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Application of SEAM to High-Performance Computing

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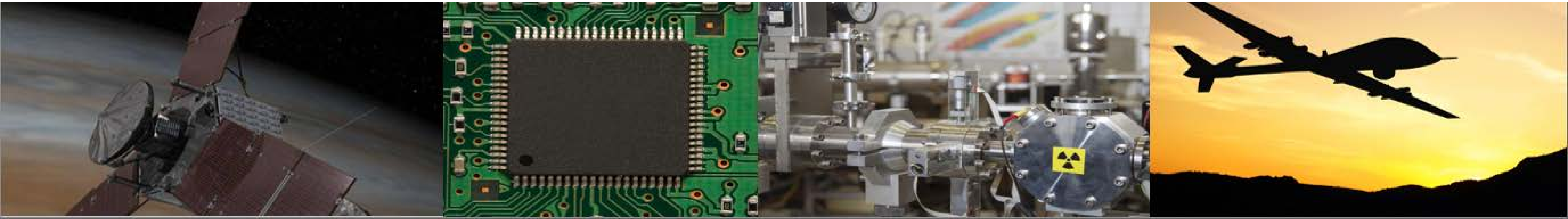

Acronyms and Abbreviations

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- **TMR** Triple Modular Redundancy
- **HDL** Hardware Description Language
- **HPC** High Performance Computing System
- **SEAM** System Engineering and Assurance Modeling
- **BBB** BeagleBone Black
- **SysML** System Modeling Language
- **COTS** Commercial Off-the-shelf
- **EDAC** Error Detection and Correction
- **SEL** Single Event Latch-Up
- **SEFI** Single Event Functional Interrupt

Performance: COTS Components under Radiation in Space

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Why COTS Work in Space

Modern Technology	Scaling, Epitaxial Fabrication	Radiation Hardening by **Process**
Mitigation	TMR – HDL Coding, EDAC	Radiation Hardening by **Design**
Dynamic Space Environment	Improved Shielding – Astronaut Habitat	Radiation Hardening by **Shielding**
Operation at Reduced Spec	Below Nominal Frequency	Radiation Hardening by **Parameters**

Devices in space that are primarily made of COTS component

Performance: COTS Components under Radiation in Space

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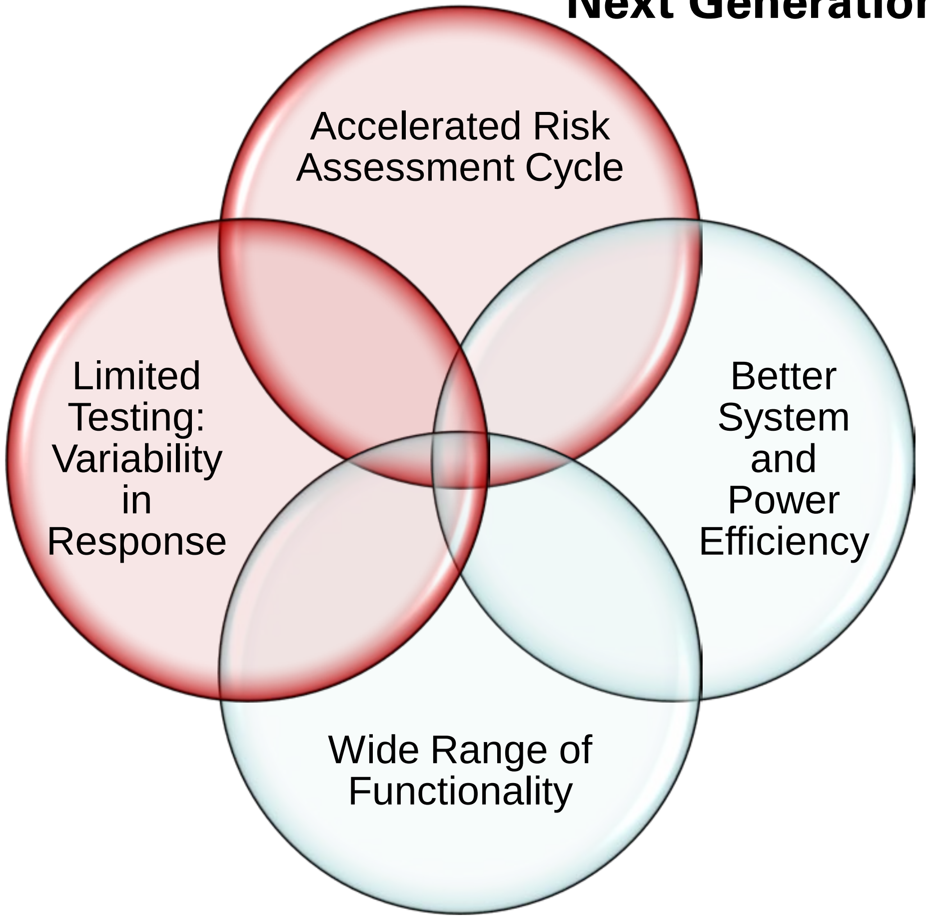

Next Generation System in Space with COTS Component

- Utilizes heavy shielding inside astronaut habitat
- In house data/ image processing
- Low communication bandwidth
- Reduced cost
- Faster data transfer

Predicting performance using model-based assurance

- Represent the system with a high-level logical model
- Validate the model to experiments
- Identify the out of specification behavior of the components
- Mitigate the existing fault or reduce the mission requirement or replace the component with a radiation hardened one.

- ❑ What is the minimal change in design/ component that would improve the reliability of a system with COTS component in space
- ❑ Will software-based mitigation suffice?

STTR Phase I : Testing of COTS Systems in Space Radiation Environments

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- NASA STTR 2019 Phase I Solicitation from Langley Research Center
- T6.05 Testing of COTS Systems in Space Radiation Environments

RFP: Investigate the feasibility of COTS electronics for *High Performance Computing (HPC)* in *space environments which are already heavily shielded*. It seeks strategies *based on a complete system analysis of HPC COTS* that include, but not limited only to, *failure modes* to mitigate radiation induced impacts to potential HPC systems in those highly shielded space environments.

High Performance Computing (HPC)

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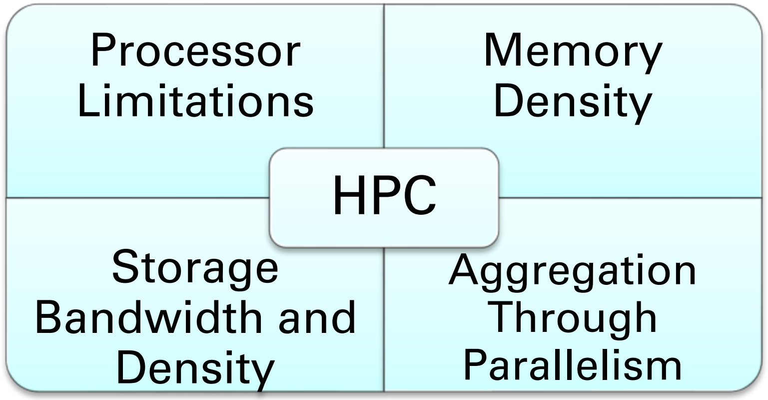
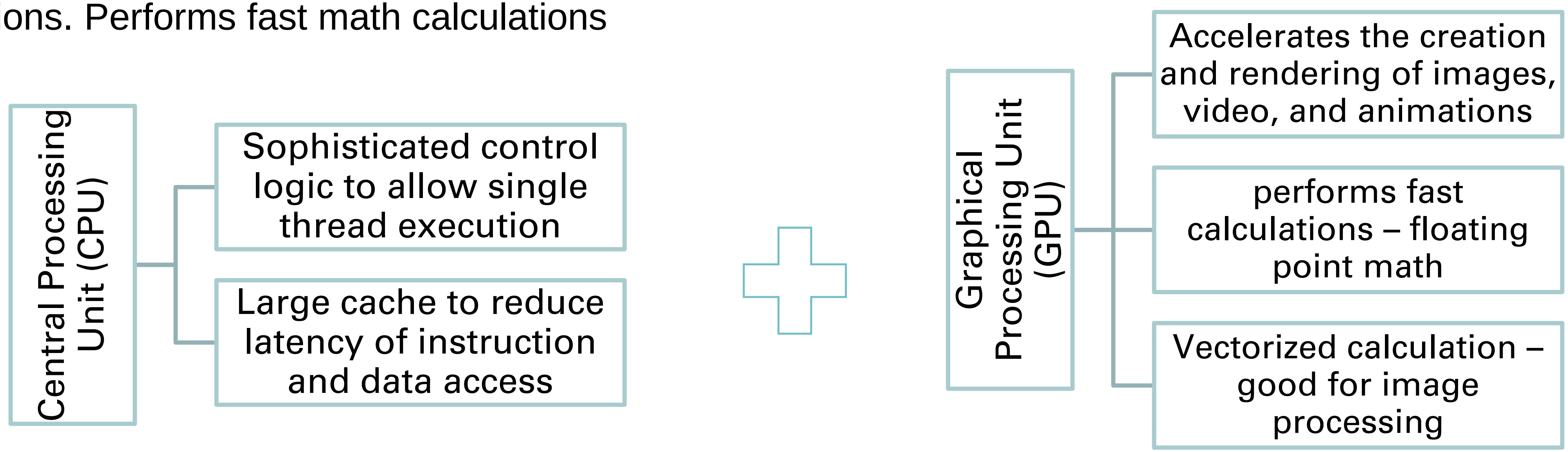
- Computing in parallel over lots of compute elements
- Make many systems look and work like ONE large, powerful system
- Used for highly computational or data-intensive tasks
- Scalable parallelism is the key for running advanced programs efficiently, reliably and quickly
- Accelerates the creation and rendering of images, video, and animations. Performs fast math calculations





