Modelling crime linkage with Bayesian Networks

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August 20, 2014

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Introduction

Problem

- When two or more similar crimes occur shortly after each other, the question arises *Is there a common offender?*
- The similarities between the crimes suggest that evidence from one crime becomes relevant for another crime.
- The underlying dependency structure of crime linkage problems can be modelled using Bayesian networks.

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Introduction

Background

- Our research extends the analysis of *Logical evaluation of evidence when a person is suspected of committing two separate offences* by Evett et al. (2002)
- Evett et al. consider the problem of drawing inferences within a legal framework when a person is a suspect for two separate offences.
- It seems to them that there is considerable potential for facilitating and extending their analysis through the use of Bayesian networks.

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Introduction

Our research

- We show how Bayesian networks can be used to model different evidential structures that can occur when linking crimes
- That is, how evidence that is obtained in one crime can be used in another and vice versa.
- The flip side of this is that the intuitive decision to "unlink" a crime in which exculpatory evidence is obtained leads to serious overestimation of the strength of the remaining crimes.
- We compare how crime linkage (schakelbewijs) is used in Dutch legal practice with how it could/should be used according to our model based on probability theory.

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Hypotheses

Hypotheses of interest

- With one crime and one suspect, one is interested in the question *Is the suspect the offender?*
- With two crimes and one suspect, three questions need to be answered;
    1. *Is the suspect the offender of the first crime?*
    2. *Is the suspect the offender of the second crime?*
    3. *Is the offender of the first crime the offender of the second crime?*
- The answers to these questions are dependent and this has implications on the evaluation of the evidence concerning these questions.

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Toy Example

Toy example - Assumptions

- All the evidence is 'relevant'. It was left by the offender and there were no errors in the analysis.
- The prior probability that the suspect is the offender of a crime is based on the number of possible offenders N.
- We assume that every person is equally likely the offender on the individual crimes.

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Toy Example

Example

- Two burglaries occur shortly after each other. In both crimes, the modus operandi is the same.
- A **footmark** and a **partial DNA profile** obtained from a crime stain are obtained from the first crime scene.
- A **footmark** and a **fingermark** are obtained from the second crime scene.
- The police has a suspect whose characteristics 'match' the evidence obtained in the different crimes.

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Bayesian network for an individual crime - Network

- A Bayesian network for the first crime only:

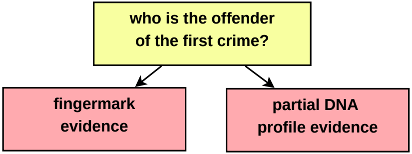

Figure: Bayesian network the first crime only

- To do calculations with the Bayesian network, we need (conditional) probability tables for the nodes.

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Bayesian network for an individual crime (toy example) - Probability tables

- The prior probability for a suspect being the offender is based on the number of potential offenders and is set to 1/1000.

who is the offender of the first/second crime?	
suspect	0.001
unknown	0.999

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Bayesian network for an individual crime (toy example) - Probability tables

- The rmp of the footmark (size 12) is assumed to be 0.01.

Footmark size 12 evidence

who is the offender of the first crime?	*suspect*	*unknown*
match with suspect	1	0.01
no match with suspect	0	0.99

- The rmp of the partial DNA profile is assumed to be 0.02.

Partial DNA profile evidence

who is the offender of the first crime?	*suspect*	*unknown*
match with suspect	1	0.02
no match with suspect	0	0.98

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Bayesian network for an individual crime (toy example) - Probability tables

- The rmp of the footmark (size 12) is assumed to be 0.01.

Footmark size 12 evidence

who is the offender of the second crime?	*suspect*	*unknown*
match with suspect	1	0.01
no match with suspect	0	0.99

- The rmp of the fingermark is assumed to be 0.03.

