BAYESIAN NETWORK AS A TOOL FOR SEISMIC INFRASTRUCTURE RISK ASSESSMENT & MANAGEMENT

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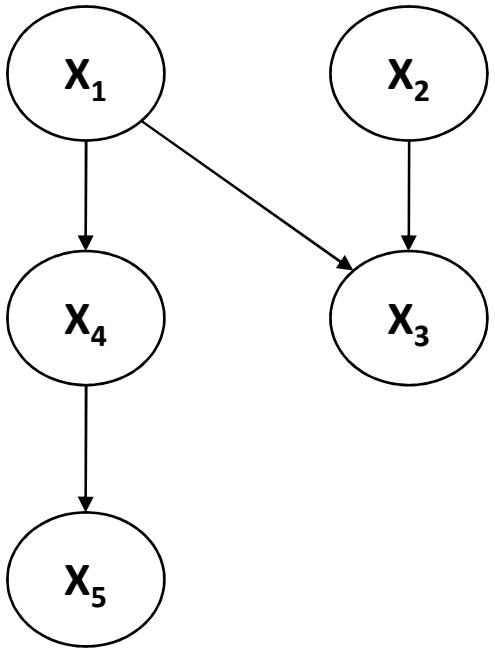
PEER Workshop on Transportation Networks
March 18, 2009

What is a Bayesian Network?

- A BN is a probabilistic graphical model that encodes a set of random variables and their probabilistic (in)dependencies.
- A BN has the following elements:
  - A set of **variables (nodes)** and **directed links**
  - Each variable has finite set of mutually exclusive states
  - Nodes/links form a directed acyclic graph
  - To each variable we attach a **CPT** representing discrete probabilities



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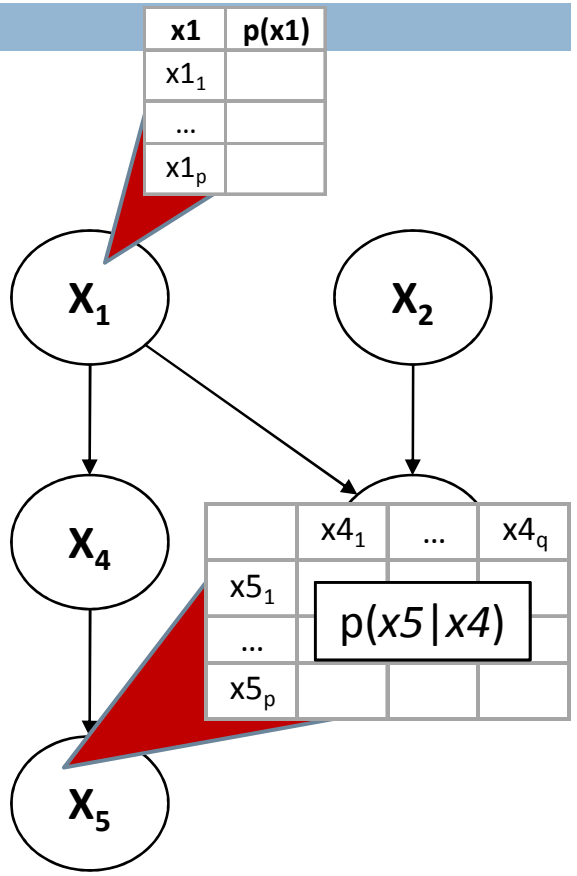
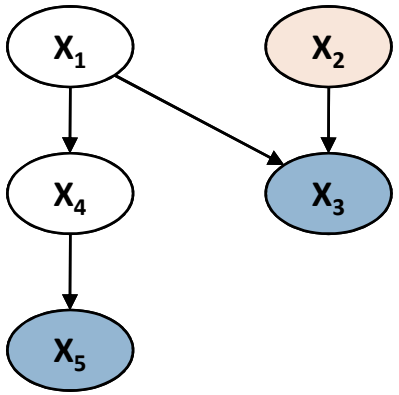


Information Updating

- Information updating:

$$p(x_2|e_3, e_5) = ?$$



Calculations in BNs

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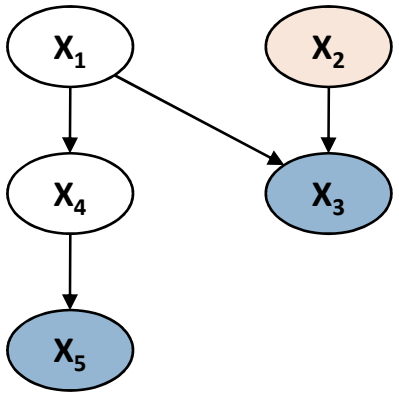

- Utilizes d-separation rules

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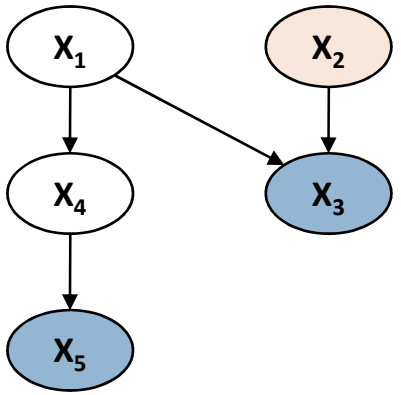
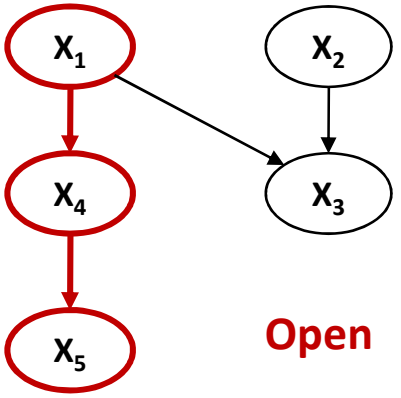


- Utilizes d-separation rules:

  Information transmits
  - Through a serial connection



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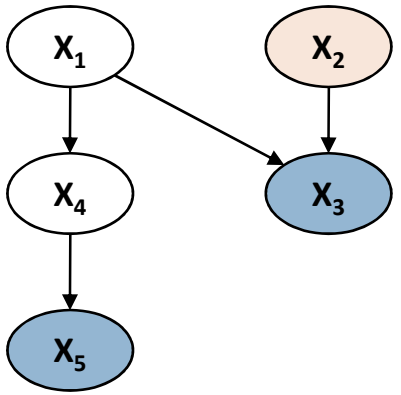

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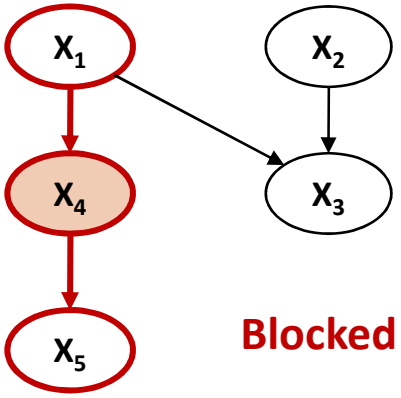

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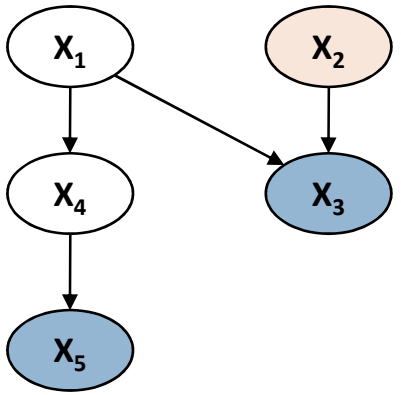

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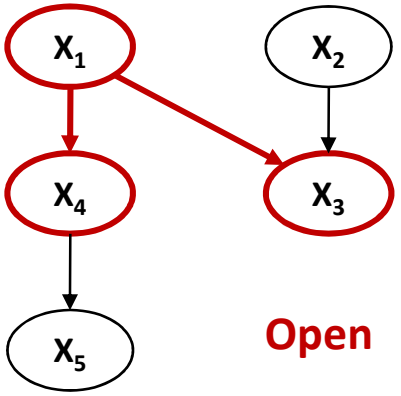

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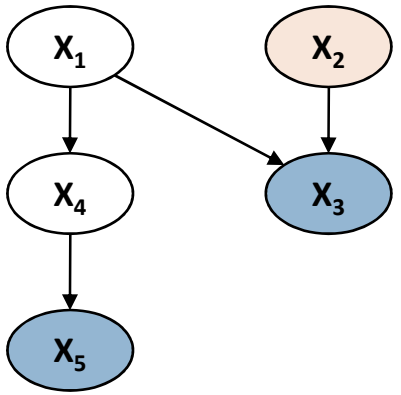

