Combining judgments with messy data to build Bayesian Network models for improved intelligence analysis and decision support

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Norman Fenton
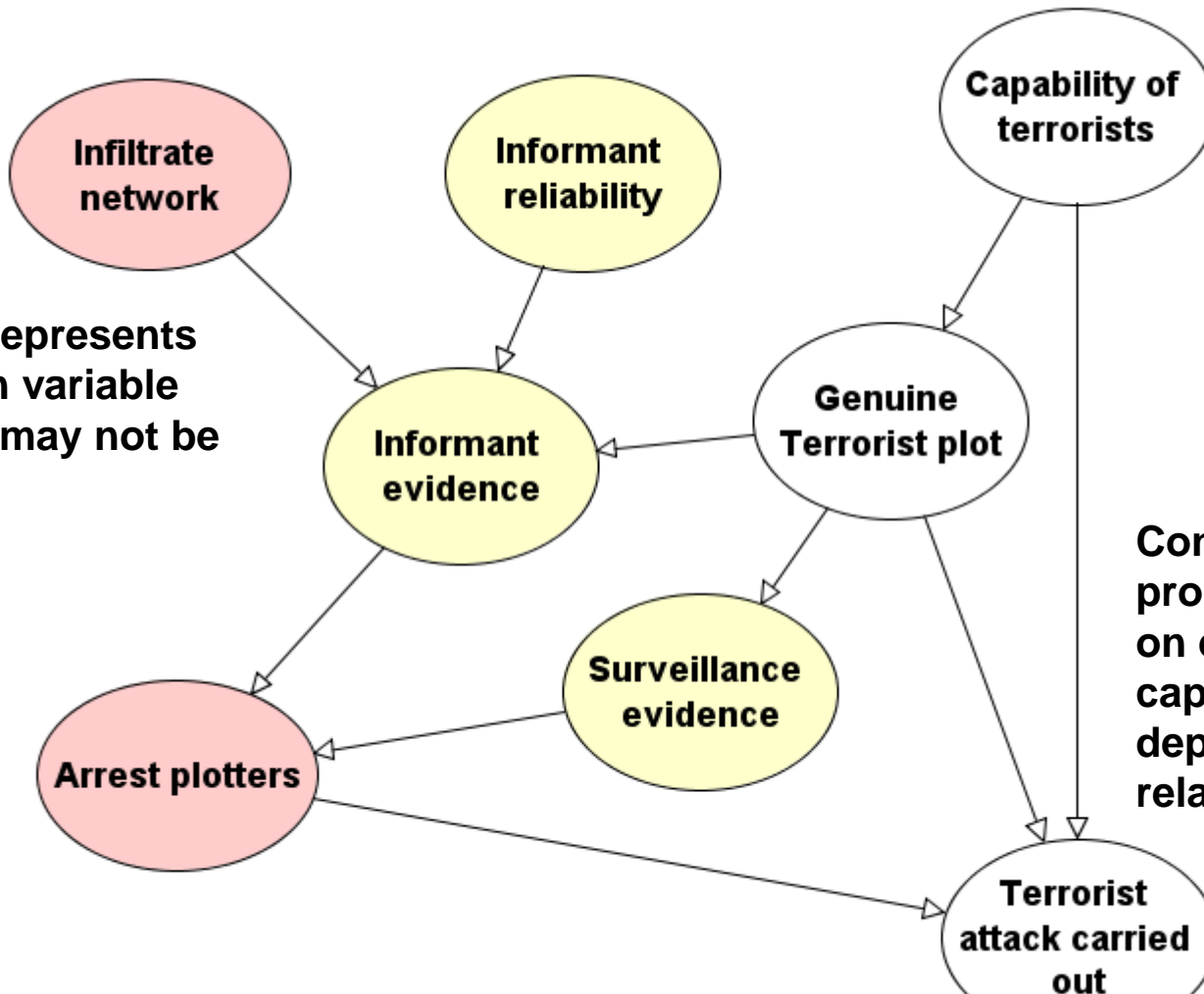**Queen Mary University of London**
and
Agena Ltd

(co-researchers: Anthony Constantinou and Martin Neil)

