

# The origin of evidence

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## Abstract

Forensic science is an applied science based on the laws of physics and chemistry. Over time, a set of fundamental concepts has developed that apply specifically to a forensic analysis. Traditionally, five concepts have been articulated: transfer, identification, individualization, association between source and target, and reconstruction. We suggest that an additional sixth concept, the idea that matter must divide before it can be transferred, is necessary to complete the paradigm. Divisible matter is particularly useful in describing physical match evidence. Additionally, we propose a paradigm that logically divides into scientific principles that govern the generation of evidence, and processes that pertain to the recognition, analysis, and interpretation of evidence. The principles of divisible matter and transfer pertain to the generation of evidence before and during the crime event; the processes of identification, classification or individualization, association, and reconstruction describe the practice of forensic science starting with the recognition of an item as evidence. © 2002 Elsevier Science Ireland Ltd. All rights reserved.

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## 1. Introduction

In 1963, Paul Kirk published a short monograph entitled *The ontogeny of criminalistics* [1]. In this, he states:

With all of the progress that has been made in this field, and on a wide front, careful examination shows that for the most part, progress has been technical rather than fundamental, practical rather than theoretical, transient rather than permanent. Many persons can identify the particular weapon that fired a bullet, but few if any can state a single fundamental principle of identification of firearms. Document examiners constantly identify handwriting, but a class of beginners studying under these same persons, would find it difficult indeed to distinguish the basic principles used. In short, there exists in the field of criminalistics a serious deficiency in basic theory and principles, as contrasted with the large assortment of effective technical procedures.

Remarkably, although Kirk goes on to suggest that “criminalistics is the science of individualization,” he fails to offer us the comprehensive set of fundamental principles whose absence he deplors.

Over the last several decades, a theoretical framework of sorts has, in fact, evolved. These fundamental concepts provide a philosophical and rational framework for the application of scientific knowledge to the forensic arena. They are concepts which guide a forensic analysis in a logical progression, starting with understanding the origin of evidence, and culminating in a statement of the significance of an analytical result. Unfortunately, these concepts have evolved in a fragmented manner and, in fact, no published record of a comprehensive organized paradigm exists. Traditionally, forensic science practitioners have come to understand the major paradigm of their work to comprise following five basic concepts [1–5]:

1. *Transfer* (Locard exchange principle) [2];
2. *Identification* (placing objects in a class) [3];
3. *Individualization* (narrowing the class to one) [1,3,4];
4. *Association* (linking a person with a crime scene) [5];
5. *Reconstruction* (understanding the sequence of past events) [3].

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This framework has served the field well for several decades, but does not provide a complete picture of the fundamentals involved. In particular, this model fails to incorporate aspects of physical match evidence that seemingly begin only at the individualization step. The model also fails to formally consider the origin, change, and subsequent relationship of physico-chemical traits in the evidence and reference samples. A basic understanding and consideration of how material divides and the effect of division on its physico-chemical properties are necessary to complete the philosophical framework of the forensic analyst's work. Additionally, we suggest that identification, individualization, association, and reconstruction are not really basic scientific principles, but relate more properly to the recognition, analysis, and interpretation of physical evidence.

We have proposed two distinct, but interdependent theses. First, we proffer an as yet unarticulated fundamental principle necessary to the understanding of forensic evidence, the principle of divisible matter. Second, we reorganize the paradigm into fundamental principles relating to the generation of evidence and essential processes relating to the practice of forensic science [6].

## 2. Divisible matter—a fundamental principle in forensic science

In thinking critically about the generation of evidence, we were struck by the seemingly obvious fact that matter must divide before it can be transferred. This suggests that an additional fundamental principle of forensic science is necessary to complete any forensic science paradigm, the principle of divisible matter.

*Matter divides into smaller component parts when sufficient force is applied. The component parts will acquire characteristics created by the process of division itself and retain physico-chemical properties of the larger piece.*

The principle of divisible matter leads directly to three corollaries with important consequences.

