ANALYSIS OF THREE HYBRID METHODS FOR REASONING WITH EVIDENCE IN PROBABILISTIC CASES

Bachelor's Project Thesis

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Abstract: In criminal cases, the goal of reasoning with evidence is to find out what underlying cause produced said evidence. However, this process of reasoning is prone to errors since one is only able to deduct the underlying cause from the observation of existing evidence. In order to identify faulty evidential reasoning, an analysis can be carried out. Three common ways of analysing reasoning with evidence in criminal cases are: probabilistic, argumentative and scenarios. These types can be combined to form hybrid methods. In this paper three hybrid methods are analyzed: Bex's hybrid method of arguments and scenarios, Verheij's case models and Vlek's hybrid method of probability and scenarios. These three models are applied to a case study involving DNA evidence and compared to each other in order to seek out their strengths and weaknesses. It is found that the three hybrid methods do not exclude one another but should rather be used in conjunction with each other to get a more robust way of analysing evidential reasoning.

1 Introduction

Reasoning with evidence plays a prominent role in criminal trials. Since the future of the suspect is at stake during these trials, wrongful reasoning, causing wrongful convictions, can therefore lead to unethical consequences. Even though determining the extent of wrongful conviction rates is difficult, due to a lack of a precise method (Huff, Rattner, Sagarin, and MacNamara, 1986), estimates have been made. Gross and O'Brien (2008) estimated a wrongful conviction rate of 2 to 5 percent in the domain of capital murder, rape and robbery while Risinger (2006) estimated around 3 to 5 percent in capital categories alone. Huff et al. (1986) suggested one of the causes of wrongful convictions could be attributed to insufficient use of important evidence. With insights like these, starting points are created to decrease the wrongful conviction percentage. One proposal based on this insight is the use of frameworks for systematic analysis of evidential reasoning. These frameworks can be categorised by three approaches: Argumentative analysis, scenario analysis and probabilistic analysis (Anderson, Schum, and Twining, 2005). In an argumentative approach, arguments for and against conviction are laid out against each other. Arguments based on evidence can be under attack or on the attack with respect to other arguments based on other pieces of evidence. This will result in arguments receiving the status: defended, overruled or justified. On the basis of these statuses a verdict can be formed (Bex, Prakken, Reed, and Walton, 2003). Scenario analysis makes use of stories that represent what could have happened (Bennet and Feldman, 1981). However, not all of these stories are always plausible. To test the plausibility of a scenario, scenario schemes are used. These schemes use information of how the world works. They can be seen as a blueprint for a certain scenarios. If no schemes match the scenario it might not be plausible. The scenarios can be compared to the available evidence. Some stories are more likely to be true than others due to evidence supporting the scenario. The last method is probabilistic analysis where hypothetical events are related to the evidence by means of probability (Vlek, Prakken, Renooij, and Verheij, 2016). This is often done with a Bayesian network. These networks have become a very useful tool in interpreting forensic evidence (Taroni, Aitken, Garbolino, and Biedermann, 2006). The probabilistic representation of the scenario nodes lends itself well for the modeling of scenarios and evidence of a case. However, Bayesian networks should be used with caution. The conditional dependencies are reliant on priori knowledge of the variables. In a criminal case, this priori knowledge is not cut-and-dry (Fenton, Lagnado, Dahlman, and Neil, 2017). Research has been devoted to come up with rigid frameworks for determining this priori probability (Fenton et al., 2017) but this probability search-space will still remain stochastic.

With these methods in place, models can be crafted to create a more systematic way of analysing evidential reasoning. People can use these frameworks to express their reasoning in a systematic way. By placing it in a framework a concrete discussion can occur by comparing models of evidential reasoning. However, all of these methods have their distinct characteristics Verheij (2014). When using an argumentative approach, an adversarial dynamic is created that intertwines the different stances on the matter through means of arguments. This suggests that all possible arguments need to be considered, in order to draw correct conclusions. The scenario approach is the relativistic comparison between possible scenarios based on the evidence found. Therefore, all possible scenarios should be considered in order to find the most probable one. When this rule is not upheld, the focus is on only a few scenarios, and tunnel vision occurs. Lastly, for a probabilistic approach to work, formalities such as probability calculus need to be followed.

Due to methods being limited by their characteristics, hybrid methods can be proposed. Examples of hybrid models are: Case models Verheij (2014), The Hybrid Theory of Stories and Arguments Bex (2020) and The Hybrid Theory of Stories and Probability Vlek et al. (2016).

A problem might arise when the reasoning within these different frameworks is compared. Frameworks can differ in their reasoning with evidence. In order to explore this problem, different hybrid models can be used on the same case to assess the extent to which they agree and disagree. This can be especially difficult when converting a case with probabilistic evidence to a non-probabilistic model. For example, DNA evidence can be modeled very effectively with a probabilistic approach Vlek et al. (2016), whereas an argumentative approach might lack the conclusiveness for a good verdict due to not being able to model the degrees of uncertainty Verheij, Bex, Timmer, Vlek, Meyer, Renooij, and Prakken (2016).

In this research evidence of a case with probabilistic evidence will be modelled in the format of the Case Model approach and The Hybrid Theory of Stories and Arguments. The hybrid method of Vlek et al. (2016) has already been created for this case and will be used as a guide to interpret the evidence since this approach is suitable for probabilistic evidence. This research will serve as a way of testing the frames of the three hybrid methods with respect to probabilistic evidence in order to understand what they can and cannot do within the domain of criminal law.

2   Case information

In the case that will be analyzed with different evidence reasoning models, the suspect (Adam) is prosecuted for helping to move the body of the victim (Chris) to the countryside out of town after he/she had been murdered by an acquaintance (Bert). In the first trial, the suspect is convicted. However, after a court appeal, it was concluded that there was not enough evidence for a conviction and therefore the suspect was deemed innocent. This case was originally taken from Vlek et al. (2016) to test their model on a case with probabilistic evidence because it involves DNA evidence. A total of three hypotheses are explored: 1. The suspect is guilty of moving the body while leaving his DNA traces on crime scene. 2. The suspect is innocent and the DNA traces were transferred onto the victim from the couch of the victim's home. 3. The suspect is innocent and the DNA traces were transferred onto the victim when the body was rolled into a blanket obtained from the victim's home.

The evidence for this case is:

- Body of victim was found in the countryside.

- Bert is convicted of the murder of the victim.

- Adam has done a testimony of what has happened.

- There is a DNA match between the DNA that has been found on the body of the victim and Adam.

- Adam's hair has been found on the duct tape around the victim's head.

- Adam's car was not seen on the cameras place on the side of the roads that lead to the crime scene.

- Traces of Adam's DNA have been found in Bert's car.

- A couple of phone calls were made between Adam and Bert on the night of the crime.

3   The three frameworks

3.1   Scenarios

In court, the found evidence can be used to make scenarios that can explain what might have happened. Scenarios can be seen as jigsaw puzzles. The pieces of the puzzle that are inside the puzzle box can be regarded as evidence. These particular scenario puzzles are missing quite a few pieces.

However, after putting all the known pieces together, if one squints both eyes, a coherent whole might be observed.

More formally, scenarios are chronological explanations of ordered events together with their causal relations. Usually only the relevant causal relations are shown explicitly. Figure 3.1 shows the scenarios of the case study. Scenarios are built from scenario elements. These elements are the events that can explain the observations. Some scenario elements can be further dissected into smaller scenario elements. These scenario elements are called sub scenarios. These elements are the smaller events that make up the sub scenario. They are visualized in figure 3.1 enclosed by a rectangles.

