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Overview and Meaning of Identification/Individualization

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Abstract

This chapter presents two common accounts of the question of inference of source in forensic science. The first, the classic view, leads to direct opinions about source propositions, either categorically or in terms of graded conclusions. The second account focuses on assessing the value of the findings with respect to competing source propositions. It is based on probability theory and represents a preliminary to the most recent, decision-theoretic conceptualization of individualization. It allows one to critically expose and resolve shortcomings, limitations and scientific drawbacks of the classic view, and to clarify the distinct duties and roles of experts and fact-finders.

Keywords

Identification
Individualization
Inference of source
Probability theory
Likelihood ratio
Decision theory

Key points

- Traditional approaches to forensic source attribution involve direct statements about source propositions, either categorically (i.e., in terms of certainty) or graded in probabilistic terms.
- Traditional reporting formats, though widely practiced, lack demonstrable and rational foundations.
- More recent evaluative frameworks, based on probability theory for dealing with uncertainty, focus on the value of the findings and abstain from expressing direct opinions about source propositions.
- The contemporary understanding of forensic individualization as a decision can be clarified in decision-theoretic terms, providing further argument in support of the view that forensic scientists should focus on the value of the evidence only

Introduction

The definition of identification in forensic science differs largely from the one accepted in other science disciplines, where the term 'identification' is mainly used to describe the attribution of an object to a particular class (i.e., classification). In forensic science, the identification process seeks, ultimately, individualization. For forensic scientists, identifying (individualizing) an object or a person means to *assert* that a particular object, trace or mark comes from a particular source, to the exclusion of all other potential sources.

In forensic literature, the problem of identity of source has traditionally been framed as a distinction between so-called 'class' and 'individual' characteristics observed during the comparison between questioned and known items (**Table 1**).

Table 1 Distinction between 'class' and 'individual' characteristics in some identification fields

Field	'Class' characteristics	'Individual' characteristics
Fingermark examination	General pattern, ridge count, ridge tracing	Minutiæ, pore structures, ridge structures
Footwear mark examination	General patterns, size, manufacturing characteristics	Cuts, accidental acquired characteristics, transient wear features
Bullet examination	Caliber, number of grooves/lands impressions, angles of grooves/lands impressions, width of lands/grooves	Striations on grooves/lands impressions

Observations of agreement in terms of class characteristics only, without major differences, are said to lead to 'group identification' conclusions. Still according to the classic account, corresponding 'individual' characteristics must be present in conjunction with class characteristics, without discrepancies, in order to enable scientists to conclude in terms of a 'positive identification' or 'individualization', i.e. the *assertion* that a given item, object or person is the source of an examined item of unknown source. In this sense, the definitions of 'class' and 'individual' characteristics are merely conventional ways of describing different levels of selectivity.

However, the problem of inferring identity of source is more complex than a simple dichotomy between class and individual characteristics. As illustrated in **Table 2**, practitioners have traditionally distinguished between forensic fields that can lead to individualization from those leading rarely (in the present state of the art) to individualization, but more commonly to conclusions in terms of (various expressions of) strength of support.

Table 2 Traditional classification of forensic evidence types (disciplines) with respect to their identification capabilities

Individualization disciplines	Non-individualizing disciplines
Earmarks Fingermarks (more generally marks left by friction ridge skin) Footwear marks Handwriting and signature Examination Toolmarks and firearms	Biological fluids (now mostly DNA) Drugs and toxicology Explosives and fire residue analysis Microtraces (glass, paint, hairs, fibers) Soils

The arguments developed in this article aim to help the reader understand that these contrasting notions (class vs. individual features; individualizing and non-individualizing disciplines) have no rational foundation. In fact, conceptual developments over the past few decades have exposed these distinctions as artificial and lacking scientific character, recognizing that essentially all types of forensic science evidence represent imperfect information that, at best, can lead to conclusions in terms of strength of support. All forensic comparison disciplines deal with outputs (i.e., findings or observations) that may be characterized in terms of *strength of support* with respect to selected propositions of interest and given task-relevant conditioning information. The evidential strengths may change from one discipline to another as a function of the discriminative capacity of the features revealed during comparative examinations between questioned and known items.

The Traditional Account of the Identification Process: Reduction Process to a Single Source

In most forensic cases, the pool of potential sources is not and cannot be exhaustively examined. The inquiry will focus on a limited set of potential sources. Had all the potential sources but the item or person of interest been validly excluded by forensic examination, then identity of source would be declared applying a trivial deductive argument (regardless of the features considered). But in typical casework, such a deductive process is not feasible, mainly because the potential source population cannot be investigated exhaustively and because even exclusions are merely inferred conclusions. For these reasons, identity of source must be inferred and the process for this is inevitably probabilistic in nature.

It was not until the work of Kwan in 1977 that forensic science saw a first reasoned account of how to infer identity of source. The identification process, according to this account, is seen as a reduction process, from an initial population to a restricted class or, ultimately, to a single item or unit. The initial population represents known objects, items or persons of interest, depending on the type of evidence. The process combines two factors:

- A relevant population of potential sources, defined by its size (and/or other particularities). Stated otherwise, each member of this population can be seen as a potential source.
- A reduction factor resulting from the combination of corresponding characteristics (or analytical features) with a given selectivity (i.e., discriminative capacity). In fact, the reduction is proportional to the rarity (occurrence) of the observed characteristics in the relevant population. This is sometimes referred to as the match probability. As Kwan indicates: "this is the sheer rarity of a feature that is important as rarity of that feature with respect to the set of suspected sources being considered. It is important to stress that rarity is relative to the situation at hand."

