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Evaluating physical and digital forensic findings given activity level propositions using Bayesian networks

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Chapter 5

A TEMPLATE BAYESIAN NETWORK FOR THE EVALUATION OF FINDINGS IN INTERDISCIPLINARY CASEWORK

5.1 A template Bayesian network

This chapter generalizes the case model in Fig. 4.3 to form a template model that can be utilized in a variety of cases. Fig. 5.1 presents this template model. The template model evaluates transfer evidence at activity level and includes disputes about the actor and/or activity, and a dispute related to item—activity. If any of these elements are not disputed, the template model can be adjusted accordingly. Node 13 to 17[1] are added to the template model from Vink & Sjerps (2023) and represent the evaluation of evidence given item—activity propositions:

13. Item 1 links to activity 1?
14. Transfer of trace type 4 from A4 to item 1 via activity 1
15. Trace type 4 present on item 1
16. Background trace type 4 on item 1
17. Findings on item 1

These nodes evaluate the evidence given that item 1 can be linked to activity 1 or not. Item 1 links to activity 1? (13) is modeled as a binary root node with states "True" and "False". The root nodes allow for prior probabilities to be set and for an evaluation of the findings on item 1 that can update these prior probabilities.

Recall from Section 4.1.1 that the specific relation between item and activity that needs to be assessed depends on the case circumstances. Therefore sweater worn by offender during incident (node 12 in Fig. 4.3) is generalized as item 1 links to activity 1? (13). Recall from Section 4.1.2.

[1]The numbering of the nodes differs slightly compared to the model in Fig. 4.3, due to an extra background node in the template.

Figure 5.1: Template model for the evaluation of transfer evidence at activity level including disputes over the actor and/or activity and a dispute about item—activity. *Trace type 1 and trace type 2 are the same and an accumulation node (node 8) can be used. If the trace types are not the same, new accumulation and background nodes (similar to nodes 8 and 10) should be introduced for trace type 2. This template Bayesian network is accessible via a QR code in Appendix A, available in both PDF and .oobn file formats.

that Item 1 links to activity 1? influences the probabilities of transfer given H_1 and H_2. If the posterior probability
P(13. Item links to activity 1? = True | 14. Trace type 4 ... on item 1 = True) exceeds zero, information may flow between the activity level propositions and the case findings on the item.

Similar to the transfer paths leading from Activity level propositions (1) to Case findings on item 1 (18), a transfer path follows from item 1 links to activity 1? (13) to Case findings on item 1 (18). The child node of item 1 links to activity 1? (13) is Transfer of trace type 4 from A4 to item 1 via activity 1 (14)[2,3]. This node is followed by Trace type 4 present on item 1 (15).

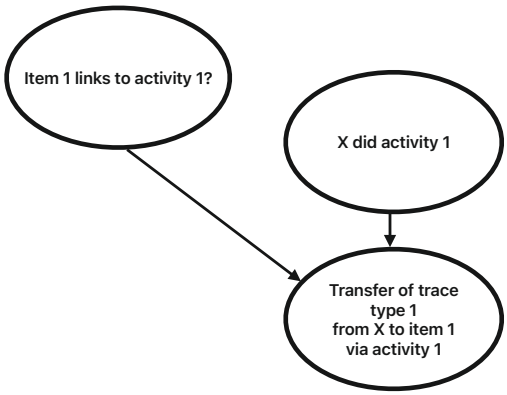
We investigated two modeling structures to combine the evaluation of evidence given the propositions relating to the item—activity and given the activity level propositions (see Fig. 5.2). Structure A contains directed links from item 1 links to activity 1? and X did activity 1 to Transfer of trace type 1 from X to item 1 via activity 1. Structure B includes a directed link from Item links to activity 1? to X did activity 1 with item 1.

We chose structure A because it is more flexible for multiple case scenarios than structure B. First, even if item 1 is not related to any activity, it is still possible for one of the activities to have occurred. Item 1 is simply not the item from which to draw an inference but other items may be. Structure A can handle this situation but structure B needs adaptation.

