Title : The progressive opening of forensic science towards criminological concerns

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Topic: Fusing Forensic Science and Criminology

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Abstract :

Technology is increasingly driving our lives and simultaneously offering new means of human behavior traceability. This situation is significantly challenging the standing, scope and role of forensic science in the criminal justice system. At the same time, criminology is developing innovative methodologies that encompass virtual worlds, and deal with the increasing quantity of accessible digital data reflecting criminal behaviors.

Identifying how these concerns overlap begs the question: should we reconsider the articulation of many aspects of both forensic science and criminology? Indeed, many opportunities exist and call for the (re-) emergence of fused approaches that rest on the information conveyed by the most fundamental element of forensic science: the 'trace', remnant of a litigious activity.

This paper proposes a progressive and systematic modeling activity along five steps: (a) the expression of the investigative logic of forensic science, which is aimed at reconstructing single events that occurred in the past by the interpretation of collected data from the scene of interest; (b) the use of theories in environmental criminology, in order to consider more explicitly the relation between the trace, its source, and the activity in the immediate physical and social environment; (c) a more systematic search for associations between traces, as well as between crime situations, which enables the eventual emergence of general models for studying crime repetitions, criminal behaviors and behaviors systems in crime; (d) find out

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studies in diverse areas of criminology that actually or potentially rely on forensic case data and (e) propose models and methods for framing the approach.

This progressive opening of forensic science towards criminological concerns is undertaken by a group of forensic scientists active in Australia, Canada and Europe and who are committed to defragment the compartmentalized fields of forensic science.

Keywords : forensic intelligence, interdisciplinary, crime science

Introduction

In 2009, the National Academies of Science reported a troublesome picture of 'forensics' in the United States (NAS 2009). The forensic science laboratories and experts were presented as often using technologies that had not been submitted to proper scientific validation. This shortfall was pointed as the source of errors in high profile cases leading to poor investigative or Court's decisions. The system was presented as fragmented, under the influence of the police leading inquiries, and relying on poor scientific underpinning. These criticisms found echoes in other countries. For instance, a recent Canadian report (Pollanen *et al*. 2013) made similar criticisms and called for specific academic research with dedicated funds that yet remain to be found. This latter report is in line with concerns expressed by academics in the wake of the NAS report (Margot 2011a; Mnookin *et al*. 2011).

At the root of a heated debate since its diffusion (Risinger 2009; Cole 2010; Risinger 2010), the NAS Report endorses the view that the contribution of natural sciences to the Criminal Justice System is highly specific, based on the use of a patchwork of disparate and difficult to use technologies, some of them being only emerging and not fully understood. In front of this complexity, the Justice System's reaction is to limit the intrusion of what is perceived as flawed information in its decision-making process by applying tight controls. This creates the view that 'forensics' is highly (over-) specialized. It consists of technical application of core enabling disciplines. Forensic chemistry, forensic biology or computer forensics must be submitted to a growing set of rules and constraints imposed by their customers. This fragmented and confined view is ratified by the use of the term 'forensics' rather than 'forensic science' as criticized in (Roux *et al*. 2012). This lack of unity leads to many different implementations in organizations between and within countries. A dominant occidental view speculates however the existence of a 'traditional laboratory' delivering 'services' mainly to the Justice or the Police (Bedford 2011). In this conception, it is ideally accredited, autonomous from police organizations, private or based on a well formalized

model of accountability, divided into separated specialized departments with few connections, technically well equipped, populated by civilian academics employees coming from a fundamental discipline or their derivative (e.g. chemistry, biology, computer science). More often than not, these scientists have no real background in either forensic science or criminology. This has shown to cause many drawbacks when these scientists are confronted to practical situations (Mennell 2006; Roux and Robertson 2009; Crispino *et al*. 2014).

The paradigm endorsed by these reports and the model of the 'traditional laboratory' further separates, as a side effect, forensic practices and research from potentially related criminological or sociological areas. There are very few incentives for criminologists and forensic scientists to meet. We argue that this framing of the disciplines is a missed opportunity to more fully exploit information conveyed by forensic case data to the benefit of the study of crime, to overall security system and, ultimately, to society at large.

Observing forensic investigators in the laboratory or at the scene occasionally would reveal an interesting picture leaning towards our argument (Delémont *et al*. 2014): They recurrently detect, collect, analyze and interpret the relics of criminal activities. They reconstruct and explain what occurred in the past and detect patterns of repetitive crime activities. They are privileged observers through their daily confrontation to crime, and the consequent experience and expertise in interpreting forensic case data they have gained over time. For example, when analyzing illicit drugs, analytical data may not only depict the chemical structures of the seized substances (Esseiva *et al*. 2003), but also identify changes in these structures. Hypotheses are drawn for explaining these changes and this may provide a dynamic picture of certain dimensions of the illicit drug market (Morelato *et al*. 2014a). The aim of the analysis and the results are however entirely devoted to the Justice System (i.e. identifying and quantifying the substance in order to charge a suspect), which illustrates a perceived limited interest in general knowledge about the crime pattern. This information, more often than not, is confined within laboratories and does not feed studies on these illicit markets, for example.