Overview

- **The power – and limitations – of Bayesian networks**

- **Building the models: the fundamental limitations of big data and machine learning**
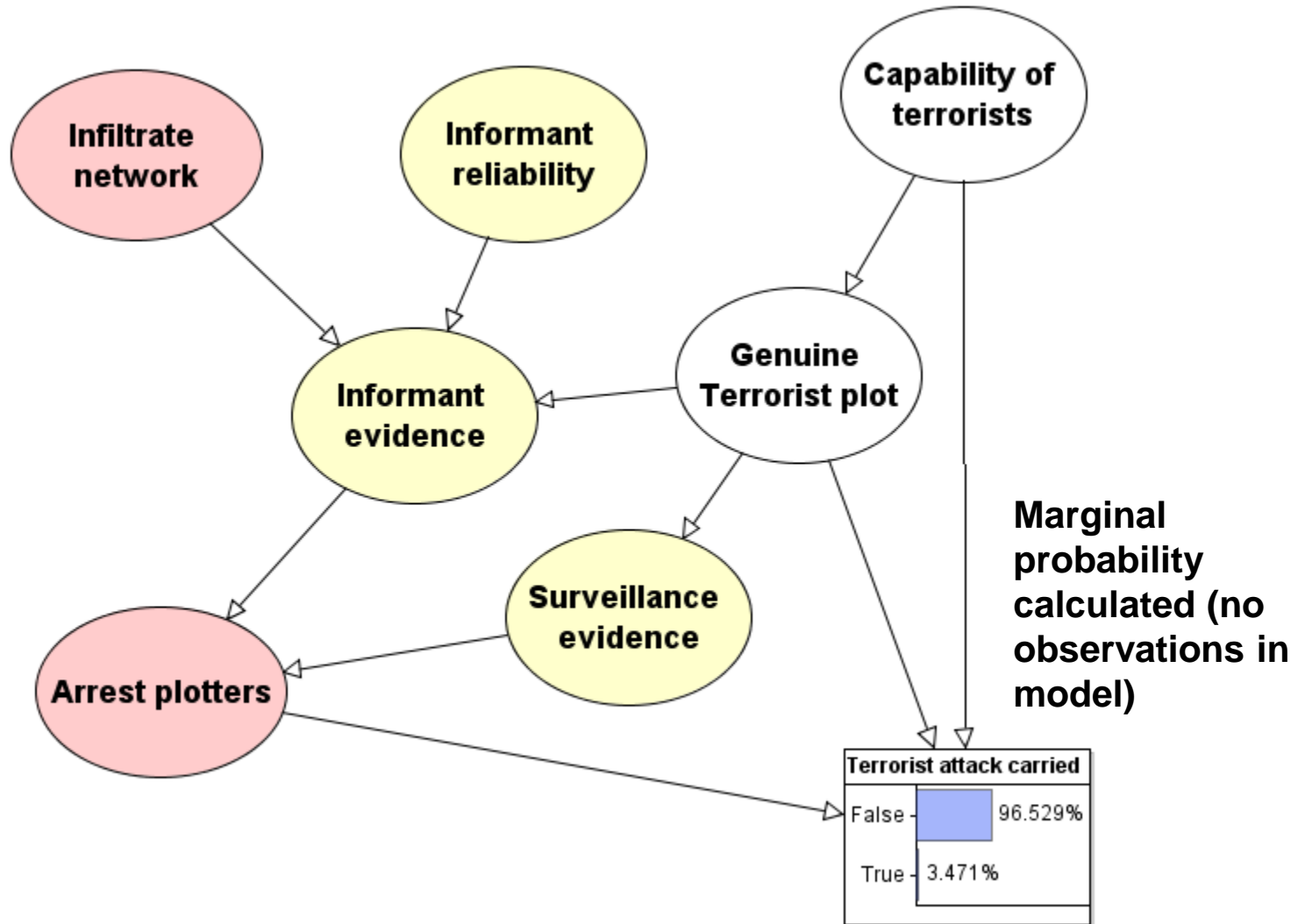
A typical Bayesian Network (BN)

