B1-25: Fault-Tolerant Techniques for Heterogenous Computing Architectures

Mission-Critical Computing
NSF CENTER FOR SPACE, HIGH-PERFORMANCE, AND RESILIENT COMPUTING (SHREC)

SHREC Annual Workshop (SAW24-25)

University of Pittsburgh · BYU Brigham Young University · Virginia Tech · UF University of Florida

January 14-15, 2025

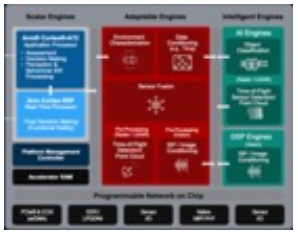
Dr. Mike Wirthlin & Dr. Jeff Goeders

Garrett Smith, MS
Jacob Brown, MS
Caleb Price, MS
Preston Walker, BS
Julia Hansen, BS
Caeden Brinkman, BS
John Rowberry, BS

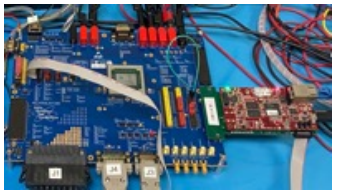
Number of requested memberships ≥ 4

Project Tasks

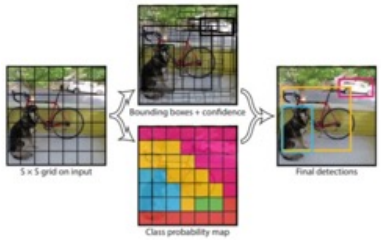
Task 1: Versal ACAP Reliability

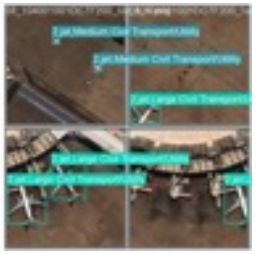


Task 2: Complex SoC Testing Tools

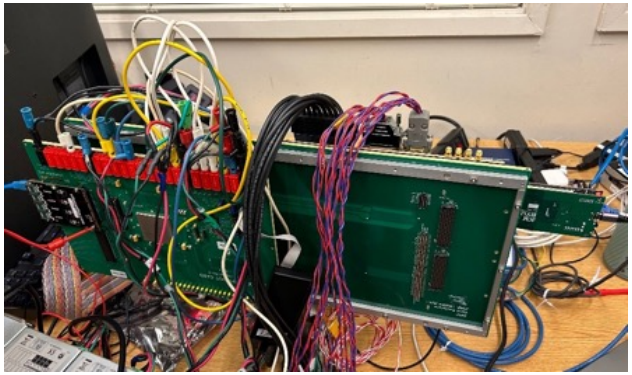


Task 3: Reliable Deep Learning





Task 4: Radiation Testing of Heterogenous Devices



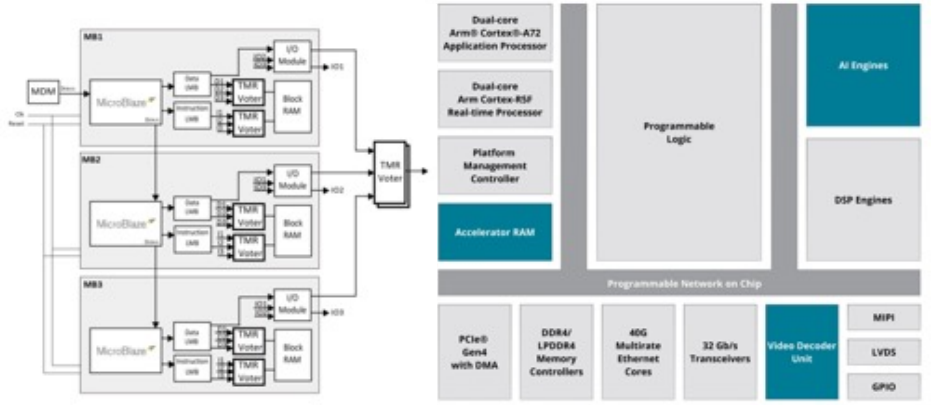
B1

Task 1 – Versal ACAP Reliability

- AMD Space Grade Versal ACAP (XQR)
  - Machine Learning Inference
  - On-board data processing
  - High-speed I/O interfaces
- Reliability Features
  - Triplicated PPU/PMU processors
  - ECC for memories and caches
  - XilSEM PL Scrubbing
- Major efforts for 2025
  - Analysis and reporting of 2024 radiation data
  - Reliability of APU/NOC/DDR
  - Linux faut tolerant features/extensions
  - High flux processor testing strategies

