P3-25: Emerging Systems

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. Alan George
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University of Pittsburgh
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University of Pittsburgh

Linus Silbernagel
Jakob Bindas
Josh Poravanthattil
Diego Wildenstein
Research Students
University of Pittsburgh

Number of requested memberships ≥ 4

Goals, Motivations, & Challenges

Goals

- Evaluate next-gen processing architectures, sensors and algorithms
- Investigate use of neuromorphic systems for space applications
- Benchmark PIM architecture and test radiation resiliency

Motivations

- Novel architectures are needed to combat SWaP-C constraints of on-board space processing
- Neuromorphic systems and PIM architectures offer power- and memory-efficient computation

Challenges

- Next-generation architecture requires unique design considerations
- Lack of software maturity with frameworks for new architectures poses challenges when designing novel solutions

PIM: Processing-in-memory
SWaP-C: Size, weight, power, and cost

Proposed Tasks for 2025

T1 — Neuromorphic Sensors and Applications

Develop and evaluate algorithms for space-related applications using EBBs

Task Members: Linus Silbernagel, Jakob Bindas

T2 — Neuromorphic System Reliability

Investigate reliability and efficiency of neuromorphic algorithms

Task Member: Joshua Poravanthattil

T3 — Processing-in-Memory Architecture

Analyze performance and determine reliability of second-generation Gemini-II APU devices

Task Member: Diego Wildenstein

EBSs: Event-based sensors
APU: Associative Processing Unit

T1 Neuromorphic Applications

Develop and evaluate algorithms for space-related applications using EBBs

Task Leader: Linus Silbernagel

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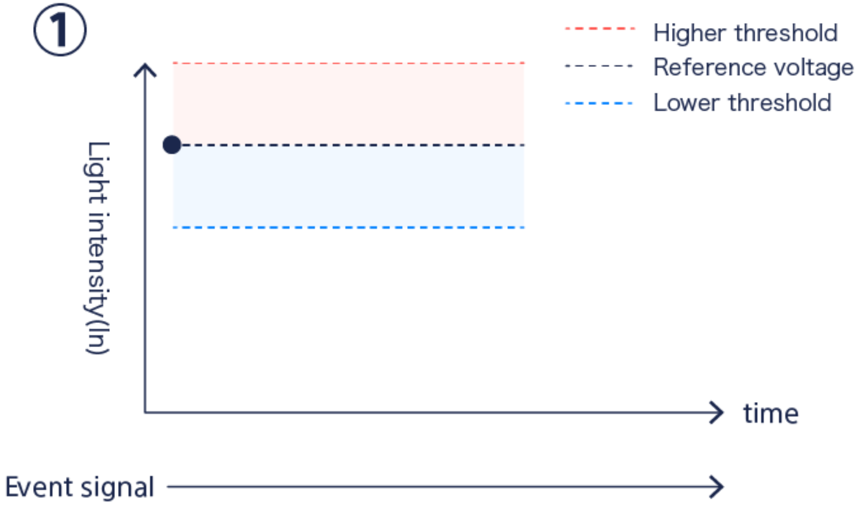
Jakob Bindas – jmb442@pitt.edu

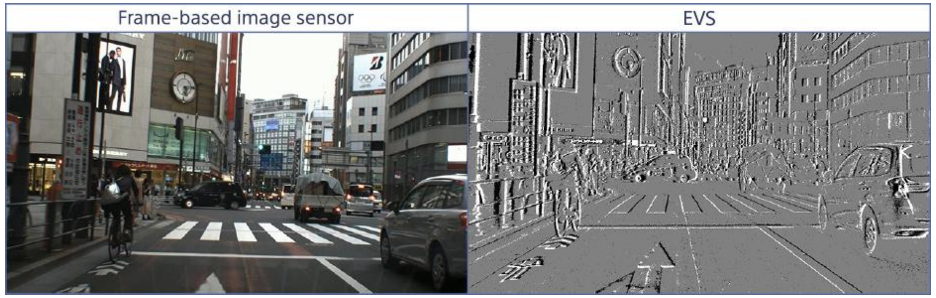
EBSs: Event-based sensors

T1: Background

Event-Based Sensors

- Event-based vision sensors produce **asynchronous events** and offer unique characteristics such as **high temporal resolution** and **high dynamic range**
- Uses **minimal power** during operations due to asynchronous nature of sensor