Recurring similar observations reinforce the assumption of a net loss of information: remnants of criminal activities can help decipher crime mechanisms. Nowadays, technology is increasingly driving our lives and is simultaneously offering new means of human behavior traceability. Potential areas for interdisciplinary researches are proliferating but need to be identified and delimited. The aim of this paper is to initiate this process and identify areas of common interests for *a priori* disconnected communities.

This is proposed by a group of forensic scientists strongly believing in the potential of this integration. It is, however, recognized that the authors have a limited view on the diverse conceptions and facets of criminology, as well as on the many controversies characterizing this discipline. A systematic and progressive approach for opening forensic science to some areas of criminology is adopted. Modestly, it identifies potential focal points where linking criminological models with forensic considerations and practices has the potential to create new pieces of knowledge and facilitate the emergence of new models for both disciplines.

The approach remains largely incomplete, and aims at providing a solid and affordable entry point to attract the attention of practitioners and researchers in new areas prone to promising developments rather than proposing a 'magic bullet' to address the fundamental issue.

As a method for structuring the debate, we suggest a return to works proposed by the pioneers in forensic science and criminology, at a time when the divide between the disciplines was not apparent. The Locard postulate is a building block that grounds a holistic view of forensic science that is much more integrated with criminological objectives than the currently dominant 'forensics' proposal.

Our approach may be rightly considered as unbalanced according to a journal focusing on security issues, and in particular the topic of this special issue: it gives more weight to a forensic science perspective. The intention behind the last section is an attempt to compensate this bias and suggests potential connections between models and methods. Further, it cautiously considers the reverse (criminology) perspective citing a selected set of works, where criminologists have shown interest in using forensic science models and data.

Finally, from a methodological perspective, adopting a case-based reasoning approach is a promising avenue for structuring the debate. Such models integrate particular cases scrutinized by forensic science with general models coming from different areas of criminology. It is pivotal for supporting the emergence of new models and methods.

The Locard postulate at the crossroad of disciplines

Forensic science rests on a postulate, often called the *Locard's exchange principle* from the name of Edmond Locard (1877-1966). This famous French scientist opened in 1910 the first laboratory servicing the Justice System. The postulate is better known under the form of 'Every contact leaves a trace'. There are however many other ways to express the basic ideas behind the exchange (Crispino 2006). For instance, the following quote is often used as a reference:

> *The truth is that none can act with the intensity induced by criminal activities without leaving multiple traces of his path. [...] The clues I want to speak of here are of two kinds: Sometimes the perpetrator leaves traces at a scene by their actions; sometimes, alternatively, he/she picked up on their clothes or their body traces of their location or presence (Locard 1920: Chapter IV, translated by the authors)*

This definition is composed of three main aspects; (a) the nature of the criminal activity influences the types of material that are exchanged, and how they are dispersed in the environment or taken by the offender; (b) these materials, remnant of the activity are the *traces* that become signs when detected, recognized, collected and measured; (c) an interpretation process aims at transforming them into clues in order to reconstruct what occurred.

The formulation 'every contact leaves a trace' does not take into consideration the nature of the activity and its specific role in the exchange. Nor does it refer to the correct inference rule ('abductive' process) that starts from the effects to identify the possible causes - what activity caused the trace? (Schuliar and Crispino 2013). Conversely, Locard's actual formulation insists on the relationship between the activity and the trace:

> *Contrarily to all other sciences, forensic science is looking at the least likely, fragmented, imperfect, uncontrolled element in an event: the trace, which, by definition, is a pattern, a signal or material transferred during an event (often unknowingly by the actors of the event). It is the remnant (the memory) of the source (identity – who, with what?) and of the activity (what, how, when, why?) that produced it. It has to be decoded and understood to elicit some knowledge about the event. The study of its relation to other traces as well as their environment provides many, and sometimes unsuspected, clues about the event and is a rich source of hypotheses to be tested as well as providing knowledge about reality. This reality is a construction that allows going back to its primitive source in a sort of recurrent logic. (Margot 2011b: 91)*

Traces are collected because they are supposed to be connected with entities of interest, and because they have a potential utility in explaining the activity they originated from. Each discipline interested in such activities thus meets forensic science at this point: Law because this activity may mean an offense; criminology, because the deciphered mechanisms can inform on disorders, deviant behaviors, or more broadly on crime. Whatever the goals of these disciplines are, forensic science cannot remain isolated as it holds a great deal of information and knowledge that are also relevant to them.

