MemoryBoost: RISC-V Temporal Isolation Through Dynamic Hypervisor-level Bandwidth Reservation

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Abstract

We introduce MemoryBoost, an open-source, hypervisor-level dynamic Memory Bandwidth Reservation (MBR) mechanism for Mixed-Criticality Systems (MCSs). MemoryBoost leverages deterministic Machine Learning and a VM-centric design for temporal isolation, maintaining OS/platform independence atop the Bao hypervisor with full RISC-V support. Preliminary results show that MemoryBoost reduces performance degradation in critical workloads by up to 70% while maintaining 80% throughput for non-critical workloads, achieving overhead as low as 1%.

MemoryBoost Overview

- Each VM has a maximum **budget** of memory accesses per **period** - VM idles if budget expires
- Designed with 4 different **criticality levels** - Catastrophical, Critical, Major, Minor
- Implemented on **Bao Hypervisor**- fully supporting RISC-V
- No specific **hardware/FPGA** dependency - designed for heterogeneous systems
- **Deterministic model** - Ideal for space-critical applications

Key Features:

- Non-Blocking **Concurrency Model**
- **Event Processing** - Bounded Modulo Hashing
- **ML-Based** budget assignment - Flattened Decision Tree
- **VM-Centric** Criticality Assigner - following ECSS-Q-ST-40C
- **Predictable time execution -** O(1) complexity, minimal memory requirements and minimal amount of branches

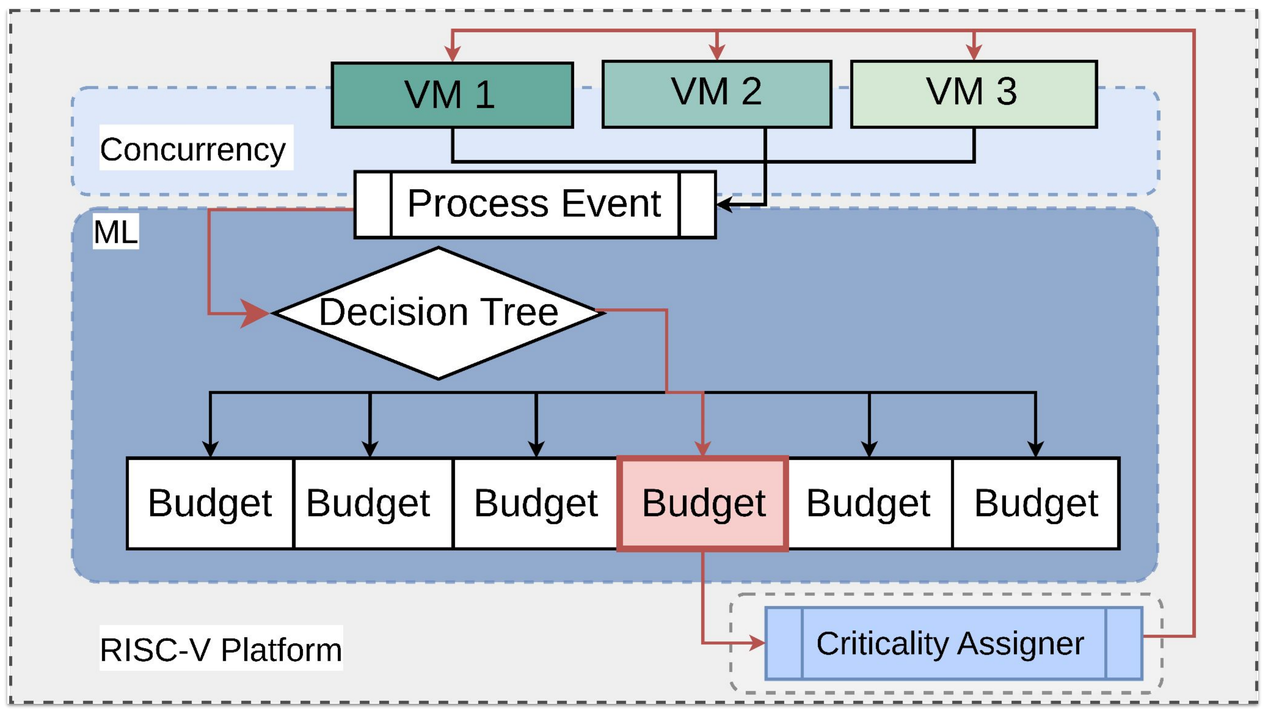

Figure 1 - MemoryBoost on RISC-V overview

Evaluation

Methodology

- To evaluate **MemoryBoost**, we use two VMs with distinct criticality:
  - **Catastrophic VM** - MiBench automotive benchmark on Linux (1 CPU)
  - **Minor VM** - Baremetal app invalidating cache lines (3 CPUs)
- We use three different setups with the existing guests
  - **Solo** - Catastrophic VM alone (MiBench baseline)
  - **Interf** - Both VMs concurrently, maximum interference (baremetal baseline)
  - **MemoryBoost** - Both VMs concurrently managed by MemoryBoost

