

# A Roadmap to Research on Bayesian Networks and other Decomposable Probabilistic Models

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## Abstract

This paper is a listing of literature on Bayesian Networks and related graphical probability models. It is my own personal notes and is continually changing, but feel free to grab a copy. If you have additions or corrections, please let me know.

*[RG: This has NOT been updated since around Dec'96.]*

## 1 Network Representations Defined

### 1.1 General Properties of Conditional Independence

*Graphical Axioms of C.I.:* [Daw79], [Daw80], [Spo80], [GP88], [Pea88b], [Smi89], [Smi90] **Critical Graph Theoretical Properties:** [LSV84], [Spe79] *Hyper-Markov laws:* [DL93b], [HB94b] *Mathematical properties of Markov Fields:* [Ish81], [Lau82] **Causal Independence:** [HB94b]

### 1.2 Bayesian Networks

**General overviews:** [Cha91], [HH88], [HBH91], [HBH88], [Pea87a], [Pea88b], [Pea93], [Jen93] **Structure Definitions:** [KP83], [Pea86b], [Pea88b], [GVP90] **Inter-causal structure:** [MD90], [D'A91]. **Noisy-OR:** [Pea86b], [Pea88b], [PR86], [Die93], [Sri92], [Sri93], [HS93], [Ago91], [ZP94], [Hec93], **Additive Models:** [DG93a], [HT87], [DGH92], [DG93a] **Alternative Representations:** [KS95] **Independence relations implied in Bayesian Network graphs** [PP85], [PV87], [Pea86b],

### 1.3 Influence Diagrams

Influence Diagrams include decision nodes and a value (utility) node. [HM84] [How90], [PGV90], [Smi90], [Pro93b], [Ken86], [TS90], [BG95], [ZQP93b], [She92], [SP92], [Ndi94], [SN93], [JJD94]

### 1.4 Undirected Networks

Also known as Markov Networks. [DLS80], [LS88], [Pea88b]

### 1.5 Alternative Representations of probability distributions

**Chain Graphs:** (Hybrid directed-undirected): Also known as “block recursive Markov random fields.” [KSC84] (studies a special case — recursive causal graphs. Only top ancestors can be connected with undirected edges, all others by directed edges), [LW89], [WL89], [WL90], [Fry90], [Bun95b], [Mee95] **Directed Cyclic Graphs:** [Spi94, Spi95], [PD96] **Similarity Networks:** [Hec90a], [Hec90b], [GH91], [GH93]

**Decision-Tree:** [Jir94] **Balloon Graphs:** Described in [She93]. Invented by G. Shafer 1993, but that book is apparently not yet published.

## 1.6 Networks of Non-probabilistic representations of Uncertainty

(These involve mostly generalizations of point probability) **Qualitative Networks:** [Wel90a], [Wel90b], [Wel90c], [PM93], [Par95] **Belief Functions:** [Dem90], [Kon86], [Mel87], [SS86], [SSM87], [SS90], [Wil90], [Xu91], [ZHS88], [WD94b], [SSS95], [Sri95] **Convex Probabilities:** [BF91], [CDM91], [CMVL93], [CDM93], [FB93], [Tes92], [dCM95], [Chr96] **Previsions:** [Gol90] **Second-Order Distributions:** [Mus93], [NK91] **Generalized Axiomatizations:** (These generalize most of the above types of networks) [She93], [SS86], [SS90], [SE91] **Potential Influence Diagrams:** [SN93] [She92], [SP92], [Ndi94], [JJD94]

## 1.7 Specialized Network Forms

### 1.7.1 Temporal Bayesian Network

Where identical stage is replicated multiple times over time: [AR90], [KD89], [KNL<sup>+</sup>93], [Kja92], [Kja95a], [OL92], [NB94], [Fun88], [DGH92], [Pro93b], [HKM<sup>+</sup>94], [DBL90], [NB92], [DG93b], [BBQ89], (embeds Semi-Markov model), [Ken86], [TS90], [Hec93], [HHNK95], [NHH95], [KKR95], Markov Decision Processes (MDPs) with each state an influence diagram: [Pro93a].

