Gemmini: Enabling Systematic Deep-Learning Architecture Evaluation via Full-Stack Integration

Hasan Genc, Seah Kim, Alon Amid, Ameer Haj-Ali, Vighnesh Iyer, Pranav Prakash, Jerry Zhao, Daniel Grubb, Harrison Liew, Howard Mao, Albert Ou, Colin Schmidt, Samuel Steffl, John Wright, Ion Stoica, Jonathan Ragan-Kelley, Krste Asanovic, Borivoje Nikolic, Yakun Sophia Shao

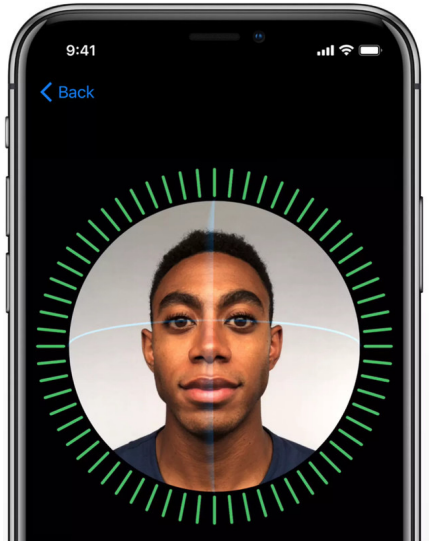
Quick Stats

- Best Paper at DAC 2021
- Tutorial at IISWC 2021
- DNN accelerator generator
  - Full-system, full-stack visibility
- Taped out
  - Intel22FL
    - ESSCIRC 2021
  - GF12
  - TSMC16