The three scenarios that are explored in this case are written down below:

Scenario 1 Adam, Bert and Chris were involved in a cannabis operation and therefore knew each other: Adam was often at the cannabis plant, Adam and Bert were often on the phone and Adam often drove in Bert's car. At one point, Bert kills Chris and had to get rid of the body: Adam helped Bert carry the body to the car and together they drove to the countryside where they dumped the body.

Scenario 2 Adam, Bert and Chris were involved in a cannabis operation and therefore knew each other: Adam was often at the cannabis plant, Adam and Bert were often on the phone and Adam often drove in Bert's car. At one point, Adam sat on the couch and left behind some of his DNA. Later, Chris got Adam's DNA from the couch. Afterwards, Chris got killed by Bert and Bert moved the body alone to the countryside.

Scenario 3 Adam, Bert and Chris were involved in a cannabis operation and therefore knew each other: Adam was often at the cannabis plant, Adam and Bert were often on the phone and Adam often drove in Bert's car. At one point, Adam's DNA fell on a blanket in the cannabis plant. Afterwards, Bert killed Chris, wrapped Chris' body in the blanket with Adam's DNA on it and moved the body to the countryside.

Scenarios are created to explain the evidence that are tied to a criminal offense. A scenario can explain evidence element e if the scenario includes events where e is found. However, scenarios are not absolute and therefore a scenario's coherence needs to be assessed. This can be done by scenario schemes of intentional action (Pennington and Hastie, 1993). A scenario scheme is a template where more detailed scenarios are built from. Then, in order to check the coherence of a scenario, the motives and observations can be compared to those of the template scenario where the detailed scenario originates from. If there are gaps in a scenario when comparing it to a scenario scheme, the scenario is said to be incoherent: The scenario cannot explain all the scenario elements that should be present in a story involving a certain scheme. In a scenario approach for reasoning with evidence, multiple scenarios need to be considered in dialectical fashion in order to reduce the chance of tunnel vision. The scenario that explains the most evidence, contradicts the least evidence and is the most plausible, is picked. In figure 3.2, the scenarios of the case study together with their scenario schemes can be seen. There are two unique scenario schemes in total. The first scheme is the "Save own skin" scheme. This scheme goes as follows: person Y kills person Z. It turns out Y, Z and X have an illegal business together. X is afraid their business will get unraveled when the police start an investigation involving the murder to Z. Therefore, X helps Y to move the body in order to save his own skin together with the business'. This scenario scheme fits with the description of scenario 1. Furthermore, scenario 1 is coherent with respect to the "Save own skin" scheme because it does not have any missing scenario elements. The other scenario scheme that was created was the "not involved" scheme. In this scheme Y kills Z. Y knew X and met up every now and then. The DNA of X gets transported onto an object. The DNA gets transported from the object to Z. Y moves the body of Z. This scheme is used for both scenario 2 and 3. Both of these scenarios are coherent with respect to the scenario elements of the "not involved" scheme.

Next to the ability to explain the observations, scenarios can predict what is expected to be observed. For example, in the first scenario of the case study, the event of Adam and Bert carrying the body to the car is included. If this event actually happened, it is very likely that that Adam's DNA is on particular body parts or belongings of the victim, which indicates moving the body. This can lead the search for more evidence in concrete directions.

3.2 Arguments

Within the argumentative framework, arguments are used to reason about the evidence. An argument consists of two parts: the premise and the conclusion. Reasoning or inference steps are used to get from the premise to the conclusion by means of evidential inference rules. Multiple arguments can be cascaded with each other, where the conclusion of one argument is the premise of another, gradually working towards a hypothetical verdict. Because of this inference, the argumentative framework lends itself well for application in criminal
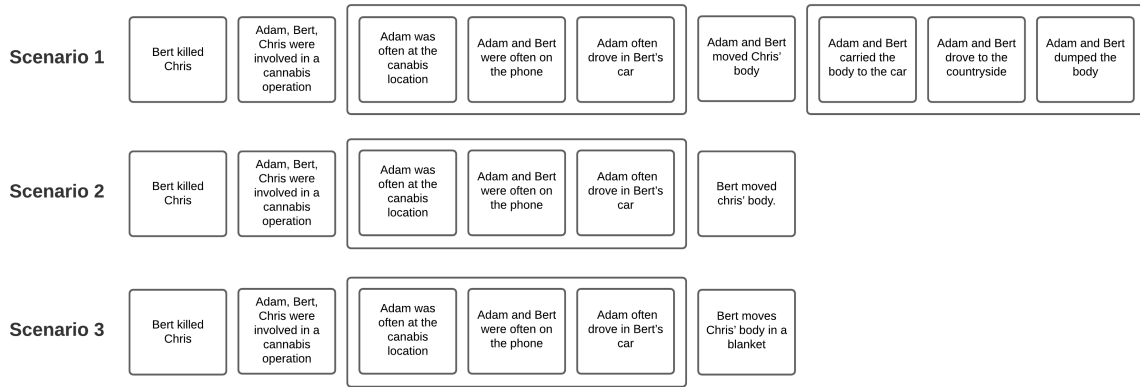
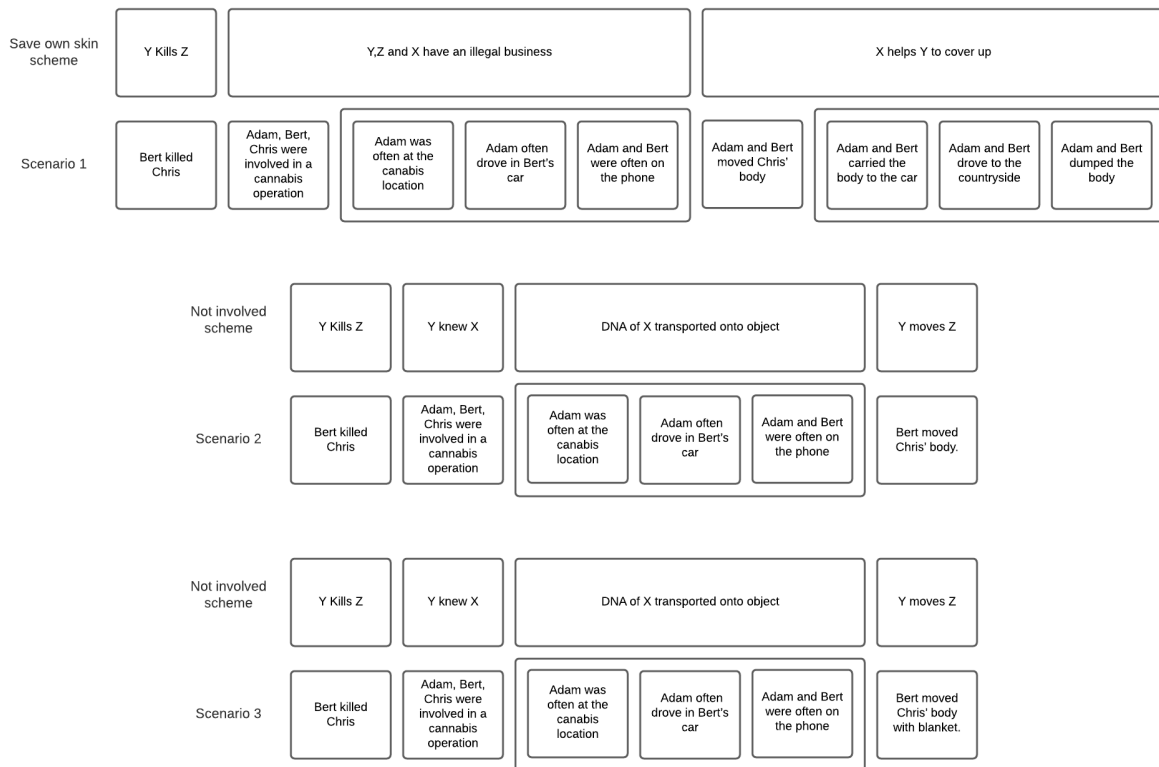**Figure 3.1: The possible scenarios that are explored in the case**

Scenario 1: Bert killed Chris | Adam, Bert, Chris were involved in a cannabis operation | Adam was often at the canabis location | Adam and Bert were often on the phone | Adam often drove in Bert's car | Adam and Bert moved Chris' body | Adam and Bert carried the body to the car | Adam and Bert drove to the countryside | Adam and Bert dumped the body

Scenario 2: Bert killed Chris | Adam, Bert, Chris were involved in a cannabis operation | Adam was often at the canabis location | Adam and Bert were often on the phone | Adam often drove in Bert's car | Bert moved chris' body.