## 1.8 Classical Statistical Uses

(e.g., Hypothesis testing, etc) [DLS80], [Lau82], [LW89], [BIS90]

## 1.9 Continuous variables and parametric distributions

**Gaussians:** [SK89], [AHSE93], [DM95] (mixture), [CF91], [Lau92], [GH94b] **CG-Distributions:** [LW89], [Ole93], **Exponential Families:** [Bun95a], [Whi90], **Issues of Conjugacy:** Dawid's response to [LS88], **Continuous Belief-Function Densities:** [WD94b], [WD94a], **others:** [AFS94], [KSC84], [GH94a], [GH95a], [Ken86],

## 1.10 Philosophical Issues

### 1.10.1 Causality and Control

refs: [Pea88a], [Pea94b], [Pea94a], [Pea95b], [Pea95a], [SGS93], [DS93], [HS94], [CS92], [BP94], [BP95], [GP95], [GP96], [HB94b], [Pea96] [Sto93]

### 1.10.2 Modeling

Various critiques and/or criticisms on the problems and issues involved in designing or using a graphical model: [Spe90].

### 1.10.3 Other

**Counterfactuals** [Bal95]

## 1.11 Important Relationships to Other formalisms

To Hidden Markov models [SHJ96].

## 2 Solution Techniques

Unification of Existing Techniques: [SAS94]

## 2.1 Types of Queries

## 2.2 Exact Marginals or Policies

### 2.2.1 Propagation on Specialized Forms

Causal Polytrees: [Pea86b], [Pea88b], [DGKP95]

### 2.2.2 Junction-Tree Propagation

Method of Compiling a propagation graph from a general network with (undirected) loops: [Spi86], [LS88], [Spi90], [Daw92], [Jen94], [JJD94], [JJ94], [JOA90], [AK93], [JLO90], [Bon87], [Dra95], [SL90]

### 2.2.3 Cutset-Conditioning

Method for dealing with undirected loops: [Pea86a], [Pea88b, pg. 204–210], [ZP92], [BG94], [Dar95], [Dear], [SC90], [PS91], [Dar94a]

### 2.2.4 Arc Reversal

General method for solving Influence diagrams: [Sha86], [Sha90] [FB93], [BF91], [Mus93]

### 2.2.5 Symbolic Solution

Surprisingly, some good results have emerged by symbolically manipulating equations defining a joint probability distribution, much like Mathematica might do. [CF91], [SDD90], [D'A90], [D'A94] [LS88, Comments by W. S. Kendall], [CGH95]

## 2.3 Exact Optimization

Finding the best (highest probability) configuration.

### 2.3.1 Junction-Tree Propagation

Max propagation: [DDP90], [Daw92]

### 2.3.2 Linear Programming

Formalizations as linear or non-linear programming problems: [San94], [LD94]

## 2.4 Approximation

### 2.4.1 Stochastic Simulation

Markov Chain Monte-Carlo based techniques (mostly Gibbs Sampling): [GG84], [CC87], [CC90], [Pea87b], [DC93], [DH93], [JKK93], [DH92], [Hry90], [Nea93], [DKL95], [Kja95b], [KKR95], [MC96]. (Of these, [JKK93, JKK95, MC96, DKL95, JKK93, JKK95, Kja95b] can be viewed as being a combinations of Gibbs sampling and exact propagation.) **Logic Sampling:** [Hen88] **Likelihood Weighting:** [FC89], [SP89] **Backward Simulation:** [FDF94] **Mean Field Theory:** [SJ95], [SJJ96]. **Monte Carlo for Dempster-Shafer:** [Wil91] **MCMC for Dempster-Shafer:** [MW94]

### 2.4.2 Structure Alteration or Abstraction

Simplifying the network structure to obtain an approximation: [Kja93], [Kja94], [PFH94], [WL94], [Pro93b], [Sar93], [Lam94], Removal of Small Probabilities: [JA90], [CBS95] **Quality of an Abstraction:** [KV95], [Las91], [Las93], [LL94]

### 2.4.3 Approximation of Cutset-Conditioning

By taking only a subsample of the conditioning variables' values: [Dar94b, GD95]

### 2.4.4 Heuristic

Searching for optimums using heuristic search: [DDP90], [Hen91] Using Genetic Algorithms: [RK93] Using Laplace's Method: [AFS94]

### 2.4.5 Anytime Algorithms

Various approaches for anytime computation: [Poo93], [DH94] (gets bounds from looking only at a subset of the network, expanding subset with time).