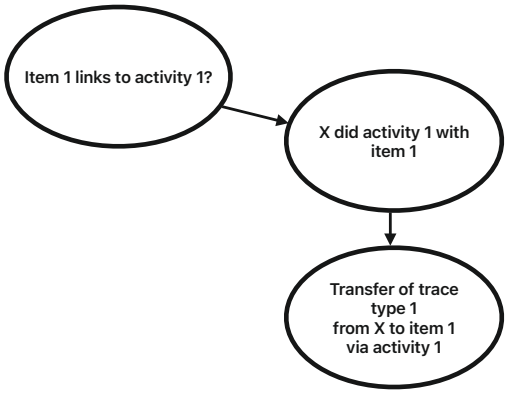
Second, if there are multiple items submitted for examination and their relation to an activity is also questioned, the expert only needs to add association nodes (similar to node 13) and transfer nodes (similar to node 14) to the

[2]A4 is the "donor" of trace type 4 and can be either an item or individual. The donor can be different from the donors in the other transfer nodes. The same holds for the trace type.

[3]Since item 1 links to activity 1 (13) is binary and already allows for only a single transfer path to follow, we decided not to use a blue activity node as a child node.



(a) Structure A



(b) Structure B

Figure 5.2: Two different modeling structures for combining the evaluations of the evidence given the item–activity propositions and given the activity level propositions. Structure (a) is the preferred method.

network - no extra activity nodes are needed. Last, model A is better suited for evaluating the evidence with regard to the main activity level question, that involves "who did activity 1?" or "what did Mr. X do?". The expert should be able to evaluate traces from multiple items and including the phrase "with item 1" in the activity node makes this impossible. Consequently, structure A is included in the template model through a parental relation of ITEM 1 LINKS TO ACTIVITY 1 (13) with the transfer nodes (5,7) that consider activity 1.

The template model is concluded with CASE FINDINGS ON ITEM 1 (18) that accumulates all the findings on item 1. CASE FINDINGS ON ITEM 1 can be set to true to derive the combined LR - only if the prior odds of the activity level propositions are set to one.

5.2 Variations to the template model

The template model in Fig. 5.1 illustrates a scenario in which one item of interest and one activity are disputed. And so, only the relation between item 1 and activity 1 is a possible dispute. There might also be a need to assess the value of evidence given the relation between the same item and another activity, or between another item and activity 1. In both cases, the expert can add a second root node representing the association propositions, as illustrated in Fig. 5.3 and Fig. 5.4. A similar transfer path as the one from ITEM 1 LINKS TO ACTIVITY 1? (13) to FINDINGS ON ITEM 1 (17) in Fig. 5.1 can be followed.

We suggest using an association node for every item for which the link to a certain activity is disputed. If multiple association nodes are being modeled, the expert should carefully investigate the possible dependencies between the association nodes—reflected by the directed link between them in Fig. 5.3. In addition, they should consider possible conditional dependencies concerning the association nodes and the transfer nodes and the subsequent changes in CPTs of the transfer nodes.

In the following sections, we will illustrate the flexibility of the template model in Fig. 5.1 by exploring two more potential variations of it. We will

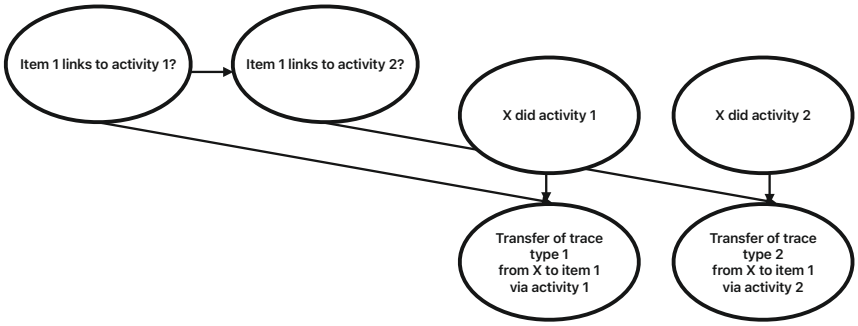


Figure 5.3: Modeling structure with two disputed relations between one item and two (disputed) activities.

