Twelve angry men

A GRAPHICAL MODEL APPROACH

JORAM KEIJSER, SIMON SZATMARI, ALLARD HENDRIKSEN

Abstract

In this paper, we examine the potential of applying Bayesian network analysis to trial proceedings, specifically the determination of guilt. We will construct a graphical model of the case of a boy who stands accused of murdering his father as depicted in the movie *Twelve Angry Men*. The movie portrays the jury's perspective as they discuss the case. This enables us to compare "classical" judicial proceedings to an analysis based on Bayesian networks. We will analyze the case from a classical and Bayesian perspective, conclude on the verdict, and reflect on the movie itself.

Contents

Introduction

In the movie *Twelve Angry Men,* a boy stands accused of the murder of his father. Twelve jurors must decide beyond reasonable doubt whether he is guilty. The movie is shot exclusively in the courthouse and shows how the jurors make their decision.

The movie

The movie centers on the decision process of the twelve-man jury. At the beginning of the movie, all but one juror are convinced of the boy's guilt. Juror number 8, the only one against convicting the boy right away, argues that sentencing someone to death requires at least some discussion, especially since the boy's defense seems inadequate. Since the jury's verdict should be unanimous, the eleven to one division of votes forces a discussion to take place. During the remainder of the film, the audience learns about the facts which incriminated the boy in the first place. Again and again, the pieces of evidence turn out to be less convincing than they seemed during the trial. Every time new light is shed on some evidence, jurors change their vote from 'guilty' to 'not guilty'. Finally, even the most stubborn juror votes for acquittal when it becomes apparent that he wanted to convict the boy based on a personal grudge. This means the jury unanimously votes 'not guilty'. The boy is acquitted.

Brief account of the murder

The prosecutor's story and the defense do not differ very much. Both agree that around 8pm the boy and his father had a fight. People across the hall heard the father hit his son twice and saw the boy leave soon afterwards. The boy admits buying a switch knife at the local neighborhood store. He claims that he went to the movies afterwards. At midnight, however, an old man living below the father's apartment heard loud noises and heard the boy scream "I'm gonna kill you!" After hearing a body fall to the ground, he ran to the door and saw the boy running down the stairs. This story is corroborated by a woman across the street, who was already trying to sleep for over an hour. She claims that she saw the boy stab his father. Even though an elevated train passed the father's apartment at that moment, she claims she could see through the carriage into the apartment. The old man called the police who later found the father with a knife in his chest. His son returns to the apartment a few hours later.

The case

The following section will identify key individuals, facts and the exact chronology of events.

People

B   Boy

The boy is defendant in this murder case. He is a 19 year old kid from the slums. He lives with his father in an apartment building with an elevated train running straight across the windows. He was regularly beaten up by his father since age five. At fifteen, he was in reform school. He has previously stolen a car and has been arrested for mugging and knife fighting. The boy will be denoted by a **B** in graphical models.

F   Father

The father of the boy is the murder victim. We will denote him by an **F** in the networks.

M   Murderer (boy or somebody else)

In the graphical model, we will sometimes want to be able to distinguish the boy from the murderer as they are a priori not the same.

WAS   Woman Across the Street

The woman across the street lies in bed and can't sleep at the time of the murder. She has been lying in bed since 11PM. Her bed was next to the open window from where she could directly look into the window across the street. She should be able to recognize the boy as she has known him all his life. At about 00:10 she saw the boy stab his father. A split second later, the lights went out.

She looked through the window of a passing elevated train. This was shown by the prosecution to be possible. She specifically remembers that the train had five cars and that she looked through the windows of the last two.

As the movie progresses, the audience finds out that the woman wears glasses. According to a juror these bifocal glasses looked quite strong (thick). This makes it unlikely that she could have identified the boy, as most people don't wear glasses while trying to sleep. Due to the light turning off immediately after the crime, she could not have had time to put them on.

OM   Old Man

The old man lives in the apartment underneath the scene of the murder. He is in ill health: he walks with a pair of canes and has had two strokes in the past three years.

Initially, his testimony seems to seal the deal. When taking into account the passing elevated train, however, jurors doubt he could have heard anyone scream, let alone hear a body fall. According to a juror, "When your windows is open and the train goes by, the noise is almost unbearable. You can't hear yourself think". They estimate it takes 10 seconds for the train to pass. The woman saw the body fall through the last two cars. Hence, the boy must have yelled while the train was passing.

The old man's credibility is not only questioned due to the implausibility of him hearing the boy. The man also claims to have seen the boy run off 15 seconds after he heard the body fall. The jurors simulate him "running" to the door. They find that it must have taken him at least 31 seconds, more than enough for the boy to get away.

The jury tries to understand why the man would lie. In our model, we will not take into account any a priori reason for the man to lie.