Conversely, the interpretation process of the forensic scientist cannot abstract from assumption about the activity. It must integrate at different points knowledge about criminal behaviors in its immediate environment. This is most obvious at the crime scene, which is the

seminal area of forensic science. Indeed most crucial decisions made at the scene will impact on the relevance, quality and quantity of traces generated by the offenders and available to further processes (Crispino 2008).

Crime scene investigation and situational analysis

Methods and techniques available for detecting, observing, recording, measuring and analyzing traces constitute the 'toolbox' of forensic science. Its use must meet identified objectives by adopting a strategy. Crime scene examiners (CSE) bring their 'toolbox' on the place where a crime is supposed to have occurred. They search systematically for relevant traces, i.e. connected with the activity of interests and useful for its explanation (who, where, when, what – with what, how, why).

The constraints of CSE at the scene concern often the means (i.e. time, available technology, restriction about the type/number of traces/exhibits to be collected) when high volume crime is investigated. However, the requirement to reach an outcome is predominant when serious crime is considered.

Crime scene investigation is not a passive process, as CSE know what kinds of traces they can expect to discover. They distinguish, in function of the physical environment, which techniques are preferable to use for detecting, without destroying or polluting, often very small quantities of material that is sometimes invisible to the naked eyes. They also appreciate the persistence of the relevant material: an item under water may still support a detectable fingermark, for example (Dulong 2004).

These kinds of knowledge come from the natural sciences and constitute the usual background of CSE. They are however insufficient for using adequately the 'toolbox' in regards to the purpose of the collection and also considering pragmatic constraints. Locard brought another element to the fore: he postulated that exchanges of material depend on the nature of the activity. Indeed, CSE imagine where the offender entered into contact with the entities that were present at the scene when the activity took place. When interviewed, CSE emphasize the need of 'thinking like an offender' and of understanding the 'big picture' to collect relevant traces able to support investigative and court processes (Wyatt 2014)

They must conceive the behavior of the offender in the immediate physical and social environment to find these 'contact points'(Barclay 2009): what were the obstacles to be overcome? Were there guardians protecting the target? What were the opportunities for the thieves? What about situational clues that may have influenced the behavior of the offender?

Did the offender follow an already known script that could help grasp movements (Turvey 2011)?

These questions obviously remind this important stream in criminology that studied opportunities for crime to occur in specific situations: what are the conditions for the motivated offenders to meet a suitable and poorly protected target (Cornish 1994; Felson and Clarke 1998; Wortley and Mazerolle 2008)? The knowledge gained by research in these area of criminology has found many practical uses through situational crime prevention and crime analysis (Clarke and Eck 2005; Boba 2009). Forensic science, including crime scene investigation, implicitly – almost naturally – embrace some of this knowledge; however it still does not seem to have grasped its potential to explicitly enrich and structure its methods in this direction (Schuliar and Crispino 2013).

The tendency is rather to guide the collection of traces by an inflation of standard operating procedures. In particular, Wyatt (2014: 445) concludes from his observation and interviews of crime scene investigators ' that specific contamination avoidance practices and the perceived absence of administrative errors enable the competent CSI to blackbox their activity and safeguard the forensic artefact from courtroom questioning'.

This administrative frame reduces crime scene investigation as a mechanical process: following harmonized procedures should ensure that justice requirements are met in the global chain of custody. Conversely, when procedures are strictly and carefully followed, CSE will be protected from contestations at Court. This approach presents moreover the managerial advantage that employees with a minimum training will be able to perform the task. When police and forensic science practitioners are interviewed, they surprisingly often agree with this viewpoint (Ludwig *et al*. 2012). This may be explained by a perception that compliance equates to quality.

However, despite this deployment of procedures, unexplained discrepancies are recurrently observed when performances of CSE are measured. Considerable differences in quantity and quality of traces collected is recurrently detected, whatever the procedures in place. They are also observed between CSE under the same constraints and facing the same forms of criminality (Tilley and Ford 1996; Bradbury and Feist 2005). This may be explained by the fact that only parts of the CSE work can be formalized and that a significant part of their actions depends on the overall situation. It may also mean that, at the scene, CSE enjoy a significant discretionary decision process that is not grasped by formal procedures.

Very little research is undertaken in this area, and this is unfortunate. We may nevertheless assume that this peculiarity of CSE work derives from a poor consideration of the 'abductive' logic for reconstructing the event at the scene (Crispino 2008). In this context, the interest of integrating the analysis of crime situations in the reasoning process of forensic science and crime scene investigation becomes more evident (Schuliar and Crispino 2013).

Forensic science in policing

Requirements of the justice system take precedence over policing strategies in forensic science: doing the things correctly in the prevision of a court trial is much more prioritized than providing knowledge serving other models of policing such as community oriented, problem oriented (Goldstein 1990), reassurance (Innes and Fieldings 2002) or intelligence-led policing (Ratcliffe 2008).