	XQRVC1902	XQRVE2302
AI Engines	100	17
DSPs	1,968	464
Logic Cells (K)	1,968	329
DDR Controllers	4	1
PL Memory (Mb)	191	86
Gigabit Tx/Rx	44	8

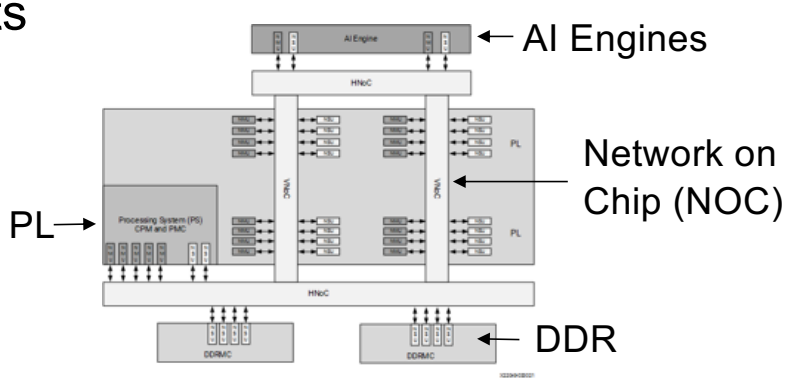
Dual core A72, Dual core R5F, 256 KB OCM

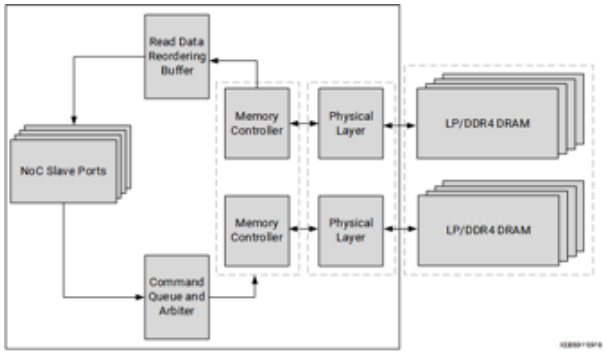


B1

Versal APU, NoC, and DDR Reliability

- Identify causes of APU failure in radiation tests
  - Analyze data from previous year's test
  - Development of specific tests targeting APU
- Investigate reliability of Network on Chip
  - Identify potential NoC failures in previous tests
  - Develop readback and scrubbing mechanisms for NoC configuration data
  - Test response to fault injection
- Test DDR Controller reliability
  - Develop mechanisms to evaluate reliability of DDR Controller
  - Add support for DDR Controller's ECC and other reliability functions

