Accelerated Reliability Analysis for Self-Healing SONET Networks

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Presentation Outline

- Introduction and objectives
- The model
- Analysis of run-time complexity
- Acceleration technique
- Experimental study and results

Prelude

- Trends in Telecom:
  - $\{\uparrow$ Traffic demand$\} \longmapsto \{\uparrow$ Speed$\} \longmapsto \{\uparrow$ Criticality$\} \longmapsto$ $\{\uparrow$ Demand in reliability$\}$
- Meet the reliability demand
  - Fault forecasting, Fault avoidance, Fault removal, Fault tolerance, etc.
- Need for reliability evaluation and modeling
- Previous work
  - Proposed model, SRMM/p
  - Proposed set of metrics

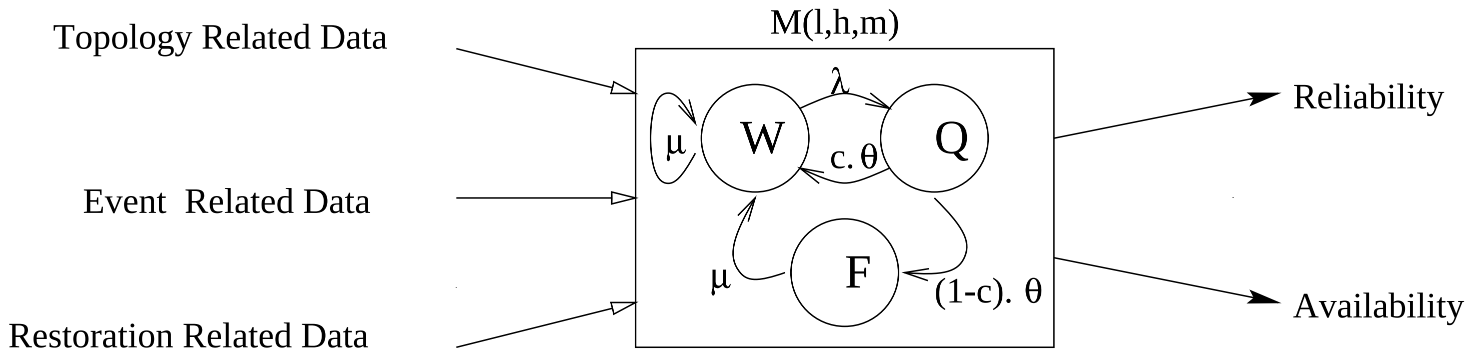
Objectives

- Observe the run-time complexity of the model
- Analyze the model to understand the cause of high complexity
- Study the options to reduce complexity
- Evaluate the pros & cons
- Accelerate the analysis
- Examine the improvement

State Reward Markov Model (SRMM/p)

- Markov Model
  - Probabilistic behavior
  - Design details
  - Coverage
  - System dependencies
- State-Reward feature
  - Performance as reward value
- Parametric feature
  - Varying performance
  - Multiple consecutive failures

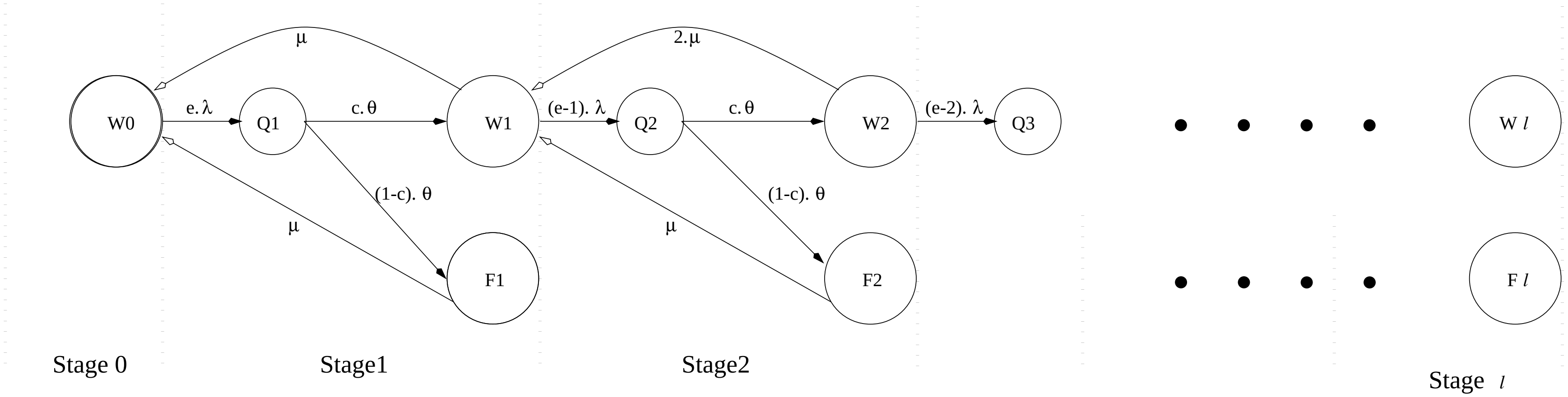
Reliability/Availability Evaluation Process



