

A Self-adaptive Resilient Method for Implementing and Managing the High-reliability Processing System

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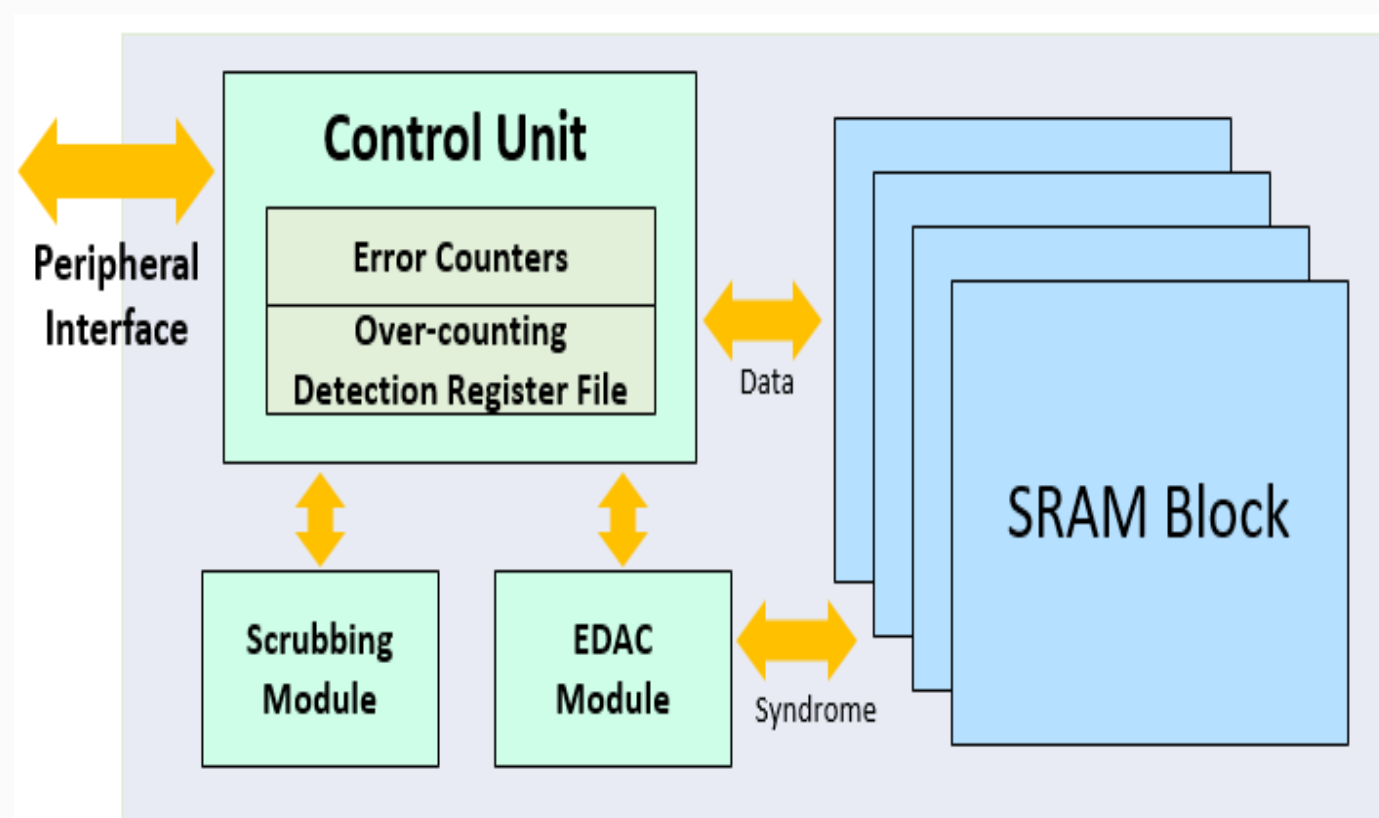
MOTIVATION

- Increasing challenges in ensuring system reliability in mission-critical applications, especially with transistor scaling reaching the deep nanometer range.
- Significant contribution of Single Event Effects (SEEs) to spacecraft anomalies.
- Inefficiencies of traditional static radiation mitigation approaches, leading to over-protection and underutilization of system resources.
- The dynamic nature of the space radiation environment, exemplified by Solar Particle Events (SPEs), requires more adaptive and responsive radiation mitigation strategies.
- An innovative approach is needed to achieve a dynamic balance between system reliability and resource efficiency, adjusted to fluctuations in the intensity of radiation.