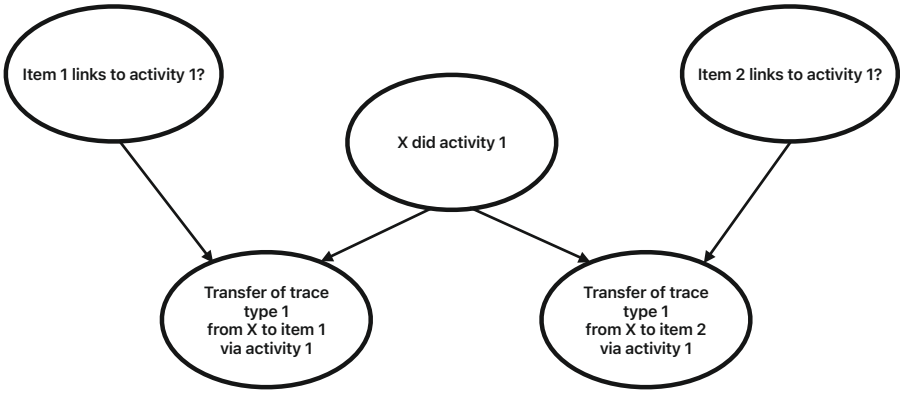


Figure 5.4: Modeling structure with two disputed relations between two items and one (disputed) activity.

expand upon the fictive case twice more to show the modifications in modeling the evaluation of evidence given item—activity propositions.

5.2.1 Variation 1: cross-transfer of fibers between sweater and person Y's top

Just as fibers can transfer from person Y's top to the sweater, fibers can also transfer from the sweater to Y's clothing. The concept of *cross-transfer* has been studied in detail before by for example Aitken *et al.* (2003); Taroni *et al.* (2020). Imagine that Y's top was also collected for fiber examination[4]. If the sweater was worn by the offender during the incident, we would expect to find fibers matching the sweater on Y's top. Conversely, if the offender did not wear the sweater but some unknown garment, we would expect to find a group of fibers not matching the sweater[5] on Y's top. The presence of such non-matching fibers and the absence of matching fibers on Y's top would support the proposition that the sweater was not worn during the incident.

Case model

The case model from Fig. 4.3 in Chapter **??** is extended with nodes to include the cross-transfer of fibers between Y's top and the sweater (see Fig. 5.5). As we now explicitly consider an unknown garment as possibly being worn by the offender, we rephrased the association node (12) to: "Which garment was worn by the offender during incident?" with states "the sweater" or "unknown garment".

[4]We still neglect cross-transfer of DNA between the sweater and Y's top in order to highlight the essence of the example. We also disregard the possibility of background fibers on either the offender's garment or Y's top being transferred between them during the incident. For example, if both the blue sweater and Y's yellow top contain rare pink fibers, this could be important evidence.

[5]Sometimes referred to as "non-matching" in this paper.

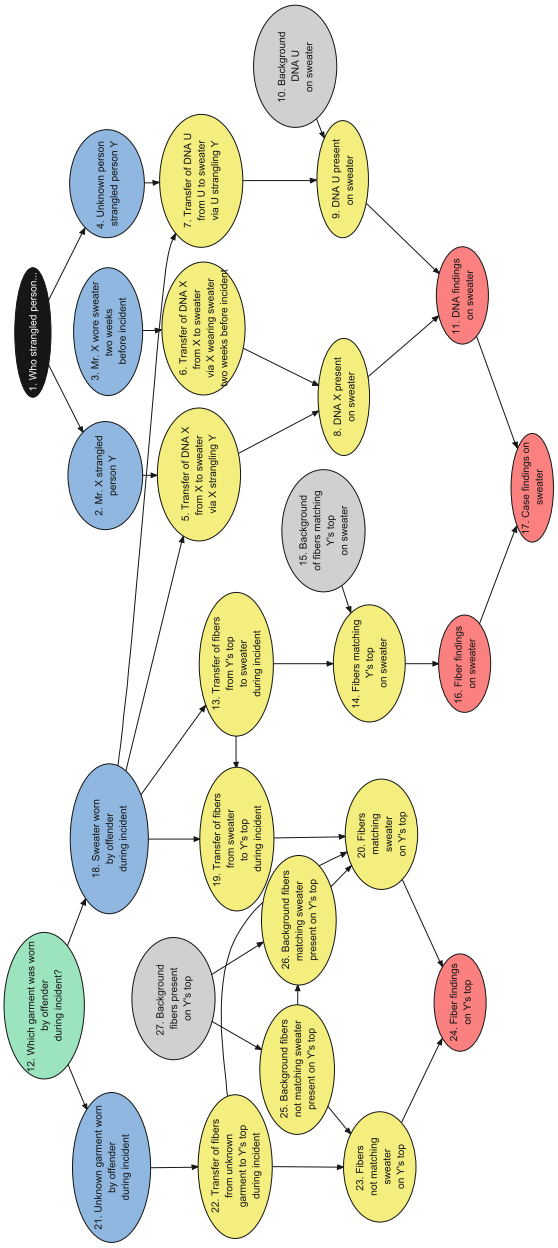


Figure 5.5: Case model including cross-transfer from Y's top to the sweater and from the sweater to Y's top. See footnote 15 for evidence that is ignored in the network.