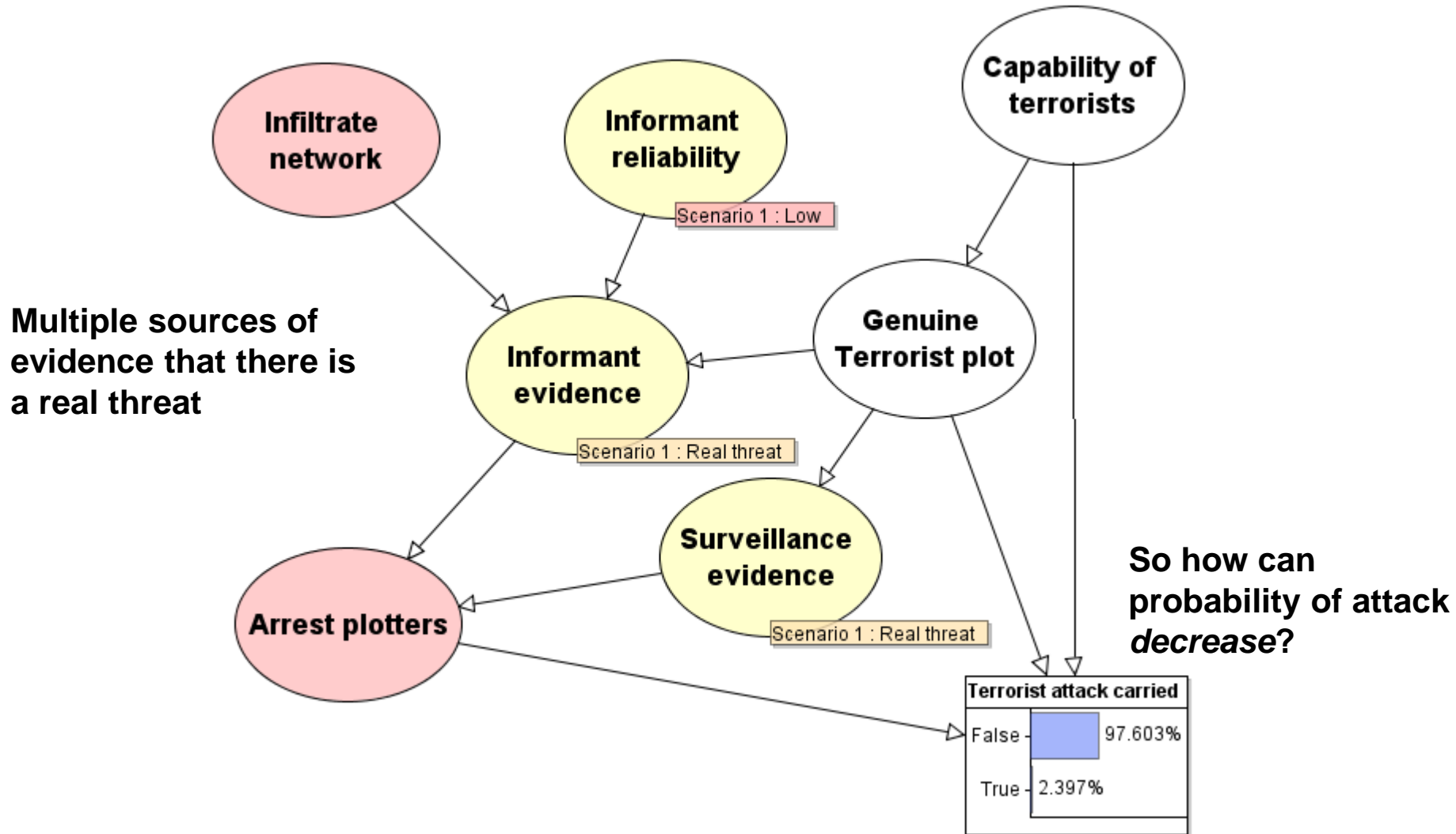Each node represents an uncertain variable that may or may not be observed

Conditional probability tables on each node capture dependence relations

Arrest plotters	No				Yes			
Genuine Terrorist plot	False		True		False		True	
Capability of terrorists	Low	High	Low	High	Low	High	Low	High
False	1.0	0.9	0.99	0.5	1.0	1.0	1.0	1.0
True	0.0	0.1	0.01	0.5	0.0	0.0	0.0	0.0

A typical Bayesian Network (BN)

A typical Bayesian Network (BN)

Infiltrate network

Informant reliability
Scenario 1 : Low

Capability of terrorists

Multiple sources of evidence that there is a real threat

Informant evidence
Scenario 1 : Real threat

Genuine Terrorist plot

Surveillance evidence
Scenario 1 : Real threat

Arrest plotters

So how can probability of attack *decrease*?

Terrorist attack carried
| False | | 97.603% |
| True | 2.397% | |

A typical Bayesian Network (BN)