Candidate Demo HPC System: BeagleBone Black (BBB)

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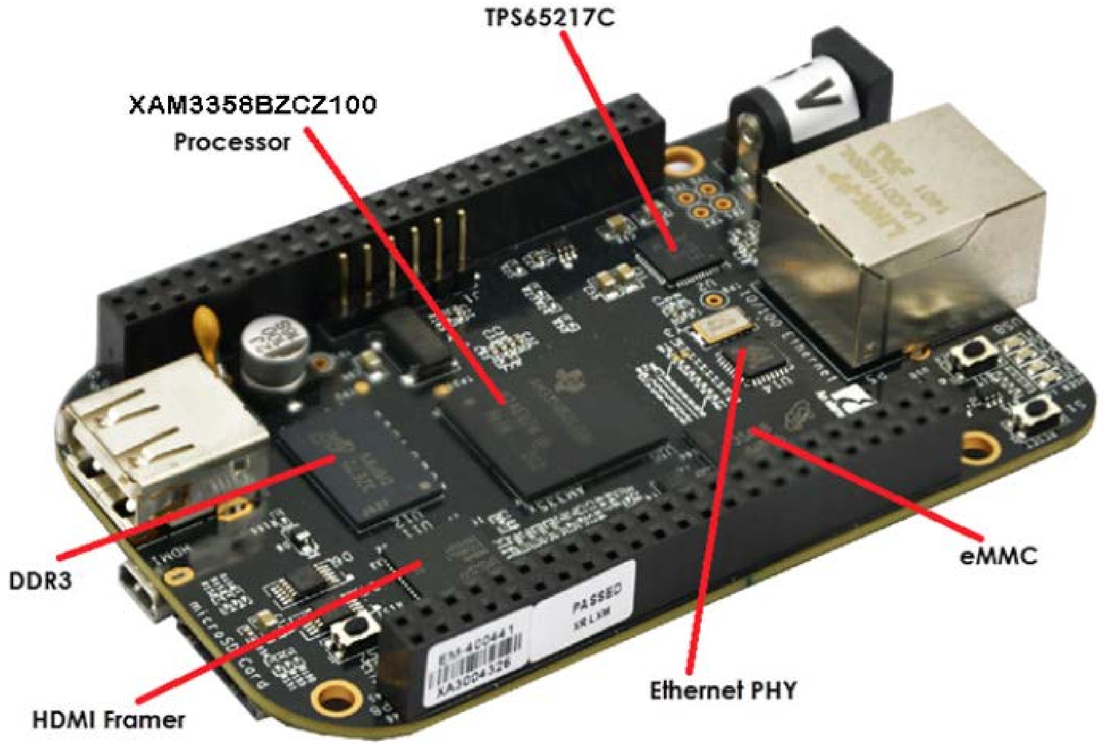
- CPU – Integer Core
- GPU – Neon Core (Floating point calculation, vectorized data processing)
- Memory – Cache, SRAM, EEPROM, FLASH, MMC, SD, ECC
- Interface – µSD, µHDMI, Ethernet, JTAG, GPIO, PWM, Serial, SPI, and I2C

BBB ~ smallest building block of high-performance computing

- Open source community
- No heatsink on processor-SE Tests
- Good availability
- Low Power – Arm Instruction



Model Based Assurance using SEAM for Complex Systems

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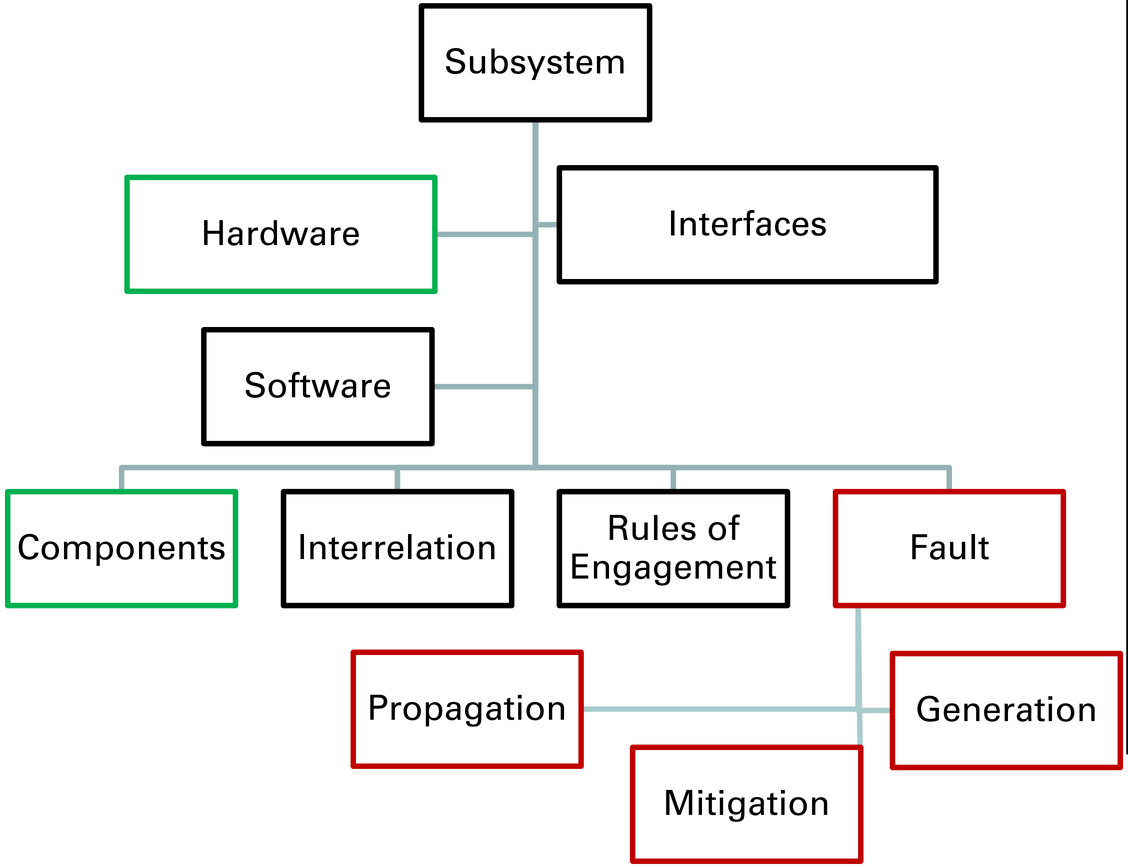
Architectural Model



Architectural Model : Define the rules of engagement for fault propagation through physical components and ports in a complex system

Goal : Calculate the sensitivity of faults to system response in a heterogeneous architecture

Challenge : Minimum cut set of failure at the component level is not definitively understood in a complex system

Proposed Solution : Validate the models by functional decomposition in conjunction to experiment