**Corollary 1.** *Some characteristics retained by the smaller pieces are unique to the original item or to the division process. These traits are useful for individualizing all pieces to the original item.*

**Corollary 2.** *Some characteristics retained by the smaller pieces are common to the original item as well as to other items of similar manufacture. We rely on these traits to classify the item.*

**Corollary 3.** *Some characteristics from the original item will be lost or changed during or after the moment of division and subsequent dispersal; this confounds the attempt to infer a common source.*

In particular, the principle of divisible matter and its logical corollaries have a profound effect on the forensic process of individualization.

## 3. Properties useful for source determination

The process of division creates physical traits not present in the original object, and may serve to associate separated progeny fragments at a later time. These traits are created at the boundary of the fracture. Boundary roughness is a natural consequence of breaking one surface into two [7], and these new surfaces are closely, but not completely, complementary. Forensic scientists use complementary edges in “physical match” comparisons to infer a common source for two items. For instance, tearing a piece of paper in half will create edges that were not present in the original piece of paper, and juxtaposing the two new edges may convince the examiner that they were once a contiguous item (Fig. 1). This is the most immediate consequence of the division of matter. Also, traits and characteristics present in the undivided object at the moment of division are carried with all pieces that originate from it. This includes all physico-chemical traits present in the undivided object except those (size and shape) that define it as intact. Examples of properties that might be inherited by the progeny fragments are color, elemental composition, and micro-crystalline structure.

To some extent, the properties inherited depend on the scale of homogeneity of the original object as compared to the scale of fragmentation. If pottery with a characteristic texture design is broken into several large pieces, the fragments will show the characteristic texture (Fig. 2). This texture would assist in associating a pottery fragment with the small class of pottery pieces of similar design. If,

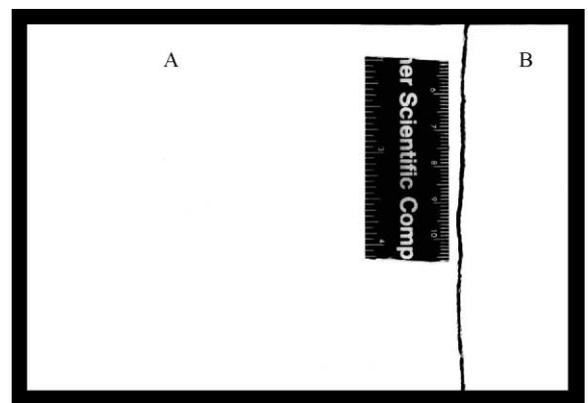


Fig. 1. Physical match evidence: juxtaposing two pieces (A and B) of torn paper reveals complementary edges. A sufficient length of such complementarity may convince the examiner that the two fragments were once one contiguous piece of paper.

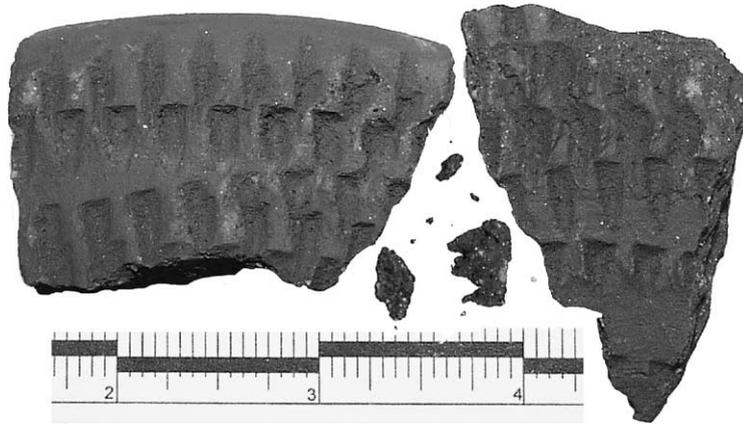


Fig. 2. Pottery: if complementary edges are insufficient to conclude a common origin for evidence and reference samples, other physico-chemical traits are required to compare the two objects. In this photograph, the texture seen in the two large pieces narrows the possible sources to those pottery manufacturers creating such a texture.

however, the pottery is shattered into small particles, it is unlikely that any one particle will clearly exhibit the characteristic texture. The fragments are likely to be placed in the larger class of pottery with similar mineral composition (Fig. 3), rather than the smaller class of items exhibiting the characteristic texture.