Infiltrate network

Informant reliability
Scenario 1 : Low

Capability of terrorists

Informant evidence
Scenario 1 : Real threat

Genuine Terrorist plot

Arrest plotters
No - 20%
Yes - 80%

Surveillance evidence
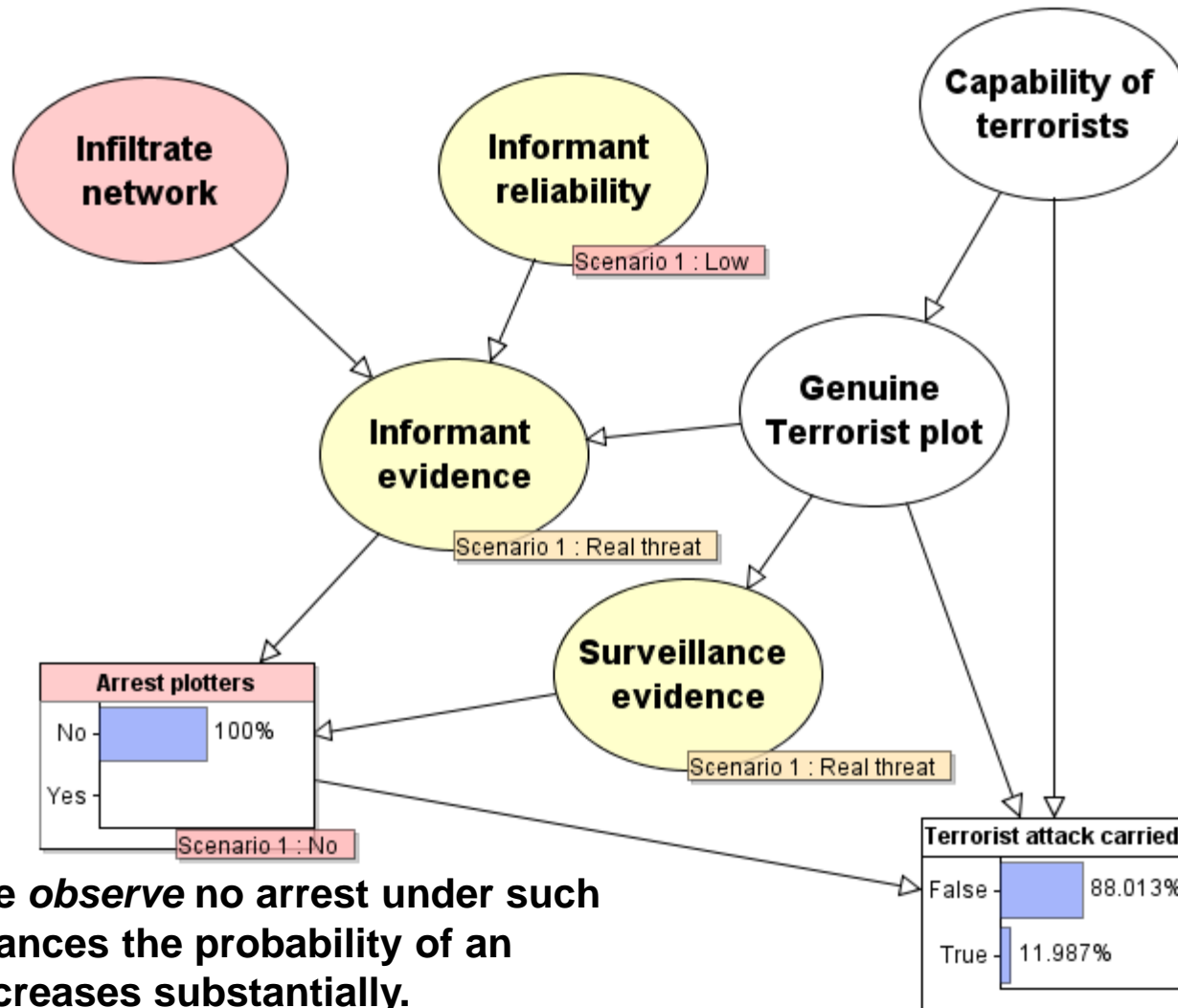Scenario 1 : Real threat

Terrorist attack carried
False - 97.603%
True - 2.397%

Because, based on the observational data and expert judgment on which model is defined, it is very likely plotters will be arrested when we have this kind of evidence

