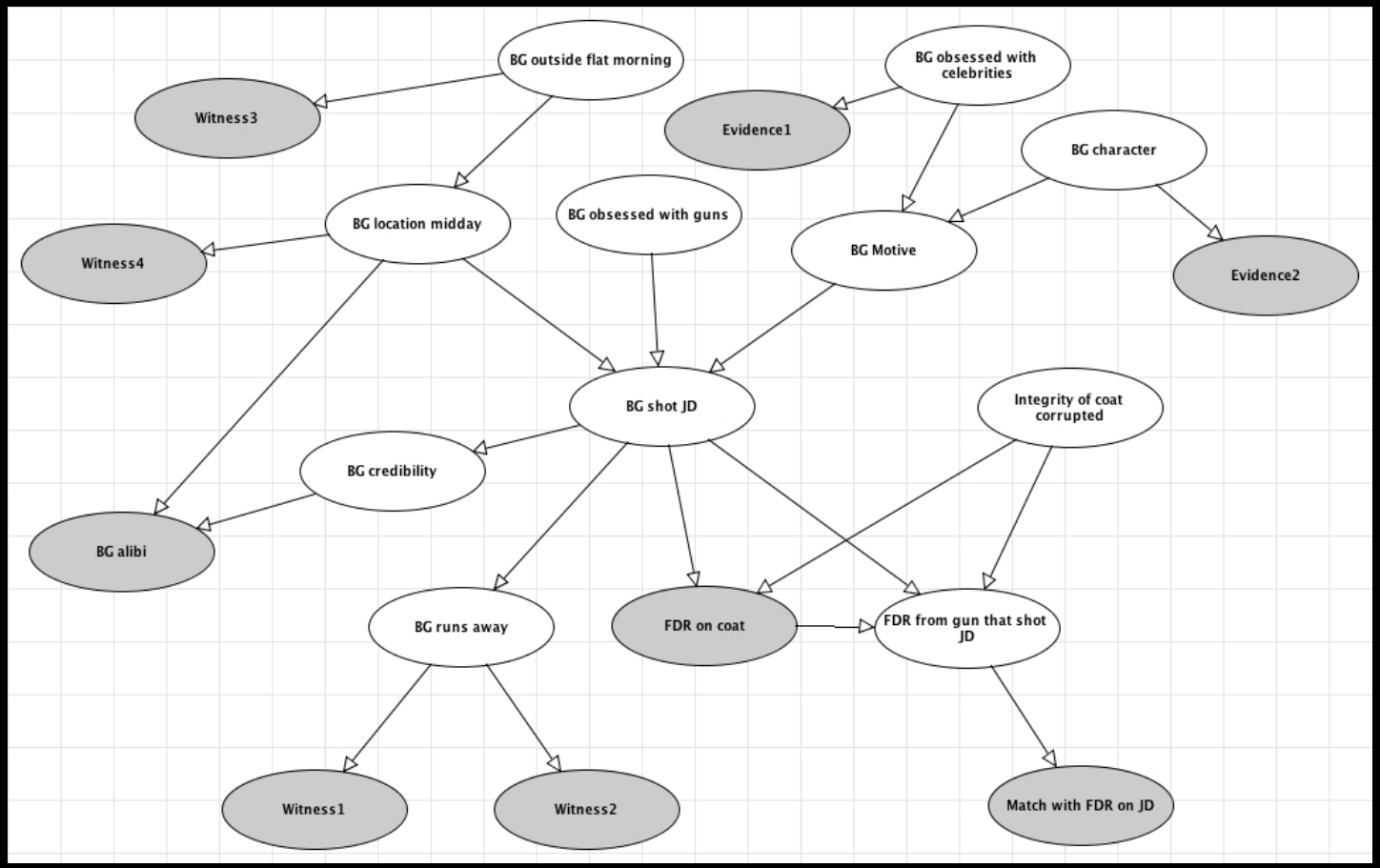


Using Bayes nets for reasoning with evidence: real life examples

David Lagnado UCL

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)

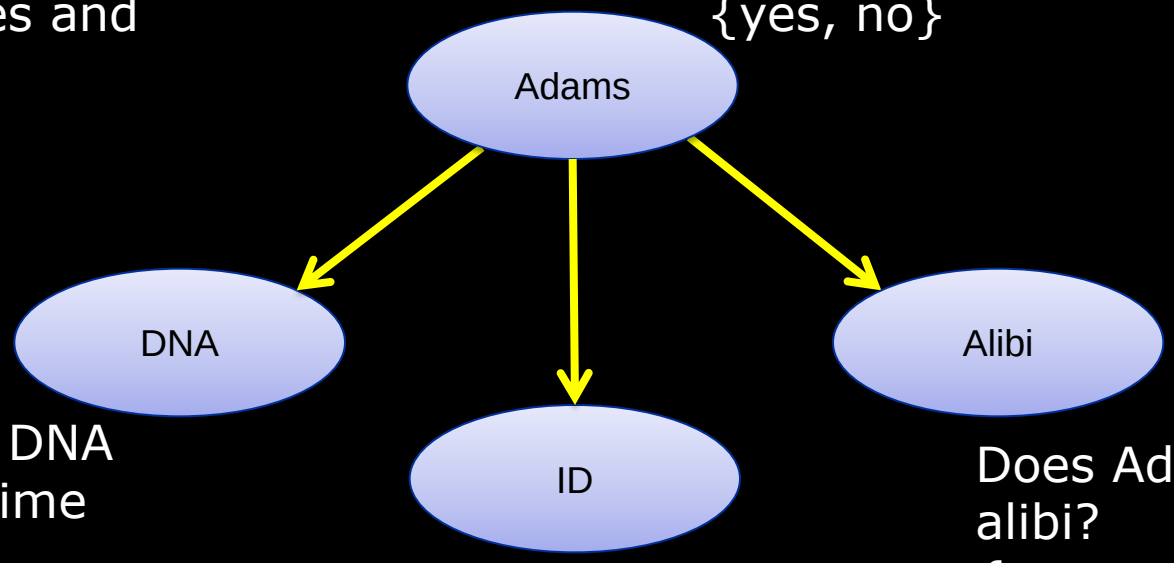
- Adams convicted of sexual assault
- Arrested because his DNA matched trace from crime
- Prosecution gave RMP of 1 in 200 million
- Defence argued for RMP of 1 in 2 million (or higher)
- Two pieces of exonerating evidence
  - Victim failed to identify Adams
  - Adams had alibi, corroborated by his girlfriend
- 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?

Bayes net of Adams case (simplified)

- NODES
  To represent hypotheses and evidence

Did Adams commit the crime?
{yes, no}



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

Does victim identify Adams?
{yes, no}

Does Adams have alibi?
{yes, no}

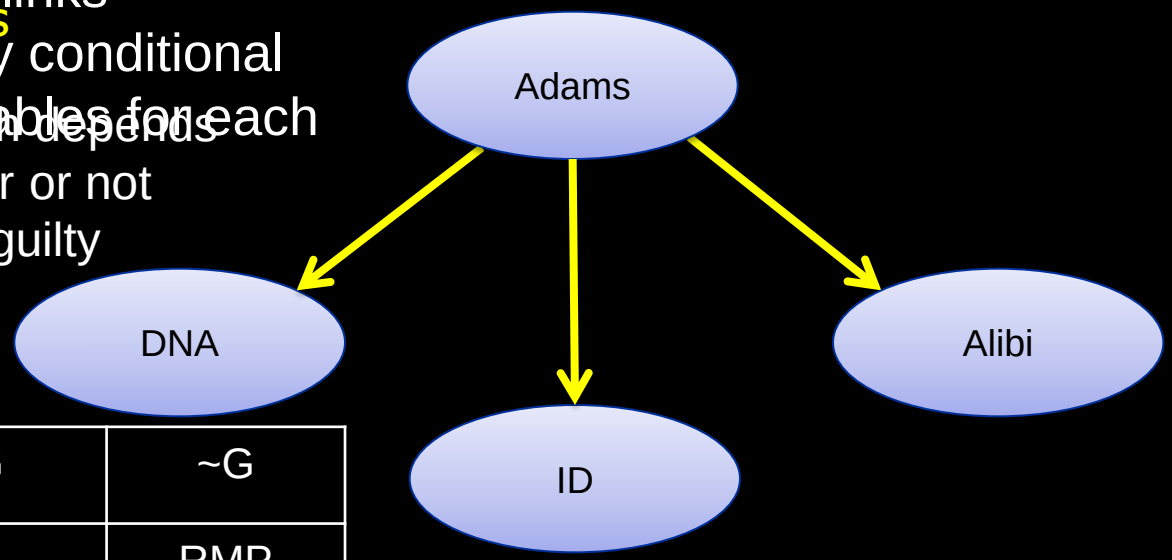
Bayes net of Adams case

- DIRECTED LINKS

To represent probabilistic dependencies

Influence of links quantified by conditional probability tables for each node

DNA match depends on whether or not Adams is guilty



	G	~G
DNA	1	RMP

P(DNA|G)

P(DNA|~G)

Captures *strength* of DNA evidence

Likelihood ratio LR

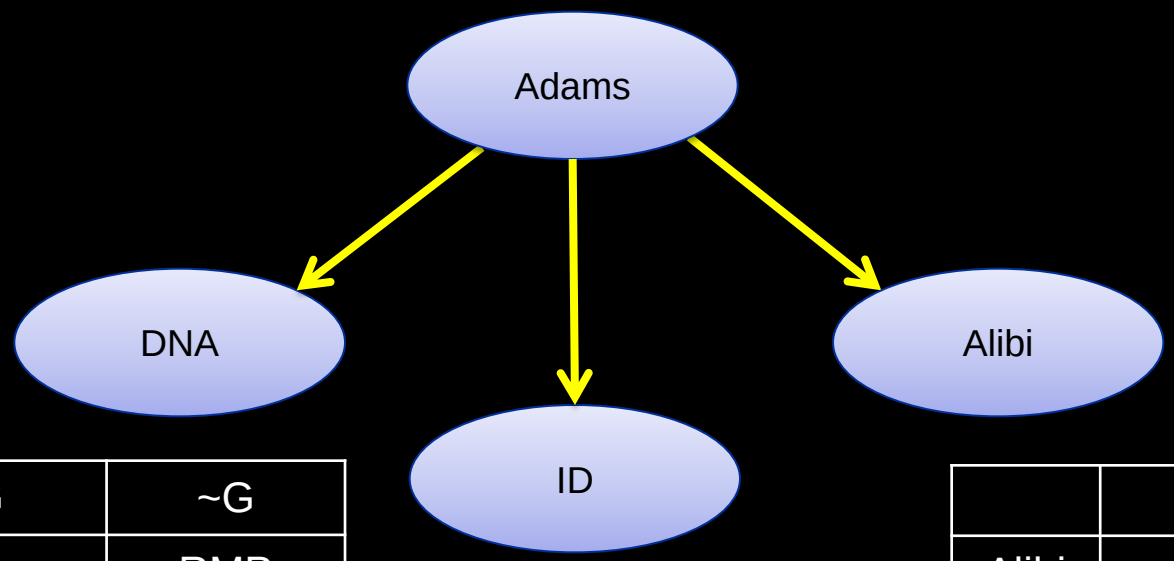
= P(DNA|G) / P(DNA|~G)

= 1/RMP

= 2 million when RMP =1/2million

DNA match is 2 million times more likely if Adams guilty vs not guilty

Bayes net of Adams case



	G	~G
DNA	1	RMP

	G	~G
~ID	.1	.9

	G	~G
Alibi	.25	.5

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

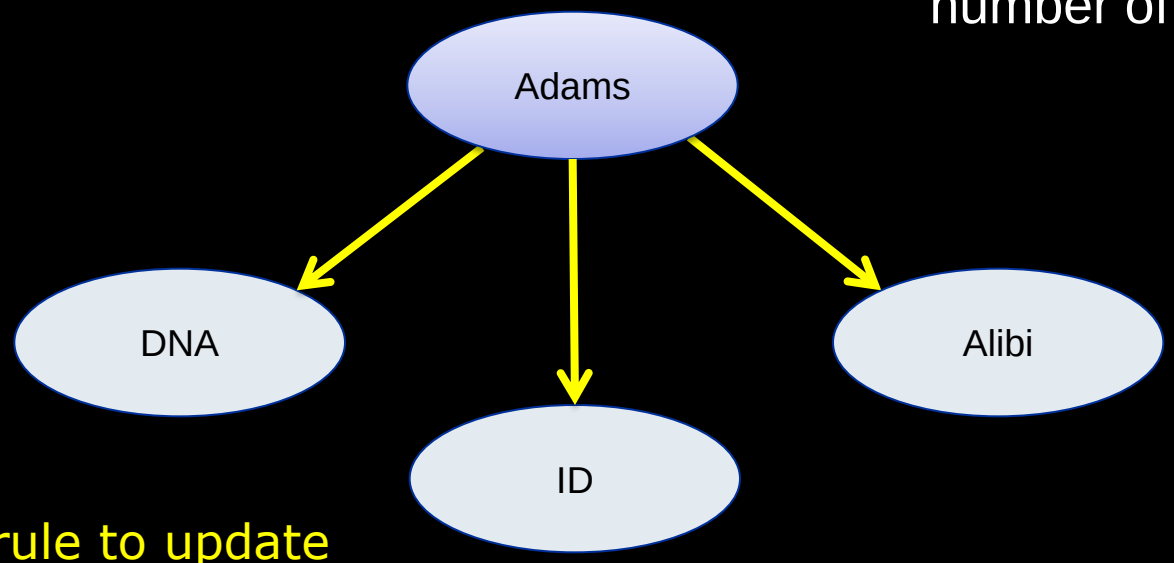
Alibi LESS likely if Adams guilty vs guilty
LR =1/2

