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Modelling crime linkage with Bayesian networks

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ABSTRACT

When two or more crimes show specific similarities, such as a very distinct modus operandi, the probability that they were committed by the same offender becomes of interest. This probability depends on the degree of similarity and distinctiveness. We show how Bayesian networks can be used to model different evidential structures that can occur when linking crimes, and how they assist in understanding the complex underlying dependencies. That is, how evidence that is obtained in one case can be used in another and vice versa. The flip side of this is that the intuitive decision to "unlink" a case in which exculpatory evidence is obtained leads to serious overestimation of the strength of the remaining cases.

1. Introduction

Suppose that two similar burglaries occur in a small village within a small time span. In the second one, a suspect is identified. The question whether this person is also responsible for the first crime arises. Clearly this depends on possible incriminating or exculpatory evidence in this first case, but also on the degree of similarity between the two burglaries. Several interesting questions arise in such common situations. For instance, can one "re-use" evidence incriminating the suspect in the second case as evidence in the first case? How does the evidence "transfer" between the two cases? How does the degree of similarity between the two cases affect this transfer? What happens when the evidence in the two cases partially overlaps, or shows dependencies? How can we make inferences for more than two cases?

In practice, it is generally assumed by the police, prosecution and legal fact finders that when there are two or more crimes with specific similarities between them there is an increase in the belief that the same offender (group) is responsible for all the crimes. The probability that there is only one offender (group) depends on the degree of similarity between the crimes. Even for a small number of crimes, the probabilistic reasoning rapidly becomes too difficult. In such situations it is recognized that a Bayesian Network (BN) model can help model the necessary probabilistic dependencies and perform the correct probabilistic inferences to evaluate the strength of the evidence [1]. We can use BNs to examine how evidence found in one case influences the probability of hypotheses about who is the offender in another case.

In this paper, we will show how BNs can help in understanding the complex underlying dependencies in crime linkage. It turns out that these complex dependencies not only help us understand the impact of crime similarities, but also produce results with important practical consequences. For example, if it is discovered that in one of the similar crimes the suspect is not involved, then simply discarding that crime from the investigation could lead to overestimation of the strength of the remaining cases due to the dependency structure of the crime linkage problem. Hence, the common procedure in law enforcement to select from a series of similar crimes only those cases where there is evidence pointing to the suspect and disregard the other cases and evidence can be misleading. Our analysis thus extends the analysis of Evett et al. [2].

The notion of 'crime linkage' may be perceived and dealt with differently at different levels in the judicial process. During investigation (i.e., not at trial) considerations are typically very broad and connections among crimes may be made on other criteria than probability. In this paper, we focus on understanding the underlying logic regarding crime linkage. The examples we present serve as "thought experiments". Such experiments are commonly used in mathematics to focus on the logic of the argumentation. In a thought experiment, a simple situation is considered that may not be very realistic but which contains the essence of the problem, showing the most important arguments. In reality all sorts of detail will complicate the problem but the essence will remain the same. Thus, although the model does not incorporate all the difficulties involved when dealing with crime linkage in

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practice, it can highlight flaws in the reasoning and create a better understanding of the main line of reasoning.

The paper is structured as follows: In Section 2 we present a selection of the relevant literature and state of the art on crime linkage. In Section 3 we will model different situations in crime linkage using BNs, starting with the simplest example of two linked cases. We introduce and extend, step-by-step, to a network with three cases in Section 4 where the evidence is directly dependent on each other (the extension to more cases is presented in the Appendix). In Section 5 we discuss our conclusions and give some ideas for future research.

2. Literature and state of the art on crime linkage

Crime linkage is a broad topic that has been extensively reported (for example in [3–5]). Here we focus only on two aspects of the literature that are relevant for our analysis, namely: (1) how to identify linked cases, and (2) how to model crime linkage. We discuss a (non extensive) selection of some key papers on these topics.

2.1. Literature on how to identify linked cases

For identifying linked cases, it is necessary to assess how similar two crimes are, how strong the link between the cases is and how sure we are that the offender in one case is also the offender in another case.

The authors of [6–8] investigate the behavioural aspects of sexual crime offenders in solved cases. These studies concentrate on the consistency of the behaviour of serial sexual assault offenders. The authors conclude that certain aspects of the behaviour can be regarded as a signature of the offender. These aspects can be used to identify possibly linked crimes.

