Using Bayes nets for reasoning with evidence: real life examples

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Plan

- What are Bayes nets?
- Why are they useful for reasoning about evidence?
- Can they be applied in legal contexts?
What is a Bayes net?

- Formal tool for handling uncertainty
- **Representation**
  - Graphical model for capturing probabilistic relations between evidence and hypotheses
- **Inference**
  - Uses efficient algorithms (based on laws of probability) to compute impact of evidence on hypotheses
What is a Bayes net?

- Bayes nets do not replace need for careful thinking, but support and encourage it
- Building a model requires expertise and judgment
- Based on causal/domain knowledge, statistical databases, reasonable estimates, commonsense logic
- Inevitable subjective element in any analysis of evidence, but Bayes net makes this explicit and open to scrutiny (and improvement)
Benefits

- Clarifies logic/structure of arguments
- Helps identify gaps and presuppositions
- Shows where new evidence/empirical data are needed
- Expert constructs model, but probabilistic inference is automated
- So analysis can go beyond intuitions of expert
- Inference underpinned by logic/probability
Where?

- Bayes nets not suitable for use in court (not yet!)
- But potential use at various stages of legal process, especially in analysis of complex cases
  - Investigators; Forensic scientists; Prosecutors (CPS)
  - Prosecution and defence teams
  - Appeals; Inquests/inquiries
- Recommended in RSS guidelines
- Used already by NFI, HK police ...
- BNs successfully used in many other areas
  - Medicine, bioinformatics, engineering, image processing, risk analysis, sports prediction ...
Legal /forensic examples

- Denis Adams
- Child abuse case
- Cognitive bias
Denis Adams (R v Adams, 1996, 1998)

- Adams convicted of sexual assault
- Arrested because his DNA matched trace from crime
- Prosecution gave RMP of 1 in 200 million
- Defence argued for RMP of 1 in 2 million (or higher)
- Two pieces of exonerating evidence
  - Victim failed to identify Adams
  - Adams had alibi, corroborated by his girlfriend
- Infamous case because in trial (and retrial) defence tried to teach jurors Bayesian reasoning

Key issue: how to combine these items of evidence to yield a final judgment?
Did Adams commit the crime? {yes, no}

Does Adams DNA match the crime profile? {yes, no}

Does Adams have alibi? {yes, no}

Does victim identify Adams? {yes, no}

NODES
To represent hypotheses and evidence

- Adams
- DNA
- ID
- Alibi

Bayes net of Adams case (simplified)
Bayes net of Adams case

- **DIRECTED LINKS**
  - To represent probabilistic dependencies

  DNA match depends on whether or not Adams is guilty

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<td>RMP</td>
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  DNA match is 2 million times more likely if Adams guilty vs not guilty

  Influence of links quantified by conditional probability tables for each node:

  \[
  \text{LR} = \frac{P(\text{DNA}|G)}{P(\text{DNA}|\sim G)} = \frac{1}{\text{RMP}}
  \]

  \[
  = 2 \text{ million } \text{ when } \text{RMP} = 1/2\text{million}
  \]

  Captures *strength* of DNA evidence

  \[P(\text{DNA}|G) = \text{1/RMP}
  \]

  \[P(\text{DNA}|\sim G) = 2 \text{ million}
  \]
DNA match is 2 million times more likely if Adams guilty vs not guilty

LR = 2 million

ID failure is LESS likely if Adams guilty vs not guilty
LR = 1/9

Alibi LESS likely if Adams guilty vs guilty
LR = 1/2
Use Bayes net to compute impact of evidence

Need estimate for PRIOR

P(guilty) = 1/200,000

Based on estimate of number of local men

- Use Bayes rule to update for posterior of guilt

Posterior Odds = LR x Prior odds

For RMP = 1/2 million
LR = 2 million

Posterior probability given DNA match = 0.91
Posterior given DNA match & ID failure = 0.53
Posterior given DNA match & ID failure & Alibi = 0.36

So ‘weak’ evidence can have big impact
Use Bayes net to compute impact of evidence

P(guilty) = 1/200,000

For RMP = 1/20 million
LR = 20 million

Posterior probability given DNA match = 0.99
Posterior given DNA match & ID failure = 0.92
Posterior given DNA match & ID failure & Alibi = 0.85
Use Bayes net to compute impact of evidence