This may look as a paradox because crime scene examination usually takes place within police structures deploying policing strategies. It may be because departments dealing with investigations often host CSE. They concentrate their efforts on structuring evidence for Court purposes. Procedures determining priorities and means for the interventions nevertheless contradict this viewpoint. They generally stem from managerial considerations related to policing strategies and/or economical constraints. In the end, in the area of crime scene investigation, organizations place the practice of forensic science in an ambivalent situation prone to create tensions. The situation is exacerbated by the absence of support from the laboratory-based forensic community which often sees crime scene investigation as a separate and mechanical activity; crime science investigation is seen as only preparatory to forensic science and not an integral part of the discipline. Misunderstandings are pervasive.

For instance, this context incites external communities to measure the effectiveness of forensic science through its contribution to solve crimes and along policing issues. Results are systematically disappointing because evaluation studies consider items that are not the focus of (traditional) scientists. Most of the imposed efforts are effectively centered on the rare cases, proportionally to the number of interventions of CSE, where evidence is presented in Court. Judgments derived from such evaluations generalized to the whole discipline are unfair (Bitzer *et al*. 2014; Roux *et al*. 2014).

Forensic science in community and reassurance policing

There is an obvious parallel between the situation of CSE and how policing was considered before empirical studies were launched in the United States in the 70s. During this period, the

professional model attributed in the USA to August Vollmer was criticized for having guided policing towards a predominance of means on ends (Goldstein 1990). These studies have recurrently showed that important decisions were effectively made in the street through the interpretation of the specific situation officers faced, rather than by the mechanical application of legal rules and procedures. To effectively study police interventions, it was suggested to forget books on policing, and to use methodology focused on observations in the field. This movement has had a great influence on the development of more decentralized way of organizing police work through community policing or problem oriented frameworks. How far and systematically such models of policing are effectively implemented is open to debate and beyond the scope of this paper. Research in the field of community policing has been nevertheless massive and supposed to have explored comprehensively possible avenues. CSE have not been truly identified as figures of interest. They are yet at the forefront to create links with communities, reassuring victims, and participating to prevention programs by the understanding of crime situations they have developed through their confrontation to crime scenes. How far the practice of forensic science should embrace such a model is open to debate, but this dual role is *de facto* endorsed by CSE in the field, expected from the public, as well as enshrined by certain practices (Delémont 2008). It would deserve much more consideration from research.

Forensic science for the analysis of repetitive crimes

The ambivalent role of forensic science is also inherited from the difficulties to configure security and justice through coherent strategies and organizations (Brodeur and Shearing 2005). The relative autonomy from law enforcement gained by modern proactive and preventive policing models demands further efforts for forensic science to re-identify and expand its role.

Modern policing centers on crime analysis to search for patterns in police data that reflect regularities in activities. These patterns provide some degree of prediction, by assuming that regularities from the past will reproduce in the future. These previsions allow proactivity and prevention. How could forensic science participate to this 4P model, i.e. Patterns, Prediction, Proactivity, and Prevention (Ratcliffe 2011) ?

At a first glance, an argument seems preventing such engagement. Locard postulate states that forensic science deals with the particular, the singular case that occurred in the past, and that

has to be reconstructed. Crime analysis, as well as criminology, is interested in the general, in patterns that provide possible generalizations.

However, reasoning in forensic science does not mean that each problem investigated should be solved in isolation. A successful experience is reused when a new similar problem is faced. In such a case-based form of reasoning, analogies is at the heart of the process: similar situations encountered are prone to reusability and even to generalization (Kolodner 1993).

Crime scene examiners are confronted to recurring similar situations of a great variety of forms. Patterns can emerge from the systematic comparison of what has been observed and assumed on separated interventions. Such forensic interventions does not limit to crime events. For instance, successive scenes of fires scrutinized by forensic scientists make occasionally appear a recurrent technical cause which, in turn demand the definition of security norms targeting prevention (Martin *et al*. 2005). The analysis of data collected by CSE could thus be fully and systematically integrated into SARA (Scanning, Analysis, Response, Assessment)-like methodologies of problem oriented policing.

This was illustrated by Braga (2008) participating to a program about youth violence in Boston. The systematic comparisons of bullets collected at different scene increased knowledge on how local gangs were structured, by identifying when and where the same guns were used.

More generally, the work by crime scene examiners attending scenes caused by prolific offenders can lead to compare traces and make links between apparently separated offenses. This process is systematized when forensic analysis models provide framework for comparing traces of different types with the support of databases (e.g. DNA profiles, footwear marks, earmarks, toolmarks, CCTV images, digital data). This analytical activity contributes further to support the rapid detection and deep analysis of repetitive crimes in broader forensic intelligence and crime analysis processes (Morelato *et al*. 2014a).

