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'The logic of inference and decision for scientific evidence'

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1. Introduction

Uncertainty is an inevitable complication encountered by members of the judiciary who face inference and decision-making as core aspects of their daily activities. Inference, in this context, is mainly inductive and relates to the use of incomplete information, to reason about propositions of interest. Applied to scientific evidence, this means, for example, to reason about whether or not a person of interest is the source of a recovered evidential material. More so, fact-finders are required to make decisions about ultimate issues, e.g. regarding a defendant's guilt. The distinct, but related roles of inference and decision require a logical assistance because unaided human reasoning is liable to fallacious conclusions. This represents a critical cause of concern because incoherent reasoning in legal proceedings places defendants at risk and can lead to miscarriages of justice. In this respect, the role of forensic scientists, whose duty is to *help* assess the probative value of scientific findings, is subjected to ongoing scrutiny. Scientists (should) provide assistance by offering to mandating authorities conclusions that are scientifically sound and logically defensible.

The choice of a normative framework – that is a coherent *standard* of reasoning – thus is widely advocated. In the current understanding, such a framework intends to implement several desirable properties for evidential assessment, such as logic, balance, robustness and transparency. Within this general evidential context, this chapter addresses two fundamental questions. The first is 'How is one to manage scientific information?', and the second is 'How is one to justify a decision?'. The focus will be on presenting and discussing the extent to which probability theory and decision theory, can contribute toward answering these questions. This chapter will acknowledge and distinguish between, on the one hand, perspectives on evidence evaluation in forensic science literature and, on the other hand, legal evidence and proof processes on the level of cases as a whole.

2. Forensic science evidence evaluation in the 21st century

Forensic science can be defined as a body of scientific principles and technical methods applied within well-defined proceedings in criminal or civil law, as well as in regulatory matters. The main purpose of forensic science is to help demonstrate the existence or past occurrence of an event of legal interest, such as a crime, and to assist members of the judiciary, especially prosecutors and legal counsel, in determining the role of target individuals in a given contested event, as well as the *modus operandi*. On a practical account, forensic science is concerned with technical aspects such as the investigation of crime scenes and the examination of victims and persons of interests, either directly or indirectly in the form of items such as clothing, vehicles, tools, weapons, mobile phones or electronic devices. Such aspects are not covered here. On a more conceptual side, forensic science is concerned with tasks such as classification (e.g. examining whether an unknown substance is an illegal drug). Forensic analysis also typically involves comparisons between evidential material (of unknown source) and material of known source (i.e. reference material), followed by an evaluative phase where the focus is on assessing the evidential value of findings within the particular context of the event under investigation.

The public, legal professionals and, to some extent, academic circles perceive these instances of forensic science theory and practice as both well-founded and reliable. Yet, the discovery of cases of miscarriage of justice provides a continuing stream of debate[1], in particular with regard to scientific standards of reliability[2]. Across legal systems, courts have repeatedly stressed that forensic scientists are required to assess their respective domains of expertise[3]. Scientists should scrutinize both the rationale underlying the various domains of expertise as well as the ways in which scientific evidence is evaluated and presented in applied contexts. It is argued that the adopted reasoning schemes should conform to sound probabilistic principles[4].

Instances that illustrate the unease of forensic science with fundamental shortcomings in interpretation and data evaluation can be found throughout the last century. Among the pioneering forensic scientists, few commentators faced this topic as openly and critically as did Kirk and Kingston[5] when they wrote:

> When we claim that criminalistics is a science, we must be embarrassed, for no science is without some mathematical background, however meager. This lack must be a matter of primary concern to the educator [...]. Most, if not all, of the

[1] Saks and Koehler 2008; NRC Report 2009; Kaye 2010; Mnookin et al. 2011; Redmayne et al. 2011; Evett et al. 2017; Judicature 2018.
[2] UK Law Commission 2011; PCAST Report 2016.
[3] Aitken et al. 2011; Murphy 2017.
[4] Saks and Koehler 2005; Garbolino 2014; Cheng 2017.
[5] Kirk and Kingston 1964, 435-436.

amateurish efforts of all of us to justify our own evidence interpretations have been deficient in mathematical exactness and philosophical understanding.