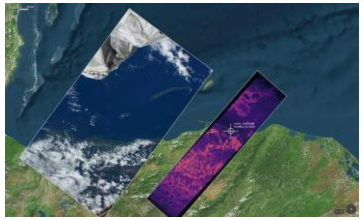


Applications

- Attractive properties of neuromorphic systems can be leveraged for **on-board space applications**
- Event-based data enables **small object tracking** with **high data efficiency**

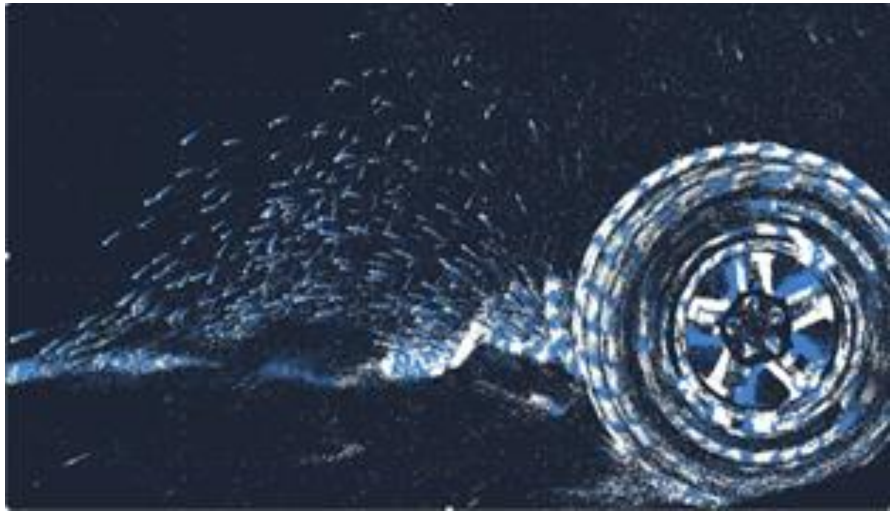
EVS: Event-based vision sensor

T1: Neuromorphic Applications



Land Feature Detection

- Develop CNN- and SNN-based algorithms for **land feature detection** from event-based sensors
- Compare performance with frame-based algorithms to **highlight advantage and disadvantages**



Plume Surface Interactions

- Explore event-based MTT algorithms to **track lunar regolith** to understand plume surface interactions
- Analyze effectiveness of MTT to produce **best-fit trajectories** for objects of interest

CNN: Convolutional neural network
SNN: Spiking neural network
MTT: Multi-target tracking