The interest to use the information conveyed by traces in proactive style of policing and in the analysis of high volume crimes is not recent. Tilley and Ford (1996) already highlighted this unused potential. This weakness was again stated when the National Intelligence Model was implemented in the UK, despite the existence of interesting local practices (Blakey 2002). Inference structures have been expressed to model how the integration of a variety of traces (e.g. footmarks, DNA profiles, CCTV, earmarks) provides intelligence for operational decision makers. Databases dedicated to crime analysis have been developed to integrate the

marks of the offenses and allow their systematic comparisons. These implementations have brought new light on the structure of high volume crimes in specific regions. In particular, groups of burglars have proved to move considerably across countries in Europe (Rossy *et al*. 2013).

Primarily conceived for identifying offenders, DNA databases have shown to be particularly useful for detecting the structure of the activity of same groups of prolific offenders across different regions. Linking DNA profiles extracted from material collected at different scenes allow this detection without knowing about the offenders themselves (Walsh *et al*. 2002; Walsh and Buckleton 2004; Walsh 2009). In Europe, the Prüm Implementation, Evaluation and Strenghtening of Forensic DNA Data Exchanges (PIES) project uses this advantage in terms of privacy. It aims at developing the systematic use of forensic links to feed a global view on organized crime that inform strategic decisions at a EU level (van Rentherghem 2014).

Some papers in this issue will illustrate how this forensic-based approach to crime analysis and intelligence still develop to detect and allow monitoring many crime problems. Expression of transversal intelligence processes for the integration of different sources of forensic case data show the willingness to make these technical information available to other communities interested in detecting, monitoring and deciphering crime mechanisms (Morelato *et al*. 2014a).

Decentralization and the increasing latitude of CSE

The links between CSE's tacit knowledge and the analysis of the information collected and treated in intelligence-led like models should be further expressed.

This is a common observation that when collectors of information are not concerned by their use, quality of the information decreases dramatically. This argument becomes critical with the development of so-called 'lab-on-a-chip' technologies. In short, a movement driven by the analytical chemistry field and the technology market tends to deploy the use of technologies directly in the field. DNA analysis, illicit drug characterization and many other treatments, kept nowadays within laboratories, will be soon, if not already, transferred closer to the scene (if not at the scene)[4]. Features extracted from traces treated at the scene or very early in the process, will be much more rapidly and in more quantities available for data treatments.

[4] see for instance forensic projects suggested in the European framework for research called Horizon 2020 : http://ec.europa.eu/programmes/horizon2020/ (accessed 22 April 2014)

This means that the role of CSE not only in collecting traces, but also in making sense of them, will still increase in the near future. This will blur the limit between the crime scene and the specialized laboratory. CSE will have more latitude in directly detecting, analyzing and using the collected data. This will further increase the discretionarily nature of their work at the scene. The unclear roles of forensic science and of CSE in the many processes they feed, and poor consideration of the fundamental logic that is used are troublesome in this emerging context.

This is particularly important in a landscape where conceptual and operational progresses mentioned above must not hide that most of implementations still lack of models for integrating biometrical technologies and forensic database into well-formed strategies. There is a point of rupture here because the order of magnitude in the quantities of data available has recently changed, and will still be boosted by the 'lab-on-a-chip movement'.

The effectiveness of forensic databases in policing

The unclear role of forensic databases in a new 'big data' context can be illustrated by how the many forensic databases have been implemented and have grown (Walsh *et al*. 2008).

In the UK, the decision to expand the use of the national DNA database has been largely justified by the aim of 'filling the justice gap' and 'thus' reducing crime by integrating all the active criminal population in the database (McCartney 2006). Consideration about criminal careers and the polymorphism of violent offenders have also brought some indication about the advantages of taking samples from offenders early in their career (Leary and Pease 2003; Walsh 2009). This process was supported by evaluative studies on the use of forensic case data in solving high volume crimes, although crime reduction, a more desirable effect in terms of security, would be difficult to prove (Burrows and Tarling 2004). The very competitive market providing services for extracting DNA profiles from specimen also stimulated this expansion that were followed by many countries.

The real value for policing of this expansion has been however criticized (McCartney 2006) and rarely addressed by empirical studies (Wilson *et al*. 2010).

Scientists at the forefront in operationalizing DNA databases themselves have occasionally complained about the lack of models for integrating their contribution in the broader criminal justice system.

> *A lack of integration between the DNA laboratories and the other components of the justice system responsible for following up on results is perhaps the biggest weakness, in that desirable outcomes have not been clearly defined or carefully researched (Bieber 2006: 231)*

Existing biometrical systems for checking identities and forensic databases generate matches in order of magnitude that have recently changed. Their number becomes intractable for the criminal justice systems. Instead of going towards an integration of forensic case data in proactive well defined models of policing, we may experience an intensification of a traditional style of policing entirely determined by matches obtained from databases. This emergent database-led style of policing highlights the urgent need to define and evaluate strategies for integrating the contributions of identification databases.