OBJECTIVE

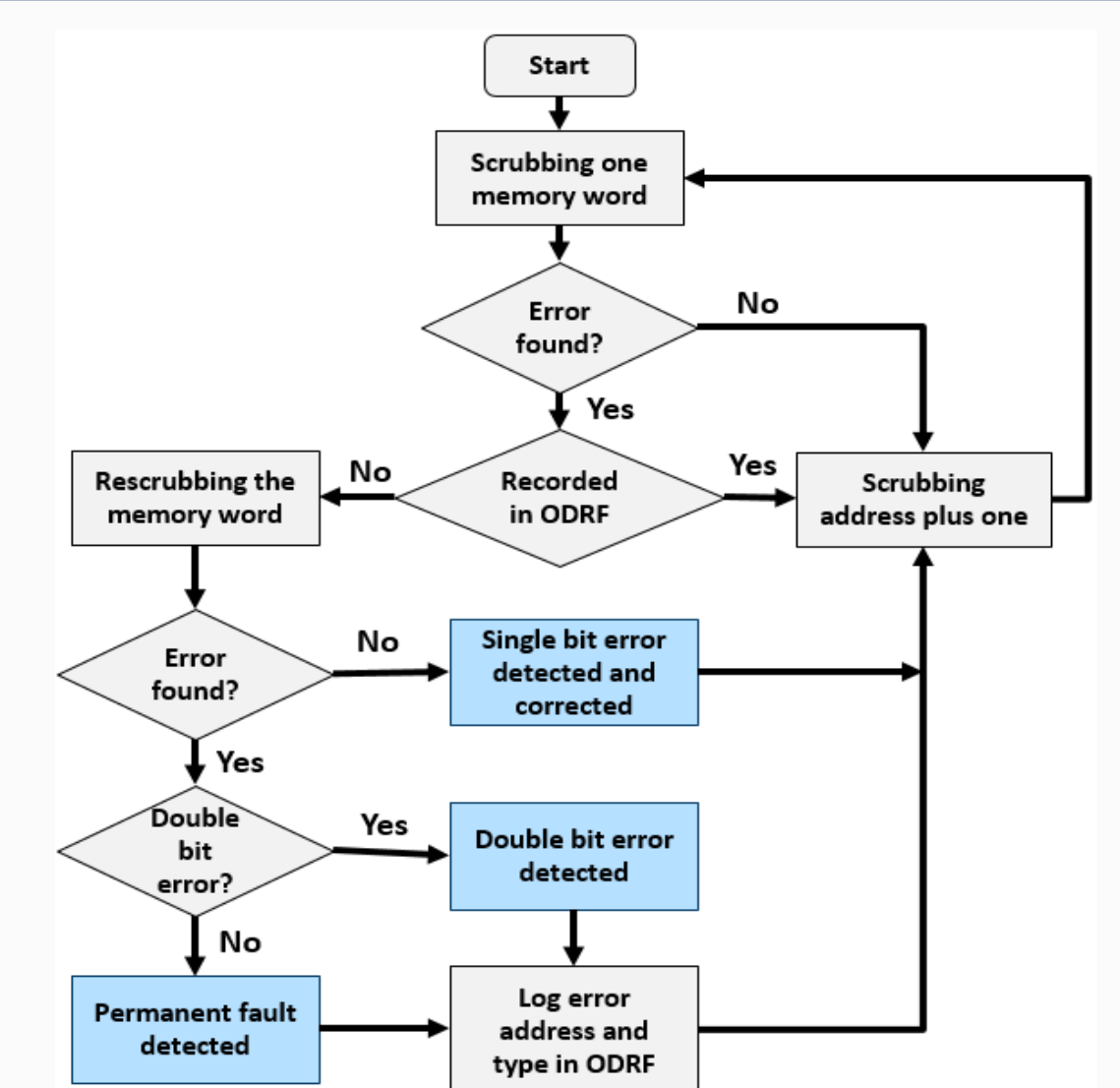
- Develop a self-adaptive processing method tailored for space applications that dynamically balances SEEs resilience, system performance, and power consumption.
- Design an onboard low-cost particle detector for in-flight radiation monitoring for electronic systems in complex radiation environments.
- Implement a prediction framework for the radiation environment and system reliability to enable proactive protection for reliability-critical systems.
- Propose a method for dynamic system optimal modes selection, integrating reconfigurable mitigation strategies with real-time system reliability assessment.
- Integrate and verify the proposed methods into a RISC-V based quad-core SoC.

