Markov Modeling of Redundant System on Chip (SoC) Systems

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California Institute of Technology

Outline

- Project Overview
- Snapdragon Usage at JPL
- Models
  - Overview
  - Model 1
  - Model 2
  - Model 3
  - Model 4
- Results
- Parameter Sensitivity
- Future work

Project Overview

Motivation:

There is… increasing cost + decreasing availability of custom SoC components

So we want to… reduce reliance on RAD750 (radiation hardened)

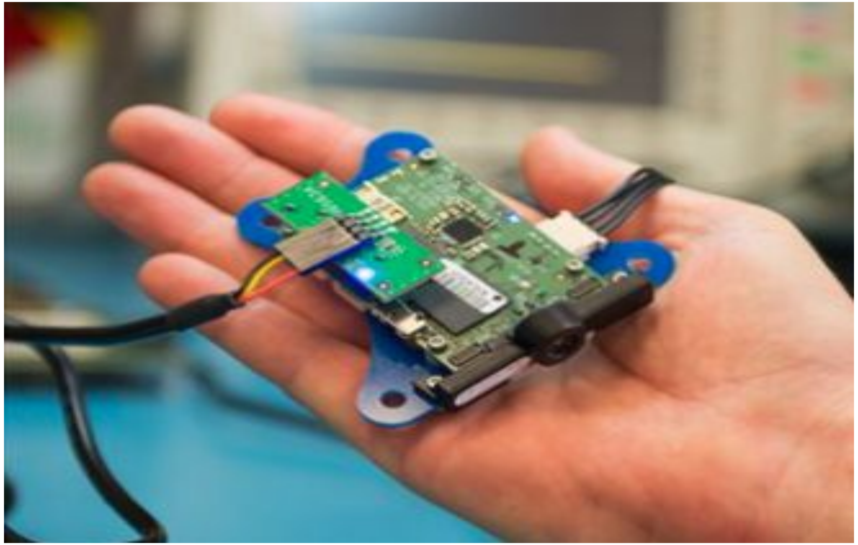
The problem is… commercially available processors are not originally designed for space environments

Task:

Model redundant System on Chip (SoC) configurations using Markov models for two Qualcomm Snapdragon processors to understand how the reliability of the chips, including common cause failures, can impact mission success probability and risk.

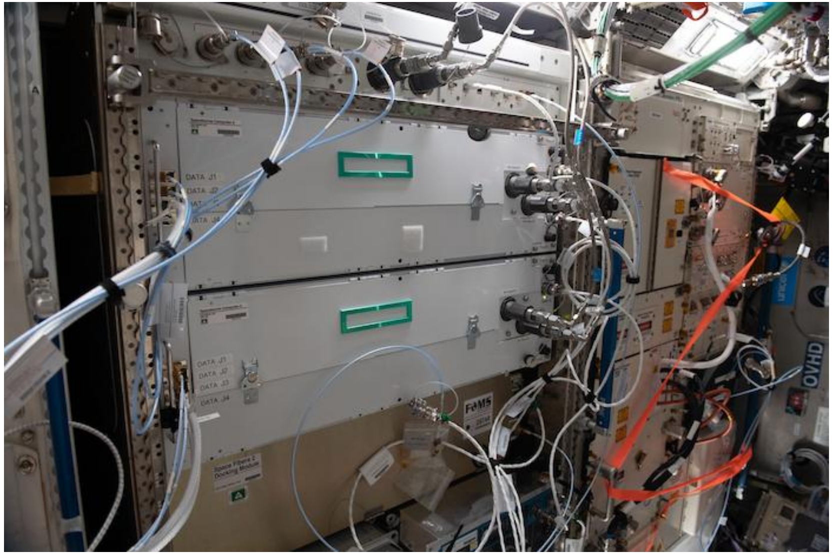
Snapdragon Usage at JPL

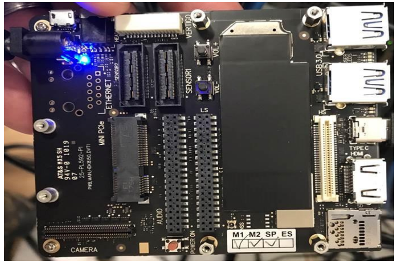
Mars Ingenuity Helicopter

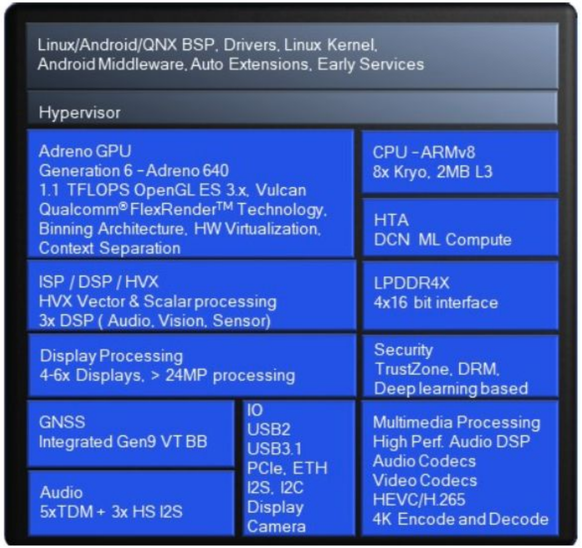


Snapdragon 801 based drone flight board used on Ingenuity for Guidance & Navigation

Snapdragon Usage at JPL







Linux/Android/QNX BSP, Drivers, Linux Kernel, Android Middleware, Auto Extensions, Early Services

Hypervisor

Adreno GPU
Generation 6 - Adreno 640
1.1 TFLOPS OpenGL ES 3.x, Vulcan
Qualcomm® FlexRender™ Technology,
Binning Architecture, HW Virtualization,
Context Separation