This is a turning point well grasped by the PIES project (see above). It illustrates that building an infrastructure for the automatic exchanges of data, in itself, offers no guarantee for providing better security; it may even obstruct the overall efficiency of the process by dramatically increasing the administrative and scientific workload related to the need for confirmation of the overabundance of possible hits. Well-defined and evaluable policing strategies that pilot the use of these infrastructures are currently lacking. This gap deviates from the right question: the evaluation of the way information conveyed by forensic case data is used according to specified security objectives. Challenges for forensic science are thus now much more about defragmenting by modeling with other communities, than creating new databases, technologies or channels.

Beyond intelligence and policing

The next step for the progressive opening of forensic science to criminological concerns consists of going beyond the practice of crime analysis and studies in policing. It is much more difficult to the authors of this paper to provide an accurate, structured and comprehensive account. However, we may search some signs that indicate possible avenues and initiate the definition of different areas of interest. This approach should be next completed by further iterations collectively elaborated through interdisciplinary research activities.

Some criminologists have perceived the potential of the trace (material or numerical) to support the study of their traditional objects. The variety of possible combinations found in the peer-reviewed literature is surprising.

The study carried out by Fortin (2014) is an original illustration of the need to consider forensic science and criminology in a common framework. He uses numerical traces collected on computers of persons convicted of downloading illegal images on the internet. He successfully deviated the traces from their use in criminal procedures to induce some learning mechanisms about how offenders access the information targeted, and test some hypotheses about the psychosocial profile of such 'collectors'.

How long offenders manage to escape an arrest has been recently studied through the use of DNA links, as well as if mobile offenders are less likely to be caught (Lammers *et al*. 2012; Lammers and Bernasco 2013). Lammers (2014) has also compared patterns of arrested offenders from those who are not arrested. In particular, these kinds of studies try to respond to concerns about a possible selection biases in the traditional focus in criminology on arrest data when evaluating spatial offending patterns. This means also that such studies can abstract from personal data by using forensic links to study patterns related to criminal careers and repeated behaviors. The scope of this set of studies, only partially reported here, emphasizes the richness of information conveyed by DNA profiles stored in databases. It feeds significant traditional areas of criminological concerns. This kind of thinking has a direct practical impact; the Belgium Be-Gen[5] and international PIES projects (see above) point to the urgency of reconsidering the way of evaluating and using these databases in a changing context (e.g. internationalization of the use, growing of the database). In particular, they propose to explore the many possibilities of extracting different types of knowledge from collections of DNA profiles in order to inform policies and strategies.

We have highlighted how links between physical traces bring other solid information on the structure of some crime mechanisms. Scientific linking can be integrated into intelligence process, but can also add value to other models. For instance, when high volume crime is considered, links can complete studies of how offenders and group of offenders are mobile (Rossy *et al*. 2013) and are structured (Jeuniaux 2014) (also this issue).

The advantages of such systematic linkage are evident with material such as false identity documents. Usually, each seizure of a false identity document constitutes a new judicial case separately treated. When the documents collected are gathered and systematically compared, their grouping provides a new pictures of the diversity of manufacturing processes and their

5 Be-Gen: Understanding the operational, strategic, and political implications of the National Genetic Database (http://www.law.ugent.be/ircp/sweetlemon/principals/belgian-science-policy-belspo, last accessed, October 26th 2014)

dynamic. Results already obtained on limited set of data show many connections that tend to indicate high concentration of prolific criminal activities (Baechler *et al*. 2012). Such hypotheses should however be further integrated into more ambitious criminological researches.

Emergent illicit markets form a common object of research studied at the same time by forensic scientists, criminologists, computer scientists, and many others, in a taxonomy of the disciplines that do not fit traditional frameworks. Collective and interdisciplinary approaches tend to emerge in order to study this object. This is illustrated by how the integration of economic variables with the interpretation of chemical profiles of amphetamines brings a new light on the structure of illicit drug markets in Quebec (Ouellet and Morselli 2014). These authors base their study on original works on illicit drug profiling proposed by forensic scientists (Esseiva *et al*. 2003; Esseiva *et al*. 2007). The latter studies also prompted forensic studies on the distribution of 3,4-methylenedioxymethylamphetamine (MDMA) (Morelato *et al*. 2014c) and methylamphetamine (MA) in Australia (Morelato *et al*. 2014b).