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 = 1/2million
LR = 2 million

Posterior probability given DNA match = 0.91

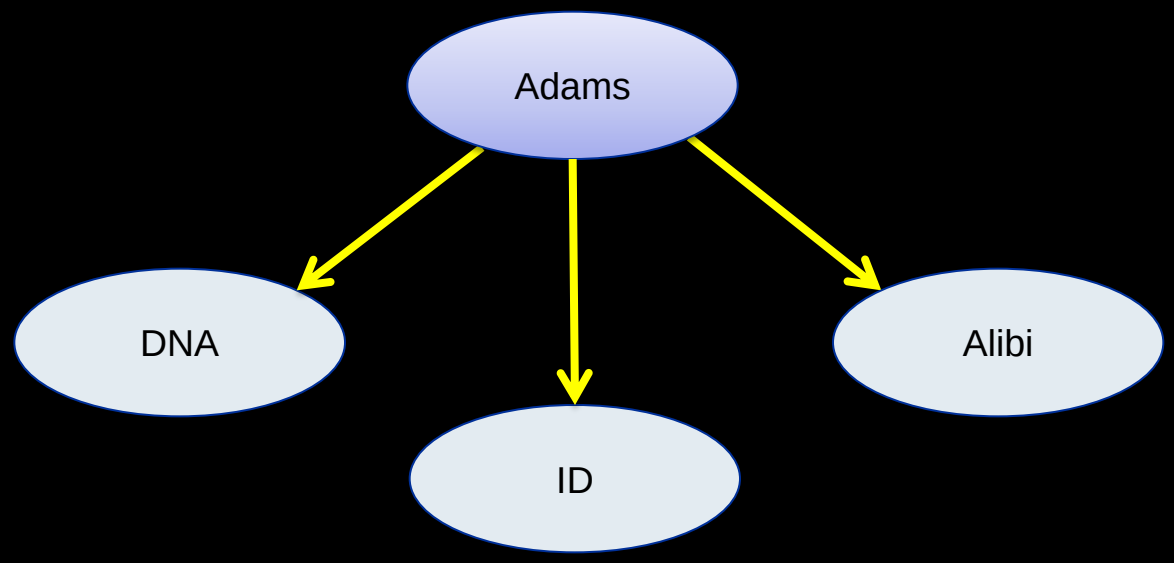
Posterior given DNA match & ID failure = 0.53

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 = 1/20million
LR = 20 million

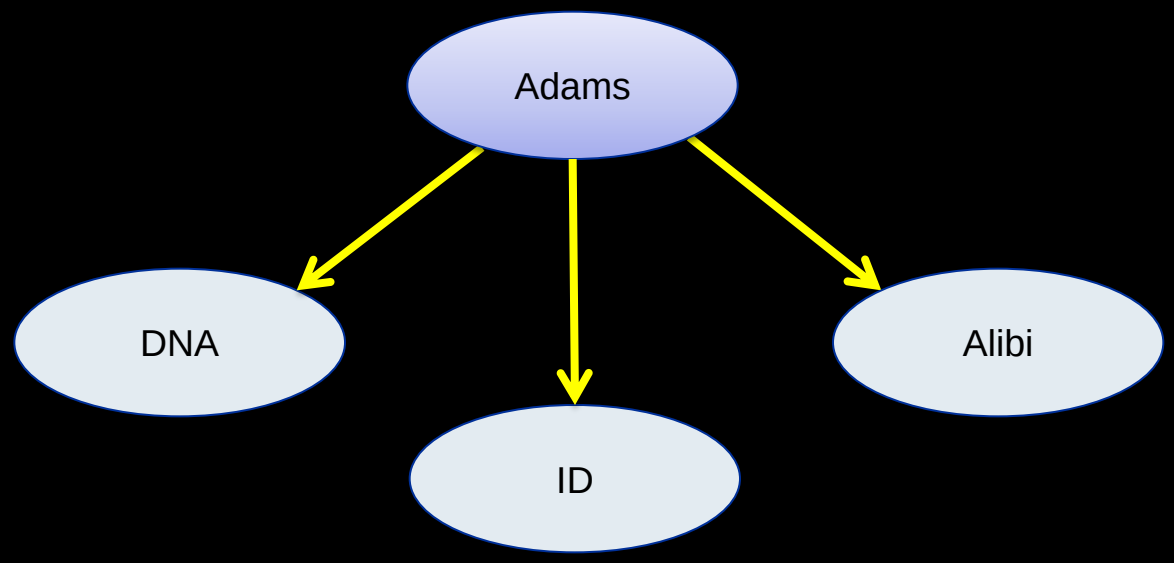
Posterior probability given DNA match = 0.99

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



Prosecution claim

RMP = 1/200million

LR = 200 million

Posterior probability given DNA match = 0.999

Posterior given DNA match & ID failure = 0.99

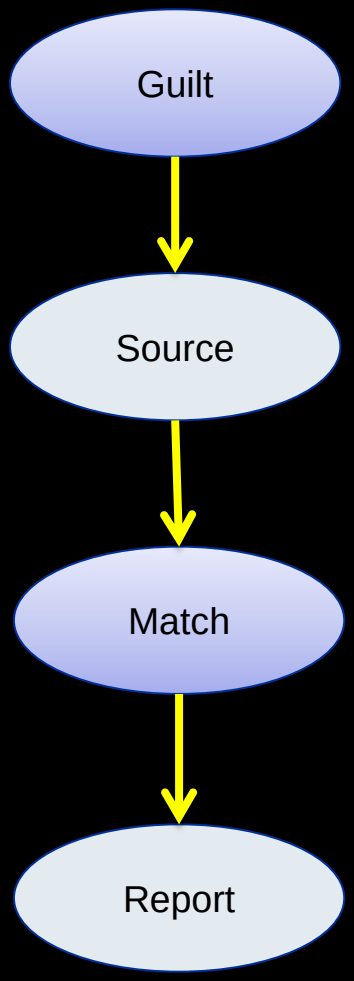
Posterior given DNA match & ID failure & Alibi = 0.98

Magnitude of RMP matters

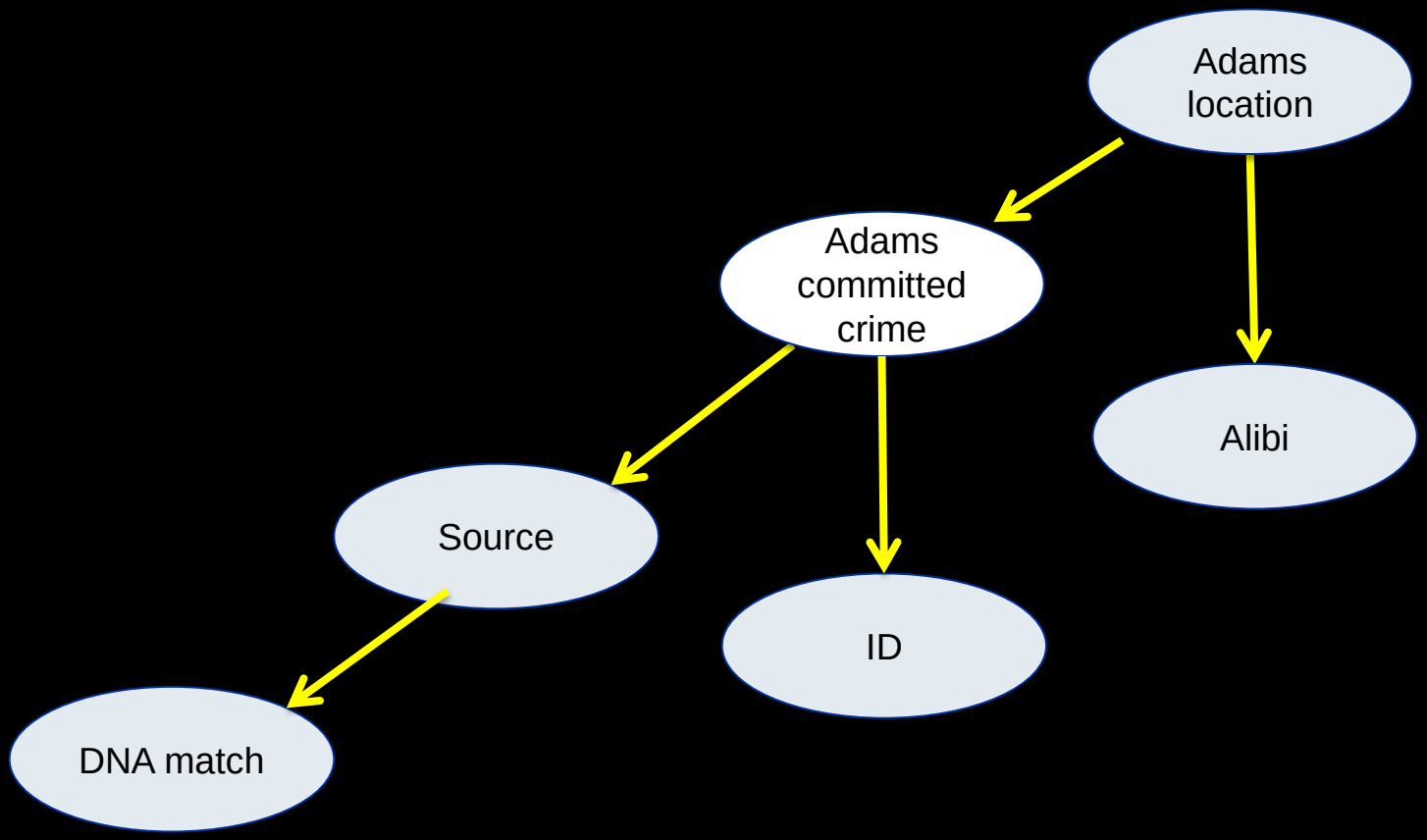
Summary

- 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

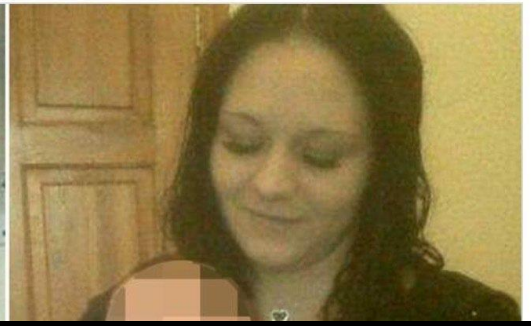
But the doctors found bruises on the baby's body

And an X-ray revealed fractures

Family courts ruled child abuse, and baby placed in adoption

Parents Vow To Get 'Stolen' Baby Back

Karrissa Cox and Richard Carter are cleared of harming their baby, three years after the child was taken away and then adopted.