DNNs are exploding in popularity…

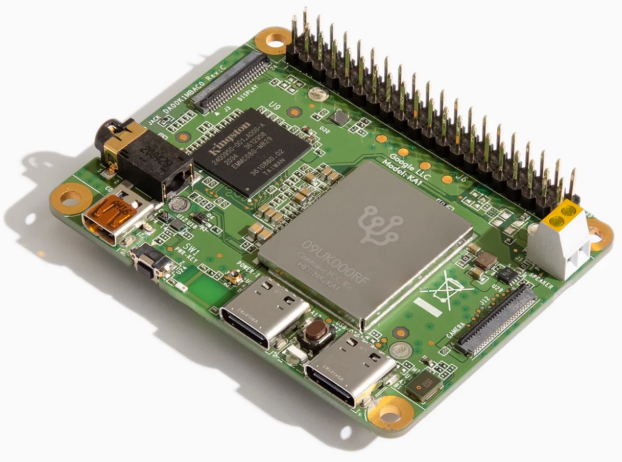
Matt Christenson/BLM/2017

By Dllu - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=64517567

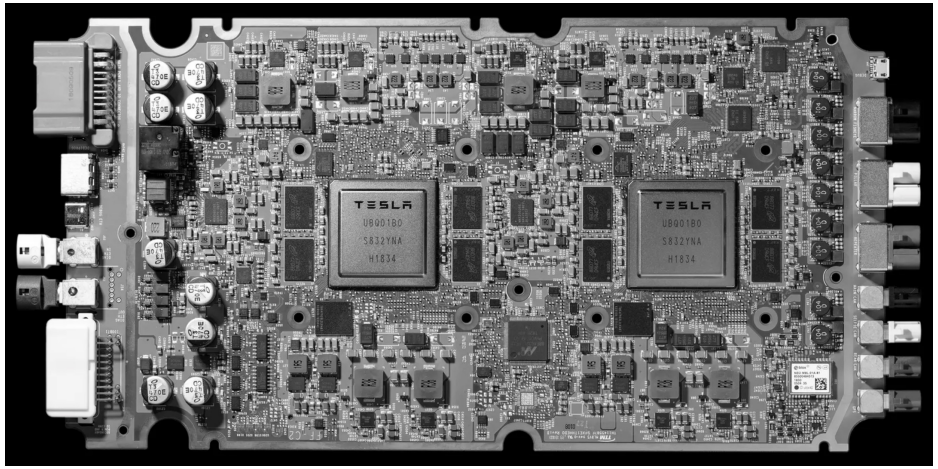


Apple Support

Which means DNN **ACCELERATORS** are exploding in popularity…



Edge TPU



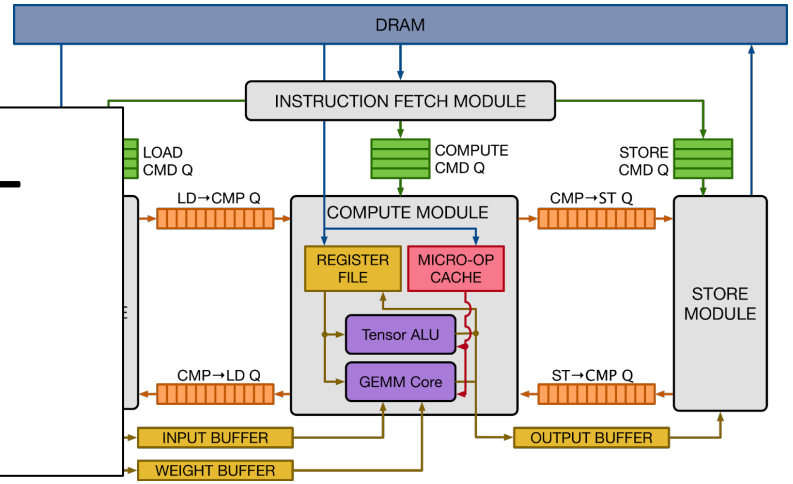
Tesla FSD

Cloud TPU

Which means DNN accelerator **GENERATORS** are exploding in popularity…

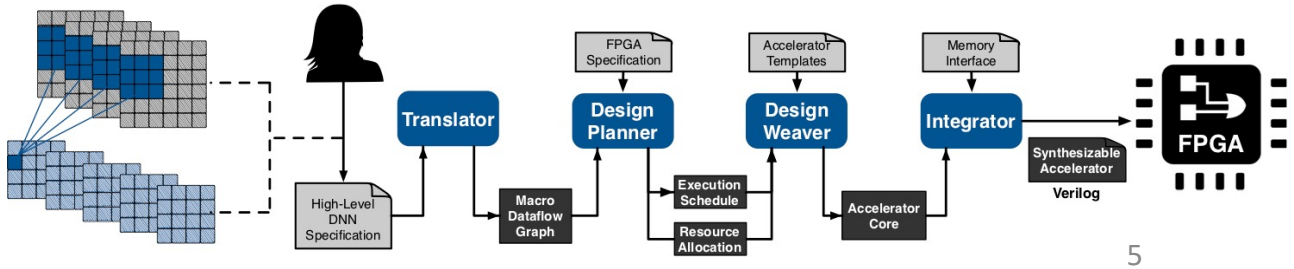
NVDLA.org

VTA

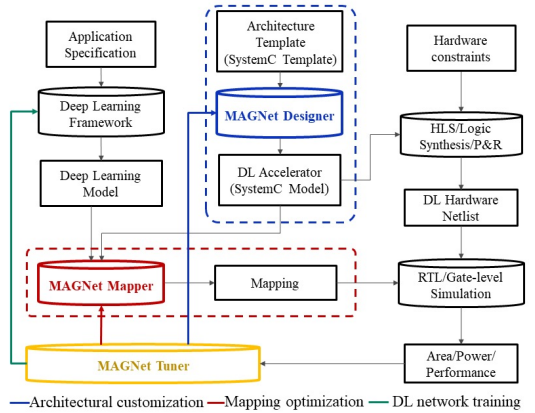