CPU - ARMv8
8x Kryo, 2MB L3

HTA
DCN ML Compute

ISP / DSP / HVX
HVX Vector & Scalar processing
3x DSP (Audio, Vision, Sensor)

LPDDR4X
4x16 bit interface

Display Processing
4-6x Displays, > 24MP processing

Security
TrustZone, DRM,
Deep learning based

GNSS
Integrated Gen9 VT BB

Audio
5xTDM + 3x HS I2S

IO
USB2
USB3.1
PCIe, ETH
I2S, I2C
Display
Camera

Multimedia Processing
High Perf. Audio DSP
Audio Codecs
Video Codecs
HEVC/H.265
4K Encode and Decode

HPE Spaceborne Computer-2 servers on board ISS
Qualcomm 855 eval board interfaced together
Commercial edge based Artificial Intelligence platforms

Qualcomm SA8155 System on a Chip

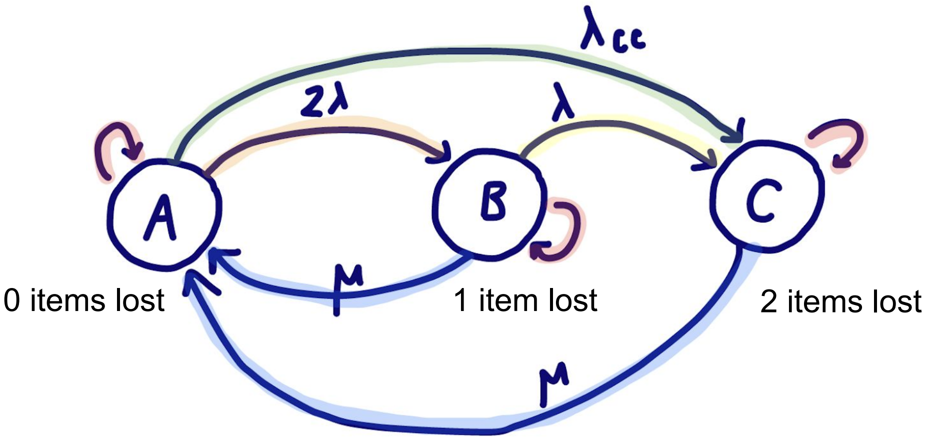
Model Overview

Notation	
Failure rate	λ
Failure rate w/ common cause factor	λ_{cc}
Recovery rate	μ

Model #	Recoverable System?	Additional Assumptions
1	Yes	Rate of recovering both processors = rate of recovering one processor
2	Yes	Processors recover independently at two separate recovery rates
3	Yes	Boot-up time of second processor > recovery time for a single processor
4	No	Same additional assumptions as Model 1

Model 1: Simplified

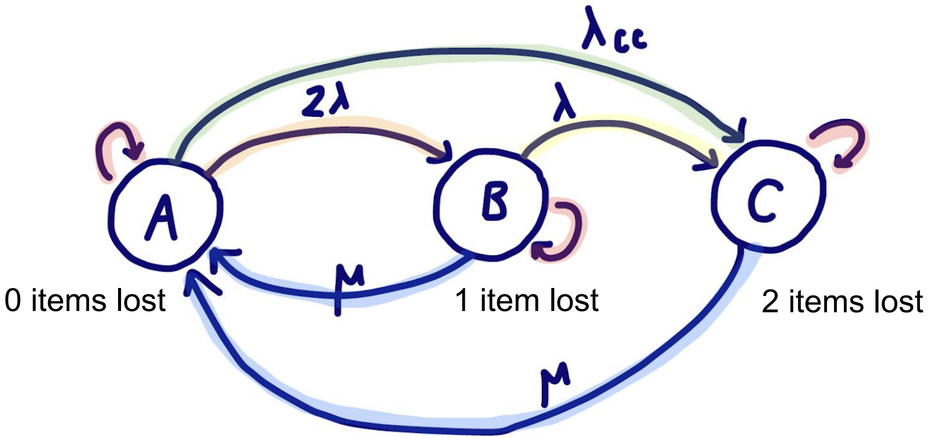
Three-State Markov Model



Model #	Recoverable System?	Additional Assumptions
1	Yes	Rate of recovering both processors = rate of recovering one processor

Model 1: Simplified

Three-State Markov Model



Transition Matrix

to

from

$$\begin{array}{c|ccc}
 & A & B & C \\
\hline
A & 1-2\lambda\Delta t-\lambda_{cc}\Delta t & 2\lambda\Delta t & \lambda_{cc}\Delta t \\
B & \mu\Delta t & 1-\mu\Delta t-\lambda\Delta t & \lambda\Delta t \\
C & \mu\Delta t & 0 & 1-\mu\Delta t
\end{array}$$

Model #	Recoverable System?	Additional Assumptions
1	Yes	Rate of recovering both processors = rate of recovering one processor

Model 1

31 States

1 with 0 items lost (center, yellow)
5 with 1 item lost (inner ring, blue)
25 with 2 items lost (outer ring, green)

Failure rates (λ)

10/day for memory failures
1/day for other failures

Recovery rate (μ)

120s of recovery per 1hr – 0.033

Common Cause Factor (cc)