The evaluation of fiber evidence on Y's top follows a similar structure as the evaluation of the fiber evidence on the sweater. However, we now have two possible transfer paths to Y's top instead of one. Therefore, two association activity nodes (18 and 21) follow from node 12 to distinguish these two transfer paths: one from the sweater to Y's top (nodes 18-20, 24) and one from an unknown garment to Y's top (nodes 21-24):

18. Sweater worn by offender during incident
19. Transfer of fibers from sweater to Y's top during incident
20. Fibers matching sweater on Y's top
21. Unknown garment worn by offender during incident
22. Transfer of fibers from unknown garment to Y's top during incident
23. Fibers not matching sweater on Y's top
24. Fiber findings on Y's top

In the case example, both matching and non-matching fibers can be found on Y's top. As a result, the four states of Fiber findings on Y's top (24) are: "only fibers matching sweater", "only fibers not matching sweater", "both matching and non-matching fibers", and "no fibers".

Matching and non-matching fibers on Y's top could be from possible transfer activities or unrelated background fibers. Hence, the findings nodes 23 and 20 are conditioned on respectively:

25. Background fibers not matching sweater present on Y's top
26. Background fibers matching sweater present on Y's top

We added a root node with the prior probability of background fibers present (non-matching and/or matching) on Y's top to combine the two different kinds of background fibers on Y's top into one background probability node:

27. Background fibers present on Y's top

We added a directed link from Transfer of fibers from Y's top to sweater during incident (13) to Transfer of fibers from sweater to Y's top during incident (19) to represent the dependency associated with cross-transfer. The probability of either transfer occurring is affected by the presence of the other transfer, and vice versa. Table 5.1 illustrates the CPT for Transfer of fibers from sweater to Y's top during the incident. The CPT contains the conditional probabilities, t and u:

$t = P$(19. Transfer..from sweater.. = True | 18. Sweater worn.. = True,
13. Transfer..from Y's top.. = False)

$u = P$(19. Transfer..from sweater.. = True | 18. Sweater worn.. = True,
13. Transfer..from Y's top.. = True)

The final adjustment to the node dependencies is that fibers transferred from an unknown upper garment to Y's top during the incident are of unknown origin but could potentially match those from the sweater. Therefore, there is a directed link between Transfer of fibers from unknown garment to Y's top during incident (22) and the accumulation node Fibers matching sweater on Y's top (20).

19. Transfer of fibers from sweater to Y's top during the incident

13. Transfer of fibers from Y's top to sweater..	False		True	
18. Sweater worn by offender..	False	True	False	True
False	1	$(1-t)$	1	$(1-u)$
True	0	t	0	u

Table 5.1: The CPT for Transfer of fibers from sweater to Y's top during the incident (19)

5.2.2 Variation 2: sweater could only have been worn by the suspect if he was the offender.

Up to this point, we have focused on the connection between the sweater and the offender, either Mr. X or an unknown person. We now adjust the case example to a situation where only Mr. X could have worn the sweater during the incident. If another person strangled person Y, they must have worn something else. For example, if the garbage bin containing the sweater was not outside Y's apartment but in the suspect's apartment, and the suspect claims to have last worn the sweater two weeks ago before putting it in the bin.If the connection between the sweater and the offender is questioned, the presence of matching fibers on Y's top can support the association of the sweater to the incident. This, in turn, strengthens the link between the suspect and the incident, given that the suspect is the only person who can be potentially connected to the sweater during the incident.

Case model

This additional case information results in three small changes in the structure of the Bayesian network (see Fig. 5.6)[6]. First, since it is undisputed that the suspect is linked to the sweater and an unknown offender cannot be connected to it during the incident, the probability of DNA transfer from an unknown

[6]As in the previous section, we ignore some aspects of the DNA evidence, fiber evidence and disregard other possible evidence. See also Footnote 15.

