Point furthest right of letter	
7	-B-	Highest point of letter	
8	-B-	Lowest point of letter	
9	-B-	Point furthest left of the beginning stroke of the top bow	
10	-B-	Inferior intersection between the beginning stroke of the top bow and the stem	
11	-B-	Highest point of stem	! If top of stem is not overlapping the top bow: point 11 = highest visible point of stem (for example intersection between stem and top bow)
12	-B-	Highest point of top bow	
13	-B-	Point furthest right of top bow	
14	-B-	Inner intersection between top and bottom bow (buckle)	! If the buckle is not present (i. e. the top and bottom bow are not connected), the intersection point is taken as the highest point of the bottom buckle
15	-B-	Point furthest left of buckle	! If the intersection terminates within the stroke of the stem: point 15 = point furthest left visible of buckle
16	-B-	Point furthest right of bottom bow	
17	-B-	Lowest point of bottom bow	
18	-B-	Lowest point of stem	
19	-B-	Point furthest left of endstroke of bottom bow	
20	-A-	Point furthest left of letter	
21	-A-	Point furthest right of letter	
22	-A-	Highest point of letter	
23	-A-	Lowest point of letter	
24	-A-	Highest point of dot	
25	-A-	Lowest point of dot	
26	-A-	Highest point of letter	
27	-A-	Point furthest left of cross bar	! If the crossbar does not overlap the left stem: point 27 and 28 = point 29
28	-A-	Superior intersection between outer left overlapping crossbar and left stem	! If the crossbar does not overlap the left stem: point 27 and 28 = point 29

29	-A-	Inferior intersection between crossbar and left stem	! If portion of stem is absent: intersection with crossbar can be taken on superior intersection
30	-A-	Inferior intersection between crossbar and right stem	! If portion of stem is absent: intersection with crossbar can be taken on superior intersection
31	-A-	Inferior intersection between outer right overlapping crossbar and right stem	! If the crossbar does not overlap the right stem: point 31 and 32 = point 30
32	-A-	Point furthest right on cross bar	! If the crossbar does not overlap the right stem: point 31 and 32 = point 30
33	-A-	Point furthest left on the left stem (and under the crossbar)	
34	-A-	Lowest point of left stem	
35	-A-	Lowest point of right stem	
36	-A-	Point furthest right of right stem (and under the crossbar)	
37	-C-	Point furthest left of letter	
38	-C-	Highest point of letter	
39	-C-	Point furthest right of upper curve	
40	-C-	Point furthest right of letter	
41	-C-	Point furthest right of bottom curve	
42	-C-	Lowest point of letter	
43	-S-	Point furthest left of letter	
44	-S-	Lowest point of letter	
45	-S-	Highest point of letter	
46	-S-	Point furthest right of letter	
47	-A-	Point furthest left of letter	
48	-A-	Point furthest right of letter	
49	-A-	Highest point of letter	
50	-A-	Lowest point of letter	
51	-A-	Highest point of letter	
52	-A-	Point furthest left of cross bar	! If the crossbar does not overlap the left stem: point 52 and 53 = point 54
53	-A-	Superior intersection between outer left overlapping crossbar and left stem	! If the crossbar does not overlap the left stem: point 52 and 53 = point 54
54	-A-	Inferior intersection between crossbar and left stem	! If portion of stem is absent: intersection with crossbar can be taken on superior intersection
55	-A-	Inferior intersection between crossbar and right stem	! If portion of stem is absent: intersection with crossbar can be taken on superior intersection
56	-A-	Inferior intersection between outer right overlapping crossbar and right stem	! If the crossbar does not overlap the right stem: point 56 and 57 = point 55
57	-A-	Point furthest right on cross bar	! If the crossbar does not overlap the right stem: point 56 and 57 = point 55

58	-A-	Point furthest left on the left stem (and under the crossbar)	
59	-A-	Lowest point of left stem	
60	-A-	Lowest point of right stem	
61	-A-	Point furthest right of right stem (and under the crossbar)	
62	-Y-	Point furthest left of main stem (i. e. foot of stem)	
63	-Y-	Lowest point of letter	
64	-Y-	Point furthest left of letter	
65	-Y-	Point furthest left of left stem	
66	-Y-	Highest point of left stem	
67	-Y-	Highest point of letter	
68	-Y-	Highest point of right stem	
69	-Y-	Point furthest right of right stem, above the intersection between both stems	
70	-Y-	Superior intersection between left and right stem	
71	-Y-	Superior intersection between overlapping end stroke of left stem and main stem	
72	-Y-	Lowest point of end stroke of left stem	

Artist n°3 - V Muro

N°	Letter	Point description	Specifications
1	Signature	Furthest point left of signature	
2	Signature	Furthest point right of signature	
3	Signature	Highest point of signature	
4	Signature	Lowest point of signature	
5	-V-	Highest point of left stem	
6	-V-	Point furthest left on the left stem	
7	-V-	Highest point of right stem	
8	-V-	Lowest point of terminal hook of right stem	! If no hook: point 8 = point 7
9	-V-	Intersection between right stem and hook	! If no hook: point 9 = Point furthest right of right stem
10	-V-	Point furthest right of hook	! If no hook: point 10 = point 9
11	-V-	Lowest point of letter (apex)	
12	-M-	Lowest point of left stem	
13	-M-	Point furthest left on the left stem	
14	-M-	Highest point of left stem	! If there are two stems (overlapping): point 15 = highest point of either stem
15	-M-	Intersection between left stem and left median stroke	! If interruption in line: point 15 = highest point of right stem
16	-M-	Inner intersection between median strokes	
17	-M-	Lowest point of apex of median strokes	
18	-M-	Intersection between right stem and right median stroke	
19	-M-	Highest point of right stem	
20	-M-	Lowest point of right stem	
21	-M-	Highest point of hook	! If hook terminates within the left stem of -U-: point 21 = Highest point of hook overlapping left stem of -U- ! If no hook: point 21 = point 20
22	-M-	Point furthest right of right stem	! If hook is continous with stroke of stem: point 22 = inner intersection between stem and hook
23	-M-	Intersection between hook and left stem of -U-	! If no hook: point 23 = point 22
24	-U-	Highest point of left stem	
25	-U-	Point furthest left on the left stem	
26	-U-	Highest point of right stem	
27	-U-	Lowest point of terminal hook of right stem	! If no hook: point 27 = point 26
28	-U-	Inner intersection between right stem and hook	! If no hook: point 28 = Point furthest right of right stem
29	-U-	Point furthest right of hook	! If no hook: point 29 = point 28

30	-U-	Lowest point of letter	
31	-R-	Highest point of stem	
32	-R-	Highest point of modified bowl	
33	-R-	Point furthest right of modified bowl	
34	-R-	Inner intersection between modified bowl and leg (buckle)	
35	-R-	Exterior intersection between modified bowl and leg	! If the intersection overlaps the stem: point 35 = intersection between stem and leg
36	-R-	Lowest point of the stem	
37	-R-	Point furthest left on the stem	
38	-R-	Lowest point of leg	
39	-O-	Highest point of letter	
40	-O-	Lowest point of letter	
41	-O-	Point furthest left letter	
42	-O-	Point furthest right of letter	
43	-O-	Final point of ending stroke	
44	-V-	Highest point of letter	
45	-M-	Highest point of letter	
46	-M-	Lowest point of letter	
47	-U-	Highest point of letter	
48	-R-	Highest point of letter	
49	-R-	Lowest point of letter	

Artist n°4 - Pasquier

N°	Letter	Point description	Specifications
1	Signature	Point furthest left of signature	
2	Signature	Point furthest right of signature	
3	Signature	Furthest point on top of signature	
4	Signature	Furthest point on bottom of signature	
5	-A-	Highest point of letter (apex)	
6	-A-	Inner intersection of both stems	
7	-A-	Point furthest left on cross bar	! If the crossbar does not overlap the left stem: point 7 and 8 = point 9
8	-A-	Superior intersection between outer left overlapping crossbar and left stem	! If the crossbar does not overlap the left stem: point 7 and 8 = point 9
9	-A-	Inferior intersection between crossbar and left stem	
10	-A-	Inferior intersection between crossbar and right stem	
11	-A-	Superior intersection between outer right overlapping crossbar and right stem	! If the crossbar does not overlap the right stem: point 11 and 12 = point 10
12	-A-	Point furthest right on cross bar	! If the crossbar does not overlap the right stem: point 11 and 12 = point 10
13	-A-	Point furthest left on the left stem (and under the crossbar)	
14	-A-	Lowest point of left stem	
15	-A-	Lowest point of right stem	
16	-A-	Point furthest right of right stem (and under the crossbar)	
17	-A-	Lowest point of letter	
18	-P-	Highest point of the modified bowl	
19	-P-	Intersection between stem and modified bowl	! If the cap of the modified bowl does not overlap the top the stem: point 21 = highest point the stem
20	-P-	Point furthest right of modified bowl	
21	-P-	Lowest point of modified bowl	
22	-P-	Point furthest right of stem	
23	-P-	Lowest point of the stem	
24	-a-	Highest point of bowl	
25	-a-	Point furthest left of letter	
26	-a-	Lowest point of modified bowl	
27	-a-	Intersection between modified bowl and stem	
28	-a-	Lowest point of stem	
29	-a-	Point furthest right of stem	! If letters -a- and -s- are linked with a connecting stroke: point 29 = point 28
30	-q-	Highest point of letter	
31	-q-	Point furthest left of letter	
32	-q-	Lowest point of modified bowl	
33	-q-	Intersection between modified bowl and stem	
34	-q-	Lowest point of stem	

35	-q-	Point furthest left of stem (and beneath point 33)	
36	-u-	Point furthest left of letter	! If intersection with stem of letter -q-, point taken at inferior intersection
37	-u-	Highest point of left stem	
38	-u-	Intersection between initial stroke and left stem	
39	-u-	Lowest point of curve	
40	-u-	Intersection between right stem and endstroke	
41	-u-	Highest point of right stem	
42	-u-	Lowest point of endstroke (connecting stroke between -u- and -i-)	
43	-i-	Intersection between initial stroke and stem	
44	-i-	Highest point of stem	
45	-i-	Lowest point of stem	
46	-i-	Point furthest right of endstroke (on the right of point 45)	
47	-e-	Highest point of dot	
48	-e-	Lowest point of dot	
49	-e-	Highest point of letter	
50	-e-	Point furthest right of eyelet	
51	-e-	Inferior intersection of eyelet with descending curve (buckle)	
52	-e-	Point furthest left of letter	
53	-e-	Superior intersection between outer left overlapping initial stroke and eyelet	! If no overlapping initial stoke: point 53 = point 52
54	-e-	Lowest point of letter	
55	-e-	Point furthest right of letter	! If endstroke is overlapping the stem of the letter -r-, the point 55 is intersecting point furthest right of the letter -e-
56	-r-	Point furthest left of the letter	
57	-r-	Highest point of stem	
58	-r-	Superior intersection between stem and arch	
59	-r-	Highest point of arch	
60	-r-	Point furthest right of letter	
61	-r-	Lowest point of letter	
62	-r-	Highest point of letter	
63	-u-	Highest point of letter (between left and right stem)	
64	-u-	Lowest point of letter (of three possibilities)	
65	-q-	Point furthest right of letter	

Artist n°5 - Schwaller

N°	Letter	Point description	Specifications
1	Signature	Point furthest left of signature	
2	Signature	Point furthest right of signature	
3	Signature	Highest point of signature	
4	Signature	Lowest point of signature	
5	-J-	Point furthest left of letter	
6	-J-	Highest point of stem	
7	-J-	Superior intersection between outer left overlapping crossbar and stem	
8	-J-	Point furthest right of stem	
9	-J-	Inferior intersection between outer left overlapping crossbar and stem	
10	-J-	Inferior intersection between outer left overlapping crossbar and stem	
11	-m-	Lowest point of letter	
12	-m-	Highest point of initial stroke	
13	-m-	Inferior intersection between initial stroke and first vertical stroke	
14	-m-	Point furthest left of first vertical stroke	
15	-m-	Lowest point of foot of first vertical stroke	
16	-m-	Inferior intersection between first and second vertical strokes	! If both strokes are not connected, point 16 = point furthest left of second stroke
17	-m-	Highest point of arch connecting first and second vertical strokes	
18	-m-	Lowest point of foot of second vertical stroke	
19	-m-	Inferior intersection between second and third vertical strokes	! If both strokes are not connected, point 19 = point furthest left of third stroke
20	-m-	Highest point of arch connecting second and third vertical stoke	
21	-m-	Lowest point of foot of third vertical stoke	
22	-m-	Lowest point of the three feet of the vertical strokes	
23	-m-	Point furthest right of letter	! If overlapping of endstoke of letter -m- and initial stroke of letter -s-: point 23 = point furthest right discernable as composing letter -m-
24	-s-	Point furthest left of letter	! If overlapping of endstoke of letter -m- and initial stroke of letter -s-: point 24 = point furthest left discernable as composing letter -s- ! If line is continuous: point 24 = point 21
25	-s-	Lowest point of initial stroke	

26	-s-	Inferior intersection between initial stroke and descending stoke	! If initial stroke and descending stroke are not connected: point 26 = highest point of initial ascending stroke
27	-s-	Lowest point of descending stroke	
28	-s-	Lowest point of letter	
29	-s-	Highest point of letter	
30	-s-	Point furthest right of the descending stroke	
31	-s-	Superior intersection between the descending stroke and the connecting stroke with letter -c-	
32	-c-	Point furthest left (under the connecting stroke)	
33	-c-	Highest point of letter	
34	-c-	Lowest point of letter	
35	-c-	Inferior intersection between endstroke of -c- and vertical stem of letter -h-	! In case of an interruption in the line stroke: point 35 = highest point of endstroke of letter -c-
36	-h-	Lowest point of stem	
37	-h-	Highest point of stem	
38	-h-	Point furthest right of stem	
39	-h-	Superior intersection between stem and arch (buckle)	
40	-h-	Highest point of arch	
41	-h-	Lowest point of second foot of arch	
42	-h-	Point furthest right of arch, above the connecting stroke (if present)	
43	-w-	Point furthest left of letter	
44	-w-	Highest point of first stem	
45	-w-	Highest point of letter	
46	-w-	Lowest point of letter	
47	-w-	Inferior intersection between terminal stem and spur	! If no terminal spur: point 47 = point 48
48	-w-	Point furthest right of letter	
49	-l-	Point furthest left of first -l-	
50	-l-	Lowest point of first -l-	
51	-l-	Point furthest left of second -l-	! If stems are overlapping: point 51 = Inferior intersection between both stems
52	-l-	Lowest point of second -l-	
53	-l-	Highest point of first -l-	
54	-l-	Point furthest right of first -l-	! If stems are overlapping: point 51 = Superior intersection between both stems
55	-l-	Highest point of second -l-	
56	-l-	Point furthest right of second -l-	
57	-e-	Point furthest left of bow of letter (without considering the initial stroke)	
58	-e-	Highest point of eyelet	
59	-e-	Point furthest right of eyelet	
60	-e-	Inferior intersection between eyelet and bow (buckle)	
61	-e-	Lowest point of letter	

62	-r-	Inferior intersection between endstroke and vertical stem	
63	-r-	Highest point of letter	
64	-r-	Point furthest right of letter	
65	-r-	Lowest point of letter	

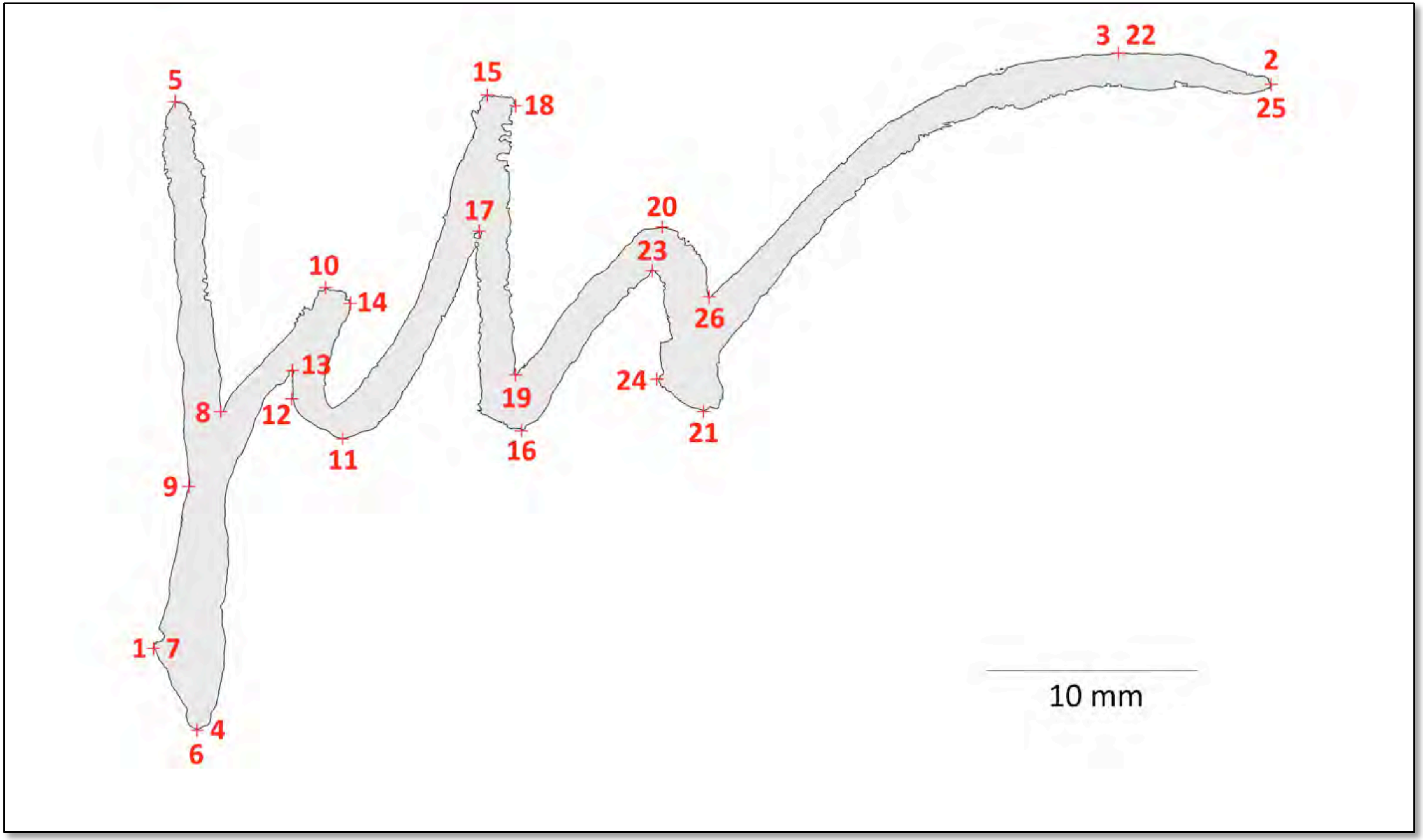


Illustration 1 - Point template for artist n°1 - Schauenberg

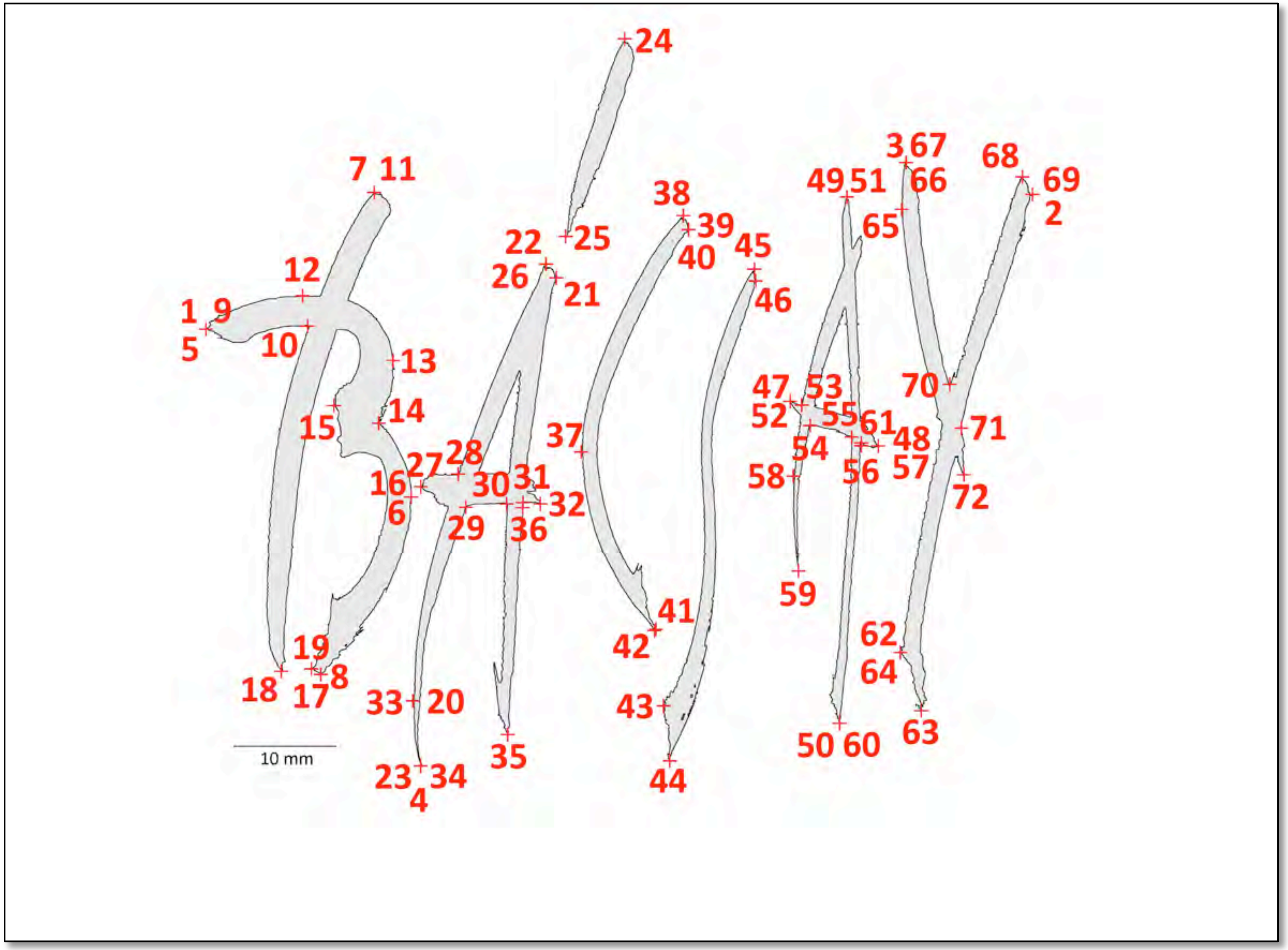


Illustration 2 - Point template for artist n°2: P Bacsay

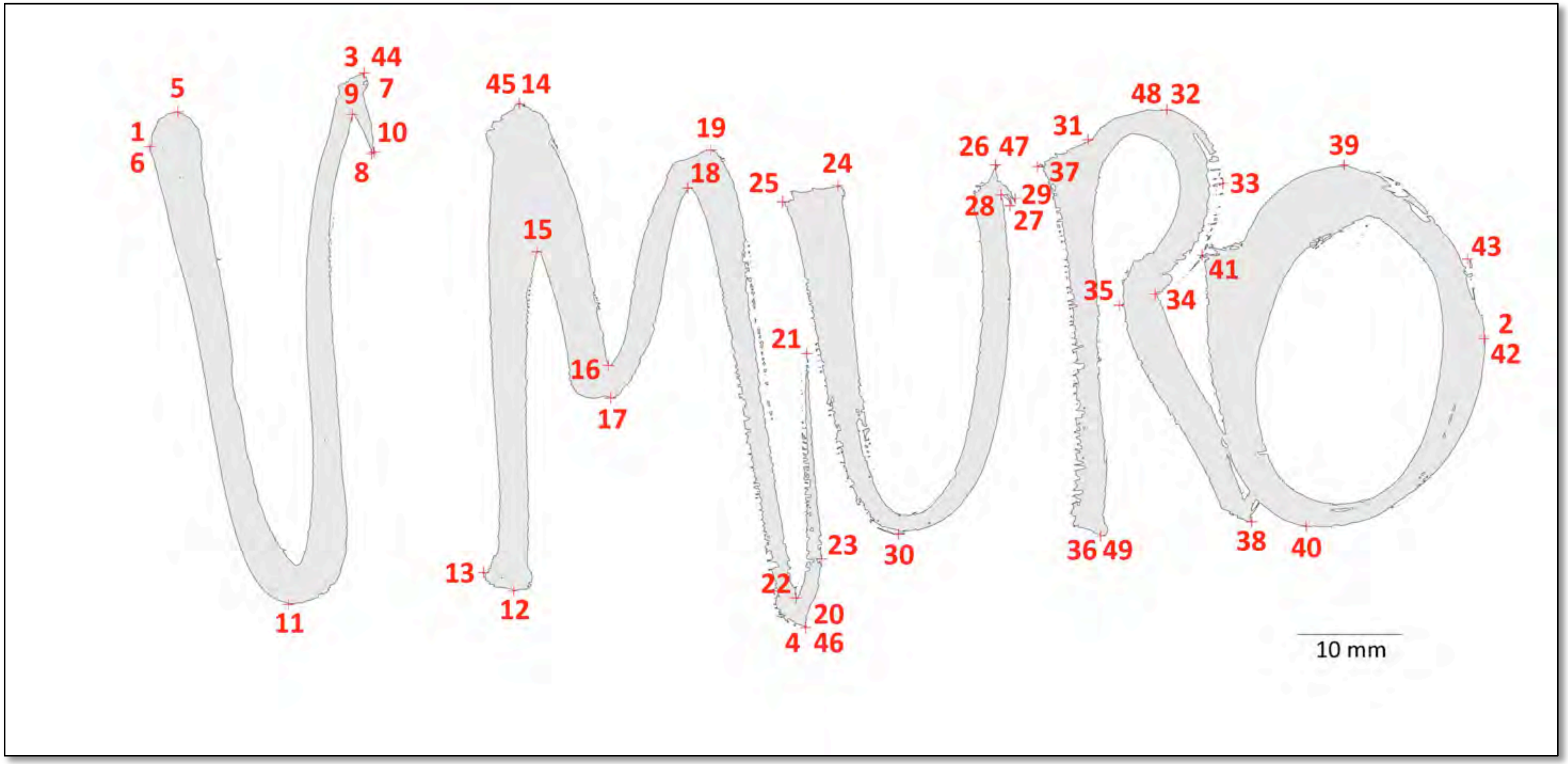


Illustration 3 - Point template for artist n°3: V Muro

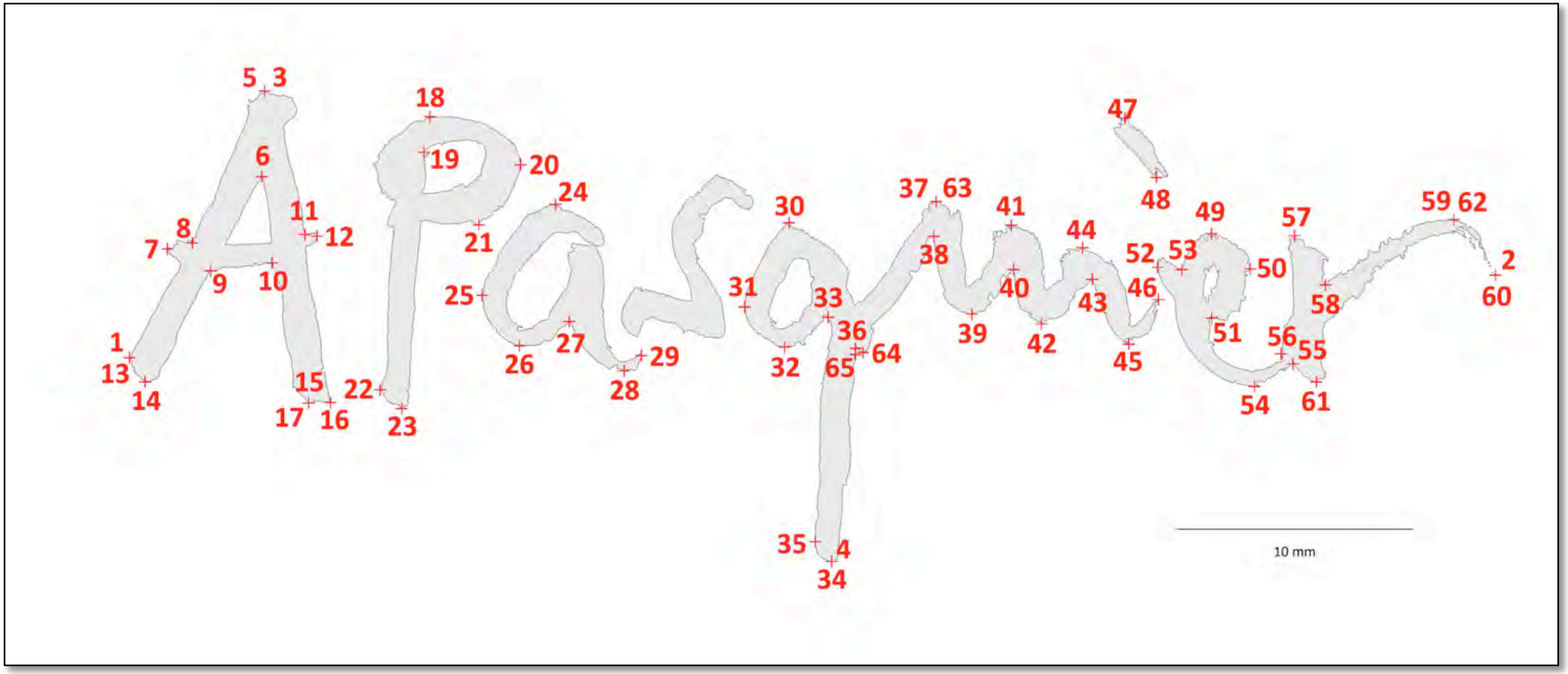


Illustration 4 - Point template for artist n°4: A Pasquier

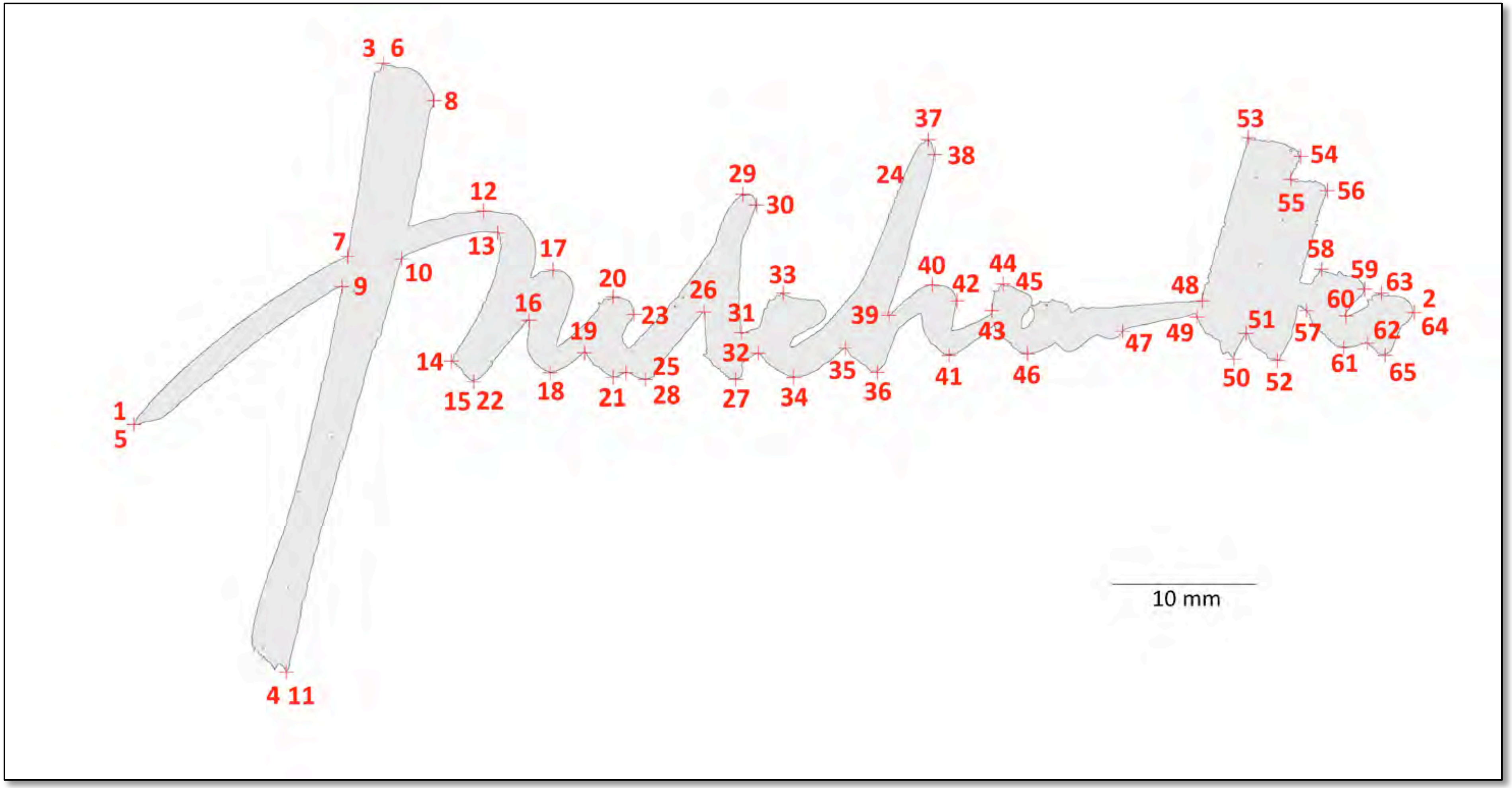


Illustration 5 - Point template for artist n°5: JM Schwaller

Appendix IX

Measurements set of each artist's (and the simulated) corpus set

Illustrated example of measurement sets for each signature type

Artist n°1 - Schauenberg

N° Measure	Pt. 1	Pt. 2	Distance	Letter	Description of measurement
1	1	2	distx	Signature	Total length of signature
2	3	4	disty	Signature	Total height of signature
3	5	6	disty	-J-	Total height of letter
4	7	8	distx	-J-	Total length of letter
5	5	8	disty	-J-	Height of stem
6	8	6	disty	-J-	Height of lower loop
7	10	11	disty	-c-	Total height of letter
8	8	11	distx	-c-	Total length of letter
9	10	8	disty	-c-	Height of ascending stroke
10	10	13	disty	-c-	Height of cusp
11	8	11	disty	-c-	Height distance between beginning of ascending stroke and the bottom of the loop
12	8	12	distx	-c-	Length distance between beginning of ascending stroke and bow of loop
13	8	13	distx	-c-	Length distance between beginning of ascending stroke and its intersection with the loop
14	12	11	distx	-c-	Length distance of loop (from bow to lowest point of the letter)
15	15	16	disty	-l-	Total height of letter (height of main stem)
16	11	19	distx	-l-	Total length of letter
17	15	11	disty	-l-	Height of ascending stroke
18	15	17	disty	-l-	Height of top loop
19	11	17	distx	-l-	Length distance of ascending stroke
20	17	19	distx	-l-	Height of stem between bottom of loop and intersection with letter -s-
21	20	21	disty	-s-	Height of loop
22	19	26	distx	-s-	Length of loop
23	20	19	disty	-s-	Height of ascending stroke, from intersection with letter -l-
24	20	23	disty	-s-	Height of cusp
25	20	26	disty	-s-	Height between tip of loop and departure of endstroke
26	23	19	disty	-s-	Height of ascending stroke, from intersection with letter -l-, up to the inner cusp
27	20	16	disty	-s-	Total height of ascending stroke
28	19	23	distx	-s-	Length of ascending stroke
29	22	21	disty	-s-	Height of endstroke
30	24	25	distx	-s-	Length of endstroke
31	19	25	distx	-s-	Total length of letter (both segments)

32	22	26	disty	-s-	Height of endstroke, from intersection with loop
33	22	25	disty	-s-	Height distance between top of endstroke and tip of endstroke
34	26	25	distx	-s-	Length of endstroke, from intersection with loop
35	5	10	disty	-J- and -c-	Height difference between both highest points of both letters
36	10	15	disty	-c- and -l-	Height difference between both highest points of both letters
37	15	20	disty	-l- and loop of -s-	Height difference between both highest points of both letters
38	20	22	disty	loop of -s- and endtroke of -s-	Height difference between both highest points of both letters
39	22	5	disty	endstroke of -s- and -J-	Height difference between both highest points of both letters
40	6	11	disty	-J- and -c-	Height difference between both lowest points of both letters
41	11	16	disty	-c- and -l-	Height difference between both lowest points of both letters
42	16	21	disty	-l- and loop of -s-	Height difference between both lowest points of both letters
43	21	25	disty	loop of -s- and endtroke of -s-	Height difference between both lowest points of both letters
44	25	6	disty	endstroke of -s- and -J-	Height difference between both lowest points of both letters
45	6	5	angle	-J-	Angle of stem
46	8	10	angle	-c-	Angle of ascending stroke
47	11	15	angle	-l-	Angle of ascending stroke
48	16	15	angle	-s-	Angle of stem
49	16	20	angle	-s-	Angle of ascending stroke
50	21	20	angle	-s-	Angle of loop
51	21	22	angle	-s-	Angle of endstroke
52	21	25	angle	-s-	Angle of endstroke

Artist n°2 - Bacsay

N° Measure	Pt. 1	Pt. 2	Distance	Letter	Description of measurement
1	1	2	distx	Signature	Total length of signature
2	3	4	disty	Signature	Total height of signature
3	5	6	distx	-B-	Total length of letter
4	7	8	disty	-B-	Total height of letter
5	11	18	disty	-B-	Height of stem
6	12	17	disty	-B-	Height of both bows
7	12	14	disty	-B-	Height of top bow
8	14	17	disty	-B-	Height of bottom bow
9	11	12	disty	-B-	Height of stem overlapping top bow
10	17	18	disty	-B-	Height difference between bottom of stem and lowest point of bottom bow
11	9	13	distx	-B-	Length of top bow
12	15	13	distx	-B-	Length of top bow, taken from buckle
13	15	16	distx	-B-	Length of bottom bow, taken from buckle
14	19	16	distx	-B-	Length of bottom bow
15	9	10	distx	-B-	Length of initial stroke left of stem
16	20	21	distx	-A-	Total length of letter
17	22	23	disty	-A-	Total height of letter
18	26	34	disty	-A-	Height of left stem
19	26	35	disty	-A-	Height of right stem
20	29	34	disty	-A-	Height of left stem under crossbar
21	30	35	disty	-A-	Height of right stem under crossbar
22	33	36	distx	-A-	Length of spreading between outer extremities of stems
23	27	28	distx	-A-	Length of crossbar stroke overlapping left stem
24	29	30	distx	-A-	Length of inner crossbar
25	31	32	distx	-A-	Length of crossbar stroke overlapping right stem
26	24	25	disty	-A-	Height of acute
27	25	26	disty	-A-	Height difference between acute and letter -A-
28	37	40	distx	-C-	Total length of letter
29	38	42	disty	-C-	Total height of letter
30	37	39	distx	-C-	Length of upper curve
31	37	41	distx	-C-	Length of lower curve
32	43	46	distx	-S-	Total length of letter
33	45	44	disty	-S-	Total height of letter
34	47	48	distx	-A-	Total length of letter
35	49	50	disty	-A-	Total height of letter
36	51	59	disty	-A-	Height of left stem
37	51	60	disty	-A-	Height of right stem
38	54	59	disty	-A-	Height of left stem under crossbar

39	55	60	disty	-A-	Height of right stem under crossbar
40	58	61	distx	-A-	Length of spreading between outer extremities of stems
41	52	53	distx	-A-	Length of crossbar stroke overlapping left stem
42	54	55	distx	-A-	Length of inner crossbar
43	56	57	distx	-A-	Length of crossbar stroke overlapping right stem
44	64	69	distx	-Y-	Total length of letter
45	67	63	disty	-Y-	Total height of letter
46	68	63	disty	-Y-	Height of right stem
47	66	70	disty	-Y-	Height of left stem, up to intersection of stems
48	68	70	disty	-Y-	Height of right stem, up to intersection of stems
49	71	72	disty	-Y-	Height of left stem overlapping right stem
50	65	69	distx	-Y-	Length of spreading between outer extremities of stems
51	12	26	disty	-B- and -A-	Height difference between both highest points of both letters
52	26	38	disty	-A- and -C-	Height difference between both highest points of both letters
53	38	45	disty	-C- and -S-	Height difference between both highest points of both letters
54	45	51	disty	-S- and -A-	Height difference between both highest points of both letters
55	51	66	disty	-A- and -Y-	Height difference between both highest points of both letters
56	68	11	disty	-Y- and -B-	Height difference between both highest points of both letters
57	17	34	disty	-B- and -A-	Height difference between both lowest points of both letters
58	35	42	disty	-A- and -C-	Height difference between both lowest points of both letters
59	42	44	disty	-C- and -S-	Height difference between both lowest points of both letters
60	44	59	disty	-S- and -A-	Height difference between both lowest points of both letters
61	60	63	disty	-A- and -Y-	Height difference between both lowest points of both letters
62	63	18	disty	-Y- and -B-	Height difference between both lowest points of both letters
63	16	27	distx	-B- and -A-	Space between -B- and left overlapping crossbar
64	16	33	distx	-B- and -A-	Space between -B- and extremity of left stem
65	32	37	distx	-A- and -C-	Space between right overlapping crossbar of -A- and -C-
66	36	37	distx	-A- and -C-	Space between extremity of right stem of -A- and -C-
67	39	46	distx	-C- and -S-	Space
68	46	52	distx	-S- and -A-	Space between -S- and left overlapping crossbar

69	57	62	distx	-A- and -Y-	Space between right overlapping crossbar of -A- and -Y-
70	61	62	distx	-A- and -Y-	Space between extremity of right stem of -A- and -Y-
71	18	11	angle	-B-	Angle of stem
72	34	26	angle	-A-	Angle of left stem
73	35	26	angle	-A-	Angle of right stem
74	29	30	angle	-A-	Angle of crossbar
75	44	45	angle	-S-	Angle (general orientation)
76	59	51	angle	-A-	Angle of left stem
77	60	51	angle	-A-	Angle of right stem
78	54	55	angle	-A-	Angle of crossbar
79	63	68	angle	-Y-	Angle of left stem
80	70	66	angle	-Y-	Angle of right stem

