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Analysing and exemplifying forensic conclusion criteria in terms of Bayesian decision theory

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ABSTRACT

There is ongoing discussion in forensic science and the law about the nature of the conclusions reached based on scientific evidence, and on how such conclusions – and conclusion criteria – may be justified by rational argument. Examples, among others, are encountered in fields such as fingermarks (e.g., 'this fingermark comes from Mr. A's left thumb'), handwriting examinations (e.g., 'the questioned signature is that of Mr. A'), kinship analyses (e.g., 'Mr. A is the father of child C') or anthropology (e.g., 'these are human remains'). Considerable developments using formal methods of reasoning based on, for example (Bayesian) decision theory, are available in literature, but currently such reference principles are not explicitly used in operational forensic reporting and ensuing decision-making. Moreover, applied examples, illustrating the principles, are scarce. A potential consequence of this in practical proceedings, and hence a cause of concern, is that underlying ingredients of decision criteria (such as losses quantifying the undesirability of adverse decision consequences), are not properly dealt with. There is merit, thus, in pursuing the study and discussion of practical examples, demonstrating that formal decision-theoretic principles are not merely conceptual considerations. Actually, these principles can be shown to underpin practical decision-making procedures and existing legal decision criteria, though often not explicitly apparent as such. In this paper, we will present such examples and discuss their properties from a Bayesian decision-theoretic perspective. We will argue that these are essential concepts for an informed discourse on decision-making across forensic disciplines and the development of a coherent view on this topic. We will also emphasize that these principles are of normative nature in the sense that they provide standards against which actual judgment and decision-making may be compared. Most importantly, these standards are justified independently of peoples' observable decision behaviour, and of whether or not one endorses these formal methods of reasoning.

1. Introduction

What degree of personal belief should be required before deciding in favour of a particular option? This question is fundamental and arises recurrently. It is inevitable not only in many situations of daily life, but also in virtually any professional area of activity (e.g., economics, engineering, and medicine) [e.g., 19]. In legal contexts, the question of decision takes a highly visible position, mainly because of the direct impact that convictions and acquittals have on all parties involved in the legal process. The ultimate issue is only one decision point, however, among many others in the legal process. Some of those decisions relate to scientific evidence presented by forensic scientists, as will be exemplified later in this paper. Other decision points relate to questions such as whether or not to hear a particular witness, or whether or not to conduct a search.

On a broad view, there are several ways to deal with decision-making. One is dismissively, often justified by reasons such as the need for practically feasible procedures or limitations of resources (e.g., time). Such an approach may be paired with trust in personal experience or a preference for intuitive proceedings. Indeed, there are many day-to-day situations in which a decision must be made and where spending too much time on introspection is neither necessary nor desirable. But there are also other situations in which it is appropriate to formalise intuition – as an integral part of logical

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reasoning in the face of uncertainty – and devote time to a serious analysis of how to make a decision, so as to guarantee that throughout decision analysis one is able to measure the quality of decisions [6]. This is typically the case when the stakes involved are high, or adverse decision consequences are severe. One very well known way to look at these different decision perspectives is through Kahneman's notion of fast and slow thinking [17]. In this paper, we posit that professional decision analysis related to the evaluative use of forensic science results in the legal context provides a strong case for the introspective approach.

Once it is agreed that questions of decision ought to be approached through an in-depth perspective, practicing and academic decision analysts commonly distinguish – in law as in other disciplines – between two main accounts, the normative and descriptive [e.g., [5]].[1] The descriptive account takes an interest in people's observable decisional and judgmental behavior. The normative account considers, instead, the rational standards by which judgment and decisions ought to be evaluated. Naturally, the descriptive approach is strongly rooted in empirical considerations. Over the past decades, there has been abundant research on, for example, the elicitation of what various subjects (e.g., judges, citizens and students) consider as 'beyond reasonable doubt' (e.g., [11,26], for a review see also Ref. [14]). Quantitative values obtained in such studies, using various elicitation procedures, vary over a broad range, depending on the experimental conditions. Such general knowledge about the observable properties of human behavior with respect to questions of judgment and decision is valuable, but the more fundamental question is what one's required level of personal degree of belief, before making a particular decision, actually means from a logical point of view. This is a question that pertains to the normative domain [9] and will be a main focus of attention in this paper. We will identify here the normative standpoint in terms of the classic decision-theoretic account, also known as Bayesian decision theory, given by probability and utility theory. Specifically, we will exemplify how this account allows one to capture the essential features of existing forensic decision procedures and conclusion schemes.

