Application Memory Isolation on Ultra-Low-Power MCUs

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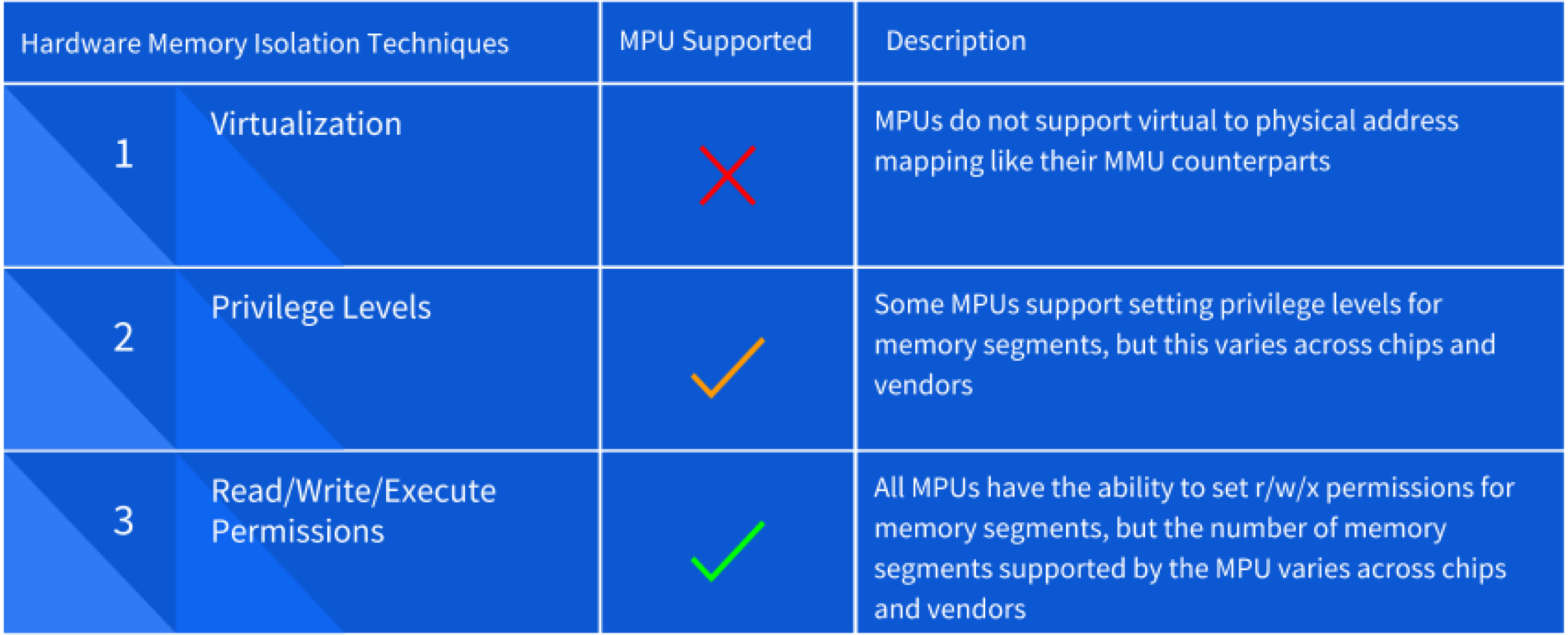
Motivation

- Many wearables and IoT devices utilize ultra-low-power MCUs to achieve long battery life

Motivation



Hardware Memory Isolation Techniques		MPU Supported	Description
1	Virtualization	✗	MPUs do not support virtual to physical address mapping like their MMU counterparts
2	Privilege Levels	✓	Some MPUs support setting privilege levels for memory segments, but this varies across chips and vendors
3	Read/Write/Execute Permissions	✓	All MPUs have the ability to set r/w/x permissions for memory segments, but the number of memory segments supported by the MPU varies across chips and vendors