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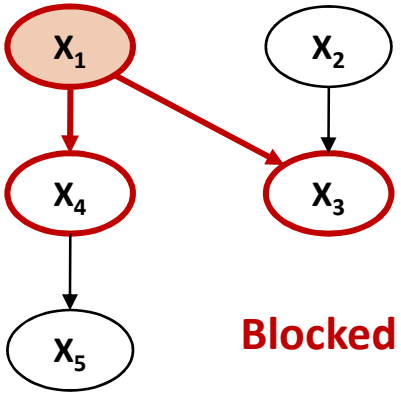

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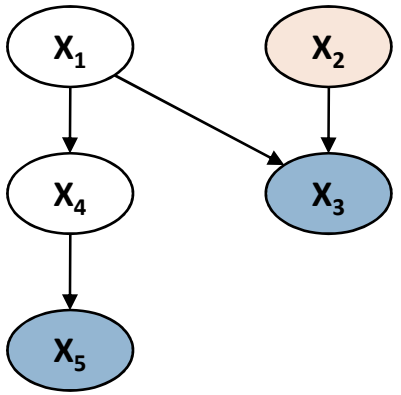

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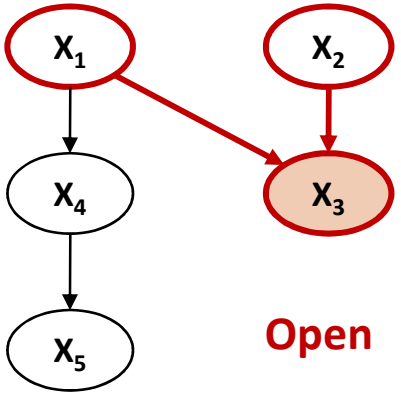

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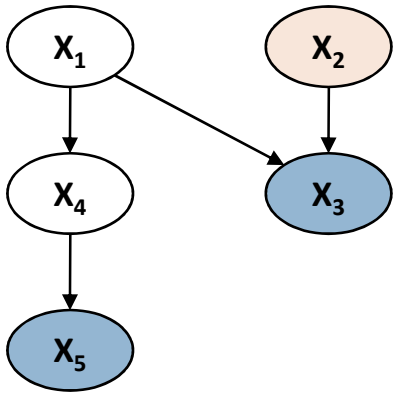

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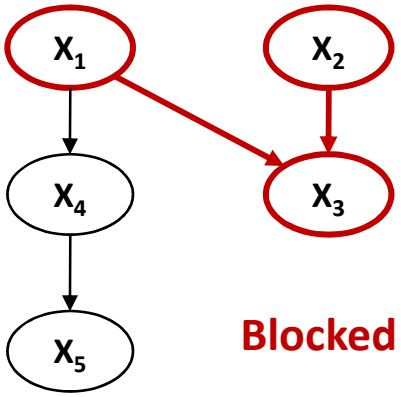

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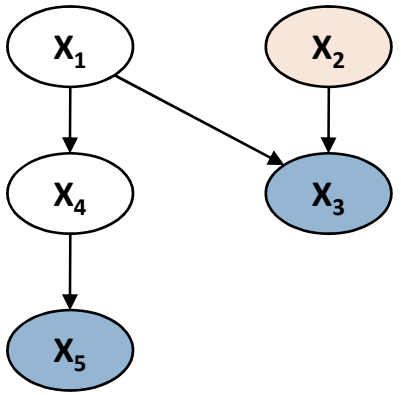

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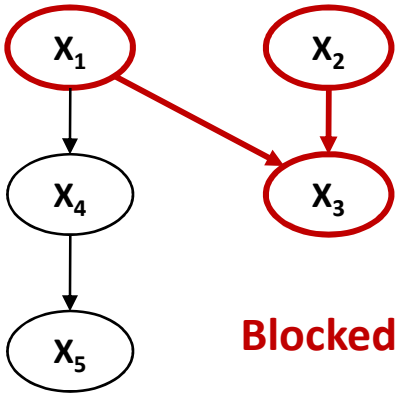


Inference algorithms are available for efficiently performing computations in BNs

Advantages/Shortcomings of BN

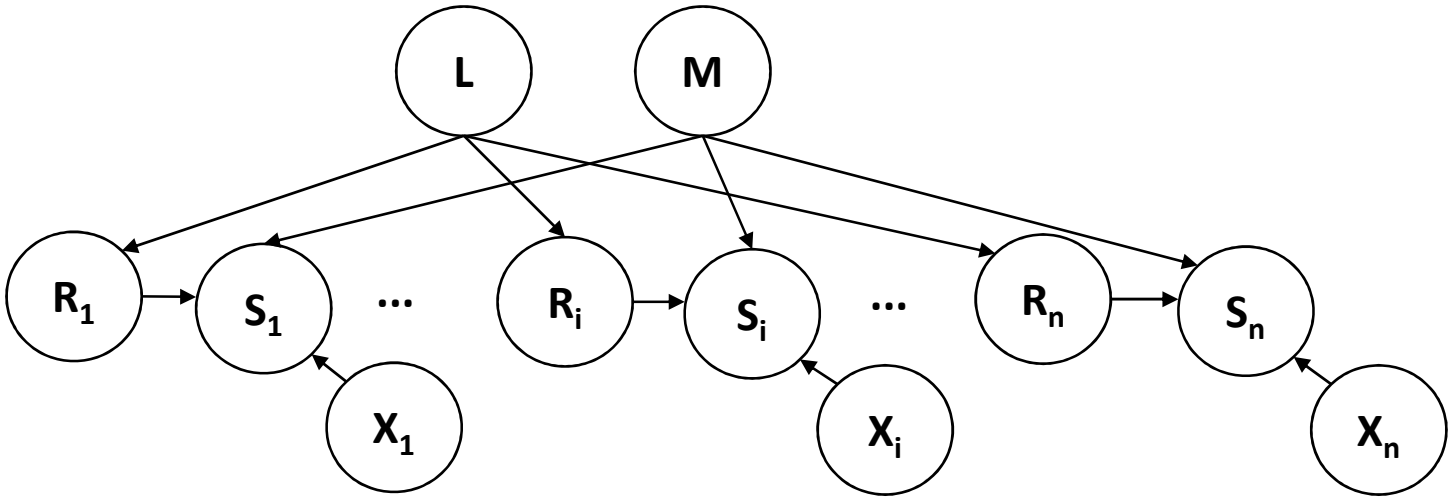
- Advantages:
  - Graphical, powerful, efficient
  - Tool for end-users (intuitive)
  - Can account for sources of uncertainty
  - Allows information updating
  - Can model multiple hazards & interdependencies
  - Can model distributed & interacting systems
  - Can identify critical component/cut sets in a system
  - Includes utility and decision nodes (solve decision problems)

- Shortcomings:
  - Can be computationally demanding for infrastructure systems having many dependent RVs
  - Discretization of continuous random variables necessary
    - exponential growth with number of states

Trade-offs!
- transparency in modeling (verifiability)
- computational complexity
- detail of modeling

