ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

PhD Seminar Autumn Semester 2007

The Probabilistic Analysis of Systems in Engineering

- Bayesian probabilistic networks
  - Introduction of available software tools
  - Statistical inferences

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Bayesian probabilistic networks

Introduction

- A Bayesian network (BN) is composed of:
  - a set of variables
    - R: “it is raining”, discrete values T/F
    - T: temperature, continuous or discrete variable
    - C: colour, discrete values {red, blue, green}
  - a graphical structure connecting the variables, and
  - a set of conditional distributions

  - A BN is commonly represented as a graph, where
    - nodes represent the variables, and
    - arcs represent the conditional dependencies in the model.
    - An arc connects a parent (influencing) node to a child (influenced) node.

Bayesian probabilistic networks:
Introduction of available software tools

- Resources
  - Kevin Murphy's Software Package Survey
    - http://www.cs.ubc.ca/~murphyk/Software/bnsoft.html
  - Google`s List of tools
    - http://directory.google.com/Top/Computers/Artificial_Intelligence/Belief_Networks/Software/
  - Decision Systems Labroratory University of Pittsburgh
    - http://dsl.sis.pitt.edu/community_services/other_software.html
  - Bayesian Network Repository
    - http://www.cs.huji.ac.il/labs/compbio/Repository/

Introduction of available software tools

TABLE B.1
Software packages: name, Web location and developers (part I)

Name	Web Location	Authors
Analytica	http://www.lumina.com	Lumina (Henrion)
Bassist	http://www.cs.Helsinki.FI/research/fdk/bassist	U. Helsinki
Bayda	http://www.cs.Helsinki.FI/research/cosco/Projects/NONE/SW/	U. Helsinki
BayesBuilder	http://www.mbfys.kun.nl/snn/Research/bayesbuilder/	Nijman (U. Nijmegen)
BayesiaLab	http://www.bayesia.com	Bayesia Ltd
Bayesware Discoverer	http://www.bayesware.com	Bayesware (Open Univ., UK)
B-course	http://b-course.cs.helsinki.fi	U. Helsinki
BN power constructor	http://www.cs.ualberta.ca/~jcheng/bnpc.htm	Cheng (U.Alberta)
BNT	http://www.ai.mit.edu/~murphyk/Software/BNT/bnt.html	Murphy (prev U.C.Berkeley, now MIT)
BNJ	http://bndev.sourceforge.net/	Hsu (Kansas)
BucketElim	http://www.ics.uci.edu/~irinar	Rish (U.C.Irvine)
BUGS	http://www.mrc-bsu.cam.ac.uk/bugs	MRC/Imperial College
Business Navigator 5	http://www.data-digest.com	Data Digest Corp
CABeN	http://www-pcd.stanford.edu/cousins/caben-1.1.tar.gz	Cousins et al. (Wash. U.)
CaMML	http://www.datamining.monash.edu.au/software/camml	Wallace, Korb (Monash U.)
CoCo+Xlisp	http://www.math.auc.dk/~jhb/CoCo/information.html	Badsberg (U. Aalborg)
CIspace	http://www.cs.ubc.ca/labs/lci/CIspace/	Poole et al. (UBC)
Deal	http://www.math.auc.dk/novo/deal	Bottcher et al.
Ergo	http://www.noeticsystems.com	Noetic systems
First Bayes	http://www.shef.ac.uk/~st1ao/1b.html	U. Sheffield
GDAGsim	http://www.staff.ncl.ac.uk/d.j.wilkinson/software/gdagsim/	Wilkinson (U. Newcastle)
GMRFsim	http://www.math.ntnu.no/~hrue/GMRFsim/	Rue (U. Trondheim)
GeNIe/SMILE	http://www.sis.pitt.edu/~genie	U. Pittsburgh (Druzdzel)
GMTk	http://ssli.ee.washington.edu/~bilmes/gmtk/	Bilmes (UW), Zweig (IBM)
gR	http://www.r-project.org/gR	Lauritzen et al.

Introduction of available software tools

TABLE B.2
Software packages: name, Web location and developers (part II)

Name	Web Location	Authors
Grappa	http://www.stats.bris.ac.uk/~peter/Grappa/	Green (Bristol)
Hugin	http://www.hugin.com	Hugin Expert (U. Aalborg, Lauritzen/Jensen)
Hydra	http://software.biostat.washington.edu/statsoft/MCMC/Hydra	Warnes (U.Wash.)
Ideal	http://yoda.cis.temple.edu:8080/ideal/	Rockwell (Srinivas)
Java Bayes	http://www.cs.cmu.edu/~javabayes/Home/	Cozman (CMU)
MIM	http://www.hypergraph.dk/	HyperGraph Software
MSBNx	http://research.microsoft.com/adapt/MSBNx/	Microsoft
Netica	http://www.norsys.com	Norsys (Boerlage)
PMT	http://people.bu.edu/vladimir/pmt/index.html	Pavlovic (BU)
PNL	http://www.ai.mit.edu/ murphyk/Software/PNL/pnl.html	Eruhimov (Intel)
Pulcinella	http://iridia.ulb.ac.be/pulcinella/Welcome.html	IRIDIA
RISO	http://sourceforge.net/projects/riso	Dodier (U.Colorado)
TETRAD	http://www.phil.cmu.edu/tetrad/	CMU Philosophy
UnBBayes	http://sourceforge.net/projects/unbbayes/	?
Vibes	http://www.inference.phy.cam.ac.uk/jmw39/	Winn & Bishop (U. Cambridge)
Web Weaver	http://snowhite.cis.uoguelph.ca/faculty_info/yxiang/ww3/	Xiang (U.Regina)
WinMine	http://research.microsoft.com/~dmax/WinMine/tooldoc.htm	Microsoft
XBAIES 2.0	http://www.staff.city.ac.uk/~rgc/webpages/xbpage.html	Cowell (City U.)

