Rethinking legal probabilism

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1 Scientific goal

As many miscarriages of justice indicate, scientific evidence is easily misinterpreted in court. This happens partially due to miscommunication between the parties involved, partially due to the usual probabilistic fallacies, but also because incorporating scientific evidence in the context of a whole case is hard. Probabilistic tools for piecemeal evaluation of scientific evidence and spotting probabilistic fallacies in legal contexts are quite well developed. Yet, the construction of a more general probabilistic model of incorporating such evidence in a wider context of a whole case, useful for theorizing about evidence evaluation and legal decision standards, remains a challenge. Legal probabilism (LP), for our purpose, is the view that this challenge can and should be met. This project intends to contribute to further development of this enterprise relying on motivations that come from different sources: formal epistemology, the development of bayesian networks, the practice of probabilistic evidence evaluation and the points raised by the critics of LP.

The assessment of evidence in the court of law can be viewed from at least three perspectives: as an interplay of arguments, as an assessment of probabilities involved, or as an interaction of competing narrations. Each perspective presents an account of legal reasoning (Di Bello & Verheij, 2018; van Eemeren & Verheij, 2017). Individually, each of these strains has been investigated. The probabilistic approach, while being fairly mature, is still underdeveloped in light of various lines of criticism developed by the representatives of the other strains.

The **goal of this project** is to **develop a probabilistic and yet narration-based modelling method of the interaction of various items of evidence and hypotheses and the resulting decisions in the court of law**. This will be achieved by accomodating important **insights provided by the critics of legal probabilism**. One crucial point is that the fact-finding process should be conceptualized as **a competition of narrations**, and standard probabilistic approaches do not capture this dimension. Another point comes from the argumentation theory framework: an adequate model should capture the structure of the arguments involved and the interplay between them, and it is not clear how this is to be achieved within the probabilistic approach. The point of departure is to represent narrations as bayesian networks enriched with additional layer of information as to which nodes correspond to evidence, and which are binary narration nodes. **The key idea is that with such bayesian networks as building material, various features requested by the critics (such as coherence, resiliency, missing evidence, explaining evidence, or ways to handle a multiplicity of proposed narrations) can be explicated in terms of corresponding properties of, operations on, and relations between bayesian networks.** Thus, the goals are three-fold:

1. Philosophical and conceptual improvement of legal probabilism by elaborating ways of representing probabilistically the narration-based perspective and the adversarial character of evidence assessment, which are typically absent from probabilistic approaches.
2. Formulation of a formal and computational probabilistic framework that incorporates features resulting from achieving goal 1. This will be done using Bayesian networks, hierarchical Bayesian models and imprecise probabilities. (**R** code capturing the technical features developed will be made openly available.)
3. Addressing the question of how evidence of different types can be aggregated and how adjudication should proceed in the presence of multiple competing narrations of what happened. The research in 1. and 2. will help to address this very practical and pressing question.

The output will be a **unifying extended probabilistic model embracing key aspects of the narrative and argumentative approaches, , with implementation in the programming language R.**
What the project will uniquely bring to the table is joining the familiarity with epistemological debates, familiarity with the details of evidence assessment in legal cases and technical skill to programmatically implement, simulate and test various theoretical moves.

2 Significance

2.1 State of the art

2.1.1 Legal probabilism

From among the three perspectives already mentioned, the probablistic approach will be my point of departure, for the following key reasons:

- The project is to be informed by and reflect on the actual practice of legal evidence evaluation, and much of scientific evidence in such contexts has probabilistic form.
- Probabilistic tools are fairly well-developed both for applications and within formal epistemology, reaching a state of fruition which should inspire deeper reflection.
- Statistical computing tools for such methods are available, which allows for programming development and preliminary computational and data-driven evaluation of the ideas to be defended.

Accordingly, the view in focus of this research is legal probabilism (LP)—an ongoing research program that comprises a variety of claims about evidence assessment and decision-making at trial. At its simplest, it comprises two core tenets: first, that the evidence presented at trial can be assessed, weighed and combined by means of probability theory; and second, that legal decision rules, such as proof beyond a reasonable doubt in criminal cases, can be explicated in probabilistic terms.

The early theorists of probability in the 17th and 18th century were as much interested in games of chance as they were interested in the uncertainty of trial decisions (Bernoulli, 1713; Daston, 1988; Franklin, 2001; Hacking, 1975). Bernoulli's prescient insights attained greater popularity in the 20th century amidst the law and economics movement (Becker, 1968; Calabresi, 1961; Posner, 1973). Finkelstein & Fairley (1970) gave one of the first systematic analyses of how probability theory, and Bayes' theorem in particular, can help to weigh evidence at trial. Lempert (1977) was one of the first to propose to use likelihood ratios for assessing the relevance of evidence. Such contributions fueled what has been called the New Evidence Scholarship, a rigorous way of studying the process of legal proof at trial (Lempert, 1986).

