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Simulation Metamodeling Using Dynamic Bayesian Networks with Multiple Time Scales

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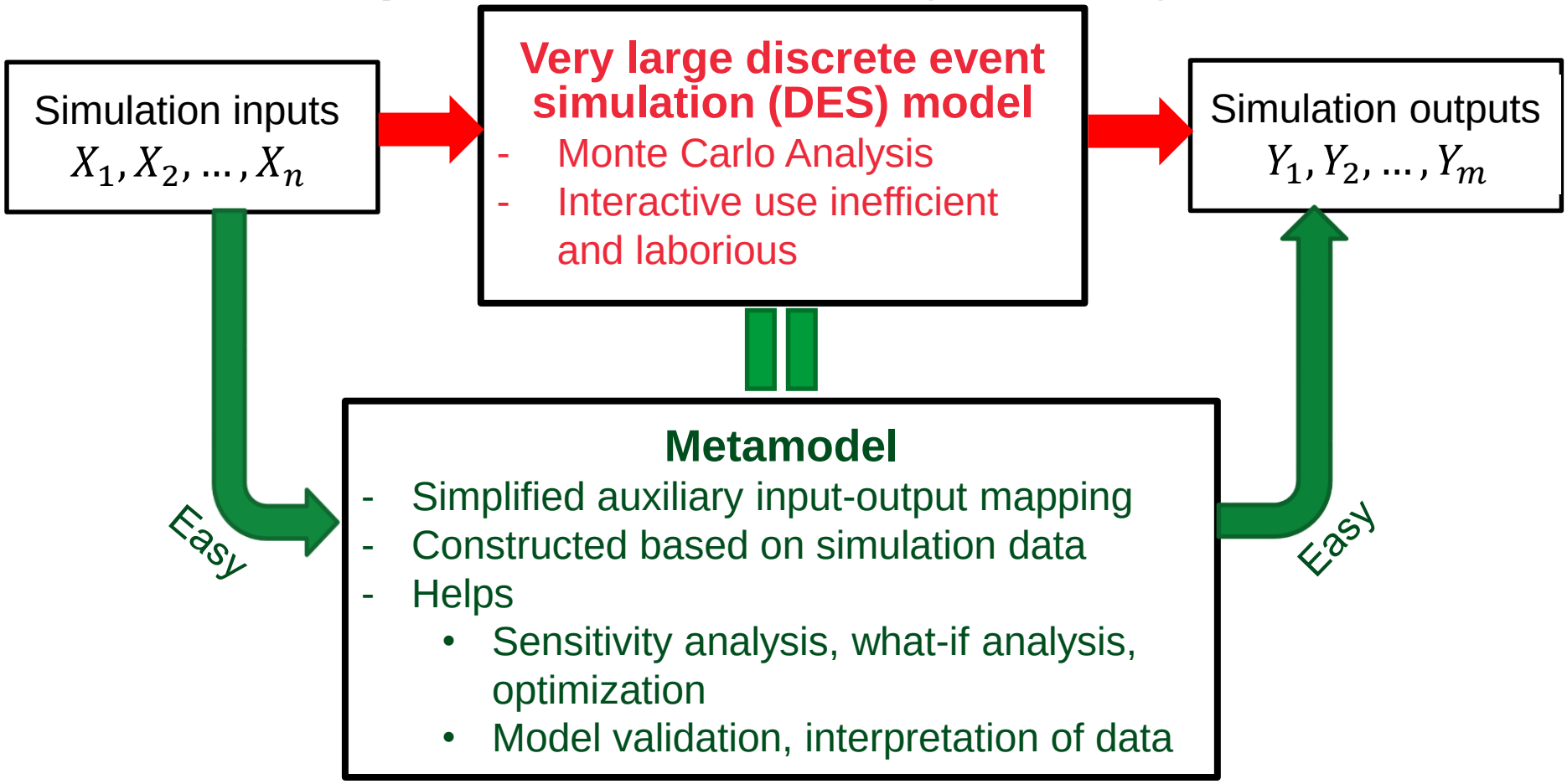
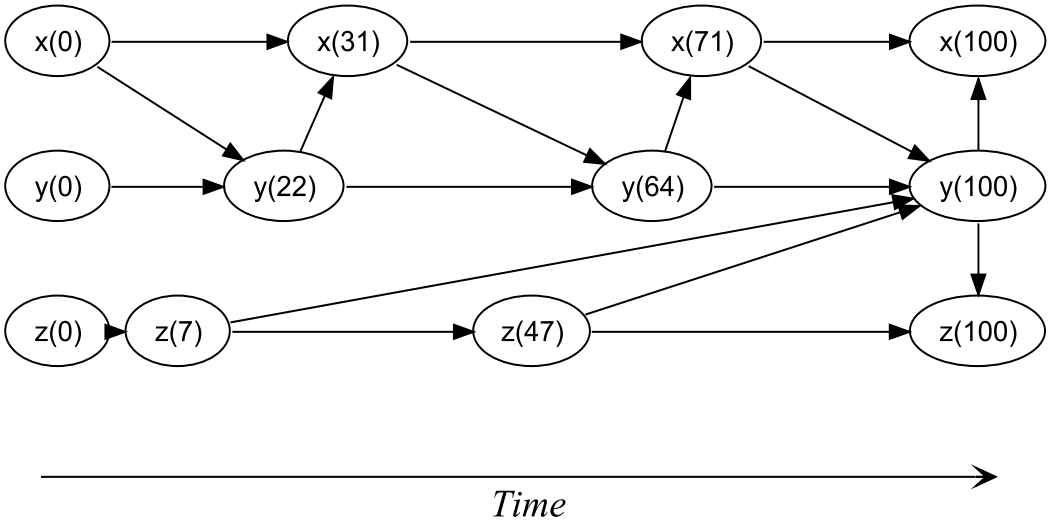
Simulation metamodeling