This quote is still of relevance today, since data evaluation has been mentioned among the most neglected areas in the entire field of forensic science[6]. In the current practice of many forensic branches, evaluations of scientific evidence can hardly be regarded as anything more than an unstructured *ad-hoc* assessment; examples are evaluations following examinations of shoe-marks, tool-marks, bullets and cartridges (firearms), gunshot residues and handwriting.

At the time of Kirk and Kingston, conclusions based on robust statistical or probabilistic reasoning were rare, but they still are so today[7], with DNA as a widely-acknowledged exception. This is so even though much well-argued judicial literature has pointed out that categorical conclusions – that is, statements of certainty – cannot be justified on logical and scientific grounds[8]. As a general starting point, it thus needs to be conceded that incomplete knowledge about both general aspects of scientific branches as well as particular items of scientific evidence in instant cases inevitably results in uncertainty that cannot be eliminated. It is, however, measurable by probability. In turn, this means that common patterns of forensic inference, such as inference of identity,[9] in order to be taken seriously, must be approached within a probabilistic framework[10]. While this need has already been recognized at the beginning of the 20th century[11], it remains an unresolved topic in contemporary debates surrounding reporting policies (see Section 5)[12]. In recent years, this has led legal scholars to express their frustration at the reluctance of some parts of the forensic community to deploy more substantial efforts to critically review the foundations of identification in general, and to addressing the challenge of probabilistic evidential assessment in particular[13]. Adopting evaluative schemes that conform to logically sound principles is a priority in efforts to avoid improper forensic testimony and forensic misconduct[14].

[6] NRC Report 2009; PCAST Report 2016.
[7] Koehler 2011; Thompson et al. 2013; 2018; Cole 2014; Science 2016.
[8] See, e.g. Finkelstein and Fairley 1970; Eggleston 1983; Twining 1994; Thompson and Cole 2007; Thompson 2012; Hahn et al. 2013; Vuille et al. 2017.
[9] Inference of identity is also commonly termed inference of source. That is, assessing whether questioned and known items come from the same source. Note, however, that propositions of common source represent only one example among several other types of propositions (e.g. propositions invoking alleged activities) that may condition the evaluation of scientific evidence (Cook et al., 1998).
[10] Lindley 1991; Robertson and Vignaux 1993; Redmayne 2002; Hahn and Oaksford 2006; Tillers 2011; Saks and Neufeld 2011.
[11] Taroni et al. 1998.
[12] Cole and Biedermann 2020.
[13] Koehler 2014; Canzio and Luparia 2018.
[14] The Innocence Project reports that, as of 14th July, 2020, 367 innocent people have been exonerated in the United States, 21 of whom were sentenced to death. Forensic science was misapplied in 46% of DNA exoneration cases.

3. Core needs in forensic science: reasoning under uncertainty

If forensic science should abandon the idea of certainty[15], it becomes necessary to conceive of a way to measure uncertainty. It is natural, then, to refer to disciplines concerned with formal methods of reasoning, such as statistics, in particular methods for the assignment of probabilities to propositions of interest. That is, when the existence of uncertainty is recognized as an inherent aspect of a given inference problem, and a formal approach is possible, then this approach represents a reference in that it captures and ranks uncertainties based upon a concise and logical line of reasoning[16].

Both judicial and psychological literature, despite relating to two fields that are different in many respects, point out the need for methods that deal with the formal analysis of rational thinking[17]. They share a common interest in challenging configurations of real-world situations that informal reasoning must confront. This is illustrated by the fact that in their reasoning tasks, investigators, scientists and legal professionals at large (including judges, prosecutors and lawyers) often need to consider multiple items of information with complicated interrelated structure. It is necessary, thus, to inquire about ways in which items of information occur in combination and how they stand in relation to each other. Such analyses reach further levels of complication because they need to be conducted in the light of complex frameworks of circumstances, and competing accounts regarding the alleged events.

