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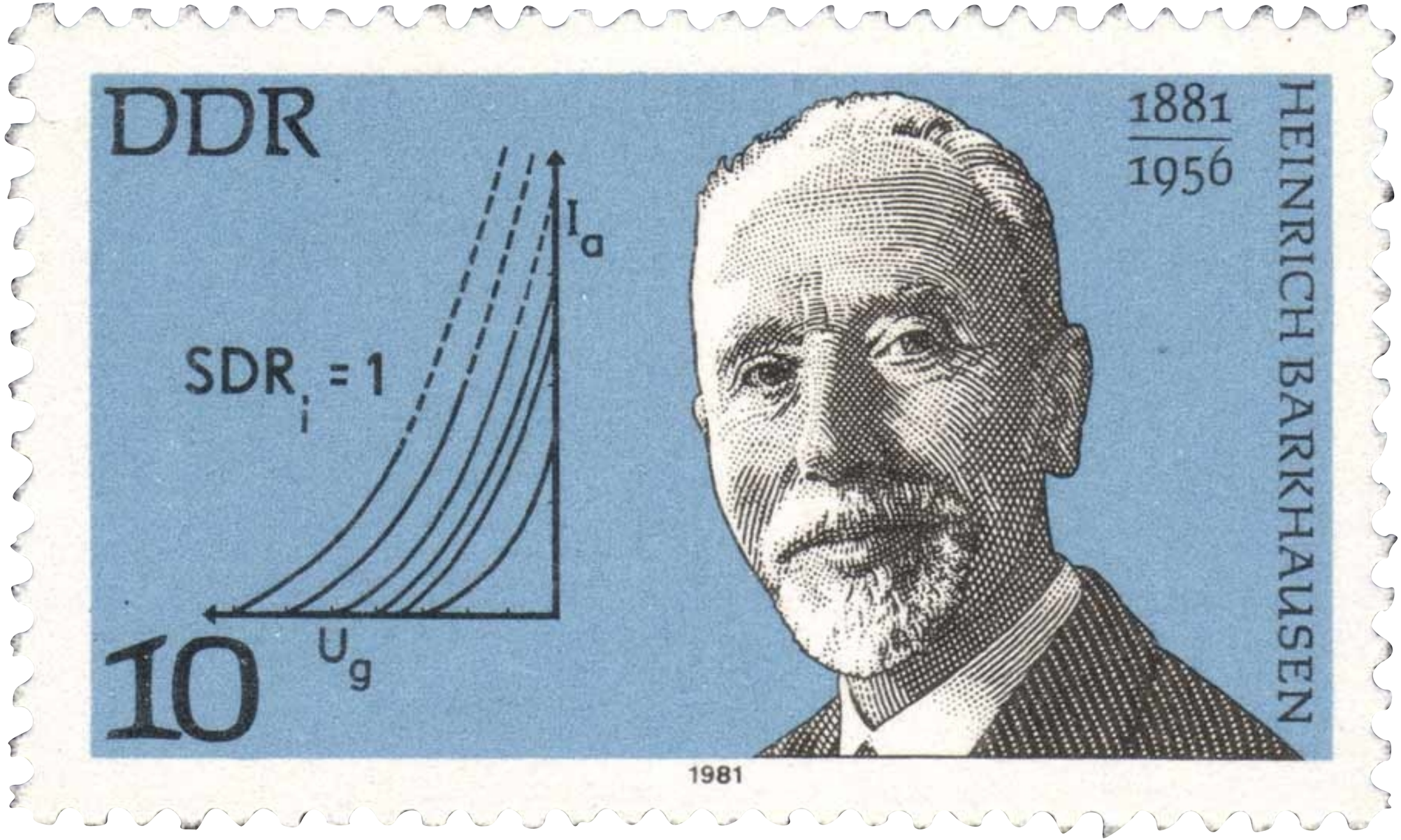
M^3 and Beyond: Secure Systems with Fast Enforcement

Michael Roitzsch


DDR
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Ia
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1881
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HEINRICH BARKHAUSEN
1981

Trustworthiness for the Tactile Internet of Things

Composability = Isolation + Cooperation

Mission

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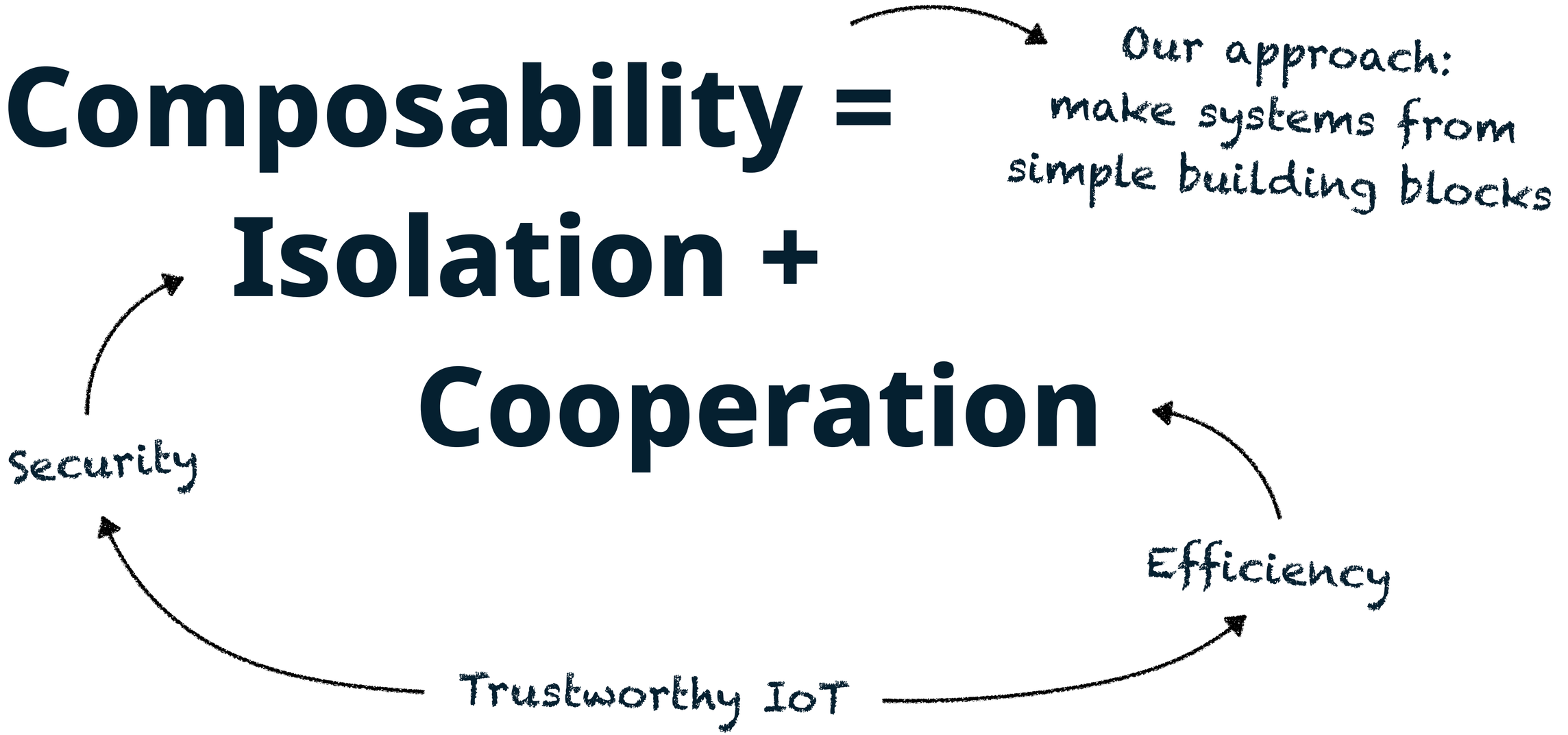
Composability =
Isolation +
Cooperation
Our approach:
make systems from
simple building blocks
Security
Efficiency
Trustworthy IoT

Agenda

The M^3 Journey in Three Papers

Lessons Learned from M^3

Future Directions

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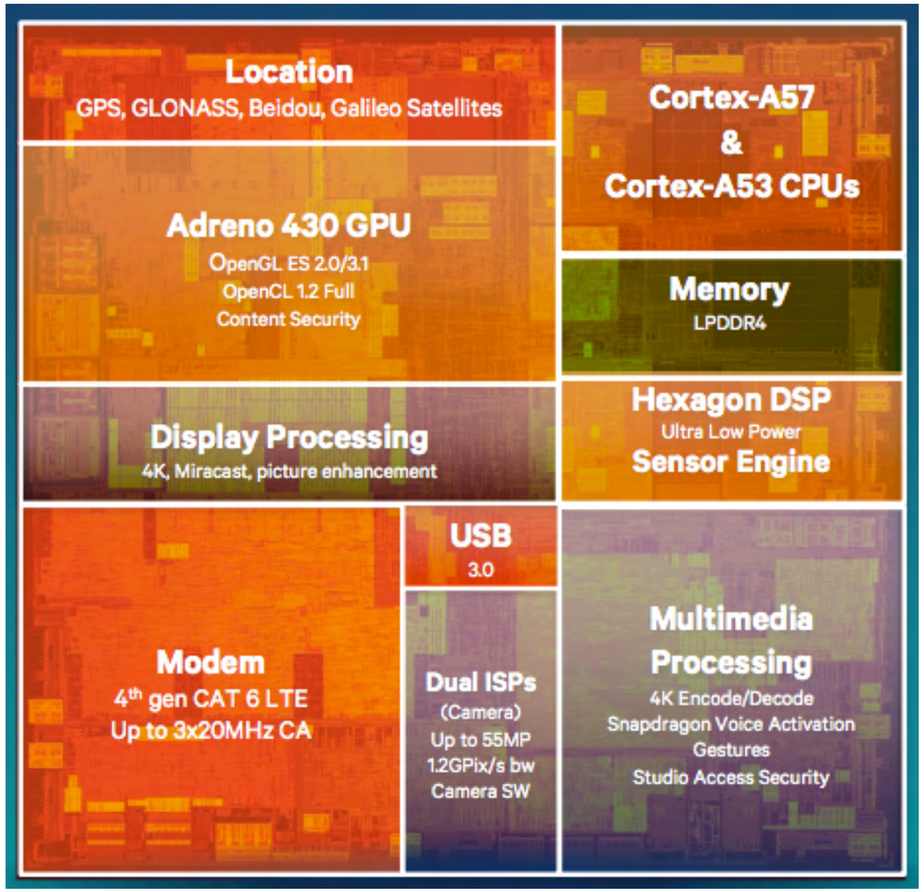
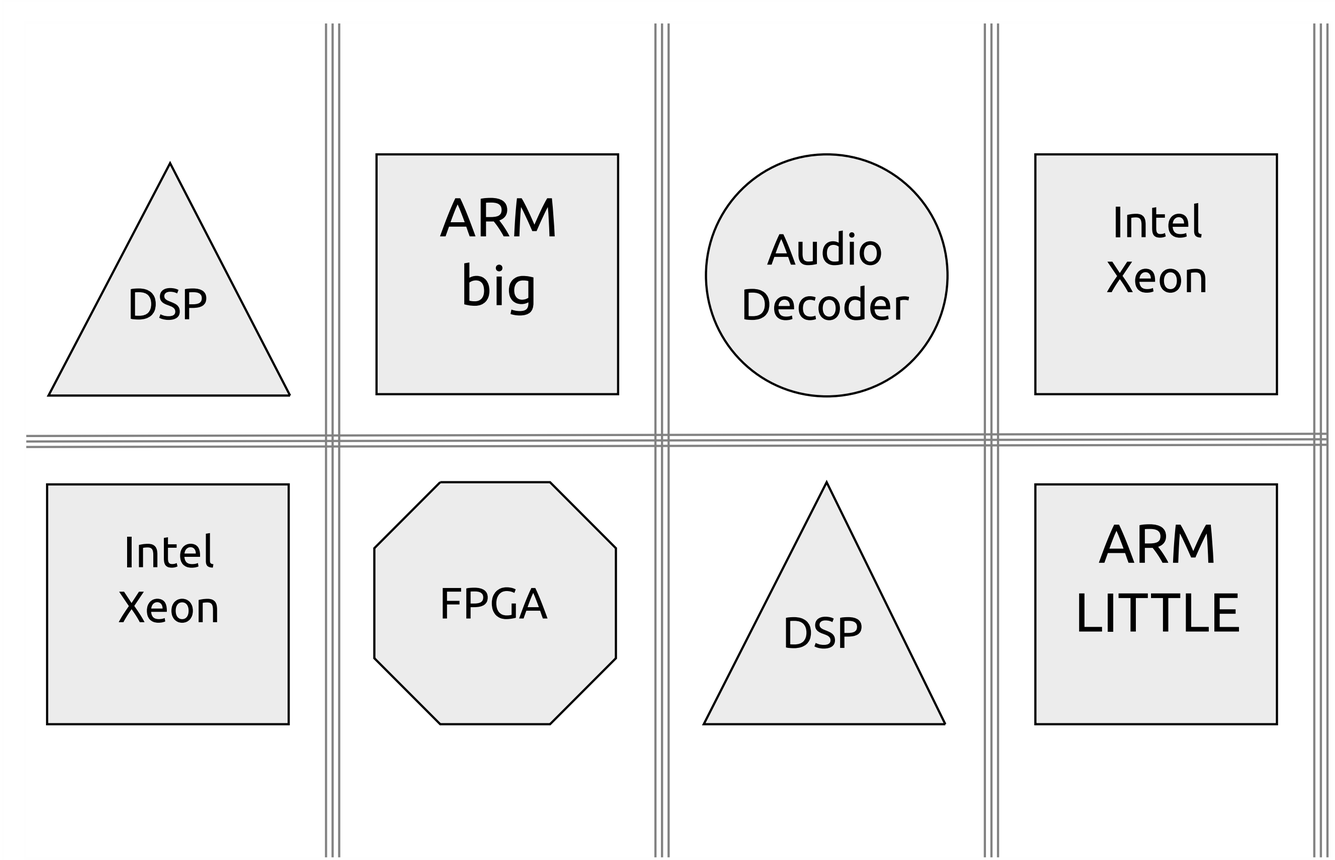
M^3 — Trustworthy SoCs for IoT and Edge

ASPLOS '16

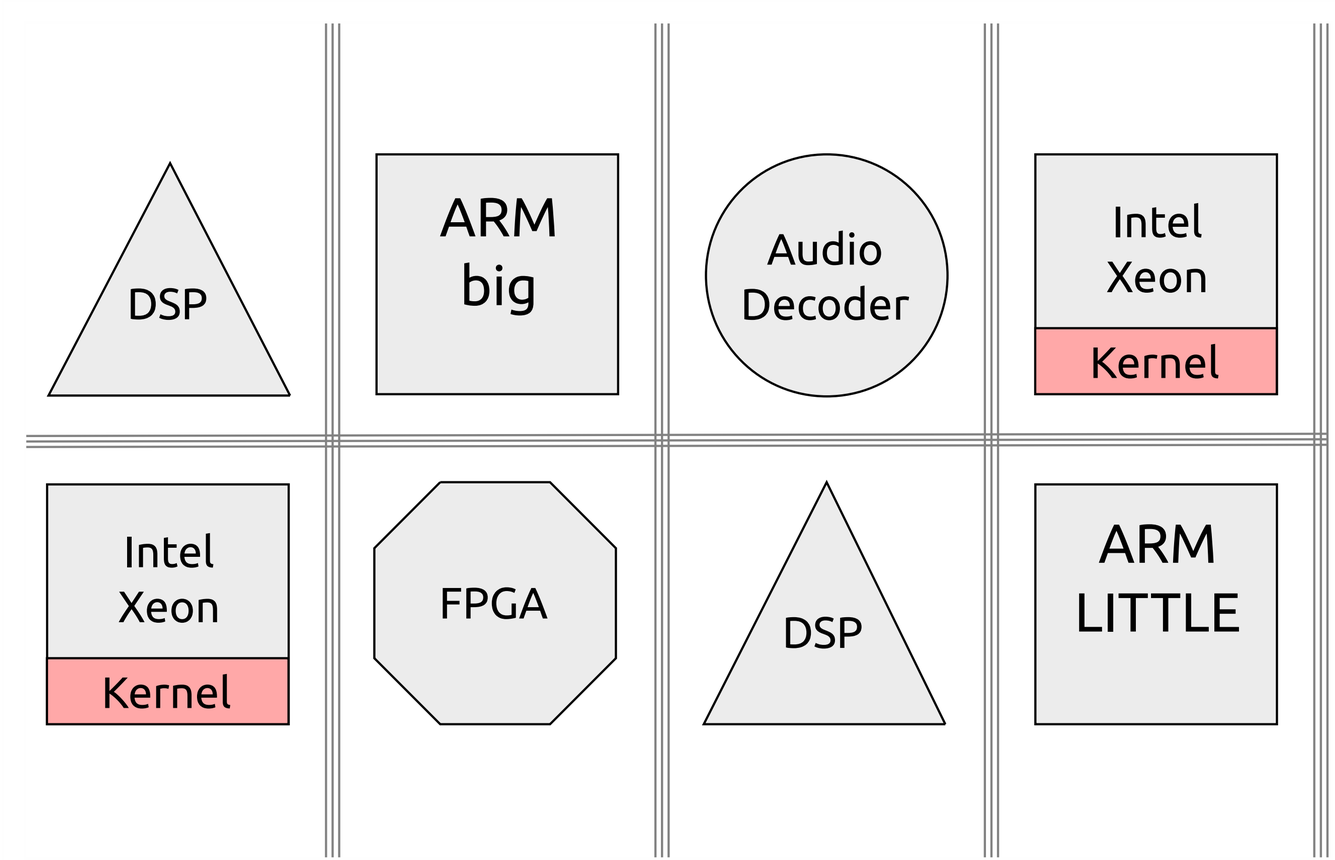
Motivation: Heterogeneous SoCs



The Problem


DSP
ARM
big
Audio
Decoder
Intel
Xeon
Intel
Xeon
FPGA
DSP
ARM
LITTLE

The Problem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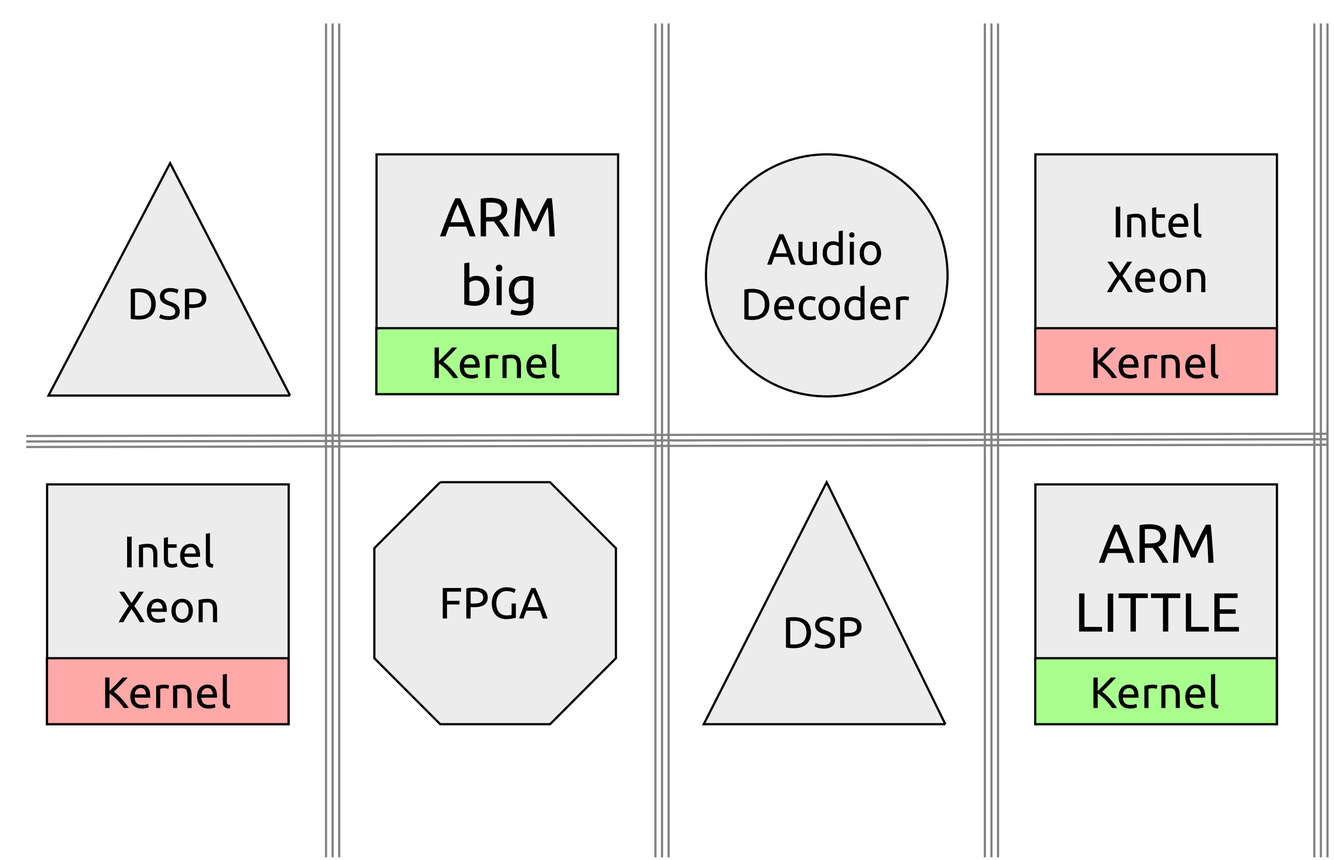
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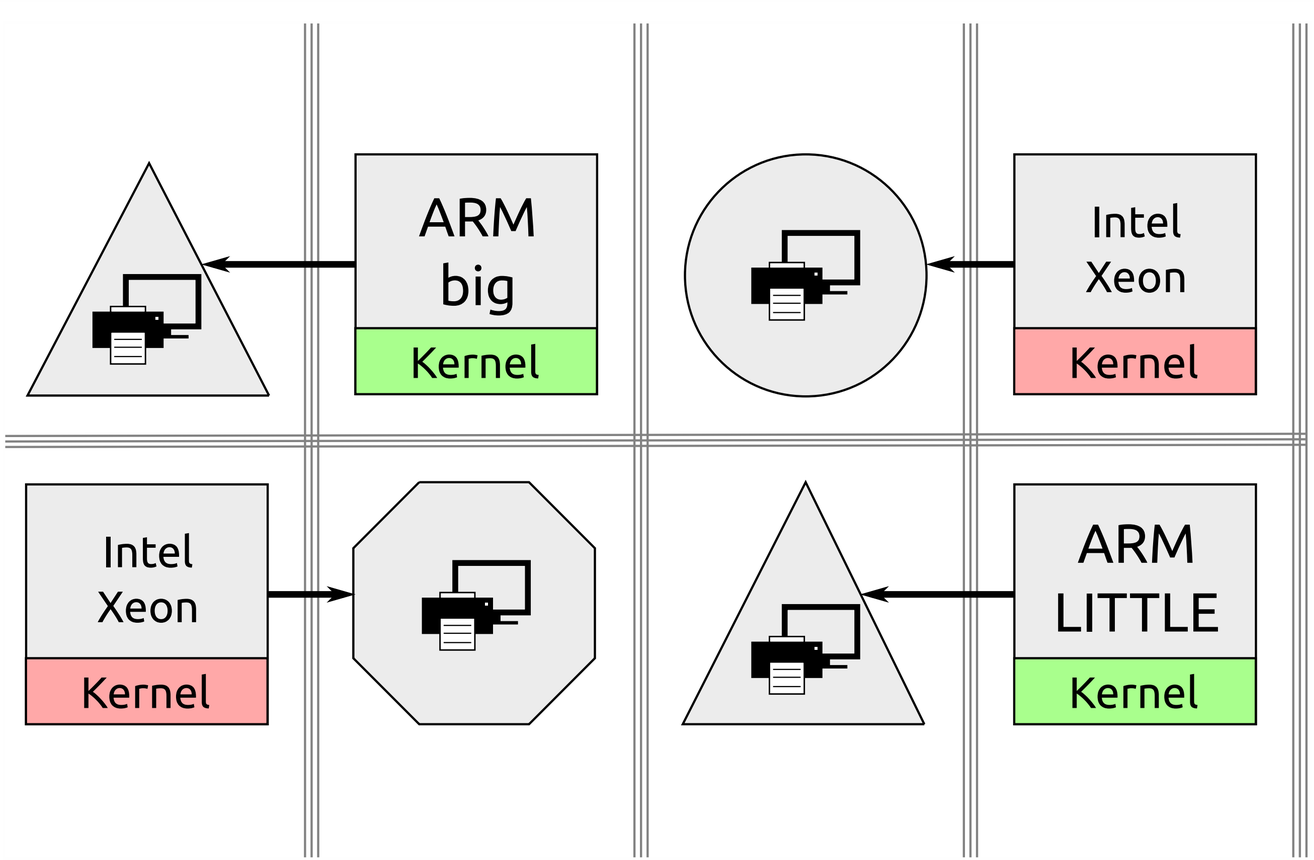
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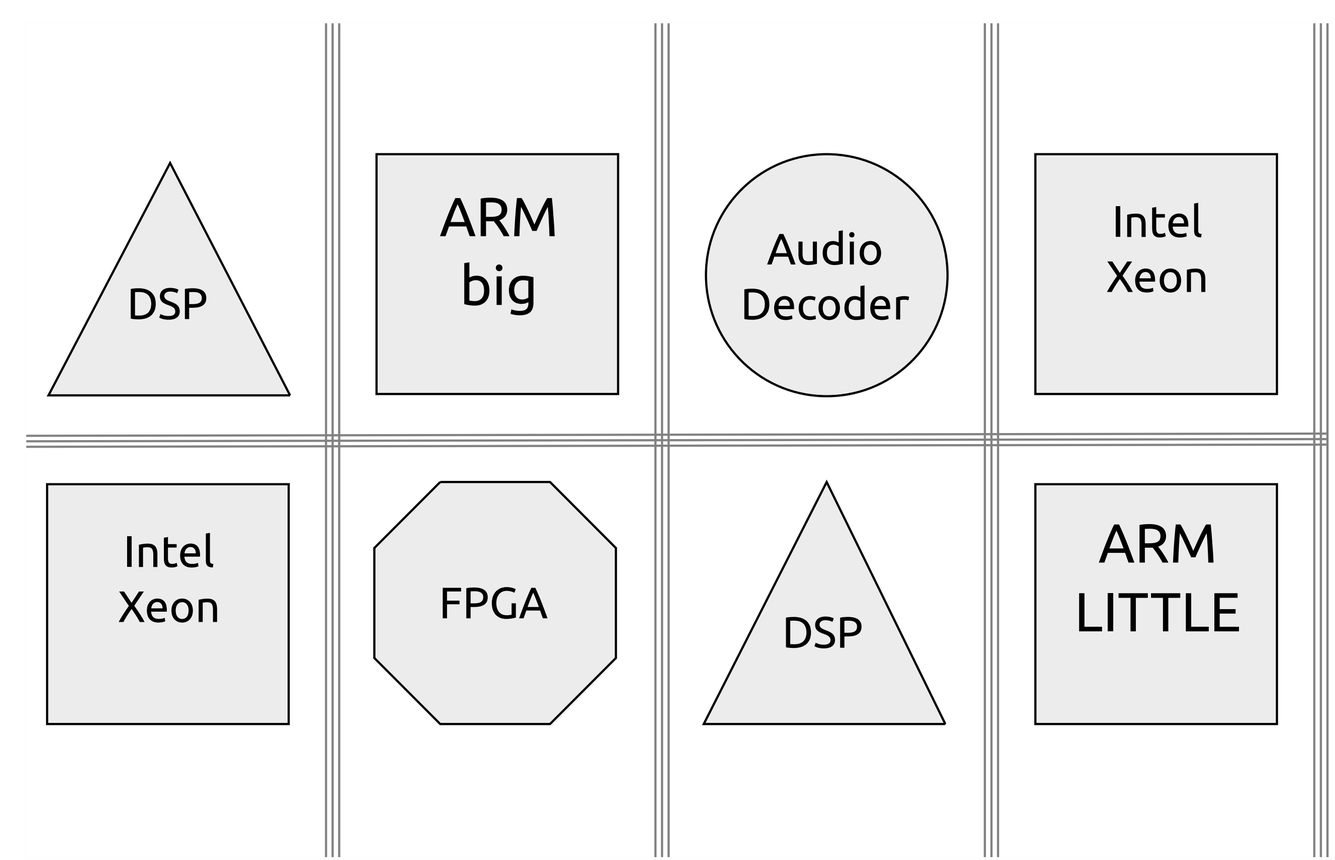

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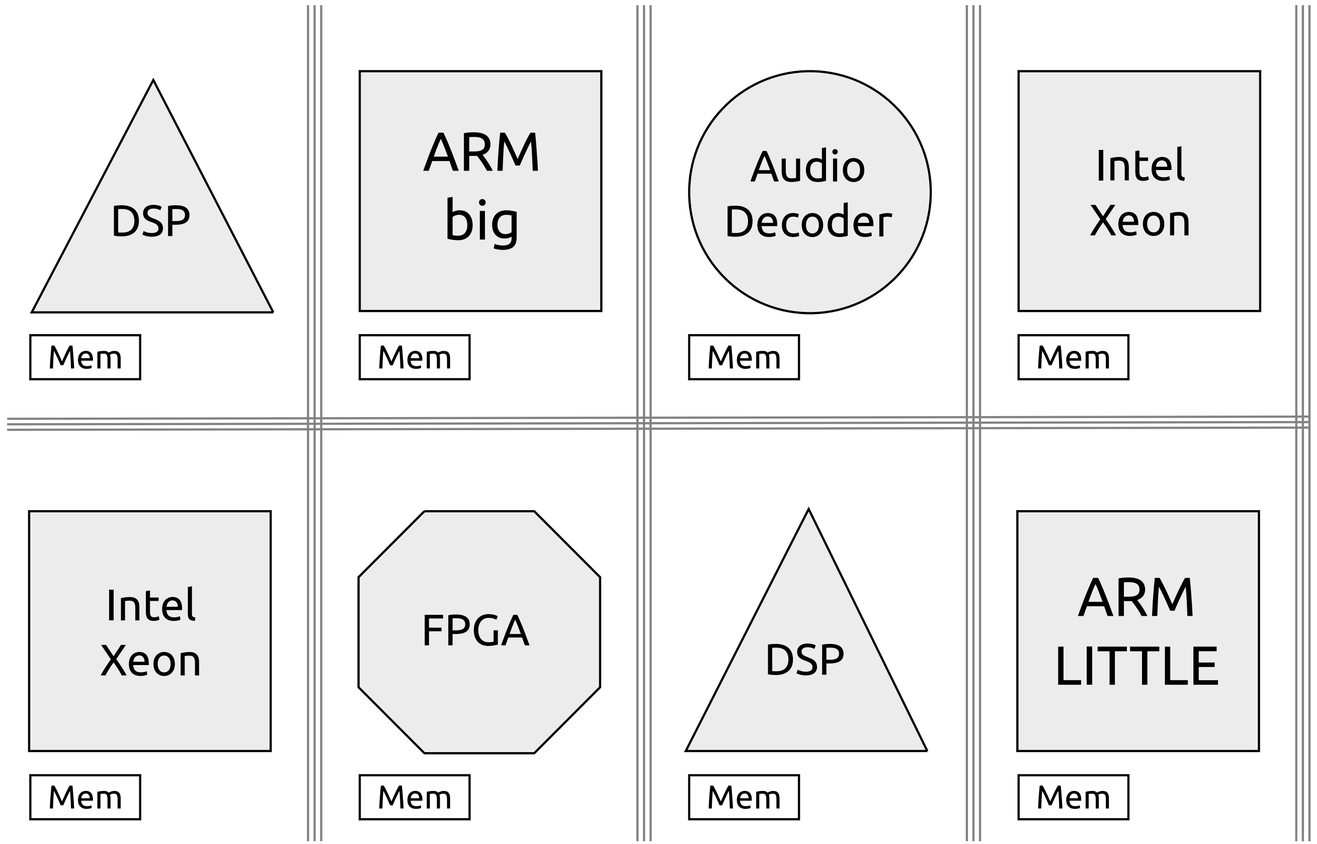

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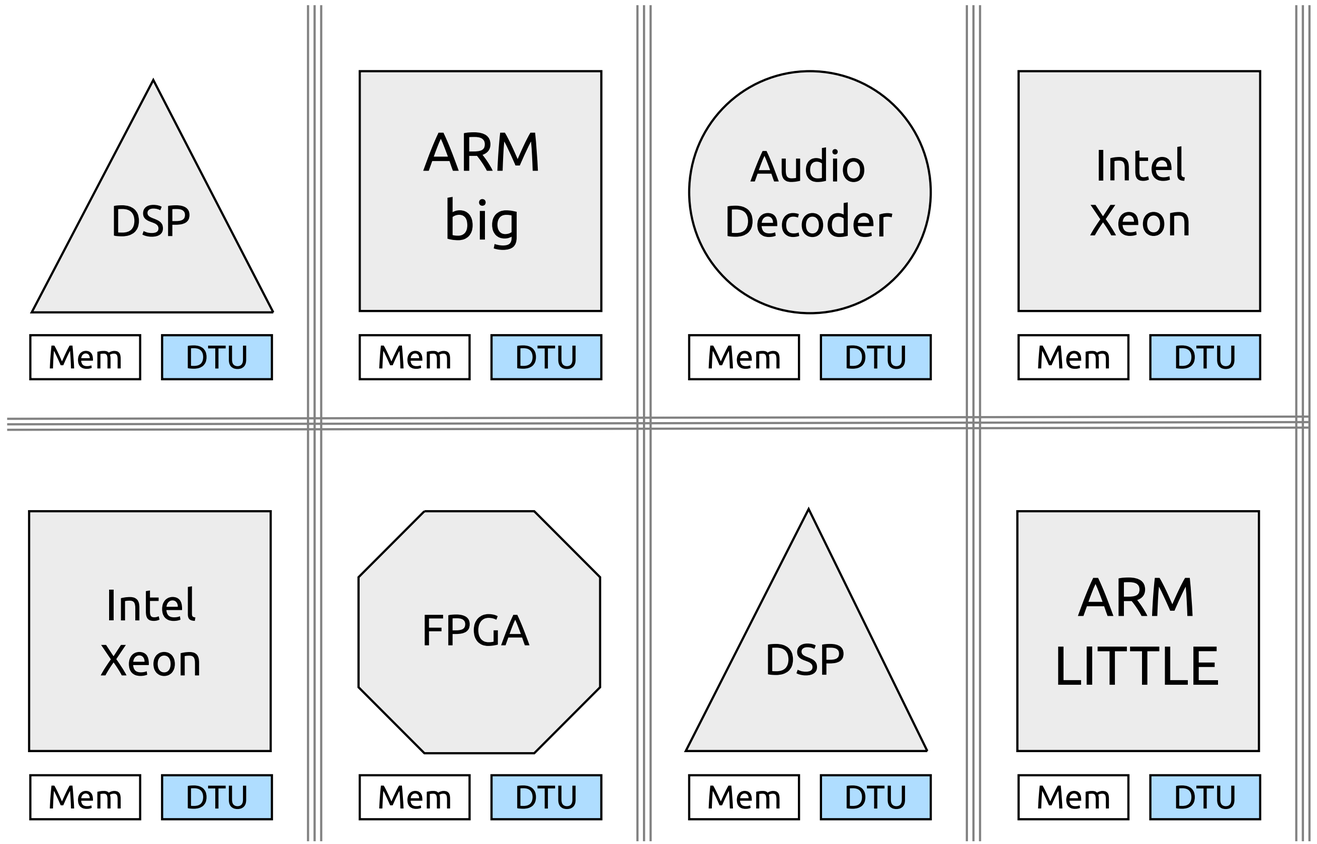

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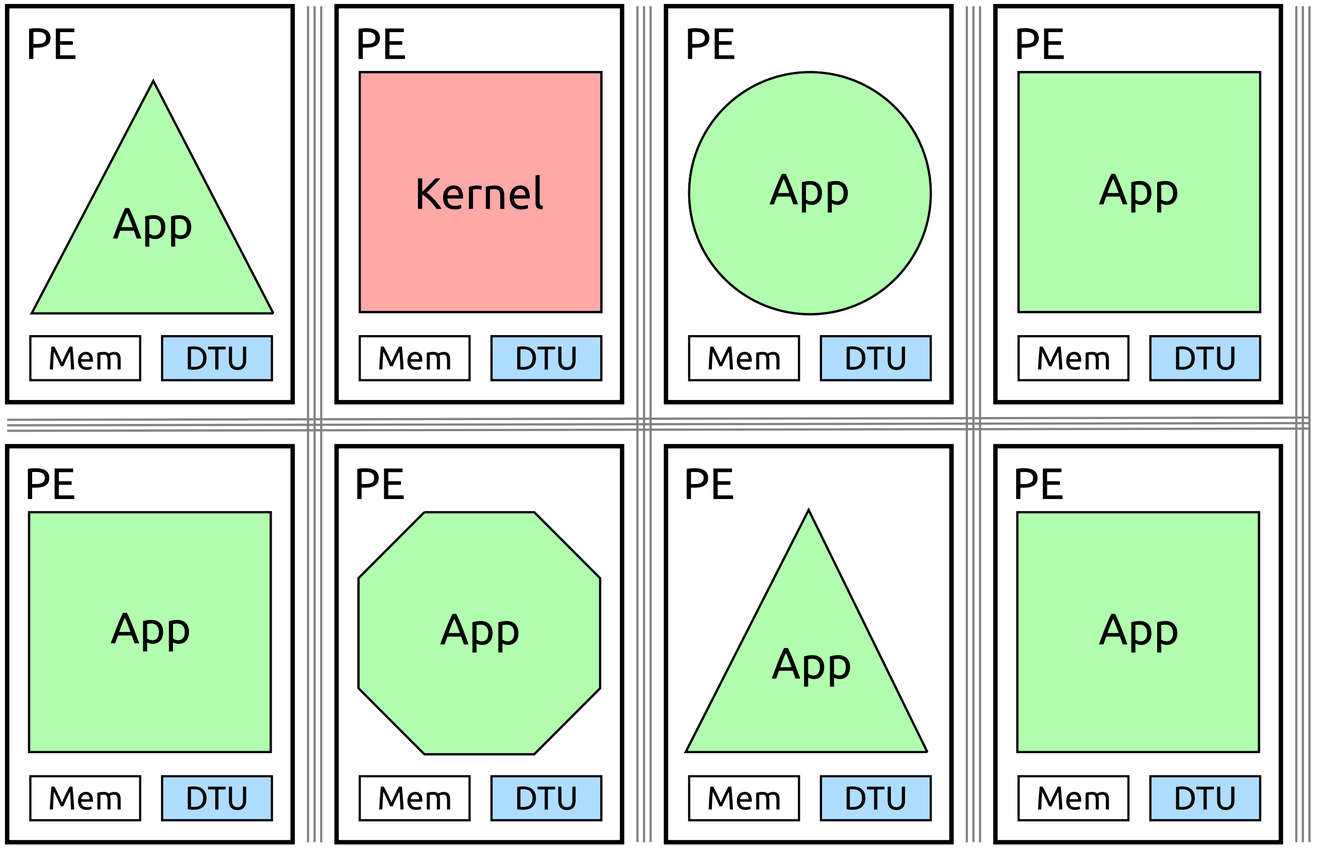

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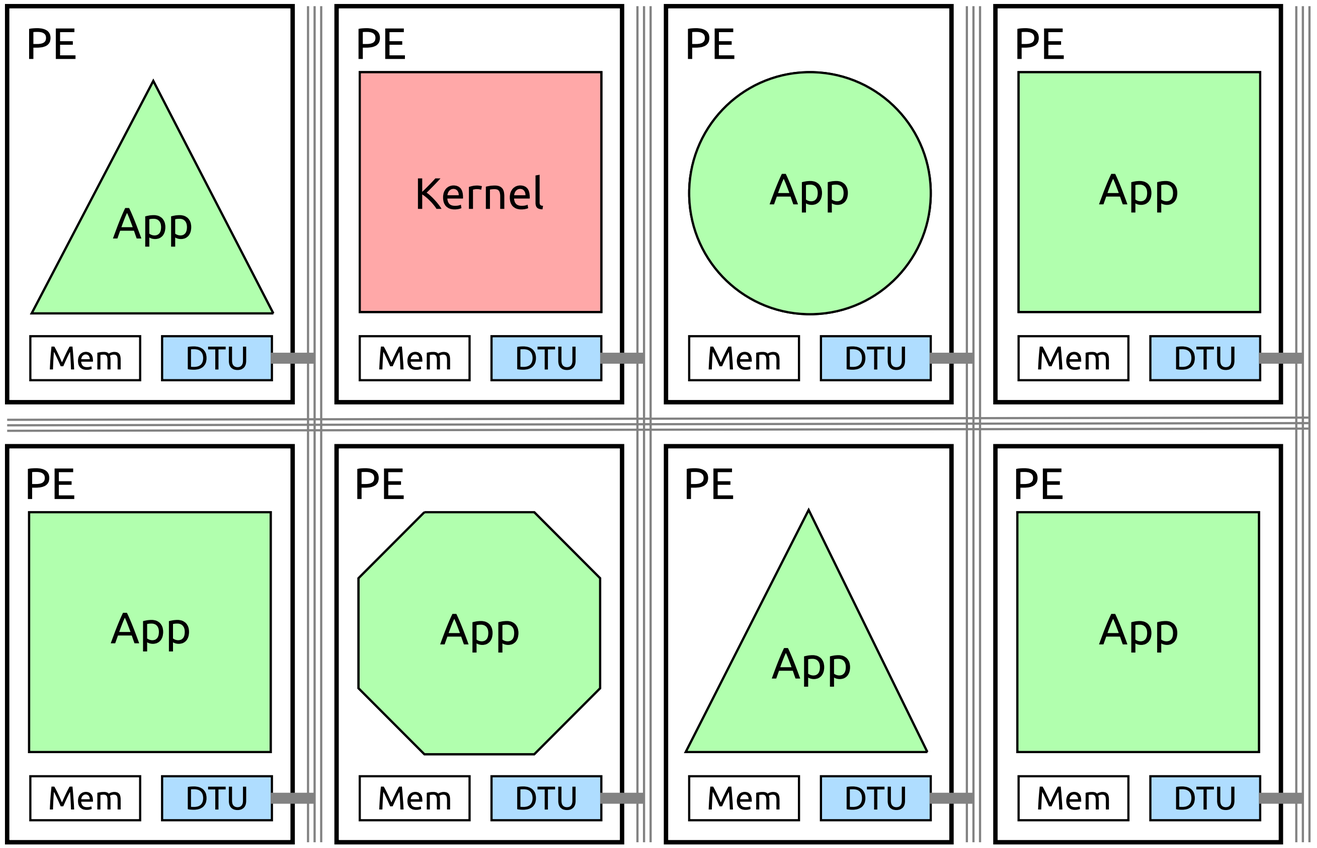

