A collaborative approach for incorporating forensic case data into crime investigation using criminal intelligence analysis and visualisation

Quentin ROSSY*, Olivier RIBAUX*

*Institut de Police Scientifique, Université de Lausanne, Batochime, 1015 Lausanne-Dorigny, Switzerland.

Corresponding author: Quentin Rossy, tel. +41216924613, quentin.rossy@unil.ch

Abstract

There is an increasing awareness that the articulation of forensic science and criminal investigation is critical to the resolution of crimes. However, models and methods to support an effective collaboration between the partners are still poorly expressed or even lacking. Three propositions are borrowed from crime intelligence methods in order to bridge this gap: (a) the general intelligence process, (b) the analyses of investigative problems along principal perspectives: entities and their relationships, time and space, quantitative aspects and (c) visualisation methods as a mode of expression of a problem in these dimensions.

Indeed, in a collaborative framework, different kinds of visualisations integrating forensic case data can play a central role for supporting decisions. Among them, link-charts are scrutinised for their abilities to structure and ease the analysis of a case by describing how relevant entities are connected. However, designing an informative chart that does not bias the reasoning process is not straightforward. Using visualisation as a catalyser for a collaborative approach integrating forensic data thus calls for better specifications.

1. Introduction

Many efforts have been dedicated to express what distinguishes the forensic scientist from the investigator, rather than to think about what they share in common. Actually, the French etymology of the term *investigation* provides the motivation for initiating a modelling process aiming at building a common conceptual framework. It relies on the term 'vestige', which means the trace or remnant of a litigious activity. This is exactly what forensic science is (should be) about [1,2].

According to this vision, the best use of forensic science is in the integrated support it provides to investigation. Indeed, detected failures have been recognised as occurring from a lack of communication, rather than to collusion with law enforcement [3,4]. Conversely, progresses are made difficult by the strength of the dominant view, which states that forensic scientists should keep their distance from investigators [5,6]. The NAS report has promoted radical solutions to protect forensic scientists from extraneous contextual information that has proved to perturb their judgement [7].

Moreover, the consensual solution to distinguish and study two types of forensic practitioners (investigators or evaluators) [5] seems to sign the divorce between science and investigation: "Expanding the forensic scientists' domain to the 'activity level' destroys the line between their expertise in their specific forensic discipline and a more general (and dangerous) claim to general investigative expertise" [6] p. 70.

This mainstream thought tends to confine laboratory scientists (or forensic analysts) within their technical specialisation. It reinforces the centralization of forensic operations in laboratories increasingly distant from investigation units. It makes specific technical areas attractive to forensic analysts but deviates their attention away from investigative requirements [1,2].

In order to compensate this movement and handle communication between the laboratory and the police, a case manager is increasingly integrated into the forensic laboratory [8]. This individual maintains a global view on a specific case and distributes tasks to specialised forensic analysts, by shielding them away from contextual influences and knowledge emanating from other pieces of evidence [9]. As a facilitator between forensic analysts and investigators, a case manager can monitor the information conveyed by the specimens analysed and can mostly defend personal independence as a member of the laboratory.

Symmetrically, investigators are often ill-informed of what forensic science can bring to help them conduct their cases. These weaknesses have long been identified, and good practices have been developed in order to mitigate their effects [10–12]. For instance, a forensic coordinator (i.e., specialist advisor) is integrated into investigations and provides intelligence from crime scene examination. Because the police is reluctant to publish information, very few of their approaches are made available in scientific literature [3,13,14].

These noticeable efforts seem to provide a possible response to De Forest [11], who points out that what is lacking is means to support teamwork and cooperative relationships between stakeholders, while maintaining scientific and investigative integrity. However, models and methods of how to share investigative approaches between partners are still lacking.

In order to fill this gap, we start from a set of general methods that were developed for structuring information processing in complex investigations. They are grouped under the umbrella of criminal intelligence analysis. We limit our approach to (a) a general process called the intelligence process, (b) the analyses of investigative problems along principal perspectives: entities and their relationships, time and space, quantitative aspects, and (c) visualisations methods as a mode of expression of a problem in these dimensions.

Visualisations methods are at the core of a collaborative approach because, when adequately used, they efficiently support teamwork. We focus on the conception and usage of link-charts that collate entities and their relationships (e.g., a car and its owner) because they are frequently used for supporting decision-making in criminal investigations. Moreover, they can integrate information conveyed by forensic data that often consists of links between entities (e.g., a mark and its source, two marks connected), but they have been little studied to date.

2. From coordination and cooperation efforts to collaboration

When a group of actors shares the task of solving a problem, it may coordinate, cooperate or collaborate. These terms do not describe the same kind of interaction that may exist between forensic science and investigation.

Coordination is a managerial approach where each member of the team may work independently to solve the case. The coordinator plans, monitors and fits all the pieces of the jigsaw together. For instance, a case manager coordinates the tasks of forensic analysts who operate independently.

Cooperation relies more on trust since, in this view, lines of inquiries chosen to solve the case may be informed by results obtained by colleagues. Their contribution is known, but may neither influence nor be used in solving the problem. It means considering the forensic scientist as an advisor who brings punctually a specialised expertise that is not necessarily integrated into the solution.

For implementing the vision of a forensic generalist fully participating in the achievement of the investigation, collaboration is a more suitable term. Collaboration is a process “through which parties who see different aspects of a problem can constructively explore their differences and search for solutions that go beyond their own limited vision of what is possible” [15] p. 5. Collaboration processes are fostered because an investigation cannot decompose from its beginning into a sequence of predefined operations. Forensic operations required may thus vary during the course of the investigation. Collaboration aims at finding solutions iteratively. All stakeholders move forwards with a shared understanding of the problem, and they share the decisions about the ways to reach the solution.