Other facts and evidence

SK   Special Knife

The "little switch-knife" that the police found at the scene of the murder is exactly the same kind as the knife that the boy bought at the store. The storekeeper who sold the knife to the boy claims that the knife is very unusual: it was the only knife of its kind he had in stock. One of the jurors, however, has exactly the same knife. It was bought from a junk shop around the corner from the boy's house.

The boy claims he bought the knife as a present for his friend and lost it on his way back from the movies: it must have fallen through his coat pocket.

There are no finger prints on the knife.

Stab wound
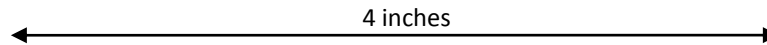
4 inches

The knife was four inches (102 mm) into the chest. This is quite deep: deep enough to pierce the heart, as can be seen in the table below.

Distance from Skin to Organs (mm)

	Pleura	Pericar-dium	Liver	Spleen	Kidney	Thoracic aorta	Abdominal	Femoral
Minimum	10	15	9	12	19	31	65	13
Maximum	48	45	36	39	79	93	102	25
Mean	22	31	19	23	37	64	87	18
Standard Deviation	7.9	7.1	6.3	7.0	13	15.1	10.3	3.9

Above Table: Forensic Pathology, 2nd ed, V. DiMaio, MD and D. DiMaio, MD, CRC Press, p. 189, 2001.

The angle of the stab wound was downward. This led to speculation among the jurors that the boy would probably not have killed his father in this way. According to a juror, "Anyone who's ever used a switch knife would never have stabbed downward. You don't handle a switch knife that way. You use it underhanded". Since the boy is shorter than his father (5 ft 8 versus 6 ft 2), the jurors conclude that it is improbable that he stabbed his father with the knife overhead.

We come to a different conclusion than the jury. We cite the following passage from (Saukko, 2004)

> *The direction of a stab wound is often a matter of contention in homicides, especially as trial lawyers (and their medical advisers) sometimes tend to over interpret the facts when trying to reconstruct the scene of the fatal assault. As mentioned above, a stabbing incident is often moving and dynamic, and the victim is rarely in a static, anatomical position. For example, a wound that enters the upper part of the left side of the chest and travels steeply downwards, is not inevitably the result of the killer being taller or situated above the victim, using a downward blow. The victim could equally well have been bending or crouching, the knife then entering on a horizontal plane relative to the floor.*

The movies – an alibi

The boy claims he was at the movies during the murder, but he cannot remember what pictures he saw. Unfortunately, the script does not reveal whether he was there with friends or whether anyone can corroborate his alibi. As the script progresses, the jurors start to entertain the possibility that the boy has simply forgotten which movies he saw. Unfortunately, we have not been able to find accurate statistics on this subject in scientific literature.

Chronology

20:00   People across the hall heard the father hit the boy twice and then saw the boy walk angrily out of the house. Boy admits leaving at 8pm.

--   Boy went to neighborhood store and bought a switch knife.

--   Boy went to the movies.

--   Boy claims that he lost his knife on the way home as it must have fallen through a hole in his coat pocket.

23:00   Woman across the street went to bed.

00:00   Coroner fixes the time of death at around midnight.

00:10   The old man heard loud noises in the upstairs apartment. Sounded like a fight.
He heard the kid scream "I'm gonna kill you!"
A second later the old man heard a body falling.
A split second later the lights were turned off.
The old man "ran" to the door of his apartment and saw the kid running down the stairs.

Later   The police, after being called by the old man, found the father with a knife in his chest.
The boy was arrested when he returned home.

Classical analysis

We will first follow the jurors' decision-making process. Then we will do our own Bayesian analysis of the case. This allows us to compare the two ways of reaching a verdict. The goal of the jury is to determine the boy's guilt beyond reasonable doubt. They must reach a unanimous verdict. This is achieved by rounds of voting interspersed with debate in which the jurors try to persuade each other of their standpoint.

The jury starts with a vote. All but one juror vote guilty. He believes the case merits at least some discussion. The other jurors start to summarize the case. They are fully confident of the two witnesses, they do not believe the boys alibi, and they note that the murderer's knife is similar to the knife bought by the boy. Also, the boy's troubled youth is emphasized.

Now, the dissenting juror pulls out a knife out of his pocket that is indistinguishable from the murder weapon, undermining the claim that the weapon is unique. Having put into question one piece of evidence, the jury decides to vote again. Another juror also votes not guilty. He believes the case merits more discussion.

The jurors discuss the old man overhearing the murder. It dawns upon them that the old man could not have heard the murder take place with a passing elevated train. Another juror changes his vote. As the jurors simulate the old man "running" from the window to his front door, they begin to question his credibility even more. He cannot have walked this distance in the 15 seconds he claims it took. They vote again: six to six.

The discussion turns to the stab wound. One of the jurors has some experience with knifes and convinces his peers that the boy, an experienced knife fighter, would never have stabbed downwards. When another vote is brought to the table the count is nine to three in favor of acquittal.