Introduction of available software tools

TABLE B.3
Murphy's feature comparison of software packages

Name	Src	API	Exec	GUI	D/C	DN	Params	Struct	D/U	Infer	Free
Analytica	N	Y	WM	Y	G	Y	N	N	D	S	$
Bassist	C++	Y	U	N	G	N	Y	N	D	MH	O
Bayda	J	Y	WUM	Y	G	N	Y	N	D	?	O
BayesBuilder	N	N	W	Y	D	N	N	N	D	?	O
BayesiaLab	N	N	-	Y	Cd	N	Y	Y	CG	JT,G	$
Bayesware	N	N	WUM	Y	Cd	N	Y	Y	D	?	$
B-course	N	N	WUM	Y	Cd	N	Y	Y	D	?	O
BNPC	N	Y	W	Y	D	N	Y	CI	D	?	O
BNT	M/C	Y	WUM	N	G	Y	Y	Y	UD	S,E(++)	O
BNJ	J	Y	-	Y	D	N	N	Y	D	JT,IS	O
BucketElim	C++	Y	WU	N	D	N	N	N	D	VE	O
BUGS	N	N	WU	Y	Cs	N	Y	N	D	GS	O
BusNav	N	N	W	Y	Cd	N	Y	Y	D	JT	$
CABeN	C	Y	WU	N	D	N	N	N	D	S(++)	O
CaMML	N	N	U	N	Cx	N	Y	Y	D	N	O
CoCo+Xlisp	C/L	Y	U	Y	D	N	Y	CI	U	JT	O
CIspace	J	N	WU	Y	D	N	N	N	D	VE	O
Deal	R	-	-	Y	G	N	N	Y	D	N	O
Ergo	N	Y	WM	Y	D	N	N	N	D	JT(+S)	$
First Bayes	A	N	W	Y	-	N	N	N	–	O	O
GDAGsim	C	Y	WUM	N	G	N	N	N	D	E	O
GeNIe/SMILE	N	Y	WU	Y	D	Y	N	N	D	JT(+S)	O
GMRFsim	C	Y	WUM	N	G	N	N	N	U	MC	O
GMTk	N	Y	U	N	D	N	Y	Y	D	JT	O
gR	R	-	-	-	-	-	-	-	-	-	O
Grappa	R	Y	-	N	D	N	N	N	D	JT	O
Hugin	N	Y	WU	Y	G	Y	Y	CI	CG	JT	$
Hydra	J	Y	-	Y	Cs	N	Y	N	UD	MC	O
Ideal	L	Y	WUM	Y	D	Y	N	N	D	JT	0
Java Bayes	J	Y	WUM	Y	D	Y	N	N	D	JT,VE	O
MIM	N	N	W	Y	G	N	Y	Y	CG	JT	$
MSBNx	N	Y	W	Y	D	Y	N	N	D	JT	O
Netica	N	Y	WUM	Y	G	Y	Y	N	D	JT	$
PMT	M/C	Y	-	N	D	N	Y	N	D	O	O
PNL	C++	Y	-	N	D	N	Y	Y	UD	JT	O
Pulcinella	L	Y	WUM	Y	D	N	N	N	D	?	O
RISO	J	Y	WUM	Y	G	N	N	N	D	PT	O
TETRAD IV	N	N	WU	Y	Cx	N	Y	CI	UD	N	O
UnBBayes	J	Y	-	Y	D	N	N	Y	D	JT	O
Vibes	J	Y	WU	Y	Cx	N	Y	N	D	?	O
Web Weaver	J	Y	WUM	Y	D	Y	N	N	D	?	O
WinMine	N	N	W	Y	Cx	N	Y	Y	UD	N	O
XBAIES 2.0	N	N	W	Y	G	Y	Y	Y	CG	JT	O

Src Is the source code included? **N=no**. If yes, what language? **J** = Java, **M** = Matlab, **L** = Lisp, **C**, **C++**, **R**, **A** = APL.

API Is an application program interface included?

N means the program cannot be integrated into your code, i.e., it must be run as a standalone executable. **Y** means it can be integrated.

Exec The **executable** runs on: **W** = Windows (95/98/2000/NT), **U** = Unix, **M** = Mac-Intosh, **-** = Any machine with a compiler.

GUI Is a **G**raphical **U**ser **I**nterface included? **Y**=Yes,**N**=No.

D/C Are continuous-valued nodes supported (as well as discrete)? **G** = (conditionally) Gaussians nodes supported analytically, **Cs** = continuous nodes supported by sampling, **Cd** = continuous nodes supported by discretization, **Cx** = continuous nodes supported by some unspecified method, **D** = only discrete nodes supported.

DN Are decision networks/influence diagrams supported? **Y**=Yes,**N**=No.

Params Does the software functionality include parameter learning? **Y**=Yes,**N**=No.

Struct Does the software functionality include structure learning? **Y**=Yes,**N**=No.

CI means **Y**, using conditional independency tests (see §6.3)

K2 means **Y**, using Cooper & Herskovits' K2 algorithm (see §8.2)

D/U What kind of graphs are supported? **U** = only undirected graphs, **D** = only directed graphs, **UD** = both undirected and directed, **CG** = chain graphs (mixed directed/undirected).

Inf Which inference algorithm is used? (See Chapter 3)

JT = Junction Tree, **VE = variable (bucket) elimination**, **PT = Pearl's polytree**, **E = Exact inference** (unspecified), **MH = Metropolis Hastings**, **MC = Markov chain Monte Carlo (MCMC)**, **GS = Gibbs sampling**, **IS = Importance sampling**, **S = Sampling**, **O = Other** (usually special purpose), **++ = Many** methods provided, **?** = Not specified, **N** = None, the program is only designed for structure learning from completely observed data.

NB: Some packages support a form of sampling (e.g., **likelihood weighting**. **MDMC**), in addition to their exact algorithm; this is indicated by (**+S**).