The notion of such a 'signature' is discussed by Petherick in the chapter *Offender Signature and Case Linkage* [9]. It is noted that a signature in criminal profiling is a concept and not a 'true' signature. A signature may suggest that it is unique, whereas in criminal profiling it can only serve as an indication of whether or not two or more crimes are connected to each other.

Bennell and Canter [10] are interested in the probability (or indication) that two commercial burglaries are linked, given the modus operandi of these crimes. They use a database of solved commercial burglaries. Some of the burglaries studied had the same offender, which made it possible to identify behavioural features that reliably distinguish between linked and unlinked crime pairs. The authors present a model in which the distance between burglary locations and/or the method of entry can be used to determine the probability that the crimes are linked.

Tonkin et al. did a similar study [11]. They concentrate on the distance between crime locations and the time between two crimes to distinguish linked and unlinked crimes. They conclude that the distance between crime locations found and/or the temporal proximity is able to achieve statistically significant levels of discrimination between linked and unlinked crimes.

The discussed papers show that, in practice, it is possible to select certain features of crimes (like the distance or temporal proximity) to assign a probability to the event 'the crimes are committed by the same person'. Taroni [12] discusses how such crime-related information may be used for the automatic detection of linked crimes.

2.2. Literature on modelling crime linkage

The papers discussed here focus on how to model possibly related crimes.

Taroni et al. [13] introduce Bayesian networks that focus on hypothesis pairs that distinguish situations where two items of evidence obtained from different crime scenes do or do not have a common source. They show how Bayesian networks can help in assigning a probability to the event where there is one offender responsible for both crimes. We concentrate on a different topic, namely the offender configuration (who is the offender in which case) and on how evidence implies guilt[1] in one case influences the probability that a suspect is guilty in another case. Taroni et al. also present a Bayesian network for linking crimes with a utility and a decision node, which can help determine the direction for further investigation. Their study concentrates on how evidence from different cases influences the belief that there is a single offender responsible for both cases.

In Evett et al. [2] the hypothesis of interest does concern the offender configuration. Two case examples of similar burglaries are considered. In the first case the evidence consists of a DNA profile with a very discriminative random match probability and in the second case the only evidence is the report of an eye witness. The influence of the evidence in the first case on the question of guilt in the second case is investigated. They vary the strength of the evidence that suggests that there is one offender responsible for both cases to see how this influences the event that a suspect is guilty in the individual cases. The most important observation from their work is that when there is evidence that there is one offender responsible for both cases, the evidence in the individual cases becomes relevant to the other cases as well. This can either increase or decrease the probability that the suspect is the offender in a particular case. Evett et al. classify evidence into two categories that concern: (1) a specific crime only and (2) evidence that relates to similarities between the two crimes. We will introduce a third type of evidence that concerns both specific crimes as well as the similarity between crimes.

The case examples discussed by Evett et al. are viewed from the decision perspective of a prosecutor. The model they present should help to decide whether the prosecutor should charge a suspect with none, one or both crimes. However, Evett et al. do not consider the interesting question of what evidence should be presented when the suspect is charged with only one crime. We will show that it is wrong to select a subset of cases from a group of possibly linked cases and present only the evidence obtained in these cases. This is because evidence that is relevant in an individual case becomes of interest for the other cases when there exists a link between them.

In practical casework, the degree of similarity between crimes is usually poorly defined and lacks a rigorous mathematical treatment. While not solving this problem, we believe that the Bayesian network framework which we develop in this paper is a step in the right direction. It shows how to draw rational inference given certain assumptions and judgements of similarity (but where these judgements come from, and how they should be assessed are still difficult questions, and the topics of the literature mentioned in Section 2.1).

In what follows, we extend the work of Evett et al. by developing a generic Bayesian network. While they presented the necessary probabilities and relatedness structure needed for a Bayesian network they did not actually model a Bayesian network themselves. We further extend their work to situations with more than two crimes and present a type of evidence that they did not recognize in their paper, namely evidence supporting the claim that there is one offender responsible for multiple cases while simultaneously supporting the claim that the suspect is this offender. We will use an example to introduce and explain how different situations can be modelled using a Bayesian network. Most importantly, we show that it is not possible to 'unlink' crimes. When you have evidence that crimes are linked, all cases should be presented in court even when the suspect is charged for only a selection of them.

3. Using Bayesian networks when there are two linked crimes

In this section we introduce as a "thought experiment" the simplest example of two linked cases. In order to focus on the essence of crime

[1] For simplicity, we shall assume that 'guilty' and 'being the offender' are equivalent even though in practice they are not. For instance, when a 4-year old kills someone, he may be the offender but he is not guilty of murder.