Framework for Failure Analysis

Model Based Assurance using SEAM for Complex Systems

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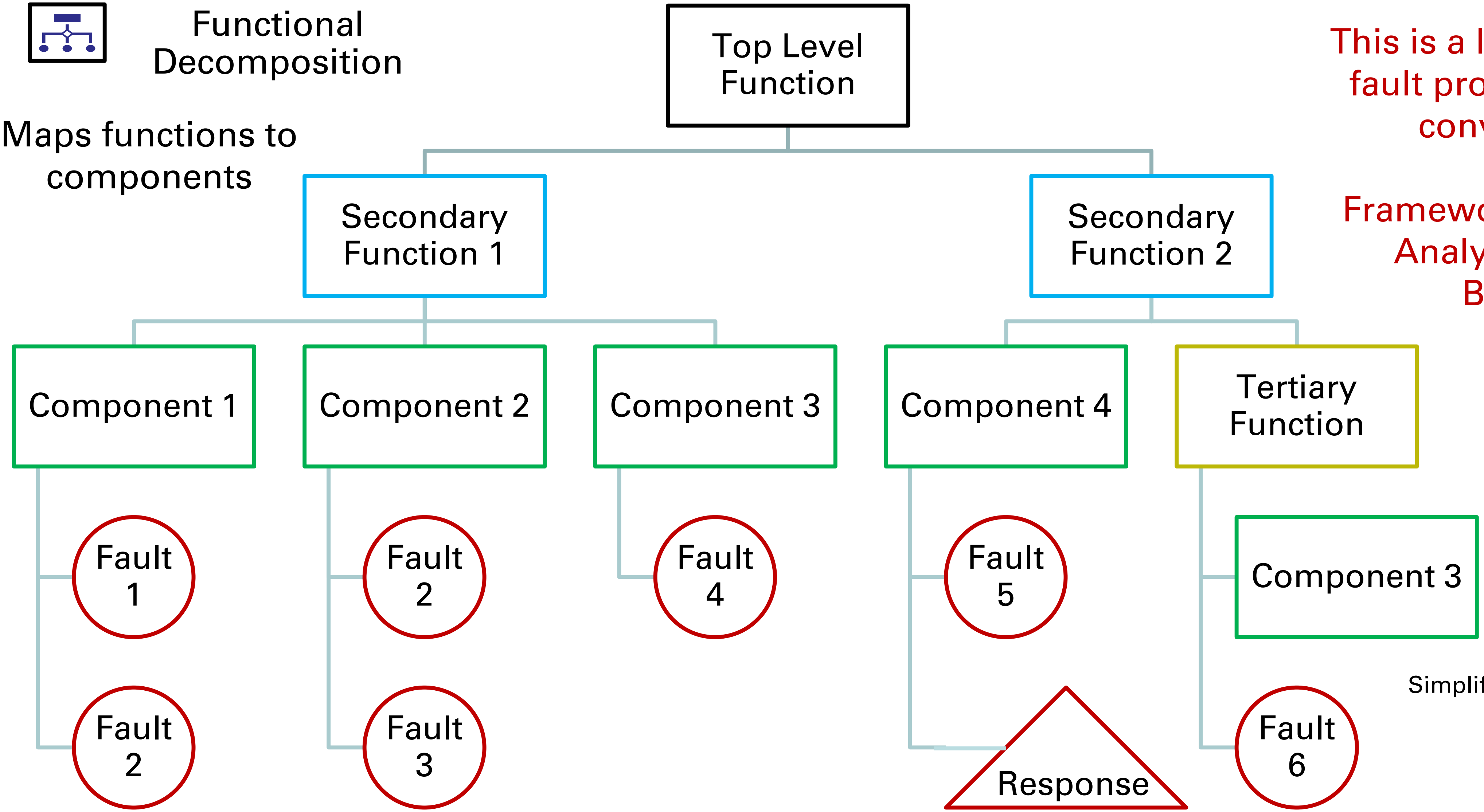
Functional Decomposition

Maps functions to components



This is a logical model where fault propagates instead of conventional data.

Framework for Probabilistic Analysis : Fault Tree / Bayesian Net

Simplified diagram shown here for brevity

Architecture- HPC System: BeagleBone Black (BBB)

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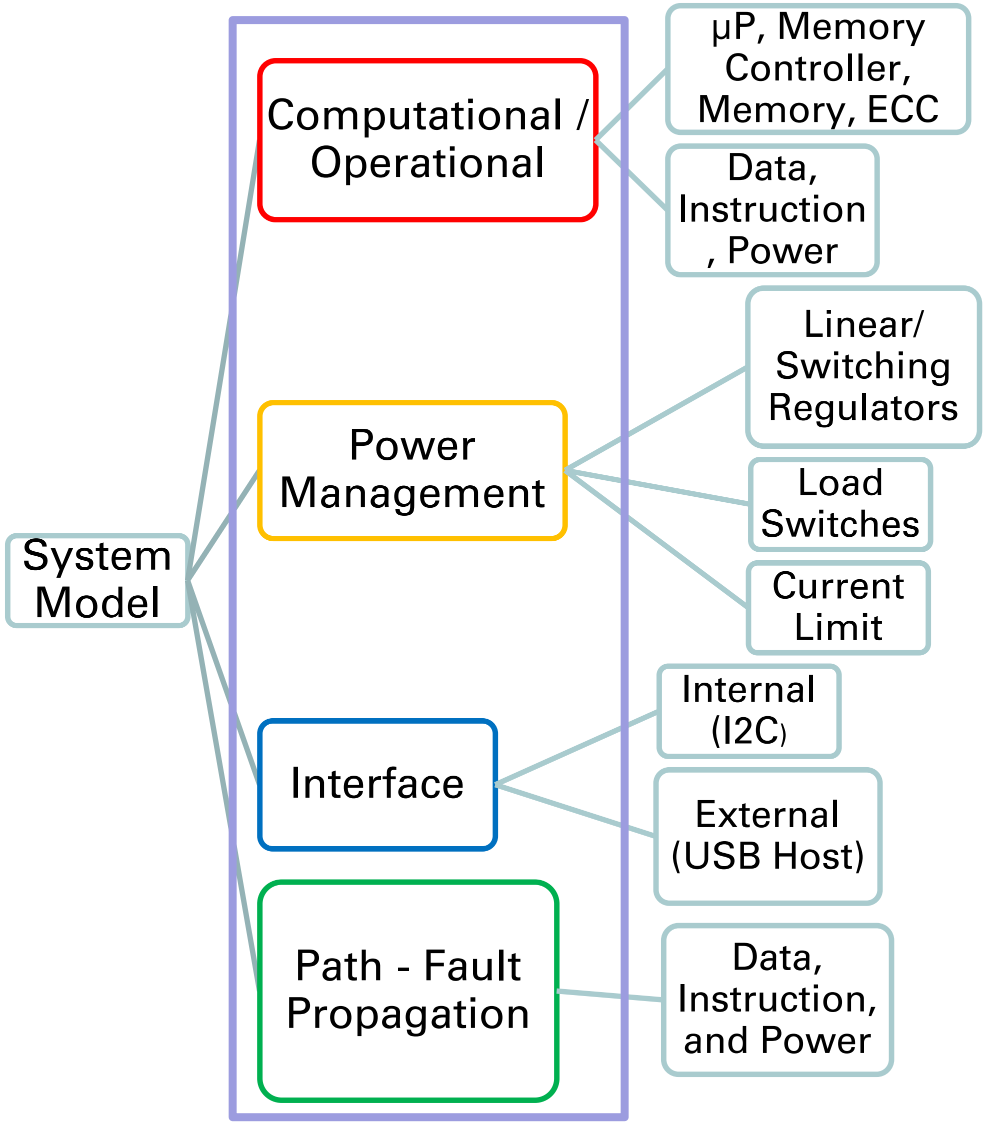
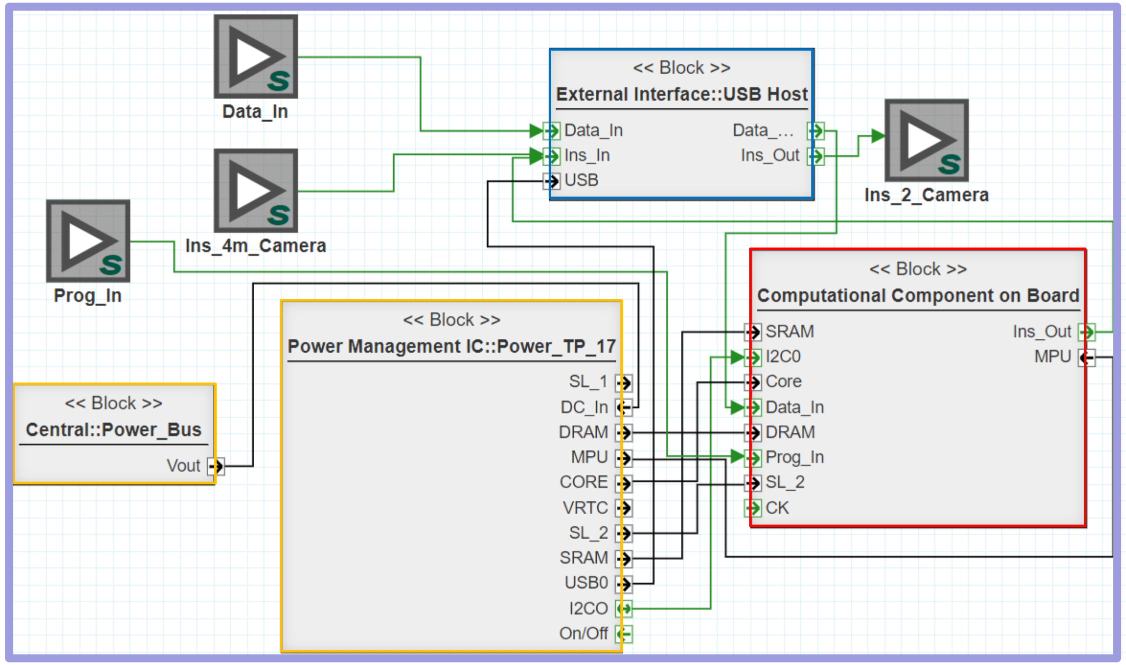