Scenario 3: Bert killed Chris | Adam, Bert, Chris were involved in a cannabis operation | Adam was often at the canabis location | Adam and Bert were often on the phone | Adam often drove in Bert's car | Bert moves Chris' body in a blanket

Figure 3.2: The scenarios with their scenario schemes

Save own skin scheme: Y Kills Z | Y,Z and X have an illegal business | X helps Y to cover up

Scenario 1: Bert killed Chris | Adam, Bert, Chris were involved in a cannabis operation | Adam was often at the canabis location | Adam often drove in Bert's car | Adam and Bert were often on the phone | Adam and Bert moved Chris' body | Adam and Bert carried the body to the car | Adam and Bert drove to the countryside | Adam and Bert dumped the body

Not involved scheme: Y Kills Z | Y knew X | DNA of X transported onto object | Y moves Z

Scenario 2: Bert killed Chris | Adam, Bert, Chris were involved in a cannabis operation | Adam was often at the canabis location | Adam often drove in Bert's car | Adam and Bert were often on the phone | Bert moved Chris' body.

Not involved scheme: Y Kills Z | Y knew X | DNA of X transported onto object | Y moves Z

Scenario 3: Bert killed Chris | Adam, Bert, Chris were involved in a cannabis operation | Adam was often at the canabis location | Adam often drove in Bert's car | Adam and Bert were often on the phone | Bert moved Chris' body with blanket.

law.

Since arguments are ways to reason about what might have happened according to premises that are available, they have an uncertain nature. It is therefore possible to get different conclusions given the same evidence. Due to this uncertainty, arguments can be attacking each other. There are two types of attacks on an argument: rebut attacks and undercut attacks. Argument A rebuts argument B if argument A infers the negation of the conclusion of argument B by different premises. Argument A undercuts argument B if A gives an exception to the general inference rule used in B.

In order to show the relations between attacking arguments, every argument can be assigned one of the following three statuses: Overruled, Defensible or Justified. Overruled means that the argument is rejected and is not reasonable anymore. Defensible means that the argument can still be reasonable by argumentation. Justified means that the argument is reasonable. Argument A is overruled if the arguments attacking A are justified. Argument A is justified if no other argument is attacking A or A's attackers are overruled. Lastly, argument A is defensible if the arguments that attack A are being attacked by A at the same time, or if the

arguments attacking A are already defensible.

For the case study, all the arguments involving the case were noted for further use during the development of the hybrid methods. Figure 3.3 and figure 3.4 show arguments that are in conflict with each other. In figure 3.3b, argument A_{cb} and argument A_{ncb} are attacking each other. The conclusions of both arguments are each other's negation, namely: Adam moved Chris' body and Adam did not move Chris' body. This means that the two arguments attack each other by a rebut attack. In figure 3.3a, argument A_{ii} is attacking argument A_{pc}. The conclusion of A_{ii}: Forensics based their conclusions on insufficient information, gives an exception to the inference rule of argument A_{pc}. This is an example of an undercut attack.

3.3 Probability

With a probabilistic approach for reasoning with evidence, hypotheses are made. These hypotheses are used as possible events that happened during the criminal offense. The goal of the probabilistic method is first to establish the probability of finding evidence e under a hypothesis h. Afterwards, the Bayes Theorem is used in order to get the probability of hypothesis h when finding evidence e.

The workings of the Bayes Theorem can best be illustrated by an example. The example that will be discussed is based on the infamous case of Sally Clark. Sally Clark was falsely convicted of the murder of her two infant sons. What had actually happened was the death of her two sons by sudden infant death syndrome (SIDS). First, a correct walk through of the Bayesian Theorem will be done for a simplified version of this example. Afterwards, the mistake that was made by court during Sally's trial will be discussed in order to indicate the dangers of misinterpreting reasoning with evidence. However, to keep things relatively simple, this hypothetical case will only have one dead infant son.

The two hypotheses for this case are:

$H_1 : Baby\ died\ from\ sudden\ infant\ death\ syndrome$
$H_2 : \neg H_1$

The evidence E for this case is the death of the son. The probability of a dead child when they have sudden infant death syndrome (SIDS) is 1. The probability of the average baby baby dying from SIDS is $1/8500 = 0.00012$. In 1996, 649489 children were born in England and Wales. From the 649489, 14 were murdered (Fenton, 2014). This means that the probability of a dead child when they do not have infant death syndrome but are for example murdered by their mother is at

most $\frac{14}{649489} = 2.15 * 10^{-5}$.

$P(H_1) = 0.00012$

$P(E|H_1) = 1$

$P(E|H_2) = 2.15 * 10^{-5}$

In order to calculate the probability of the cause of death being sudden infant death syndrome when the baby died, the Bayes Theorem can be used:

$$P(H1|E) = \frac{P(E|H1) * P(H1)}{P(E)}$$

$P(H_1)$, and $P(E|H_1)$ are known. However, P(E) still needs to be calculated:

$$P(E) = P(E|H_1) * P(H_1) + P(E|H_2) * P(H_2)$$
$$= 1 * 0.00012 + 2.15 * 10^{-5} * (1 - 7.93 * 10^{-8})$$
$$= 0.00014$$

Now, the Bayes Theorem can be applied:

$$P(H_1|E) = P(E|H_1) * \frac{P(H_1)}{P(E)} = \frac{0.00012}{0.00014}$$

As can be seen from the equation above, the probability of the baby having died from SIDS is around 0.86, meaning that the baby most likely died from SIDS.

In the real life case of Sally Clark, a pediatrician told the judges that the probability of two children getting sudden infant death syndrome was around 1 in 73 million. This probability was calculated by squaring the probability of one baby having SIDS. This is already a faulty calculation because as it turns out, the probability of having a child that dies from SIDS increases when you already had a child that died from SIDS. On top of that, the judges misinterpreted this 1 in 73 million as the probability of Sally Clark being innocent. The last but most fundamental flaw that was made during this trial was that the prior probability of SIDS baby deaths was treated individually without comparing the prior probability of babies being murdered by parents (Fenton, 2014). If this was done properly, regardless of the faulty 1 in 73 million calculation, Sally would not have been wrongfully convicted.