Artist n°3 - V Muro

N° Measure	Pt. 1	Pt. 2	Distance	Letter	Description of measurement
1	1	2	distx	Signature	Total length of signature
2	3	4	disty	Signature	Total height of signature
3	44	11	disty	-V-	Total height of letter
4	6	9	distx	-V-	Total length of letter
5	5	11	disty	-V-	Height of left stem
6	7	11	disty	-V-	Height of right stem
7	7	8	distx	-V-	Height of hook
8	9	10	disty	-V-	Length of hook
9	45	46	disty	-M-	Total height of letter
10	13	22	distx	-M-	Total length of letter
11	14	12	disty	-M-	Height of left stem
12	14	17	disty	-M-	Height of left median stroke
13	19	17	disty	-M-	Height of right median stroke
14	19	20	disty	-M-	Height of right stem
15	15	16	distx	-M-	Length of left median stroke
16	16	18	distx	-M-	Length of right median stroke
17	14	19	disty	-M-	Height difference between apexes of both stems
18	21	20	disty	-M-	Height of final hook
19	22	23	distx	-M-	Length of final hook
20	12	20	disty	-M-	Distance height difference between lowest points of both stems
21	47	30	disty	-U-	Total height of letter
22	25	28	distx	-U-	Total length of letter
23	24	30	disty	-U-	Height of left stem
24	26	30	disty	-U-	Height of right stem
25	26	27	disty	-U-	Height of hook
26	28	29	distx	-U-	Length of hook
27	48	49	disty	-R-	Total height of letter
28	37	38	distx	-R-	Total length of letter
29	32	34	disty	-R-	Height of modified bowl
30	35	33	distx	-R-	Length of modified bowl
31	31	36	disty	-R-	Height of stem
32	34	38	disty	-R-	Height of leg
33	34	38	distx	-R-	Length of leg
34	32	31	disty	-R-	Height difference between top of stem and top of modified bowl
35	38	36	disty	-R-	Height difference between lowest point of stem and lowest point of leg
36	39	40	disty	-O-	Total height of letter
37	41	42	distx	-O-	Total length of letter
38	39	43	disty	-O-	Height difference between terminal point and highest point

39	43	42	distx	-O-	Length difference between terminal point and point furthest right
40	7	14	disty	-V- and -M-	Height difference between both highest points of both letters
41	19	24	disty	-M- and -U-	Height difference between both highest points of both letters
42	26	31	disty	-U- and -R-	Height difference between both highest points of both letters
43	32	39	disty	-R- and -O-	Height difference between both highest points of both letters
44	39	5	disty	-O- and -V-	Height difference between both highest points of both letters
45	11	12	disty	-V- and -M-	Height difference between both lowest points of both letters
46	20	30	disty	-M- and -U-	Height difference between both lowest points of both letters
47	30	36	disty	-U- and -R-	Height difference between both lowest points of both letters
48	38	40	disty	-R- and -O-	Height difference between both lowest points of both letters
49	40	11	disty	-O- and -V-	Height difference between both lowest points of both letters
50	9	13	distx	-V- and -M-	Space
51	22	25	distx	-M- and -U-	Space
52	28	37	distx	-U- and -R-	Space
53	34	41	distx	-R- and -O-	Space
54	11	5	angle	-V-	Angle of left stem
55	11	7	angle	-V-	Angle of right stem
56	12	14	angle	-M-	Angle of left stem
57	17	14	angle	-M-	Angle of left median stroke
58	17	19	angle	-M-	Angle of right median stroke
59	20	19	angle	-M-	Angle of left stem
60	36	31	angle	-R-	Angle of stem
61	38	34	angle	-R-	Angle of leg
62	40	43	angle	-O-	Angle between lowest point of letter and tip of endstroke

Artist n°4 - Pasquier

N° Measure	Pt. 1	Pt. 2	Distance	Letter	Description of measurement
1	1	2	distx	Signature	Total length of signature
2	3	4	disty	Signature	Total height of signature
3	5	17	disty	-A-	Total height of letter
4	13	16	distx	-A-	Total length of letter
5	5	14	disty	-A-	Height of left stem
6	5	15	disty	-A-	Height of right stem
7	9	14	disty	-A-	Height of left stem under crossbar
8	10	15	disty	-A-	Height of right stem under crossbar
9	13	16	distx	-A-	Length of spreading between extremities of stems - discarded
10	9	10	distx	-A-	Length of inner crossbar
11	7	8	distx	-A-	Length of crossbar stroke overlapping left stem
12	11	12	distx	-A-	Length of crossbar stroke overlapping right stem
13	18	23	disty	-P-	Total height of letter
14	22	20	distx	-P-	Total length of letter
15	18	21	disty	-P-	Height of modified bowl
16	19	20	distx	-P-	Length of modified bowl
17	21	23	disty	-P-	Height of stem under lowest point of modified bowl
18	24	28	disty	-a-	Total height of letter
19	25	29	distx	-a-	Total length of letter
20	24	26	disty	-a-	Height of bowl
21	25	27	distx	-a-	Length of bowl
22	24	27	disty	-a-	Height of superior section of bowl
23	27	26	disty	-a-	Height of inferior section of bowl
24	27	28	disty	-a-	Height of stem
25	26	28	disty	-a-	Height of stem under lowest point of bowl
26	27	29	distx	-a-	Length of stem
27	30	34	disty	-q-	Total height of letter
28	31	65	distx	-q-	Total length of letter
29	30	32	disty	-q-	Height of bowl
30	31	33	distx	-q-	Length of bowl
31	30	33	disty	-q-	Height of superior section of bowl
32	33	32	disty	-q-	Height of inferior section of bowl
33	33	34	disty	-q-	Height of stem
34	32	34	disty	-q-	Height of stem under lowest point of bowl
35	33	65	distx	-q-	Length of stem, taken from intersection of bowl with stem
36	35	65	distx	-q-	Length of stem
37	63	64	disty	-u-	Total height of letter
38	36	42	distx	-u-	Total length of letter

39	37	36	disty	-u-	Height of initial stroke
40	37	39	disty	-u-	Height of left stem
41	41	39	disty	-u-	Height of right stem
42	41	42	disty	-u-	Height of endstroke (connecting with letter -i-)
43	36	38	distx	-u-	Length of initial stroke
44	38	40	distx	-u-	Length distance between left and right stems
45	44	45	disty	-i-	Total height of letter
46	42	46	distx	-i-	Total length of letter
47	42	43	distx	-i-	Length of initial stroke
48	43	46	distx	-i-	Length of stem
49	44	42	disty	-i-	Height of initial stroke
50	47	48	disty	-i-	Height of dot
51	48	44	disty	-i-	Height difference between dot and letter -i-
52	49	54	disty	-e-	Total height of letter
53	52	55	distx	-e-	Total length of letter
54	49	51	disty	-e-	Height of eyelet
55	53	50	distx	-e-	Length of eyelet
56	52	53	distx	-e-	Length of outer left overlapping initial stroke and eyelet
57	55	54	disty	-e-	Height difference between final ascending curve and lowest point of letter
58	52	50	distx	-e-	Length of eyelet, including initial overlapping stroke
59	62	61	disty	-r-	Total height of letter
60	56	60	distx	-r-	Total length of letter
61	57	61	disty	-r-	Height of stem
62	57	58	disty	-r-	Height of stem above arch
63	58	60	distx	-r-	Length of arch
64	59	61	disty	-r-	Height of arch, taken from lowest point of stem
65	5	18	disty	-A- and -P	Height difference between both highest points of both letters
66	18	24	disty	-P- and -a-	Height difference between both highest points of both letters
67	24	30	disty	-a- and -q-	Height difference between both highest points of both letters
68	30	37	disty	-q- and -u-	Height difference between both highest points of both letters
69	41	44	disty	-u- and -i-	Height difference between both highest points of both letters
70	44	49	disty	-i- and -e-	Height difference between both highest points of both letters
71	49	57	disty	-e- and -r-	Height difference between both highest points of both letters
72	59	5	disty	-r- and -A-	Height difference between both highest points of both letters
73	15	23	disty	-A- and -P	Height difference between both lowest points of both letters

74	23	26	disty	-P- and -a-	Height difference between both lowest points of both letters
75	28	32	disty	-a- and -q-	Height difference between both lowest points of both letters
76	34	39	disty	-q- and -u-	Height difference between both lowest points of both letters
77	39	45	disty	-u- and -i-	Height difference between both lowest points of both letters
78	45	54	disty	-i- and -e-	Height difference between both lowest points of both letters
79	54	61	disty	-e- and -r-	Height difference between both lowest points of both letters
80	61	14	disty	-r- and -A-	Height difference between both lowest points of both letters
81	16	22	distx	-A- and -P	Space
82	19	25	distx	stem of -P- and -a-	Space
83	20	25	distx	-P- and -a-	Space
84	29	31	distx	-a- and -q-	Space
85	33	38	distx	-q- and -u-	Space
86	40	43	distx	-u- and -i-	Space
87	46	52	distx	-i- and -e-	Space
88	50	56	distx	-e- and -r-	Space
89	14	5	angle	-A-	Angle of left stem
90	15	5	angle	-A-	Angle of right stem
91	9	10	angle	-A-	Angle of crossbar
92	23	19	angle	-P-	Angle of stem
93	35	33	angle	-q-	Angle of stem
94	61	57	angle	-r	Angle of stem

Artist n°5 - Schwaller

N° Measure	Pt. 1	Pt. 2	Distance	Letter	Description of measurement
1	1	2	distx	Signature	Total length of signature
2	3	4	disty	Signature	Total height of signature
3	6	11	disty	-J-	Total height of letter
4	5	8	distx	-J-	Total length of letter
5	6	7	disty	-J-	Height of upper stem (above crossbar)
6	9	11	disty	-J-	Height of lower stem (below crossbar)
7	5	7	distx	-J-	Length of initial stroke left of stem
8	12	22	disty	-m-	Total height of letter
9	10	23	distx	-m-	Total length of letter
10	12	15	disty	-m-	Height of first stem
11	17	18	disty	-m-	Height of second stem
12	20	21	disty	-m-	Height of third stem
13	12	17	disty	-m-	Height difference between both highest points of first and second stem
14	17	20	disty	-m-	Height difference between both highest points of second and third stem
15	10	13	distx	-m-	Length of initial stroke
16	14	16	distx	-m-	Length of first stem
17	16	19	distx	-m-	Length of second stem
18	19	23	distx	-m-	Length of third stem
19	29	28	disty	-s-	Total height of letter
20	24	30	distx	-s-	Total length of letter
21	29	25	disty	-s-	Height of initial stroke
22	29	27	disty	-s-	Height of descending stroke
23	26	27	disty	-s-	Height of descending stroke, taken from intersection of initial and descending stroke
24	29	31	disty	-s-	Height of descending stroke upto connecting stroke with -c-
25	24	26	distx	-s-	Length of initial stroke
26	24	31	distx	-s-	Length of initial and terminal stroke, upto connecting stroke with -c-
27	33	34	disty	-c-	Total height of letter
28	31	35	distx	-c-	Total length of letter
29	31	32	distx	-c-	Length of connecting stroke
30	32	35	distx	-c-	Length of bow
31	32	34	disty	-c-	Height of lower section of bow
32	37	36	disty	-h-	Total height of letter
33	35	42	distx	-h-	Total length of letter
34	37	35	disty	-h-	Height of stem, taken from intersection with terminal stroke of -c-
35	39	36	disty	-h-	Height of left foot
36	39	42	distx	-h-	Length of arch, taken from intersection of stem with arch (buckle)

37	40	36	disty	-h-	Height of arch
38	40	41	disty	-h-	Height of second foot of arch (right stem)
39	40	39	disty	-h-	Height of arch, taken from intersection of stem with arch (buckle)
40	45	46	disty	-w-	Total height of letter
41	43	48	distx	-w-	Total length of letter
42	43	47	distx	-w-	Length of three stems
43	47	48	distx	-w-	Length of spur
44	44	46	disty	-w-	Height of first stem
45	53	50	disty	-l-	Total height of letter
46	49	54	distx	-l-	Total length of letter
47	55	52	disty	-l-	Total height of letter
48	51	56	distx	-l-	Total length of letter
49	58	61	disty	-e-	Total height of letter
50	57	62	distx	-e-	Total length of letter
51	58	60	disty	-e-	Height of eyelet
52	57	59	distx	-e-	Length of eyelet
53	62	61	disty	-e-	Height difference between final ascending curve and lowest point of letter
54	63	65	disty	-r-	Total height of letter
55	62	64	distx	-r-	Total length of letter
56	62	65	disty	-r-	Height of stem (taken from intersection with terminal stroke of -e-)
57	6	12	disty	-J- and -m-	Height difference between both highest points of both letters
58	20	29	disty	-m- and -s-	Height difference between both highest points of both letters
59	29	33	disty	-s- and -c-	Height difference between both highest points of both letters
60	33	37	disty	-c- and -h-	Height difference between both highest points of both letters
61	40	45	disty	-h- and -w-	Height difference between both highest points of both letters
62	45	53	disty	-w- and -l-	Height difference between both highest points of both letters
63	53	55	disty	-l- and -l-	Height difference between both highest points of both letters
64	55	58	disty	-l- and -e-	Height difference between both highest points of both letters
65	58	63	disty	-e- and -r-	Height difference between both highest points of both letters
66	11	15	disty	-J- and -m-	Height difference between both lowest points of both letters
67	21	25	disty	-m- and -s-	Height difference between both lowest points of both letters
68	27	34	disty	-s- and -c-	Height difference between both lowest points of both letters
69	34	36	disty	-c- and -h-	Height difference between both lowest points of both letters
70	41	46	disty	-h- and -w-	Height difference between both lowest points of both letters
71	46	50	disty	-w- and -l-	Height difference between both lowest

					points of both letters
72	50	52	disty	-l- and -l-	Height difference between both lowest points of both letters
73	52	61	disty	-l- and -e-	Height difference between both lowest points of both letters
74	61	65	disty	-e- and -r-	Height difference between both lowest points of both letters
75	8	10	distx	-J- and -m-	Space
76	23	24	distx	-m- and -s-	Space
77	30	32	distx	-s- and -c-	Space
78	34	35	distx	-c- and -h-	Space
79	42	43	distx	-h- and -w-	Space
80	48	49	distx	-w- and -l-	Space
81	54	51	distx	-l- and -l-	Space
82	56	57	distx	-l- and -e-	Space
83	59	62	distx	-e- and -r-	Space
84	11	6	angle	-J-	Angle of stem
85	25	26	angle	-s-	Angle of initial stroke
86	27	29	angle	-s-	Angle of descending stroke
87	36	37	angle	-h-	Angle of stem, taken from highest point of letter
88	36	38	angle	-h-	Angle of stem, taken from point furthest right of stem
89	50	53	angle	-l-	Angle of stem, taken from highest point of letter
90	49	54	angle	-l-	Angle of stem, taken from point furthest right of stem
91	52	55	angle	-l-	Angle of stem, taken from highest point of letter
92	51	56	angle	-l-	Angle of stem, taken from point furthest right of stem

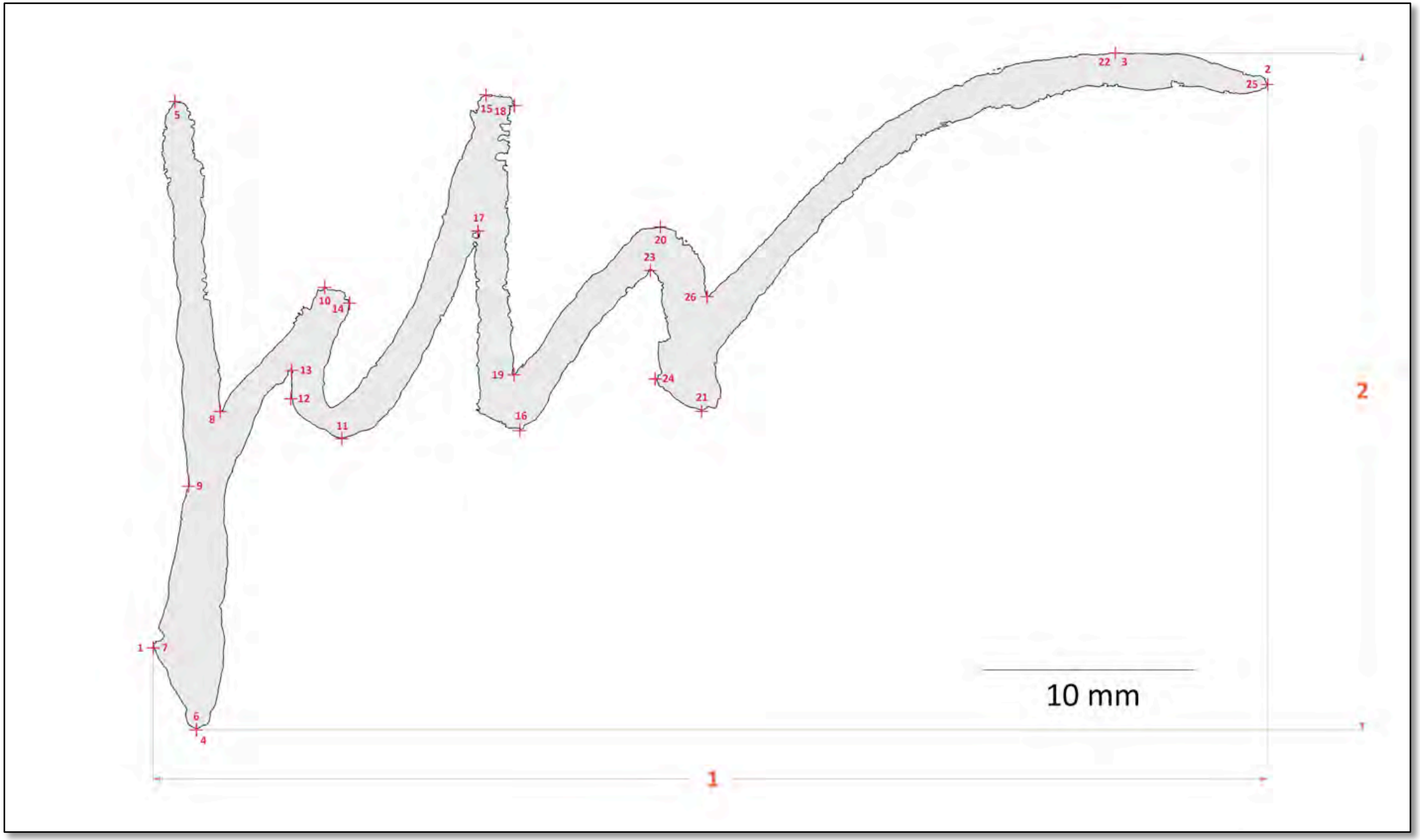


Illustration 1 - Total height and length measurements of the signature of artist n°1: JC Schauenberg

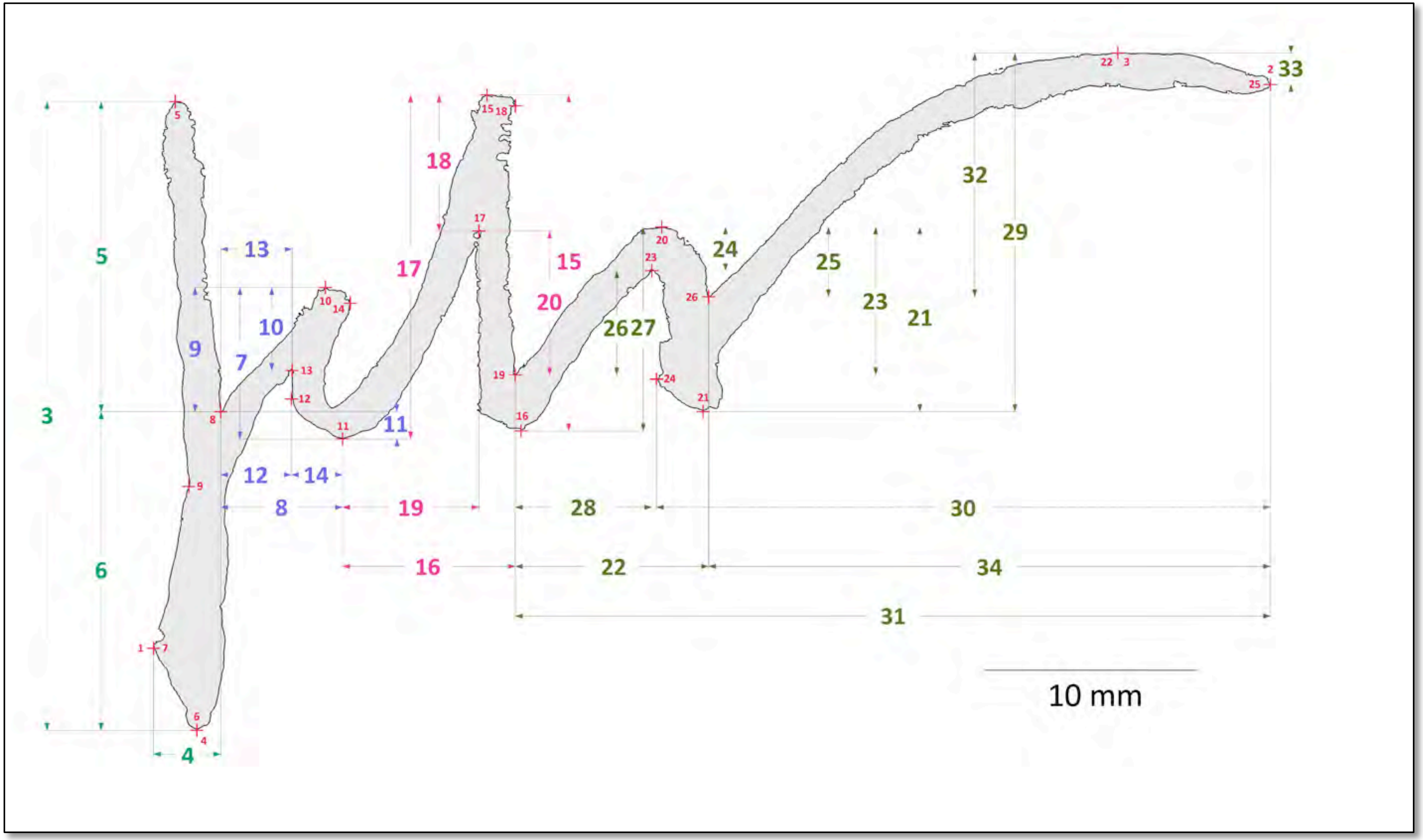


Illustration 2 - Intra-letter measurements of each letter of the signature of artist n°1: JC Schauenberg

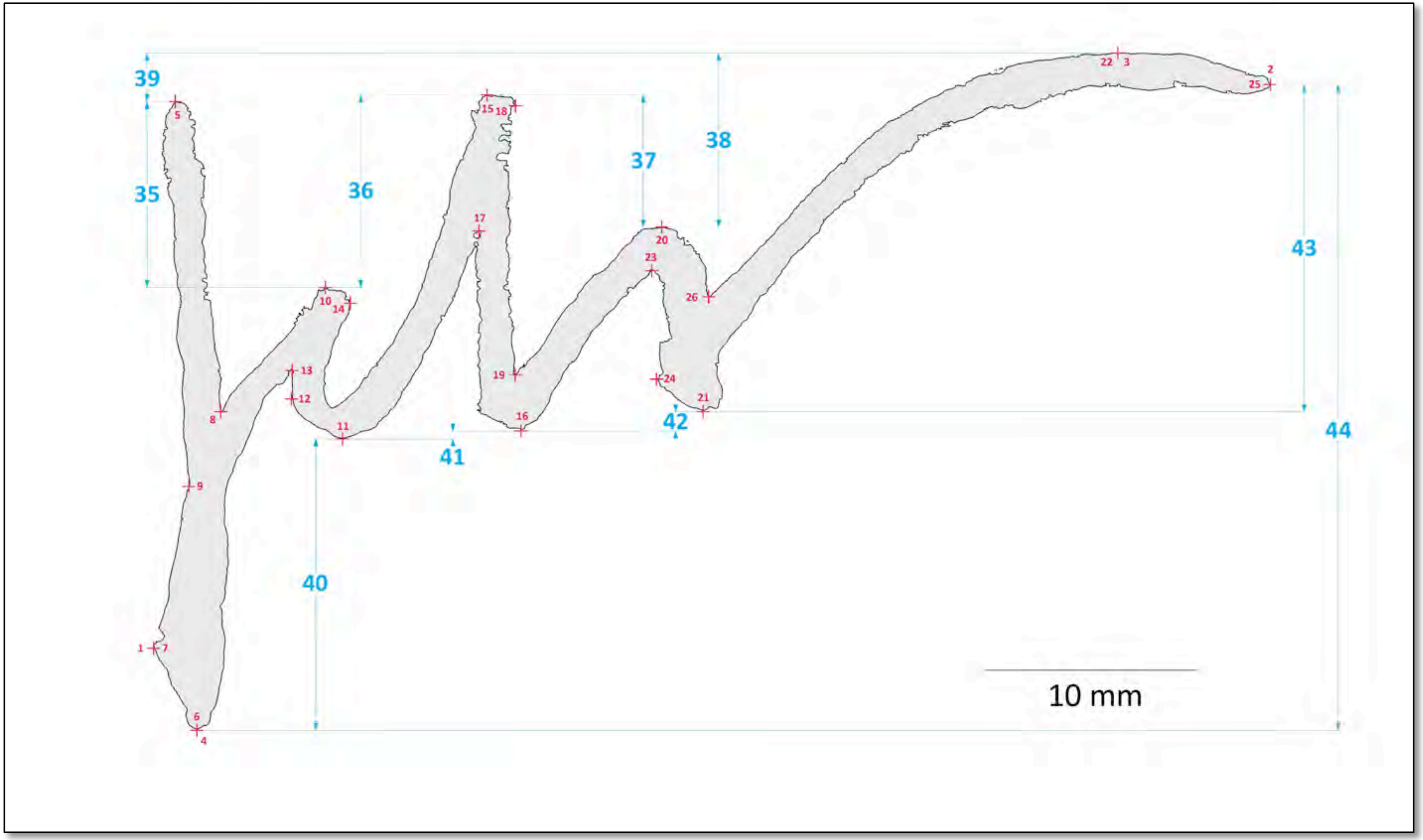


Illustration 3 - Height differences measurements of the signature of artist n°1: JC Schauenberg

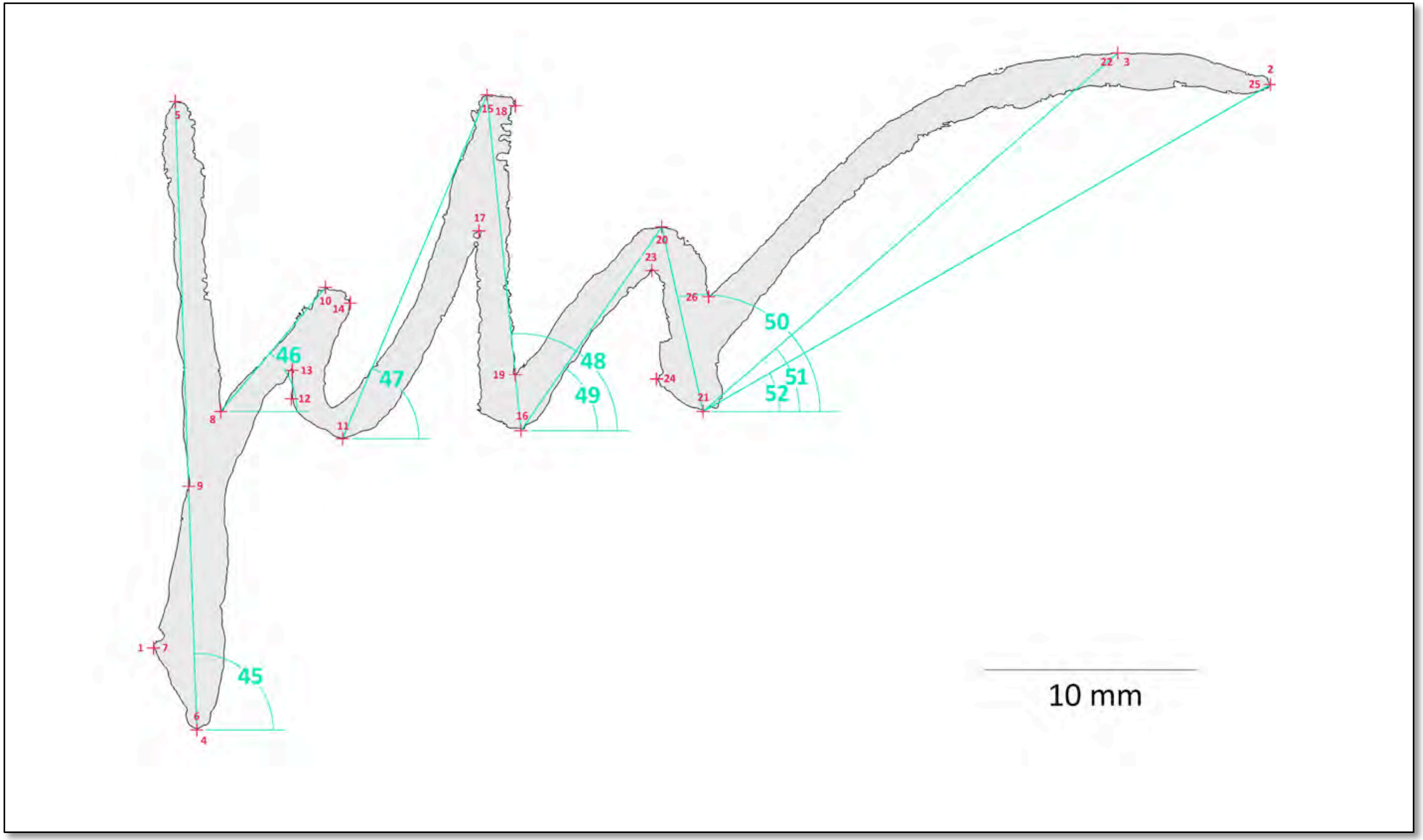


Illustration 4 - Angles measurements of the signature of artist n°1: JC Schauenberg

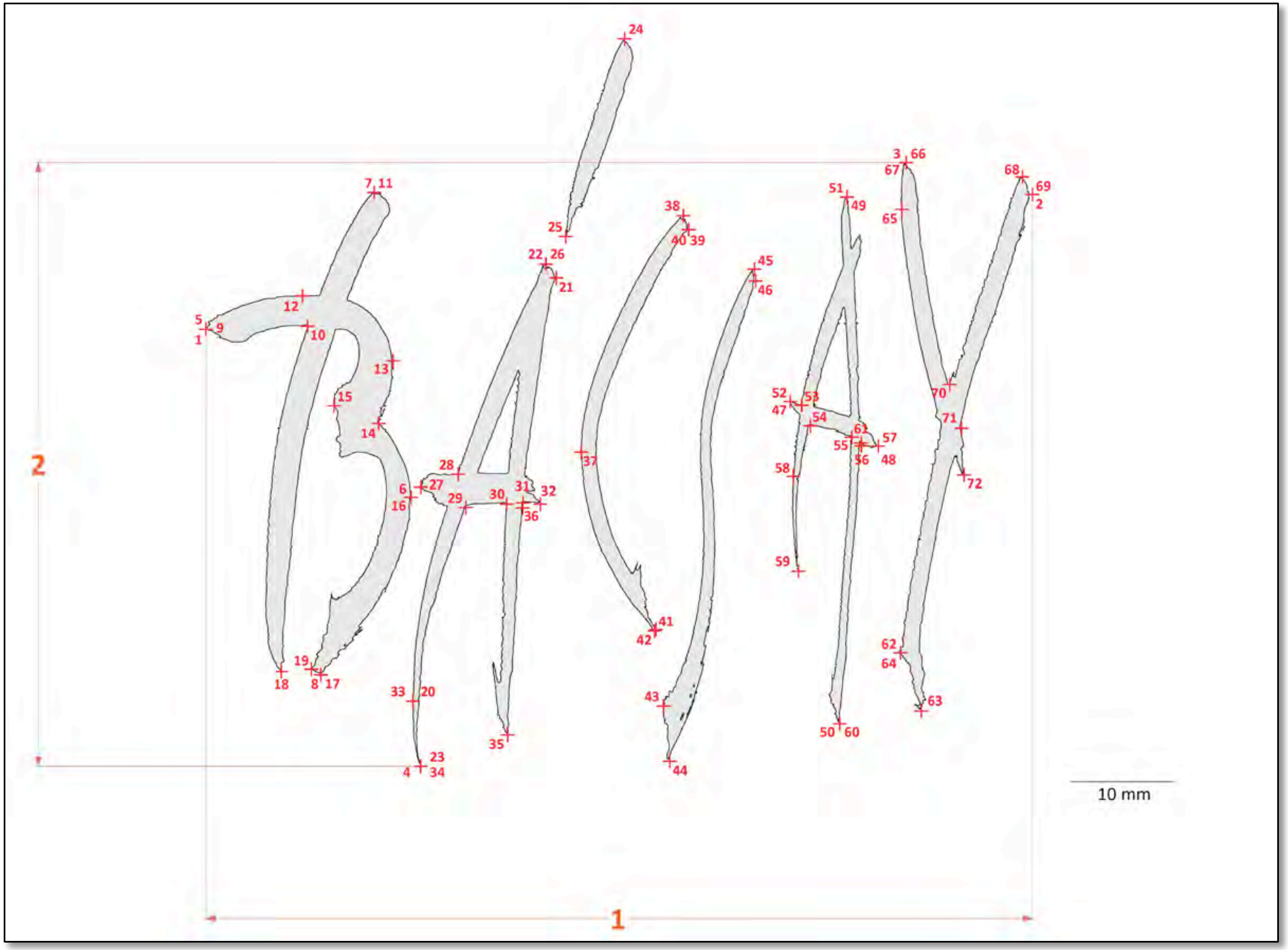


Illustration 5 - Total height and length measurements of the signature of artist n°2: P Bacsay

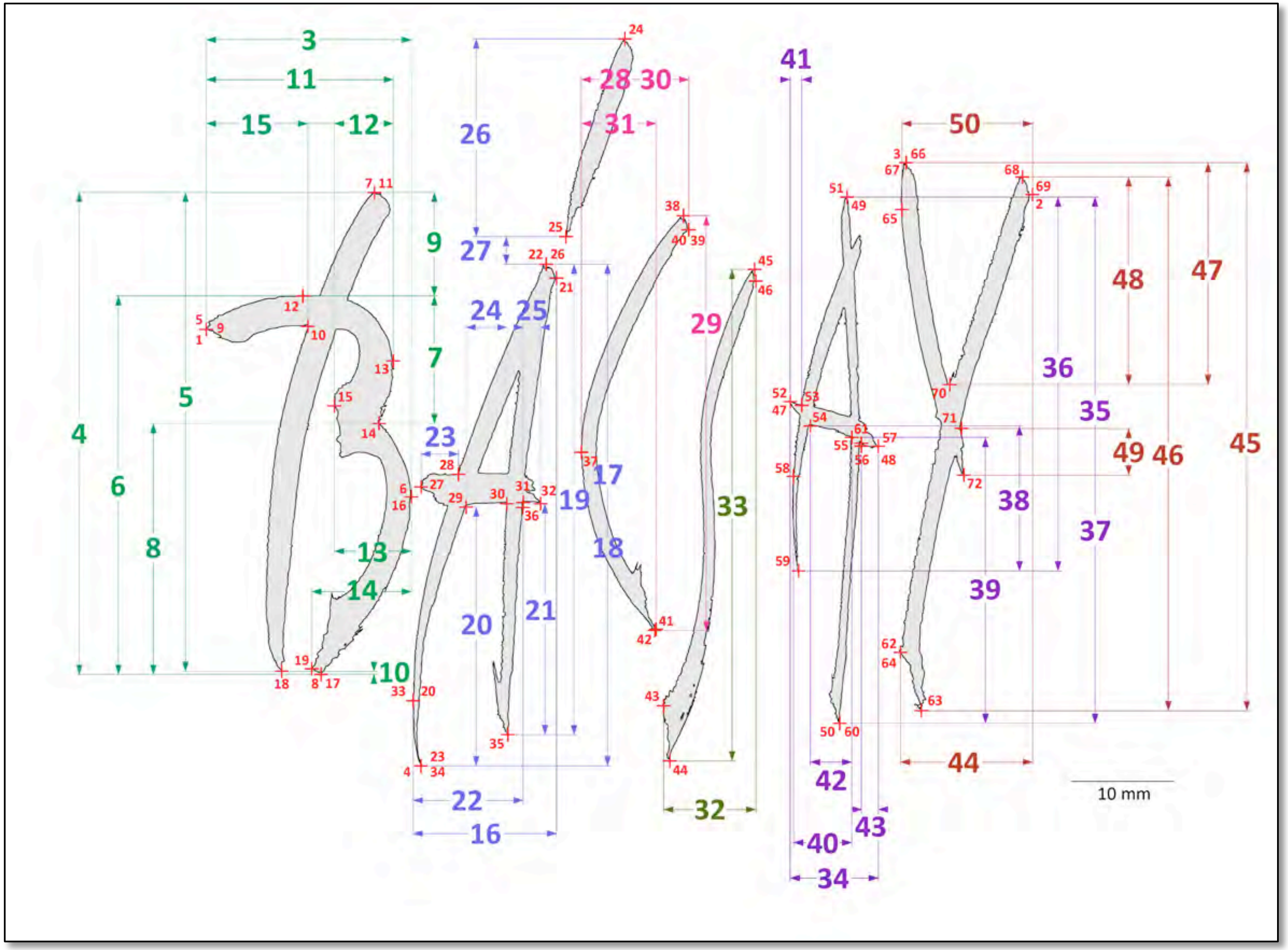


Illustration 6 - Intra-letter measurements of each letter of the signature of artist n°2: P Bacsay

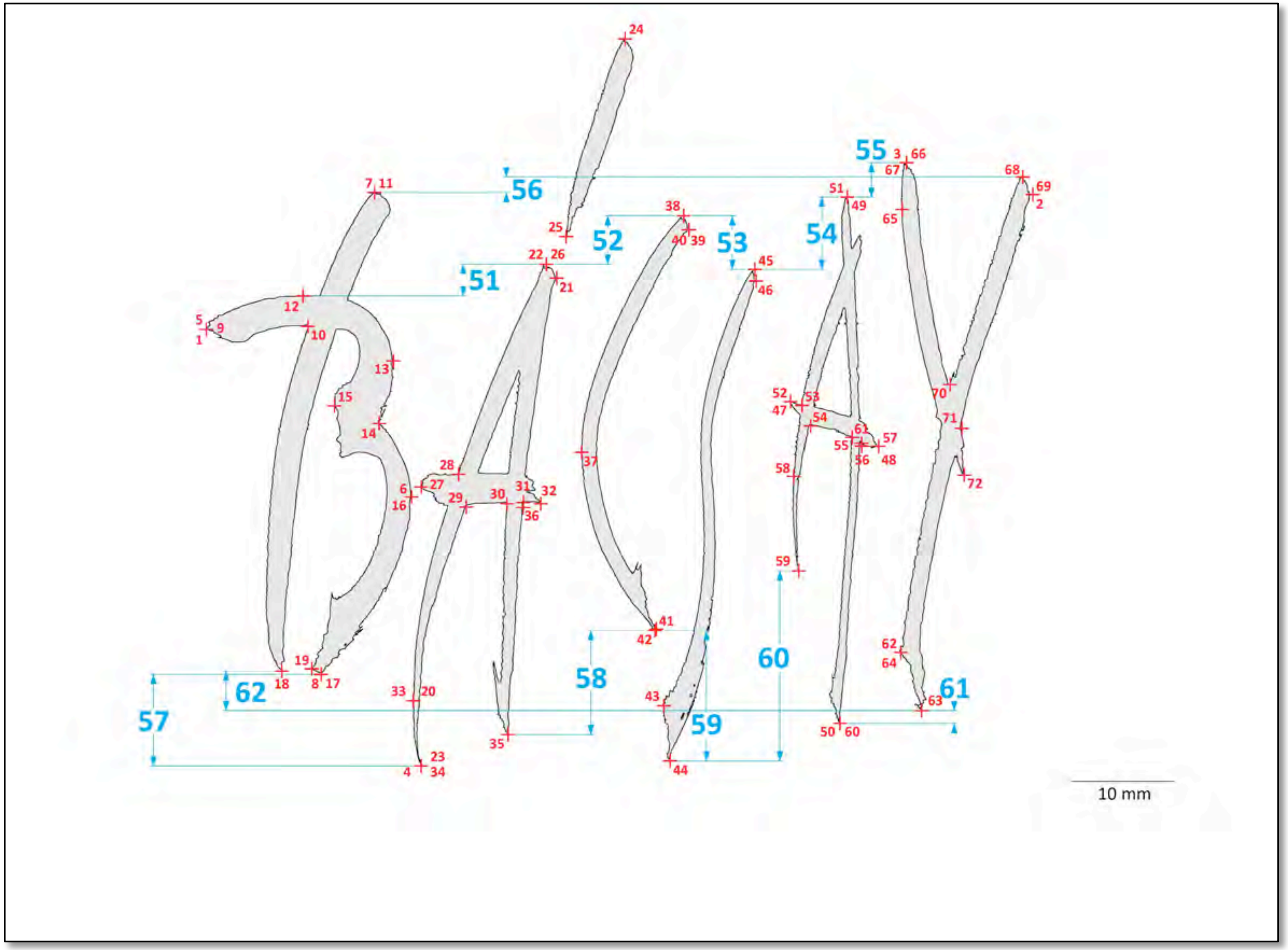


Illustration 7 - Height differences measurements of the signature of artist n°2: P Bacsay