Our Proposal

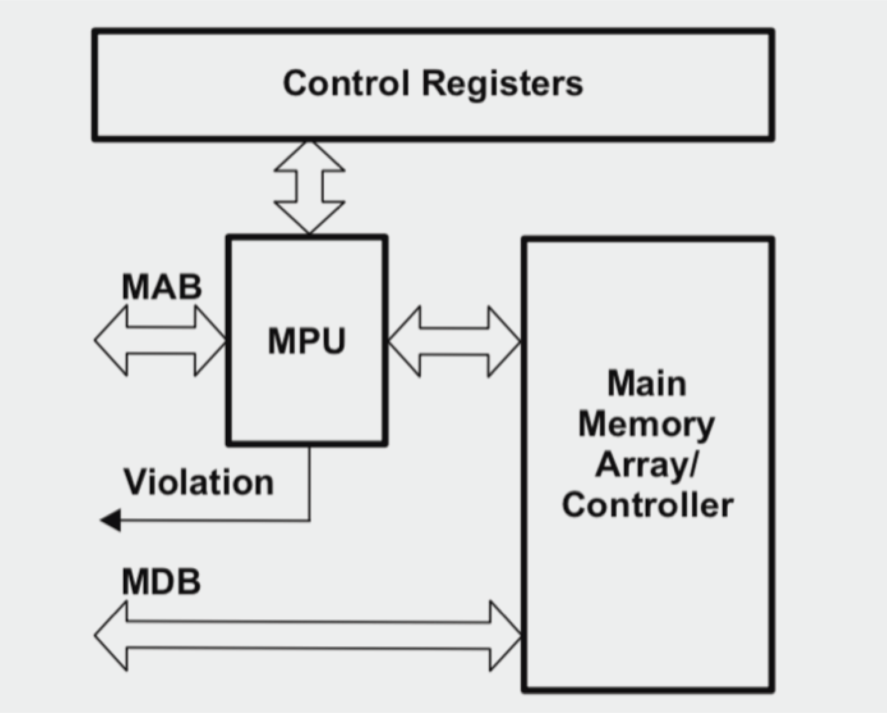
Utilize MPU to **relax** language restrictions and achieve **better** runtime performance

System Design: Platform

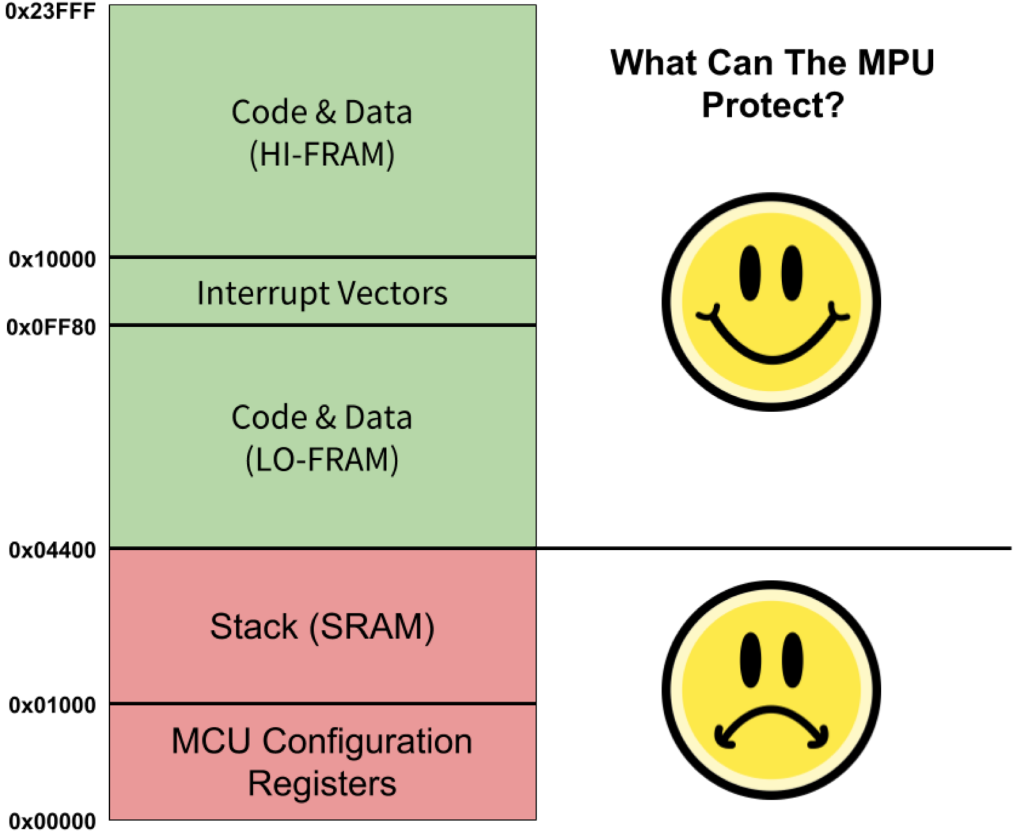
- Amulet Platform
  - Open-source software & hardware
  - Multi-application
  - Low-power MSP430 MCU
  - Memory isolation via language restrictions and runtime bounds checks