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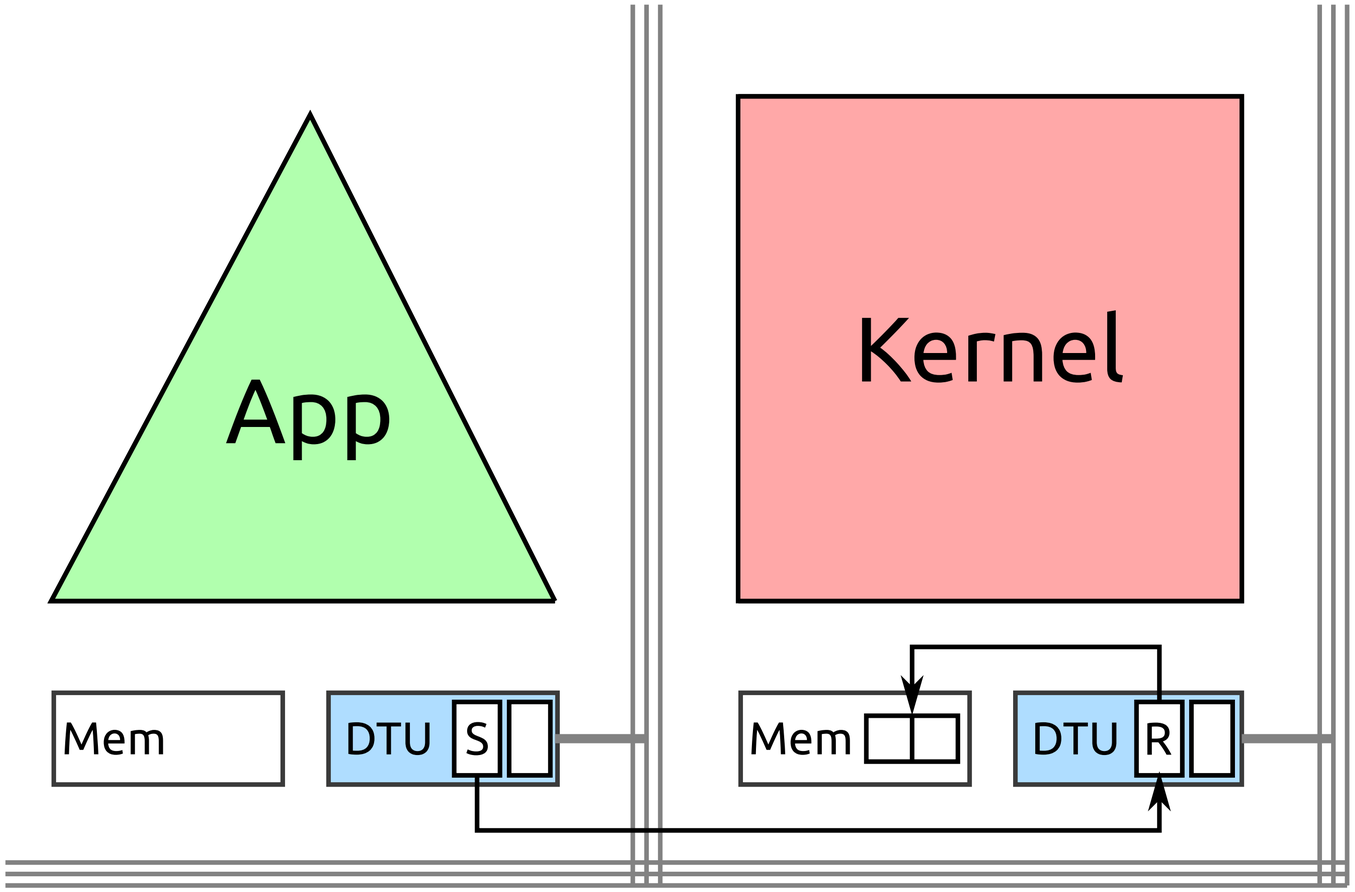
Data Transfer Example



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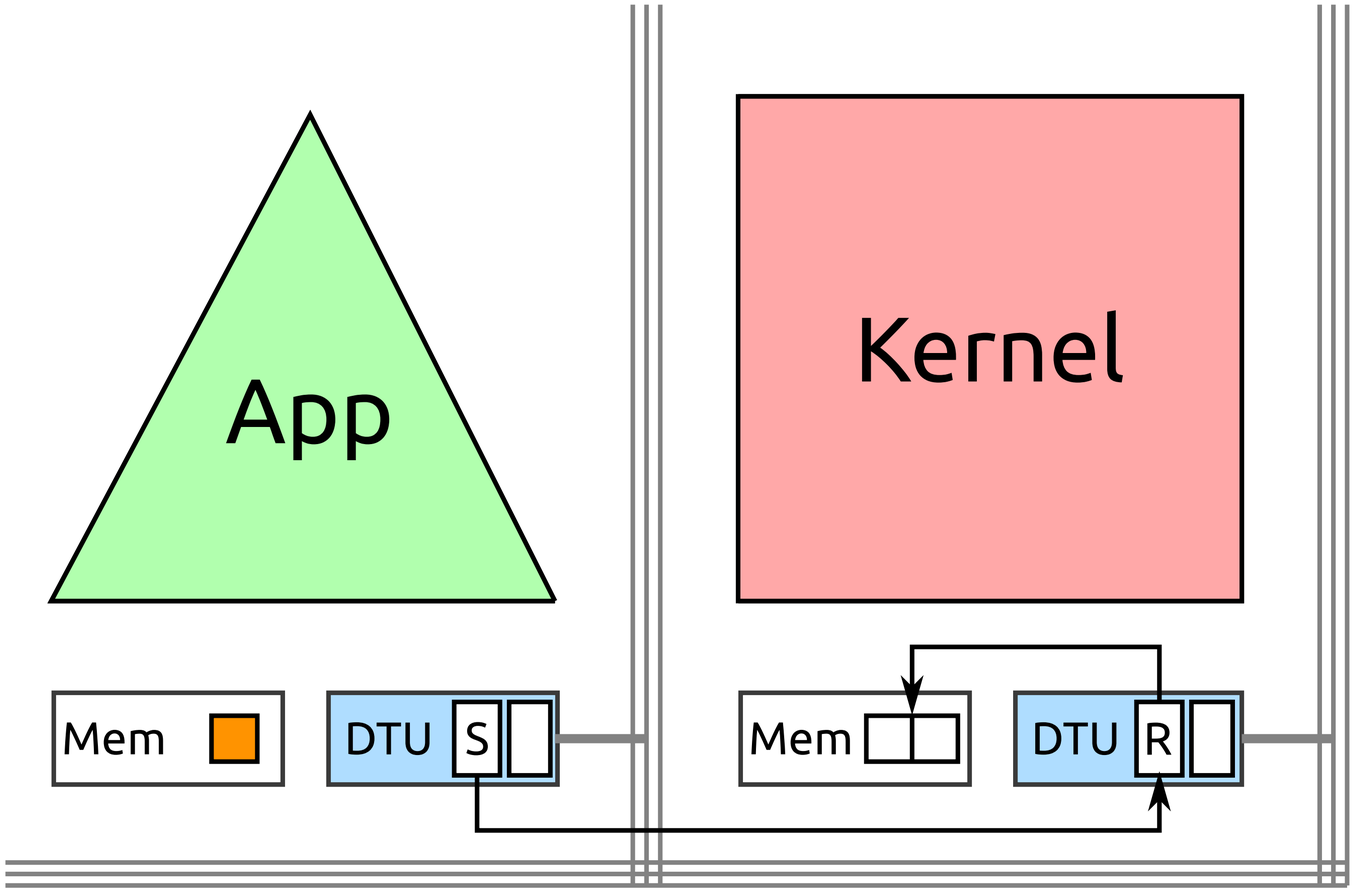

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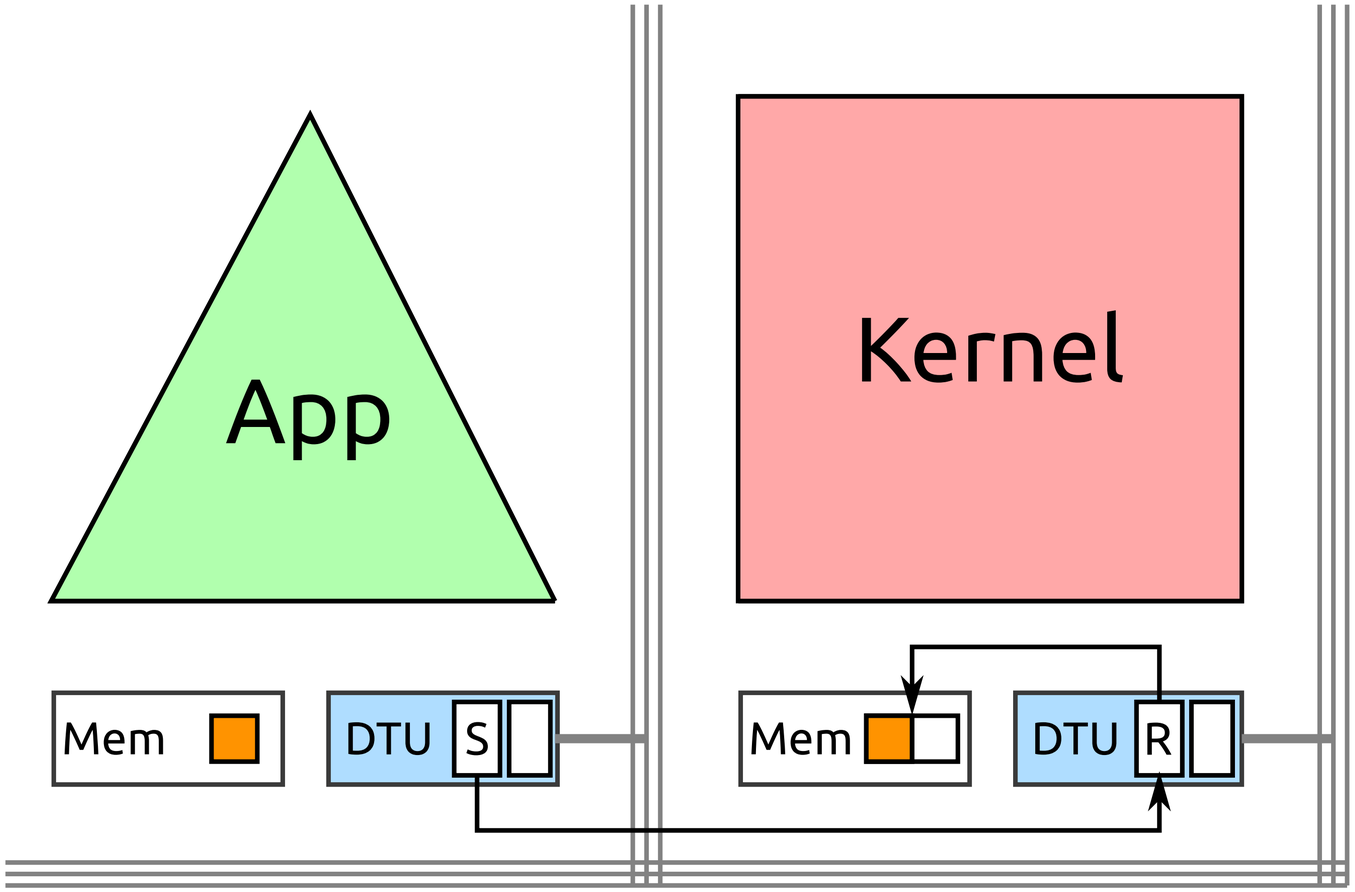

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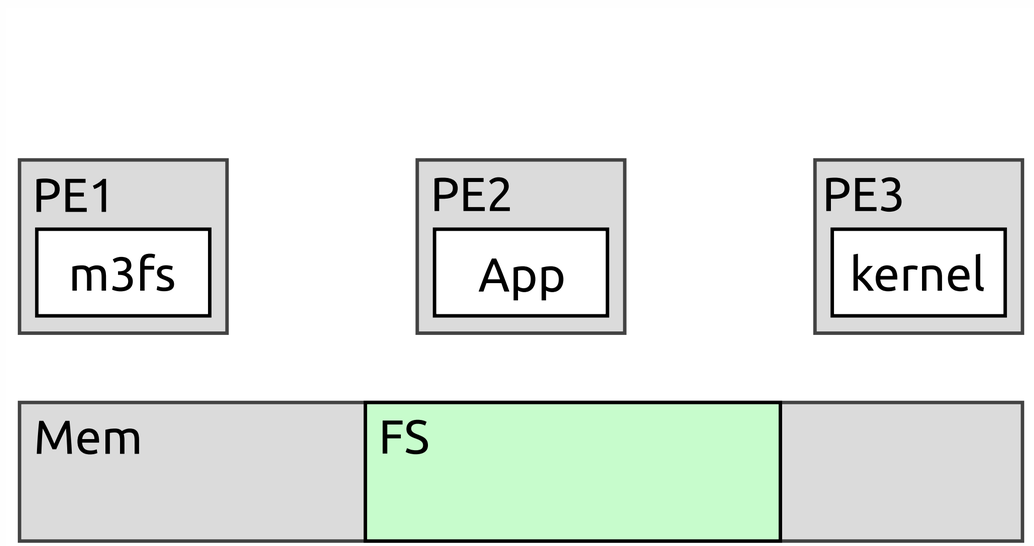

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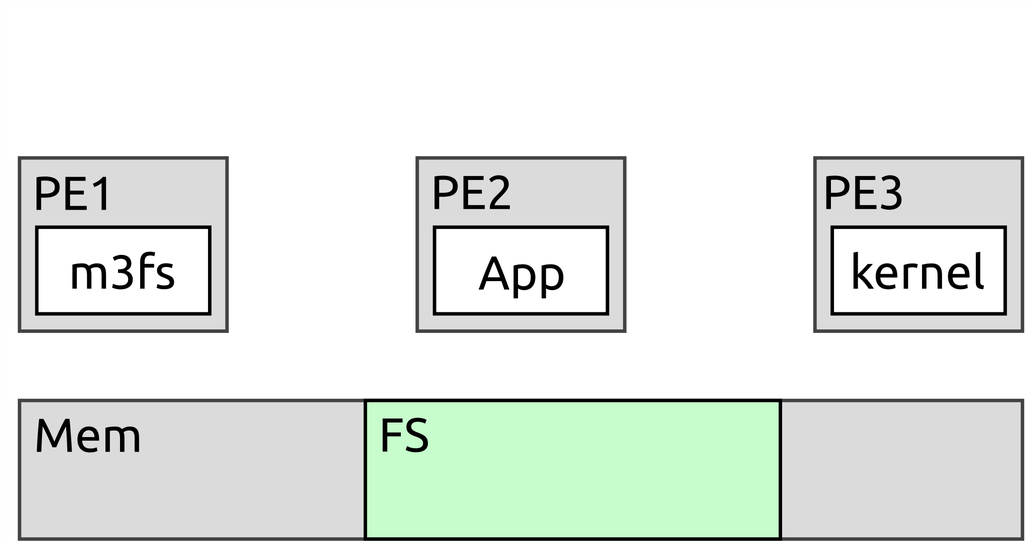

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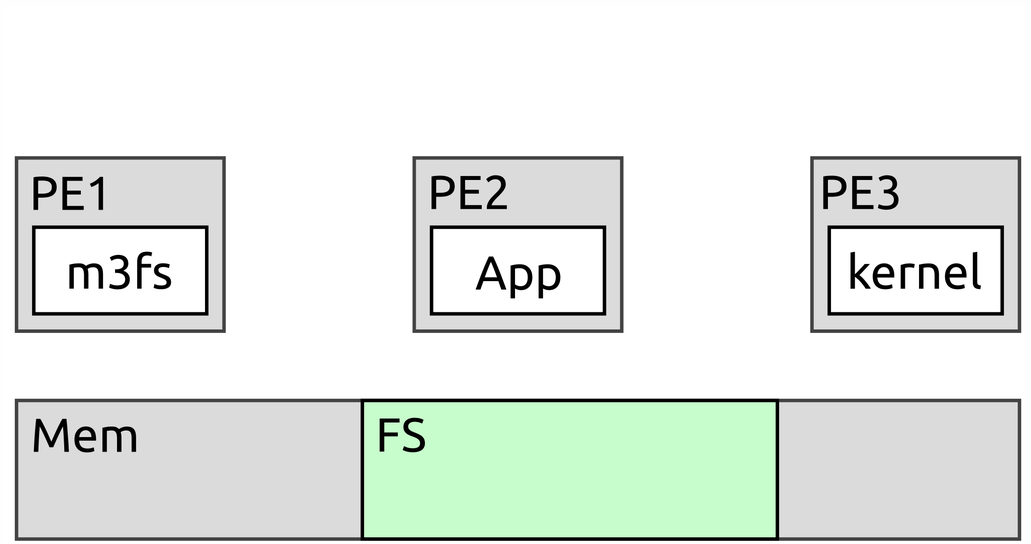

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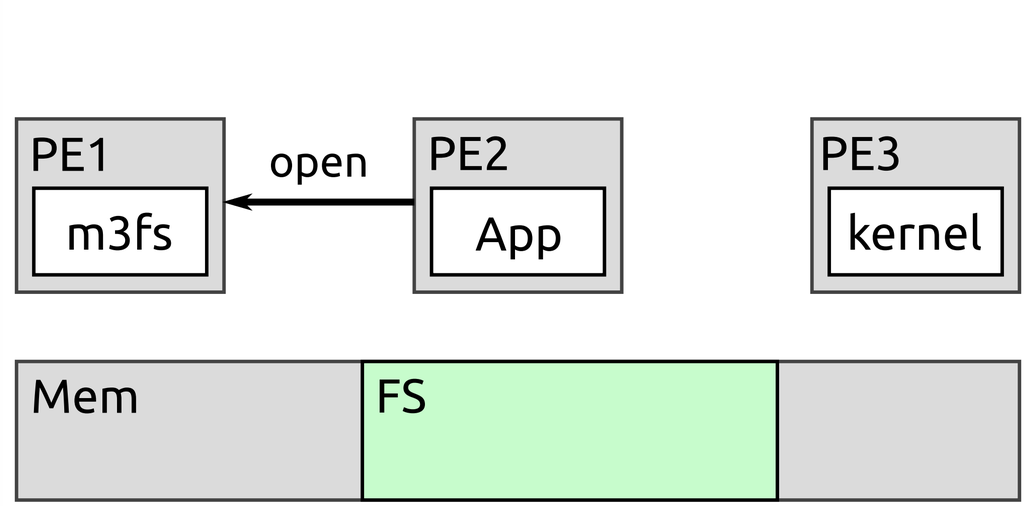

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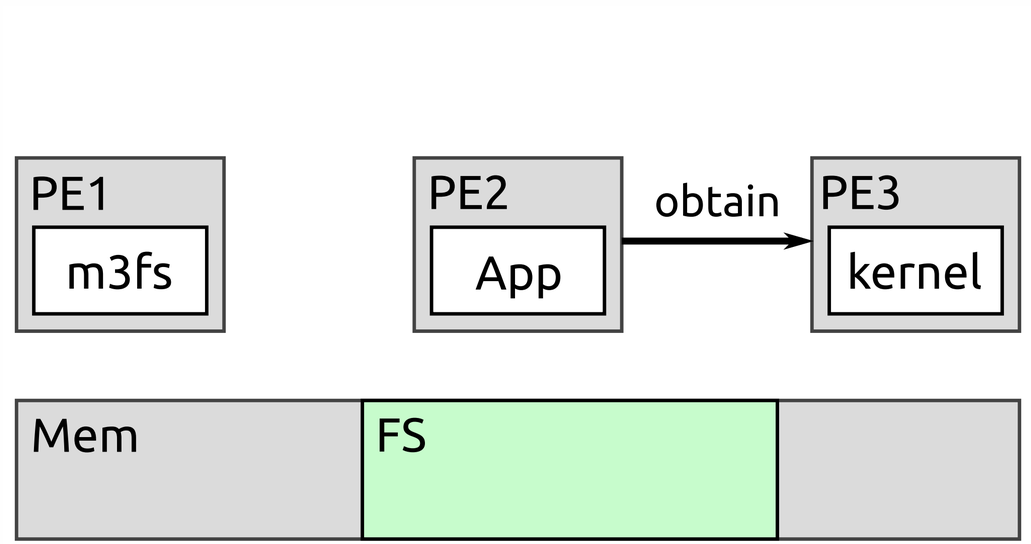

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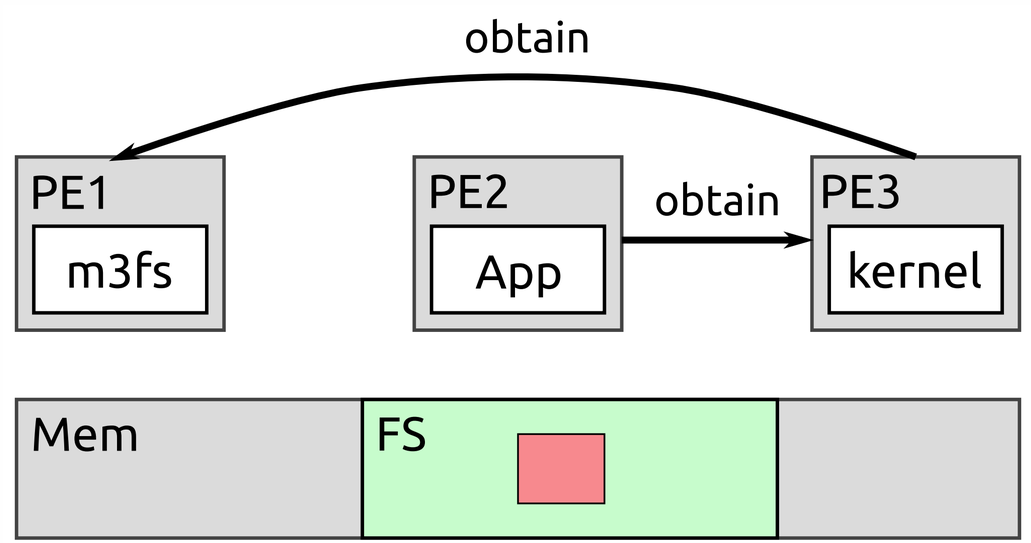

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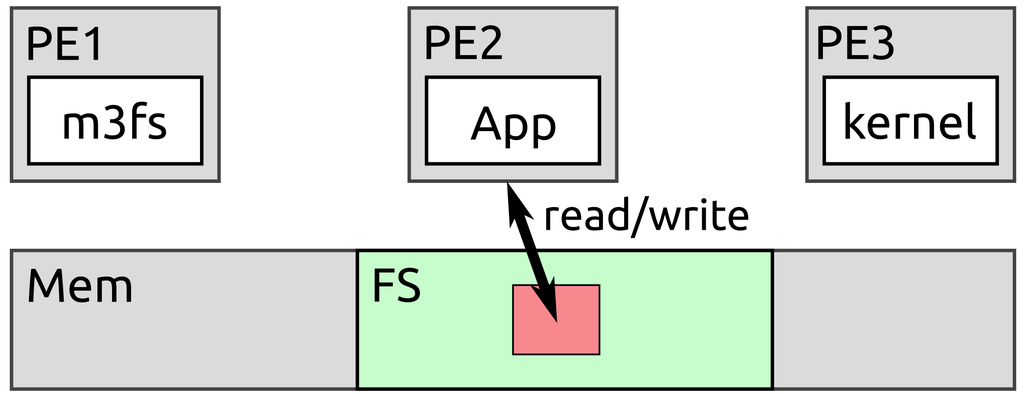

Evaluation

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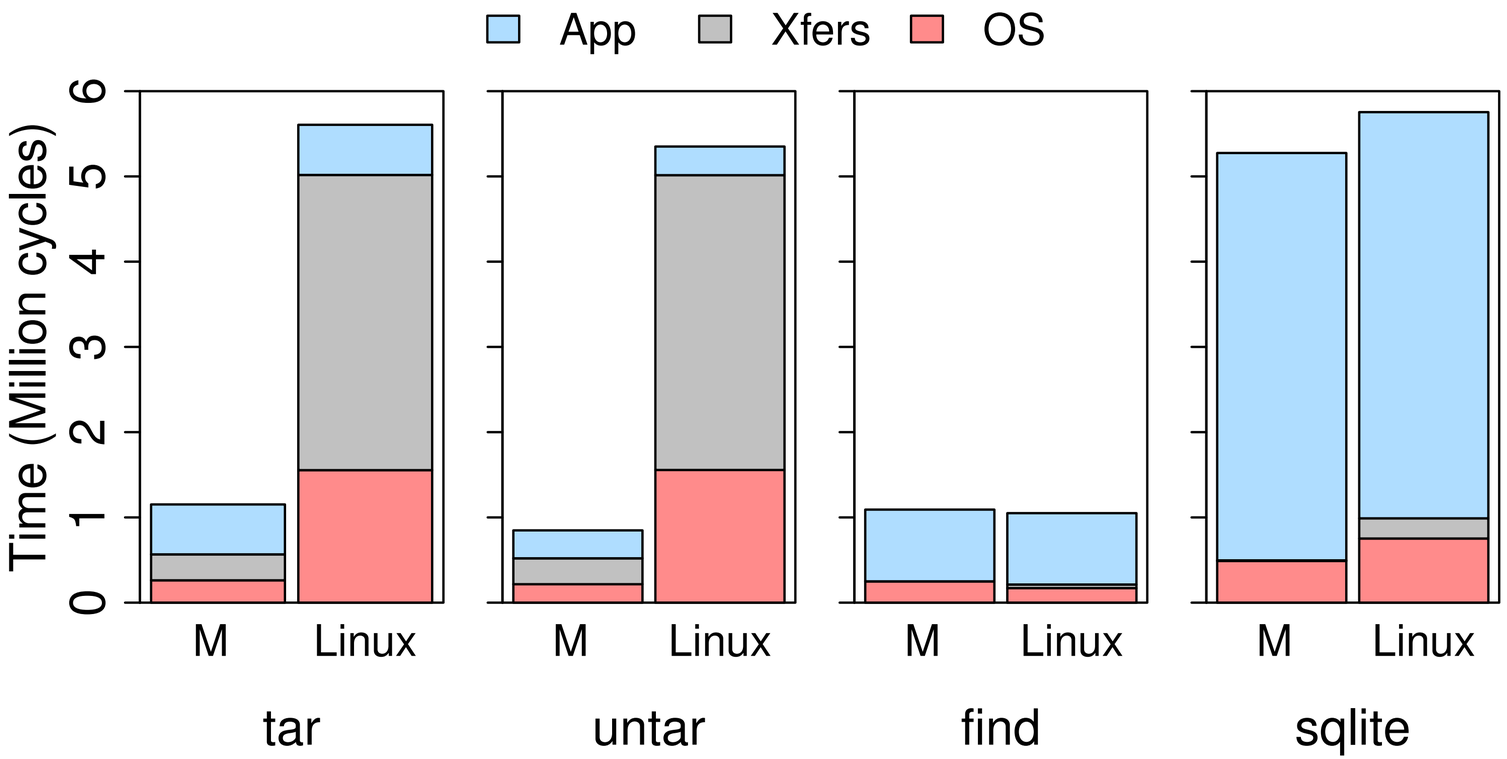
- **equal compute performance** of the cores

Application-Level Benchmarks



Summary

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A new design point for trustworthy and heterogeneous SoCs

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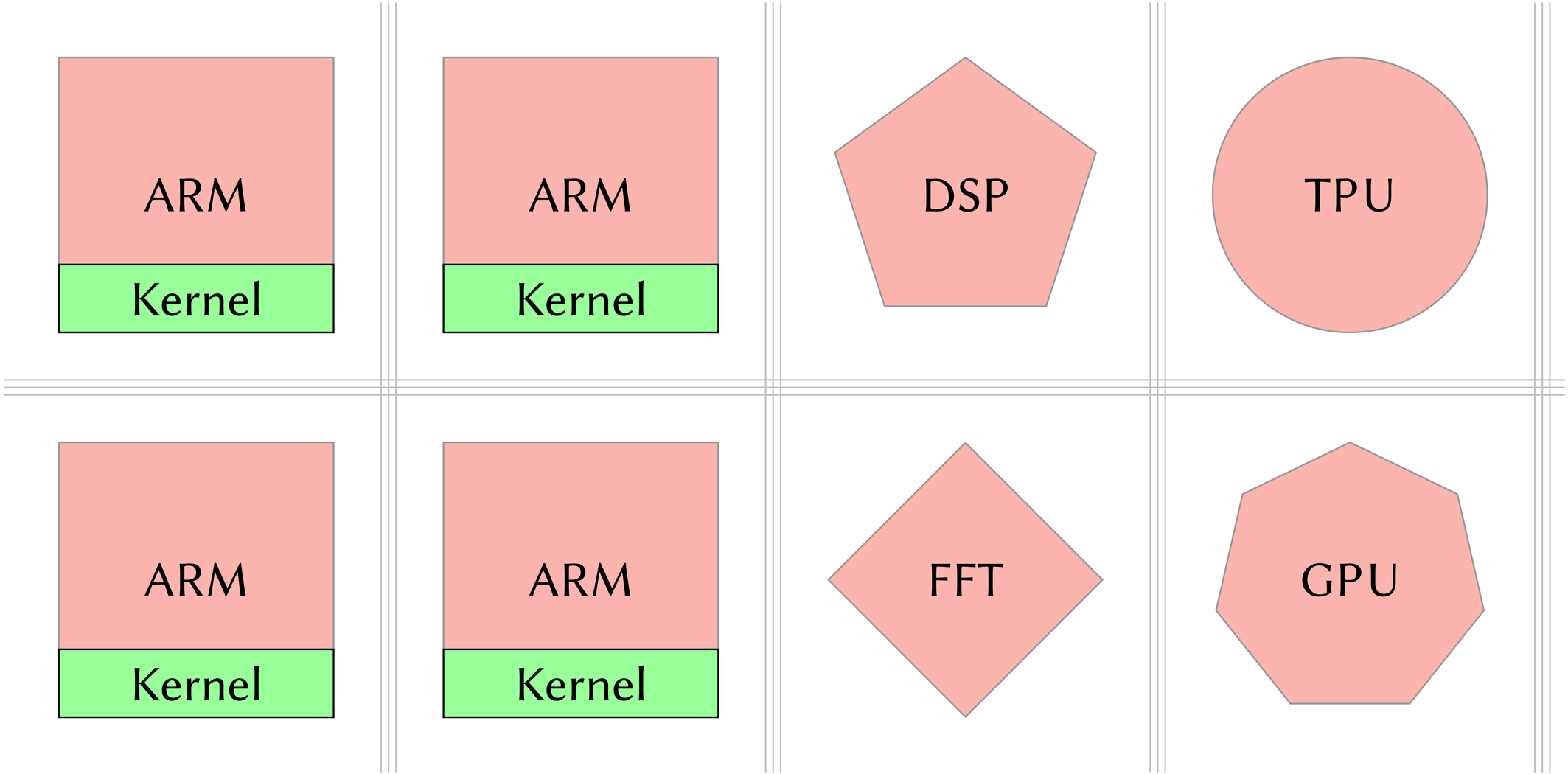
M^3x — Autonomous Accelerator Chains

ATC ’19

Accelerators and Energy Efficiency



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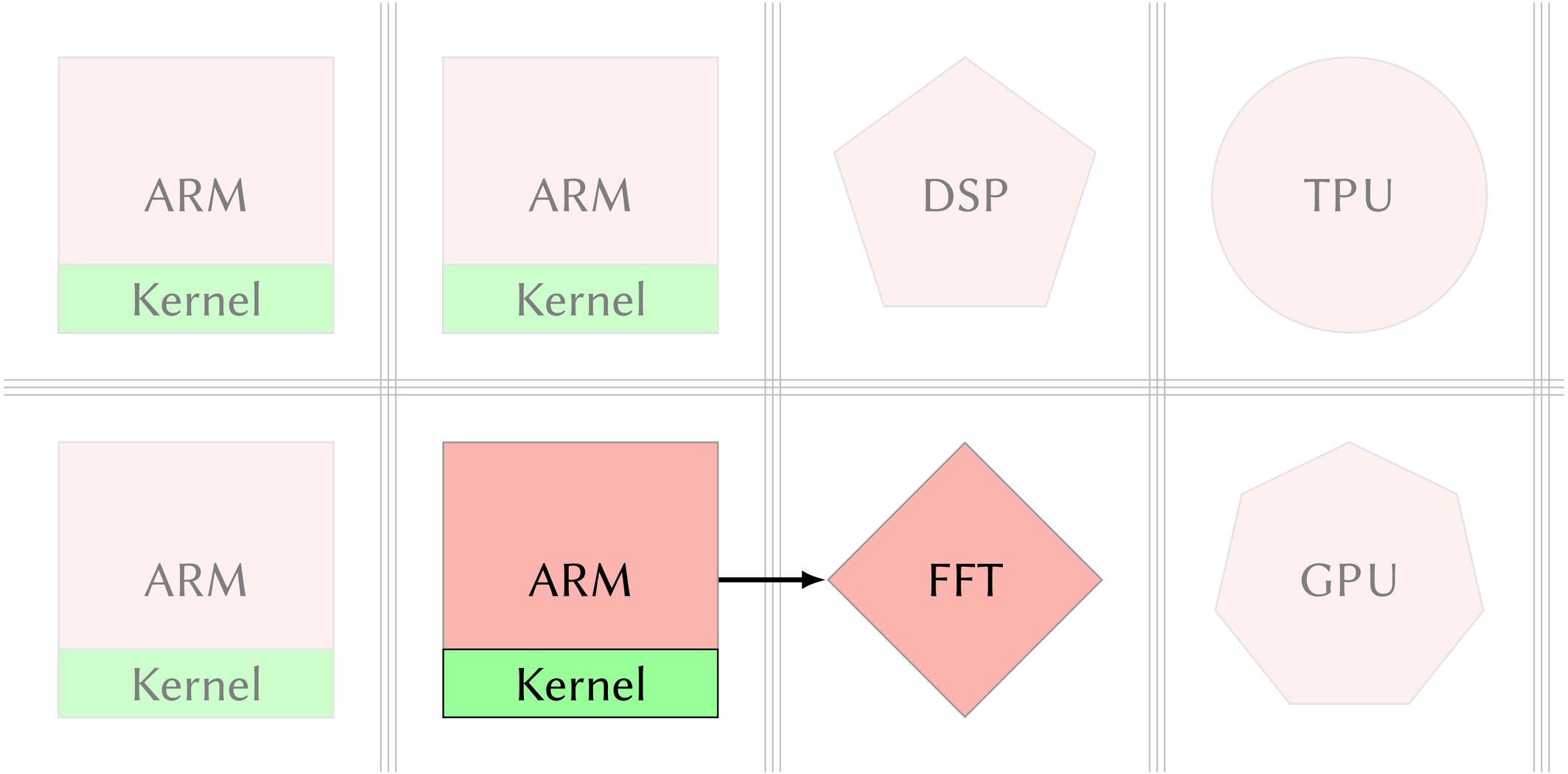

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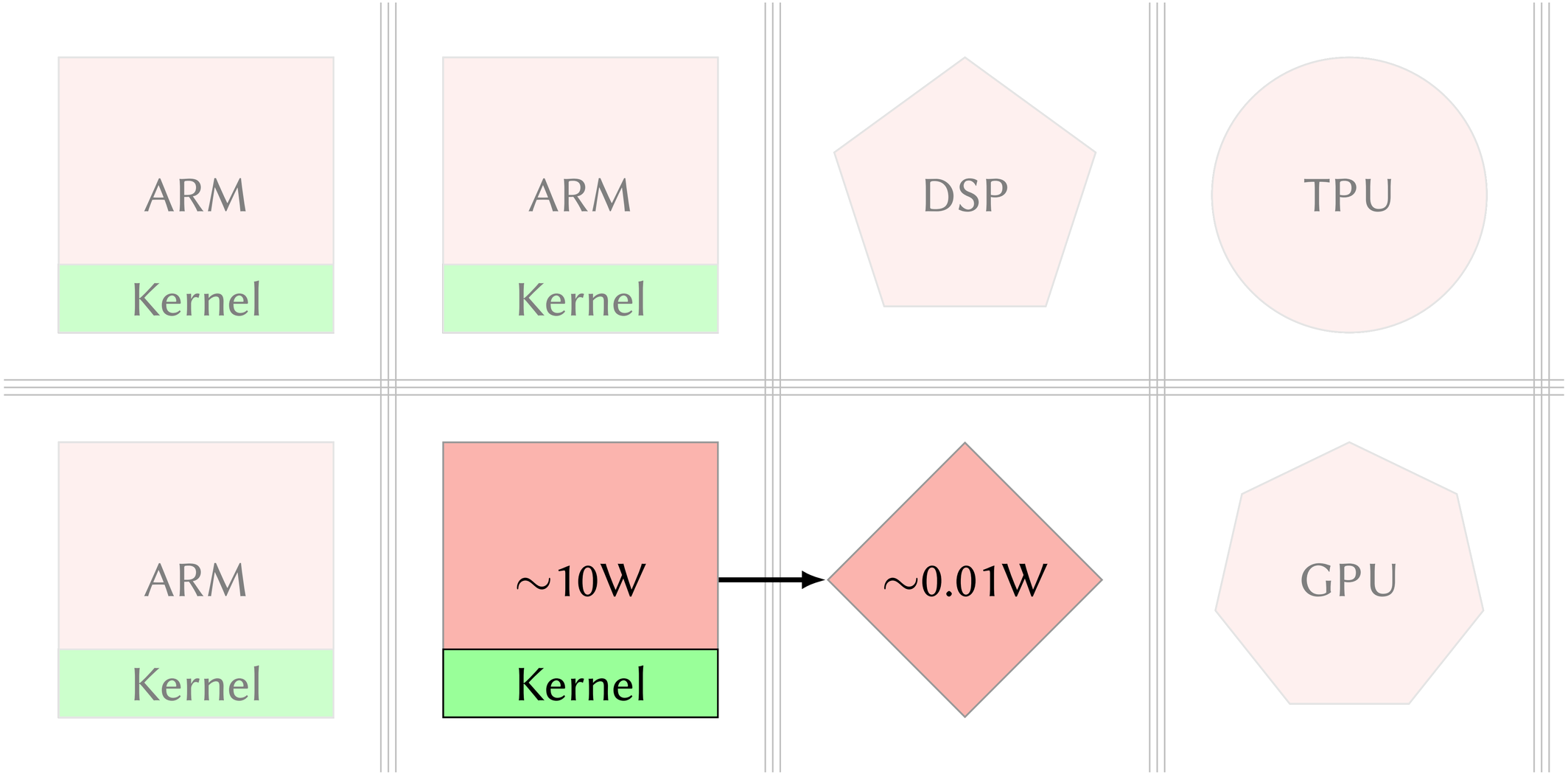

Accelerators and OS Services

```
sh$ decode in.png | fft |  mul | ifft > out.raw
```

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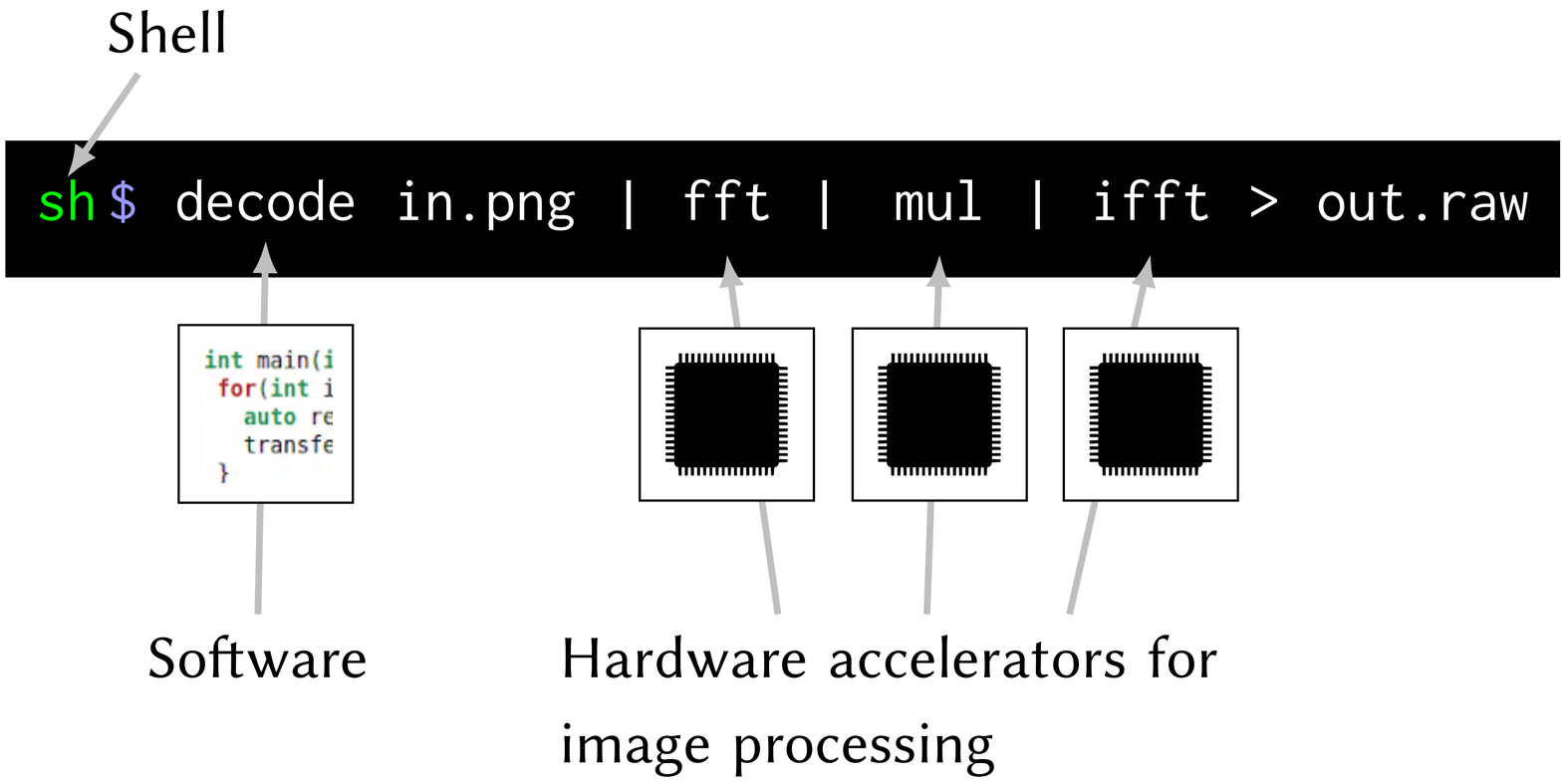