These distinctions remain generally fuzzy and not understood in a common way by all the actors. For instance, a study has shown that crime scene examiners have difficulties qualifying themselves as forensic investigators (i.e., collaborative) or forensic advisors (i.e., cooperative), while investigators prefer to view crime scene examiners as cooperating advisors [16]. These confusions feed tensions between the communities. We argue that there is a position for a forensic generalist to contribute in a collaborative way to investigations.

3. Criminal intelligence analysis contribution

From the late seventies, it was recognised that investigators should better structure and more transparently express the way they process information. Progressively, a new discipline called criminal intelligence analysis gained a central position in crime investigation. Its main task is to treat information in a manner that makes it intelligible to decision makers, whether they are forensic scientists, crime scene examiners, investigators or magistrates. Its methods are thus good candidates to initiate a collaborative framework for supporting the scientific investigation of crime that integrates information conveyed by forensic data.

3.1 Rationality of the intelligence process

The basic method of criminal intelligence analysis has since become a classic in the investigation culture and is broadly documented [17,18]. It consists of a very general process, or iterative cycle: planning, collection, collation, analysis, dissemination and feedback. The methods aim to timely, but progressively, turn raw data into hypotheses and intelligence that provides lines of inquiries to decision makers. It is conceived with several underlying objectives [19]:

- covering a broad diversity of criminal investigation problems;
- bringing forward a holistic and shared view on information, gathered from different sources, in a common memory. This aims to reduce linkage blindness [20], enabling a progressive structuring of different kinds of information, from often totally unstructured data to a more structured and formalised model;
- facilitating a collaborative development of explicit and alternative hypothesis;
- postponing the development of hypotheses at the end of the process in order to avoid drawing hasty conclusions;
- adapting to a new situation by iteratively reassessing hypotheses in the light of new information.

The implementation of such a process calls for a great variety of techniques to structure data, explore the available information and draw inferences.

The method insists on a critical aspect that has important consequences on the way to envisage the integration of forensic data in the process. It states that it is undesirable to immediately jump to complex formalisms, in order to enable an iterative integration of new pieces of information, and to converge towards an adequate form of expression for the specific problem to be solved. In this view, forensic scientists, rather than delivering their own independent products, have to actively participate to this shared progressive modelling process.

The role of visualisation to promote and support this collaborative approach is critical. Different types of visualisations describe what is known on a case in a qualitative way. They support analysis and exploration of information by decomposing the problem into simpler perspectives. The next sections describe opportunities offered and risks of using such representations in the collaborative resolution of problems.

3.2. Envisioning information

Visualisation in crime intelligence rests upon methods that are all embracing and significant in scope. General roles, benefits and risks have been identified and formalised by different researchers, active in many disciplines (in particular [21–25]).

Visualisations can be viewed as an external aid aiming at prolonging human cognition in four complementary tasks:

- *Memorise:* to maintain an overview, visualisation extends memory by grouping pieces of information in a common visual workspace (i.e., gather and summarise data). For instance, investigators use them to quickly recall relevant information after an absence or to prepare reports, meetings and police interviews. In court, they are used to summarise evidence scattered in reports or statements, in regards to questions posed;
- *Explore:* to infer hypotheses from data, visualisations help to discover patterns (i.e. relationships, correlations or tendencies) and exceptions (i.e. anomalies, errors or missing data). Visualisations are used during crime investigations to express and support the analysis of many types of complex structures, such as criminal networks or chronologies of events. Forensic data, such as telephone records and financial transactions, are frequently explored using visual abstractions.
- *Evaluate:* to test hypotheses, visualisations enable the evaluation of identified patterns or the interpretation of assumed relationships between entities. In this sense, they support many decisions during inquiries. For instance, specific link-charts are used to gather all relevant information needed to decide which specimen to send to the

laboratory for analyses. Other typical visualisations enable the evaluation of crime series by displaying on a single chart all the cases and their assumed links.

- *Communicate:* to impart knowledge, visualisations conveniently improve the global apprehension of complex problems. In particular, they aim at easing the follow-up of what is known on a case in an investigation team.

Visualisations combine with the many other techniques, which support similar functions, such as databases to memorise, data mining or social networks metrics to explore, probabilistic models to evaluate and texts or videos to communicate. However, visualisations have become increasingly important in caseworks, as they make possible the exploration of a vast amount of inhomogeneous data. They are intuitive, do not require the understanding of complex mathematical formalisms and enable a quick and qualitative overview of complex problems [26]. They capture the essential elements by an adequate use of abstractions and simplifications, deliberately leaving out the rest [24]. All this background makes visualisation a promising means to address the diversity of investigative problems. They force one to identify the main aspects of the problem addressed before jumping to mathematical formulas and computations.

3.3. Limits and risks of visualisation

Nevertheless, if visualisations provide many benefits, they may also endanger the rationality of the investigative process. Two distinct families of causes have been identified: (a) the designer choices, whether they are intentional or not, and (b) the user induced effects (e.g., confusion, distraction or misinterpretation) [27].

Indeed, visual choices are not neutral. The design involves selection and aggregation processes, impacting both analysis and communication. For instance, the designer may oversimplify the problem and leave aside crucial elements. This may induce biases unintentionally. Occasionally, this offers opportunities for feeding rhetoric in court.

The discretional nature of the design process of link-charts has been evaluated through an experiment [28]. The extent of variations in the design has been measured on different populations with forensic science or investigation backgrounds. An incredible disparity between designers put under the same conditions has been noticed. Ambiguities and evident interpretation mistakes have also been detected.