SRAM-based Radiation Monitor



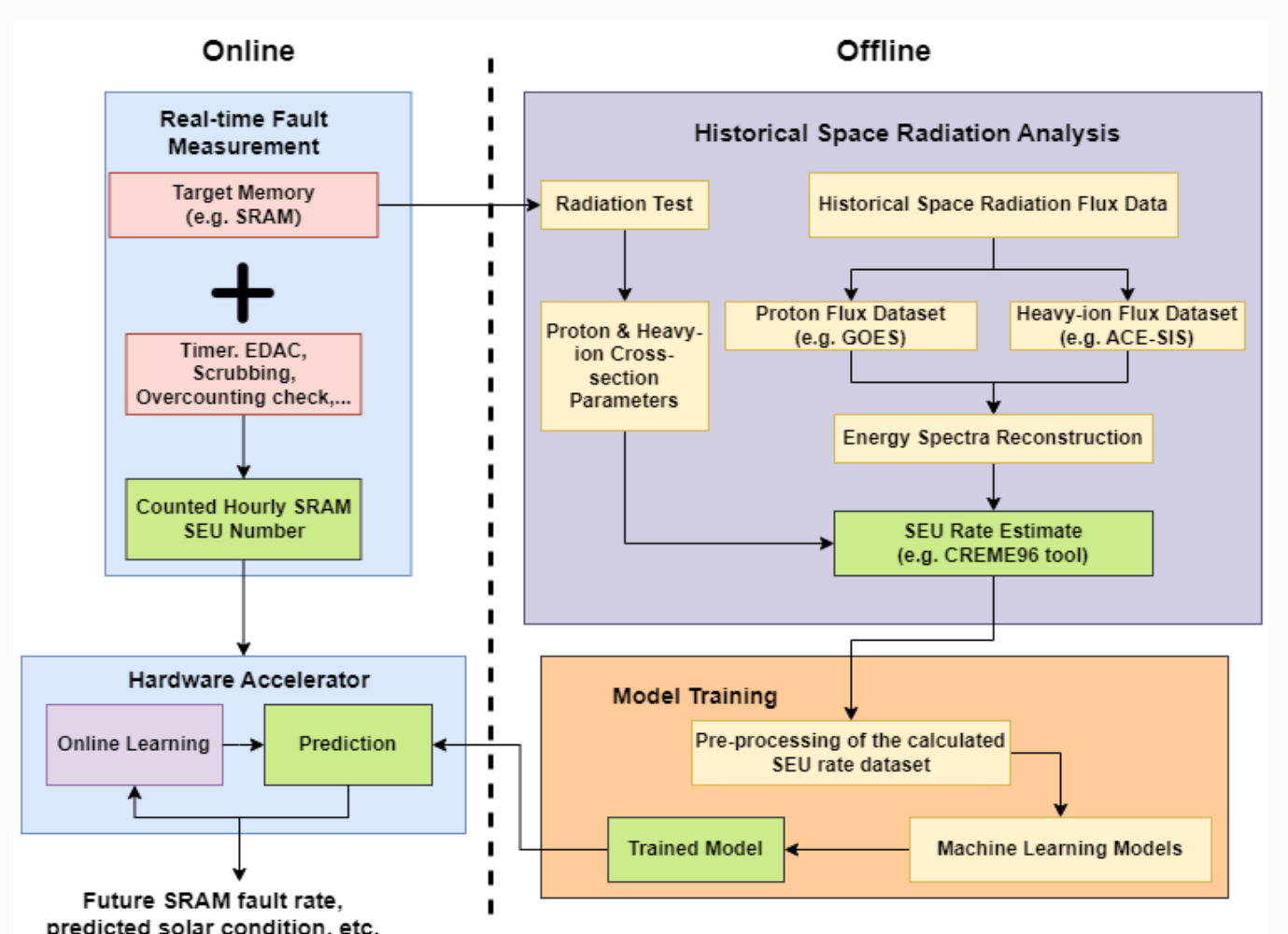
↑ On-chip SRAM-based Single Event Upset Monitor.