4. Inference and decision-making under uncertainty

Probability theory is among the primary candidates discussed in legal literature and philosophy of science for dealing with uncertainty in evidence evaluation as it forms a reference scheme for measuring uncertainty[18]. Throughout this chapter, the discussion of probability will emphasise its personalist interpretation, that is an interpretation that focuses on degrees of belief and how rational agents should make up their minds about events of the past, present and future that are uncertain to them. This view is particularly helpful with respect to the needs of forensic science[19]. Even critical commentators note that 'none of the conceptualizations of probability except probability as subjective degrees of belief can function at trial'[20]. Notwithstanding, we acknowledge that by choosing probability as a framework for reasoning under uncertainty, it is not suggested that, descriptively, it provides a model for the working of the legal process as a whole. Instead, the general argument is that probability theory helps formulate precepts for logically sound modes of reasoning, ask relevant

[15] Lindley 2014.
[16] Cole 2010; Frosini and Taroni 2015.
[17] See, e.g. Kahneman 2011; Roberts and Zuckerman 2010.
[18] Lindley 2014.
[19] Taroni et al. 2001, 2016.
[20] Allen 2013, 104.

questions and define the boundaries between the competence of expert witnesses and legal decision-makers. There is no suggestion that the responsibility for reasoning and decision-making processes is to be delegated to an abstract mathematical theory. In any case, as noted by Kaye, 'additional argument is necessary to bridge the gap from a general mathematical truth to a substantive application'[21].

While providing general principles for the coherent measurement of uncertainty, probability is not a static concept. In practice, it is often necessary to re-assess probabilities given newly acquired data or, more generally speaking, information. For this purpose, a standard result is available, Bayes' theorem, though its use in legal contexts has both proponents and critics. Broadly speaking, Bayes' theorem specifies how to re-organise one's state of mind based on new data, that is how to update initial beliefs (i.e., prior to data acquisition) about propositions of interest in light of such data. This idea of updating beliefs in the light of new information is conceptualized also in terms of the so-called Likelihood Ratio, a rigorous concept for a balanced measure of the degree to which particular evidence is capable of discriminating between competing propositions put forward by parties at trial. It measures the change produced by the evidence in one's beliefs in favour of one proposition as opposed to another[22]. Likelihood ratios are mainly studied by forensic scientists as a mean to quantify the probative value of scientific evidence, though further argument is necessary to convey results in a way that is understandable to recipients of expert information.

Probability and Bayes' theorem represent normative viewpoints, though not normative in a legal sense,[23] but in the sense of a standard that allows reasoners to think coherently in argument construction[24]. For example, when the scientist observes features of trace material and characterises their rarity within a relevant population, such an assessment cannot be directly transposed into a conclusion regarding the proposition according to which the person of interest is the source of the trace recovered on the crime scene. The role of probability is nothing less than to ensure logical reasoning. It is in this sense that the framework is considered to provide a suitable approach to many issues that pertain to the coherent management of imperfect evidence[25].

As much as there is debate about the suitability of probability theory and Bayes' theorem, and the extent to which practitioners are able to apply this framework, as much it is overlooked that the ultimate goal of formal methods of reasoning is not limited to quantify one's uncertainty about propositions of interest. Once all the evidence has been considered, one needs to act upon one's beliefs about what is (most probably) true. In legal contexts, acting (or deciding) means rendering a verdict

[21] Kaye 1999, 27.
[22] Kass and Raftery 1995.
[23] For an account on the normative perspective, as compared to descriptive and prescriptive perspectives, see e.g. Baron 2008; 2012.
[24] Kahneman 2011; Biedermann et al. 2014.
[25] Eggleston 1991; Redmayne 2001; Aitken and Taroni 2004; Oaksford and Chater 2007; Canzio and Luparia 2018.

in order to bring legal disputes to an end. Hence, the use of probability to deal with uncertainty is not an end by itself, but a means to an end which is decision-making.

From a formal perspective, probability theory pairs with decision theory to extend coherent reasoning to coherent decision-making. In essence, decision theory formalises the idea that one decides on the basis of two elements. These are, on the one hand, one's beliefs about uncertain events and, on the other hand, one's expression of desirability among the various possible decision consequences. The latter aspect is captured by the concept of utility (or loss). Probability and utility, operate within a general theory of decision that allows one to derive formal rules for decision-making (e.g. the maximisation of expected utility)[26].

Like probability, decision theory has a difficult stand among discussants who emphasize practicality and operational feasibility. First, because decision theory involves probability which itself is challenging in fully quantified applications. Second, because it involves the quantification of the desirability of decision consequences as an additional hurdle. The conceptualist reply to this is analogous to arguments in support of probability. Kaplan[27] has concisely noted that

> […] although we are in most legal areas far away from a usable quantification of our problems, the effort of thinking through the abstract quantitative relations among different variables turns out to provide a host of insights into the workings of our legal system.