This paper is structured as follows. Section 2 introduces notation and one of the forms in which the Bayesian decision-theoretic criterion can be stated. The format we choose is based on the notion of loss for qualifying decision consequences. It is our preferred choice for the purpose of this paper because, compared to other formats, it helps to break down some of the formulaic burden. Further technicalities are confined to the Appendix. Section 3 will exemplify how the criterion allows one to clarify the preferences among decision consequences that are implied by current decision thresholds as used, for example, in kinship analyses in different legal systems. We will also discuss these insights and their relevance for decision practices in other areas of forensic science, such as fingermarks and comparative handwriting examinations. In Section 4, we will emphasize the prescriptive value of the approach. By prescriptive value we mean the potential to provide incentives and means for improving the practical understanding of how to decide based on forensic science results, and how to ensure coherence between decision policies across different forensic disciplines.

2. The Bayesian decision criterion

The basic tenet of the Bayesian decision-theoretic approach is – in one of its formulations – the weighing of losses, quantifying the undesirability of wrong decisions, with one's personal probabilities for such outcomes. In the legal context, typical examples for adverse decision outcomes are the conviction of an innocent person or the acquittal of person who is actually the offender. It is readily seen that such consequences parallel with false identifications and exclusions in the context of forensic identification (or, individualization) [e.g., 7]. More generally, an outcome is defined as what would occur if one makes a decision (e.g., convicting or acquitting, identifying or excluding) given that a particular state of nature holds (e.g., the prosecution's or the defense's case being true). When expressing losses for decision outcomes numerically, and combining them with probabilities for states of nature, one obtains to the concept of expected loss. Decisions can be characterized by their expected loss, and one can use expected loss as a basis to choose among available decisions. In Bayesian decision theory, a common principle says to choose the decision with minimum expected loss.[2] The use of this principle, in a prescriptive sense, as a basis for decision is controversial in the law [e.g., [2]], a topic that is beyond the scope of this paper. Here we will solely concentrate on the analytical use of this principle for the study and review of decision problems that arise in the restricted scope of forensic science.

The concept of expected loss is considered here because, at the time when a decision must be made, the actual state of nature is not known — it is uncertain. If it would be known which state of nature holds, it would be straightforward to select the decision that is optimal under that state of nature, and there would be no necessity to approach the decision problem in a structured way. Clearly, for example, if one would know for sure that a person of interest is *not* the source of a trace found at a crime scene, not identifying that person as the source of the trace would be the optimal decision. If, however, there is uncertainty about the actual state of nature, the presumably sensible way to proceed is to consider the loss that is *expected* for each decision (e.g. considering the loss due to a missed individualization and the loss due to a false identification), and then choose the decision which has the minimum expected loss. Further development of the comparison of the expected losses of two decisions, call them d_1 and d_2, leads to the following standard decision criterion [e.g., [6]] (see Appendix):

$$\text{decide } d_1 \text{ rather than } d_2 \text{ if and only if } \frac{\Pr(\theta_1 \mid I)}{\Pr(\theta_2 \mid I)} > \frac{\mathrm{L}(C_{12})}{\mathrm{L}(C_{21})}, \qquad (1)$$

where θ_1 and θ_2 are the two states of nature (e.g., the competing propositions of the prosecution and defense), $Pr(\cdot \mid I)$ denotes probability conditioned on information I, and $\mathrm{L}(\cdot)$ denotes loss associated with a particular consequence C_{ij}, that is the consequence of deciding d_i $(i = 1, 2)$ when the actual state of nature is θ_j $(j = 1, 2)$. Notice that Eq. (1) supposes that correct conclusions, that is deciding d_1 when proposition θ_1 is true, and deciding d_2 when proposition θ_2 is true, have zero losses.[3] In turn, the decisions with adverse consequences C_{12}, that is wrongly deciding d_1 when in fact θ_2 holds, and C_{21}, that is wrongly deciding d_2 when in fact θ_1 holds, have non-zero losses.

A crucial insight of the decision criterion that is exemplified in Eq. (1) is that the question of 'what to decide' does not have an absolute answer, but a relative one. It is relative in the sense that one's degrees of belief, expressed in terms of the odds in favour of θ_1 over θ_2, must be compared against the ratio of the relative losses associated with the two possible ways of deciding wrongly. In particular, the prior (posterior) odds ratio on the left-hand side of Eq. (1) must

[1] From a philosophical perspective, we may add the interpretive account, which concentrates on, for example, the meaning of decision [10].

[2] Note that one can also work with utilities instead of losses. Then the criterion states that one should choose a decision that maximizes the expected utility.

[3] Note that the approach is flexible enough to consider, if required, variations to the assumption that the two correct decision consequences have identical losses. Stated otherwise, the decision-maker may consider that the results of the two ways of deciding correctly are *not* equally desirable. However, in such a case, the reader should observe Eq. (2) in the Appendix instead of the simplified Eq. (1) in Section 2.