T2 Neuromorphic System Reliability

Investigate reliability and efficiency of neuromorphic hardware

Task Leader: Joshua Poravanthattil

P3

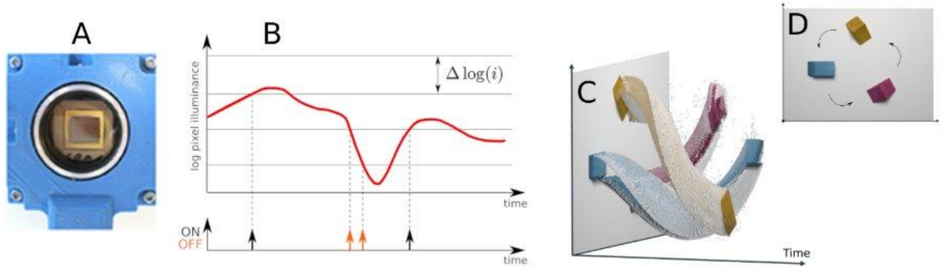
T2: Background

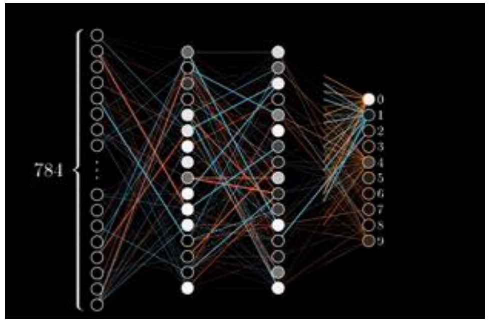
Event-Based Sensors and Algorithms

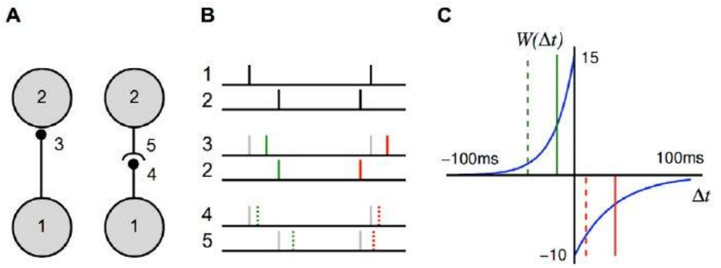
- SNNs are **powerful** and **efficient**, especially when paired with event-based sensor data
- Our prior simulation strongly suggests that backprop SNNs exhibit **intrinsic reliability** to radiation-induced noise

Resiliency Exploration with SOTA

- SNNs differ from CNNs by addition of **temporal** features and **discrete** data
- How do **resiliency** of these algorithms compare under radiation-induced noise

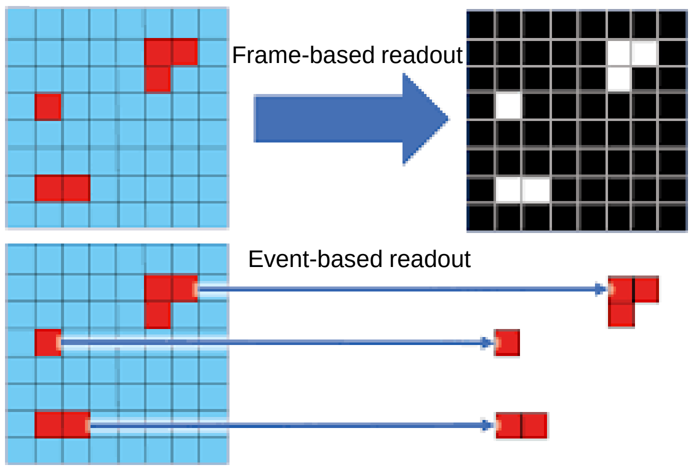






SNN: Spiking Neural Network
SOTA: State-of-the-Art
CNN: Convolutional Neural Network

T2: Neuromorphic Algorithm Studies



Compare CNN- and SNN-Algorithms

- Algorithms tasked with object **classification** using event-based sensor data
- Inject **noise** as previously tested with SHREC's RINSE fault injector and parameter variation

What Will We Measure?

- Classification **accuracy** across varying NR and AOI parameters with both algorithms
- **Runtime** and **power utilization** statistics for hardware implementations

CNN: Convolutional Neural Network
SNN: Spiking Neural Network
RINSE: Radiation-Induced Noise Simulation Environment
NR: Noise Rate
AOI: Angle of Incidence

T3 Processing-in-Memory Architecture

Analyze performance and determine reliability of second-generation Gemini-II APU devices