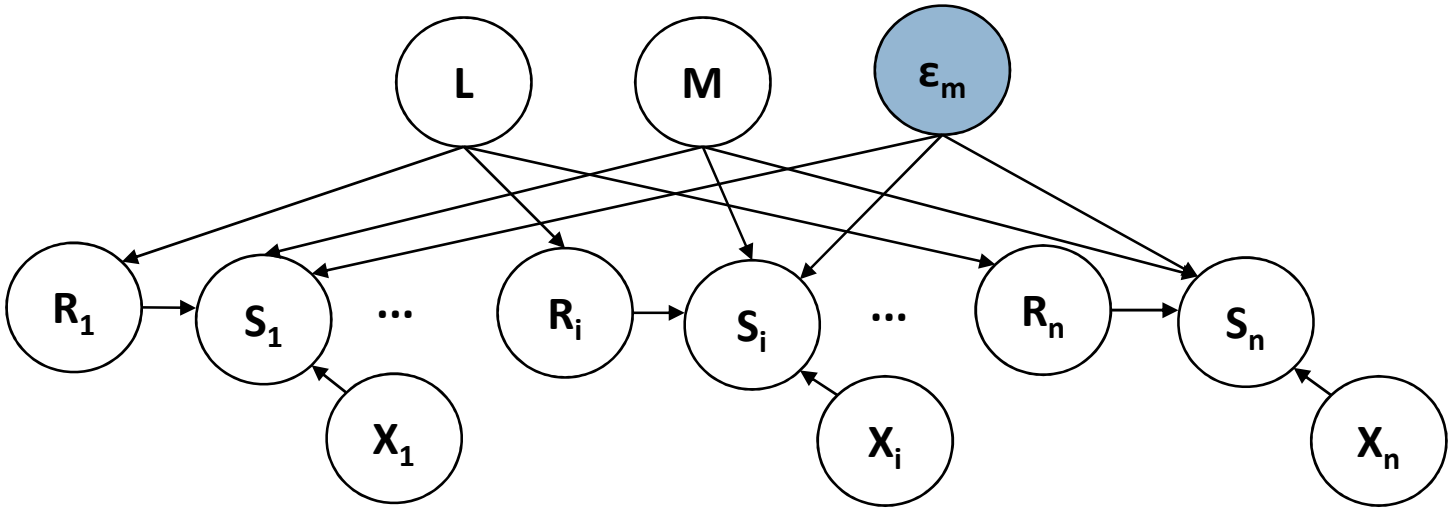
Model of Ground Motion Intensity

$$\ln(S_i) = f(M, R_i, \mathbf{X}_i)$$



Model of Ground Motion Intensity

$$\ln(S_i) = f(M, R_i, \mathbf{X}_i) + \varepsilon_m$$



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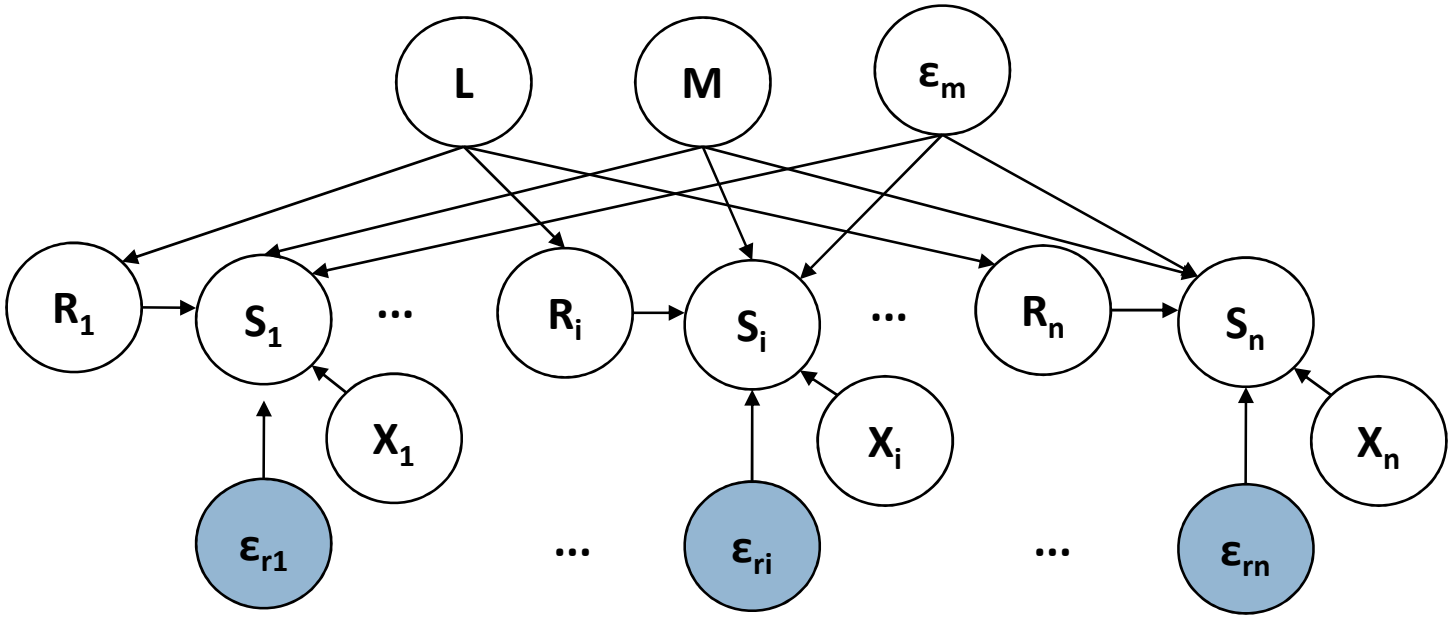

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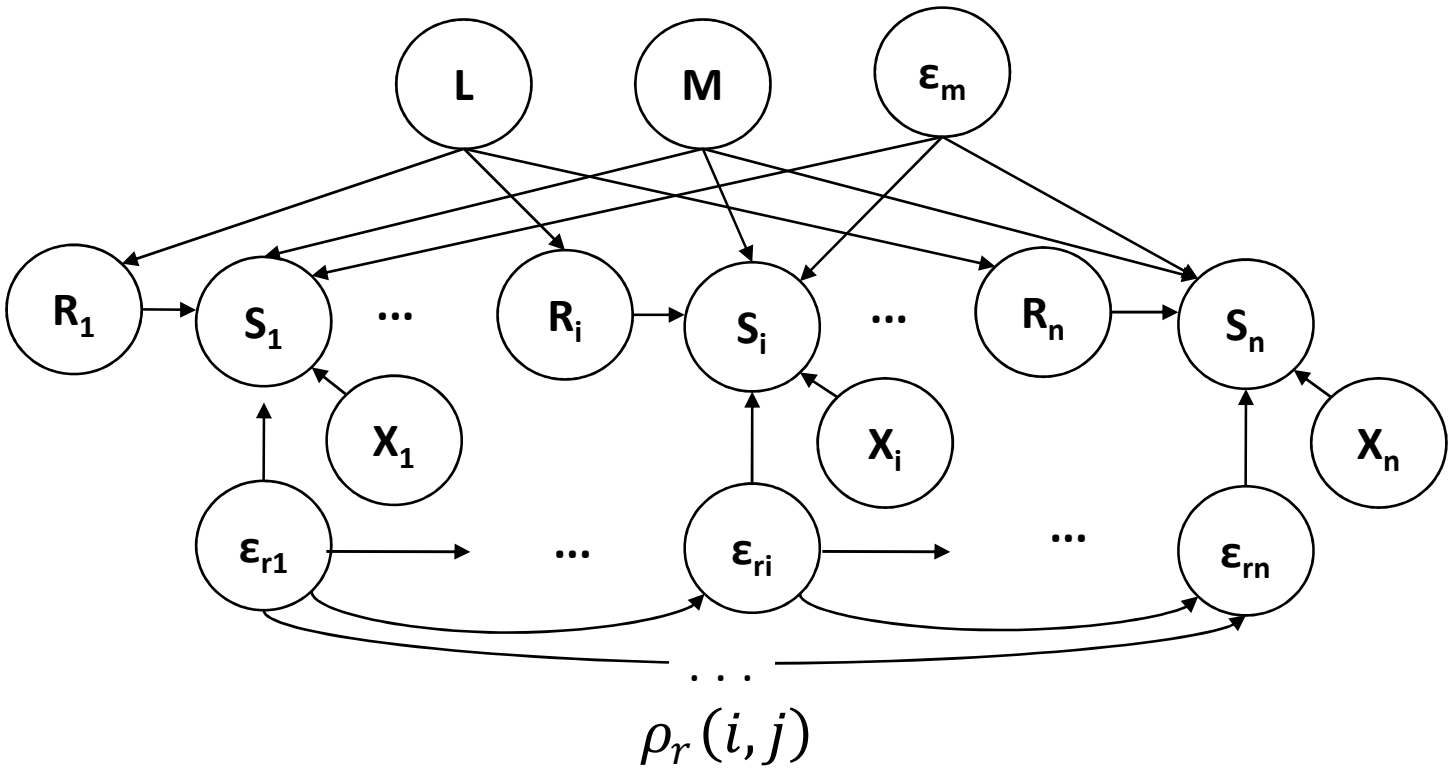