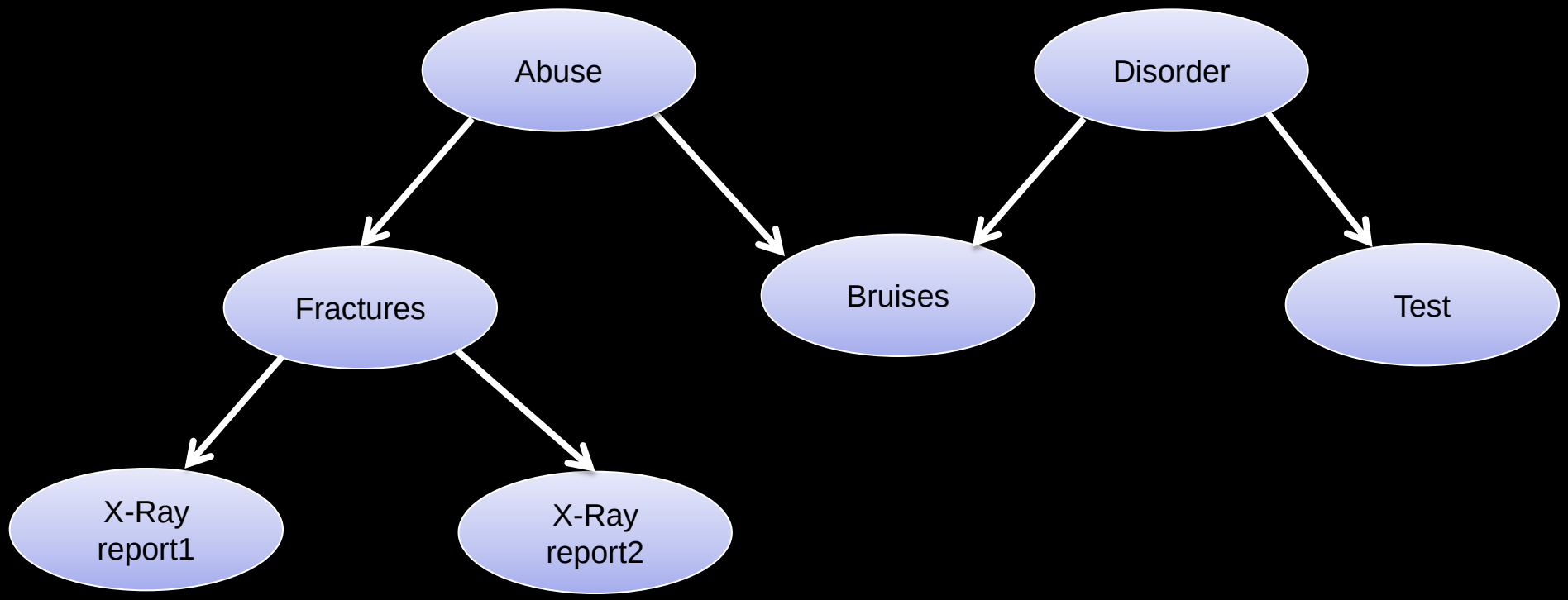


But child was suffering from a rare blood disorder

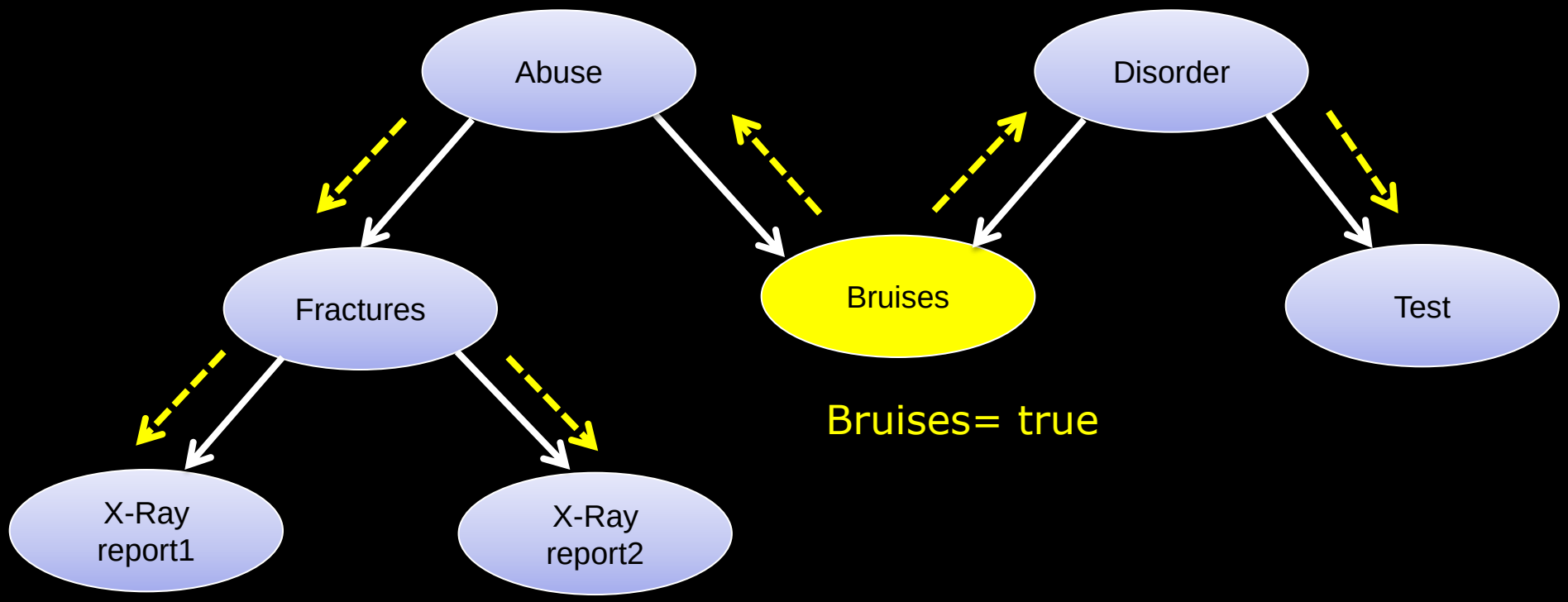
Causes bruising and bleeding

Radiologist argued there were no fractures

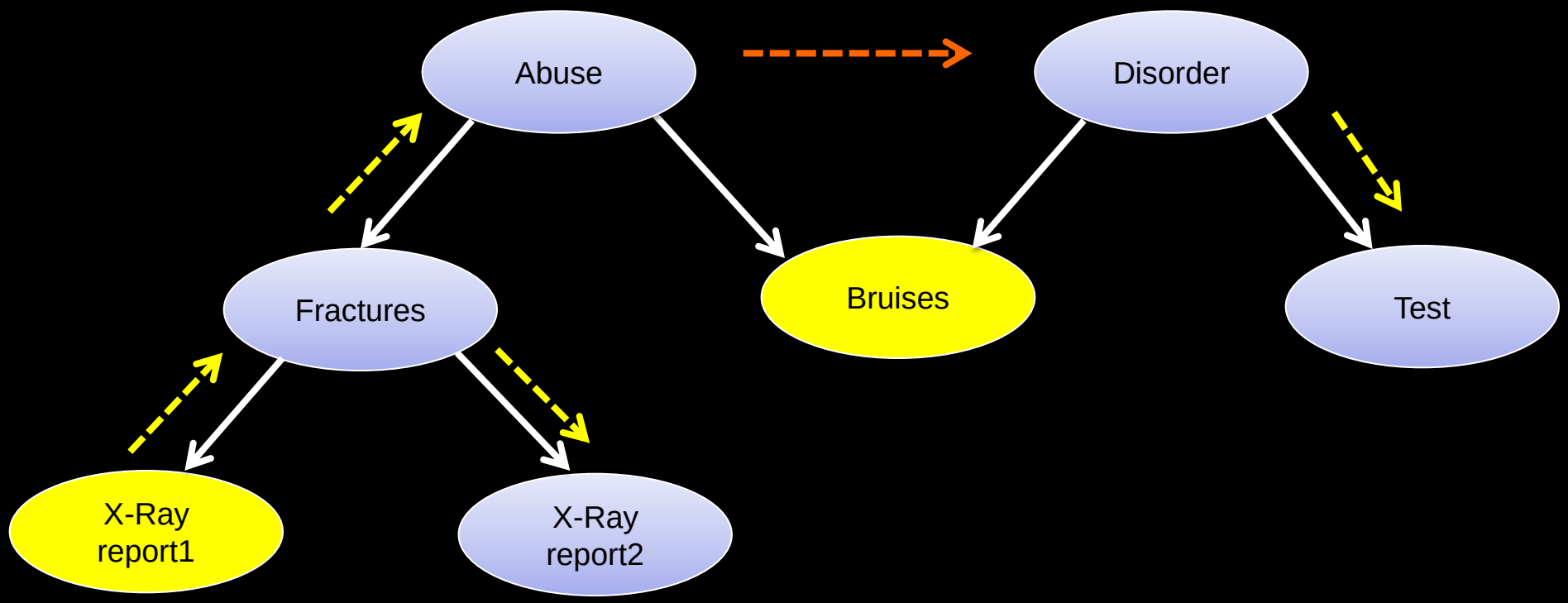
Court exonerates couple -- now fighting to get child back



Simplified Bayes net of case



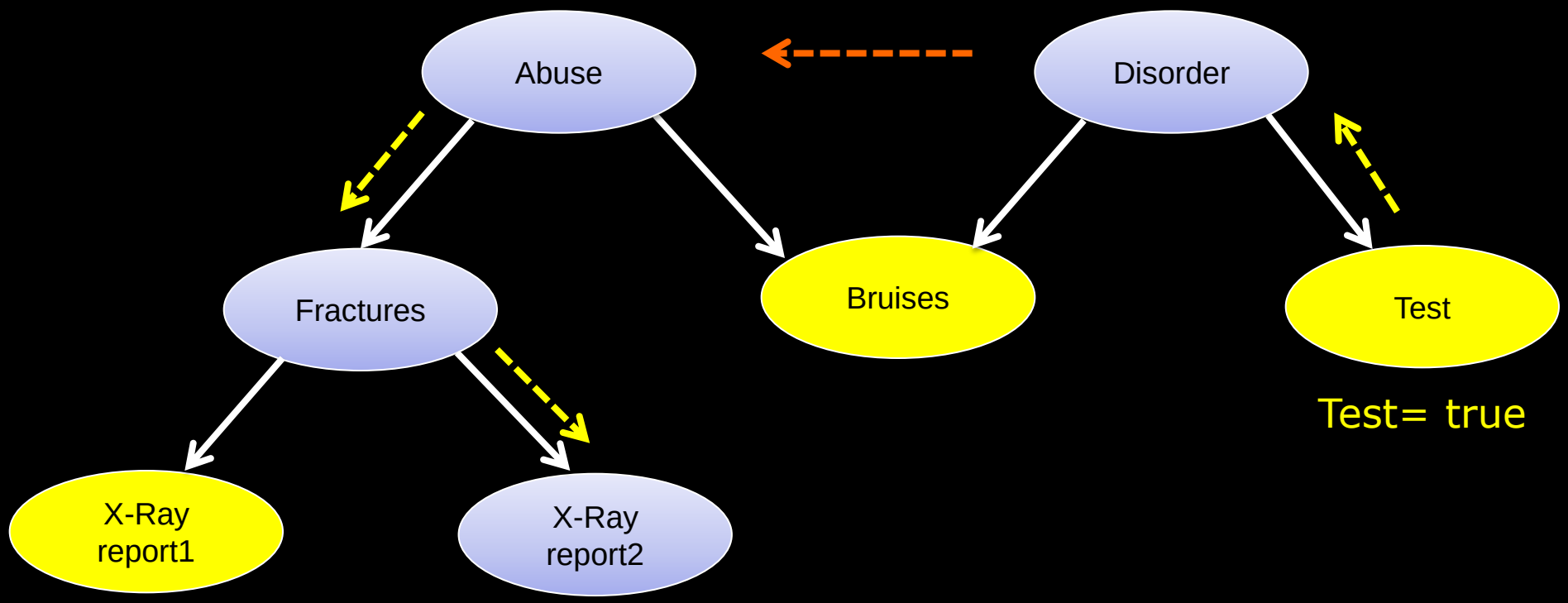
- Probability of abuse and disorder BOTH increase
- Probabilty of fractures increase



X-Ray report1= true

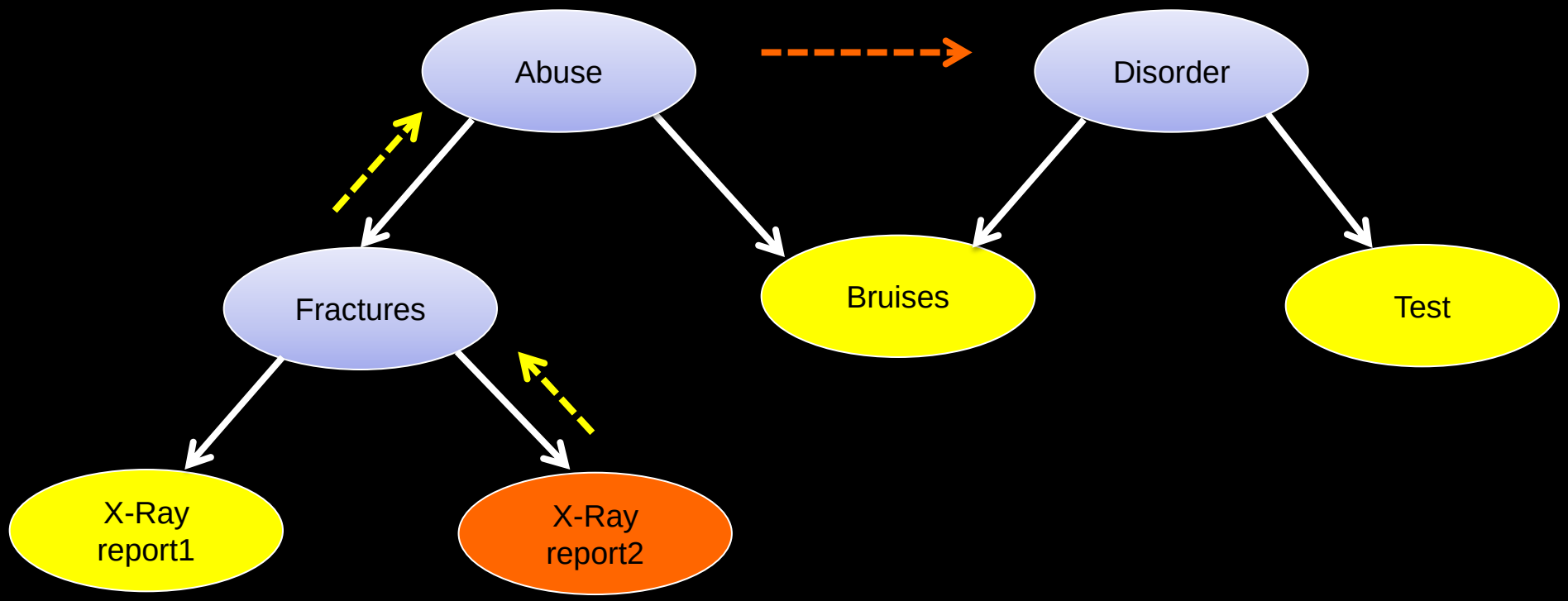
- X-ray report increases probability of fractures and thus abuse
- Disorder is reduced ‘explaining away’