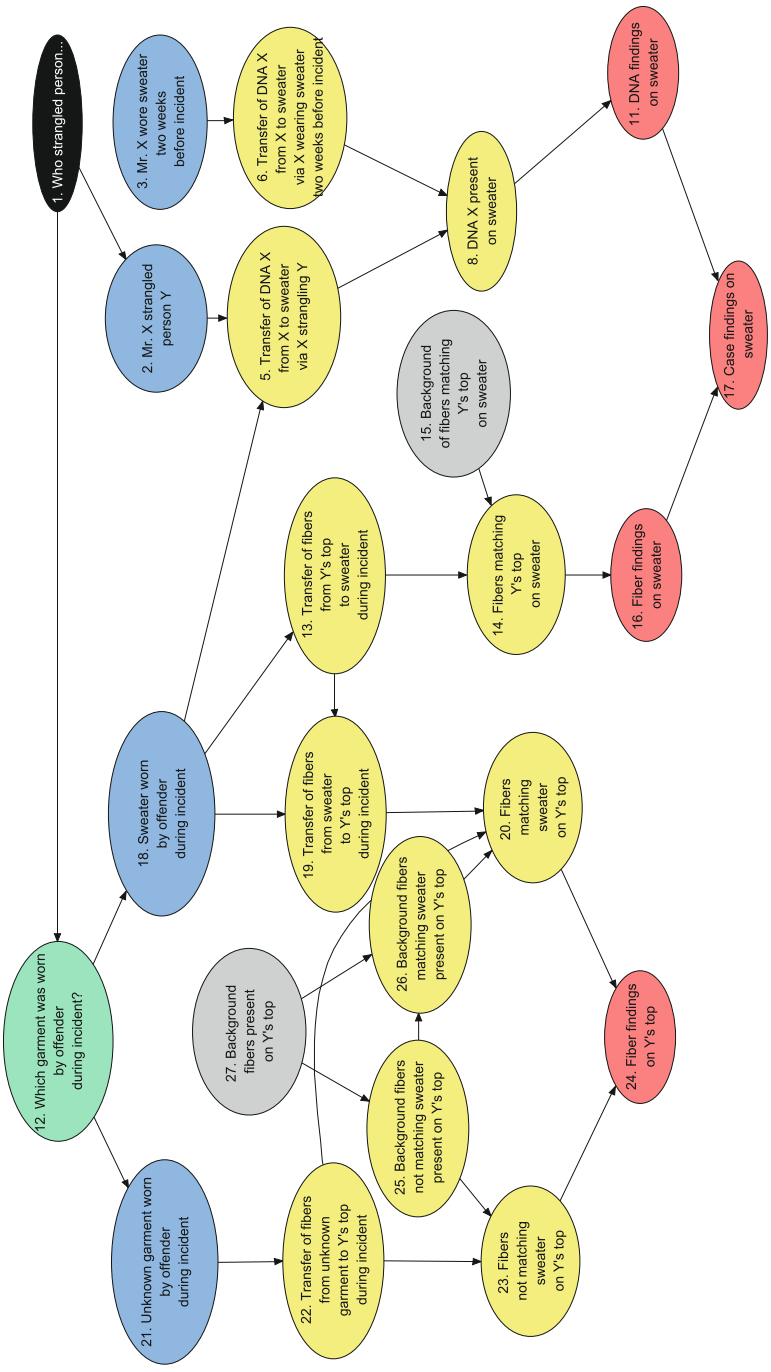


Figure 5.6: Case model including cross-transfer and offender-specific item—activity propositions. See footnote 15 for parts of the evidence not shown in this BN.

12. Which garment was worn by offender during incident?

1. Who strangled person Y?	H_1 : Suspect	H_2 : Unknown person
Sweater	0.5	0
Other garment	0.5	1

Table 5.2: The CPT for WHICH GARMENT WAS WORN BY THE OFFENDER DURING THE INCIDENT? (12)

offender to the sweater during the event is zero. As a result, nodes 4, 7, 9, and 10, which represent the potential transfer path from an unknown person to the sweater, are excluded from the updated case model.

Second, the question shifts from whether the offender wore the sweater during the incident to which garment was worn by whom during the incident: the sweater by the suspect or an unknown garment by the suspect or an unknown person. Node 18 is changed to "sweater worn by the *suspect* during the incident".