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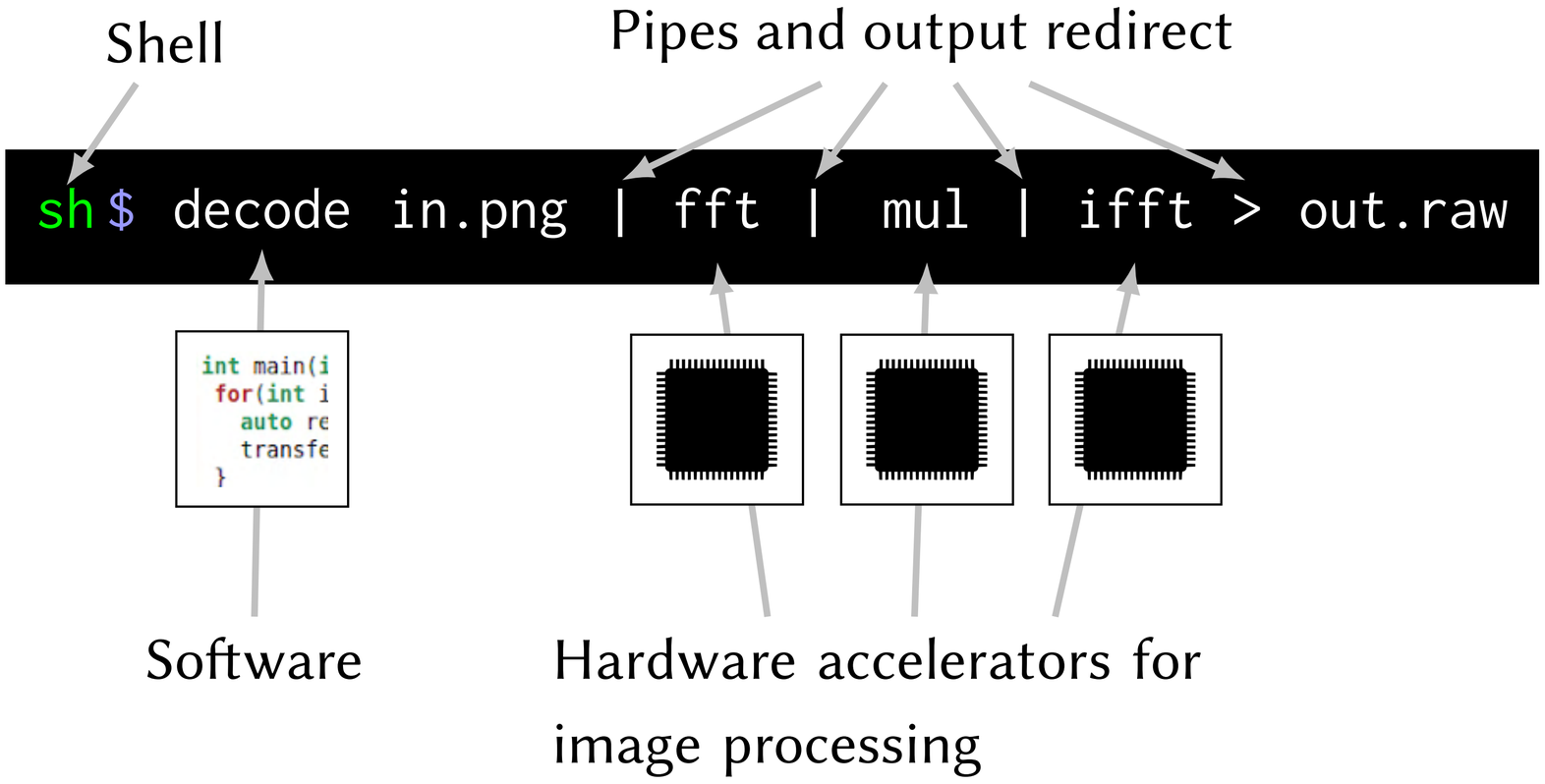

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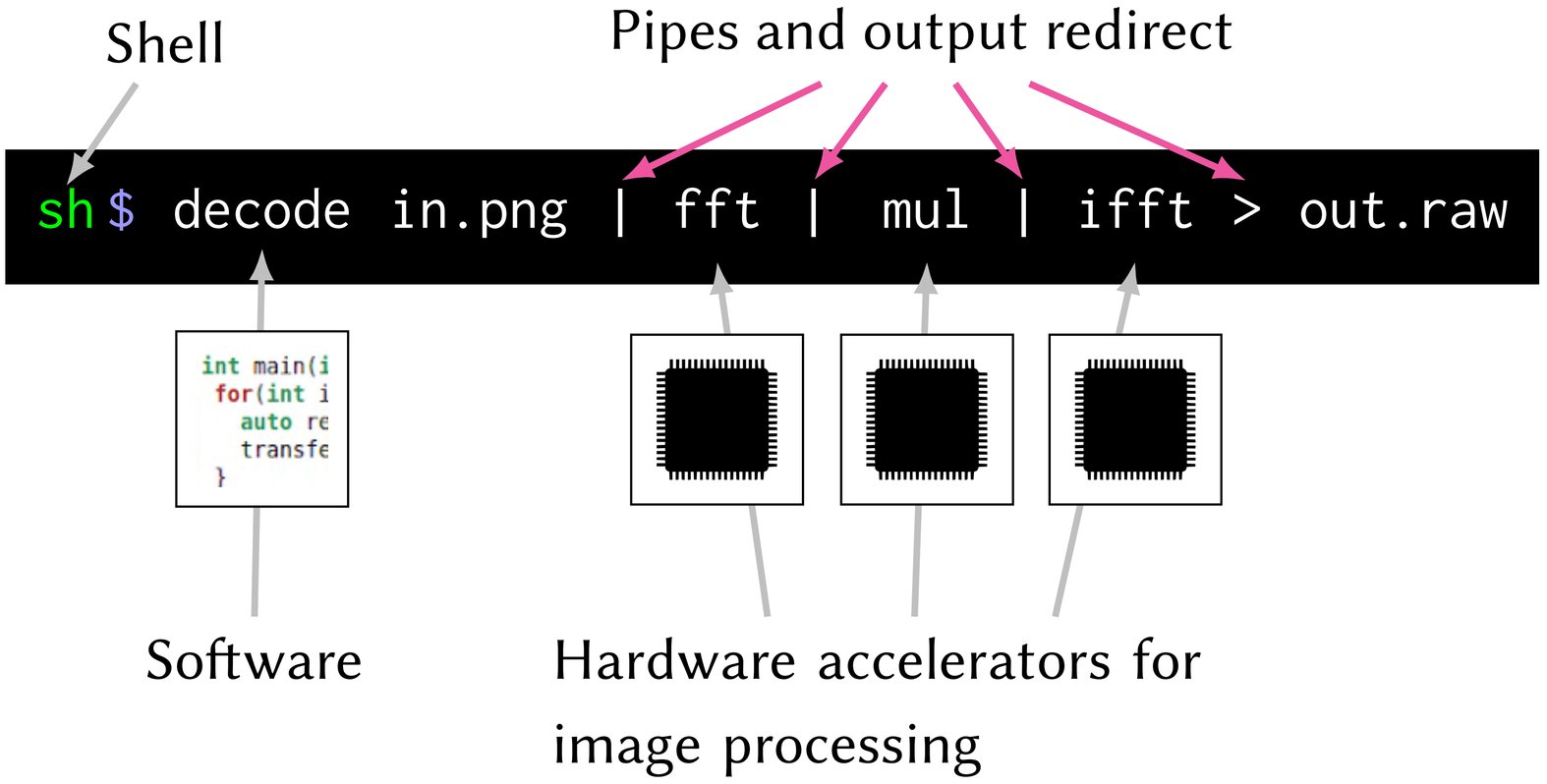

Challenges:

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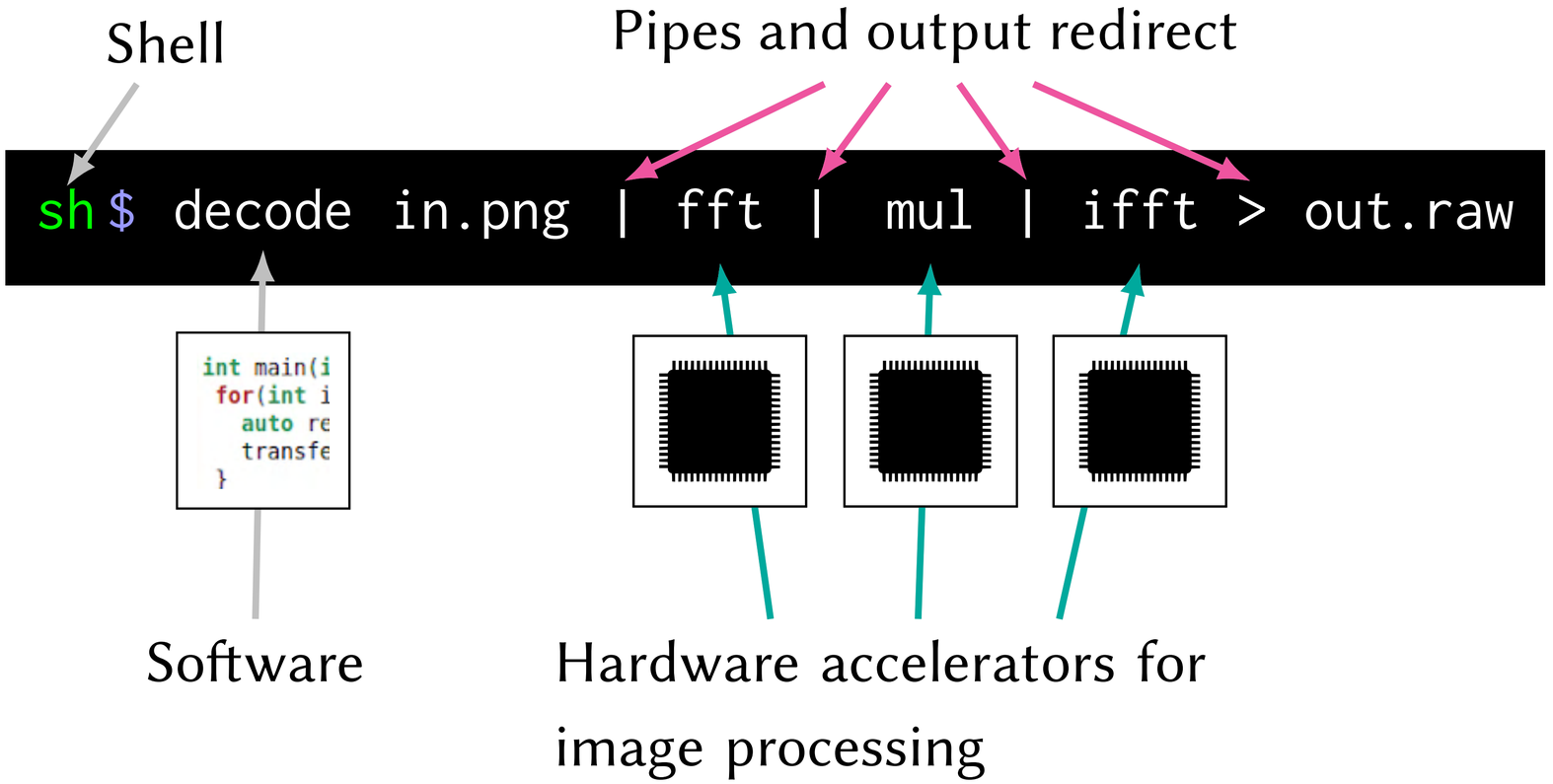

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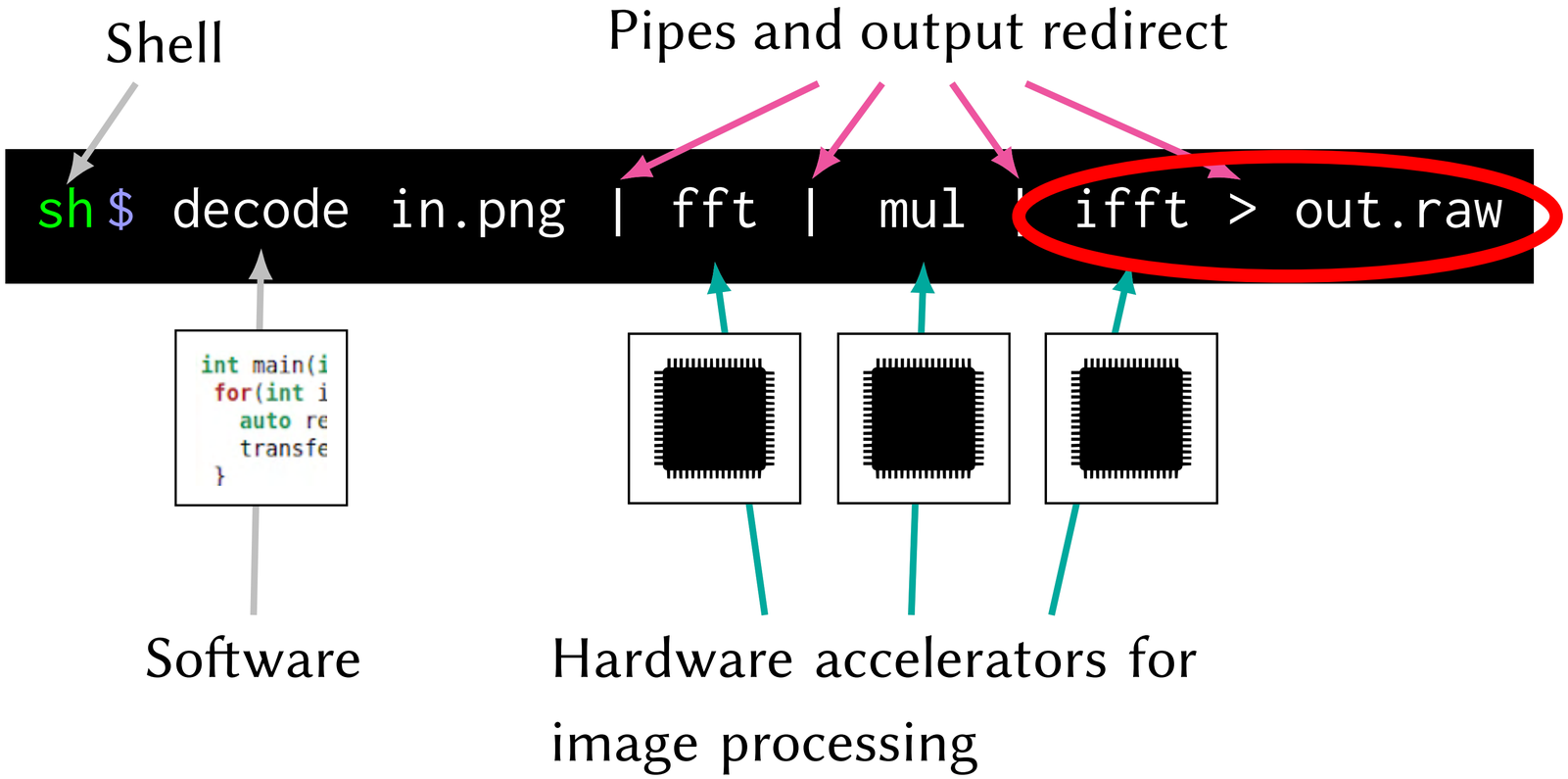

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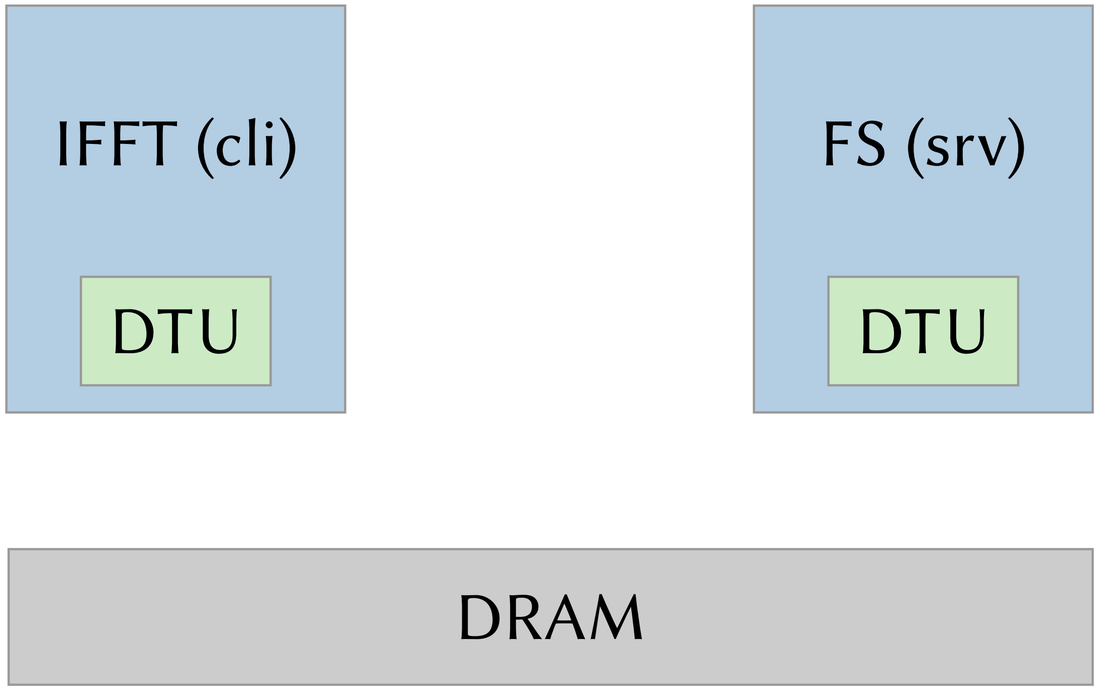
Generic Protocol for Data Streams



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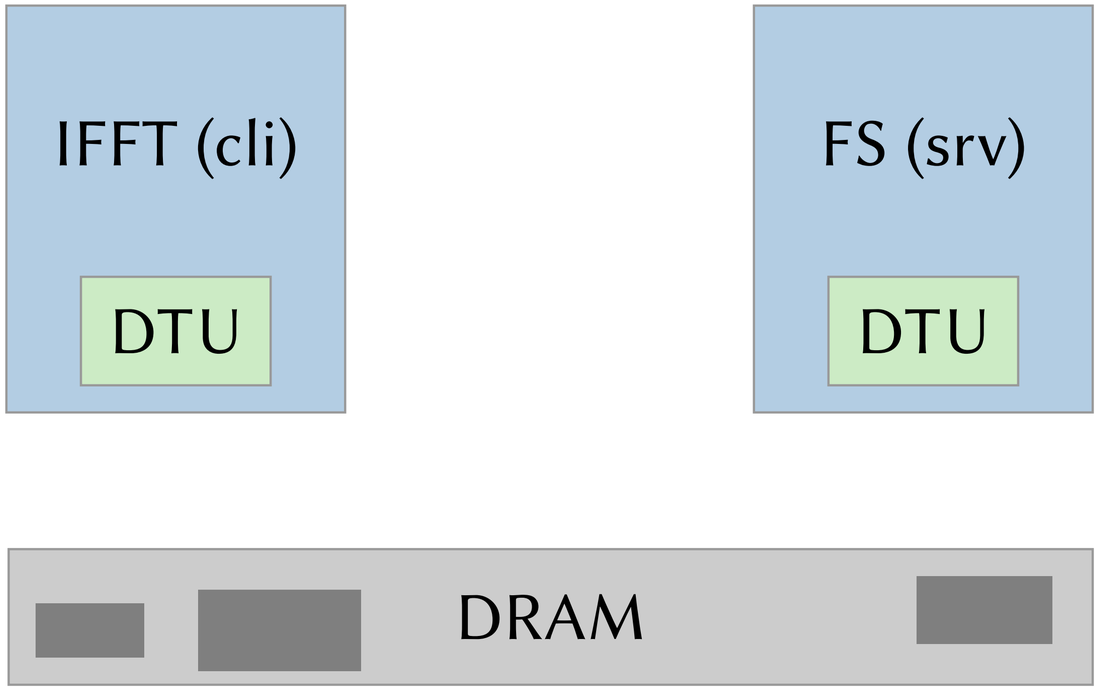

File protocol:

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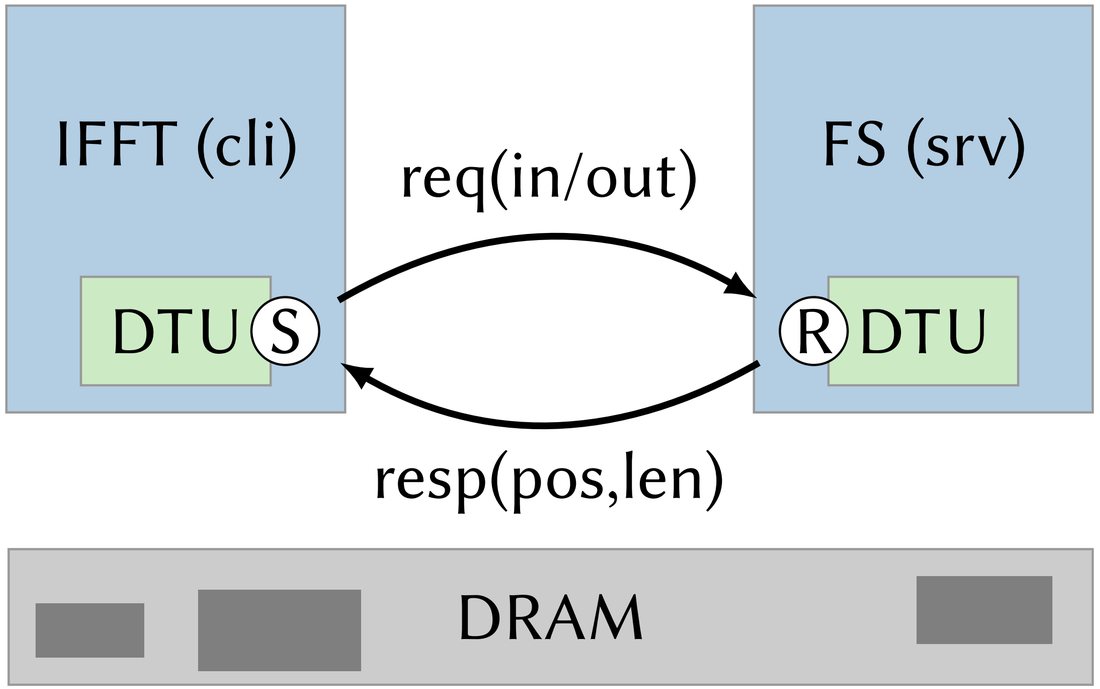

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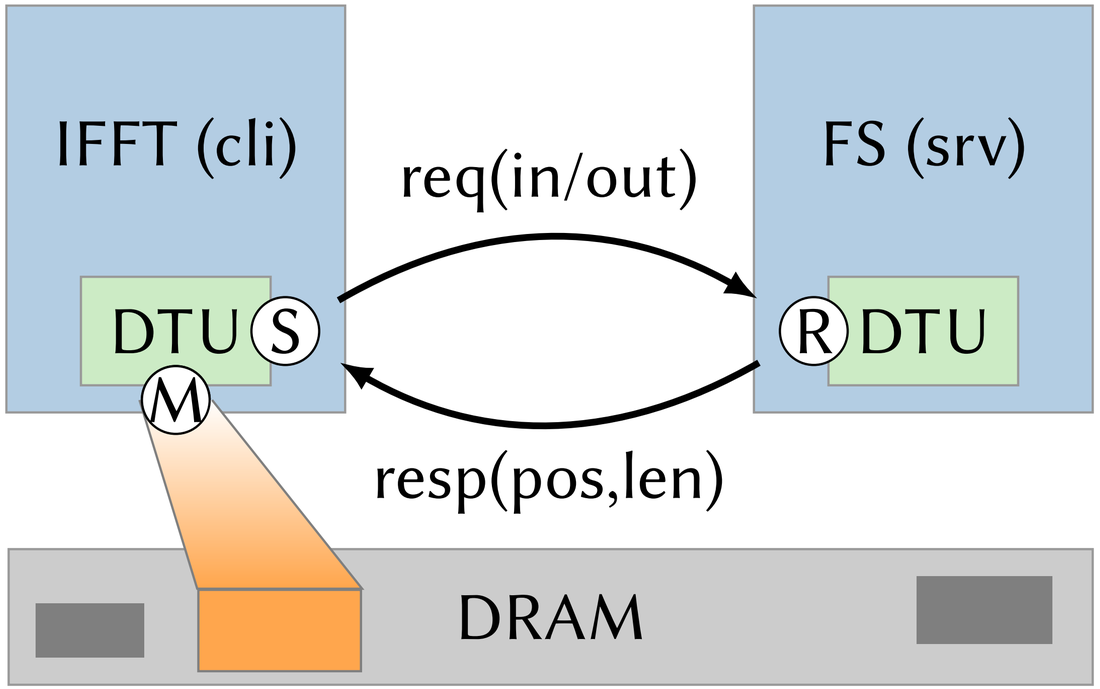

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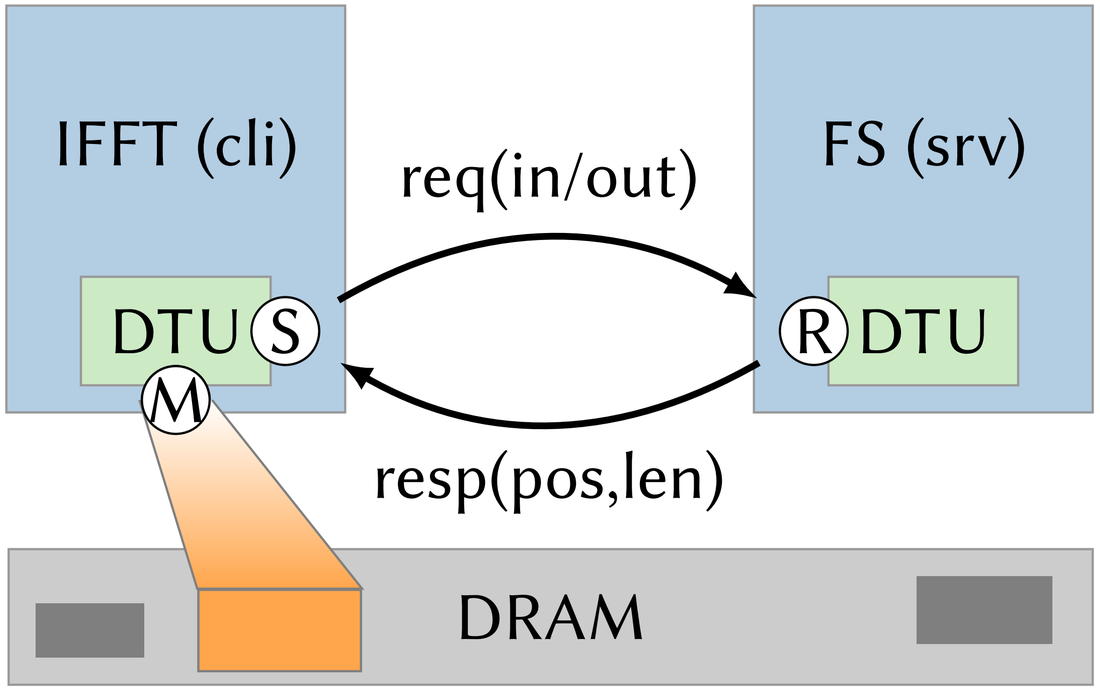

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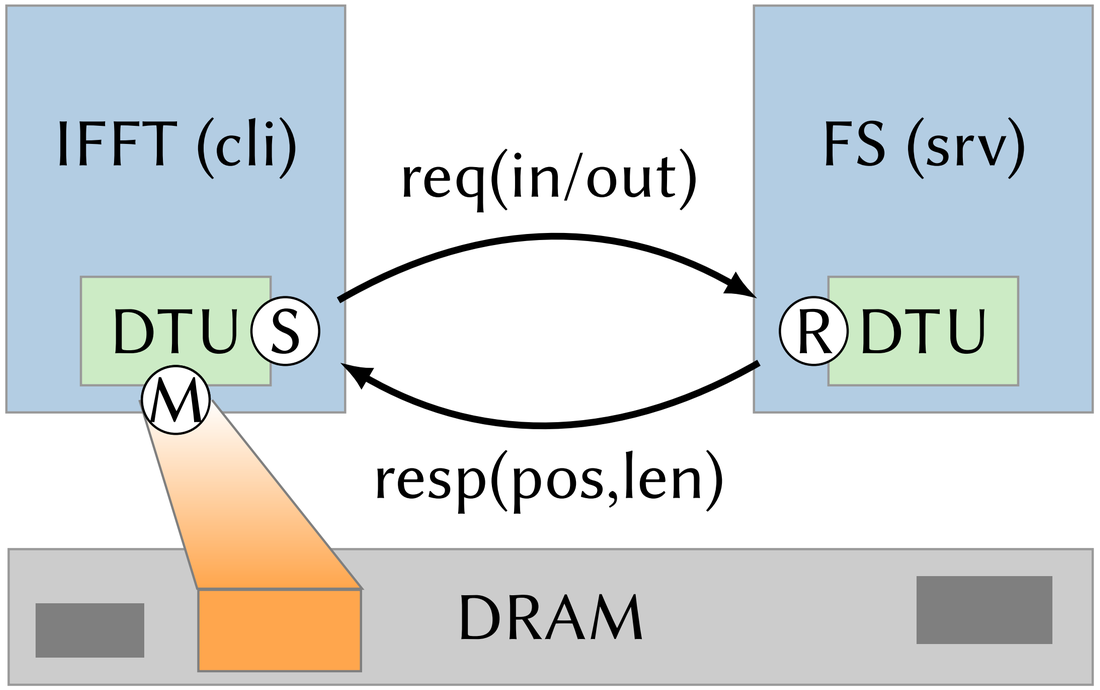

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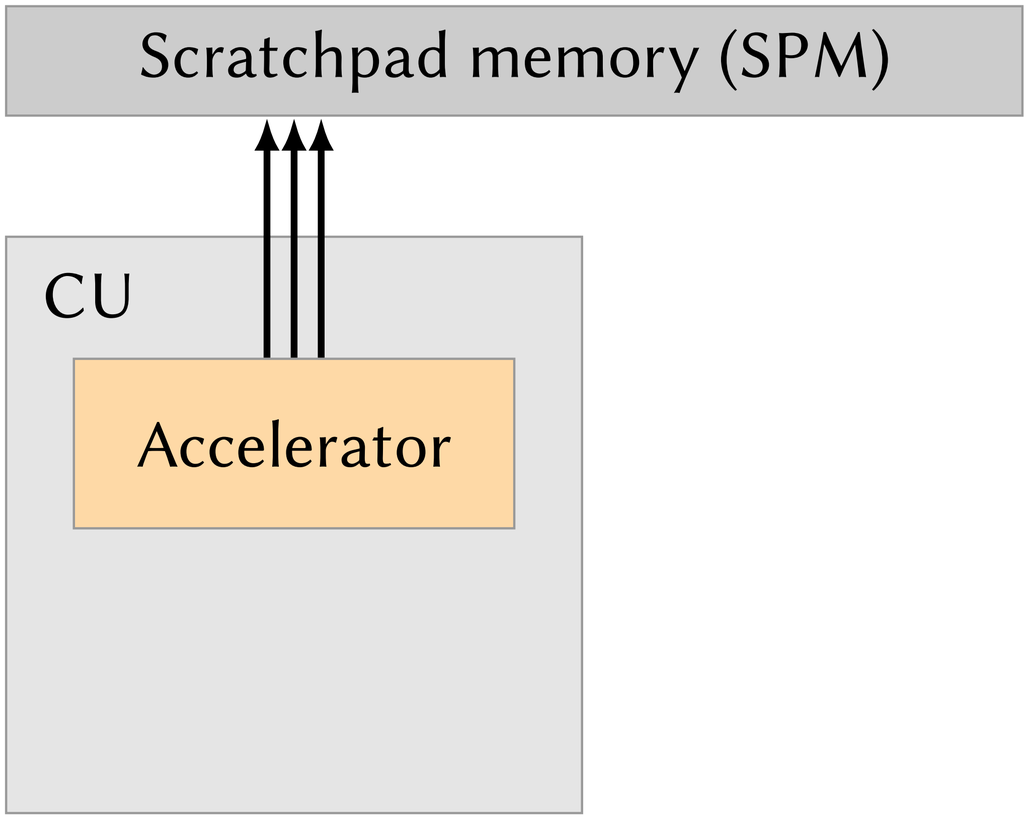
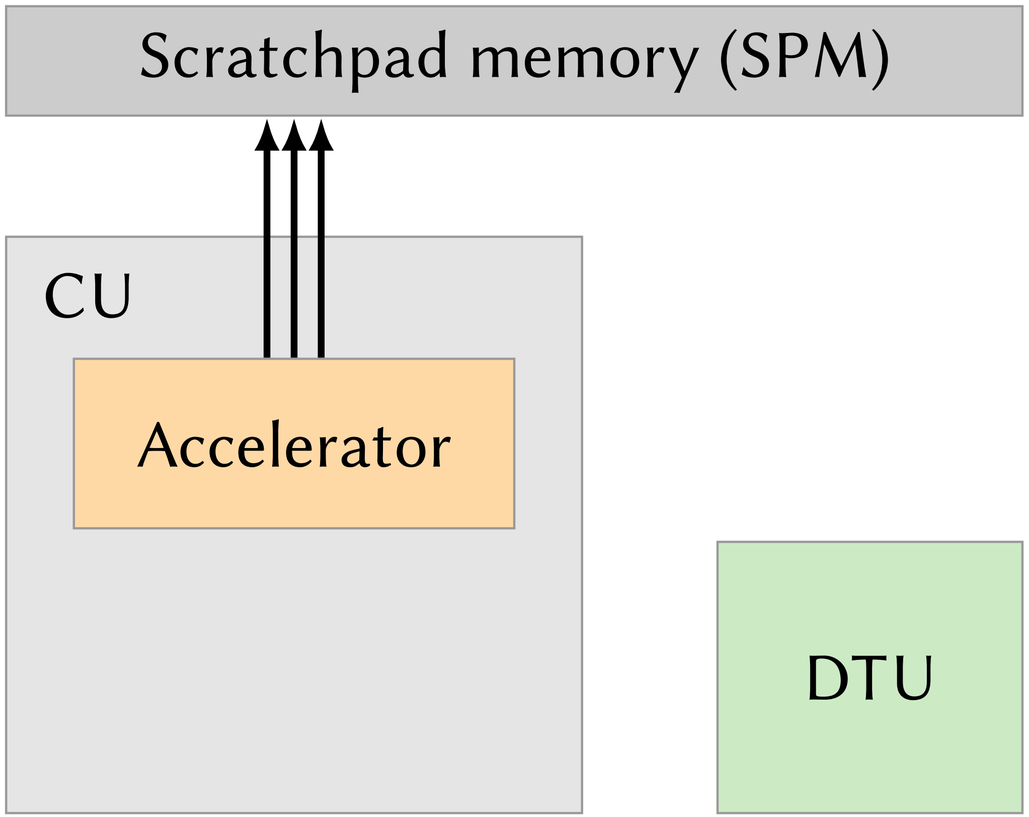
- Used by *all* CUs

Protocol Implementation for Accelerators



Off-the-shelf accelerators

Protocol Implementation for Accelerators



Off-the-shelf accelerators

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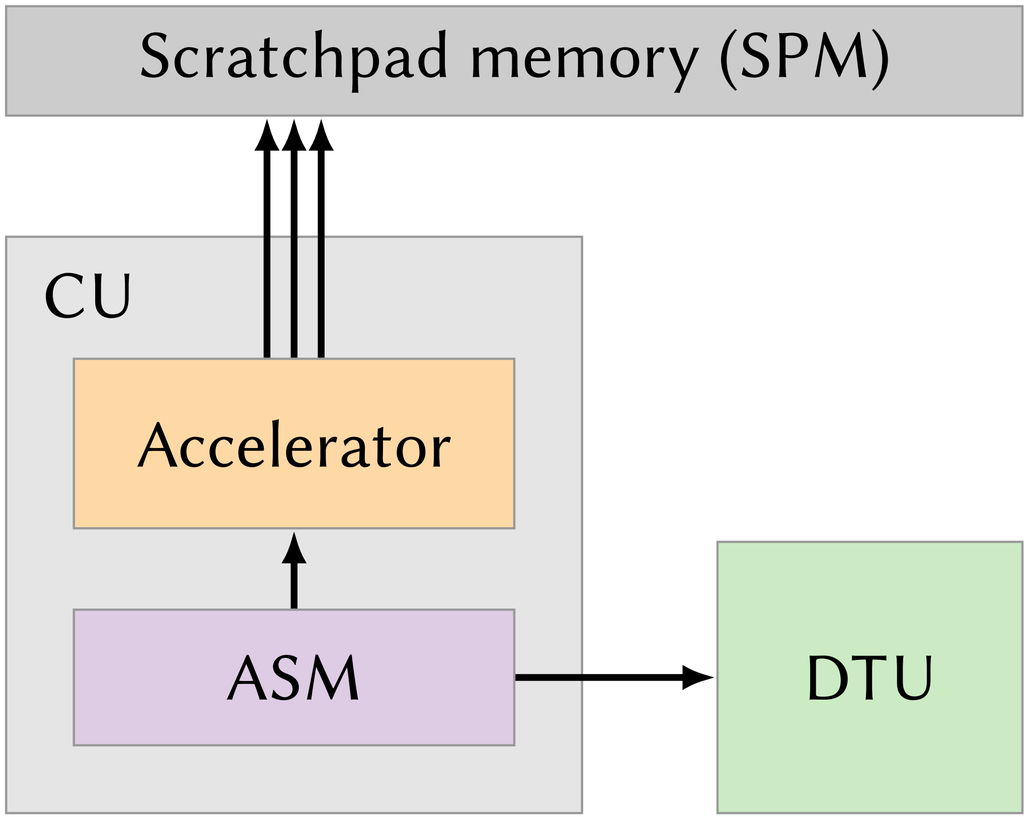
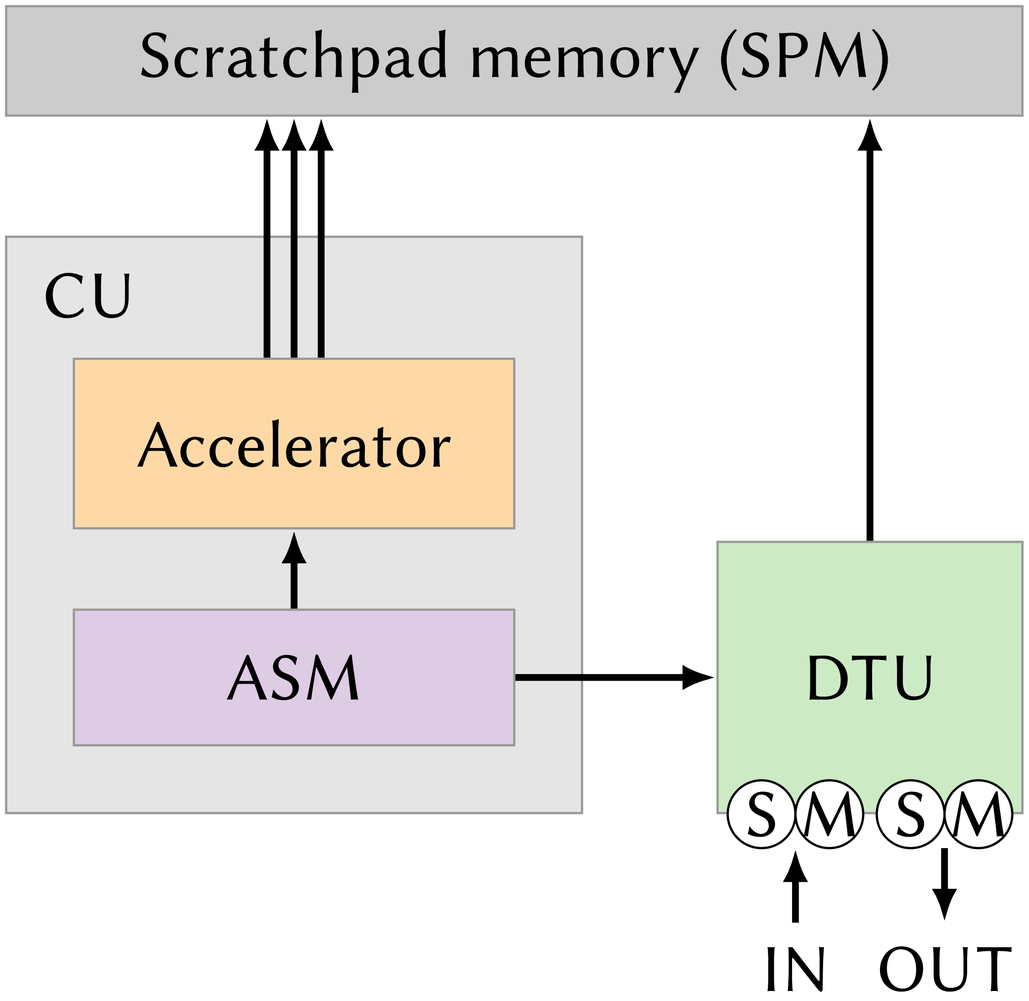


Off-the-shelf accelerators

Accelerator Support Module (ASM):

