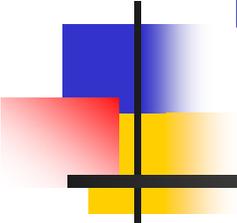


On the practical application of Bayesian networks in the courtroom



Henry Prakken

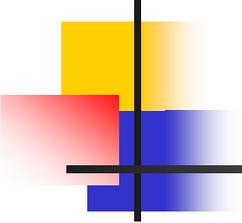
San Diego

11 June 2015

Legal proof in criminal cases with Bayesian probability theory



- We want to know the probability that the suspect is guilty **given** the available evidence
 - Assuming that this evidence has sufficient weight to make inferences from
- Which questions must be answered?
- Who should answer these questions?



The odds version of Bayes' theorem

$\frac{\text{The prob of H given E}}{\text{The prob of not-H given E}}$

=

$\frac{\text{The prob of E given H}}{\text{The prob of E given not-H}}$

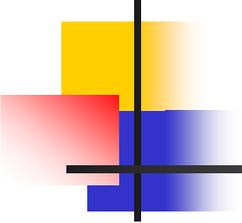
x

$\frac{\text{The prob of H}}{\text{The prob of not-H}}$

Then the computer computes the **posterior prob** of H given E

Determine or ask an expert to determine the **likelihood ratio** of E wrt H and not-H

