Probabilistic Graphical Models in Strategic Planning

An Overview of the ESP (Environment for Strategic Planning) Project

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Overview

- Decision Systems Laboratory
- Bayesian networks and directed graphs
- Practical challenges
- Software demo
- Concluding remarks

Essentially, a handful of slides followed by software demos. A somewhat informal overview of what we have done in the project and where the project is going.
Decision Systems Laboratory

• Our research group at the University of Pittsburgh.

• Diverse crowd, interdisciplinary work.

• Focused on computational tools that aid decision making (recent focus on strategic planning).

• Theoretical work, system building, and empirical studies.

• Probabilistic, decision-theoretic, and econometric techniques combined with artificial intelligence approaches.

• Considerable attention to human interface.

http://dsl.sis.pitt.edu/
... and to other good things in life.
What is strategic planning?

Decision making (typically in organizations) that may potentially impact the very well-being of the decision maker.

Typically domain of top-level management.

Examples:
1. Political alliances
2. Corporate takeovers
3. Introduction of a new line of products
4. Introduction of third shift on a factory floor
5. ...
What are the typical tools used in strategic planning?

“When you have a hammer, everything looks like a nail”

To avoid this trap, we need to become aware of the capabilities and limitations of our tools.
Unaided/intuitive decision making

Shown to be inferior to even the simplest mathematical tools (e.g., predictions of violent behavior, marriage counseling)
Spreadsheets models

• Quite likely the most popular tools at the moment
• What’s wrong with this picture?

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Spreadsheet models

- They could also be viewed as graphs.
- Graphs would show causal dependences among cells (variables).
- Of course, for any practical spreadsheet, we would essentially get a spaghetti of connections 😊.
- We know how to do it better.
Visual spreadsheets

- Fix almost everything that has been wrong with spreadsheets
- Great, but I believe that they could still be improved on 😊!

e.g., Analytica (http://www.lumina.com/)
A Bayesian network [Pearl 1988] is an acyclic directed graph consisting of:

The **qualitative part**, encoding a domain's variables (nodes) and the probabilistic (usually causal) influences among them (arcs).

The **quantitative part**, encoding the joint probability distribution over these variables.
Bayesian networks: Numerical parameters

Prior probability distribution tables for nodes without predecessors (Age)

Conditional probability distributions tables for nodes with predecessors (HPV, Pap test, Cervix)
The most important type of reasoning in Bayesian networks is updating the probability of a hypothesis (e.g., a diagnosis) given new evidence (e.g., medical findings, test results).

Example:
What is the probability of invasive cervical cancer in a (female) patient with high grade dysplasia with a history of HPV infection?

\[ P(\text{CxCa} \mid \text{HPV}=\text{positive}, \text{HSIL}=\text{yes}) \]
[Oniško et al.] 70 variables; 2,139 numerical parameters
Pittsburgh Cervical Cancer Screening Model

[Oniško et al.] 18 variables; 295,163 numerical parameters

Probabilistic Graphical Models in Strategic Planning
Equation-based systems

\[ \text{classsize} = \frac{\text{nstud} \times \text{cload}}{\text{nfac} \times \text{tload}} \]

\[ \text{facsal} = \frac{\text{oinc} + \text{tuition} \times \text{nstud}}{\text{nfac} \times (1 + \text{overh})} \]

\[ \text{stratio} = \frac{\text{nstud}}{\text{nfac}} \]

\[ \text{cload} = 15 \]
\[ \text{tload} = 6 \]
\[ \text{nstud} = 22102 \]
\[ \text{nfac} = 3006 \]
\[ \text{oinc} = 30000000 \]
\[ \text{tuition} = 12000 \]
\[ \text{overh} = 0.48 \]

Together they determine the structure of the model
Equation-based systems: Reversibility of causal ordering

\[
\text{classsize} = (\text{nstud} \times \text{cload}) / (\text{nfac} \times \text{tload}) \\
\text{facsal} = (\text{oinc} + \text{tuition} \times \text{nstud}) / (\text{nfac} \times (1 + \text{overh})) \\
\text{stratio} = \text{nstud} / \text{nfac} \\
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\text{tuition} = 12000 \\
\text{overh} = 0.48
\]

Setting \text{stratio} to be exogenous at the expense of \text{nfac}

The new model structure

Explication of the asymmetries due to Herb Simon (early 1950s)
Advantages of directed graphs

- May be built to reflect the causal structure of a model (helps with obtaining insight into the problem)
- Can accommodate representation of uncertainty
- Can be reconfigured as needed
- Have sound theoretical foundations
Hard problems in fielding this technology

1. **Computation**: How do perform inference in general/flexible models?
2. **Modeling**: How to translate the complexity of a system into a manageable model?
3. **User interface**: How to show the results so that they are useful and make a difference?
Our choice: Directed (causal) graphs

(a.k.a. “influence nets,” “causal diagrams,” etc.)