So BN predictions *already incorporate likely decisions*. But what if we want to make decisions?
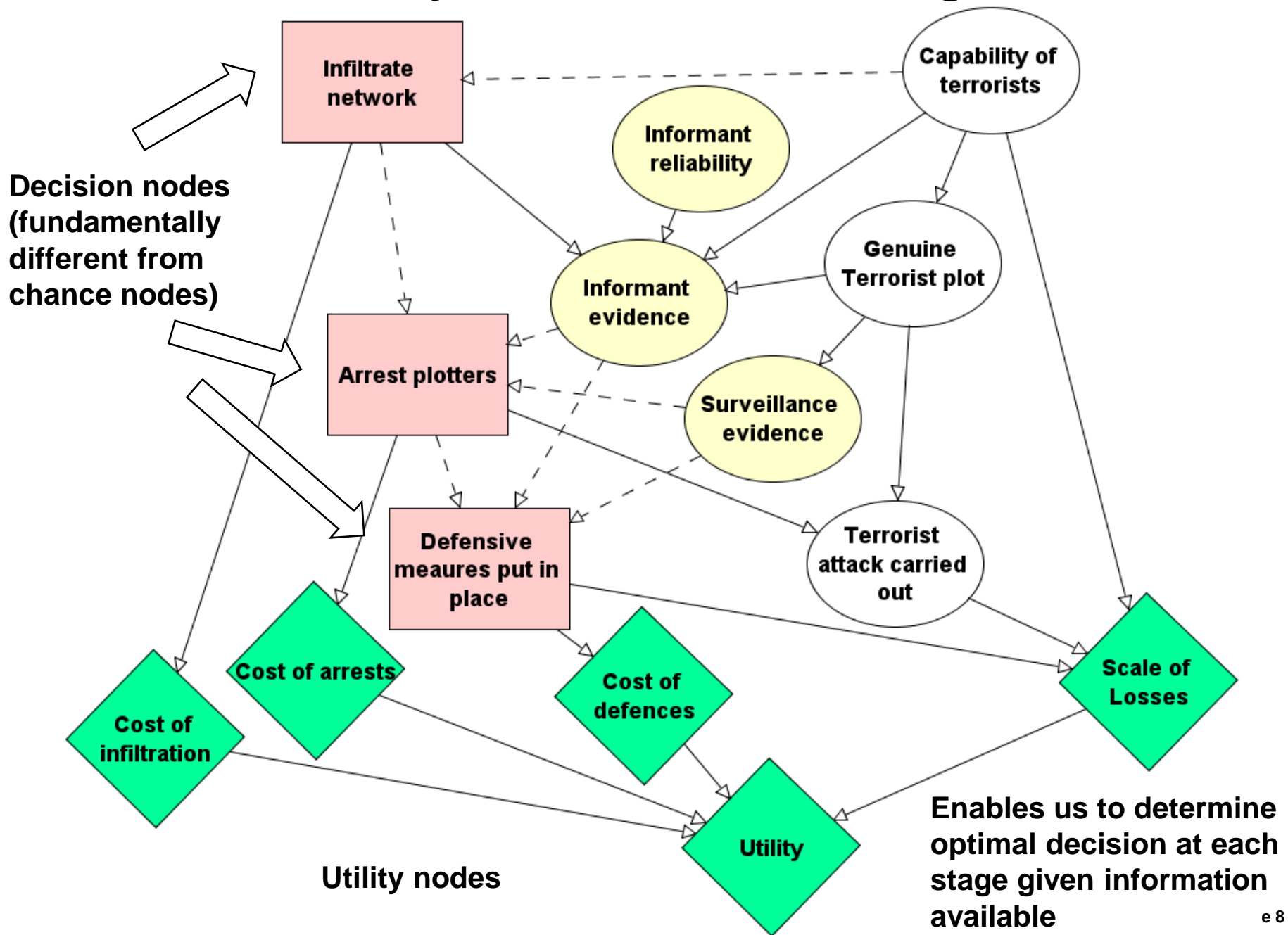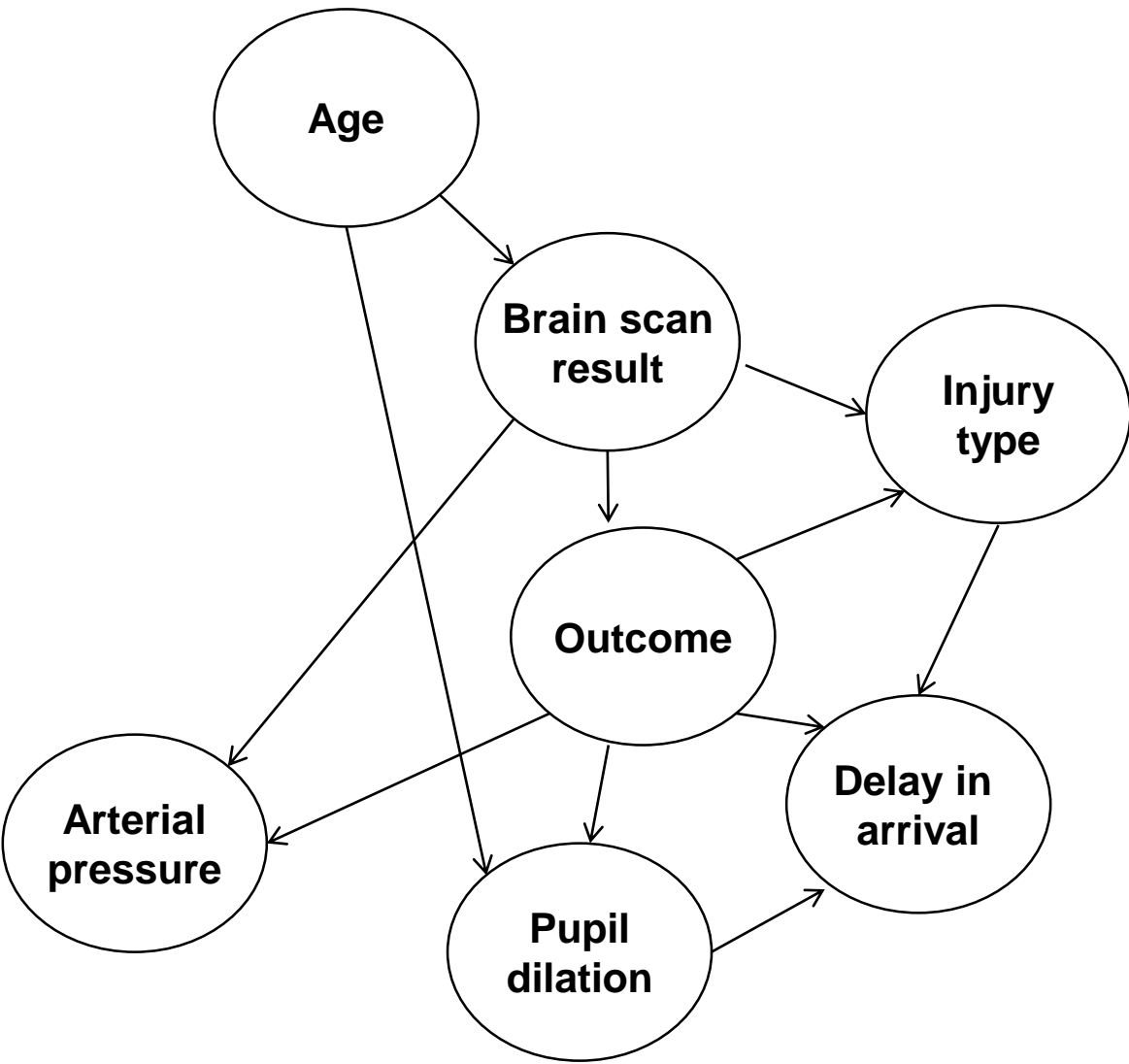
A typical Bayesian Network (BN)