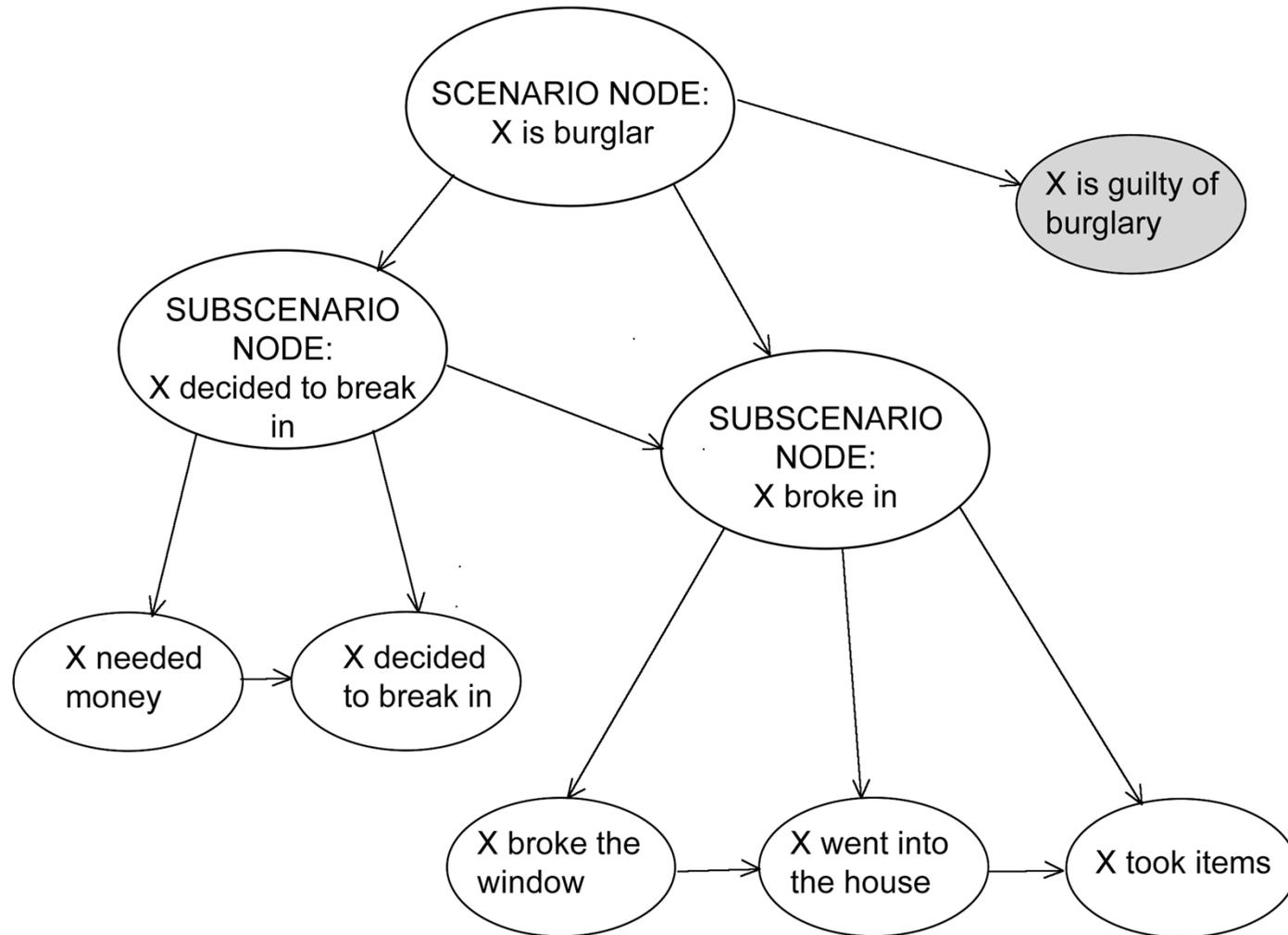
Determine the **prior prob** of H

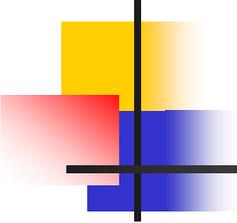


Proof with `naive Bayes'

- What is the probability that the suspect is guilty **given** the available evidence?
 - What is the **posterior probability** of hypothesis H given evidence E?
- Required information:
 - Hypothesis and evidence
 - The **prior probability** of guilt
 - The **conditional** probability of every piece of evidence given guilt, respectively innocence

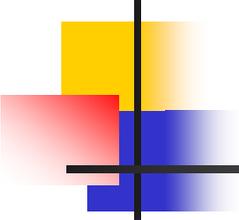
A Bayesian network of a simple burglary (Charlotte Vlek et al. 2013)





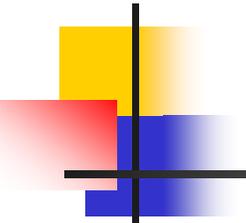
Proof with Bayesian networks

- What is the probability that the suspect is guilty **given** the available evidence?
 - What is the **posterior probability** of hypothesis H given evidence E?
- Required information:
 - Hypotheses, evidence and intermediate propositions
 - **Dependency relations between propositions**
 - The **prior probability** of propositions that do not depend on other propositions
 - The **conditional probability** of propositions given other propositions



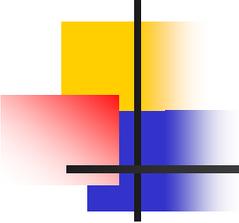
Who determines the probabilities?

- Many forensic scientists:
 - **We** determine the **conditional** probabilities (either based on scientific knowledge or from experience)
 - **The judge or jury** determines the **prior** probabilities
- But this model does not apply to Bayesian networks



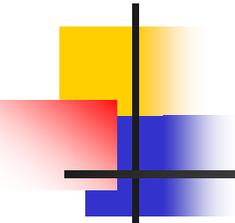
Question 1: What are the statistical dependencies?

- `Naive Bayes' will often not be applicable
- Assumptions about (in)dependency should be **justified**
- Who answers this question?
 - Statistician if probabilities can be determined from data?
 - But who if this cannot be done?



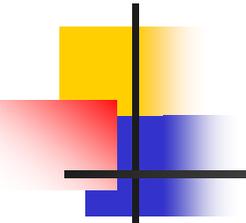
Kinds of experts

- Experts in statistics and/or probability theory
- Experts in a domain
 - DNA experts
 - Footprint experts
 - Vingerprint experts
 - Memory experts
 - ...
- The reasonable man (commonsense)
 - Judge?
 - Expert?



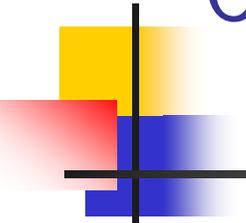
Question 2: what are the prior probabilities?

- Can sometimes be based on **statistics** or “**closed-room situations**”
- Else often a **subjective** estimate
 - Danger of circularity
- **Ignorance** is not the same as uncertainty:
- Cf. a lottery with one prize:
 - “I don’t know the probability that my ticket will win”: the number of tickets is unknown
 - “The probability that my ticket will win is 0.5”: the number of tickets is 2
- Who determines the priors?
 - Many forensic scientists: the judge



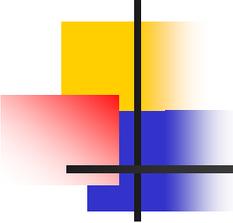
Question 3: what are the conditional probabilities?

- Based on statistics?
 - Based on expert knowledge?
 - Based on commonsense?
 - ...
-
- And who determines these probabilities?