- Main evidence in family court

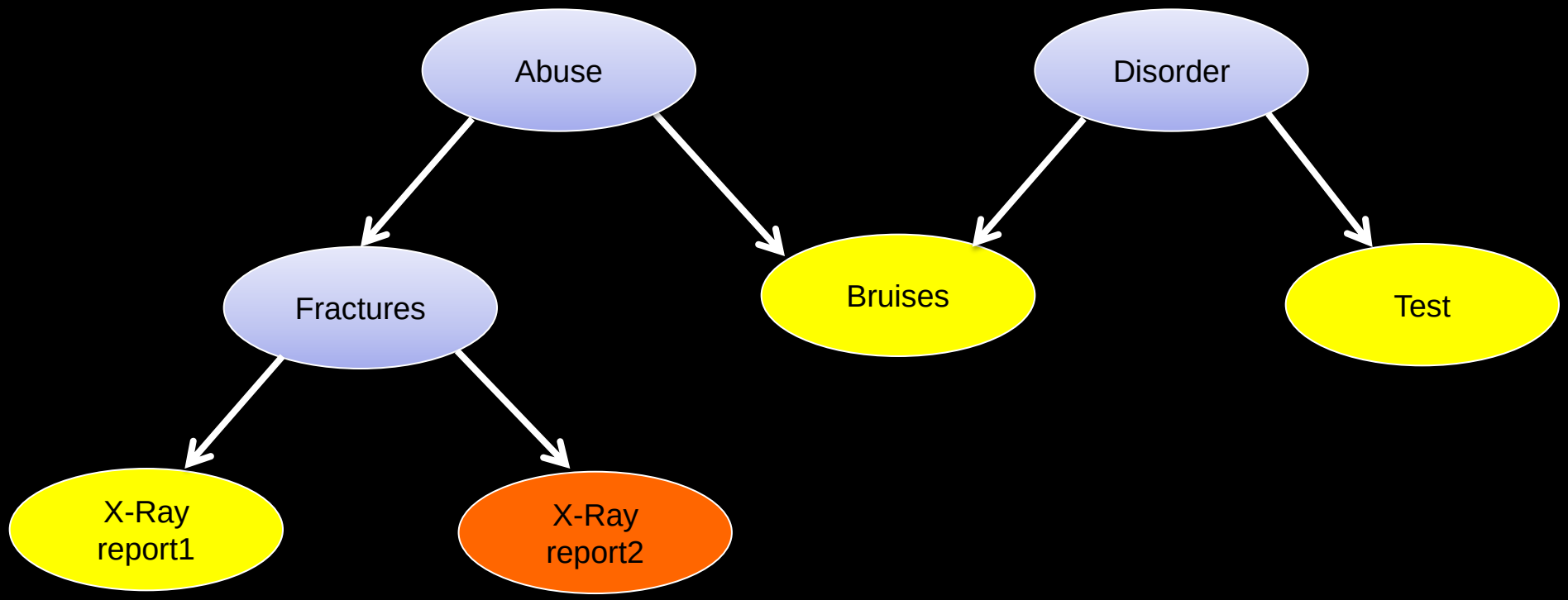


- Evidence for criminal court

- 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

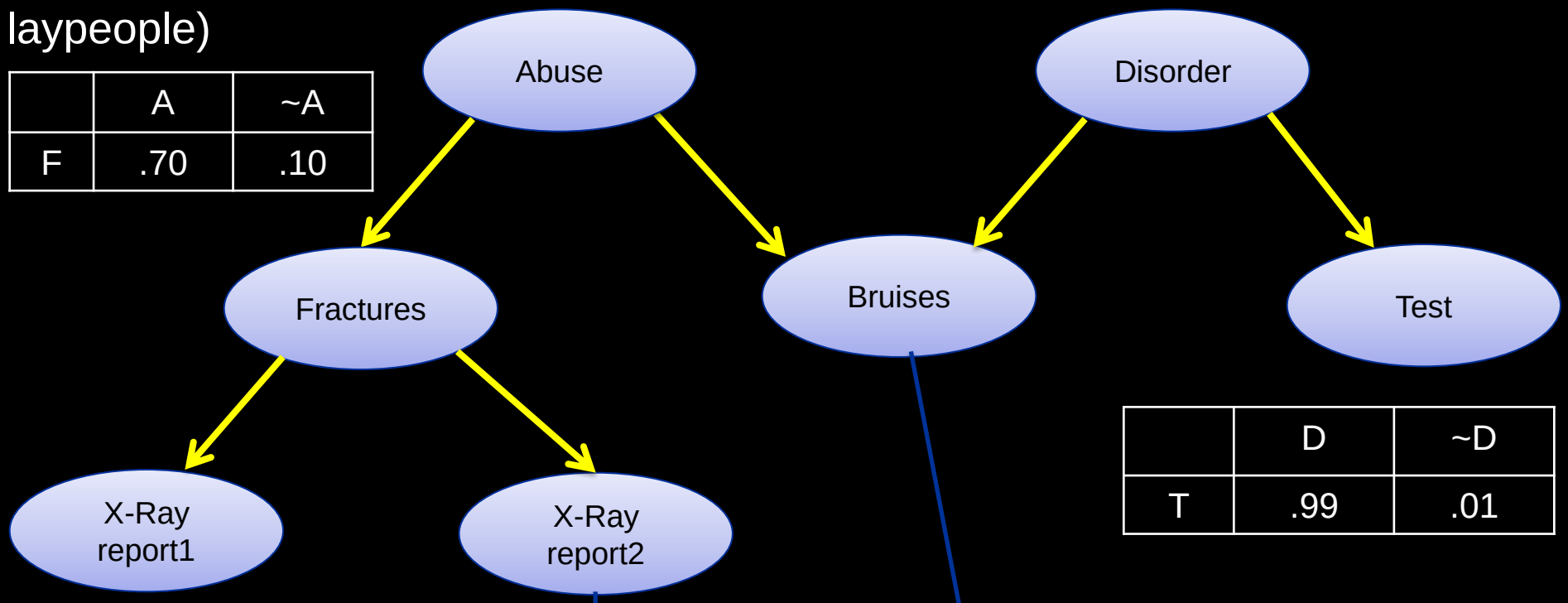


- Complex patterns of inference
- People follow qualitative side of reasoning
- But we can be more precise with quantitative inference
- Eg taking account of differing test/report reliabilities, medical/crime databases of incidences of abuse and disorder etc

Probabilities (elicited from laypeople)