The point here is that decision theory captures the fundamental aspects of problems that decision-makers face, irrespective of their argumentative viewpoint and level to commitment to formal theories. Among these aspects is the notion of *decision* under uncertainty, in analogy to *reasoning* under uncertainty. Because, at the time a decision needs to be made, it cannot be known with certainty which state of nature holds, one cannot directly tell which decision leads to the favourite consequence. What the decision analyst can do, however, is to map out the various decision paths, including the possible states of nature and associated outcomes, their probabilities and relative (un-) desirability. Technically, this amounts to a decision tree[28], which provides a detailed sketch of the anatomy of a decision problem[29]. By what is called 'folding back' the branches of such trees, one can work out the expected value for each branch which, in turn, provides a criterion for comparing the various options. The result thus consists of a qualifier for the appropriateness of particular decisions quantified on the basis of the (un-)desirability of the outcomes.

But again, it is the nature and the rigour of this framework that provide valuable insights. In this sense, decision theory is a useful framework for the exploration and scrutiny of alternative courses of action.

[26] See, e.g. Lindley 1985.
[27] Kaplan 1968, 1066.
[28] See, e.g. Raiffa 1968.
[29] See, e.g. Moore and Thomas 1988.

Decision theory forces decision-makers to formalize their preference structure and to assess the desirability of each decision outcome. It also encourages decision-makers to recognize that deciding *not* to take an action is just as much a decision as deciding which action to take, and that selecting an unnecessary action or failing to select a necessary action may represent an error. Decision theory also helps to ensure that thinking processes consider all relevant possibilities and avoid undesirable consequences. Since Kaplan's foundational paper[30], decision theory has regularly been discussed in legal literature[31] and in forensic science[32].

5. A discussion of recurrent sceptical viewpoints

A natural way of advocating the use of formal approaches to inference in legal contexts is by drawing an analogy to the concept of evidence and proof in science, which relies on the idea that formal procedures are easier to explain and justify than informal ones[33]. Yet, sceptical readers may wish to see further argument in support of the formalisms presented throughout this chapter. This is a critical aspect because experience shows that many scientists, when confronted with the discipline of statistics, tend to rely on definitional aspects of probability and statistical methods too uncritically. Ideally, however, researchers and practitioners would have an understanding of the rationale behind the underlying theory and refer to it because they are convinced that it is sound and addresses practical needs adequately. This raises a series of contentious issues that, in what follows, are grouped and discussed in view of two recurrent questions. The first addresses the question of why understanding probability as a degree of belief. The second addresses the question of what insight can be drawn from a decision theoretic perspective to selected aspects of evidence and proof processes.

5.1 Why regard probability as a degree of belief?

5.1.1 Operational limitations of frequentism

Part of an argument in favour of viewing probability as a degree of belief stems from the fact that other interpretations of probability encounter applicability problems. A good example for this is the (im-)possibility to assume stable conditions between instances of long sequences of events as suggested by frequentist definition. This includes attempts to derive probabilities from base rates.
In legal contexts, it is readily seen that one cannot easily conceive of (countable) outcomes of past events to determine relative frequencies.

[30] Kaplan 1968.
[31] See, e.g. Kaye 1988; Cheng 2013; Cole 2014.
[32] Biedermann et al. 2014; 2018; Taroni et al. 2005; 2020.
[33] Edwards 1988.

What is the chance that the defendant is guilty? Are we to imagine a sequence of trials in which the judgements, 'guilty' or 'not guilty', are made and the frequency of the former found? It will not work (…) because it is impossible to conceive of a suitable sequence. (…) The whole idea of chance is preposterous in this context.[34]

Similar observations apply to many fields including history, economics and forensic science[35]. What events in these contexts have in common is that they are singular and unique. In anything other than idealized situations, definitions of probability other than based on the notion of degrees of belief prove unworkable[36].

5.1.2 Justified subjectivism

The fact that subjective probability regards the probability of an event as a measure of personal belief in the occurrence of that event should not seem surprising. Even sceptics admit that it is natural to think in terms of personal probabilities, such as when betting on the outcome of a football game. A personal degree of belief is based on a person's entirety of knowledge, experience and information with respect to the truth of a given statement or event. While it may be questioned whether uncertainties in matters of legal interest should be assimilated to uncertainties encountered in daily life, it is difficult to contest the fact that assessments of probabilities (1) *do* depend on available information, (2) may change as the information changes and (3) may vary among individuals, not least because different individuals may have different information or assessment criteria.