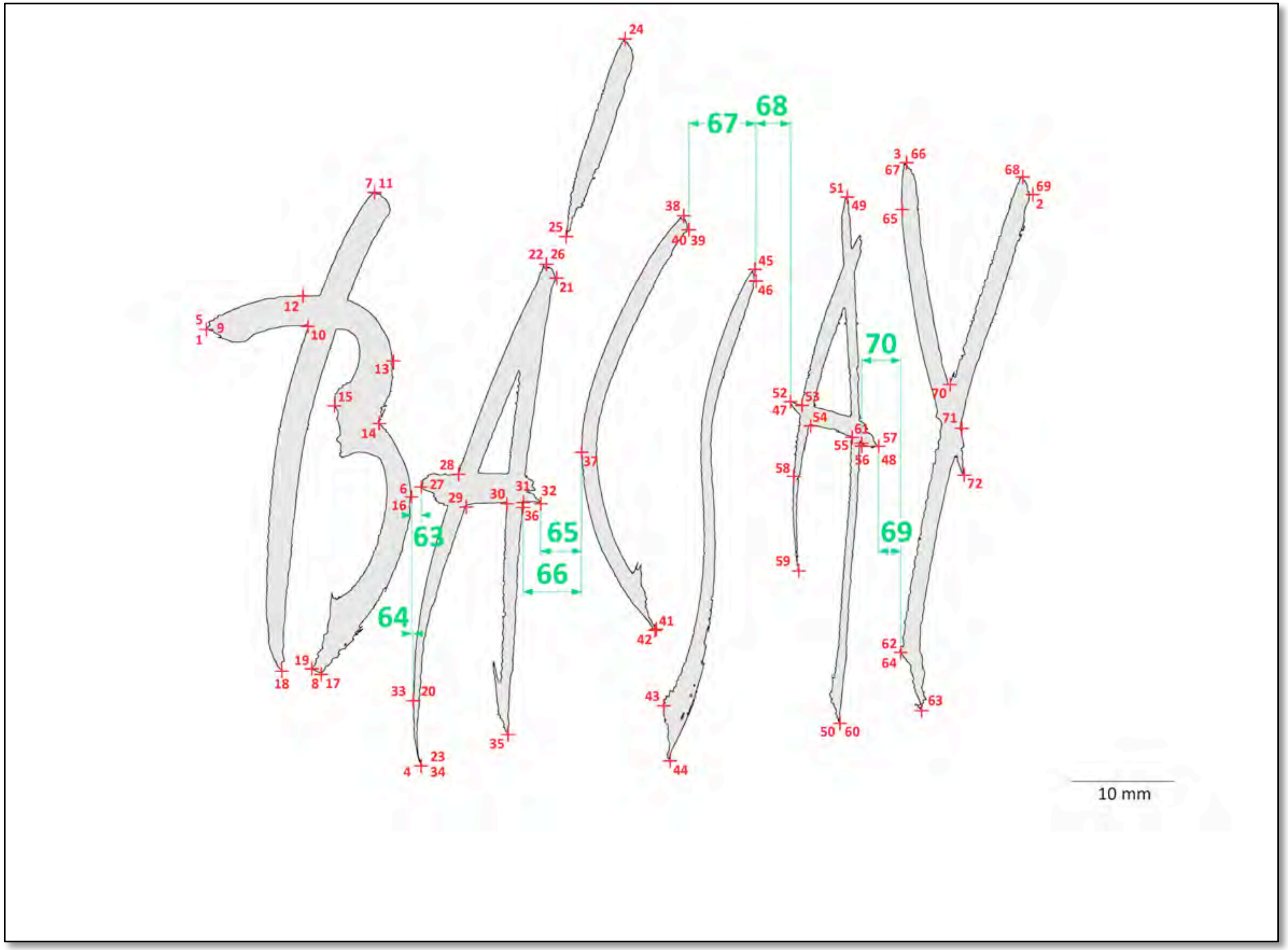


Illustration 8 - Space measurements of the signature of artist n°2: P Bacsay

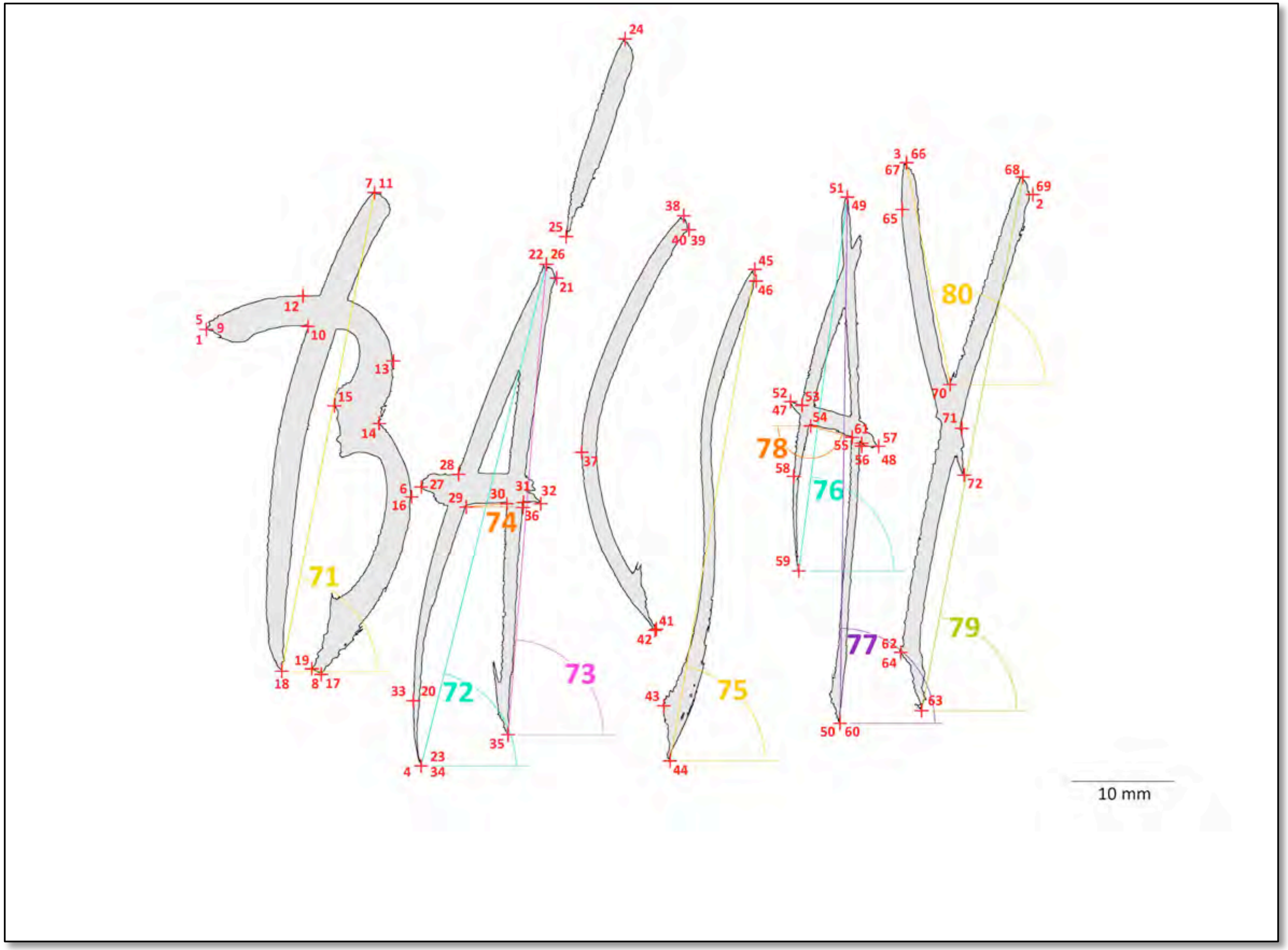


Illustration 9 - Angles measurements of the signature of artist n°2: P Bacsay

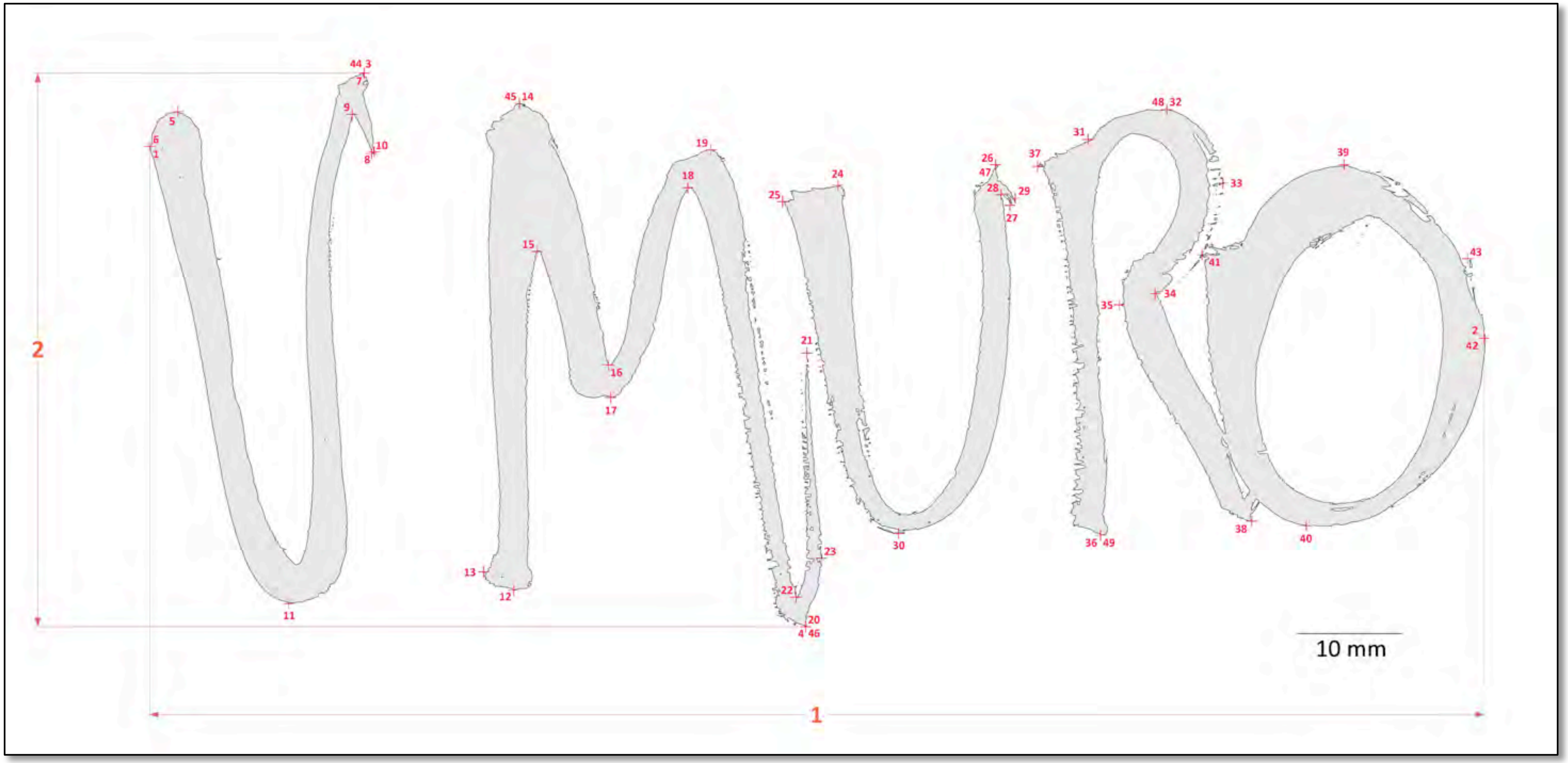


Illustration 10 - Total height and length measurements of the signature of artist n°3: V Muro

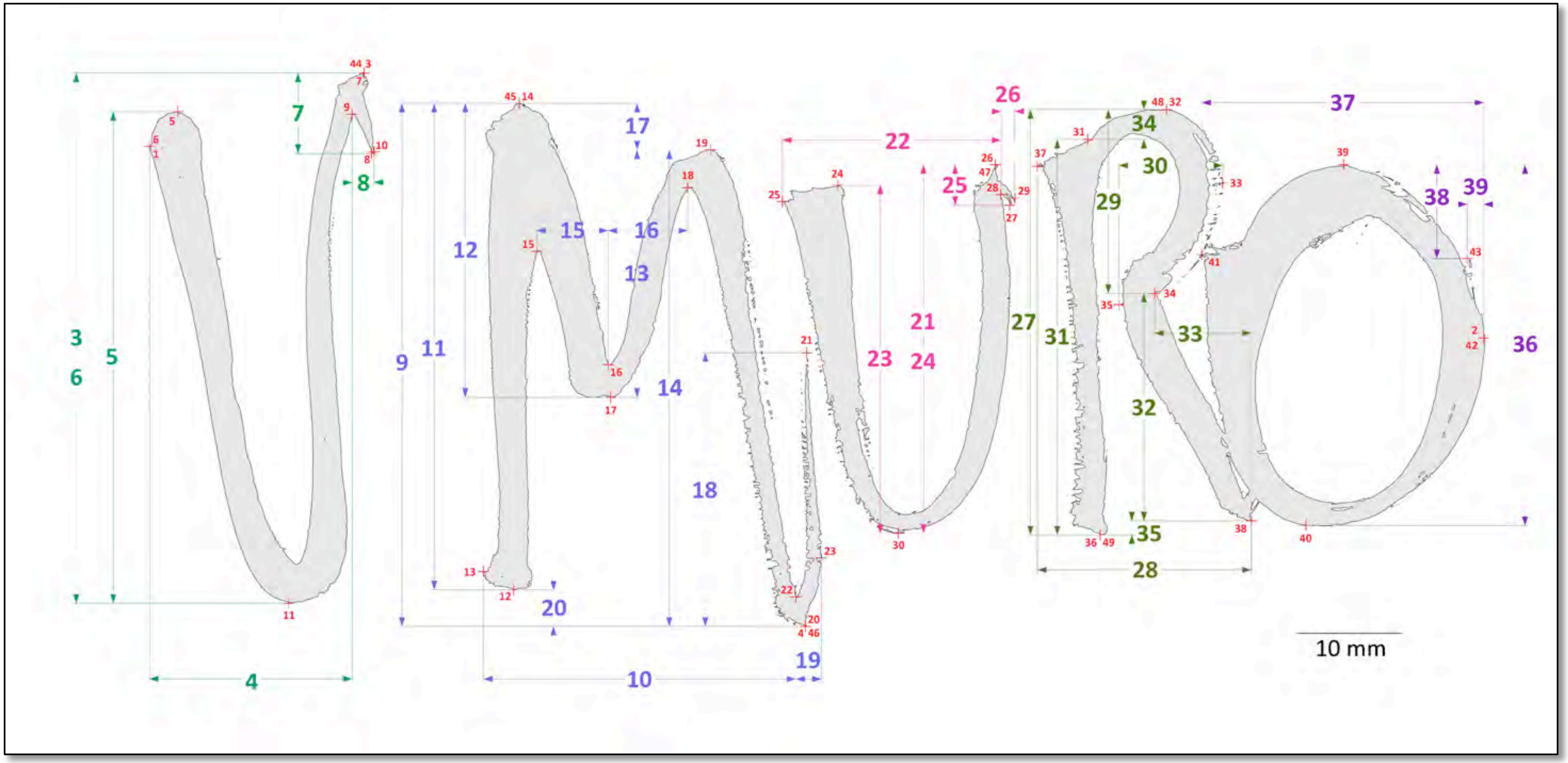


Illustration 11 - Intra-letter measurements of each letter of the signature of artist n°3: V Muro

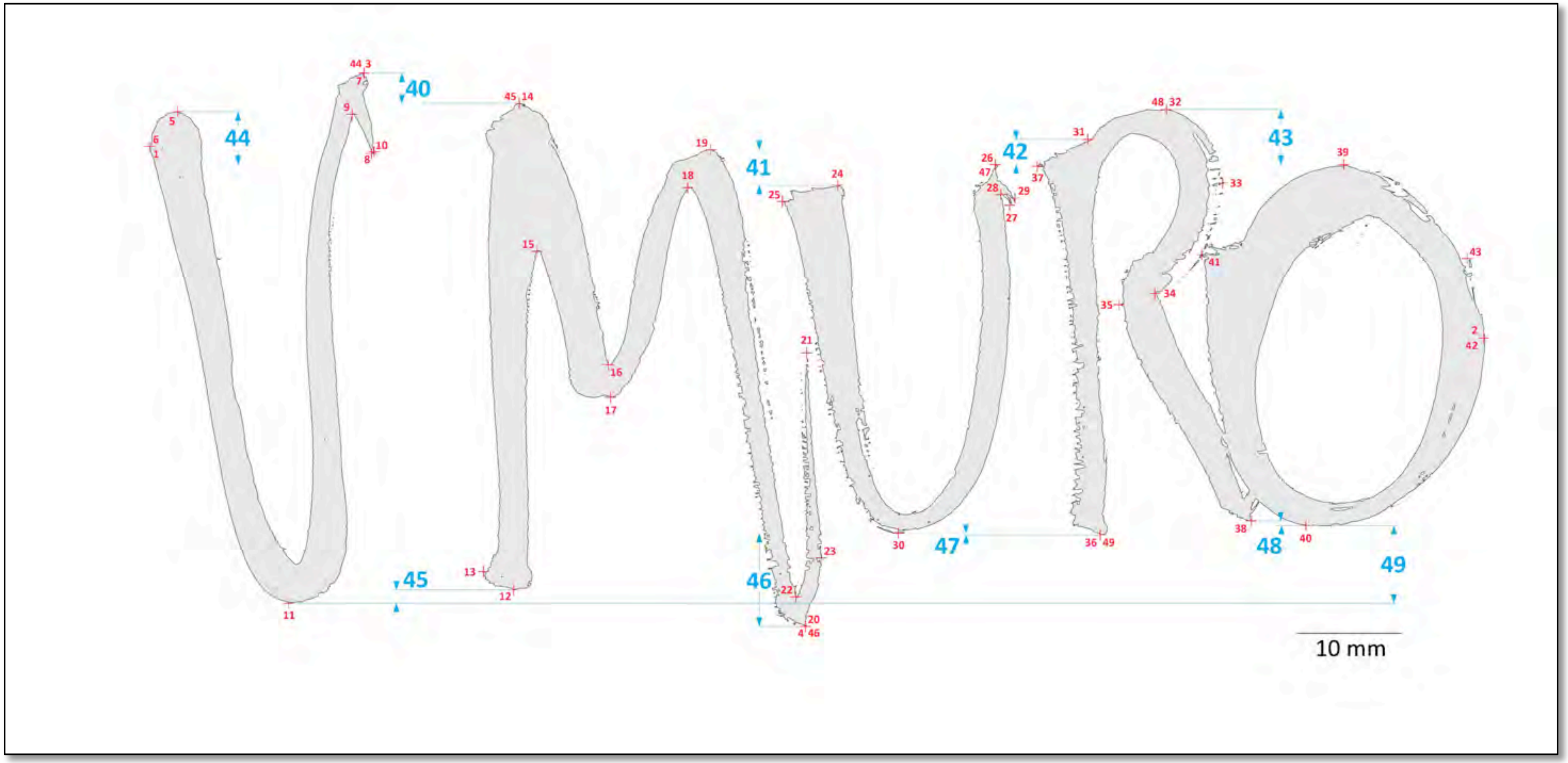


Illustration 12 - Height differences measurements of the signature of artist n°3: V Muro

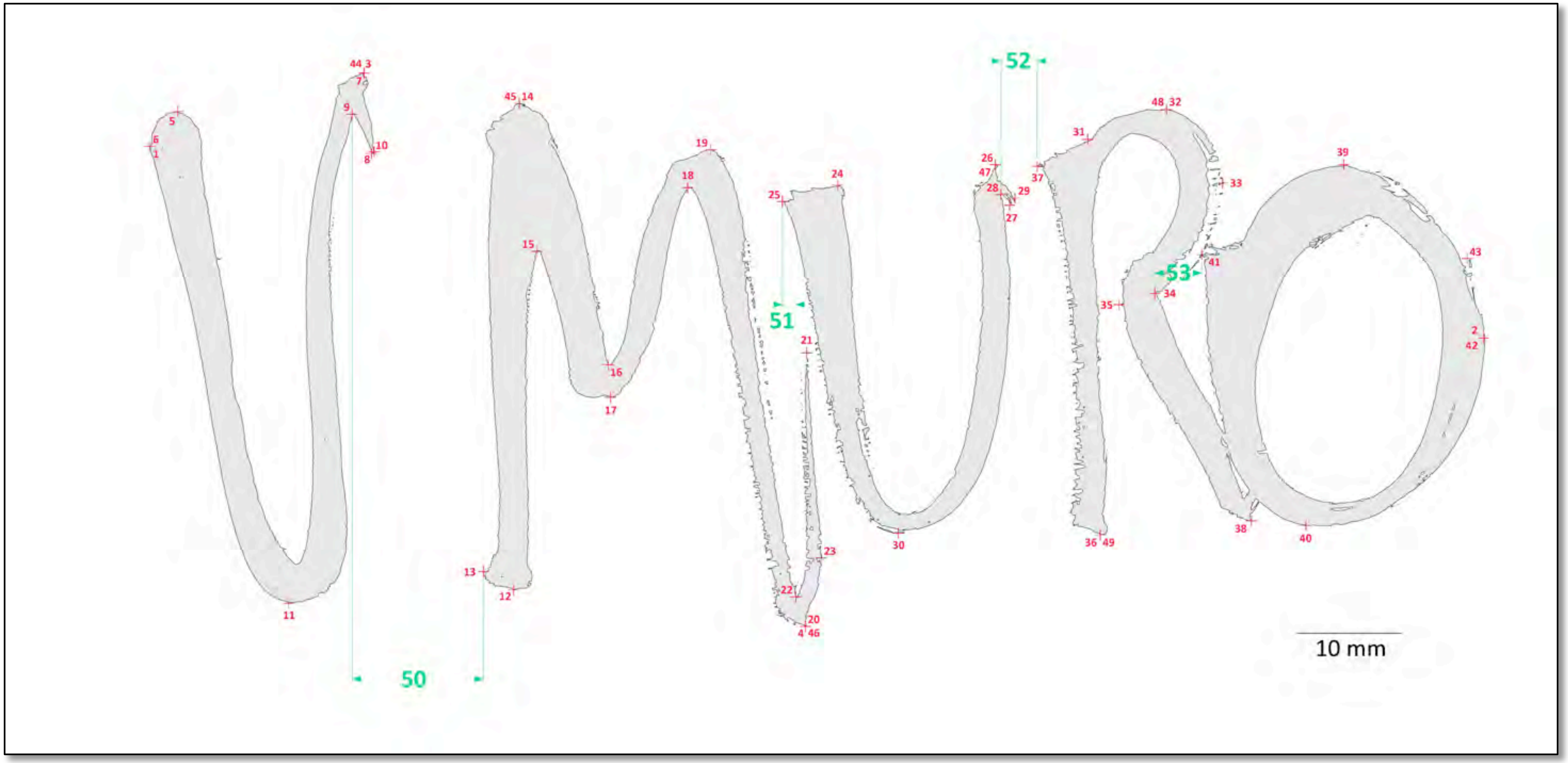


Illustration 13 - Space measurements of the signature of artist n°3: V Muro

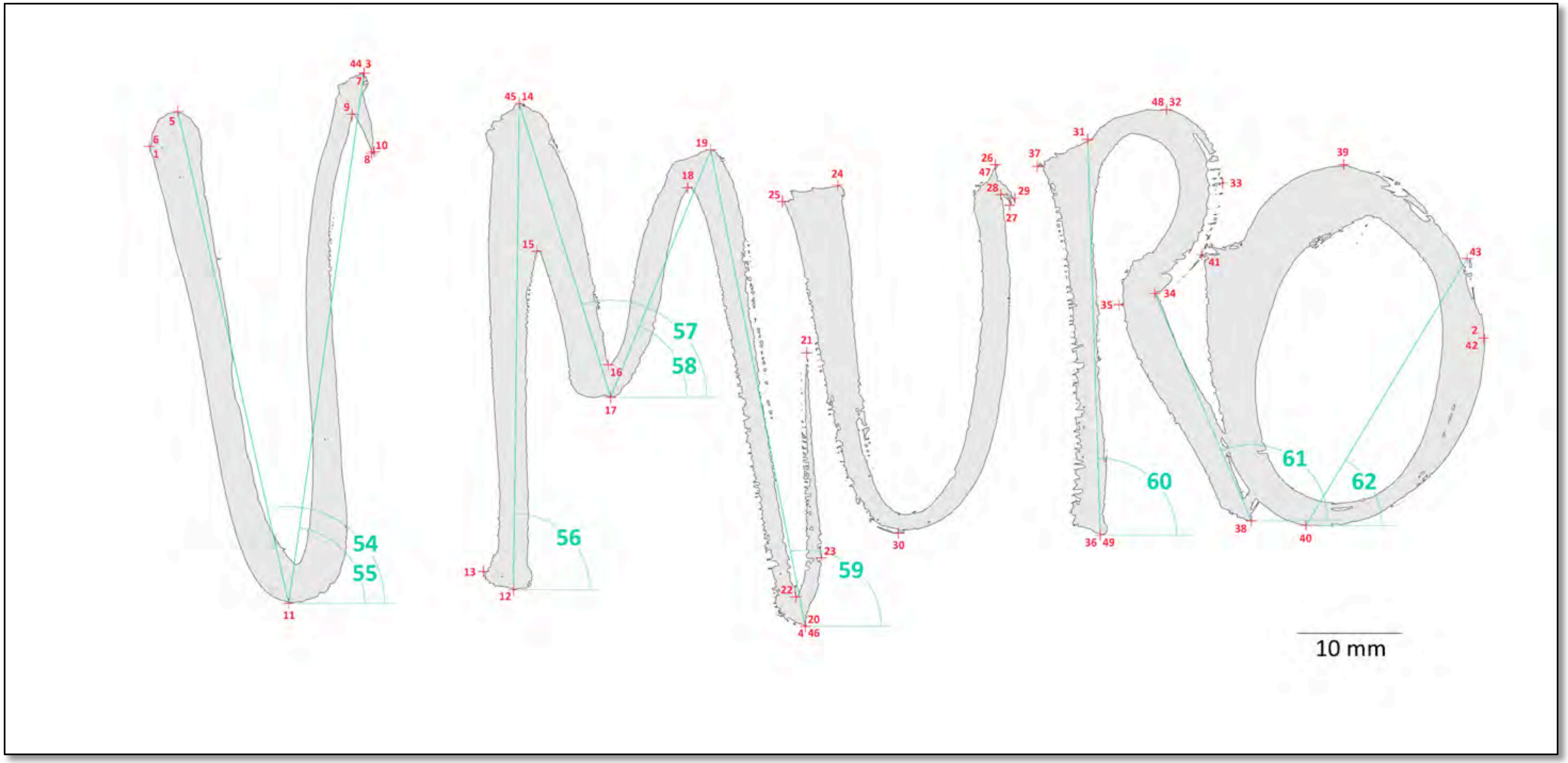


Illustration 14 - Angles measurements of the signature of artist n°3: V Muro

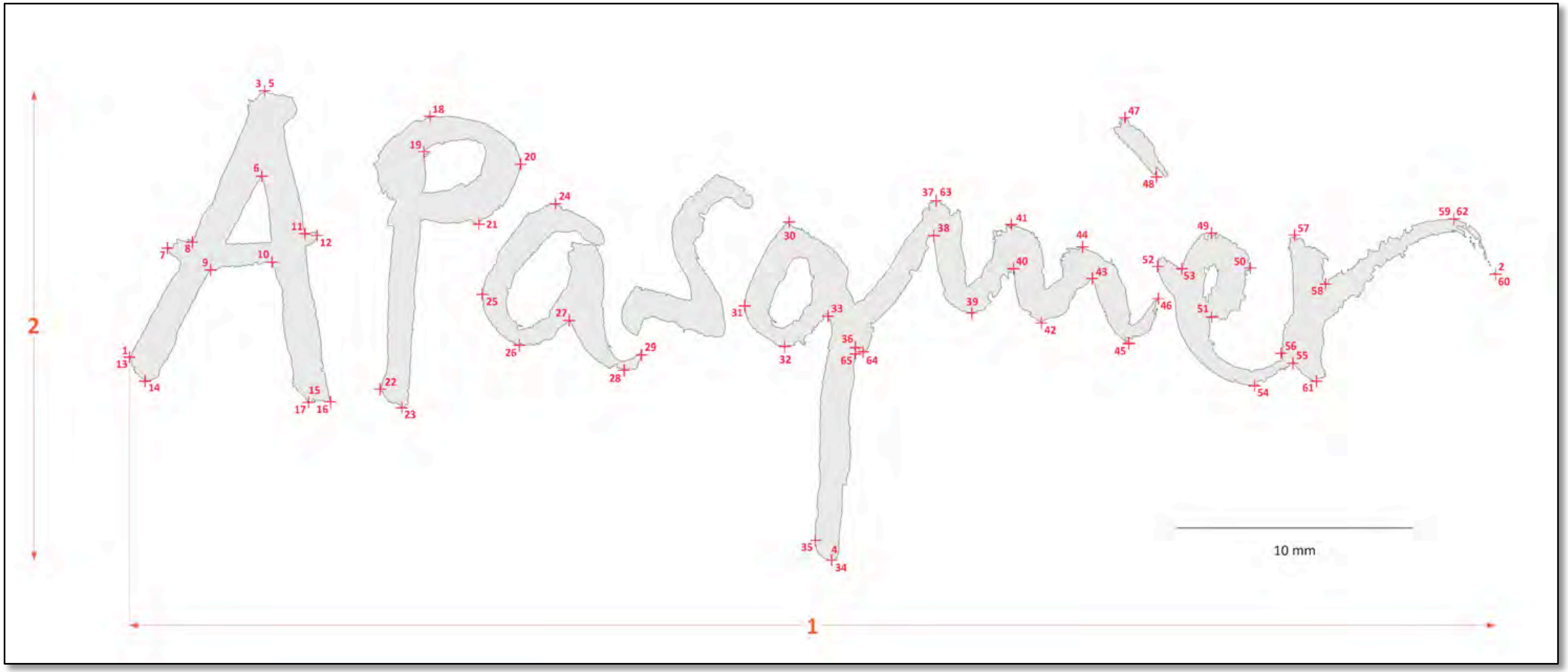


Illustration 15 - Total height and length measurements of the signature of artist n°4: A Pasquier

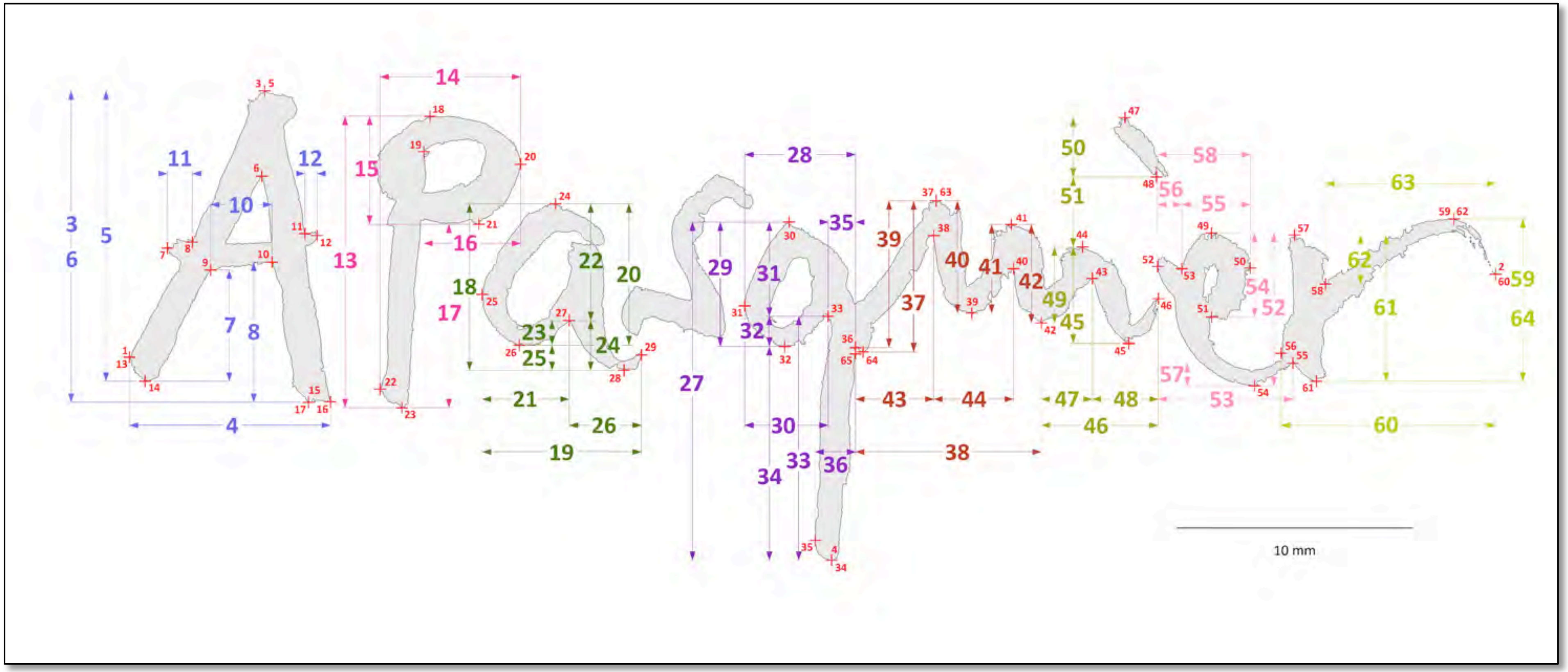


Illustration 16 - Intra-letter measurements of each letter of the signature of artist n°4: A Pasquier

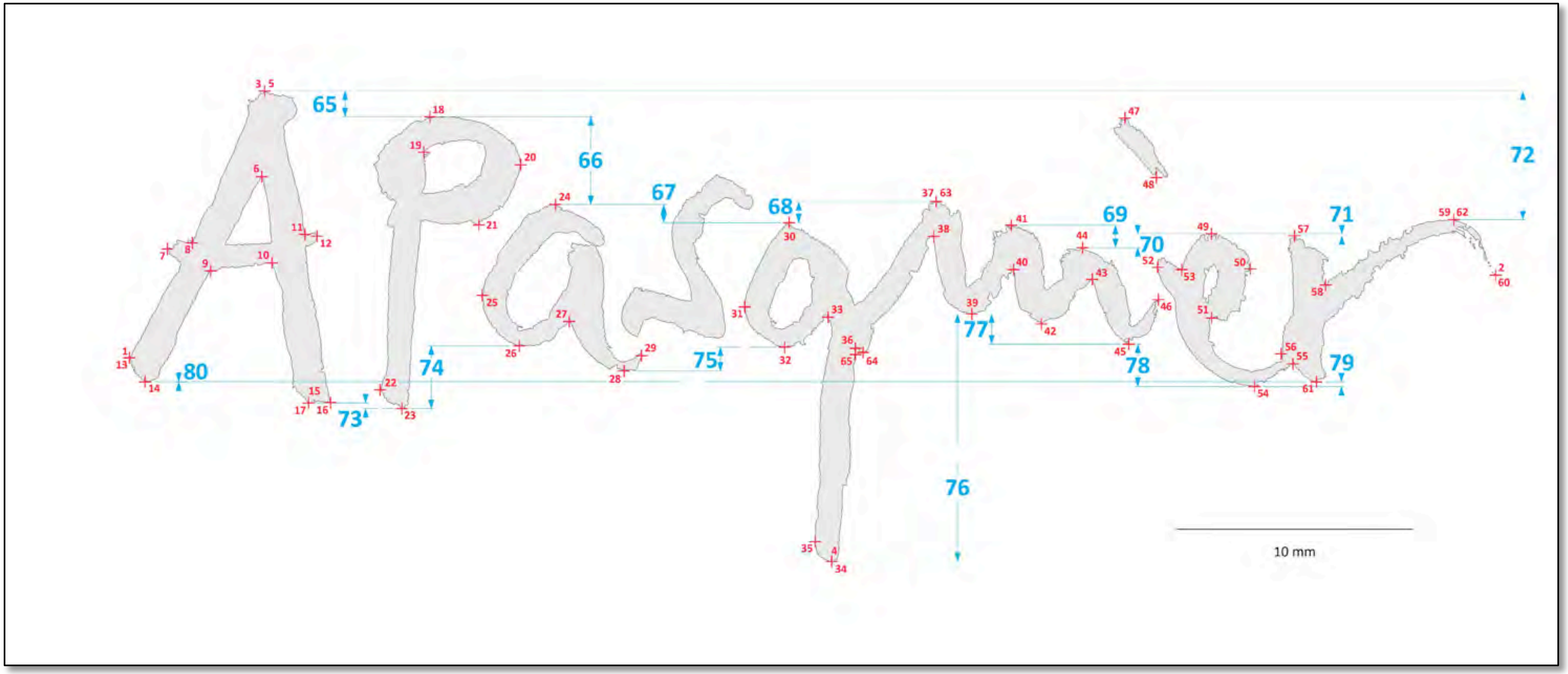


Illustration 17 - Height differences measurements of the signature of artist n°4: A Pasquier

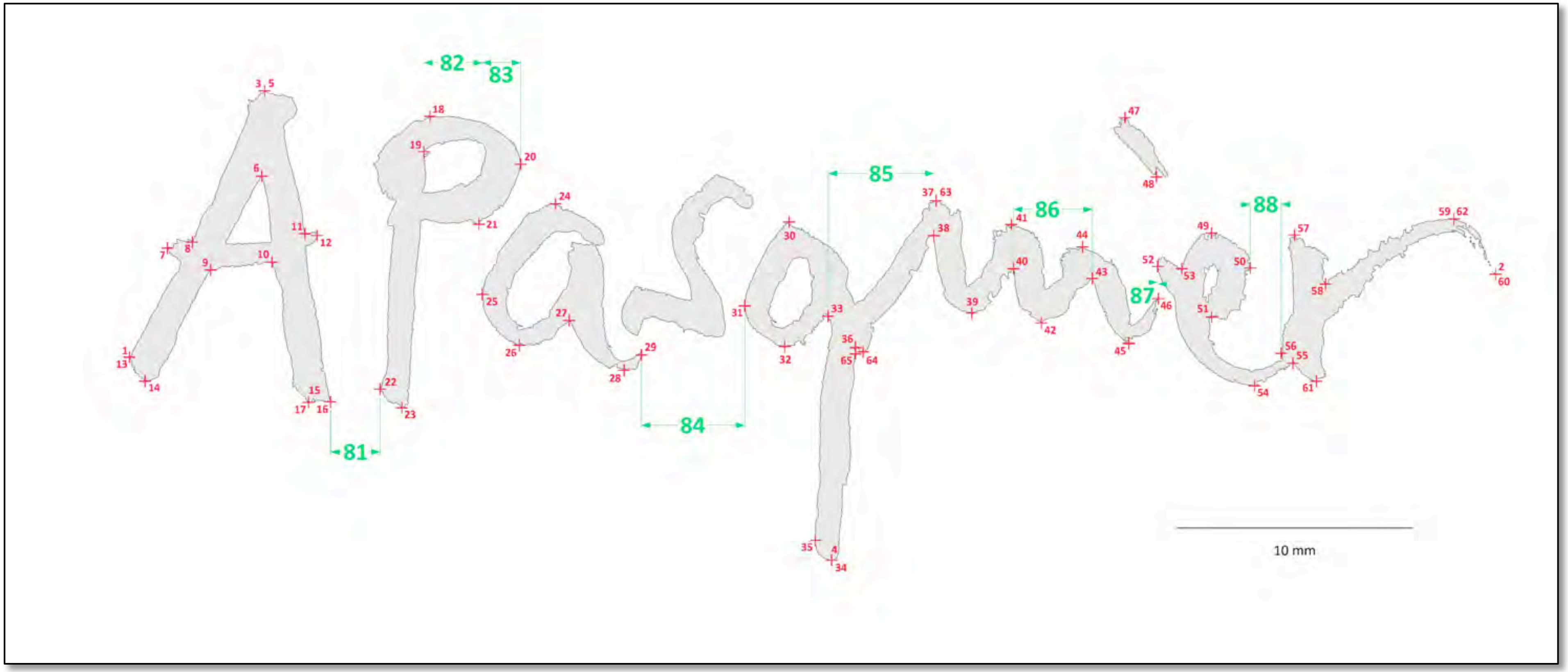


Illustration 18 - Space measurements of the signature of artist n°4: A Pasquier

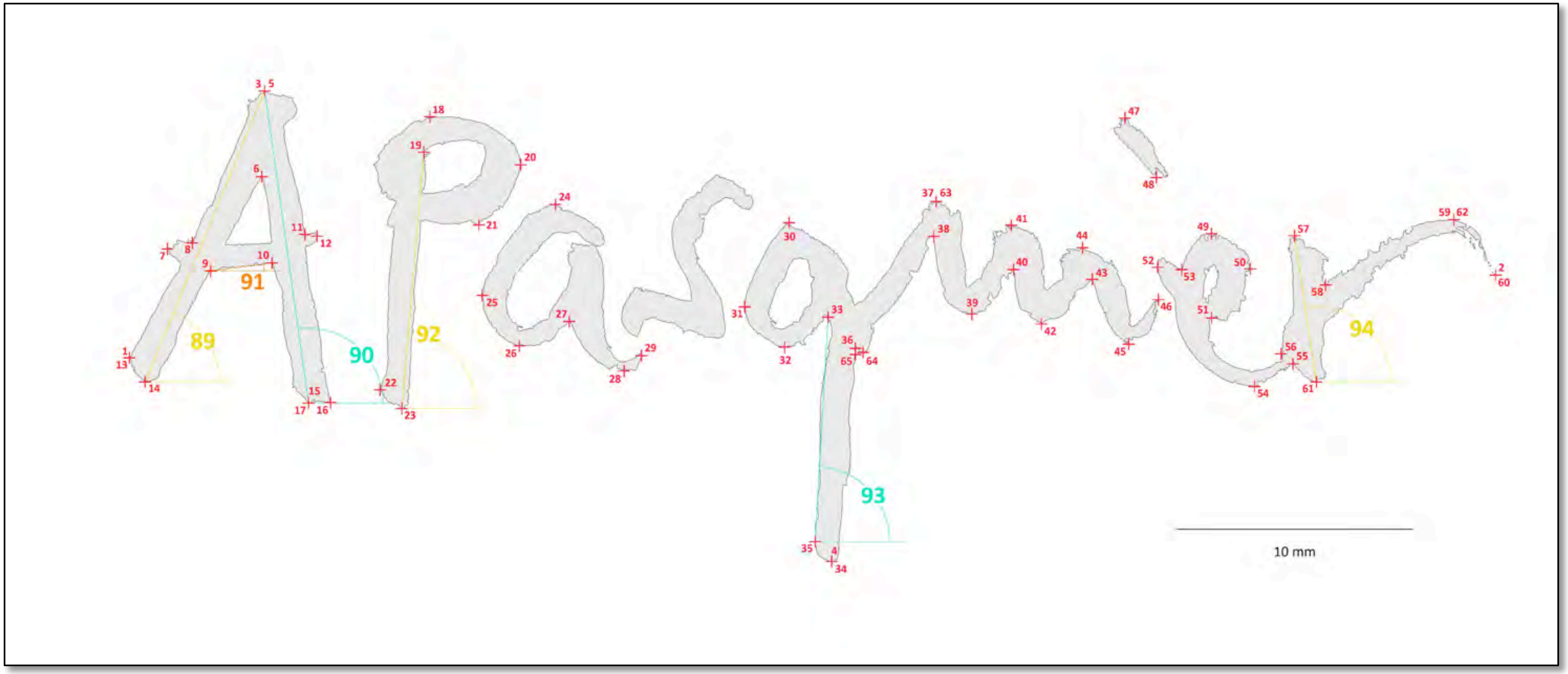


Illustration 19 - Angles measurements of the signature of artist n°4: A Pasquier

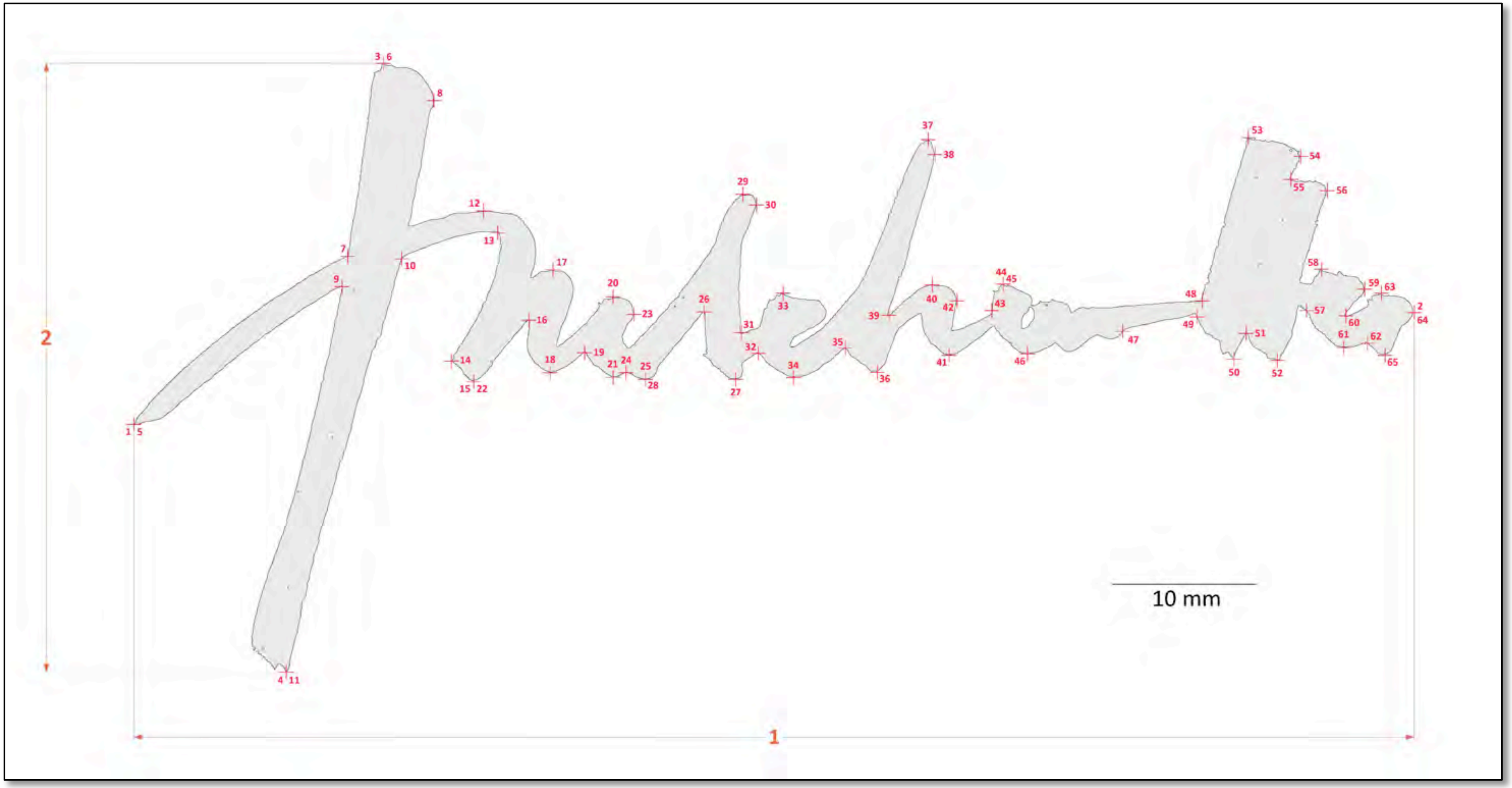


Illustration 20 - Total height and length measurements of the signature of artist n°5: JM Schwaller