Free Is a free version available? **O**=Free (though possibly only for academic use), **$** = Commercial (although most have free versions which are restricted in various ways, e.g., the model size is limited, or models cannot be saved, or there is no API.)

FIGURE B.1
Description of features used in Murphy's BN software survey, in Table B.3.

Introduction of available software tools

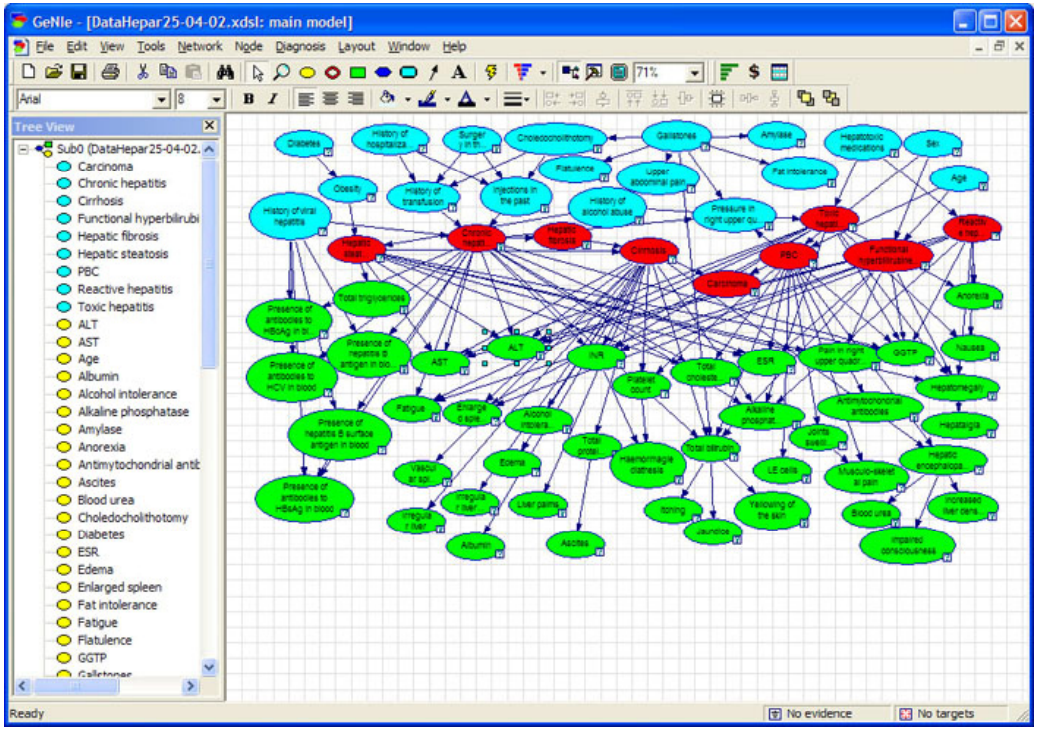
- GeNIe (**G**raphical **N**etwork **I**nterface)

  - Developed by Decision System Laboratory, University of Pittsburgh
  - http://genie.sis.pitt.edu/

  - Primary Features
    - Graphical editor to create and modify network models
    - Uses the SMILE Engine. You may develop models in GeNIe and create a custom interface for them using SMILE
    - Supports chance nodes with General, Noisy OR/MAX and Noisy AND distribution
    - Open multiple networks and cut and paste sections of models between them
    - Complete integration with MS. Excel, cut and paste data into internal spreadsheet view of GeNIe
    - Cross compatibility with other software. Supports all major file types (e.g. Hugin, Netica, Ergo)
    - Support for handling observation costs of nodes
    - Support for diagnostic case management

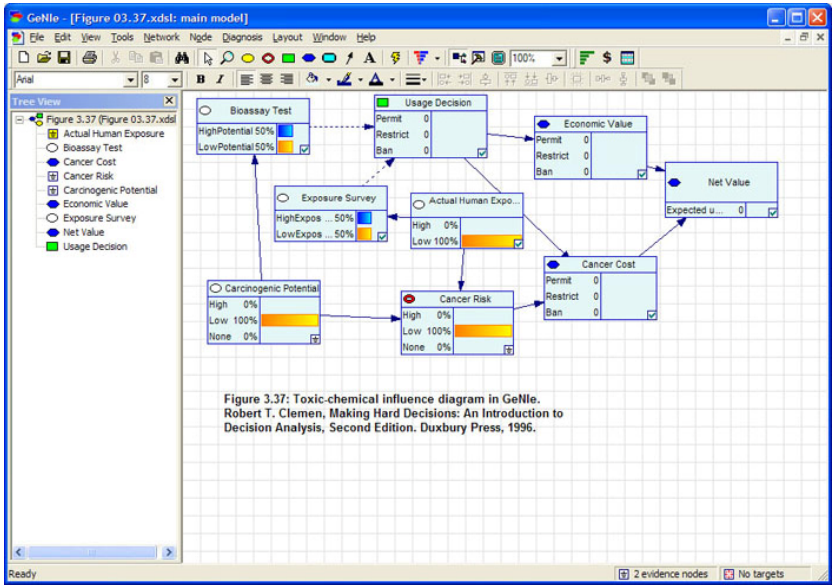
Introduction of available software tools

- GeNIe (Screenshots)