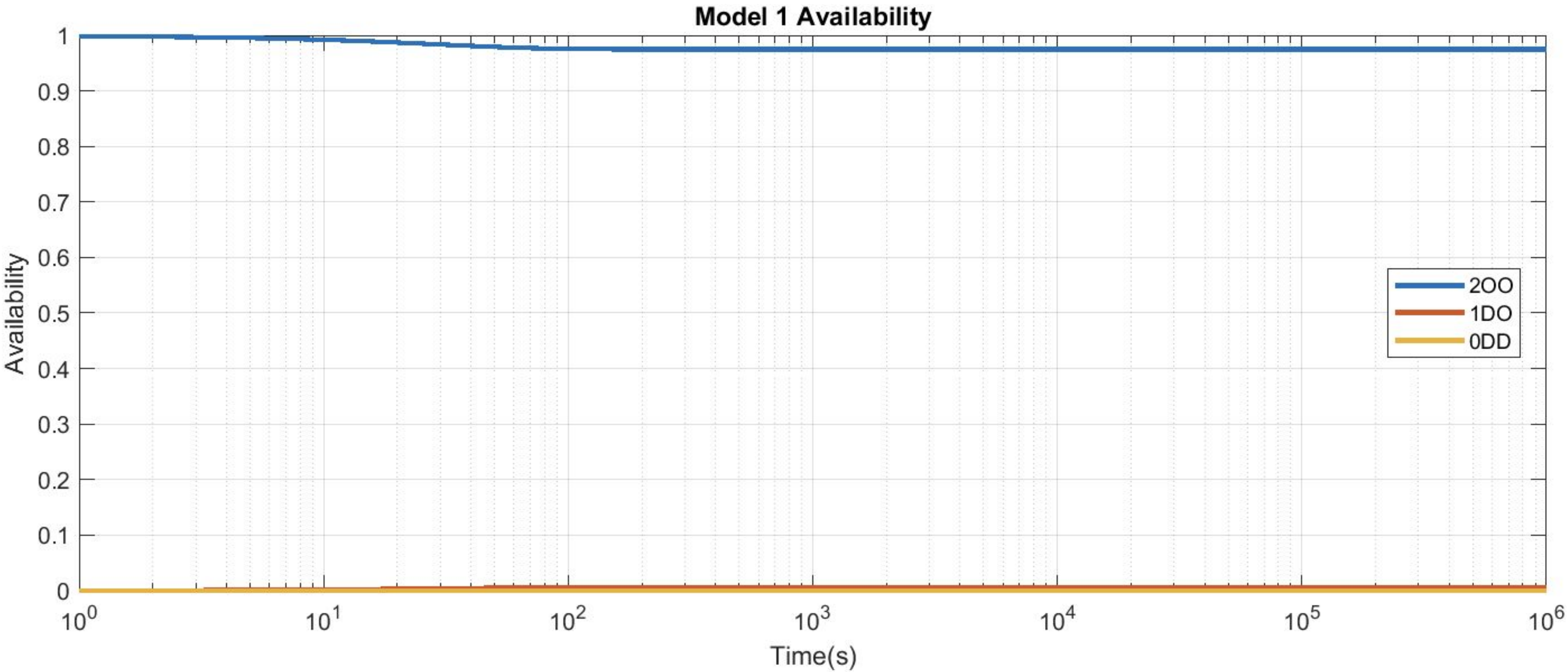
10%

5 Upset Types

Memory DDR [D], Memory LFS [U]
Memory FRAM [F], PMIC [P], SOC [S]

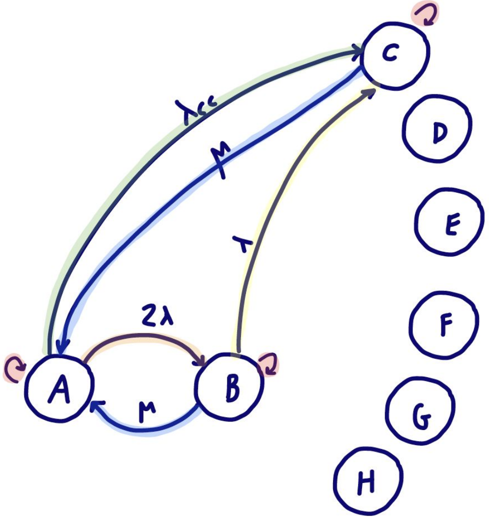
	# of states available	first upset type	second upset type
2OO	2	O	O
1DO	1	D	O
0DU	0	D	U

Model 1: Results

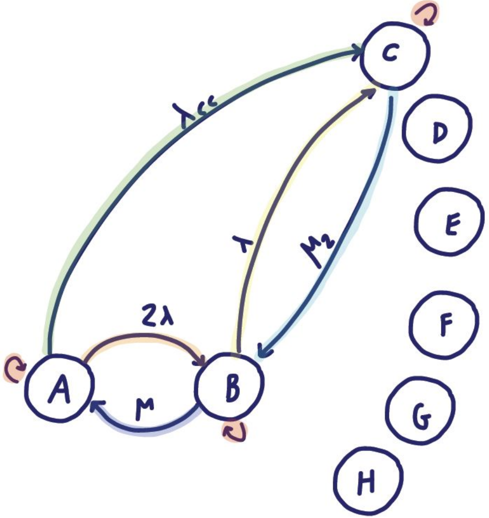


Model 2: Simplified

Model 1: Assumes we can recover two items at a time, at rate μ



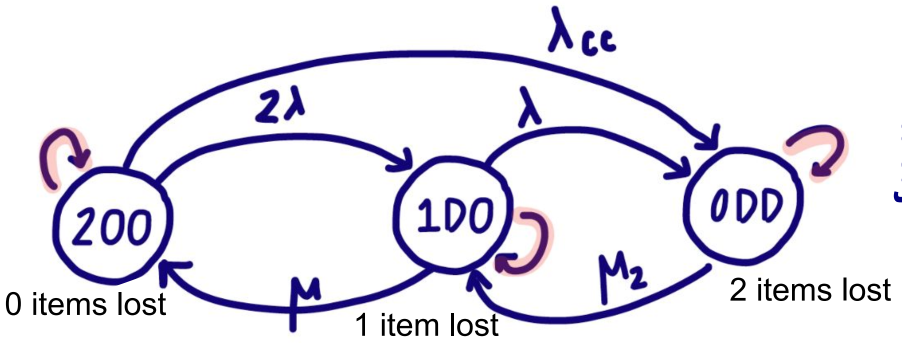
Model 2: Assumes we can recover one item at a time, at rates μ and μ_2