However, they lack full-system and full-stack visibility

DNNWeaver

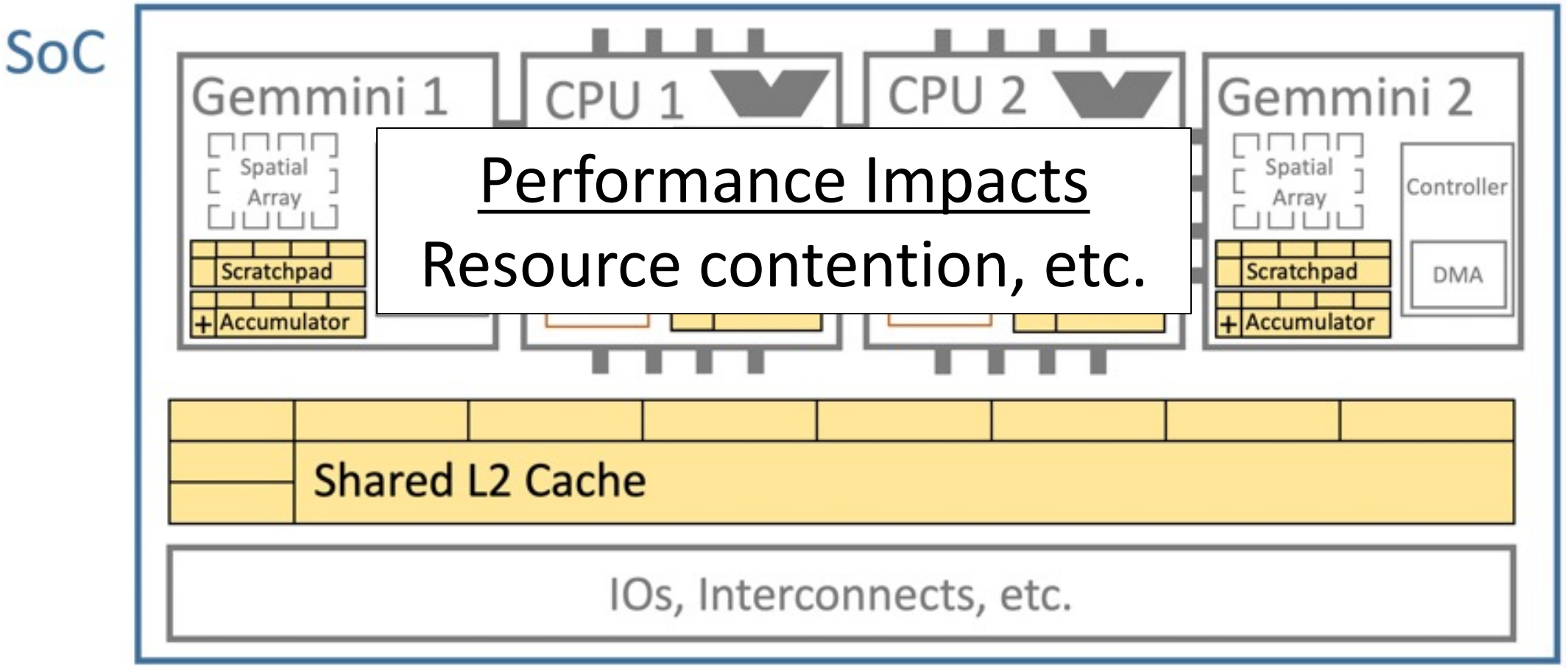


MAGNet

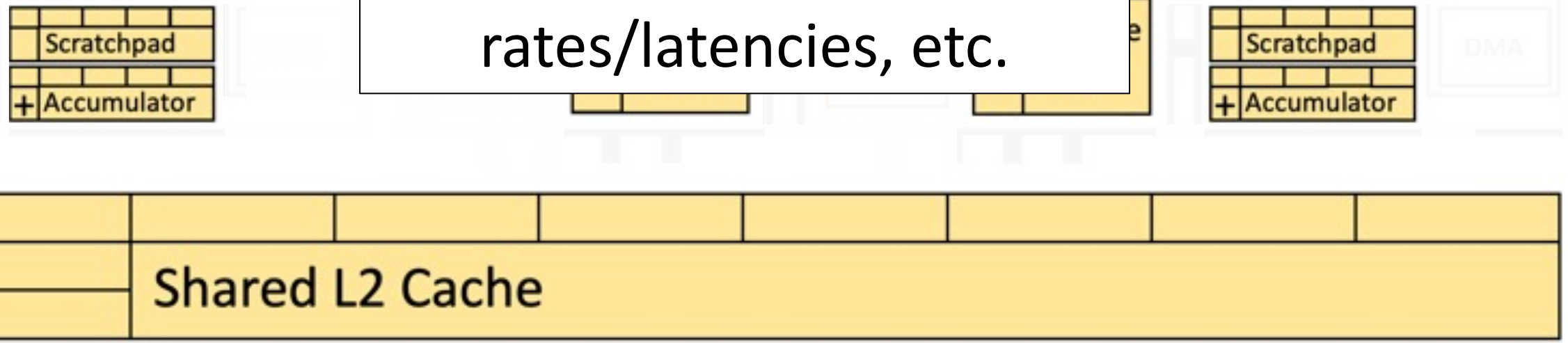


Full-System Visibility

Full-System Visibility: SoC



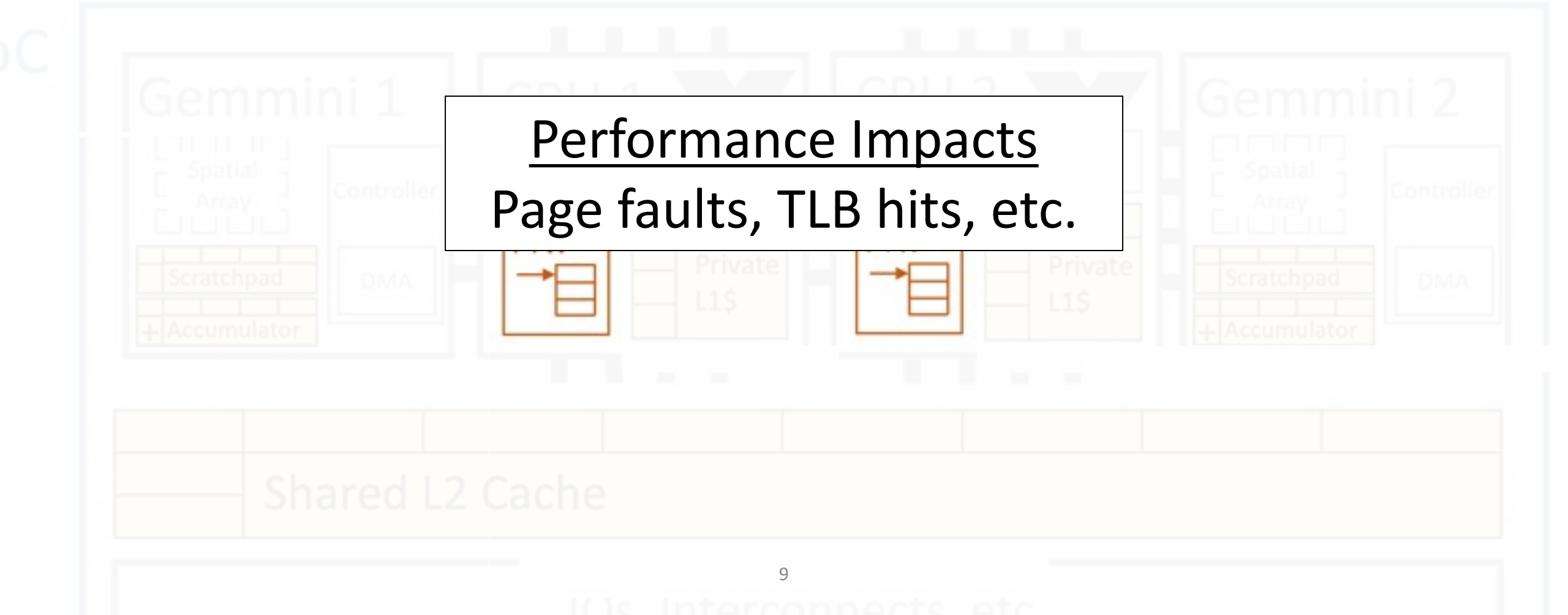
Full-System Visibility: Memory Hierarchy



Performance Impacts

Cache coherence, miss rates/latencies, etc.

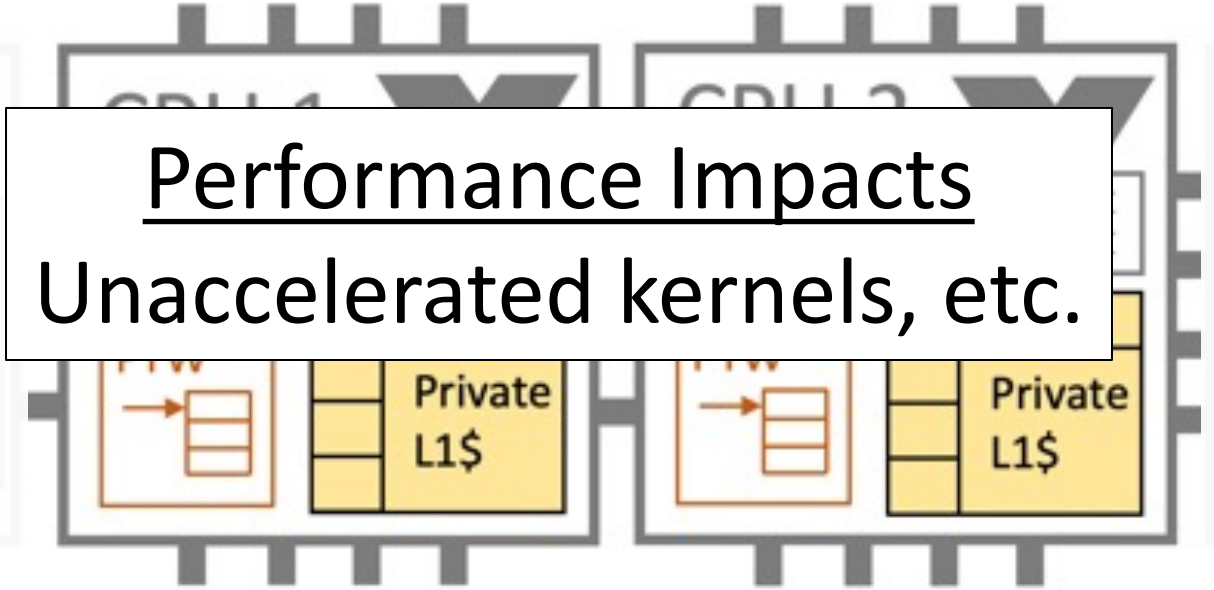
Full-System Visibility: Virtual Addresses



Performance Impacts

Page faults, TLB hits, etc.