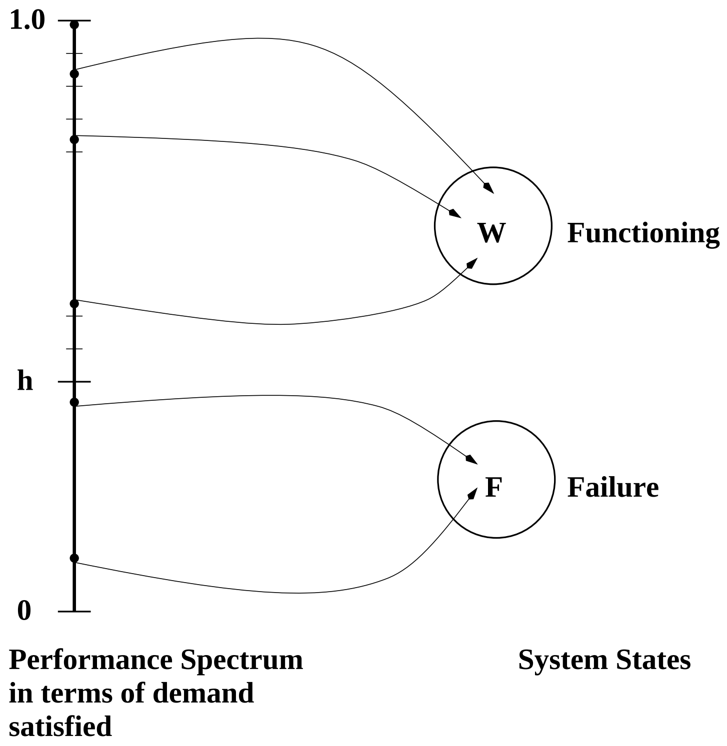
Model Parameters

- Parameter l
  - Number of stages in the model
  - Trade-off between complexity and accuracy
- Parameter h
  - Threshold performance
- Parameter m
  - Number of different performance levels above h
  - Trade-off between complexity and accuracy