- Embeds with onboard SRAM to monitor and measure SEU rates in real time, preserving the primary function of memory storage.
- Detects and categorizes multiple fault types, including single-bit, multi-bit upsets and permanent faults, with a dedicated detection flow and error correction code.
- Prevents data corruption through a scrubbing module that periodically corrects radiation-induced faults in the target memory blocks.
- Validated through fault injection tests and case study implementation in a RISC-V SoC, confirming accurate detection and system integration.
- Maintains system efficiency with less than 1% area overhead and minimal power consumption during SEU detection operations.
- Offers a scalable and integrated solution, improving upon standalone particle detectors by enhancing sensitivity and reducing complexity.

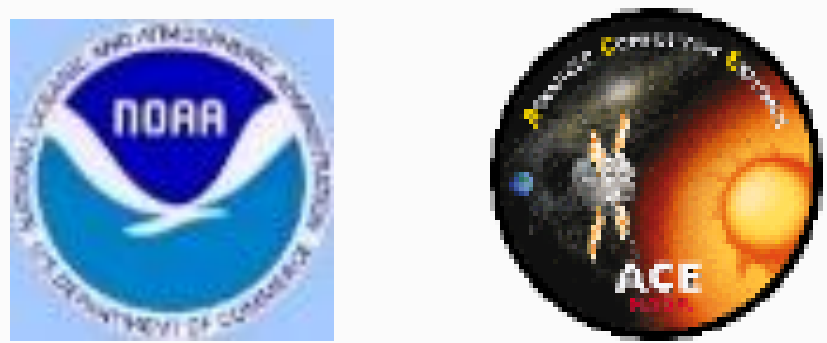


↑ Dedicated faults detection flowchart of the proposed monitor.