2.1.2 Challenges to New Evidence Scholarship

Tribe (1971) attacked what he called 'trial by mathematics', by listing well-known cases of misuse or probabilities in legal contexts and practical difficulties in assessing the probability of someone's criminal or civil liability, and pointing out the dehumanization of trial decisions that legal probabilism seems to propose. After Tribe, many argued that probabilistic models are either inadequate or unhelpful (Allen, 1986; Brilmayer, 1986; Cohen, 1986; Dant, 1988; Underwood, 1977). This negative trend has been somewhat mitigated by the discovery of DNA fingerprinting in the eighties and progress in forensic science in general, with the increasing role of quantitative evidence in the court of law (Kaye, 1986, 2010; Koehler, 1996; National Research Council, 1992; Robertson & Vignaux, 1995).

Skepticism about wider mathematical and quantitative models of legal evidence is still widespread among prominent legal scholars and practitioners (see, for example, Allen & Pardo, 2007). This is partially in light of conceptual difficulties extensively discussed in the literature, which arise when one wants to formulate a probabilistic decision criterion for the court of law. Imagine you are a trier of fact in a legal proceeding in which the defendant's guilt is identified as equivalent to a certain factual statement G and that somehow you succeeded in properly evaluating $P(G|E)$—-the probability of G given the total evidence presented to you, E. One question that arises in such a situation is: when should you decide against the defendant? When is the evidence good enough? What we are after here is a condition Ψ, formulated in (primarily) probabilistic (and perhaps decision-theoretic) terms, such that the trier of fact, at least ideally, should accept any relevant claim A (including G) just in case $\Psi(A, E)$. One straightforward attempt might be to say: convict if $P(G|E)$ is above a certain threshold, otherwise acquit (Dekay, 1996; Kaye, 1979; see, for example Laplace, 1814; Laudan, 2006).

This move, however, seems to be blocked by the so-called paradoxes of legal proof or puzzles of naked statistical evidence. Nesson (1979), Cohen (1981), and Thomson (1986) formulated scenarios in which, even if the probability of guilt or civil liability, based on the available evidence, is particularly high, a verdict against the defendant seems unwarranted. A variant of such a scenario—the gatecrasher paradox—goes as follows. Suppose our guilt threshold is high, say at 0.99. Consider the situation in which 1000 fans enter a football stadium, and 991 of them avoid paying for their tickets. A random spectator is tried for not paying. The probability that the

spectator under trial did not pay exceeds 0.99. Yet, intuitively, a spectator cannot be considered liable on the sole basis of the number of people who did and did not pay. While recently some doubt the relevance of abstract philosophical examples for the actual practice (Hedden, 2019; Ross, 2020), at least conceptual challenges remain.

Another conceptual problem is the so-called difficulty about conjunction. It arises, because intuitively there should be no difference between the trier's acceptance of A and B separately, and her acceptance of their conjunction, $A \wedge B$, that is, that $\Psi(A, E)$ and $\Psi(B, E)$ just in case $\Psi(A \wedge B, E)$. If $\Psi(H, E)$ is just the threshold criterion requiring that $P(H|E)$ be sufficiently high, Ψ in general fails to satisfy this equivalence, as the probability of a conjunction generally can be lower than the probability of any of the conjuncts.

Arguably, these problems underscore a theoretical difficulty with probabilistic accounts of legal standards of proof. How to define them, or whether they should be even defined in the first place, remains contentious (Diamond, 1990; Horowitz & Kirkpatrick, 1996; Laudan, 2006; Newman, 1993; Walen, 2015). Judicial opinions offer different paraphrases, sometimes conflicting, of what these standards mean. In the last decade, philosophers have also joined the debate (Gardiner, 2018; for critical surveys see Redmayne, 2008).

At least *prima facie*, then, it seems that some conditions other than high posterior probability of liability have to be satisfied for the decision to penalize (or to find liable) to be justified. Accordingly, various informal notions have been claimed to be essential for a proper explication of judiciary decision standards (Haack, 2014; Wells, 1992). For instance, evidence is claimed to be insufficient for conviction if it is not *sensitive* to the issue at hand: if it remained the same even if the accused was innocent (Enoch & Fisher, 2015). Or, to look at another approach, evidence is claimed to be insufficient for conviction if it doesn't *normally support* it: if—given the same evidence—no explanation would be needed even if the accused was innocent (Smith, 2017). A legal probabilist needs either to show that these notions are unnecessary or inadequate for the purpose at hand, or to indicate how they can be explicated in probabilistic terms.

2.1.3 The alternative perspectives

More recently, alternative frameworks for modeling evidential reasoning and decision-making at trial have been proposed. They are based on inference to the best explanation (Allen, 2010; Hastie, 2019; Ho, 2019; Nance, 2019; Pardo & Allen, 2008; Schwartz & Sober, 2019), narratives and stories (Allen, 1986, 2010; Allen & Leiter, 2001; Clermont, 2015; Pardo, 2018; Pennington & Hastie, 1991a), and argumentation theory (Bex, 2011; Gordon, Prakken, & Walton, 2007; Walton, 2002). Those who favor a conciliatory stance have combined legal probabilism with other frameworks, offering preliminary sketches of hybrid theories (Urbaniak, 2018a; Verheij, 2014).