The Model with Multiple Stages

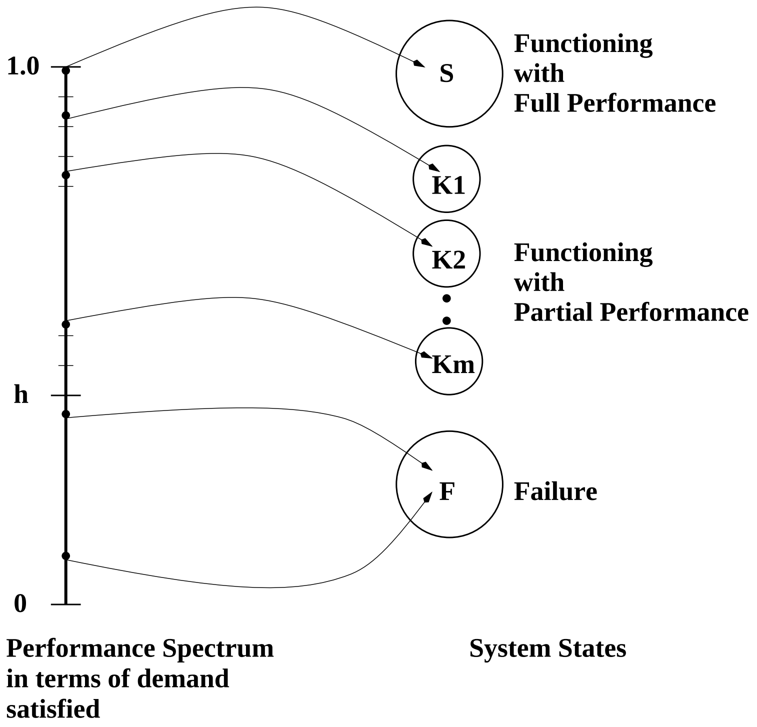


Performance Mapping into Two States



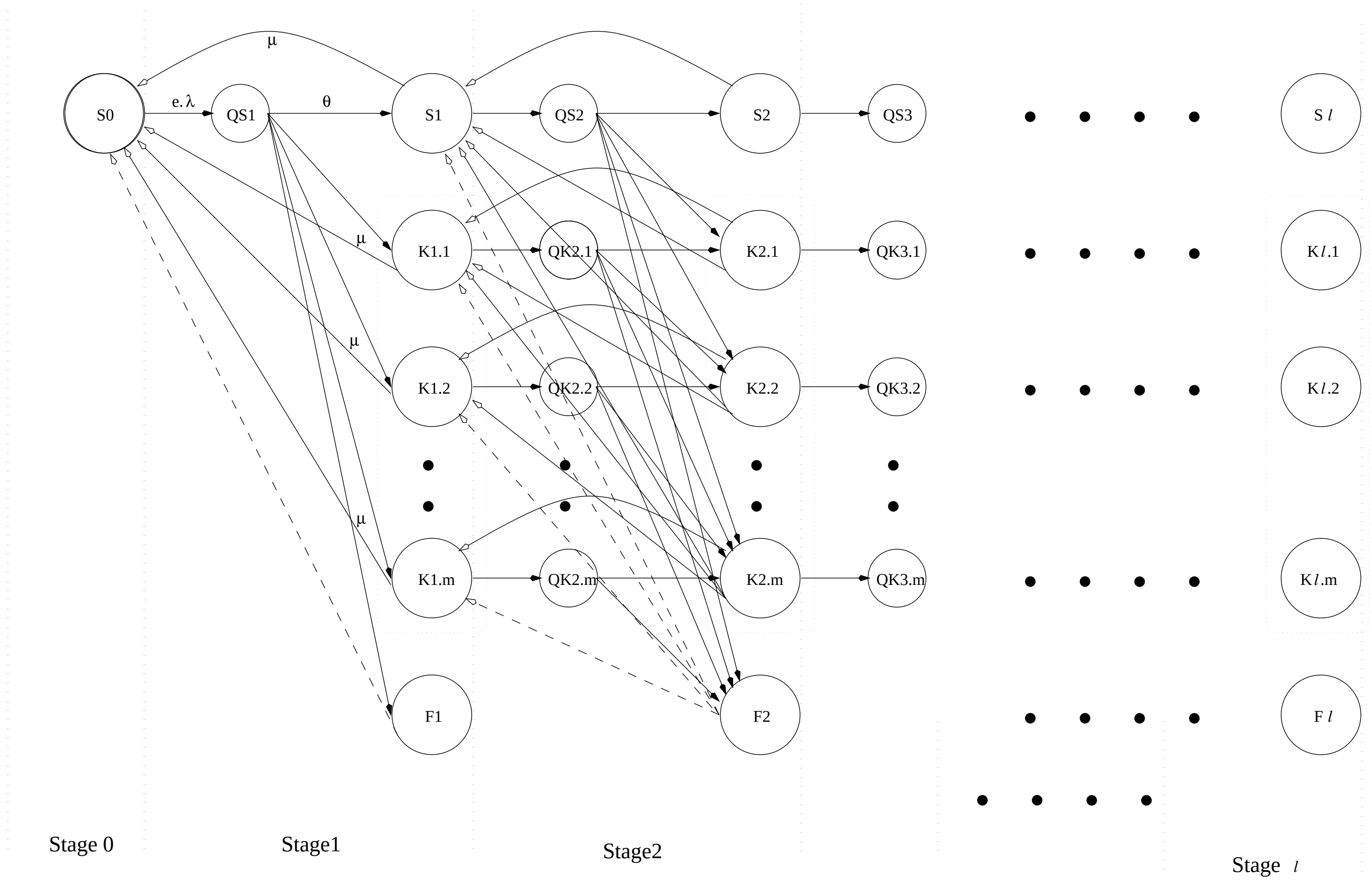
$$X(\xi) = \begin{cases} W, & \text{if } \xi \geq h; \\ F, & \text{if } \xi < h. \end{cases}$$

Performance Mapping into Multiple States



$$\tilde{X(\xi)} = \begin{cases} S, & \text{if } \xi = 100\%; \\ K_i, & \text{if } b_i \leq \xi < b_{i-1} \; i = 1, 2, ..., m; \\ F, & \text{if } \xi < h. \end{cases}$$

The Model


μ
S0
e.λ
QS1
θ
S1
QS2
S2
QS3
S l
μ
K1.1
QK2.1
K2.1
QK3.1
K l.1
μ
K1.2
QK2.2
K2.2
QK3.2
K l.2
μ
K1.m
QK2.m
K2.m
QK3.m
K l.m
F1
F2
F l
Stage 0
Stage1
Stage2
Stage l

Run-Time Complexity

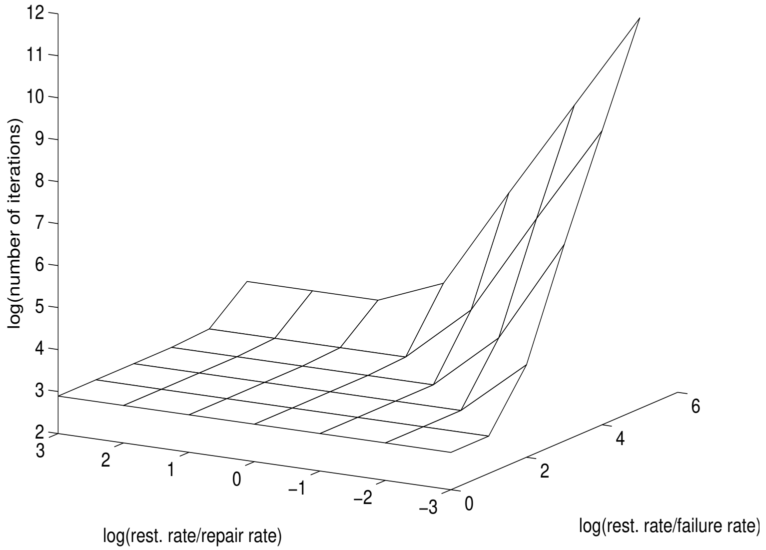
- Steady-state Behavior
  - Balance equations
  - Linear equation system
- Transient Behavior
  - Kolmogorov equations
  - Differential equation system
    - Adaptive Runge-Kutta method
    - Rate of change
    - Iteration interval