Even if some general guidelines are available to draw up such link-charts, the possibilities left to the discretion of the designer remains too high, occasionally resulting in poor and misleading representations.

Thus, using visualisation as a catalyser for a collaborative approach integrating forensic data demands a better specification of the design method. We postulate that a set of simple principles and guidelines can dramatically reduce undesirable outcomes.

The first critical decision is selecting an appropriate visualisation in regard to the investigative problem faced. There are many possibilities among diagrams, maps, timelines or graphs. Determining the most 'efficient' type should be guided by a clear definition of the problem resulting from a strict application of the intelligence process. It is then influenced by the identification of what we call the dominant perspective under which a case deserves scrutiny at a certain time to answer a specific question.

3.4. Addressing investigative problems through dominant dimensions and perspectives

More often than not, the 5W+H (Who, What, When, Where, Why and How) model is considered as a generic investigative problem solving approach. Additionally, "With Whom", "With What" and "How Many" also drive the forensic science approach to problems, and are recurrent and important questions. When facing a problem, this questioning orients the choice towards adequate visualisation techniques.

Spatiotemporal visualisation techniques are evidently chosen when the 'When' and 'Where' questions are crucial. Indeed, the *spatial* and *temporal* dimensions cover a broad range of crime investigation and forensic concerns [29]. It is thus not a surprise to observe how spatiotemporal visualisations have developed through the systematic use of geographical information systems.

Other typical central investigative questions relate to the detection and analysis of relationships between entities (such as persons, objects, traces collected at the scene, or other pieces of evidence brought together): who did what with whom, with what, etc. They constitute the third main perspective under which an investigative problem may be scrutinised, and where forensic science has obviously a great role to play. Indeed, forensic case data are commonly used to link entities by comparing characteristics of specimen collected at crime scenes with reference material.

The importance of this dimension is well illustrated by how relational databases, graph-like visualisations and social network metrics have developed to support the analysis of relations between entities in many investigative contexts. Different languages have already been proposed to analyse problems with graphs for a long time; in a court context at least since the 19^{th} century [30], in social science to detect social patterns [31] and more recently as a root method for criminal intelligence analysis [32]. However, the popularity of this kind of visualisation has grown in the early 90s when computerised tools offered easy-to-use facilities to draw so-called link-charts. This period corresponds also to the intensification of international inquiries in complex cases and in a multi-language environment. This was particularly critical in Europe. There is no doubt that the extensive use of these graphical tools has brought progresses in efforts made by investigators to build models about what is known on a case. They forced the expression of clear propositions and making informed decisions about the choice of lines of inquiries.

These three-dimensional workspaces cover a broad range of investigative questions, but the addition of a fourth *quantitative* dimension is necessary to complete the set of visualisations tools. Actually, quantitative questions are recurrent. They are used in investigations to search patterns in forensic case data, such as telephone records and financial transactions. In fact, many dedicated visual methods have been developed for quantitative analysis. They are widely studied as evidenced by the encyclopaedic list of methods gathered by Robert L. Harris [33], the seminal work of Edward Tufte [25] and the root theory of their design invented by Jacques Bertin [21]. Stephen Few has added some useful distinctions by defining quantitative analysis as the study of relationships between quantitative values (while the relational dimension covers relationships between entities). Consequently, dedicated visualisations can be classified accordingly: part-to-whole and rankings, deviations, distributions, correlations and multi-valuated patterns [34].

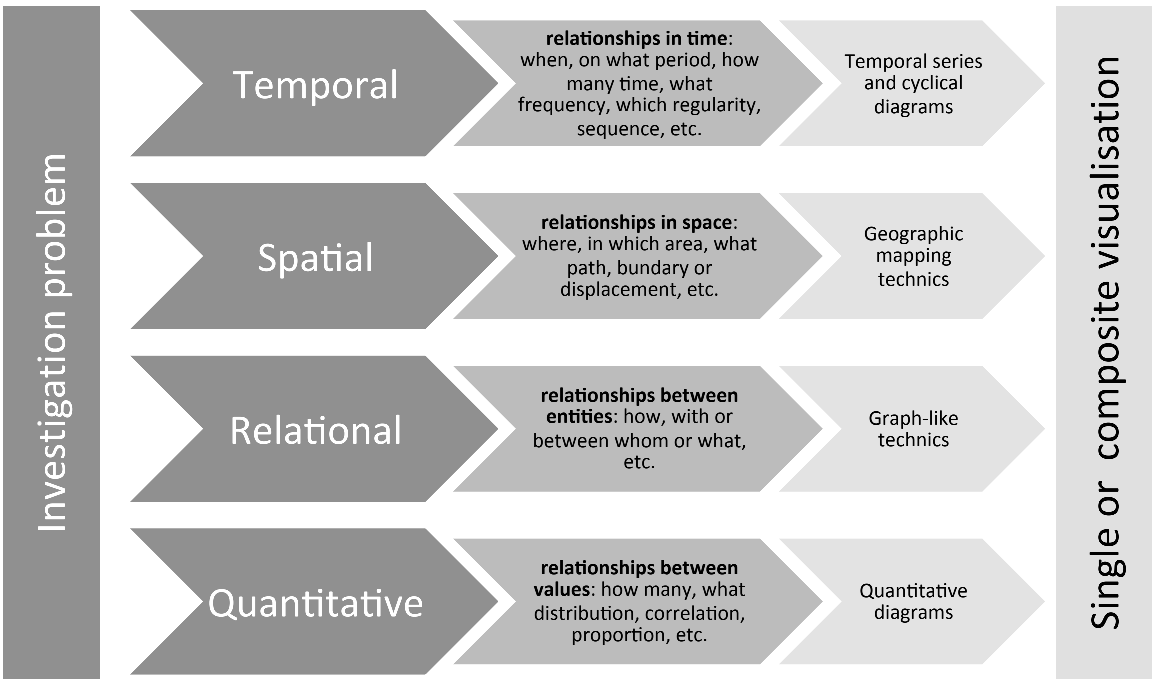

Figure 1 Analysis of investigation problem through dominant dimensions. A dimension refers to a space in which variability is observed and where dedicated questions are defined.