Fingermark evidence

who is the offender of the second crime?	*suspect*	*unknown*
match with suspect	1	0.03
no match with suspect	0	0.97

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Bayesian network for an individual crime - Inserting evidence

Inserting evidence

- The *prior* probability that the suspect is the offender in crime 1 is 0.001.
- By inserting the evidence in the Bayesian network, we obtain the *posterior* probability that the suspect is the offender.
- The *posterior* probability that the suspect is the offender in crime 1 is 0.833, after inserting the evidence.
- For crime 2 we can do something similar. Since we assumed slightly different random match probabilities, the resulting posterior probability that the suspect is the offender is 0.769.

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Bayesian network linking both crimes - Offender configurations

Offender configurations

- When linking 2 crimes, there are 5 possible hypotheses regarding who the offender(s) is/are.
  - The suspect is the offender in both crimes.
  - The suspect is the offender in the first crime; an unknown person is the offender in the second crime.
  - An unknown person is the offender in the first crime; the suspect is the offender in the second crime.
  - An unknown person is the offender in both crimes.
  - An unknown person is the offender in the first crime; another unknown person is the offender in the second crime.

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Bayesian network linking both crimes - Prior probabilities

Offender configurations

- If we assume that there are 1000 possible offenders, and everyone is equally likely the offender of the individual crimes, we get the following prior probabilities.

offender configuration		
crime 1	*crime 2*	*prior probability*
suspect	suspect	0.000001
suspect	unknown	0.000999
unknown	suspect	0.000999
unknown 1	unknown 1	0.000999
unknown 1	unknown 2	0.997002

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Bayesian network linking both crimes - Same offender evidence

Modus operandi

- When linking the crimes, we include the evidence that the modus operandi of the two crimes was the same.
- The probability to observe the same modus operandi in two crimes when they have different offenders depends on how specific it is.
- In our example, we assume that it is 10 000 more likely to observe the same modus operandi in two crimes when they have the same offender than when they don't.

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Bayesian network linking both crimes - Dependent evidence

Dependent DNA evidence

- When linking crimes, we need to be aware that there can be pieces of evidence that are conditionally dependent of each other.
- For example, when the evidential pieces are of the same type (i.e. footmarks, eyewitness descriptions, DNA profiles).
- In our example, a size 12 footmark was observed on both crime scenes.
- Given that the offender of the first crime was the same person as the offender of the second crime (not necessarily the suspect), both footmarks will be of the same size.

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Bayesian network linking both crimes - Dependent evidence

Conditional probability table

footmark crime 2							
offender 2	*unknown*				*suspect*		
same offender	*no*		*yes*		*no*		*yes*
footmark 1	*other*	*size 12*	*other*	*size 12*	*other*	*size 12*	*size 12*
other	0.99	0.99	1	0	0	0	0
size 12	0.01	0.01	0	1	1	1	1

Table: Conditional probability table for the **footmark crime 2** node

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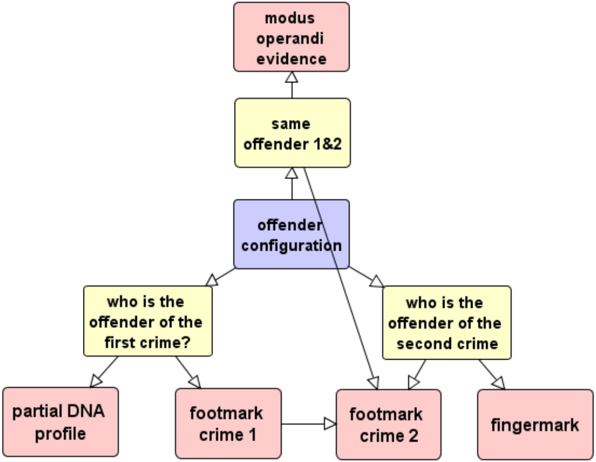
Bayesian network linking both crimes - Network



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Bayesian network linking both crimes - Inserting evidence

Inserting evidence

- For each crime, the *prior* probability that the suspect is the offender is 0.001.
- After including all the evidence *except* for the similar modus operandi the *posterior* probability that the suspect is the offender
  - in crime 1 is 0.833.
  - in crime 2 is 0.769.
- After including the similar modus operandi evidence, the *posterior* probability that the suspect is the offender
  - in crime 1 is 0.994.
  - in crime 2 is 0.994.