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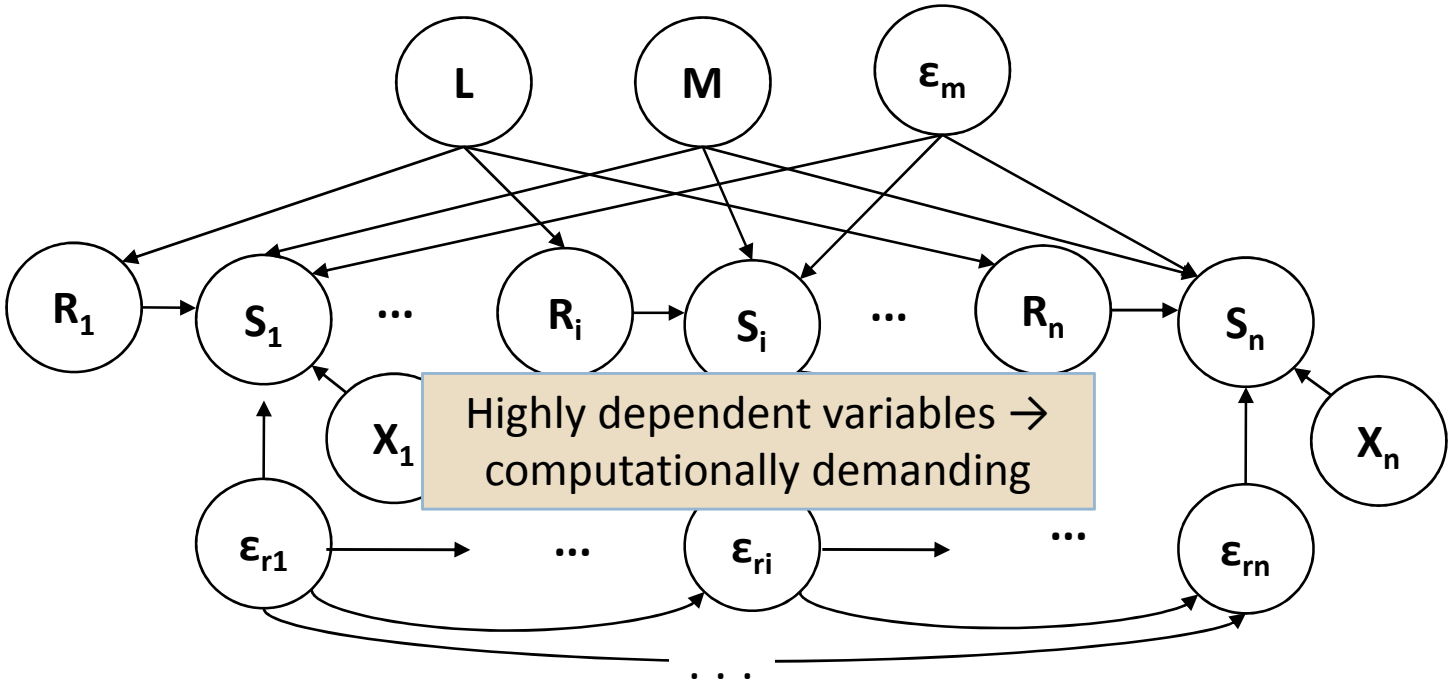

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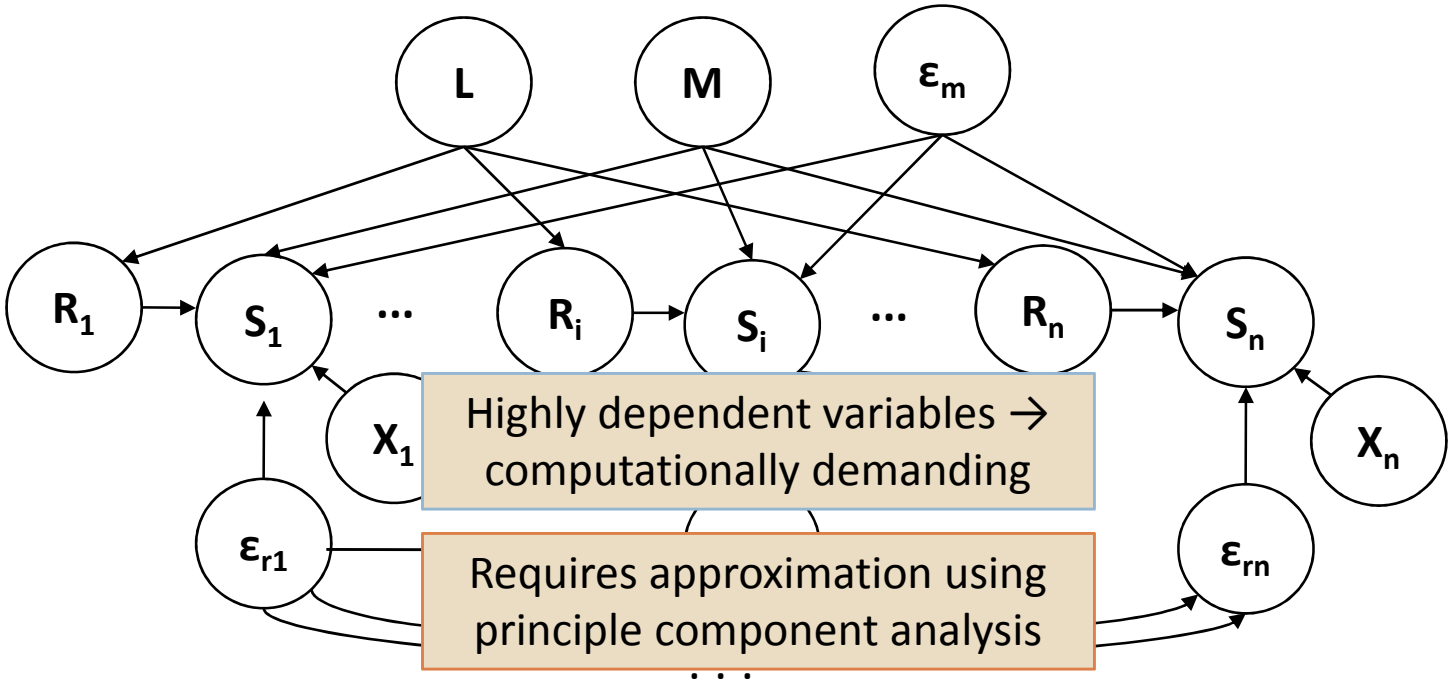

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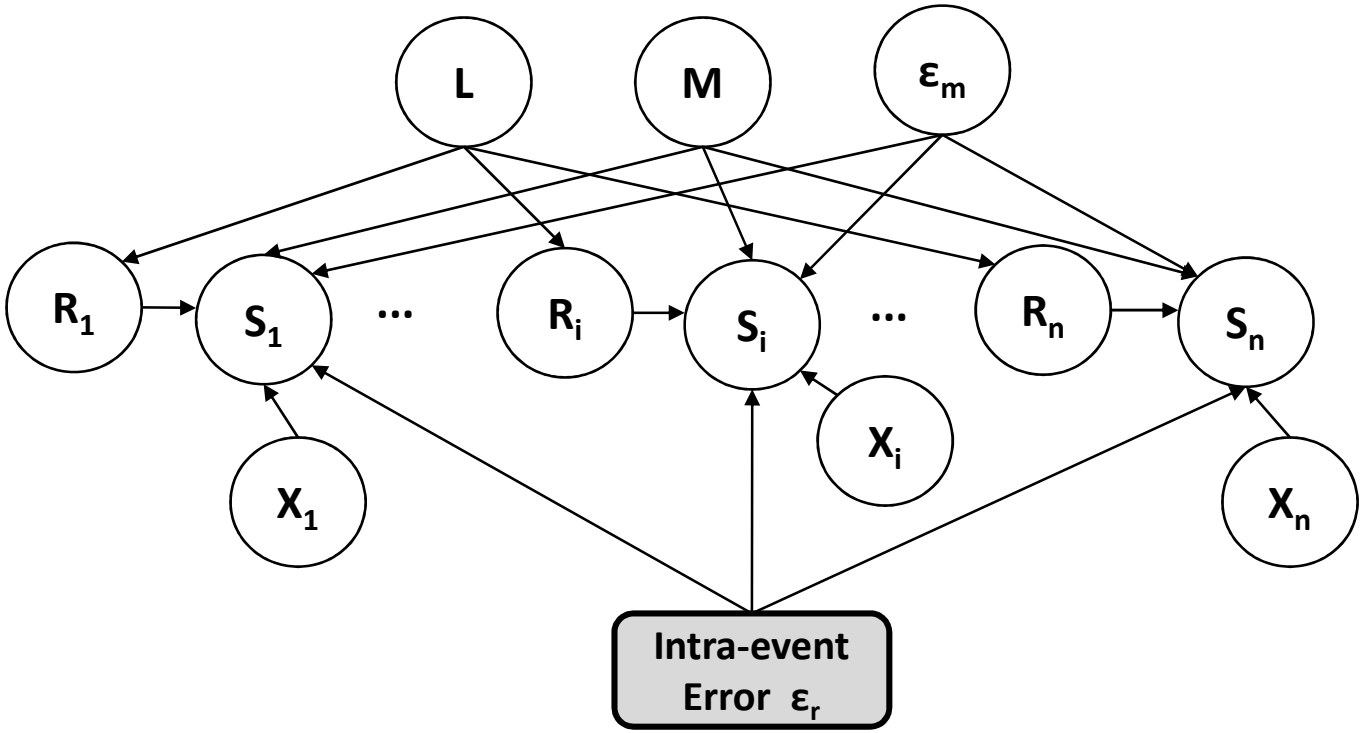