Radiation Environment & SEU Rate Prediction

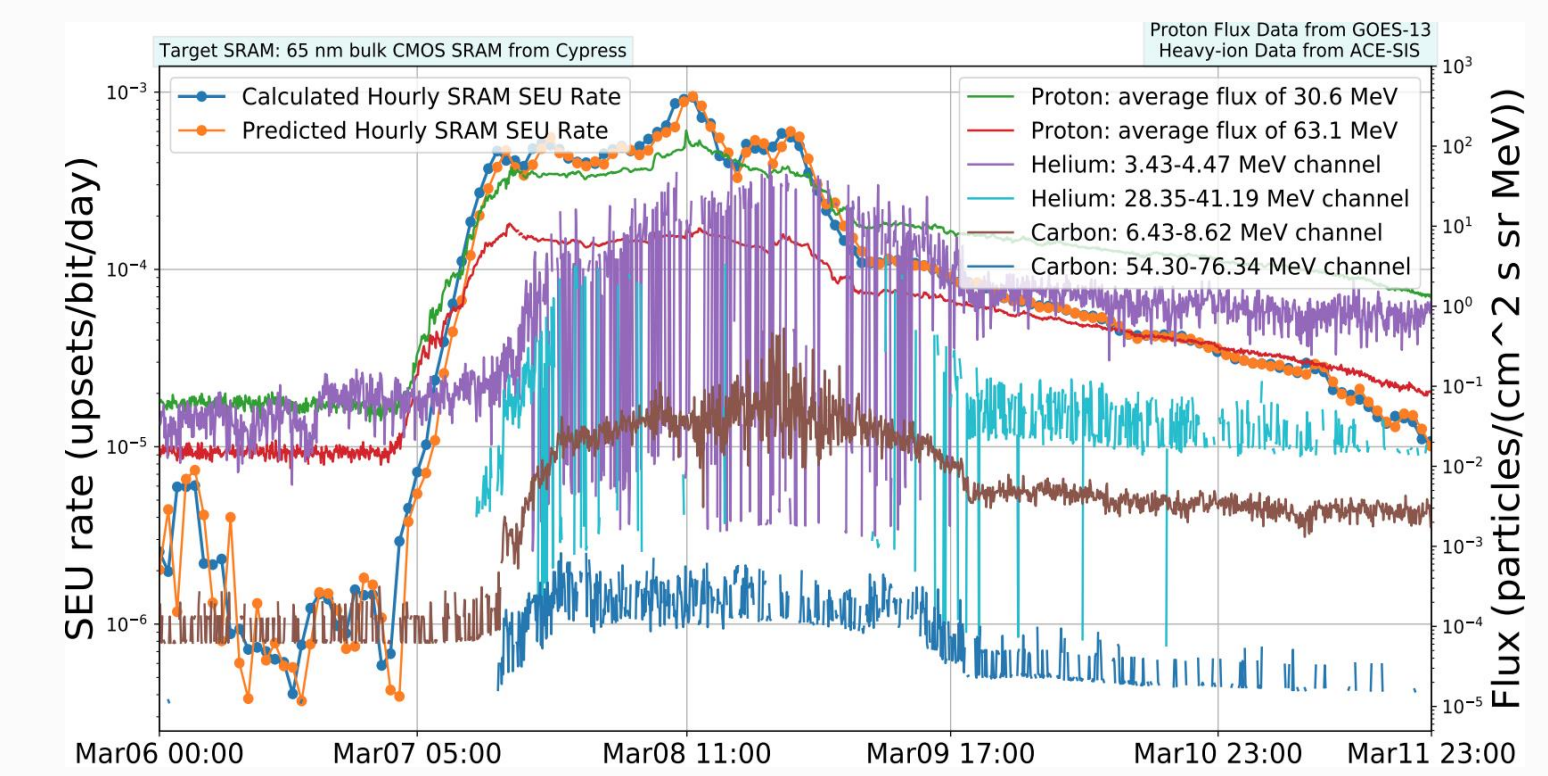


↑ Block diagram of the proposed solar condition prediction method.

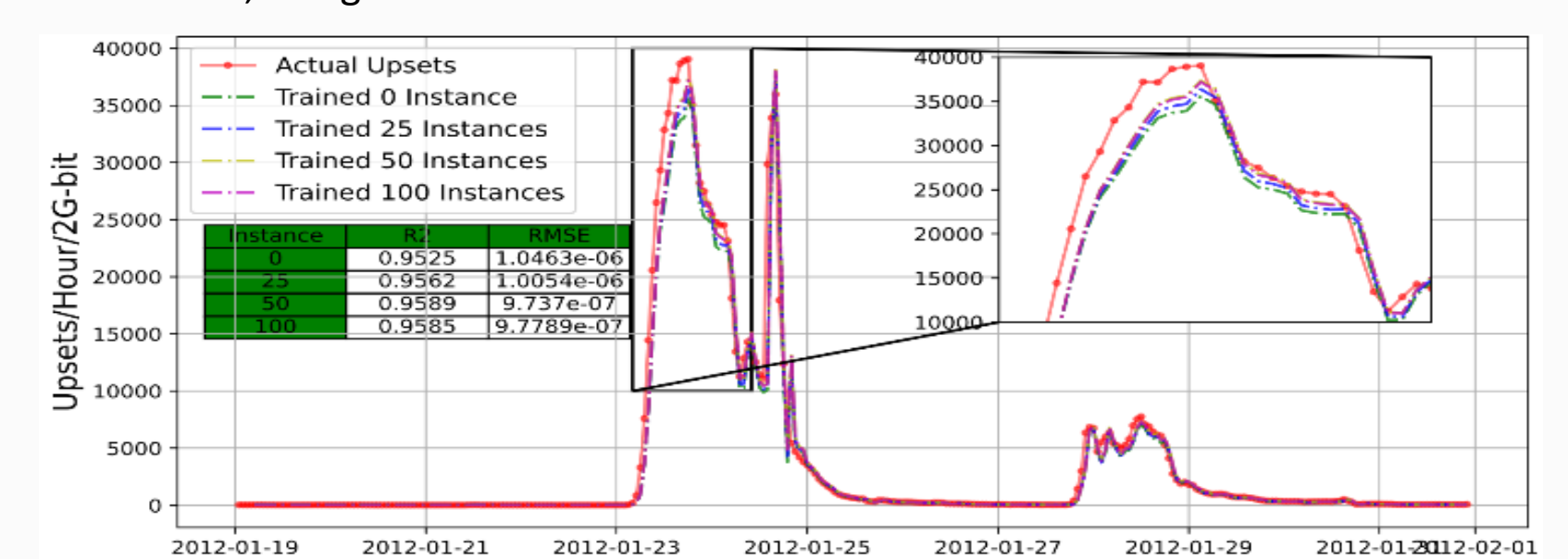


↑ Proton and heavy-ion database.