Model #	Recoverable System?	Additional Assumptions
2	Yes	Processors recover independently at two separate recovery rates

Model 2: Simplified

Three-State Markov Model



Transition Matrix

to

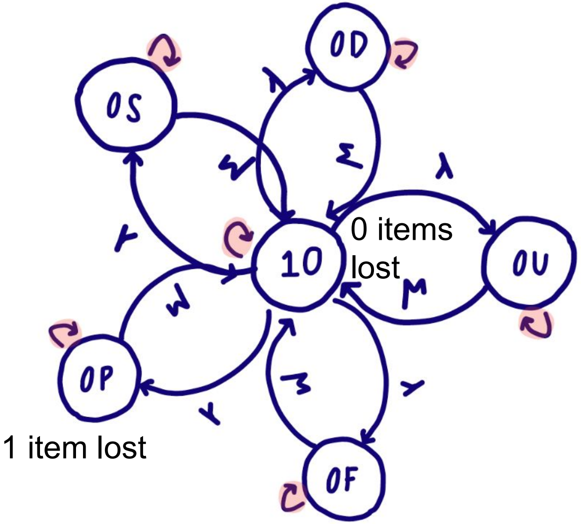
from

$$
\begin{array}{c|ccc}
 & 200 & 1DD & 0DD \\
\hline
200 & 1-2\lambda\Delta t-\lambda_{cc}\Delta t & 2\lambda\Delta t & \lambda_{cc}\Delta t \\
1DD & \mu\Delta t & 1-\mu\Delta t-\lambda\Delta t & \lambda\Delta t \\
0DD & 0 & \mu_2\Delta t & 1-\mu_2\Delta t
\end{array}
$$

Model #	Recoverable System?	Additional Assumptions
2	Yes	Processors recover independently at two separate recovery rates

Model 3: Simplified

Six-State Markov Model



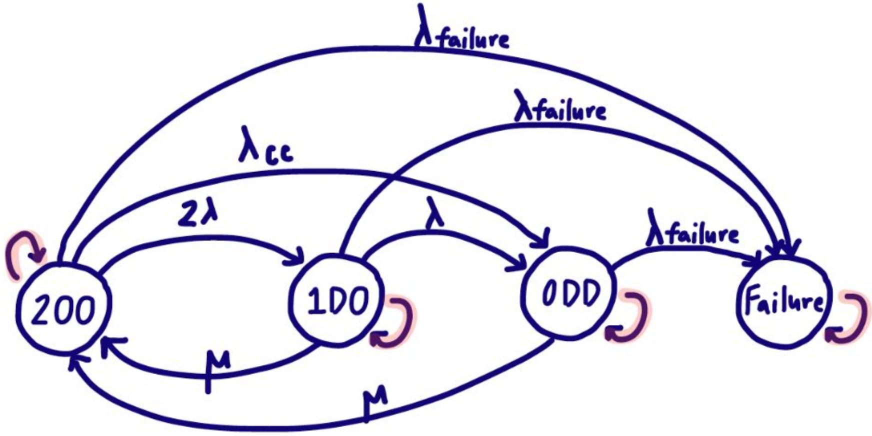
Transition Matrix

$$\begin{array}{c|cccccc} & & & \text{to} & & & \\ & 10 & OD & OU & OF & OP & OS \\ \hline \text{from} \quad 10 & 1-5\lambda\Delta t & \lambda\Delta t & \lambda\Delta t & \lambda\Delta t & \lambda\Delta t & \lambda\Delta t \\ OD & \mu\Delta t & 1-\mu\Delta t & 0 & 0 & 0 & 0 \\ OU & \mu\Delta t & 0 & 1-\mu\Delta t & 0 & 0 & 0 \\ OF & \mu\Delta t & 0 & 0 & 1-\mu\Delta t & 0 & 0 \\ OP & \mu\Delta t & 0 & 0 & 0 & 1-\mu\Delta t & 0 \\ OS & \mu\Delta t & 0 & 0 & 0 & 0 & 1-\mu\Delta t \end{array}$$

Model #	Recoverable System?	Additional Assumptions
3	Yes	Boot-up time of second processor > recovery time for a single processor