The classification of a specific problem by identifying its dominant dimension (temporal, spatial, relational or quantitative) allows a very general approach to each specific investigation problem. It orients towards selecting the most appropriate and effective visual abstraction although they are highly interconnected. Frequently, a combined approach is chosen (e.g., a spatiotemporal visualisation).

As link-charts play an important role in integrating forensic data, further aspects of their design are discussed in the following section.

4. Prospects to improve link-chart design

Guidance for a suitable design has been published more in practical criminal intelligence analysis manuals than in scientific papers. They remain limited and hardly go beyond very simple rules, such as a dotted-line convention to express uncertain relationships between entities and global layout advices, such as ‘minimising edge crossings’ and ‘favouring orthogonally’ to improve the readability of the chart [35,36].

There is a need for completing these recommendations on the basis of the issues presented in the previous sections. The proposed framework contains three components:

1. The definition of the characteristics of a visual language for drawing useful link-charts;
2. The formalisation of a general methodology for designing link-charts;

3. The identification of suitable visual model for expressing typical investigative sub-problems.

4.1. A better definition of visual languages without limiting their scope

Every graphical language is based on conventions between the writer and the reader. The relation between the visual sign (signifier) and its underlying meaning (signified) should be clearly defined. A visual language is expressible if it can encode all the underlying facts and only them [23]. One of the identified flaws in the design process of link-charts is the lack of a formal definition of the visual language [37].

Promising developments are based on so-called arguments and story-based diagramming approaches [38,39]. In short, they support the hypothetical-deductive reasoning of criminal investigation with causal graphs. This formalism depicts causal relations between the information collected and the hypotheses. It increases the analyst's abilities to generate and evaluate scenarios. However, their practical use may not be straightforward in practical settings, as they demand from the receiver of the information the capability of handling the formalism. On the other hand, most importantly, formalisms themselves are generally adequate to represent some aspects of a problem but are very poor in expressing other dimensions. They may limit the practical scope of the language. The complexity of many investigations, the amount of clues and the necessity to pay particular attention to specific aspects of the problem make the use of sophisticated formal analysis impracticable [40]. In particular, the kind of visualisation generally proposed does not cover many situations where link-charts have been proved particularly adequate (e.g., the analysis of criminal networks, chronologies of crime series, analysis of digital traces). De Forest highlights this tension regarding crime-scene investigation, but it is easily transposable to many investigative problems: "There is an apparent contradiction. How can we eschew a rigid protocol to be able to have the adaptability necessary to deal with the unique aspects of each case while simultaneously maintaining a systematic approach?" [11] p. 200.

Actually, the language must be sufficiently flexible to adequately grasp the most common situations. Its formalism has to be reasonably solid to avoid ambiguities, but it has to remain easy to understand for the collaborative actors solving a particular investigation problem.

We postulate that link-charts, even formally imperfect, can meet these requirements if used adequately. In this view, the production of a link-chart is considered as an intermediary modelling step in the whole process, from the early phase of the investigation to the ultimate presentation of evidence in court.

The main languages used in practice for designing link-charts are available through computerised tools such as the Analyst's Notebook®. Thus, the designers of those tools have defined the language and *de facto* impose it. In the balance suggested by De Forest, the graphical language (symbol) provided remains very flexible and simple. These qualities are certainly reasons for the great success of this tool worldwide.

Conversely, at the same time, the language has still many weaknesses. There is really a lack of convention about how to use and interpret symbols. Moreover, common situations in crime investigation cannot be represented. For instance, multiple associations (i.e., relations between more than two entities like an email with multiple receivers) or negation (i.e., a connection between entities that is known to be absent) are lacking from dedicated and widely accepted visual forms. Moreover, the language also fails to distinguish an entity from a set of entities, such as a set of persons or a bundle of goods.

In order to consolidate and enrich the language without rigidifying it, new symbols and conventions have to be adopted. Such developments and the discussion about the relevancy of new formalisms are beyond the scope of this article. Some propositions can be found in [41].

4.2. A general method to design link-charts

Conceiving an appropriate chart and reading it are thus not mechanical processes. They rather relate to the capacity of modelling a complex problem, handling uncertainties and applying critical thinking. More often than not, they rely on tacit knowledge and informal assumptions about both the question to address and the available data gathered throughout the investigation. The methodology that orients the design of a link-chart must remain sufficiently general. From the background expressed in the previous sections, we suggest the following framework:

1. Clearly define the aims of the visualisation by the identification of
    - the nature of decisions it has to support
    - the receivers and their expectations;
2. Identify the relevant entities and relationships on which their reasoning relies
3. Handle the complexity of the problem to visualise and make appropriate design choices, in particular:
    - detect and visualise uncertainties and incompleteness in data
    - distinguish facts from assumptions
    - select only relevant information, leaving out the rest

- identify appropriate visual items to express underlying concepts;

4. be aware of the biases that may be added by inappropriate visual choices:
   - handle levels of abstraction and simplification to avoid misinterpretation
   - know visualisation limits and risks to avoid unwanted effects
   - document visual choices and conventions to avoid ambiguity.