The main point of criticism of LP is that legal proceedings are back-and-forth between opposing parties in which cross-examination is of crucial importance, reasoning goes not only evidence-to-hypothesis, but also hypotheses-to-evidence (Allen & Pardo, 2007; Wells, 1992) in a way that seems analogous to inference to the best explanation (Dant, 1988), which notoriously is claimed to not be susceptible to probabilistic analysis (Lipton, 2004), and the process is an interaction of multiple arguments that remain in fairly complicated relations. An informal philosophical account inspired by such considerations—The **No Plausible Alternative Story (NPAS)** theory (Allen, 2010)—is that the courtroom is a confrontation of competing narrations (Ho, 2008; Wagenaar, Van Koppen, & Crombag, 1993) offered by the sides, and the narrative to be selected should be the most plausible one. The view is conceptually plausible (Di Bello, 2013), and finds support in psychological evidence (Pennington & Hastie, 1991b, 1992) (while the psychological support does not prove that this approach is rational, it suggests that a narration-related approach, if rational, might be more realistic).

It would be a great advantage of LP if it could model phenomena captured by the narrative approach. But how is the legal probabilist to make sense of them? From her perspective, the key disadvantage of NPAS is that it abandons the rich toolbox of probabilistic methods and takes the key notion of plausibility to be a primitive notion which should be understood only intuitively. It would be even better for LP if the incorporation of such insights could lead to the resolution of the already mentioned conceptual difficulties.

2.1.4 Bayesian networks as a tool for legal probabilism

The idea that Bayesian networks can be used for probabilistic reasoning in legal fact-finding started gaining traction in late eighties and early nineties (Edwards, 1991), and it found its way to nowadays standard textbooks on the topic (Fenton & Neil, 2018a; Taroni, Biedermann, Bozza, Garbolino, & Aitken, 2014).

A Bayesian network comprises two components: first, a directed acyclic graph of relations of dependence (represented by arrows) between variables (represented by nodes); second, conditional probability tables. Consider the graphical component first. The graph is acyclic: the arrows connecting the nodes do not form loops. As an illustration, let H be the claim that the suspect committed the murder, BT the presence of a blood type B match with a crime scene stain, and W the fact that an eyewitness observed the suspect near the scene around the time of the crime. The graphical component of the Bayesian network would look like this.
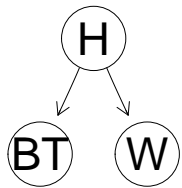
The *ancestors* of a node are all those nodes from which we can reach it by following the arrows going forwards. The *parents* of a node are those for which we can do this in one step. The *descendants* of a node are all which can be reached from it by following the arrows going forward. The *children* are those for which we can do this in one step. In the example, H is the parent (and ancestor) of both W and BT, which are its children (and descendants). There are no non-parent ancestors or non-children descendants.

The variables, which are represented by nodes and are connected by arrows, stand in relation of probabilistic dependence. To describe these relations, the graphical model is accompanied by conditional probability tables. For instance, they can look as follows (the blood type frequency estimate is realistic (Lucy, 2013), and so are the conditional probabilities for the eyewitness identification, although for complications about assessing eyewitness testimony see Wixted & Wells (2017) and Urbaniak, Kowalewska, Janda, & Dziurosz-Serafinowicz (2020)).

	H = murder	H=no.murder
W = seen	.7	.4
W = not.seen	.3	.6

	H = murder	H=no.murder
BT = match	1	.063
BT = no.match	0	.937

(A prior for the root node(s) is also required; here, say, $P(H = murder) = .01$ and $P(H = no.murder) = 0.99$.)

While the Bayesian network above—comprising a directed acyclic graph along with probability tables—is simple, a correct intuitive assessment of the probability of the hypothesis given the evidence is already challenging. The reader is invited to try to estimate intuitively the probability that the defendant committed the murder (H=murder) given the following states of the evidence:

- The suspect's blood type matches the crime stain but information about the witness is unavailable.
- The suspect's blood type matches the crime stain but the witness says they did not see the suspect near the crime scene.
- The suspect's blood type matches the crime stain and the witness says they saw the suspect near the crime scene.

	H=murder
BT = match,W=?	.138
BT = match,W=not.seen	.074
BT = match, W=seen	.219

Already at this level of complexity, calculations by hand become cumbersome. In contrast, software for Bayesian networks will easily give the results visible on the left. Perhaps surprisingly, the posterior probability of H is about .22 even when both pieces of evidence are incriminating (BT=match, W=seen).

In a similar vein, fairly simple graphical patterns (called *idioms*) often appear while modeling the relationships between evidence and hypotheses. Complex graphical models can be constructed by combining these basic patters in a modular way. Discussion of general methods for Bayesian network constructions can be found in (Bovens & Hartmann, 2004; Friedman, 1974; Hepler, Dawid, & Leucari, 2007; Neil, Fenton, & Nielson, 2000) and general idioms are discussed in (Fenton, Neil, & Lagnado, 2013).