Model 4: Simplified

Four-State Markov Model



0 items lost 1 item lost 2 items lost

Transition Matrix

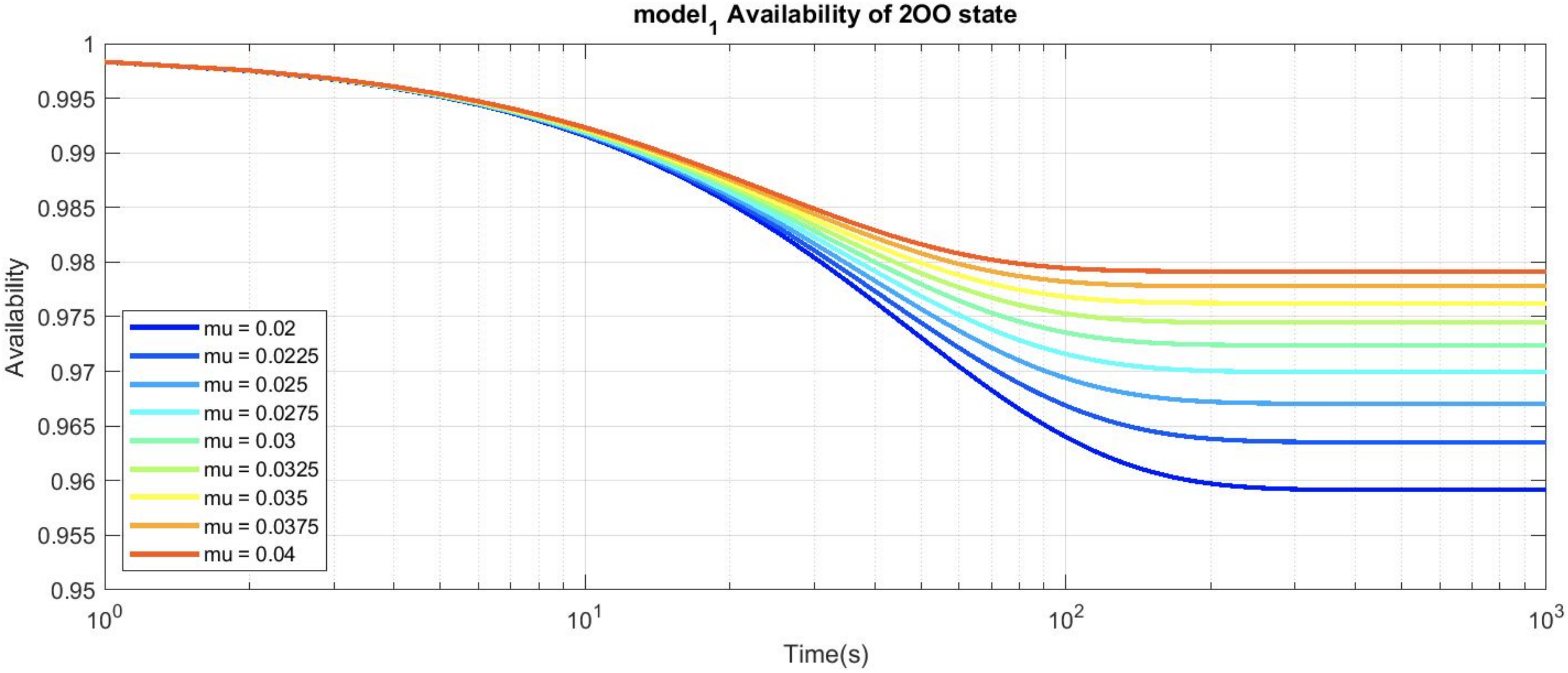
$$\begin{array}{c|cccc}
\text{from} \backslash \text{to} & 200 & 1D0 & 0DD & \text{Failure} \\
\hline
200 & 1-2\lambda\Delta t-\lambda_{cc}\Delta t-\lambda_{failure} & 2\lambda\Delta t & \lambda_{cc}\Delta t & \lambda_{failure} \\
1D0 & \mu\Delta t & 1-\mu\Delta t-\lambda\Delta t-\lambda_{failure} & \lambda\Delta t & \lambda_{failure} \\
0DD & \mu\Delta t & 0 & 1-\mu\Delta t-\lambda_{failure} & \lambda_{failure} \\
\text{Failure} & 0 & 0 & 0 & 1
\end{array}$$

Model #	Recoverable System?	Additional Assumptions
4	No	Same additional assumptions as Model 1