Complex and stochastic dynamic system

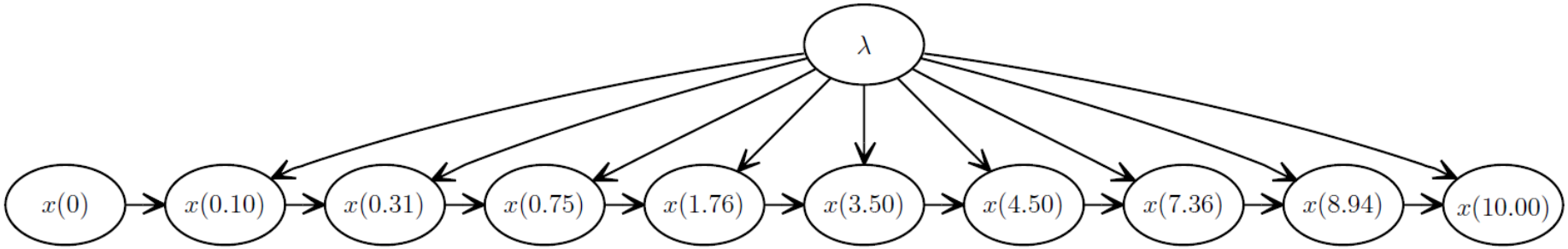


Dynamic Bayesian Network (DBN)

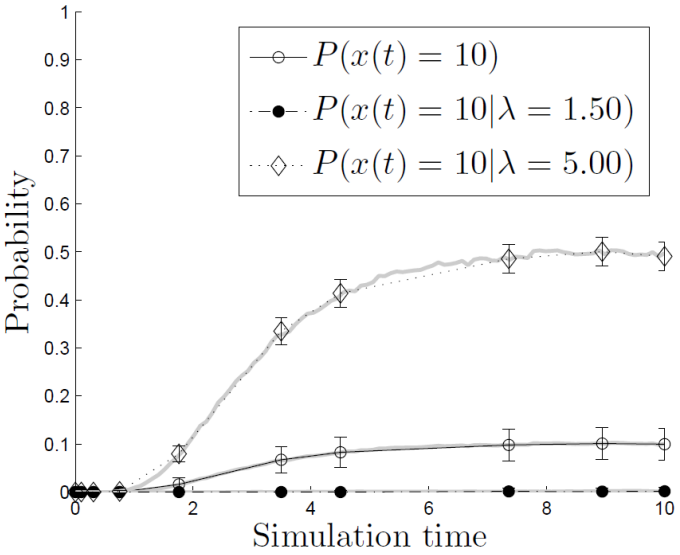
- Joint probability distribution of a sequence of discrete valued random variables
- Dynamic variables
  - Nodes
  - Specific time instants
- Dependencies
  - Arcs
  - Conditional probability tables