With respect to the size of the relevant population, an 'open set' framework is distinguished from a 'closed set' framework.

- The open set framework refers to the population at large. In the extreme case, this means that all living persons on Earth or all produced objects on Earth are taken into consideration as potential sources. Given the population considered here, the term 'Earth population paradigm' is sometimes used to describe this framework. Note, however, that this a rarely meaningful viewpoint because, most of the time, there is at least some case-specific information that allows one to frame the relevant population to less than the 'Earth population'.
- The closed set framework corresponds to a situation in which the number of potential sources is restricted to a specified subset (e.g., by taking into account other evidence available from the inquiry describing the potential sources).

To illustrate the identification process graphically, we will assume a generic case in which a certain amount of similarities and differences are observed during comparative examinations. A mark is found on a crime scene. Following inquiry, a potential source (e.g., an object or reference material from a person of interest) is submitted to the laboratory for examination. Hereinafter, we refer to the features observed on the recovered and the control materials as forensic findings or results. Suppose that the examiner observes no major differences. It is worth noting that the arguments will hold, without loss of generality, when the features would guide toward exclusion. In the case here, the identification process can be illustrated as shown in **Figure 1**. The identification process (in an open set or a closed set framework) is a narrowing-down process, reducing the number of possible sources or hypotheses. The proposition that a particular person of interest or object is the source is then said to be 'proven' by demonstrating that all alternative hypotheses are excluded. Note however that, strictly speaking, the use of the term 'proven' is not warranted here as there is *no empirical demonstration* of the exclusion of all potential sources other than the selected item or person of interest. As argued in later sections, concluding to an individualization requires more than the scientist's findings. Individualization amounts to a decision based on all available evidence in a case, combined with the decision-maker's value judgement regarding various decision consequences, in particular adverse consequences such as erroneous identification and exclusion.

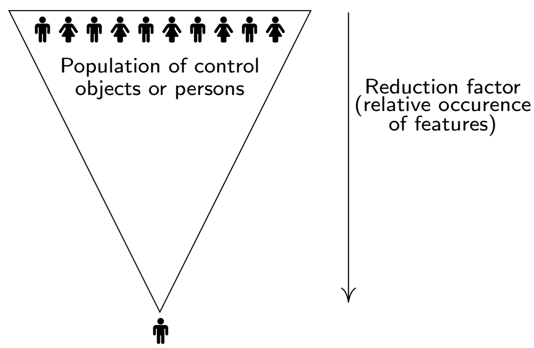

Figure 1 Illustration of the individualization process (here focused on individuals, applies analogously to objects).

Critical Review of Main Accounts of Individualization in Forensic Science

In practice, for obscure reasons, the identification process leading to individualization is commonly operated in a claimed open set framework, i.e. in terms of the Earth population paradigm. Underlying this practice are two distinct inferential schemes: one involves examiners – if allowed – expressing individualization conclusions, while the other amounts to graded conclusions regarding a contrasting pair of competing source propositions (e.g., 'the person of interest is the source' vs. 'an unknown person/item is the source'). Note that the latter account is to be distinguished, as explained later in this Chapter, from the probabilistic account of the value of findings that *abstains* from opining directly on source propositions.

Individualization Conclusions and the Rise of the Notion of Decision

For Tuthill and George, "[t]he individualization of an impression is established by finding agreement of corresponding individual characteristics of such number and significance as to preclude the possibility (or probability) of their having occurred by mere coincidence, and establishing that there are no differences that cannot be accounted for."

Following this definition, the size of the population of potential sources is systematically set to its maximum (i.e., the so-called open set framework). This practice is commonly used and implicitly required in fields such as fingerprints, footwear marks, tool marks, or firearms. The conclusion of individualization thus is an opinion, i.e. an examiner's statement expressing the view that the chance of observing, on Earth, another object or person presenting the same characteristics is so small that (for practical purposes) it can considered negligible. For the expert, at this stage, he/she cannot conceive of any contrary evidence (e.g., an alibi) that will ever shake his/her certainty. However, note again that the implicit assertion that 'all others are excluded' remains an empirically unwarranted claim, i.e. it is not covered by the extent (i.e., number) of observations actually made. As to the mechanism used by examiners to reach a statement of certainty, Stoney (1991) describes it as something analogous to a 'leap of faith.' That is, given the inherently imperfect nature of forensic findings, a categorical source conclusion can only be achieved by sidestepping any remaining uncertainty, i.e. a leap of faith.