We postulate that there are still possibilities to go further in providing guides for designing relevant and efficient link-charts, keeping in mind not to rigidify the approach. A complementary prospect is thus proposed to these general recommendations. Through a bottom-up approach, some typical tasks encountered during crime investigations are systematically identified. They are then expressed by specific visual arrangements of entities in link-charts called ‘design patterns’. They are devised to be easily and unambiguously interpretable by the different actors of a collaborative approach.

4.3. Formalising design patterns

In addition to the general method, we argue that some specific forms of link-charts can be formalised. They consist of dedicated visual patterns aimed at supporting recurring tasks that occur in the course of typical investigations. Patterns are thus descriptions of specific solutions to recurring design problems [42,43]. One of these patterns is presented as an example. It covers the design of link-charts typically supporting the triage function of selecting which traces collected from the scene has to be submitted to a laboratory for analysis.

4.3.1 Visual pattern for supporting the decision to select forensic data to be analysed

In serious crime investigation, keeping an overview of all collected specimens (biological stains, among others), and of results obtained from previous operations is critical to ascertain which specimens to further submit (or not) for forensic examination. Dedicated link-charts can be used to more easily evaluate the potential of forensic operations to produce new insights. They aim at supporting joint decision-making by all stakeholders (forensic scientists, investigators and magistrates) through a collaborative discussion.

Relevant entities and conceptual model

Beyond the seriousness of the case and financial considerations, many prospects must be considered in the triage process. They contain the specific location where the specimen was collected in order to evaluate the chance to detect a profile depending on the substrate, results from previously analysed specimens, and an evaluation of the potential investigative usefulness of the forensic operation [11,44]. All of these parameters define the relevant entities that are arranged in a conceptual model suitable for handling the problem.

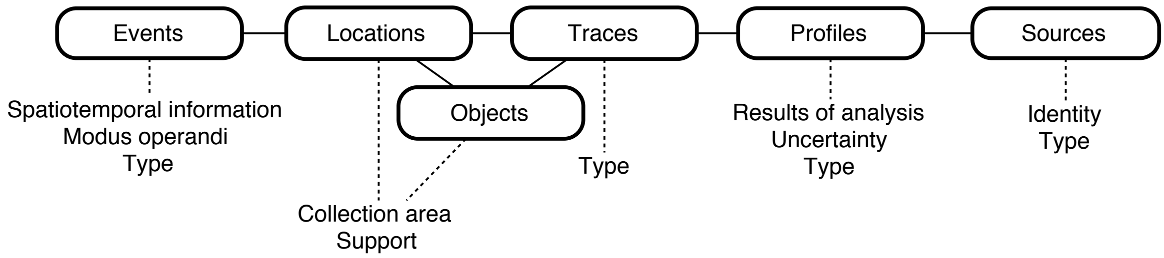

Figure 2 Conceptual model integrating the main entities involved to ascertain which traces to send to laboratory for analysis

Visualisation model

A visual model integrating several simplifications and design choices is then derived from the conceptual model. For instance, results from forensic operations are represented as coloured attributes of the nodes, which represent specimens. Icons depict the class of each entity (e.g., the DNA icon represents biological stains). Figure 3 describes the general visual model, and its application to a simple case is presented in Figure 4.

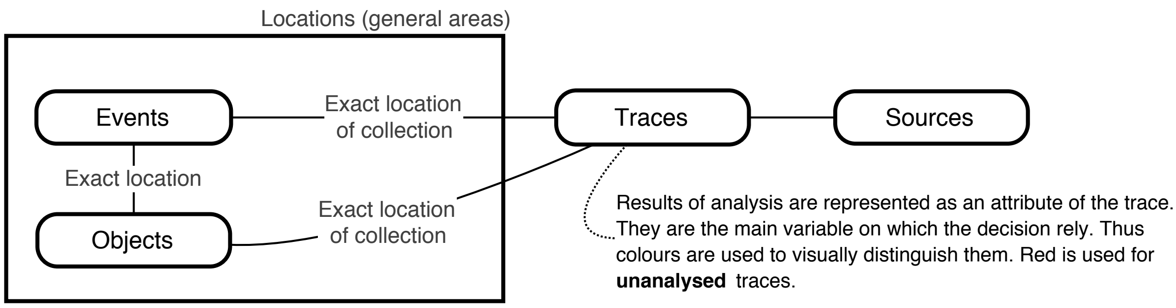

Figure 3 Visual model used to create link-charts to ascertain which traces to send to laboratory for analysis