What Drives the Complexity

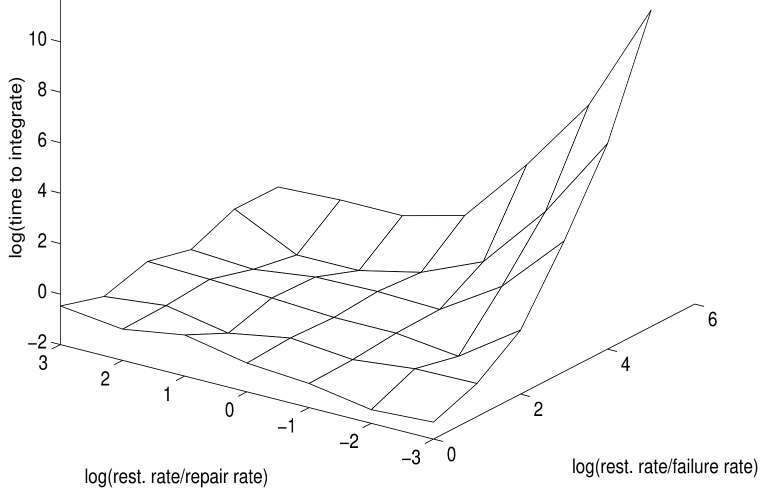
- Number of states in the model
  - Model parameters: l and m
- Time span of the transient behavior
- Number of iterations
  - Transition rates