Over the years, an increasing number of forensic scientists and other members of the judiciary became aware of the difficulty to defend identification conclusions framed along the lines exposed above, thus leading to various reactions. For example, a memorandum from the U.S. Attorney General has given strong directions against the use or suggestion of expressions of certainty by scientists.[1] And, in a document entitled Uniform Language for Testimony and Reports for the Forensic Latent Print Discipline (ULTR), the U.S. Department of Justice states that federal examiners "shall not assert that two friction ridge skin impressions originated from the same source with absolute or 100% certainty", yet maintains the definition of "Source Identification" as "an examiner's conclusion that two friction ridge skin impressions originated from the same source."[2] Problems with such stances are inevitable, as is evidenced by reactions from the judiciary, such as Judge Campbell who "queried how an examiner logically could state that a mark came from a particular defendant without saying it *didn't* come from another person."[3]

The deeper problem underlying the above impasse is that reform initiatives by forensic scientists focus mainly on language and terminology only while trying to maintain at the core of their reporting scheme the possibility of declaring or conveying categorical individualizations (Cole, 2009, 2014). One particularly visible aspect of reforms of reporting schemes over the last decade was the emergence of the term "decision" to characterize the nature of individualization conclusions (see Cole and Biedermann, 2020). That is, a source attribution conclusion through a leap of faith amounts, ultimately, to an examiner's decision. An example is the definition issued by SWGFAST in 2011, according to which individualization is the "decision by an examiner that there are sufficient features in agreement to conclude that two areas of friction ridge impressions originated from the same source. Individualization of an impression to one source is the decision

[1] Memorandum from the Attorney General to Heads of Department Components (Sept. 9.2016), https://www.justice.gov/opa/file/891366/download.
[2] U.S. Department of Justice, Uniform Language for Testimony and Reports for the Forensic Latent Print Discipline, vers. 08.15.20 (2020), https://www.justice.gov/olp/page/file/1284786/download (last accessed 05 March 2021)
[3] Committee on Rules of Practice and Procedure, Washington, DC June 25, 2019.

that the likelihood the impression was made by another (different) source is so remote that it is considered as a practical impossibility.”

However, this shift in language has not been accompanied with by fundamental move or commitment to understanding the notion of decision in terms of the *logic of decision* as stipulated by (Bayesian) decision theory. The decision-theoretic conceptualization of individualization requires an assessment of the probative value of the scientist’s findings, its combination with so-called prior information as well as the specification of a utility (or loss) function to characterize the decision-maker’s preferences among various decision consequences, i.e. accurate and erroneous source attributions and exclusions (Biedermann et al., 2008, 2016). Further details of this account are given in later parts of this Chapter. The schematic description of the identification process can now include this decision step toward individualization (**Figure 2**).

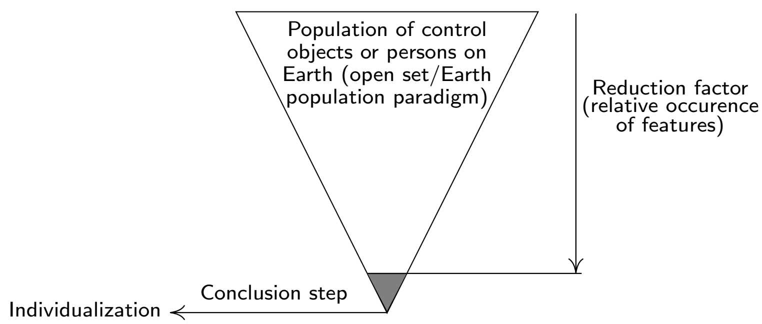

Figure 2 Illustration of the process resulting in a conclusion in terms of individualization.

Overall, attempts by forensic scientists to reach individualization conclusions raise several fundamental problems:

- It is odd to set the size of the relevant population at its maximum by default. Indeed, the number of a mark’s potential sources may reasonably be restricted by other available evidence (e.g., witness testimonies, other forensic evidence, etc.). Presenting the forensic findings in an open set framework is rather conservative, adopting systematically the extreme defense attorney’s position, trying to make the court believe that all persons or objects on Earth should be considered as potential sources of the marks of interest. Forensic scientists or courts rarely question this systematic reliance on the Earth population paradigm.
- Structurally, the conclusion threshold – the so-called leap of faith – is, in essence, a qualification of the acceptable level of remaining doubt, that is a probability threshold, weighted against an expression of relative utilities (or losses). To some extent, this bears resemblance with how legal scholars interpret legal standards of proof, such as the criminal standard ‘beyond reasonable doubt’ (e.g., Kaye 1999). Strangely, however, courts across legal orders largely accept to delegate identification decisions to forensic examiners.

While there currently is a rising awareness among practitioners that individualization amounts to a decision, the framework of 'open set' vs. 'closed set' as well as the necessity to specify value judgments (here utilities/losses) remains largely implicit. As soon as it is made explicit, as we will argue in later parts of this chapter, a decision scheme is no longer tenable in forensic science.

Provision of Graded Conclusions about Source Propositions

In some forensic fields, typically fingerprints, practitioners have voluntarily excluded graded conclusions regarding source propositions – unlike exclusion and individualization – from their reporting language. All results between the extremes of exclusion and individualization are reported as 'inconclusive.' Yet, there is no prima facie valid reason for abstaining from less affirmative statements that would help examiners avoid overstating the value of their findings when providing identifications and exclusions only. Each piece of information is of value to the extent that it renders the matter that requires proof more or less probable than otherwise. Hence, a piece of information that does *not* amount to a categorical statement about a proposition of interest (e.g., a source proposition), but to a statement regarding the degree of support in favor of a proposition, compared to a given alternative proposition, constitutes relevant information that should not be ignored. Thus, there is reason to insist that experts grade the value of their findings with a probability statement, verbally or numerically.

Hitherto, examiners have expressed what they perceive as the meaning of their findings in mostly pragmatic terms. Informally speaking, these expressions relate to some sort of power of reduction of the initial population, and some disciplines have agreed on terminology. For example, the ASTM standard E 1658–04 for document examination enforces the following terms: *strong probability (highly probable, very probable), probable*, *indications (evidence to suggest)*, *no conclusion (totally inconclusive, indeterminable)*, *indications did not*, *probably did not*, and *strong probability did not.*

This identification process scheme, leading to the provision of corroborative information is illustrated in **Figure 3**. Note that there is no statement of decision involved here, the conclusion being only a verbal translation of the position reached down the funnel (combination of the population of controls with the reduction factor).