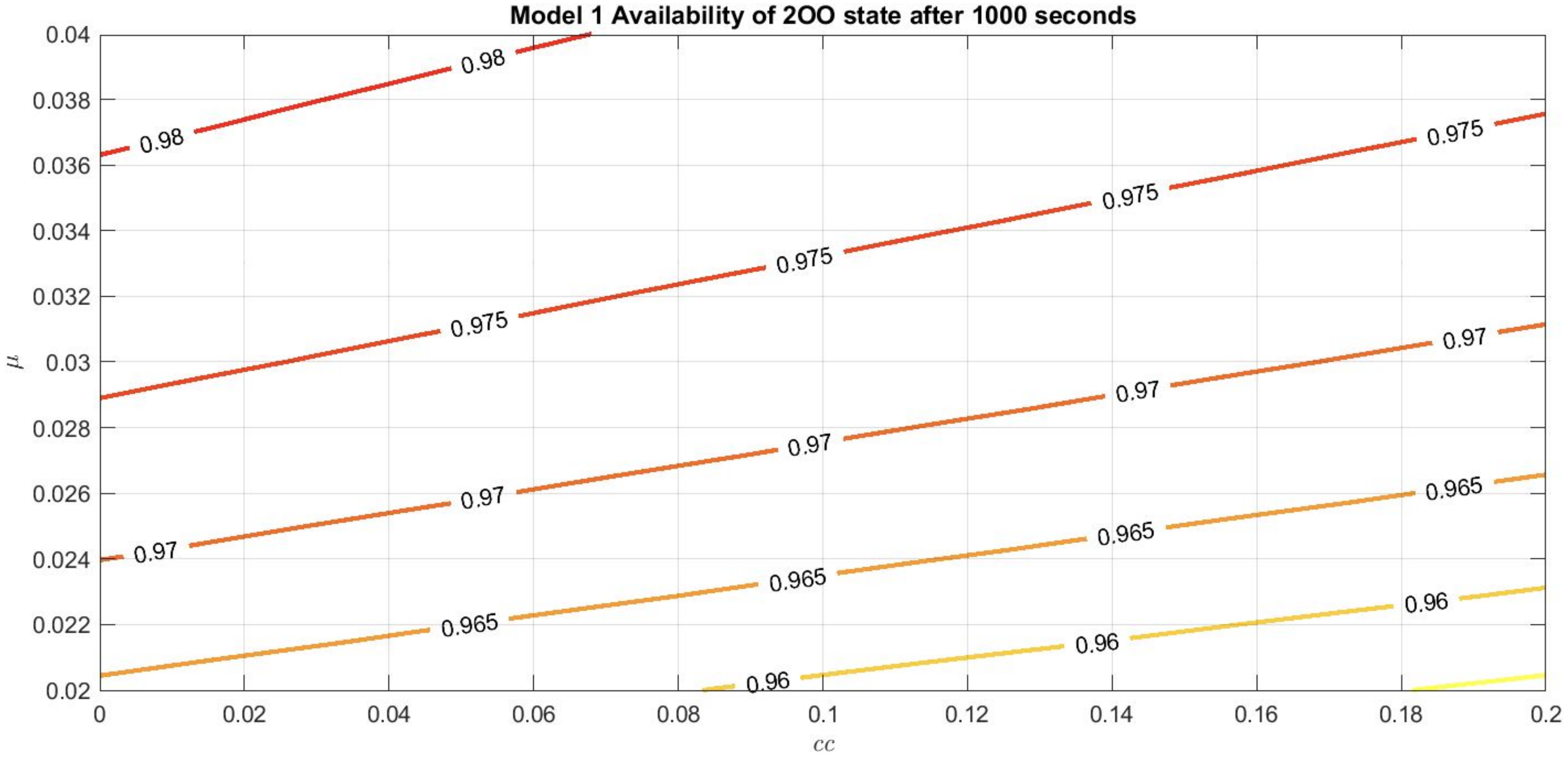
Results Summary

Model #	Recoverable System?	Additional Assumptions	Availability of 2OO State after 10^6 seconds
1	Yes	Rate of recovering both processors = rate of recovering one processor	**0.975**
2	Yes	Processors recover independently at two separate recovery rates	**0.970**
3	Yes	Boot-up time of second processor > recovery time for a single processor	**0.989**
4	No	Same additional assumptions as Model 1	**0.344**

Parameter Sensitivity: Model 1, vary μ



Parameter Sensitivity: Model 1, vary μ and cc



Future Work

1) Model with larger recovery periods (between 12 and 24 hours)
    a) Accounts for human intervention if the system goes into safe mode

2) Expand on preliminary efforts to count the number of upsets in each model

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Extra Slides

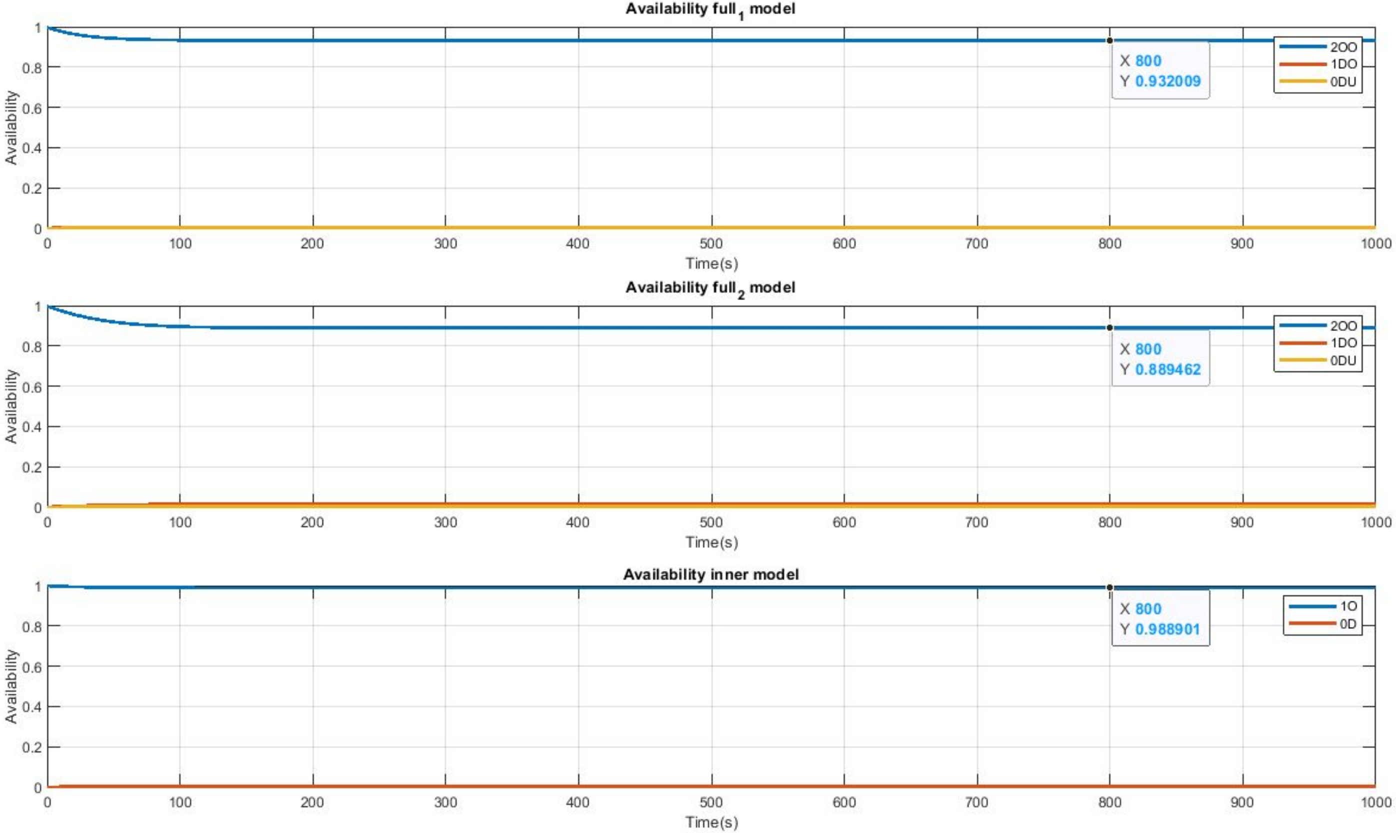
What is a Markov Model?