The jurors turn their focus to the last witness, the woman across the street. Thus far, she has remained a convincing and decisive witness. One of the jurors notes that she wore quite strong bifocal glasses. Her testimony could hardly be true if she wasn't wearing them. The jurors convince themselves that she could not have worn them in bed and are put to a final vote. Unanimously, they vote for acquittal.

Bayesian analysis

In this section we will analyze the case from the perspective of a Bayesian forensic statistician. The goal is to provide the judge with the likelihood ratio of the evidence, the last term in the equation below. The judge must then supply his own prior odds on the hypothesis of the prosecutor versus that of the defense. Under the presumption of innocence, a judge might always assign 1 in 100 odds of an individual being guilty. When the posterior odds exceed 1, the judge convicts the defendant.

$$\frac{P(Prosecutor \mid Evidence)}{P(Defense \mid Evidence)} = \frac{P(Prosecutor)}{P(Defense)} \frac{P(Evidence \mid Prosecutor)}{P(Evidence \mid Defense)}$$

We will first set up a framework of propositions. Using this framework, we will develop a causal graph of the case. From this causal graph, we construct a Bayesian network. Finally, we will fill in the evidence and conclude on the likelihood ratio.

Three levels of analysis

Following the exposition in (Aitken, 2004), we will first examine the "hierarchy of propositions". They divide propositions into three levels: the source level (level I), the activity level (level II), and the crime level (level III).

Propositions at source level pertain to material facts. For example: "DNA found in the collar of the victim coincides with that of the defendant" or "the knife used in the murder is identical to the knife bought in the store". In this case, the knife is the only subject of source level propositions.

At activity level, propositions relate to an activity. Our case is rich in activity level propositions, for example: "the boy went to the movie" and "the boy stabbed his father". Unless filmed, these activities cannot be proven in the same manner as source level propositions. Arguments in favor and against depend on source level propositions, witness accounts, and other sorts of evidence.

The same activity can result in a different verdict in differing situations. Whether a crime occurred is described by crime level propositions. At activity level, two people may have had sexual intercourse. It is at crime level that one decides whether it is rape.

In our case we determine the following propositions at each level (see below). The judge orders the jurors to determine the boy's guilt of murder in the first degree. We identify four actions that pertain to him killing his father and three possible material facts arising from a murder. The case is not particularly rich in material facts.

- Crime level
    - o The boy is guilty of murder in the first degree – premeditated homicide – of his father.

- Activity level
  - The boy went to the movies.
  - The boy stabbed his father.
  - The boy yells "I'm gonna kill you".
  - The boy runs down the stairs after the murder.
- Source level
  - The boy's knife is identical to the murder weapon.
  - The father has a downward stab wound.
  - The murder weapon is rare.
  - The boy's fingerprints are on the murder weapon.

Note that the three levels mostly exclude witness credibility issues. Also, it is awkward to conceive in this framework the question whether an experienced knife fighter would leave a downward stab wound. Is the boy being a knife fighter a material fact? And how does the orientation of the wound relate to the activity level proposition? We propose an additional two "levels" of which we give some example propositions.

- Witness activity level
  - The woman across the street was wearing glasses while trying to sleep.
  - The old man saw the boy run down the stairs.
- General conjecture level
  - A knife fighter stabs underhanded.
  - The woman across the street is credible.

Causal graph

After having examined the different levels of propositions, we will construct a causal graph of the case. The central node is the activity level proposition: the boy killed his father with the special knife. In assessing the crime level proposition we will take into account that he was in possession of a knife on the night of his father's murder.

The graph is structured around the witnesses and evidence we have seen before. The top right is concerned with the uniqueness and possession of the special knife. Below, the orientation of the stab wound is examined. Next, we draw three nodes for the boy's alibi. The old man's testimony takes up the lower part of the graph. His testimony is connected to that of the woman across the street by the (passing) elevated train.

The hypothesis of interest is chosen to be 'The boy killed his father with a switch knife'. The sole purpose of our Bayesian analysis is to determine the likelihood ratio of the evidence, conditioned on the hypothesis. We chose the hypothesis to extend beyond the guilt of the boy. This is justified by the fact that there is no reasonable hypothesis in which the knife was not the murder weapon. By including the fact that the switch knife is the murder weapon, we establish a direct dependence of the hypothesis on important pieces of evidence. Restricting the hypothesis to just the matter of guilt would preclude establishing these causal relationships.