In summary, both the new complementary boundaries resulting from division, and the physico-chemical traits of materials, are useful for individualizing two objects, leading to an inference of common origin.

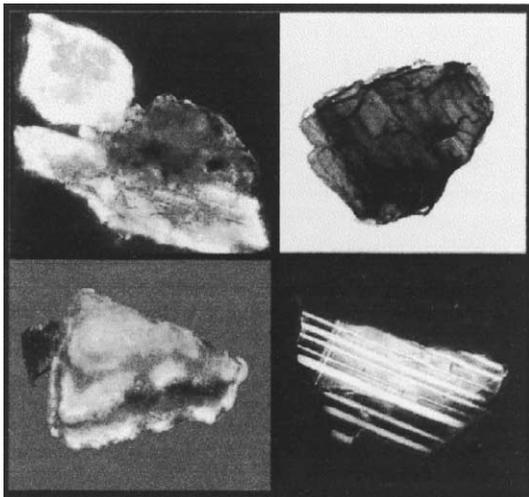


Fig. 3. Minerals: if gross manufacturing traits are not present in either the evidence or the reference material, more common physico-chemical characteristics are compared. In this circumstance, only the mineral composition is available for analysis and comparison. Pottery from many manufacturers may be included as possible sources for the evidence fragments.

#### 4. Properties confounding source determination

At the moment of division, the separated fragments commence to change and become different both from each other and from the original object. We call this phenomenon temporal instability to indicate change over time; it is, most simply, a consequence of increasing entropy. After the process of division and dispersal, each property of the newly created items will diverge from the others at some discontinuous rate,  $k$ . This temporal instability will affect the ability to accurately assess the original values at and before division. A future comparative analysis of both items might lead to the detection of different values and a potentially erroneous conclusion of different sources for the items.

Consider again the example of torn paper. As a result of non-uniform exposure to local environmental factors, the edges of each piece, as well as the physico-chemical traits, will begin to diverge from their original values. At some point, it might become impossible to associate the two paper fragments by either physical matching of their complementary edges or by physico-chemical traits.

In addition, the very act of division inevitably results in the loss of some characteristics that define the original material. From a consideration of a fragment of paper, one cannot infer the number of remaining pieces, nor the exact size and shape of the original item. One cannot, as another example, infer a sweater by examining a single fiber divided from it.

In the absence of physical matching between an evidence and reference item, ambiguity about the original global character of the intact item leads to the consideration of more than one possible source for the evidence. No analysis can determine which source is correct, even if the true source item is recovered and compared. Even assuming all of the physical and chemical traits from an evidence/reference pair correspond, ambiguity will preclude an inference that the

source was *this* sweater, as opposed to all other sweaters manufactured at the same time, or any other item made from the precursor yarn(s).

**5. The paradigm**

With the introduction of divisible matter, we conclude that this fundamental concept, along with the previously understood fundamental concept of transfer, define scientific principles that relate to the generation of evidence. We suggest that the concepts of identification, classification or individualization, association, and reconstruction are integral to the practice of forensic science and are processes we use in our attempt to answer the various investigative questions: “who, what, where, why, when, and how”. In the rest of this paper, we refine our understanding of these processes and relate them to the generation of evidence via divisible matter and transfer through the crime event.

Fig. 4 is a pictorial representation of the paradigm as we understand it. All of the ideas we have discussed are arranged around a physical and temporal focus, the crime event. The interactive elements of a scene, a victim, a suspect, and witnesses are not novel. However, they are

usually depicted as a triangle with the victim, suspect, and witnesses as apices surrounding the physical scene. We prefer to think of these elements as overlapping domains. Regardless, the crime defines the border between the generation of evidence and the recognition and subsequent analysis and interpretation of evidence.