System Design: MPU Capabilities

- **No** privilege levels
- **3** variable size memory segments
- Only protects memory addresses **above** 0x4400



System Design: Memory Layout



What Can The MPU Protect?

0x23FFF

Code & Data (HI-FRAM)

0x10000

Interrupt Vectors

0x0FF80

Code & Data (LO-FRAM)

0x04400

Stack (SRAM)

0x01000

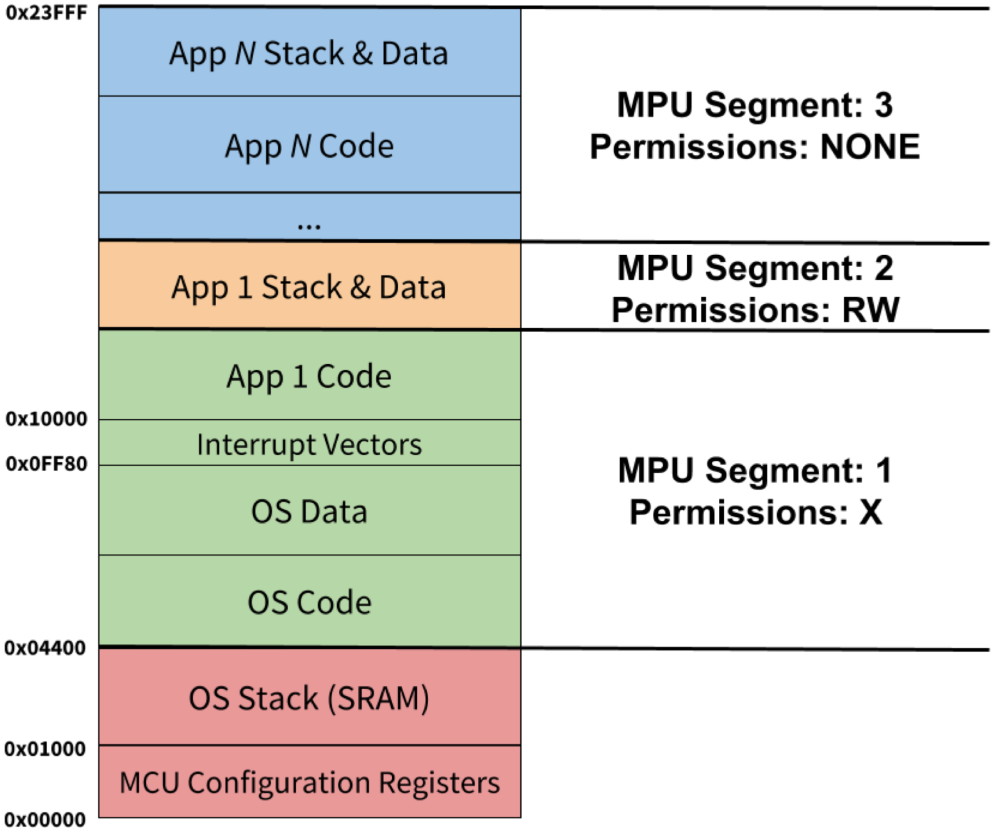
MCU Configuration Registers

0x00000

System Design: Memory Violations

- Memory Accesses
  - Application data
  - Indirect function calls
- Context Switches
  - Passing a pointer to the OS
  - Changing return address