Credibility construction

The graphical model gives us the opportunity to model the credibility of the witnesses. In our case, two testimonies are very unlikely given the circumstances, e.g. the old man could not have heard a body falling to the floor with an elevated train passing by his window. We have just seen that this convinces the jurors of his lack of trustworthiness. In our network, we have used the following construction to model witness credibility.
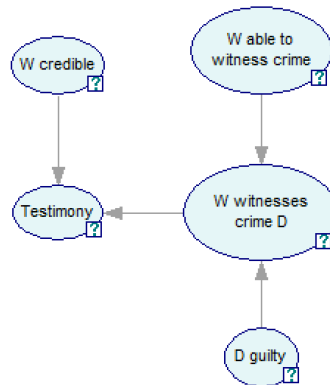
Here, W denotes the witness and D denotes the defendant. The testimony can be either "D guilty" or "D innocent". The node "W able to witness crime" is false when, for example, a testimony depends on eye sight and the witness has none. The witness can only witness a crime committed by the defendant when the witness is able to witness the crime *and* the defendant is guilty. We can observe the ability of a witness to testify and we can observe their testimony.
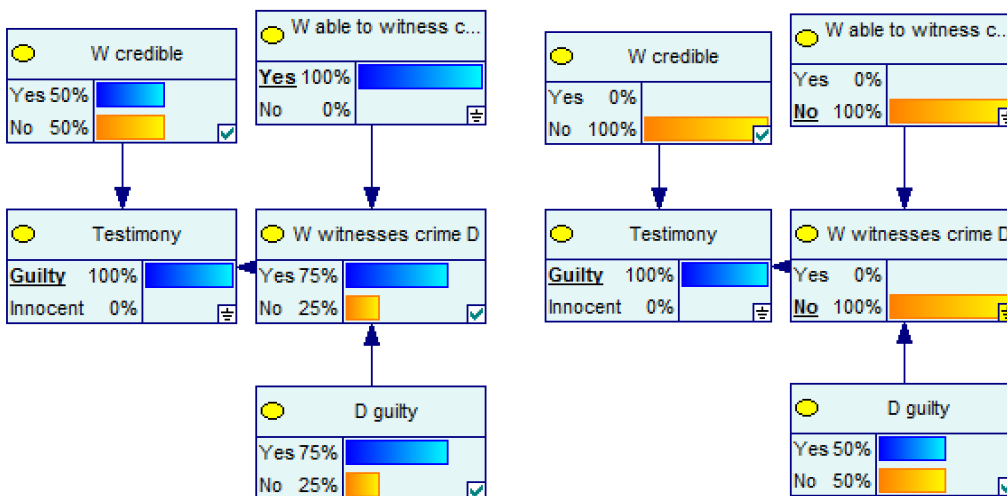
As we see above, when a witness testifies that the defendant is guilty and he is able to do so, his credibility is unchanged[1]. Also, the posterior odds that the defendant is guilty improve. On the other hand, when we find out that he was unable to identify the defendant, his credibility drops and the posterior odds of guilt remain unchanged. We use this construction for the credibility of the woman across the street and the old man.

---

[1] For simplicity, the marginal odds of the *credibility*, *guilt*, and *ability to testify* nodes are set to 50/50.

● Old man

We have mentioned the two claims made by the old man. His first claim is hearing the boy yell. The probability of the man actually hearing this is influenced by the passing of the elevated train and whether or not the boy indeed yelled "I'm going to kill you". The probability distribution of the old man's claim depends on what he actually heard and on his credibility.

Second, the old man claims he saw the boy flee. As with the other claim, the probability of him making this claim is dependent on the actual fact ('saw the man see the boy flee?') together with the old man's credibility. In turn, the old man seeing the boy flee depends on three things. First, the old man ran to the door upon hearing the boy yell (according to the old man's story). Secondly, the man seeing the boy flee depends whether the boy was present to murder his father and, finally, on whether he took time to clean his knife.

● Woman across street

The woman across the street ('WAS') testified [that] she recognized the boy as he killed his father. Obviously, this is impossible [if] (in case) the boy didn't kill his father, but very well possible if he did. As such, 'WAS recognized B' is dependent on the 'B killed F with SK'. However, the woman may have been short sighted. Hence, 'WAS is short sighted' decreases the probability of 'WAS recognized B'. On the other hand, any short sightedness is irrelevant in case the woman was wearing her glasses at the moment of the murder. Hence, 'WAS recognized B' is dependent on both 'WAS is short sighted' and 'WAS wore glasses'.

Next, we're moving to the most interesting part of the network, which is concerned with the credibility of the witnesses. The general setup is outlined in the section Credibility construction.

The first occurrence of this construction is the one about the woman. She claims [that] she recognized the boy. The probability of her making this claim depends on whether she indeed recognized him, and her credibility.

● The elevated train and its relation to witness credibility

The woman also claims that the elevated train passed at the instant of the murder. Again, the distribution of the claim is dependent on the actual event 'El train passes', as well as on 'WAS credible'. Note that if the elevated train did not pass, the woman's credibility decreases.