**6. The principles**

Only two of the concepts we have discussed thus far emerge from the fundamental nature of matter, divisible matter and transfer. These principles exist independently of any human intervention, or even recognition; therefore, we accord them a different status than the processes that begin with the recognition of evidence by human beings. However, although all matter is constantly dividing and transferring, it does not become evidence until division and transfer occur in conjunction with a criminal event. Note that for some types of evidence, the contact necessary for transfer may be the force for division. For example, a collision between two vehicles causes the simultaneous division and transfer of paint.

Because the concept of transfer arose through the study of dusts and other microscopic material [2], we are used to

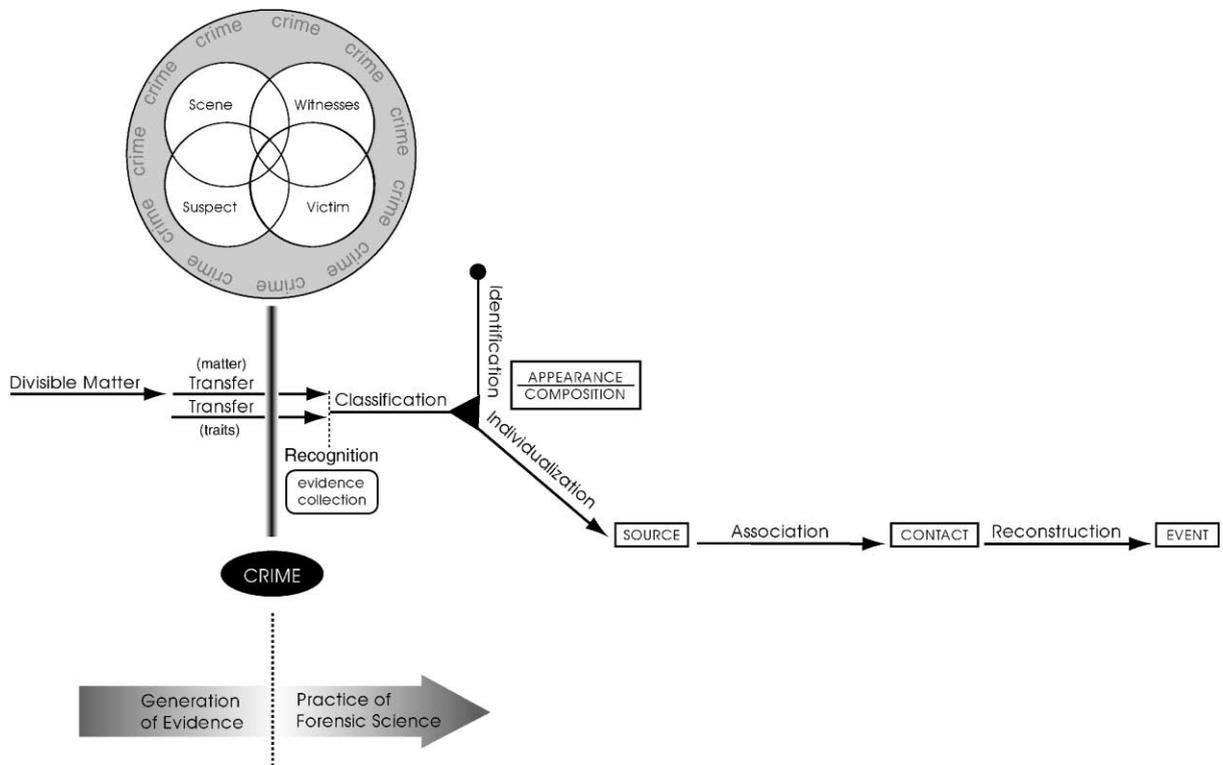


Fig. 4. A forensic paradigm: individuals practicing a profession need a common map to guide them through their work. While never fully articulated in an organized fashion, over the years a map of the discipline of criminalistics has emerged. Numerous workers have contributed to the conceptual framework presented in this paper. The paradigm includes the principles of evidence formation (the origin of evidence) and the processes of analysis that describe the profession of criminalistics.

thinking about transfer only on a microscopic scale. In fact, it is inordinately useful to consider transfer on a macroscopic scale as well. For instance, the scrap of paper used to write the ransom note is only one-half of the original intact piece, the other half of which is still in the kidnapper's pocket. Because it is impossible to draw an arbitrary line between microscopic evidence and that which is easily visible to the naked eye, we will take the liberty of creating the term "macro-transfer" to describe this situation.