The limits between disciplines definitely blur further when the study of illicit markets using the infrastructure of the internet is considered. Both the material manufactured and distributed (illicit drugs, doping substances, counterfeited materials) and web-based traces are needed to gain some understanding (Pazos *et al*. 2013). The monitoring of other 'similar' markets by using different traces scattered into databases owned by many stakeholders (e.g. private companies such as credit cards issuers or pharmaceutical companies, police, customs) is another step. It goes towards the development of new monitoring methodologies. For example, Dégardin at al. (Degardin *et al*. 2014) have proposed ways of studying counterfeited medicine markets by using the same approach. They systematically link available products collected through the extraction and comparison of sets of chemical/physical features. This process is completing or even changing available pictures over the problem. The authors show that despite severe potential repercussions on health due to the occasional use of toxic compounds and economical consequences, legalist responses have been so far inapplicable. They claim that the scope and evolution of the problem, including risks for the health system, can become more explicit through forensic monitoring. In turn, the latter help engage with and mobilize relevant organizations and networks, be government or private.

New approaches to anti-doping show many similarities by using biomarkers and web traces in order to gain knowledge on the size, extend and dynamic of the market. It extends ways for addressing more proactively the problem. This is a necessity as laboratories struggle to adapt

to the evolution of the market of banned substances: estimated prevalence is definitely of a higher order of magnitude than detection rates reported by laboratories (Marclay *et al*. 2013). This is where the obtained results should be carefully framed by solid criminological considerations.

Counterfeited watches show a lot of analogies as an illicit market. The simultaneous analyses of websites and examination of watches seized allows keeping a global view on the problem. As one of the responses, the massive sending of targeted e-mails informs concerned host providers about the presence of counterfeited watches on the sites they host. These e-mails remind them about their liability with regards of this illicit content. This kind of actions has changed the order of magnitude of the response and seem to bring promising effects, even not scientifically evaluated (Aubert and Stauffer 2010).

In many other areas, less published works concern the monitoring of illicit traffics of manufactured products distributed over the internet. These activities cause damage to the economy and frequently endanger public health (e.g. traffic of cigarettes). A common response is to call for new set of laws that go beyond criminal codes and necessitate to obtain an international global view due to the fragmentations of these crime systems. It is also necessary to involve private companies that are custodians of relevant data and have obvious interests in protecting their supply chains. The monitoring uses both web and manufacturing process traces.

Ultimately common features of this family of monitoring processes lead to the conception of a transversal, transparent and modular architectures, where components are easy to reuse, implement into computerized system, compare or teach (Morelato *et al*. 2014a). This theoretical framework can be conceived as an emergence from a transdisciplinary approach combining computational methods, criminology and forensic sciences (Grossrieder *et al*. 2013).

By analogy, it is not difficult to identify similar strategies for protecting other natural or man-produced assets at the level of a company or even a state, as repressive means are generally out of reach due market globalization. Indeed, criminological studies identifying the reality of a suspected problem could trigger forensic awareness of public and private authorities, to request forensic science to produce evidence of an organized network, which could be easier to tackle at political or commercial exchange levels.

As the next example, the analysis of wastewater for detecting traces of the metabolites of illicit drugs or of other products can support the identification of patterns and complete the view on illicit drug consumption tendencies (Thomas *et al*. 2012; Béen 2014; Ort *et al*. 2014). These researches open the path to further assessment of criminological study or prevention programs related to the consumption of illicit drug in dedicated environment, as emphasized by Delémont et al. (2014).

This tendency towards more integration of the disciplines stimulated by the development of numerical environments is epitomized by recent studies of how some criminals interact in virtual networks (Frank *et al*. 2010; Décary-Hétu *et al*. 2012; Morselli and Décary-Hétu 2013). Social network analysis plays a key role in the investigation of these new spaces. It helps detect relevant structures potentially reflecting behavior systems in crime (Sutherland 1947). However, in their exploratory research, the authors also acknowledge that criminal mechanisms relying on virtual worlds cannot be studied only with traditional criminological methods and tools. Interdisciplinarity and collaborative approaches will usefully support the study of such complex and specific emerging structures in crimes.

What these thematic and apparently disparate studies have, however, in common, is that they all rely on forensic science case data. Forensic science provides the link between physical and virtual worlds. It constitutes the substrate from which is it difficult to totally abstract in the study of many forms of crimes and offending patterns.

A next step: gaining further independence from the justice system, and elaborating frameworks

These progresses rest on how to further increase the independence of forensic science from the Justice System and exclusive compliance (or allegiance as described in (Rudin and Inman 2013)) to the specific needs of the Court. By gaining such autonomy, forensic science will be much more inclined to prioritize its efforts towards some form of natural integration with areas of criminology. This new available support for criminology will be welcome in a transforming crime landscape.