Task Leader: Diego Wildenstein

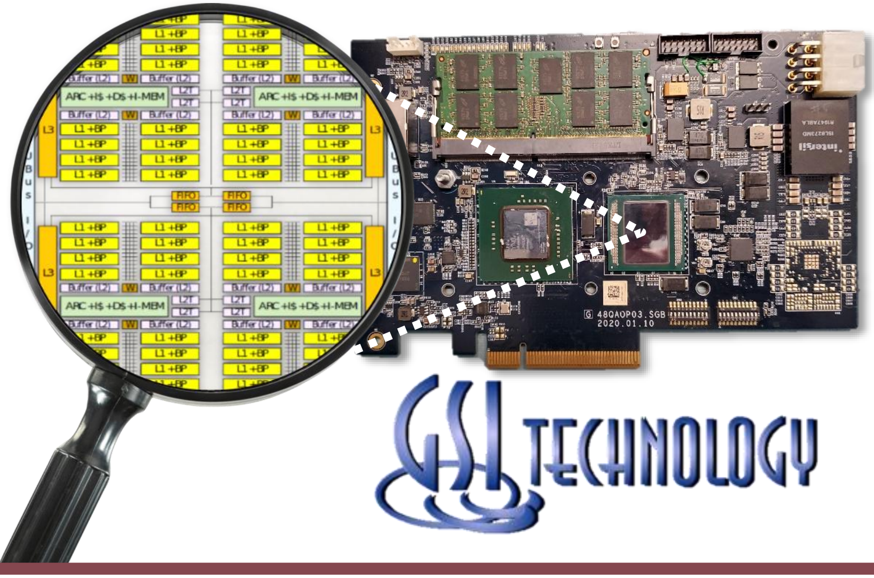
Diego Wildenstein – diw29@pitt.edu

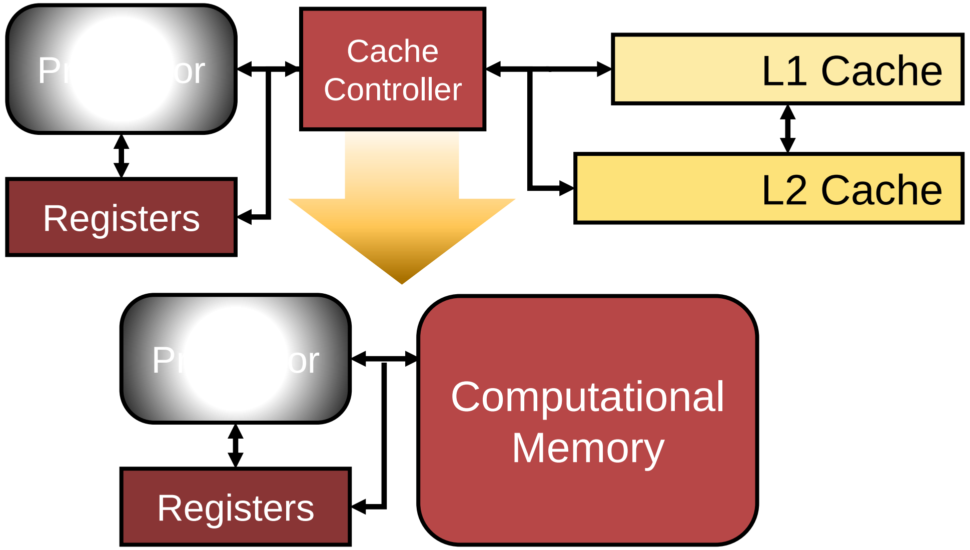
APU: Associative Processing Unit

T3: Background

In-Memory Processing

- Architectures with processing logic **directly integrated** into top-level cache memory cells
- **Improves runtime latency** by reducing need for frequent memory transfers





Gemini-II APU

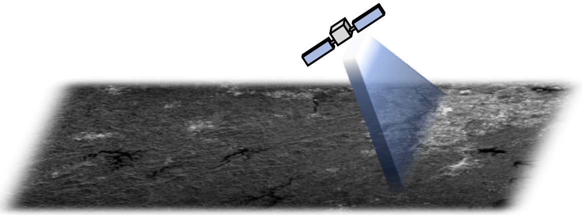
- New generation of state-of-the-art PIM devices with over **2 million bit-processor** memory cells
- Device exhibits **low power usage** profile and **consistent, fast performance** for memory-bound apps

APU: Associative Processing Unit
PIM: Processing-in-memory

T3: Processing-in-Memory Studies

SpaceBench

$$\begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \\ A_{41} & A_{42} & A_{43} \\ A_{51} & A_{52} & A_{53} \\ A_{61} & A_{62} & A_{63} \end{bmatrix} \times \begin{bmatrix} B_{11} \\ B_{21} \\ B_{31} \end{bmatrix} = \begin{bmatrix} C_{11} \\ C_{21} \\ C_{31} \\ C_{41} \\ C_{51} \\ C_{61} \end{bmatrix}$$