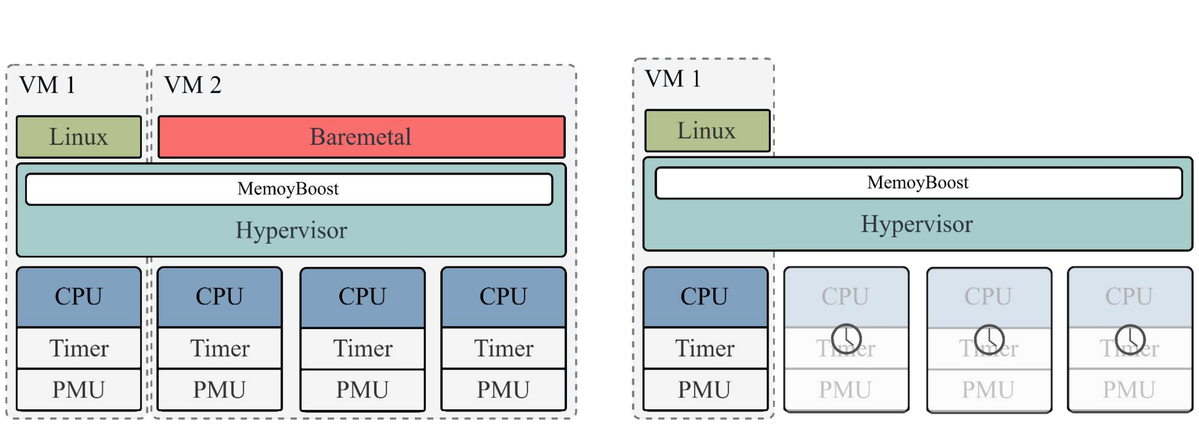

Figure 2 - Methodology overview - Non-idle and Idle state of Minor VM

Results

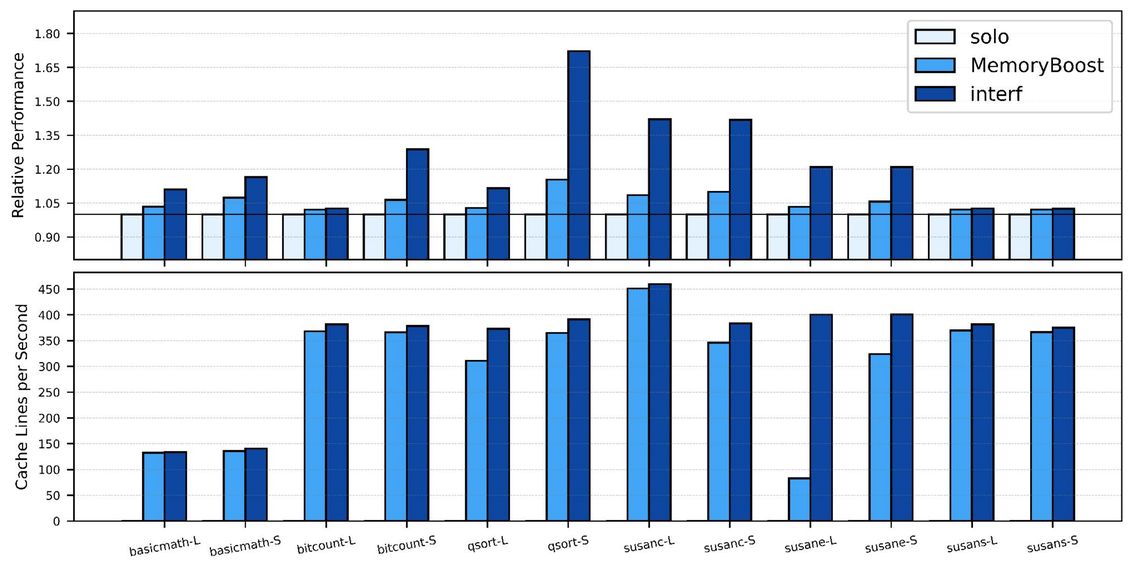

Figure 3 - Overview of results for Solo, Interf and MemoryBoost setups

- **MemoryBoost**'s improvements:
  - **Temporal Isolation**: Performance degradation in the Catastrophic VM was reduced by up to 80%.
  - **Performance Stability**: The Minor VM maintained robust performance, achieving up to 90% of its baseline.
  - **Efficiency**: MemoryBoost introduced minimal overhead, consistently below 1% at a 100 µs regulation period.

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