Power Fault

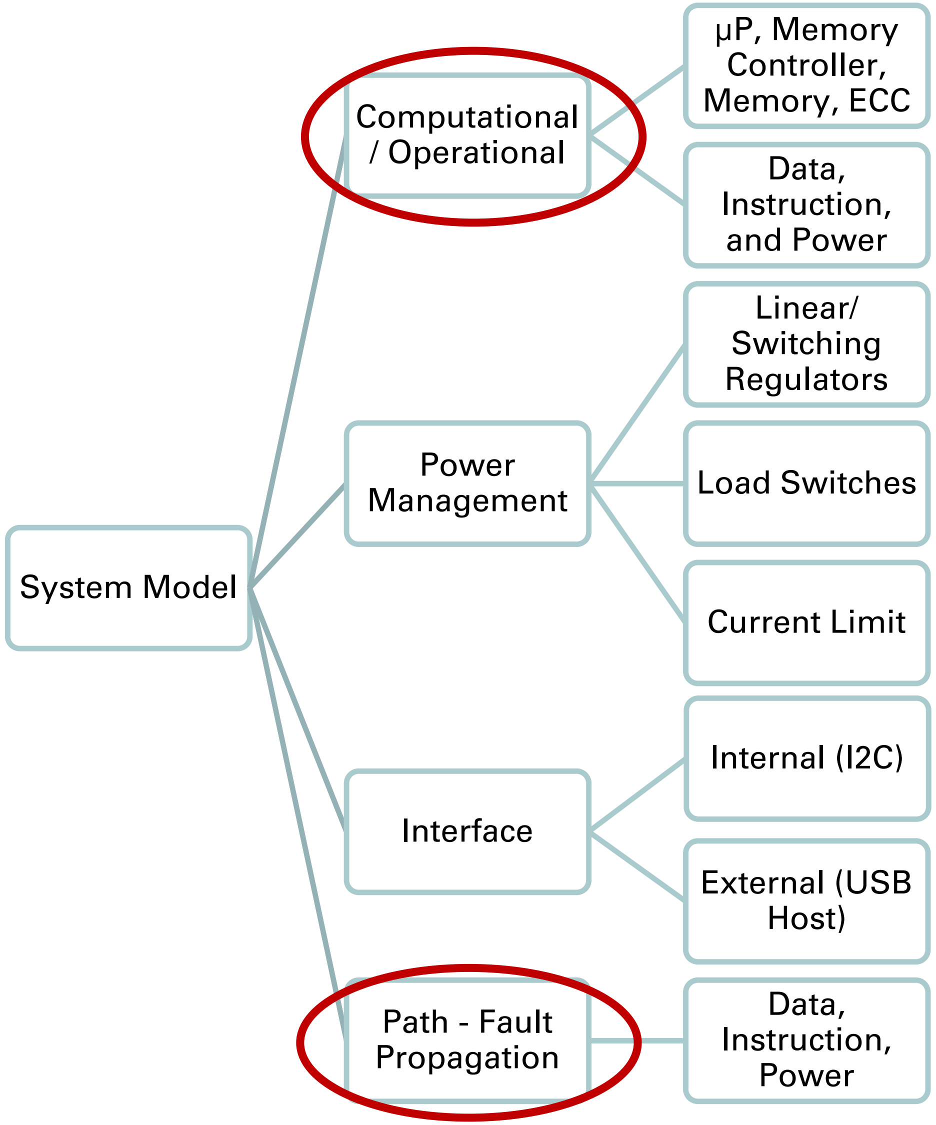
Data Fault

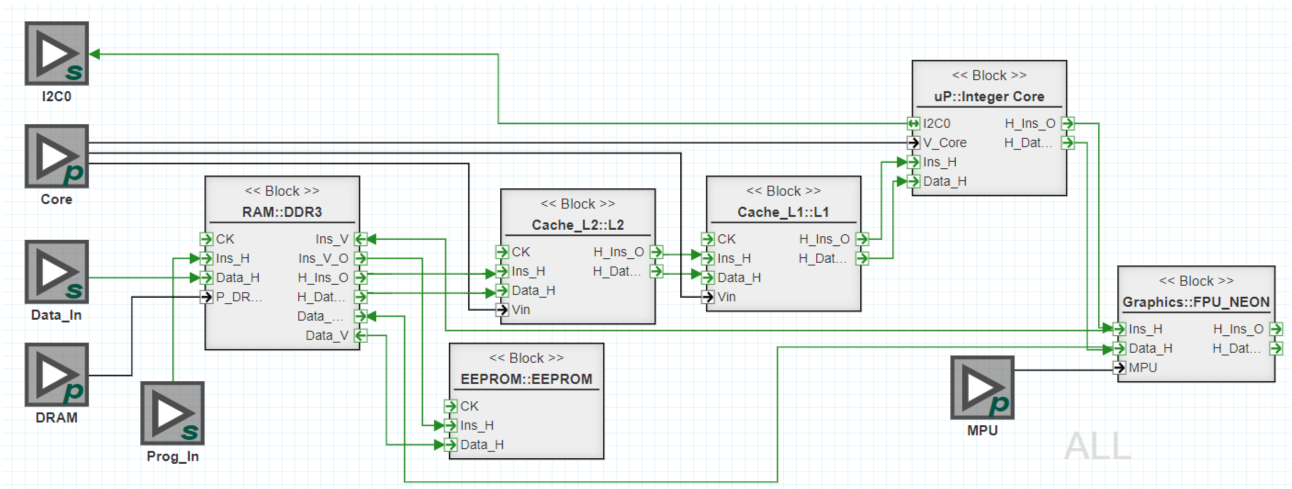
Complex cycles of operation : integer/ floating point core, memory management

How to model complex system with limited information?



Computational Components in HPC





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Computational Components in HPC

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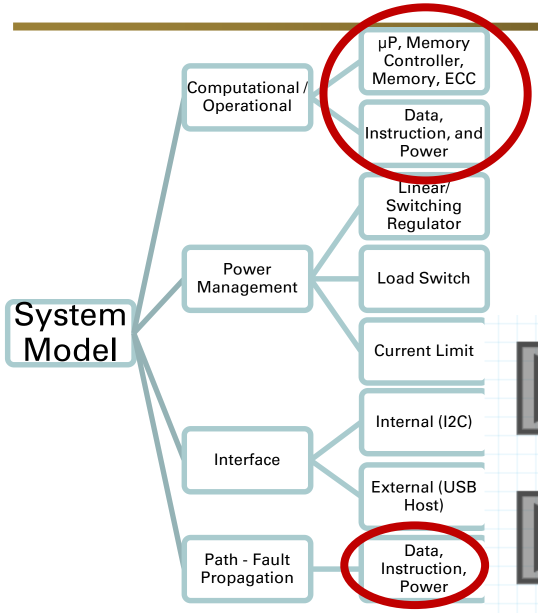