Effect of Discrepancy in Transition Rates

- Number of iterations



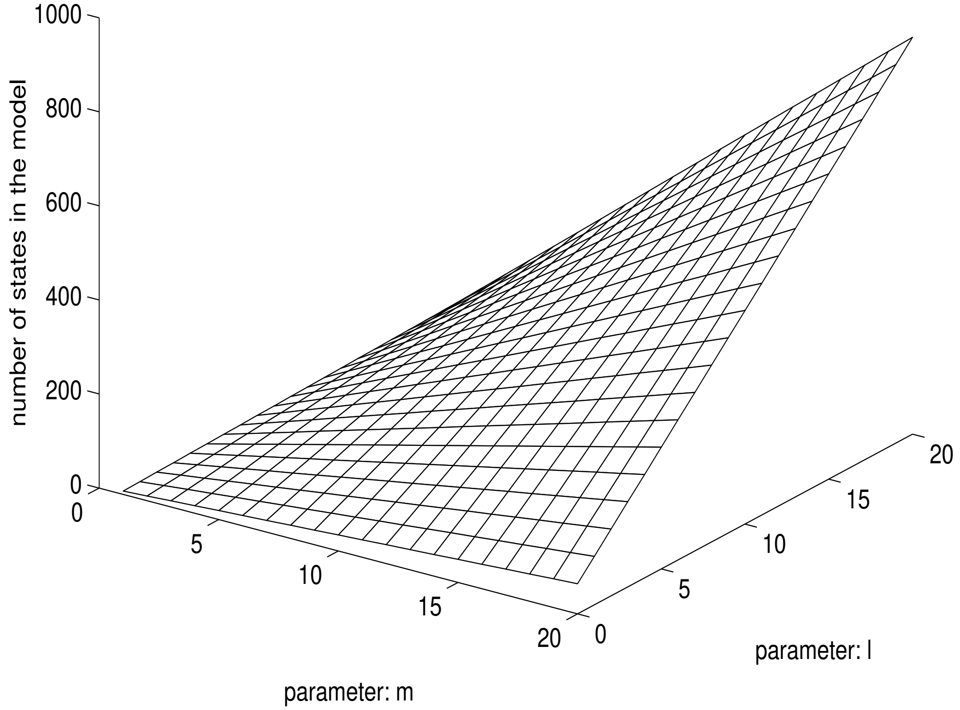
- Time to integrate



- Determines the transient behavior

Effect of Model Parameters

- $s(l, m) = m(2l - 1) + 3l + 4$

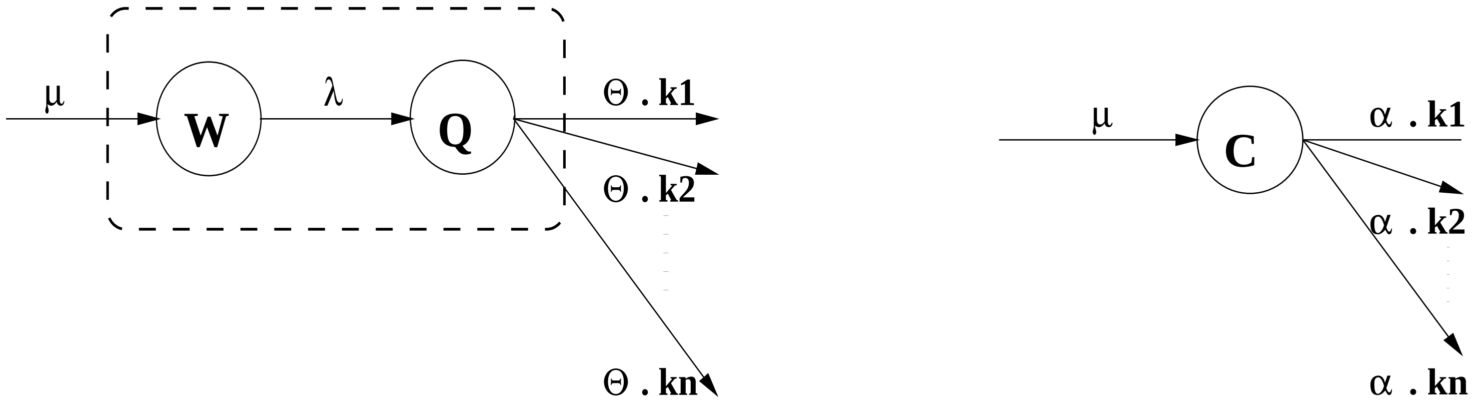


Options to Accelerate the Run-Time

- Behavioral decomposition
  - Near-complete decomposition
- Importance sampling
  - Needs good heuristics
- State Aggregation
  - Fusing states

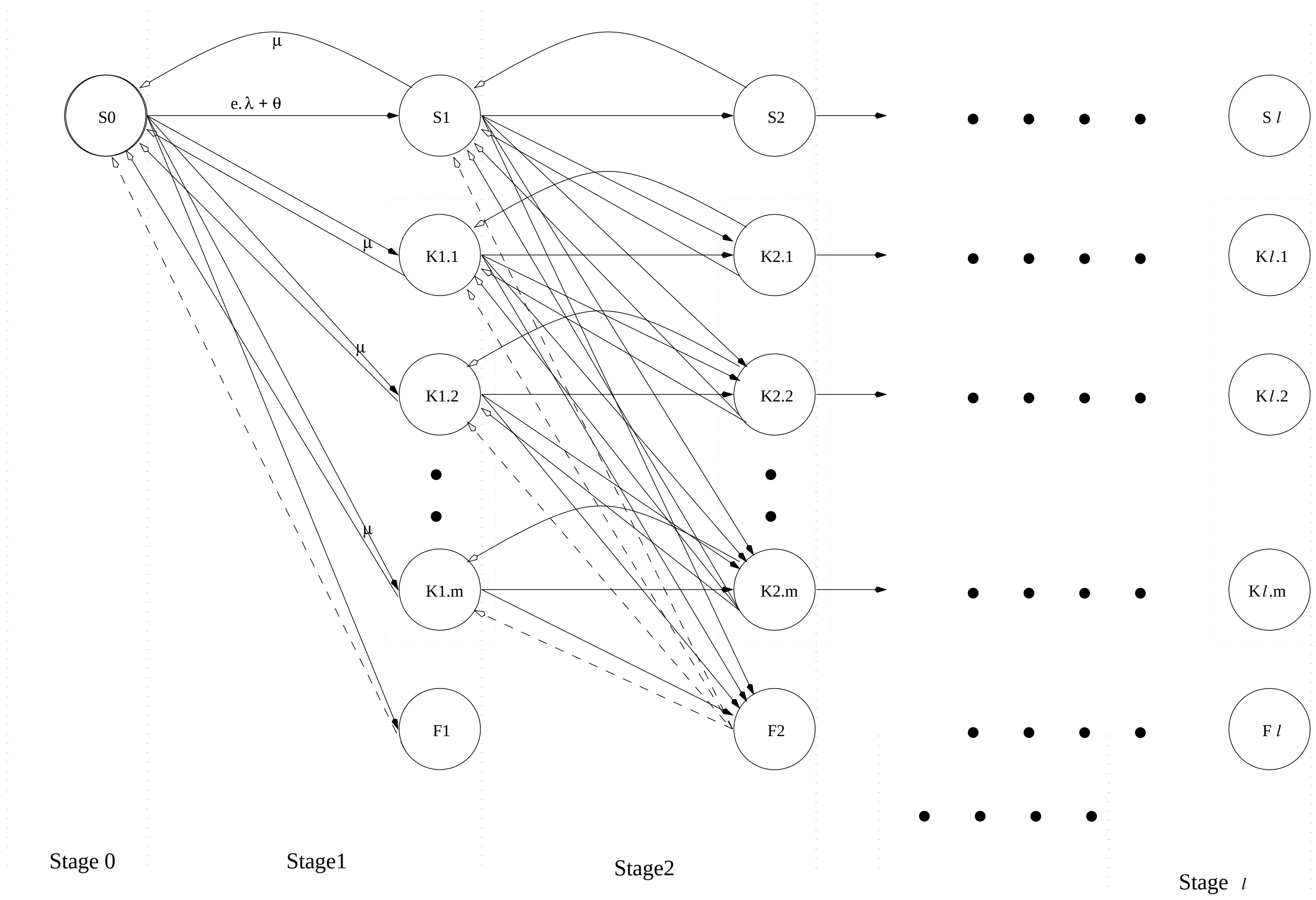
State Aggregation

- Inter-arrival time for both failure and restoration are exponentially distributed
- Aggregation of working and restoration states