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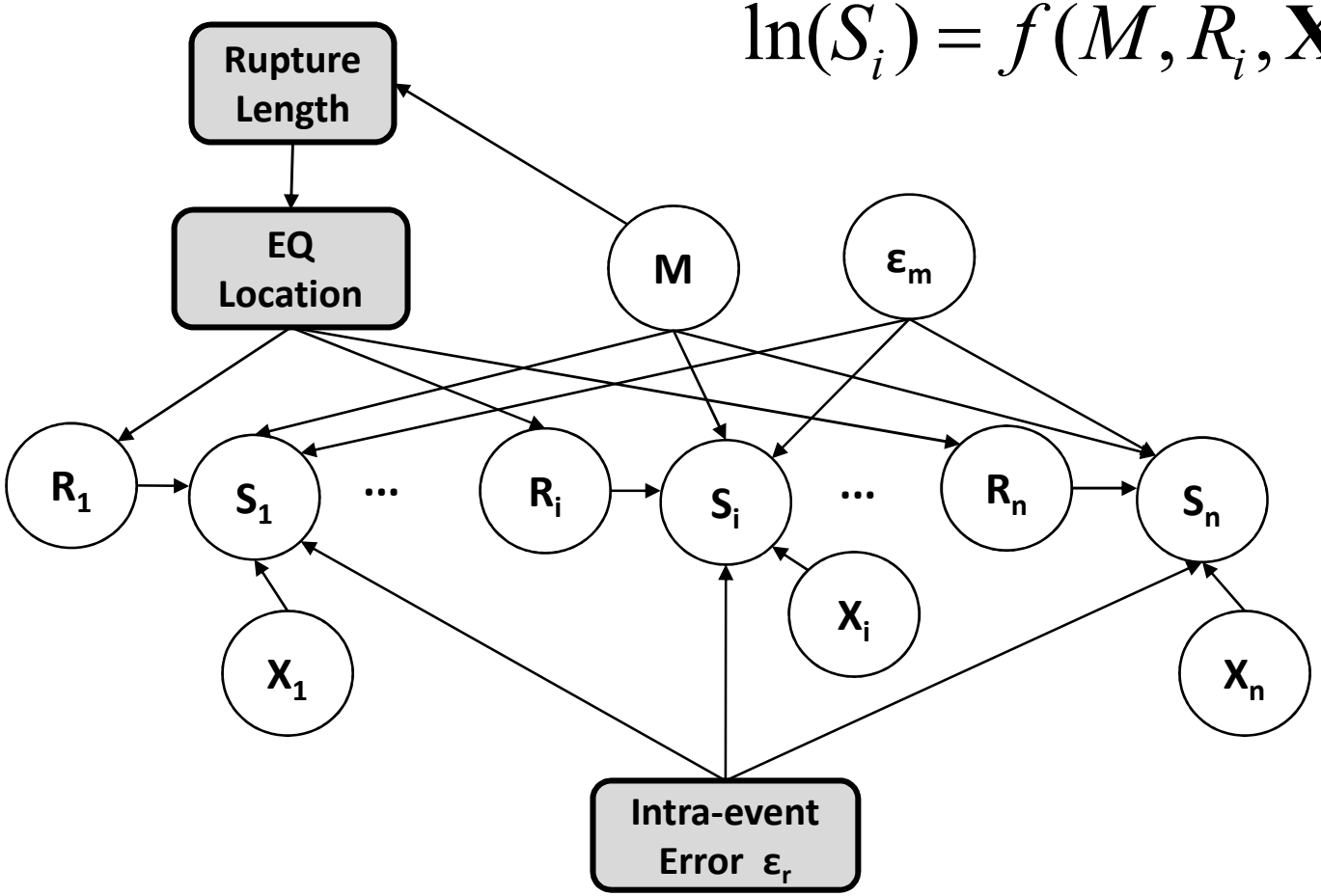
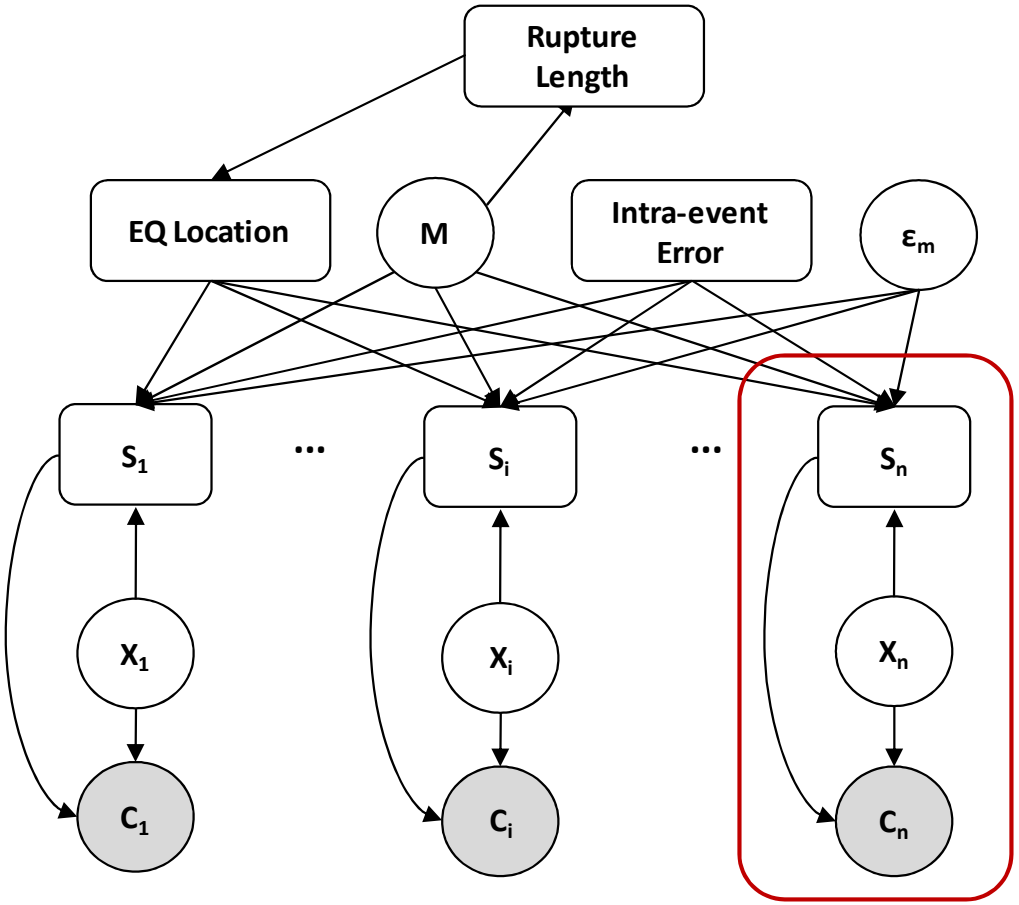
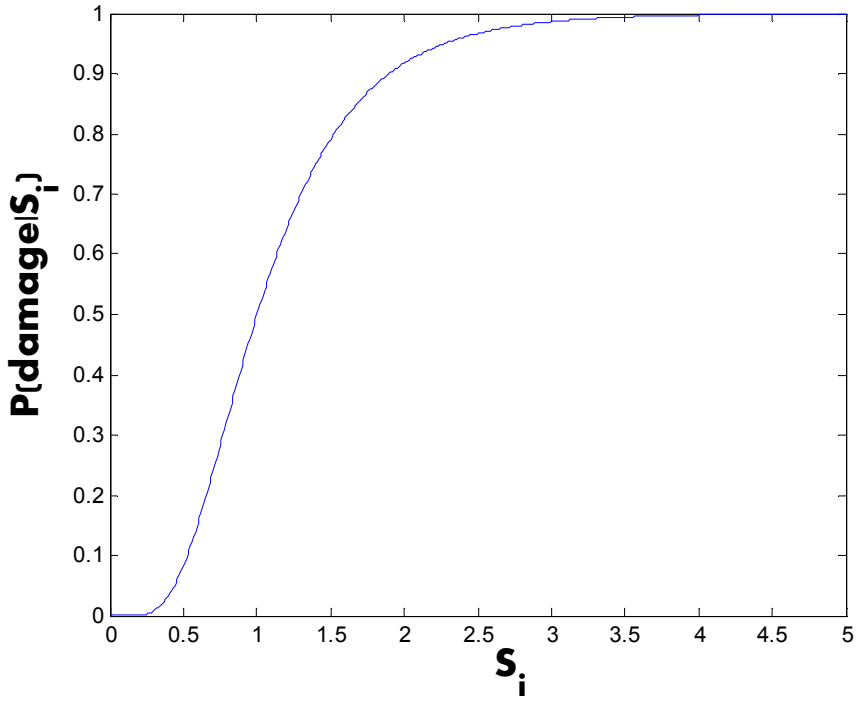
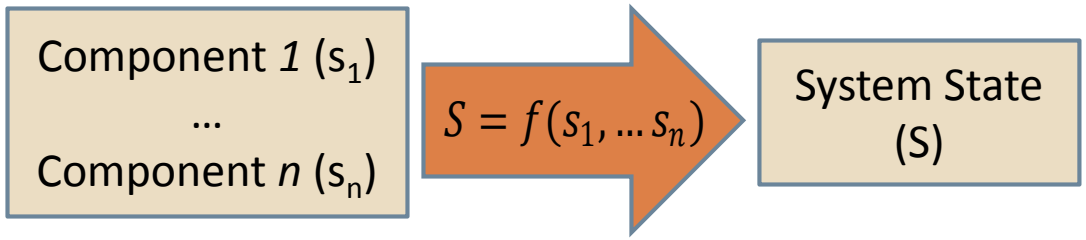