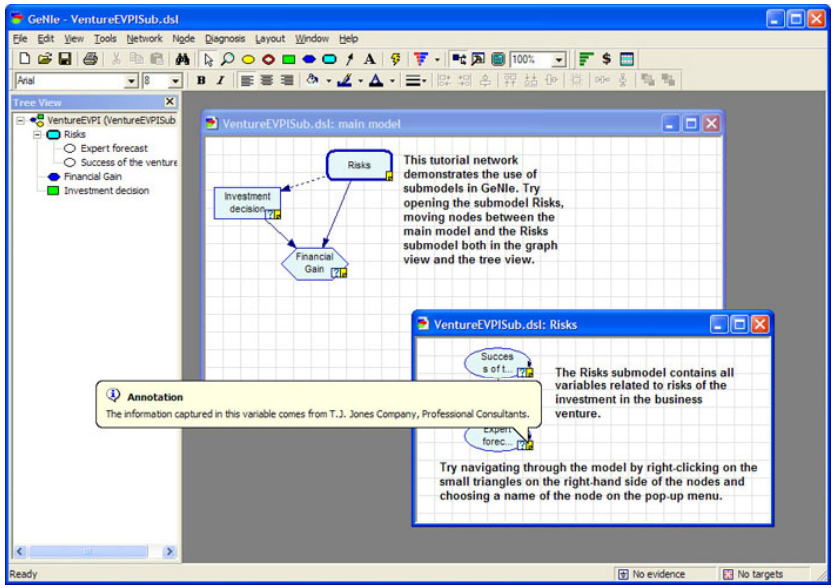


Introduction of available software tools

- GeNIe (Screenshots)



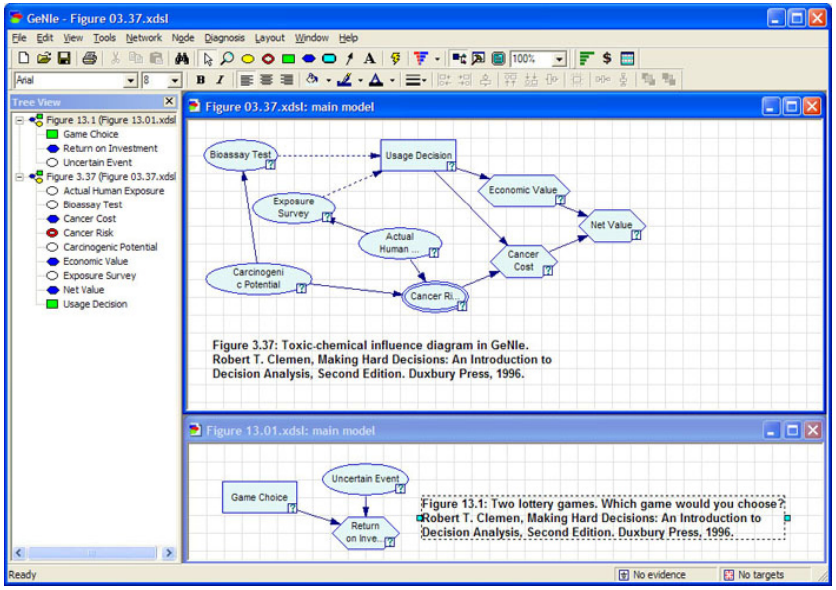
Nodes as Charts



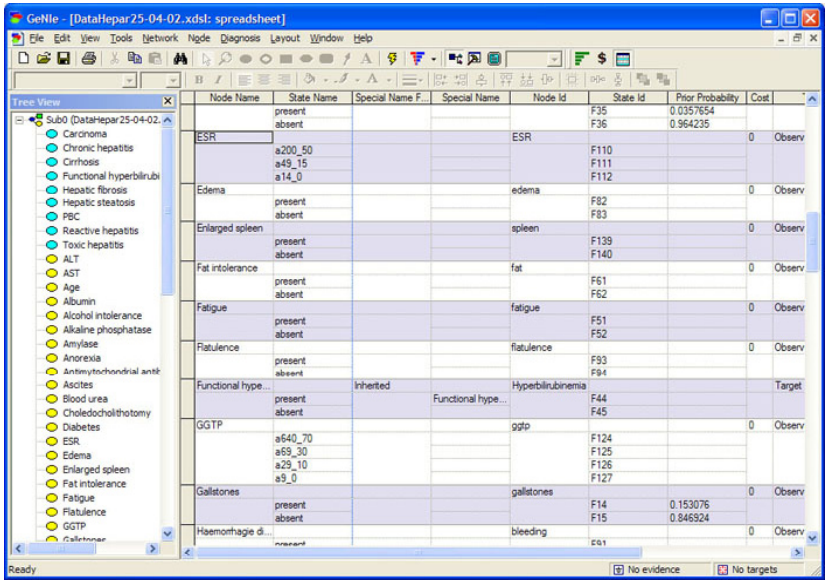
Submodels

Introduction of available software tools

- GeNIe (Screenshots)