$$\alpha = \Theta + \lambda$$

The Reduced Model



Reduction in Transition Rate Ratio

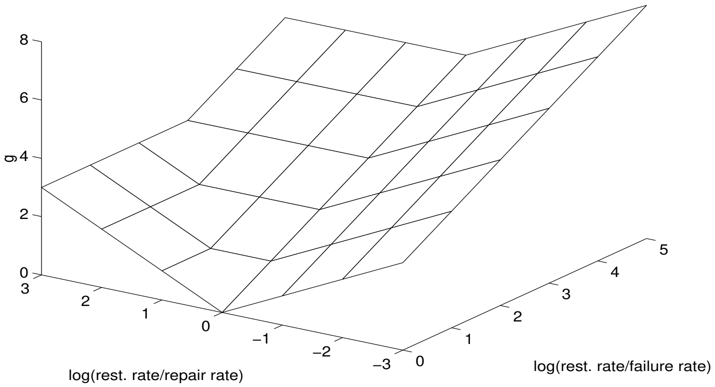
Functions to quantify the effect of transition rates

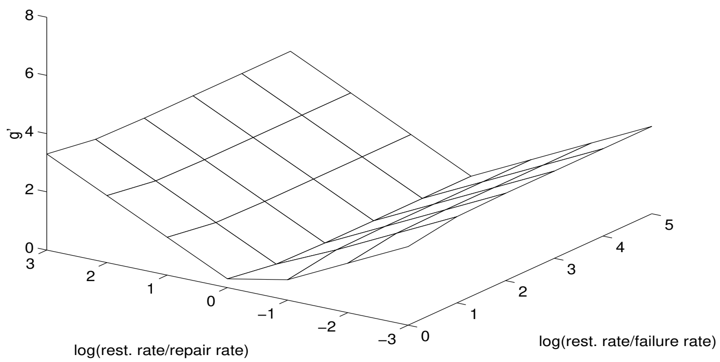
- For the original model:

$$g(\Theta, \lambda, \mu) = max(|\log \frac{\Theta}{\lambda}|, |\log \frac{\Theta}{\mu}|, |\log \frac{\mu}{\lambda}|)$$

- For the reduced model:

$$g'(\Theta, \lambda, \mu) = |\log \frac{\Theta + \lambda}{\mu}|$$





Reduction in Number of States

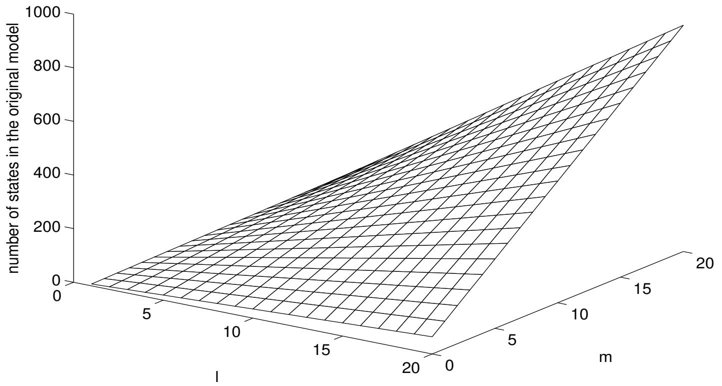
Functions to quantify the effect of model parameters

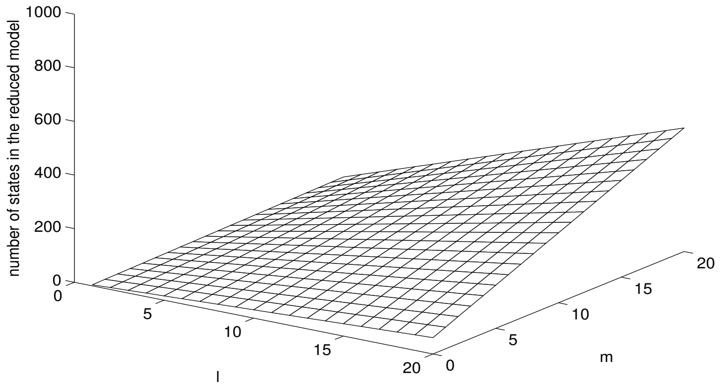
- For the original model:

$$s(m,l) = m(2l-1) + 3l + 4$$

- For the reduced model:

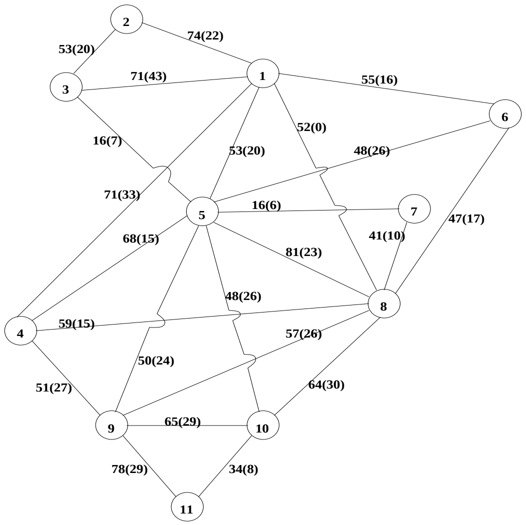
$$s'(m,l) = ml + 3l + 1$$



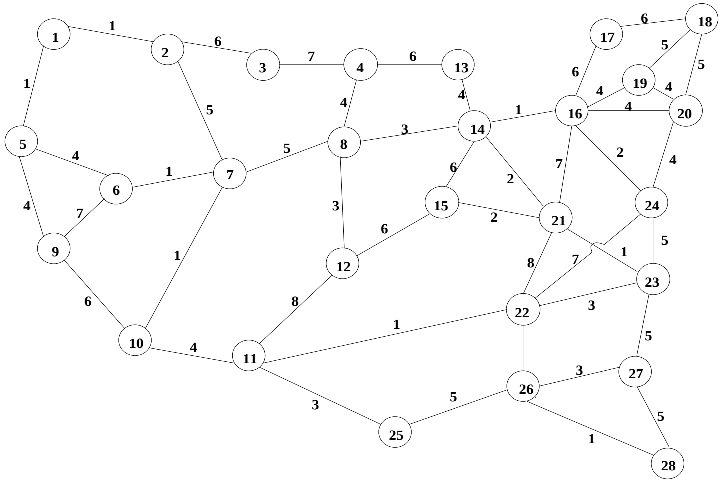


Networks Used in the Experimental Study

- New Jersey Network

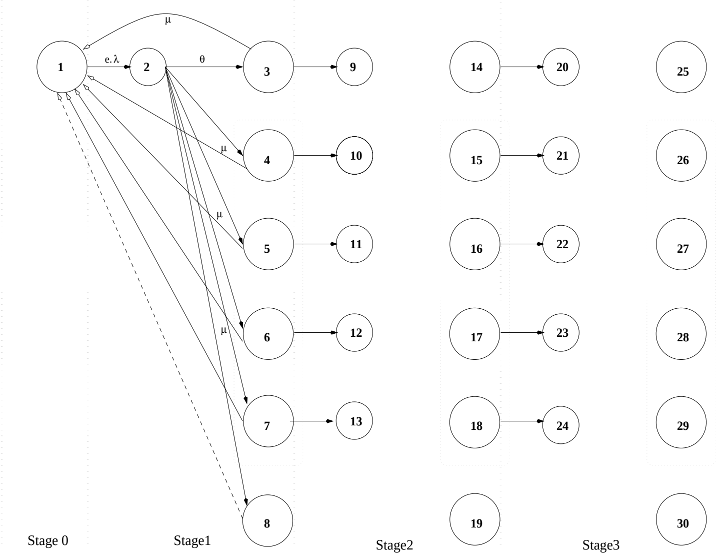


- US Network

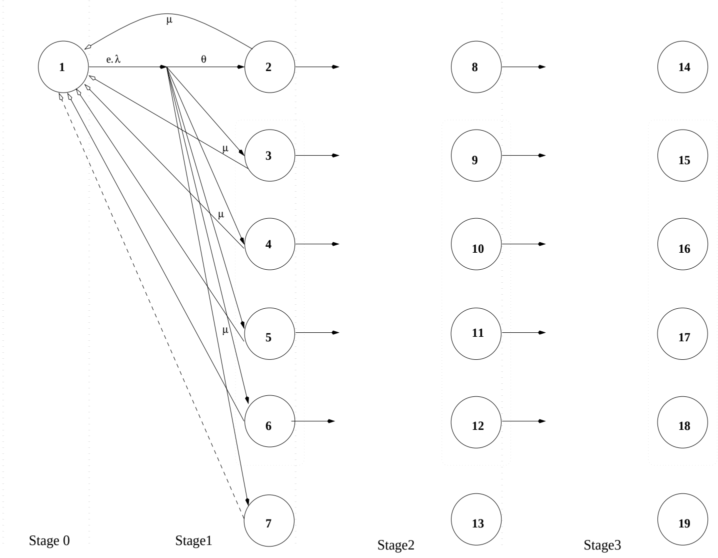


Models Used: M(3,0.5,4)

- Original Model
- 30 State



- Reduced Model
- 19 State



Iterations for the Original & Reduced Models

- New Jersey Network

Simulated analysis period (hr)	Number of steps	
	Original (30 State)	Reduced (19 State)
1	1295	18
2	2586	19
3	3878	22
4	5168	24
5	6460	25
6	7752	26
7	9043	27
8	10335	28
9	11626	29
10	12917	32
20	25831	72
50	77485	183
100	129141	368

- US Network

Simulated analysis period (hr)	Number of steps	
	Original (30 State)	Reduced (19 State)
1	821	18
2	1636	21
3	2452	25
4	3267	27
5	4082	29
6	4897	31
7	5714	32
8	6530	33
9	7346	34
10	8162	34
20	16320	63
50	40791	152
100	68014	301