While this could appear as an improvement over the dichotomous identification-exclusion reporting format, graded conclusions come with their own problems:

- The conversion between the end position in the reduction process and the verbal statement is (almost) never declared or explained. That is, underlying a verbal conclusion is, usually, no quantification of the size of the pool of remaining potential sources. This inevitably leads to variations between conclusions from different examiners when assessing the same case.

- Allegiance to the Earth population paradigm is either not questioned or the logic of the terminology is justified using a highly debatable 0.5 prior probability as discussed by Biedermann, Taroni, and Garbolino (2007). Adopting a prior probability of 50% is akin to consider that, outside any consideration of the case circumstances, only two potential sources are considered initially, the source under investigation being one of them, and both are assigned the same probability. The adoption, by the forensic scientist, of such a default starting position is highly prejudicial to the source under investigation.

- Most importantly, graded conclusions amount to opinions on propositions. This is problematic for various conceptual and procedural reasons. There now is a firm tendency in forensic science to consider that the appropriate way for forensic examiners to express themselves is in terms of the value of their findings *given* particular propositions, not the reverse (i.e., the probability of the propositions given the findings) (e.g., ENFSI, 2015). We will elaborate on the logic of this perspective in later parts of this chapter.

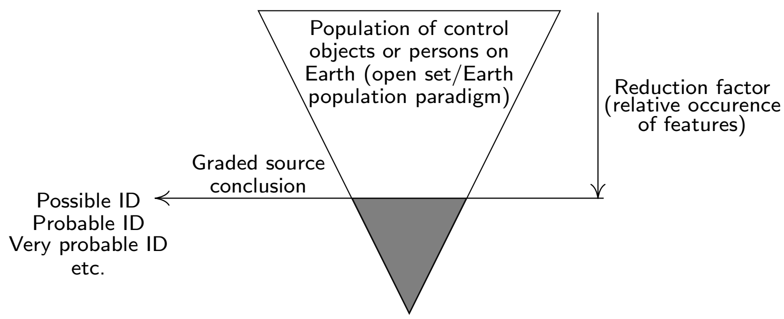

Figure 3 Illustration of individualization process leading to the provision of graded source conclusions.

Relationship with Probabilities

From a probabilistic point of view, concluding individualization requires the probability (Pr) of the event 'identification' (short for 'the questioned and known items or materials come from the same source'), given the scientist's findings and the all the task-relevant information, to be equal to 1. We anticipate that, in real cases, this is never possible. Yet, it is insightful to go through a series of considerations to critically expose the impossibility of individualization from a probabilistic point of view. Stated otherwise, probability theory allows us to expose the assumptions that examiners *would need* to make *if they wished* to logically justify individualization.

The probability of the proposition 'same source' (i.e., individualization), given the forensic findings, can be written more shortly as Pr(S|E). Here, S denotes the event (or, proposition) that questioned and known items come from the same source, which is uncertain, and E denotes the information available, i.e. the results of the forensic examination taken into account. Thus, the vertical bar "|" is shorthand notation for 'given.'

We have seen, at this stage, that the identification process is related to the discriminative capacity of the mark or trace under examination – its relative occurrence in the relevant population

– and the size (N) of the relevant population being considered. The probability that we are interested in then is conditioned on both E and N, and becomes Pr(S|E,N).

We can derive the probabilities of interest by using the odds form of Bayes' theorem:

$$\frac{\Pr(\mathrm{S}|\mathrm{E},\mathrm{N})}{\Pr(\bar{\mathrm{S}}|\mathrm{E},\mathrm{N})}=\frac{\Pr(\mathrm{E}|\mathrm{S},\mathrm{N})}{\Pr(\mathrm{E}|\bar{\mathrm{S}},\mathrm{N})}\times\frac{\Pr(\mathrm{S}|\mathrm{N})}{\Pr(\bar{\mathrm{S}}|\mathrm{N})} \quad [1]$$

Let us denote $\Pr(\mathrm{E}|\bar{\mathrm{S}},\mathrm{N})$, the relative occurrence of the features, by γ. Note further that $\Pr(\bar{\mathrm{S}}|\mathrm{N}) = 1-\Pr(\mathrm{S}|\mathrm{N})$, and $\Pr(\bar{\mathrm{S}}|\mathrm{E},\mathrm{N}) = 1-\Pr(\mathrm{S}|\mathrm{E},\mathrm{N})$. In addition, for the sake of the example here, assume that that $\Pr(\mathrm{E}|\mathrm{S},\mathrm{N}) = 1$ and $\Pr(\mathrm{S}|\mathrm{N}) = 1/\mathrm{N}$. Thus, by rearranging Eq. [1], we obtain:

$$\Pr(\mathrm{S}|\mathrm{E},\mathrm{N}) = \frac{1}{[1+(\mathrm{N}-1)\gamma]} \quad [2]$$

$$\gamma = \frac{1-\Pr(\mathrm{S}|\mathrm{E},\mathrm{N})}{\Pr(\mathrm{S}|\mathrm{E},\mathrm{N})(\mathrm{N}-1)} \quad [3]$$

At this stage, a note on the assumption of a prior probability Pr(S|N) of 1/N is in order. Under the Earth population paradigm, it is natural to assign to each member of the population a prior probability greater than 0. Indeed, by definition, to be considered a member of the pool of possible sources, it is necessary that the prior probability for each source is greater than 0. But the form of the probability distribution that should be adopted is not a trivial matter. If a forensic scientist operates within an open set framework and the available information leaves the scientist indifferent between the potential sources, this state of belief is reflected by a uniform prior distribution, hence the suggestion of 1/N. Note, however, that this constraint will be relaxed later in this article.