Both, systems of equations and joint probability distributions, can be pictured by acyclic directed graphs.
The long-term goal of the ESP (Environment for Strategic Planning) project is to combine the advantages of Bayesian networks and structural equation models into a hybrid modeling tool with the following characteristics:

• based on graphical models
• has a user interface that supports “quest for insight” in addition to “number crunching”
• allows for both continuous and discrete variables
• allows for modeling functional, stochastic, and mixed relationships
• supports manipulation (choice of policy variables) and derives the new structure by reconfiguring the model accordingly
• autonomously searches for opportunities and generates decision alternatives given objectives and costs
• is open for addition of Operations Research techniques, creativity enhancement tools, automatic model building, data mining tools
We try all our research to point (at least tangentially) in that direction.
Probabilistic Graphical Models in Strategic Planning

Models with equations and continuous variables and distributions

GeNIe allows for modeling systems of equations with uncertainty (modeled by continuous probability distributions). It derives the probability distribution over effect variables.

Directional probabilistic graphs
Practical challenges
Software demo
Concluding remarks
GeNIe/SMILE have the capability to analyze data, discover causal patterns in them, and build models based on these data.
**Qualitative inference**

-QGeNIe is a special version of the programs that hide numbers and operate on rough, order of magnitude estimates. This is especially useful in complex domain, in which it is hard to create exact models. Models like this have been shown extremely useful in group discussions focusing on problem solving.

Underlying numerical specification allows for indentifying most effective actions that achieve a specified goal.
Temporal reasoning

Temporal models allow for tracking development of a system over time and support decision making in complex environments, where not only the final effect counts.
Our software

A developer’s environment for graphical decision models (http://genie.sis.pitt.edu/).

Model developer module: GeNIe.
Implemented in Visual C++ in Windows environment.

Wrappers: SMILE.NET©, jSMILE©, Pocket SMILE©.
Allow SMILE© to be accessed from applications other than C++ compiler.

Reasoning engine: SMILE© (Structural Modeling, Inference, and Learning Engine).
A platform independent library of C++ classes for graphical models.

Support for model building: ImaGeNIe

Learning and discovery module: SMiner

Diagnosis: Diagnosis

Qualitative interface: QGeNIe

Decision Systems Laboratory
Directed probabilistic graphs
Practical challenges
Software demo
Concluding remarks

Probabilistic Graphical Models in Strategic Planning
Demonstration

Directed probabilistic graphs
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Concluding remarks
How good are GeNIe & SMILE?

• User interface (GeNIe) is probably the best there is in the World – we have paid a lot of attention to it.
• SMILE is reliable – it has been under heavy use for over ten years now.
• We have had well over 20,000 downloads, have heavy industrial users, and many university/research users.
• SMILE is faaaaaaaaaaaaast! It compares very favorably to commercial market leaders.
How fast are GeNIE & SMILE?♥?

- Results of the Uncertainty in Artificial Intelligence (UAI-06) Software Evaluation (Which team are we ♥?)
How fast are GeNIe & SMILE? 🙂

- Results of the Uncertainty in Artificial Intelligence (UAI-06) Software Evaluation (Which team are we? 😄)
How fast are GeNIe & SMILE?

Results of the Uncertainty in Artificial Intelligence (UAI-08) Software Evaluation (Hugin is an industry leader)

How fast are GeNIe & SMILE?

Results of the Uncertainty in Artificial Intelligence (UAI-08) Software Evaluation (Hugin is an industry leader)

Next steps

Inference in hybrid models (mixtures of discrete and continuous variables and probability distributions).

Causal graphs and causal reasoning.

Effective user interfaces:
- support for interactive building of structure
- enhancement of the parameter elicitation module
- graphical presentation of results
- model exploration (“instant gratification” interface)
- graphical and verbal explanation of results

Embedding decision-theoretic techniques: sensitivity analysis, value of information, etc.

Automatic search for opportunities and decision alternatives.
Thank you