- Interacts with DTU and accelerator

Protocol Implementation for Accelerators

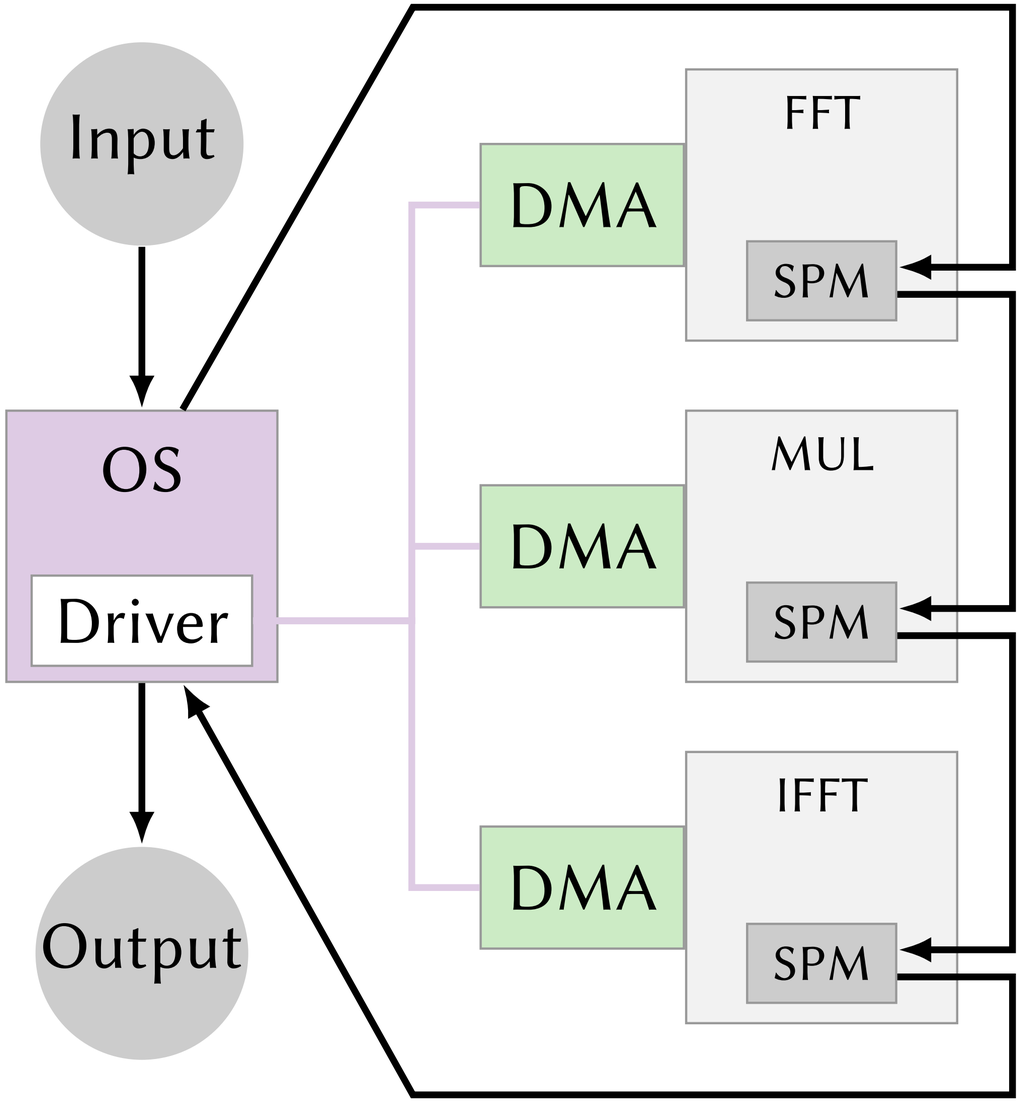


Off-the-shelf accelerators

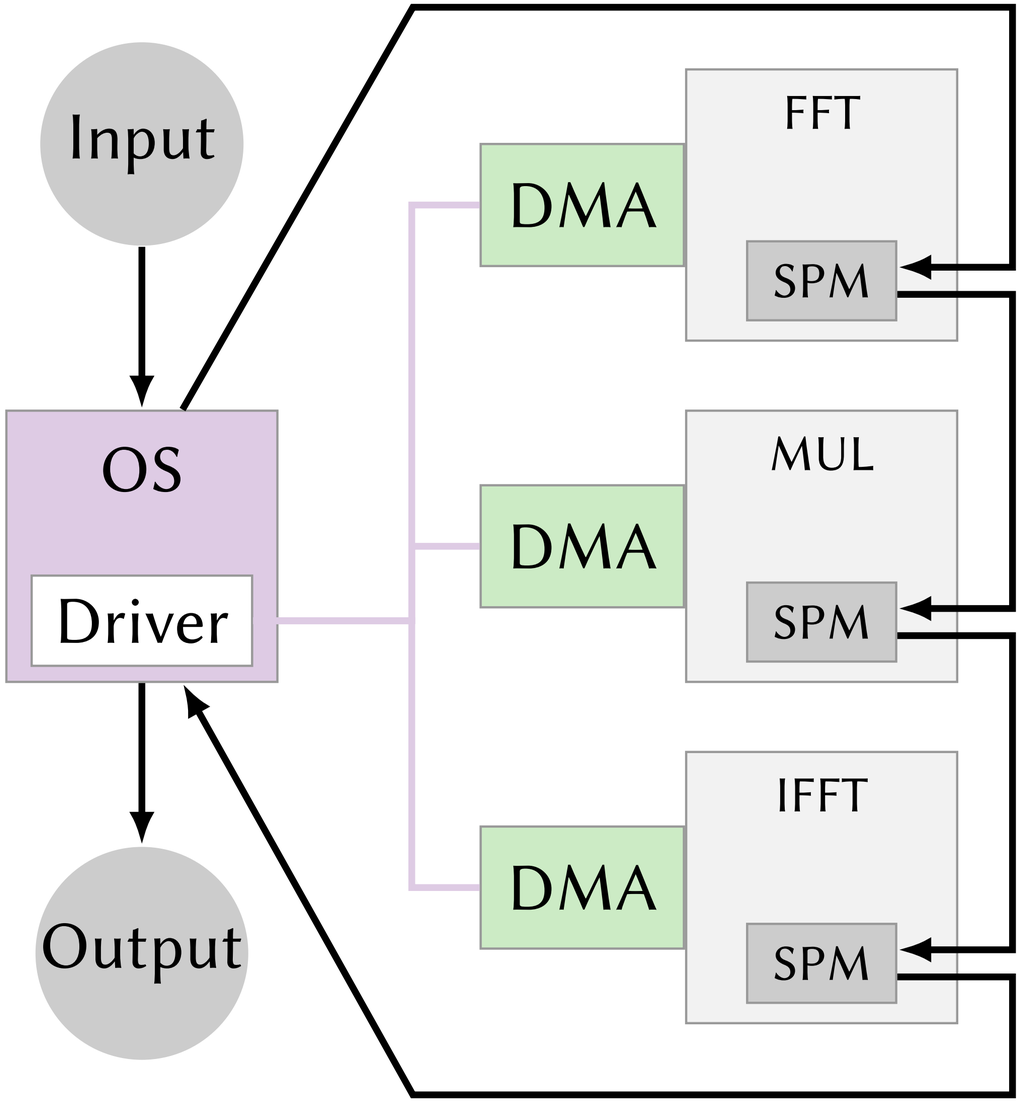
Accelerator Support Module (ASM):

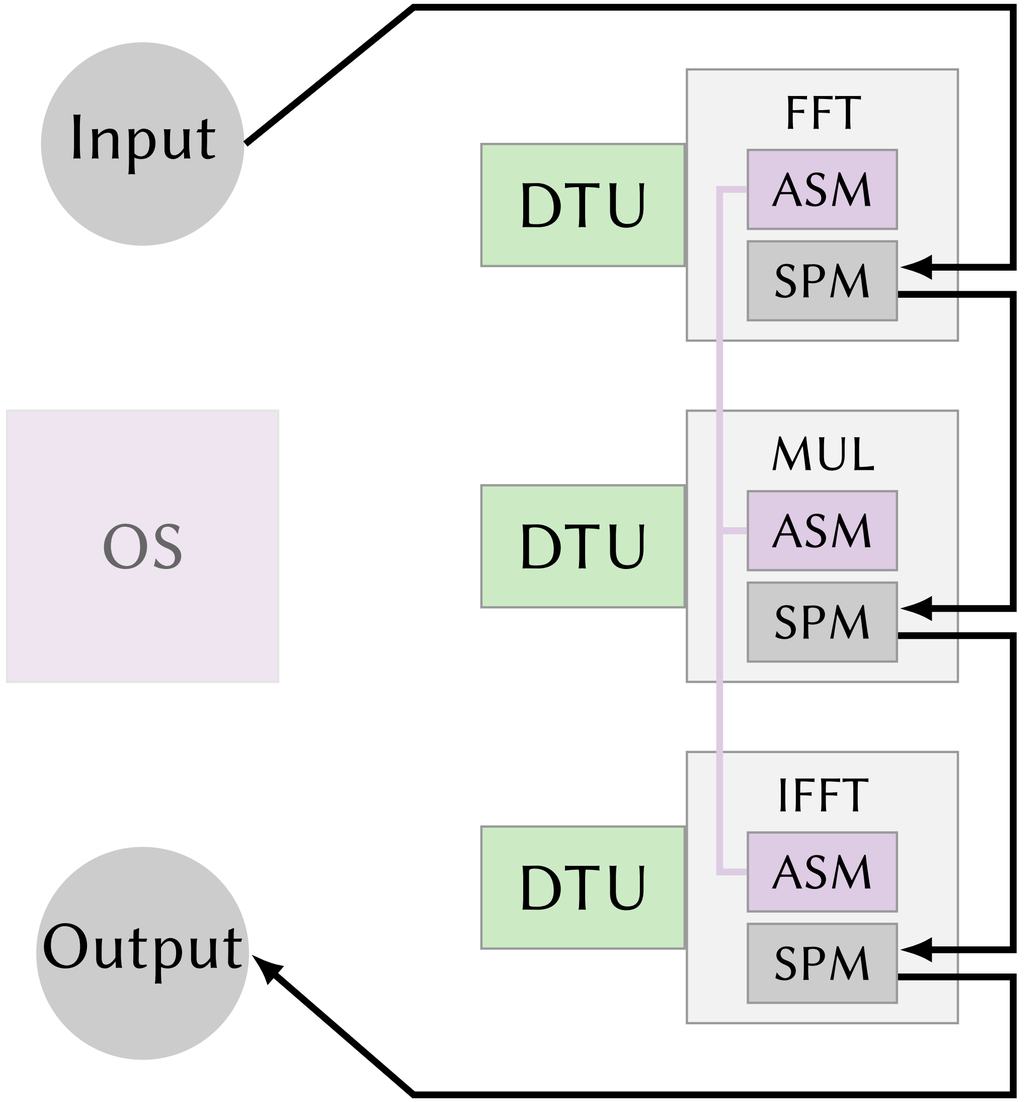
- Interacts with DTU and accelerator
- Implements file protocol for input and output channel

Assisted vs. Autonomous

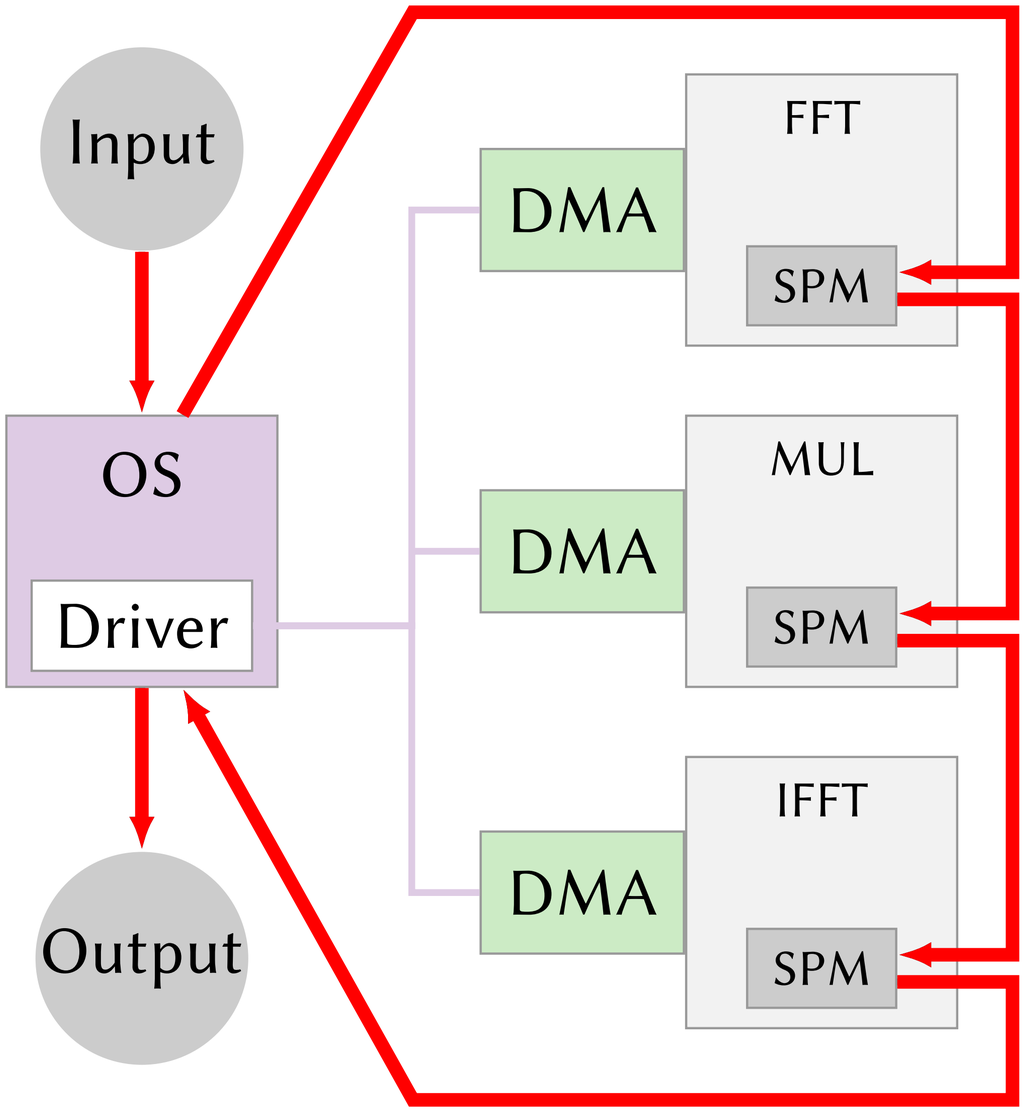


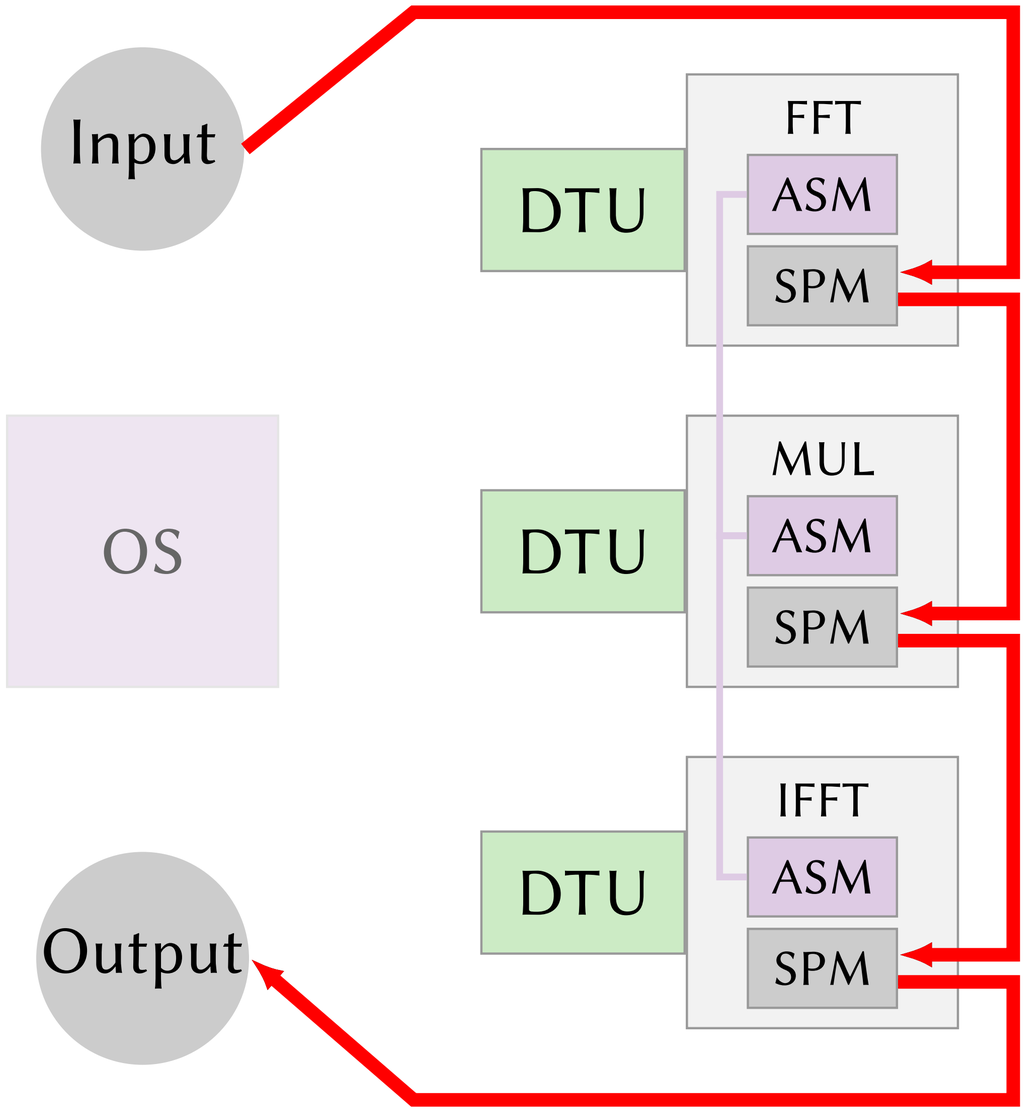
Assisted vs. Autonomous





Assisted vs. Autonomous





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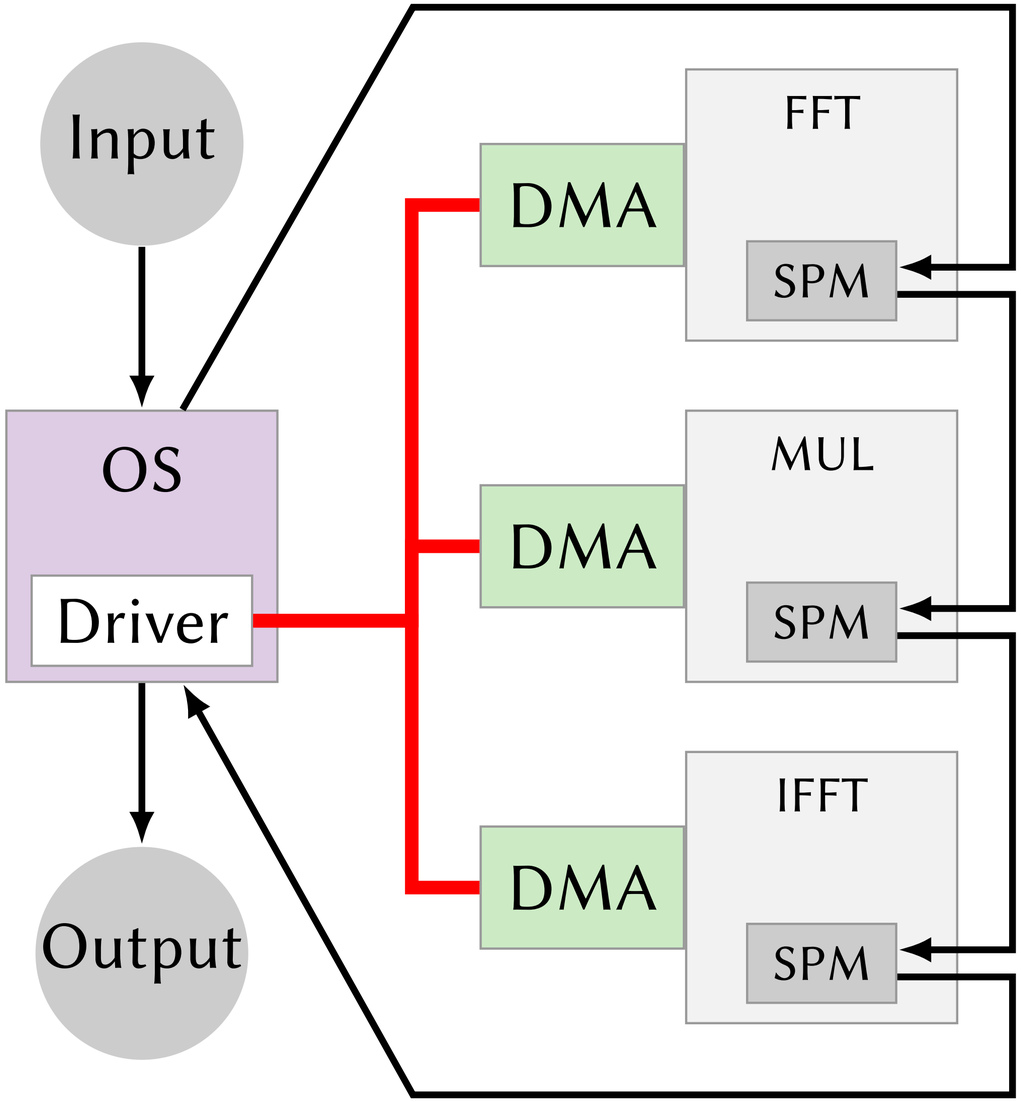
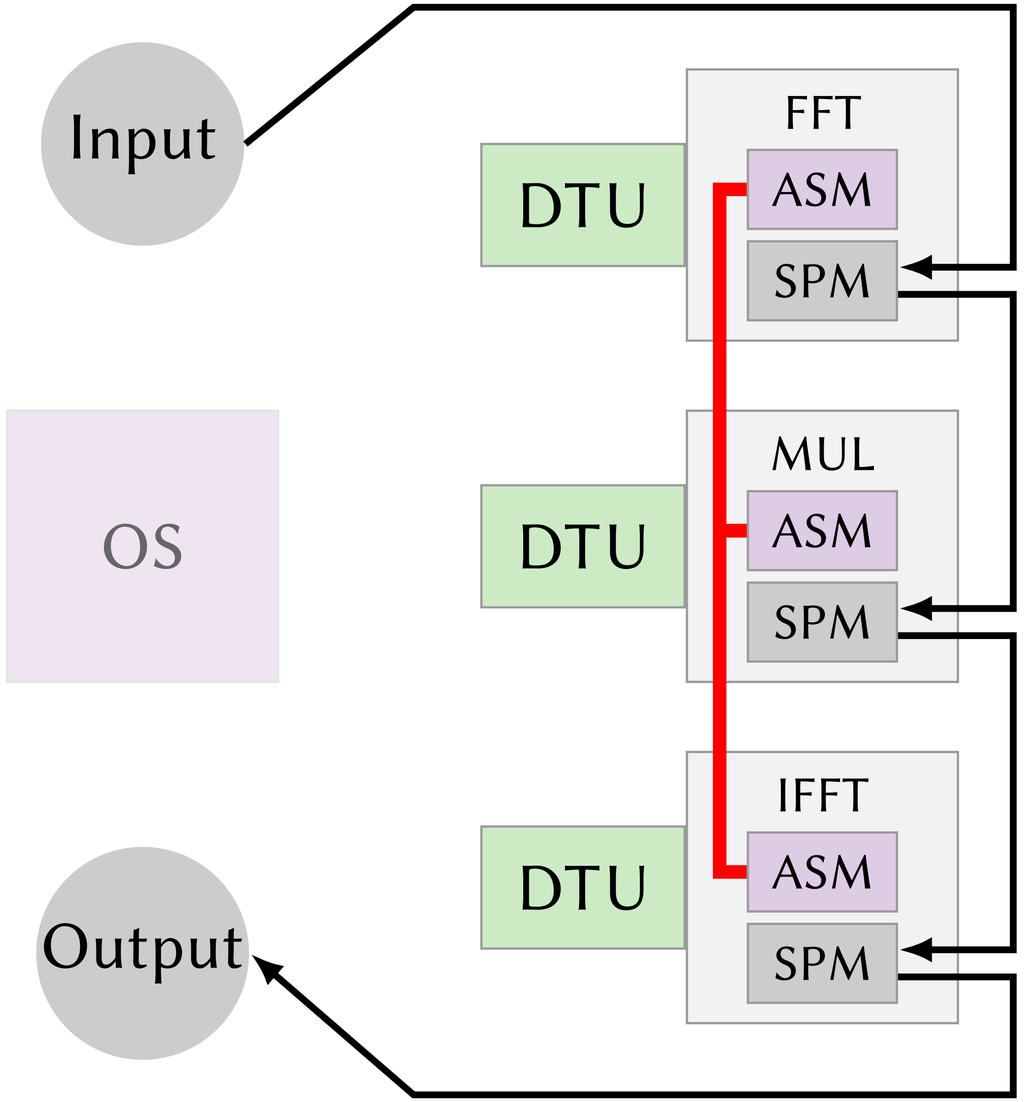
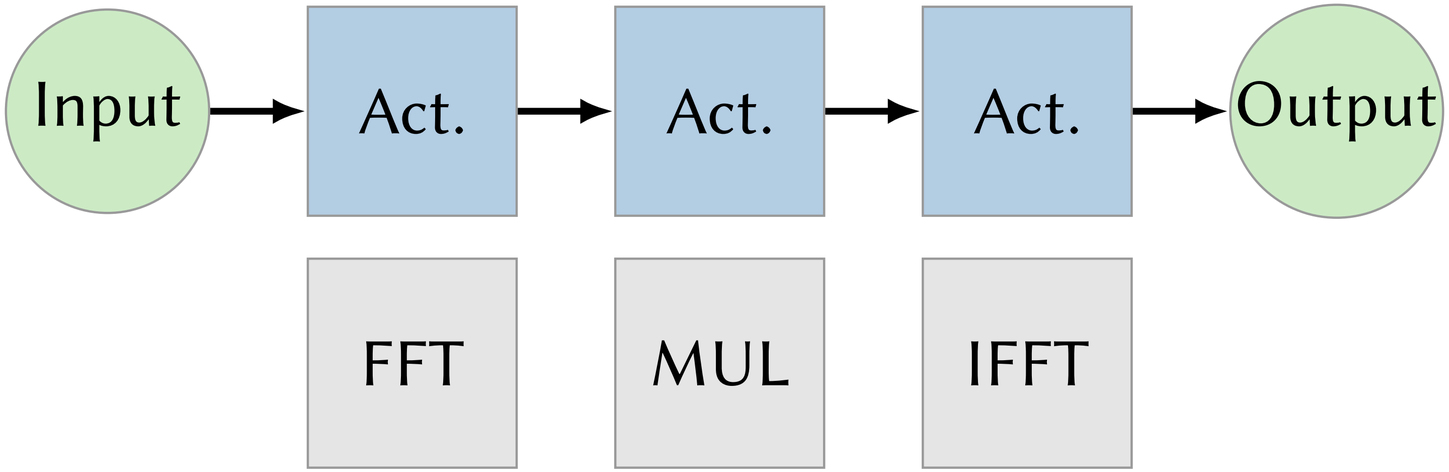




Evaluation

Evaluation



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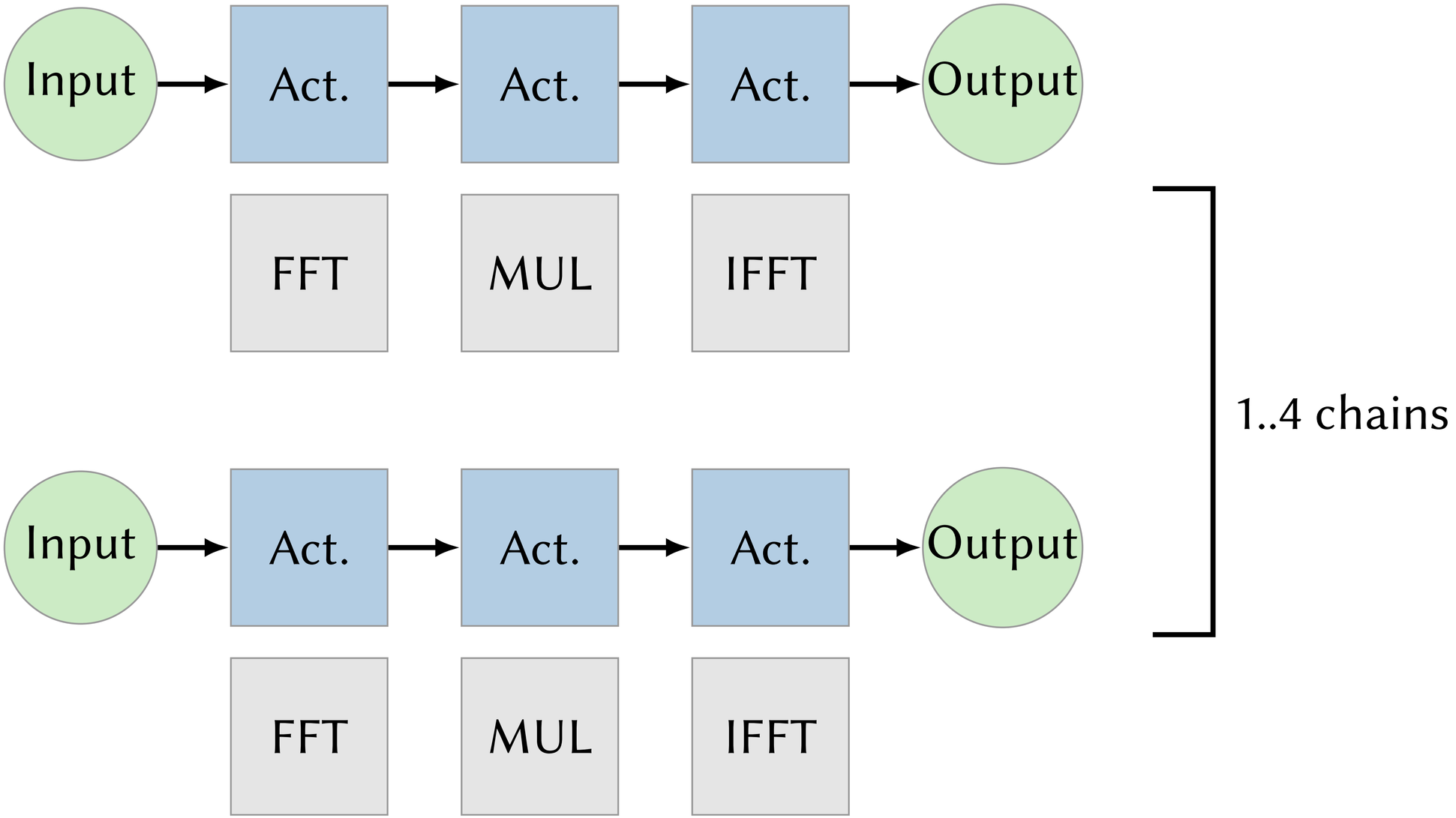
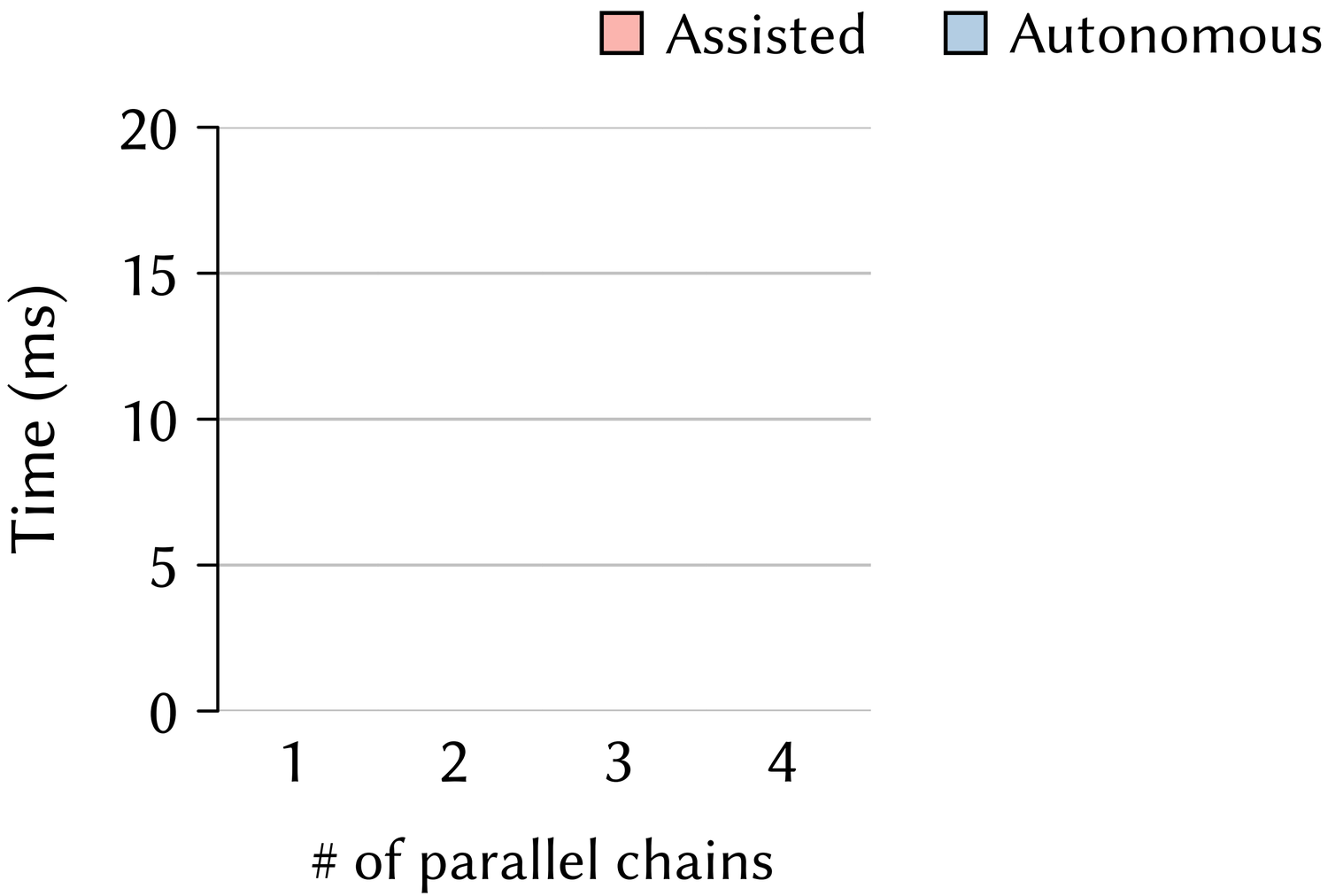
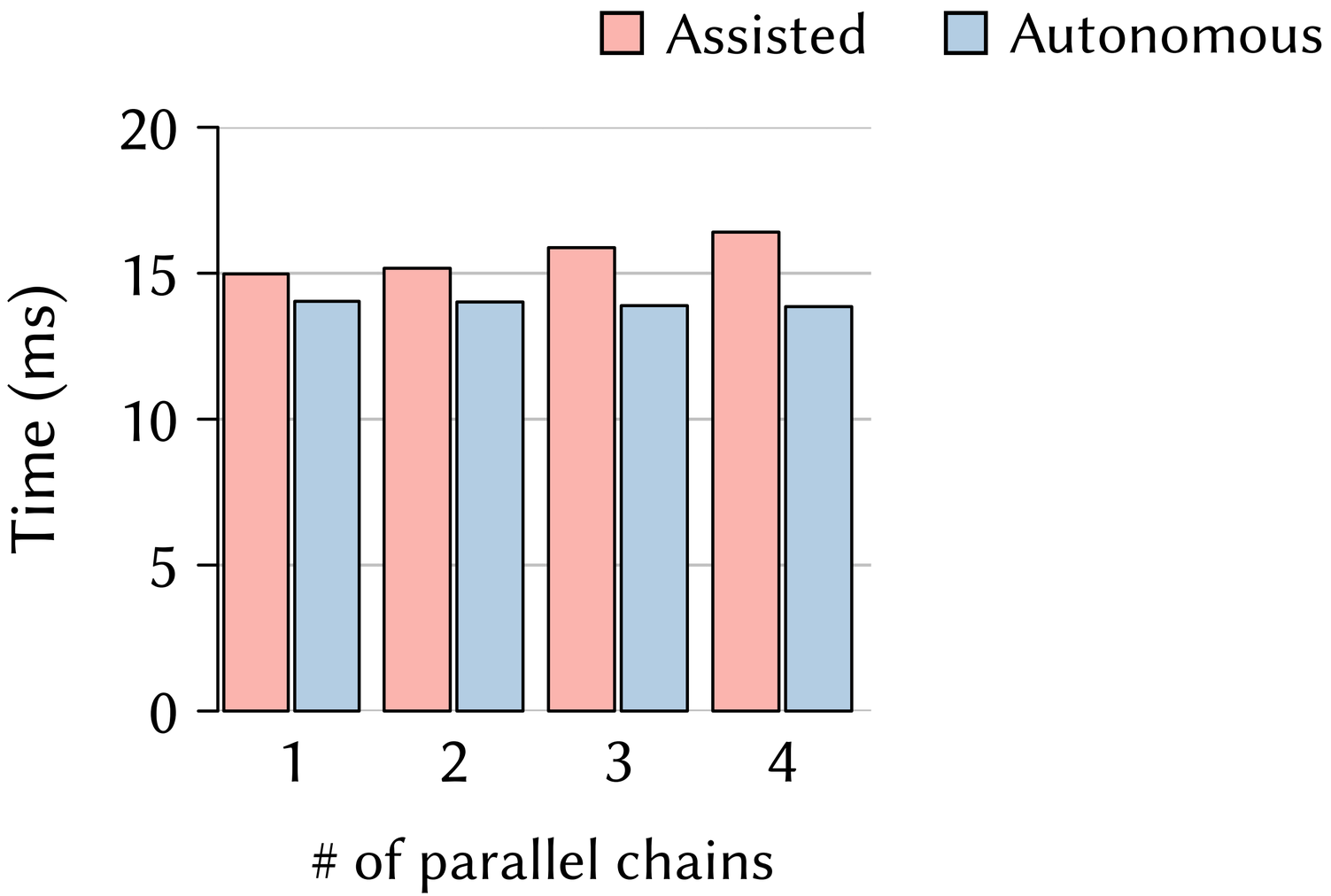

Input
Act.
Act.
Act.
Output
FFT
MUL
IFFT
Input
Act.
Act.
Act.
Output
FFT
MUL
IFFT
1..4 chains

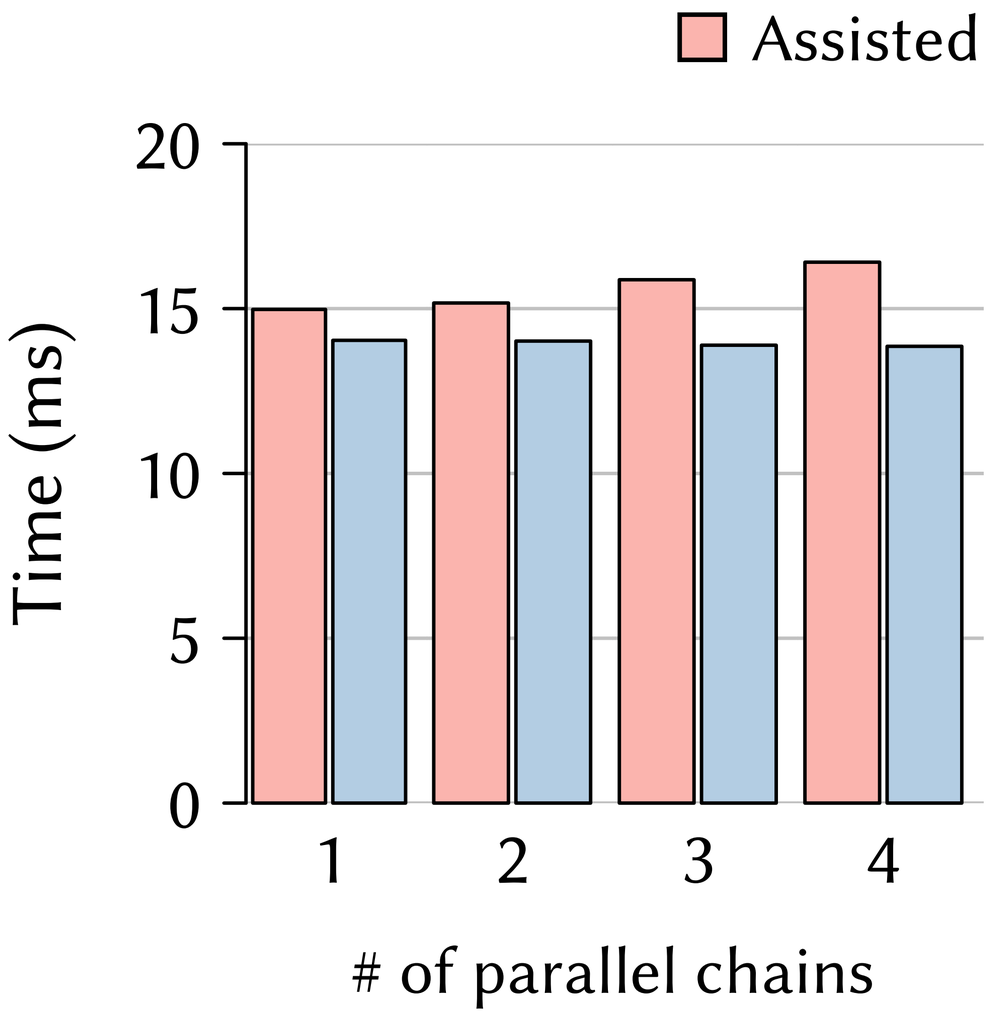
Evaluation

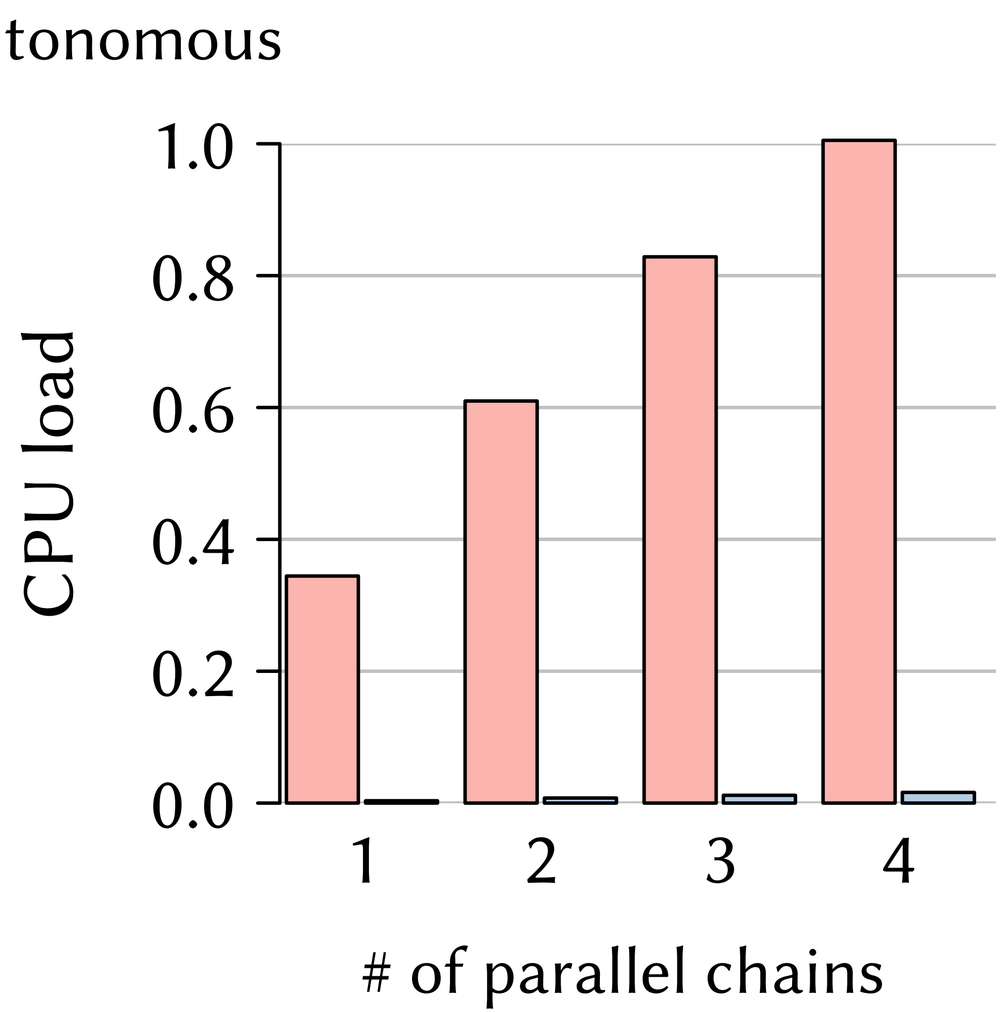

Assisted
Autonomous
20
15
10
5
0
Time (ms)
1
2
3
4
# of parallel chains

Evaluation

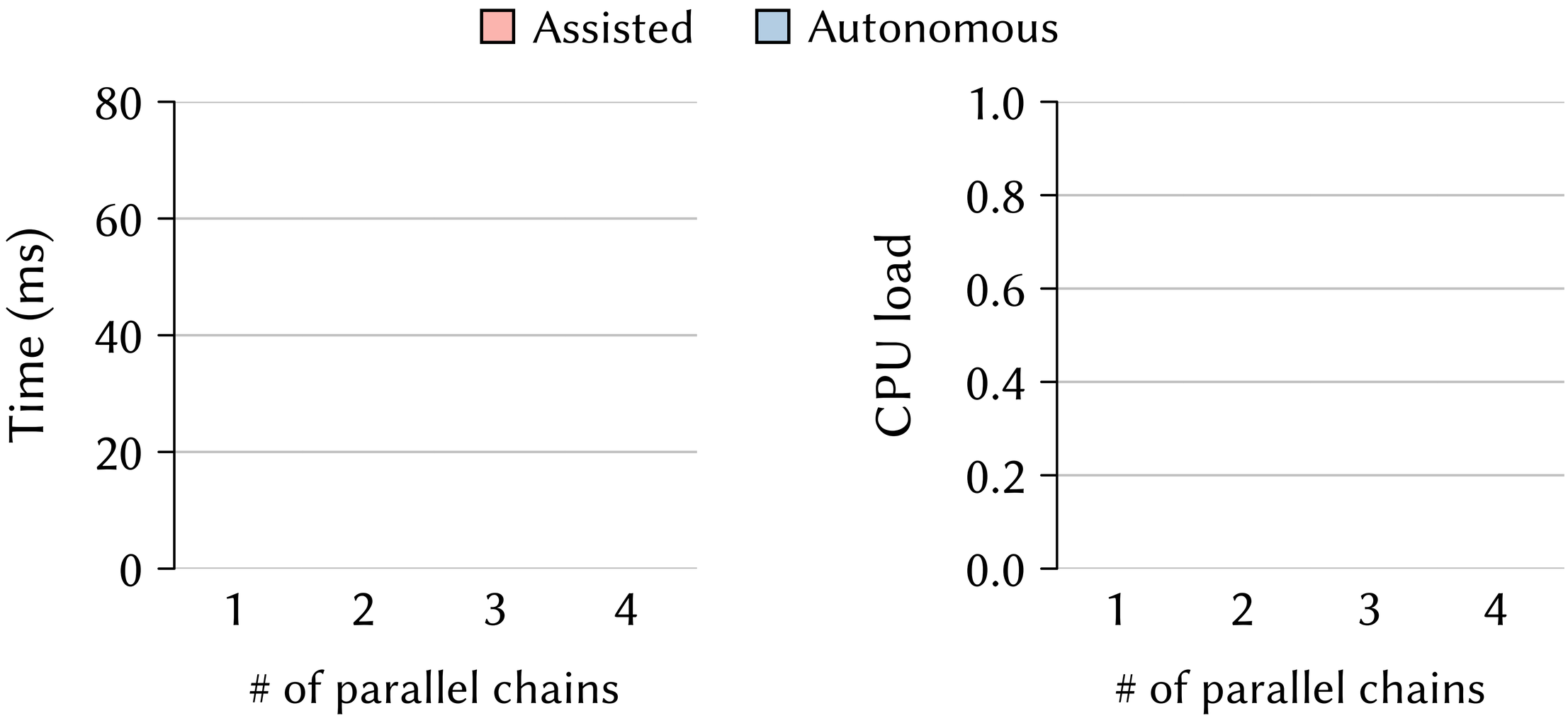

Assisted
Autonomous
20
15
10
5
0
Time (ms)
1
2
3
4
# of parallel chains

Evaluation


Assisted
Autonomous
Time (ms)
20
15
10
5
0
1
2
3
4
# of parallel chains


CPU load
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3
4
# of parallel chains