Where we *observe* no arrest under such circumstances the probability of an attack increases substantially.

But this is an *observation* and not an *intervention*. Standard BN does not support correct inference for interventions
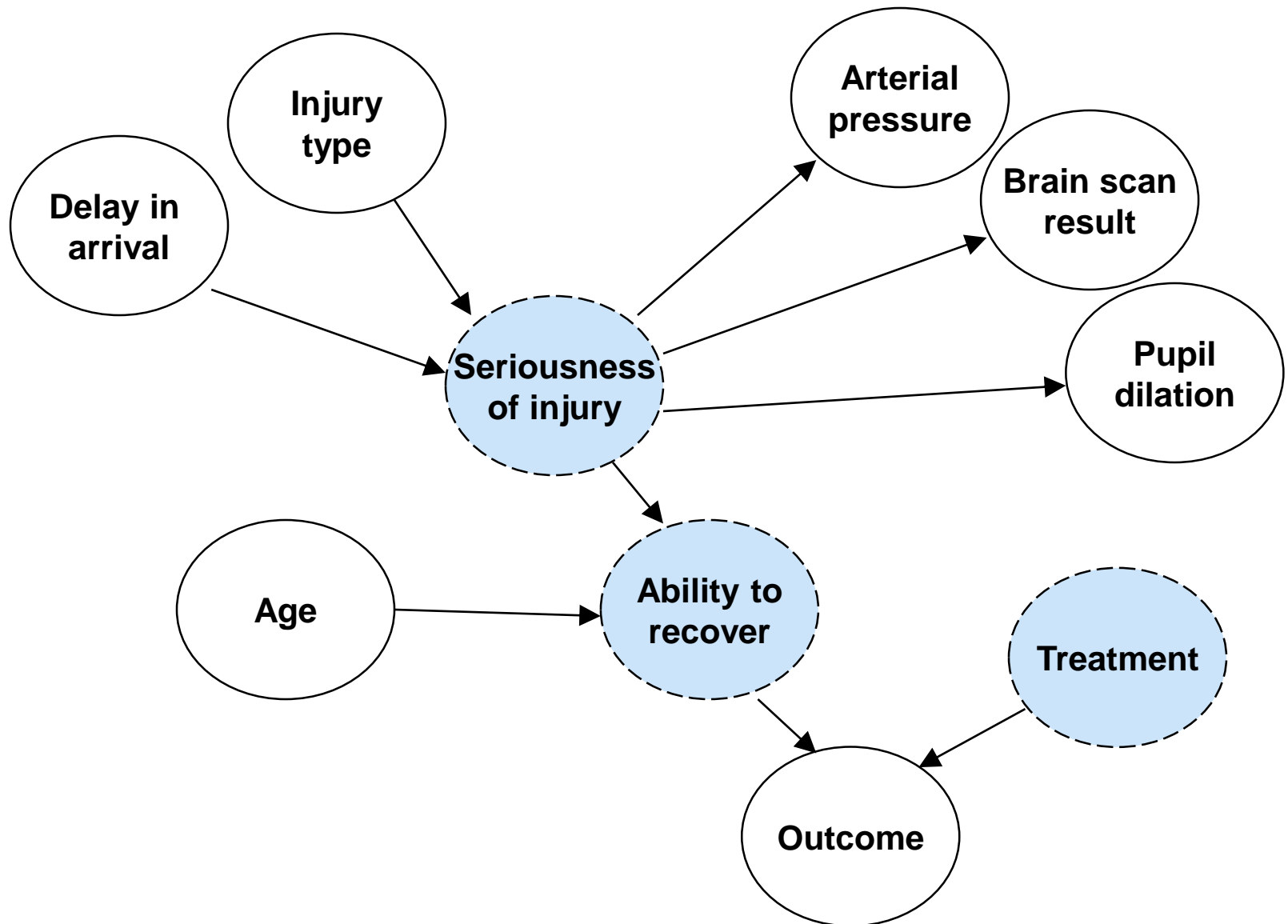
Need Bayesian Influence Diagram