Some attempts have been made to use Bayesian networks to weigh and assess complex bodies of evidence consisting of multiple components. On one hand, we have serious reconstructions of real complex cases. Kadane & Schum (2011) made one of the first attempts to model an entire criminal case, Sacco & Vanzetti from 1920, using probabilistic graphs. Here is another, more recent, example by Fenton & Neil (2018b), who constructed a Bayesian network for the famous Sally Clark case.
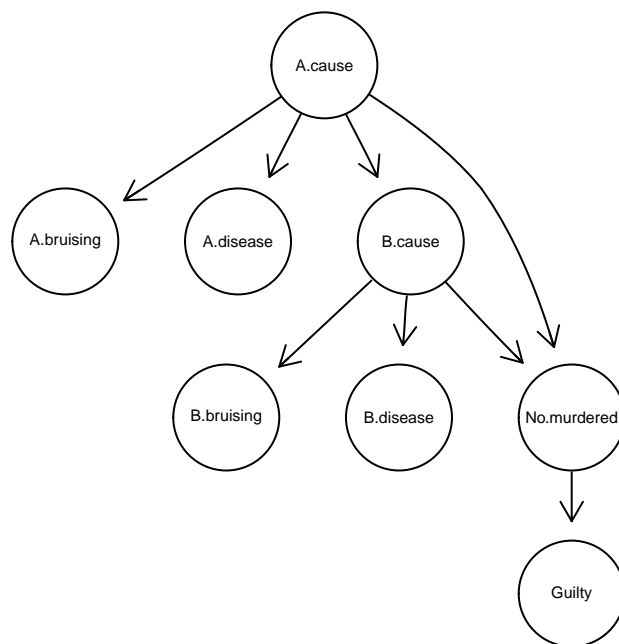
The arrows depict relationships of influence between variables. Whether Sally Clark's sons, call them *A* and *B*, died by SIDS or murder (A.cause and B.cause) influences whether signs of disease (A.disease and B.disease) and bruising (A.bruising and B.bruising) were present. Since son A died first, whether A was murdered or died by SIDS (A.cause) influences how son B died (B.cause). How the sons died determines how many sons were murdered (No.murdered), and how many sons were murdered decides whether Sally Clark is guilty (guilty).

Evidence (cumulative)	P(Clark guilty)
A bruising	.2887
A no signs of disease	.3093
B bruising	.6913
B no signs of disease	.7019

In Fenton's calculation, the prior probability of Guilty = Yes should be .0789. After taking into account the incriminating evidence presented at trial, such as that there were signs of bruising but no signs of a preexisting disease affecting the children, the posterior probabilities are as in the table on the left.

The literature contains examples of more general methodological reflection on the use of BNs for modeling whole cases. The main idea is that once all the pieces of evidence and claims are represented as nodes, one should use the *scenario idiom* to model complex hypotheses, consisting of a sequence of events organized in space and time: a scenario (Vlek, Prakken, Renooij, & Verheij, 2014). A discussion of modelling crime scenarios by means of graphical devices mixed with probabilities can be also found in the work of Shen, Keppens, Aitken, Schafer, & Lee (2007), Bex (2011), Bex (2015) and Verheij (2017). See also the survey by Di Bello & Verheij (2018). Dawid & Mortera (2018) give a treatment of scenarios in terms of BNs.

A graphical model that uses the scenario idiom would consist of the following components: first, nodes for the states and events in the scenario, with each node linked to the supporting evidence; second, a separate scenario node that has all the other as its children; finally, a node corresponding to the ultimate hypothesis as a child of the scenario node. Such a model could look like this:

Scenario

Guilt   State/event 1

Evidence 1   State/event 2

Evidence 2   State/event 3

Evidence 3
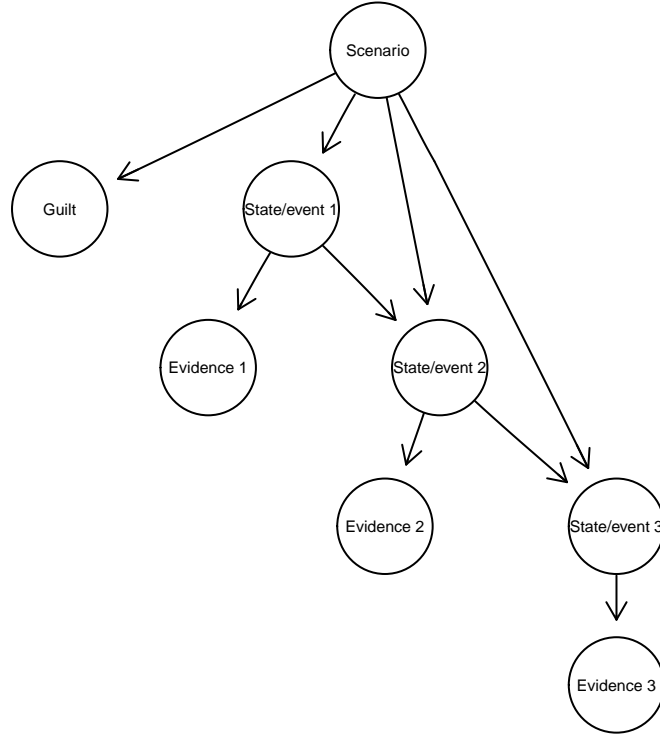
Note that the scenario node unifies the different events and states. Because of this unifying role, changing the probability of one part of the scenario (say State/event 2) will also change the probability of the other parts (State/event 1 and State/event 3). This is intended to capture the idea that the different components of a scenario form a whole.