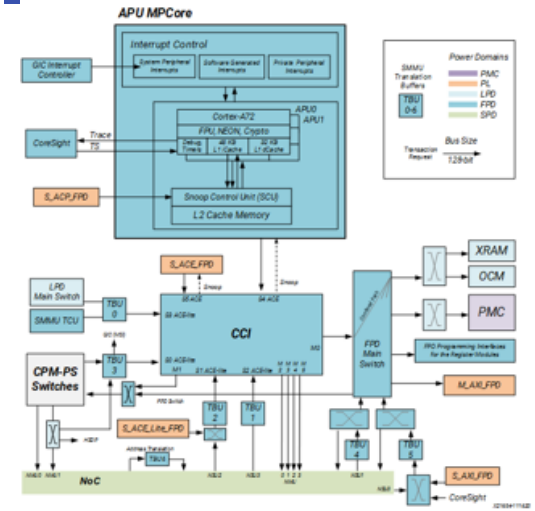


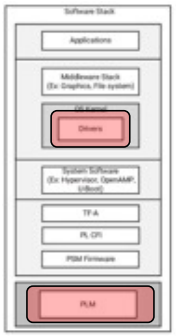


B1

Fault Tolerant Linux for Versal

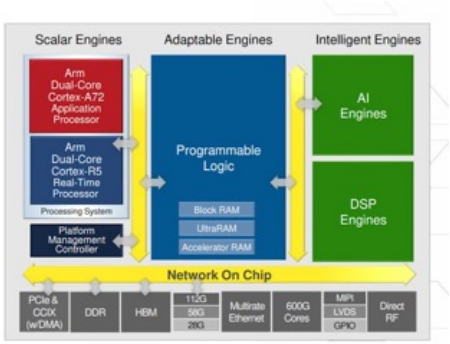
- Linux build on Versal APU Core
  - Dual core ARM Cortex A72 processor
- Integrate enhanced Versal firmware into Linux image
  - Adds memory scrubbing, ECC, and TMR support to PSM PLM firmware
- Provide Linux hooks to support reliability features
  - PL CRAM scrubbing and logging
  - Interface and reporting of PPU and PSM errors
- Support for error handling and memory scrubbing
  - APU Cache error reporting
  - Periodic cache flushing
  - OCM memory scrubbing
  - Priority scrubbing approaches



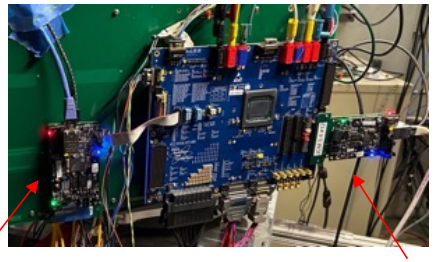


Task 2 - Complex SoC Testing Tools

- Challenges with radiation testing of complex SoC devices
  - Large amount of data to extract
  - Difficult to identify fault mode
  - Multiple internal processors
  - Large internal memory requiring scrubbing
- Data extraction tools
  - JCM (SMAP, JTAG)
  - PCIe
- Scrubbing Approaches
  - SMAP and JTAG
  - PCIe
  - XilSEM



PCIe Data Extraction (PolarFire and Versal)

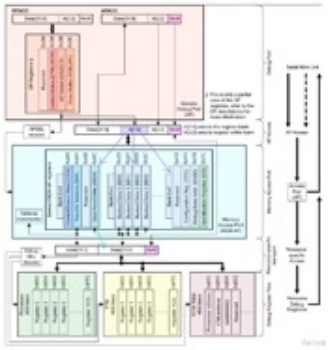


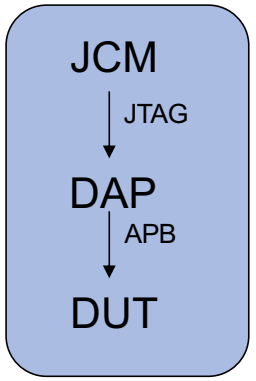
JCM DAP Controller

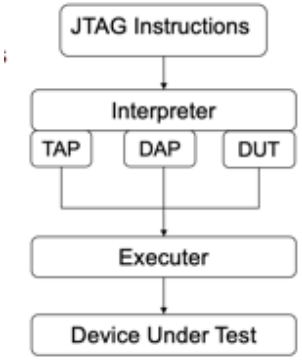
JCM SMAP Controller

JCM DAP Interface Support

- ARM Debug Access Port
  - Debug Port -> external access (JTAG)
  - Access Port -> access on chip resources
    - Memory Mapped Access (AXI), CoreSight Debug tools (CoreSight APB Bus), Daisy Chained Devices (JTAG)
- Versal Applications
  - Debug access to APU, RPU, PPU and PSM registers
  - Access to virtual UART's of processors
  - Access to global address space, ability to read and write control registers
- JCM DAP Support
  - JTAG instruction interpreter
  - Firmware updates
  - New linux driver