Evaluation: PCIe Latency



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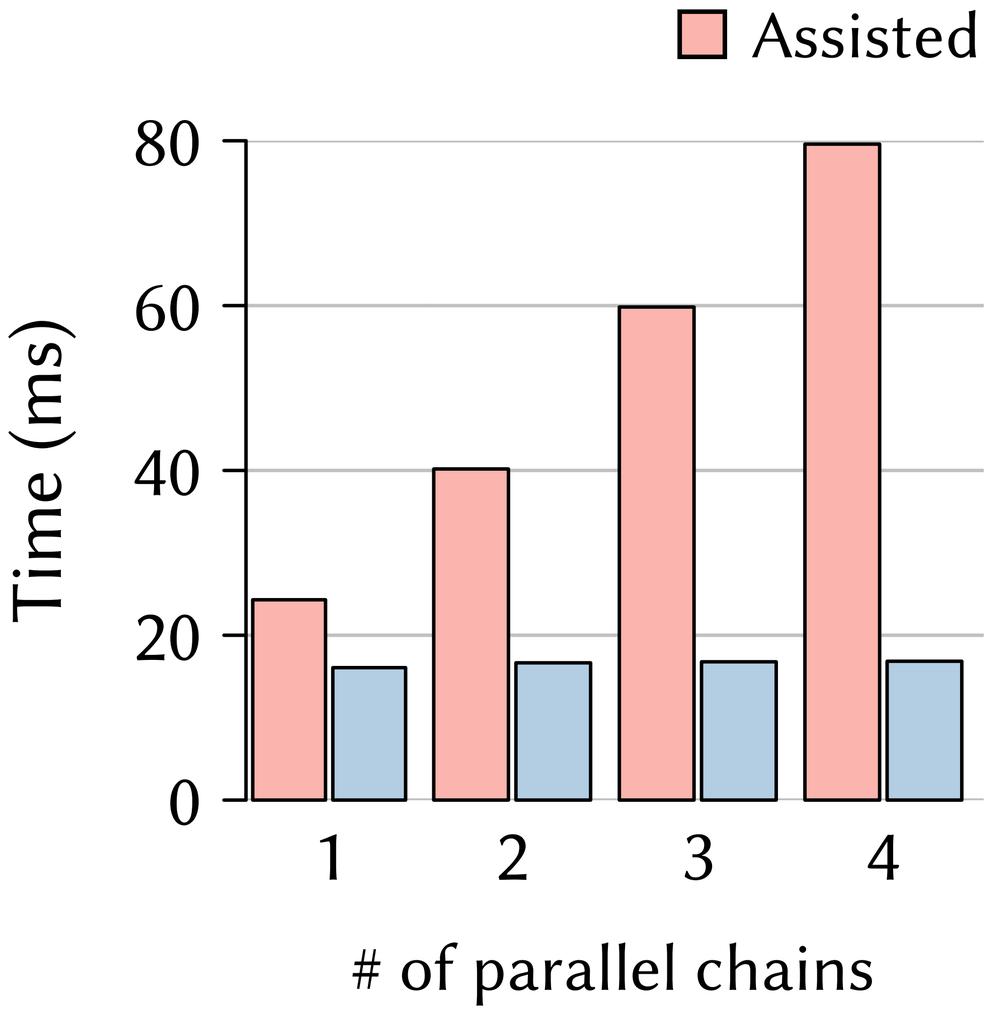
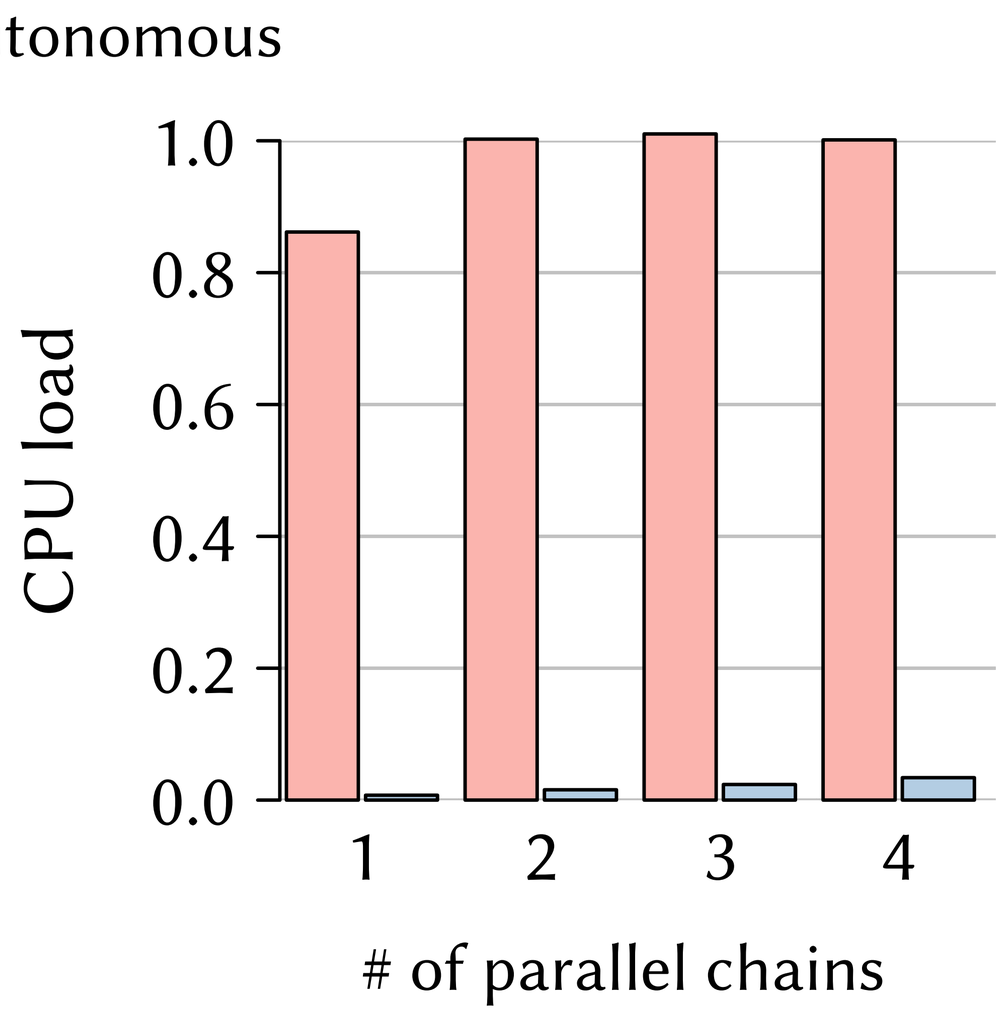
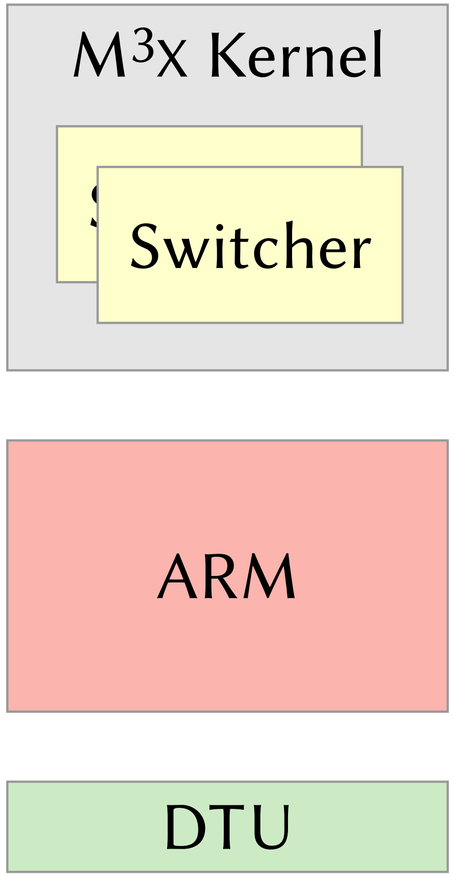




Addendum: Context Switching



- Kernel handles complex part
  - Schedules/migrates activities
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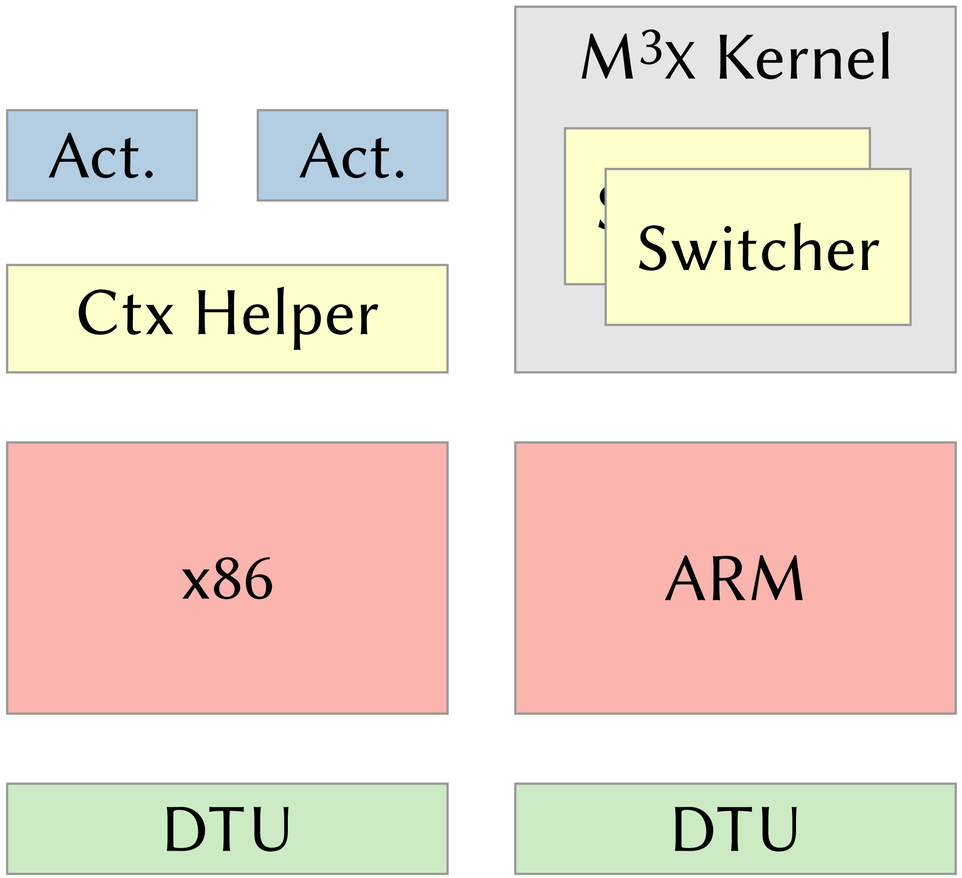

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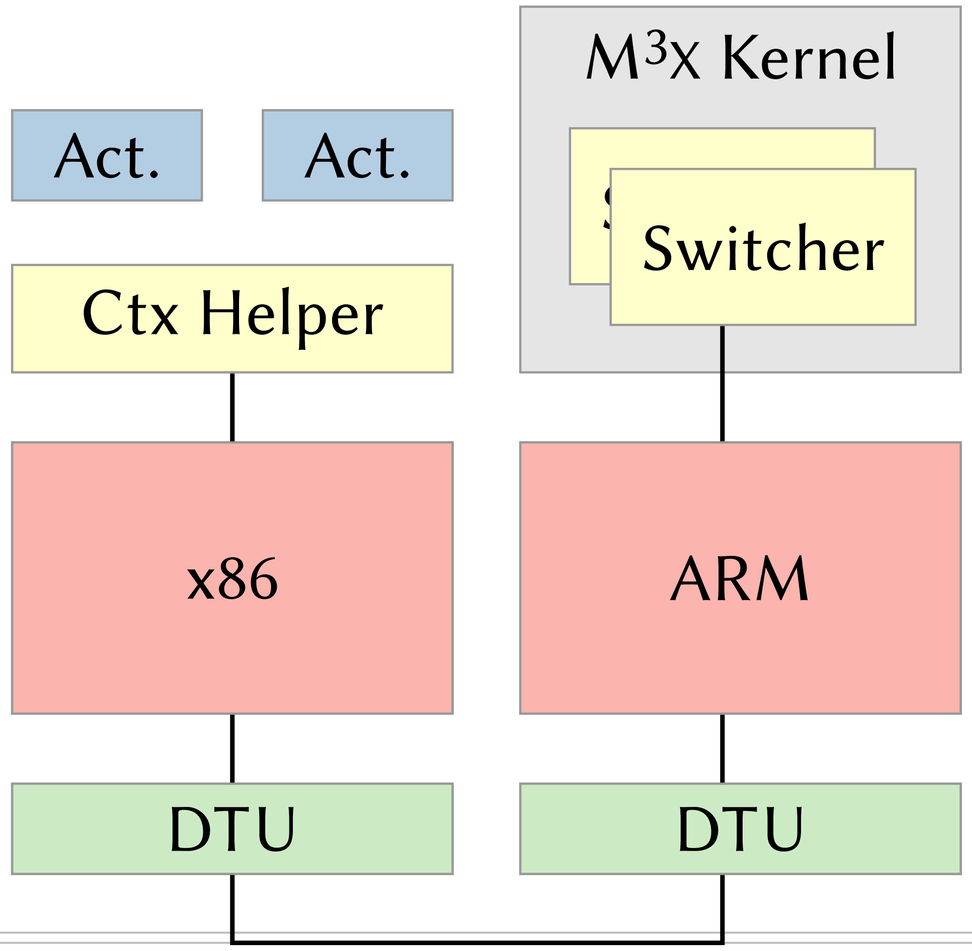

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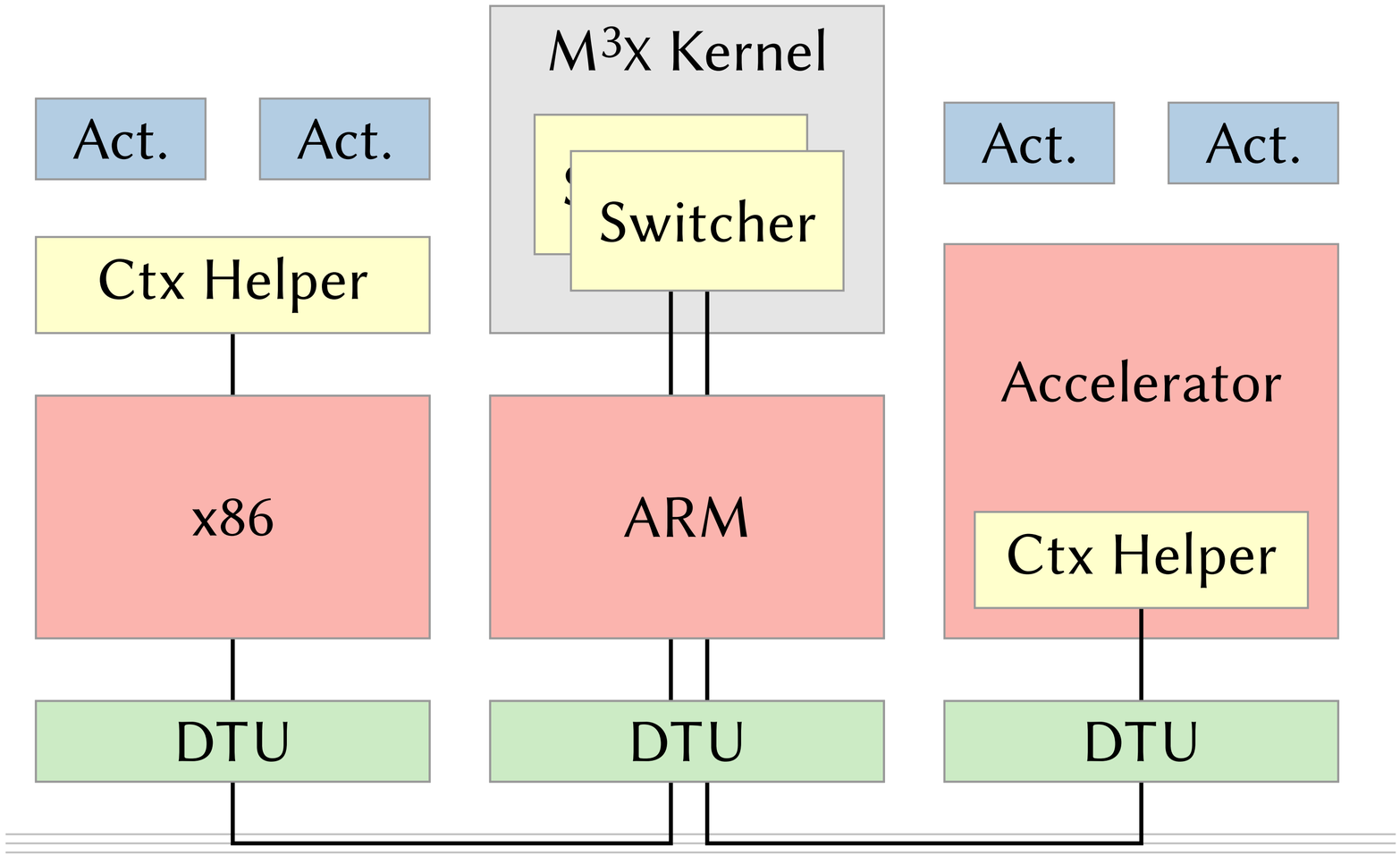

- Kernel handles complex part
  - Schedules/migrates activities
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- Helper on user tiles implements save/restore
  - General purpose tiles: Software helper
  - Accelerator tiles: Helper implemented in hardware as part of ASM

Summary

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Autonomous accelerator chains

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- communication without involving the kernel or an orchestration core

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Limitations

Summary

Autonomous accelerator chains

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- all tiles implement a uniform data stream protocol
- lightweight hardware implementation for fixed-function accelerators
- autonomous accelerator chains **reduce CPU load by a factor of 30**

Limitations

- remote context switching

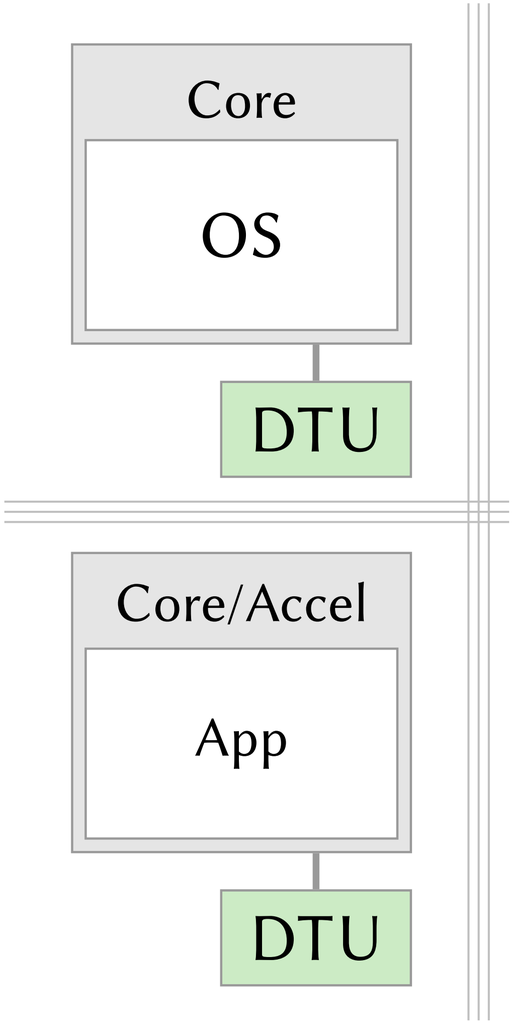
barkhausen institut

M³v — Virtualizing the DTU for Fast Context Switching

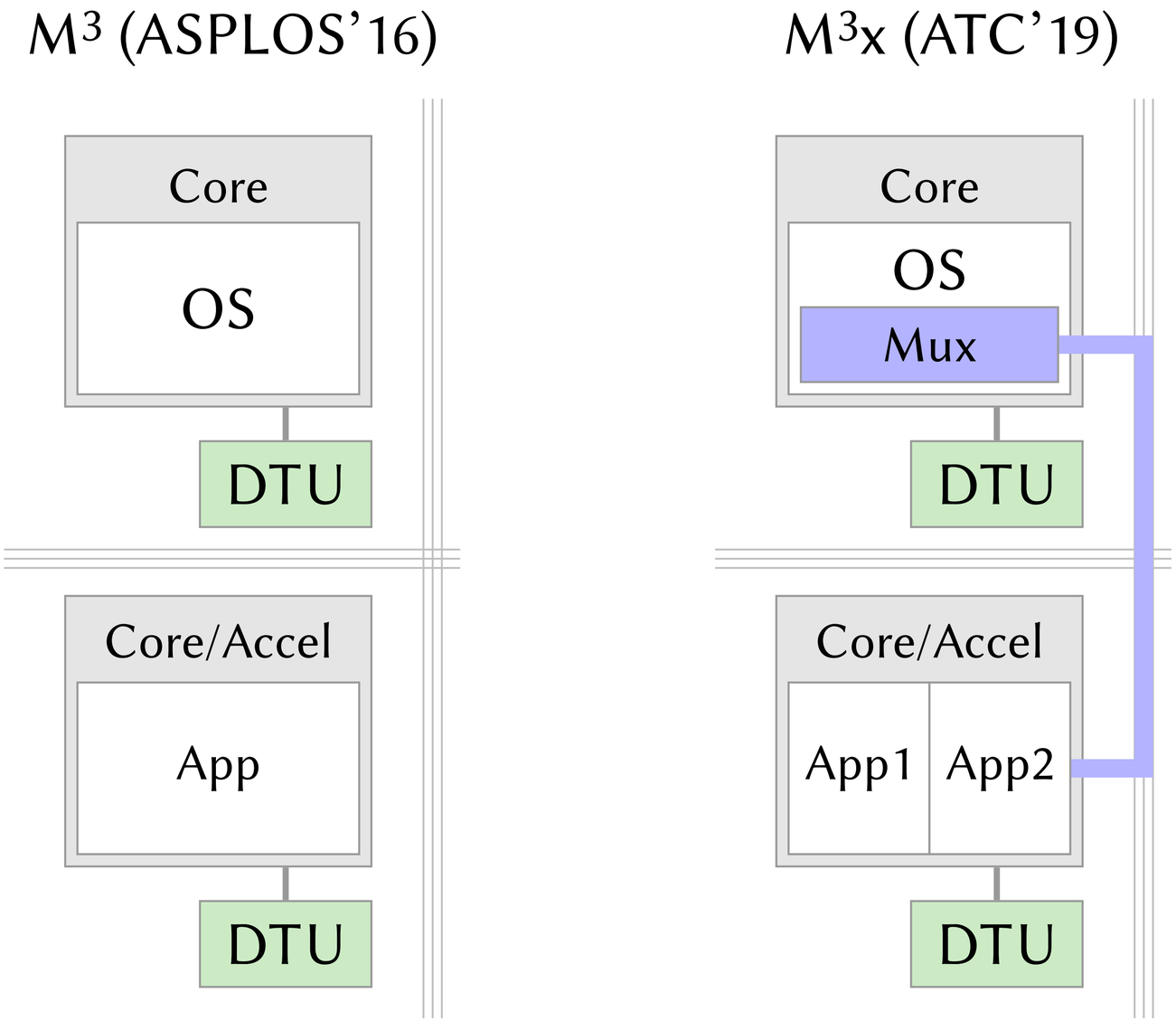
ASPLOS '22

Multiplexing Approaches

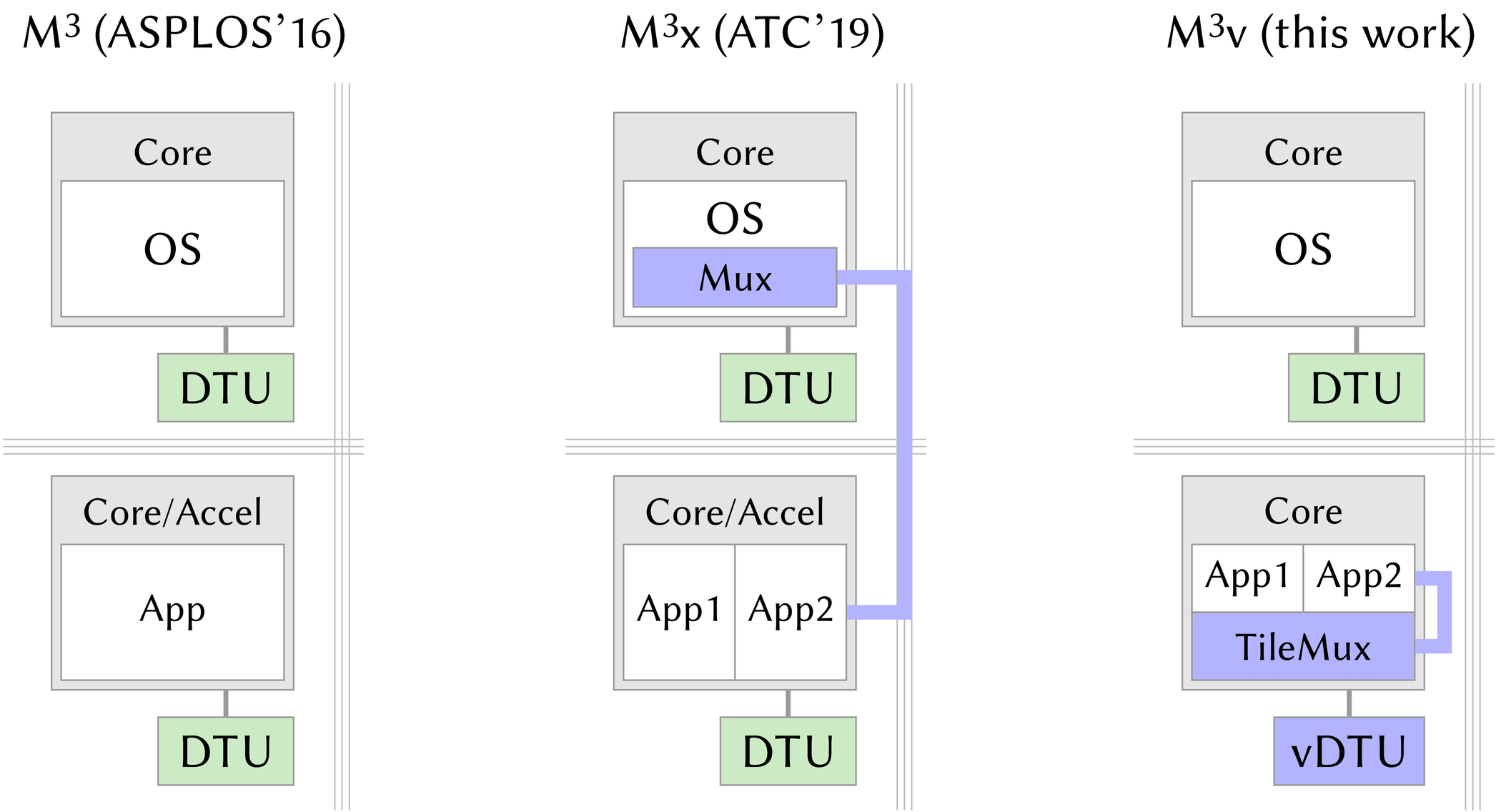
M³ (ASPLOS'16)



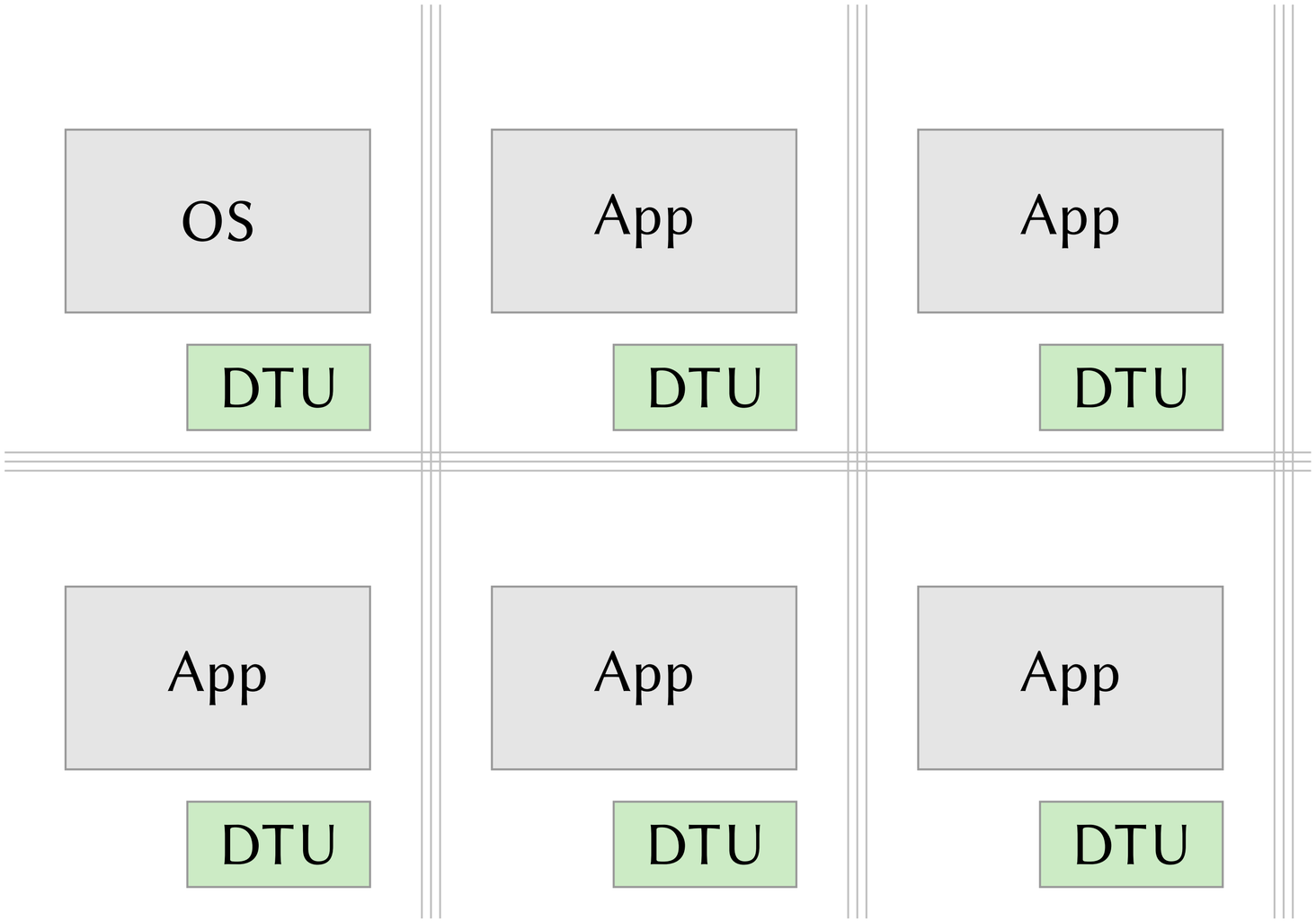
Multiplexing Approaches



Multiplexing Approaches



Multiplexing vs. Fast-Path Communication



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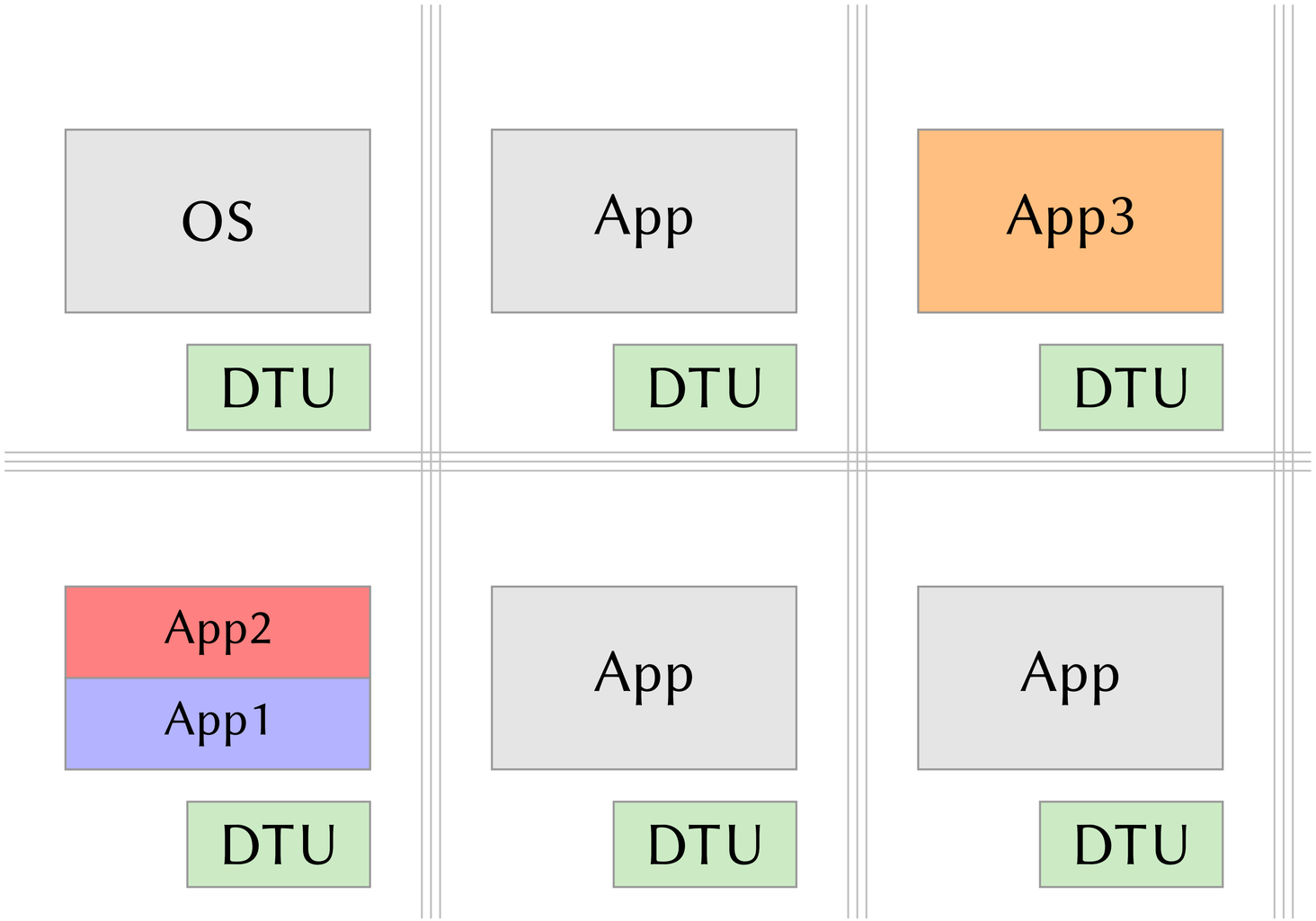

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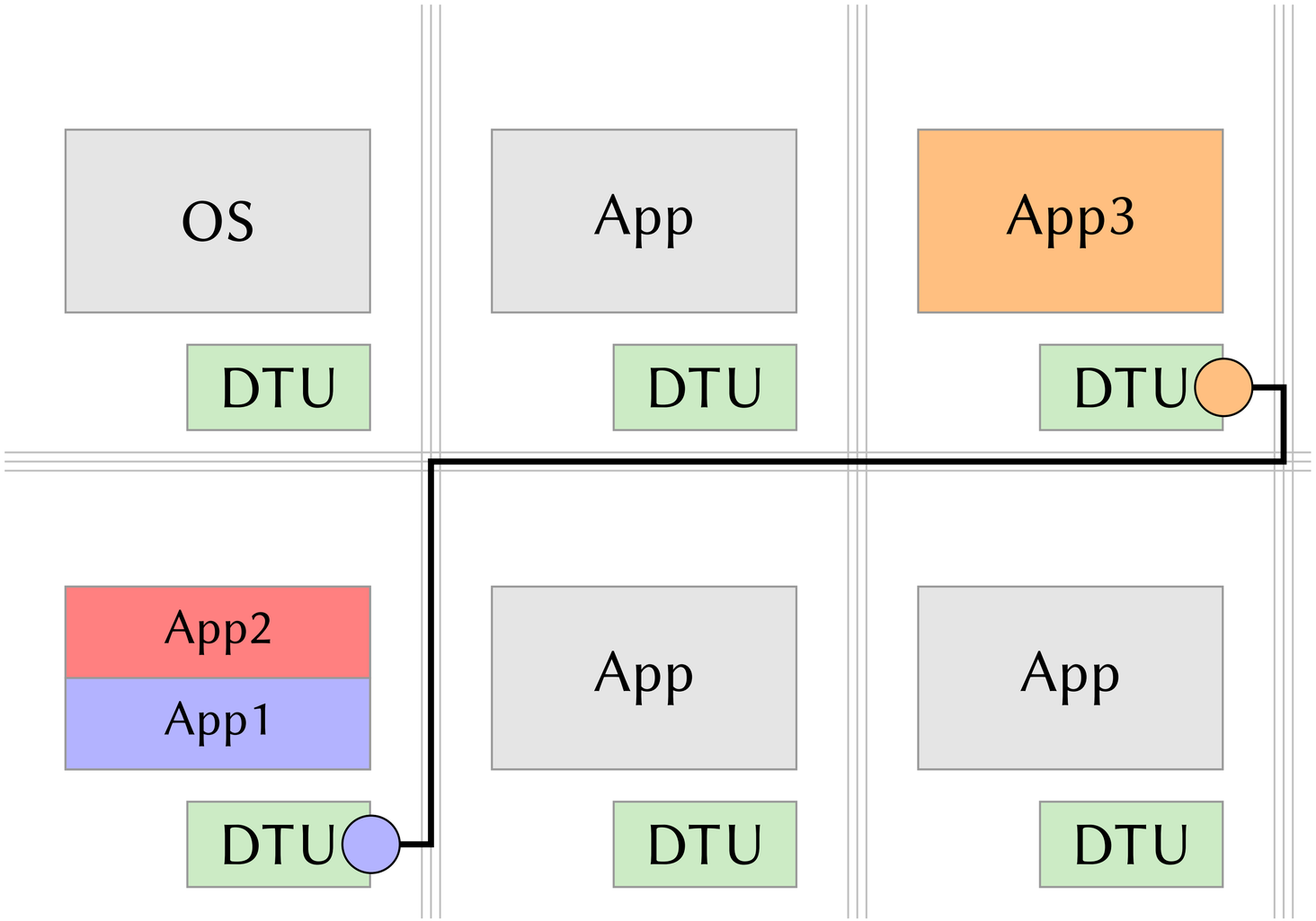