One challenge that this strategy is supposed to help with is the question of how to make sense of the notion of the coherence of a scenario as different from its probability given the evidence. On this approach (Vlek, 2016; Vlek, Prakken, Renooij, & Bart Verheij, 2015; Vlek, Prakken, Renooij, & Verheij, 2013; Vlek et al., 2014), coherence is identified with the prior probability of the scenario node.

Another challenge that the framework is supossed to meet is the question of how to formally represent reasoning with multiple scenarios on the table. On this approach (called scenario merging), given a class of narrations, all the nodes used in some of the separate BNs are to be used to build one large BN, and separate scenario nodes are to be added to it, so that one BN supposedly represents multiple scenarios at once.

A somewhat alternative approach to representation of and reasoning with multiple scenarios has been developed by Neil, Fenton, Lagnado, & Gill (2019). They correctly criticize (Urbaniak, 2018a) where I only sketch some theoretical moves in a second-order language towards the probabilistic modelling of the narrative approach. The critics point out the paper makes no connection to BNs and so it "fails to offer a convincing and operational means to structure and compare competing narratives." This is a fair assessment of the limits of what I have achieved so far. They propose to represent separate narrations in terms of separate BNs, and to deploy bayesian model comparison and averaging as a tool for reasoning with multiple scenarios. That is, Bayes Theorem with hypotheses as models (BNs), yields:

$$\mathsf{P}(M = m_i | E) = \frac{\mathsf{P}(E | M = m_i)\mathsf{P}(M = m_i)}{\sum_{i=1}^{n} \mathsf{P}(E | M = m_i)\mathsf{P}(M = m_i)} \tag{1}$$

Then, assuming equal priors, models with higher likelihoods will have higher posterior probabilities, and the most plausible model will be the one with the highest posterior (that is, with equal priors, with highest likelihood). Alternatively, they propose averaging the predictions for a given variable φ by taking the ensemble model:

$$\mathsf{P}(\varphi | E) = \sum_{i=1}^{n} \mathsf{P}(\varphi | M = m_i, E)\mathsf{P}(M = m_i | E) \tag{2}$$

where the weights are identified with the posteriors of the models given the evidence, which are calculated using (1). The priors of the form $\mathsf{P}(M = m_i)$ used in (1) are either taken to be equal for all i, or postulated to be different. Fenton in an example uses 0.8 for the prosecution model and 0.2 for the defense model, but no clear guidance as to how model priors are to be chosen is provided.

2.2 Pioneering nature of the project

2.2.1 Points of disagreement

Here are the key reasons why I am convinced the scenario node approach is not satisfactory:

A. The use of a scenario idiom is problematic. Adding a parent node by *fiat* without any good reasons to think the nodes are connected other than being a part of a single story, introduces probabilistic dependencies between the elements of a narration. Merely saying that, say, the defenendant made jointly some claims is not a good reason to assume they are probabilistically dependent.

B. Another problem results from the identification of prior probability with coherence. This does not add up intuitively. After all, it is quite coherent with my views that if I win a lottery, I'll buy a large house in Auckland and move there, while both the prior and the posterior given the total available evidence of this scenario are rather low.

C. In general, the legal probabilistic approach to coherence is very simple and fails to engage with rich philosophical literature exactly on this topic (Douven & Meijs, 2007; Fitelson, 2003a, 2003b; Glass, 2002; Meijs & Douven, 2007; Olsson, 2001; Shogenji, 1999), including a long list of counterexamples to the existing proposals and desiderata that a probabilistic coherence measure should satisfy (Akiba, 2000; Bovens & Hartmann, 2004; Crupi, Tentori, & Gonzalez, 2007; Koscholke, 2016; Merricks, 1995; Schippers & Koscholke, 2019; Shogenji, 1999, 2001, 2006; Siebel, 2004, 2006).

D. The merging procedure with scenario nodes assumes that for the nodes that are common to the networks to be merged, both the directions of the arrows in the DAGs and the conditional probability tables are the same across different narrations. This is suboptimal. Different sides in court might construe causal dependencies differently, and even if they agree about the direction of an arrow, they might disagree about the probability table associated with it. Even a single side might consider different scenarios with different probabilities, say, when there is some uncertaintly inolved in the probability assignment itself.

Here are the key limitations of the approach proposed by Neil et al. (2019):

E. The idea that model priors should be equal is highly debatable. For one thing, this approach would render prior probabilities quite sensitive to the choice of hypotheses and thus potentially arbitrary. In addition, this approach seems particularly unsuitable for criminal cases. If the only two hypotheses/models on the table ultimately say "the defendant is guilty" and "the defendant is innocent", the prior probability of each would be 50%. But defendants in criminal cases, however, should be presumed innocent until proven guilty. A 50% prior probability of guilt seems excessive. Some (Williamson, 2010) try to defend a variant of the principle of indifference by reference to informational entropy, and a proposal along this line has been used in practical recommendation by expert committees (ENFSI Expert Working Group Marks Conclusion Scale Committee, 2006). However, this attempt has been sensibly criticized by Biedermann, Taroni, & Garbolino (2007). The question remains, what should the proper application of informational entropy in the context of BN selection and averaging look like, given that information entropy considerations independently are in epistemologically decent standing? Importantly, whatever conclusions in such contexts are epistemologically justified, how do they square with the presumption of innocence? Some take the presumption to mean that the prior probability of guilt should be set to a small value (Friedman, 2000; Friedman, Allen, Balding, Donnelly, & Kaye, 1995), but it is not clear whether this interpretation can be justified on epistemological or decision-theoretic grounds.