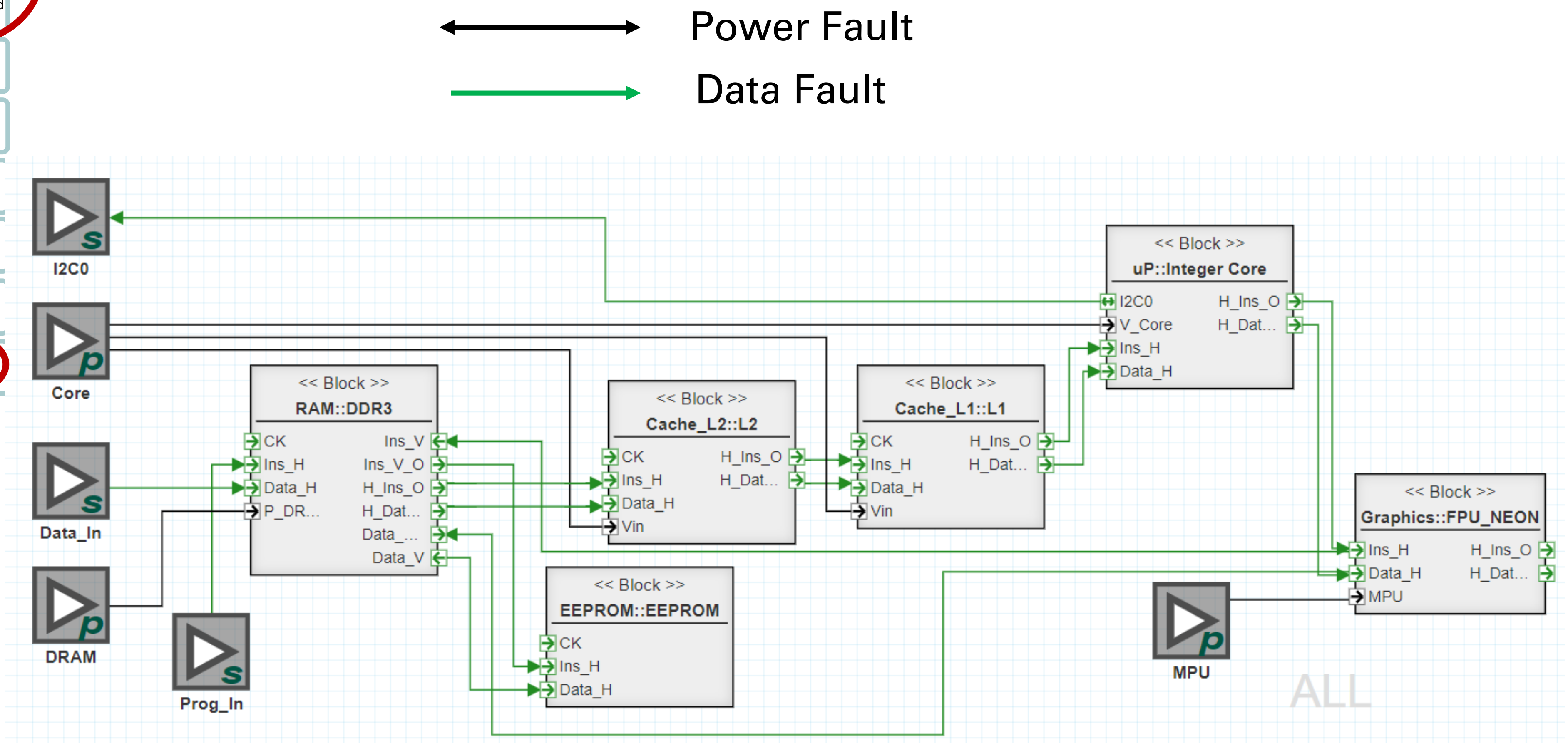

Definitions : Logical Modeling of Failure Propagation

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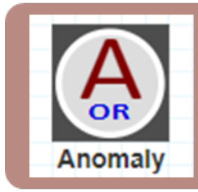
Fault Propagation Models show how fault originate in components and their effects propagate through the structure of the system.

The **radiation-effects** such as ‘**TID**’ and ‘**SEL**’ are captured as **fault: ‘F’** nodes



Fault (‘**F**’ nodes) leads to **anomalies** (‘**A**’ nodes) such as ‘Bad_Data’ or ‘Low_Vout’

Anomalies lead to the functional **response effects** representing ‘Degraded Operations’ or ‘Mitigation Mechanisms’

Heterogeneous Dependence of Failure: Random Access Memory (RAM) - BBB

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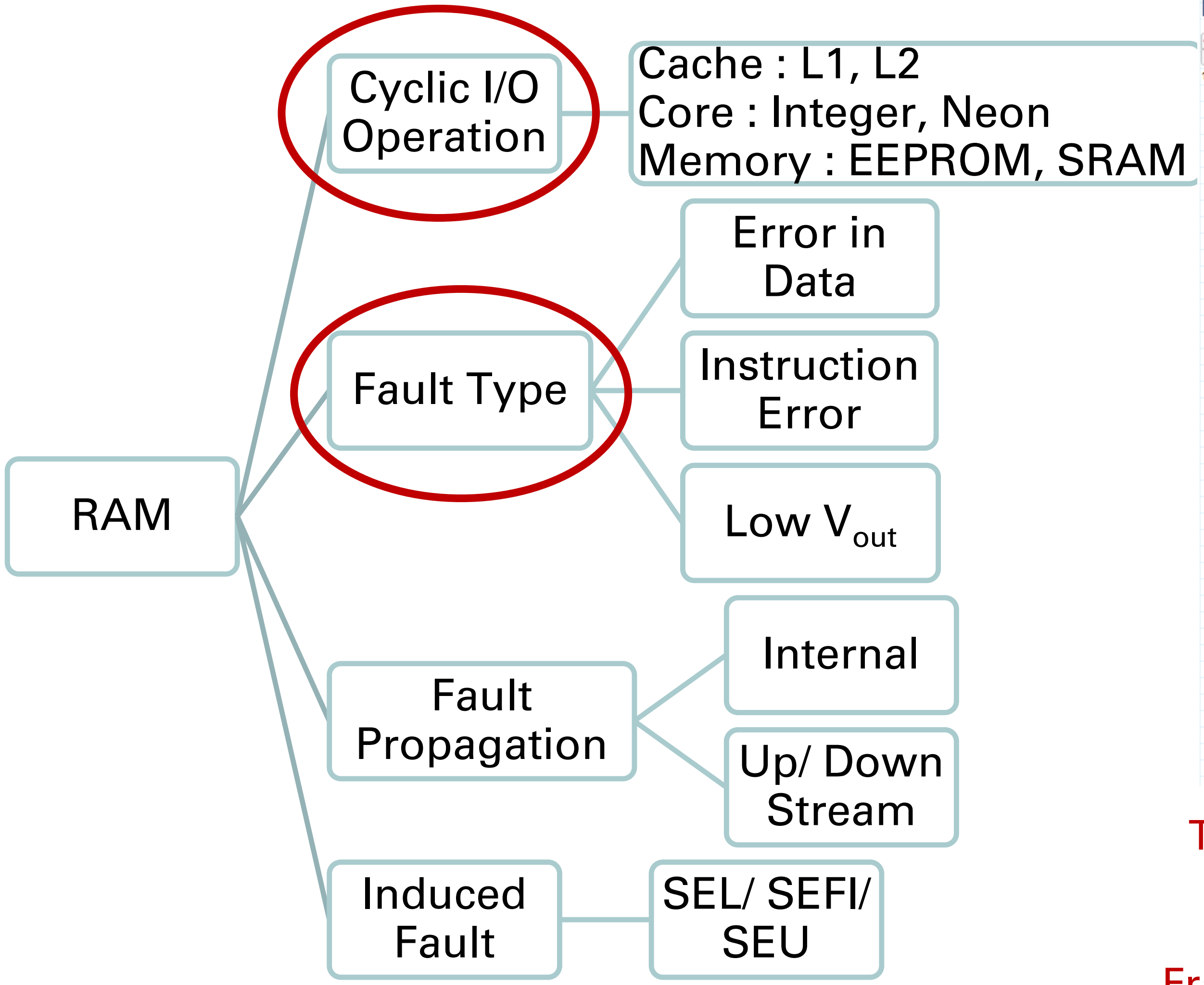