- Utilizes a machine learning framework, trained on historical space radiation flux data, to predict solar particle events and system SRAM SEU rates in space systems.
- Integrates real-time SRAM SEU monitoring with predictive analytics to enable advanced warnings and proactive mitigation strategies.
- Employs a two-stage predictive process with offline historical analysis and online real-time data assessment for precise forecasting.
- Leverages RNN with LSTM and linear regression models validated against NOAA's solar event records for high-accuracy SPE predictions.
- Features an innovative hardware accelerator designed for on-the-fly machine learning computations, optimizing space and power efficiency.
- Adopts Stochastic Gradient Descent (SGD) algorithm for continuous model improvement, enhancing prediction accuracy during missions.
- The method's capability to forecast radiation environment and target SRAM SEU rates an hour in advance with a high degree of accuracy.
- Implement a new method in space electronics systems' resilience by enabling self-adaptive responses to dynamic space weather conditions.

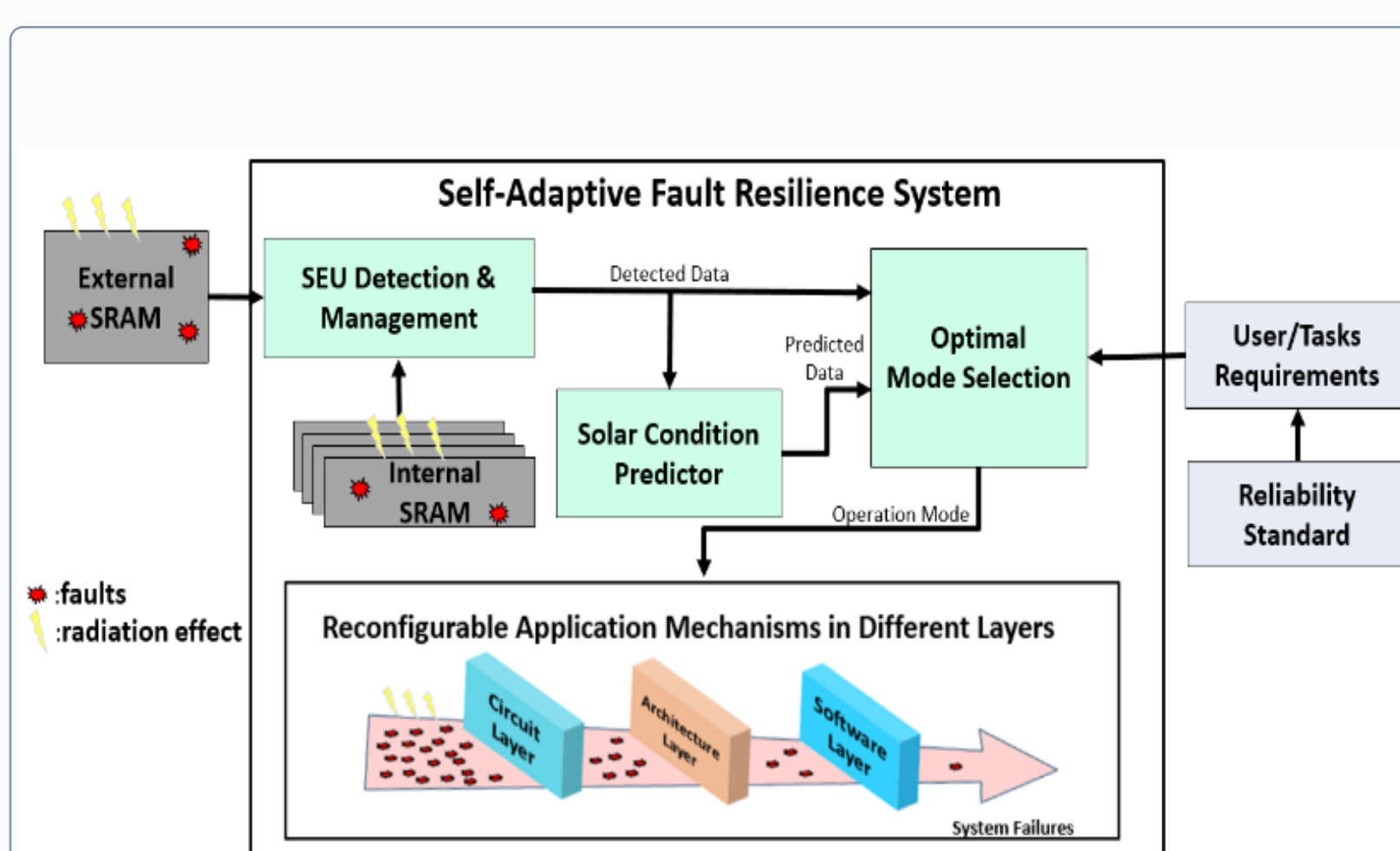


↑ The predicted and actual hourly SEU rate for a 65 nm SRAM during a March 6-11, 2012 solar event, using data from GOES and ACE-SIS databases.