F. More recent models rely on relevant background information, for example, geographical information about people's opportunities to commit crimes [Fenton, Lagnado, Dahlman, & Neil (2019). But even if these models are successful in giving well-informed assessments of prior probabilities any evidence-based assessment of prior probabilities, they are likely to violate existing normative requirements of the trial system (Dahlman, 2017; Engel, 2012; Schweizer, 2013). For instance, if the assessment of prior probabilities relies on demographic information, people who belong to certain demographic groups will be regarded as having a higher prior probability of committing a wrong than others. This is what a well-informed assessment should amount to. Yet, if some people's priors are higher than other people's priors, it will be easier to convict or find liable those who are assigned higher priors, even if the evidence against them is the same as the evidence against those assigned lower priors. This outcome can be seen as unfair (Di Bello & O'Neil, 2020). The question remains: what procedure of choosing the priors both is justified by epistemological considerations and does not generate tension with fairness considerations?

G. Model selection based on likelihood (given equal priors) or posterior model probabilities in general (if priors are not assumed to be equal) boils down to a variant of the threshold view, and so all the difficulties with the threshold view apply.

H. Model averaging in the proposed form boils down to taking a weighted average of the probabilities provided by the models (weighted linear pooling). However, there is a rich literature on the difficulties that linear pooling runs into (see the surveys in Dietrich & List, 2016; Franz Dietrich & List, 2017a, 2017b). One problem is that the method satisfies the unanimity assumption: whenever all models share a degree of belief in a claim, this is exactly the output degree for that belief. But clearly, a claim can receive additional boost from multiple agents with different pieces of evidence agreeing on something (for instance, in witness corroboration). Another problem is that linear pooling does not preserve probabilistic independence (List & Pettit, 2011): even if all models agree that certain nodes are independent, they might end up being dependent in the output. There is also a variety of impossibility theorems in the neighborhood (Gallow, 2018).

2.2.2 Strategy and novelty

First, we need to represent narrations with their argumentative and dynamic structure in probabilistic terms. Once this is done, the resulting resulting representation tools can be used to work out an explication of the notion of coherence that does a better job than merely probabilistic explications that are available. Once this is done, various methods of dealing with multiple BNs, be it ensemble methods or some model selection methods, should be put into place, by explaining in a principled way which of these methods should be used in what context and why. One key novelty is in the formulation and BN implementation of selection criteria that so far have only been discussed informally in philosophical literature. Once this explication is obtained, further investigation of the role these criteria should play and their principled justification will proceed. I cover these steps in more detail now.

Representation. I will use BNs taken separately without scenario nodes to represent various narrations. Crucially, I will not assume the conditional probability tables or directions of edges are the same across the BNs, thus allowing for more realistic flexibility. To be able to accommodate insights provided by NPAS and other critics of LP, I will add another layer of information: for each BN one needs to specify a set of binary nodes such that a certain combination of their states counts as a narration, and a set of evidence nodes, which are supposed to support this narration.

Dynamic BNs If what we are modeling is cross-examination, averaging does not seem to be the right way to go. To model cross-examination, we need to take the argumentative approach seriously and to be able to model relations such as "undercutting" and "rebutting". And these relations can be modelled by adding or removing nodes or arrows in the network in a suitable manner. But this means we might have to consider another dimension: BNs changing through time in light of other BNs. How to make sense of this formally so that the result makes sense philosophically remains an open question.

BN-based coherence. With Alicja Kowalewska I have developed a coherence measure that diverges from the known candidates in three important respects: (1) It is not a function of a probabilistic measure and a set of propositions alone, because it is also sensitive to the selection and direction of arrows in a Bayesian Network representing an agent's credal state. (2) Unlike in the case of quite a few coherence measures, it is not obtained simply by taking a mean of some list of all possible intermediate values (such as confirmation levels between all subsets of a narration). It is also sensitive to the minimal values of the intermediate values. (3) The intermediate values used are not simply confirmation levels, but rather confirmation levels weighted by the probabilities of their antecedents. Preliminary tests on existing philosophical counterexamples suggests the performance of the measure is much better than the existing coherence measures. Now, it needs to be deployed (implemented in **R** for BNs) and properly tested on real-life cases discussed in the LP literature.