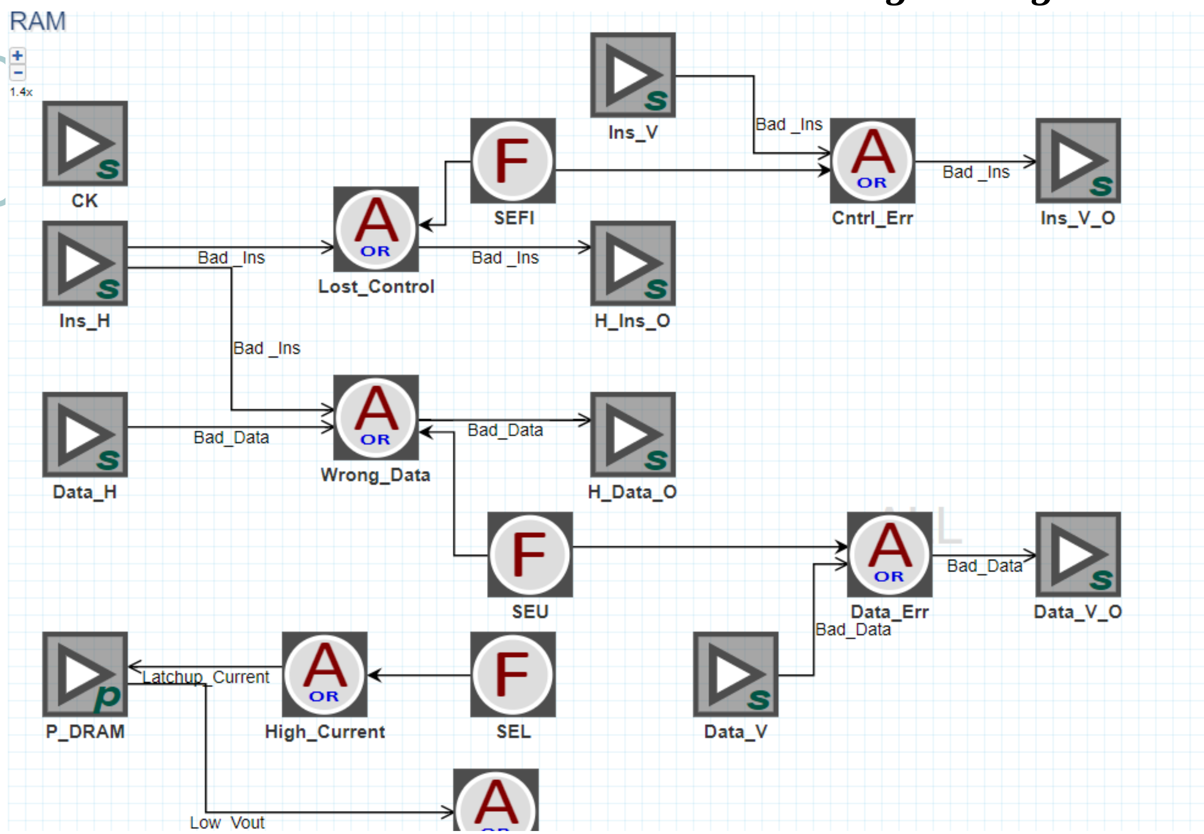

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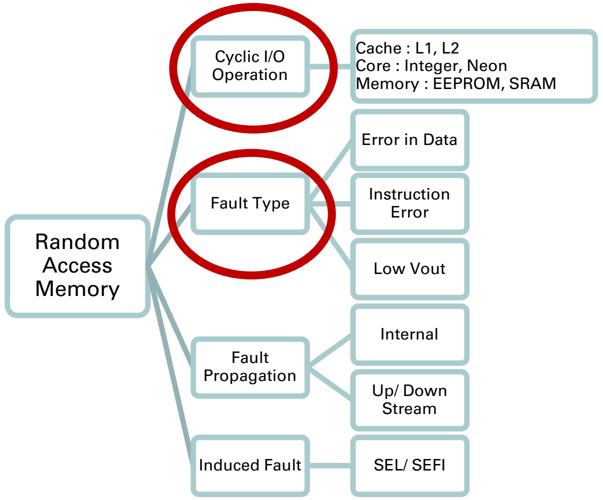

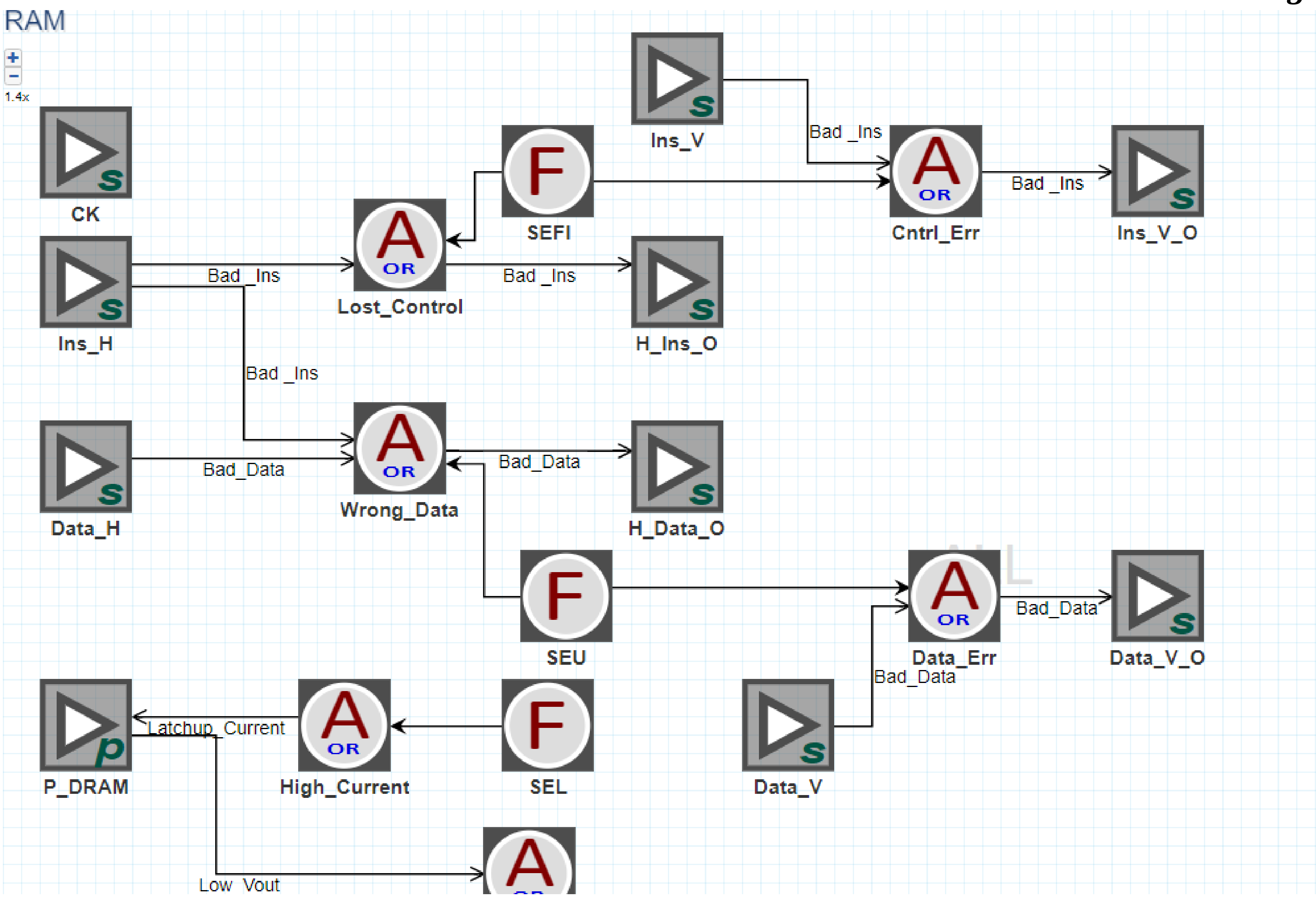

Critical Component to Failure: Power Management IC - BBB

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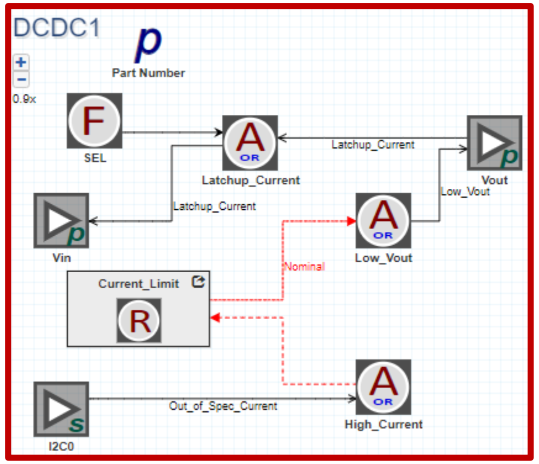
System is highly sensitive to power faults

- Low V_{out} to components (Downstream)
- High Current to Regulators (Upstream)
- Mitigation (Current Limit/ Power Reset)