There is a need to develop and use frameworks for guiding the integration and promoting the forms of inderdisciplinarities that will make emerge new models. There are many possible approaches that can be adopted to initiate such a modeling activity. Among them, we have mentioned above case-based reasoning (Kolodner 1993). We strongly believe it consists of a pivotal model to be adapted and further exploited for this purpose.

Indeed, criminology is more often interested in general models, while forensic science deals with reconstructing past single events. Case-based reasoning, as a psychological model, integrates in a single structured framework the possibility to articulate the general with the particular. The 'case' treated by the investigator or the forensic scientist is an atomic entity to be remembered when new similar events occur. Similarities detected can point to more general problems or mechanisms to be further deciphered; these may even reveal unknown or underestimated crime or security problems (Delémont *et al*. 2014). Successful solutions to previous problems or cases have to be recognized, adapted and reused. Analogy, that take many different forms, is at the heart of this inductive process (Hofstadter and Sander 2013).

This proposition needs obviously to be further and more precisely worked out, and a number of other models and methods are welcome in this growing debate.

In summary:

- Some forms of crime and behavioral crime systems are radically changing with new virtual and economic worlds to be explored;
- The study of these types of crimes cannot totally abstract from the traces caused by criminal activities;
- Frameworks for the interpretation of the information conveyed by traces in their sociological context are required;
- Underlying problems have an increased complexity and cannot be addressed by one single discipline within exclusive paradigms; new transversal methodologies must be developed;
- Much more interdisciplinarity, and even trans-disciplinarity, and the collective resolution of problems is the path to be followed.

Conclusion

This journey along obvious links between practices in forensic science and models that were developed in policing show the richness and the many dimensions that remain largely unexplored. However, the fundamental questions go well beyond. To paraphrase a group of scholars in police studies (Manning 2014), research in forensic science must not only focus on the development and validation of new technologies feeding the 'forensics' paradigm of recent reviews or particular policing strategies and models. Forensic science should be treated

as an entity, a true academic discipline, where future research can take place to relocate its position in the landscape of a variety of disciplines concerned by crime. In simple terms, shouldn't we switch from research *for* forensic science to research *on* forensic science ?

August Vollmer (1876-1955) was a key player in the evolution of the relationships between forensic science, policing and criminology. He was actually a great promoter of the use of technologies in policing and stimulated the implementation of the first forensic laboratory in US in 1924 (Los Angeles Police Laboratory). Paul Leland Kirk's legacy (1902-1970) to forensic science is the so-called 'principle of individuality', i.e. the idea that forensic science is dedicated to the individualization of the source of a trace. He is a precursor of the contemporary model of the forensic laboratory. Both pioneers met at Berkeley and were at the origin of the school of criminology at the University in 1950. This school was criticized in 1960 for being too 'police' based and not sufficiently focused on a sociology-based study of crime and offending. This change of paradigm did not resist to the many troubles that prevailed during the sixties and seventies. The school was closed in 1975, separating institutionally the forensic scientists from the criminologists. This is to be noted that distinguished 'pure' scientists such as George Sensabaugh, a pioneer in the use of DNA in the criminal justice system, has obtained a PhD in criminology from this school. This seems absurd in the contemporary models, but it is a trace of this rupture that continued to inhibit the emergence of new interdisciplinary approaches for studying crime in a stimulating environment. This link must almost be entirely re-established. It is difficult to identify where this could lead to, even if some initiatives such as the so-called 'crime science' movement provide promising reframing of the relevant disciplines (Pease 2010).

The complex articulating of all the disciplines sharing crime and offending as their objects, has indeed never been stable and has shown to diverge between the USA and Europe along historical contingencies. It will continue its mutations with the many, and occasionally counterproductive, initiatives for decoupling the system along specific lines.

Forensic science should find its place in this moving landscape, as most of new crime problems have to be studied through the traces left by offenders. It is evident for some criminologists that they must ground their approach in the physical world or on computer infrastructures. In the same way, forensic scientists have to be aware that their investigations would benefit from a deeper awareness of criminological knowledge. This whole enterprise may be intractable for single communities. The development of more collaborative frameworks is not spontaneous or natural. Of importance is the balance in this kind of

collaboration. It may be that forensic science could be considered as 'data suppliers' by criminologists ignoring the fundamentals of this discipline. With this view, forensic science would not gain the independency that was called for, but only make allegiance to another discipline. There is no hope that in these circumstances, the full potential of this discipline would be fully realized.

It is however inevitable that research must become more collective and interdisciplinary to address contemporary security and criminological problems. This is an exciting change that will, hopefully, stimulate scientists to take distance from their technologies in order to address contemporary problems. It will also attract the interest of criminologists to integrate new technical data in their study of crime and criminal behavior. Beyond individual efforts, research policies are eventually needed to provide support to those kinds of collaborative attitudes.

The future is challenging, but as usual in such circumstances, it brings opportunities and we should not shy away from them because they have extraordinary potential.

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