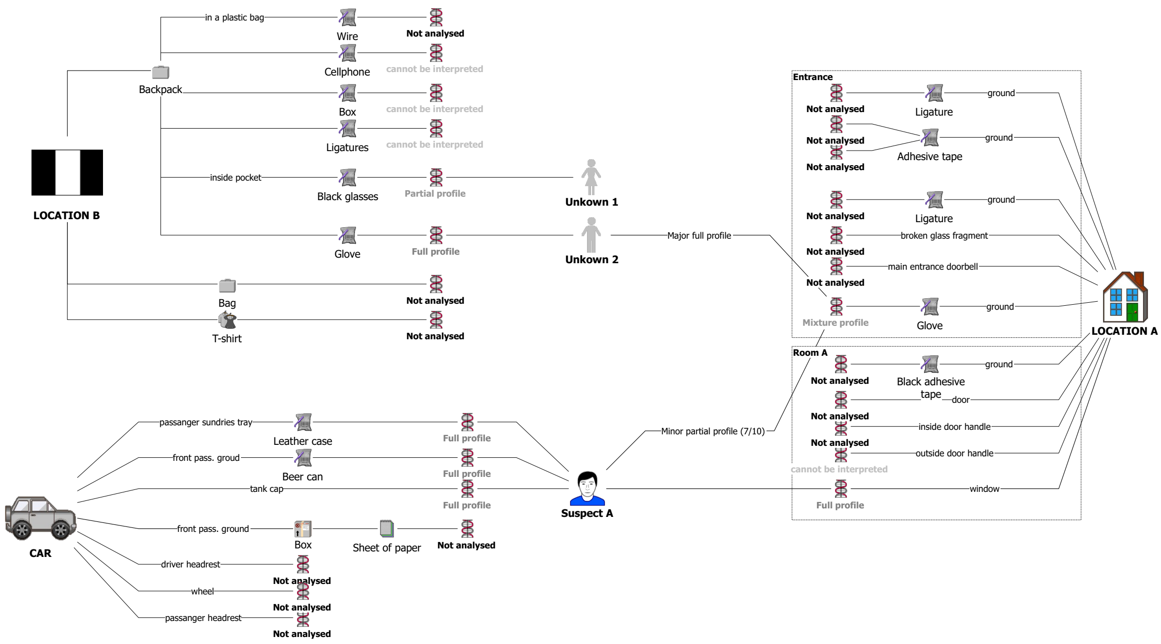

Figure 4 Simple example of visual model application

An iterative design process was conducted to maximise the final readability with known design recommendations (e.g., minimise edge crossing, maximise orthogonally, avoid distraction and orient to relevant comparisons).

Evaluations in experimental settings should still be performed, but this design pattern has demonstrated its usability in several investigations, as in the following case.

Case study

During the investigation of a robbery in a museum, more than one hundred specimens were collected at the crime scene: in vehicles used by the offenders and at the location where the stolen objects were retrieved. Half of the specimens (biological stains) were easily evaluated as relevant to the case (e.g., on pathway of introduction, ligatures, on stolen goods, etc.). They were, therefore, quickly sent for forensic examination. A few months later, the magistrate in charge (the case occurred in a jurisdiction with the inquisitorial system) asked the investigator and crime-scene examiners to evaluate the opportunity to analyse more specimens. Due to the complexity of the task, the link-chart presented in Figure 5 was produced to support the discussion with the magistrate who had to make the decision.

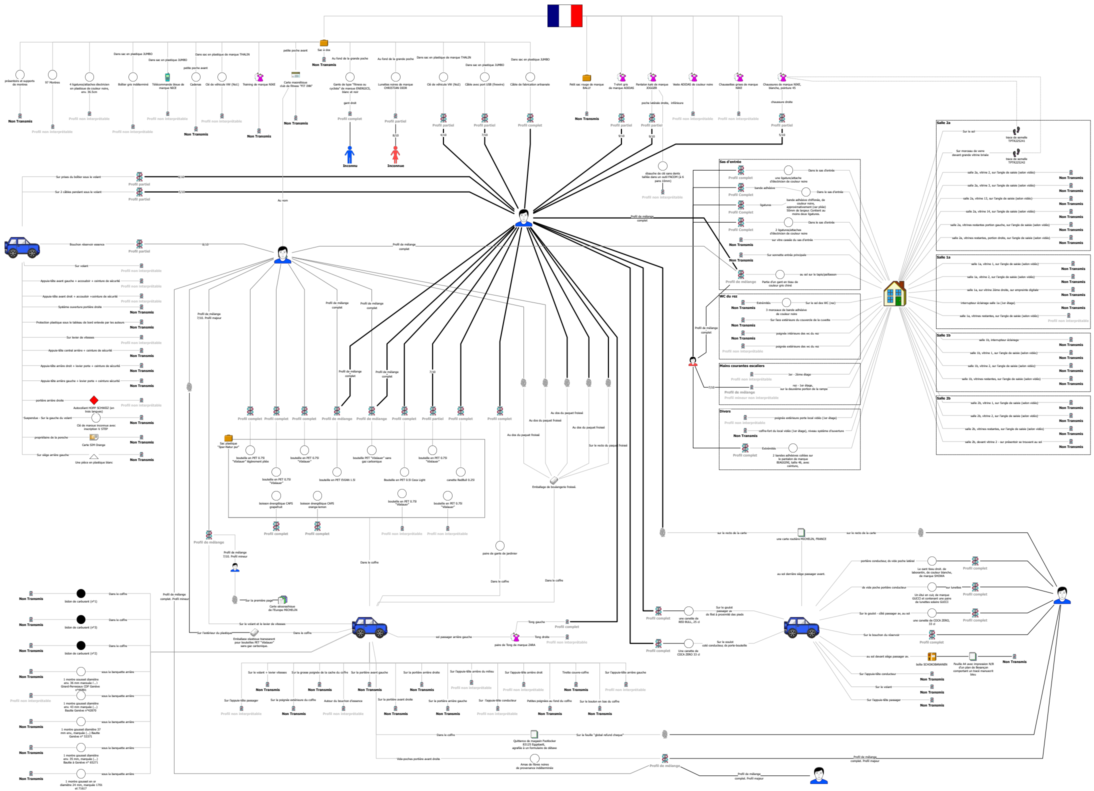

Figure 5 Link-chart designed to review a robbery case to ascertain which specimens to submit (or not) for forensic examination

The chart was printed on large page used as a shared workspace to support the decision-making process. During forty-five minutes of discussion, the opportunity to examine each specimen was evaluated, and the chart was annotated with red circles to memorise the chosen items. All relevant information needed for the task was present on the chart, and each specimen's potential to bring new investigative insight was evaluated.