P(abuse) = .10

P(disorder) = .05



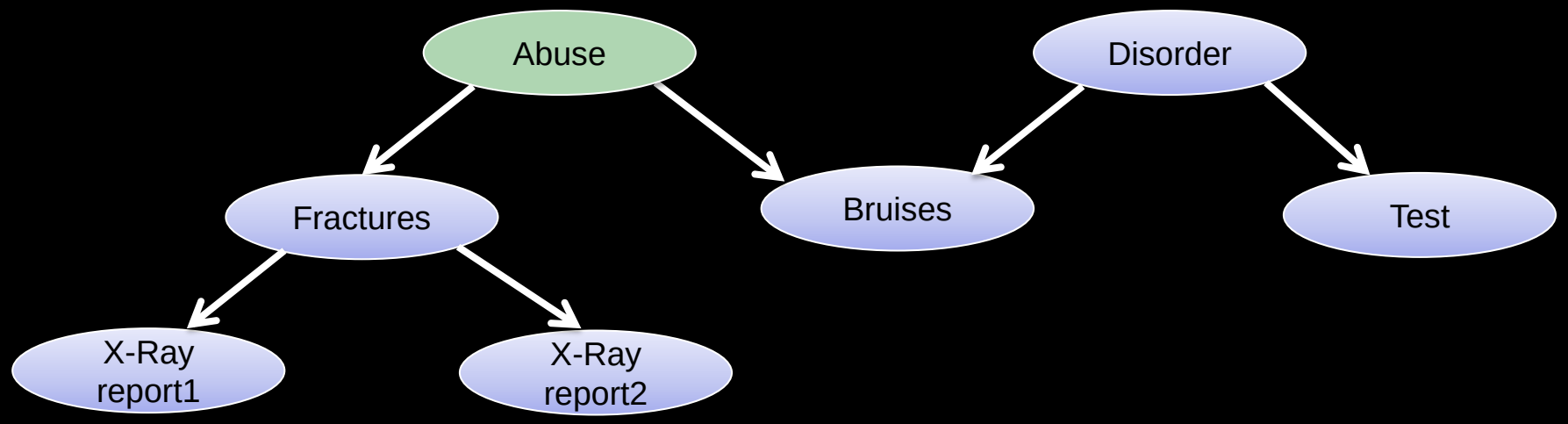
	A	~A
F	.70	.10

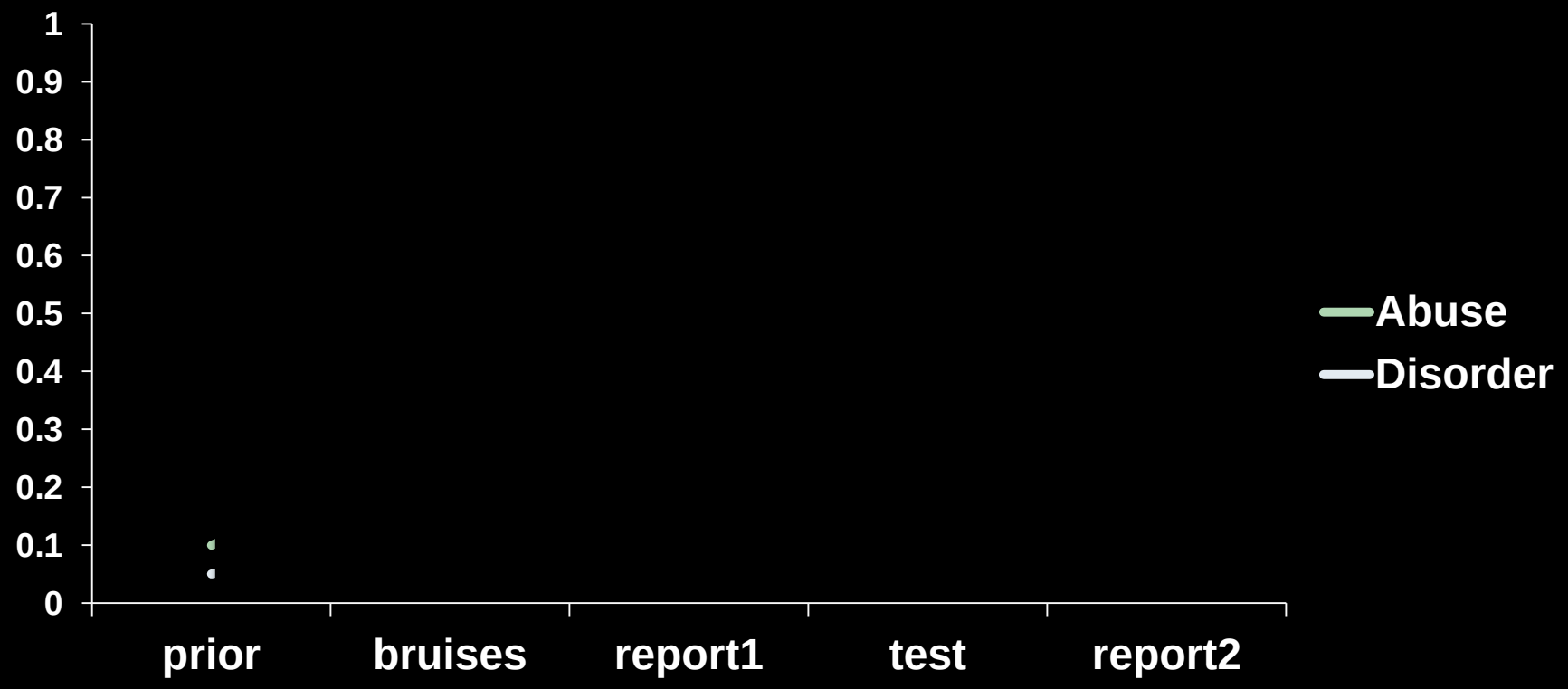
	D	~D
T	.99	.01

	F	~F
R1	.90	.10

	A & D	A & ~D	~A & D	~A&~D
B	.90	.75	.75	.20

	F	~F
R2	.95	.05


Abuse
Disorder
Fractures
Bruises
Test
X-Ray report1
X-Ray report2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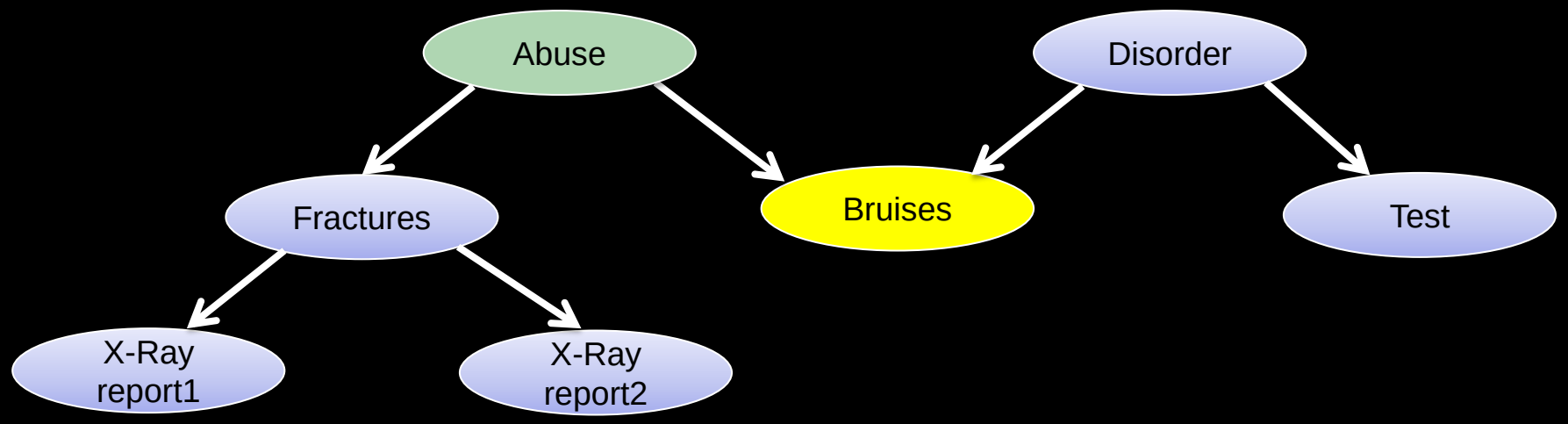
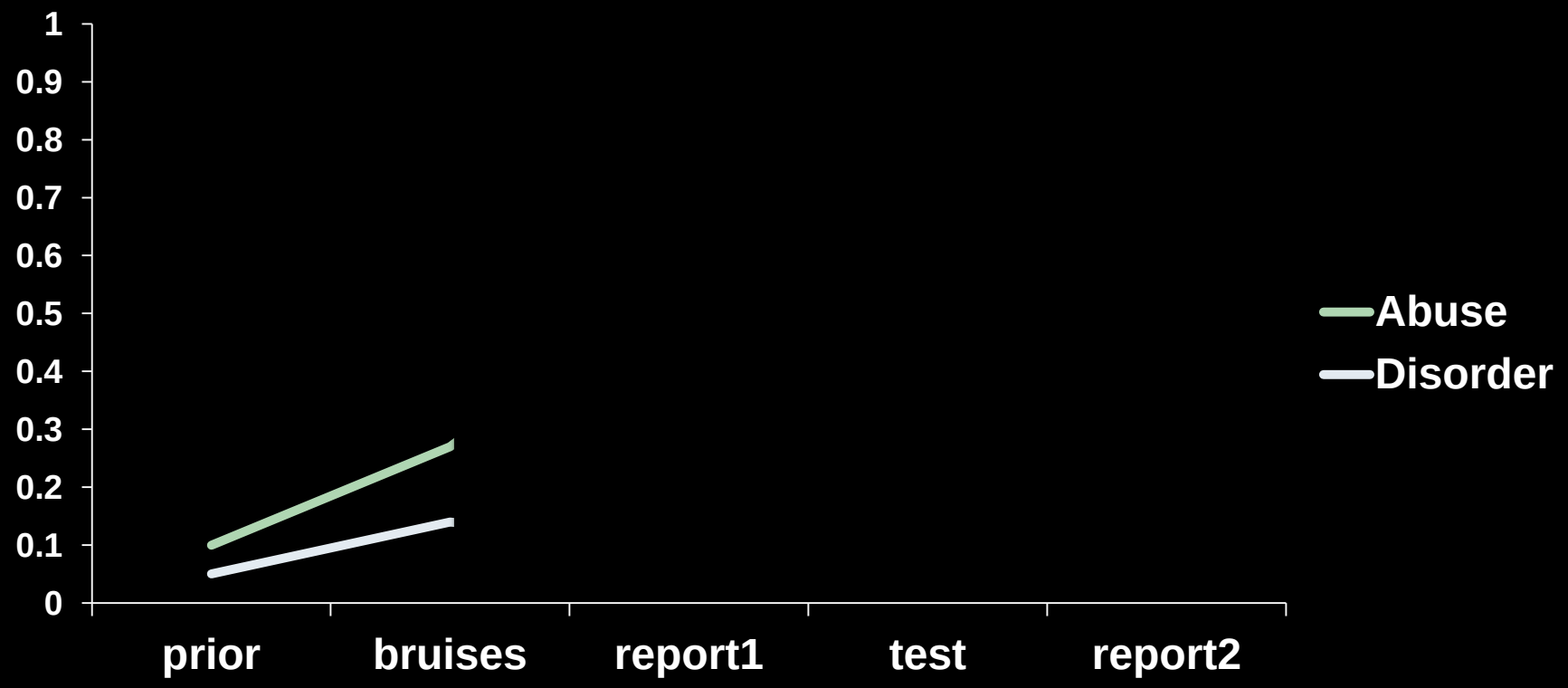
prior
bruises
report1
test
report2
Abuse
Disorder


Abuse
Disorder
Fractures
Bruises
Test
X-Ray report1
X-Ray report2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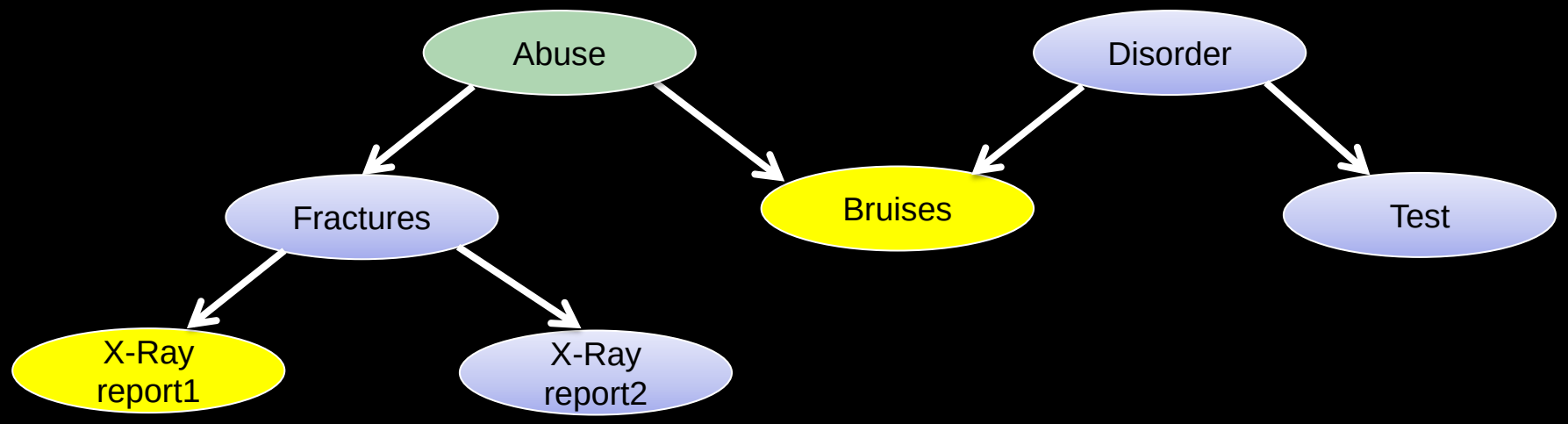
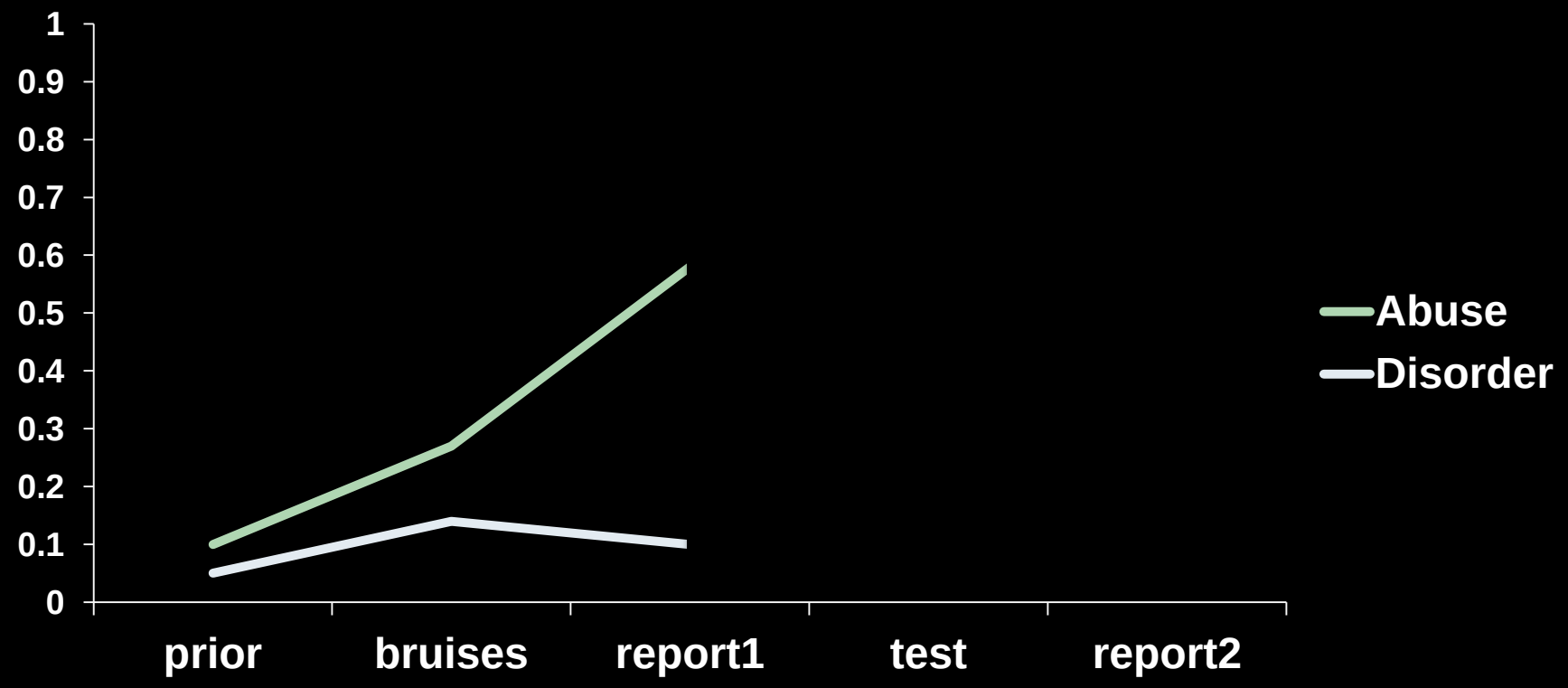
Disorder


Abuse
Disorder
Fractures
Bruises
Test
X-Ray report1
X-Ray report2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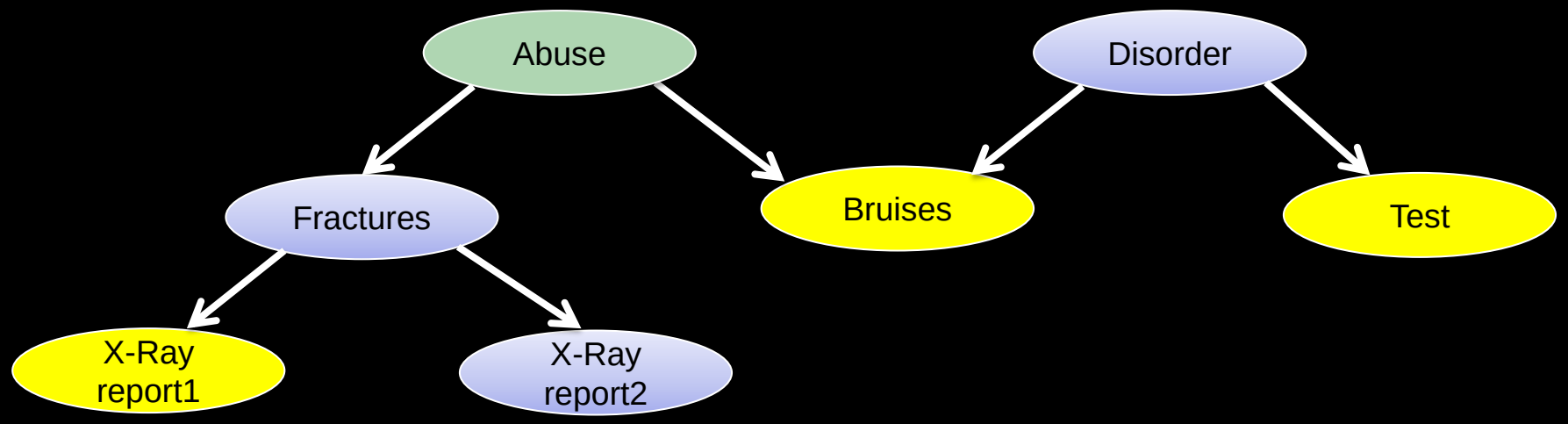
Abuse
Disorder