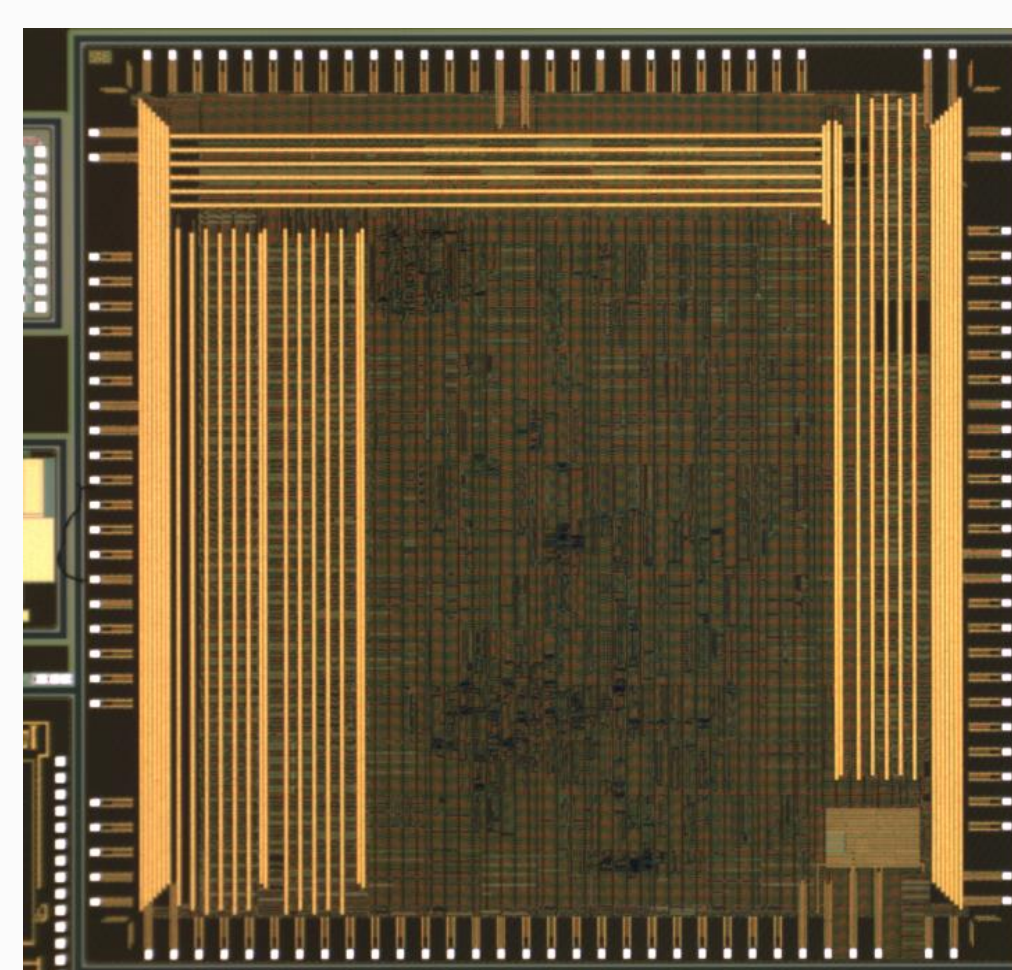


↑ The prediction performance for online learning optimization.