System Design: Memory Layout

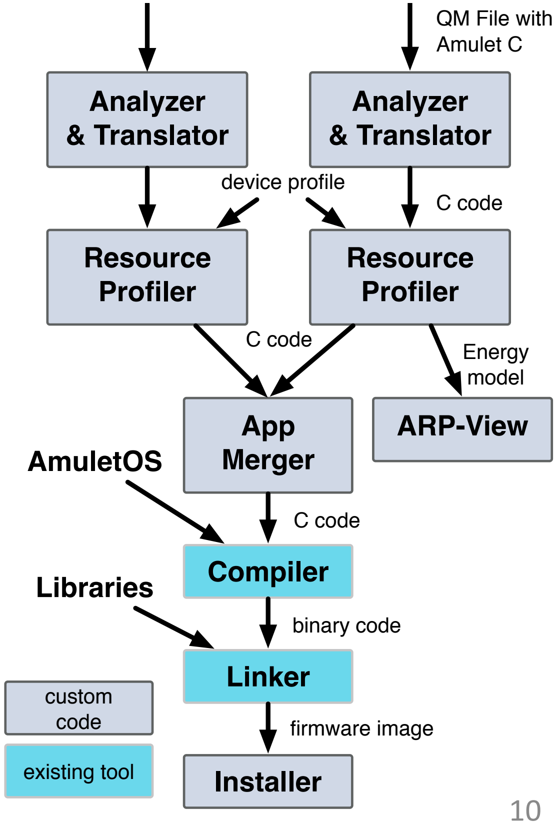


System Design: MPU Model

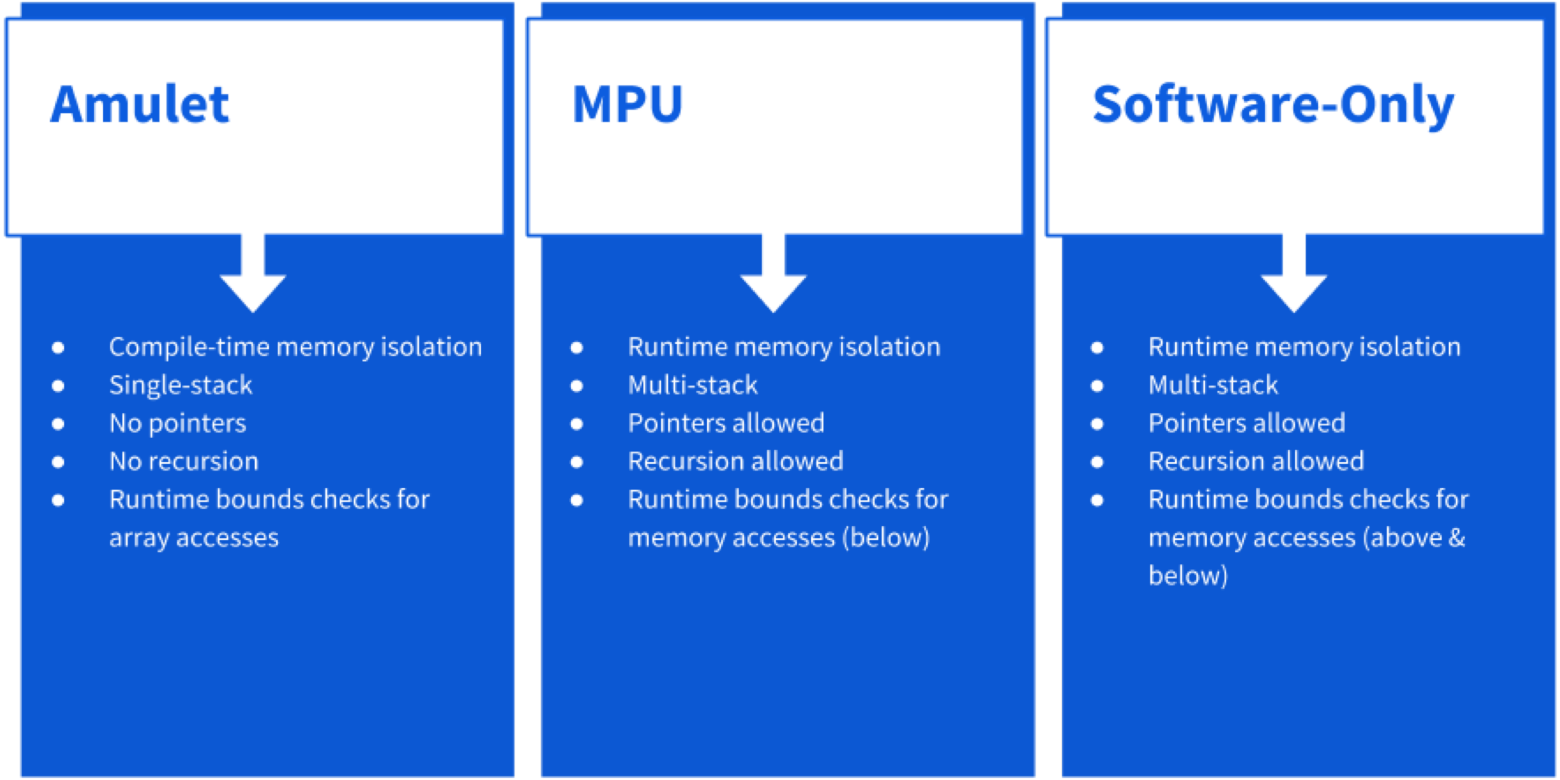
- MPU prevents memory accesses and indirect calls **above** the current app’s memory space
- Runtime software checks handle accesses and indirect calls **below** the current app’s memory space
- Each application has its **own** stack
- Runtime software checks verify return addresses