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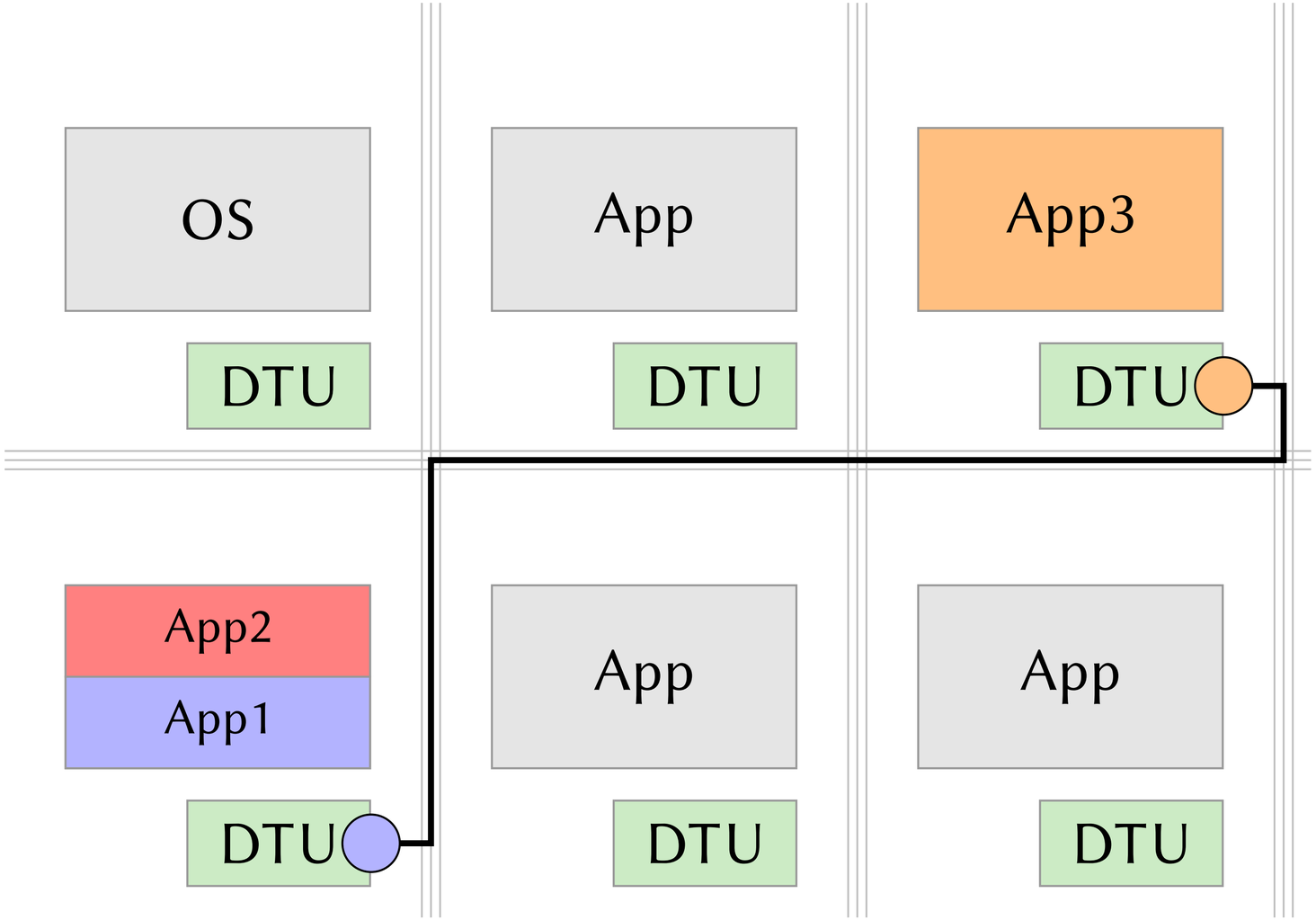
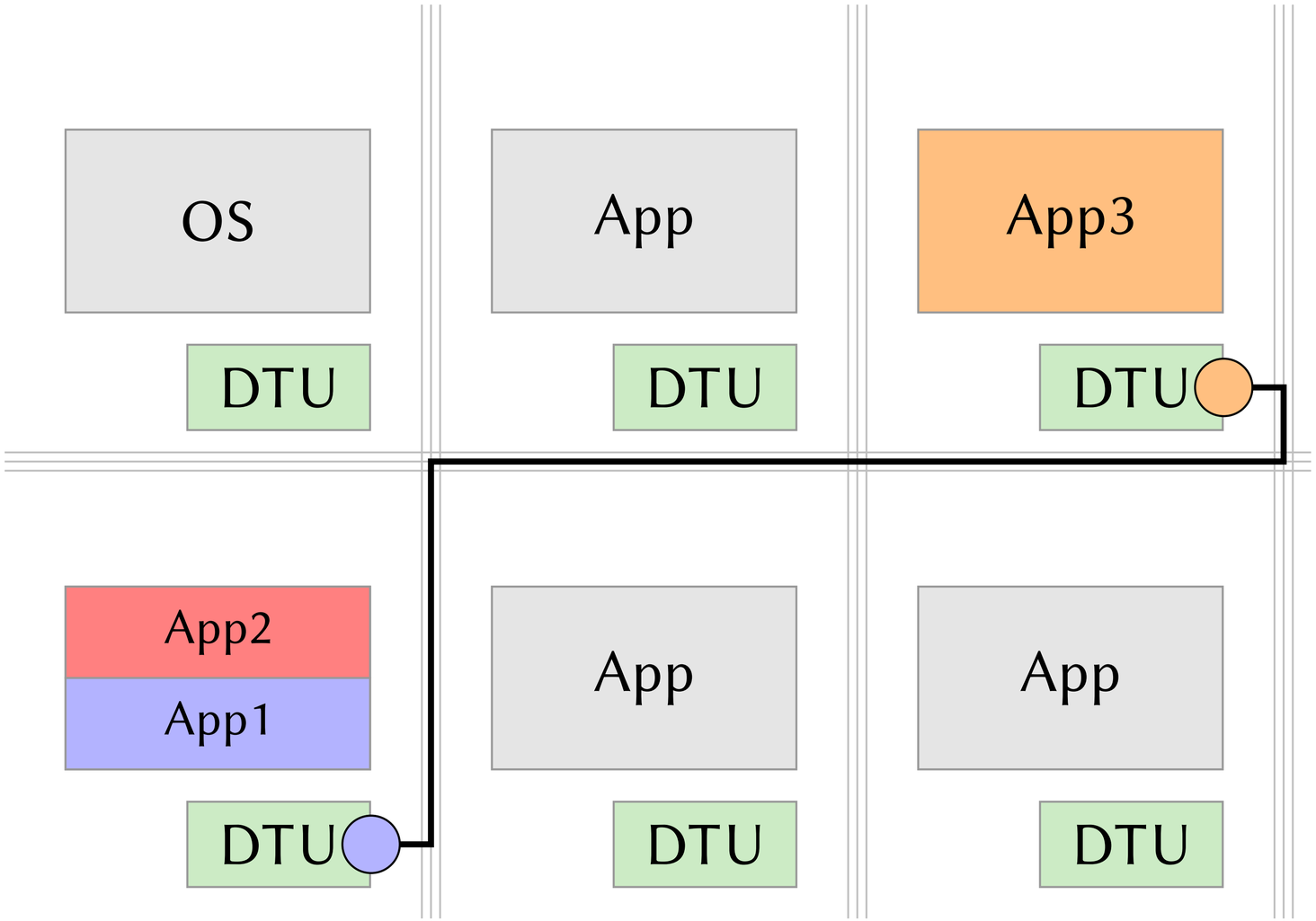


- Suspend App1 until new message, schedule App2

Multiplexing vs. Fast-Path Communication



- Suspend App1 until new message, schedule App2
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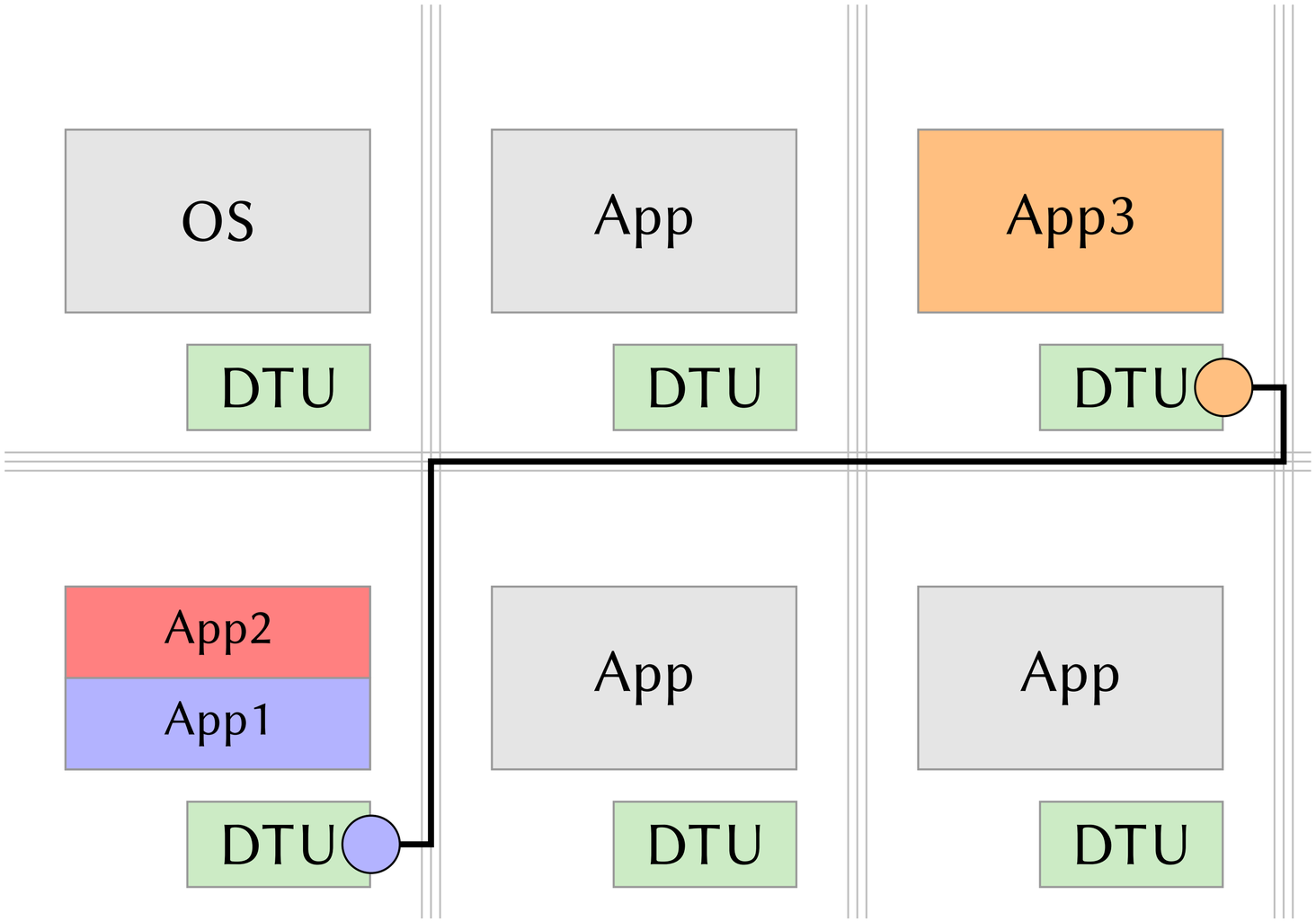
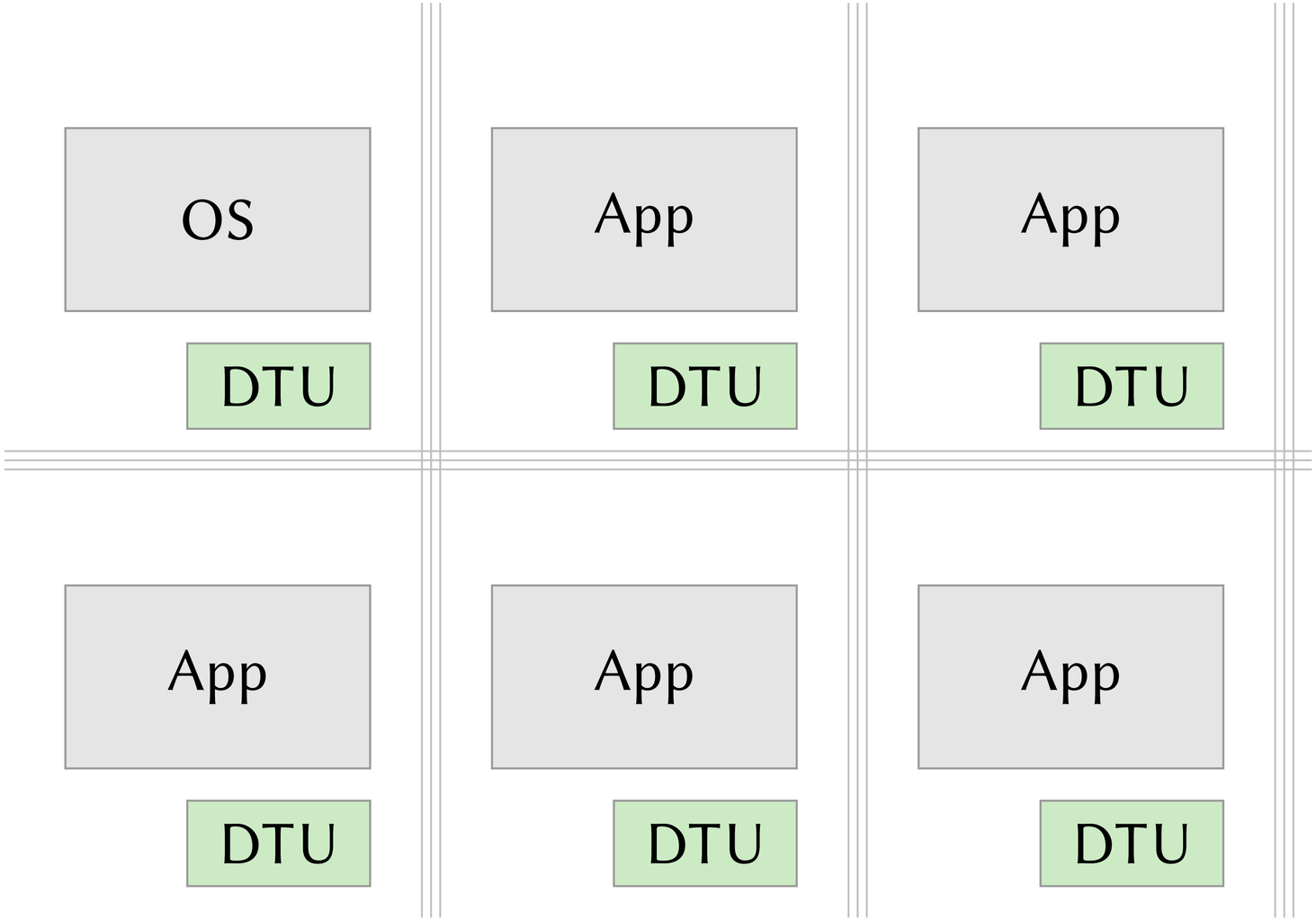
Multiplexing vs. Fast-Path Communication



- Suspend App1 until new message, schedule App2
- Resume App1 upon new message
- Multiplexing conflicts with fast-path communication

Multiplexing vs. Tile Isolation



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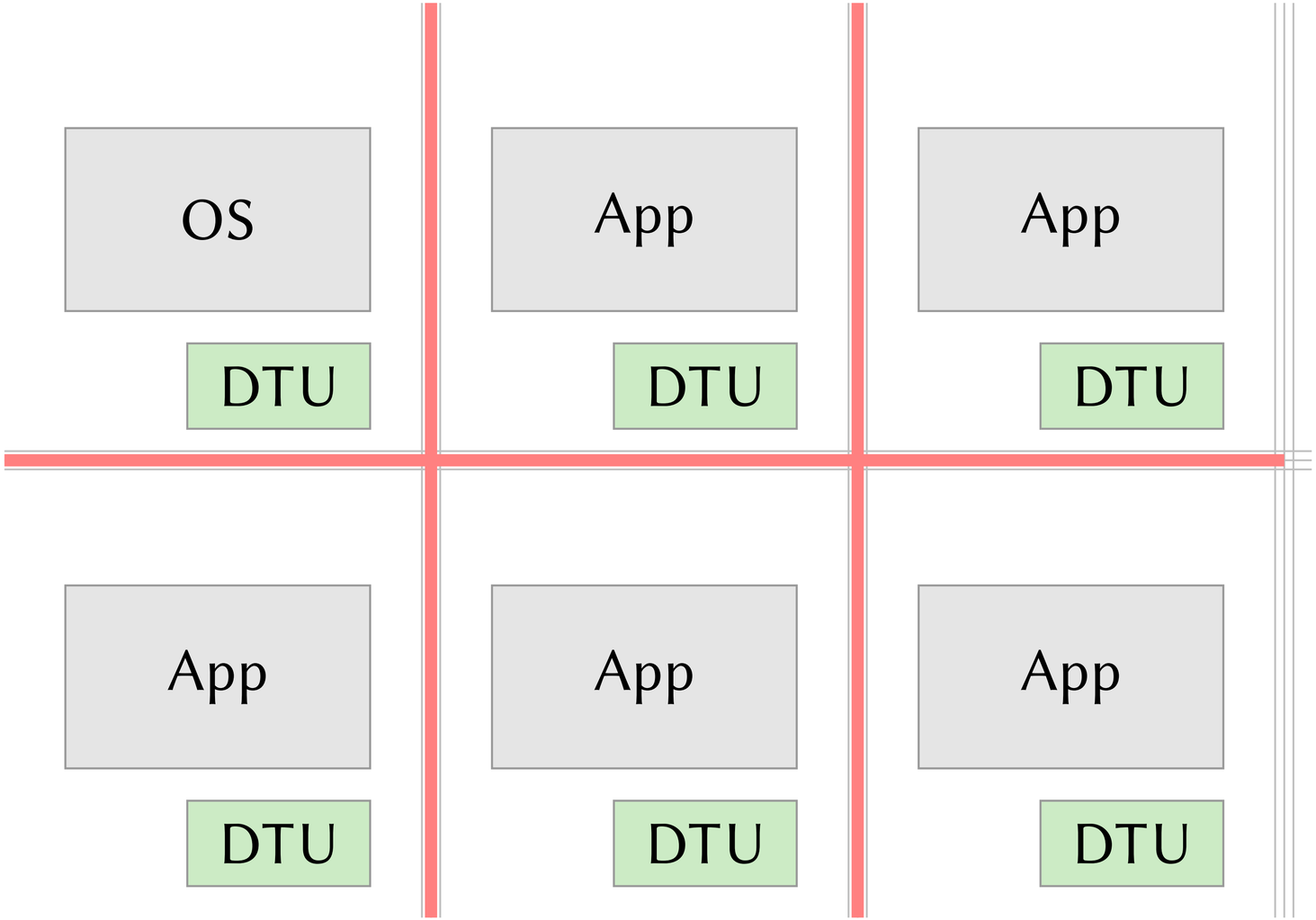

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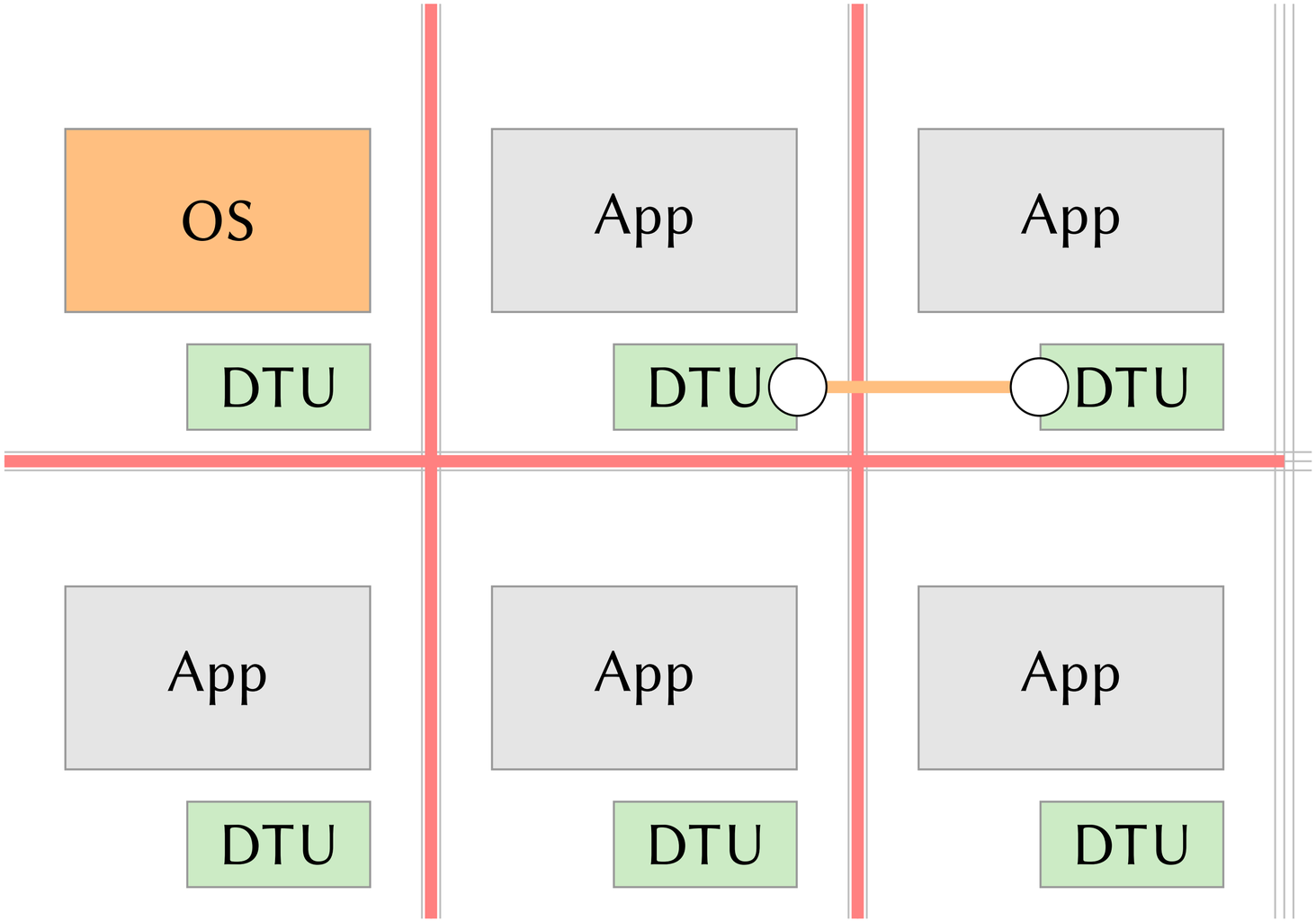
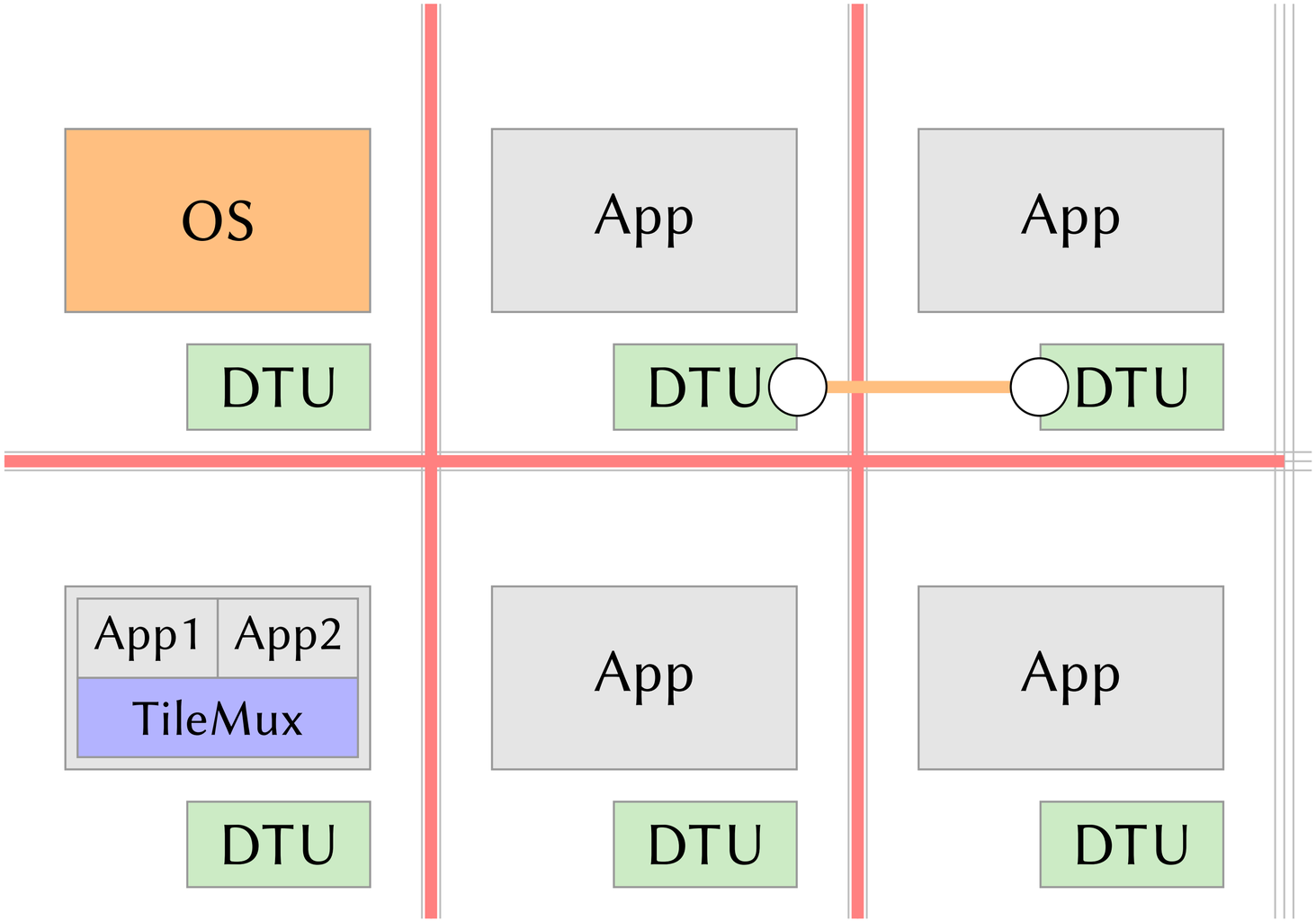


- Only the OS can provide access to tile-external resources

Multiplexing vs. Tile Isolation



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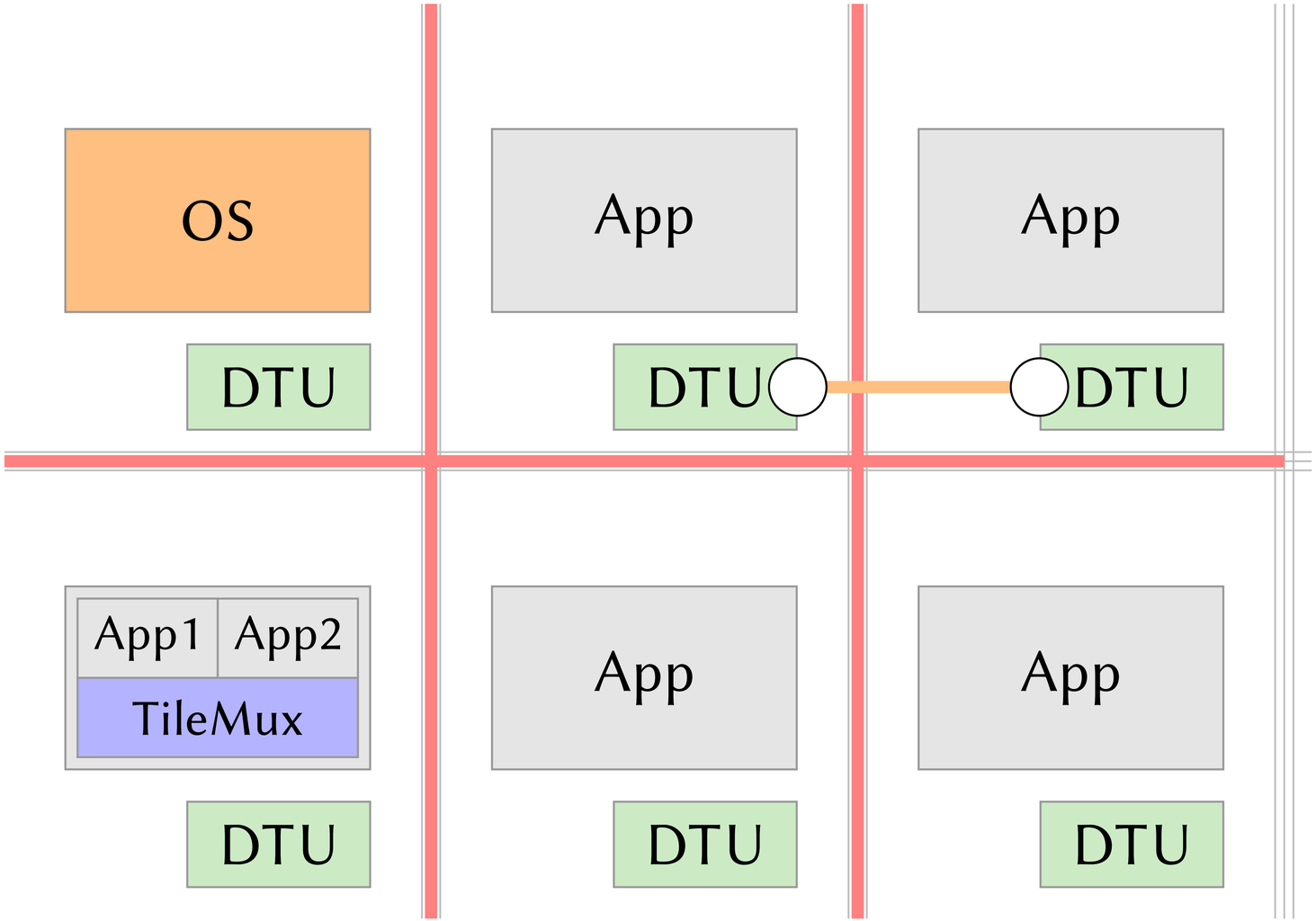
Multiplexing vs. Tile Isolation



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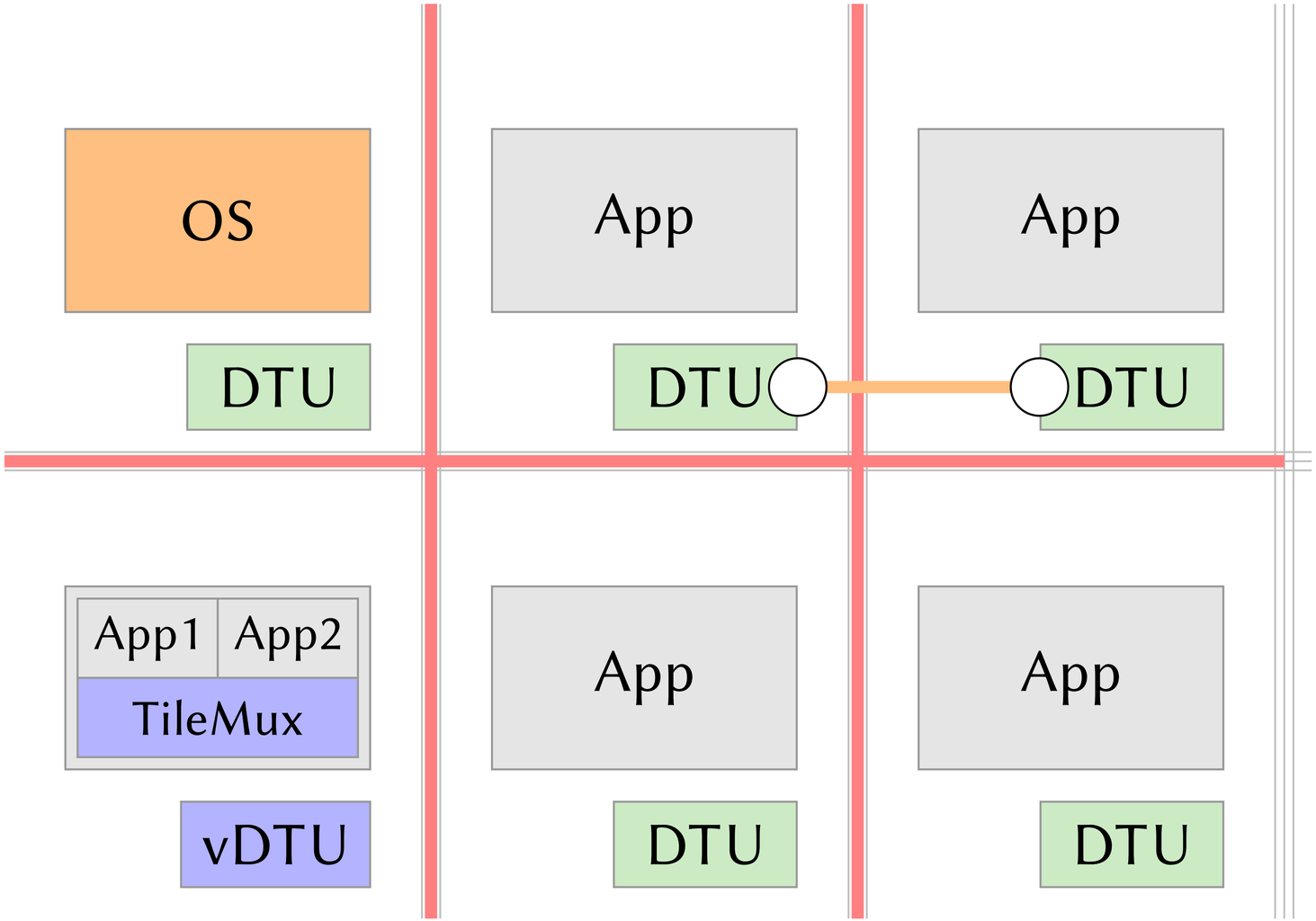

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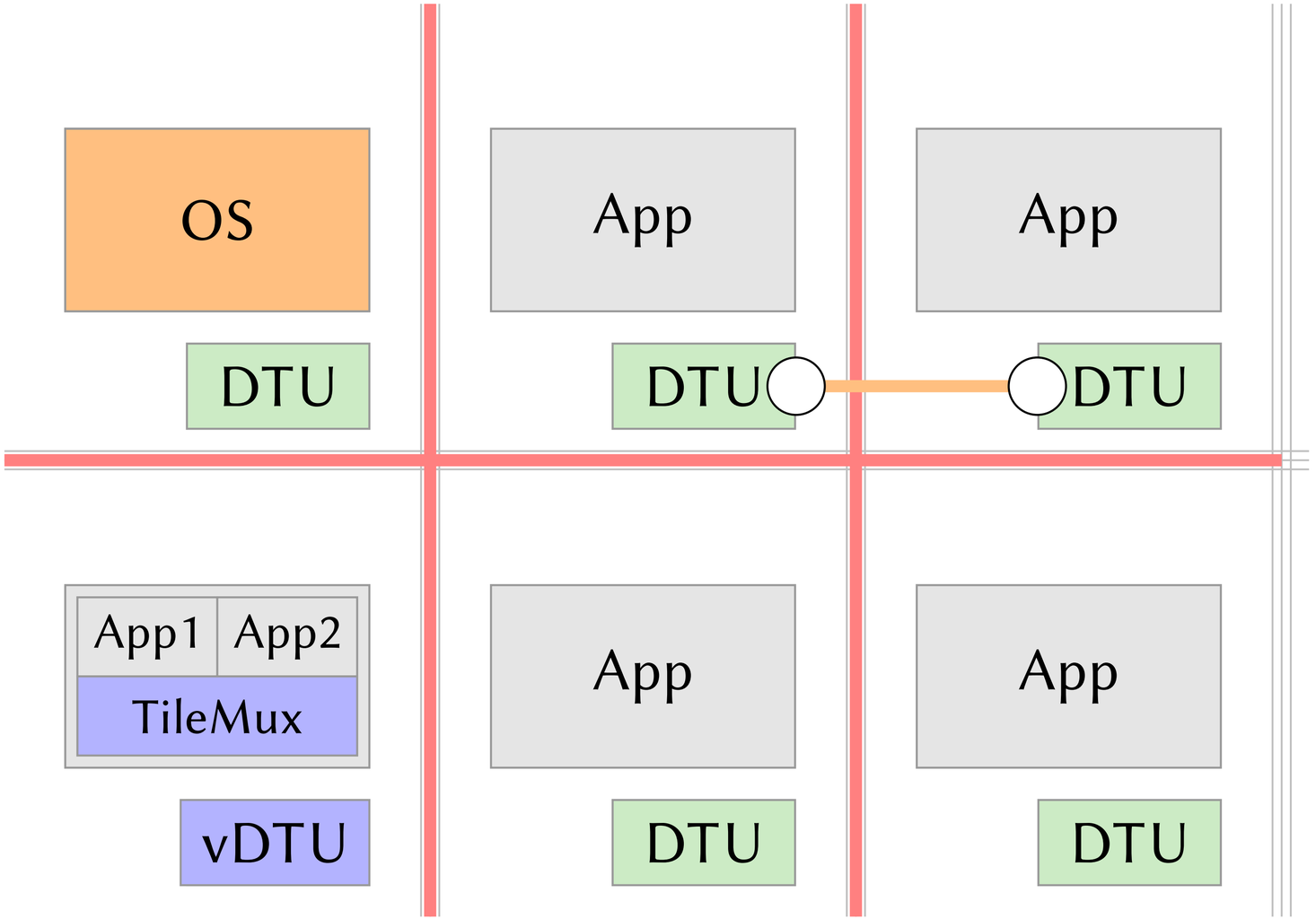
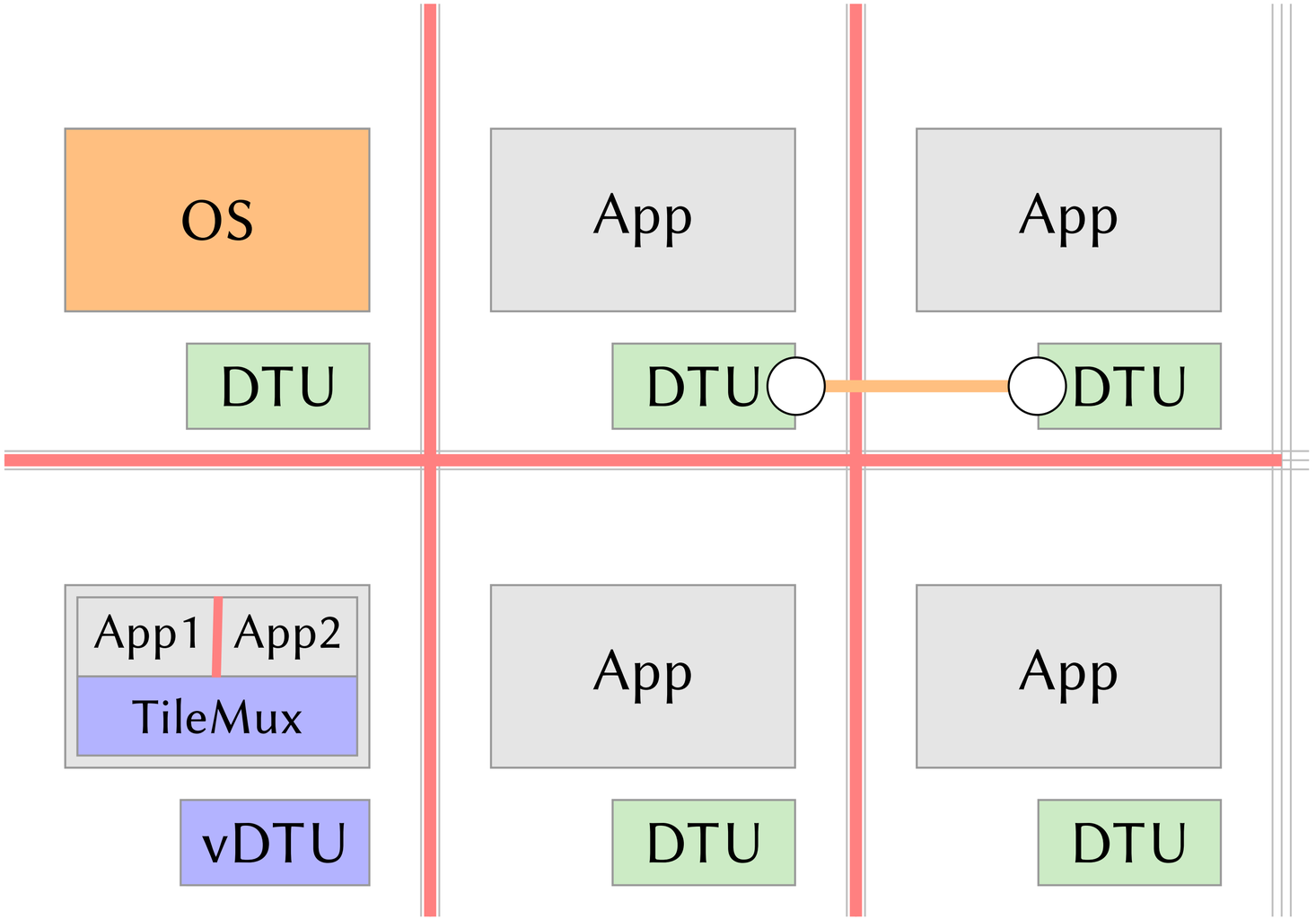