Conditional probabilities: complications with DNA evidence

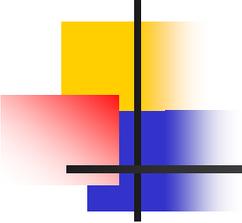
- The step from “The found DNA is from the suspect” to “the suspect is guilty” requires further reasoning
 - The “random-match probabilities” are irrelevant here
- How can the required conditional probabilities be justified?
- Who determines these probabilities?



A recent Dutch murder case

A DNA expert stated that the presence of the suspect's DNA on the victim's cloths is much more probable if the transfer was caused by direct physical contact than if caused by indirect transfer at the murder location (a house in Nijmegen)

Can this be the same expert as the expert who determines the random-match probabilities?



Complications with likelihood ratio: more than two alternatives

The prob of H given E
The prob of not-H give nE

=

The prob of E given H
The prob of E given not-H

X

The prob of H
The prob of not-H

Then the computer
computes the **posterior prob**
of H given E

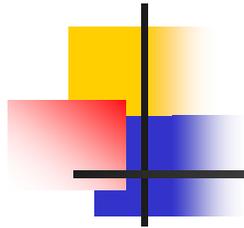
Determine or ask an expert
to determine the **likelihood
ratio** of E wrt H and not-H

Determine the **prior
prob** of H

This only holds if the hypotheses:

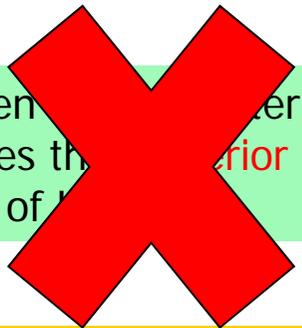
- **exclude** each other; and
- jointly **exhaust** all possibilities

Complications with likelihood ratio: more than two alternatives



$$\frac{\text{The prob of H given E}}{\text{The prob of not-H given E}} = \frac{\text{The prob of E given H}}{\text{The prob of E given not-H}} \times \frac{\text{The prob of H}}{\text{The prob of not-H}}$$

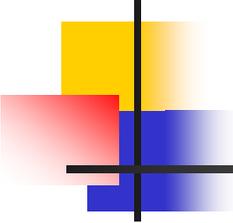
Then the expert
computes the **prior prob**
of H



Determine or ask an expert
to determine the **likelihood ratio**
of E wrt H and not-H

Determine the **prior prob**
of H

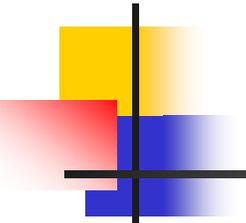
This only holds if the hypotheses:
- **exclude** each other; and
- **jointly exhaust** all possibilities



A recent Dutch murder case

A **DNA expert** stated that the presence of the suspect's DNA on the victim's cloths is **much more probable if** the transfer was caused by direct physical contact than if caused by indirect transfer at the murder location (a house in Nijmegen)

The court: the expert has **overlooked the possibility** that the transfer happened during the transport of the victim to the location outside Nijmegen where he was found

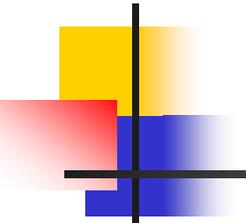


Conditional probabilities: witness testimonies

- E: Witness says he saw suspect at place of crime
- H: Suspect was at place of crime
- **likelihood ratio:**

The probability of E given H
The probability of E given not-H

- Who should determine these probabilities?
 - A Bayesian expert? But what do they know about the reliability of witness testimonies?
 - A psychological expert?

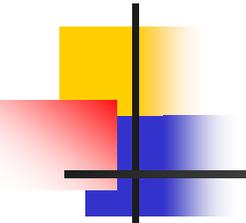


Conditional probabilities: commonsense

- E: shortly before the crime the suspect's mobile phone make contact with a telecom mast near the place of the crime
- H: The suspect is involved in the crime
- **Likelihood ratio:**

The probability of E given H
The probability of E given not-H

- Who should determine these probabilities?
 - A Bayesian expert? But what do they know about the world?
 - Another kind of expert?



Proof with Bayes: critical questions

- What are the relevant evidence and hypotheses?
- To what extent are the pieces of evidence **statistically independent**?
- Can the **priors** be rationally determined?
- Can the conditional probabilities be rationally determined?
- Do the considered alternatives exhaust all possibilities?
- Does the body of available evidence have sufficient weight to make inferences from?
- In all these cases: who can answer these questions?