I2C Port

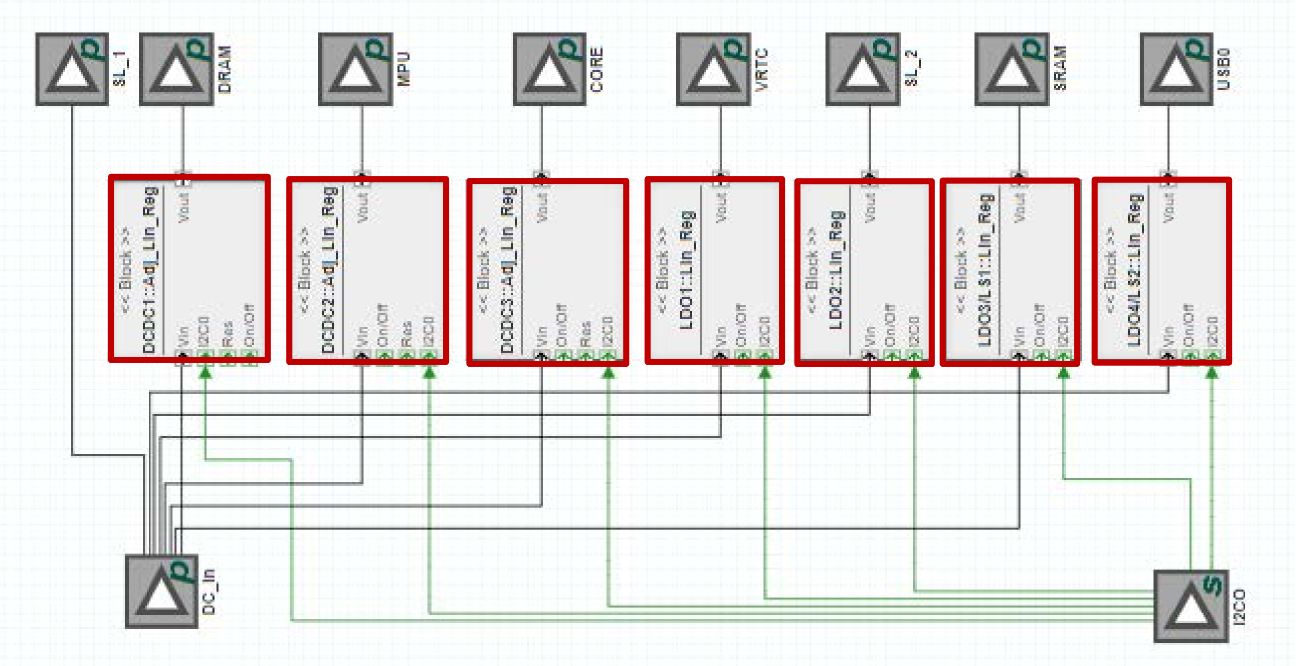
- Communication with Integer Core

Primary Component

- Linear Regulator/ Logic Switch

Instructions of Current Control

- Integer Core



Functional Decomposition of the Operation of the BBB

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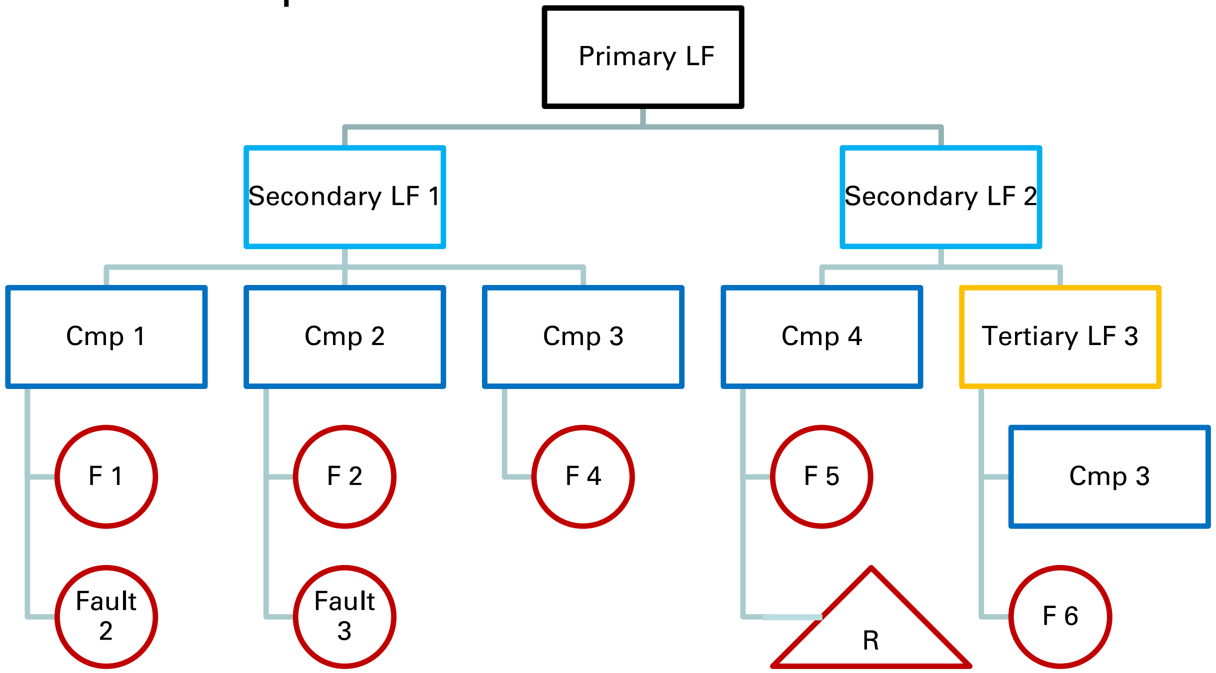
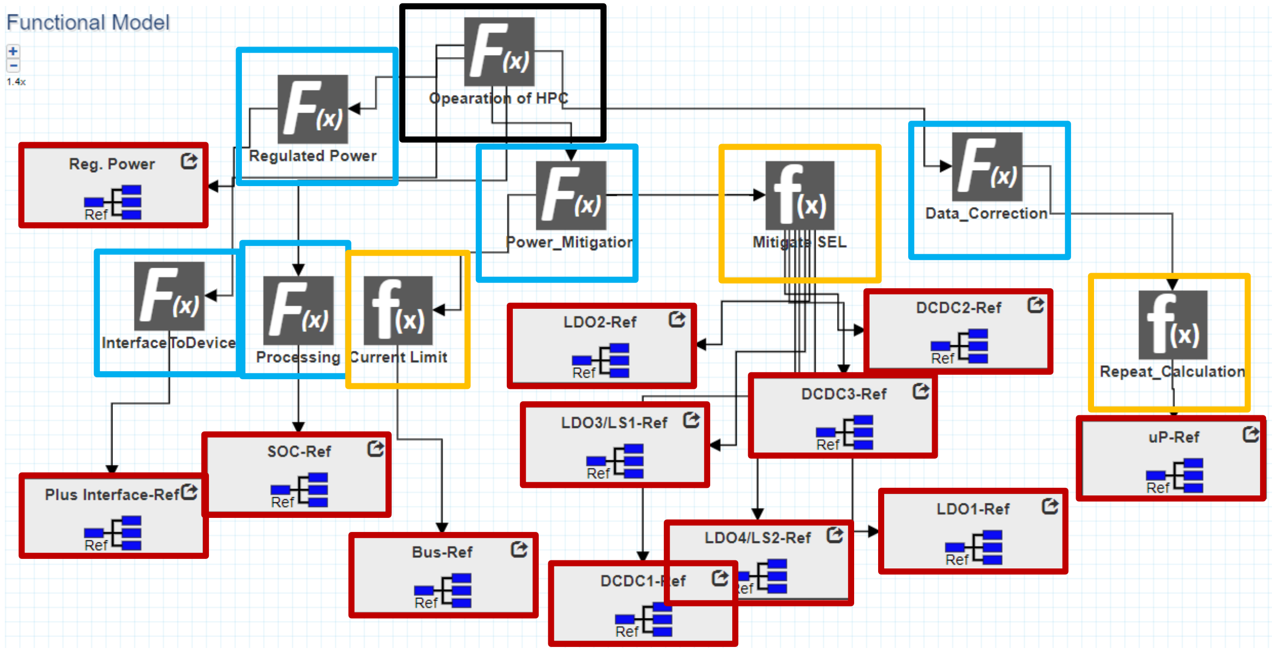
LF : Lost Function
Cmp : Component
F : Fault
R: Response