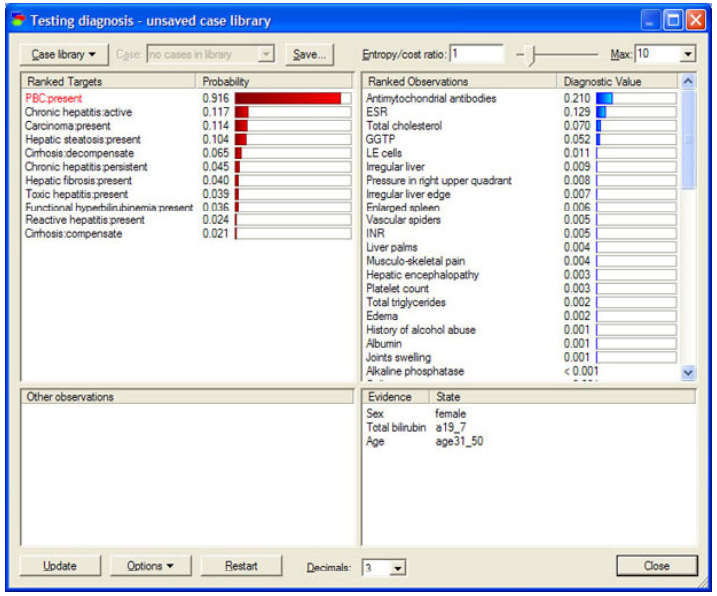
Multiple Models



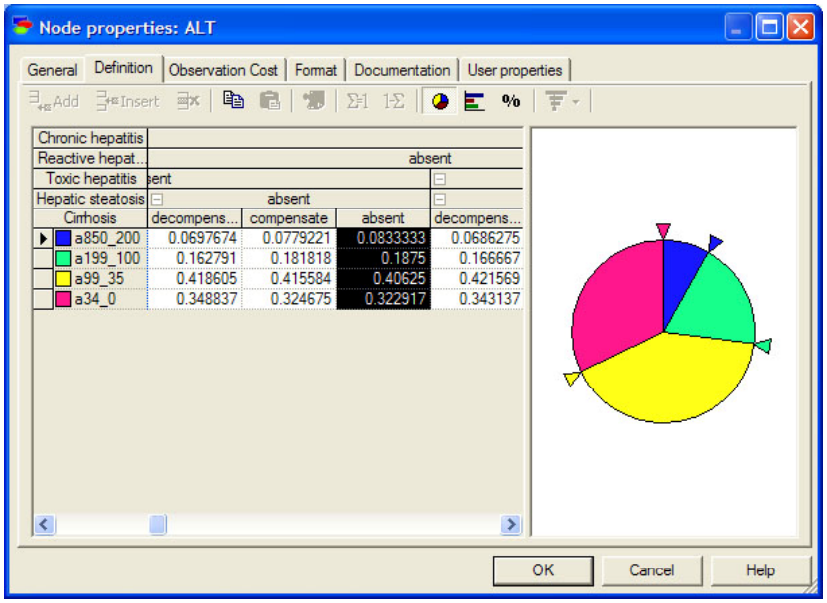
Spreadsheet View

Introduction of available software tools

- GeNIe (Screenshots)



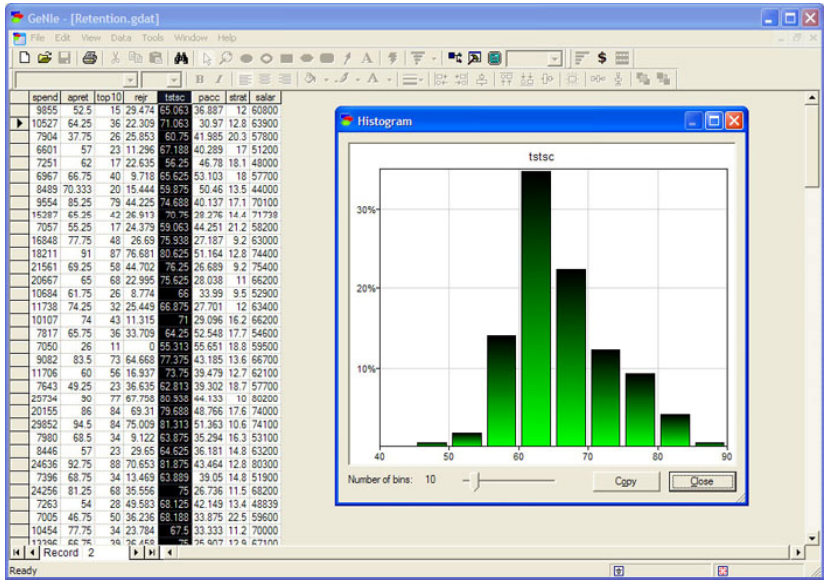
Diagnosis



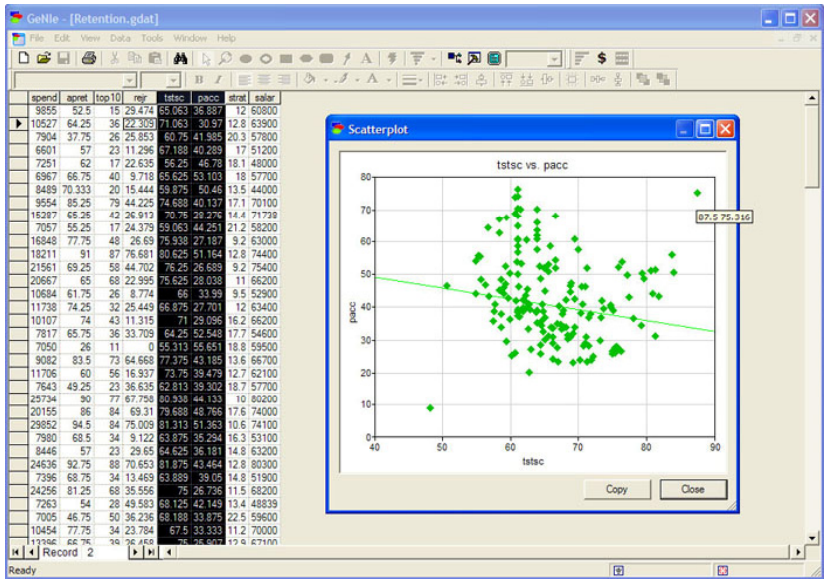
CPT Ellicitation

Introduction of available software tools

- GeNIe (Screenshots)



Data Histogramm



Data Scatterplot

Introduction of available software tools

- Hugin

  - Originally developed by a group at Aalborg University
  - http://www.hugin.com

- Primary Features
  - HUGIN Graphical User Interface
  - Construction of object-oriented Bayesian networks and influence diagrams models
  - Discrete chance and decision nodes with subtypes labelled, boolean, numbered and interval
  - More than one utility node
  - Conditional Gaussian distributed variables (exact inference)
  - Table Generator supporting Discrete and Continuous distributions
  - Learning Wizard supporting Data acquisition and preprocessing, Structural learning, structural constraints, Estimation of the conditional probability distributions
  - Revision, Analysis, Development and Documentation