Self-adaptive Fault Resilience System

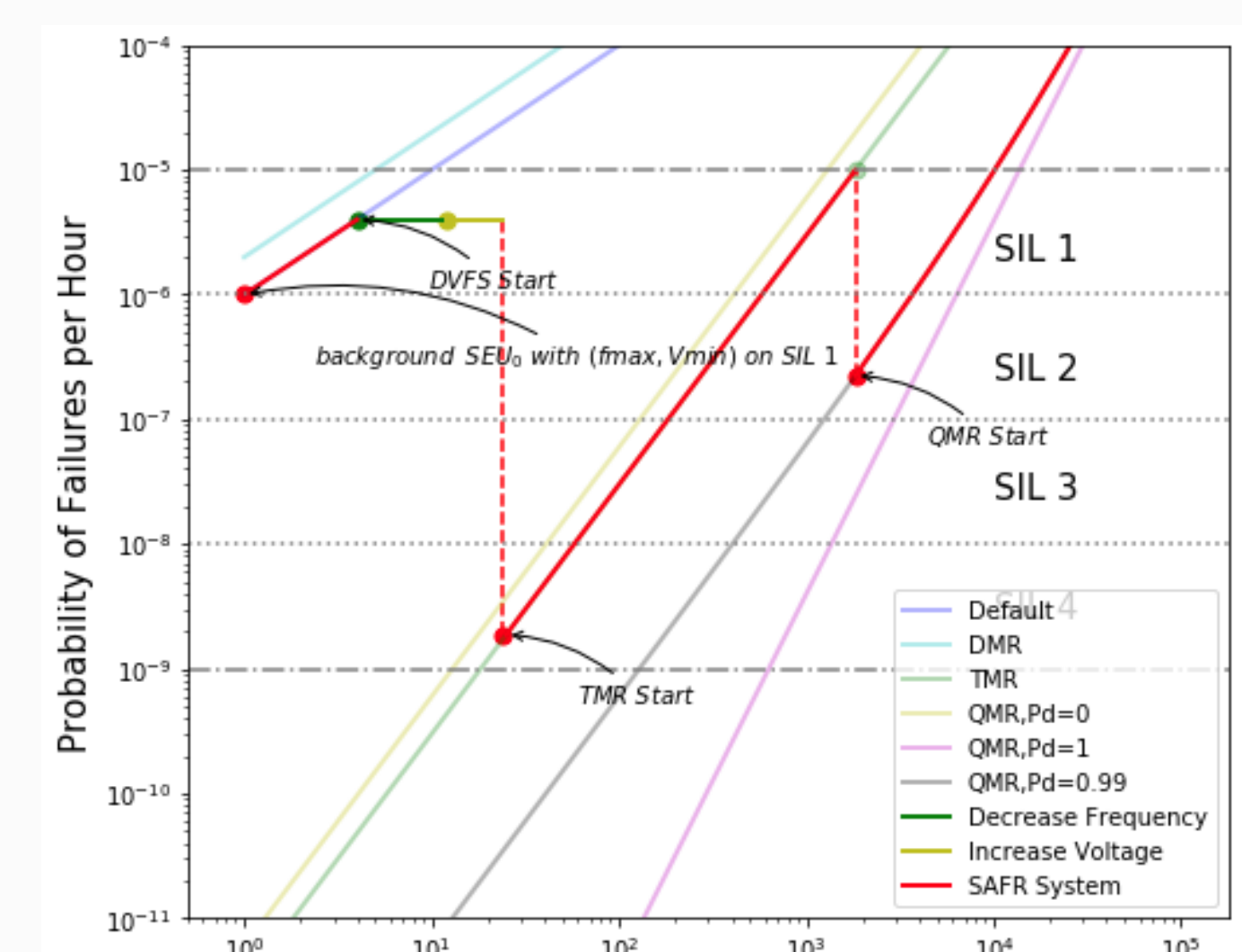


↑ Block diagram of the proposed self-adaptive resilient processing system.



↑ The die photo of the RISC-V based quad-core SoC.

- The SAFR system revolutionizes fault resilience by using a cross-layer approach, leveraging multiprocessor hardware redundancy, and dynamically adjustable mechanisms to optimize reliability and resource efficiency in space applications..
- Based on IEC 61508 standards, propose a decision-tree method for real-time mode selection, ensuring optimal operation by balancing SIL requirements with detected and predicted environmental conditions.
- Validated by a RISC-V based quad-core processing system, the SAFR framework demonstrates excellent reliability and performance in dynamic radiation environments, demonstrating its innovative adaptability to mission-critical systems.



↑ Example of SAFR optimal mode selection for a quad-core system's core-level n-module redundancy and dynamic voltage and frequency scaling technologies.

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