We now turn back to the question of the orders of magnitude of Pr(S|E,N) and γ in the mind of an examiner at the moment of forming the conclusion. If the population is set to $N = 7$ billion (including the control), as suggested by the Earth population paradigm, and $\gamma = 1$ in 7 billion, then, using eqn [1], Pr(S|E,N) is very close to 0.5. This means that if you have a control object or person at hand with such extremely rare features, the probability that the item at hand is *not* the source is about 0.5! Thus, in order to have probabilities for the same source proposition higher than 0.5, we need probabilities of occurrence of the analytical features, γ, that are much lower than the inverse of N, the size of the population of potential sources. This is counterintuitive, but correct in the context of the present Earth population paradigm.

If we accept that Pr(S|E,N) must be above a certain threshold value in order to declare an individualization, then it is possible to calculate the probability γ necessary to achieve such a preset value. For example, if Pr(S|E,N) is fixed at 0.9998 – meaning 'I want to be sure at 99.98% that the person (object, etc.) of interest is the source of the trace (mark, etc.)' – with N = 7 billion, using eqn [3], we see that γ must be equal to 2.9E-14, which represents 1 in about 5000 times the size of the initial population of 7 billion. It is difficult to make sense out of such tiny figures.

Thus, if a conclusion of individualization under the above assumption requires the expression of such small probabilities, then we face the prospect of articulating probabilities beyond the realm of today's systematic research. That is, as such tiny numbers cannot be derived from any sort of empirical relative frequency data, they would need to be derived from areas of extreme model extrapolation. Yet, the current state-of-the-art in scientific research offers no way to investigate the robustness of such extreme model output. Taking DNA as an example, the recent published statistical research would allow us to quote confidently rarity figures on the order of one in a billion (Hopwood et al., 2012). Articulating any smaller number (down to the probability of zero) thus is difficult if not impossible to support.

In summary, the above treatment tends to demonstrate that individualization conclusions made by practitioners cannot defensibly be made in the open set framework. They necessarily need to operate implicitly in an undefined closed set. Moreover, the two traditional accounts of individualization, i.e. categorical statements (of individualiuation or exclusion) and graded conclusions (regarding individualization), run into a series of counterintuitive and paradoxical consequences. While exposition of these shortcomings is by far not exhaustive, it is sufficient to demonstrate the need of a more robust, defensible and balanced framework to results of forensic examinations. The remaining parts of this chapter present the currently most robust, transparent, flexible and logical account of forensic individualiuation. It is based on elements of probability and decision theory.

Probabilistic Evaluation of Identification Findings and Individualization Decisions

Probabilistic Account of the Probative Value of the Findings

In a probabilistic perspective, both closed set and open set situations can be handled. The open set merely represents a special case. From information gathered through investigation or through the use of a database, a limited number of people or objects, or even a single person or object, can be pinpointed in a general or limited population. Rather than expressing a direct opinion about a source proposition, as would be done in the traditional accounts of individualization exposed in the previous sections, the probabilistic account focuses on the value of the findings. That is, the scientist evaluates the strength of the forensic findings with respect to two competing perspectives or viewpoints. The first of these assumes that the designated person or object is the source of the questioned item, trace or material. The second assumes that an unknown person or object from the relevant population is the source. The probabilistic approach to evaluating findings provides a measure (i.e., metric) that recipients of expert information can use to adjust uncertainty about the truth or otherwise of an issue (here: the individualization S), based on new information (here: the forensic findings). This framework shows how data can be combined with prior or background information to give posterior probabilities for particular issues. The following variables can be defined from the previous example:

- I: Some background information has been collected before the forensic examination. For example, data from investigation, eyewitness statements, or data from the criminal historical record of the person of interest will contribute to I. Typically this information will reduce the number of potential sources (persons or objects) of the mark, trace or impression.
- E: Similarities and differences observed during comparative examinations of questioned and known materials.
- S, $\bar{\mathrm{S}}$: The mark, trace or impression comes from the person or object of interest (S) and the mark, trace or impression comes from an unknown person or object ($\bar{\mathrm{S}}$). The definition of two mutually exclusive propositions (S and $\bar{\mathrm{S}}$) requires consideration of the context of the case (e.g., the defense's strategy). They are not always as straightforward or exhaustive as our running example may suggest.