Abuse
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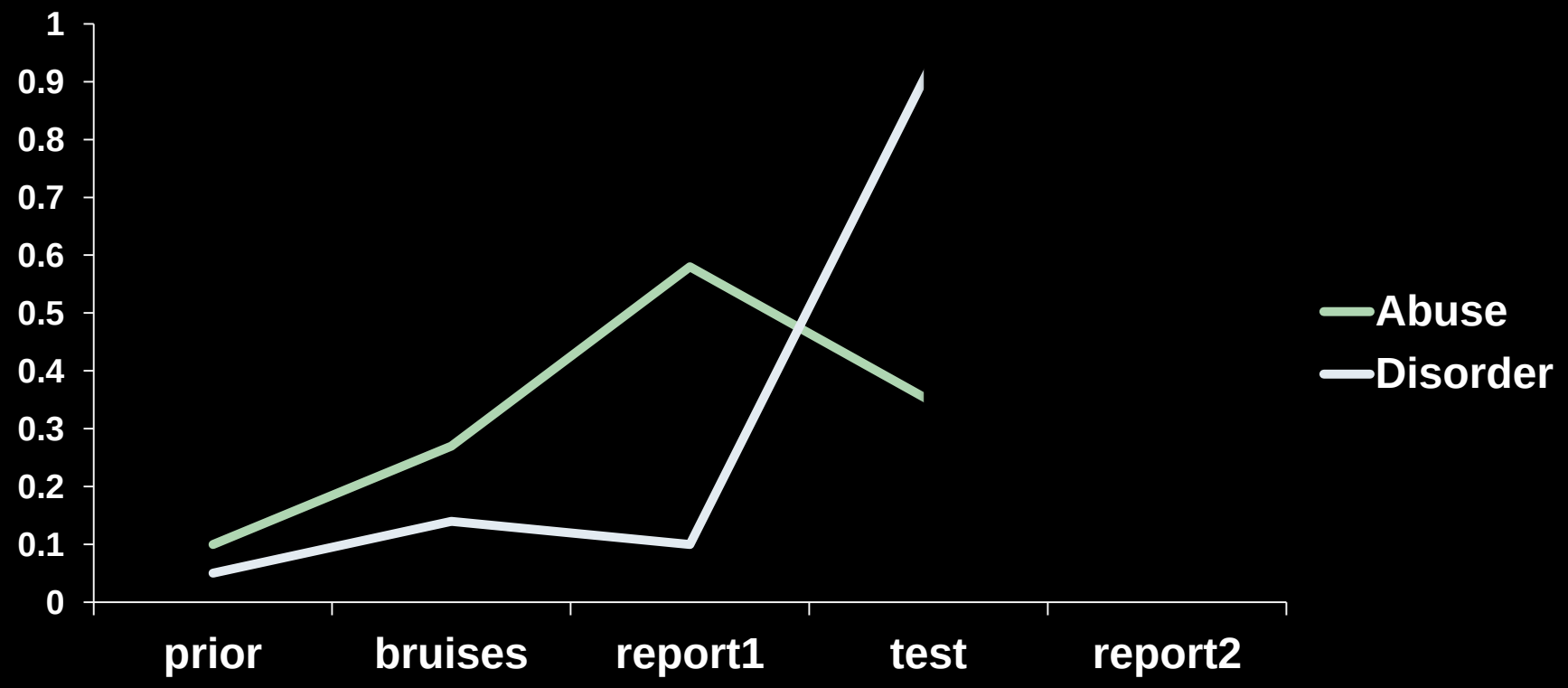
X-Ray report1
X-Ray report2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report1
test
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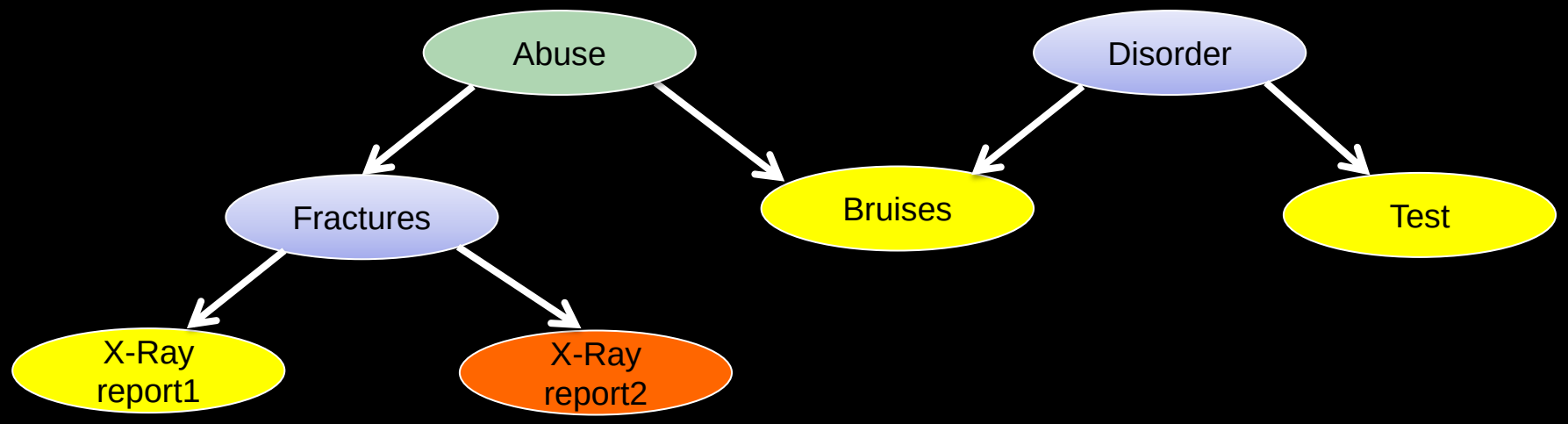
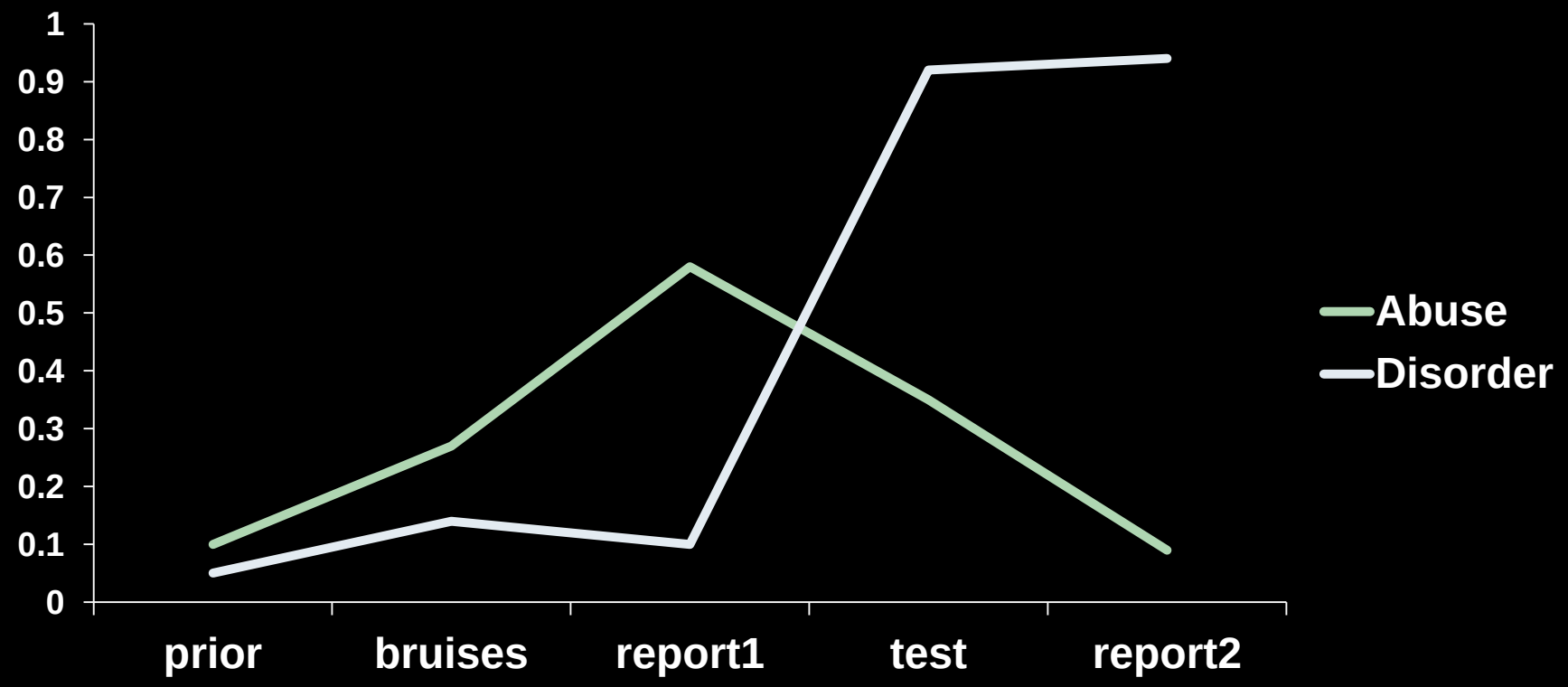
Abuse
Disorder


Abuse
Disorder
Fractures
Bruises
Test
X-Ray report1
X-Ray report2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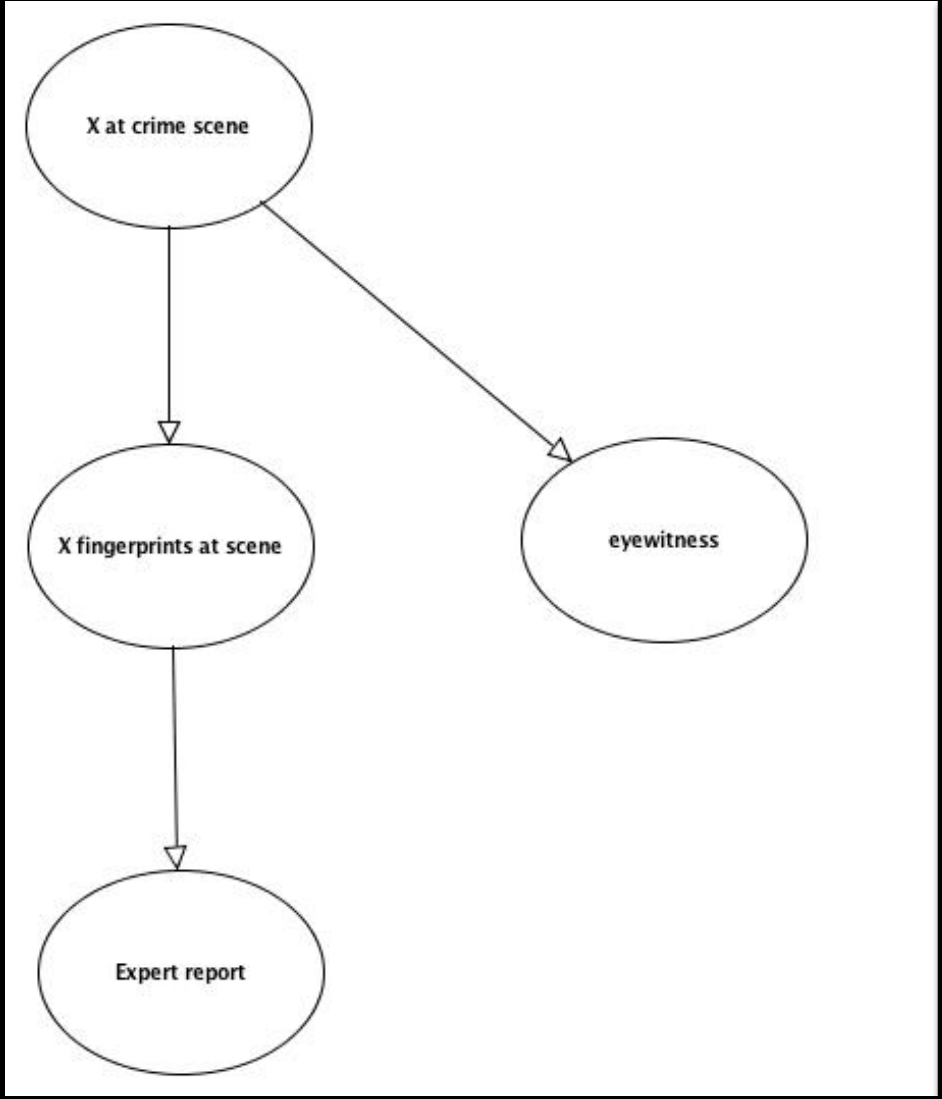
0.4
0.3
0.2
0.1
0
prior
bruises
report1
test
report2
Abuse
Disorder

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 (eg 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)



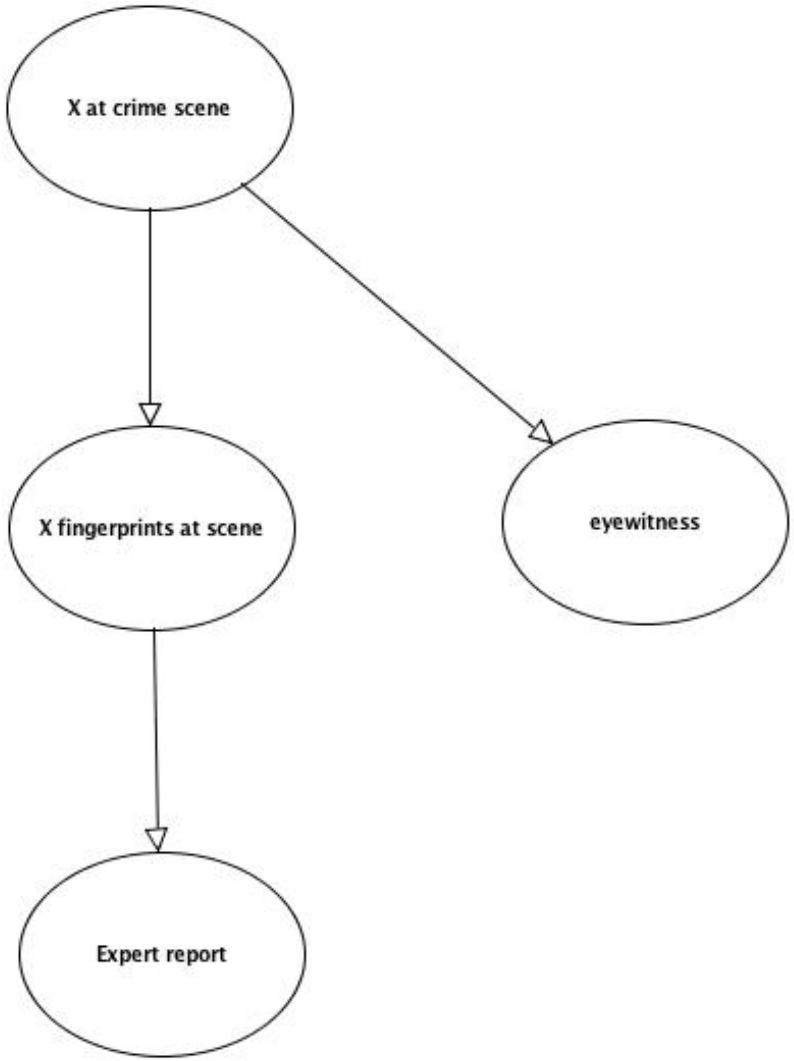
- Target hypothesis: Was X at crime scene?
- Fingerprints found at scene
- Expert compares crime prints with X's prints
- Reports 'match'
- Eyewitness testimony that X at crime scene