Key to this understanding is that while probability can, in principle, take any value between zero and one, this does not mean that it is an arbitrary assignment from within this range of possible values. In any context of application where decision-making involves potentially adverse consequences, personal probability assignment is naturally expected to be accompanied by a justification. Stated otherwise, it is *constrained* by a warrant. This is in contrast to unconstrained, deliberate, unjustified, speculative or fanciful assertions that lack the credentials of a justified assertion[37].

Subjective probabilists are well aware of this subtlety, especially the fact that the rules of probability, as well as devices for eliciting probabilities, provide a liberal framework with rather few formal constraints. There are at least two ways to tackle this difficulty. The first is to argue that subjective probability comes with an obligation to take responsibility for one's choice as noted by de Finetti:

You are completely *free* in this respect and it is entirely your own *responsibility*; but you should beware of superficiality. The danger is twofold: on the one hand, You may think that the choice, being subjective, and therefore arbitrary, does not

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[34] Lindley 1991, 48.
[35] Kadane and Schum 1996.
[36] Press and Tanur 2001.
[37] Biedermann et al. 2018.

require too much of an effort in pinpointing one particular value rather than a different one; on the other hand, it might be thought that no mental effort is required, since it can be avoided by the mechanical application of some standardized procedure.[38]

The second, deeper point, is the proper distinction between subjective probability as opposed to the notions of objectivism and objectivity. Indeed, even the founding father of twentieth century subjective probabilism, de Finetti, was not opposed to objective notions[39]. Dawid and Galavotti concisely summarise this point:

(...) de Finetti's claim should *not* be taken to suggest that subjectivism is an anarchist approach according to which probability can take whatever value you like. De Finetti struggles against *objectivism*, or the idea that probability depends entirely on some aspects of reality, not against *objectivity*. He strongly opposes the "the distortion" of "identifying objectivity and objectivism", deemed a "dangerous mirage" (...), but does not deny that there is a *problem of objectivity* of evaluations of probability.[40]

5.1.3 Conceptual devices for measuring belief

Personal probabilities are sometimes viewed cautiously because it is asked how such an abstract concept could be captured in a nontrivial way. People may be reluctant to express their probabilities numerically, suggesting that this interpretation of probability remains an inaccessible concept. Such perceptions are overly restrictive because they disregard the fact that probabilities can be elicited and investigated empirically using various conceptual devices. One possibility to do this is in terms of bets that an individual is willing to accept. For instance, the probability maintained by an individual in the truth of a proposition can be compared with the probability of drawing a black ball from an urn, a setting that can be represented in terms of two gambles involving the same prize (with no stakes). This method for measuring the probability an individual entertains in the truth of a proposition consists in considering the choice between a gamble which offers a certain prize if the proposition is true and a gamble which offers the same prize if a black ball is drawn from an urn of known composition: if the person chooses the first game, this means that, for her, the probability of the proposition at issue is greater than the proportion p of black balls in the urn; if the individual chooses the second game, this means that, for her, the probability of the proposition is smaller than the proportion of black balls. Ideally, one can vary the proportion p up to the point where the person feels indifferent between the two gambles: that value p will be this person's probability for the proposition[41]. People who dislike the urn scheme may think of other devices, such as the spun of a

[38] de Finetti 2017, 153.
[39] A discussion on the role of frequencies to inform a probability assignment, can be found in Taroni et al. 2018.
[40] Dawid and Galavotti 2009, 98.
[41] See, e.g. Lindley 1985.

betting wheel where the pointer may stop on segments of varying size that determine the probability of winning[42].

A further method considers probability assignment as a decision[43]. It relies on proper scoring rules that are used to assign a score to the probability that the individual chooses to assert. This conceptualisation requires the formalization of an optimal probability statement according to which one's actual probability corresponds to that one that minimizes the expected score. This should invite people to state their probability honestly.