System Design: AFT

- Amulet Firmware Toolchain (AFT)
  - Analyze,
  - Transform
  - Merge
  - Compile



Eval: Isolation Models



Amulet

- Compile-time memory isolation
- Single-stack
- No pointers
- No recursion
- Runtime bounds checks for array accesses

MPU

- Runtime memory isolation
- Multi-stack
- Pointers allowed
- Recursion allowed
- Runtime bounds checks for memory accesses (below)

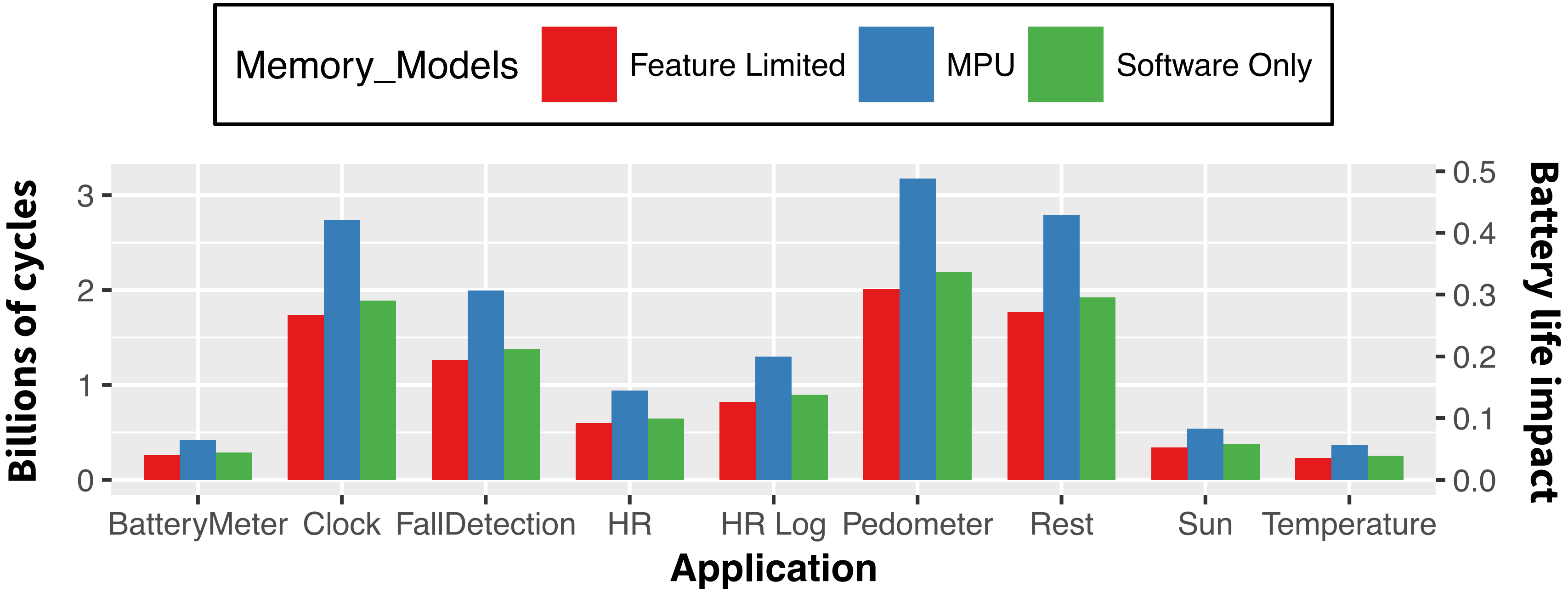
Software-Only

- Runtime memory isolation
- Multi-stack
- Pointers allowed
- Recursion allowed
- Runtime bounds checks for memory accesses (above & below)