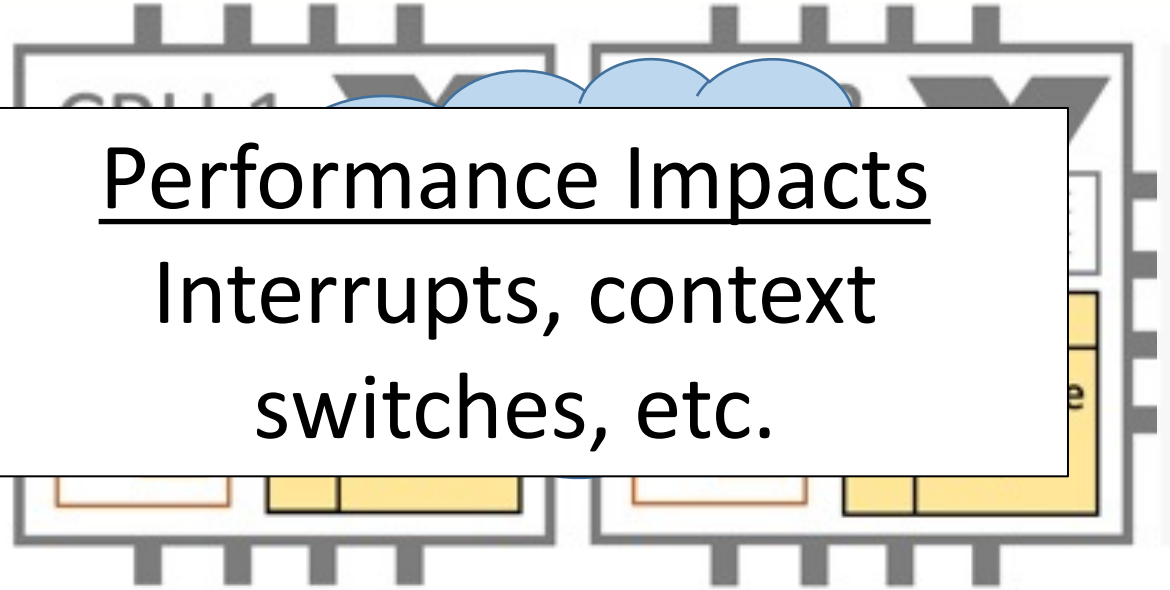
Full-System Visibility: Host CPUs



Performance Impacts

Unaccelerated kernels, etc.

Full-System Visibility: Operating System



Performance Impacts

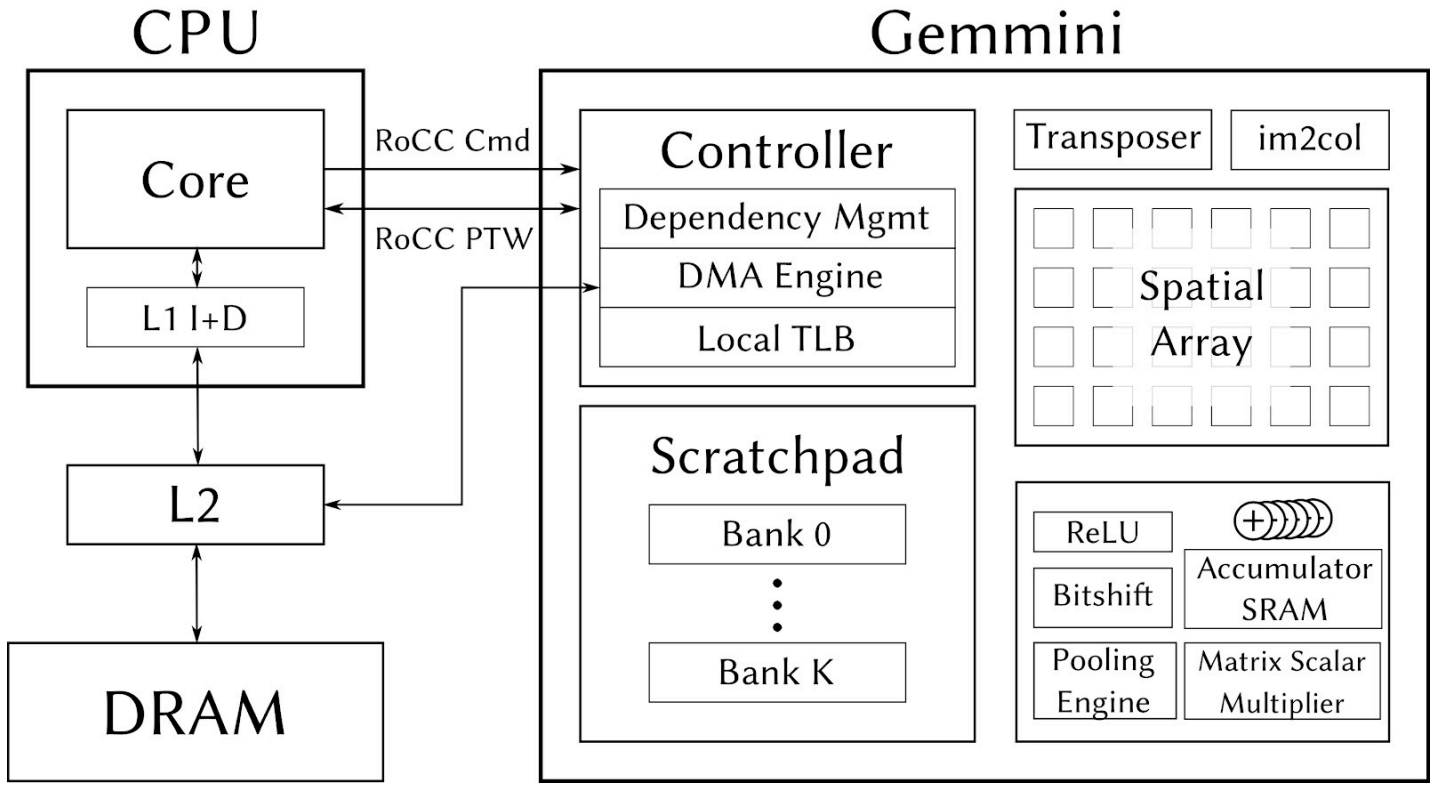
Interrupts, context switches, etc.