Bayes' theorem (Eq. [4], similar to Eq. [1]) shows how prior odds on S, $\mathrm{O}(\mathrm{S}|\mathrm{I})$, are modified by the results E to obtain posterior odds $\mathrm{O}(\mathrm{S}|\mathrm{E},\mathrm{I})$:

$$\mathrm{O}(\mathrm{S}|\mathrm{E},\mathrm{I}) = \frac{\Pr(\mathrm{E}|\mathrm{S},\mathrm{I})}{\Pr(\mathrm{E}|\bar{\mathrm{S}},\mathrm{I})} \times \mathrm{O}(\mathrm{S}|\mathrm{I}). \quad [4]$$

Note that $\mathrm{O}(\mathrm{S}|\mathrm{I}) = \Pr(\mathrm{S}|\mathrm{I})/\Pr(\bar{\mathrm{S}}|\mathrm{I})$ and $\mathrm{O}(\mathrm{S}|\mathrm{E},\mathrm{I}) = \Pr(\mathrm{S}|\mathrm{E},\mathrm{I})/\Pr(\bar{\mathrm{S}}|\mathrm{E},\mathrm{I})$. The probability of observing the similarities and differences between the questioned and known materials given that the person or object of interest is the source, and given information I, Pr(E|S,I), is often assessed as close to 1, but this is not a requirement. In turn, the probability of observing the similarities and differences between the questioned and known materials given that an unknown person or object is the source, and given information I, $\Pr(\mathrm{E}|\bar{\mathrm{S}},\mathrm{I})$, is commonly understood as an expression of the rarity of the observed combination of features, i.e. γ.

In this probabilistic account, the open set framework covers the situation where the prior odds are assigned with respect to the largest possible population (i.e., when information I does not allow one to reduce the Earth population). Conversely, any situation where the assignment of prior odds is based on information that directs the evaluation to a more restricted population can be viewed as a closed set framework.

The only difference between Eq. [1] and Eq. [4] is that I is used instead of N. In discussion of Eq. [2] it was suggested that the prior probability was strictly related N. Here, however, N is omitted and replaced by I to emphasize the fact that the prior probability depends on further considerations than N only, that is, investigative elements or eyewitness statements, etc. In fact, each case bears its own specificity in this regard. But, generally, these aspects are not known to the forensic examiner and are outside his or her area of competence. The assessment of the prior odds is the duty of the fact finder (judges, members of the jury, etc.). As a consequence, before the presentation of the expert's results, it will be up to the fact finder – and not the forensic scientist – to assess the prior odds regarding the propositions S and $\bar{\mathrm{S}}$. In addition, it is up to the fact finder to reach posterior beliefs.

Ultimately, the framework for inference of source itself does not belong to the forensic scientist, but to the fact finder. The statement (numerical or in terms of an order of magnitude) a scientist communicates to the court should, then, only be the expression of the reduction factor the court should use to modify its initial opinion. Here, 'initial opinion' means the so-called prior odds, i.e. the odds prior to considering the knowledge derived from the scientific results. Lacking the competence for dealing with prior odds, it is not possible for the scientist to make direct statements about the source propositions (e.g., the probability that a particular person or object has produced this mark). The scientist can, at best, only state the degree of support given to this proposition (or version) versus the relevant alternative proposition. The strength of the forensic findings is then given by the probability of observing the findings under two propositions (here S and $\bar{S}$). This ratio is called the 'likelihood ratio' (see term in the center of Eq. [4]).

The statement given by the scientist alone is not sufficient to reach a *decision* regarding the question of common source (proposition S). The scientist's statement is fundamentally different from the fact finder's ultimate determination regarding the proposition S. The concept of the weight assigned by forensic scientists to their results is, therefore, relative: the statement shows how observations *should* be interpreted as support for or against S versus its counterpart, but it makes no mention of how those observations should be interpreted as evidence in relation to S alone. Thus, the same piece of information may be insufficient proof for a fact finder in one context, but may be the factor essential for clinching the case in another. The odds in favor of the proposition that the person or object of interest has produced the mark, given the circumstances of the case (background information I) and the observations made by the forensic scientist (results E), are posterior odds. These incorporate the entirety of evidence available to the fact finder at the time a decision needs to be made regarding the question of source. The essence of the decision regarding individualization remains the province of the fact finder.

Note that the probabilistic account outlined above is a conceptual framework that lays out how to rationally process information in reasoning under uncertainty. As widely emphasized in jurisprudence and in doctrine, it is not suggested that judicial decision makers actually do or should engage in fully-fleshed probabilistic calculations. Indeed, ample evidence from research and practice demonstrates that people experience difficulties in conforming to rationally ideal reasoning procedures. Yet, what the probabilistic account can achieve, besides helping to prevent pitfalls of intuition, is to clarify the position of the scientist with respect to the recipients of expert information (e.g., judge, jury). It can also help scientists acquire a better understanding of the kinds of questions they can and cannot (logically) address, which is an important preliminary to thinking about strategies for the coherent verbal communication of the value of findings. The essential message is that the scientist is concerned solely with the value of the findings (likelihood ratio), whereas the fact finder deals with the propositions of interest (odds on the individualization, **Figures 4 and 5**) and, as outlined in the next section, the associated ultimate decisions.

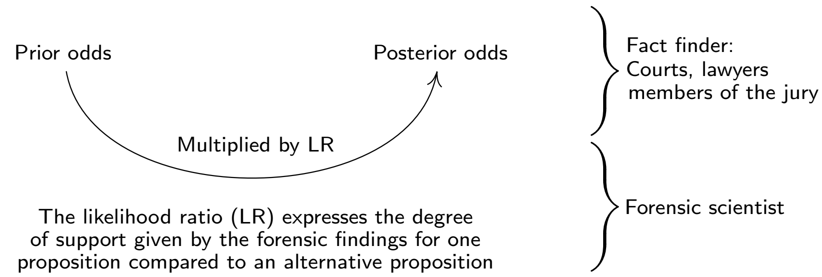

Figure 4 Illustration of the probabilistic account of inference of source and the separation of duties of actors in the legal process.