We discuss the mutually exclusive nature of woman's and of the old man's credibility, which arises from the passing of the elevated train. It is stressed in the movie that the passing of an elevated train is extremely noisy, up to the point where "one cannot hear himself think".

Therefore, if the woman across the street is telling the truth and indeed she saw the murder through the windows of the elevated train, it then becomes quite unlikely for the old man to have heard the boy yell "I am going to kill you".

On the other hand, if the old man is telling the truth and indeed heard the boy yell "I am going to kill you", then the passage of an elevated train becomes unlikely, which casts a doubt over the claim of the woman across the street.
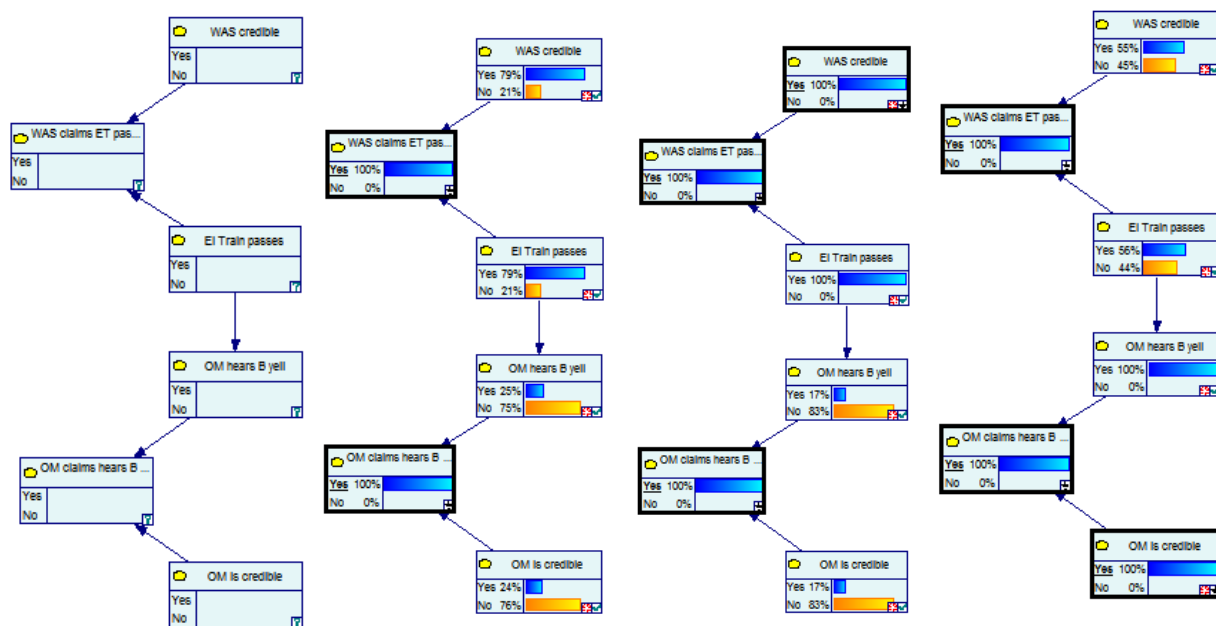
In the following structure (see figure on the next page) we only instantiate the claim nodes. We know that the woman across the street claims to have seen the boy kill his father and we know that the old man claims to have heard the boy yell "I am going to kill you".

Remember that if A, B, C are nodes and we have the following structure, A --> B <-- C, then instantiating B renders A and C conditionally dependent. Otherwise A and C are independent. If A, B, C are linked up in series, A--> B --> C, then instantiating B renders A and C conditionally independent, otherwise A and C are conditionally dependent. Finally, if we have the structure A <-- B --> C, then A and C are independent, until B is instantiated and then A and C become independent.

Keeping this in mind, instantiate the woman's claim that the elevated train has passed, as well as the old man's claim that he (the old man) has heard the boy yell "I am going to kill you". Since the woman's credibility node, the woman's claim and the passing of the train are in a converging connection, the woman's credibility is conditionally dependent on the passing of the train. Similarly, the old man hearing the boy yell, the claim that he heard the boy yell and his credibility form a converging connection. Thus the old man hearing the boy yell is conditionally dependent on the old man's credibility. Finally, since the passing of the train is conditionally dependent on the old man hearing the boy yell, we have that the credibility of the woman is conditionally dependent on the credibility of the old man.

Instantiating the claim nodes, we see that the woman's credibility is at 79%, whereas the old man's credibility is at 24%. However, this is not enough to establish the mutually exclusive nature of the credibility of either. To bring this to light, leaving the claims instantiated, we instantiate the woman to be credible (setting her to be 100%): we see that the credibility of the old man decreases from 24% to 17%. If we set the old man to be credible (setting him to be 100%), then the credibility of the woman crumbles from 79% to 55%!

Thus the credibility of the woman and of the old man are inversely correlated, linked together in this inverse dependency by the elevated train passing (or not).