Full-Stack Visibility

Direct hardware configuration, low-level ISA

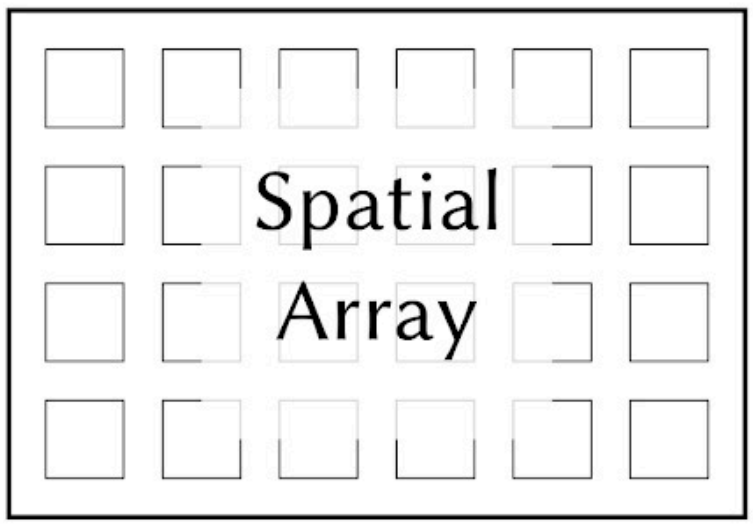
Gemmini

- DNN accelerator generator
  - RTL
  - Simulations
  - Runs Linux
- Flexible hardware template
- Full-stack
- Full-system