However, divisible matter does not account for a large category of evidence, that of pattern transfer evidence, such as prints and impressions. Although small amounts of physical matter may be transferred,<sup>1</sup> it is the pattern of transfer that concerns us, not the substance. Therefore, divisible matter does not apply. The transfer of matter requires its prior division; the transfer of traits may not.<sup>2</sup>

## 7. The processes

At some point after the commission of a crime, evidence may be recognized as such and collected. The recognition of evidence, and the processes that follow in a forensic investigation, all result from decisions made and actions performed by people. We therefore separate the practice of forensic science from the fundamental scientific principles upon which the generation of evidence rests. If the crime is never discovered or the evidence is never detected, matter has still divided and transferred, and traits have still transferred. But it is only by attempting to answer investigative questions about a crime that the recognized processes of identification, individualization, association, and reconstruction are employed. We also suggest a refinement in which identification becomes an end in and of itself, and we accord the process of classification a formal status distinct from identification.

### 7.1. Identification

Kirk and others emphasize the process of individualization, the reduction of a class of evidence to one member. It is useful to take a step back and realize that identification, the categorization of evidence, can be an end in itself. For some purposes, for instance the recognition of illegal drugs or the quantitation of blood alcohol level, the forensic process stops with identification. The criminal justice system is

<sup>1</sup> For instance, sweat, oils, and even a few cells are transferred in leaving a fingerprint. We could choose to analyze the substance, for instance the cells for DNA, rather than the pattern. This evidence would then be considered a product of divisible matter.

<sup>2</sup> It has recently been suggested to us that the transfer of matter and the transfer of traits might be considered as two ends of a continuum, effecting a convergence of theory to easily allow divisible matter to explain the origin of all physical evidence. We present our original thoughts in this paper and assume that the ideas will inevitably be refined with time and scrutiny.

not necessarily concerned with the marijuana field or methamphetamine lab from which the drugs originated (although sometimes they may be); simple possession of the scheduled substance fulfills the criteria of illegality. Similarly, the quantity of alcohol present in an individual's bloodstream while operating a motor vehicle is the result of interest, not the vintage of the wine. The process of identification answers the forensic investigation question: "what is it?"

### 7.2. Individualization

Identification may also occur as a step leading to individualization. To distinguish it from end-point identification as discussed in the previous section, we will refer to the intermediate process that may lead to individualization as classification. Several authors [3,4,8,9] have remarked on the special meaning of individualization in a forensic context as a conclusion of common source for two items. Any forensic analysis that proceeds on the path towards individualization relies on a comparison of at least two items. Physics and logic determine that any individual object is unique; this is not the question. The forensic question asks whether items share a common origin. There may be some disagreement about whether an item must be classified before it is individualized. We believe that, whether intentionally or not, the analyst will know what the item is by the time, he concludes a common source. If ambiguity exists about the classification of an item, the individualization to a common source is also compromised. The process of individualization answers the questions: "which one is it?" or "whose is it?" depending on whether the item is animate or inanimate; it does this by inferring a common source or origin.

### 7.3. Association

Although the word association is used freely in describing the results of a forensic examination, no clear definition seems to exist, at least not in published literature. We propose that association be defined as an inference of contact between the "source" of the evidence and a "target". Such an inference is based on the detection of transferred evidence. The source and the target are relative operational definitions defined by the structure of the case; if transfer is detected in both directions, for instance, each item is both a source and a target of evidence.

The association process involves the evaluation of all of the evidence for and against the inference of common source; in other words, competing hypotheses are compared. The probability of the evidence under competing hypotheses is an expression of the likelihood of the evidence given that the target and source items were in physical contact, contrasted with the likelihood of the evidence given that the target was in contact with a different unrelated source. This process requires combining the strength of the evidence

established during the individualization process with additional information (such as may be provided by manufacturers of materials and empirical studies), as well as assumptions made by the analyst. Others have commented on the complexity of determining the significance of an association, including Robertson and Vignaux [10], and Evett and co-workers [8].