- A stochastic model used to model pseudo-randomly changing systems
- Future states depend only on the current state, not on the events that occurred before it
  - Assumes the Markov property
  - “Memoryless”

$$\Pr(X_{n+1} = x \mid X_1 = x_1, X_2 = x_2, \ldots, X_n = x_n) = \Pr(X_{n+1} = x \mid X_n = x_n)$$

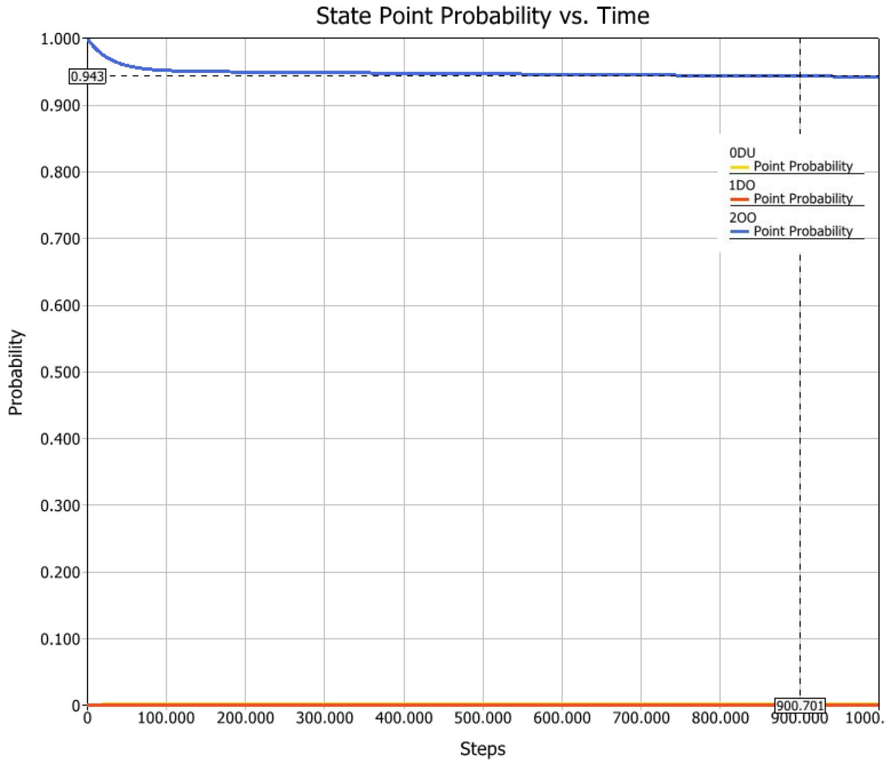
- System is fully observable and autonomous, call it a **Markov chain**