Divide and conquer. In fact, dealing with multiple models is difficult in this context. On one hand, many machine learning methods are not available. For instance, one cannot evaluate models in terms of their performance with respect to the data. Whenever you want to use resampling methods (such as cross-validation), or some information criterion scoring (suchs as Akaike Information Criterion), you need to have a dataset with multiple datapoints to start with, and such datasets are usually not available (and often conceptually unimaginable) for the problems typically faced in the court of law. On the other hand, averaging often doesn't

make sense either. After all, often no epistemological or decision-related progress might be gained based on averaging the prosecutor's and the defendant's stories, if they disagree about crucial elements of the case. I propose that ensemble methods should be deployed for multiple narration variants available from one side (as in when, say, the prosecution story comes with uncertainty about the direction of an arrow or about a particular probability table, and averaging helps to gauge the uncertainty involved), but selection methods should be used when final decision is to be made between narrations proposed by the opposing sides.

Ensemble methods. One question that arises is whether the general concerns about linear pooling arise for such limited applications. If not, the remaining concern is what priors should be used. In light of the controversial nature of equal priors, I plan to study the consequences of rescaling coherence scores (already mentioned) to constitute model priors. The idea is that given that narrations are to be developed by the sides themselves, taking coherence of their narration as determining the prior might be more fair than using equal priors or relying on geographical or population statistics. If yes, perhaps some other methods boiling down to a variant of sensitivity analysis can be deployed: look at all BNs corresponding to some variant of the narration of one of the sides, find the one that supports the ultimate conclusion the most, and the one that supports it the least, and these give you a range of possible outcomes.

Selection criteria. The so-called New Legal Probabilism (NLP) is an attempt to improve on the underspecificity of NPAS (Di Bello, 2013). While still being at most semi-formal, the approach is more specific about the conditions that a successful accusing narration is to satisfy for the conviction beyond reasonable doubt to be justified. Di Bello identifies four key requirements that a successful convicting narration should satisfy:

(Evidential support)	The defendant's guilt probability on the evidence should be sufficiently supported by the evidence, and a successful accusing narration should explain the relevant evidence.
(Evidential completeness)	The evidence available at trial should be complete as far as a reasonable fact-finders' expectations are concerned.
(Resiliency)	The prosecutor's narrative, based on the available evidence, should not be susceptible to revision given reasonably possible future arguments and evidence.
(Narrativity)	The narrative offered by the prosecutor should answer all the natural or reasonable questions one may have about what happened, given the content of the prosecutor's narration and the available evidence.

Prima facie, it is far from obvious that such conditions are susceptible to a Bayesian networks explication. However, I have already developed a more expressive probabilistic framework (call it Narration-Friendly Probabilism (NFP)) capable of expressing such features within a formalized higher-order language (Urbaniak, 2018b). On NFP, the notion of narration is quite wide: narrations not only contain factual statements about what happened, but also claims about evidence, about narrations, about relations between evidence and various parts of various narrations etc. I extend the basic propositional language with propositional operators N_i and E corresponding to "... *is part of narration i*" and "... *is part of the evidence*," and model narrations as finite sets of sentences from this language. Due to this intuitive move, many important aspects of narrations normally discussed only informally, similar to those discussed by Di Bello, become expressible in terms of probabilistic measures for such a formal language. Let's very briefly gesture towards a few examples:

- A defending narration explains a piece of evidence e just in case if there is an attacking narration whose posterior is raised conditional on e, the probability of e conditional on this defending narration is above the negligibility threshold.
- An attacking narration misses some evidence just in case there are some statements not in the evidence set such that the probability of the claim that at least one of them is part of evidence conditional on the existing evidence ($\{\varphi|\varphi \in \text{Evidence}\}$), its description ($\{E\varphi|\varphi \in \text{Evidence}\}$), and on this attacking narration is above the strong plausibility threshold.
- A narration contains gaps just in case there are some claims which are not part of it, but conditional on the content and the description of this narration and the evidence available, their disjunction is strongly plausible, and it is strongly plausible conditional on the content (but not on the description) of this narration and on evidence that at least one of these claims is part of the narration.
- A narration is dominant just in case it doesn't miss any evidence, it doesn't contain any gap, and in light of all available information and evidence it is at least as likely as any other narration, and is strongly

plausible.

While threshold- or likelihood-ratio-based selection criteria for models are unlikely to succeed, as already discussed, I am convinced the criteria formulated in philosophical terms in (Di Bello, 2013) and in higher-order terms in (Urbaniak, 2018a) are in better standing. The key hypothesis is that they can be recast in terms of properties of BNs and that the existing BN programming tools can be extended to implement testing for these criteria, intended as seprately necessary and jointly sufficient requirements for the winning narration. This will make them susceptible to programmatic implementation and further study by means of computational methods. The hope is that on one hand, they will do better than the existing proposals, and where they fail, further insights can be gained by studying the reasons behind such failures.