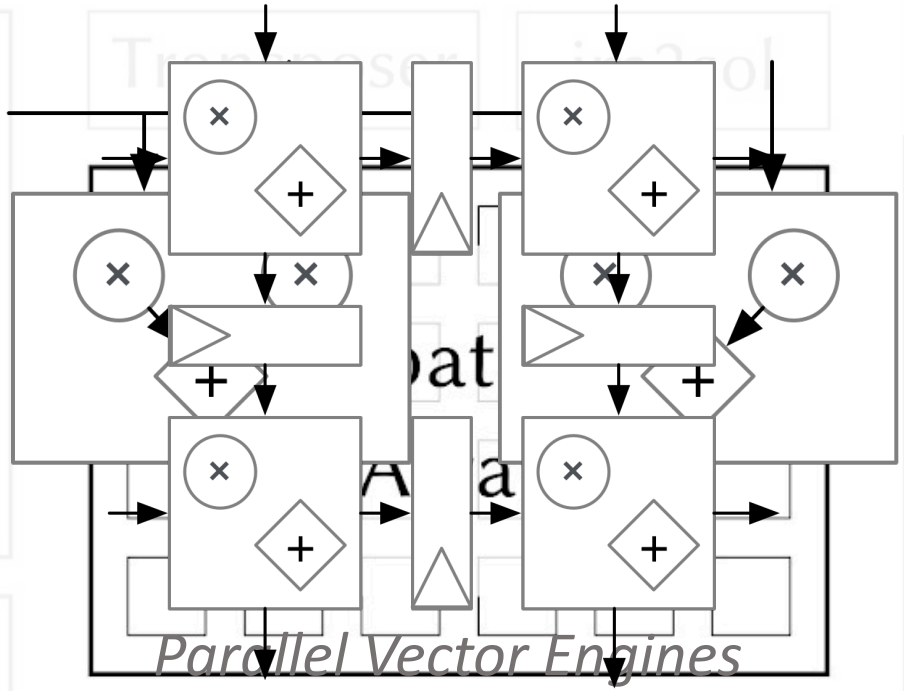
Gemmini: Spatial Array

- Parameters:
  - Dataflow
  - Datatypes
  - Dimensions
  - Pipelining



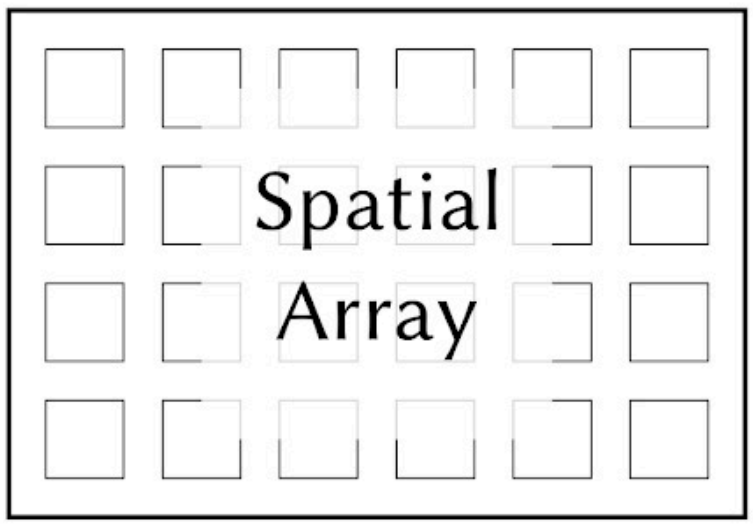
Gemmini: Spatial Array

- Parameters:
  - Dataflow
  - Datatypes
  - Dimensions
  - Pipelining



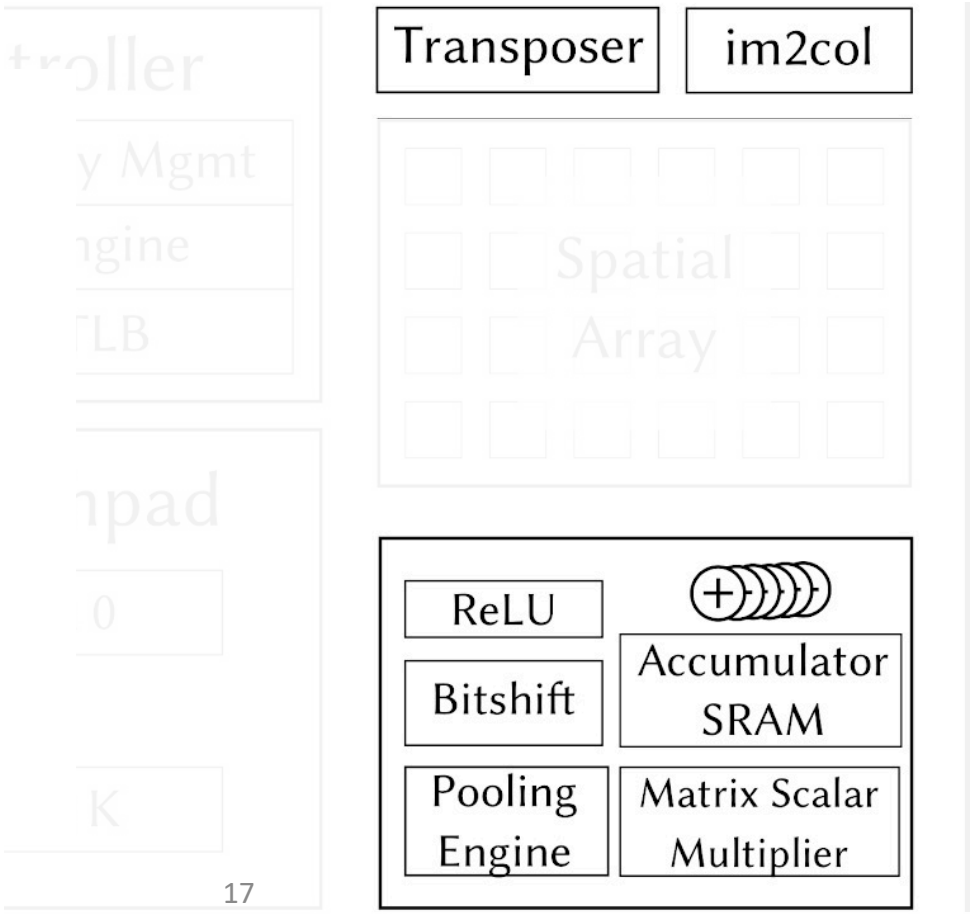
Gemmini: Spatial Array

- Parameters:
  - Dataflow
  - Datatypes
  - Dimensions
  - Pipelining



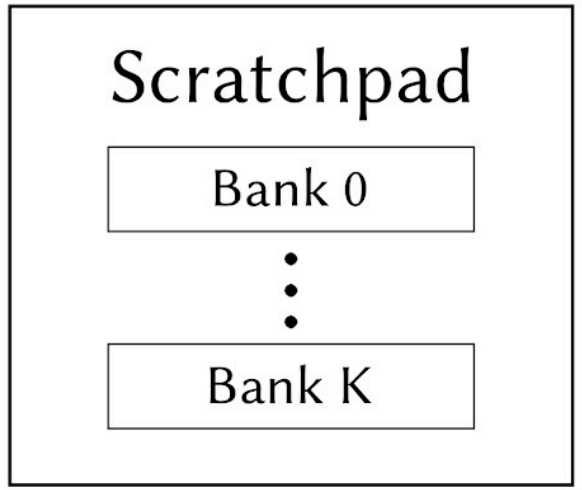
Gemmini: Non-GEMM Functionality