Consider a fiber collected from the body of a deceased individual. The evidence fiber from the body and the reference fibers from the van carpet are found to be the same type and to contain indistinguishable dye components. These physico-chemical similarities are expected if the van carpet is the source of the evidence fiber, if the fiber was transferred during the crime, and if it persisted on the body until collected. Next, an evaluation is made of all other possible sources of fibers indistinguishable from the evidence fiber, including all carpets made from such fibers and any other items manufactured from indistinguishable fibers. From this information, the probability of finding the fiber on the deceased if it derived from some other source can be estimated.

Comparing these alternative explanations allows the analyst to decide whether the evidence supports an inference of contact between the deceased individual and the van carpet. Note the distinction between a conclusion of common source (the evidence and reference fiber are classified or individualized as sharing a common source) and an inference of contact between a source and a target (the carpet and the deceased are associated).

#### 7.4. Reconstruction

We consider reconstruction to be the ordering of associations in space and time. Reconstruction attempts to answer the questions: “where, how, and when”. It should be stressed that the “when” usually refers to an ordering in relative time only; was the sweater in contact with the couch before, during, or after the murder took place? The last remaining question, “why” can never, of course, be addressed by a consideration of physical evidence.

## 8. Summary

In considering a fundamental scientific basis for the discipline of forensic science, we have articulated an additional principle, that of divisible matter. The principle of divisible matter states that, when sufficient force is applied, matter divides. In Corollaries 1–3, we find that the process of

division creates traits or characteristics that can be used to individualize two objects in the context of a forensic investigation. In particular, this principle supplies a novel model for the generation and understanding of physical match evidence, a concept that the previous paradigm failed to address. Divisible matter allows for formal consideration of the factors affecting change or loss of physical properties and presages incorporation of those factors into a statement of significance at the conclusion of the analysis.

We have also proposed an organization of the forensic paradigm centered around the crime event. The principles of divisible matter and transfer interact in the generation of evidence before and during the crime. The practice of forensic science begins after the crime event with the recognition of evidence. Divisible matter and transfer are the two fundamental principles upon which the forensic analysis of physical evidence is based. Identification, classification or individualization, association, and reconstruction form the infrastructure for the practice of forensic science.

## References

- [1] P.L. Kirk, The ontogeny of criminalistics, *J. Crim. Law Criminol. Police Sci.* 54 (1963) 235–238.
- [2] E. Locard, *L'Enquête criminelle et les Methodes scientifiques*, Flammarion, Paris, 1920.
- [3] P. DeForest, R. Gaensslen, H. Lee, *Forensic Science: An Introduction to Criminalistics*, McGraw Hill, New York, 1983.
- [4] P.L. Kirk, in: John Thornton (Ed.), *Criminal Investigation*, 2nd Edition, Wiley, New York, 1974.
- [5] J.W. Osterburg, *The Crime Laboratory: Case Studies of Scientific Criminal Investigation*, Indiana University Press, 1968.
- [6] K. Inman, N. Rudin, *Principles and Practice of Criminalistics: The Profession of Forensic Science*, CRC Press, Boca Raton, FL, 2001.
- [7] R.K. Kalia, A. Nakano, A. Omeltchenko, K. Tsuruta, P. Vashishta, Role of ultrafine microstructures in dynamic fracture in nanophase silicon nitride, *Phys. Rev. Lett.* 78 (1997) 2144–2147.
- [8] R. Cook, I.W. Evett, G. Jackson, P.J. Jones, J.A. Lambert, A hierarchy of propositions: deciding which level to address in casework, *Sci. Justice* 38 (1998) 231–239.
- [9] H. Tuthill, *Individualization: Principles and Procedures in Criminalistics*, Lightening Powder Company, Salem, OR, 1994.
- [10] B. Robertson, G.A. Vignaux, *Interpreting Evidence*, Wiley, Chichester, 1995.