Sandia National Laboratories

Energy, Climate, & Infrastructure Security

Bayesian Networks

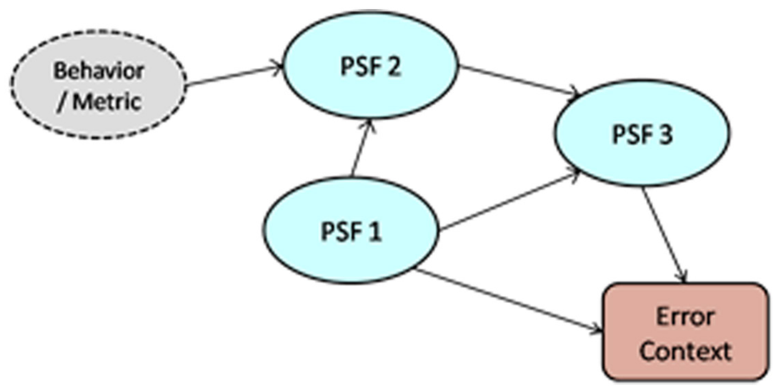
Decision support for complex systems

What are Bayesian Networks?

A tool for encoding our knowledge of system relationships in terms of three parts:

- Relevant variables and their states
- (In)dependency among variables
- The system's simplified joint probability distribution

Analysts use this generic knowledge base to perform reasoning about specific events (e.g., future states, root causes). Probability helps summarize information. Using probability allows analyst to leverage probability calculus, which allows them to distinguish between different qualitative beliefs.



Vision

To enhance the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure problems.

What do they do?

Bayesian networks (BNs) provide a framework that supports decision making for complex systems.

- BNs allow one to combine information from different sources. For situations where a probability model is not available, BNs are a way to develop this model. They are a framework that transforms information into knowledge about a system.
- BNs provide a basis for reasoning with incomplete or imperfect information, about uncertain events.
- BNs use probabilities to summarize causal information.

> "Probability is not really about numbers; it is about the structure of reasoning."
> *- Glenn Shafer, Rutgers*

When do we use BNs?

- Inference: Forward propagation, from causes to events. Analysts use BNs when reasoning about unknown events (e.g., interpreting a new situation, predicting the probability of being in various states, conducting "what-if" analyses, or choosing a corrective action for a specific situation).
- Diagnostics: Backward propagation, from events to causes. Analysts use BNs when seeking to understand why an event happens. By observing certain variables being in various states (e.g. knowing that temperature is high or pressure is low) they can enter that information in the network and get updated probabilities for unobserved variables. This is used to understand possible root causes given observed symptoms.

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Applications:

Analysts can apply BNs to any task that requires drawing conclusions from uncertain and incomplete information.

- Diagnosis and forecasting
- Sensor information fusion
- Handwriting/text/image recognition
- Elicitation of a probability distribution
- Decision support
- Probabilistic risk assessment

Key features:

- Documentation: All variables and relationships deemed relevant to the problem space are explicitly represented.
- Simplification: The BN documents how a large-scale decision problem is decomposed into manageable pieces.
- Efficiency: Independencies encoded in the structure reduces complexity of eliciting the joint distribution and reduces computation time.
- Credibility: The BN allows analyst to assemble information from multiple sources into a single model; this facilitates populating the model with the most credible information.
- Modifiability: Analysts can update conditionally independent sections of the model without changing the entire model.
- Completeness: Includes all relevant variables, not just easily observable variables or variables where data is plentiful. Allows variables to be interdependent.
- Insight: Enables analysts to make predictions without perfect information; enables understanding of cause-and-effect behavior, performing "what-if" analyses.

Future applications in nuclear energy:

- Developing probability models for soft risk factors – expanding model-based probabilistic risk assessment to include aging, common cause failure, and human error.
- Smart procedures for nuclear power – building dynamic response solutions based on the probability of different scenarios, combined with the observations about current events.
- Discovering relationships and weights from Human Reliability Analysis (HRA) data – exploring available data for meaningful, consequential patterns; updating existing HRA knowledge base.

References

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