4 Hybrid methods

4.1 Bex method

The Bex method combines scenarios and arguments in order to reason with evidence. The method was taken from Bex (2020). In this method arguments for and against scenario elements are considered together with their status. Going back to our case,
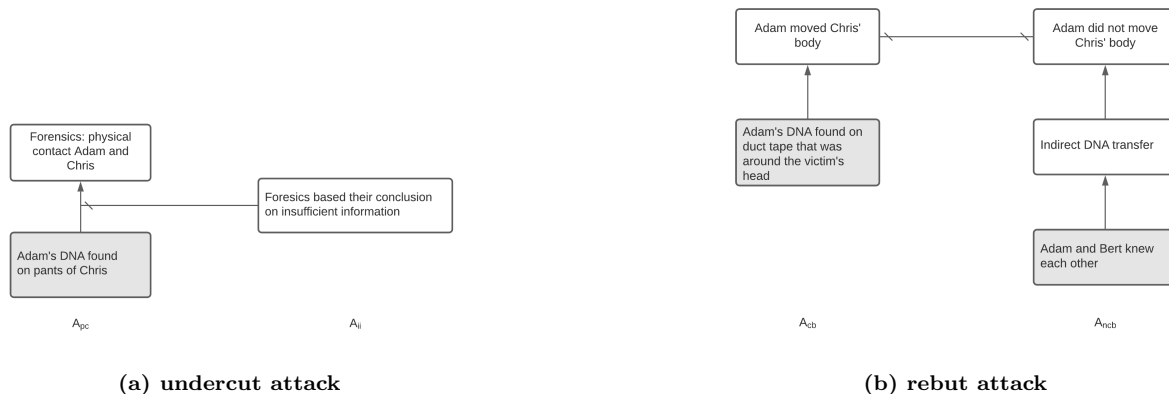
(a) undercut attack   (b) rebut attack

Figure 3.3: Arguments from the case study.

in figure 3.3 b, an example of a scenario element being attacked and defended by an argument is shown. The scenario element in question is Adam moved Chris' body. The defending argument A_{cb} for this scenario element has the following structure. The premise of the argument is that Adam's DNA is found on the duct tape that was around the victim's head and the conclusion is the scenario element Adam moved Chris' body. This scenario element is also attacked by an argument. Argument A_{ncb} that is attacking scenario element Adam moved Chris' body has the structure: Adam and Bert knew each other, therefore indirect DNA transfer could have taken place, therefore Adam did not move Chris' body. From both of these argument's conclusions, it can be seen that they are attacking one another because they are each other's negation. In Bex's method, an argumentation scheme similar to figure 3.3 b is created for each scenario element in a scenario. Afterwards, these argumentation schemes can be evaluated based on a set of critical questions formulated by Bex and Verheij (2012). The enumeration of these critical questions taken from Bex (2020) are written down below:

1. **Explanation (CQ-Ex)** Are all the important observations in the case explained by the story?

2. **Prediction (CQ-Pr)** Which observations would we expect to find given story S?

3. **Alternative explanations (CQ-AltEx)** Have alternative stories been sufficiently considered?

4. **Evidential support (CQ-ES)** Which elements of story S are supported? Which evidence supports (only) S? How much evidence supports S?

5. **Evidential Contradiction (CQ-EC)** Which elements of story S are contradicted? Which evidence contradict (only) S? How much evidence contradict S?

6. **Plausibility (CQ-Pl)** Which elements of story S are implausible? Which assumptions conflict with (only) S? How many assumptions contradict S?

7. **Story schemes (CQ-SS)** Which story schemes are relevant for story S? Are these schemes plausible? Does the story fit the story scheme; that is, are there story elements missing (incompleteness) or noticeably different (plausibility)?

8. **Argumentation Schemes (CQ-AS)** Which argumentation schemes are relevant for the arguments? Are there possible exceptions to the general scheme (undercut attacks)?

9. **Attacking arguments (CQ-AA)** Are there possible counterarguments to the arguments? What is the status of the arguments (justified, defensible, overruled)?

The supporting and contradicting arguments of each scenario can be seen in tables 4.2, 4.3 and 4.4. These tables can help answer the critical questions in order to come to an appropriate verdict.

4.1.1 Scenario 1: Adam helped move the body (table 4.2)

First and foremost, the scenario needs to explain all the important observations in the case (CQ-Ex). In this case, the 8 important pieces of evidence, listed in section 2, are all explained by scenario 1. Looking at the scenario scheme relating to scenario 1 in figure 3.2, there are no missing scenario elements, therefore the story is complete and plausible with respect to this scenario scheme (CQ-SS, CQ-Pl). Adam moving the body of Chris would have caused DNA to be left behind on the dead

Scenario 1	Supporting arguments	Contradicting arguments
Bert killed Chris	$(A_b)(e_b)$ Bert is convicted of the murder	
Adam, Bert, Chris were involved in cannabis operation subscenario:	$(A_{inv1})(e_{adam})$ Adam's testimony	
Adam was often at the cannabis location		
Adam drove often in Bert's car		
Adam and Bert were often on the phone		
Adam and Bert moved Chris' body subscenario:	$(A_{cb})(e_{cb})$ Adam's DNA found on duct tape that was around the victim's head **(A/D)** $(A_{cs1})(e_{cs1})$ Witness saw white van riding towards crime scene **(A/O)** $(A_{cs2})(e_{cs2})$ Adam's DNA found in Bert's car **(A/D)** (A_{move3}) Forensics: physical contact Adam and Chris (e_{move3}) Adam's DNA found on pants of Chris **(A/O)**	(A_{ncb}) Adam did not move Chris' body (A_{inter1}) Indirect DNA transfer (e_{adam}) Adam and Bert knew each other **(A/D)** (A_{ncs1}) Adam did not drive to the countryside (A_{inter2}) Reason for DNA found in Bert's car (e_{adam}) Adam lost blood in Bert's car to moving a gas stove **(A/D)** (A_{ncs2}) Adam did not drive to the countryside (e_{adam}) Adam's car was not on the cameras **(A/D)**
Adam and Bert carried the body to the car		
Adam and Bert drove to the countryside		
Adam and Bert dumped the body		

Table 4.1: Scenario 1

body of Chris which is supported by scenario 1 (CQ-PR). The main scenario element of scenario 1 is that Adam and Bert moved Chris' body. The supporting arguments can be seen in the second column (CQ-ES) and the contradicting arguments in the third column (CQ-EC). Both supporting and contradicting arguments have a status indicating their correctness (CQ-AA). These statuses can be read off the table by looking at what is inside the bold parenthesis at the end of each argument, e.g. **(A/D)**. **A** stands for attacked and **D** stands for defensible. The variances that one comes across with in this Bex model are: attacked and defensible **(A/D)**, attack and overruled **(A/O)**. Scenario 1 by itself cannot answer the critical question regarding tunnel vision (CQ-AltEx). It will be answered while considering the other scenarios.