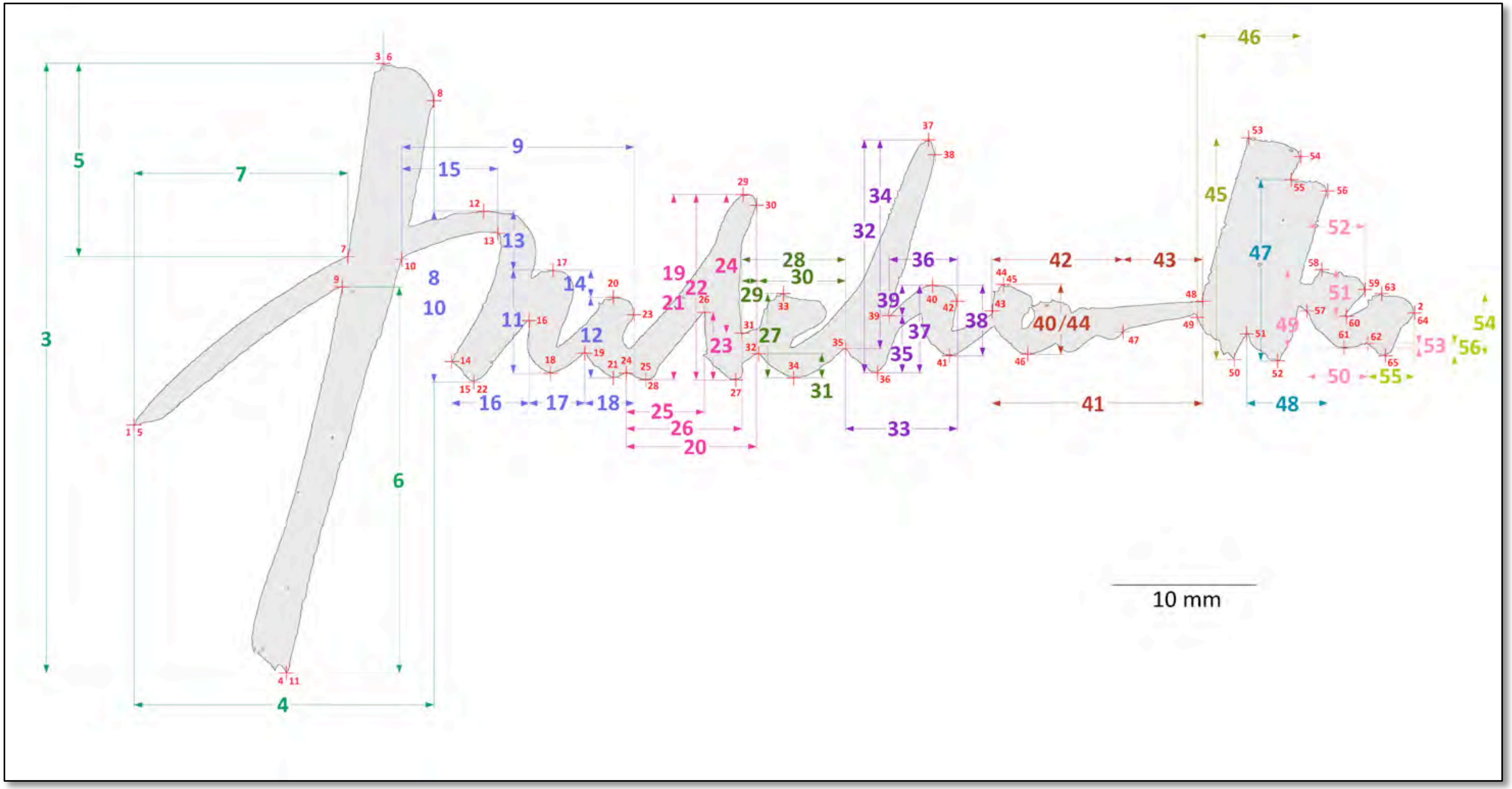


Illustration 21 - Intra-letter measurements of each letter of the signature of artist n°5: JM Schwaller

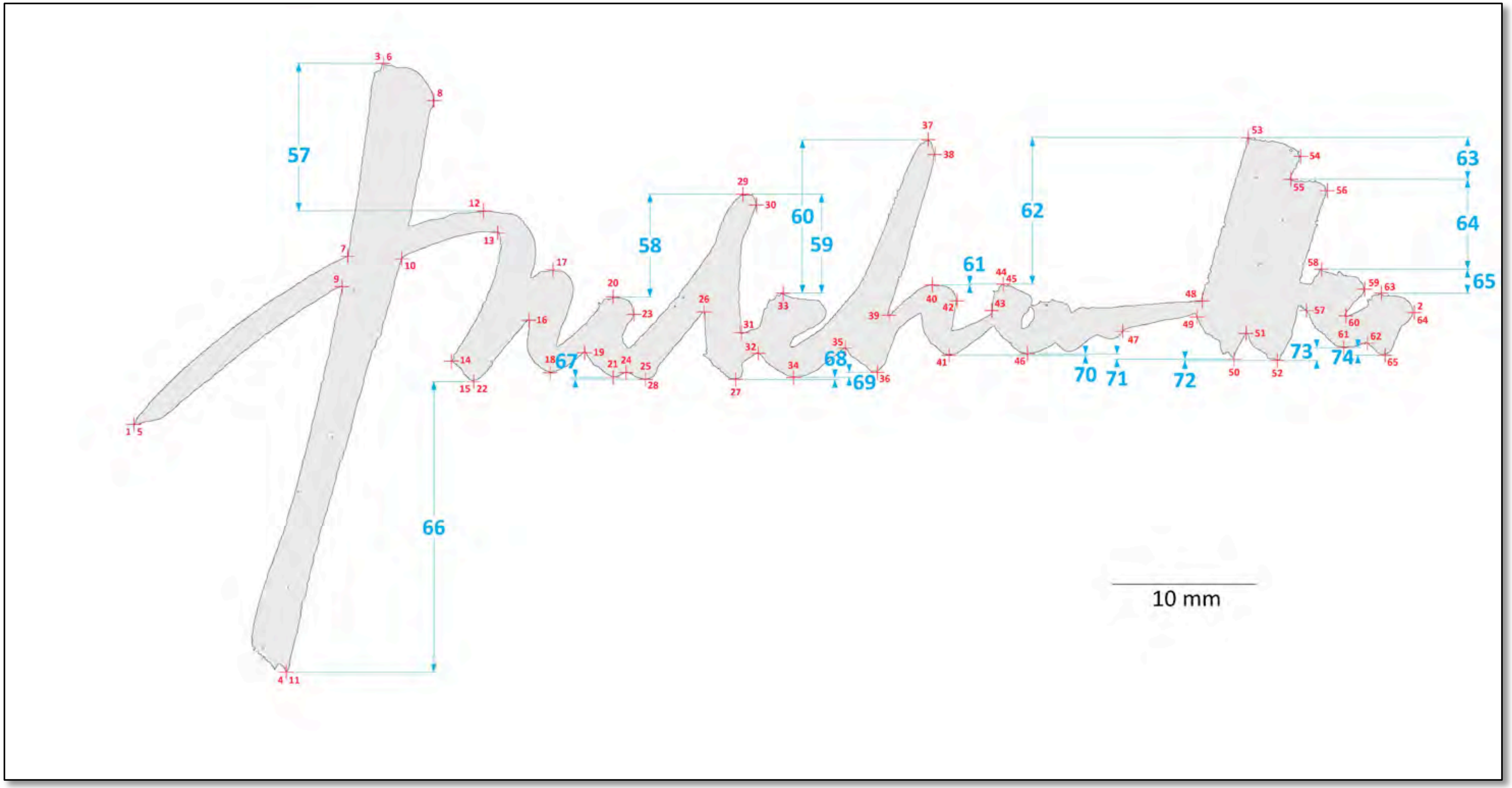


Illustration 21 - Height differences measurements of the signature of artist n°5: JM Schwaller

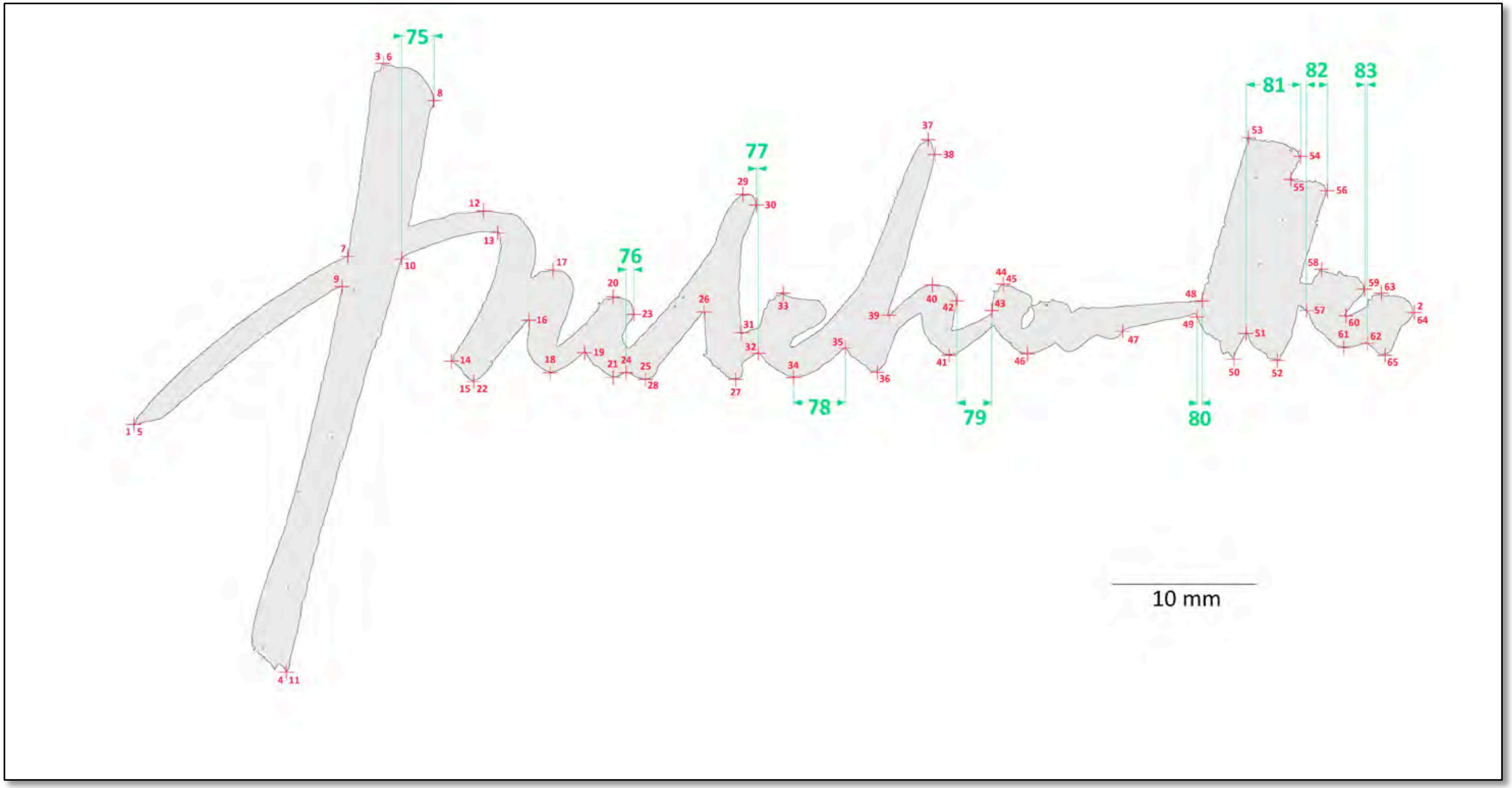


Illustration 22 - Space measurements of the signature of artist n°5: JM Schwaller

Illustration 23 - Angles measurements of the signature of artist n°5: JM Schwaller

Appendix X

Set of characteristics for each signature type

Artist n°1 - Schauenberg

N°	M1	M2	Feature class	Letter	Description of feature
C1	1	2	Length signature / Height signature	Signature	
C2	4	1	Length letter / Length signature	L -J- / L tot	
C3	8	1	Length letter / Length signature	L -c- / L tot	
C4	16	1	Length letter / Length signature	L -l- / L tot	
C5	22	1	Length letter / Length signature	L -s- / L tot	
C6	30	1	Length letter / Length signature	L -s- / L tot	
C7	4	2	Length letter / Height signature	L -J- / H tot	
C8	8	2	Length letter / Height signature	L -c- / H tot	
C9	16	2	Length letter / Height signature	L -l- / H tot	
C10	22	2	Length letter / Height signature	L -s- / H tot	
C11	30	2	Length letter / Height signature	L -s- / H tot	
C12	3	2	Height letter / Height signature	H -J- / H tot	
C13	7	2	Height letter / Height signature	H -c- / H tot	
C14	15	2	Height letter / Height signature	H -l- / H tot	
C15	21	2	Height letter / Height signature	H -s- / H tot	
C16	29	2	Height letter / Height signature	H -s- / H tot	
C17	3	1	Height letter / Length signature	H -J- / L tot	
C18	7	1	Height letter / Length signature	H -c- / L tot	
C19	15	1	Height letter / Length signature	H -l- / L tot	
C20	21	1	Height letter / Length signature	H -s- / L tot	
C21	29	1	Height letter / Length signature	H -s- / L tot	
C22	4	8	Length letter / Length letter after	L -J- / L -c-	
C23	8	16	Length letter / Length letter after	L -c- / L -l-	
C24	16	22	Length letter / Length letter after	L -l- / L -s-	
C25	22	30	Length letter / Length letter after	L -s- / L -s-	
C26	30	4	Length letter / Length letter after	L -s- / L -s-	

C27	3	7	Height letter / Height letter after	H -J- / H -c-	
C28	7	15	Height letter / Height letter after	H -c- / H -l-	
C29	15	21	Height letter / Height letter after	H -l- / H -s-	
C30	21	29	Height letter / Height letter after	H -s- / H -s-	
C31	29	3	Height letter / Height letter after	H -s- / H -s-	
C32	35	3	Height difference (sup.) / Height letter before	H -J- and -c- / H -J-	
C33	36	7	Height difference (sup.) / Height letter before	H -c- and -l- / H -c-	
C34	37	15	Height difference (sup.) / Height letter before	H -l- and -s- / H -l-	
C35	38	21	Height difference (sup.) / Height letter before	H -s- and -s- / H -s-	
C36	39	29	Height difference (sup.) / Height letter before	H -s- and -s- / H -s-	
C37	40	3	Height difference (inf.) / Height letter before	H -J- and -c- / H -J-	
C38	41	7	Height difference (inf.) / Height letter before	H -c- and -l- / H -c-	
C39	42	15	Height difference (inf.) / Height letter before	H -l- and -s- / H -l-	
C40	43	21	Height difference (inf.) / Height letter before	H -s- and -s- / H -s-	
C41	44	29	Height difference (inf.) / Height letter before	H -s- and -s- / H -s-	
C42	4	3	Length letter / Height letter	L -J- / H -J-	
C43	8	7	Length letter / Height letter	L -c- / H -c-	
C44	16	15	Length letter / Height letter	L -l- / H -l-	
C45	22	21	Length letter / Height letter	L -s- / H -s-	
C46	30	29	Length letter / Height letter	L -s- / H -s-	
C47	5	3	Intraletter	-J-	Height of stem / Height letter
C48	6	4	Intraletter	-J-	Height of lower loop / Length letter
C49	9	7	Intraletter	-c-	Height of ascending stroke / Height letter
C50	9	8	Intraletter	-c-	Height of ascending stroke / Length letter

C51	10	7	Intraletter	-c-	Height of cusp / Height letter
C52	10	8	Intraletter	-c-	Height of cusp / Length letter
C53	12	7	Intraletter	-c-	Length distance between beginning of ascending stroke and bow of loop / Height letter
C54	13	7	Intraletter	-c-	Length distance between beginning of ascending stroke and its intersection with the loop / Height letter
C55	13	8	Intraletter	-c-	Length distance between beginning of ascending stroke and its intersection with the loop / Length letter
C56	14	7	Intraletter	-c-	Length distance of loop (from bow to lowest point of the letter) / Height letter
C57	14	8	Intraletter	-c-	Length distance of loop (from bow to lowest point of the letter) / Length letter
C58	17	15	Intraletter	-l-	Height of ascending stroke / Total height of letter (height of main stem)
C59	18	15	Intraletter	-l-	Height of top loop / Total height of letter (height of main stem)
C60	19	16	Intraletter	-l-	Length distance of ascending stroke / Length letter
C61	19	17	Intraletter	-l-	Length distance of ascending stroke / Height of ascending stroke
C62	20	15	Intraletter	-l-	Height of stem between bottom of loop and intersection with letter -s- / Total height of letter (height of main stem)
C63	31	29	Intraletter	-s-	Total length of letter (both segments) / Height of endstroke
C64	23	21	Intraletter	-s-	Height of ascending stroke, from intersection with letter -l- / Height of loop
C65	24	21	Intraletter	-s-	Height of cusp / Height of loop
C66	25	21	Intraletter	-s-	Height between tip of loop and departure of endstroke / Height of loop
C67	26	21	Intraletter	-s-	Height of ascending stroke, from intersection with letter -l-, up to the inner cusp / Height of loop
C68	27	21	Intraletter	-s-	Total height of ascending stroke / Height of loop
C69	28	22	Intraletter	-s-	Length of ascending stroke / Length of loop
C70	34	31	Intraletter	-s-	Length of endstroke, from intersection with loop / Total length of letter (both segments)
C71	24	22	Intraletter	-s-	Height of cusp / Length of loop
C72	26	22	Intraletter	-s-	Height of ascending stroke, from intersection with letter -l-, up to the inner cusp / Length of loop

C73	32	29	Intraletter	-s-	Height of endstroke, from intersection with loop / Height of endstroke
C74	33	29	Intraletter	-s-	Height distance between top of endstroke and tip of endstroke / Height of endstroke
C75	30	31	Intraletter	-s-	Length of endstroke / Total length of letter (both segments)
C76	34	30	Intraletter	-s-	Length of endstroke, from intersection with loop / Length of endstroke
C77	32	34	Intraletter	-s-	Height of endstroke, from intersection with loop / Length of endstroke, from intersection with loop
C78	45	-1	Angle	-J-	Angle of stem
C79	46	-1	Angle	-c-	Angle of ascending stroke
C80	47	-1	Angle	-l-	Angle of ascending stroke
C81	48	-1	Angle	-s-	Angle of stem
C82	49	-1	Angle	-s-	Angle of ascending stroke
C83	50	-1	Angle	-s-	Angle of loop
C84	51	-1	Angle	-s-	Angle of endstroke
C85	52	-1	Angle	-s-	Angle of endstroke

Artist n°2: Bacsay

N°	M1	M2	Feature class	Letter	Description of feature
C1	1	2	Length signature / Height signature	Signature	
C2	3	1	Length letter / Length signature	L -B- / L tot	
C3	16	1	Length letter / Length signature	L -A- / L tot	
C4	28	1	Length letter / Length signature	L -C- / L tot	
C5	32	1	Length letter / Length signature	L -S- / L tot	
C6	34	1	Length letter / Length signature	L -A- / L tot	
C7	44	1	Length letter / Length signature	L -Y- / L tot	
C8	3	2	Length letter / Height signature	L -B- / H tot	
C9	16	2	Length letter / Height signature	L -A- / H tot	
C10	28	2	Length letter / Height signature	L -C- / H tot	
C11	32	2	Length letter / Height signature	L -S- / H tot	
C12	34	2	Length letter / Height signature	L -A- / H tot	
C13	44	2	Length letter / Height signature	L -Y- / H tot	
C14	4	2	Height letter / Height signature	H -B- / H tot	
C15	17	2	Height letter / Height signature	H -A- / H tot	
C16	29	2	Height letter / Height signature	H -C- / H tot	
C17	33	2	Height letter / Height signature	H -S- / H tot	
C18	35	2	Height letter / Height signature	H -A- / H tot	
C19	45	2	Height letter / Height signature	H -Y- / H tot	
C20	4	1	Height letter / Length signature	H -B- / L tot	
C21	17	1	Height letter / Length signature	H -A- / L tot	
C22	29	1	Height letter / Length signature	H -C- / L tot	
C23	33	1	Height letter / Length signature	H -S- / L tot	
C24	35	1	Height letter / Length signature	H -A- / L tot	
C25	45	1	Height letter / Length signature	H -Y- / L tot	
C26	3	16	Length letter / Length letter after	L -B- / L -A-	
C27	16	28	Length letter /	L -A- / L -C-	

			Length letter after		
C28	28	32	Length letter / Length letter after	L -C- / L -S-	
C29	32	34	Length letter / Length letter after	L -S- / L -A-	
C30	34	44	Length letter / Length letter after	L -A- / L -Y-	
C31	44	3	Length letter / Length letter after	L -Y- / L -B-	
C32	4	17	Height letter / Height letter after	H -B- / H -A-	
C33	17	29	Height letter / Height letter after	H -A- / H -C-	
C34	29	33	Height letter / Height letter after	H -C- / H -S-	
C35	33	35	Height letter / Height letter after	H -S- / H -A-	
C36	35	45	Height letter / Height letter after	H -A- / H -Y-	
C37	45	4	Height letter / Height letter after	H -Y- / H -B-	
C38	51	4	Height difference (sup.) / Height letter before	H -B- and -A- / H -B-	
C39	52	17	Height difference (sup.) / Height letter before	H -A- and -C- / H -A-	
C40	53	29	Height difference (sup.) / Height letter before	H -C- and -S- / H -C-	
C41	54	33	Height difference (sup.) / Height letter before	H -S- and -A- / H -S-	
C42	55	35	Height difference (sup.) / Height letter before	H -A- and -Y- / H -A-	
C43	56	45	Height difference (sup.) / Height letter before	H -Y- and -B- / H -Y-	
C44	57	4	Height difference (inf.) / Height letter before	H -B- and -A- / H -B-	
C45	58	17	Height difference (inf.) / Height letter before	H -A- and -C- / H -A-	
C46	59	29	Height difference (inf.) / Height letter before	H -C- and -S- / H -C-	
C47	60	33	Height difference (inf.) / Height letter before	H -S- and -A- / H -S-	
C48	61	35	Height difference (inf.) / Height letter before	H -A- and -Y- / H -A-	
C49	62	45	Height difference (inf.) / Height	H -Y- and -B- / H -Y-	

			letter before		
C50	63	16	Space / Length letter after	-B- and -A- / L -A-	Space between -B- and left overlapping crossbar
C51	64	16	Space / Length letter after	-B- and -A- / L -A-	Space between -B- and extremity of left stem
C52	65	28	Space / Length letter after	-A- and -C- / L -C-	Space between right overlapping crossbar of -A- and -C-
C53	66	28	Space / Length letter after	-A- and -C- / L -C-	Space between extremity of right stem of -A- and -C-
C54	67	32	Space / Length letter after	-C- and -S- / L -S-	Space
C55	68	34	Space / Length letter after	-S- and -A- / L -A-	Space between -S- and left overlapping crossbar
C56	69	44	Space / Length letter after	-A- and -Y- / L -Y-	Space between right overlapping crossbar of -A- and -Y-
C57	70	44	Space / Length letter after	-A- and -Y- / L -Y-	Space between extremity of right stem of -A- and -Y-
C58	3	4	Length letter / Height letter	L -B- / H -B-	
C59	16	17	Length letter / Height letter	L -A- / H -A-	
C60	28	29	Length letter / Height letter	L -C- / H -C-	
C61	32	33	Length letter / Height letter	L -S- / H -S-	
C62	34	35	Length letter / Height letter	L -A- / H -A-	
C63	44	45	Length letter / Height letter	L -Y- / H -Y-	
C64	5	4	Intraletter	-B-	Height of stem / Height letter
C65	6	4	Intraletter	-B-	Height of both bows / Height letter
C66	7	4	Intraletter	-B-	Height of top bow / Height letter
C67	8	4	Intraletter	-B-	Height of bottom bow / Height letter
C68	9	5	Intraletter	-B-	Height of stem overlapping top bow / Height of stem
C69	10	5	Intraletter	-B-	Height difference between bottom of stem and lowest point of bottom bow / Height of stem
C70	7	8	Intraletter	-B-	Height of top bow / Height of bottom bow
C71	7	11	Intraletter	-B-	Height of top bow / Length of top bow
C72	8	14	Intraletter	-B-	Height of bottom bow / Length of bottom bow
C73	11	12	Intraletter	-B-	Length of top bow / Length of top bow, taken from buckle
C74	12	13	Intraletter	-B-	Length of top bow, taken from buckle / Length of bottom bow, taken from buckle
C75	13	14	Intraletter	-B-	Length of bottom bow, taken from buckle / Length of bottom bow
C76	11	3	Intraletter	-B-	Length of top bow / Length letter
C77	12	3	Intraletter	-B-	Length of top bow, taken from buckle / Length letter

C78	13	3	Intraletter	-B-	Length of bottom bow, taken from buckle / Length letter
C79	14	3	Intraletter	-B-	Length of bottom bow / Length letter
C80	15	3	Intraletter	-B-	Length of initial stroke left of stem / Length letter
C81	18	19	Intraletter	-A-	Height left stem / Height right stem
C82	20	18	Intraletter	-A-	Height of left stem under crossbar / Height left stem
C83	21	19	Intraletter	-A-	Height of right stem under crossbar / Height right stem
C84	24	16	Intraletter	-A-	Length of inner crossbar / Length letter
C85	23	16	Intraletter	-A-	Length of crossbar stroke overlapping left stem / Length letter
C86	25	16	Intraletter	-A-	Length of crossbar stroke overlapping right stem / Length letter
C87	22	16	Intraletter	-A-	Length of spreading between outer extremities of stems / Length letter
C88	26	17	Intraletter	-A-	Height of acute / Height letter
C89	27	17	Intraletter	-A-	Height difference between acute and letter -A- / Height letter
C90	30	31	Intraletter	-C-	Length of upper curve / Length of lower curve
C91	36	37	Intraletter	-A-	Height left stem / Height right stem
C92	38	36	Intraletter	-A-	Height of left stem under crossbar / Height left stem
C93	39	37	Intraletter	-A-	Height of right stem under crossbar / Height right stem
C94	42	34	Intraletter	-A-	Length of inner crossbar / Length letter
C95	41	34	Intraletter	-A-	Length of crossbar stroke overlapping left stem / Length letter
C96	43	34	Intraletter	-A-	Length of crossbar stroke overlapping right stem / Length letter
C97	40	34	Intraletter	-A-	Length of spreading between outer extremities of stems / Length letter
C98	47	48	Intraletter	-Y-	Height of left stem, up to intersection of stems / Height of right stem, up to intersection of stems
C99	50	44	Intraletter	-Y-	Length of spreading between outer extremities of stems / Length letter
C100	47	46	Intraletter	-Y-	Height of left stem, up to intersection of stems / Height of right stem
C101	48	46	Intraletter	-Y-	Height of right stem, up to intersection of stems / Height of right stem

C102	49	47	Intraletter	-Y-	Height of left stem overlapping right stem / Height of left stem, up to intersection of stems
C103	71	-1	Angle	-B-	Angle of stem
C104	72	-1	Angle	-A-	Angle of left stem
C105	73	-1	Angle	-A-	Angle of right stem
C106	74	-1	Angle	-A-	Angle of crossbar
C107	75	-1	Angle	-S-	Angle (general orientation)
C108	76	-1	Angle	-A-	Angle of left stem
C109	77	-1	Angle	-A-	Angle of right stem
C110	78	-1	Angle	-A-	Angle of crossbar
C111	79	-1	Angle	-Y-	Angle of left stem
C112	80	-1	Angle	-Y-	Angle of right stem

Artist n°3 - V Muro

N°	M 1	M 2	Feature class	Letter	Description of feature
C1	1	2	Length signature / Height signature	Signature	
C2	4	1	Length letter / Length signature	L -V- / L tot	
C3	10	1	Length letter / Length signature	L -M- / L tot	
C4	22	1	Length letter / Length signature	L -U- / L tot	
C5	28	1	Length letter / Length signature	L -R- / L tot	
C6	37	1	Length letter / Length signature	L -O- / L tot	
C7	4	2	Length letter / Height signature	L -V- / H tot	
C8	10	2	Length letter / Height signature	L -M- / H tot	
C9	22	2	Length letter / Height signature	L -U- / H tot	
C10	28	2	Length letter / Height signature	L -R- / H tot	
C11	37	2	Length letter / Height signature	L -O- / H tot	
C12	3	2	Height letter / Height signature	H -V- / H tot	
C13	9	2	Height letter / Height signature	H -M- / H tot	
C14	21	2	Height letter / Height signature	H -U- / H tot	
C15	27	2	Height letter / Height signature	H -R- / H tot	
C16	36	2	Height letter / Height signature	H -O- / H tot	
C17	3	1	Height letter / Length signature	H -V- / L tot	
C18	9	1	Height letter / Length signature	H -M- / L tot	
C19	21	1	Height letter / Length signature	H -U- / L tot	
C20	27	1	Height letter / Length signature	H -R- / L tot	
C21	36	1	Height letter / Length signature	H -O- / L tot	
C22	4	10	Length letter / Length letter after	L -V- / L -M-	
C23	10	22	Length letter / Length letter after	L -M- / L -U-	
C24	22	28	Length letter / Length letter after	L -U- / L -R-	
C25	28	37	Length letter / Length letter after	L -R- / L -O-	
C26	37	4	Length letter / Length letter after	L -O- / L -V-	

C27	3	9	Height letter / Height letter after	H -V- / H -M-	
C28	9	21	Height letter / Height letter after	H -M- / H -U-	
C29	21	27	Height letter / Height letter after	H -U- / H -R-	
C30	27	36	Height letter / Height letter after	H -R- / H -O-	
C31	36	3	Height letter / Height letter after	H -O- / H -V-	
C32	40	3	Height difference (sup.) / Height letter before	H -V- and -M- / H -V-	
C33	41	9	Height difference (sup.) / Height letter before	H -M- and -U- / H -M-	
C34	42	21	Height difference (sup.) / Height letter before	H -U- and -R- / H -U-	
C35	43	27	Height difference (sup.) / Height letter before	H -R- and -O- / H -R-	
C36	44	36	Height difference (sup.) / Height letter before	H -O- and -V- / H -O-	
C37	45	3	Height difference (inf.) / Height letter before	H -V- and -M- / H -V-	
C38	46	9	Height difference (inf.) / Height letter before	H -M- and -U- / H -M-	
C39	47	21	Height difference (inf.) / Height letter before	H -U- and -R- / H -U-	
C40	48	27	Height difference (inf.) / Height letter before	H -R- and -O- / H -R-	
C41	49	36	Height difference (inf.) / Height letter before	H -O- and -V- / H -O-	
C42	50	10	Space / Length letter after	-V- and -M- / L -M-	
C43	51	22	Space / Length letter after	-M- and -U- / L -U-	
C44	52	28	Space / Length letter after	-U- and -R- / L -R-	
C45	53	37	Space / Length letter after	-R- and -O- / L -O-	
C46	4	3	Length letter / Height letter	L -V- / H -V-	
C47	10	9	Length letter / Height letter	L -M- / H -M-	
C48	22	21	Length letter / Height letter	L -U- / H -U-	
C49	28	27	Length letter / Height letter	L -R- / H -R-	

C50	37	36	Length letter / Height letter	L -O- / H -O-	
C51	5	6	Intraletter	-V-	Height left stem / Height right stem
C52	7	8	Intraletter	-V-	Height hook / Length hook
C53	7	3	Intraletter	-V-	Height hook / Height letter
C54	8	4	Intraletter	-V-	Length hook / Length letter
C55	11	14	Intraletter	-M-	Height left stem / Height right stem
C56	12	13	Intraletter	-M-	Height of left median stroke / Height of right median stroke
C57	12	11	Intraletter	-M-	Height of left median stroke / Height left stem
C58	13	14	Intraletter	-M-	Height of right median stroke / Height right stem
C59	17	11	Intraletter	-M-	Height difference between apexes of both stems / Height left stem
C60	20	11	Intraletter	-M-	Distance height difference between lowest points of both stems / Height left stem
C61	15	16	Intraletter	-M-	Length of left median stroke / Length of right median stroke
C62	15	10	Intraletter	-M-	Length of left median stroke / Length letter
C63	16	10	Intraletter	-M-	Length of right median stroke / Length letter
C64	18	19	Intraletter	-M-	Height hook / Length hook
C65	18	9	Intraletter	-M-	Height hook / Height letter
C66	19	10	Intraletter	-M-	Length hook / Length letter
C67	23	24	Intraletter	-U-	Height left stem / Height right stem
C68	25	26	Intraletter	-U-	Height hook / Length hook
C69	25	21	Intraletter	-U-	Height hook / Height letter
C70	26	22	Intraletter	-U-	Length hook / Length letter
C71	29	30	Intraletter	-R-	Height of modified bowl / Length of modified bowl
C72	29	27	Intraletter	-R-	Height of modified bowl / Height letter
C73	30	28	Intraletter	-R-	Length of modified bowl / Length letter
C74	31	27	Intraletter	-R-	Height stem / Height letter
C75	32	33	Intraletter	-R-	Height leg / Length of leg
C76	32	27	Intraletter	-R-	Height leg / Height letter
C77	33	28	Intraletter	-R-	Lenght leg / Length letter
C78	34	31	Intraletter	-R-	Height difference between top of stem and top of modified bowl / Height of stem
C79	35	31	Intraletter	-R-	Height difference between lowest point of stem and lowest point of leg / Height of stem
C80	38	36	Intraletter	-O-	Height difference between terminal point and highest point / Height

					letter
C81	39	37	Intraletter	-O-	Length difference between terminal point and point furthest right / Length letter
C82	54	-1	Angle	-V-	Angle of left stem
C83	55	-1	Angle	-V-	Angle of right stem
C84	56	-1	Angle	-M-	Angle of left stem
C85	57	-1	Angle	-M-	Angle of left median stroke
C86	58	-1	Angle	-M-	Angle of right median stroke
C87	59	-1	Angle	-M-	Angle of left stem
C88	60	-1	Angle	-R-	Angle of stem
C89	61	-1	Angle	-R-	Angle of leg
C90	62	-1	Angle	-O-	Angle of terminal stroke

Artist n°4 - Pasquier

N°	M 1	M 2	Feature class	Letter	Description of feature
C1	1	2	Length signature / Height signature	Signature	
C2	4	1	Length letter / Length signature	L -A- / L tot	
C3	14	1	Length letter / Length signature	L -P- / L tot	
C4	19	1	Length letter / Length signature	L -a- / L tot	
C5	28	1	Length letter / Length signature	L -q- / L tot	
C6	38	1	Length letter / Length signature	L -u- / L tot	
C7	46	1	Length letter / Length signature	L -i- / L tot	
C8	53	1	Length letter / Length signature	L -e- / L tot	
C9	60	1	Length letter / Length signature	L -r- / L tot	
C10	4	2	Length letter / Height signature	L -A- / H tot	
C11	14	2	Length letter / Height signature	L -P- / H tot	
C12	19	2	Length letter / Height signature	L -a- / H tot	
C13	28	2	Length letter / Height signature	L -q- / H tot	
C14	38	2	Length letter / Height signature	L -u- / H tot	
C15	46	2	Length letter / Height signature	L -i- / H tot	
C16	53	2	Length letter / Height signature	L -e- / H tot	
C17	60	2	Length letter / Height signature	L -r- / H tot	
C18	3	2	Height letter / Height signature	H -A- / H tot	
C19	13	2	Height letter / Height signature	H -P- / H tot	
C20	18	2	Height letter / Height signature	H -a- / H tot	
C21	27	2	Height letter / Height signature	H -q- / H tot	
C22	37	2	Height letter / Height signature	H -u- / H tot	
C23	45	2	Height letter / Height signature	H -i- / H tot	
C24	52	2	Height letter / Height signature	H -e- / H tot	
C25	59	2	Height letter / Height signature	H -r- / L tot	
C26	3	1	Height letter / Length signature	H -A- / L tot	

C27	13	1	Height letter / Length signature	H -P- / L tot	
C28	18	1	Height letter / Length signature	H -a- / L tot	
C29	27	1	Height letter / Length signature	H -q- / L tot	
C30	37	1	Height letter / Length signature	H -u- / L tot	
C31	45	1	Height letter / Length signature	H -i- / L tot	
C32	52	1	Height letter / Length signature	H -e- / L tot	
C33	59	1	Height letter / Length signature	H -r- / L tot	
C34	4	14	Length letter / Length letter after	L -A- / L -P-	
C35	14	19	Length letter / Length letter after	L -P- / L -a-	
C36	19	28	Length letter / Length letter after	L -a- / L -q-	
C37	28	38	Length letter / Length letter after	L -q- / L -u-	
C38	38	46	Length letter / Length letter after	L -u- / L -i-	
C39	46	53	Length letter / Length letter after	L -i- / L -e-	
C40	53	60	Length letter / Length letter after	L -e- / L -r-	
C41	60	4	Length letter / Length letter after	L -r- / L -A-	
C42	3	13	Height letter / Height letter after	H -A- / H -P-	
C43	13	18	Height letter / Height letter after	H -P- / H -a-	
C44	18	27	Height letter / Height letter after	H -a- / H -q-	
C45	27	37	Height letter / Height letter after	H -q- / H -u-	
C46	37	45	Height letter / Height letter after	H -u- / H -i-	
C47	45	52	Height letter / Height letter after	H -i- / H -e-	
C48	52	59	Height letter / Height letter after	H -e- / H -r-	
C49	59	3	Height letter / Height letter after	H -r- / H -A-	
C50	65	3	Height difference (sup.) / Height letter before	-A- and -P / H -A-	
C51	66	13	Height difference (sup.) / Height letter before	-P- and -a- / H -P-	
C52	67	18	Height difference (sup.) / Height letter before	-a- and -q- / H -a-	
C53	68	27	Height difference	-q- and -u- /	

			(sup.) / Height letter before	H -q-	
C54	69	37	Height difference (sup.) / Height letter before	-u- and -i- / H -u-	
C55	70	45	Height difference (sup.) / Height letter before	-i- and -e- / H -i-	
C56	71	52	Height difference (sup.) / Height letter before	-e- and -r- / H -e-	
C57	72	59	Height difference (sup.) / Height letter before	-r- and -A- / H -r-	
C58	73	3	Height difference (inf.) / Height letter before	-A- and -P / H -A-	
C59	74	13	Height difference (inf.) / Height letter before	-P- and -a- / H -P-	
C60	75	18	Height difference (inf.) / Height letter before	-a- and -q- / H -a-	
C61	76	27	Height difference (inf.) / Height letter before	-q- and -u- / H -q-	
C62	77	37	Height difference (inf.) / Height letter before	-u- and -i- / H -u-	
C63	78	45	Height difference (inf.) / Height letter before	-i- and -e- / H -i-	
C64	79	52	Height difference (inf.) / Height letter before	-e- and -r- / H -e-	
C65	80	59	Height difference (inf.) / Height letter before	-r- and -A- / H -r-	
C66	81	14	Space / Length letter after	-A- and -P / L -P-	
C67	82	19	Space / Length letter after	stem of -P- and -a- / L -a-	
C68	83	19	Space / Length letter after	-P- and -a- / L -a-	
C69	84	28	Space / Length letter after	-a- and -q- / L -q-	
C70	85	38	Space / Length letter after	-q- and -u- / L -u-	
C71	86	46	Space / Length letter after	-u- and -i- / L -i-	
C72	87	53	Space / Length letter after	-i- and -e- / L -e-	
C73	88	60	Space / Length letter after	-e- and -r- / L -r-	
C74	4	3	Length letter / Height letter	L -A- / H -A-	