4.3.2 Toward the development of a catalogue of patterns

The pattern described in the previous section is an example of an approach that can be broadened. Such a bottom-up approach starts from pieces of investigative problems for which suitable expressive visual methods have been designed, whether they are relational, quantitative, temporal or spatial ones, or a composition of several of them.

The visual arrangements that have proven efficiency during investigations are then systematically collated. This process tends to develop a catalogue of design patterns. Indeed, several patterns already initiate this catalogue, such as the reconstruction and evaluation of crime series through dedicated spatiotemporal and relational visualisations. The analysis of illicit traffics of goods with flow charts or the analysis of transactions data, such as telephone and financial records, are others common examples where typical multidimensional visualisations can be used.

This process opens the opportunity to reuse solutions found for typical investigative issues, and to converge towards the adoption of a common language between partners investigating in a collaborative way.

5. General discussion and conclusions

Due to the value and nature of information conveyed by forensic case data, a collaborative approach should be promoted in crime investigation. However, it is difficult to implement in practice in typical organisations and still largely remains to be formalised. The diversity and complexity of criminal investigation notably require methods, which enable a flexible progression in the structuring of information. We have shown how visualisation methods can contribute as an external aid to support collaborative thinking and to support joint decision-making processes. These basic methods constitute promising components of a shared methodology in line with criminal intelligence analysis.

We have shown how investigative problems can be visually analysed through four main perspectives and models: temporal, spatial, relational and quantitative. In this article, the focus was on link-charts designed to structure relationships between relevant entities, such as persons, events, traces, objects and locations.

However, the lack of guidelines and the discretional nature of the design process may occasionally lead to poor and misleading visual forms. Using visualisation as a catalyser of a collaborative approach to integrating forensic data thus calls for better specifications. Three directions have been investigated to that end. First, a better definition and an extension of the visual language are suggested to more efficiently express investigative problems. Secondly, a general methodological approach to design link-charts has been defined. Finally, the development of a catalogue of patterns has been initiated to formalise solutions to recurring and typical investigative sub-problems.

The proposed methodological improvements are not yet formally evaluated, but they have proven efficiency in real case settings. Their effects on analytic quality should be further investigated and evaluated [41]. A recent pilot study has especially shown that link-charts have a positive impact on biases reduction [45].

Finally, these methods are often left in the hand of specialists (i.e., criminal intelligence analysts), as they demand to master software functionalities. However, structuring information and stating propositions is not about using a tool; it is rather about modelling, which is the affair of all the actors. Every actor in the system should therefore be involved in the process through a collaborative endeavour. Charting is relevant not only to investigators or intelligence analysts, but also to magistrates and forensic scientists whether they are crime scene investigators or forensic analysts in laboratories. Visualisations are convenient and promising methods to structure information, support reasoning and promote collaborative work. What are still considered today as specialised activities will soon become the bread and butter of crime investigation.

6. References

[1] P. Margot, Forensic science on trial - What is the law of the land?, Australian Journal of Forensic Sciences. 43 (2011) 89–103.

[2] C. Roux, F. Crispino, O. Ribaux, From Forensics to Forensic Science, Current Issues in Criminal Justice. 24 (2012) 7–24.

[3] D. Barclay, Using forensic science in major crime inquiries, in: J. Fraser, R. Williams (Eds.), Handbook of Forensic Science, Williams Publishings, 2009: pp. 337–358.

[4] J. Robertson, Forensic science, an enabler or dis-enabler for criminal investigation?, Australian Journal of Forensic Sciences. 44 (2012) 83–91.

[5] G. Jackson, S. Jones, G. Booth, C. Champod, I.W. Evett, The nature of forensic science opinion--a possible framework to guide thinking and practice in investigations and in court proceedings., Science Justice Journal of the Forensic Science Society. 46 (2006) 33–44.

[6] D.M. Risinger, Reservations about likelihood ratios (and some other aspects of forensic “Bayesianism”), Law, Probability and Risk. 12 (2013) 63–73.

[7] NAS, Strengthening Forensic Science in the United States: A Path Forward, National Academies Press, Washington, D.C., 2009.

[8] W.C. Thompson, What role should investigative facts play in the evaluation of scientific evidence?, Australian Journal of Forensic Sciences. 43 (2011) 123–134.

[9] W.C. Thompson, S. Ford, J.R. Gilder, K. Inman, A. Jamieson, R. Koppl, et al., Commentary on: Thornton JI. Letter to the editor-a rejection of “working blind” as a cure for contextual bias. J Forensic Sci 2010;55(6):1663, Journal of Forensic Sciences. 56 (2011) 562–563.

[10] S.S. Kind, The scientific investigation of crime, Forensic Science Services Ltd, Harrogate, 1987.

[11] P.R. De Forest, Recapturing the essence of criminalistics, Science & Justice : Journal of the Forensic Science Society. 39 (1999) 196–208.

[12] K. Inman, N. Rudin, Principles and practices of criminalistics: the profession of forensic science, CRC Press, Boca Raton, 2001.

[13] F. Crispino, Le coordonnateur en criminalistique : un nouvel acteur du renseignement criminel, Revue de La Gendarmerie Nationale. 233 (2009) 6–14.

[14] Y. Schuliar, La coordination scientifique dans les investigations criminelles. Proposition d'organisation, aspects éthiques ou de la nécessité d'un nouveau métier, Ph.D. Thesis. Université Paris 5 - Descartes Faculté de Médecine and Université de Lausanne, Institut de Police Scientifique, Paris and Lausanne, 2009.