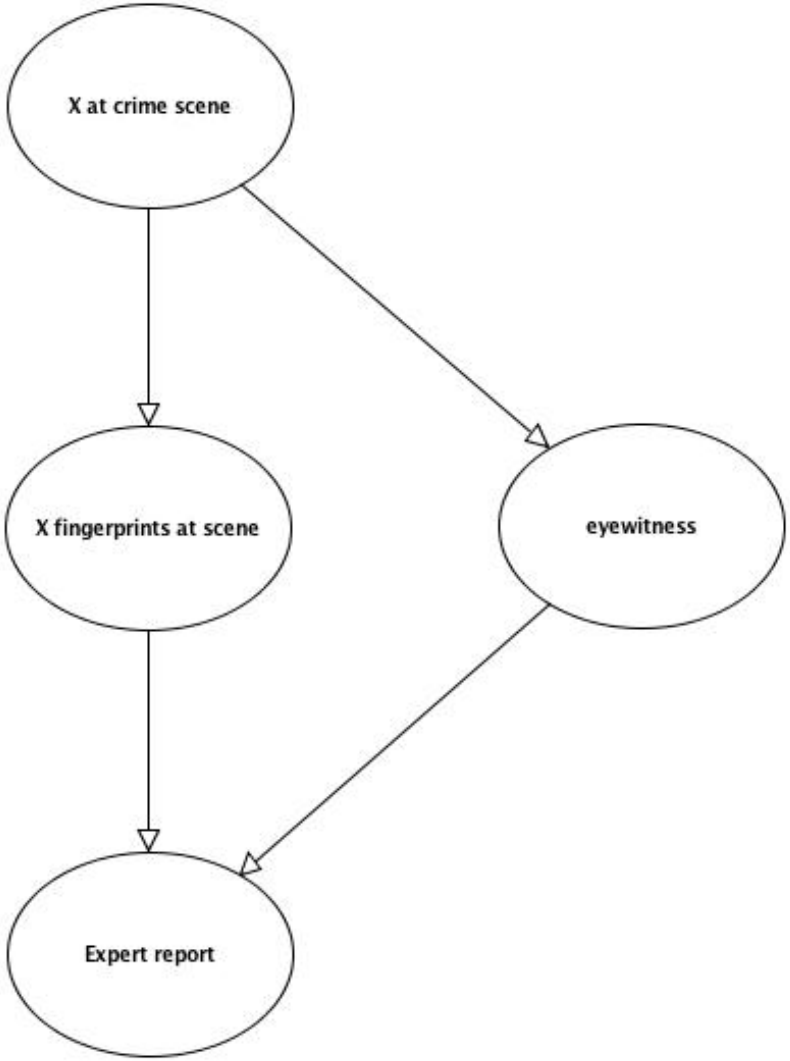
CASE 1

- Expert blind to witness report
- No direct link from witness report to expert report

CASE 2

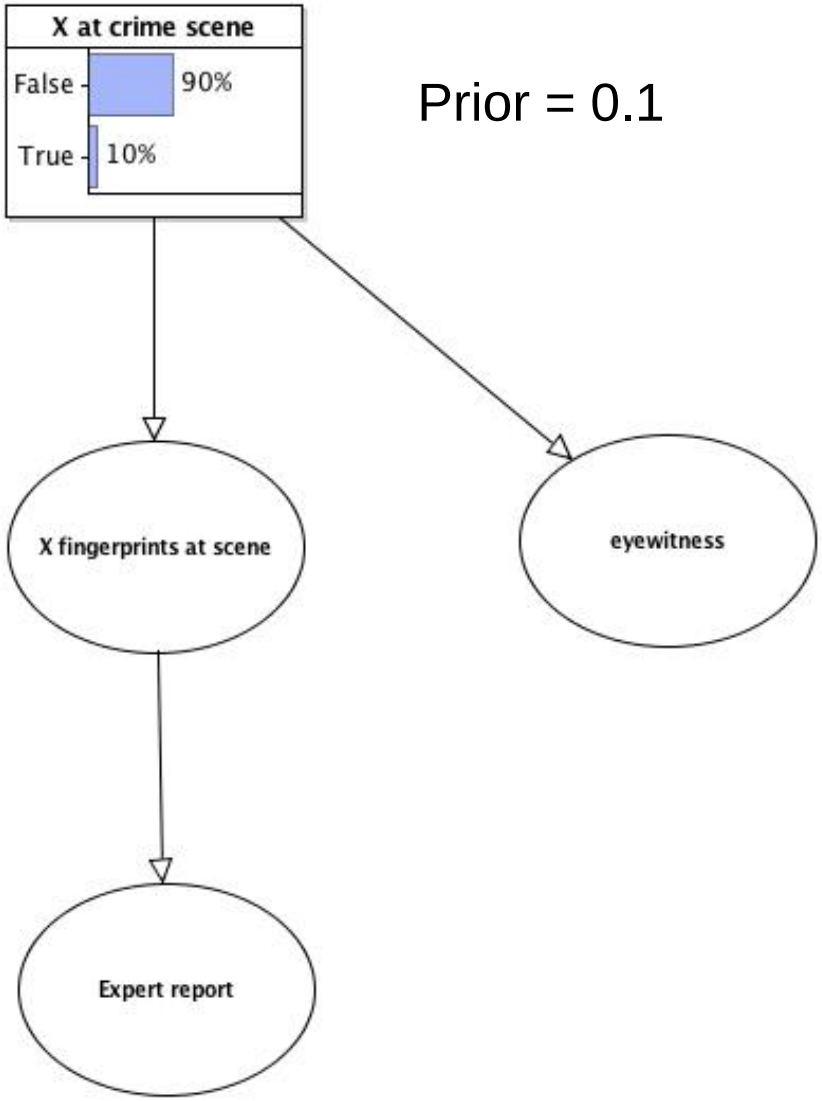
- Expert knows about eyewitness report
- Direct link from witness report to expert report

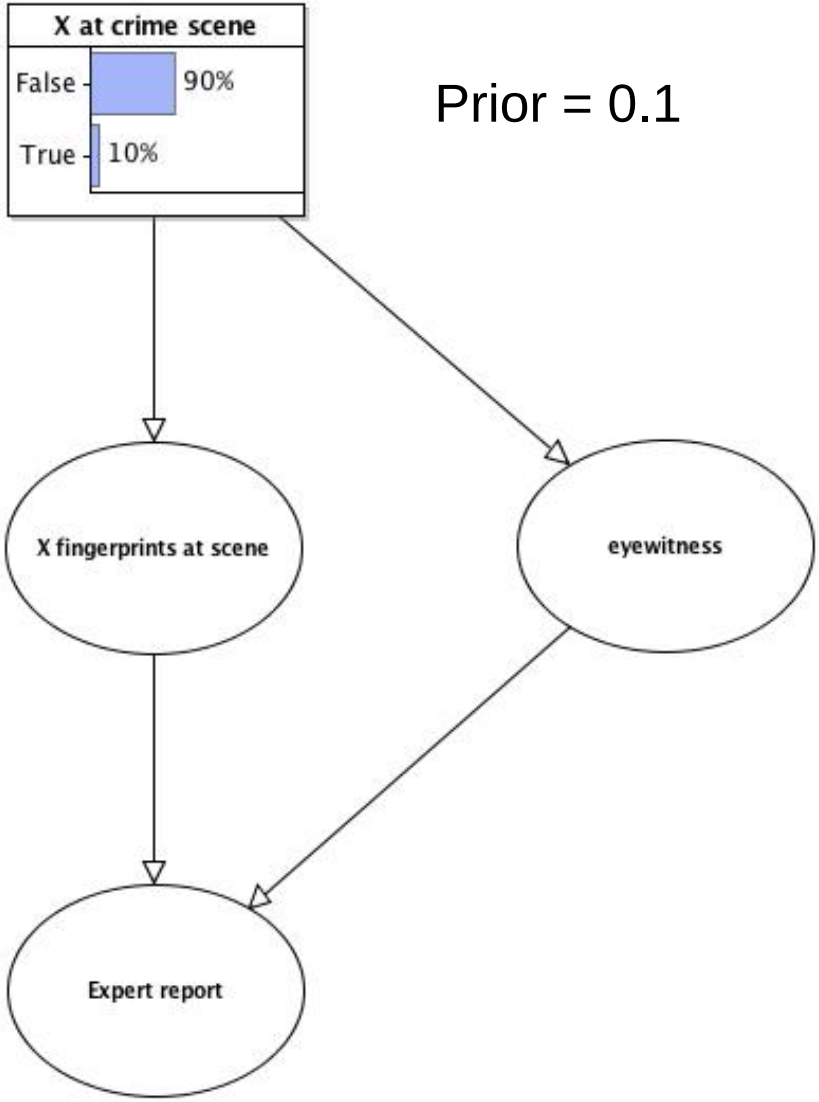


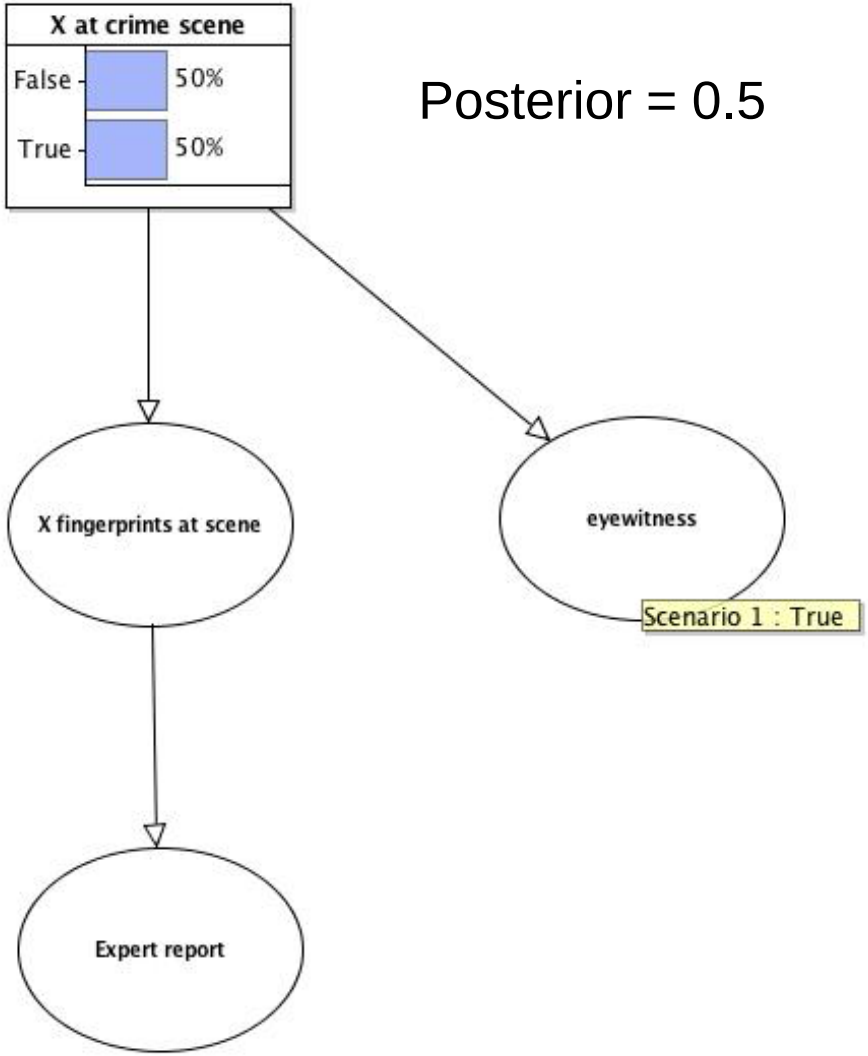


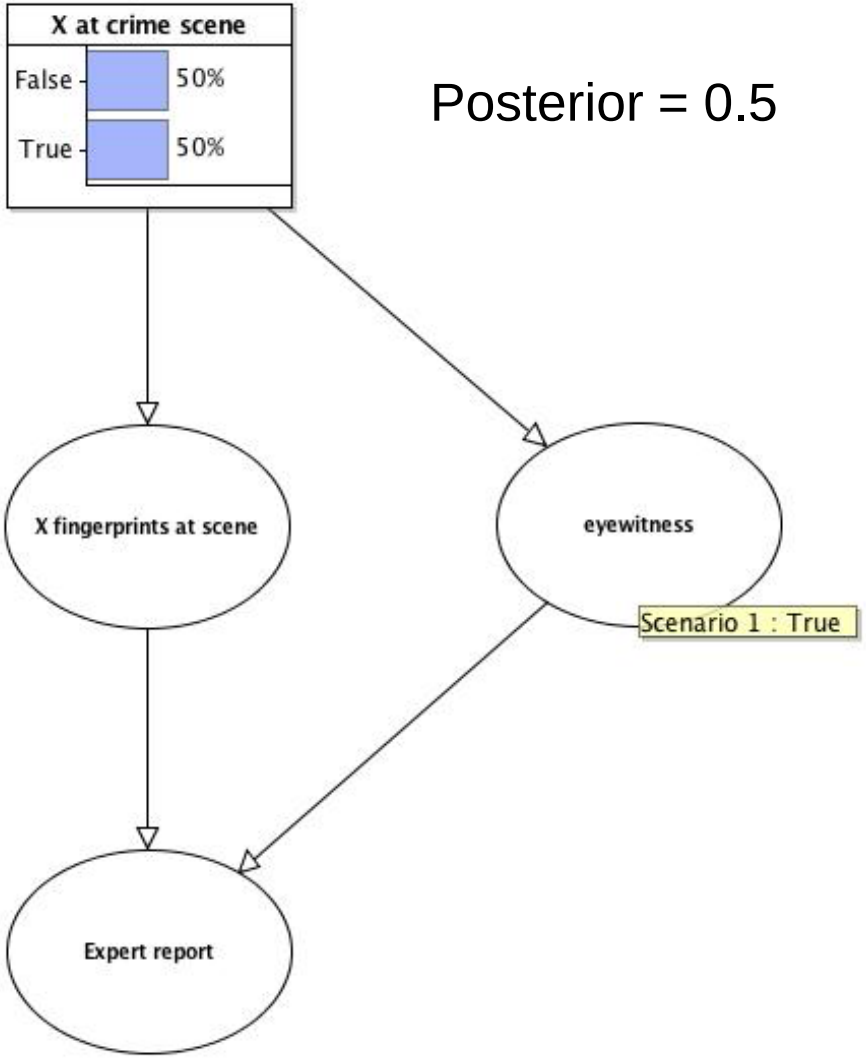
Expert report depends only on fingerprint evidence