- Can be optimized out at elaboration-time



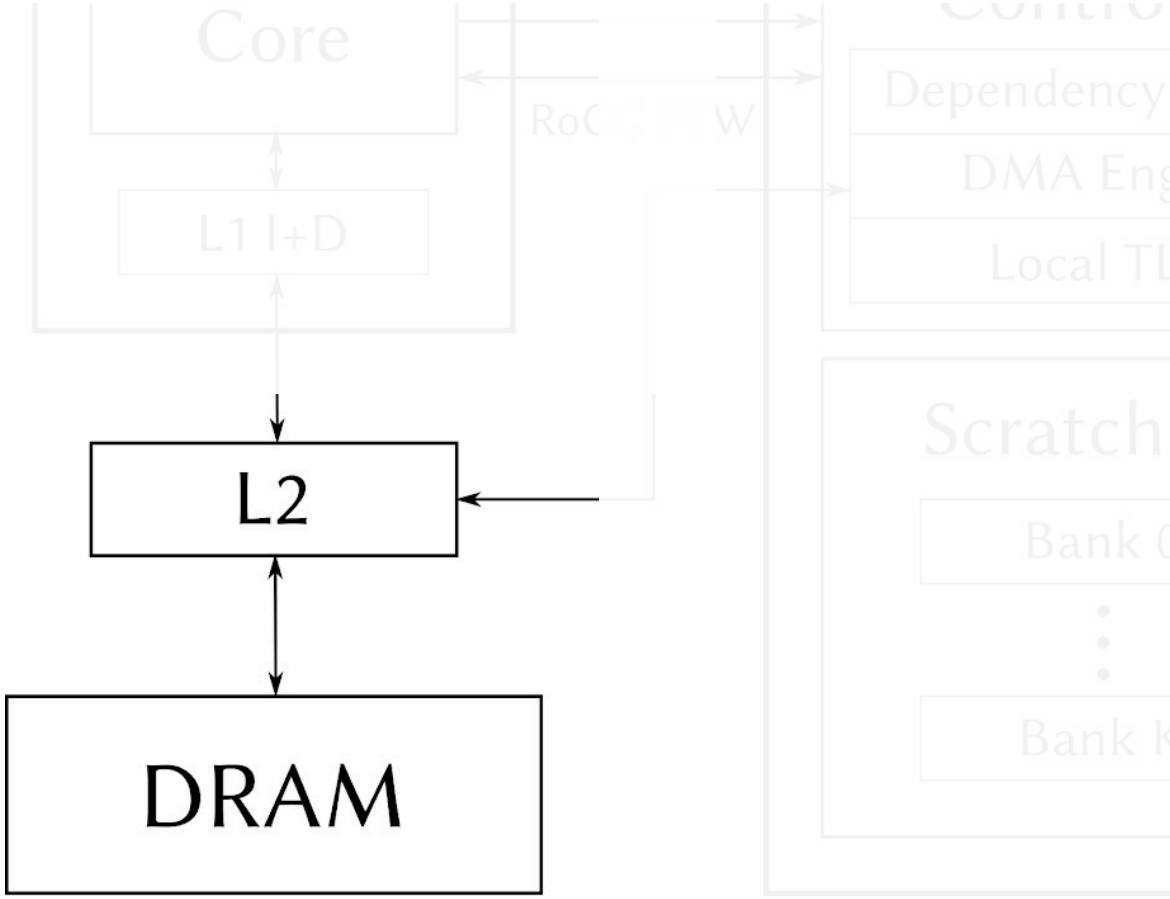
Gemmini: Local Scratchpad

- Parameters:
  - Capacity
  - Banks
  - Single- or dual-port



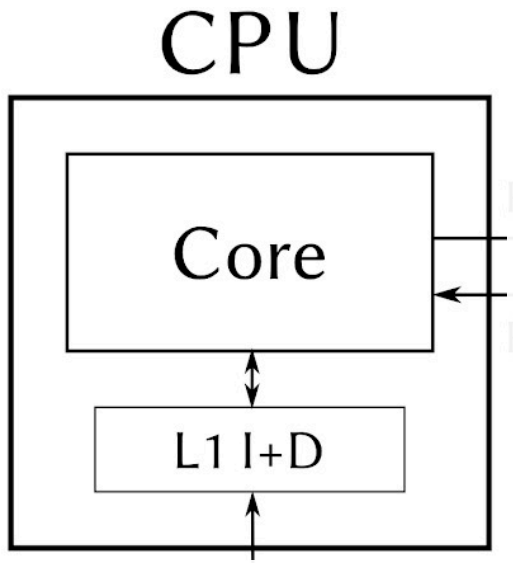
Gemmini: Global Memory

- Parameters:
  - Capacity
  - Banks
  - DRAM controller



Gemmini: Host CPU

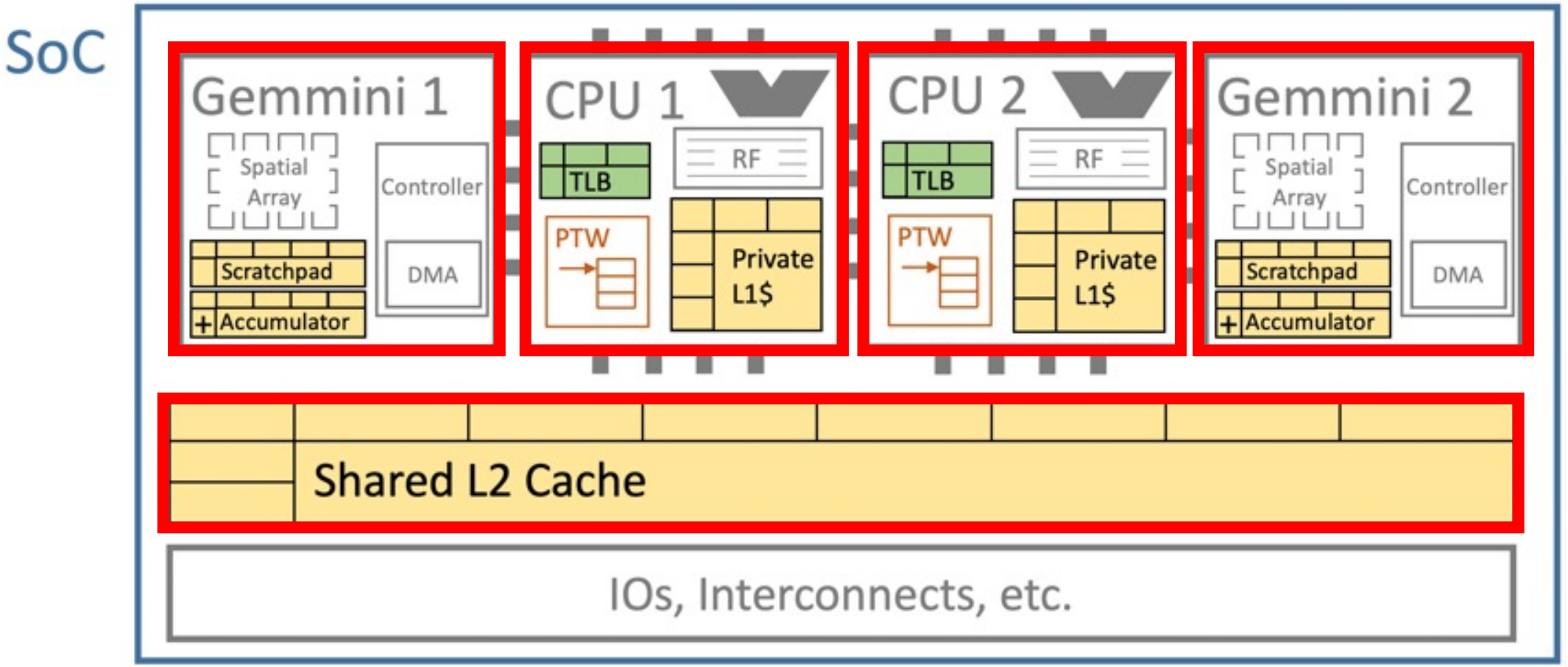
- Parameters:
  - In-order/out-of-order
  - ROB capacity
  - L1 capacity
  - Branch predictor