- M³* provides better isolation than conventional architectures

Multiplexing vs. Tile Isolation



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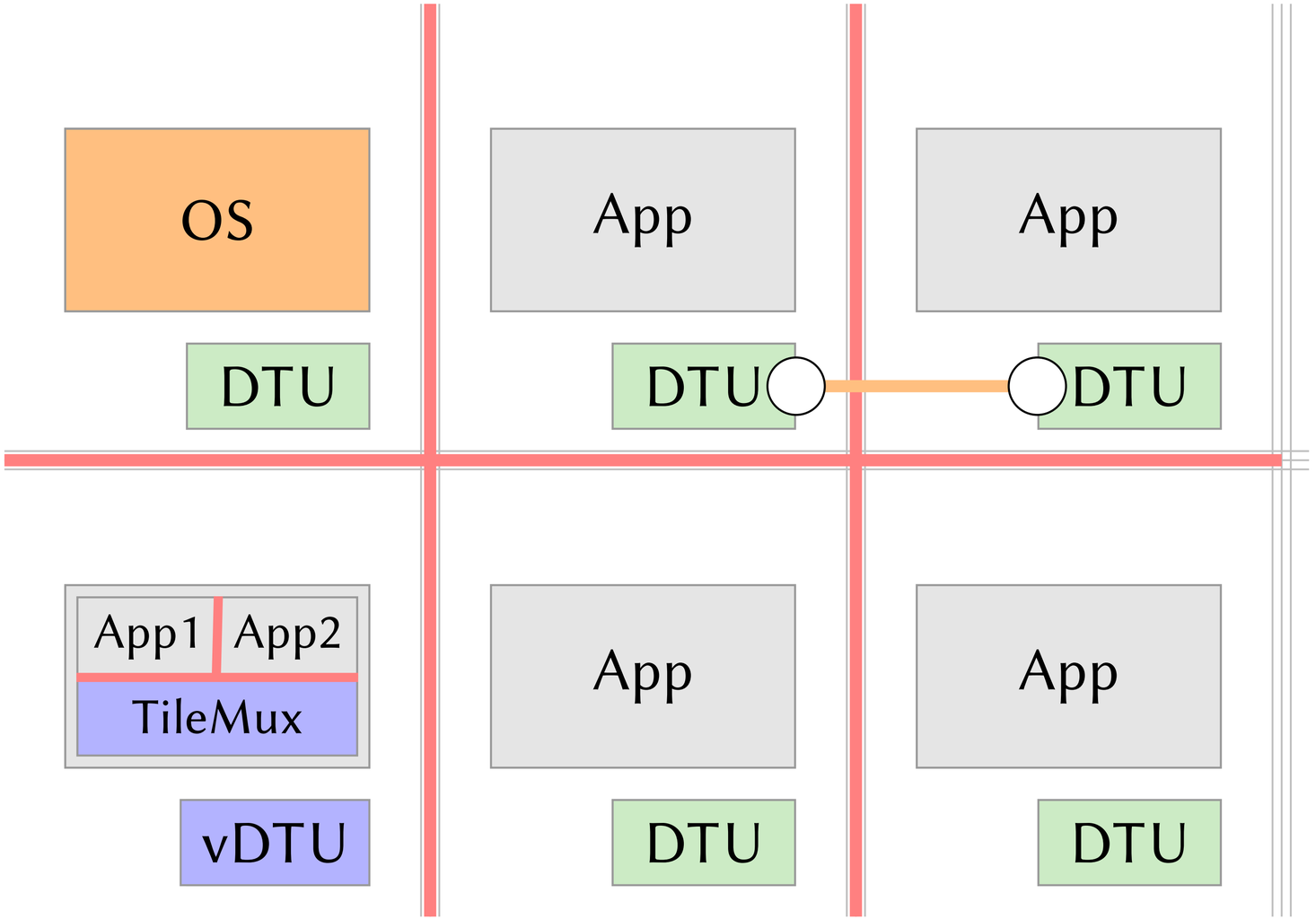
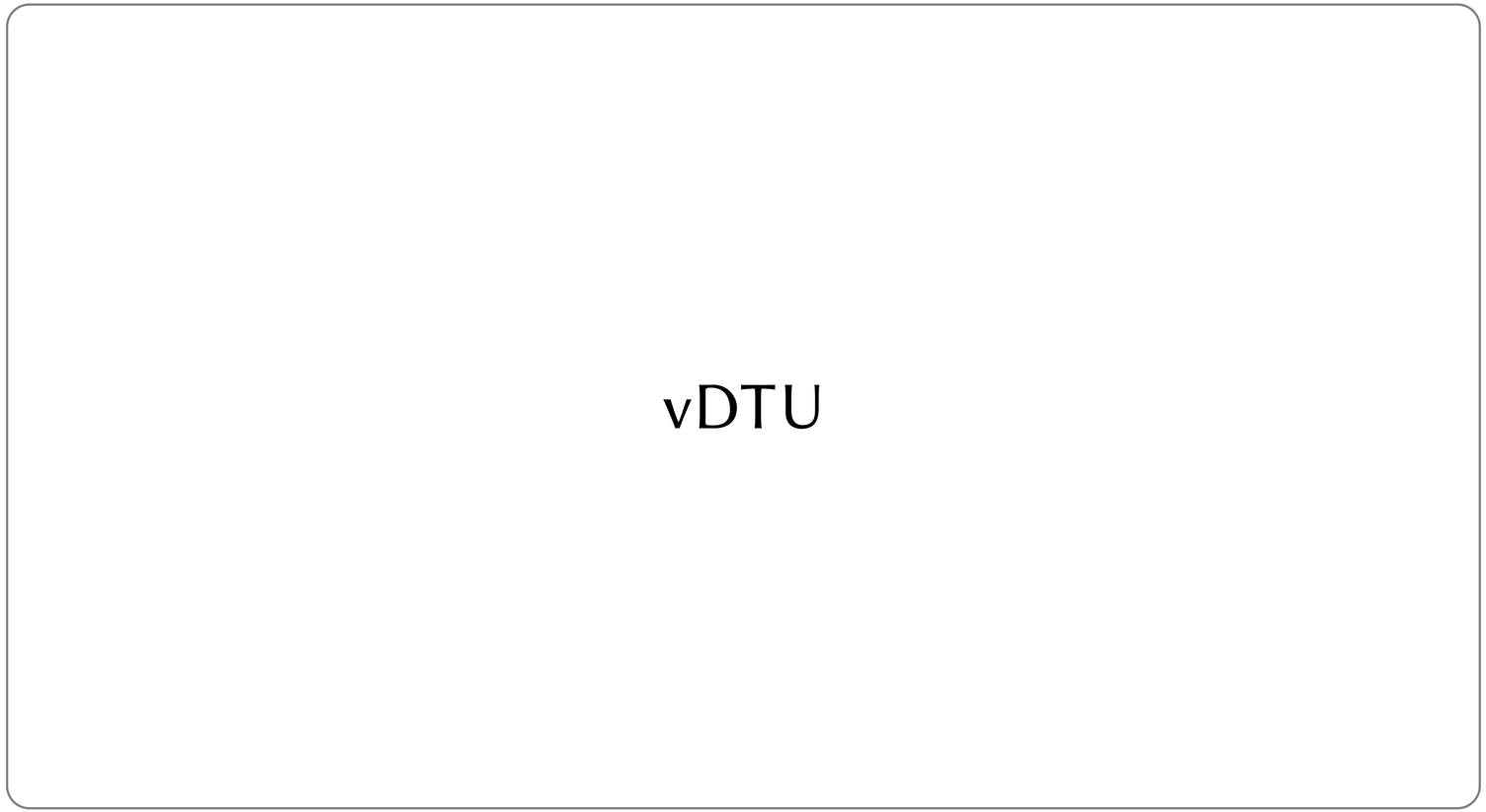
Multiplexing vs. Tile Isolation

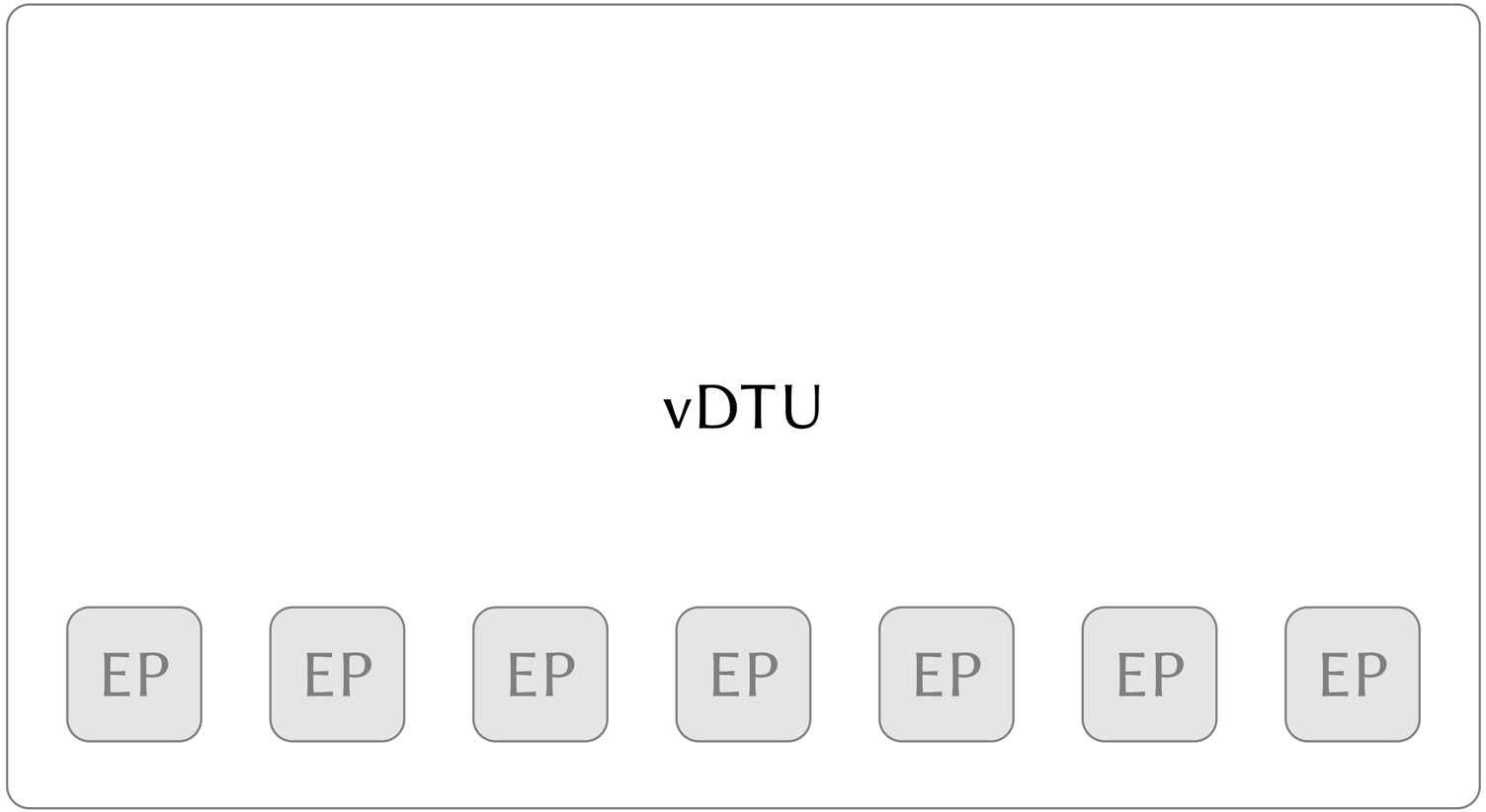


- M³* provides better isolation than conventional architectures
- M³x and M³v trade some isolation for better resource utilization
- M³v trades some more isolation for better efficiency

Virtualizing the DTU



Virtualizing the DTU



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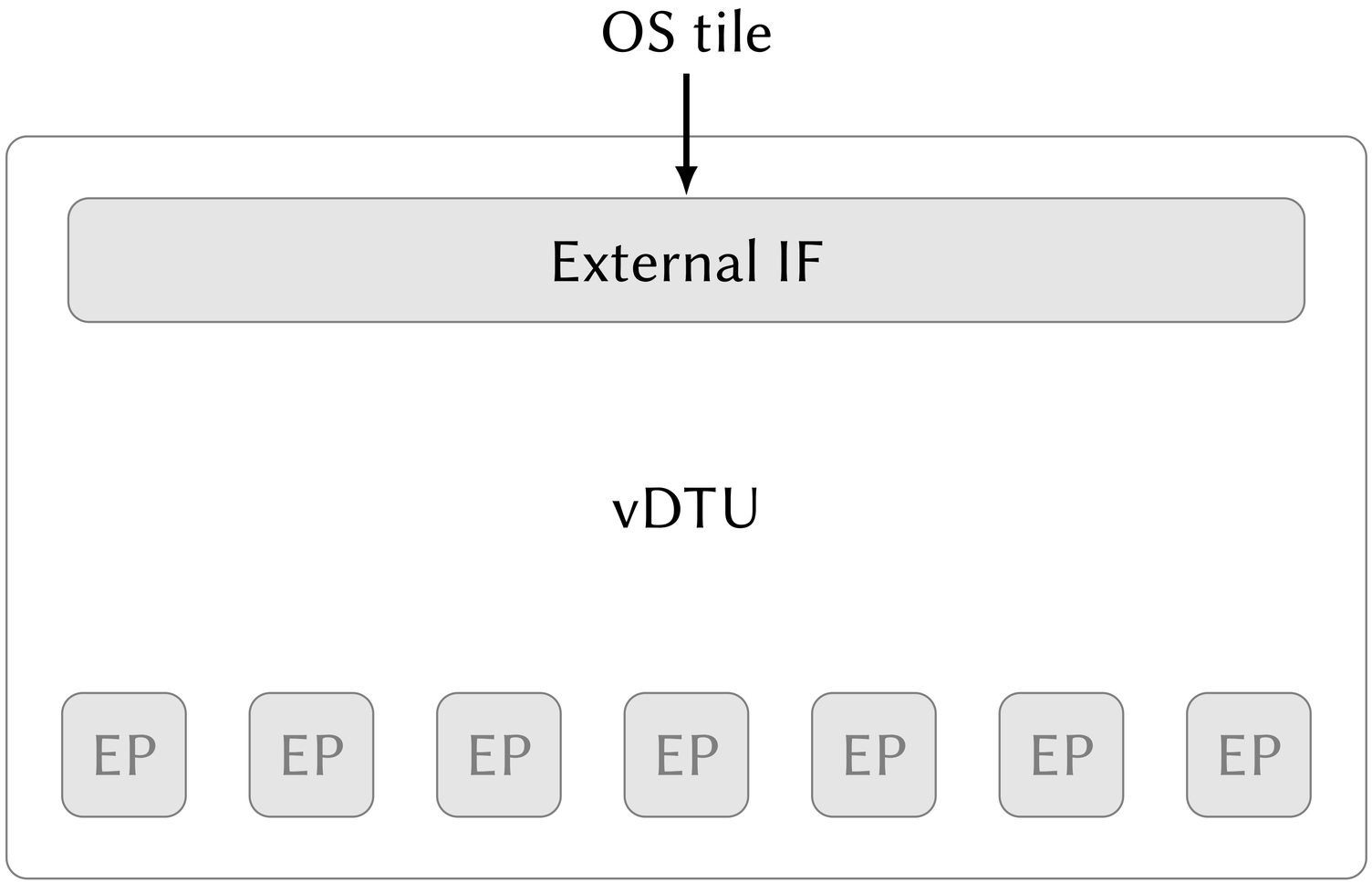

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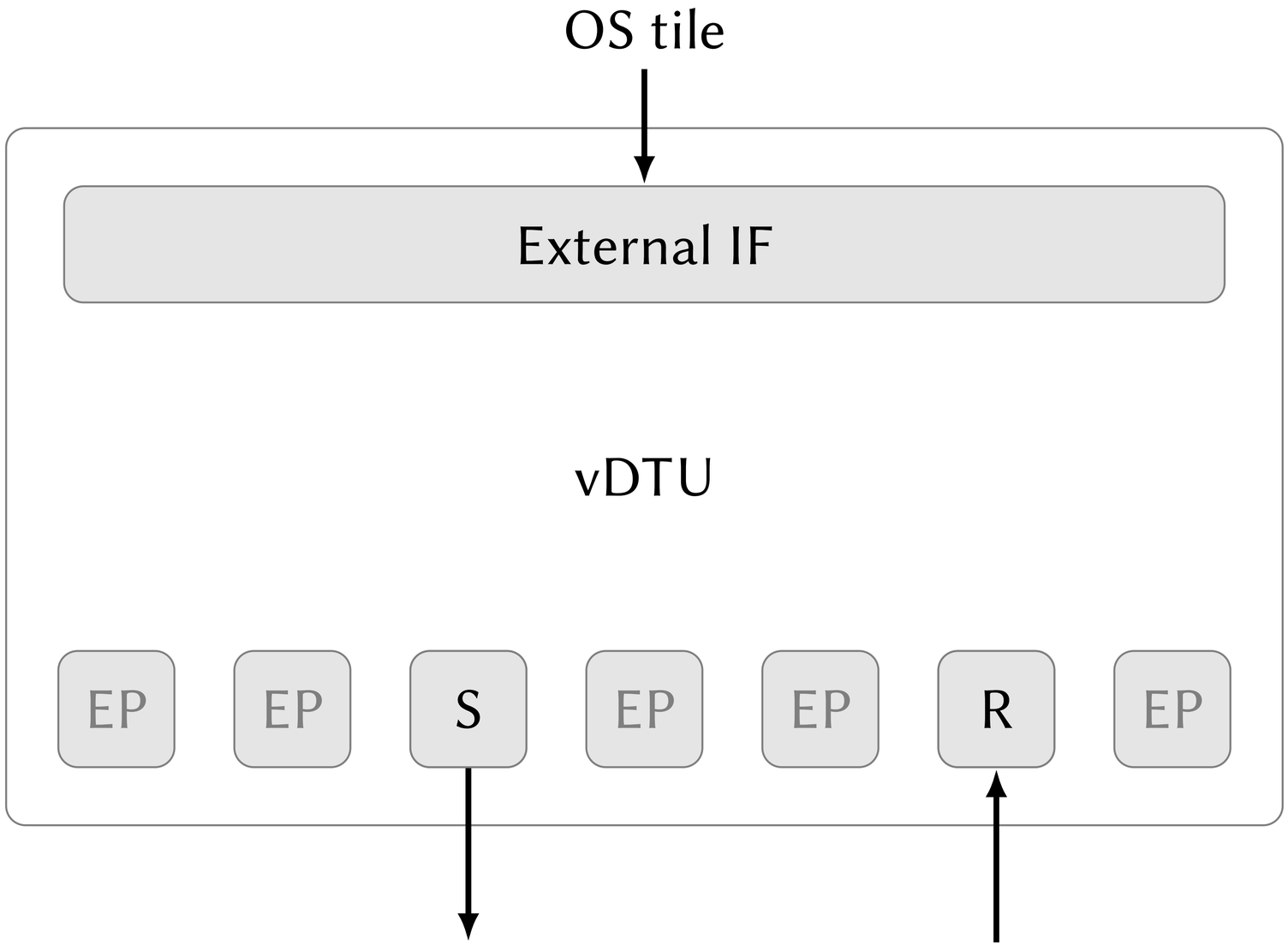

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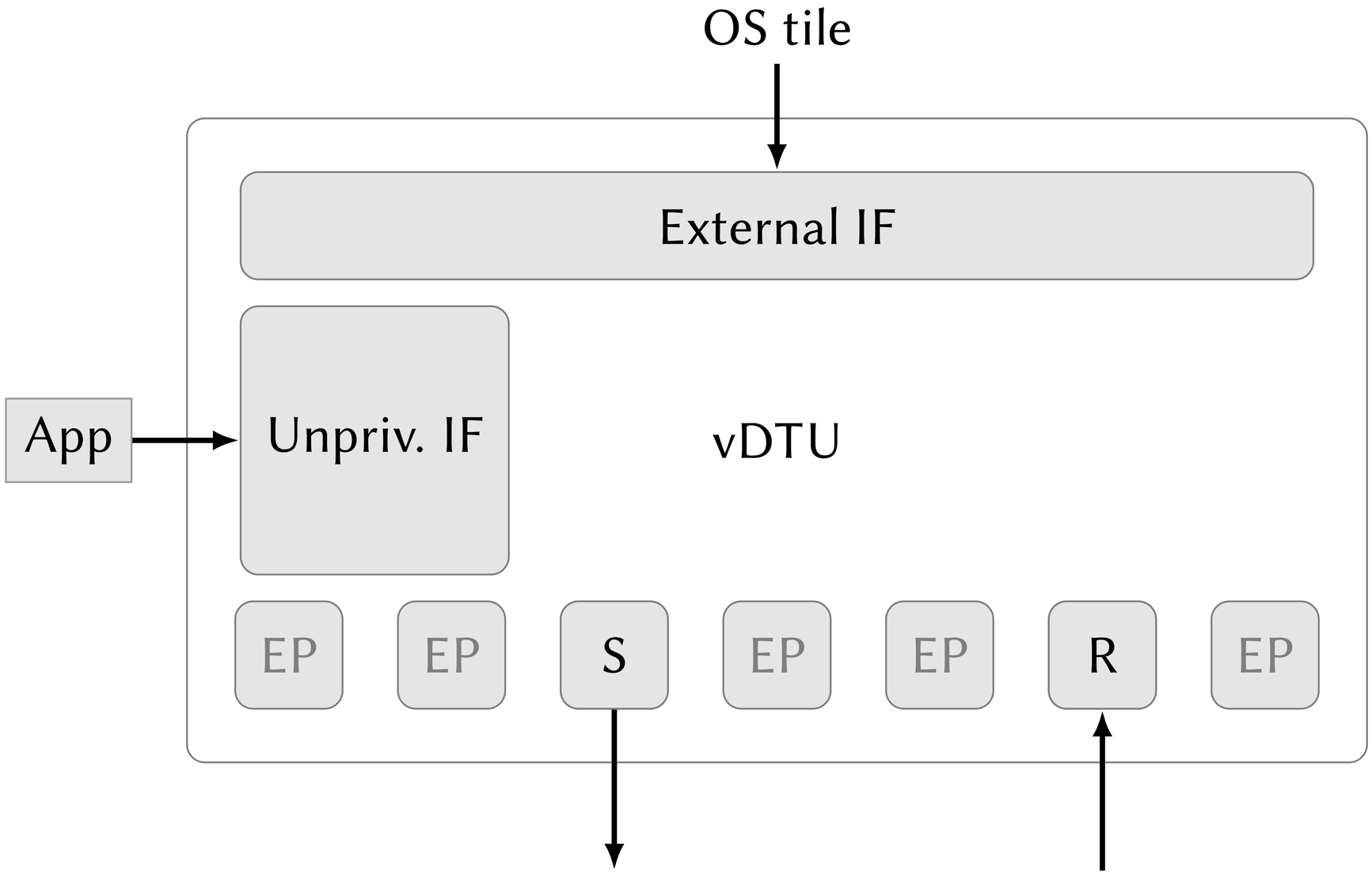

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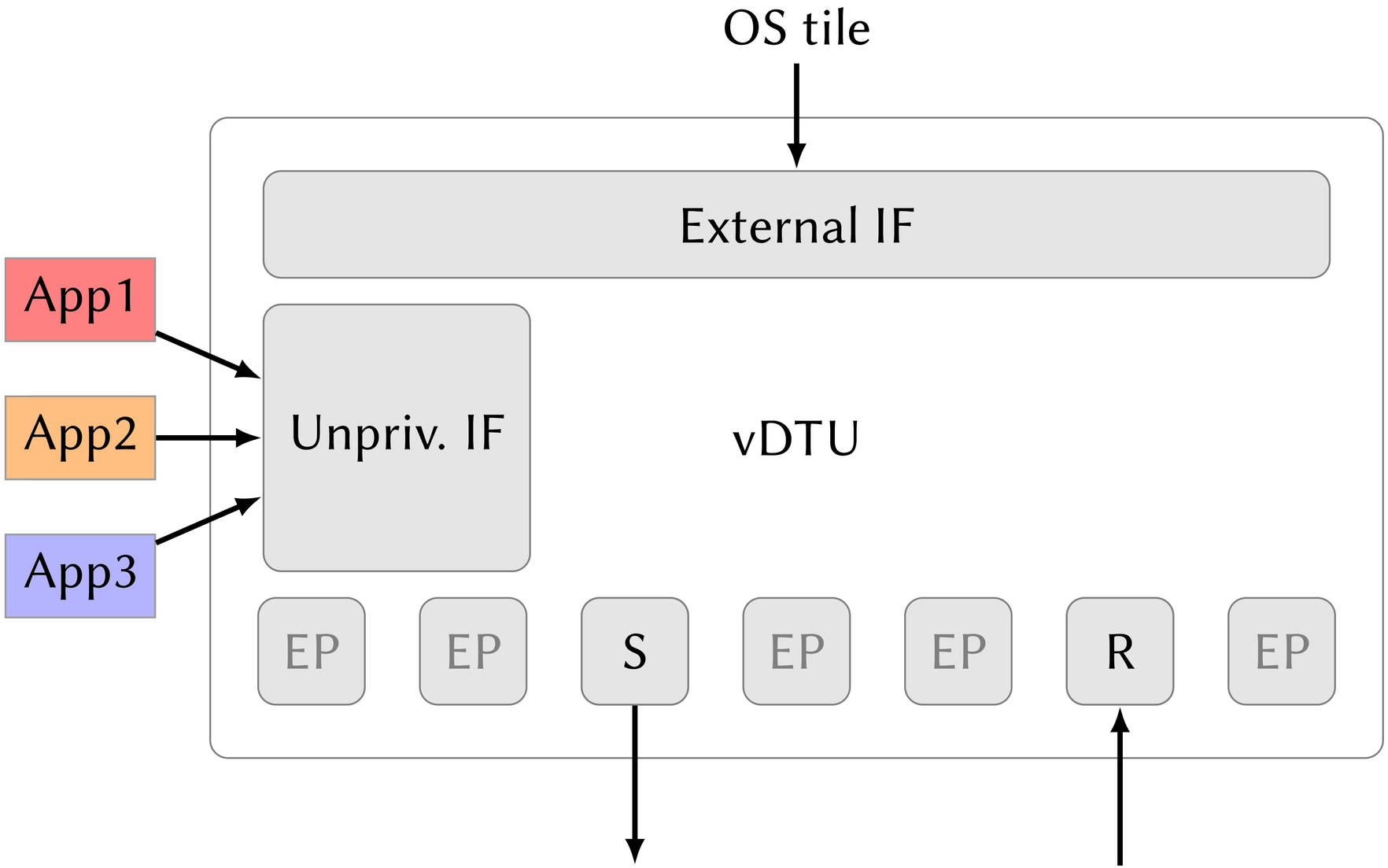

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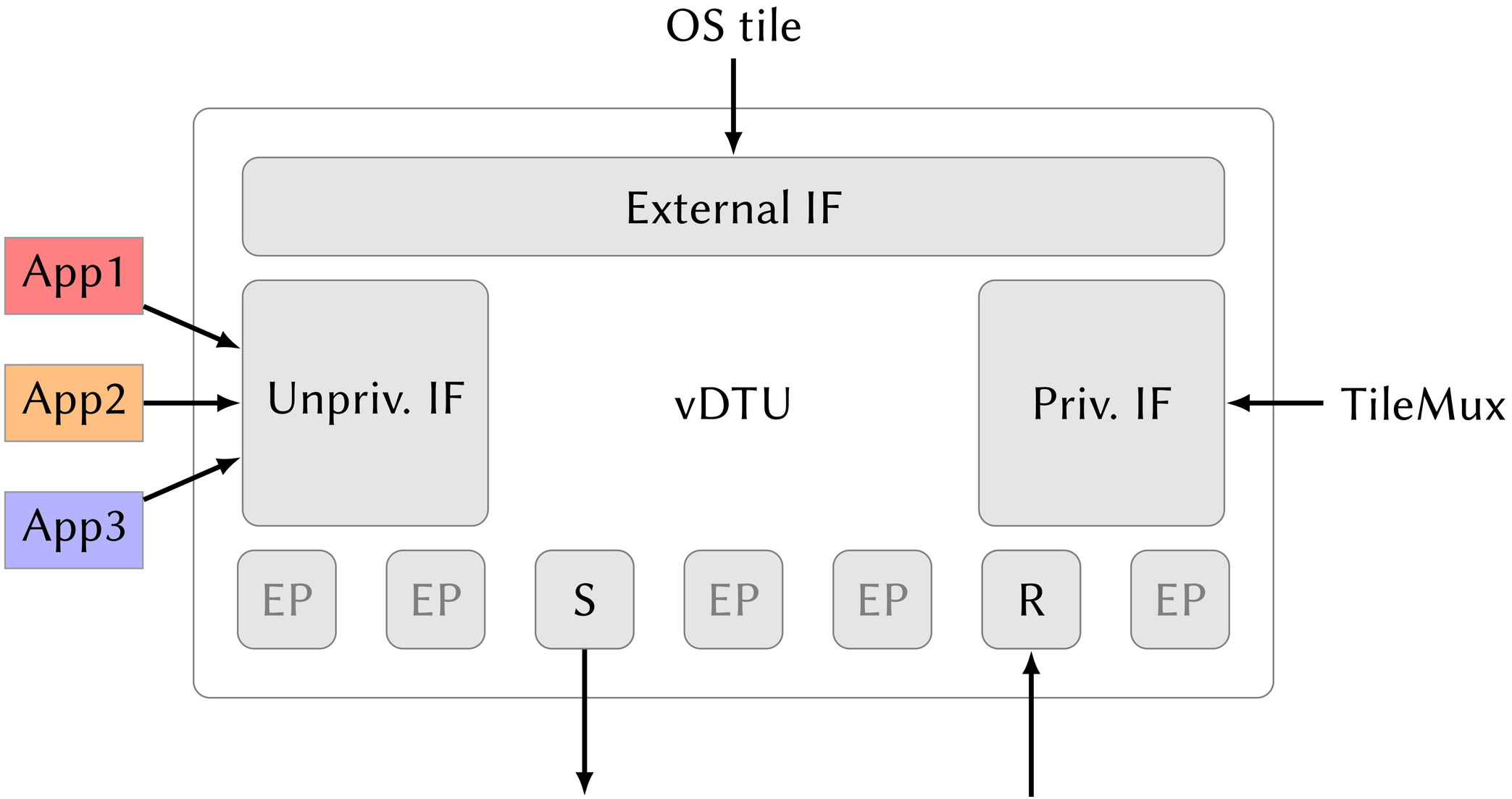

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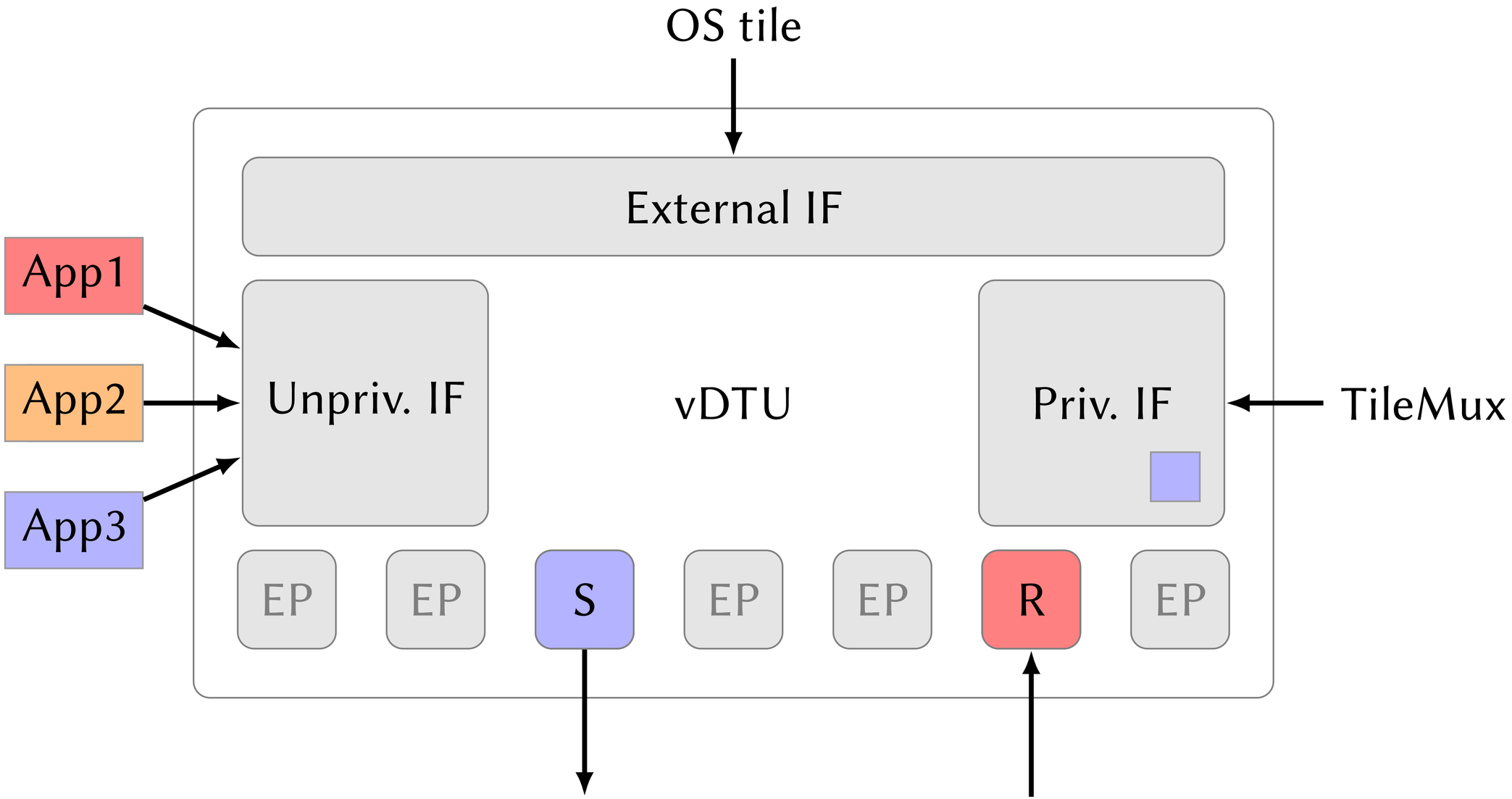

Blocking Applications

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- race condition: check for new message and blocking (like lost wakeup)

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- privileged interface can atomically switch to a new application

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- OS tile never involved, TileMux only involved if receiver is not running

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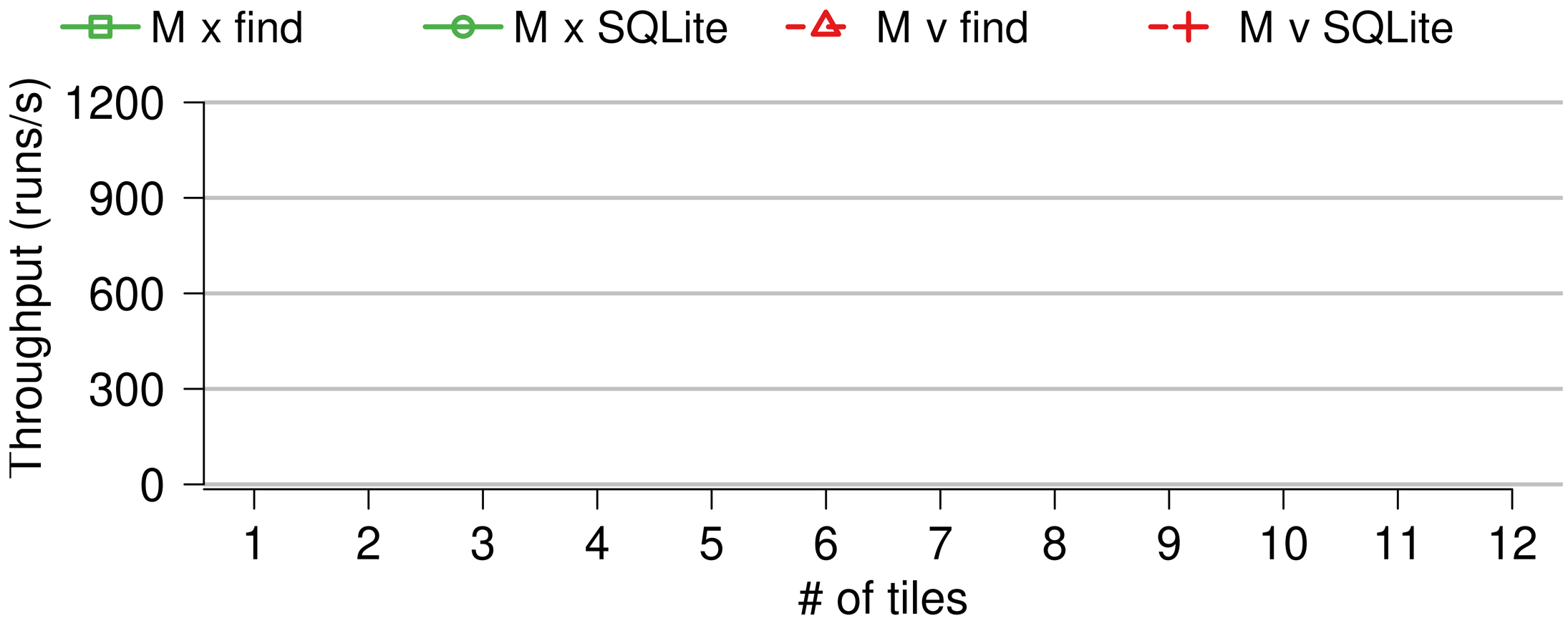

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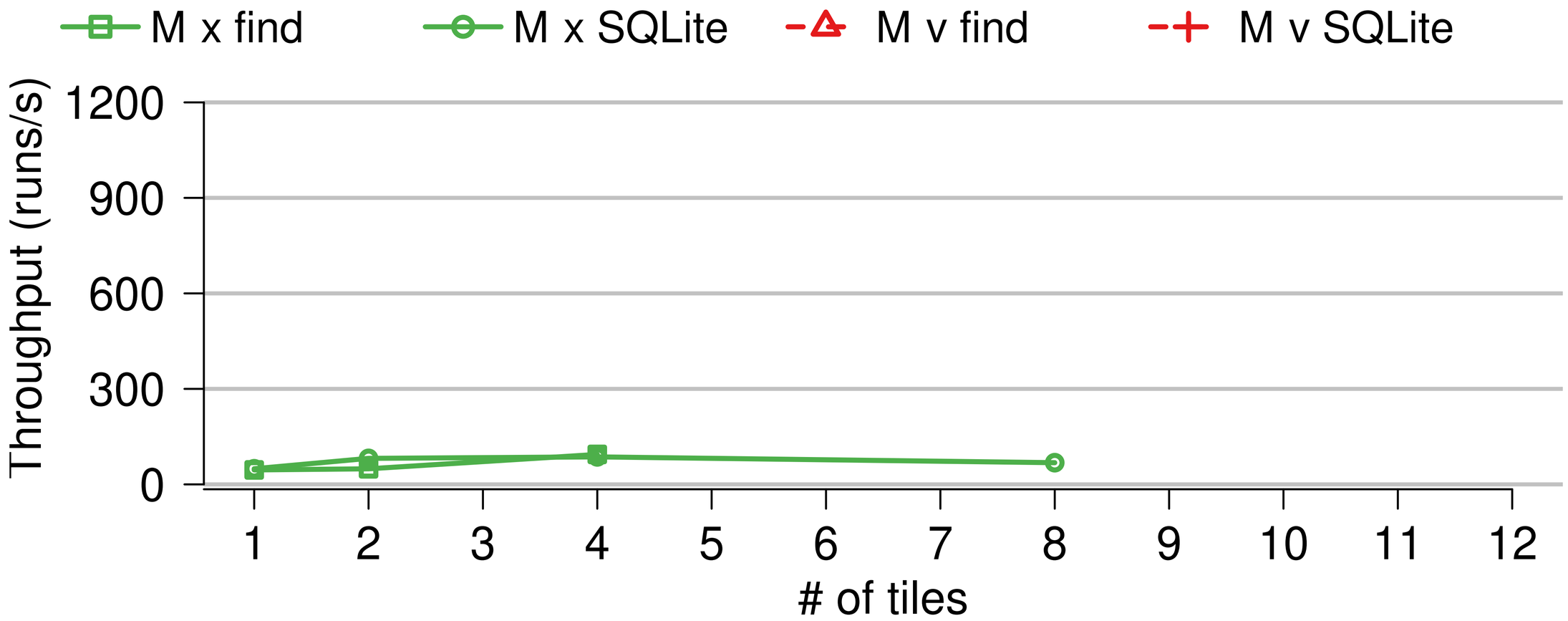

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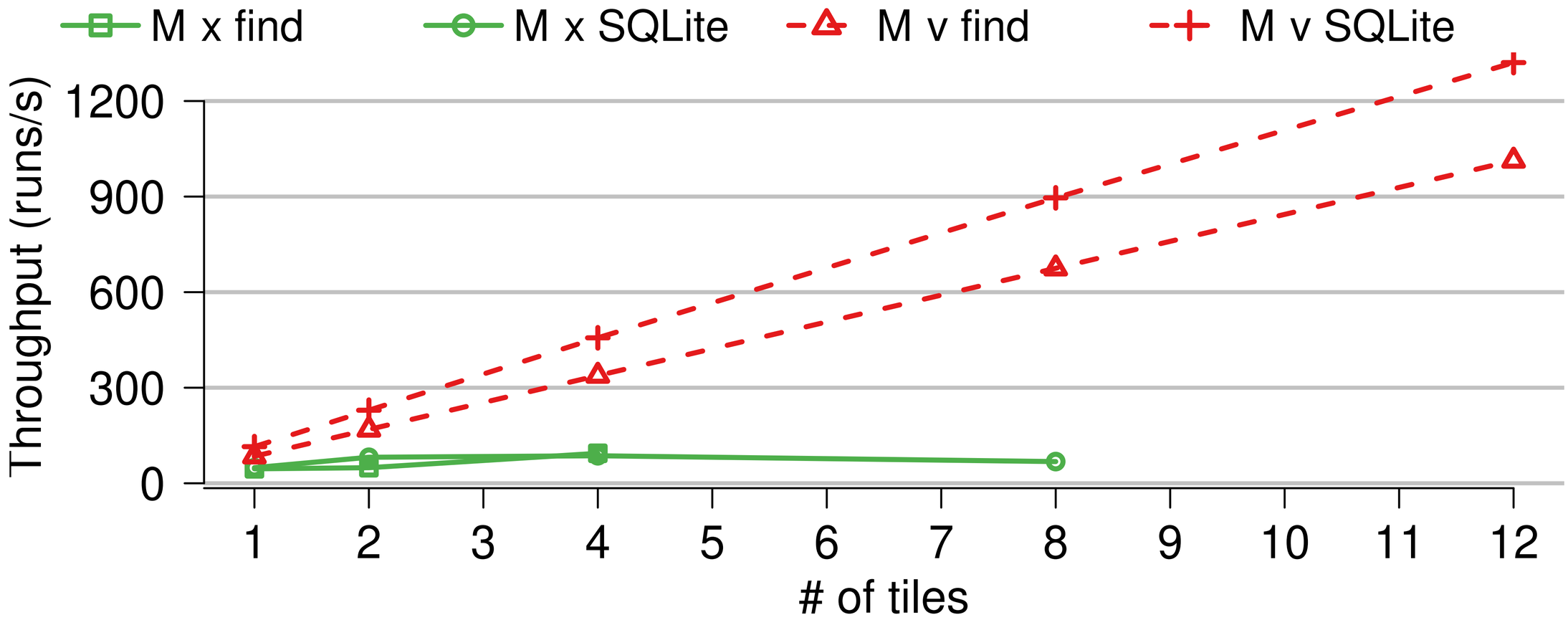

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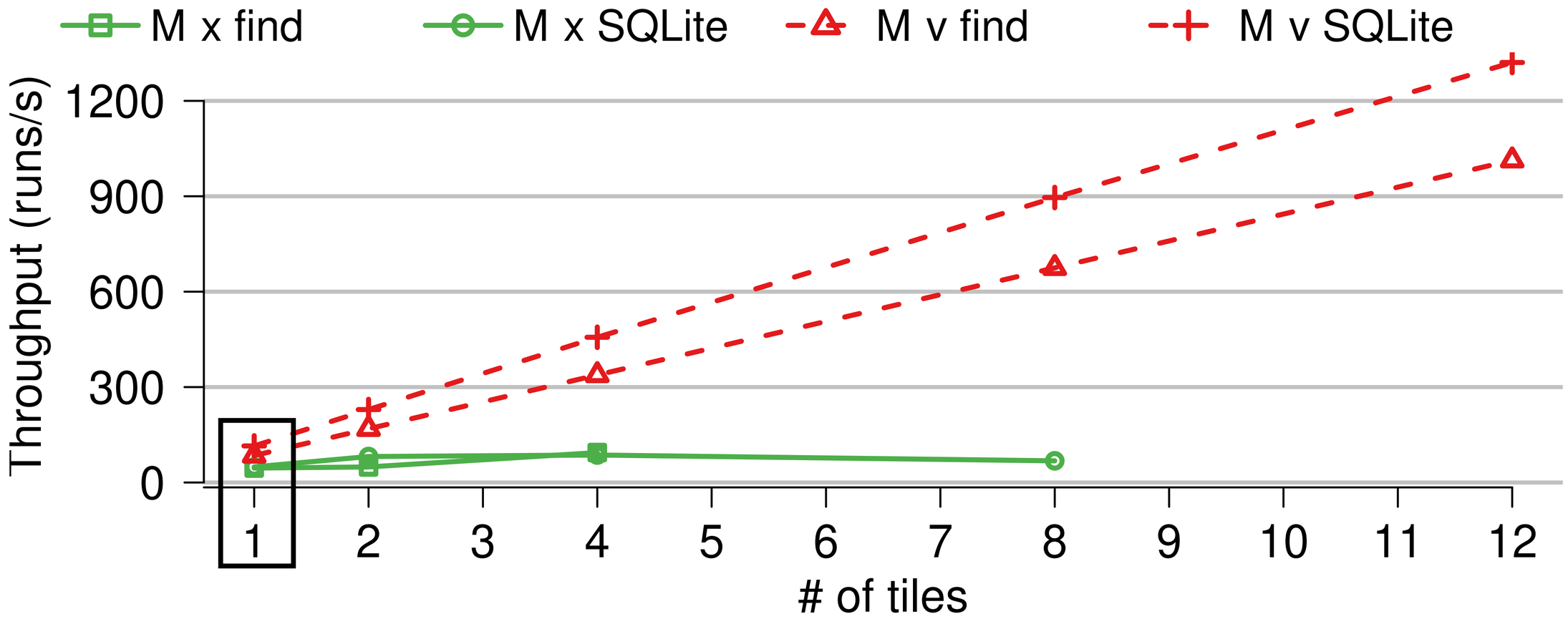