WAS credible — Yes / No

WAS claims ET pas... — Yes / No

EI Train passes — Yes / No

OM hears B yell — Yes / No

OM claims hears B ... — Yes / No

OM is credible — Yes / No

WAS credible — Yes 79% / No 21%

WAS claims ET pas... — Yes 100% / No 0%

EI Train passes — Yes 79% / No 21%

OM hears B yell — Yes 25% / No 75%

OM claims hears B ... — Yes 100% / No 0%

OM is credible — Yes 24% / No 76%

WAS credible — Yes 100% / No 0%

WAS claims ET pas... — Yes 100% / No 0%

EI Train passes — Yes 100% / No 0%

OM hears B yell — Yes 17% / No 83%

OM claims hears B ... — Yes 100% / No 0%

OM is credible — Yes 17% / No 83%

WAS credible — Yes 55% / No 45%

WAS claims ET pas... — Yes 100% / No 0%

EI Train passes — Yes 56% / No 44%

OM hears B yell — Yes 100% / No 0%

OM claims hears B ... — Yes 100% / No 0%

OM is credible — Yes 100% / No 0%

● The knife

The victim was found with a switch knife in his chest. The node 'SK is found' corresponds to the fact that this knife is of a particular type. The boy admitted buying this type of switch knife directly after the fight with his father at 8PM, but before the murder which happened around midnight. The node 'B possessed knife before murder' corresponds to this piece of evidence. It is not connected to other parts of the network. The purchase of the knife precedes the murder. This means that in any case, the hypothesis should depend on the purchase. But buying a knife does not actually cause a murder. This is why 'B possessed knife before murder' is not connected to the rest of the network. The node just serves as a gentle reminder for the judge to incorporate this evidence into his prior belief about the boy being guilty.

First, the jurors believe the knife is very rare. Subsequently, it turns out that this is not the case and that the knife is quite common. The peculiarity of this knife influences the probability of finding such a knife. This relation is modelled by the dependency of 'SK is found' on 'SK is rare'. Furthermore, whether or not the boy murdered his father with this 'special' type of switch knife obviously influences the probability of finding the knife.

After the murder, the boy did not possess the knife. A potential explanation could be that the boy used this knife to murder his father. Hence the dependence of 'B possessed knife after murder' on the hypothesis node. The alternative explanation, as offered by the defense, is that the knife fell through the boy's pocket. This also influences the probability of the boy possessing the knife after the murder.

● Downward stab

Now we discuss the 'Downward stab wound' evidence. Since the boy is shorter than his father, if he killed his father then the murderer (boy) is shorter than the victim (father). If the boy didn't kill his father, then the probability of the murderer being shorter than the victim is determined by the probability of any murderer being shorter than the father. Hence, the hypothesis influences the 'M shorter' node.

Analogously, 'M is knife fighter' is dependent on the hypothesis. It is likely that the boy is a knife fighter. This means that if he is guilty, then the murderer is a knife fighter. On the other hand, if the boy is not guilty, then the probability of the 'M is knife fighter' is the probability of anyone who committed a murder with a knife being a knife fighter.

Finally, the evidence shows that the stab wound in the victim's chest is from a downward angle. The probability of observing this piece of evidence is more likely in case the murderer is shorter than the victim. On the other hand, it is less likely in the case the murderer was a knife fighter. It is claimed that anyone who knows how to handle a knife would stab upwards.

● Alibi

The boy attested being at the movies at the time of the murder. This is impossible in case he is guilty, but it is very well possible if he is not. Hence, 'B @ movies during murder' is dependent on the hypothesis. In case the boy went to the movies, he is very likely to remember which movie he actually saw. This way, 'B @ movies during murder' influences the probability of 'B remembers movie'.

● Fingerprints

No fingerprints were found on the knife: the 'Knife is clean' node is set as evidence. If the murderer handled the knife bare handed then this becomes less likely. The same is true if the boy cleaned the knife after committing the murder. In turn, it is more probable the murderer cleaned the knife if he indeed handled the knife bare handed. This gives the dependency of 'B cleans knife' and 'Knife is clean' on 'M handles knife bare handed'. In addition, cleaning a knife takes time. If the boy did clean the knife, this would have given the old man time to walk to the door and see him fleeing. Hence, the probability of the man seeing the boy flee is increased in case the knife was cleaned. Obviously, whether the boy was the murderer has most influence on the probability of 'OM sees B flee'.

Conditional probability tables

The conversion from a causal graph to a Bayesian network involves filling in all the conditional probability tables. Since we have 28 nodes with a varying degree of incoming arcs, we will not discuss all nodes, just those that are interesting. All probabilities can be inspected in the attached network file.