C75	14	13	Length letter / Height letter	L -P- / H -P-	
C76	19	18	Length letter / Height letter	L -a- / H -a-	
C77	28	27	Length letter / Height letter	L -q- / H -q-	
C78	38	37	Length letter / Height letter	L -u- / H -u-	
C79	46	45	Length letter / Height letter	L -i- / H -i-	
C80	53	52	Length letter / Height letter	L -e- / H -e-	
C81	60	59	Length letter / Height letter	L -r- / H -r-	
C82	5	6	Intraletter	-A-	Height left stem / Height right stem
C83	7	5	Intraletter	-A-	Height of left stem under crossbar / Height left stem
C84	8	6	Intraletter	-A-	Height of right stem under crossbar / Height right stem
C85	10	4	Intraletter	-A-	Length of inner crossbar / Length letter
C86	11	4	Intraletter	-A-	Length of crossbar stroke overlapping left stem / Length letter
C87	12	4	Intraletter	-A-	Length of crossbar stroke overlapping right stem / Length letter
C88	15	13	Intraletter	-P-	Height of modified bowl / Height letter
C89	17	13	Intraletter	-P-	Height of stem under lowest point of modified bowl / Height letter
C90	16	14	Intraletter	-P-	Length of modified bowl / Length letter
C91	15	16	Intraletter	-P-	Height of modified bowl / Length of modified bowl
C92	20	18	Intraletter	-a-	Height of bowl / Height letter
C93	22	18	Intraletter	-a-	Height of superior section of bowl / Height letter
C94	23	18	Intraletter	-a-	Height of inferior section of bowl / Height letter
C95	24	18	Intraletter	-a-	Height of stem / Height letter
C96	25	18	Intraletter	-a-	Height of stem under lowest point of bowl / Height letter
C97	26	19	Intraletter	-a-	Length of stem / Length letter
C98	21	19	Intraletter	-a-	Length of bowl / Length letter
C99	20	21	Intraletter	-a-	Height of bowl / Length of bowl
C100	24	26	Intraletter	-a-	Height of stem / Length of stem
C101	29	27	Intraletter	-q-	Height of bowl / Height letter
C102	31	27	Intraletter	-q-	Height of superior section of bowl / Height letter
C103	32	27	Intraletter	-q-	Height of inferior section of bowl / Height letter
C104	33	27	Intraletter	-q-	Height of stem / Height letter
C105	34	27	Intraletter	-q-	Height of stem under lowest point of

					bowl / Height letter
C106	30	28	Intraletter	-q-	Length of bowl / Length letter
C107	35	28	Intraletter	-q-	Length of stem, taken from intersection of bowl with stem / Length letter
C108	36	28	Intraletter	-q-	Length of stem / Length letter
C109	29	30	Intraletter	-q-	Height of bowl / Length of bowl
C110	33	35	Intraletter	-q-	Height of stem / Length of stem, taken from intersection of bowl with stem
C111	39	37	Intraletter	-u-	Height of initial stroke / Height letter
C112	40	37	Intraletter	-u-	Height of left stem / Height letter
C113	41	37	Intraletter	-u-	Height of right stem / Height letter
C114	42	37	Intraletter	-u-	Height of endstroke (connecting with letter -i-) / Height letter
C115	43	38	Intraletter	-u-	Length of initial srtoke / Length letter
C116	44	38	Intraletter	-u-	Length distance between left and right stems / Length letter
C117	39	40	Intraletter	-u-	Height of initial stroke / Height of left stem
C118	40	41	Intraletter	-u-	Height of left stem / Height of right stem
C119	41	42	Intraletter	-u-	Height of right stem / Height of endstroke (connecting with letter -i-)
C120	43	44	Intraletter	-u-	Length of initial stroke / Length distance between left and right stems
C121	43	39	Intraletter	-u-	Length of initial stroke / Height of initial stroke
C122	44	40	Intraletter	-u-	Length distance between left and right stems / Height left stem
C123	44	41	Intraletter	-u-	Length distance between left and right stems / Height right stem
C124	49	45	Intraletter	-i-	Height of initial stroke / Height letter
C125	47	46	Intraletter	-i-	Length of initial stroke / Length letter
C126	48	46	Intraletter	-i-	Length of stem / Length letter
C127	48	47	Intraletter	-i-	Length of stem / Length of initial stroke
C128	47	49	Intraletter	-i-	Length of initial stroke / Height of initial stroke
C129	48	45	Intraletter	-i-	Length of stem / Height letter
C130	50	45	Intraletter	-i-	Height of dot / Height letter
C131	51	45	Intraletter	-i-	Height difference between dot and letter -i- / Height letter
C132	57	52	Intraletter	-e-	Height difference between final ascending curve and lowest point of letter / Height letter
C133	54	52	Intraletter	-e-	Height of eyelet / Height letter
C134	55	53	Intraletter	-e-	Length of eyelet / Length letter

C135	58	53	Intraletter	-e-	Lenght of eyelet, including initial overlapping stroke / Length letter
C136	54	55	Intraletter	-e-	Height of eyelet / Length of eyelet
C137	56	55	Intraletter	-e-	Length of outer left overlapping initial stroke and eyelet / Length of eyelet
C138	63	60	Intraletter	-r-	Length of arch / Total length of letter
C139	61	64	Intraletter	-r-	Height of stem / Height of arch, taken from lowest point of stem
C140	62	61	Intraletter	-r-	Height of stem above arch / Height of stem
C141	89	-1	Angle	-A-	Angle of left stem
C142	90	-1	Angle	-A-	Angle of right stem
C143	91	-1	Angle	-A-	Angle of crossbar
C144	92	-1	Angle	-P-	Angle of stem
C145	93	-1	Angle	-q-	Angle of stem
C146	94	-1	Angle	-r	Angle of stem

Artist n°5 - Schwaller

N°	M 1	M 2	Feature class	Letter	Description of feature
C1	1	2	Length signature / Height signature	Signature	
C2	4	1	Length letter / Length signature	L -J- / L tot	
C3	9	1	Length letter / Length signature	L -m- / L tot	
C4	20	1	Length letter / Length signature	L -s- / L tot	
C5	28	1	Length letter / Length signature	L -c- / L tot	
C6	33	1	Length letter / Length signature	L -h- / L tot	
C7	41	1	Length letter / Length signature	L -w- / L tot	
C8	46	1	Length letter / Length signature	L -l- / L tot	
C9	48	1	Length letter / Length signature	L -l- / L tot	
C10	50	1	Length letter / Length signature	L -e- / L tot	
C11	55	1	Length letter / Length signature	L -r- / L tot	
C12	4	2	Length letter / Height signature	L -J- / H tot	
C13	9	2	Length letter / Height signature	L -m- / H tot	
C14	20	2	Length letter / Height signature	L -s- / H tot	
C15	28	2	Length letter / Height signature	L -c- / H tot	
C16	33	2	Length letter / Height signature	L -h- / H tot	
C17	41	2	Length letter / Height signature	L -w- / H tot	
C18	46	2	Length letter / Height signature	L -l- / H tot	
C19	48	2	Length letter / Height signature	L -l- / H tot	
C20	50	2	Length letter / Height signature	L -e- / H tot	
C21	55	2	Length letter / Height signature	L -r- / H tot	
C22	3	2	Height letter / Height signature	H -J- / H tot	
C23	8	2	Height letter / Height signature	H -m- / H tot	
C24	19	2	Height letter / Height signature	H -s- / H tot	
C25	27	2	Height letter / Height signature	H -c- / H tot	
C26	32	2	Height letter / Height signature	H -h- / H tot	

C27	40	2	Height letter / Height signature	H -w- / H tot	
C28	45	2	Height letter / Height signature	H -l- / H tot	
C29	47	2	Height letter / Height signature	H -l- / H tot	
C30	49	2	Height letter / Height signature	H -e- / H tot	
C31	54	2	Height letter / Height signature	H -r- / H tot	
C32	3	1	Height letter / Length signature	H -J- / L tot	
C33	8	1	Height letter / Length signature	H -m- / L tot	
C34	19	1	Height letter / Length signature	H -s- / L tot	
C35	27	1	Height letter / Length signature	H -c- / L tot	
C36	32	1	Height letter / Length signature	H -h- / L tot	
C37	40	1	Height letter / Length signature	H -w- / L tot	
C38	45	1	Height letter / Length signature	H -l- / L tot	
C39	47	1	Height letter / Length signature	H -l- / L tot	
C40	49	1	Height letter / Length signature	H -e- / L tot	
C41	54	1	Height letter / Length signature	H -r- / L tot	
C42	4	9	Length letter / Length letter after	L -J- / L -m-	
C43	9	20	Length letter / Length letter after	L -m- / L -s-	
C44	20	28	Length letter / Length letter after	L -s- / L -c-	
C45	28	33	Length letter / Length letter after	L -c- / L -h-	
C46	33	41	Length letter / Length letter after	L -h- / L -w-	
C47	41	46	Length letter / Length letter after	L -w- / L -l-	
C48	46	48	Length letter / Length letter after	L -l- / L -l-	
C49	48	50	Length letter / Length letter after	L -l- / L -e-	
C50	50	55	Length letter / Length letter after	L -e- / L -r-	
C51	55	4	Length letter / Length letter after	L -r- / L -J-	
C52	3	8	Height letter / Height letter after	H -J- / H -m-	
C53	8	19	Height letter / Height letter after	H -m- / H -s-	
C54	19	27	Height letter / Height letter after	H -s- / H -c-	

C55	27	32	Height letter / Height letter after	H -c- / H -h-	
C56	32	40	Height letter / Height letter after	H -h- / H -w-	
C57	40	45	Height letter / Height letter after	H -w- / H -l-	
C58	45	47	Height letter / Height letter after	H -l- / H -l-	
C59	47	49	Height letter / Height letter after	H -l- / H -e-	
C60	49	54	Height letter / Height letter after	H -e- / H -r-	
C61	54	3	Height letter / Height letter after	H -r- / H -J-	
C62	57	3	Height difference (sup.) / Height letter before	-J- and -m- / H -J-	
C63	58	8	Height difference (sup.) / Height letter before	-m- and -s- / H -m-	
C64	59	19	Height difference (sup.) / Height letter before	-s- and -c- / H -s-	
C65	60	27	Height difference (sup.) / Height letter before	-c- and -h- / H -c-	
C66	61	32	Height difference (sup.) / Height letter before	-h- and -w- / H -h-	
C67	62	40	Height difference (sup.) / Height letter before	-w- and -l- / H -w-	
C68	63	45	Height difference (sup.) / Height letter before	-l- and -l- / H -l-	
C69	64	47	Height difference (sup.) / Height letter before	-l- and -e- / H -l-	
C70	65	49	Height difference (sup.) / Height letter before	-e- and -r- / H -e-	
C71	66	3	Height difference (inf.) / Height letter before	-J- and -m- / H -J-	
C72	67	8	Height difference (inf.) / Height letter before	-m- and -s- / H -m-	
C73	68	19	Height difference (inf.) / Height letter before	-s- and -c- / H -s-	
C74	69	27	Height difference (inf.) / Height letter before	-c- and -h- / H -c-	
C75	70	32	Height difference (inf.) / Height letter before	-h- and -w- / H -h-	

C76	71	40	Height difference (inf.) / Height letter before	-w- and -l- / H -w-	
C77	72	45	Height difference (inf.) / Height letter before	-l- and -l- / H -l-	
C78	73	47	Height difference (inf.) / Height letter before	-l- and -e- / H -l-	
C79	74	49	Height difference (inf.) / Height letter before	-e- and -r- / H -e-	
C80	75	9	Space / Length letter after	-J- and -m- / L -m-	
C81	76	20	Space / Length letter after	-m- and -s- / L -s-	
C82	77	28	Space / Length letter after	-s- and -c- / L -c-	
C83	78	33	Space / Length letter after	-c- and -h- / L -h-	
C84	79	41	Space / Length letter after	-h- and -w- / L -w-	
C85	80	46	Space / Length letter after	-w- and -l- / L -l-	
C86	81	48	Space / Length letter after	-l- and -l- / L -l-	
C87	82	50	Space / Length letter after	-l- and -e- / L -e-	
C88	83	55	Space / Length letter after	-e- and -r- / L -r-	
C89	4	3	Length letter / Height letter	L -J- / H -J-	
C90	9	8	Length letter / Height letter	L -m- / H -m-	
C91	20	19	Length letter / Height letter	L -s- / H -s-	
C92	28	27	Length letter / Height letter	L -c- / H -c-	
C93	33	32	Length letter / Height letter	L -h- / H -h-	
C94	41	40	Length letter / Height letter	L -w- / H -w-	
C95	46	45	Length letter / Height letter	L -l- / H -l-	
C96	48	47	Length letter / Height letter	L -l- / H -l-	
C97	50	49	Length letter / Height letter	L -e- / H -e-	
C98	55	54	Length letter / Height letter	L -r- / H -r-	
C99	5	3	Intraletter	-J-	Height of upper stem (above crossbar) / Height letter
C100	6	3	Intraletter	-J-	Height of lower stem (below crossbar) / Height letter
C101	7	4	Intraletter	-J-	Length of initial stroke left of stem / Length letter

C102	10	8	Intraletter	-m-	Height of first stem / Height letter
C103	11	8	Intraletter	-m-	Height of second stem / Height letter
C104	12	8	Intraletter	-m-	Height of third stem / Height letter
C105	13	8	Intraletter	-m-	Height difference between both highest points of first and second stem / Height letter
C106	14	8	Intraletter	-m-	Height difference between both highest points of second and third stem / Height letter
C107	15	9	Intraletter	-m-	Length of initial stroke / Length letter
C108	16	9	Intraletter	-m-	Length of first stem / Length letter
C109	17	9	Intraletter	-m-	Length of second stem / Length letter
C110	18	9	Intraletter	-m-	Length of third stem / Length letter
C111	10	11	Intraletter	-m-	Height of first stem / Height of second stem
C112	11	12	Intraletter	-m-	Height of second stem / Height of third stem
C113	13	11	Intraletter	-m-	Height difference between both highest points of first and second stem / Height of second stem
C114	14	12	Intraletter	-m-	Height difference between both highest points of second and third stem / Height of third stem
C115	16	17	Intraletter	-m-	Length of first stem / Length of second stem
C116	17	18	Intraletter	-m-	Length of second stem / Length of third stem
C117	16	10	Intraletter	-m-	Length of first stem / Height of first stem
C118	17	11	Intraletter	-m-	Length of second stem / Height of second stem
C119	18	12	Intraletter	-m-	Length of third stem / Height of third stem
C120	25	20	Intraletter	-s-	Length of initial stroke / Length letter
C121	26	20	Intraletter	-s-	Length of initial and terminal stroke, upto connecting stroke with -c- / Length letter
C122	21	22	Intraletter	-s-	Height of initial stroke / Height of descending stroke
C123	24	22	Intraletter	-s-	Height of descending stroke upto connecting stroke with -c- / Height of descending stroke
C124	23	22	Intraletter	-s-	Height of descending stroke, taken from intersection of initial and descending stroke / Height of descending stroke
C125	29	28	Intraletter	-c-	Length of connecting stroke / Length letter

C126	30	27	Intraletter	-c-	Length of bow / Height letter
C127	30	28	Intraletter	-c-	Length of bow / Length letter
C128	31	27	Intraletter	-c-	Height of lower section of bow / Height letter
C129	34	32	Intraletter	-h-	Height of stem, taken from intersection with terminal stroke of -c- / Height of letter
C130	36	32	Intraletter	-h-	Length of arch, taken from intersection of stem with arch (buckle) / Height letter
C131	36	33	Intraletter	-h-	Length of arch, taken from intersection of stem with arch (buckle) / Length letter
C132	37	32	Intraletter	-h-	Height of arch / Height letter
C133	35	37	Intraletter	-h-	Height of left foot / Height of arch
C134	37	38	Intraletter	-h-	Height of arch / Height of second foot of arch (right stem)
C135	39	38	Intraletter	-h-	Height of arch, taken from intersection of stem with arch (buckle) / Height of second foot of arch (right stem)
C136	42	41	Intraletter	-w-	Length of three stems / Length letter
C137	43	41	Intraletter	-w-	Length of spur / Length letter
C138	44	40	Intraletter	-w-	Height of first stem / Height letter
C139	51	49	Intraletter	-e-	Height of eyelet / Height letter
C140	52	50	Intraletter	-e-	Length of eyelet / Length letter
C141	53	49	Intraletter	-e-	Height difference between final ascending curve and lowest point of letter / Height letter
C142	51	52	Intraletter	-e-	Height of eyelet / Length of eyelet
C143	56	54	Intraletter	-r-	Height of stem (taken from intersection with terminal stroke of -e-) / Height letter
C144	84	-1	Angle	-J-	Angle of stem
C145	85	-1	Angle	-s-	Angle of initial stroke
C146	86	-1	Angle	-s-	Angle of descending stroke
C147	87	-1	Angle	-h-	Angle of stem, taken from highest point of letter
C148	88	-1	Angle	-h-	Angle of stem, taken from point furthest right of stem
C149	89	-1	Angle	-l-	Angle of stem, taken from highest point of letter
C150	90	-1	Angle	-l-	Angle of stem, taken from point furthest right of stem
C151	91	-1	Angle	-l-	Angle of stem, taken from highest point of letter
C152	92	-1	Angle	-l-	Angle of stem, taken from point furthest right of stem

Appendix XI

Analysis scripts used with R software

Conversion of coordinate points into measurements and angles -
Calculation of measurements into characteristics
Adaptation of angles

```
# LECTURE DATA
get.DATA = function(file.DAT, file.MES, file.CARA) {

### FUNCTION GET DIST ###
f.dist = function(i1,i2,DATAX,DATAY) {
(sqrt(
(DATAX[,i1]-DATAX[,i2])^2+
(DATAY[,i1]-DATAY[,i2])^2))
}
dist.x = function(i1,i2,DATAX,DATAY) {
((DATAX[,i2]-DATAX[,i1]))
}
dist.y = function(i1,i2,DATAX,DATAY) {
((DATAY[,i2]-DATAY[,i1]))
}
angle = function(i1,i2,DATAX,DATAY) {
atan2((DATAY[,i1]-DATAY[,i2]),(DATAX[,i2]-DATAX[,i1]))*180/pi # angle en
 degrees
}

get.dist = function(x) {
if(x == "dist")
return(f.dist)
else if(x == "distx")
return(dist.x)
else if(x == "disty")
return(dist.y)
else if(x=="angle")
return(angle)
else
return(NULL)
}

##########
## DATA ##
##########

DAT = read.table(file.DAT, sep=",")  # Raw data file of coordinate points
MES = read.table(file.MES, sep=",", header=T) # File of list of measurements
CARA = read.table(file.CARA, sep=",") # File of list of characteristics


# Points File:
l0 = (dim(DAT)[2]-1)/2
HEADER = DAT[,1]

DAT[, 1+(1:l0)] -> DATAX
```

```
DATAY <- DAT[, 1+l0+(1:l0)]

# Measurement file:
MES[,2] = as.numeric(MES[,2])
MES[,3] = as.numeric(MES[,3])


# Definition of Authentic and Simulation groups
GROUP = rep("FX", length(HEADER))
GROUP[which(HEADER == 1)] = "VR"

# M = MEASUREMENT MATRIX
m = matrix(ncol = dim(MES)[1], nrow =  dim(DATAX)[1])
for(i in 1:dim(MES)[1])
{
d.func = get.dist(MES[i,4])
m[,i] = d.func(i1 = MES[i,2], i2 = MES[i,3],DATAX = DATAX, DATAY = DATAY)
}

# TRANSFORMATION OF NULL VALUES INTO 1
m[which(m==0)] = 1

# TRANSFORMATION OF NEGATIF ANGLES
w2 = which(MES[,4] == "angle")

if(length(w2 > 0)) {
for(i in w2) {
w1 = which(m[,i]<0)
if(length(w1 > 0))
m[w1,i]=m[w1,i] + 360
}}

# RES = CHARACTERISITICS MATRIX
res = matrix(ncol = dim(CARA)[1], nrow =  dim(DATAX)[1])
for(i in 1:dim(CARA)[1])
{
mes1 = CARA[i,2]
mes2 = CARA[i,3]
if(CARA[i,3] == -1) {
res[,i] = m[,mes1]
} else {
res[,i] = m[,mes1]/abs(m[,mes2])
}}

colnames(res) = CARA[,1]

w1 = which(HEADER == 1)
w2 = which(HEADER == 2)

list(res[w1,],res[w2,])

}
```

```
# FUNCTION TO ADAPT ANGLES

ajust.ANGLE.180 = function(angle) {

w1 = which(angle >= 0 & angle < 180)
angle[w1] = angle[w1] + 180
angle[-w1] = angle[-w1] - 180
angle
}
```

Calculation of lists of measures and characteristics
Determination of feature selection vector
Likelihood ratio assessment

```
##### EXECUTIF SCRIPT
source("FCT-1.R") # DATA READING
source("FCT-2.R") # DATA ANALYSIS

file.DAT = "jcs_data.csv"
file.MES = "jcs_liste mesures.csv"
file.CARA ="caracteristics_jcs.csv"
alpha = 0.05


#### FUNCTION GET DATA
DATA = get.DATA(file.DAT, file.MES, file.CARA)
n1 = dim(DATA[[1]])[1] # List 1 = authentic signatures
n2 = dim(DATA[[2]])[1] # List 2 = simulation signatures

DATA.I = rbind(DATA[[1]],DATA[[2]]); # Conversion of list into matrix


#### FACTOR DETERMINATION ##########################################
### FACTOR - Autenthic and Simulations
FAC.I  =  c(rep("Authentic",n1),rep("Simulations",n2)) # factors=Authentic or
 Simulations

### FACTOR - 1 and 2
FACS   =  c(rep(1,n1),rep(2,n2)) # factors= 1 for Authentic and 2 for Simulations

### FACTOR - By distinguishing groups of Simulators
F1 = c("Authentic","Res-Cons","Artists","FHE")
F2 = c(n1,40,15,15)

FAC.2 = unlist(sapply(1:4, function(i) {
rep(F1[i], F2[i])
}))


##### FEATURE SELECTION #############################################
source("get.BORUTA.R")
# Output of get.BORUTA = DATA.B (by inverse order of importance)

DATA1 = list(DATA.B[1:n1,],DATA.B[-(1:n1),]) # Conversion into a list of two
 matrixes


##### NORMALITY SELECTION ###########################################
NORM.DATA = get.NORM(DATA1,alpha)
```

```
##### LRs ############################################################
LR = get.LR1(NORM.DATA[,-1])

LR.to = get.LR(NORM.DATA[,-1],2,dim(NORM.DATA)[2]-1)


##### CLLR ############################################################
w1 = 1:n1
w2 = which(FAC.I == "Simulations")

CLLR = get.CLLR(LR.to,w1,FAC.I, "Simulations")


###### FUNCTIONS ########
##############################

#### Feature reduction: Boruta #####
library("Boruta")
library("randomForest")

DD = data.frame(FAC.I, DATA.I)
Boruta1 <- Boruta(FAC.I ~., data = DD, ntree=100000, maxRuns = 1000)

SelectedVariables2 <-
rownames(as.matrix(Boruta2$finalDecision[Boruta2$finalDecision=="Confirmed
 "| Boruta2$finalDecision=="Tentative"]))

c1 = colMeans(Boruta2$ImpHistory)[SelectedVariables2]
VA = SelectedVariables2[ rev(order(c1)) ]

DATA.B = DATA.I[,VA]


#### Feature reduction: Normality testing #####
get.NORM = function(DATA,alpha) {
p = dim(DATA[[1]])[2]

SHAP.P =  sapply(DATA, function(data) {

apply(data,2, function(C)
shapiro.test(C)$p.value)})
rownames(SHAP.P) = paste("C", 1:p)

SHAP.T = SHAP.P > alpha
QQPL.T = SHAP.T[,1] == TRUE  & SHAP.T[,2] == TRUE

w.T = which(QQPL.T)
w.F = (1:p)[-w.T]
cbind(SHAP.T,QQPL.T)
DATA1 = rbind(DATA[[1]],DATA[[2]])
DATA1[,w.T]
}
```

```
##### Likelihood ratio #####
get.LR1 = function(DATA) {

LR =
sapply(1:dim(DATA)[1], function(j) {

temp1 = DATA[-j,]
w.W = which(FACS[-j] == 1)
w.B = which(FACS[-j] == 2)

Y = DATA[j,]

mu1 = colMeans(temp1[w.W,])
mu2 = colMeans(temp1[w.B,])
sig1 = cov(temp1[w.W,])
sig2 = cov(temp1[w.B,])

c(
dmvnorm(Y,mu1,sig1,log = T),
dmvnorm(Y,mu2,sig2,log = T))
})

LR
}


get.LR = function(DATA, from, to) {

LR = sapply(1:dim(DATA)[1], function(j) {

temp1 = DATA[-j,]
w.W = which(FACS[-j] == 1)
w.B = which(FACS[-j] == 2)

Y = DATA[j,]
sapply(seq(from,to,by=1), function(xx) {
x = 1:xx

print(xx)
mu1 = colMeans(temp1[w.W,x])
mu2 = colMeans(temp1[w.B,x])
sig1 = var(temp1[w.W,x])
sig2 = var(temp1[w.B,x])

dmvnorm(Y[x],mu1,sig1,log = T)-
dmvnorm(Y[x],mu2,sig2,log = T)
})
})
rownames(LR) = from:to
LR
}
```

```
##### CLLR #####
get.CLLR = function(LR,w1, FFA, LI) {
FFA = as.factor(FFA)
w2 = which(FFA ==  LI)
LR.temp = exp(LR)

apply(LR.temp, 1, function(lr) CLLR(lr,w1,w2))

}


CLLR = function(lr,ww1,ww2) {
0.5 *
(
sum(log2(1+(1/lr[ww1])))/length(ww1)+
sum(log2(1+lr[ww2]))/length(ww2)
)
}
```

Appendix XII

Normality test results for the characteristics of the Authentic and Simulated signature sets of each artist

Artist n°1 - Schauenberg

	Authentic	Simulations	Feature class	Letter
C1	0.773	0.533	1 Length signature / Height signature	Signature
C2	**2.93E-03**	**2.57E-04**	2 Length letter / Length signature	L -J- / L tot
C3	0.979	0.594		L -c- / L tot
C4	**1.30E-03**	0.035		L -l- / L tot
C5	0.123	0.265		L -s- / L tot
C6	**8.92E-03**	0.016		L -s- / L tot
C7	0.050	**8.03E-04**	3 Length letter / Height signature	L -J- / H tot
C8	0.274	0.784		L -c- / H tot
C9	0.311	0.380		L -l- / H tot
C10	0.962	0.262		L -s- / H tot
C11	0.558	**1.36E-03**		L -s- / H tot
C12	0.304	0.175	4 Height letter / Height signature	H -J- / H tot
C13	0.014	0.457		H -c- / H tot
C14	0.383	0.219		H -l- / H tot
C15	0.474	0.288		H -s- / H tot
C16	0.477	0.108		H -s- / H tot
C17	0.495	0.028	5 Height letter / Length signature	H -J- / L tot
C18	0.019	0.050		H -c- / L tot
C19	0.478	0.409		H -l- / L tot
C20	0.355	0.594		H -s- / L tot
C21	0.437	0.512		H -s- / L tot
C22	0.070	**3.44E-09**	6 Length letter / Length letter after	L -J- / L -c-
C23	0.062	0.011		L -c- / L -l-
C24	0.494	0.027		L -l- / L -s-
C25	**5.21E-03**	0.051		L -s- / L -s-
C26	0.639	**4.04E-12**		L -s- / L -s-
C27	0.361	**3.66E-03**	7 Height letter / Height letter after	H -J- / H -c-
C28	0.102	0.147		H -c- / H -l-
C29	0.399	**9.03E-04**		H -l- / H -s-
C30	0.251	0.524		H -s- / H -s-
C31	0.269	0.075		H -s- / H -s-
C32	0.261	0.800	8 Height difference (sup.) / Height letter before	H -J- and -c- / H -J-
C33	0.744	**2.98E-03**		H -c- and -l- / H -c-
C34	0.164	0.195		H -l- and -s- / H -l-
C35	0.436	**5.93E-06**		H -s- and -s- / H -s-
C36	0.142	0.018		H -s- and -s- / H -s-
C37	0.341	0.310	9 Height difference (inf.) / Height letter before	H -J- and -c- / H -J-
C38	0.896	0.999		H -c- and -l- / H -c-
C39	0.204	**4.57E-03**		H -l- and -s- / H -l-
C40	0.327	**3.04E-05**		H -s- and -s- / H -s-
C41	0.983	**2.46E-08**		H -s- and -s- / H -s-
C42	0.101	**6.01E-03**	11 Length letter /	L -J- / H -J-
C43	0.784	0.912		L -c- / H -c-

C44	0.152	0.679	Height letter	L -l- / H -l-
C45	**8.48E-03**	**1.93E-04**		L -s- / H -s-
C46	0.377	**2.01E-05**		L -s- / H -s-
C47	0.835	0.076	12 Intraletter	-J-
C48	0.091	**1.75E-10**		-J-
C49	0.745	0.012		-c-
C50	0.077	**1.07E-04**		-c-
C51	0.890	0.015		-c-
C52	0.232	**1.59E-07**		-c-
C53	0.480	0.526		-c-
C54	0.693	0.167		-c-
C55	0.022	**1.86E-04**		-c-
C56	0.157	0.249		-c-
C57	0.068	**3.26E-03**		-c-
C58	0.723	0.590		-l-
C59	0.890	0.067		-l-
C60	0.280	0.816		-l-
C61	0.399	0.174		-l-
C62	**1.36E-04**	0.314		-l-
C63	0.671	**3.86E-04**		-s-
C64	0.011	0.996		-s-
C65	0.512	0.139		-s-
C66	0.893	0.648		-s-
C67	0.098	0.711		-s-
C68	0.025	**3.31E-04**		-s-
C69	0.127	0.175		-s-
C70	0.047	0.494		-s-
C71	0.784	0.017		-s-
C72	0.918	0.633		-s-
C73	0.944	0.180		-s-
C74	0.314	**1.31E-05**		-s-
C75	0.180	0.164		-s-
C76	0.645	0.110		-s-
C77	0.851	0.445		-s-
C78	0.211	**3.05E-04**	13 Angle	-J-
C79	**1.08E-03**	0.189		-c-
C80	0.037	0.684		-l-
C81	0.281	0.134		-s-
C82	0.694	0.453		-s-
C83	0.283	0.487		-s-
C84	0.803	0.670		-s-
C85	0.900	0.523		-s-

Results of the Shapiro–Wilk normality test for the characteristics of the Authentic and Simulated signature sets of artist JCS. The significant p-values (<0.01) are highlighted in bold.

Artist n°2: Bacsay

N°	Authentic	Simulation	Feature class	Letter
C1	0.729	**2.47E-03**	1 Length signature / Height signature	Signature
C2	0.965	0.086	2 Length letter / Length signature	L -B- / L tot
C3	0.880	**2.77E-04**		L -A- / L tot
C4	0.831	**2.98E-03**		L -C- / L tot
C5	0.558	0.360		L -S- / L tot
C6	0.760	0.026		L -A- / L tot
C7	0.137	0.082		L -Y- / L tot
C8	0.872	**3.50E-03**	3 Length letter / Height signature	L -B- / H tot
C9	0.571	**1.80E-04**		L -A- / H tot
C10	0.456	**9.85E-04**		L -C- / H tot
C11	0.527	0.017		L -S- / H tot
C12	0.738	**2.86E-05**		L -A- / H tot
C13	0.219	**8.16E-06**		L -Y- / H tot
C14	0.691	0.277	4 Height letter / Height signature	H -B- / H tot
C15	0.931	0.164		H -A- / H tot
C16	0.042	0.481		H -C- / H tot
C17	0.426	**9.35E-03**		H -S- / H tot
C18	0.741	0.077		H -A- / H tot
C19	0.042	**8.00E-04**		H -Y- / H tot
C20	0.113	0.600	5 Height letter / Length signature	H -B- / L tot
C21	0.056	0.018		H -A- / L tot
C22	0.041	0.011		H -C- / L tot
C23	0.084	0.025		H -S- / L tot
C24	0.034	0.100		H -A- / L tot
C25	0.049	**1.60E-03**		H -Y- / L tot
C26	0.653	**9.62E-03**	6 Length letter / Length letter after	L -B- / L -A-
C27	0.586	**8.42E-11**		L -A- / L -C-
C28	0.212	**3.61E-06**		L -C- / L -S-
C29	0.262	0.543		L -S- / L -A-
C30	0.873	**1.86E-05**		L -A- / L -Y-
C31	0.035	0.073		L -Y- / L -B-
C32	0.018	0.822	7 Height letter / Height letter after	H -B- / H -A-
C33	0.149	0.513		H -A- / H -C-
C34	0.299	0.281		H -C- / H -S-
C35	0.910	0.341		H -S- / H -A-
C36	0.112	**1.81E-03**		H -A- / H -Y-
C37	0.084	0.066		H -Y- / H -B-
C38	0.226	0.024	8 Height difference (sup.) / Height letter before	H -B- and -A- / H -B-
C39	0.808	0.276		H -A- and -C- / H -A-
C40	0.926	**2.45E-04**		H -C- and -S- / H -C-
C41	0.218	0.152		H -S- and -A- / H -S-
C42	0.017	**2.60E-04**		H -A- and -Y- / H -A-
C43	0.996	0.873		H -Y- and -B- / H -Y-

C44	0.273	0.687	9 Height difference (inf.) / Height letter before	H -B- and -A- / H -B-
C45	0.014	0.195		H -A- and -C- / H -A-
C46	0.664	0.991		H -C- and -S- / H -C-
C47	0.149	0.437		H -S- and -A- / H -S-
C48	0.403	0.184		H -A- and -Y- / H -A-
C49	0.214	0.794		H -Y- and -B- / H -Y-
C50	0.104	**1.56E-03**	10 Space / Length letter after	-B- and -A- / L -A-
C51	0.014	0.589		-B- and -A- / L -A-
C52	**1.41E-04**	**4.84E-04**		-A- and -C- / L -C-
C53	**9.92E-03**	**3.61E-08**		-A- and -C- / L -C-
C54	0.181	**1.24E-03**		-C- and -S- / L -S-
C55	0.302	0.510		-S- and -A- / L -A-
C56	0.711	0.265		-A- and -Y- / L -Y-
C57	0.807	0.011		-A- and -Y- / L -Y-
C58	0.846	0.110	11 Length letter / Height letter	L -B- / H -B-
C59	0.566	**9.61E-03**		L -A- / H -A-
C60	0.864	**6.30E-05**		L -C- / H -C-
C61	0.916	**7.90E-04**		L -S- / H -S-
C62	0.398	**6.53E-04**		L -A- / H -A-
C63	0.193	**1.44E-04**		L -Y- / H -Y-
C64	**3.37E-03**	**7.69E-13**	12 Intraletter	-B-
C65	0.373	**5.74E-04**		-B-
C66	0.542	0.519		-B-
C67	0.090	0.084		-B-
C68	**1.03E-03**	**2.16E-04**		-B-
C69	0.898	**1.18E-04**		-B-
C70	0.532	0.632		-B-
C71	0.405	**4.19E-10**		-B-
C72	**9.96E-03**	**1.90E-05**		-B-
C73	0.010	**1.47E-05**		-B-
C74	0.296	**3.12E-06**		-B-
C75	0.836	0.258		-B-
C76	**2.67E-03**	**2.29E-06**		-B-
C77	0.173	**8.83E-03**		-B-
C78	0.485	0.521		-B-
C79	0.244	0.075		-B-
C80	0.701	**2.16E-04**		-B-
C81	0.468	0.067		-A-
C82	0.734	0.039		-A-
C83	0.950	0.093		-A-
C84	**8.92E-03**	0.021		-A-
C85	0.077	0.655		-A-
C86	0.928	**7.76E-05**		-A-
C87	0.296	**1.21E-03**		-A-
C88	0.678	**2.41E-03**		-A-
C89	0.996	0.909		-A-
C90	0.200	**1.88E-14**		-C-

C91	0.288	0.565		-A-
C92	0.381	0.215		-A-
C93	0.018	0.455		-A-
C94	0.059	0.245		-A-
C95	0.077	0.182		-A-
C96	0.387	**6.16E-04**		-A-
C97	0.892	**3.00E-03**		-A-
C98	0.188	0.013		-Y-
C99	0.127	**1.40E-07**		-Y-
C100	0.977	0.435		-Y-
C101	0.948	0.779		-Y-
C102	0.270	**6.36E-06**		-Y-
C103	0.982	**2.59E-04**	13 Angle	-B-
C104	0.487	**1.01E-03**		-A-
C105	0.129	**2.58E-03**		-A-
C106	**1.09E-03**	0.189		-A-
C107	0.232	0.556		-S-
C108	0.175	**1.37E-03**		-A-
C109	0.225	**1.11E-04**		-A-
C110	**2.43E-04**	0.792		-A-
C111	0.649	0.023		-Y-
C112	0.288	**6.34E-04**		-Y-

Results of the Shapiro–Wilk normality test for the characteristics of the Authentic and Simulated signature sets of artist Bacsay. The significant p-values (<0.01) are highlighted in bold.

Artist n°3 - V Muro

	Authentic	Simulations	Feature class	Letter
C1	0.563	0.077	1 Length signature / Height signature	Signature
C2	0.846	0.102	2 Length letter / Length signature	L -V- / L tot
C3	0.497	0.193		L -M- / L tot
C4	0.669	0.216		L -U- / L tot
C5	0.026	0.122		L -R- / L tot
C6	0.034	0.098		L -O- / L tot
C7	**3.58E-03**	0.567	3 Length letter / Height signature	L -V- / H tot
C8	**7.37E-05**	0.561		L -M- / H tot
C9	0.459	0.644		L -U- / H tot
C10	0.811	0.074		L -R- / H tot
C11	0.874	0.219		L -O- / H tot
C12	0.201	0.146	4 Height letter / Height signature	H -V- / H tot
C13	0.047	**2.74E-03**		H -M- / H tot
C14	0.925	0.560		H -U- / H tot
C15	0.978	0.255		H -R- / H tot
C16	0.528	0.735		H -O- / H tot
C17	0.211	**2.85E-03**	5 Height letter / Length signature	H -V- / L tot
C18	0.495	0.061		H -M- / L tot
C19	0.961	0.317		H -U- / L tot
C20	**6.50E-04**	**7.14E-03**		H -R- / L tot
C21	0.221	0.482		H -O- / L tot
C22	0.689	0.145	6 Length letter / Length letter after	L -V- / L -M-
C23	0.050	0.198		L -M- / L -U-
C24	0.034	0.032		L -U- / L -R-
C25	0.578	**1.88E-06**		L -R- / L -O-
C26	0.339	**2.65E-07**		L -O- / L -V-
C27	0.206	0.053	7 Height letter / Height letter after	H -V- / H -M-
C28	0.143	**5.81E-04**		H -M- / H -U-
C29	0.478	0.142		H -U- / H -R-
C30	0.021	**2.35E-08**		H -R- / H -O-
C31	0.204	0.409		H -O- / H -V-
C32	0.835	**2.01E-03**	8 Height difference (sup.) / Height letter before	H -V- and -M- / H -V-
C33	0.766	**2.29E-05**		H -M- and -U- / H -M-
C34	0.937	**1.09E-07**		H -U- and -R- / H -U-
C35	0.564	0.014		H -R- and -O- / H -R-
C36	0.114	0.108		H -O- and -V- / H -O-
C37	0.393	**2.29E-05**	9 Height difference (inf.)	H -V- and -M- / H -V-
C38	0.809	**7.14E-03**		H -M- and -U- / H -M-

C39	0.769	**8.06E-08**	/ Height letter before	H -U- and -R- / H -U-
C40	0.042	0.019		H -R- and -O- / H -R-
C41	0.380	0.075		H -O- and -V- / H -O-
C42	0.431	0.564	10 Space / Length letter after	-V- and -M- / L -M-
C43	0.059	0.952		-M- and -U- / L -U-
C44	0.424	0.872		-U- and -R- / L -R-
C45	0.367	0.021		-R- and -O- / L -O-
C46	0.028	0.759	11 Length letter / Height letter	L -V- / H -V-
C47	0.024	**6.77E-03**		L -M- / H -M-
C48	0.115	0.076		L -U- / H -U-
C49	0.590	**6.39E-06**		L -R- / H -R-
C50	0.435	**1.99E-03**		L -O- / H -O-
C51	0.264	0.256	12 Intraletter	-V-
C52	0.052	**3.53E-11**		-V-
C53	**2.68E-04**	**4.14E-08**		-V-
C54	**8.51E-04**	**4.14E-10**		-V-
C55	0.513	0.298		-M-
C56	0.173	**1.04E-04**		-M-
C57	0.925	0.333		-M-
C58	0.859	0.464		-M-
C59	0.343	0.534		-M-
C60	0.240	0.332		-M-
C61	**4.76E-04**	**1.54E-05**		-M-
C62	9.02E-01	0.064		-M-
C63	0.460	**1.32E-04**		-M-
C64	0.061	**1.08E-05**		-M-
C65	0.050	**9.93E-06**		-M-
C66	**1.47E-04**	**2.23E-05**		-M-
C67	0.934	0.046		-U-
C68	**3.25E-07**	**6.12E-18**		-U-
C69	**6.53E-04**	**4.38E-16**		-U-
C70	**1.85E-04**	**1.64E-16**		-U-
C71	0.045	0.403		-R-
C72	0.362	0.522		-R-
C73	0.196	0.558		-R-
C74	0.017	**2.17E-06**		-R-
C75	0.264	**7.38E-03**		-R-
C76	0.012	0.437		-R-
C77	0.753	0.209		-R-
C78	0.378	**2.25E-04**		-R-
C79	0.654	0.034		-R-
C80	0.096	**1.88E-03**		-O-

C81	0.284	0.142		-O-
C82	0.903	0.782	13 Angle	-V-
C83	0.199	0.852		-V-
C84	0.582	0.458		-M-
C85	0.096	**7.23E-03**		-M-
C86	0.952	0.127		-M-
C87	0.796	0.027		-M-
C88	0.819	0.936		-R-
C89	0.401	0.742		-R-
C90	0.018	**1.84E-07**		-O-

Results of the Shapiro–Wilk normality test for the characteristics of the Authentic and Simulated signature sets of artist Muro. The significant p-values (<0.01) are highlighted in bold.