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

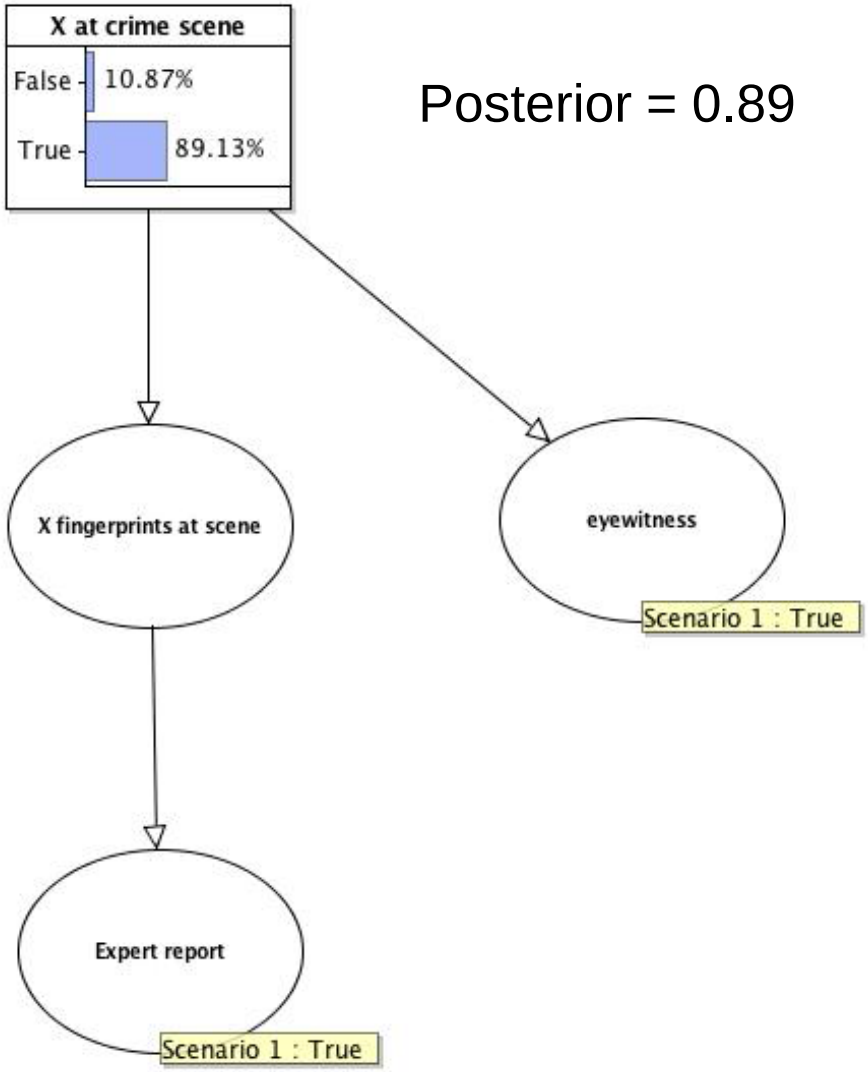

X at crime scene
False
90%
True
10%
Prior = 0.1
X fingerprints at scene
eyewitness
Expert report


X at crime scene
False
90%
True
10%
Prior = 0.1
X fingerprints at scene
eyewitness
Expert report

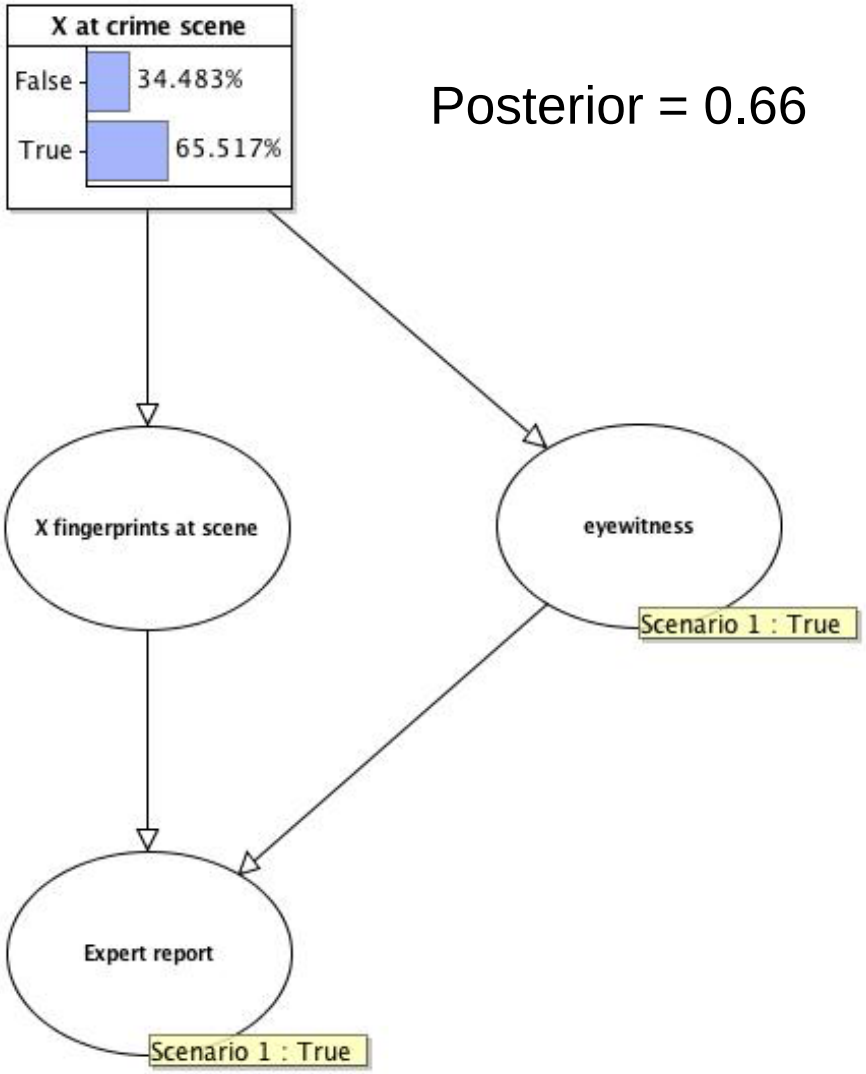




Eyewitness report that he saw X at crime scene



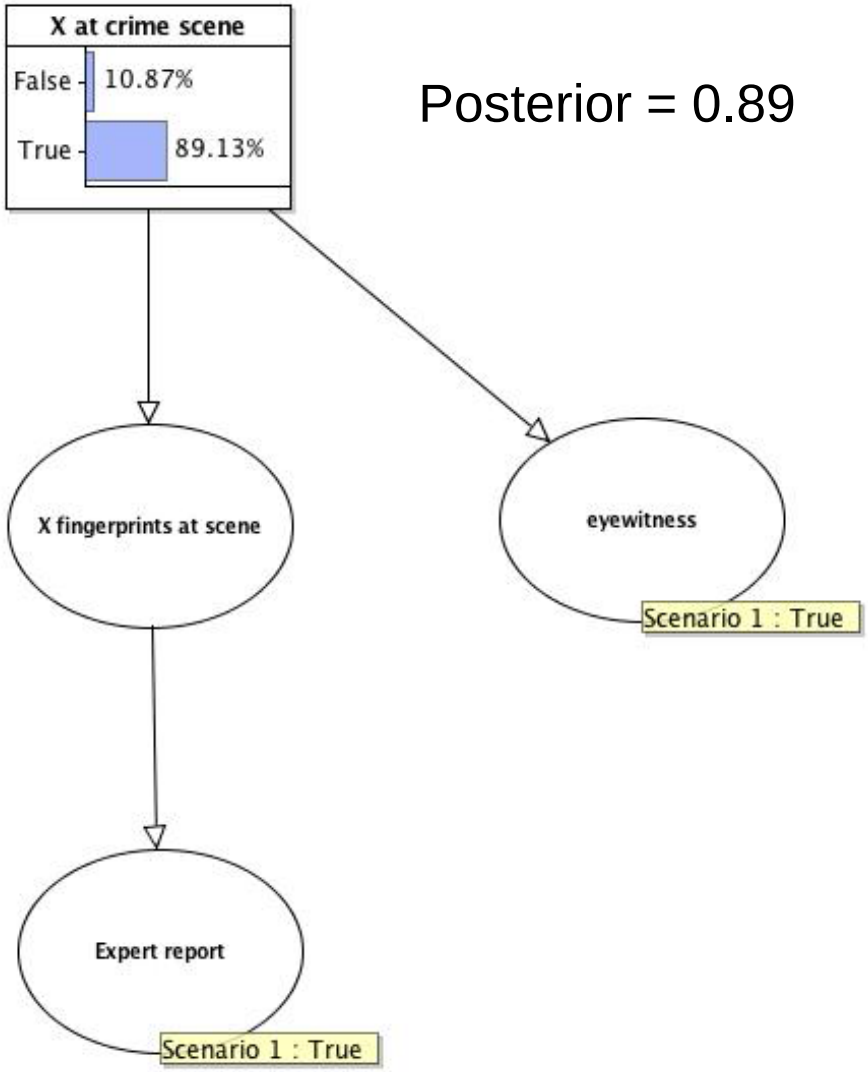
Posterior = 0.89



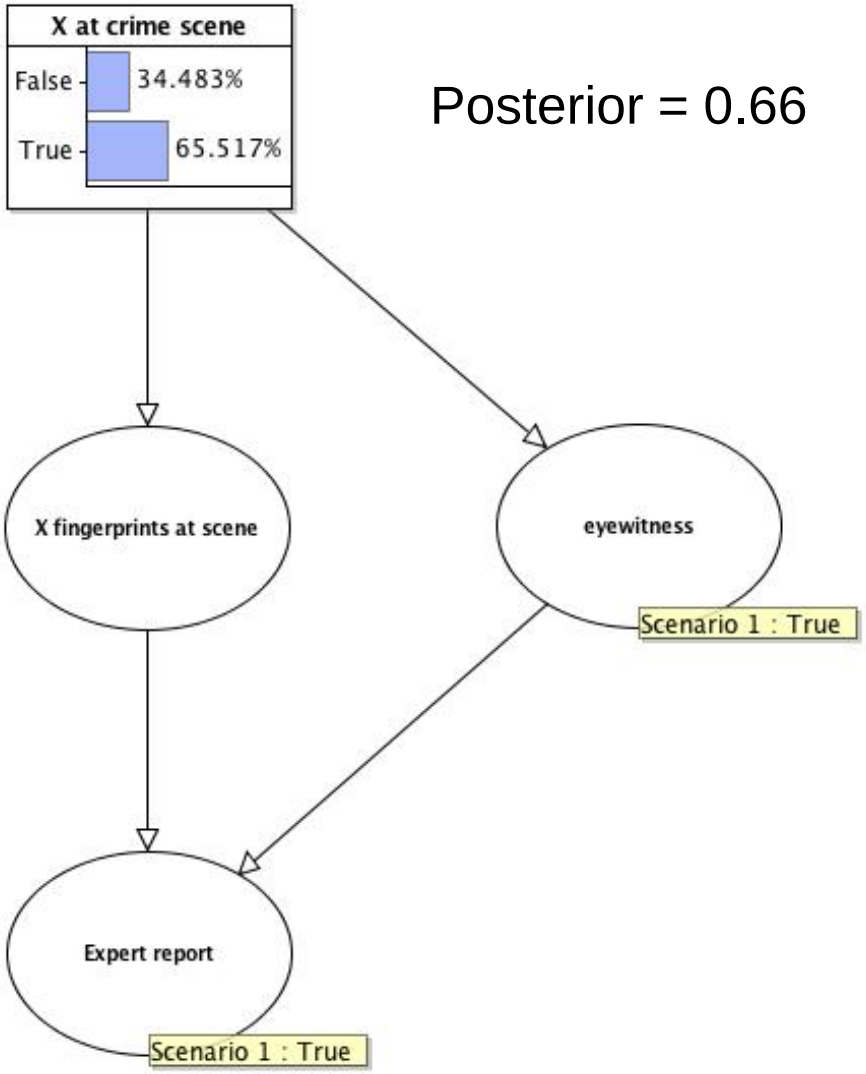
Posterior = 0.66

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

Summary

- 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