Introduction of available software tools

- **MSBNx**
  - http://research.microsoft.com/adapt/MSBNx/

  - Primary features
    - Graphical Editing of Bayesian networks
    - Exact Probability Calculations using clique-tree propagation methods
    - Decision-Theoretic Diagnosis, Troubleshooting, and Recommendations
    - Using your cost information or defaults, MSBNx dynamically recommends troubleshooting steps
    - It bases its recommendations on a cost-benefit analysis

Introduction of available software tools

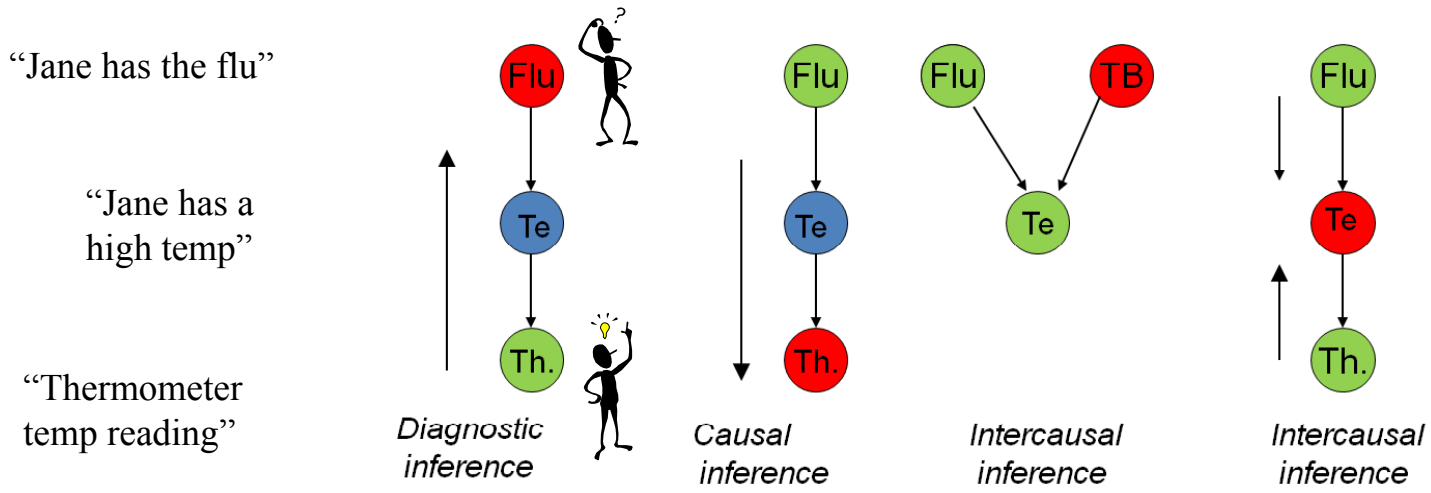
- BUGS
  - BUGS **B**ayesian inference Using **G**ibbs **S**ampling
  - http://www.mrc-bsu.cam.ac.uk/bugs/

  - Primary features
    - BUGS provides Analysis of complex statistical models using Markov Chain Monte Carlo (MCMC)
    - BUGS features a graphical user interface and on-line monitoring and convergence diagnostics
    - BUGS provides a language for specifying a Bayesian Network, a compiler for processing the model and data and sets up the sampling distributions required for the Gibbs sampling
    - Appropriate sampling algorithms to simulate values of the unknown quantities in the model

Bayesian probabilistic networks

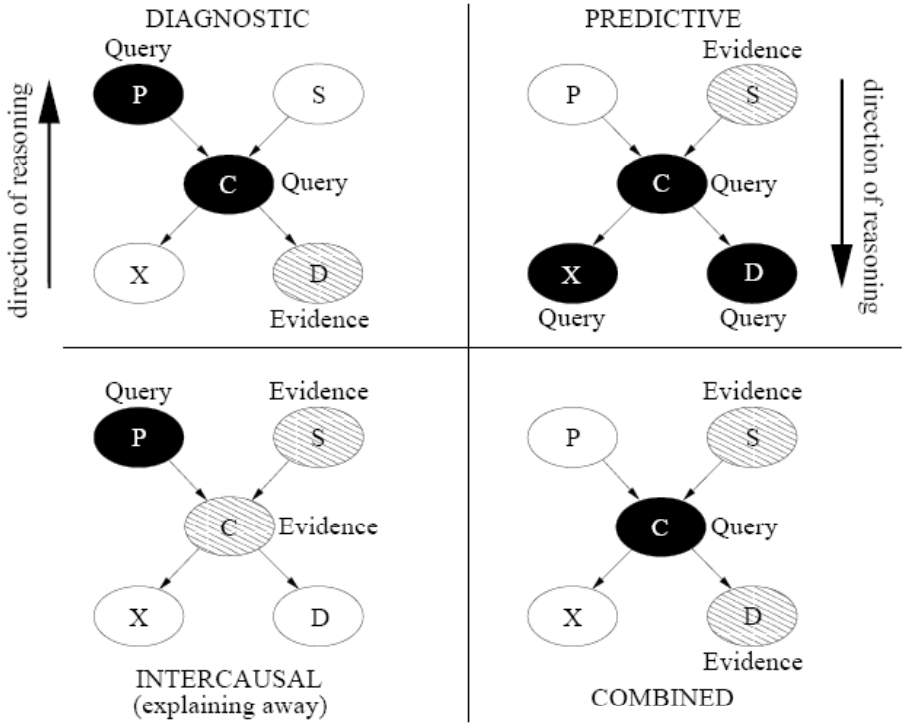
Statistical inferences

- Reasoning within BN
  - Also called conditioning or belief updating or inference
  - Inference is an observation of a specific state
  - The task is to compute the posterior probabilities for **query** node(s) given **evidence**