DBN metamodels



- Variables of DES models and DBNs equated
- Joint distribution of all variables
- Key time instants for state variables
- Construction is challenging



Construction of DBN Metamodels

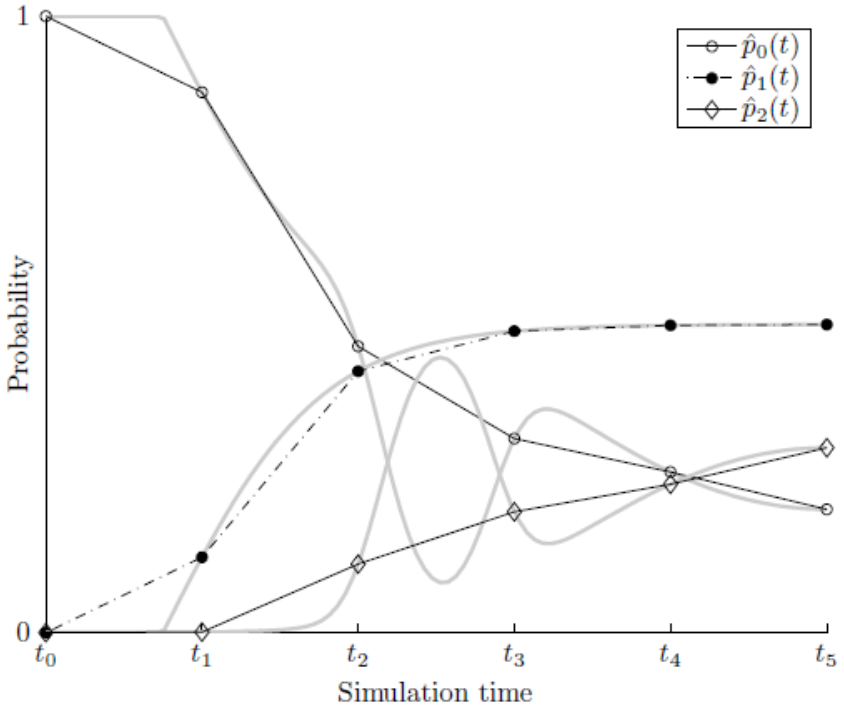
1) Selection of variables
2) Collecting simulation data
3) Optimal selection of time instants
4) Determination of network structure
5) Estimation of probability tables
6) Inclusion of simulation parameters
7) Validation

Optimal Selection of Time Instants

- Probability curves $p_i(t) = P(x(t) = i)$ estimated from simulation data
- DBN gives probabilities at discrete times $T = \{t_0, \ldots, t_f\}$
- Piecewise linear interpolation