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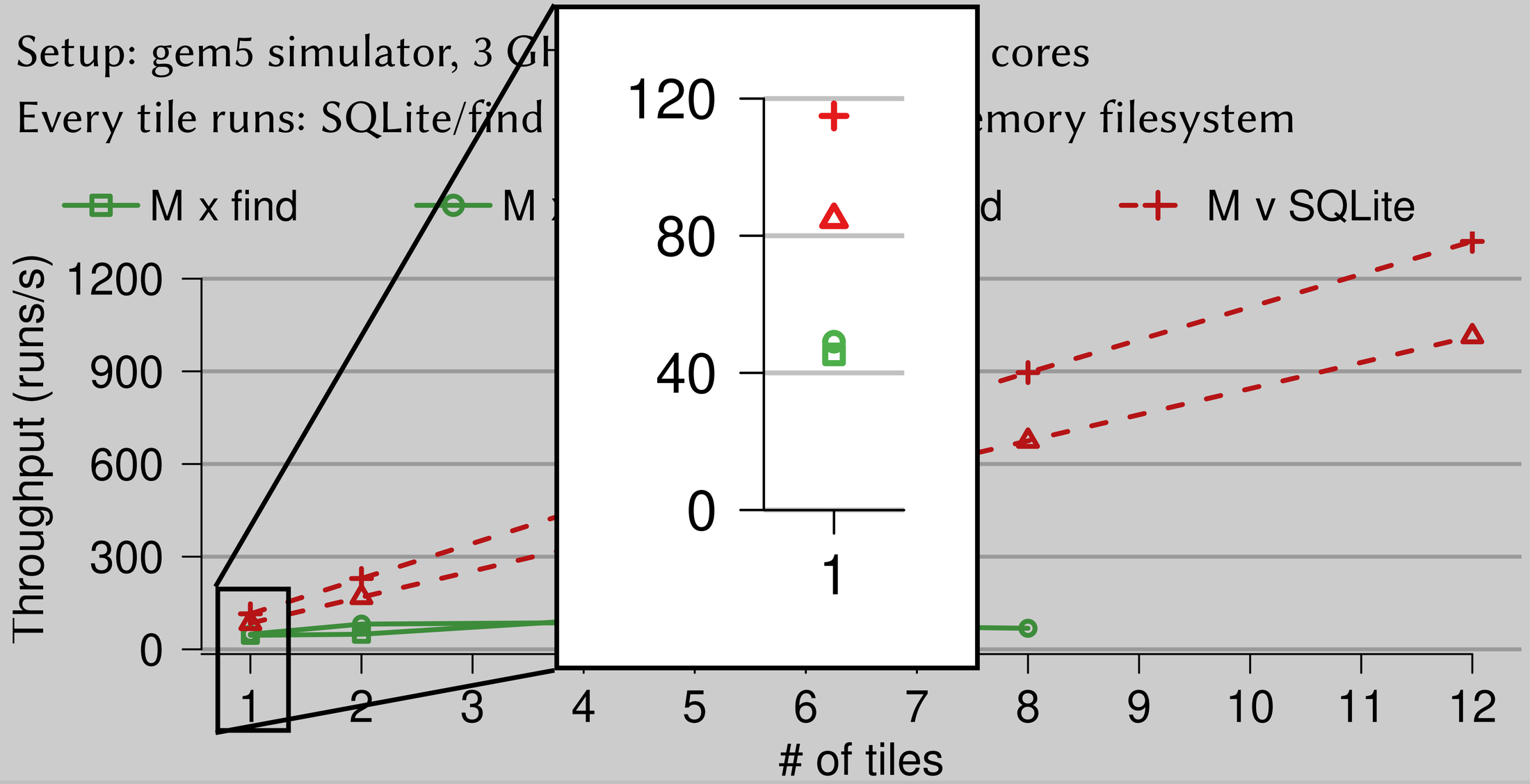

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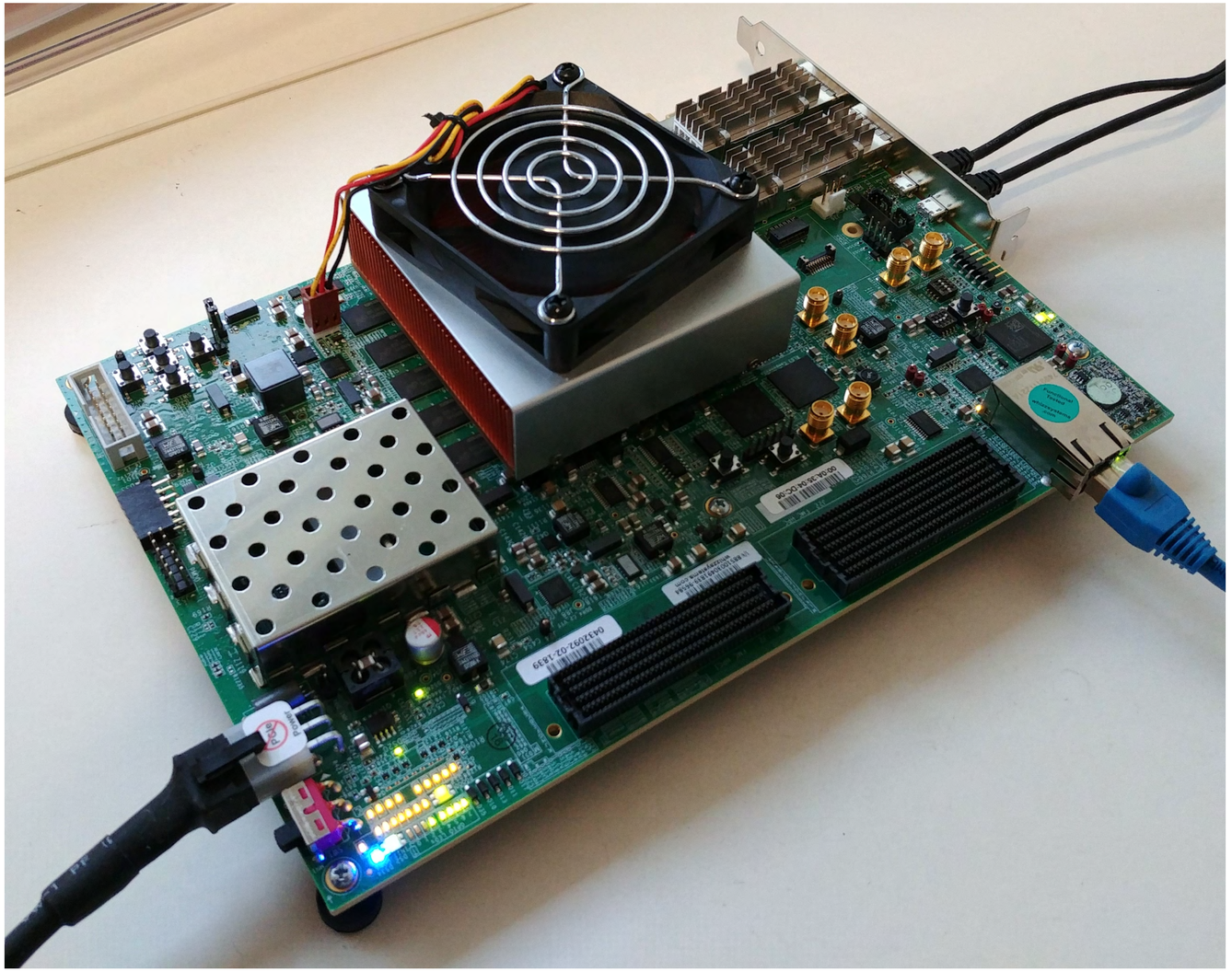

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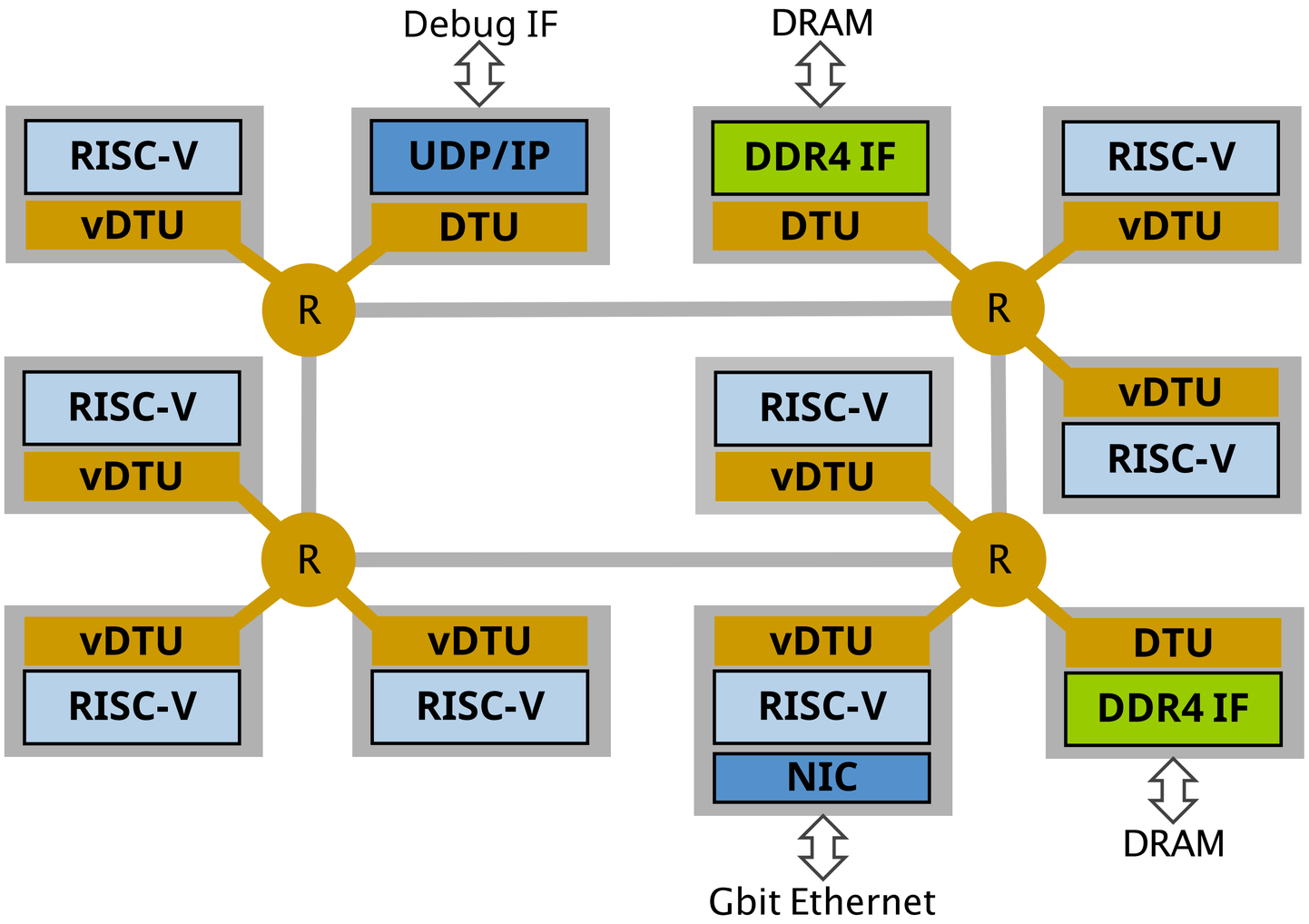

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- RISC-V: in-order Rocket or out-of-order BOOM
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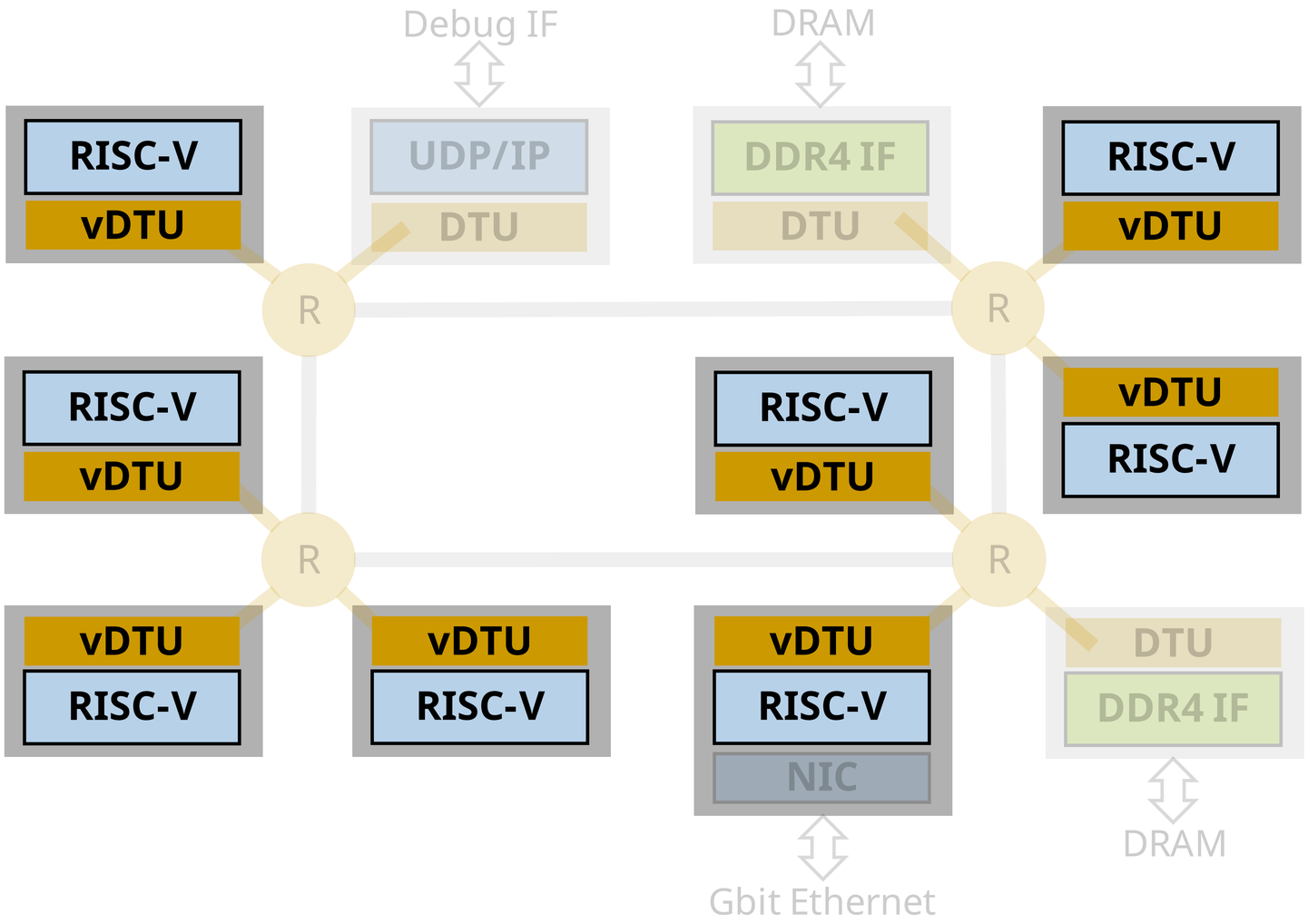

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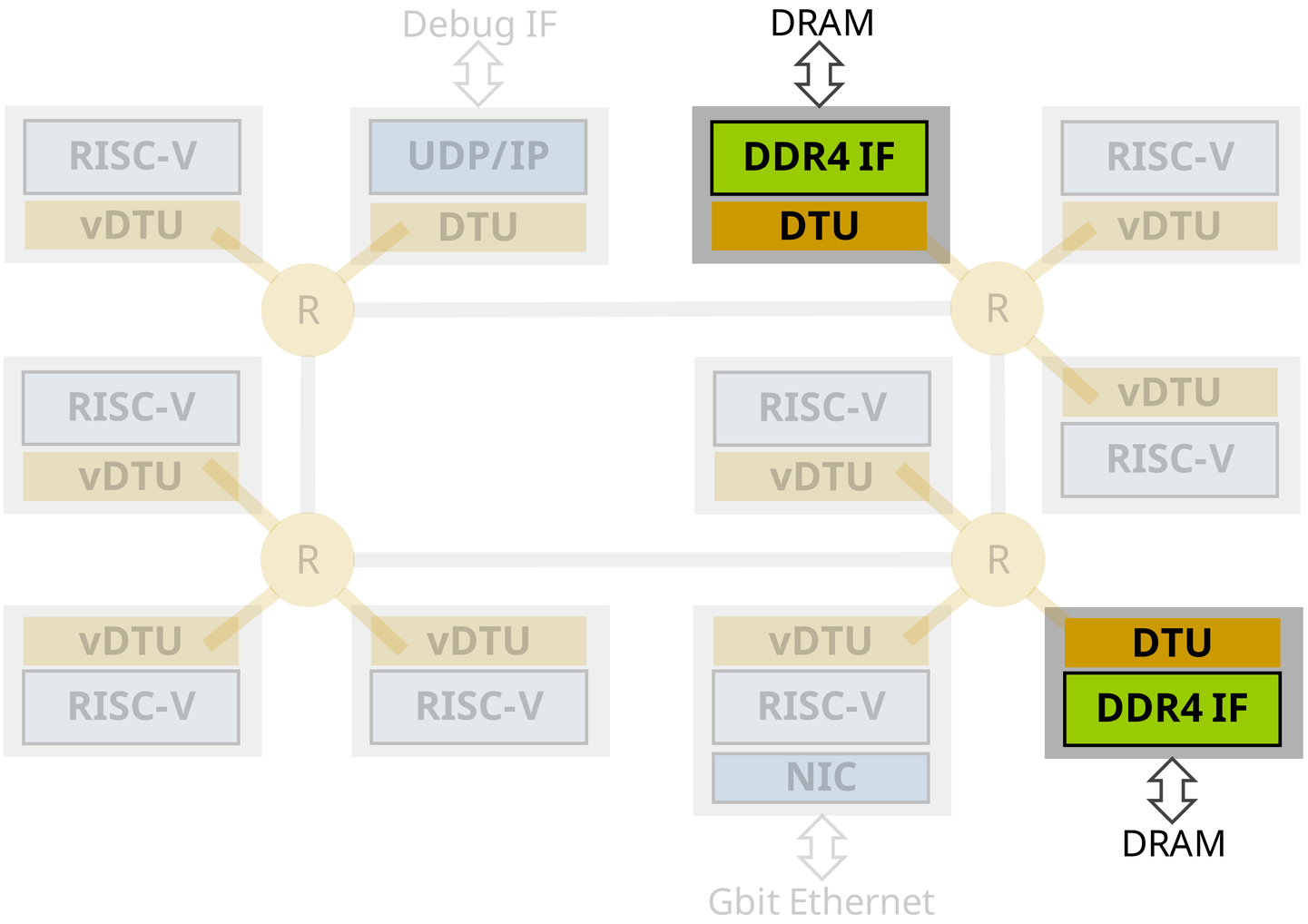

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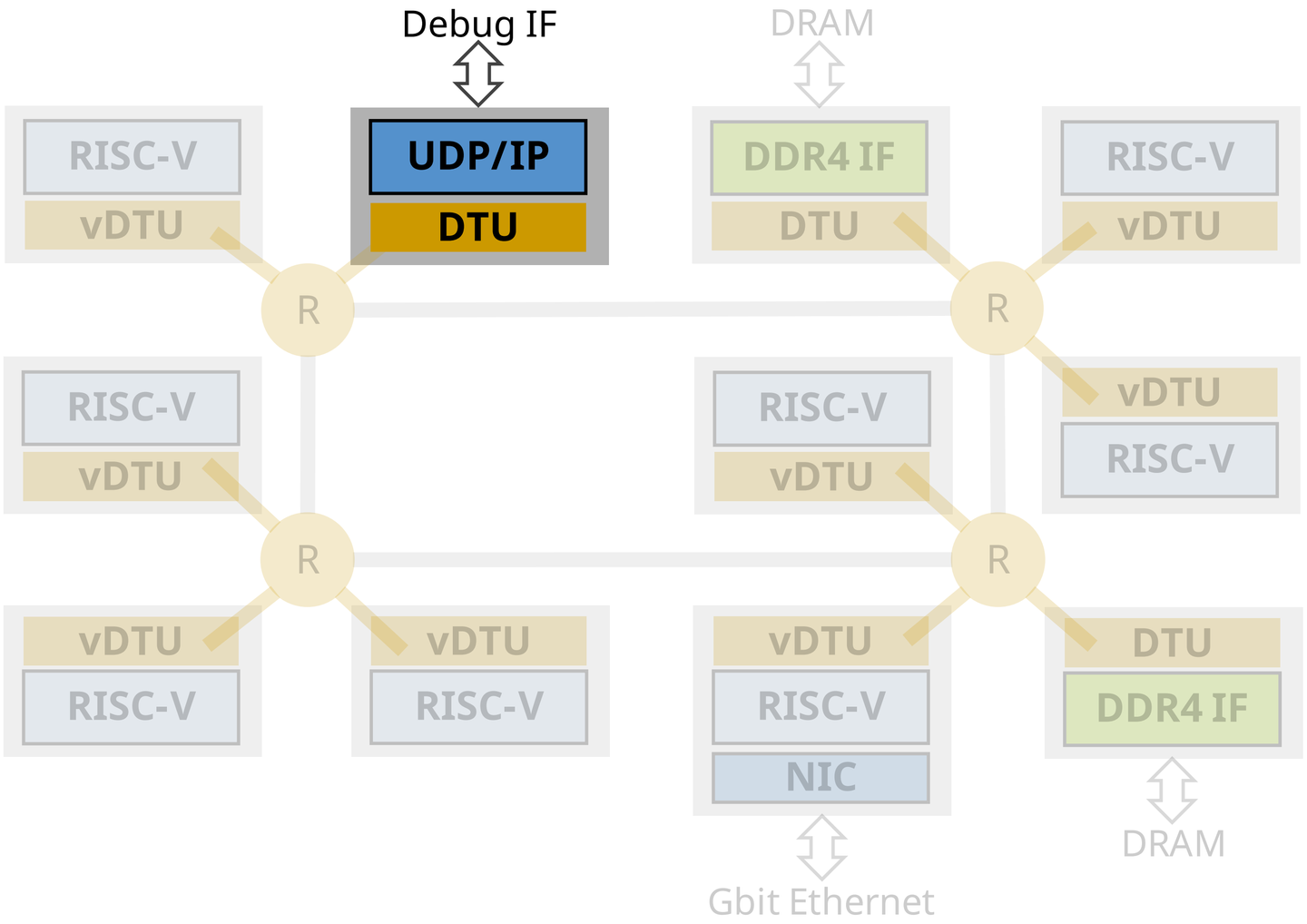

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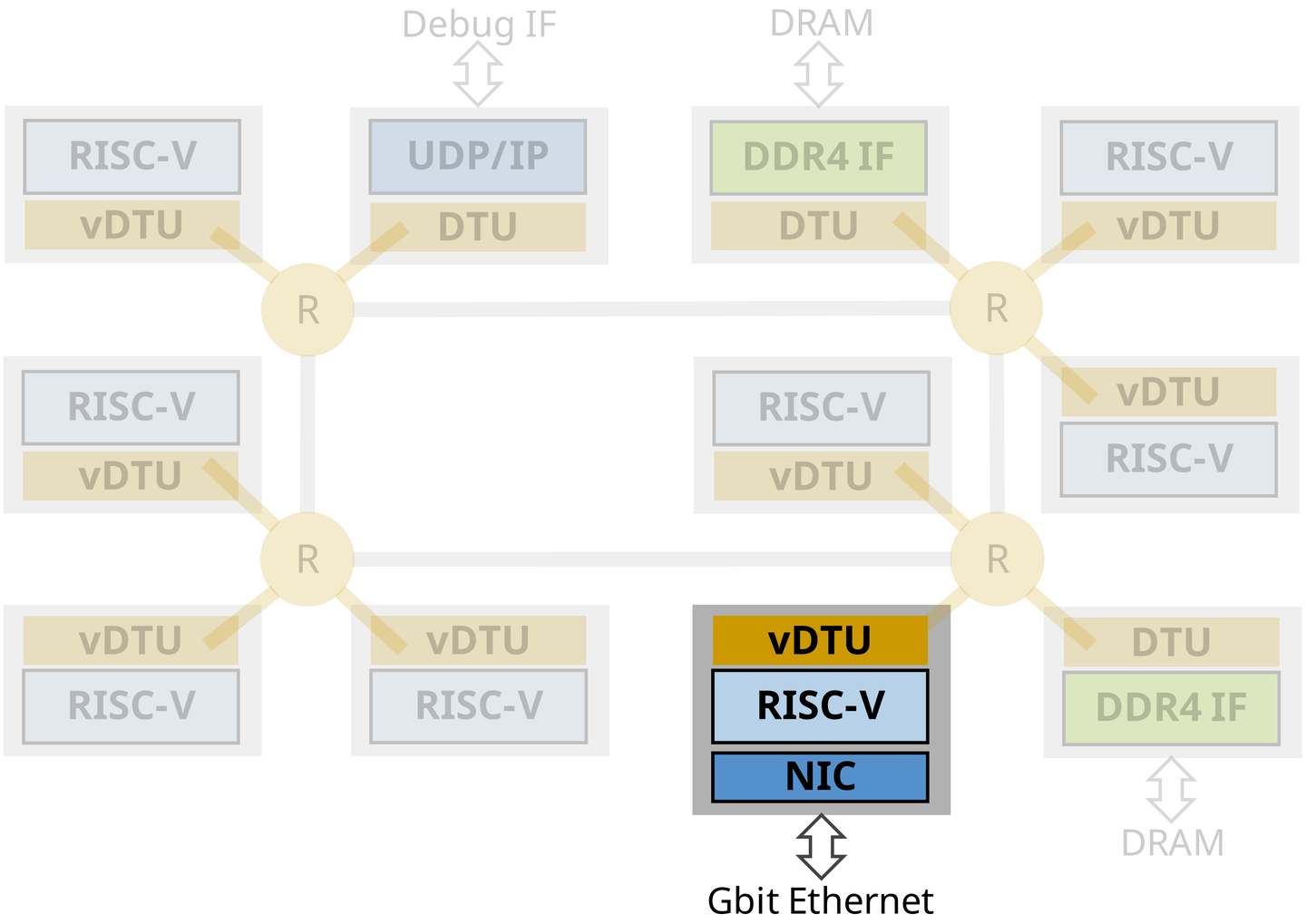

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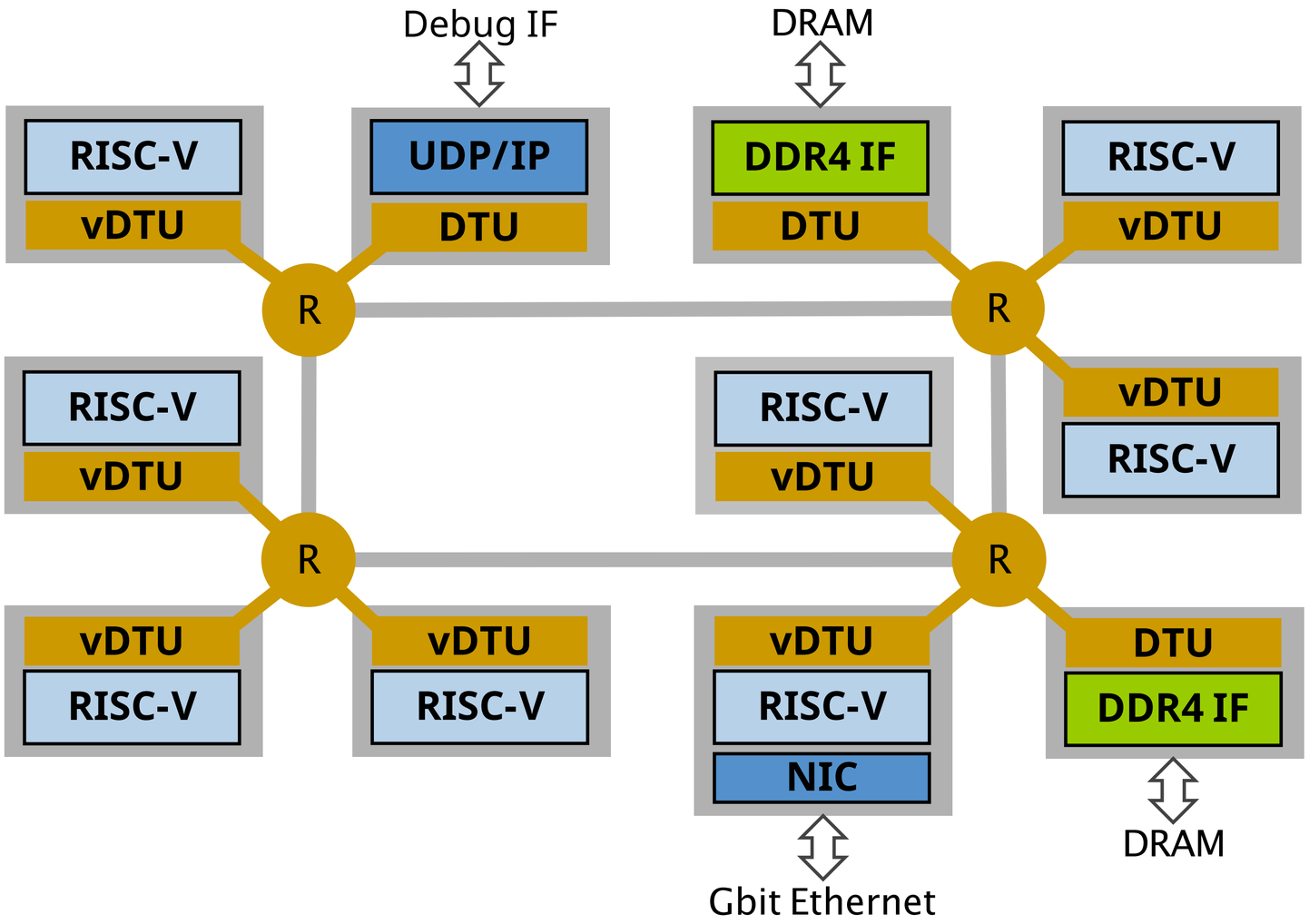

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DTU Size and Complexity

	LUTs [k]	FFs [k]	BRAMs
BOOM	143.8	71.8	159
Rocket	46.6	22.0	152
NoC router	3.4	2.2	0
vDTU	15.2	5.8	0.5
Control Unit	10.3	3.3	0.5
NoC CTRL	3.2	1.5	0
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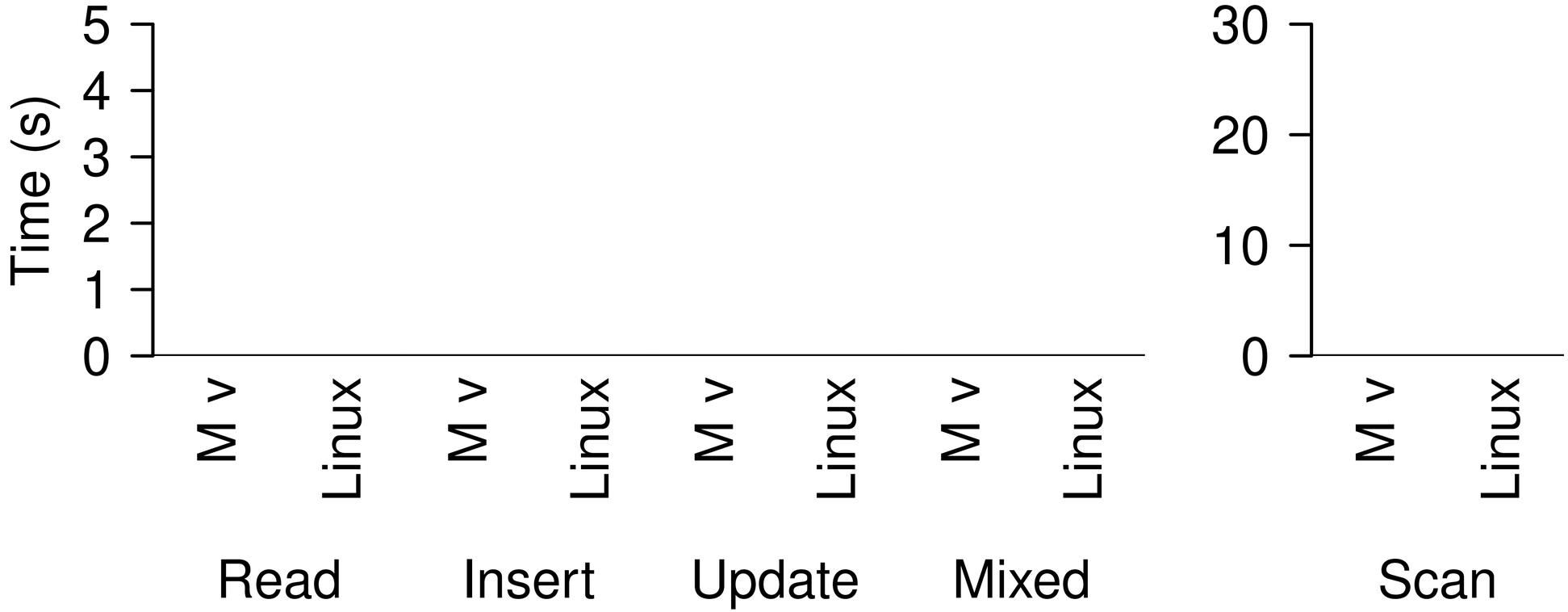

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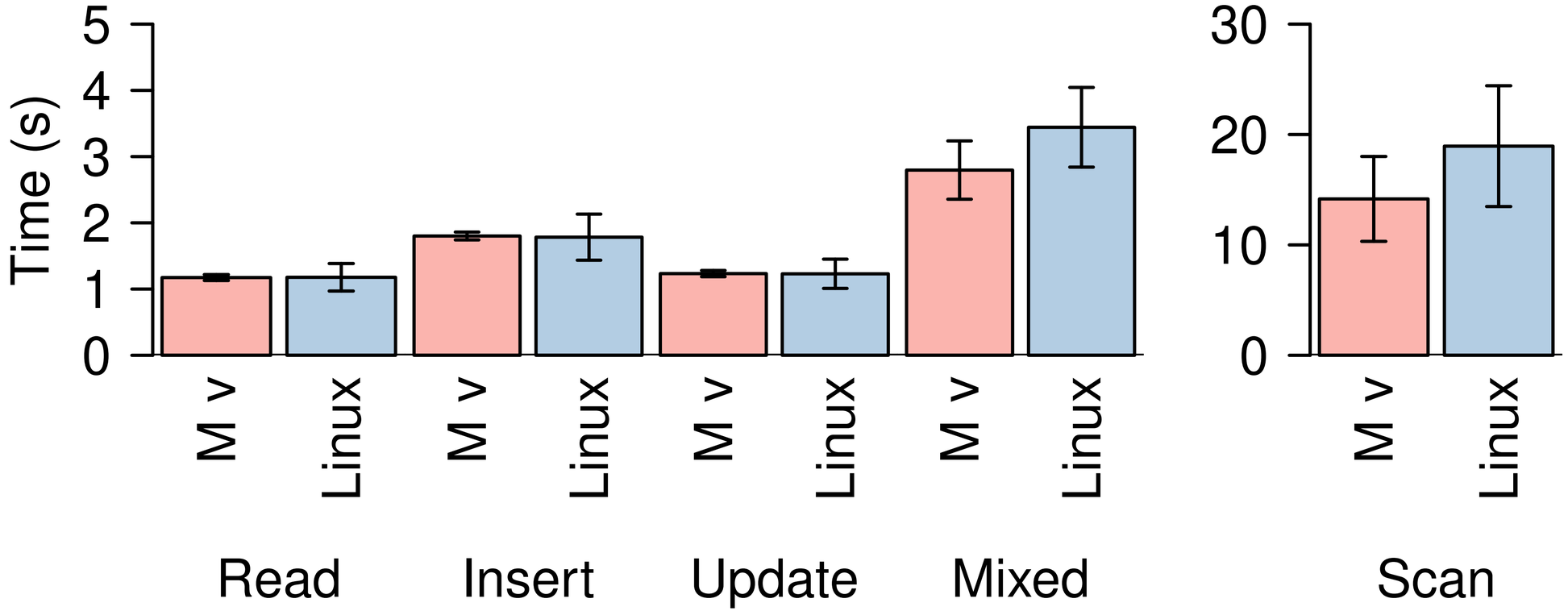

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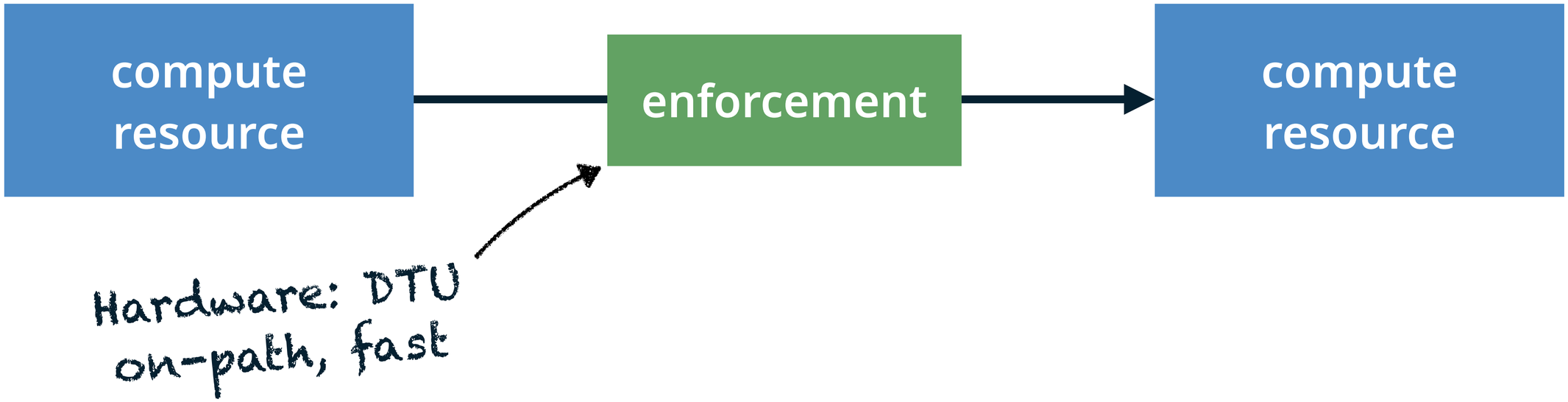

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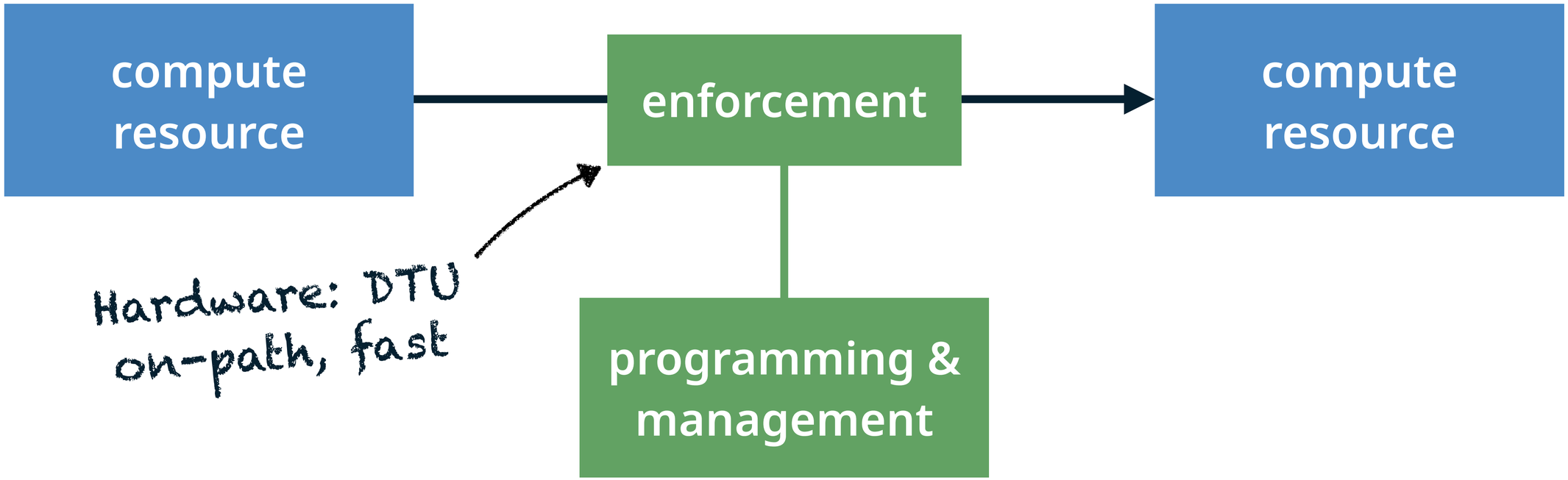

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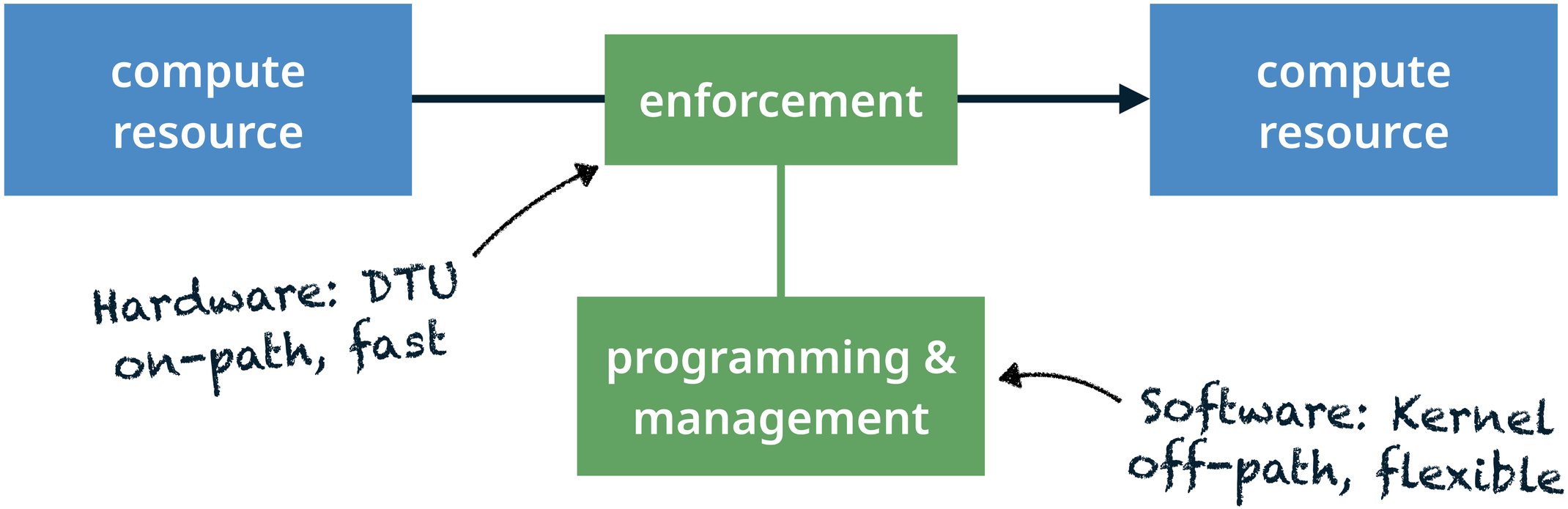

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