5.1.4 The 'problem' of where to start: the seemingly incommensurable prior probability

A recurrent issue is the question of how to assess probabilities measuring uncertainty about events for which only a partial reconstruction is possible, but that can be revised in the light of new information, in particular throughout Bayes' theorem. Critics refer to prior probability as something unknown, or unknowable in principle. Common reactions to this challenge are attempts to conceive devices or definitions for prior probability assignment. However, both ideas, unknowable probabilities and the design of ad-hoc definitions for their assignment are ill conceived. The reasons for this are twofold. First, unknowable probability is a contradiction in terms that de Finetti called a 'pseudo-problem'[44]: probability *is* one's ascertainment as a function of the extent of one's knowledge. It is not that one does not know one's probability, the point is that one may not be willing or feel able to assert it. More forcefully he stated:

> Among the answers that do not make sense, and cannot be admitted, are the following: 'I do not know', 'I am ignorant of what the probability is', 'in my opinion the probability does not exist'. Probability (or prevision) is not something which in itself can be known or not known: It exists in that it serves to express, in a precise fashion, for each individual, his choice in his given state of ignorance.[45]

Second, and in view of the above, attempts to define what one's prior probability ought to be, by reference to notions such as the principle of indifference, or symmetry considerations, is tantamount to breaking with the idea of (prior) probability as the expression of a person's specific degree of belief in an instant case. That is, while probability is ideally designed to capture any initial opinion, attempting to constraint this fundamental feature amounts to depriving it from one of its most powerful features.

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[42] See, e.g. Jackson et al. 2003; von Winterfeldt and Edwards 1986.
[43] See, e.g. de Finetti 2008; Lindley 1982.
[44] de Finetti 1972, 63.
[45] de Finetti 1972, 72.

Instead, the fact that probabilistic reasoning requires the assessment of probabilities, should be seen as an opportunity for reasoners to transparently articulate their beliefs about a phenomenon at hand. As noted by Kadane, the possibility to declare prior probabilities is a highly desirable property because it can be taken as a 'step toward honesty in analysis'[46]. These considerations illustrate that it is not very helpful to discuss prior probabilities without placing them into the framework to which they belong. An awareness is required of their role in Bayes' theorem in order to develop a constructive relationship between events on which we are uncertain. If this can be ensured, then one should be able to assert the prior probabilities that are most suitable for the problem at hand, or ignore them if they are irrelevant[47].

5.2 Why should legal researchers and practitioners be aware of decision theory?

5.2.1 Argumentative implications of decision-theory and -analysis for forensic science

Legal practice involves two distinct, but related functions: reasoning and decision making under uncertainty. For decades, forensic scientists have struggled, and continue to do so today, with understanding how to interact with and contribute to reasoning and decision-making processes in the law. They struggle with explaining how available information may be used to assist a judiciary action, in particular how to present the value of evidence.

The difficulty that scientists encounter has two dimensions. The first relates to the understanding of the principles and constraints of coherent reasoning and decision making (Section 4). They experience difficulties in understanding which conclusions can and cannot legitimately be drawn from forensic evidence, and why. The second relates to confusions about the scientist's role in decision making processes. All too often, instead of limiting their reporting to quantifying the probative value of their findings, forensic scientists tacitly make or suggest decisions. One of the most visible examples of this are so-called identification decisions, such as the attribution of a fingermark (of unknown source) to a (known) person of interest. Here, assessing the probative value of evidence would mean to assess the support the findings provide to one proposition (e.g., the fingermark comes from the person of interest) as compared to a given alternative proposition (e.g., the fingermark comes from an unknown person)[48]. Yet, this is not what most examiners do. They go beyond such evaluative statements and actually make decisions: they *decide* to conclude – categorically – that a given person of interest is the source of the fingermark. Decision theory can help reveal what is involved in such decisions[49]; in particular, it can be shown that such decisions require assessments (i.e., probabilities of the state of

[46] Kadane 1995, 314.
[47] D'Agostini 1999.
[48] Champod et al. 2016.
[49] See, e.g. Cole and Biedermann 2020.

nature and utilities or losses quantifying the desirability or undesirability of decision outcomes) which are beyond the area of competence of scientists[50]. This insight, drawn from formal decision theoretic analyses, is part of an argument to require that forensic scientists should no longer make identification *decisions*: because such decisions require value judgments for which scientists are not competent. Scientists who nevertheless make identification decisions, render their work unscientific. Stoney has concisely noted:

> For over 100 years the courts and the public have expected, and fingerprint examiners have provided, expert testimony that fuses these three elements: offering testimony not as evidence, but as proof, assuming priors and including decision making preferences. This created an overwhelming and unrealistic burden, asking fingerprint examiners, in the name of science, for something that science cannot provide. As a necessary consequence, fingerprint examiners became unscientific.[51]