$$\hat{p}_j(t) = p_j(t_-) + \frac{p_j(t_+) - p_j(t_-)}{t_+ - t_-}$$

$$t_- = \max\{v \in T | v \leq t\}$$
$$t_+ = \min\{v \in T | v \geq t\}$$



Optimization Problem

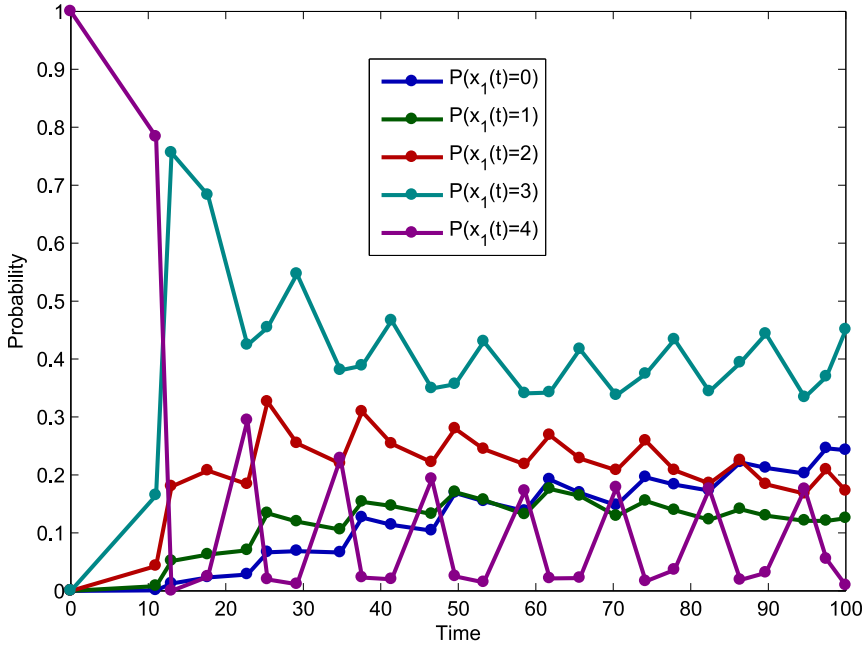
- Separately for each state variable by solving an optimization problem
  - Piecewise linear approximation sought for the time evolution of probabilities, i.e., a curve fitting problem
  - Minimize error of approximation
  - Break points of the approximation selected as the time instants
- Solved by an algorithm based on dynamic programming
  - Initial dense discretization of the timeline
  - Optimal subsets of time instants determined
  - Different solutions for different numbers of time instants

Example: Simulated Operation of Air Base

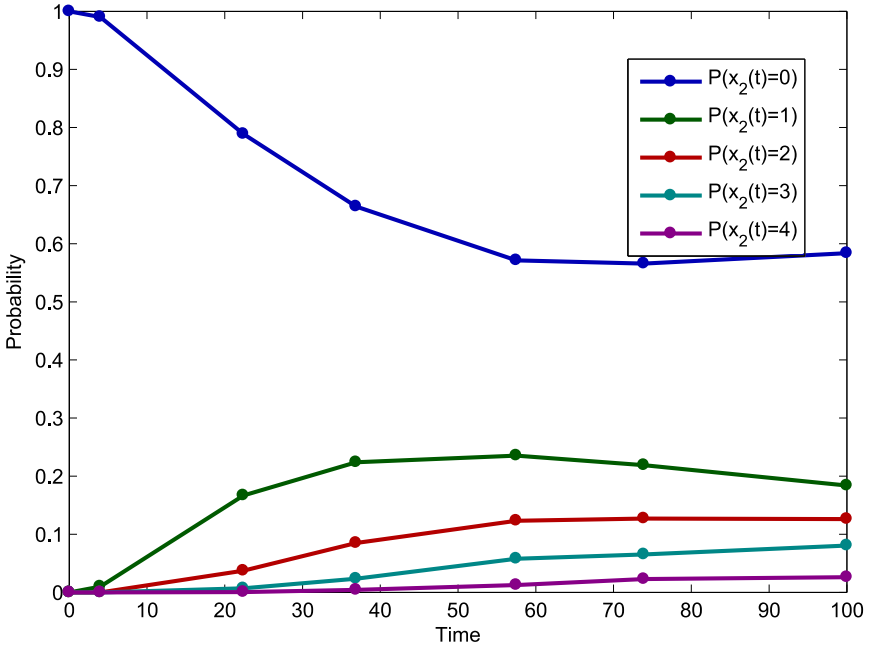
- Aircraft go through a four stage cycle
  - Mission assignment
  - Mission execution
  - Repair (only if damaged)
  - Service
- Two types of missions
  - Regularly scheduled patrol missions
  - Combat missions, whose generation is random and dependent on an input variable
- Random duration of mission execution, repair, and service