4.1.2 Scenario 2: Adam's DNA was transferred by couch (table 4.3)

Scenario 2 gives an alternate explanation for Adam's DNA that is found on the victim (CQ-AltEx). Comparing this scenario to the *Not involved* scenario scheme shows no gaps in the scenario and therefore makes the story complete and plausible with respect to the *Not involved* scenario scheme (CQ-SS, CQ-PL). The scenario element of *Adam, Bert and Chris were involved in a cannabis operation* explains why DNA of Adam was found on the victim's body. Furthermore, it shows the possibility of Adam's non-involvement. More specifically, Adam would not be involved in moving the dead body of Chris because the DNA was transmitted by couch and not by direct contact with the victim

Scenario 2		Supporting arguments	Contradicting arguments
Bert killed Chris		$(A_b)(e_b)$ Bert is convicted of the murder	
Adam, Bert, Chris were involved in cannabis operation		$(A_{inv1})(e_{adam})$ Adam's confession	
subscenario:			
	Adam was often at the cannabis location		
	Adam drove often in Bert's car		
	Adam and Bert were often on the phone		
Only Bert moved Chris' body		$(A_{bc})(e_{ars})$ Adam's car not on cameras **(A/D)**	$(A_{cb})(e_{cb})$ Adam's DNA found on duct tape that was around the victim's head **(A/D)**

Table 4.2: Scenario 2

Scenario 3		Supporting arguments	Contradicting arguments
Bert killed Chris		$(A_b)(e_b)$ Bert is convicted of the murder	
Adam, Bert, Chris were involved in cannabis operation		$(A_{inv1})(e_{adam})$ Adam's confession	
subscenario:			
	Adam was often at the cannabis location		
	Adam drove often in Bert's car		
	Adam and Bert were often on the phone		
Only Bert moved Chris' body in a blanket		$(A_{bcb})(e_{adam})$ Adam's testimony	(A_{nbc}) No blanket found

Table 4.3: Scenario 3

(CQ-Pr). In order to challenge the coherence of the scenario, arguments attacking and defending the scenario elements are noted in table 4.3 in a similar fashion to table 4.2 (CQ-ES, CQ-EC, CQ-AA).

4.1.3 Scenario 3: Adam's DNA was transferred by blanket (table 4.4)

Scenario 3 gives another alternate explanation for finding the DNA of Adam on the crime scene (CQ-AltEx). This scenario was proposed by the defendant in order to prove Adam's innocence. The scheme belonging to scenario 3 is the same one used for scenario 2 because both of these scenarios are about indirect contact between Chris and Adam whereas scenario 1 suggests direct contact between the two. No gaps are found when comparing the *Not involved* scenario scheme with scenario 3 (CQ-SS, CQ-PL). The main scenario element of scenario 3 is *Bert moves Chris' body in a blanket*. The absence of Adam in this scenario element is explained by the scenario element *Adam, Bert and Chris were involved in a cannabis operation*. However, if the DNA of Adam was transferred by a blanket in which the victim was transported, a blanket should have been found. This blanket has not been found (CQ-PR). In order to challenge the validity of the scenario, arguments attacking and defending the scenario elements are noted in table 4.4 in a similar fashion to table 4.3 and 4.2 (CQ-ES, CQ-EC, CQ-AA).

4.1.4 Verdict

The three scenarios discussed above are: Adam is guilty (table 4.2), Adam is innocent and his DNA was transferred by couch (table 4.3) and Adam is innocent and his DNA was transferred by blanket (table 4.4). Overlap can be seen between these three scenarios. The first two scenario elements *Bert killed Chris* and *Adam, Bert, Chris were involved in cannabis operation* are included in all three scenarios. Both scenario elements have no contradicting arguments and the arguments supporting these scenario elements are not attacked. This means that all three scenarios agree on the first two scenario elements. The divergence happens at the third scenario element. This scenario element is different for all three scenarios: *Adam and Bert moved Chris' body* for scenario 1, *Only Bert moved Chris' body* for scenario 2 and *Only Bert moved Chris' body in a blanket* for scenario 3. Furthermore, these scenario elements all have supporting and contradicting arguments. It can be seen from their statuses that there is no scenario element that is beyond reasonable doubt the truth: All arguments for the *Adam and Bert moved Chris' body* scenario element of scenario 1 are either defensible or overruled, the arguments for the *Only*

Bert moved Chris' body scenario element of scenario 2 are both defensible and for the *Only Bert moved Chris' body in a blanket* both arguments are not attacked. However there is only one supporting argument for this scenario element, namely the testimony of the suspect which is considered a weak argument. All in all, considering all the critical questions answered for each scenario, no scenario can be picked as the truth beyond reasonable doubt.

4.2 Case models

Case models make use of the presumptive nature of presumptive arguments. Presumptive arguments do not have the standard structure usually attributed to arguments where the premise logically implies the conclusion. A presumptive argument is only based on beliefs and goes beyond its premise (Verheij, 2017). Since these arguments do not have an inductive or deductive reasoning structure, it might be difficult to reason with them. It is therefore helpful to rewrite presumptive arguments as cases. Cases consist of the conjunction of the premise and conclusion of the argument. Alternatively, in the case model method, these cases consist of scenario elements and evidence. Presumptive arguments are usually defeasible due to them being based on beliefs. In order to defease a presumptive argument, the premise should be extended until the conclusion is no longer feasible from the premise. The cases with the same premise but different conclusions can be compared to each other based on the strength of a case. Comparing of cases is a fundamental part of the case model method.

The case model method incorporates all three frameworks discussed in section 3: It is probabilistic because by determining the strength of cases, a numerical interpretation of the probability can be given. It is argumentative because it is based on the argumentation theory of presumptive arguments. Lastly, it is scenario-based because it uses both evidence and scenarios to create cases.

In case models, cases are created by adding evidence step-by-step to the hypotheses. After adding all the evidence, the presumptive arguments can be read off the cases and based on the strength of the cases, a verdict can be formed.

4.2.1 Hypothesis gathering (base cases)

In the criminal trial used for this research, the three hypotheses that were explored by the court were: Adam helped Bert move the dead body of Chris, Adam did not help move the dead body instead the DNA was found due to DNA transference from Adam to couch to Chris, Adam did not help move the dead body instead the DNA was found due

to DNA transference from Adam to the blanket
to Chris whose body who was carried inside said
blanket.

1. Adam_helped_Bert
2. ¬Adam_helped_Bert ∧ DNA_from_couch
3. ¬Adam_helped_Bert ∧ ¬DNA_from_couch
   ∧ DNA_from_blanket

4.2.2 Visualizing evidence accumulation (figure 4.1)

Determining the hypotheses before the addition of
evidence helps determine the strength of cases while
adding evidence. After setting up the hypotheses,
a visual representation of the creation of the cases
is constructed that can be seen in figure 4.1. On
the right side, the pieces of evidence that are added.
On the left side, cases that are currently in line
with all the evidence up to that point are shown
together with their probability indicated by the
size of the boxes. Figure 4.1 can be interpreted as
follows.

Firstly, the body of Chris has been found in
the countryside (*Body_in_countryside*). At this
point, nothing yet indicates that the Chris was
murdered. Then, Bert is convicted of murdering
Chris (*Bert's conviction*) and therefore it is now
safe to assume Chris has been murdered. As it
turns out Adam, Bert and Chris had a cannabis
plant together and therefore Adam was often in
contact with the two (*Adam's testimony*). When
DNA of Adam was found (*DNA_match*) together
with the knowledge of Adam's testimony, Adam
became the suspect of helping Bert move the dead
body of Chris. However, two alternate explanations
were also drawn from Adam's testimony. These
are the three hypotheses from the previous sub-
section. At some point, hair of Adam was found
on the duct tape that was around Chris' head
(*hair_on_duct_tape*) suggesting that Adam was in-
volved in moving the body. However, Adam's car
was not found on the cameras along the road to the
crime scene (*Adam_car_not_ARS*). What has been
found were traces of Adam's DNA in Bert's car
(*traces_Adam_in_car_Bert*), which means Adam
could have still driven to the countryside in Bert's
car. The last piece of evidence is that phone records
show that Adam and Bert had a couple of phone
calls at midnight right after the time of the murder
(*phone_calls_Adam_Bert*).

4.2.3 Case creation

From the visualization of the effect of the evi-
dence on the three hypotheses, cases can be created.
These cases consist of a hypothesis extended with
evidence and scenario elements that are coherent
with the hypothesis. In order to keep the notation

concise, the evidence that is coherent with all hy-
potheses (body_in_countryside ∧ Bert's_conviction
∧ Bert_killed_Chris ∧ Adam's_testimony ∧
Adam_Bert_Chris_cannabis_plant) is abbreviated
to the letter E.