[15] B. Gray, Collaborating: Finding Common Ground for Multiparty Problems, Jossey-Bass, 1989.

[16] A. Ludwig, J. Fraser, R. Williams, Crime Scene Examiners and Volume Crime Investigations: An Empirical Study of Perception and Practice, Forensic Science Policy & Management: An International Journal. 3 (2012) 53–61.

[17] M.B. Peterson, B. Morehouse, E. Wright, Intelligence 2000: revising the basic elements, Law Enforcement Intelligence Unit and International Association of Law Enforcement Intelligence Analysts, Lawrenceville, NJ, 2000.

[18] H. Atkin, Criminal intelligence analysis: a scientific perspective, IALEIA Journal. 13 (2000) 1–15.

[19] P. Aepli, O. Ribaux, E. Summerfied, Decising making in policing, EPFL Press, Lausanne, Switzerland, 2011.

[20] S. Egger, A working definition of serial murder and the reduction of linkage blindness, Journal of Police Science and Administration. 12 (1984) 348–357.

[21] J. Bertin, Sémiologie graphique: les diagrammes - les réseaux - les cartes, 4ème éd., Les ré-impressions des Editions de l'Ecole des Hautes Etudes en Sciences Sociales, Paris, 2005.

[22] J.W. Tukey, Exploratory Data Analysis, Addison-Wesley Publishing, 1977.

[23] J. Mackinlay, Automating the design of graphical presentations of relational information, in: M.T. Maybury, W. Wahlster (Eds.), Morgan Kaufmann Publishers Inc., San Francisco, CA, 1986: pp. 177–193.

[24] D.A. Norman, Things that make us smart: defending human attributes in the age of the machine, Basic Books, New York, NY, 1993.

[25] E.R. Tufte, The visual display of quantitative information, 2nd ed., Graphics Press, Cheshire, CT, 2001.

[26] D. Keim, M. Ward, Visualization, in: M. Berthold, D.J. Hand (Eds.), Intelligent Data Analysis, 2nd ed., Springer, Berlin Heidelberg, 2007: pp. 403–427.

[27] S. Bresciani, M. Eppler, The risks of visualization. A classification of disadvantages associated with graphic representations of information, in: P.J. Schulz, U. Hartung, S. Keller (Eds.), Identität Und Vielfalt Der Kommunikations-wissenschaft, UVK Verlagsgesellschaft mbH, Konstanz, Germany, 2009.

[28] Q. Rossy, O. Ribaux, La conception de schémas relationnels en analyse criminelle: au-delà de la maîtrise des outils, Revue Internationale de Criminologie et de Police Technique et Scientifique. LXV (2012) 345–362.

[29] C. Weyermann, O. Ribaux, Situating forensic traces in time, Science and Justice. 52 (2012) 68–75.

[30] J.H. Wigmore, The principles of judicial proof as given by logic, psychology, and general experience, and illustrated in judicial trials, Little, Brown, and company, Boston, 1913.

[31] J.L. Moreno, Who shall survive?, NY: Beacon House. (1953).

[32] W.R. Harper, D.H. Harris, The application of link analysis to police intelligence, Human Factors. 17 (1975) 157–164.

[33] R.L. Harris, Information graphics: a comprehensive illustrated reference, 1ère éd., Oxford University Press, New York, NY, 2000.

[34] S. Few, Now you see it: simple visualization techniques for quantitative analysis, 1ère éd., Analytics Press, Oakland, CA, 2009.

[35] M.K. Sparrow, The application of network analysis to criminal intelligence: an assessment of the prospects, Social Networks. 13 (1991) 251–274.

[36] C. Mowbray, Analytical charting, in: S. Gwinn, C. Bruce, J.P. Cooper, S. Hick (Eds.), 2ème éd., BookSurge Publishing, Overland Park, KS, 2009.

[37] R.N. Reed, P. Kocura, Conceptual graph based criminal intelligence analysis, in: F. Dau, M.-L. Mugnier (Eds.), Kassel university press, Kassel, Germany, 2005: pp. 146–159.

[38] F. Bex, S.W. van den Braak, H. van Oostendorp, H. Prakken, B. Verheij, G. Vreeswijk, Sense-making software for crime investigation: how to combine stories and arguments?, Law, Probability and Risk. 6 (2007) 145−168.

[39] S.W. van den Braak, Sensemaking software for crime analysis, Ph.D. Thesis. Department of Information and Computing Sciences, Utrecht University, 2010.

[40] P. Tillers, Introduction: visualizing evidence and inference in legal settings, Law, Probability and Risk. 6 (2007) 1–4.

[41] Q. Rossy, Méthodes de visualisation en analyse criminelle: approche générale de conception des schémas relationnels et développement d'un catalogue de patterns, Ph.D. Thesis. School of criminal justice, University of Lausanne, 2011.

[42] C. Alexander, The timeless way of building, Oxford University Press, New York, NY, 1979.

[43] E. Gamma, R. Helm, R. Johnson, J. Vlissides, Design patterns: elements of reusable object-oriented software, Addison-Wesley Longman Publishing Co., Inc., Boston, MA, 1995.

[44] N. Tilley, A. Ford, Forensic Science and Crime Investigation, Crime Prevention and Detection Series paper 73, London: Home Office, 1996.

[45] D.R. Kretz, B.J. Simpson, C.J. Graham, A game-based experimental protocol for identifying and overcoming judgment biases in forensic decision analysis, in: Homeland Security (HST), 2012 IEEE Conference on Technologies For, 2012: pp. 439–444.