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Bayesian network linking both crimes - Conclusion

Conclusion

Evidence relevant for the hypothesis that there is a common offender makes that it is possible to use evidence from one crime in another crime.

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Chain evidence - use of modus operandi and the locomotive

Schakelbewijs

- In the Dutch legal system, so called schakelbewijs (chain evidence) can be used to link several crimes.
- To do so, it is required that at least one crime has sufficient evidence to reach a verdict without linking them (the locomotive/anchor).
- A new crime with a similar modus operandi that is added to the chain has a higher *prior* probability of guilt, due to the similarities.
- As a consequence, less 'crime-specific' evidence is needed to reach a verdict in this 'new' crime.

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Chain evidence - Locomotive pitfall

Pitfall

Although the above reasoning is valid, there are some pitfalls. The locomotive isn't as strong as one might think and when linking crimes one might disregard important exculpatory evidence.

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Chain evidence - pitfalls

Schakelbewijs

- We consider the previous example, where we linked two crimes.
- Suppose a third crime with the same modus operandi and the footmark of size 12 comes up.
- Naturally, the prosecution would like to add this crime to the chain.

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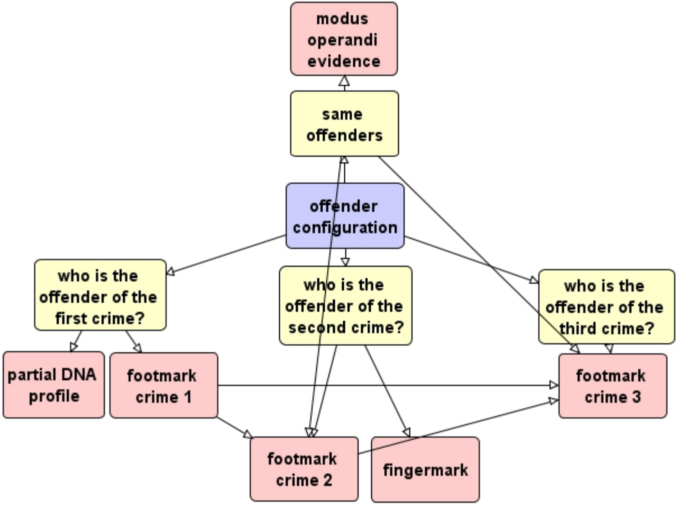
Chain evidence - Network for 3 crimes



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Bayesian network for three crimes - Inserting evidence

Inserting evidence

- For each crime, the *prior* probability that the suspect is the offender is 0.001.
- After including all the evidence the *posterior* probability that the suspect is the offender
  - in crime 1 is 0.994.
  - in crime 2 is 0.994.
  - in crime 3 is 0.993.
- So, after linking this crime to the others, the posterior probability of guilt in all three cases is approximately the same.

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Bayesian network for three crimes - Inserting exculpatory evidence

Inserting exculpatory evidence

- Now, suppose that there is exculpatory evidence in the third crime that excludes the suspect as a possible offender.
- The prosecution can do two things.
  1. Drop the 3rd case against the suspect and continue with the first 2.
  2. Bring all 3 cases to court, including the exculpatory evidence of the third crime.
- The first option results in posterior probabilities of guilt equal to 0.994.
- The second option shows completely different posterior probabilities. The posterior probability that the suspect is the offender
  - in crime 1 is 0.146.
  - in crime 2 is 0.144.
  - in crime 3 is 0.

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Conclusion

Conclusion

- Linking crimes is a double edged sword.
- Evidence that influences our belief that there is a common offender enables the use of evidence from one case in another case.
- Even a case that is a locomotive when considered separately can become uncertain when it is linked to others