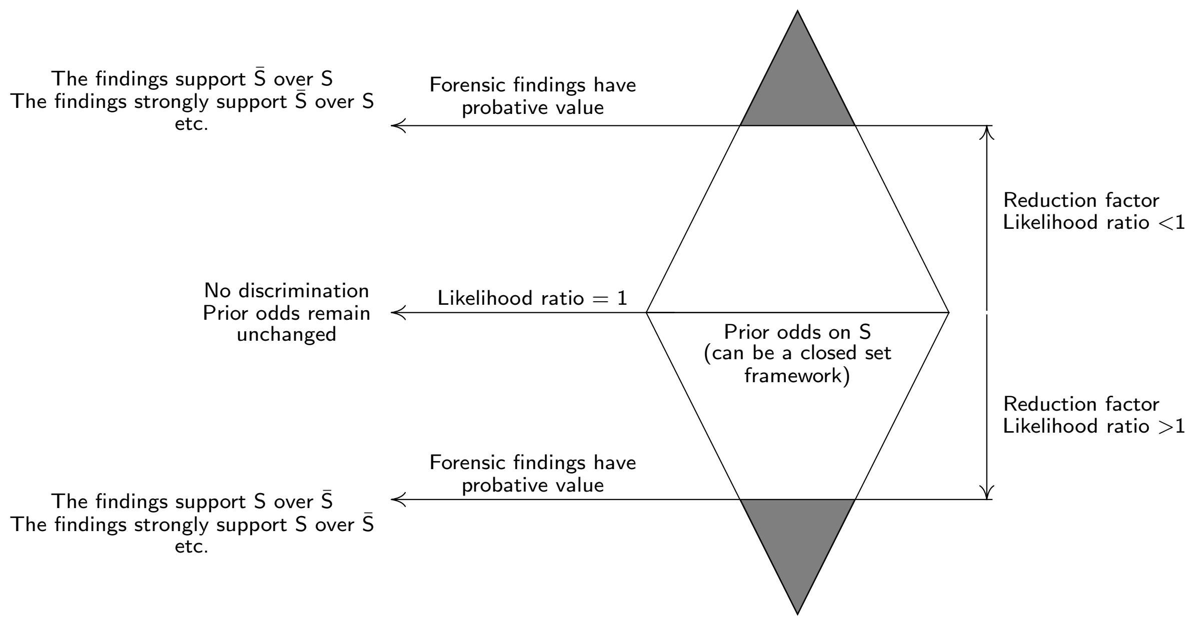

Figure 5 Illustration of the value of forensic findings (or results) in the individualization process.

Decision-theoretic account of individualization

The probabilistic account of inference of source exposed in the previous section clarifies how a value of evidence statement provided by a scientist can be used to inform the fact finder's odds regarding the propositions S and $\bar{\text{S}}$. We have mentioned that the fact finder's strength of belief in the truth or otherwise of the proposition that the person or object of interest is the source of the questioned trace, mark or impression is a necessary, but not sufficient preliminary to making a *decision* regarding individualization, i.e. to act as if proposition S or $\bar{\text{S}}$ is true. We have also mentioned that making a decision regarding individualization requires one to specify value judgments, that is express preferences among decision consequences.

Decision theory, an extension of probability theory, allows one to make these understandings formally precise and provide a decision criterion for individualization decisions (Biedermann et al. 2008, 2016; Taroni et al., 2020). More specifically, in this account, the decision maker needs to characterize the relative (un-)desirability of the consequences of deciding to individualize and not to individualize in the event that the person (or object) of interest is the source of the trace, mark or impression, as well as in the event that an unknown person (or object) is the source. Preferences among these decision consequences can either be specified in terms of utilities or losses. Of particular concern are the adverse outcomes of deciding to individualize when in fact the person or object is *not* the source of the trace at hand (also sometimes called a false or erroneous individualization), and deciding not to individualize when the person or object of interest in fact *is* the source of the trace at hand (also called a missed individualization). Note, however, that actual losses (utilities) cannot be minimized (maximized) because one does not know the ground truth state (i.e., whether or not the person or object of interest is the source). Thus, at best, the decision maker may consider the *expected* loss (utility) of each decision, and select the decision with the smallest (highest) expected loss (utility).

One version of the full decision-theoretic development for forensic individualization leads to the conclusion that in order for the decision to individualize to be the optimal decision – i.e., the decision that minimizes *expected* loss – the decision maker's (posterior) odds of the proposition S against the proposition $\bar{S}$ must be *greater* than the ratio of the losses associated with, respectively, an erroneous individualization and a missed individualization (e.g., Biedermann et al., 2016). In other words, and without going into further mathematical details, this result means that the more serious (i.e., undesirable) the decision maker views an erroneous individualization compared to a missed individualization, the higher his or her (posterior) odds ought to be in order to warrant an individualization decision. It is not necessary to work this criterion out in full numerical terms to see that it captures a precept that fact finders presumably already use. Informally, this precept says that the higher the stakes involved (i.e., the more one can 'lose'), the more one shall be sure *before* one decides (Biedermann and Vuille, 2018).