Node	Odds yes	Odds no
B killed F with SK	50	50
El Train passes	300	10
WAS/OM credible	99	1
WAS wore glasses in bed	1	200
Knife clean | NOT M cleans knife, M handles knife barehanded	9	1
SK is found | NOT SK is unique, NOT B killed F with SK	1	9

Of course the root node, *B killed F with SK*, deserves special consideration. In order to easily calculate the likelihood ratio, we have given 50:50 odds to both yes and no. This serves as the prior. When the evidence is set, this node contains the posterior distribution. We can simply divide the two posterior probabilities to obtain the likelihood ratio.

We assume the elevated train passes every five minutes and takes ten seconds to pass. So the odds of the train passing at the instant of murder are 300:10. The odds of the woman across the street and the old man being credible are set 99:1. This is of course entirely subjective, but we don't know of a

principled way to determine these odds. We also had to estimate the odds of the woman wearing glasses while trying to sleep. A number of arguments can be brought to bear both of increasing our estimate and decreasing it. The consequence of our estimate is that we expect the woman to wear glasses three times in two years an hour after going to bed.

The conditional probabilities we will discuss are both related to the knife. When the murderer has not cleaned his knife and handles the knife barehanded, the odds of the knife containing finger prints are 9:1. This is based on the following quote from (Hueske, 2008).

> *It is widely accepted as unlikely, for example, that identifiable fingerprints will be found on firearms. Identifiable fingerprints will be found probably less than 10 percent of the time. When a suspect's fingerprints are not found on a murder weapon, however, defense attorneys often present this fact as an indication of their client's innocence.*
>
> *Contrary to portrayals in the movies and on television, fingerprints are not always easy to find on certain items of evidence. In the author's experience identifiable fingerprints are found on guns, knives, clubs, and the like in less than 10 percent of the cases.*

We also estimate the chance that a knife of the same special type is found at the scene when the boy is innocent and the knife type is not as rare as suggested by the prosecution. This means that an unknown murderer has killed the father with a different type of knife. We estimate the odds to be 9:1 in favor of a different type of knife being found. This estimate slightly favors the boy's innocence, as it is unlikely that one in ten stabbings in New York are carried out with this specific type of switch knife. We also have to take into account, though, that the juror could buy exactly the same knife a few blocks from the father's house.

Results

In order to compare our analysis with that of the jury, we will set similar evidence in the Bayesian network. We will also incorporate our knowledge of stab wound orientation to arrive at an alternative judgement.

Node	Jury's evidence	Alternative evidence
WAS is short sighted	Yes	Yes
WAS claims recognized B	Yes	Yes
WAS claims ET passed	Yes	Yes
OM claims hears B yell	Yes	Yes
OM claims sees B flee	Yes	Yes
Knife is clean	Yes	Yes
B remembers movie	No	No
Downward stab wound	*Yes*	*Not set*
B possessed SK afterwards	No	No
SK is found	Yes	Yes
SK is unique	No	No

Given the jurors' evidence, the likelihood ratio is 55:1 in favor of the prosecutor, i.e. the case presented by the prosecutor is 55 times more likely to explain the evidence. Under the presumption of innocence, this likelihood ratio is probably inadequate to convict the boy. Hence, the Bayesian analysis agrees with that of the jurors in the movie.

It is interesting to note that the posterior probabilities of the woman across the street and the old man being credible are 9% and 53% respectively. Effectively, the model does not believe the witnesses. The jurors did not put much trust in them either. When we remove from consideration the testimonies of the two witnesses, it is a comforting thought that this set of evidence did not lead to a high likelihood ratio, as a conviction based on two pieces of evidence (the knife being identical and the boy forgetting his alibi) would not fly in a real court case.

When we take into account the forensic literature on stab wounds, however, the picture changes dramatically. The jurors assumed that the boy was very unlikely to stab his father overhanded. As we saw in the discussion of the stab wound, forensic experts are hesitant to draw a conclusion from the orientation of a stab wound. When we don't set this evidence, we get a likelihood ratio of 2272:1 in favor of the prosecutor. In this case, even a lenient jury would vote guilty.

Note that the credibility of the witnesses was not increased by the removal of this piece of evidence[2], yet the likelihood ratio changed dramatically. In the judicial system, this would not constitute sufficient evidence, yet the likelihood ratio is already quite high – perhaps enough to convict with a strict prior.

Conclusion

Looking at the case, we can conclude that the evidence and particularly the witness accounts leave a lot to be desired. The defense lawyer could have done a much better job, especially in protesting the uniqueness of the knife. Also, the case of the defense could have been greatly bolstered by a more convincing alibi.

Nonetheless, both the jurors and the Bayesian model agree that there is reasonable doubt that the boy murdered his father. When the orientation of the stab wound is dropped as evidence, the likelihood ratio of the Bayesian network becomes rather high. A strict judge might convict based on this ratio, yet we believe that the jurors would still abstain from convicting the boy. They distrust both witnesses and will not convict based on the sole evidence of the knife being identical, the boy losing his knife, and the boy forgetting his alibi.