Run-Time for the Original & Reduced Models

- New Jersey Network

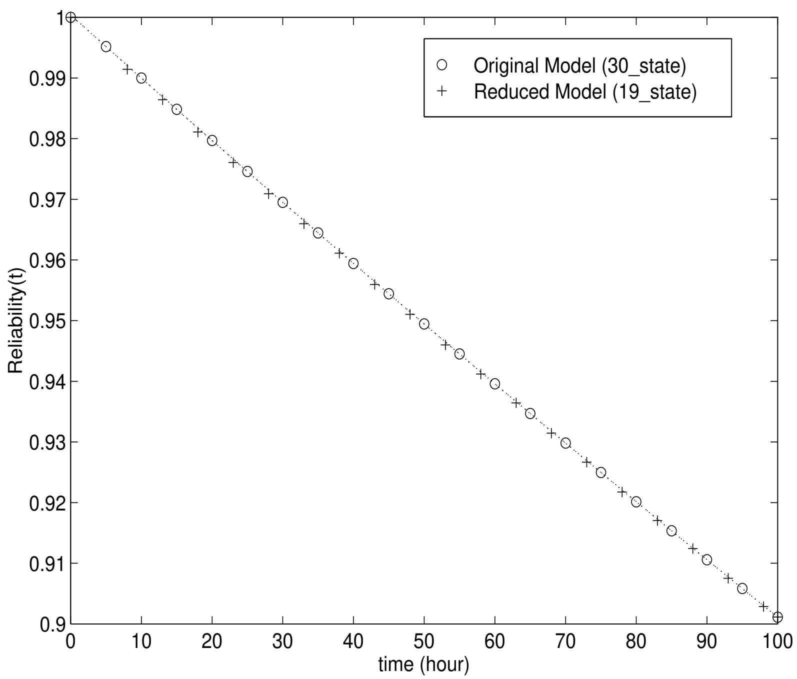
Simulated analysis period (hr)	Run-Time (hr:min:sec)	
	Original (30 State)	Reduced (19 State)
1	00:03:49	00:00:00.23
2	00:08:56	00:00:00.21
3	00:15:27	00:00:00.24
4	00:23:10	00:00:00.26
5	00:32:25	00:00:00.28
6	00:51:64	00:00:00.29
7	00:57:11	00:00:00.30
8	01:16:21	00:00:00.58
9	01:26:40	00:00:00.45
10	01:58:19	00:00:00.70
20	02:48:32	00:00:04
50	06:25:11	00:00:08
100	46:38:46	00:00:19

- US Network

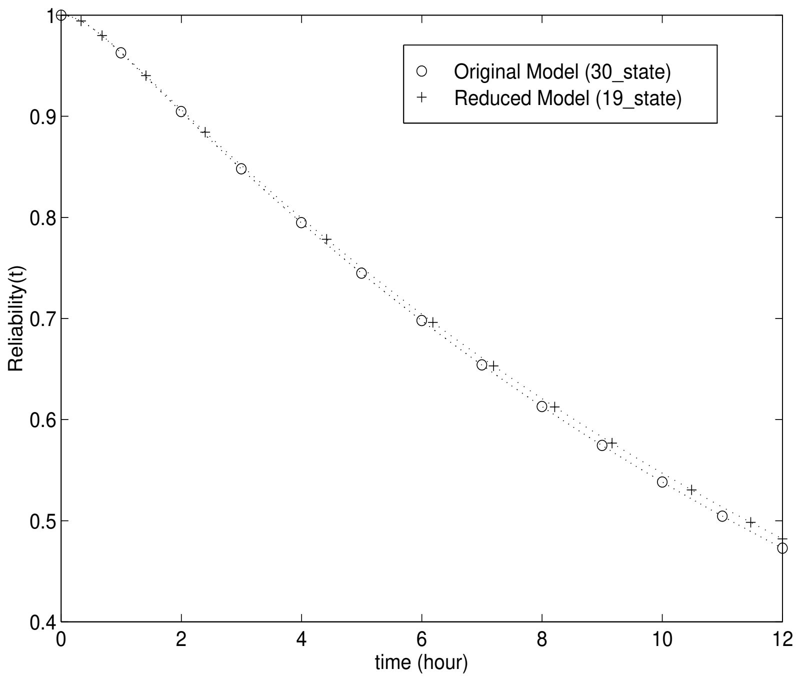
Simulated analysis period (hr)	Run-Time (hr:min:sec)	
	Original (30 State)	Reduced (19 State)
1	00:00:42	00:00:00.21
2	00:01:42	00:00:00.23
3	00:03:05	00:00:00.28
4	00:04:51	00:00:00.30
5	00:07:13	00:00:00.32
6	00:09:35	00:00:00.35
7	00:12:30	00:00:00.52
8	00:16:25	00:00:00.61
9	00:20:27	00:00:00.71
10	00:24:11	00:00:00.57
20	00:38:03	00:00:03
50	01:42:23	00:00:07
100	12:15:22	00:00:17

Reliability of the Experimental Networks

- New Jersey Network



- US Network



Availability of the Experimental Networks

Experimental Networks	Availability	
	Original Model (30 State)	Reduced Model (19 State)
"New Jersey" network	0.999833389953	0.999833410915
"US" network	0.9843426772	0.9843461500

Conclusion

- Major run-time reduction
  - Order of thousands
- Minor accuracy lost
  - Order of 10^{-6}
- Non divergent transient behavior
- Complementary use of both models