1: Adam_helped_Bert ∧ E ∧ DNA_match
   ∧ hair_on_duct_tape ∧ Adam_Bert_moved_body
   ∧ ¬Adam_car_not_ARS
2: Adam_helped_Bert ∧ E ∧ DNA_match
   ∧ hair_on_duct_tape ∧ Adam_Bert_moved_body
   ∧ Adam_car_not_ARS
   ∧ traces_Adam_in_Bert's_car
   ∧ phone_calls_Adam_Bert
3: ¬Adam_helped_Bert ∧ DNA_from_couch
   ∧ E ∧ DNA_match ∧ ¬hair_on_duct_tape
4: ¬Adam_helped_Bert ∧ DNA_from_couch
   ∧ E ∧ DNA_match ∧ hair_on_duct_tape
   ∧ Adam_Bert_moved_body ∧ Adam_car_not_ARS
   ∧ traces_Adam_in_Bert's_car
   ∧ ¬phone_calls_Adam_Bert
5: ¬Adam_helped_Bert ∧ DNA_from_couch
   ∧ E ∧ DNA_match ∧ hair_on_duct_tape
   ∧ Adam_Bert_moved_body ∧ Adam_car_not_ARS
   ∧ traces_Adam_in_Bert's_car
   ∧ phone_calls_Adam_Bert
6: ¬Adam_helped_Bert ∧ ¬DNA_from_couch
   ∧ DNA_from_blanket ∧ E ∧ DNA_match
   ∧ ¬hair_on_duct_tape
7: ¬Adam_helped_Bert ∧ ¬DNA_from_couch
   ∧ DNA_from_blanket ∧ E ∧ DNA_match
   ∧ hair_on_duct_tape ∧ Adam_Bert_moved_body
   ∧ Adam_car_not_ARS ∧ traces_Adam_in_Bert's_car
   ∧ ¬phone_calls_Adam_Bert
8: ¬Adam_helped_Bert ∧ ¬DNA_from_couch
   ∧ DNA_from_blanket ∧ E ∧ DNA_match
   ∧ hair_on_duct_tape ∧ Adam_Bert_moved_body
   ∧ Adam_car_not_ARS ∧ traces_Adam_in_Bert's_car
   ∧ phone_calls_Adam_Bert

4.2.4 Verdict

Each box in figure 4.2 represents a case with its
strength portrayed by the size of the box. The
three colored boxes are the cases that conform
with all the evidence: red is case 2, blue is case
5, purple is case 8. Since there are three of these
cases, in order to reach a verdict, these cases are
the most important ones to be ranked based on
their sizes. The ranking is as follows: case 2 > case
8 > case 5. From the three colored cases, three dif-
ferent interpretation of the case model can be given.

Arguments

Arguments from the cases are validated in three
ways: coherence, conclusiveness and presumptive
validity. An argument in a case is coherent when
there is a case that both includes the premise and
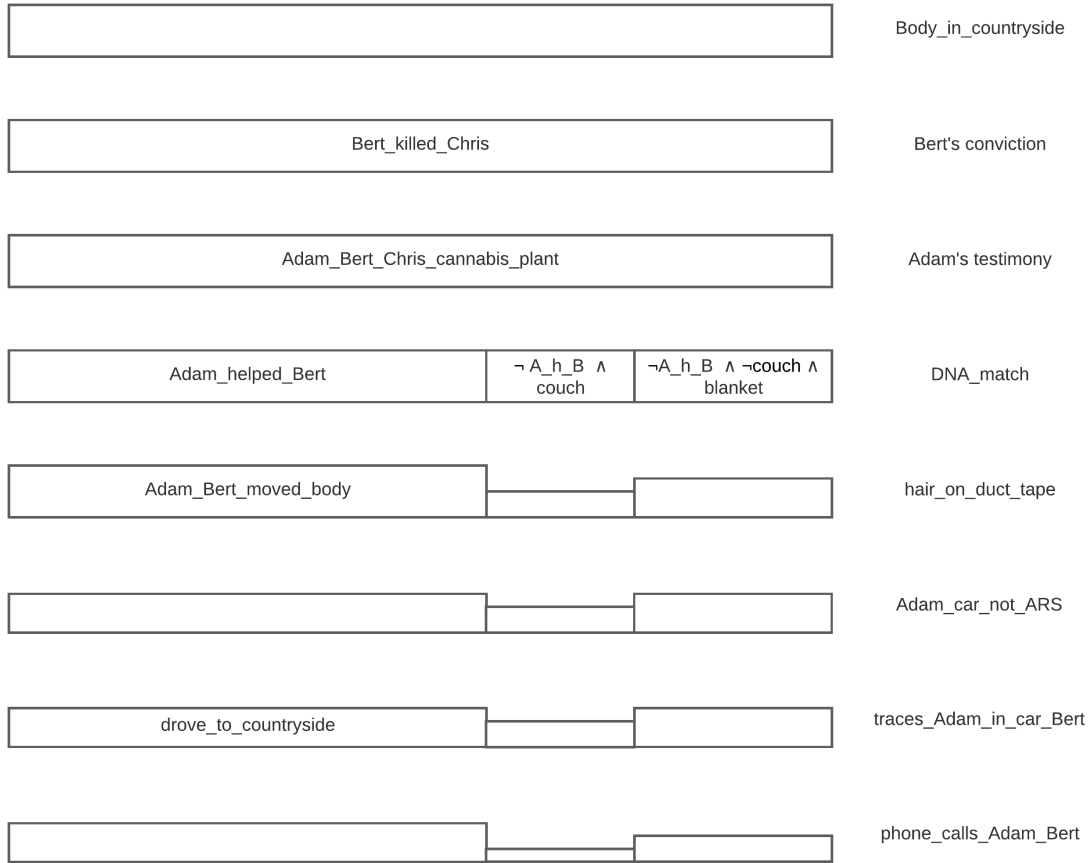the conclusion. An argument is conclusive when in

Figure 4.1: Visualization of the creation of case model

Figure 4.2: Case model with most coherent cases colored

all cases that contain the argument's premise also contain the argument's conclusion. Lastly, an argument is presumptively valid when the argument is contained in the case that has the highest strength. On the basis of the case model of this case study, the arguments validity can be assessed.

The arguments $(Body\_in\_countryside \land Bert's\_conviction \land Adam's\_testimony, Bert\_killed\_Chris)$ and $(Body\_in\_countryside \land Bert's\_conviction \land Adam's\_testimony, Adam\_Bert\_Chris\_cannabis\_plant)$ are coherent, conclusive and presumptively valid since all the cases agree on these.

The argument $(Body\_in\_countryside \land Bert's\_conviction \land Adam's\_testimony \land DNA\_match \land hair\_on\_duct\_tape \land adam\_car\_not\_ARS \land traces\_Adam\_in\_car\_Bert \land phone\_calls\_Adam\_Bert, Adam\_helped\_Bert)$ is coherent and presumptively valid but not conclusive because $(Body\_in\_countryside \land Bert's\_conviction \land Adam's\_testimony \land DNA\_match \land hair\_on\_duct\_tape \land adam\_car\_not\_ARS \land traces\_Adam\_in\_car\_Bert \land phone\_calls\_Adam\_Bert, \neg Adam\_helped\_Bert \land DNA\_from\_couch)$ and $(Body\_in\_countryside \land Bert's\_conviction \land Adam's\_testimony \land DNA\_match \land hair\_on\_duct\_tape \land adam\_car\_not\_ARS \land traces\_Adam\_in\_car\_Bert \land phone\_calls\_Adam\_Bert, \neg Adam\_helped\_Bert \land \neg DNA\_from\_couch \land DNA\_from\_blanket)$ are both coherent as well. This means that even when the premise of the guilty and innocent arguments are extended with all the found evidence, their conclusions cannot be retracted.