Statistical inferences

- Types of Reasoning

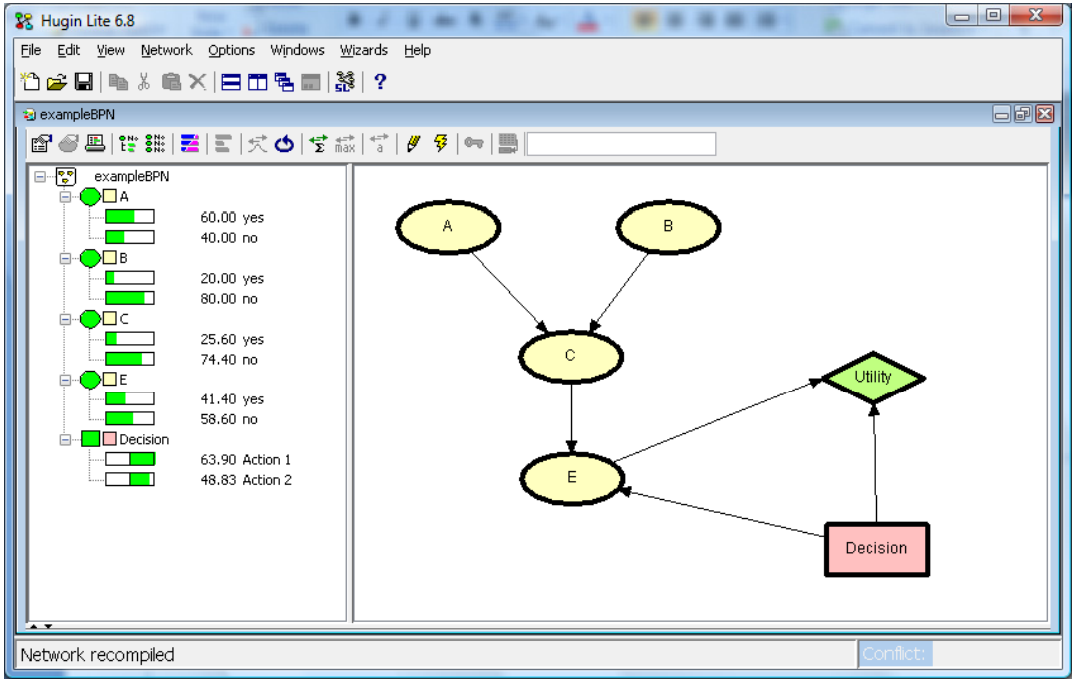


- Types of evidence
  - Specifc evidence: a definite finding that a node X has a particular value, x.
  - Negative evidence: a finding that node Y is not in state y_1 (but may take any other values)
  - "virtual" or "likelihood" evidence: source of information is not certain

Example: e=radiologist is 80% sure that Xray=positive

Statistical inferences

- Hugin Example: Bayesian network



A

yes	0.6
no	0.4

B

yes	0.2
no	0.8

C

B	yes		no	
A	yes	no	yes	no
yes	0.2	0.7	0.3	0.1
no	0.8	0.3	0.7	0.9

E

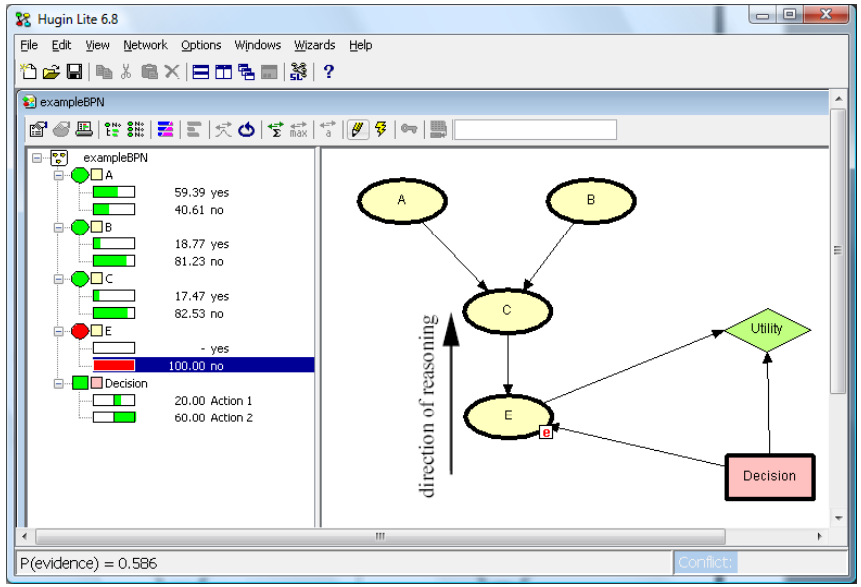
Decision	Action 1		Action 2	
C	yes	no	yes	no
yes	0.4	0.6	0.8	0.1
no	0.6	0.4	0.2	0.9

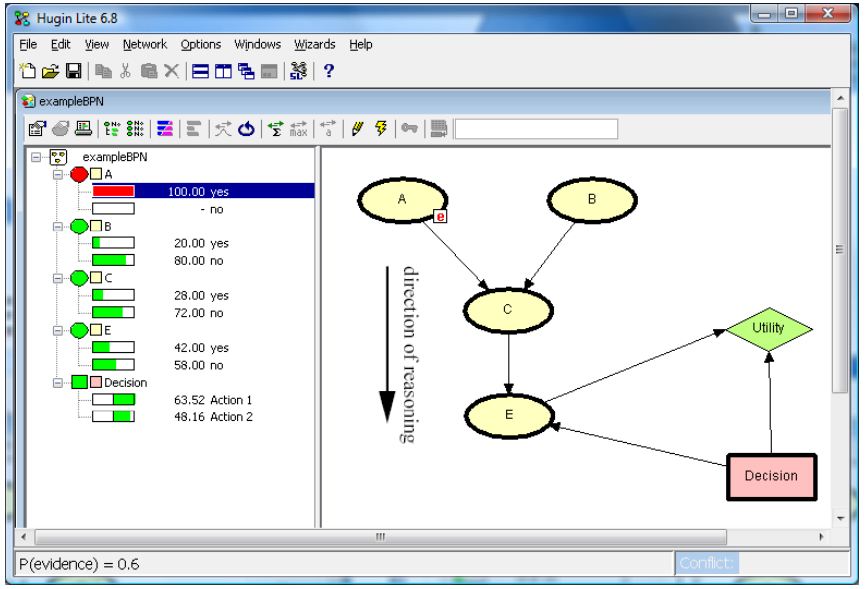
Utility

E	yes		no	
Decision	Action 1	Action 2	Action 1	Action 2
Utility	100.0	20.0	20.0	60.0