Also, the case demonstrates that a seemingly innocuous piece of evidence can have a major impact on the likelihood ratio. This is of course true for a real trial as well, but in a real trial one usually has a realistic expectation of the impact of a piece of evidence. Introducing another piece of evidence in a graphical model can result in all kinds of unexpected changes in the posterior belief. We did not expect the orientation of the stab wound to make a factor 40 difference.

Comparing the two modes of analysis, we notice that the graphical model approach invites much more consideration of previously unrecognized possibilities. The jurors, for instance, did not consider the possibility that the elevated train did not pass and the old man could actually hear the boy yell. They

---

[2] The credibility of the old man rose from 53% to 54%. The credibility of the woman across the street remains unchanged.

also failed to consider that the old man could not have seen the boy running down the stairs if he had not heard him.

Furthermore, as inconsistencies in the testimonies are uncovered, the jurors entirely discard the witness accounts as evidence. The Bayesian network, on the other hand, provides us with an intuitive and rational representation of its trust of the witnesses. Also, the Bayesian network considers the witness accounts in the posterior odds, though with a very small weight.

Discussion

The Bayesian analysis uncovers several plot shortcomings. We will highlight two of them. According to the woman across the street, the lights went out a 'split second' after the murder. However, any time difference of under a second between the stabbing and the light going out seems highly unrealistic. Even for a knife fighter, stabbing someone is not a routine operation which can instantaneously and smoothly be followed by switching off the light.

The second plot shortcoming is related to the first. In reality, a stab wound does not immediately kill. According to the literature,

> *Unless the stab wound involves the brainstem, death is not instantaneous, and victims of stabbing are capable of energetic actions, such as running and climbing stairs before they collapse.*
>
> *If the heart or great vessels are targeted, the assault may be enough to 'drop' the victim straight away, but consciousness will not necessarily be lost immediately.*
>
> *Thoresen and Rognum (1986) found that 72% of those who had acting capability following the assault were dead within 30 minutes, and those who sustained penetrating injury to the heart were unlikely to survive longer than 12 hours.*
>
> *Source: http://www.forensicmed.co.uk/wounds/sharp-force-trauma/stab-wounds/*

These two facts show that the the story of the murder is quite unrealistic. Two observations are in place. First, the lack of realism can partly be attributed to a lack of credibility of the woman across the street. Modelling the precise implications of these unrealistic parts in the shorty would be a topic of further investigation. Second, these observations show how one has to deal with imperfect information when Bayesian modelling a fictional crime. Any fictional account of a crime will have to leave some gaps in the description of the events. As soon as one starts to go beyond the role of audience by doing a thorough analysis, these gaps will soon become clear. This certainly turned out to be the case during our analysis of the Twelve Angry Men case.

What surprised us most during our work on this project is the subjectivity of the network structure. Any two persons charged with making a Bayesian network of a court case will inevitably end up with a different structure. The subjectivity of the structure is not our only concern. The parameters in the probability tables are also highly subjective. This does not inspire much confidence in the repeatability of the Bayesian approach.

Further work could be done on investigating the impact of the probabilities in the conditional probability tables. It would be useful to know, for instance, within which band the probability should fall of the woman across the street wearing glasses in order not change the judge's ruling. Also, prosecutor and defense lawyers would want to know *which* probabilities to nudge in order to make the biggest impact on the likelihood ratio. Then, a lot of time could be saved by not discussing irrelevant parameters and focusing on those parameters that have the biggest impact on the case. Furthermore, we believe that the Bayesian approach could also be made to work when the hypothesis of guilt is not the root node.

Finally, it would be interesting to investigate the effect of a more thoughtful prior. In our current analysis, we took the prior odds on the hypothesis to be 1. That is, before seeing any evidence we assume the probability of either hypothesis to be 50%. A more defensible approach would be to base the prior on all facts which led to the boy becoming the suspect in the first place. We learned about this approach from the presentation of Frans Alkemade (Alkemade). A first start is the single node 'Boy posessed switch knife before murder'. Pursuing this approach could be a very fruitful extension of the current analysis. This would also yield a more intuitive interpretation of the posterior odds.

References

Aitken, C. G. (2004). *Statistics and the evaluation of evidence for forensic scientists.* Chichester: Wiley.

Alkemade, F. (n.d.). *Presentation on the use of Bayesian statistics in court, held during the final meeting for the Forensic Statistics and Graphical Models course.*

Characteristics of stab wounds. (n.d.). http://www.forensicmed.co.uk/wounds/sharp-force-trauma/stab-wounds/.

DiMaio, D. a. (2001). *Forensic pathology.* CRC press.

Hueske, E. E. (2008). *Firearms and Fingerprints.* Infobase Publishing.

Saukko, P. a. (2004). *Knight's forensic pathology.* CRC Press.