Balancing System Availability and Lifetime with Dynamic Hidden Markov Models

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Abstract

- Electronic components in space applications are subject to high levels of ionizing and particle radiation, causing transient errors and permanent failure.
- Transient errors can be detected and corrected using memory scrubbing. However, this causes an overhead that reduces both the availability and the lifetime of the system.
- We present a mechanism based on dynamic hidden Markov models that balances availability and lifetime by estimating and predicting the probability of the occurrence of permanent and transient faults.
- Results show that our model leads systems to their desired lifetime, and it outperforms rule-based and traditional hidden Markov models approaches.

1. Motivation

In space, integrated circuits are exposed to:

- High level of radiation.
- Heavy ion impacts.

These factors can disrupt circuits' behavior.
Methods for the detection/recovery of transient errors exist [1], but there are no clear guidelines on how to deal also with permanent faults.
Typical approaches consist of:

- Repeated computation.
- A threshold on consecutive errors [2].

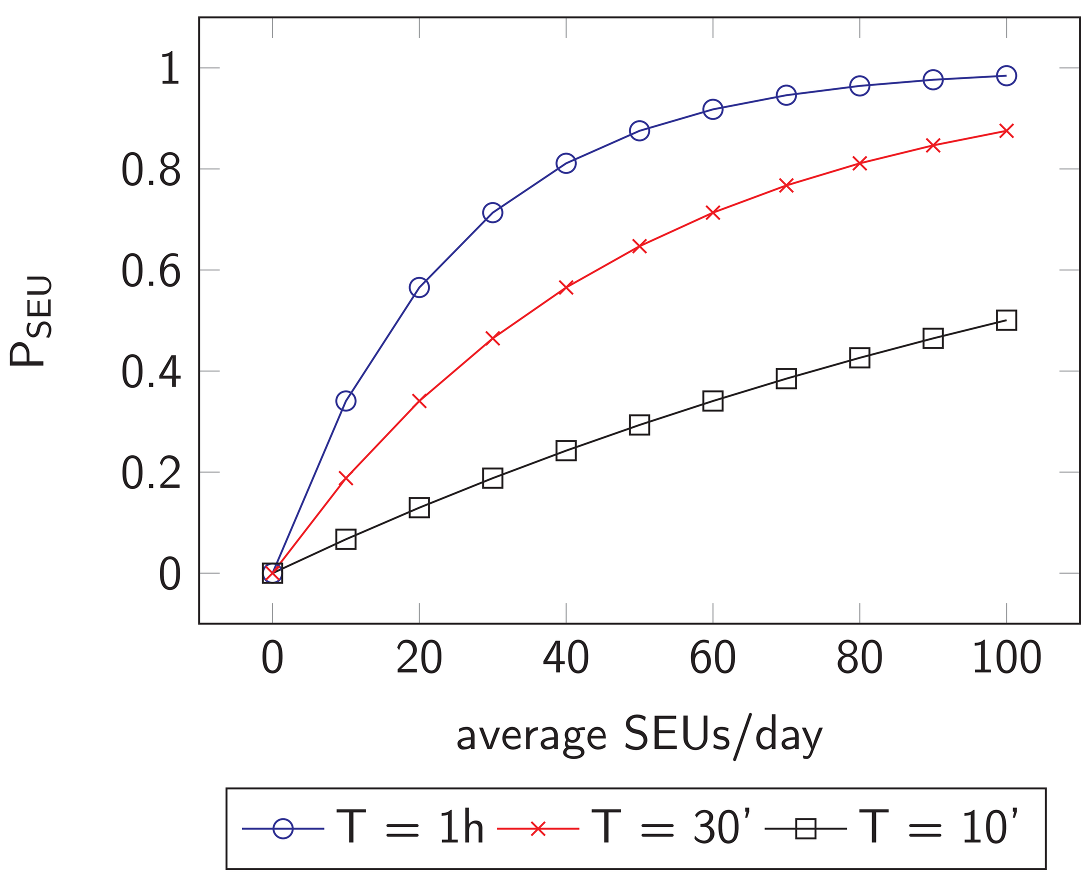
However, this methodology requires additional resources, reduces system availability, and accelerates the wear of the electronics.

2. Single Event Upsets

We use probability theory to model the occurrence of faults.
SEUs are caused by high-energy particles:

- Whose impacts are independent.
- Which happen at a constant average rate.
- The rate is mission phase-dependent.

The number of impacts in a scrubbing period of length T is a Poisson rand variable.