Decision nodes (fundamentally different from chance nodes)

Infiltrate network

Capability of terrorists

Informant reliability

Informant evidence

Genuine Terrorist plot

Arrest plotters

Surveillance evidence

Defensive meaures put in place

Terrorist attack carried out

Cost of arrests

Cost of defences

Scale of Losses

Cost of infiltration

Utility

Utility nodes

Enables us to determine optimal decision at each stage given information available
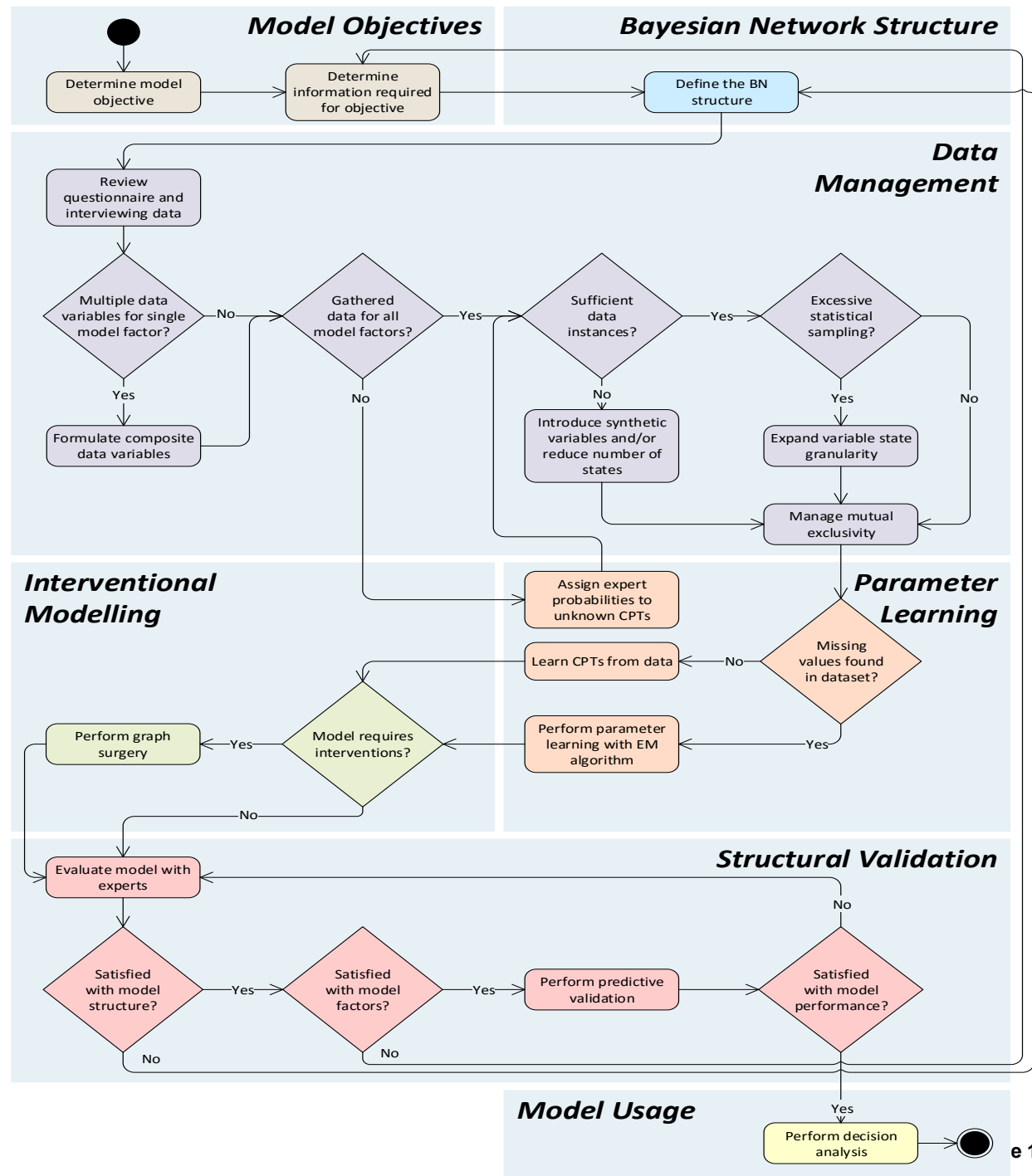
A BN Model learnt purely from data