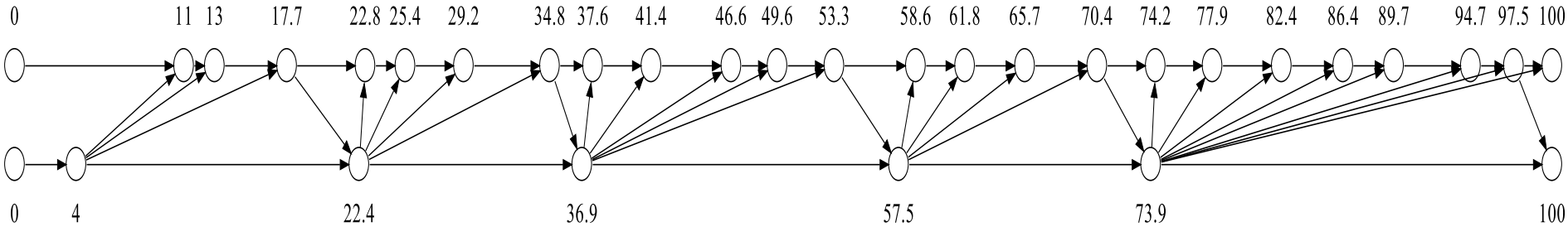
State Variables

- Aircraft in mission assignment



- Aircraft in repair





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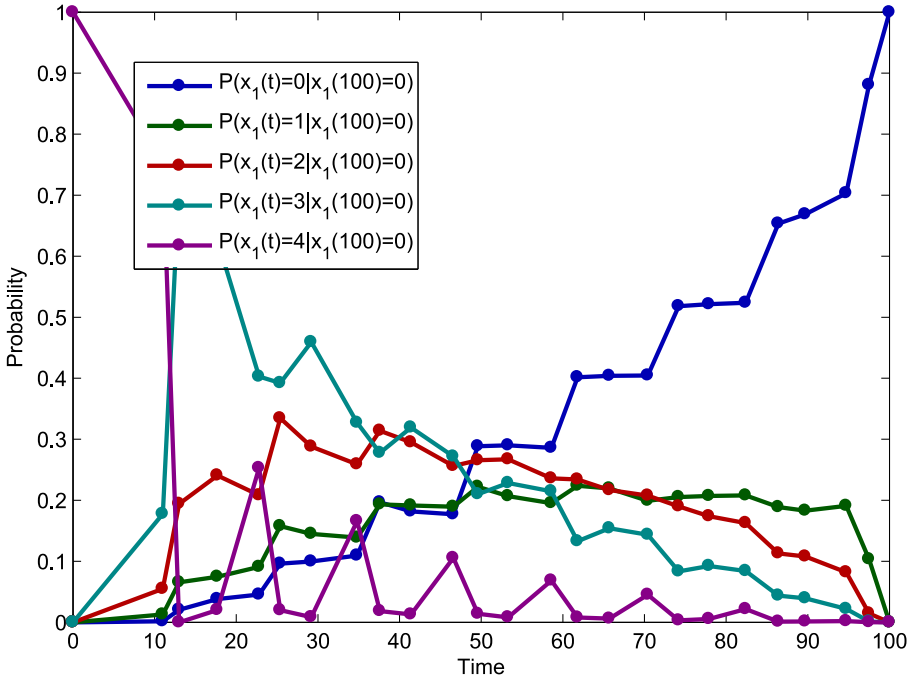
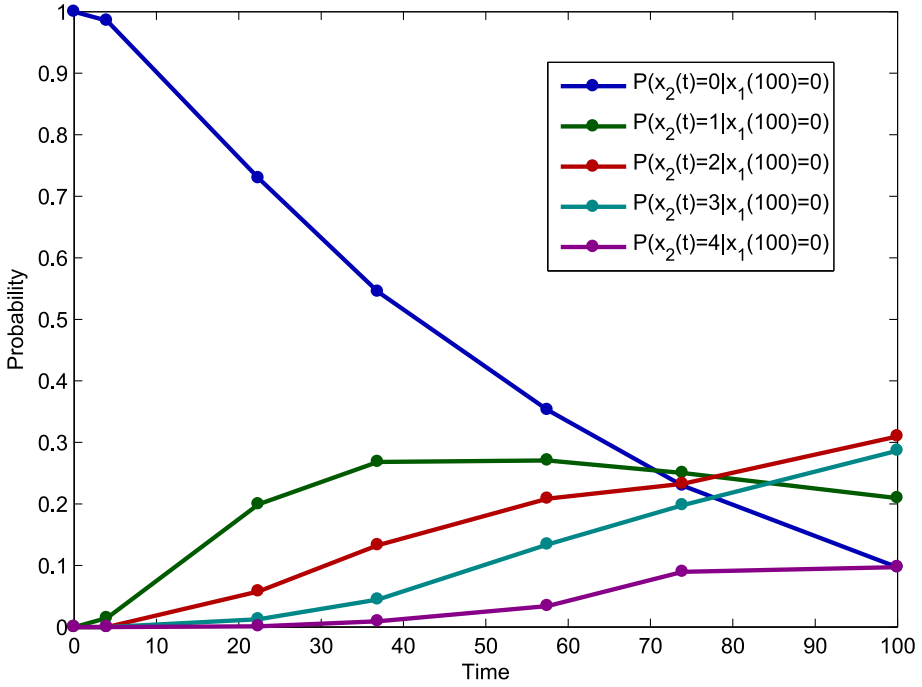
What-if Analysis