Model Comparison

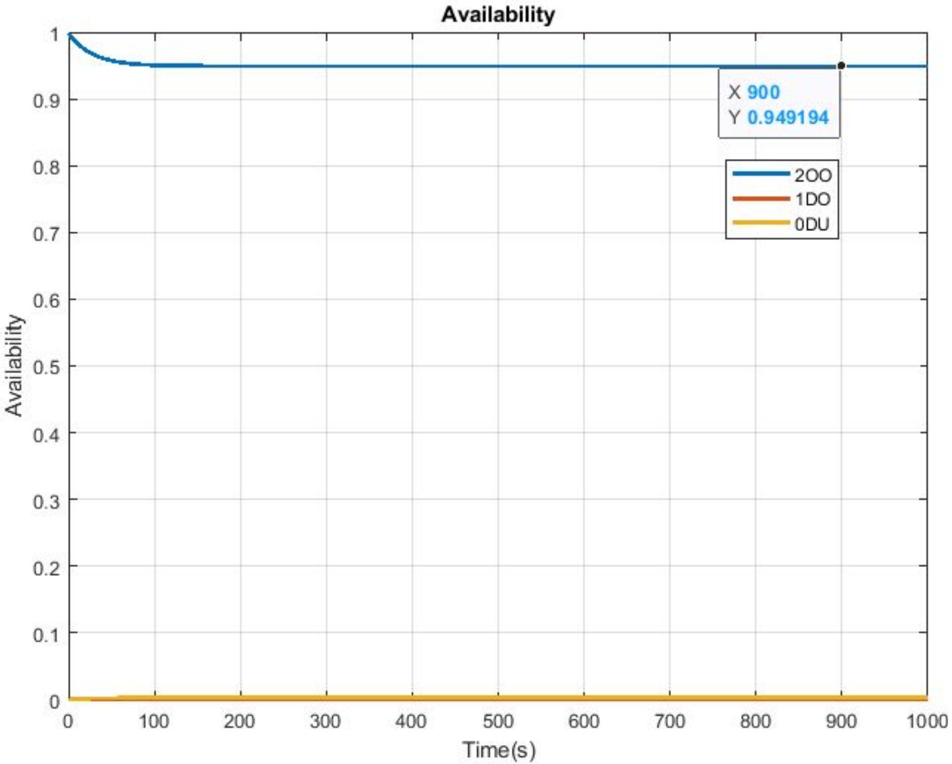


Model 1 - BlockSim vs. MATLAB

BlockSim

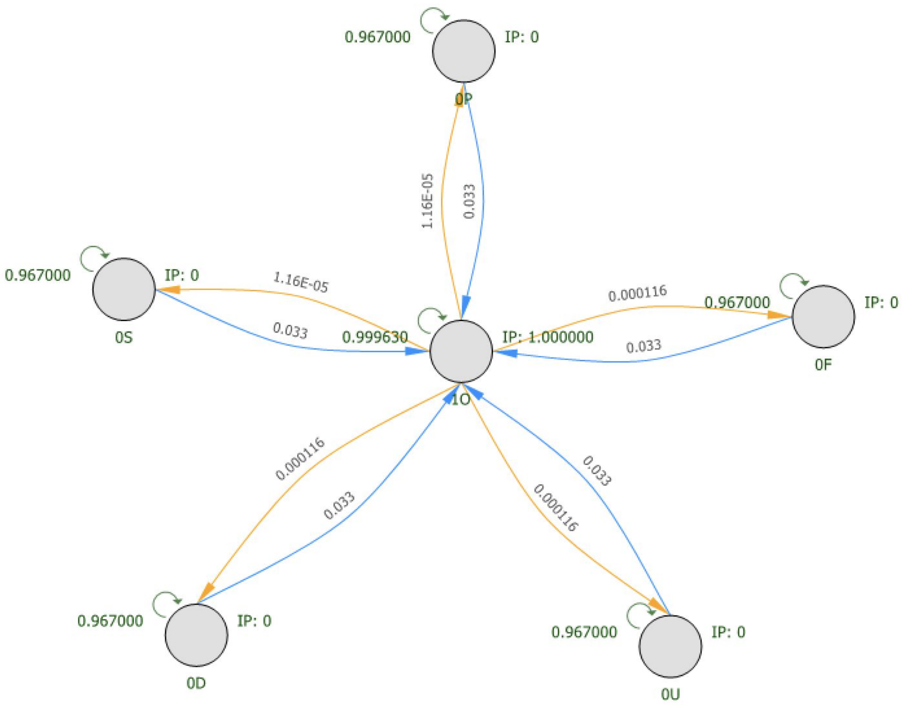


MATLAB

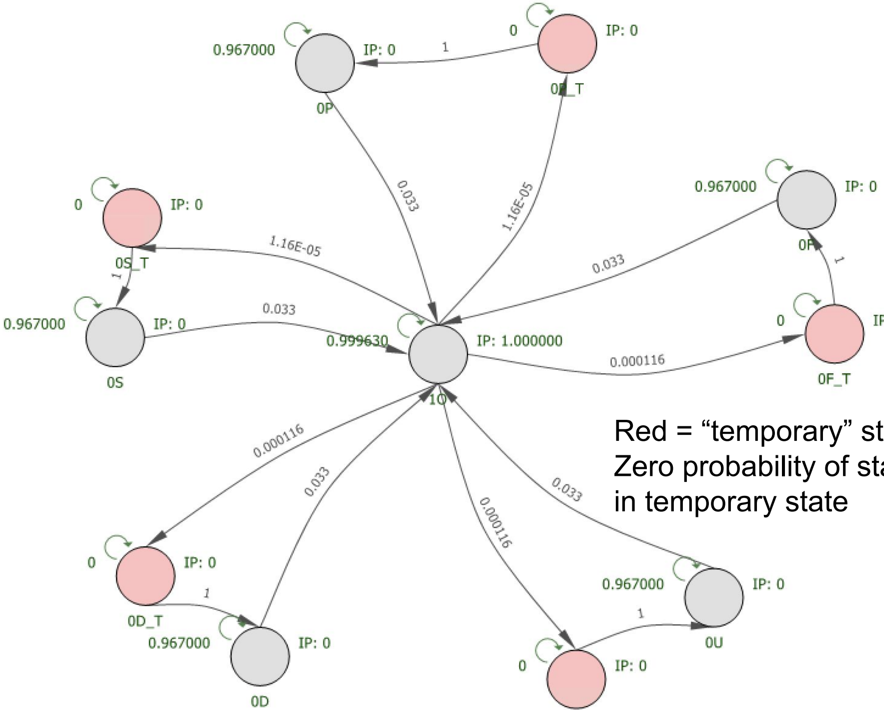


Fail Counting with Inner Model

Inner Model



Inner Fail Counting Model



Red = “temporary” state
Zero probability of staying in temporary state

Fail Counting with Inner Model

Inner Model

Results After 1000 Steps				
State Name	**Initial Prob.**	**Mean Prob.**	**Point Prob.**	**Steps Spent in State**
1O	1	0.989232	0.988905	989.231786
0D	0	0.003365	0.003467	3.364994
0U	0	0.003365	0.003467	3.364994
0F	0	0.003365	0.003467	3.364994
0S	0	0.000337	0.000347	0.336616
0P	0	0.000337	0.000347	0.336616

Inner Fail Counting Model

Results After 1000 Steps				
State Name	**Initial Probability**	**Mean Probability**	**Point Probability**	**Steps Spent in State**
1O	1	0.988881	0.988543	988.880742
0D	0	0.00336	0.003466	3.360336
0U	0	0.00336	0.003466	3.360336
0F	0	0.00336	0.003466	3.360336
0P	0	0.000336	0.000347	0.33615
0S	0	0.000336	0.000347	0.33615
0D_T	0	0.000114	0.000114	0.114357
0U_T	0	0.000114	0.000114	0.114357
0F_T	0	0.000114	0.000114	0.114357
0S_T	0	0.000011	0.000011	0.01144
0P_T	0	0.000011	0.000011	0.01144

BlockSim results table for inner model and inner fail counting model, same parameters