Statistical inferences

- Hugin Example: Bayesian network





Diagnostic Reasoning

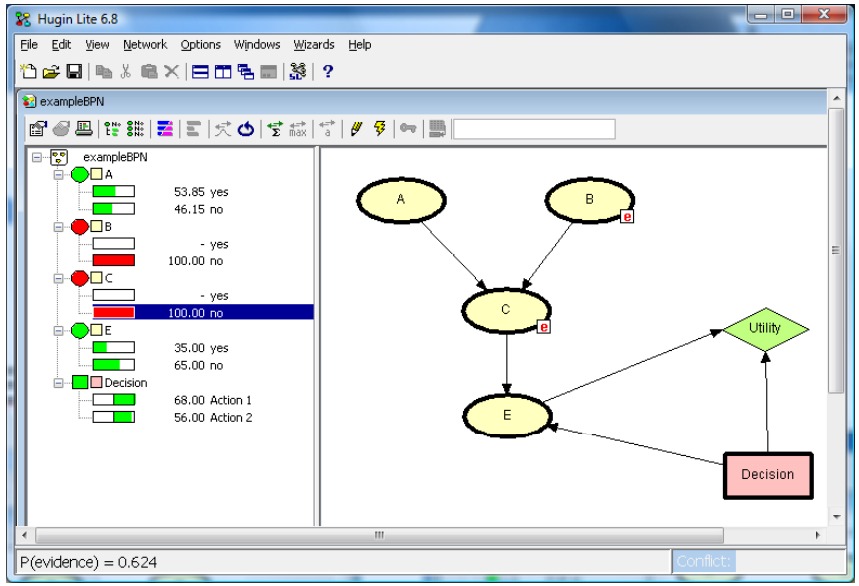
- Evidence in E
- Query Variables = C and A

Predictive Reasoning

- Evidence in A
- Query Variables = C and E

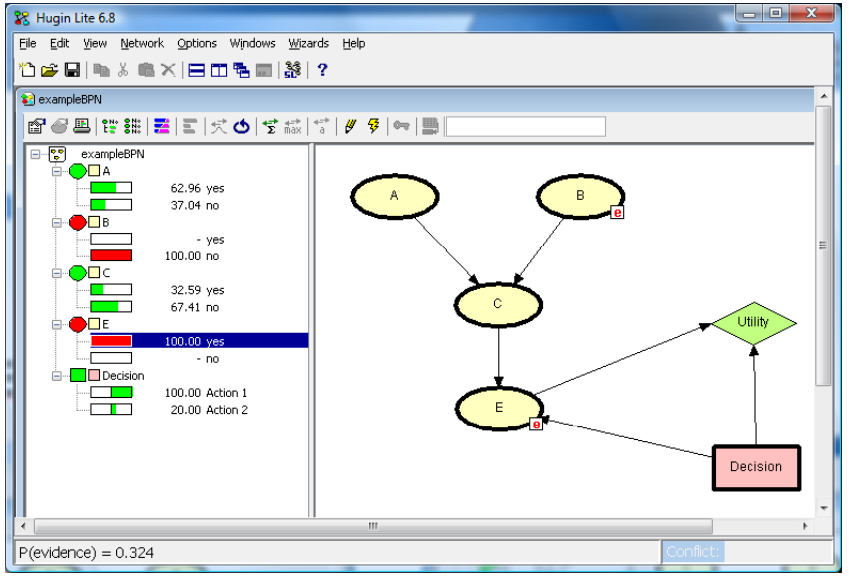
Statistical inferences

- Hugin Example: Bayesian network



Intercausal Reasoning

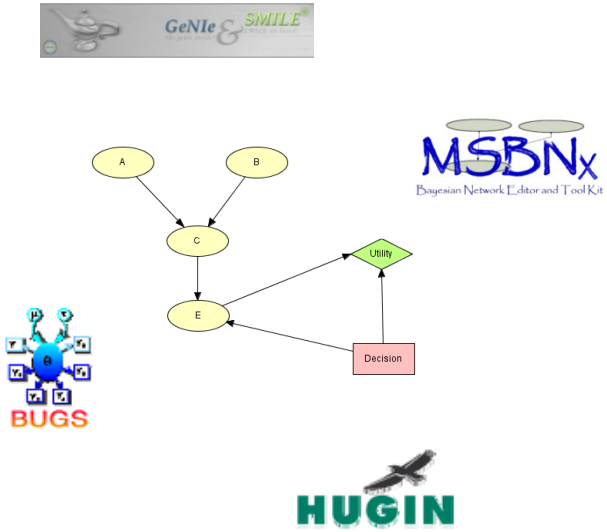
- Evidence in B and C
- Query Variables = A



Combined Reasoning

- Evidence in B and E
- Query Variables = C

Conclusion Bayesian probabilistic networks



- Introduction of available software tools
  - Kevin Murphy‘s listing is good source for information for software packages for BN
  - Describtion of GeNIe, Hugin, MSBNx and BUGS and their key features
  - In general all the packages include advanced GUI features
- Statistical inferences
  - Reasoning within Bayesian Networks
  - Types of evidence (Specifc, negative, virtual)
  - Example in Hugin

Everyday life presents us with many situations in which the accumulation of evidence leads to a conclusion.

Thank you for your attention!