Scenarios

The scenarios for each case can be read off the case model visualization (figure 4.1) and can also be found in the logical sentences of the cases itself. Case 2, the red box in figure 4.2, includes

scenario 1 (guilty scenario). Case 8, the purple box in figure 4.2, includes scenario 3 (innocent, blanket scenario). Case 5, the blue box in figure 4.2, includes scenario 2 (innocent, couch scenario).

Probability

In order to interpret the case model in a probabilistic fashion, the surfaces of the colored boxes are calculated. Dividing these surfaces by the total surface area results in the probabilities for the cases. Calculating this results in a probability of 72.5% for scenario 1, a probability of 7.5% for scenario 2 and a probability of 20.0 % for scenario 3.

4.3 Vlek method

The Vlek method model for this case was created by Vlek et al. (2016). A Vlek model is modelled by creating a Bayesian network of scenario idioms and evidence as nodes of the graph and the relations between these nodes as their edges (figure 4.3). Scenario idioms are scenario nodes with their child nodes being the scenario elements. In order to get mutually exclusive scenarios, constraint nodes are added to the network (Vlek et al., 2016). Since this method uses both scenarios and creates probabilities by means of a Bayesian network, it can be classified as a hybrid method of scenarios and probability. Each node in the graph has a conditional probability table that gives the probability of the node being true or false based on the truth values of the parent nodes. The eventual goal of this Bayesian network is to calculate the probability of the scenario nodes when all the found evidence is true: $P(S_1|e_1, e_2, e_3, e_4, e_5, e_6, e_7)$, $P(S_2|e_1, e_2, e_3, e_4, e_5, e_6, e_7)$, $P(S_3|e_1, e_2, e_3, e_4, e_5, e_6, e_7)$. This will result in a joint probability table of all the nodes that are connected to each other between S_1, S_2, S_3 and $e_1, e_2, e_3, e_4, e_5, e_6, e_7$. From this table, the probabilities of a scenario node being true when all the evidence is true can be calculated. In order to see the progression of the probability when adding evidence step-by-step, evidence nodes can be set to true in a stepwise fashion and calculating the posterior probability of a scenario node after each step. In table 4.4, the probability for each scenario when adding evidence stepwise can be seen.

4.3.1 Verdict

The verdict of the Bayesian network can be read off table 4.4 by looking at its last row. After having added all the evidence, the probability of scenario 1 being true is 55% (P(Scenario1) = 55%), the probability of scenario 2 being true is 14% (P(Scenario2) = 14%) and the probability of scenario 3 being true is 31% (P(Scenario3) = 31%).

5 Evaluation

The verdicts for all three methods are that Adam is innocent due to insufficient conclusive evidence. This is partly due to the uncertain nature of the DNA evidence and the low amount of evidence in general.

In Vlek's method this verdict can be seen by looking at the probabilities of each scenario: P(Scenario1) = 55%, P(Scenario2) = 14%, P(Scenario3) = 31%. These probabilities are calculated from conditional tables that are created between the scenario and evidence nodes. All three scenarios still have a significant chance of being true and therefore it cannot be said beyond reasonable doubt that the defendant is guilty.

In Verheij's case model method, the verdict can be read off figure 4.2 by looking at the colored boxes. The ordering of the cases that conform with all evidence are case 2 > case 8 > case 5. Case 2 represents the guilty scenario, case 8 represents the DNA transferred by blanket scenario and case 5 represents the DNA transferred by couch scenario. By looking at the arguments for each of the three cases, a lack of conclusiveness can be seen because all three hypotheses conform with all evidence. Another indication of a lack of conclusiveness is that all the premises of arguments relating to evidence used in Bex's method can be read off all three cases. Even though the size of the case 2 box is much larger than the other two, a probabilistic interpretation results in inconclusiveness of a true scenario: P(Scenario1) = 72.5%, P(Scenario2) = 7.5% and P(Scenario3) = 20.0%.

In Bex's method, the verdict cannot be given a probabilistic interpretation, unlike the other two methods. The verdict is based on critical questions relating to the scenarios. Most supporting and contradicting arguments for the main element of scenario 1 *Adam and Bert moved Chris' body* have the status of defensible which means this scenario cannot be accepted as the true scenario nor can it be excluded as a possibility. For the other two scenarios, there is a lack of arguments directly supporting and contradicting the main scenario element of Adam's innocence *Only Bert moved Chris' body* and *Only Bert moved Chris' body in a blanket*. All these findings point towards inconclusiveness of being guilty or innocent.

From the creation of the three hybrid methods: Vlek's method, Bex's method and Verheij's method, the importance of scenarios for reasoning with evidence is apparent. All three of the methods use scenarios as a framework to reason with evidence in order to make the methods more understandable. Furthermore, Including a narrative approach like scenarios is advantageous because it is said to be in line with how jurors form a verdict (Bennett and
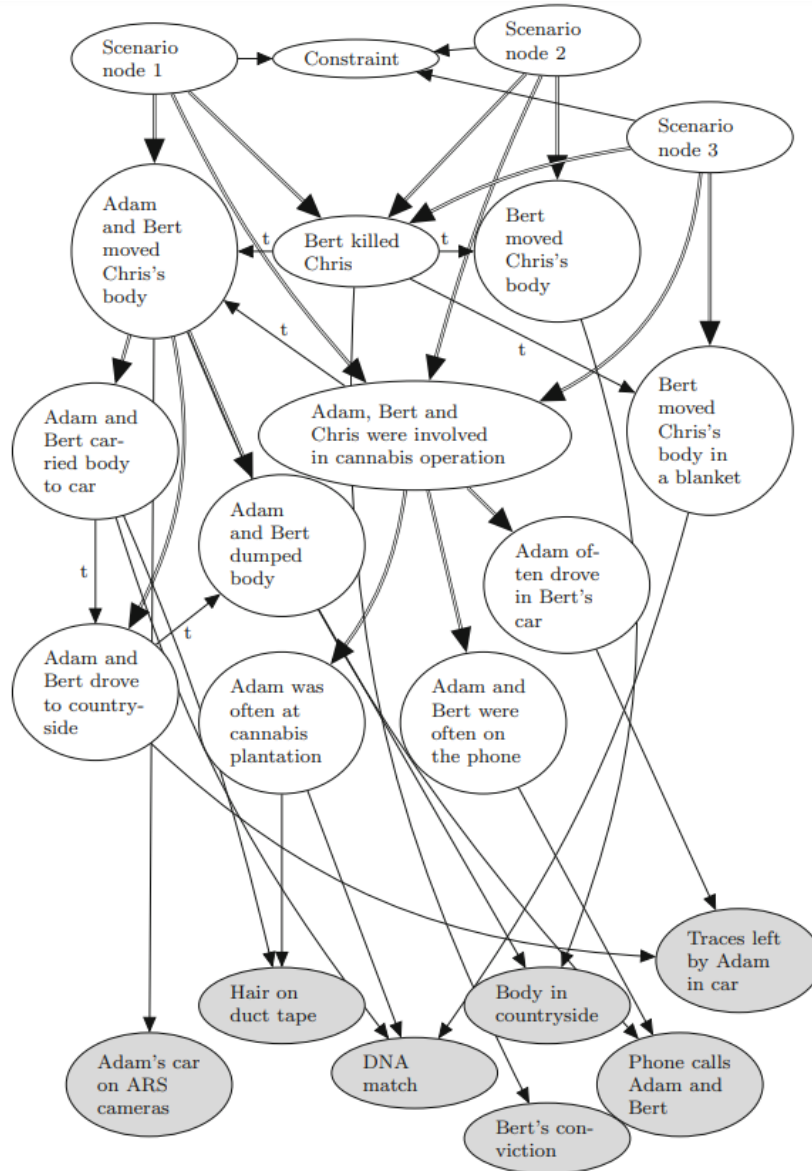
Figure 4.3: Bayesian network of Vlek method taken form Vlek et al. (2016)