Component Performance

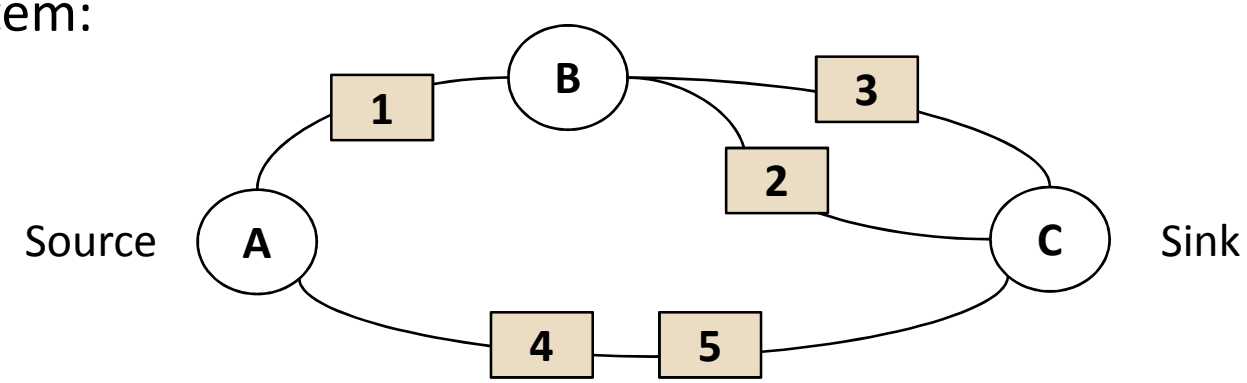




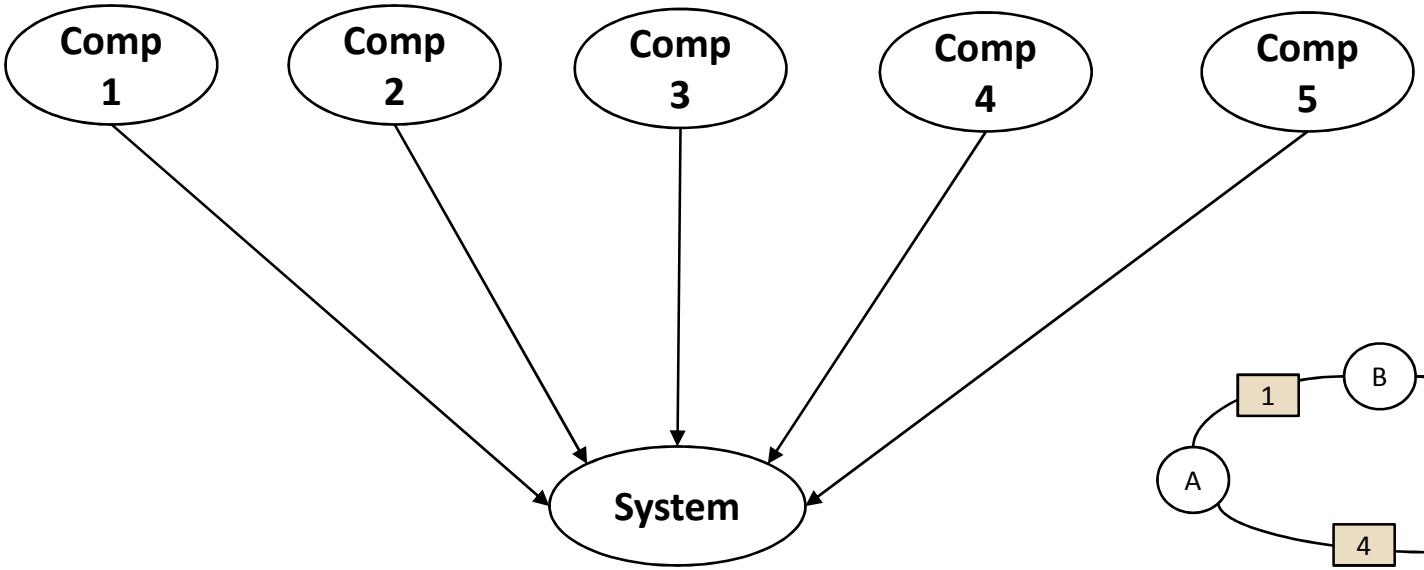
Classic System Analysis → BN framework for system connectivity

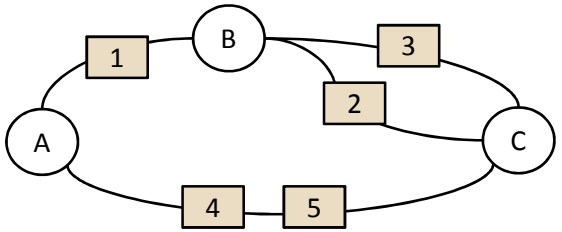


- Five different formulations for modeling system connectivity within the context of BN
- Focus here on binary components/system
  - Currently expanding to consider multi-state problems
- Example system:



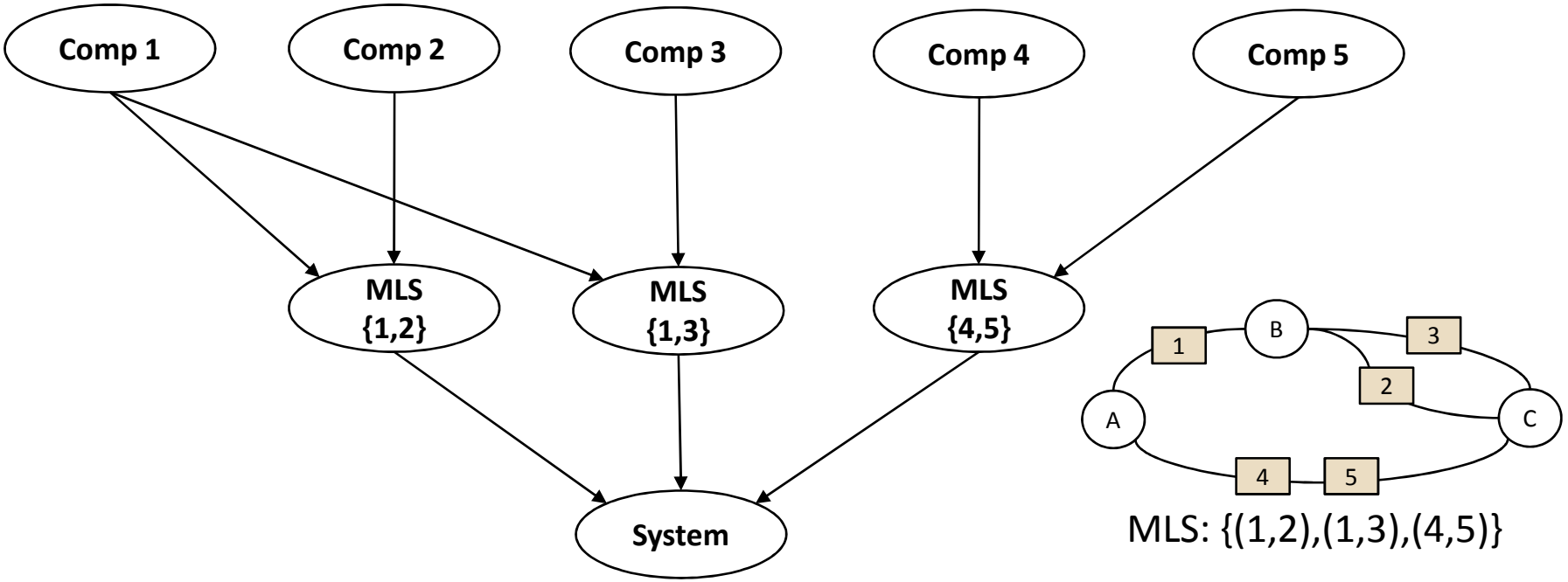
(1) Naïve Formulation





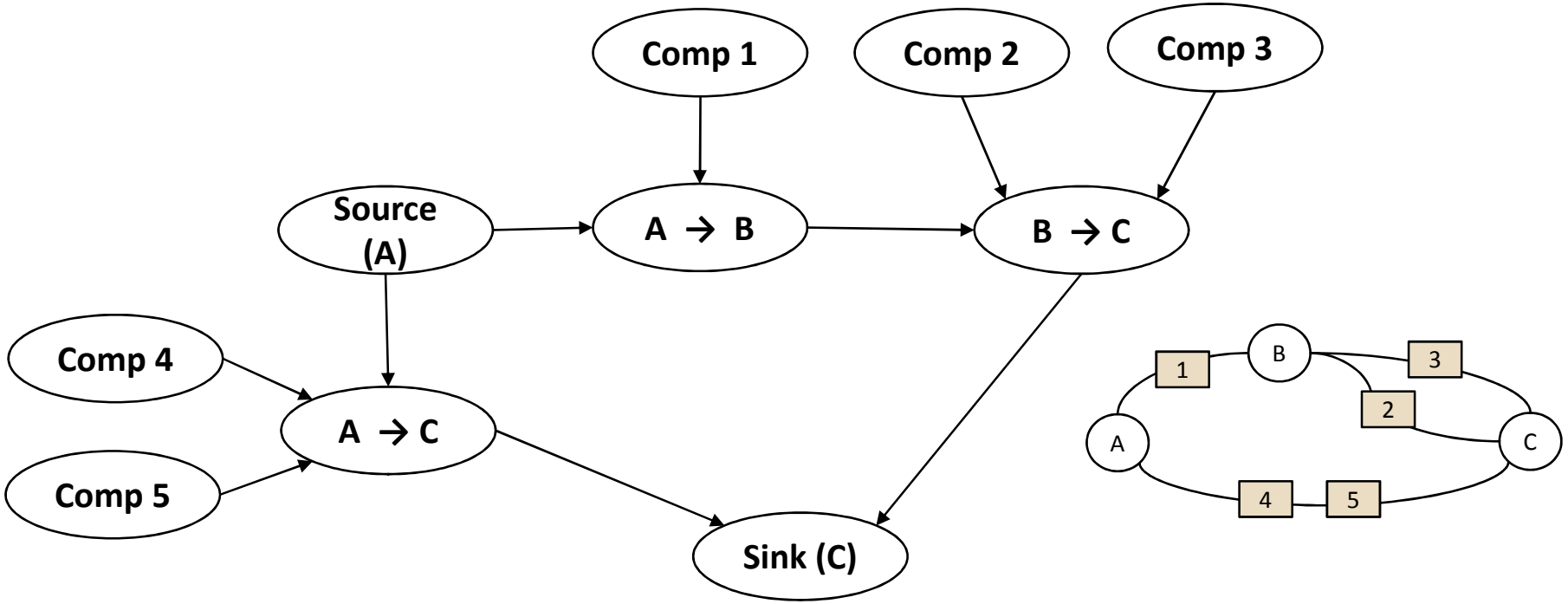
- Advantages:
  - Easy to formulate
- Disadvantages:
  - Computationally inefficient
  - Poor readability
  - Difficult for third-party interaction

(2) Minimum Link Set Formulation



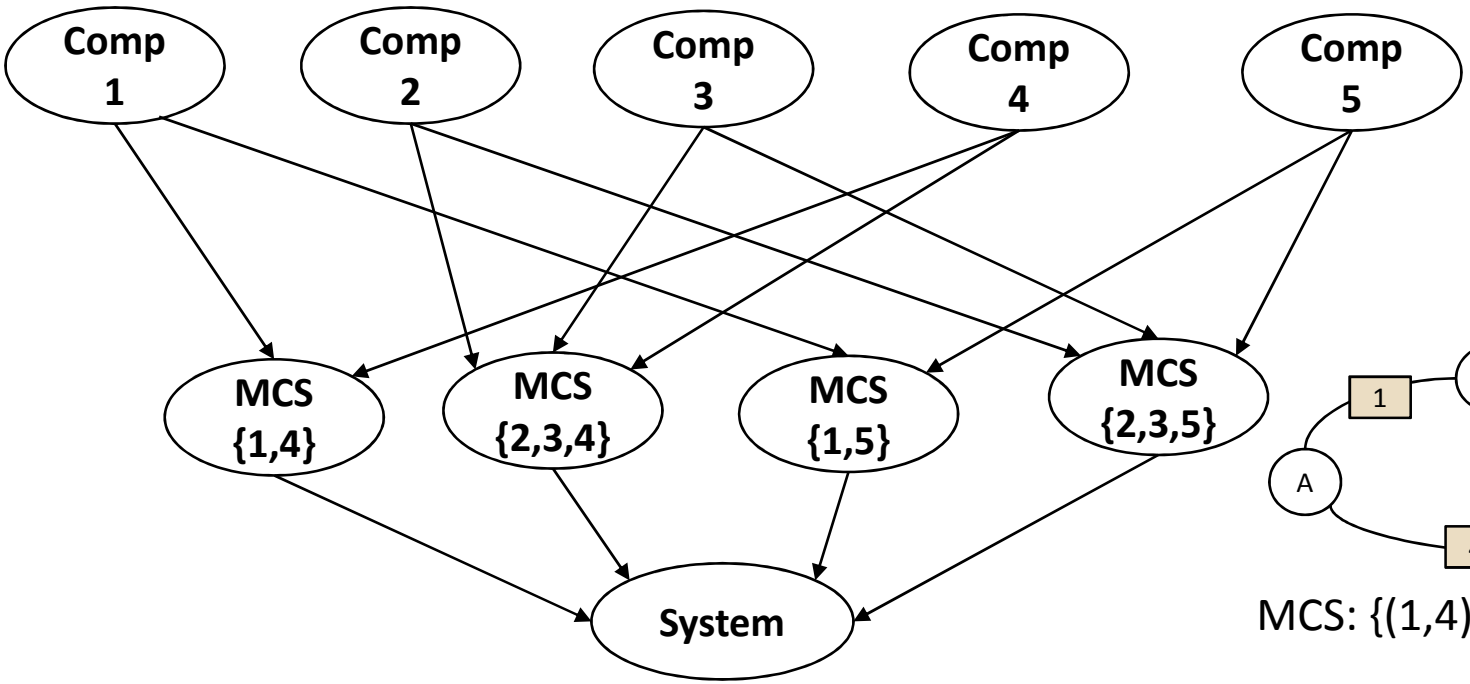
- Advantages:
  - Systematic
  - More efficient (smaller CPTs)
- Disadvantages:
  - Difficult readability
  - Difficult for third-party interaction

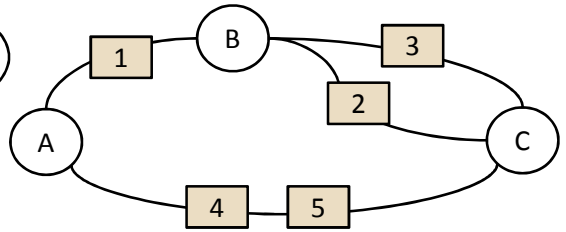
(3) Explicit Connectivity Formulation



- Advantages:
  - Intuitive (better for third-party interaction)
  - Smaller CPTs than Naïve
- Disadvantages:
  - not systematic