3 Work plan

Stage 1 Philosophical & formal unification	Obtain a unifying extended probabilistic framework by incorporating further insights from philosophical and psychological accounts of legal narrations, and from the argumentation approach. Defend its philosophical plausibility. (6 months)
Stage 2 AI implementation	Develop Bayesian Network Methods for the obtained formal framework, so that the insights from the argumentation approach and informal epistemology, mediated through it, can be incorporated in AI tools. (12 months)
Stage 3 Case studies	Evaluate the developed framework and AI tools by conducting case studies from its perspective. (6 months)
Stage 4 Back to challenges & output	Investigate the extent to which the new framework helps to handle the issues raised in points A.-H., finalize the book. (12 months)

The planned publication output is as follows:

- Stage 1 will result in one philosophical paper published in an academic journal such as *Synthese*, *Mind* or *Ratio Juris*. Working title: *Why care about narration selection principles?*

- Stage 2 will lead to one technical paper published in a journal such as *IfCoLog Journal of Logics and their Applications*, *Law, Probability and Risk* or *Artificial Intelligence and Law*. Working title: *Implementation of narration assessment criteria in Bayesian Networks with **R**.*

- Stage 3 will lead to a publication of one paper on how the formal framework handles case studies and a further paper on how the developed AI tools handle real-life situations in journals such as *Artificial Intelligence* or *Argument & Computation*. Working titles: *Rethinking the famous BN-modeled cases within the narration framework* and *BNarr, an **R** package to model narrations with Bayesian Networks*.

- Throughout the whole project I plan to cooperate with Marcello Di Bello. Over the last year we co-authored the Stanford Encyclopedia of Philosophy entry on Legal Probabilism. We decided to continue our fruitful cooperation. For over two months we have been working on a book proposal to be submitted to Oxford University Press exactly on the issues to be studied in this research project. Marcello Di Bello is an excellent philsopher with extensive research experience in the philosophy of legal evidence, and he would bring his expertise to the table when working both on the book and on the papers, whereas I would be focused on the technical aspects and the underlying formal philosophy. During the last year of the research **I plan a six months' stay at Arizona State University**, to work in person with Di Bello on finalizing the book that presents the results with special focus on issues investigated in Stage 4 (especially chapters 6 and 8-14 cover the relevant issues).

The tentative list of planned chapters is as follows (two of them already exist as sample chapters for the book proposal submission):

Apart from publications, the results will be presented at various conferences devoted to legal reasoning. These include the yearly conferences of the *International Association for Artificial Intelligence and Law* and of the *Foundation for Legal Knowledge Based Systems (JURIX)*, and more general conferences gathering formal philosophers, so that the research is inspired by interaction not only with legal evidence scholars, computer scientists, but also philosophers. I am also already an invited speaker at the upcoming "Probability and Proof"

conference that will be part of an international conference on the philosophy of legal evidence ("The Michele Taruffo Girona Evidence Week") in Girona (Spain) May 23-27 2022.

4 Methodology

Standard arguments for the legitimacy of Bayesianism[1] deploy usually rather abstract pieces of reasoning to the effect that if one's degrees of beliefs satisfy certain conditions, they also have to satisfy the probabilistic requirements. My approach to thinking about the plausibility of Bayesian epistemology is rather unlike such approaches. Instead, I prefer the *proof-of-the-pudding* methodology. I am convinced that an important part of the philosophical assessment of the Bayesian research program has to do with its achievements or failures in contributing to debates in philosophy which are not themselves debates about the status of Bayesianism itself. In particular, it would be great news if insights from Bayesian epistemology could be used to further develop forensic AI and deepening our understanding of judiciary decision making.

What the project will uniquely bring to the table is joining the familiarity with epistemological debates on the nature of coherence (which legal probabilists ignore or are unaware of), familiarity with the details of evidence assessment in legal cases (which formal epistemologists ignore or unaware of) and technical skill to programmatically implement, simulate and test various theoretical moves.

I will be using four methods: (a) informal conceptual analysis; (b) formal conceptual analysis; (c) computational metods (R simulations, etc.); and (d) case studies. I will rethink and model the existing impliementions of whole-case-scale-BNs in legal evidence from the perspective of the new framework and reconstruct cases which extensively use probabilistic reasoning, but for which BNs have not been yet proposed. Both the literature already listed and many textbooks on quantitative evidence in forensics are great sources of such cases.

A larger initiative involving reconstructing various cases using different representation methods and comparing the representations, called *Probability and statistics in forensic science*, took place at the Isaac Newton Institute for Mathematical Sciences. My approach will be in the same vein.

I have extensive experience in analytic philosophy, conceptual analysis, philosophical logic and probabilistic and decision-theoretic methods as deployed in philosophical contexts. I also have teaching and publishing record that involves statistical programming in the **R** language (my sample programming projects can be visited at https://rfl-urbaniak.github.io/menu/projects.html), and so am also competent to develop AI implementations and tests of the ideas to be developed.

One research risk is that it will turn out that some of the informal requirements cannot be spelled out in probabilistic terms, or expressed in terms of properties of Bayesian networks. In such an event, I will study the reasons for this negative result. It might happen that there are independent reasons to abandon a given condition, or it might be the case that probabilistic inexplicability of a given condition is an argument against the probabilistic approach. Either way, finding out which option holds and why would also lead to a deeper understanding of the framework and lead to a publication in academic journals. Another research risk is that the case studies will show that other methods are more efficient or transparent. This would itself constitute a result that could be used to further modify the framework so that its best aspects could be preserved, while the disadvantages discovered during case studies avoided.

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[1] See for example (Earman, 1992; Urbach & Howson, 1993) for an early yet fairly comprehensive survey, or (Pettigrew, 2011) for a discussion of more recent contributions. See also (Bovens & Hartmann, 2004; Bradley, 2015; Swinburne, 2001).

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