Artist n°4 - Pasquier

	M 1	M 2	Feature class	Letter
C1	0.102	**5.08E-03**	1 Length signature / Height signature	Signature
C2	0.289	0.347	2 Length letter / Length signature	L -A- / L tot
C3	0.352	**1.25E-06**		L -P- / L tot
C4	0.429	0.138		L -a- / L tot
C5	0.040	0.260		L -q- / L tot
C6	**5.44E-04**	0.115		L -u- / L tot
C7	0.188	0.012		L -i- / L tot
C8	0.149	0.610		L -e- / L tot
C9	0.778	0.543		L -r- / L tot
C10	0.408	0.227	3 Length letter / Height signature	L -A- / H tot
C11	0.761	0.040		L -P- / H tot
C12	0.903	0.065		L -a- / H tot
C13	0.062	**3.89E-03**		L -q- / H tot
C14	0.498	**1.14E-03**		L -u- / H tot
C15	0.186	**2.97E-04**		L -i- / H tot
C16	0.167	0.059		L -e- / H tot
C17	0.497	0.322		L -r- / H tot
C18	0.818	0.122	4 Height letter / Height signature	H -A- / H tot
C19	0.174	0.889		H -P- / H tot
C20	**5.66E-03**	0.918		H -a- / H tot
C21	0.992	0.147		H -q- / H tot
C22	0.885	**3.64E-09**		H -u- / H tot
C23	0.943	0.167		H -i- / H tot
C24	0.601	0.868		H -e- / H tot
C25	0.718	0.185		H -r- / L tot
C26	0.575	0.467	5 Height letter / Length signature	H -A- / L tot
C27	0.640	0.743		H -P- / L tot
C28	0.094	0.467		H -a- / L tot
C29	0.513	0.516		H -q- / L tot
C30	0.541	**1.00E-04**		H -u- / L tot
C31	0.959	0.449		H -i- / L tot
C32	0.087	0.110		H -e- / L tot
C33	0.771	0.712		H -r- / L tot
C34	0.077	**8.31E-03**	6 Length letter / Length letter after	L -A- / L -P-
C35	0.171	**8.74E-04**		L -P- / L -a-
C36	0.637	**5.60E-07**		L -a- / L -q-
C37	0.683	**2.13E-03**		L -q- / L -u-
C38	0.013	**5.48E-03**		L -u- / L -i-

C39	0.455	**1.97E-05**		L -i- / L -e-
C40	0.409	**1.66E-06**		L -e- / L -r-
C41	0.441	0.386		L -r- / L -A-
C42	0.109	**6.33E-08**	7 Height letter / Height letter after	H -A- / H -P-
C43	0.699	0.056		H -P- / H -a-
C44	0.216	0.372		H -a- / H -q-
C45	0.768	0.495		H -q- / H -u-
C46	0.028	**2.91E-08**		H -u- / H -i-
C47	0.164	0.105		H -i- / H -e-
C48	0.749	0.374		H -e- / H -r-
C49	0.685	0.482		H -r- / H -A-
C50	0.085	0.030	8 Height difference (sup.) / Height letter before	-A- and -P / H -A-
C51	0.262	**5.87E-05**		-P- and -a- / H -P-
C52	0.233	0.933		-a- and -q- / H -a-
C53	0.635	0.553		-q- and -u- / H -q-
C54	0.236	0.102		-u- and -i- / H -u-
C55	0.055	**3.40E-05**		-i- and -e- / H -i-
C56	0.541	0.087		-e- and -r- / H -e-
C57	0.691	**4.97E-03**		-r- and -A- / H -r-
C58	0.249	0.619	9 Height difference (inf.) / Height letter before	-A- and -P / H -A-
C59	0.747	**3.39E-06**		-P- and -a- / H -P-
C60	0.639	0.850		-a- and -q- / H -a-
C61	0.530	0.122		-q- and -u- / H -q-
C62	0.715	**2.87E-04**		-u- and -i- / H -u-
C63	0.034	0.011		-i- and -e- / H -i-
C64	0.100	0.571		-e- and -r- / H -e-
C65	0.465	0.707		-r- and -A- / H -r-
C66	0.997	**8.88E-08**	10 Space / Length letter after	-A- and -P / L -P-
C67	0.757	0.787		stem of -P- and -a- / L -a-
C68	0.296	**5.67E-05**		-P- and -a- / L -a-
C69	0.522	0.249		-a- and -q- / L -q-
C70	0.922	**2.03E-03**		-q- and -u- / L -u-
C71	0.598	0.874		-u- and -i- / L -i-
C72	0.244	0.126		-i- and -e- / L -e-
C73	0.983	**1.16E-04**		-e- and -r- / L -r-
C74	0.645	0.179	11 Length letter / Height letter	L -A- / H -A-
C75	0.728	0.014		L -P- / H -P-
C76	0.718	0.029		L -a- / H -a-
C77	0.204	0.108		L -q- / H -q-
C78	0.783	0.375		L -u- / H -u-
C79	0.617	0.015		L -i- / H -i-

C80	0.223	0.500		L -e- / H -e-
C81	**7.49E-03**	0.204		L -r- / H -r-
C82	0.561	0.103	12 Intraletter	-A-
C83	0.575	0.360		-A-
C84	0.562	0.908		-A-
C85	0.333	0.181		-A-
C86	0.448	0.041		-A-
C87	**3.04E-03**	**1.50E-06**		-A-
C88	0.087	**1.40E-04**		-P-
C89	0.087	**1.40E-04**		-P-
C90	0.177	0.564		-P-
C91	**7.95E-03**	0.246		-P-
C92	0.550	0.077		-a-
C93	0.321	0.018		-a-
C94	0.117	**5.83E-03**		-a-
C95	0.321	0.018		-a-
C96	0.550	0.077		-a-
C97	0.917	0.014		-a-
C98	0.917	0.014		-a-
C99	0.365	0.755		-a-
C100	0.159	**9.67E-08**		-a-
C101	0.805	0.022		-q-
C102	0.905	0.059		-q-
C103	0.042	**4.33E-06**		-q-
C104	0.905	0.059		-q-
C105	0.805	0.022		-q-
C106	0.028	**3.26E-03**		-q-
C107	0.028	**3.26E-03**		-q-
C108	**8.65E-04**	0.013		-q-
C109	0.219	0.468		-q-
C110	0.172	0.434		-q-
C111	**6.41E-03**	**1.55E-05**		-u-
C112	0.110	**1.62E-08**		-u-
C113	0.041	**9.84E-06**		-u-
C114	0.121	**1.51E-06**		-u-
C115	0.379	0.391		-u-
C116	0.217	0.153		-u-
C117	0.752	**1.21E-12**		-u-
C118	0.338	**2.81E-09**		-u-
C119	0.636	**1.68E-04**		-u-
C120	0.927	**5.75E-05**		-u-
C121	0.032	**2.92E-05**		-u-

C122	0.479	**3.50E-05**		-u-
C123	0.926	0.092		-u-
C124	0.508	0.933		-i-
C125	0.277	0.872		-i-
C126	0.277	0.872		-i-
C127	0.018	**1.05E-10**		-i-
C128	0.379	0.327		-i-
C129	0.520	**8.15E-04**		-i-
C130	0.067	**3.87E-05**		-i-
C131	0.297	**1.64E-04**		-i-
C132	0.035	0.356		-e-
C133	0.391	0.531		-e-
C134	0.765	0.731		-e-
C135	0.510	0.398		-e-
C136	0.084	**3.45E-09**		-e-
C137	0.071	**1.44E-15**		-e-
C138	0.942	0.310		-r-
C139	**4.87E-04**	0.281		-r-
C140	0.693	**1.46E-04**		-r-
C141	0.880	0.030	13 Angle	-A-
C142	0.192	0.166		-A-
C143	0.057	0.408		-A-
C144	0.043	0.303		-P-
C145	0.309	**2.43E-11**		-q-
C146	0.047	0.531		-r

Results of the Shapiro–Wilk normality test for the characteristics of the Authentic and Simulated signature sets of artist Pasquier. The significant p-values (<0.01) are highlighted in bold.

Artist n°5 - Schwaller

	Authentic	Simulation	Feature class	Letter
C1	0.717	0.013	1 Length signature / Height signature	Signature
C2	0.271	0.608	2 Length letter / Length signature	L -J- / L tot
C3	0.273	0.545		L -m- / L tot
C4	0.083	0.301		L -s- / L tot
C5	0.540	0.612		L -c- / L tot
C6	0.265	**9.78E-04**		L -h- / L tot
C7	0.017	0.014		L -w- / L tot
C8	0.608	0.062		L -l- / L tot
C9	0.520	0.505		L -l- / L tot
C10	0.269	0.973		L -e- / L tot
C11	0.558	**9.70E-08**		L -r- / L tot
C12	0.795	0.185	3 Length letter / Height signature	L -J- / H tot
C13	0.448	**6.50E-03**		L -m- / H tot
C14	0.313	0.698		L -s- / H tot
C15	0.661	0.020		L -c- / H tot
C16	0.890	0.035		L -h- / H tot
C17	0.439	**5.89E-05**		L -w- / H tot
C18	0.691	0.806		L -l- / H tot
C19	0.874	0.012		L -l- / H tot
C20	0.821	0.014		L -e- / H tot
C21	0.477	**2.60E-06**		L -r- / H tot
C22	0.110	**3.69E-17**	4 Height letter / Height signature	H -J- / H tot
C23	0.298	**6.91E-04**		H -m- / H tot
C24	0.036	**5.61E-03**		H -s- / H tot
C25	0.992	0.202		H -c- / H tot
C26	0.180	0.791		H -h- / H tot
C27	0.328	**1.25E-05**		H -w- / H tot
C28	0.328	0.403		H -l- / H tot
C29	0.274	0.937		H -l- / H tot
C30	0.783	**1.79E-03**		H -e- / H tot
C31	**8.67E-03**	0.014		H -r- / H tot
C32	0.310	0.858	5 Height letter / Length signature	H -J- / L tot
C33	0.153	0.016		H -m- / L tot
C34	0.571	0.017		H -s- / L tot
C35	0.773	0.560		H -c- / L tot
C36	0.127	0.654		H -h- / L tot
C37	0.113	**2.13E-05**		H -w- / L tot
C38	0.674	0.519		H -l- / L tot
C39	0.359	0.378		H -l- / L tot
C40	0.513	0.053		H -e- / L tot
C41	0.014	0.203		H -r- / L tot
C42	0.262	**2.68E-03**	6 Length letter /	L -J- / L -m-
C43	0.076	0.454		L -m- / L -s-

C44	0.061	**6.94E-07**	Length letter after	L -s- / L -c-
C45	0.670	0.162		L -c- / L -h-
C46	**4.05E-04**	**5.86E-03**		L -h- / L -w-
C47	0.595	**7.79E-07**		L -w- / L -l-
C48	0.559	0.288		L -l- / L -l-
C49	0.020	**1.58E-03**		L -l- / L -e-
C50	0.413	**1.68E-04**		L -e- / L -r-
C51	0.056	**1.90E-07**		L -r- / L -J-
C52	0.028	0.699	7 Height letter / Height letter after	H -J- / H -m-
C53	0.179	0.107		H -m- / H -s-
C54	**3.55E-03**	**2.63E-05**		H -s- / H -c-
C55	0.995	0.640		H -c- / H -h-
C56	0.439	0.497		H -h- / H -w-
C57	0.244	**4.81E-06**		H -w- / H -l-
C58	0.457	**2.75E-04**		H -l- / H -l-
C59	0.766	**2.29E-03**		H -l- / H -e-
C60	0.201	**2.81E-04**		H -e- / H -r-
C61	**8.70E-03**	0.016		H -r- / H -J-
C62	0.121	0.430	8 Height difference (sup.) / Height letter before	-J- and -m- / H -J-
C63	0.237	**1.48E-04**		-m- and -s- / H -m-
C64	0.196	**4.27E-04**		-s- and -c- / H -s-
C65	0.368	**6.34E-06**		-c- and -h- / H -c-
C66	0.753	**3.53E-03**		-h- and -w- / H -h-
C67	0.746	0.424		-w- and -l- / H -w-
C68	0.273	0.016		-l- and -l- / H -l-
C69	0.241	0.151		-l- and -e- / H -l-
C70	0.539	0.708		-e- and -r- / H -e-
C71	0.865	0.171	9 Height difference (inf.) / Height letter before	-J- and -m- / H -J-
C72	0.035	**2.48E-07**		-m- and -s- / H -m-
C73	0.886	0.039		-s- and -c- / H -s-
C74	0.792	**1.90E-04**		-c- and -h- / H -c-
C75	0.331	**7.86E-04**		-h- and -w- / H -h-
C76	0.408	0.221		-w- and -l- / H -w-
C77	0.670	0.376		-l- and -l- / H -l-
C78	0.091	0.285		-l- and -e- / H -l-
C79	0.061	0.480		-e- and -r- / H -e-
C80	0.609	**4.57E-04**	10 Space / Length letter after	-J- and -m- / L -m-
C81	0.422	0.132		-m- and -s- / L -s-
C82	0.328	**2.25E-08**		-s- and -c- / L -c-
C83	0.861	0.047		-c- and -h- / L -h-
C84	0.668	**2.21E-04**		-h- and -w- / L -w-
C85	**6.36E-06**	0.289		-w- and -l- / L -l-
C86	0.541	**3.54E-04**		-l- and -l- / L -l-
C87	0.078	0.119		-l- and -e- / L -e-
C88	0.992	**1.10E-06**		-e- and -r- / L -r-
C89	0.797	0.191	11 Length letter /	L -J- / H -J-
C90	0.903	0.266		L -m- / H -m-

C91	0.697	0.087	Height letter	L -s- / H -s-
C92	0.644	**8.06E-03**		L -c- / H -c-
C93	0.795	0.483		L -h- / H -h-
C94	0.568	**8.17E-03**		L -w- / H -w-
C95	0.583	**5.86E-04**		L -l- / H -l-
C96	0.260	**9.22E-03**		L -l- / H -l-
C97	0.955	0.015		L -e- / H -e-
C98	0.062	**5.58E-07**		L -r- / H -r-
C99	0.279	0.299	12 Intraletter	-J-
C100	0.516	0.461		-J-
C101	0.257	0.683		-J-
C102	**9.07E-06**	**1.17E-08**		-m-
C103	0.043	0.314		-m-
C104	0.276	0.057		-m-
C105	0.801	0.168		-m-
C106	0.468	0.447		-m-
C107	0.458	0.635		-m-
C108	0.084	0.223		-m-
C109	0.024	0.012		-m-
C110	0.831	**2.18E-05**		-m-
C111	0.443	**5.60E-03**		-m-
C112	0.044	**2.15E-04**		-m-
C113	0.165	**9.43E-05**		-m-
C114	0.067	**6.53E-04**		-m-
C115	0.126	**2.49E-07**		-m-
C116	**2.83E-04**	**1.16E-03**		-m-
C117	0.900	0.669		-m-
C118	0.334	0.881		-m-
C119	0.399	**3.95E-06**		-m-
C120	0.868	0.547		-s-
C121	0.384	0.079		-s-
C122	0.259	**4.21E-05**		-s-
C123	0.933	0.591		-s-
C124	0.052	0.025		-s-
C125	0.226	**9.44E-04**		-c-
C126	0.130	0.054		-c-
C127	0.226	**9.44E-04**		-c-
C128	0.174	0.199		-c-
C129	0.018	**5.64E-06**		-h-
C130	0.588	0.144		-h-
C131	0.930	0.399		-h-
C132	0.043	0.861		-h-
C133	0.029	**6.67E-08**		-h-
C134	0.581	**1.25E-05**		-h-
C135	**8.47E-03**	**3.94E-08**		-h-
C136	0.135	0.084		-w-
C137	0.135	0.084		-w-

C138	**2.79E-05**	**9.31E-09**		-w-
C139	0.030	0.066		-e-
C140	0.080	**2.44E-03**		-e-
C141	0.390	0.923		-e-
C142	0.165	0.386		-e-
C143	0.688	0.066		-r-
C144	0.142	0.354	13 Angle	-J-
C145	0.107	0.718		-s-
C146	0.148	0.414		-s-
C147	0.506	0.728		-h-
C148	0.742	**5.25E-03**		-h-
C149	0.429	0.185		-l-
C150	0.672	**9.61E-08**		-l-
C151	0.142	0.629		-l-
C152	0.722	0.126		-l-

Results of the Shapiro–Wilk normality test for the characteristics of the Authentic and Simulated signature sets of artist Schwaller. The significant p-values (<0.01) are highlighted in bold.

Appendix XIII

Feature reduction results

Artist n°1 - Schauenberg

Feat-ure	Normality		Boruta meanZ (Importance)	Feature class		Letter specification	Features chosen
	Auth.	Sim.					
C14	true	true	126.96	4	Height letter / Height signature	H -l- / H tot	C14
C24	true	true	81.06	6	Length letter / Length letter after	L -l- / L -s-	C24
C82	true	true	70.32	13	Intraletter	-J- : Angle of ascending stroke	C82
C13	true	true	65.76	4	Height letter / Height signature	H -c- / H tot	C13
C74	true	false	64.96	12	Intraletter	-s- : Height distance between top of endstroke and tip of endstroke / Height of endstroke	
C78	true	false	55.36	13	Angle	-J- : Angle of stem	
C38	true	true	53.42	9	Height difference (inf.) / Height letter before	H -c- and -l- / H -c-	C38
C79	false	true	51.58	13	Angle	-c- : Angle of ascending stroke	
C37	true	true	49.19	9	Height difference (inf.) / Height letter before	H -J- and -c- / H -J-	C37
C61	true	true	48.65	12	Intraletter	-l- : Length distance of ascending stroke / Height of ascending stroke	C61
C58	true	true	42.22	12	Intraletter	-l- : Height of ascending stroke / Total height of letter (height of main stem)	C58
C5	true	true	40.79	2	Length letter / Length signature	L -s- / L tot	C5
C36	true	true	40.54	8	Height difference (sup.) / Height letter before	H -s- and -s- / H -s-	C36
C9	true	true	36.11	3	Length letter / Height signature	L -l- / H tot	C9
C4	false	true	30.61	2	Length letter / Length signature	L -l- / L tot	

Results of the Boruta (ntree=10000) testing for artist 1 (Schauenberg), listed by the order of importance of the features. For the Shapiro–Wilk normality testing, the significant p-values (<0.01) are given as "false", otherwise as "true". The final column lists the features chosen.

Artist n°2: Bacsay

Feat-ure	Normality		Boruta meanZ (Importance)	Feature class		Letter specification	Feature chosen
	Auth.	Sim.					
C103	true	false	46.60	13	Angle	-B- : Angle of stem	
C80	true	false	38.19	12	Intraletter	-B- : Length of initial stroke left of stem / Length letter	
C99	true	false	24.47	12	Intraletter	-Y- : Length of spreading between outer extremities of stems / Length letter	
C109	true	false	24.43	13	Angle	1st -A- : Angle of right stem	
C105	true	false	23.87	13	Angle	2nd -A- : Angle of right stem	
C20	true	true	21.55	5	Height letter / Length signature	H -B- / L tot	C20
C112	true	false	20.20	13	Angle	-Y- : Angle of right stem	
C87	true	false	17.24	12	Intraletter	1st -A- : Length of spreading between outer extremities of stems / Length letter	
C42	true	false	16.82	8	Height difference (sup.) / Height letter before	H -A- and -Y- / H -A-	
C39	true	true	15.41	8	Height difference (sup.) / Height letter before	H -A- and -C- / H -A-	C39
C75	true	true	14.55	12	Intraletter	-B- : Length of bottom bow, taken from buckle / Length of bottom bow	C75
C102	true	false	14.50	12	Intraletter	-Y- : Height of left stem overlapping right stem / Height of left stem, up to intersection of stems	
C111	true	true	14.12	13	Angle	-Y- : Angle of left stem	C111
C4	true	false	13.28	2	Length letter / Length signature	L -C- / L tot	
C108	true	false	13.05	13	Angle	2nd -A- : Angle of left stem	
C43	true	true	12.65	8	Height difference (sup.) / Height letter before	H -Y- and -B- / H -Y-	C43
C49	true	true	12.04	9	Height difference (inf.) / Height letter	H -Y- and -B- / H -Y-	C49

					before		
C13	true	false	11.68	3	Length letter / Height signature	L -Y- / H tot	
C56	true	true	11.63	10	Space / Length letter after	-A- and -Y- / L -Y- : Space between right overlapping crossbar of -A- and -Y-	C56
C90	true	false	11.51	12	Intraletter	-C- : Length of upper curve / Length of lower curve	
C107	true	true	10.87	13	Angle	-S- : Angle (general orientation)	C107
C97	true	false	10.49	12	Intraletter	2nd -A- : Length of spreading between outer extremities of stems / Length letter	
C7	true	true	10.15	2	Length letter / Length signature	L -Y- / L tot	C7
C41	true	true	9.89	8	Height difference (sup.) / Height letter before	H -S- and -A- / H -S-	C41
C38	true	true	9.84	8	Height difference (sup.) / Height letter before	H -B- and -A- / H -B-	C38
C45	true	true	9.81	9	Height difference (inf.) / Height letter before	H -A- and -C- / H -A-	C45
C1	true	false	9.30	1	Length signature / Height signature	Signature	
C10	true	false	8.94	3	Length letter / Height signature	L -C- / H tot	

Results of the Boruta (ntree=10000) testing for artist 2 (Bacsay), listed by the order of importance of the features. For the Shapiro–Wilk normality testing, the significant p-values (<0.01) are given as "false", otherwise as "true". The final column lists the features chosen.

Artist n°3 - V Muro

Feat-ure	Normality		Boruta meanZ (Importance)	Feature class		Letter specification	Feature chosen
	Auth.	Sim.					
C64	true	false	39.47	12	Intraletter	-M- : Height hook / Length hook	
C85	true	false	37.88	13	Angle	-M- : Angle of left median stroke	
C68	false	false	31.40	12	Intraletter	-U- : Height hook / Length hook	
C43	true	true	27.99	10	Space / Length letter after	-M- and -U- / L -U-	C43
C69	false	false	27.76	12	Intraletter	-U- : Height hook / Height letter	
C83	true	true	25.05	13	Angle	-V- : Angle of right stem	C83
C42	true	true	24.63	10	Space / Length letter after	-V- and -M- / L -M-	C42
C46	true	true	22.01	11	Length letter / Height letter	L -V- / H -V-	C46
C54	false	false	20.25	12	Intraletter	-V- : Length hook / Length letter	
C66	false	false	20.21	12	Intraletter	-M- : Length hook / Length letter	
C7	false	true	19.75	3	Length letter / Height signature	L -V- / H tot	
C87	true	true	19.47	13	Angle	-M- : Angle of left stem	C87
C71	true	true	16.66	12	Intraletter	-R- : Height of modified bowl / Length of modified bowl	C71
C63	true	false	15.38	12	Intraletter	-M- : Length of right median stroke / Length letter	
C16	true	true	13.52	4	Height letter / Height signature	H -O- / H tot	C16
C35	true	true	13.45	8	Height difference (sup.) / Height letter before	H -R- and -O- / H -R-	C35
C36	true	true	13.07	8	Height difference (sup.) / Height letter before	H -O- and -V- / H -O-	C36
C70	false	false	11.96	12	Intraletter	-U- : Length hook / Length letter	
C44	true	true	11.94	10	Space / Length letter after	-U- and -R- / L -R-	C44
C18	true	true	9.98	5	Height letter / Length signature	H -M- / L tot	C18
C88	true	true	9.01	13	Angle	-R- : Angle of stem	C88

C59	true	true	8.48	12	Intraletter	-M- : Height difference between apexes of both stems / Height left stem	C59
C1	true	true	8.41	1	Length signature / Height signature	Signature	C1
C22	true	true	8.35	6	Length letter / Length letter after	L -V- / L -M-	C22
C40	true	true	8.00	9	Height difference (inf.) / Height letter before	H -R- and -O- / H -R-	C40
C65	true	false	7.95	12	Intraletter	-M- : Height hook / Height letter	

Results of the Boruta (ntree=10000) testing for artist 3 (Muro), listed by the order of importance of the features. For the Shapiro–Wilk normality testing, the significant p-values (<0.01) are given as "false", otherwise as "true". The final column lists the features chosen.

Artist n°4 - Pasquier

Feat-ure	Normality		Boruta meanZ (Importance)	Feature class		Letter specification	Feature chosen
	Auth	Sim.					
C51	true	false	36.68	8	Height difference (sup.) / Height letter before	-P- and -a- / H -P-	
C62	true	false	35.10	9	Height difference (inf.) / Height letter before	-u- and -i- / H -u-	
C124	true	true	25.66	12	Intraletter	-i- : Height of initial stroke / Height letter	C124
C59	true	false	25.21	9	Height difference (inf.) / Height letter before	-P- and -a- / H -P-	
C39	true	false	23.53	6	Length letter / Length letter after	L -i- / L -e-	
C88	true	false	20.09	12	Intraletter	-P- : Height of modified bowl / Height letter	
C89	true	false	20.08	12	Intraletter	-P- : Height of stem under lowest point of modified bowl / Height letter	
C100	true	false	18.83	12	Intraletter	-a- : Height of stem / Length of stem	
C106	true	false	18.74	12	Intraletter	-q- : Length of bowl / Length letter	
C107	true	false	18.73	12	Intraletter	-q- : Length of stem, taken from intersection of bowl with stem / Length letter	
C52	true	true	17.68	8	Height difference (sup.) / Height letter before	-a- and -q- / H -a-	C52
C7	true	true	16.55	2	Length letter / Length signature	L -i- / L tot	C7
C24	true	true	15.14	4	Height letter / Height signature	H -e- / H tot	C24
C81	false	true	14.93	11	Length letter / Height letter	L -r- / H -r-	
C129	true	false	14.11	12	Intraletter	-i- : Length of stem / Height letter	
C95	true	true	14.06	12	Intraletter	-a- : Height of stem / Height letter	C95
C136	true	false	13.99	12	Intraletter	-e- : Height of eyelet / Length of eyelet	
C93	true	true	13.99	12	Intraletter	-a- : Height of superior section of bowl / Height letter	C93
C103	true	false	13.23	12	Intraletter	-q- : Height of inferior section of bowl / Height letter	
C45	true	true	12.76	7	Height letter / Height	H -q- / H -u-	C45

					letter after		
C110	true	true	12.49	12	Intraletter	-q- : Height of stem / Length of stem, taken from intersection of bowl with stem	C110
C38	true	false	11.68	6	Length letter / Length letter after	L -u- / L -i-	
C108	false	true	11.08	12	Intraletter	-q- : Length of stem / Length letter	
C118	true	false	11.05	12	Intraletter	- u- : Height of left stem / Height of right stem	
C71	true	true	10.88	10	Space / Length letter after	-u- and -i- / L -i-	C71
C48	true	true	10.71	7	Height letter / Height letter after	H -e- / H -r-	C48
C85	true	true	10.68	12	Intraletter	-A- : Length of inner crossbar / Length letter	C85
C1	true	false	10.56	1	Length signature / Height signature	Signature	
C14	true	false	10.37	3	Length letter / Height signature	L -u- / H tot	
C92	true	true	10.37	12	Intraletter	-a- : Height of bowl / Height letter	C92
C96	true	true	10.35	12	Intraletter	-a- : Height of stem under lowest point of bowl / Height letter	C96
C10	true	true	10.05	3	Length letter / Height signature	L -A- / H tot	C10
C79	true	true	9.69	11	Length letter / Height letter	L -i- / H -i-	C79
C113	true	false	9.21	12	Intraletter	-u- : Height of right stem / Height letter	
C19	true	true	9.21	4	Height letter / Height signature	H -P- / H tot	C19
C64	true	true	9.14	9	Height difference (inf.) / Height letter before	-e- and -r- / H -e-	C64
C16	true	true	9.02	3	Length letter / Height signature	L -e- / H tot	C16
C125	true	true	8.84	12	Intraletter	-i- : Length of initial stroke / Length letter	C125
C126	true	true	8.77	12	Intraletter	-i- : Length of stem / Length letter	C126
C127	true	false	8.73	12	Intraletter	-i- : Length of stem / Length of initial stroke	
C84	true	true	8.71	12	Intraletter	-A- : Height of right stem under crossbar / Height right stem	C84
C22	true	false	8.60	4	Height letter / Height signature	H -u- / H tot	

C119	true	false	7.79	12	Intraletter	-u- : Height of right stem / Height of endstroke (connecting with letter -i-)	
C32	true	true	7.66	5	Height letter / Length signature	H -e- / L tot	C32
C31	true	true	7.57	5	Height letter / Length signature	H -i- / L tot	C31
C109	true	true	7.53	12	Intraletter	-q- : Height of bowl / Length of bowl	C109
C20	false	true	7.39	4	Height letter / Height signature	H -a- / H tot	
C15	true	false	7.20	3	Length letter / Height signature	L -i- / H tot	

Results of the Boruta (ntree=10000) testing for artist 4 (Pasquier), listed by the order of importance of the features. For the Shapiro–Wilk normality testing, the significant p-values (<0.01) are given as "false", otherwise as "true". The final column lists the features chosen.

Artist n°5 - Schwaller

Feat-ure	Normality		Boruta meanZ (Importance)	Feature class		Letter specification	Feature chosen
	Auth	Sim.					
C21	true	false	30.32	3	Length letter / Height signature	L -r- / H tot	
C135	false	false	28.73	12	Intraletter	-h- : Height of arch, taken from intersection of stem with arch (buckle) / Height of second foot of arch (right stem)	
C56	true	true	26.58	7	Height letter / Height letter after	H -h- / H -w-	C56
C134	true	false	24.04	12	Intraletter	-h- : Height of arch / Height of second foot of arch (right stem)	
C11	true	false	23.24	2	Length letter / Length signature	L -r- / L tot	
C72	true	false	22.09	9	Height difference (inf.) / Height letter before	-m- and -s- / H -m-	
C71	true	true	20.18	9	Height difference (inf.) / Height letter before	-J- and -m- / H -J-	C71
C82	true	false	19.91	10	Space / Length letter after	-s- and -c- / H -c-	
C93	true	true	19.65	11	Length letter / Height letter	L -h- / H -h-	
C133	true	false	18.82	12	Intraletter	-h- : Height of left foot / Height of arch	
C141	true	true	18.74	12	Intraletter	-e- : Height difference between final ascending curve and lowest point of letter / Height letter	C141
C60	true	false	17.76	7	Height letter / Height letter after	H -e- / H -r-	
C51	true	false	17.67	6	Length letter / Length letter after	L -r- / H -J-	
C70	true	true	16.61	8	Height difference (sup.) / Height letter before	-e- and -r- / H -e-	C70
C33	true	true	15.58	5	Height letter / Length signature	H -m- / L tot	C33
C100	true	true	14.94	12	Intraletter	-J- : Height of lower stem (below crossbar) / Height letter	C100

C125	true	false	13.87	12	Intraletter	-c- : Length of connecting stroke / Length letter	
C99	true	true	13.86	12	Intraletter	-J- : Height of upper stem (above crossbar) / Height letter	C99
C127	true	false	13.83	12	Intraletter	-c- : Length of bow / Length letter	
C101	true	true	13.59	12	Intraletter	-J- : Length of initial stroke left of stem / Length letter	C101
C67	true	true	13.10	8	Height difference (sup.) / Height letter before	-w- and -l- / H -w-	C67
C84	true	false	12.98	10	Space / Length letter after	-h- and -w- / H -w-	
C37	true	false	12.75	5	Height letter / Length signature	H -w- / L tot	
C148	true	false	12.40	13	Angle	-h- : Angle of stem, taken from point furthest right of stem	
C63	true	false	12.39	8	Height difference (sup.) / Height letter before	-m- and -s- / H -m-	
C94	true	false	12.18	11	Length letter / Height letter	L -w- / H -w-	
C62	true	true	10.91	8	Height difference (sup.) / Height letter before	-J- and -m- / H -J-	C62
C52	true	true	10.35	7	Height letter / Height letter after	H -J- / H -m-	C52
C146	true	true	9.65	13	Angle	-s- : Angle of descending stroke	C146
C23	true	false	9.05	4	Height letter / Height signature	H -m- / H tot	
C76	true	true	8.98	9	Height difference (inf.) / Height letter before	-w- and -l- / H -w-	C76
C41	true	true	8.93	5	Height letter / Length signature	H -r- / L tot	C41
C53	true	true	8.54	7	Height letter / Height letter after	H -m- / H -s-	C53
C115	true	false	8.31	12	Intraletter	-m- : Length of first stem / Length of second stem	
C73	true	true	8.20	9	Height difference (inf.) / Height letter before	-s- and -c- / H -s-	C73

C39	true	true	8.19	5	Height letter / Length signature	H -l- / L tot	C39
C4	true	true	8.14	2	Length letter / Length signature	L -s- / L tot	C4
C109	true	true	8.06	12	Intraletter	-m- : Length of second stem / Length letter	C109
C130	true	true	8.06	12	Intraletter	-h- : Length of arch, taken from intersection of stem with arch (buckle) / Height letter	C130
C55	true	true	8.00	7	Height letter / Height letter after	H -c- / H -h-	C55
C65	true	false	8.00	8	Height difference (sup.) / Height letter before	-c- and -h- / H -c-	
C137	true	true	7.83	12	Intraletter	-w- : Length of spur / Length letter	C137
C136	true	true	7.83	12	Intraletter	-w- : Length of three stems / Length letter	C136
C81	true	true	7.71	10	Space / Length letter after	-m- and -s- / H -s-	C81

Results of the Boruta (ntree=10000) testing for artist 5 (Schwaller), listed by the order of importance of the features. For the Shapiro–Wilk normality testing, the significant p-values (<0.01) are given as "false", otherwise as "true". The final column lists the features chosen.

Appendix XIV

Likelihood ratio results

Artist n°1 - Schauenberg - Authentic signatures

Feature combination	Signature n°							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
2	0.792	**-0.306**	0.796	0.132	1.909	2.331	0.226	1.251
3	1.654	0.108	1.601	0.793	0.426	3.259	0.495	**-3.801**
4	2.394	0.060	3.210	0.839	0.885	4.435	1.016	**-2.061**
5	2.858	**-0.023**	3.728	1.841	**-0.562**	5.430	1.242	**-2.497**
6	2.759	**-1.542**	3.339	1.141	**-2.129**	5.669	1.969	**-2.497**
7	3.250	**-1.292**	3.105	1.656	**-4.507**	6.216	**-0.633**	**-2.822**
8	3.885	**-0.323**	1.998	2.028	**-5.303**	5.663	**-0.491**	**-2.473**
9	3.960	**-0.148**	2.315	2.228	**-8.737**	5.308	**-0.688**	**-4.570**
10	4.635	**-0.850**	1.807	2.783	**-7.912**	8.984	**-4.709**	**-34.176**
11	5.221	**-0.214**	1.900	3.139	**-8.403**	9.718	**-8.020**	**-49.331**
	Signature n°							
	9	**10**	**11**	**12**	**13**	**14**	**15**	**16**
2	**-0.361**	1.605	0.134	1.215	0.476	1.091	**-1.099**	0.013
3	0.301	1.917	0.868	1.943	1.264	1.528	**-0.410**	0.742
4	**-0.671**	2.198	1.587	2.138	1.494	0.633	**-0.241**	0.711
5	0.357	**-0.652**	1.406	1.873	2.221	0.704	0.832	1.112
6	0.921	**-1.032**	**-1.474**	1.783	2.938	**-0.025**	1.661	2.000
7	1.494	**-0.633**	**-0.912**	1.288	3.125	**-1.649**	2.353	1.584
8	**-0.847**	**-5.172**	**-7.072**	2.100	3.205	**-1.394**	3.184	2.588
9	0.662	**-8.112**	**-10.731**	2.656	3.445	**-1.007**	3.464	3.410
10	1.082	**-9.494**	**-10.427**	1.936	3.920	**-0.525**	1.445	2.933
11	1.576	**-9.024**	**-11.486**	1.273	1.790	0.111	1.994	**-2.043**
	Signature n°							
	17	**18**	**19**	**20**	**21**	**22**	**23**	
2	1.087	2.322	**-2.070**	**-0.553**	1.349	**-0.603**	1.550	
3	1.980	2.668	**-1.440**	0.421	0.895	0.316	2.300	
4	1.609	2.988	**-7.107**	0.432	0.911	**-1.397**	2.395	
5	2.342	3.963	**-6.708**	**-0.252**	1.530	**-2.249**	2.843	
6	3.002	3.830	**-6.623**	0.620	2.085	**-3.111**	2.545	
7	2.886	4.347	**-9.027**	**-2.284**	2.738	**-2.849**	3.119	
8	3.532	5.029	**-11.898**	**-1.579**	3.639	**-5.286**	3.104	
9	3.624	4.962	**-19.644**	**-24.761**	3.550	**-5.249**	3.240	
10	3.554	6.404	**-19.469**	**-40.567**	4.004	**-4.110**	3.895	
11	0.840	6.755	**-19.826**	**-85.211**	4.541	**-31.546**	4.347	

Results of the likelihood ratio (given in the logarithmic form) assessment for each signature of artist n°1. For each signature, the results are listed for each feature vector combination (with a combination of the first two features, first three features, etc.). Log(LR) below zero are highlighted in red.

Artist n°1 - Schauenberg - Simulated signatures

		Signature n°							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Feature combinations	**2**	-1.673	-2.185	-3.089	-4.388	-2.754	-2.300	-0.944	-4.107
	3	-1.965	-13.388	-6.929	-6.979	-7.222	-1.969	-4.542	-5.531
	4	-1.992	-14.863	-7.913	-10.835	-9.961	-1.167	-4.254	-5.275
	5	-1.180	-29.007	-17.659	-12.677	-13.650	-2.603	-14.801	-18.962
	6	-1.940	-28.965	-17.315	-13.236	-12.836	-2.003	-10.455	-18.911
	7	-1.879	-29.322	-17.817	-12.619	-12.029	-4.208	-10.545	-18.021
	8	-0.860	-37.443	-28.261	-13.802	-11.191	-10.359	-11.818	-17.564
	9	-0.489	-55.079	-34.724	-14.079	-14.302	-11.992	-15.531	-13.990
	10	-3.803	-53.988	-34.874	-14.770	-14.270	-11.296	-20.020	-13.230
	11	-2.954	-58.292	-43.261	-25.208	-30.835	-13.630	-19.400	-23.239

		Signature n°							
		9	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Feature combinations	**2**	**1.061**	-2.265	-1.241	**0.383**	-0.623	**2.060**	-0.061	**0.755**
	3	**1.845**	-4.459	-0.692	**0.337**	**0.285**	**3.039**	-3.279	**1.416**
	4	**2.676**	-5.070	-0.372	**0.973**	**0.656**	**3.963**	-3.286	-1.646
	5	-3.829	-7.217	**0.883**	**0.785**	**2.282**	**4.235**	-9.718	-0.974
	6	-3.895	-7.383	**2.006**	**1.173**	**1.450**	**4.178**	-9.244	-0.939
	7	-3.553	-7.360	**0.518**	**1.522**	**2.676**	**4.566**	-11.205	-1.481
	8	-7.736	-9.578	**0.745**	**2.170**	**2.744**	**4.499**	-14.470	-8.188
	9	-43.314	-5.362	**1.149**	**1.561**	**2.867**	**4.296**	-14.767	-9.774
	10	-67.305	-3.805	-11.181	**1.419**	**4.674**	**5.776**	-27.122	-11.173
	11	-66.064	-3.225	-10.499	**2.016**	**4.933**	**5.721**	-28.382	-13.896

		Signature n°							
		17	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Feature combinations	**2**	-0.065	**0.693**	**0.152**	**1.689**	-1.544	-4.654	-1.036	-2.030
	3	**0.260**	**0.291**	-2.791	**1.789**	-1.432	-3.794	-5.697	-4.997
	4	-0.220	**0.675**	-2.115	-0.100	-1.540	-3.100	-4.824	-3.341
	5	-11.025	**1.650**	-12.311	**0.243**	-0.829	-3.457	-4.377	-2.950
	6	-10.671	-2.139	-12.330	**0.915**	-0.811	-3.579	-2.977	-3.633
	7	-10.147	-2.579	-11.852	**2.205**	-0.275	-2.938	-2.358	-2.912
	8	-11.607	-4.592	-11.081	**6.333**	-0.013	-7.342	-4.665	-12.057
	9	-16.516	-4.294	-12.449	**3.271**	-1.207	-6.239	-10.285	-13.796
	10	-19.750	-8.962	-16.294	**7.982**	-1.482	-9.672	-9.354	-14.664
	11	-18.744	-8.822	-17.245	**8.485**	-2.901	-23.902	-10.947	-16.555

		Signature n°							
		25	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Feature combinations	**2**	**0.603**	**0.598**	-0.283	**0.975**	-0.677	-1.742	-0.516	-1.653
	3	**0.101**	-5.057	**0.906**	-0.359	**0.019**	-3.847	-2.867	-1.109
	4	-0.076	-4.618	**0.740**	**0.827**	**0.032**	-3.749	-2.622	-4.502
	5	**0.409**	-5.530	-2.033	-1.136	-10.704	-8.986	-4.791	-7.761
	6	**0.159**	-4.997	-2.262	-1.493	-10.706	-8.395	-3.818	-9.157
	7	-0.191	-4.872	-1.278	-0.923	-10.518	-7.787	-5.568	-8.999
	8	**0.706**	-3.896	-0.987	-0.409	-9.721	-7.504	-8.677	-31.994

	9	-0.332	-10.167	-7.806	-13.590	-26.020	-9.075	-8.349	-31.733
	10	**0.902**	-11.533	-7.945	-13.128	-25.946	-9.974	-13.136	-32.948
	11	**0.839**	-11.492	-7.379	-12.627	-25.270	-11.830	-13.411	-33.155
		Signature n°							
		33	**34**	**35**	**36**	**37**	**38**	**39**	**40**
Feature combinations	**2**	-4.045	-1.500	-1.852	-0.257	-2.288	-1.117	-1.468	-0.678
	3	-3.172	-2.652	-7.558	-0.587	-1.447	-0.852	-0.581	-4.975
	4	-4.125	-4.550	-8.945	-0.319	-1.368	-0.757	-0.499	-3.745
	5	-17.344	-4.718	-17.559	**0.698**	-1.852	-2.392	-9.152	-2.974
	6	-19.646	-4.832	-20.825	**0.998**	-1.809	-2.262	-9.753	-3.294
	7	-19.816	-4.868	-20.680	-3.652	-5.248	-8.071	-10.399	-3.439
	8	-27.707	-4.259	-27.156	-4.787	-10.750	-7.506	-10.032	-6.830
	9	-33.224	-4.634	-27.008	-4.516	-14.013	-9.361	-18.910	-8.334
	10	-35.697	-3.860	-28.625	-8.743	-17.859	-15.153	-18.450	-13.997
	11	-35.266	-2.778	-29.540	-8.153	-17.575	-16.628	-17.263	-13.476
		Signature n°							
		41	**42**	**43**	**44**	**45**	**46**	**47**	**48**
Feature combinations	**2**	-1.239	-2.561	**0.660**	-1.326	-3.348	**0.981**	-1.079	-3.578
	3	-1.401	-1.695	**0.773**	-3.996	-2.685	**1.752**	-3.341	-2.971
	4	-1.162	-1.996	-0.951	-3.931	-2.160	-0.810	-5.937	-4.565
	5	-0.021	-2.536	-2.433	-6.424	-1.300	-1.847	-5.678	-3.596
	6	-0.599	-2.456	-5.732	-6.434	-1.266	-3.986	-5.972	-4.116
	7	-0.549	-4.205	-6.309	-7.767	-0.672	-3.176	-5.070	-3.831
	8	**0.284**	-5.547	-7.101	-7.801	-5.537	-2.262	-4.219	-2.965
	9	**0.015**	-5.337	-11.490	-6.848	-5.119	-3.162	-3.679	-2.722
	10	-2.655	-5.118	-18.118	-6.725	-6.557	-2.846	-8.835	-11.529
	11	-2.374	-11.995	-17.986	-5.889	-7.447	-3.265	-11.345	-20.011
		Signature n°							
		49	**50**	**51**	**52**	**53**	**54**	**55**	**56**
Feature combinations	**2**	**0.159**	-1.778	**1.112**	-2.234	**1.134**	-0.801	-2.090	-2.194
	3	**0.920**	-1.297	-2.097	-3.975	**0.620**	-4.100	-1.288	-4.905
	4	-0.617	-2.331	-2.074	-4.188	**0.836**	-3.742	-0.971	-4.444
	5	-1.312	-1.514	-6.575	-14.999	-3.360	-9.382	-9.967	-9.105
	6	-2.611	-1.931	-6.351	-15.322	-3.611	-9.328	-9.493	-8.978
	7	-1.936	-1.287	-9.109	-16.567	-5.976	-10.636	-19.273	-8.749
	8	-1.164	-0.428	-8.401	-26.511	-5.835	-9.930	-19.265	-7.608
	9	-2.055	**0.307**	-14.735	-40.158	-7.778	-12.954	-29.911	-12.585
	10	-3.135	-4.869	-14.335	-46.753	-8.000	-14.396	-27.366	-17.530
	11	-4.082	-11.889	-16.586	-46.819	-8.038	-14.574	-29.812	-16.558
		Signature n°							
		57	**58**	**59**	**60**	**61**	**62**	**63**	**64**
Feature combinations	**2**	-0.995	-1.786	**0.017**	-2.428	**0.607**	-0.242	-0.681	**0.067**
	3	-0.267	-11.292	-7.034	-26.072	-0.639	-0.314	-1.173	-1.645
	4	-0.321	-11.618	-7.644	-29.100	-1.378	-0.669	-3.538	-2.063
	5	**1.189**	-11.171	-7.538	-37.365	-0.877	-0.423	-3.346	-2.096
	6	**0.617**	-11.180	-7.428	-39.641	-0.691	-0.385	-3.224	-1.922
	7	-6.502	-12.985	-15.367	-38.652	-0.662	-0.275	-2.521	-1.255

	8	-10.771	-12.915	-15.536	-56.907	**0.065**	**0.468**	-1.786	-0.961
	9	-13.769	-14.308	-16.758	-58.486	-1.246	**0.939**	-1.969	-0.460
	10	-21.744	-24.636	-30.090	-58.501	-0.688	**1.580**	-0.837	**0.015**
	11	-21.497	-25.822	-30.283	-67.469	-1.198	**1.997**	-0.524	**0.215**
		Signature n°							
		65	**66**	**67**	**68**	**69**	**70**		
Feature combinations	**2**	-0.599	-0.649	**0.926**	**0.988**	-0.416	-0.017		
	3	**0.192**	-0.671	**0.865**	**1.386**	**0.453**	**0.775**		
	4	-0.826	-1.164	**0.669**	**0.903**	**0.517**	-0.846		
	5	-0.952	**0.047**	**0.870**	**1.361**	**0.771**	-0.322		
	6	-1.144	**0.796**	-0.174	-0.403	**0.805**	-0.154		
	7	-0.745	**1.356**	-1.308	-1.950	**1.296**	**0.088**		
	8	-0.128	**2.479**	**0.025**	-11.940	**1.899**	**0.652**		
	9	-1.593	**3.492**	-3.391	-9.924	**2.261**	**0.140**		
	10	-4.852	**4.188**	-5.557	-18.276	**3.176**	-1.550		
	11	-4.462	**5.289**	-7.065	-17.920	**2.845**	-0.752		

Results of the likelihood ratio (given in the logarithmic form) assessment for each simulated signature of artist n°1. For each signature, the results are listed for each feature vector combination (with a combination of the first two features, first three features, etc.). Log(LR) below zero are highlighted in red.