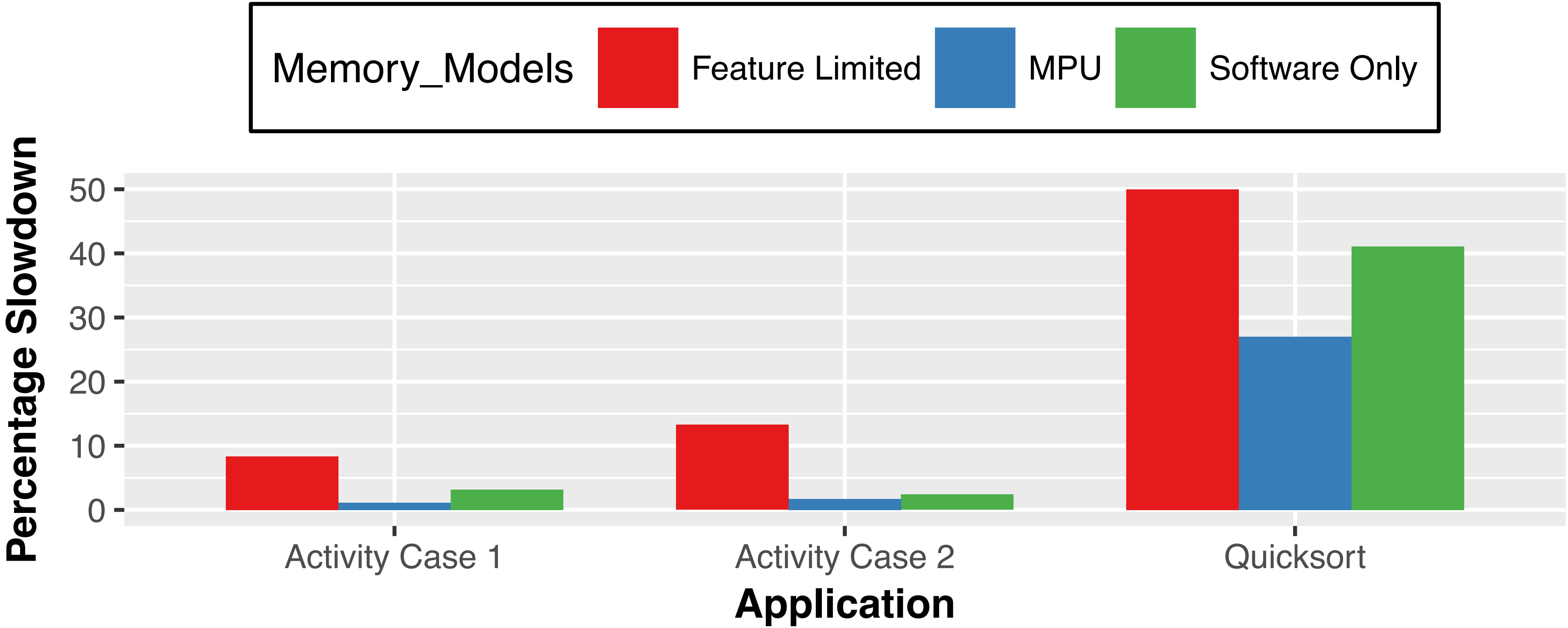
Eval: Simulation

- Simulated 9 applications from the Amulet suite using the Amulet Resource Profiler (ARP)
- Each application was simulated using
  - Amulet isolation
  - MPU isolation
  - Software-only isolation

Eval: Simulation Results



Eval: Amulet Deployment Results



Summary

- MPU can provide performance benefits for applications with high frequency of memory accesses
- While our approach was not effective for apps with frequent context switches, our MPU approach had, for all applications, less than 0.5% battery impact

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Amulet Platform: amulet-project.org

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