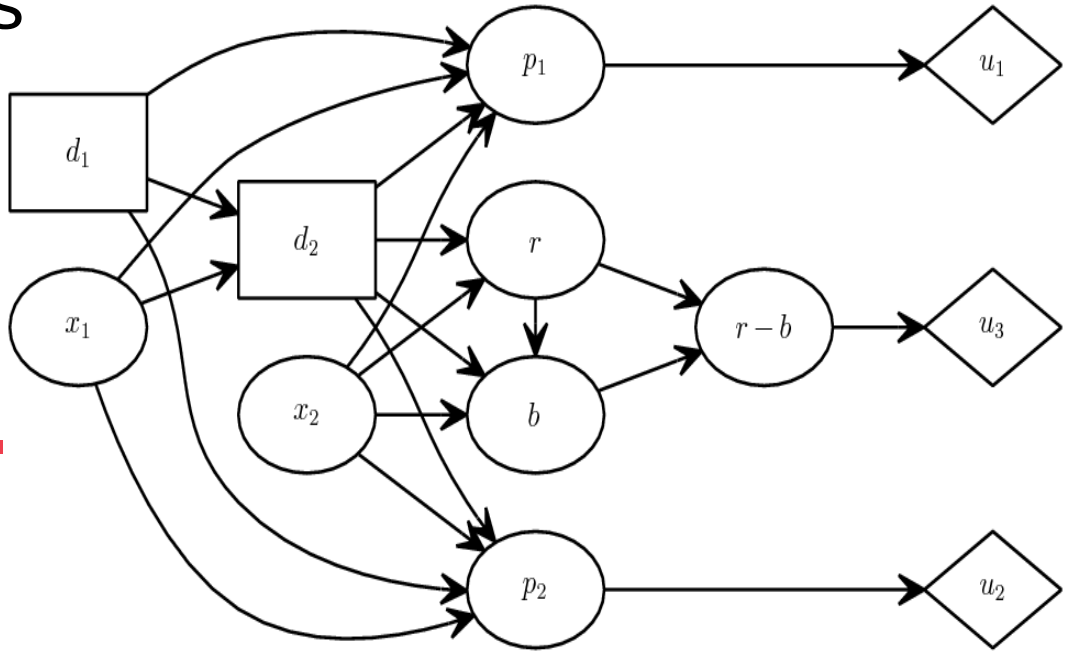
- What if no aircraft are available for mission assignment at time instant 100?





Conclusions

- Dynamic Bayesian networks in simulation metamodeling
  - Time evolution of simulation
  - Simulation parameters as random variables
  - What-if analysis
- Simulation metamodeling using (dynamic) influence diagrams
  - Decision making problems
  - Optimal decision suggestions



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