Maps Functions to Components

Framework for Probabilistic Analysis : Fault Tree / Bayesian Net

Functional Decomposition of the BBB System

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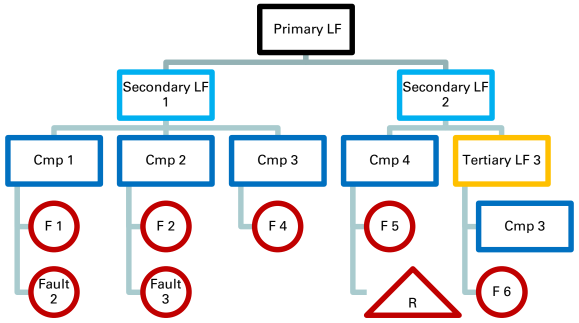

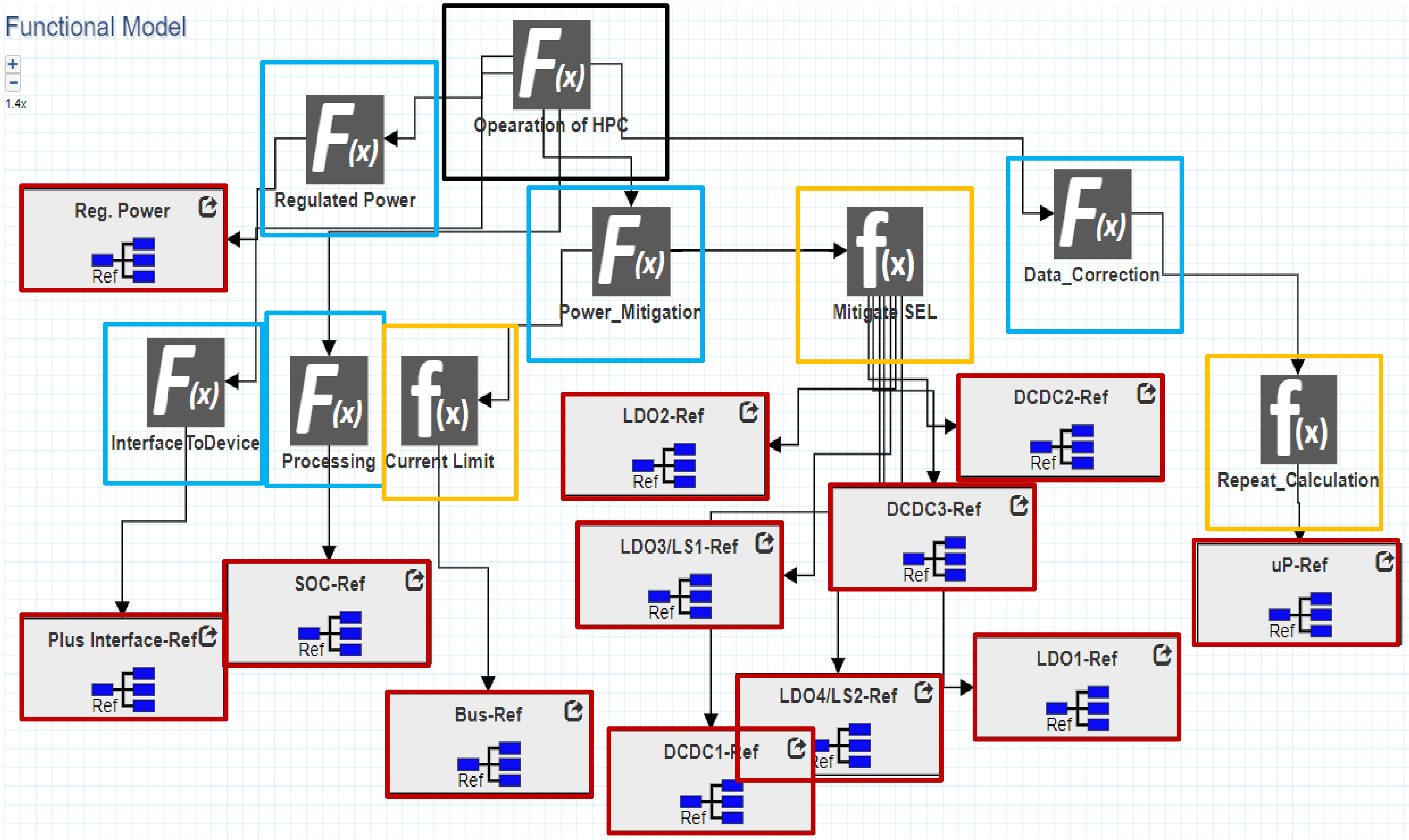

Each component block is cross-referenced to the system model where the faults are originated, propagated, and in some case, mitigated.

Fault Tree Analysis
- Based on Functional Decomposition

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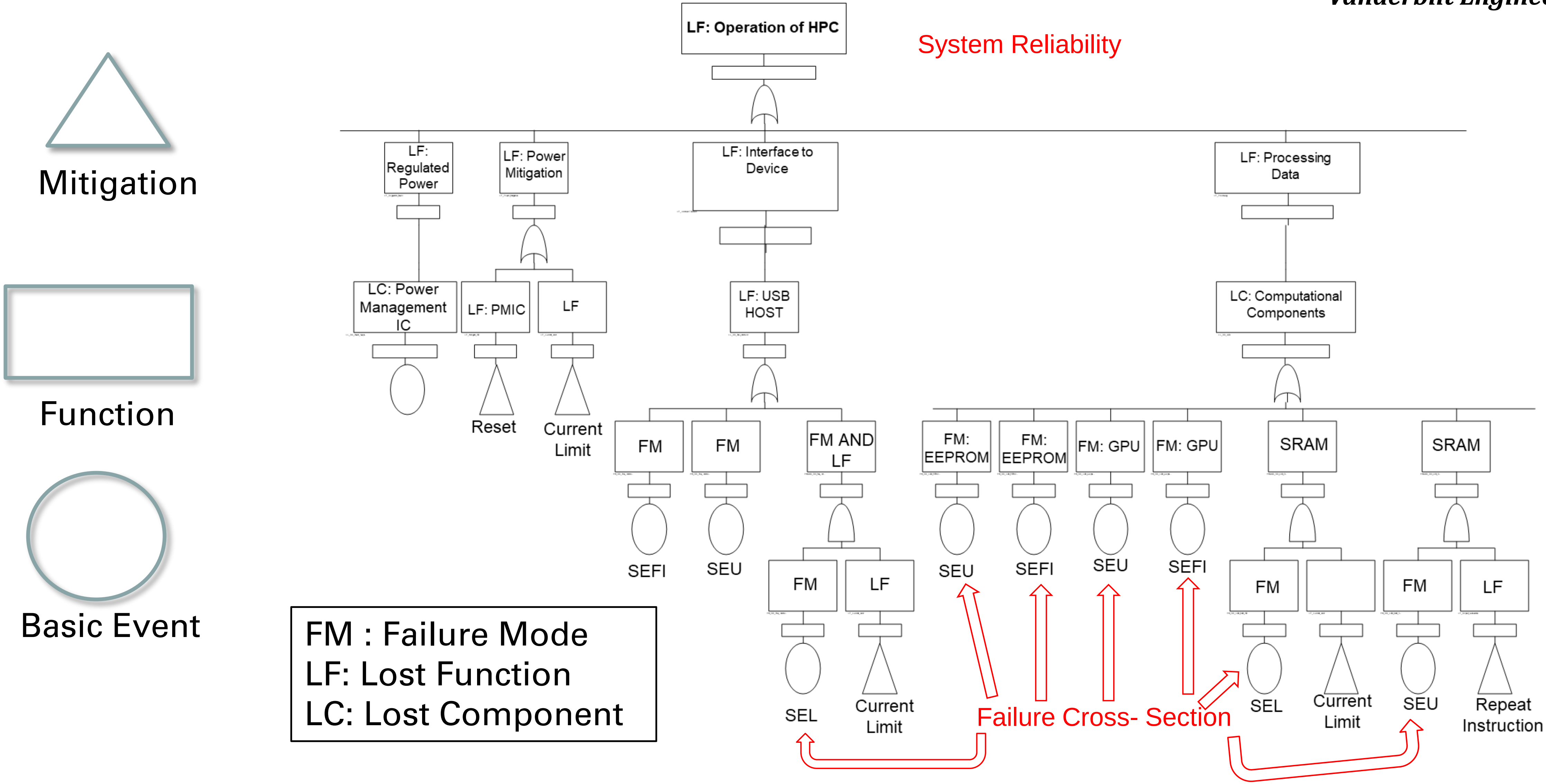

Summary

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Developed the logical model to calculate system response of a BBB

Functional decomposition of a system/ architectural model enables failure analysis

Developed model is easy to update to changing rules or change in radiation cross-section of a component