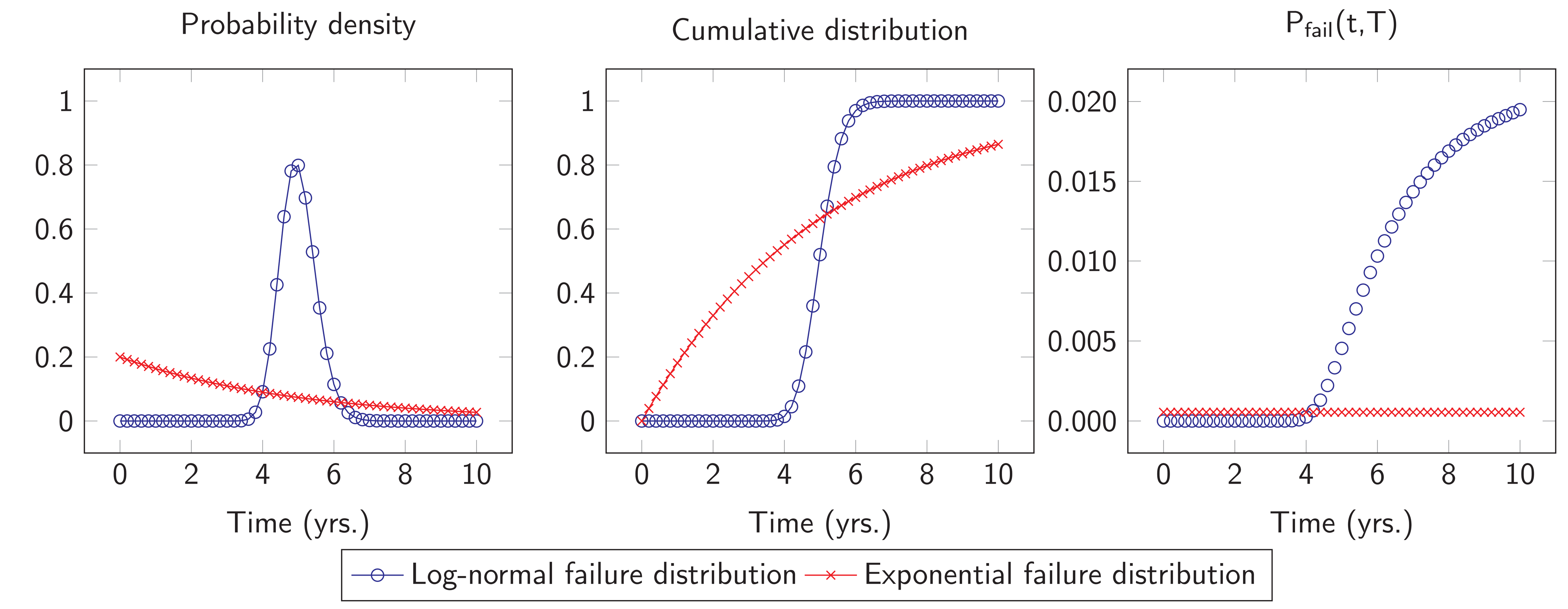


3. Permanent Faults

The probability that a permanent fault will occur by time t, given that the system was still functional at the end of the previous scrubbing period of length T, is $P_{fail}(t, T)$.

- The memoryless exponential probability distribution is frequently used in the literature.
- Because memorylessness neglects wear, we adopt a log-normal failure distribution.

Comparison of exponentially and log-normally distributed failures with MTTF = 5 yrs.

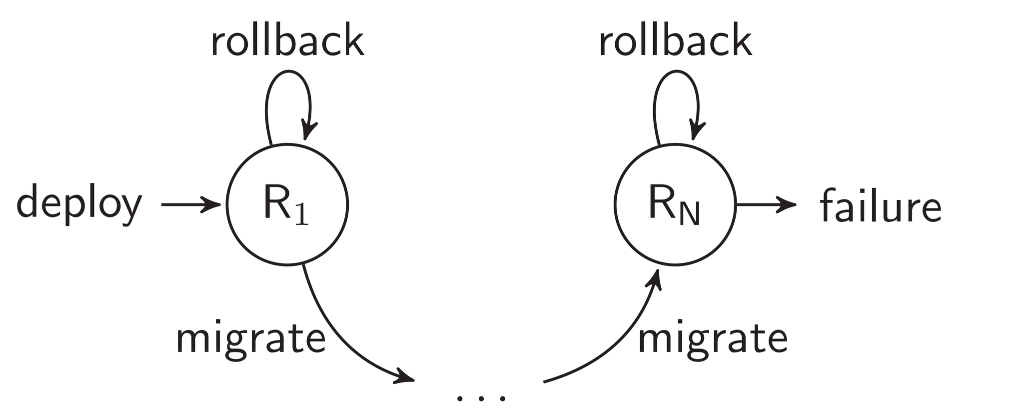


4. Computing Model

The computing model abstracts:

- Homogeneous multi-core systems.
- Any N-times modular redundant system.

Hastily declaring failures reduces *lifetime*.
Lingering for too long reduces *availability*.