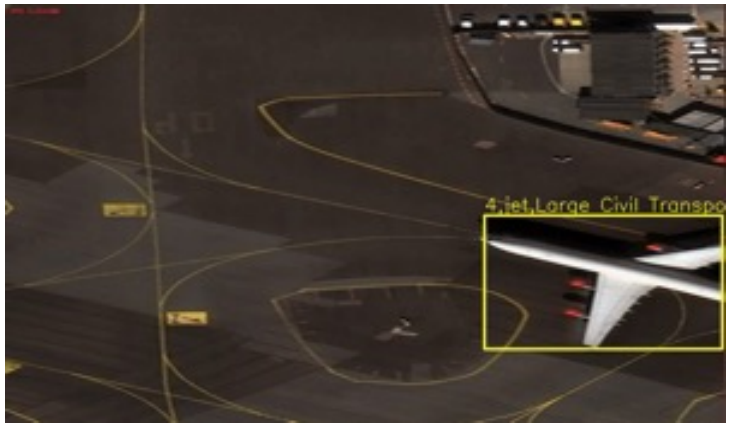






Task 3 - Reliable Real-Time Machine Learning

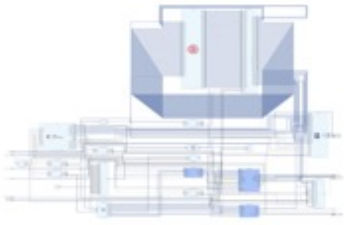
- Goal: Demonstrated improved reliability on real-time ML applications
  - Exploit advancements from Tasks 1 & 2
  - Demonstrate real-world, real-time applications
- Application examples for Versal ACAP
  - YOLO “Rare Plane” Image Classification
  - RF Modulation Recognition
- Apply Fault Tolerant Techniques
  - PL and Memory Scrubbing, TMR
  - Linux FT approaches
- Validate with fault injection and radiation testing



B1

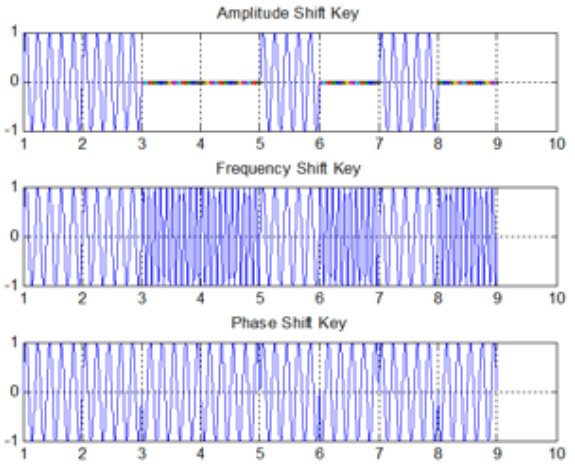
Yolo “Rare Planes” Image Classification

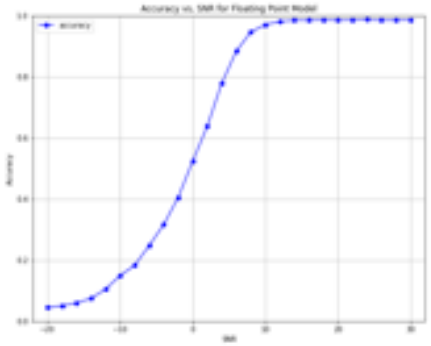
- Custom PL/AIE implementation of YOLO
  - Implementation from 2024 based on AMD “DPU”
    - AMD DPU IP is encrypted, cannot apply fault tolerance strategies
    - Limited visibility
  - New implementation based on PL (HLS) / AIE (custom kernels)
- Reliability Extensions
  - Integrate FT Versal Linux from Task 1
  - Apply TMR to PL (from previous years efforts)
  - Fault detection code for AIE
- Reliability Validation
  - Extensive fault injection with Versal FI kernel
  - Heavy Ion radiation test



RF Modulation Recognition

- Use DNNs to perform automatic modulation recognition
- Goal: receiver can detect and demodulate the signal without this explicit knowledge of the modulation type and encoding method
  - Exploit existing AMD Vitis RF Modulation demonstrations
  - Integrate with reliability enhancements from Task 1
- Collect additional data sets from member partners
- Demonstrate reliability improvements
  - Fault injection
  - Radiation testing