Last, we added a directed link from WHO STRANGLED PERSON Y to WHICH GARMENT WAS WORN BY OFFENDER DURING INCIDENT to account for the offender-specific item—activity relation. Table 5.2 displays the CPT for WHICH GARMENT WAS WORN BY OFFENDER DURING THE INCIDENT (22). The conditional probabilities indicate that only the suspect could have worn the sweater at the time of the incident. If H_2 is true, an unknown person strangled person Y, and thus, an unknown garment must have been worn by the offender. If H_1 is true, the suspect strangled person Y using either the sweater or an unknown upper garment. The prior probabilities of the suspect wearing the sweater or an unknown upper garment during the incident are included in the CPT for WHICH GARMENT WAS WORN BY OFFENDER DURING THE INCIDENT (22). Here we assume equal prior probabilities but this is an assumption that should be further investigated. In contrast with the prior probabilities of SWEATER WORN BY OFFENDER DURING INCIDENT (12) in Fig. 4.3 we believe these prior probabilities are actually outside the expert's domain.

Final remarks on Part III

We have developed a template model that can be used to evaluate transfer evidence given activity level propositions in cases where there is a dispute about the actor and/or activity, and/or the relation between items and activities. The evaluation of evidence given item—activity propositions is a prerequisite for evaluating the evidence given the propositions at activity level. The evaluation may sometimes be carried out by a different forensic discipline and therefore the template model is particularly valuable in interdisciplinary casework. We believe that developing such template models, both here and elsewhere, will encourage the practical application of Bayesian networks (BNs) in casework. This promotion is urgently needed, as forensic practice is lagging behind theory and the relevant court questions relate to activities rather than trace sources.

The dispute about the relation between item and activities are introduced as an association dispute concerning association propositions with prior probabilities. There is currently no consensus on how to deal with such prior probabilities in casework. We argued that the forensic expert can provide the prior probabilities as long as they explain to the fact finder how these priors influence the LR. For instance, an expert could use a range of priors and report their effect on the LR. Alternatively, one could select these priors in collaboration with the appropriate person(s). In any case, dealing with these prior probabilities cannot be avoided. This makes it an interesting topic for further research.

The template model provides a middle ground between a ready-to-use network and a generic network. The model is sufficiently specific to provide the forensic practitioner with a starting point but the model is also flexible enough to be used in a wide variety of cases. We acknowledge that the case examples provided in our research paper may appear simplified. We fully recognize the complexity and nuance intrinsic to real-world forensic cases. For example, in our case example, there may be fingermarks in Y's neck, video images from surveillance cameras, information from the suspect's mobile phone, analysis of

the cell type of the DNA samples, and so on. By focusing on the essence of the problem, which is the combination of different type of evidence such as fiber and DNA evidence, and evaluating evidence given association propositions, we aim to demonstrate the potential of this model in a clear and understandable manner.

The forensic practitioner can consult the collection of idioms for modeling evidence evaluations given activity level propositions (Vink & Sjerps, 2023) to adjust and expand the template model. The work on using Object Oriented Bayesian Networks (OOBNs) for legal and forensic casework (e.g., Biedermann & Taroni (2012); Hepler *et al.* (2007); Taylor *et al.* (2018, 2021)) may also be very useful in practice. For example when the evaluation includes multiple items of interest that all accompany an evaluation of similar modeling structure. While objects may not directly enhance readability, they can prevent large BN from being too overwhelming for the recipient.

BNs have proven to be very useful tools for the forensic expert to structure their reasoning, calculate the combined LR and for making their thinking explicit. But with great transparency comes many details and subtleties that increase complexity and so there is still debate about whether or not to use BNs in the communication with the court (see for example Gittelson *et al.* (2016a); Sjerps & Berger (2012); Taylor & Kokshoorn (2023)). We believe that if one relies on a BN to calculate a LR, this should not be buried in the case file without any mention of it in the expert's report to the court. Instead, we suggest BNs as a structuring and probabilistic tool to assist in the understanding of complex reasoning under uncertainty.

In conclusion, our research bridges the gap between theoretical advancements and practical applications. It paves the way for a better understanding of reasoning about complex casework, enabling experts to write logical, transparent, balanced, robust, and not the least, clear reports for the court.