P(guilty) = 1/200,000

Posterior probability given DNA match = 0.999
Posterior given DNA match & ID failure = 0.99
Posterior given DNA match & ID failure & Alibi = 0.98

Prosecution claim
RMP = 1/200 million
LR = 200 million

Magnitude of RMP matters
Summary

- Use Bayes net to explore sensitivity of posterior to different RMPs, priors, and other estimates.
- Both magnitude of RMP and ‘weak’ evidence play a critical role.
- BN is over simplistic
- Usually need to distinguish ‘X is source’ from ‘X committed crime’
- Include various possible sources of error in DNA testing
- Captured by fuller Bayes nets
- DNA analyses often more complex, use sophisticated statistical models (and BNs)

With more complex cases cannot do computations by hand – need a tool to support inference
More realistic model for Adams case
Child abuse case
Couple accused of intentionally harming their baby

They took the baby to the hospital when they discovered bleeding in his mouth

But the doctors found bruises on the baby’s body

And an X-ray revealed fractures

Family courts ruled child abuse, and baby placed in adoption

But child was suffering from a rare blood disorder

Causes bruising and bleeding

Radiologist argued there were no fractures

Court exonerates couple -- now fighting to get child back
Simplified Bayes net of case
- Probability of abuse and disorder BOTH increase
- Probability of fractures increase

Bruises = true
- X-ray report increases probability of fractures and thus abuse
- Disorder is reduced ‘explaining away’
- Main evidence in family court
- Evidence for criminal court
- Positive test raises probability of disorder
- Lowers probability of abuse ‘explaining away’
- Lowers probability of fractures
New X-ray report undermines previous report
Reduces probability of fractures and therefore abuse
And further boosts probability of disorder
• Complex patterns of inference
• People follow qualitative side of reasoning
• But we can be more precise with quantitative inference
• Eg taking account of differing test/report reliabilities, medical/crime databases of incidences of abuse and disorder etc
P(abuse) = .10
P(disorder) = .05

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Probabilities (elicited from laypeople)
Summary

- BN captures complex pattern of inferences and impact of different tests
- Empirical studies suggest that people’s qualitative reasoning fits with BN model
- BN allows for quantitative analysis too
- We can use statistically derived base rates (e.g., incidence of abuse & disorder), test reliabilities and error rates
- Support for our intuitive reasoning
Cognitive bias

- Forensic experts are susceptible to cognitive bias, especially when making judgments based on difficult/ambiguous information.
  - Eg fingerprint experts more likely to report ‘match’ if they know suspect has confessed vs has alibi (Dror & Charlton, 2006).

- Occurs in numerous areas of forensic science, including DNA analysis.

- Danger of overestimating probative value of evidence (Thompson, 2016).
CASE 1
- Expert blind to witness report
- No direct link from witness report to expert report

CASE 2
- Expert knows about eyewitness report
- Direct link from witness report to expert report

- Target hypothesis: Was X at crime scene?
- Fingerprints found at scene
- Expert compares crime prints with X’s prints
- Reports ‘match’
- Eyewitness testimony that X at crime scene
Expert report depends only on fingerprint evidence

Expert report depends both on fingerprint evidence AND on eyewitness report
More likely to report match if eyewitness gives positive ID
Prior = 0.1

- X at crime scene
  - False: 90%
  - True: 10%

- X fingerprints at scene

- Expert report

- Eyewitness

Prior = 0.1
Eyewitness report that he saw X at crime scene
Expert reports ‘match’

Combined evidence has less probative value in Case 2
Posterior = 0.89  
Posterior = 0.66

BUT if decision maker is unaware of this dependency

Will treat Case 2 as Case1, and overestimate strength of evidence
Bayes nets capture dependencies between evidence.
Therefore avoid overestimating probative value of combined evidence.
Could be used to help analysts identify when cognitive bias is likely, and use appropriate procedures to avoid it (Thompson, 2016).
Conclusions

- Bayes nets as a formal tool for probabilistic inference
- Framework for combining evidence and assessing impact on hypotheses
- Handles interrelations between evidence and multiple hypotheses
- Once model & assumptions agreed, then BN tool does correct probabilistic inference (which can’t be done by hand)
- A tool to support reasoning not replace it