## 2.5 Theoretical Complexity

NP-Hardness results: [Coo87], [Coo90], [DL93a],[Shi94], [VP93] (Note: [Ros75] actually proved the NP-hardness of exact solution by proving NP-hardness of a special case called fault trees. However, [Coo87] is the better known result.)

## 2.6 Other forms of queries

### 2.6.1 Value of Information

How valuable would one additional piece of evidence be: [How66] [DBL90], [Mat90], [ZQP93a], [HHM91], [HHM93], [JL94], [Eza94]

### 2.6.2 Fast Retraction of Evidence

How does result change if one (or more) item(s) of evidence is not included (related also to Sensitivity Analysis): [Daw92], [Jen95]

### 2.6.3 Sensitivity Analysis

How sensitive are answers to model probabilities: [Kor90], [HS93], [Las93], [CNKE93], [NK91], [NA91], [Pro91], [CS95] **Derivatives:** [Bun95a]

### 2.6.4 K-most probable cases

Compute the  $K$  most probable configurations, rather than just the single most probable one: [Hen90], [SG94], These find  $K$ -highly probable plans but no necessarily the  $K$  best: [KNL<sup>+</sup>93]

### 2.6.5 Generating Explanations

Explaining an inference: [Shi93], [LD93]

### 2.6.6 Other

Obtaining a simple description of the optimal policy in an Influence diagram: [LS93]

## 3 Learning/Acquiring Models

Survey: [Bun95a], [Hec95b]

### 3.1 Learning probabilities given structure:

(General purpose EM techniques not listed) [LPP95], [Mus93]

### 3.2 Learning structure

**Bayesian Learning Approaches:** [HGC94, HGC95], [HG95], [CGH94], [Hec95b], [Hec95a], [GH95a], [GH95b], [HB94a], [DL93b], [CH91b], [CH91a], [AC94], [Bad92], [Bun94], [CH92], [Coo95b], [Coo95a] [SDLC93] [Bou94], [Bun91], [Bun95b], [GH94b] **MDL:** [LB93], [Suz93] **Non-Bayesian Learning Approaches:** These usually involve statistical tests to find conditional independencies, followed by searches for good network encodings of these independencies. [PV91], [VP92], [SGS93], [SG91] [SV93], [FC90], [GPP93], [Chi95], [Mee95] **Acquiring Models from Experts:** [Mer90], [Hec93], [Jir90], [DvdG95] **Refinement of Existing Models:** [PH93], [CDS93], [OLJ92], [Las91]

## 4 Model-Based Knowledge Construction

Constructing a simplified problem-instance specific model from a larger and more general knowledge base: [BGW94], [WBG92], [Wel90a], [Bac93], [Poo93], [LL94], [SE94], [NB94], [Pro94], [PFH94], [Had94], [XPB92], [BGHK94], [Bre92], [NH95b, NH95a], [HHNK95, NHH95], [GC93, GC90] [DS94], [Pro93a], [GK95], Fusing Multiple Networks: [MA93], [Sha91]

## 5 Applications

Surveys: [HMW95] (and CACM March 1995 issue), [NO93], **Medical:** [BBQS92], [Coo84], [Hen90], [SEH90], [dBP90], [Spi87], [Spi90], [Hec89], [DG93b], [BBS91], [KRW+95], [Pro93a] **Monitoring (non-medical):** [HB95] **Tracking:** [KC90], [Fun88], [HKM+94] **High Risk Analysis:** [OY90], (Nuclear:)[PH90], **Troubleshooting:** [HBR94], [BH95] **Vision:** [JCJ93], [JCN92] **Classification:** [MC93], [PFH94] **Market Forecasting:** [Abr91], [DGH92] **Finance:** [ES95]

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