Artist n°2: Bacsay - Authentic signatures

Feature combination	Signature n°							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
2	2.058	0.129	1.169	1.179	-0.099	-0.441	-1.015	-0.707
3	2.775	1.202	2.363	2.610	-2.483	-0.454	-0.371	-0.667
4	2.352	1.301	2.967	1.372	-2.055	-0.044	0.351	-0.082
5	2.593	3.196	3.384	2.608	-1.960	0.895	1.763	0.014
6	2.839	1.308	3.830	2.960	-2.054	-0.443	1.806	0.193
7	3.335	1.822	4.424	3.216	-0.954	-0.027	1.905	-0.038
8	6.784	5.613	7.910	5.964	0.059	-1.369	3.094	0.658
9	6.508	5.548	7.548	5.821	0.512	-6.186	5.066	1.216
10	5.974	3.768	6.768	4.474	-0.339	-7.144	3.062	-0.300
11	1.851	4.015	6.918	4.316	-1.712	-6.997	3.934	-1.169
12	-12.136	-3.110	2.204	8.821	-1.414	-5.864	4.316	-0.509
	Signature n°							
	9	**10**	**11**	**12**	**13**	**14**	**15**	**16**
2	1.835	-0.167	-0.087	-0.893	4.354	3.678	1.239	1.240
3	2.315	0.153	0.282	-0.294	4.983	5.063	1.610	1.915
4	4.173	1.391	0.236	0.069	8.010	6.700	-0.459	0.921
5	4.753	3.387	0.947	1.116	7.897	4.716	0.240	2.175
6	5.161	3.794	0.935	0.798	8.347	5.177	0.684	0.277
7	5.600	4.258	2.408	-1.240	9.315	6.211	1.965	0.492
8	6.190	4.926	2.119	-1.789	9.679	8.572	-3.997	1.179
9	8.920	5.071	1.833	-1.356	7.900	7.369	-3.581	1.112
10	8.606	5.881	1.586	0.043	6.302	9.066	-7.429	-4.201
11	7.961	5.753	0.655	-0.006	6.440	7.438	-8.423	-4.256
12	8.887	5.495	1.150	1.058	7.939	10.455	-8.000	-8.310
	Signature n°							
	17	**18**	**19**	**20**	**21**	**22**	**23**	**24**
2	0.836	1.371	-0.524	-0.423	0.749	-1.055	1.427	-0.987
3	0.457	-1.795	0.098	-0.206	0.557	-0.519	-0.675	-0.522
4	1.014	-1.437	0.649	0.772	2.578	-0.908	-0.350	-0.350
5	1.143	-1.953	-0.646	0.972	1.633	1.050	-0.252	-3.137
6	-1.899	-1.543	-0.245	1.344	0.445	1.091	0.334	-2.733
7	-2.133	-2.422	0.359	0.758	-0.936	0.900	-0.372	-4.526
8	-0.498	-0.631	-1.492	-2.357	-1.102	2.286	-0.043	-3.625
9	-1.394	-2.256	-1.572	-0.836	-1.449	1.964	-0.203	-4.343
10	6.284	-3.442	-2.741	-1.798	-1.969	2.324	1.614	-3.709
11	1.579	-7.219	-3.180	-2.147	-2.208	-3.494	1.822	-4.130
12	0.322	-8.083	-4.693	-1.943	-1.161	-8.189	3.443	-5.771

Results of the likelihood ratio (given in the logarithmic form) assessment for each signature of artist n°2. For each signature, the results are listed for each feature vector combination (with a combination of the first two features, first three features, etc.). Log(LR) below zero are highlighted in red.

Artist n°2: Bacsay - Simulated signatures

		Signature n°							
		1	2	3	4	5	6	7	8
Feature combinations	2	-0.845	0.365	-0.894	-0.635	-0.609	-0.667	-0.930	-0.986
	3	-0.563	0.726	-1.382	-0.226	-0.187	-2.362	-1.806	-3.126
	4	-0.263	-6.418	-2.108	-0.349	-0.071	-1.764	-3.769	-3.890
	5	1.157	-5.357	-11.633	-3.993	-1.480	-1.749	-5.176	-6.305
	6	1.547	-5.392	-11.140	-7.999	-2.165	-2.976	-7.503	-7.474
	7	1.185	-29.439	-14.510	-9.102	-4.958	-2.463	-8.355	-8.712
	8	-0.718	-30.450	-18.253	-9.562	-5.016	-1.901	-7.397	-11.324
	9	-0.997	-29.072	-22.858	-13.619	-7.830	-1.252	-8.610	-11.078
	10	-1.555	-27.146	-25.133	-35.098	-13.018	-5.890	-7.626	-20.464
	11	-1.487	-26.601	-25.099	-35.443	-11.399	-6.022	-7.172	-20.489
	12	-1.319	-40.251	-29.332	-34.261	-11.502	-6.070	-31.689	-20.430
		Signature n°							
		9	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Feature combinations	2	-0.779	-0.998	0.043	1.215	0.030	-0.002	-0.973	0.639
	3	-3.624	-3.733	0.470	4.207	-0.553	-1.286	-0.670	1.162
	4	-7.210	-6.125	0.505	3.372	-0.457	-3.117	-1.799	0.693
	5	-7.485	-8.748	-1.637	7.055	0.674	-3.632	-1.948	0.658
	6	-7.871	-8.900	-1.303	7.228	1.029	-2.995	-1.509	0.435
	7	-9.810	-10.297	-1.950	8.373	-0.056	-4.482	-2.779	-0.417
	8	-10.424	-14.221	-10.156	-0.817	0.327	-11.605	-1.861	0.029
	9	-10.601	-14.832	-11.287	0.701	0.090	-16.299	-2.033	-0.400
	10	-14.362	-22.271	-11.068	-2.519	-0.141	-17.116	-2.333	-0.771
	11	-14.293	-22.810	-9.879	-4.536	0.315	-17.002	-1.788	-0.663
	12	-15.250	-22.467	-6.275	-4.252	-1.487	-17.751	-1.898	-11.768
		Signature n°							
		17	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Feature combinations	2	0.327	-0.735	-1.073	-0.557	-0.803	-0.478	-0.171	-0.392
	3	1.059	-0.428	-1.188	-0.280	-0.402	-0.301	-0.343	-0.562
	4	-1.628	0.510	-7.941	-9.106	-1.746	-5.817	-2.121	-2.946
	5	-1.115	0.956	-8.777	-8.073	-5.033	-7.947	-5.490	-7.418
	6	-1.075	0.422	-8.320	-7.591	-5.014	-8.200	-4.954	-7.152
	7	-0.094	1.454	-5.697	-10.818	-4.298	-6.593	-4.478	-6.654
	8	2.477	2.247	-5.678	-13.678	-3.731	-7.706	-6.016	-7.749
	9	1.486	2.947	-7.595	-18.753	-3.190	-8.056	-6.536	-8.855
	10	-0.296	2.637	-10.572	-21.835	-5.718	-7.160	-9.234	-10.436
	11	-0.379	2.373	-12.251	-22.301	-5.896	-7.287	-9.440	-11.123
	12	3.802	2.265	-12.780	-23.982	-6.248	-7.086	-9.758	-11.830
		Signature n°							
		25	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Feature combinat.	2	-0.616	-0.115	-0.632	0.448	-0.412	-0.007	-0.965	-0.854
	3	-0.405	-1.686	-0.294	0.475	0.142	0.557	-0.326	-0.172
	4	-4.152	-1.286	-1.365	0.284	-0.743	0.557	-0.007	0.095
	5	-8.882	-1.745	-2.249	0.677	-1.579	0.692	-2.495	-5.271

	6	-8.961	-1.135	-1.800	1.320	-1.326	0.019	-2.384	-5.035
	7	-8.513	-4.035	-3.459	1.702	-1.104	0.523	-1.783	-8.502
	8	-12.694	-4.979	-3.038	-1.343	-1.322	2.649	-3.182	-8.228
	9	-13.163	-5.302	-3.674	-3.553	-1.697	2.182	-3.249	-8.479
	10	-14.838	-6.150	-4.570	-4.591	-1.157	2.093	-4.444	-8.736
	11	-15.321	-6.183	-5.103	-2.703	-1.225	2.095	-4.938	-9.040
	12	-14.910	-5.356	-4.845	0.211	-2.374	1.370	-5.417	-9.598
		Signature n°							
		33	**34**	**35**	**36**	**37**	**38**	**39**	**40**
Feature combinations	**2**	-0.862	-0.678	-0.630	0.377	-0.562	-0.146	0.322	-1.034
	3	-0.248	-0.728	0.083	1.012	-0.486	0.244	0.735	-1.595
	4	-0.783	0.999	0.800	2.654	1.174	0.732	0.855	-1.943
	5	-4.929	-3.415	-3.864	3.550	2.152	0.754	0.735	-3.337
	6	-5.643	-2.928	-3.404	3.151	2.638	0.362	0.660	-2.838
	7	-5.898	-2.074	-6.711	4.246	2.466	-2.617	1.547	-7.359
	8	-5.317	-2.355	-6.177	4.155	-8.227	-2.876	2.134	-6.737
	9	-5.771	-2.769	-6.770	3.407	-12.933	-2.985	1.410	-8.538
	10	-5.143	-3.940	-6.635	2.109	-14.276	-3.136	2.470	-11.002
	11	-5.474	-4.687	-7.118	2.223	-17.207	-3.015	2.098	-12.064
	12	-8.281	-5.583	-7.067	1.882	-18.366	-10.373	3.232	-10.763
		Signature n°							
		41	**42**	**43**	**44**	**45**	**46**	**47**	**48**
Feature combinations	**2**	-0.174	0.095	0.001	-0.742	-0.514	-0.065	-0.858	-0.172
	3	-1.294	-0.170	-0.714	-3.455	-1.402	-1.145	-1.474	-2.131
	4	-0.731	0.694	-0.868	-2.770	-1.371	-0.903	-2.721	-7.974
	5	-0.705	1.020	-0.673	-2.050	-3.607	-2.292	-6.491	-12.540
	6	-0.216	1.086	-3.701	-5.884	-7.082	-4.250	-5.992	-12.853
	7	0.442	0.946	-3.213	-5.709	-6.715	-4.658	-5.634	-14.270
	8	-0.340	0.889	-4.304	-6.059	-6.164	-4.206	-8.109	-13.748
	9	-0.891	0.624	-4.668	-10.278	-4.228	-4.301	-8.334	-12.562
	10	-1.291	1.551	-7.140	-11.773	-6.647	-4.776	-8.695	-12.725
	11	-1.192	2.528	-7.724	-12.827	-6.434	-4.549	-8.535	-12.805
	12	-3.308	0.337	-12.890	-14.680	-8.152	-8.088	-8.506	-13.530
		Signature n°							
		49	**50**	**51**	**52**	**53**	**54**	**55**	**56**
Feature combinations	**2**	1.326	-0.058	-0.908	0.936	-0.284	-0.486	-1.024	-0.386
	3	0.594	-3.222	-0.786	1.457	0.134	0.387	-2.518	-4.053
	4	-3.750	-10.388	-7.369	-6.466	-5.538	-3.618	-4.902	-3.301
	5	-8.008	-9.407	-7.511	-8.287	-7.559	-11.763	-9.235	-4.734
	6	-7.728	-10.110	-8.659	-8.347	-7.596	-11.275	-9.556	-4.108
	7	-8.674	-13.745	-6.340	-8.530	-21.270	-10.809	-9.076	-3.771
	8	-7.471	-11.878	-20.575	-7.493	-20.843	-18.833	-14.136	-5.266
	9	-5.666	-11.991	-21.787	-7.369	-22.015	-18.738	-15.091	-5.473
	10	-6.206	-12.635	-21.356	-9.663	-23.326	-19.516	-15.870	-6.458
	11	-5.762	-12.581	-21.324	-9.463	-23.860	-19.801	-16.001	-6.622
	12	-8.468	-12.250	-19.891	-12.408	-23.164	-19.420	-15.569	-12.192
		Signature n°							

		57	58	59	60	61	62	63	64
Feature combinations	2	-1.058	1.214	-0.905	-1.057	-0.541	-0.748	-1.077	-0.789
	3	-3.776	-1.150	-3.323	-2.737	-0.084	-1.332	-1.301	-0.919
	4	-4.597	-0.792	-3.817	-3.760	0.040	-1.452	-1.932	-2.195
	5	-5.151	0.366	-4.684	-4.252	0.125	-2.363	-2.791	-1.244
	6	-6.149	1.038	-4.575	-4.429	0.075	-1.887	-2.815	-1.715
	7	-8.154	-4.378	-8.132	-9.736	-0.875	-4.107	-7.400	-8.093
	8	-7.742	-18.906	-9.303	-13.015	-0.607	-3.588	-7.479	-7.597
	9	-8.296	-18.742	-9.332	-13.286	-0.978	-4.327	-6.797	-10.489
	10	-8.910	-19.338	-8.805	-13.601	-1.269	-5.704	-6.927	-14.760
	11	-8.495	-19.323	-7.463	-13.907	-1.286	-6.545	-7.015	-14.531
	12	-21.950	-25.855	-19.374	-33.144	0.258	-6.847	-13.956	-13.078
		Signature n°							
		65	66	67	68	69	70		
Feature combinations	2	-1.011	0.008	-0.026	0.111	-0.511	0.157		
	3	-0.922	0.315	0.327	0.690	-0.201	0.621		
	4	-2.787	-1.174	-0.543	-0.251	-0.879	-2.015		
	5	-3.170	-1.163	-1.303	1.328	-4.618	-1.533		
	6	-3.146	-1.486	-0.954	0.467	-4.132	-2.304		
	7	-6.561	-2.227	0.100	0.214	-5.447	-4.261		
	8	-5.980	-3.982	-5.197	-1.066	-7.859	-6.685		
	9	-8.627	-4.610	-2.328	0.209	-8.424	-7.529		
	10	-12.734	-5.299	-2.753	0.120	-10.461	-9.625		
	11	-13.040	-5.174	-1.401	0.430	-10.659	-8.485		
	12	-12.739	-5.081	-0.690	-0.039	-10.312	-10.369		

Results of the likelihood ratio (given in the logarithmic form) assessment for each simulated signature of artist n°2. For each signature, the results are listed for each feature vector combination (with a combination of the first two features, first three features, etc.). Log(LR) below zero are highlighted in red.

Artist n°3 - V Muro - Authentic signatures

Feature combination	Signature n°							
	1	2	3	4	5	6	7	8
2	0.971	1.222	0.121	0.106	0.996	-0.458	2.759	1.950
3	0.412	1.178	0.128	0.077	0.445	-0.437	2.302	1.302
4	0.218	1.057	-0.605	-0.150	0.574	-2.498	2.144	1.206
5	0.839	-2.626	0.272	0.527	0.626	-2.296	3.557	2.239
6	0.990	-2.258	0.601	0.891	0.394	-2.703	2.131	2.246
7	1.106	-0.453	2.268	0.860	1.313	-1.704	4.247	4.049
8	1.003	0.657	0.529	1.452	1.985	-1.376	4.727	4.862
9	1.327	-0.442	-1.201	2.136	2.495	-2.015	4.828	5.451
10	0.426	0.091	-1.178	1.516	-0.760	-2.873	4.337	5.709
11	-2.041	2.364	-8.236	1.941	-3.741	-4.491	4.361	5.959
12	-1.542	3.252	-8.738	2.738	-7.222	-3.377	3.769	6.373
13	2.473	2.207	-6.886	2.868	-8.625	-13.495	2.885	6.489
14	3.366	5.265	-14.649	-1.560	-8.471	-16.022	3.602	5.048
15	2.024	5.838	-14.641	-4.197	-9.793	-14.570	1.899	-1.317
16	-1.943	6.199	-23.819	-4.427	-61.732	-30.574	-2.045	-1.288
	Signature n°							
	9	**10**	**11**	**12**	**13**	**14**	**15**	**16**
2	-0.376	1.690	1.004	0.312	1.496	0.368	0.545	1.846
3	-0.402	0.881	1.872	1.013	5.076	0.297	0.743	2.228
4	-0.990	0.822	1.731	1.040	4.268	0.115	0.757	2.046
5	-1.558	1.236	1.046	1.306	5.081	0.948	1.379	3.043
6	-1.406	0.701	1.255	6.945	7.485	1.407	1.736	5.481
7	-1.264	-1.805	1.311	1.222	-4.946	2.090	2.702	6.845
8	-6.941	-3.497	-0.232	-2.027	-5.163	2.350	3.112	4.982
9	-8.303	-6.774	0.233	-1.437	-4.891	2.691	3.563	6.284
10	-10.439	-8.720	0.395	0.074	-13.952	3.029	3.942	11.993
11	-10.291	-9.727	-0.092	1.912	-13.258	3.766	5.190	15.708
12	-9.535	-9.132	-0.194	1.356	-13.054	4.153	4.629	15.727
13	-9.499	-14.768	1.639	-0.142	-12.666	5.582	4.794	12.380
14	-10.522	-13.876	-7.723	-3.919	-18.779	6.447	6.370	13.893
15	-9.165	-24.124	-8.142	-7.632	-15.743	6.235	7.297	13.072
16	-7.537	-20.585	-15.143	-9.214	-20.531	5.764	6.536	-15.865
	Signature n°							
	17	**18**	**19**	**20**	**21**	**22**	**23**	**24**
2	1.242	1.586	1.453	0.471	0.009	2.439	1.097	1.110
3	8.553	6.039	1.266	0.244	-1.929	2.611	2.072	3.815
4	7.871	6.528	1.121	-0.075	-2.507	2.723	2.304	3.572
5	8.714	7.201	1.939	-0.354	-1.731	3.330	2.777	4.283
6	16.198	9.565	2.232	1.188	-1.548	3.014	3.072	3.881
7	17.002	10.487	2.329	1.657	-0.396	3.794	3.648	3.485
8	17.806	12.814	2.296	1.756	-0.668	4.626	4.569	4.403
9	21.135	15.156	0.981	0.392	-5.033	5.195	4.384	2.813

10	21.071	26.703	2.179	1.086	-3.822	10.742	10.177	4.721
11	21.102	25.726	2.832	1.225	-2.818	12.767	11.421	4.872
12	21.638	24.556	-7.351	0.080	-5.897	12.004	12.225	0.959
13	21.126	16.192	-18.284	0.294	-8.892	13.331	12.338	1.144
14	21.262	15.997	-20.226	-11.285	-10.642	11.703	13.198	2.060
15	23.123	12.696	-17.245	-7.628	-8.814	7.572	14.413	2.639
16	24.198	12.082	-18.529	-6.595	-9.385	6.888	14.503	2.662

	Signature n°	
	25	**26**
2	0.556	2.484
3	1.207	2.960
4	1.081	3.004
5	1.381	0.868
6	2.744	-0.650
7	3.514	0.369
8	4.091	1.645
9	3.774	0.623
10	4.359	8.291
11	-1.087	10.614
12	-2.400	11.547
13	-21.221	12.093
14	-21.079	13.460
15	-31.694	10.056
16	-56.902	8.160

Results of the likelihood ratio (given in the logarithmic form) assessment for each signature of artist n°3. For each signature, the results are listed for each feature vector combination (with a combination of the first two features, first three features, etc.). Log(LR) below zero are highlighted in red.

Artist n°3 - Muro - Simulated signatures

		Signature n°							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Feature combinations	**2**	-3.063	-4.381	-11.674	-8.187	-5.930	-0.207	-0.070	-6.318
	3	-4.038	-5.294	-11.849	-13.720	-7.131	-0.215	-0.098	-6.961
	4	-4.164	-3.749	-12.810	-14.084	-7.993	0.007	0.336	-7.289
	5	-3.271	-7.944	-19.190	-18.457	-19.012	0.428	0.982	-6.966
	6	-2.492	-15.890	-35.198	-33.898	-36.549	-2.426	1.587	-9.837
	7	-2.565	-17.236	-29.214	-31.715	-38.906	-1.695	2.017	-11.285
	8	-15.563	-18.406	-38.098	-47.489	-55.461	-4.968	0.249	-10.415
	9	-15.253	-20.324	-42.839	-50.805	-57.021	-8.107	0.776	-9.798
	10	-49.153	-25.301	-50.088	-69.577	-53.880	-13.905	1.251	-10.719
	11	-48.969	-31.455	-61.238	-66.858	-53.441	-13.296	-0.148	-7.970
	12	-50.874	-31.389	-73.332	-87.238	-73.353	-14.196	2.707	-10.326
	13	-51.060	-38.693	-81.110	-89.499	-89.187	-15.884	5.131	-11.922
	14	-49.773	-38.514	-80.465	-92.206	-93.818	-20.869	-11.402	-30.928
	15	-57.320	-53.425	-130.185	-98.991	-108.814	-16.857	-19.613	-37.131
	16	-57.358	-58.052	-133.879	-100.942	-124.935	-22.434	-19.734	-37.782
		Signature n°							
		9	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Feature combinations	**2**	-2.633	1.930	1.653	1.194	1.254	-0.711	-1.252	0.689
	3	-2.752	1.874	2.059	-3.593	-2.057	-1.084	-2.124	-0.300
	4	-3.166	1.702	2.111	-3.909	-1.101	-0.536	-2.045	-0.463
	5	-8.411	3.207	0.041	-4.122	-2.650	-0.170	-1.242	0.361
	6	-7.273	2.971	-0.877	-6.743	-2.226	-0.896	-1.250	0.349
	7	-6.995	2.219	-6.219	-8.119	-3.586	0.263	1.509	0.737
	8	-6.385	2.735	-5.452	-7.179	-5.173	-0.710	2.431	0.455
	9	-6.424	-2.847	-5.284	-16.705	-7.961	-2.785	3.446	-1.083
	10	-6.428	-3.991	-11.292	-23.736	-8.434	-2.269	3.802	-2.847
	11	-9.834	-6.838	-20.607	-22.239	-20.460	-1.606	0.363	-3.770
	12	-28.635	-9.243	-28.649	-32.575	-19.919	-0.302	-0.197	-6.053
	13	-28.649	-18.696	-32.599	-34.299	-23.398	0.351	-1.020	-6.166
	14	-29.841	-30.450	-35.182	-33.816	-23.984	-31.102	-9.950	-10.214
	15	-30.008	-49.456	-57.768	-70.461	-27.073	-31.219	-24.674	-22.686
	16	-34.033	-60.748	-58.386	-70.709	-24.147	-32.561	-28.913	-22.541
		Signature n°							
		17	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Feature combinations	**2**	0.043	-1.043	2.540	0.346	-1.762	0.076	-0.920	1.144
	3	-0.119	0.564	0.411	0.788	-1.854	0.029	-1.001	0.110
	4	-0.302	0.194	0.489	0.647	-2.185	-0.133	-1.296	-0.025
	5	-0.002	1.000	-5.152	0.960	-2.256	-0.747	-1.505	-3.639
	6	-1.430	-9.347	-5.563	0.766	-2.951	-2.461	-4.551	-6.397
	7	-1.292	-8.846	-3.651	-0.987	-2.477	-5.634	-7.695	-6.696
	8	-0.768	-8.590	-2.734	-0.364	-2.000	-5.763	-9.669	-6.150
	9	-0.246	-8.387	-2.285	-0.864	-2.546	-5.457	-6.440	-10.576
	10	-0.860	-8.038	-8.577	-9.689	-2.575	-9.973	-18.080	-10.451

	11	-1.761	-8.081	-8.185	-12.531	-5.746	-10.265	-19.102	-10.568
	12	-1.823	-7.561	-7.391	-39.707	-25.715	-10.924	-27.261	-12.652
	13	-4.926	-7.170	-3.797	-39.492	-25.900	-18.559	-29.953	-14.746
	14	-11.545	-14.298	-3.860	-39.253	-24.631	-19.569	-30.634	-12.705
	15	-66.278	-58.228	-12.158	-76.651	-79.833	-61.722	-29.752	-45.789
	16	-68.242	-59.568	-10.902	-76.812	-80.593	-63.691	-35.085	-47.940
		Signature n°							
		25	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Feature combinations	**2**	-4.021	-0.384	1.477	-0.136	-0.264	-6.976	-4.925	-7.575
	3	-4.884	-0.584	1.294	-0.174	-0.052	-13.584	-7.180	-11.620
	4	-5.509	-0.755	1.157	0.331	0.496	-13.177	-7.787	-11.112
	5	-4.703	0.056	1.549	-1.046	1.410	-12.437	-16.185	-11.524
	6	-9.227	-0.592	2.087	-2.469	0.239	-19.499	-15.602	-11.102
	7	-10.307	-1.479	1.923	-1.994	-2.446	-18.601	-15.510	-10.865
	8	-10.033	-2.819	1.047	-2.729	-2.500	-17.973	-15.217	-10.723
	9	-9.393	-2.213	1.679	-4.934	-2.197	-32.038	-16.238	-10.140
	10	-8.892	-4.311	0.382	-4.862	-2.583	-31.623	-21.845	-17.634
	11	-7.896	-7.116	0.130	-3.868	-1.443	-43.401	-32.826	-26.507
	12	-7.507	-31.814	-1.558	-4.695	-0.754	-42.914	-43.517	-28.566
	13	-8.438	-31.325	-1.154	-4.073	0.908	-42.643	-43.481	-28.041
	14	-8.208	-30.980	-10.607	-4.445	1.055	-51.101	-50.909	-31.406
	15	-25.089	-102.327	-23.876	-57.232	2.258	-50.640	-124.229	-43.617
	16	-26.397	-102.057	-22.352	-60.560	-1.601	-49.322	-126.426	-43.412
		Signature n°							
		33	**34**	**35**	**36**	**37**	**38**	**39**	**40**
Feature combinations	**2**	-11.448	-3.715	-7.902	0.449	-1.236	-0.225	-10.910	-10.803
	3	-23.723	-3.985	-11.287	0.478	-2.194	-0.340	-14.626	-18.410
	4	-24.043	-4.475	-11.876	0.304	-1.888	-0.556	-15.452	-19.552
	5	-28.585	-5.637	-16.905	1.269	-1.362	-0.199	-14.867	-35.013
	6	-30.070	-4.944	-17.469	0.264	-2.042	0.050	-13.303	-34.644
	7	-29.631	-4.348	-16.925	-2.520	-4.774	-10.946	-27.428	-34.298
	8	-29.351	-5.140	-19.276	-2.430	-4.727	-9.893	-28.438	-33.745
	9	-27.570	-5.058	-19.129	-2.737	-7.384	-10.300	-30.312	-32.867
	10	-28.699	-5.322	-41.708	-16.911	-7.849	-11.258	-38.900	-34.831
	11	-40.042	-7.622	-50.218	-19.366	-13.929	-27.287	-61.280	-38.737
	12	-49.375	-10.060	-53.933	-17.644	-12.783	-28.701	-78.723	-60.143
	13	-53.103	-9.865	-53.926	-27.437	-17.171	-35.409	-87.900	-61.233
	14	-56.357	-9.153	-72.779	-70.363	-33.969	-49.167	-94.935	-63.990
	15	-57.707	-16.154	-103.343	-98.815	-51.781	-50.122	-96.018	-74.336
	16	-59.098	-13.494	-104.315	-104.932	-59.222	-56.400	-102.360	-76.684
		Signature n°							
		41	**42**	**43**	**44**	**45**	**46**	**47**	**48**
Feature combination	**2**	-4.895	-0.704	-2.984	-12.669	-11.999	-7.660	-1.469	-3.289
	3	-5.549	-1.309	-3.039	-26.836	-19.731	-11.100	-1.413	-4.907
	4	-6.265	-1.174	-3.522	-27.721	-19.542	-9.642	-1.640	-5.138
	5	-5.638	-3.199	-2.989	-26.835	-18.744	-8.864	-2.785	-14.587
	6	-10.098	-4.074	-4.579	-30.061	-25.902	-7.905	-2.106	-17.269

	7	-23.444	-14.866	-9.148	-34.310	-31.714	-10.363	-1.585	-19.308
	8	-22.565	-14.448	-9.132	-35.884	-31.581	-9.576	-0.952	-20.096
	9	-21.540	-17.949	-10.361	-55.833	-43.980	-9.071	-2.814	-17.496
	10	-24.943	-18.128	-16.261	-55.870	-43.780	-11.020	-2.363	-17.039
	11	-37.201	-33.793	-21.176	-91.147	-60.220	-26.360	-6.794	-38.294
	12	-33.455	-32.811	-19.219	-90.057	-59.065	-28.218	-8.978	-38.357
	13	-55.462	-47.383	-19.304	-91.689	-61.170	-27.801	-9.323	-40.601
	14	-87.392	-46.030	-31.821	-113.496	-73.567	-30.357	-15.889	-42.681
	15	-90.556	-45.077	-33.761	-138.021	-78.106	-29.901	-26.269	-38.497
	16	-87.830	-42.554	-38.257	-140.903	-82.063	-30.513	-26.188	-40.989
		Signature n°							
		49	**50**	**51**	**52**	**53**	**54**	**55**	**56**
Feature combinations	**2**	-4.895	-0.704	-2.984	-12.669	-11.999	-7.660	-1.469	-3.289
	3	-5.549	-1.309	-3.039	-26.836	-19.731	-11.100	-1.413	-4.907
	4	-6.265	-1.174	-3.522	-27.721	-19.542	-9.642	-1.640	-5.138
	5	-5.638	-3.199	-2.989	-26.835	-18.744	-8.864	-2.785	-14.587
	6	-10.098	-4.074	-4.579	-30.061	-25.902	-7.905	-2.106	-17.269
	7	-23.444	-14.866	-9.148	-34.310	-31.714	-10.363	-1.585	-19.308
	8	-22.565	-14.448	-9.132	-35.884	-31.581	-9.576	-0.952	-20.096
	9	-21.540	-17.949	-10.361	-55.833	-43.980	-9.071	-2.814	-17.496
	10	-24.943	-18.128	-16.261	-55.870	-43.780	-11.020	-2.363	-17.039
	11	-37.201	-33.793	-21.176	-91.147	-60.220	-26.360	-6.794	-38.294
	12	-33.455	-32.811	-19.219	-90.057	-59.065	-28.218	-8.978	-38.357
	13	-55.462	-47.383	-19.304	-91.689	-61.170	-27.801	-9.323	-40.601
	14	-87.392	-46.030	-31.821	-113.496	-73.567	-30.357	-15.889	-42.681
	15	-90.556	-45.077	-33.761	-138.021	-78.106	-29.901	-26.269	-38.497
	16	-87.830	-42.554	-38.257	-140.903	-82.063	-30.513	-26.188	-40.989
		Signature n°							
		57	**58**	**59**	**60**	**61**	**62**	**63**	**64**
Feature combinations	**2**	-6.445	-3.659	-6.891	-4.026	-2.323	-7.080	-1.802	-5.132
	3	-7.420	-3.571	-3.858	-2.107	-4.106	-13.541	-2.737	-7.748
	4	-7.974	-2.924	-2.919	-1.612	-4.414	-14.155	-2.993	-8.065
	5	-7.291	-3.597	-2.091	-4.408	-3.869	-14.902	-2.580	-8.852
	6	-8.372	-4.898	-1.752	-11.807	-3.950	-14.958	-2.207	-8.426
	7	-11.396	-8.952	-4.488	-17.120	-5.912	-14.273	-4.458	-9.536
	8	-16.180	-14.350	-17.612	-18.670	-5.396	-13.023	-3.837	-10.326
	9	-24.361	-19.947	-18.772	-17.995	-6.511	-22.011	-3.333	-12.225
	10	-27.062	-26.256	-20.372	-15.453	-5.460	-24.528	-2.419	-11.336
	11	-60.432	-51.901	-46.879	-26.148	-10.712	-35.015	-4.415	-22.236
	12	-84.291	-96.640	-54.239	-26.022	-14.289	-37.499	-4.903	-26.211
	13	-86.181	-97.447	-68.615	-52.046	-15.757	-37.802	-9.080	-26.420
	14	-86.236	-97.629	-68.388	-90.415	-15.553	-37.388	-8.346	-33.723
	15	-135.104	-176.402	-200.930	-203.687	-16.294	-35.630	-14.076	-38.474
	16	-137.199	-179.766	-201.155	-206.406	-18.156	-36.964	-14.034	-38.734
		Signature n°							
		65	**66**	**67**	**68**	**69**	**70**		
	2	-4.929	-4.714	0.304	0.313	-0.758	1.353		

	3	-8.760	-5.660	0.564	0.335	-1.119	-0.994		
	4	-9.195	-6.380	0.516	0.285	-1.280	-1.203		
	5	-8.310	-6.242	-0.260	-1.909	-0.902	-0.548		
	6	-10.517	-9.946	1.129	-1.884	-0.540	0.342		
	7	-16.679	-8.768	1.104	-1.534	-4.777	1.005		
	8	-16.103	-9.110	0.859	-0.859	-4.016	2.314		
	9	-17.366	-8.283	1.438	-0.168	-3.295	2.359		
	10	-15.932	-13.108	1.584	0.615	-5.434	2.120		
	11	-26.852	-14.619	2.355	-0.894	-5.222	4.310		
	12	-30.393	-14.422	-0.623	0.939	-5.664	2.835		
	13	-36.378	-15.456	2.067	-3.007	-3.514	-0.420		
	14	-35.796	-13.056	2.257	-1.733	-5.433	-0.256		
	15	-48.207	-14.197	-3.897	-5.680	-14.225	-16.803		
	16	-50.207	-14.262	-4.653	-6.869	-15.103	-17.842		

Results of the likelihood ratio (given in the logarithmic form) assessment for each simulated signature of artist n°3. For each signature, the results are listed for each feature vector combination (with a combination of the first two features, first three features, etc.). Log(LR) below zero are highlighted in red.

Artist n°4 - Pasquier - Authentic signatures

Feature combination	Signature n°							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
2	0.538	1.151	1.619	1.723	0.514	1.984	0.806	-0.557
3	0.988	1.592	2.261	0.458	1.173	2.384	-0.386	1.345
4	2.484	3.802	3.945	1.770	2.052	3.456	1.382	-1.815
5	3.419	4.038	4.557	1.870	2.533	3.846	1.934	0.285
6	2.920	4.598	4.688	2.279	2.654	4.680	-0.715	0.722
7	0.778	12.172	3.117	5.392	-0.153	10.618	-1.567	-1.342
8	2.228	11.910	3.700	4.045	0.085	10.554	-2.938	-5.988
9	1.959	6.661	4.073	3.630	0.009	12.554	-3.415	-6.450
10	2.365	16.345	0.956	4.266	-2.002	22.677	-9.716	-0.356
11	-5.444	15.400	2.923	2.913	0.414	23.553	-9.107	0.429
12	-7.029	9.900	3.772	3.136	0.543	23.706	-9.978	0.450
13	-5.984	3.293	-15.951	0.679	-6.361	23.956	-9.686	1.979
14	-6.540	-15.469	-18.225	0.278	-6.823	22.630	-6.915	3.988
15	-28.768	-18.848	-17.713	-0.014	-10.014	23.708	-27.304	1.510
16	-40.397	-17.680	-101.764	0.497	-10.531	30.919	-39.104	6.396
17	-44.120	-41.563	-103.786	-0.404	-18.180	31.791	-47.027	9.821
18	-49.942	-33.169	-113.337	1.031	-18.681	29.255	-100.678	-12.345
19	-77.265	-45.464	-110.310	2.788	-43.260	27.484	-97.364	-17.604
20	-3192.399	-43.178	-984.769	-13.589	-741.543	7.063	-107.387	-33.341
21	-5702.283	-128.794	-1016.678	-59.704	-12112.274	-1347.717	-430.097	-75.879
	Signature n°							
	9	**10**	**11**	**12**	**13**	**14**	**15**	**16**
2	1.674	1.117	0.565	1.438	1.976	1.631	-0.790	1.794
3	1.658	2.204	1.943	2.261	2.887	2.844	1.075	2.251
4	3.286	2.897	-0.443	2.592	3.609	2.727	1.651	3.999
5	3.952	3.197	-1.601	2.257	4.198	2.522	-3.697	4.106
6	4.833	4.254	-0.880	-0.130	4.964	2.640	-3.358	4.907
7	3.261	6.430	0.176	0.747	4.272	1.702	-6.081	10.068
8	4.092	3.112	0.027	-4.051	0.891	1.847	-4.549	10.618
9	3.251	4.893	-2.208	-8.967	2.539	4.216	-3.348	11.135
10	6.217	14.431	-3.450	-26.529	12.123	9.456	4.014	16.056
11	6.015	-3.452	-3.005	-27.149	11.139	8.183	4.581	14.527
12	5.677	-2.418	-15.390	-26.708	11.049	9.785	4.776	15.105
13	6.486	-4.062	-17.997	-28.226	4.519	10.791	6.156	15.925
14	5.514	-0.852	-18.574	-41.809	3.899	11.821	7.967	5.704
15	2.119	-4.496	-21.513	-42.442	2.438	12.228	8.539	-20.018
16	3.100	-2.520	-28.714	-71.043	2.992	12.184	6.559	-402.548
17	-12.377	-32.555	-35.636	-120.375	-4.074	2.151	-7.045	-406.768
18	-87.581	-61.667	-82.594	-121.065	-2.697	3.333	-4.015	-406.490
19	-88.374	-244.782	-119.329	-118.817	-4.948	-16.198	-2.533	-1463.397
20	-175.249	-695.647	-116.619	-133.428	-18.037	-53.598	-4.288	-3749.261
21	-202.798	-815.070	-495.552	-730.878	-46.139	-72.848	-61.800	-4373.828

	Signature n°							
	17	**18**	**19**	**20**	**21**	**22**	**23**	24
2	1.563	0.803	0.586	0.664	-0.326	1.949	0.981	
3	2.530	0.361	1.299	0.290	0.141	1.695	0.676	
4	3.683	1.902	2.908	2.140	2.142	3.057	0.578	
5	3.736	2.321	1.160	2.245	1.898	2.399	0.439	
6	4.577	3.152	2.250	-2.427	2.580	3.221	-0.038	
7	5.115	4.362	3.256	-1.528	3.875	5.187	4.195	
8	5.728	4.857	3.933	-1.554	4.301	5.759	4.089	
9	8.616	4.678	-2.661	-0.366	6.657	7.265	6.181	
10	12.883	5.007	-4.820	-2.705	11.496	8.328	14.141	
11	14.454	5.293	-9.128	-4.253	13.001	9.397	14.189	
12	6.823	2.337	-9.342	-3.778	12.451	9.370	14.447	
13	6.349	3.433	-13.139	-7.079	13.261	9.029	15.088	
14	7.844	3.544	-30.275	-6.248	10.368	8.034	15.119	
15	9.074	2.362	-139.739	-11.751	8.396	8.467	14.212	
16	9.050	-5.003	-174.961	-11.268	9.067	-9.622	14.705	
17	-4.580	-5.506	-189.789	-12.876	1.503	-9.221	15.453	
18	-4.892	-12.502	-209.018	-15.831	-6.747	-7.160	-20.614	
19	-57.938	-42.490	-524.925	-20.127	-2.997	-318.705	-30.656	
20	-107.446	-48.785	-534.571	-51.597	-1.118	-319.741	-70.823	
21	-261.070	-503.692	-1888.118	-500.264	0.898	-518.983	-194.902	

Results of the likelihood ratio (given in the logarithmic form) assessment for each signature of artist n°4. For each signature, the results are listed for each feature vector combination (with a combination of the first two features, first three features, etc.). Log(LR) below zero are highlighted in red.