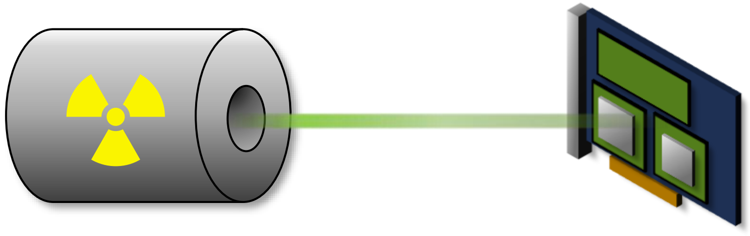


APU Performance

- **Benchmark G2 APU** device with compute kernels commonly used in machine-learning apps
- **Compare performance** of G2 APU with other upcoming **spaceflight CPU and GPU** devices

Device Reliability

- Test G2 APU devices under ionizing radiation to determine **single-event upset rates** and **failure modes**
- Explore potential **fault-mitigation strategies** for next-gen APU architecture



G2 APU: Gemini-II Associative Processing Unit

Milestones, Deliverables, & Budget

MILESTONES

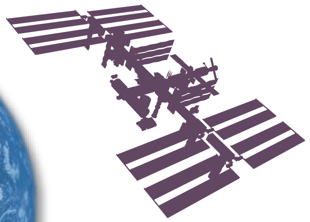
- SMW24 (Jun 25): Showcase preliminary results on all project tasks
- SAW25-26 (Jan 26): Completion of all project tasks

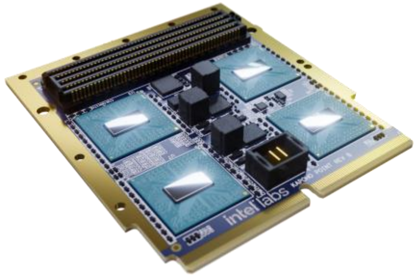
DELIVERABLES

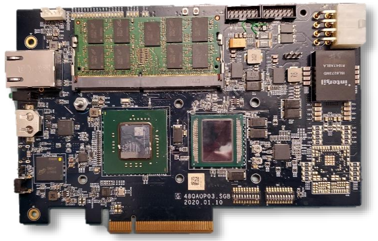
- Monthly progress reports from all projects
- Midyear and end-of-year full reports from all projects
- 4 conference or journal publications

BUDGET

- Minimum recommended: Four (4) memberships
  (200 Votes)



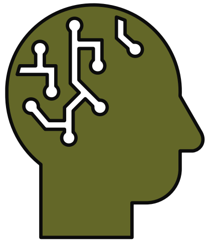


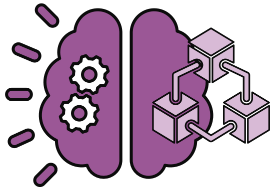


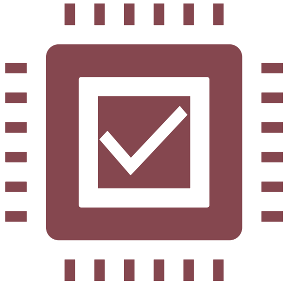
Conclusions & Member Benefits

Conclusions

- Analyze performance of CNN- and SNN-based algorithms for **land feature detection** using event-based sensors
- Evaluate **event-based MTT** algorithms for plume-surface interactions
- Compare state-of-the-art CNN algorithms against SNN-based algorithms for **classifying event-based data**
- Characterize performance and reliability of second-generation **in-memory processing** devices







Member Benefits

- Direct influence over processors and frameworks studied
- Direct influence over apps and datasets studied
- Direct benefit from new methods, data, code, models, and insights from metrics, benchmarks, and emulations

CNN: Convolutional neural network
SNN: Spiking neural network
MTT: Multi-target Tracking