Expert causal BN with hidden explanatory and intervention variables

Method for developing BNs and Influence diagrams from incomplete and messy data

Constantinou A., Fenton N., Marsh W, and Radlinski L. ,
"From complex questionnaire and interviewing data to intelligent Bayesian network models for medical decision support.,"
Artif. Intell. Med., vol. 67, pp. 75–93, Jan. 2016.

Model Objectives

- Determine model objective
- Determine information required for objective

Bayesian Network Structure

- Define the BN structure

Data Management

- Review questionnaire and interviewing data
- Multiple data variables for single model factor? — Yes → Formulate composite data variables; No →
- Gathered data for all model factors? — Yes; No →
- Sufficient data instances? — Yes; No → Introduce synthetic variables and/or reduce number of states
- Excessive statistical sampling? — Yes → Expand variable state granularity; No →
- Manage mutual exclusivity

Interventional Modelling

- Assign expert probabilities to unknown CPTs
- Perform graph surgery — Yes ← Model requires interventions? — No

Parameter Learning

- Missing values found in dataset? — No → Learn CPTs from data; Yes → Perform parameter learning with EM algorithm
- Learn CPTs from data

Structural Validation

- Evaluate model with experts
- Satisfied with model structure? — Yes; No
- Satisfied with model factors? — Yes; No
- Perform predictive validation
- Satisfied with model performance? — No; Yes

Model Usage

- Perform decision analysis

Big Data … or Smart Data?

Conclusions

BNs provide excellent basis for prediction in intelligence analysis

Extension to influence diagrams needed for interventions and decision making

The challenge of building *effective* BN models and influence diagrams will NOT be solved by big data and machine learning

We need effective methods to incorporate expert judgment with available data
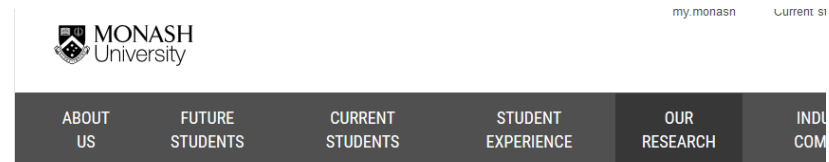
Smart data – not big data

Follow up

RISK ASSESSMENT AND DECISION ANALYSIS WITH BAYESIAN NETWORKS

NORMAN FENTON
MARTIN NEIL
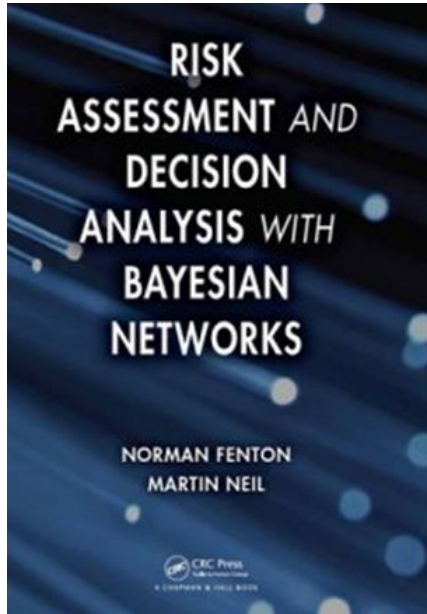
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BARD: Bayesian ARgumentation via Delphi

" BARD - Bayesian Argumentation via Delphi - uses causal Bayesian networks as underlying structured representations for argument analysis and automated Delphi methods to bring groups of analysts to a consensus analysis. This five-year project involves researching and designing new means of interacting with Bayesian networks, including new means of assessing their potential in causal explanations.

BARD Project

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European Research Council
Established by the European Commission
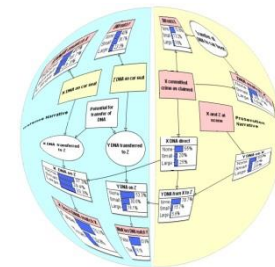
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