Evidence	P(Scenario1) in %	P(Scenario2) in %	P(Scenario3) in %
Body in countryside	33	33	33
Bert's conviction	33	33	33
DNA match	44	14	41
Hair on duct tape	72	11	16
Adam's car not on ARS-cameras	53	14	33
Traces left by Adam in car	53	14	33
Phone calls Adam and Bert	55	14	31

Table 4.4: hybrid model of scenarios and probability .

Feldman, 2014). Since all three of these methods use scenarios as one of their frameworks, relating evidence to scenarios can be understood in the same way for all three methods. This results in easier transferability between the three. Furthermore, the arguments used in Bex's method, where only the validity of the arguments can be tested by their status, can also be validated by the case model approach, which adds extra validation to arguments and shows more transferability and cooperation between these two hybrid methods. Vlek's method lacks this synergy and transferability due to the

absence of arguments within this hybrid theory.

Even though all three methods use scenarios, the process that leads to reasoning with the evidence is different for all three methods. Bex's method explores arguments in an adversarial setting and relates them to scenario elements qualitatively. Because of this, the transparency of the method is high. Verheij's method does not relate arguments directly to scenarios but build up scenarios using the stepwise addition of evidence for a qualitative analysis, making the use of scenario scheme from Bex's method superfluous. Furthermore, use of cases and building the cases as more evidence is found, adds to this method's transparency. After all evidence has been added, the cases of evidence and scenario elements are ranked and can be given a probabilistic interpretation as a quantitative measure. In Vlek's method the conditional relation between evidence and scenario elements is modelled by mean of a Bayesian graph for qualitative analysis. Afterwards, by inference the posterior probabilities for each scenario given all the evidence can be calculated as a quantitative measure.

Since the creation of these hybrid methods models are not autonomous but are made by humans, reasoning with the evidence can be faulty which can lead to wrongful conviction. In Bex's method and Verheij's method, these faulty evidential reasoning can be detected easily due to their intuitive creation and their local scope. On the other hand, detecting faulty reasoning in Vlek's method is more difficult since it uses a wide scope where the evidence has an impact on and faulty priors are not always easily noticed.

In a criminal trial, eventually a verdict needs to be reached. Quantitative measures give numerical interpretations that can help steer the verdict in the right direction. However, having a quantitative measure locks the interpretation of the evidence into place, there is no room for other interpretations as seen from the probabilities given above from Verheij's method and Vlek's method. In order to calculate the posterior probabilities with Vlek's method, lots of prior numbers are needed whose distributions are unknown most of the time. Therefore, they are determined with uncertainty, which is shown to be prone to errors (Taroni et al., 2006). This greatly reduces the transparency of Vlek's method. Verheij's case model method solves this issue by getting rid of numerical values and subjectively attributing strengths to cases using sizes. Verheij's method still uses the subjective interpretation of evidence of the person that creates the case model however his/her choices can easily and intuitively be explained, unlike Vlek's method. Bex's method does not have to cope with this issue because it does not have quantitative measures. This leaves the method open to interpretation from both defendant and prosecutor.

The case on which the hybrid methods were applied included probabilistic evidence, namely Adam's DNA is found on the victim. Both Verheij's method and Vlek's method could handle this type of evidence well since gradations can be given where the evidence came from. However, in Bex's method these gradations for the validity of arguments are missing. Only the status of the arguments is used: defensible, justified and overruled. The evidence that Adam's DNA is found on the victim can have multiple reasons and therefore, using this piece of evidence as a premise of arguments will result in defensible arguments regardless how weak the arguments are.

6 Conclusion

During this research, three hybrid methods of reasoning with evidence are used. More specifically, the hybrid method of scenarios and arguments by Bex (2020), the hybrid method of scenarios and probability by Vlek et al. (2016) and the hybrid method of arguments, probability and scenarios (Case models) by Verheij (2014). Afterwards, the three models were evaluated and compared to each other. It was found that a narrative approach to guide the evidence is important. The verdict of all three hybrid methods show a lack of conclusiveness towards the guilty scenario, which suggests these hybrid methods share a fundamental way of evidential reasoning.

Verheij's case model method was created first for this case study. The creation was intuitive and user friendly. The stepwise addition of the evidence without the need for a necessary numeric interpretation created a deeper understanding of the hypotheses within the case study. However, ranking the cases within the case model was not always clear. Bex's method was also intuitive to create but reading off a verdict was not as simple as Verheij's method and Vlek's method due to their probabilistic interpretation. The Vlek's method implementation of this case study was created by Vlek et al. (2016) and therefore not much could be said about the experience of setting up such Bayesian network. But what can already be seen from figure 4.3 is that Vlek's method shows evidence nodes being intertwined with other scenario nodes meaning that the evidence has impact on each scenario in various different ways whereas Verheij's method and Bex's method zoom in on a more specific region of the case when reasoning with evidence.

Over all three hybrid methods, a big trade off can be seen. Vlek's method is very nuanced in the sense that it can reason with evidence in a refined way by giving numeric estimates. As a trade off,

this results in it becoming less comprehensible and manageable. Verheij's method and Bex's method give a less nuanced type of evidential reasoning. However, this makes the methods more accessible.

Furthermore, Vlek's method suffers from a need of numbers as priors that are not always known. For smaller cases with DNA evidence like this case study, it is still be manageable. However, modelling a case with more pieces of evidence can become more troublesome. But if a good approximation of the priors can be achieved, Vlek's method is powerful. A more practical limitation of Vlek's method is that it is not as accessible to jurors due to its statistical nature, whereas Verheij's method and Bex's method are both intuitive to work with. Even though Vlek's method incorporate scenarios in order to make the model more understandable, it still lack transparency due to the use of a Bayesian network. Bex's method suffers from a lack of expressiveness of arguments due to only being able to assign an argument a qualitative statuses (defensible, overruled or justified). Similar to Vlek's method, a limitation of Verheij's method is that the coherence is subjective. However, this coherence can be easily explained by the cases in the case model whereas Vlek's method lacks the transparency to convey the reasons.

Because there are limitations for each independent hybrid method, combining them together and using the strengths of each method can result in a more robust and substantiated verdict. Bex's method's lack of expressiveness of arguments can be reduced by validating the arguments based on conclusiveness, coherence and presumptive validity by means of a case model approach. The brittle final probabilities of the Vlek method and Verheij's method can be loosened by using the solely qualitative approach of the Bex's method in order to see other interpretations. The quest for well established priors in Vlek's method can be guided by Verheij's method. However, in order to get a better understanding of these synergies within the three hybrid methods, a more elaborate case study should be chosen to compare the three methods. The case study for this research only had 8 pieces of evidence and the scenarios were not long. It would be interesting to see how these three methods would compare when used in a large and better documented case.

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