5.2.2 Decision-theoretic deconstruction of misconceived legal probabilism and Bayesianism

Legal literature is replete with attempts to model elements of legal evidence and proof processes in probabilistic terms. As much as such attempts have been accompanied with enthusiasm, as much they have attracted critiques. Consider proposals for evaluating, in colloquial terms, 'the probability of a defendant's *guilt*' in the light of evidence through the use of Bayes' theorem. This is an unfruitful attempt in principle because it involves a misconception about the object to be modelled in the first place. Probability pertains to a reasoner's uncertainty about state of nature, that is a proposition regarding a real-world event. Guilt, however, is *not* a proposition; guilt is ascribed through a decision (here, a verdict). A guilty verdict is a decision to be contemplated in the light of uncertainty about the proposition of whether the defendant is the person who committed the acts of interest in the case at hand. Stated in more simple terms, probability merely addresses the question what one should believe, whereas decision is concerned with the question of what one ought to do[52].

While the misconception about the so-called 'guilt hypotheses' can be avoided by a proper reformulation of the propositions of interest, this still does not render purely probabilistic analyses suitable for modelling legal evidence and proof processes. In particular, widespread discussions about the required level of probability for deciding a case, which includes discussions concerning naked statistical evidence do not pay sufficient attention to the fact that the anatomy of decision making does not reduce to probability alone. Stated otherwise, one does not *only* decide based on what one

[50] Biedermann et al. 2008; 2016.
[51] Stoney 2012, 400.
[52] Royall 1997.

believes (i.e., one's probability for a proposition of interest), but also based on one's preferences among the possible consequences. The decision-theoretic account of legal factfinding, widely attributed to Kaplan's foundational paper[53], makes this formally precise. It defines the optimal decision in terms of the relative desirability of the various possible decision consequences, weighted by their probability of occurrence. Although this understanding can be pinned down numerically, such an advanced level of specification is not necessary to convey the underlying argumentative implications. For example, in the context of a simple decision problem with two possible options, such as liable or not liable, the decision-theoretic account maps well onto the intuitive understanding according to which the optimal decision is a function of the relative loss associated with the two ways in which the decision may go wrong. Specifically, deciding for one option based solely on a high probability for that option may not be sufficient if the loss of an adverse consequence 'outweighs' the loss associated with the adverse consequence that may be incurred with the alternative option[54].

6. Conclusions

Normative accounts of inference and decision for scientific evidence have been studied both by scientists and legal scholars, though often in isolated streams of research. A consequence of this was a lack of exchange at the intersection between (forensic) science and the law. For example, while the law saw intensive debates around the Collins case, followed by movements such as the new evidence scholarship in the 1980s[55], it was not until the early 1990s that forensic science started a systematic, in-depth study of probabilistic methods of inference[56]. At the same time, it is not always acknowledged that there are differences in the scope of the study of methods of inference and decision in science and the law. Forensic scientists often concentrate on assessing the probative value of selected items of evidence related to their respective area of interest. Lawyers are faced with the need to solve 'the problem of proof' on the level of the instant case as a whole. This is one of the reasons why claims by scientists regarding the use of formal methods of reasoning cannot easily be carried over to the conceptual problems encountered by lawyers and, hence, are met with scepticism. This raises the deeper question of what formal approaches to inference and decision in science and the law can and should achieve.

The argument developed throughout this chapter is that conceptual frameworks provide standards of reasoning useable to examine whether a given argument has the necessary credentials in order to be considered sound and, thus, whether reasoners are logically entitled to their conclusions. This corresponds to a conceptually normative perspective, though it is important to understand that this

[53] Kaplan 1968.
[54] See, e.g. Friedman 2018.
[55] Lempert 1988.
[56] See, e.g. Aitken and Stoney 1991.

standpoint does not claim to make any prescriptive statements for the functioning of the legal process. Any insight drawn from conceptually normative reflections still requires additional argument in order to be meaningfully used in legal applications. This is readily illustrated by academic discourses around largely theoretical topics such as 'naked statistical evidence' which are based on peculiar sets of assumptions that hardly ever map suitably onto problems encountered by legal systems in operation, not least because the problem in the first place is not one of probability, but decision. What normative accounts of inference and decision can achieve, however, is to provide arguments in favour of the division of labour between science and the law, and ways to define the role and limitations of the use of scientific evidence in the wider perspectives of legal evidence and proof processes.

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