The deeper insight that derives from the decision-theoretic account of individualization is that it provides a strong if not definite argument against the idea of forensic scientists making individualization decisions (e.g., Cole and Biedermann, 2020). It suffices to realize that individualization decisions require not only posterior odds which, as we have explained in previous sections, are beyond the reach of forensic scientists, but also value judgments (here utilities or losses) which, by definition, are not within the scientist's area of competence.

Conclusion

We have started out with exposing the traditional approaches to the question of how to reach forensic source conclusions. They lead to either categorical statements of individualization/exclusion or to the provision of graded conclusions in terms of, for example, ‘possibly (probably, very probably, etc.) same source rather than different source’. Both of these accounts are often operated with reference to a relevant population size set to its maximum, the so-called an open set framework (or the Earth population paradigm).

These schemes perpetuate the idea that forensic scientists can defensively deal with – sometimes without being aware of – prior or posterior probabilities when reaching source conclusions, though this is completely unwarranted. The probabilistic relationship between verbal statements and probability of occurrence of corresponding (analytical) features can lead to counterintuitive and paradoxical consequences. Moreover, a well-informed (common) source conclusion requires more evidence than the forensic scientist’s findings, in particular other evidence available in a case, which disqualifies the scientist from reaching case-tailored individualization conclusions. Claiming otherwise inevitably leads to an overstatement of scientific evidence.

These observations call the suitability of the traditional approaches to individualization fundamentally into question. Another scheme, the probabilistic account, with its focus on the value of the findings, contrasts sharply with the traditional accounts. While the latter lead to an examiner’s direct opinion about source propositions, which invades the fact finder’s area of competence, probabilistic value of evidence statements overcome most of the difficulties of the traditional accounts. In particular, value of evidence statements do not require assumptions about the size of the potential source population, nor do they involve a questionable decision step. A value of evidence statement provides a coherent way of assessing and presenting scientific evidence, and helps to clarify the distinct roles of scientists and fact finders. Understanding individualization as a decision makes the separation of duties, here the provision of information by scientists as opposed to the fact finder’s decision-making mandate, formally precise and logically defensible. The future of responsible individualization in forensic science hinges upon the capacity of participants of the legal process to understand what exactly scientific evidence can and cannot provide, and that the decision-making prerogative properly belongs to fact finders.

References / Further Readings

Biedermann A, Bozza S, and Taroni F (2008) Decision theoretic properties of forensic identification: Underlying logic and argumentative implications. *Forensic Science International* 177(2–3): 120–132.

Biedermann A, Bozza S, and Taroni F (2016) The decisionalization of individualization. *Forensic Science International* 266(2–3): 29–38.

Biedermann A, Taroni F, and Garbolino P (2007) Equal prior probabilities: Can one do any better? *Forensic Science International* 172(2–3): 85–93.

Biedermann A and Vuille J (2018) Understanding the logic of forensic identification decisions (without numbers). *sui-generis*: 397–413, doi.org/10.21257/sg.83.

Champod C (2008) Fingerprint examination: Towards more transparency. *Law, Probability and Risk* 7(2): 111–118.

Champod C and Evett IW (2001) A probabilistic approach to fingerprint evidence. *Journal of Forensic Identification* 51(2): 101–122.

Cole SA (2009) Forensics without uniqueness, conclusions without individualization: The new epistemology of forensic identification. *Law, Probability and Risk* 8(3): 233–255.

Cole SA (2014) Individualization is dead, long live individualization! Reforms of reporting practices for fingerprint analysis in the United States. *Law, Probability and Risk* 13(2): 117–150.

Cole SA and Biedermann A (2020) How can a forensic result be a "decision'"? A critical analysis of ongoing reforms of forensic reporting formats for federal examiners. *Houston Law Review* 57: 551–592.

European Network of Forensic Science Institutes (ENFSI) (2015), ENFSI Guideline for evaluative reporting in forensic science.

https://enfsi.eu/wp-content/uploads/2016/09/m1_guideline.pdf

Hopwood AJ et al. (2012) Consideration of the probative value of single donor 15-plex STR profiles in UK populations and its presentation in UK courts. *Science & Justice* 52: 185–190.

Kaye DH (2011) Probability, individualization, and uniqueness in forensic science evidence: Listening to the academies. *Brooklyn Law Review* 75(4): 1163–1185.

Kaye DH (1999) Clarifying the burden of persuasion: what Bayesian decision rules do and do not do. *The International Journal of Evidence & Proof* 3(1): 1–29.

Kaye DH, Bernstein DE, and Mnookin JL (eds.) (2011) *The New Wigmore, a Treatise on Evidence: Expert Evidence*, 2nd edn., ch. 15, pp. 665–697. New York: Aspen Publishers Inc., ch. 15.

Kirk PL (1963) The ontogeny of criminalistics. *Journal of Criminal Law, Criminology and Police Science* 54: 235–238.

Kwan QY (1977) *Inference of Identity of Source*. PhD Thesis, Berkeley: University of California PhD Thesis.

Stoney DA (1991) What made us ever think we could individualize using statistics? *Journal of the Forensic Science Society* 31(2): 197–199.

Tuthill H and George G (2002) *Individualization: Principles and Procedures in Criminalistics*. Jacksonville: Lightning Powder Co.

Taroni F, Bozza S and Biedermann A. 2020, Decision theory. In Banks DL, Kafadar K, Kaye DH and Tackett M (eds.), Handbook of forensic statistics, Chapman & Hall/CRC Handbooks of Modern Statistical Methods, pp. 103–130. Boca Raton: CRC Press.