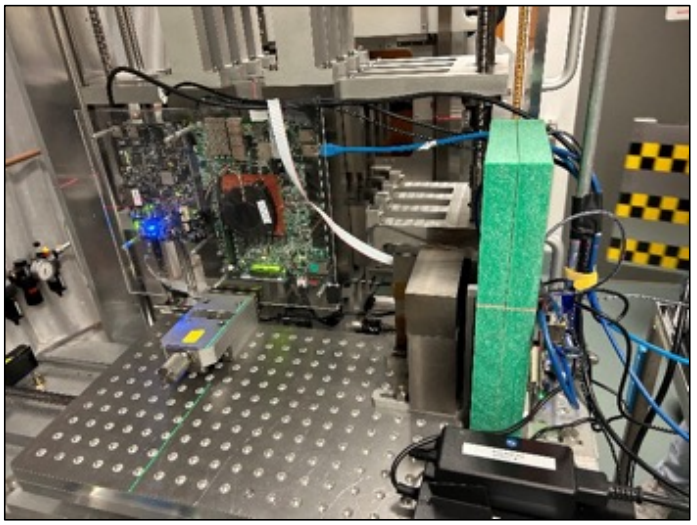




See: https://github.com/Xilinx/Vitis-AI-Tutorials/tree/2.5/Tutorials/RFModulation_Recognition/

Task 4 – Radiation Testing

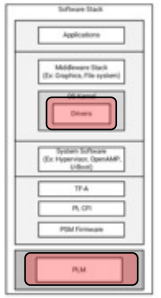
- Radiation testing necessary for understanding complex device failures
  - Identify failure mechanisms and single-event functional interrupts
  - Measure improvement of fault tolerant techniques
- Novel radiation testing methodologies needed for complex devices
  - High-flux testing approaches
  - Simultaneous device testing strategies
  - Low cross-section technologies
- Radiation Testing efforts for 2025
  - Analyze data from 2024
  - FT Yolo Rare Planes AI application
  - FT Linux/APU testing
  - Validate PCIe Scrubbing
  - XRTC DDR Interface Testing

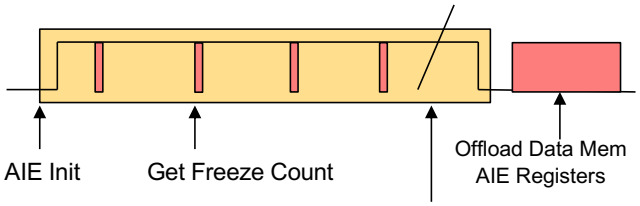


Application Testing

B1

- Fault Tolerant Versal Linux
  - Measure improvements in Linux FT approaches
  - More detailed fault analysis of Linux failure modes
  - Experiment interactively with mitigation approaches
- Reliable Yolo Rare Planes Classifier
  - Custom HLS based implementation
  - Incorporate FT Linux/APU efforts
  - Measure sensitive cross-section
  - Identify failure modes
- Versal AI Engine Testing
  - Continuous beam testing approach
  - Test other AIE features (Vector engine/SIMD instructions)
  - More complex AIE application, AIE-ML

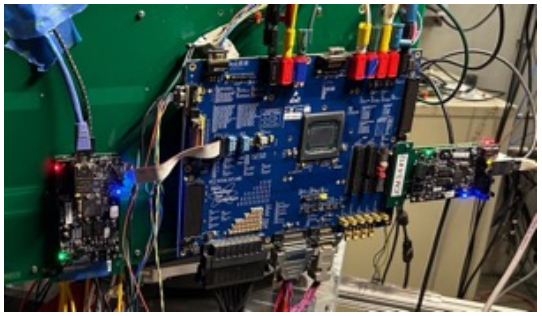




B1

Validate Scrubbing Approaches

- JCM ARM DAP Data Extraction Validation
  - Validate ability to extract complete system state
  - Demonstrate improved data transfer rates
  - Support multi-threaded DAP UART extraction
- Improved PCIe Scrubbing Approaches
  - Versal PCIe scrubbing was very successful in 2024
    - XilSEM UE recovery
    - High speed data extraction
  - Improve reliability and speed of “Bare Metal” PolarFire
  - Identify scrubbing failure modes
- XRTC DDR Interface Board Testing
  - Assist in validation of XRTC DDR/NOC testing



B1

Anticipated Radiation Test Experiments

- Berkeley National Laboratory/NSRL (Heavy Ion)
  - Yolo Rare Planes Application Test
  - XRTC DDR Interface Test
  - PCIe scrubbing
  - JCM DAP IF validation
- ChipIR, UK (Neutron)
  - Versal Neutron testing
  - Processor testing methodologies

Brookhaven National Laboratory

BERKELEY LAB
Lawrence Berkeley National Laboratory

ChipIR

Questions?

B1