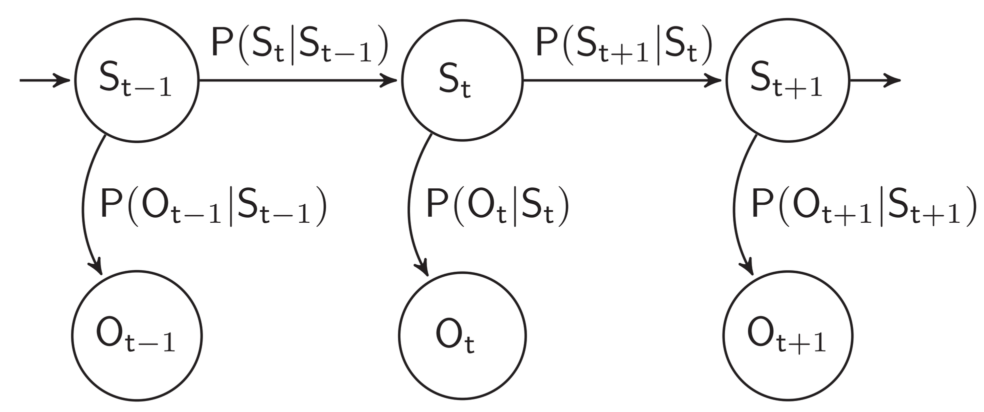


5. Hidden Markov Models

A mathematical framework to model:

- Discrete stochastic systems.
- Evolving stochastic systems.
- Partial-observability/imperfect sensors.

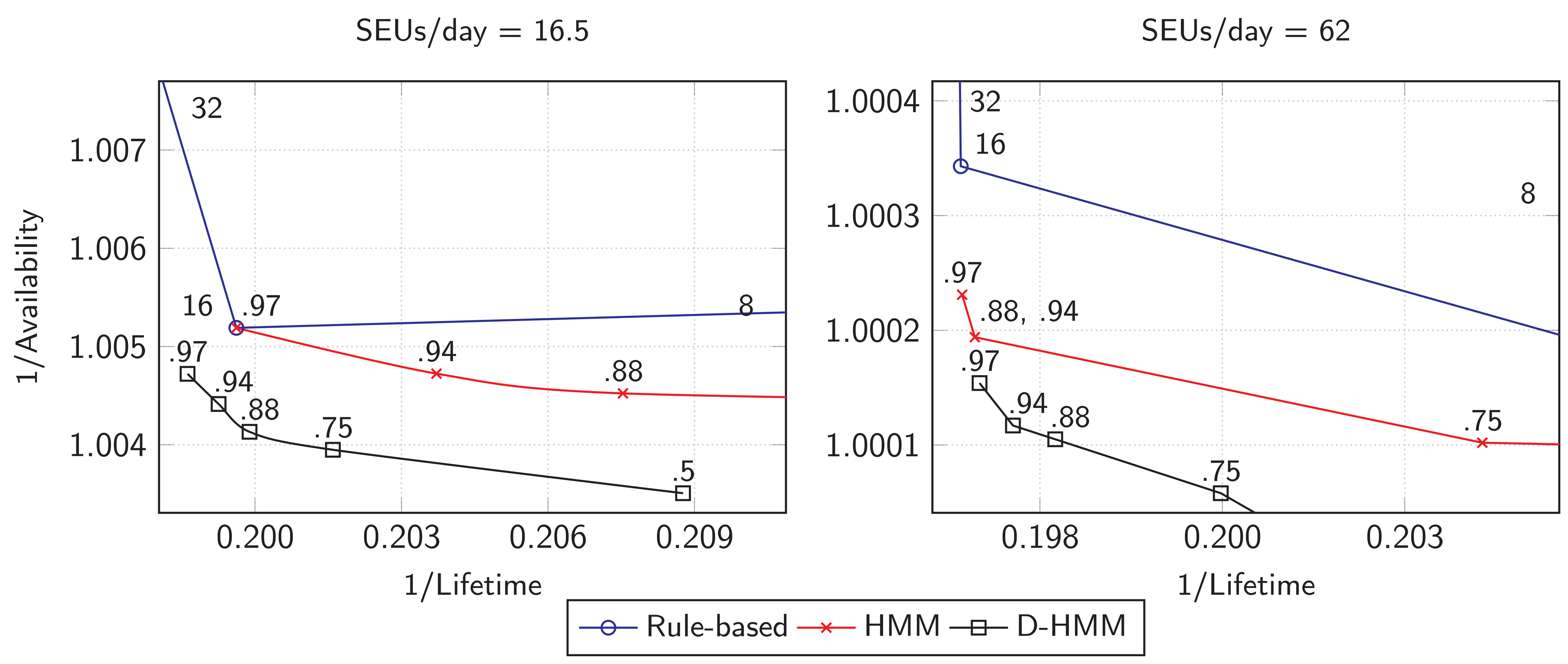
HMMs can predict the next system status.



6. Simulation Results

Lifetime-availability trade-offs in the form of Pareto Curves.

- Comparison of 3 failure detection models (rule-based, HMM, and D-HMM).
- SEU rates representative of a low-Earth orbit (LEO) and in a highly-elliptical orbit (HEO).
- System redundancy is N = 10, and data scrubbing is assumed to take T= 10 minutes.



References

[1] E. Petersen, *Single event effects in aerospace*, 2011.
[2] S. Gupta, A. Ansari, S. Feng, and S. Mahlke, "Adaptive online testing for efficient hard fault detection," in *2009 IEEE Int. Conf. Comput. Des.* IEEE, Oct. 2009, pp. 343–349.

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