(4) Minimum Cut Set Formulation

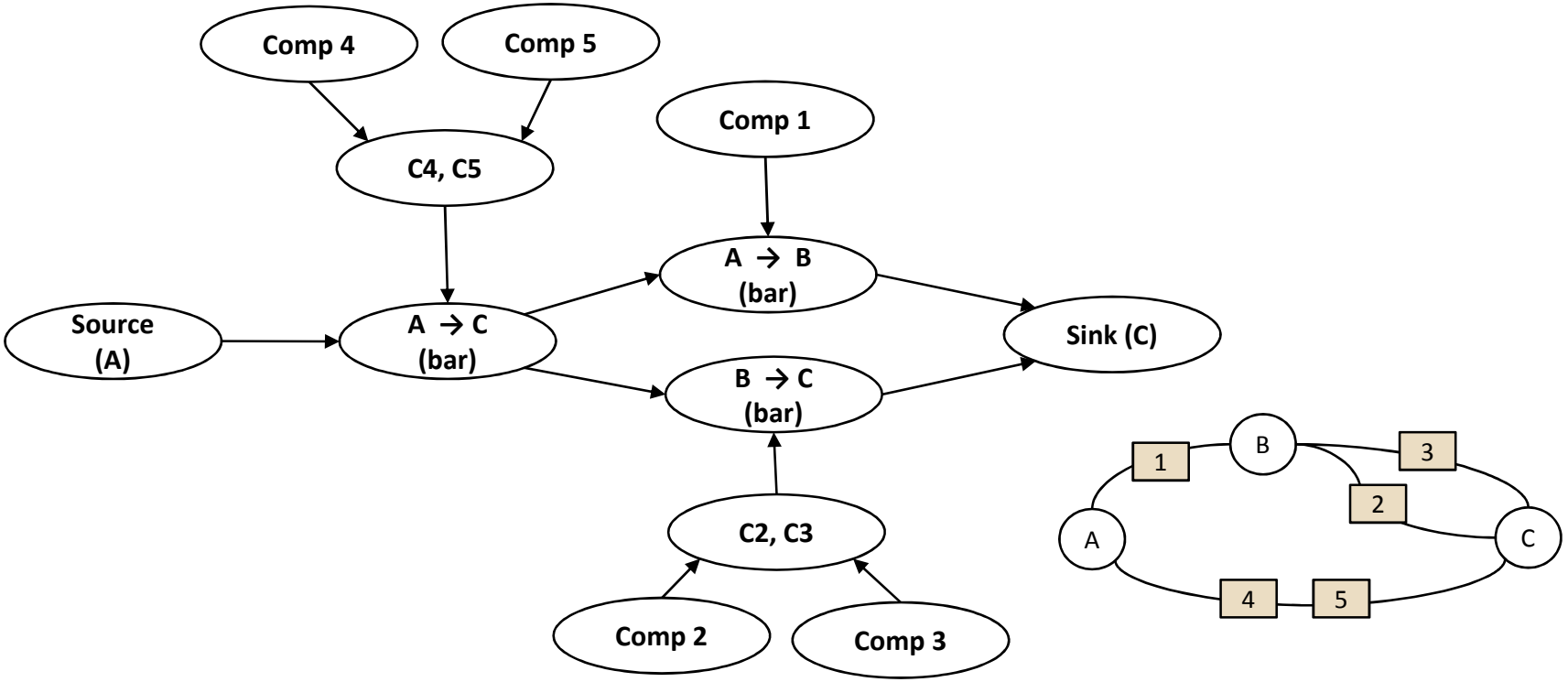




MCS: {(1,4),(2,3,4),(1,5),(2,3,5)}

- Advantages:
  - Systematic
  - More efficient (smaller CPTs) than Naïve formulation
- Disadvantages:
  - Difficult readability
  - Difficult for third-party interaction

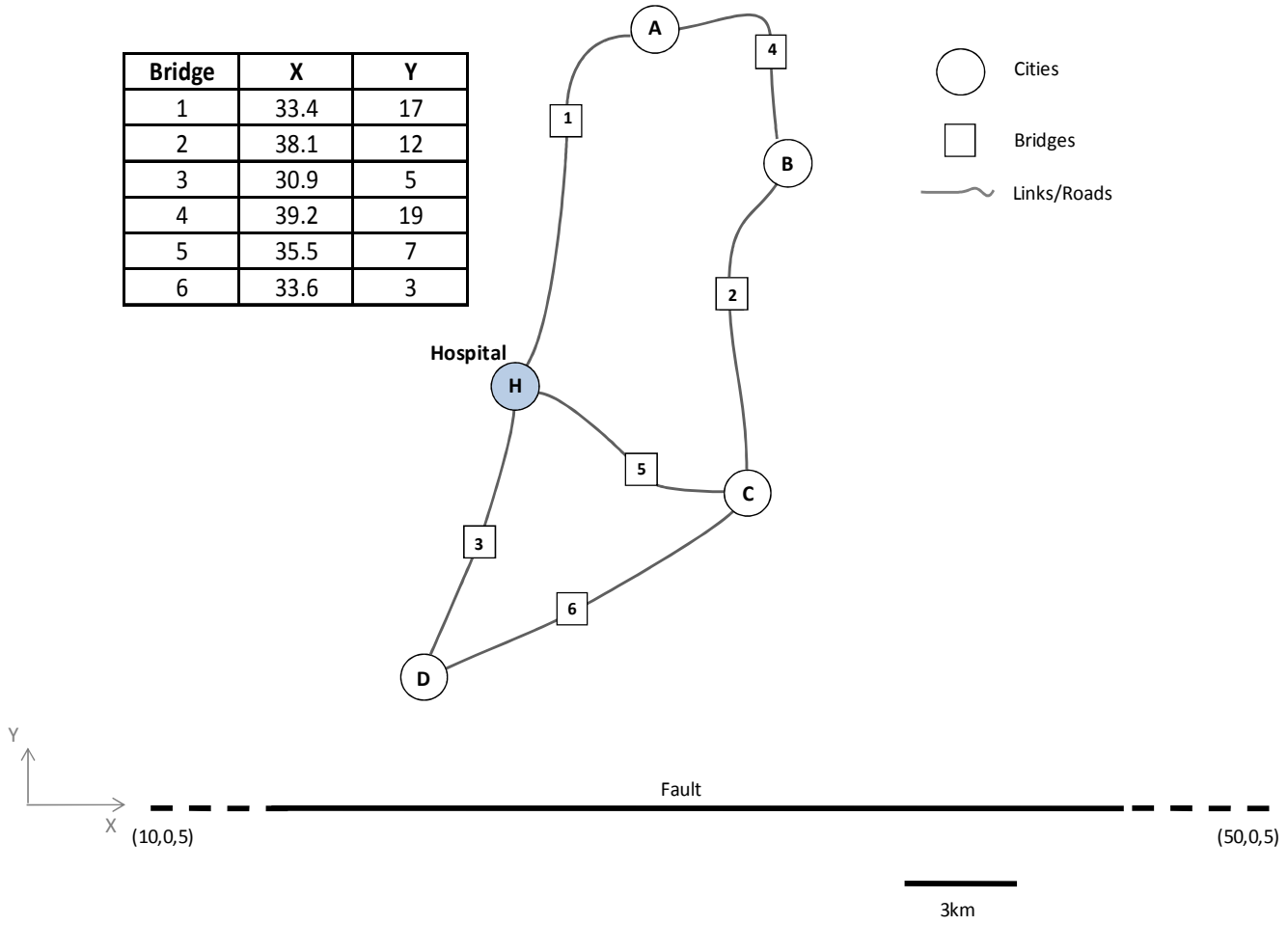
(5) EDC Formulation



- Advantages:
  - Can be more efficient (for systems with small number of MCSs)
- Disadvantages:
  - Less intuitive
  - Not systematic

Example & Demonstration: Transportation System

Bridge	X	Y
1	33.4	17
2	38.1	12
3	30.9	5
4	39.2	19
5	35.5	7
6	33.6	3



Illustrative Example

- Live demonstration…

Future Work

- Improve and expand seismic demand model
  - Multiple seismic sources
  - Include other hazards: fault rupture, liquefaction
- Identify optimal modeling approaches
  - Inclusion of spatial correlation
    - Sensitivity to fragility function & evidence
  - System connectivity formulation
  - Multi-state components and system
- Expand the BN
  - Incorporate utility/decision nodes
- Develop a prototype DSS

Thank you.





This material is based upon work supported under a
National Science Foundation Graduate Research Fellowship, PEER Lifelines Program, & UCB Taisei Chair funds.

Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.