Artist n°4 - Pasquier - Simulated signatures

		Signature n°							
		1	2	3	4	5	6	7	8
Feature combinations	2	-15.956	-14.179	-17.497	-7.816	-17.496	-6.580	-4.263	-5.497
	3	-18.186	-13.639	-17.413	-8.225	-18.934	-6.911	-6.466	-5.590
	4	-55.211	-37.805	-21.250	-18.426	-30.956	-15.296	-12.073	-15.369
	5	-53.863	-38.292	-21.426	-17.716	-31.172	-15.410	-11.794	-15.411
	6	-53.084	-41.165	-22.454	-17.996	-32.415	-24.309	-21.526	-28.554
	7	-61.730	-46.072	-25.999	-22.030	-38.511	-25.858	-25.319	-29.872
	8	-65.359	-45.238	-25.532	-21.571	-38.971	-24.358	-26.107	-29.219
	9	-71.176	-46.074	-27.122	-24.613	-39.711	-27.720	-27.090	-31.687
	10	-71.001	-46.041	-30.144	-26.366	-47.315	-34.862	-33.157	-33.634
	11	-70.798	-45.843	-30.550	-26.222	-50.612	-34.550	-32.134	-33.410
	12	-70.867	-53.046	-30.232	-28.748	-44.913	-34.938	-31.925	-33.928
	13	-73.169	-53.016	-28.884	-30.415	-45.330	-34.046	-58.983	-32.761
	14	-72.437	-52.252	-28.013	-29.574	-44.501	-40.740	-81.921	-56.471
	15	-134.126	-57.451	-50.272	-48.707	-48.421	-102.880	-104.263	-65.124
	16	-151.907	-58.632	-49.158	-51.980	-60.986	-112.188	-113.499	-74.068
	17	-179.798	-111.791	-59.680	-86.912	-66.163	-165.960	-172.596	-89.571
	18	-217.875	-117.000	-59.368	-122.997	-65.802	-166.394	-174.294	-88.436
	19	-221.753	-899.540	-292.173	-125.509	-86.317	-174.068	-228.003	-673.751
	20	-1396.249	-8427.166	-2166.568	-796.940	-83.034	-216.487	-2837.365	-1228.778
	21	-1418.310	-8587.606	-2277.062	-809.731	-105.993	-215.467	-2838.507	-1503.426
		Signature n°							
		9	10	11	12	13	14	15	16
Feature combinations	2	-13.521	-1.792	-5.067	0.547	1.939	0.660	2.093	0.434
	3	-13.285	-5.205	-11.379	0.118	2.376	-7.603	2.465	-0.883
	4	-47.184	-5.870	-25.965	0.536	-1.989	-13.270	-1.938	-6.932
	5	-49.444	-4.598	-28.899	1.125	-1.935	-13.016	-2.529	-5.933
	6	-70.313	-18.650	-52.524	-5.594	-7.790	-32.951	-1.434	-7.490
	7	-76.943	-22.462	-55.049	-6.391	-7.310	-33.646	-4.010	-9.019
	8	-79.132	-23.151	-54.650	-15.860	-9.836	-33.486	-3.790	-10.226
	9	-81.052	-27.863	-54.682	-14.113	-9.487	-35.412	-4.143	-17.467
	10	-86.383	-46.645	-64.704	-18.103	-13.822	-36.267	-3.593	-17.077
	11	-84.774	-49.259	-84.035	-17.286	-16.549	-34.825	5.385	-16.925
	12	-85.006	-53.831	-83.812	-21.096	-15.966	-32.128	0.234	-19.128
	13	-83.241	-50.737	-98.599	-28.297	-15.016	-55.889	-12.382	-18.118
	14	-110.580	-78.989	-100.195	-28.495	-13.883	-52.871	-26.531	-17.216
	15	-113.992	-123.151	-100.422	-27.278	-13.315	-54.415	-45.719	-22.411
	16	-118.201	-130.764	-134.961	-29.609	-13.197	-87.021	-47.831	-36.324
	17	-264.676	-303.599	-209.630	-28.209	-24.418	-103.602	-46.378	-41.808
	18	-270.527	-302.536	-252.809	-21.164	-45.304	-105.268	-43.970	-39.937
	19	-394.756	-367.022	-2637.174	-20.929	-304.376	-655.630	-144.263	-64.616
	20	-391.897	-366.957	-3351.027	-415.370	-536.437	-816.120	-2769.291	-277.465
	21	-505.953	-469.322	-3430.037	-457.100	-535.203	-1130.427	-2808.562	-323.072
		Signature n°							

		17	18	19	20	21	22	23	24
Feature combinations	2	-5.139	-0.731	-20.986	-1.081	-8.485	-1.174	-7.293	0.160
	3	-7.387	-1.616	-23.414	-8.657	-8.631	-2.577	-7.012	-6.654
	4	-26.379	-3.133	-50.295	-11.036	-45.393	-17.869	-28.462	-26.257
	5	-27.188	-9.415	-54.941	-13.909	-47.775	-20.820	-29.473	-25.815
	6	-27.178	-8.039	-58.243	-14.985	-61.063	-20.260	-28.623	-26.314
	7	-30.680	-9.983	-61.823	-15.358	-65.523	-24.583	-34.573	-32.518
	8	-31.965	-12.932	-63.182	-14.359	-65.197	-27.617	-35.364	-36.706
	9	-38.089	-12.501	-64.292	-15.421	-63.713	-25.424	-32.939	-35.415
	10	-37.938	-11.988	-64.787	-15.486	-85.849	-31.957	-39.740	-41.343
	11	-38.945	-17.498	-64.312	-18.214	-85.527	-41.458	-56.320	-42.372
	12	-49.513	-17.414	-68.732	-26.448	-95.364	-58.866	-89.396	-45.008
	13	-48.555	-18.823	-76.343	-30.072	-105.593	-58.465	-95.386	-44.086
	14	-47.554	-21.953	-75.515	-29.710	-109.657	-64.270	-94.399	-64.770
	15	-93.995	-24.095	-76.654	-29.681	-109.916	-62.876	-100.296	-65.158
	16	-94.703	-33.182	-75.391	-43.037	-132.868	-69.799	-124.011	-73.968
	17	-101.549	-108.316	-82.551	-42.450	-133.726	-77.382	-180.363	-73.222
	18	-116.258	-135.853	-127.032	-61.719	-160.869	-84.341	-195.347	-110.460
	19	-125.739	-239.679	-1246.575	-411.317	-547.932	-247.131	-343.352	-753.389
	20	-326.061	-352.291	-1243.910	-1219.866	-563.193	-762.219	-1893.084	-1382.630
	21	-396.217	-412.044	-1371.153	-1295.000	-608.968	-757.964	-2038.606	-1574.704
		Signature n°							
		25	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Feature combinations	2	-10.041	0.229	0.099	-4.156	-16.114	-6.432	-8.460	-3.459
	3	-9.656	0.047	-0.009	-3.726	-16.156	-6.661	-10.174	-8.090
	4	-50.630	-16.094	-6.494	-27.211	-50.396	-28.050	-37.863	-12.735
	5	-51.464	-15.428	-6.308	-28.103	-49.845	-30.218	-38.298	-13.554
	6	-51.219	-19.686	-6.620	-30.085	-49.163	-31.927	-39.779	-13.518
	7	-54.621	-24.407	-10.719	-35.233	-56.081	-36.982	-44.916	-16.484
	8	-62.871	-23.957	-10.248	-35.495	-60.044	-37.656	-49.288	-16.369
	9	-68.663	-25.252	-11.769	-38.013	-58.813	-39.847	-54.476	-16.791
	10	-68.206	-24.952	-12.056	-37.655	-61.374	-37.169	-53.379	-16.802
	11	-67.058	-25.339	-13.890	-44.757	-64.701	-36.777	-55.556	-16.433
	12	-68.096	-25.556	-18.018	-56.930	-57.016	-37.635	-56.125	-15.850
	13	-66.982	-27.507	-21.043	-76.275	-65.413	-50.340	-54.745	-23.398
	14	-68.709	-27.752	-23.896	-75.082	-66.523	-61.467	-55.008	-24.321
	15	-74.150	-32.323	-23.132	-76.733	-93.263	-65.149	-69.746	-26.292
	16	-75.200	-41.375	-48.677	-86.435	-131.909	-67.810	-73.586	-25.366
	17	-106.855	-47.241	-48.185	-94.727	-150.555	-66.829	-97.296	-51.655
	18	-101.531	-61.769	-47.672	-93.811	-180.616	-86.969	-97.846	-48.248
	19	-100.082	-224.042	-111.428	-319.502	-198.625	-976.307	-192.299	-489.501
	20	-326.845	-247.446	-663.705	-3199.170	-2625.924	-1045.420	-1359.638	-1470.786
	21	-382.013	-292.081	-671.595	-3404.990	-2658.327	-1162.186	-1418.178	-1469.996
		Signature n°							
		33	**34**	**35**	**36**	**37**	**38**	**39**	**40**
	2	-3.928	-7.566	-8.308	-0.114	0.845	-0.832	1.424	-2.764
	3	-3.829	-7.477	-9.937	-1.786	1.677	-0.723	1.789	-3.669

	4	-20.056	-10.841	-13.843	-5.883	4.168	-9.684	0.731	-2.870
	5	-24.396	-10.544	-14.321	-6.357	3.193	-11.048	1.030	-2.490
	6	-28.421	-11.038	-21.045	-5.498	3.751	-11.476	1.978	-3.331
	7	-19.239	-11.025	-22.763	-7.357	2.675	-13.633	1.141	-4.780
	8	-21.008	-12.992	-22.460	-8.291	4.165	-16.251	1.246	-4.008
	9	-22.181	-14.676	-22.264	-9.076	5.629	-17.848	0.625	-4.636
	10	-20.395	-16.518	-22.595	-11.068	7.637	-19.149	-0.195	-5.580
	11	-20.497	-17.104	-22.441	-11.456	-3.236	-23.142	0.071	-5.540
	12	-19.846	-25.707	-21.619	-11.147	-14.226	-23.667	0.159	-5.090
	13	-21.678	-24.564	-20.881	-12.060	-15.109	-22.746	0.739	-8.436
	14	-24.775	-26.904	-23.923	-20.026	-23.587	-33.799	-5.150	-17.779
	15	-29.611	-28.360	-28.941	-22.702	-21.841	-38.769	-4.437	-17.775
	16	-36.187	-29.797	-31.317	-23.097	-30.092	-38.117	-8.153	-24.550
	17	-60.284	-17.570	-45.889	-36.757	-47.445	-93.631	-43.600	-30.237
	18	-61.682	-16.830	-44.168	-38.946	-51.029	-93.226	-48.148	-32.614
	19	-85.612	-969.096	-63.933	-57.561	-540.884	-297.033	-177.791	-122.529
	20	-270.375	-9170.186	-60.700	-64.572	-1388.360	-870.647	-533.611	-120.020
	21	-291.727	-10265.19	-82.135	-64.511	-1482.971	-871.877	-539.444	-118.728
		Signature n°							
		41	**42**	**43**	**44**	**45**	**46**	**47**	**48**
Feature combinations	**2**	1.364	-9.821	-20.117	-12.104	0.449	-1.803	0.230	1.696
	3	-3.974	-9.727	-19.251	-13.331	-7.584	-1.022	1.182	2.269
	4	-5.910	-8.956	-19.808	-15.798	-7.048	-4.053	1.163	1.491
	5	-8.146	-8.697	-20.394	-15.234	-6.481	-4.902	-0.601	1.156
	6	-9.023	-6.762	-18.245	-15.048	-7.401	-4.593	-1.153	1.651
	7	-11.268	-8.308	-19.193	-16.235	-9.473	-6.856	-3.732	-0.721
	8	-11.295	-7.701	-19.211	-14.913	-8.995	-8.243	-3.961	-1.605
	9	-12.267	-9.091	-20.978	-14.914	-9.878	-10.316	-7.351	-2.621
	10	-11.277	-11.682	-21.792	-17.285	-9.199	-10.178	-6.952	-2.283
	11	-14.815	-12.178	-22.185	-16.682	-10.869	-9.698	-6.253	-1.864
	12	-14.660	-15.990	-34.677	-17.101	-13.237	-9.958	-7.901	-2.588
	13	-16.378	-58.948	-72.448	-56.941	-24.471	-8.653	-6.769	-1.904
	14	-16.074	-58.795	-71.156	-55.516	-23.953	-7.784	-5.920	-0.672
	15	-15.434	-60.045	-69.653	-60.784	-23.894	-15.358	-11.393	-0.417
	16	-35.212	-140.970	-116.777	-91.826	-52.178	-20.616	-21.087	-4.675
	17	-34.709	-141.877	-117.852	-92.405	-53.289	-20.791	-20.530	-5.875
	18	-38.290	-142.962	-121.935	-103.962	-52.606	-22.284	-24.531	-7.295
	19	-207.209	-144.853	-131.045	-440.453	-98.669	-48.941	-142.192	-15.169
	20	-1300.250	-3026.484	-924.565	-1450.545	-472.889	-402.067	-953.898	-16.839
	21	-1407.224	-3207.084	-1044.265	-1466.461	-502.871	-438.058	-1018.427	-15.615
		Signature n°							
		49	**50**	**51**	**52**	**53**	**54**	**55**	**56**
Feature combinations	**2**	0.603	0.265	-2.942	-0.857	-3.564	-6.580	-0.534	-3.222
	3	0.672	0.944	-2.495	0.082	-3.856	-7.065	-0.304	-8.334
	4	0.575	-5.336	-27.101	-11.713	-33.448	-19.192	-24.565	-15.225
	5	-0.624	-5.632	-31.354	-11.300	-35.825	-19.347	-27.301	-16.471
	6	-1.529	-5.420	-38.058	-11.651	-34.461	-19.192	-26.440	-16.989

	7	-3.075	-8.981	-42.184	-15.066	-37.725	-23.096	-31.552	-17.748
	8	-7.157	-7.872	-41.246	-14.684	-37.592	-22.665	-33.072	-17.800
	9	-8.625	-10.326	-41.078	-10.815	-40.356	-20.680	-35.856	-18.140
	10	-8.471	-11.871	-41.327	-20.945	-40.963	-24.996	-35.785	-17.249
	11	-8.389	-12.691	-42.117	-25.261	-40.890	-27.621	-35.620	-16.945
	12	-9.993	-13.954	-43.055	-48.776	-40.541	-27.864	-36.350	-19.162
	13	-7.905	-15.672	-58.166	-51.936	-39.965	-30.767	-33.712	-22.519
	14	-7.283	-14.818	-57.590	-51.672	-41.974	-40.687	-33.261	-22.390
	15	-7.255	-20.115	-54.253	-51.152	-59.346	-39.619	-38.285	-30.299
	16	-12.471	-45.403	-53.882	-61.641	-60.348	-45.109	-41.599	-40.273
	17	-18.288	-46.151	-53.905	-63.989	-88.425	-45.608	-56.558	-41.998
	18	-19.249	-55.824	-59.715	-68.764	-90.011	-43.127	-60.133	-50.129
	19	-46.632	-75.986	-1341.853	-313.080	-133.844	-50.679	-64.476	-64.217
	20	-481.225	-526.423	-1416.574	-1213.787	-654.762	-460.901	-323.576	-61.413
	21	-545.041	-534.680	-1785.831	-1395.659	-652.784	-465.934	-494.174	-85.116
		Signature n°							
		57	**58**	**59**	**60**	**61**	**62**	**63**	**64**
Feature combinations	**2**	-10.116	-4.746	-5.471	-6.599	-2.263	-14.466	-9.560	-2.959
	3	-9.618	-5.121	-4.653	-5.943	-1.448	-13.606	-8.888	-1.987
	4	-11.984	-5.566	-6.271	-6.724	-14.937	-41.362	-23.356	-18.029
	5	-11.681	-5.784	-5.966	-7.390	-15.160	-41.533	-24.801	-17.634
	6	-12.293	-9.255	-9.351	-9.944	-14.500	-42.055	-24.320	-16.479
	7	-15.307	-12.454	-10.361	-10.580	-14.932	-42.956	-26.483	-15.715
	8	-15.714	-12.840	-10.164	-12.342	-20.602	-41.832	-26.915	-15.607
	9	-16.132	-12.909	-10.324	-13.561	-26.503	-44.257	-28.322	-21.697
	10	-18.435	-15.642	-10.415	-13.905	-28.098	-43.164	-30.716	-21.693
	11	-18.305	-17.174	-10.884	-16.895	-28.274	-47.810	-30.927	-21.717
	12	-18.784	-17.533	-9.504	-15.951	-29.502	-47.447	-34.480	-23.094
	13	-18.238	-22.160	-8.638	-15.029	-32.403	-129.629	-53.143	-35.633
	14	-17.225	-46.362	-8.791	-18.556	-35.010	-132.827	-53.285	-35.065
	15	-23.725	-66.085	-14.029	-22.119	-34.600	-145.917	-52.313	-47.511
	16	-34.968	-97.267	-20.444	-34.815	-42.625	-155.405	-52.749	-50.509
	17	-54.871	-188.207	-21.731	-61.741	-42.585	-152.957	-55.288	-51.017
	18	-60.125	-187.354	-23.873	-62.255	-42.504	-159.105	-54.298	-50.032
	19	-196.187	-704.585	-21.800	-1359.647	-40.002	-703.765	-112.211	-58.608
	20	-1099.759	-2410.199	-243.590	-4828.353	-185.592	-4412.326	-936.155	-424.212
	21	-1106.734	-2407.204	-319.607	-5059.191	-197.175	-4416.569	-932.561	-437.250
		Signature n°							
		65	**66**	**67**	**68**	**69**	**70**		
Feature combinations	**2**	-0.067	1.491	0.503	1.065	-2.370	1.632		
	3	0.629	1.966	0.974	1.702	-1.832	0.223		
	4	-5.113	3.297	-1.929	-1.504	-12.053	-2.720		
	5	-4.823	2.306	-2.626	-1.908	-11.430	-3.133		
	6	-4.456	3.125	-4.235	-4.884	-10.805	-2.232		
	7	-6.658	2.221	-5.408	-5.774	-13.495	-5.116		
	8	-6.264	-0.386	-5.000	-9.983	-13.039	-4.918		
	9	-8.779	-2.714	-6.882	-12.844	-15.856	-5.796		

	10	-8.124	-1.791	-7.104	-12.476	-15.919	-3.138		
	11	-12.637	-1.512	-6.875	-12.200	-16.439	-2.444		
	12	-24.572	0.797	-6.807	-13.218	-20.339	-2.069		
	13	-25.571	-0.837	-6.244	-14.758	-23.964	-20.063		
	14	-24.361	0.231	-7.003	-13.937	-23.085	-18.004		
	15	-25.875	-6.279	-7.044	-11.511	-22.403	-17.568		
	16	-26.553	-18.986	-14.748	-20.949	-43.747	-21.562		
	17	-26.807	-18.265	-21.437	-43.071	-47.175	-20.518		
	18	-36.084	-21.896	-35.692	-45.485	-48.176	-20.968		
	19	-493.511	-19.800	-66.209	-169.822	-49.790	-114.839		
	20	-1523.639	-273.852	-87.370	-194.094	-267.040	-584.616		
	21	-1708.292	-290.965	-98.153	-226.257	-278.962	-583.153		

Results of the likelihood ratio (given in the logarithmic form) assessment for each simulated signature of artist n°4. For each signature, the results are listed for each feature vector combination (with a combination of the first two features, first three features, etc.). Log(LR) below zero are highlighted in red.

Artist n°5 - Schwaller - Authentic signatures

Feature combination	Signature n°							
	1	2	3	4	5	6	7	8
2	3.584	0.230	1.183	1.104	3.052	2.557	3.234	3.550
3	-1.935	0.048	2.638	2.695	4.216	3.569	1.698	5.325
4	-3.572	-0.044	3.473	1.050	4.347	3.350	-1.042	5.494
5	-4.501	0.273	3.034	-2.722	4.376	3.632	-9.970	4.965
6	-3.482	1.368	4.447	-3.524	5.197	4.783	-10.544	4.910
7	-2.868	2.430	5.584	-3.058	6.046	5.530	-9.147	5.952
8	-1.785	1.961	5.420	-3.142	5.954	4.804	-6.278	2.019
9	-1.203	2.712	5.804	-4.492	6.028	4.553	-8.601	2.032
10	-13.363	1.068	5.970	-4.718	2.028	2.189	-9.184	-0.167
11	-13.514	-2.819	6.916	-3.615	2.702	3.272	-9.907	-3.151
12	-21.676	-2.528	6.137	-2.802	4.528	2.207	-8.977	-0.043
13	-14.015	-3.983	7.828	-1.622	6.117	4.293	-2.501	-11.645
14	-15.476	-2.204	10.251	-27.357	7.231	1.554	-2.173	-4.004
15	-16.825	-4.590	11.133	-68.270	1.984	1.641	-1.922	-5.661
16	-18.767	-5.648	11.337	-95.560	-7.032	0.261	-1.325	-5.207
17	-22.033	-4.783	2.848	-102.822	-6.319	1.425	-43.129	-6.000
18	-20.920	-6.972	-7.307	-112.095	-52.086	-17.923	-46.671	-6.181
19	-22.230	-8.378	-10.516	-111.055	-194.894	-22.449	-49.422	-68.558
20	-405.572	-12.077	-16.585	-153.628	-545.118	-44.502	-68.473	-305.687
21	-3582.317	-37.004	-16.997	-156.364	-726.654	-1292.533	-71.548	-304.515
	Signature n°							
	9	10	11	12	13	14	15	16
2	1.065	2.548	0.167	2.575	2.601	1.660	0.783	0.085
3	2.466	3.694	0.808	3.893	3.919	3.206	1.698	1.364
4	2.045	4.272	1.367	4.288	3.684	3.620	1.998	2.272
5	3.270	4.540	1.500	4.725	4.052	4.572	3.309	2.575
6	-0.105	4.050	-0.158	5.550	3.864	5.533	4.632	4.070
7	-0.602	3.501	-4.365	6.620	-0.179	6.911	5.552	3.594
8	-3.747	3.004	-5.079	9.674	0.439	6.480	5.889	3.911
9	-3.317	0.507	-4.507	10.016	-8.722	6.638	0.396	4.386
10	-3.961	0.672	-4.074	8.490	-8.232	6.997	0.238	4.755
11	-0.605	1.584	-2.444	9.722	-12.639	7.480	-0.593	5.387
12	-3.019	-0.684	-1.788	9.127	-18.799	7.229	-13.528	4.453
13	-1.656	-0.612	-0.619	9.250	-14.246	10.349	-15.121	4.797
14	-4.904	0.214	-14.785	11.637	-21.858	10.636	-12.081	5.419
15	-6.074	1.499	-20.722	12.397	-109.522	9.086	-12.345	2.804
16	-47.561	-1.454	-21.737	13.111	-111.543	8.671	-10.310	-82.288
17	-50.416	-3.841	-22.362	-12.429	-250.458	1.845	-16.401	-154.657
18	-51.631	-14.821	-46.212	-12.715	-250.573	-31.243	-18.809	-320.426
19	-152.583	-14.182	-108.062	-21.577	-338.769	-31.439	-41.421	-358.482
20	-276.234	-13.884	-165.913	-154.519	-557.047	-38.952	-40.892	-451.731

21	-415.662	-66.600	-33798.639	-153.057	-944.057	-193.271	-3431.557	-494.012
	Signature n°							
	17	**18**	**19**	**20**	**21**	**22**	**23**	
2	-0.174	-1.196	0.441	1.486	-0.293	1.502	2.041	
3	0.991	-0.024	1.252	2.084	0.812	2.795	1.277	
4	1.606	1.315	2.540	2.785	0.394	3.854	0.174	
5	2.765	2.347	3.070	3.131	1.397	0.670	0.779	
6	3.722	3.482	3.481	3.805	2.340	2.173	1.314	
7	5.670	4.775	5.242	5.088	0.146	2.578	1.399	
8	4.913	4.743	5.105	4.834	-0.087	2.673	1.846	
9	5.345	5.081	5.664	5.701	-2.238	0.888	2.634	
10	4.778	5.816	6.066	5.803	-3.482	-0.058	-0.284	
11	6.088	0.390	6.452	2.134	-9.227	-1.830	0.871	
12	5.522	0.882	7.294	3.547	-12.176	-5.142	1.331	
13	3.981	0.820	1.816	-18.991	-15.112	-4.682	3.582	
14	2.088	1.361	5.086	-20.391	-12.872	-9.165	4.512	
15	1.053	0.811	-26.737	-34.611	-14.330	-14.324	5.261	
16	1.616	-1.973	-26.690	-168.559	-13.665	-13.648	4.677	
17	2.568	-10.153	-35.423	-170.021	-12.741	-13.209	6.719	
18	3.594	-14.352	-43.298	-171.024	-11.798	-17.048	4.578	
19	-19.960	-62.917	-44.165	-247.557	-33.985	-17.267	-1.270	
20	-1079.392	-709.913	-253.472	-2059.847	-35.895	-25.170	-9.304	
21	-1726721.13	-2937.037	-261.110	-127184.083	-2264.186	-23.767	-466.492	

Results of the likelihood ratio (given in the logarithmic form) assessment for each signature of artist n°5. For each signature, the results are listed for each feature vector combination (with a combination of the first two features, first three features, etc.). Log(LR) below zero are highlighted in red.

Artist n°5 - Schwaller - Simulated signatures

		Signature n°							
		1	2	3	4	5	6	7	8
Feature combinations	2	-0.697	-1.168	-0.905	3.158	-0.549	-1.436	-15.317	0.842
	3	0.064	-0.636	0.202	5.435	0.571	-9.614	-14.909	2.598
	4	-9.881	-1.190	1.352	5.988	-4.921	-11.635	-18.524	3.690
	5	-18.774	-11.946	-0.823	6.116	-11.604	-14.549	-18.807	3.744
	6	-43.827	-16.608	-3.891	4.081	-20.166	-28.096	-61.830	-41.467
	7	-46.810	-16.112	-3.496	-0.502	-19.856	-37.008	-61.554	-41.214
	8	-51.873	-16.652	-3.913	-5.631	-22.129	-45.138	-67.533	-41.866
	9	-66.307	-16.333	-5.855	-6.127	-21.378	-59.625	-79.612	-39.672
	10	-66.107	-16.429	-5.551	-5.374	-20.596	-58.092	-75.496	-37.067
	11	-68.108	-27.108	-4.731	-2.082	-26.292	-58.221	-107.711	-83.892
	12	-67.661	-25.644	-4.535	-1.915	-22.543	-94.862	-149.386	-83.720
	13	-65.239	-27.725	-7.437	-47.211	-23.103	-206.834	-385.228	-83.740
	14	-81.004	-26.928	-6.967	-46.094	-21.799	-217.776	-391.237	-83.105
	15	-78.437	-58.230	-4.512	-77.521	-30.435	-221.993	-389.677	-111.599
	16	-92.151	-58.158	-9.813	-80.246	-28.407	-221.617	-388.946	-136.555
	17	-146.985	-49.927	-21.907	-144.915	-44.498	-226.253	-446.208	-146.616
	18	-173.346	-75.223	-40.123	-181.244	-42.891	-278.867	-458.166	-305.602
	19	-208.975	-76.056	-38.506	-197.882	-68.969	-373.717	-477.445	-317.902
	20	-220.328	-82.612	-40.168	-196.827	-71.910	-371.462	-486.940	-385.667
	21	-325.217	-81.502	-67.583	-238.600	-83.757	-562.263	-651.447	-399.296
		Signature n°							
		9	10	11	12	13	14	15	16
Feature combinations	2	0.271	-0.267	-6.311	-15.372	-0.481	-6.270	-5.593	-8.387
	3	-7.984	-1.693	-5.549	-15.507	-20.345	-8.293	-5.734	-8.385
	4	-7.498	-0.966	-6.182	-10.618	-20.202	-8.963	-6.001	-9.228
	5	-10.442	-0.561	-7.820	-15.536	-40.410	-8.994	-5.067	-8.156
	6	-18.796	-7.972	-32.595	-15.460	-47.433	-9.338	-5.136	-5.727
	7	-18.086	-9.032	-39.783	-17.337	-55.317	-10.747	-11.284	-6.139
	8	-15.847	-8.118	-38.493	-18.846	-55.498	-13.176	-10.882	-5.058
	9	-23.255	-22.228	-37.870	-19.364	-71.035	-17.421	-17.513	-5.174
	10	-22.616	-22.716	-39.280	-23.437	-82.974	-23.972	-27.465	-11.481
	11	-69.869	-32.055	-147.565	-30.323	-91.086	-29.450	-65.293	-26.200
	12	-80.190	-43.595	-170.121	-37.237	-92.428	-30.311	-94.040	-27.065
	13	-84.246	-41.041	-251.335	-64.537	-93.437	-55.878	-92.908	-33.592
	14	-87.241	-39.611	-250.531	-66.405	-132.129	-92.476	-107.871	-36.122
	15	-104.379	-63.021	-315.380	-66.033	-134.489	-92.009	-119.064	-36.936
	16	-120.254	-61.131	-378.055	-69.460	-134.083	-102.150	-138.095	-36.640
	17	-134.969	-112.013	-410.917	-125.579	-216.181	-100.517	-135.958	-35.807
	18	-155.676	-110.874	-793.970	-144.729	-207.462	-99.641	-163.523	-33.449
	19	-155.935	-108.779	-952.553	-168.420	-365.435	-190.116	-164.020	-209.777
	20	-176.791	-104.611	-1033.905	-180.541	-378.497	-196.055	-159.267	-210.416
	21	-179.552	-104.780	-1045.002	-186.762	-377.436	-254.340	-185.359	-245.699

		Signature n°							
		17	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Feature combinations	**2**	-3.254	-2.587	-5.272	-5.978	0.913	0.246	-0.762	-1.293
	3	-16.393	-7.669	-3.837	-9.720	0.642	-6.707	-2.808	-3.230
	4	-17.916	-7.303	-4.341	-10.621	1.719	-5.536	-3.756	-5.419
	5	-23.429	-7.024	-2.246	-13.893	1.977	-5.401	-3.623	-4.650
	6	-22.367	-10.006	-22.902	-12.975	0.702	-4.564	-2.401	-3.625
	7	-23.710	-11.596	-26.391	-13.669	-3.700	-4.323	-2.686	-3.181
	8	-23.102	-11.430	-26.396	-13.426	-6.975	-4.449	-2.713	-3.508
	9	-25.583	-16.898	-26.819	-21.399	-6.877	-16.808	-0.672	-2.800
	10	-30.442	-20.204	-29.094	-33.189	-7.810	-16.542	-2.543	-1.491
	11	-50.255	-51.704	-97.310	-60.072	-10.058	-30.313	-10.692	-0.823
	12	-50.193	-52.021	-96.712	-60.533	0.217	-35.002	-8.816	-0.608
	13	-68.015	-59.290	-109.673	-66.094	-0.300	-34.192	-15.193	-7.257
	14	-70.187	-57.720	-114.858	-69.388	-56.188	-39.828	-30.591	-11.870
	15	-69.630	-74.440	-135.735	-70.469	-54.958	-34.743	-42.292	-13.776
	16	-69.082	-70.942	-138.418	-74.546	-52.843	-34.035	-41.141	-13.892
	17	-79.497	-73.271	-147.058	-78.138	-57.007	-35.871	-47.705	-16.147
	18	-87.094	-72.791	-148.940	-147.333	-58.174	-33.956	-47.598	-30.458
	19	-183.800	-178.502	-150.337	-251.788	-131.231	-87.393	-82.954	-94.198
	20	-211.628	-173.958	-198.202	-304.085	-150.400	-94.158	-114.342	-105.392
	21	-207.875	-183.241	-203.261	-322.783	-187.699	-113.873	-158.629	-129.477

		Signature n°							
		25	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Feature combinations	**2**	0.177	-2.424	0.118	-1.239	1.832	-0.942	1.446	1.832
	3	0.372	-2.086	-1.437	-5.970	3.442	0.116	-1.227	1.542
	4	1.021	-4.605	-9.032	-9.249	2.530	-4.588	-1.325	2.120
	5	1.587	-6.241	-10.110	-8.840	-0.752	-2.085	-1.728	2.448
	6	2.196	-36.492	-29.786	-15.541	-6.940	-12.762	-2.194	3.710
	7	-2.529	-35.689	-28.672	-16.930	-9.215	-15.812	-4.065	4.333
	8	-2.404	-40.879	-28.459	-18.058	-11.349	-16.603	-4.964	4.538
	9	-6.644	-45.221	-45.601	-22.693	-10.196	-14.628	-6.425	5.903
	10	-5.359	-45.017	-46.114	-23.080	-10.908	-14.471	-5.326	6.104
	11	-6.556	-79.321	-46.600	-27.068	-9.780	-14.073	-10.642	6.786
	12	-4.863	-78.703	-45.888	-26.728	-8.275	-13.363	-23.719	7.371
	13	-3.853	-77.548	-46.045	-28.914	-6.069	-14.176	-83.546	-0.243
	14	-12.333	-86.092	-56.675	-28.243	-7.688	-16.106	-83.078	-20.114
	15	-13.725	-99.472	-54.260	-31.178	-12.673	-18.668	-96.190	-27.704
	16	-15.560	-114.227	-55.956	-35.326	-11.907	-24.742	-94.467	-26.217
	17	-20.531	-124.750	-130.304	-78.708	-33.027	-60.237	-102.101	-27.256
	18	-33.856	-267.294	-122.688	-104.841	-41.914	-153.973	-113.174	-74.327
	19	-76.522	-266.905	-121.556	-115.886	-44.982	-172.545	-126.692	-87.909
	20	-79.005	-296.066	-128.722	-115.880	-53.029	-182.255	-128.386	-87.335
	21	-116.728	-294.089	-126.811	-124.657	-66.128	-187.971	-127.180	-96.334

		Signature n°							
		33	**34**	**35**	**36**	**37**	**38**	**39**	**40**
o m	**2**	-2.007	-2.411	-0.814	-0.374	-4.233	-6.740	-8.489	-2.096

	3	-23.502	-10.254	-3.922	-2.717	-9.162	-17.101	-10.677	-3.049
	4	-23.569	-10.874	-5.118	-1.915	-10.227	-17.110	-11.027	-3.699
	5	-23.585	-12.086	-5.036	-1.028	-10.610	-16.738	-13.379	-4.113
	6	-25.526	-13.155	-2.836	-3.150	-15.393	-18.974	-36.064	-25.360
	7	-25.271	-12.722	-2.960	-2.506	-17.826	-19.859	-39.795	-27.285
	8	-23.002	-9.728	-5.660	-3.458	-26.213	-27.333	-52.953	-30.806
	9	-28.200	-15.815	-8.205	-5.681	-26.363	-42.538	-58.325	-37.157
	10	-27.897	-24.604	-8.321	-5.588	-26.343	-41.710	-58.605	-36.875
	11	-26.927	-25.879	-7.320	-4.860	-33.994	-51.570	-65.194	-36.874
	12	-35.300	-27.395	-5.652	-4.201	-79.351	-99.054	-160.185	-65.550
	13	-48.016	-29.645	-5.659	-4.960	-148.089	-244.874	-365.037	-97.643
	14	-71.790	-55.669	-6.104	-3.725	-147.376	-252.491	-365.048	-97.866
	15	-82.583	-55.981	-5.252	-6.862	-166.886	-270.568	-378.251	-98.381
	16	-82.962	-57.275	-9.879	-6.273	-166.162	-269.927	-383.328	-105.205
	17	-82.090	-56.408	-13.732	-11.920	-174.985	-273.385	-383.447	-129.058
	18	-80.478	-68.016	-42.401	-14.836	-198.844	-360.132	-445.888	-169.854
	19	-296.960	-107.663	-47.967	-27.945	-348.370	-699.816	-646.348	-215.099
	20	-299.216	-126.548	-61.129	-26.695	-345.582	-699.407	-646.573	-224.084
	21	-401.789	-127.606	-70.073	-71.445	-355.121	-779.947	-708.971	-217.077
		Signature n°							
		41	**42**	**43**	**44**	**45**	**46**	**47**	**48**
Feature combinations	**2**	-0.806	-1.413	-1.974	-1.902	0.163	-28.933	-14.776	-11.643
	3	-0.063	-0.633	-0.833	-7.277	1.541	-27.553	-14.329	-11.517
	4	-8.285	-1.713	-4.273	-12.685	-1.253	-32.618	-18.420	-12.178
	5	-12.320	-9.594	-7.381	-15.409	-2.275	-42.908	-21.706	-11.625
	6	-41.911	-49.118	-48.167	-26.816	-7.066	-78.119	-71.779	-17.626
	7	-41.703	-46.907	-50.664	-26.386	-7.378	-78.540	-71.984	-17.026
	8	-45.704	-49.981	-59.711	-27.730	-5.983	-99.833	-77.459	-19.298
	9	-48.421	-56.820	-60.959	-34.682	-10.994	-99.000	-79.378	-17.935
	10	-48.451	-56.988	-60.771	-34.249	-12.690	-98.715	-79.098	-17.635
	11	-47.108	-59.051	-65.344	-37.481	-15.636	-99.242	-117.129	-21.713
	12	-58.770	-64.938	-73.673	-35.860	-15.944	-251.712	-124.358	-38.644
	13	-88.372	-78.287	-93.891	-39.149	-14.372	-678.918	-192.672	-131.439
	14	-91.674	-80.097	-117.616	-43.766	-13.825	-698.978	-256.716	-133.929
	15	-90.818	-89.005	-117.263	-48.295	-11.088	-735.676	-255.978	-140.549
	16	-89.760	-90.416	-117.685	-48.617	-8.879	-737.710	-307.495	-151.315
	17	-158.604	-135.533	-147.797	-72.737	-14.340	-776.844	-303.666	-164.908
	18	-158.735	-146.753	-181.324	-201.299	-129.760	-786.299	-398.065	-164.627
	19	-157.161	-153.935	-180.950	-197.355	-126.491	-871.479	-406.865	-218.503
	20	-158.045	-151.945	-191.133	-198.705	-125.874	-917.854	-460.379	-243.785
	21	-157.944	-163.641	-194.956	-232.707	-222.018	-1056.585	-466.356	-329.269
		Signature n°							
		49	**50**	**51**	**52**	**53**	**54**	**55**	**56**
Feature combinat	**2**	-7.452	-3.173	-10.729	-7.002	-12.428	-0.123	-4.957	-2.577
	3	-6.368	-2.594	-13.189	-8.969	-14.699	-2.305	-8.047	-22.049
	4	-10.862	-7.004	-14.315	-9.554	-16.204	-2.939	-12.476	-23.157
	5	-20.921	-9.428	-14.724	-10.129	-15.950	-2.793	-12.332	-22.036

	6	-137.547	-54.166	-30.085	-35.368	-47.172	-9.078	-29.321	-21.296
	7	-136.028	-55.890	-36.333	-42.030	-54.450	-15.057	-30.200	-24.744
	8	-144.011	-61.101	-50.375	-51.872	-69.051	-19.534	-36.326	-27.406
	9	-148.037	-64.050	-55.274	-63.455	-76.492	-27.230	-39.598	-30.844
	10	-148.526	-63.852	-59.088	-65.433	-80.205	-27.910	-41.027	-31.972
	11	-266.279	-100.605	-67.812	-73.975	-79.978	-35.417	-39.502	-33.621
	12	-265.682	-99.997	-170.607	-188.580	-197.144	-41.495	-68.047	-37.545
	13	-278.995	-116.618	-454.184	-522.219	-452.157	-61.517	-115.377	-39.915
	14	-376.587	-148.996	-453.482	-521.793	-453.027	-60.029	-115.993	-41.657
	15	-423.350	-146.522	-485.111	-557.015	-477.473	-63.314	-134.640	-40.549
	16	-452.938	-145.203	-486.966	-576.203	-480.706	-69.116	-139.885	-44.914
	17	-539.559	-168.183	-493.445	-575.409	-481.860	-82.491	-139.850	-45.077
	18	-640.346	-190.487	-627.550	-831.059	-576.078	-116.725	-160.960	-56.594
	19	-643.187	-205.049	-781.115	-1000.322	-692.301	-141.693	-216.748	-126.522
	20	-695.226	-208.744	-780.506	-1005.240	-701.032	-150.147	-215.938	-125.293
	21	-706.360	-207.520	-931.773	-1090.301	-864.686	-148.454	-268.822	-182.502
		Signature n°							
		57	**58**	**59**	**60**				
Feature combinations	**2**	-5.802	0.103	-3.016	-4.739				
	3	-7.331	-6.731	-3.442	-7.364				
	4	-10.265	-6.317	-2.531	-6.450				
	5	-10.185	-6.602	-2.206	-5.907				
	6	-14.649	-5.604	-2.887	-7.789				
	7	-14.135	-5.045	-2.315	-7.140				
	8	-17.328	-5.430	-3.370	-11.510				
	9	-25.881	-9.715	-4.178	-14.931				
	10	-23.447	-9.203	-2.808	-13.297				
	11	-34.353	-10.603	-2.033	-16.341				
	12	-33.656	-11.656	-2.914	-20.042				
	13	-67.702	-10.364	-3.872	-25.296				
	14	-73.164	-9.418	-19.678	-37.544				
	15	-75.461	-9.600	-19.444	-38.611				
	16	-75.449	-26.172	-25.164	-38.503				
	17	-100.696	-27.588	-24.253	-58.221				
	18	-112.240	-55.818	-40.375	-70.133				
	19	-343.005	-101.852	-55.974	-117.233				
	20	-342.361	-106.709	-54.670	-128.081				
	21	-388.115	-108.865	-62.857	-137.830				

Results of the likelihood ratio (given in the logarithmic form) assessment for each simulated signature of artist n°5. For each signature, the results are listed for each feature vector combination (with a combination of the first two features, first three features, etc.). Log(LR) below zero are highlighted in red.