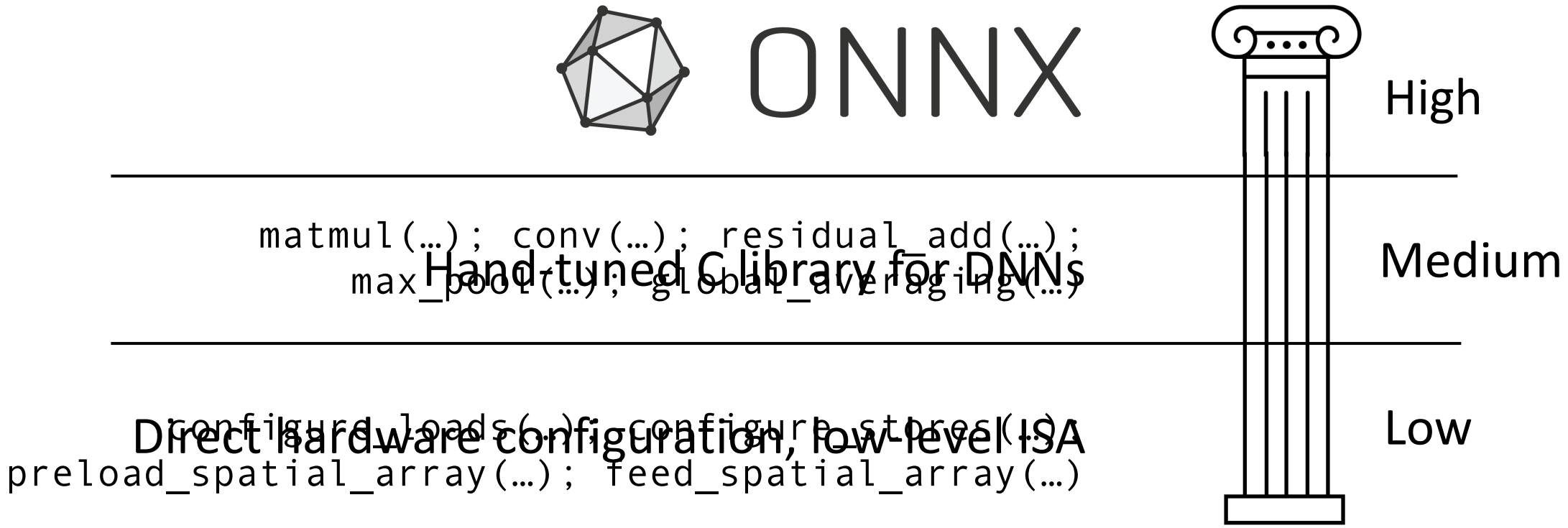
Gemmini: Virtual Address Translation

- Parameters:
  - TLB capacity
  - TLB hierarchy
    - e.g. L2 TLB

Gemmini: Full SoC

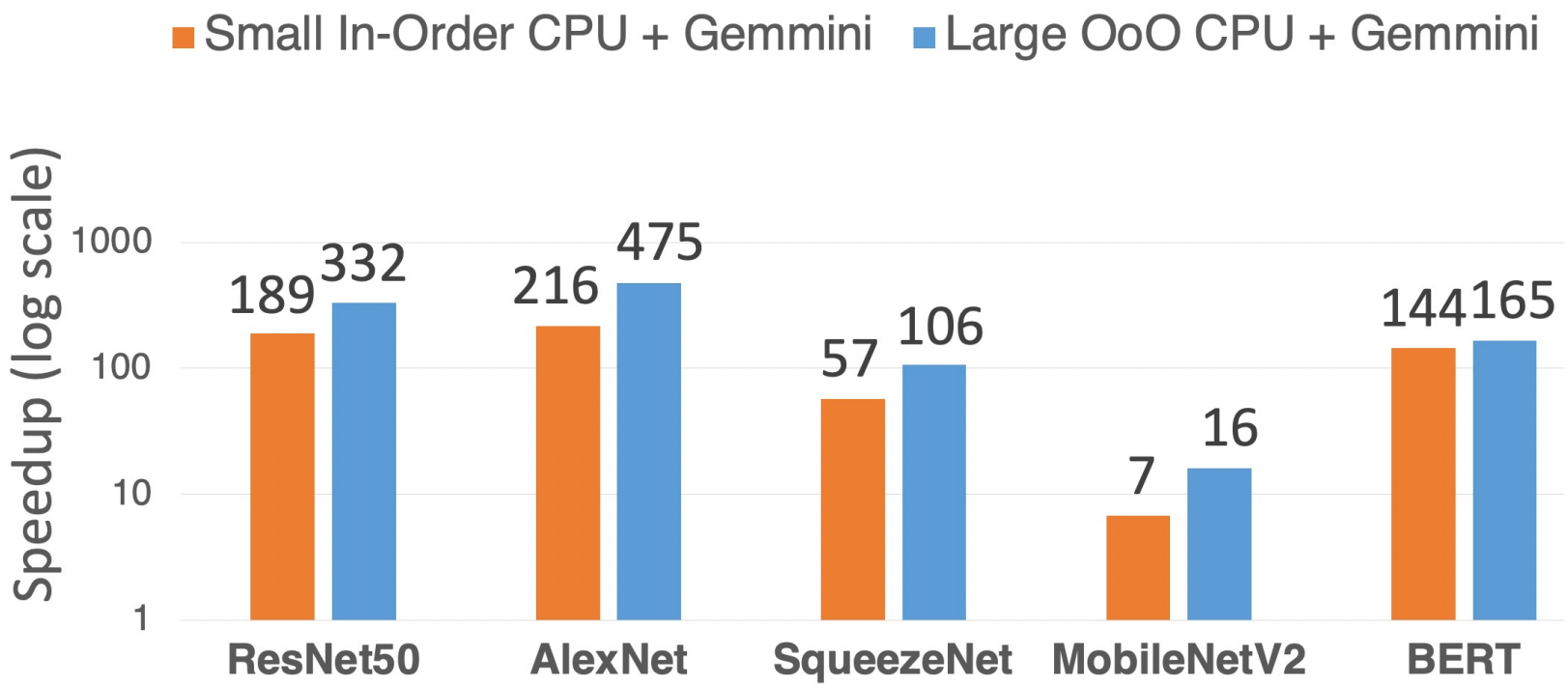


Gemmini: Programming Model



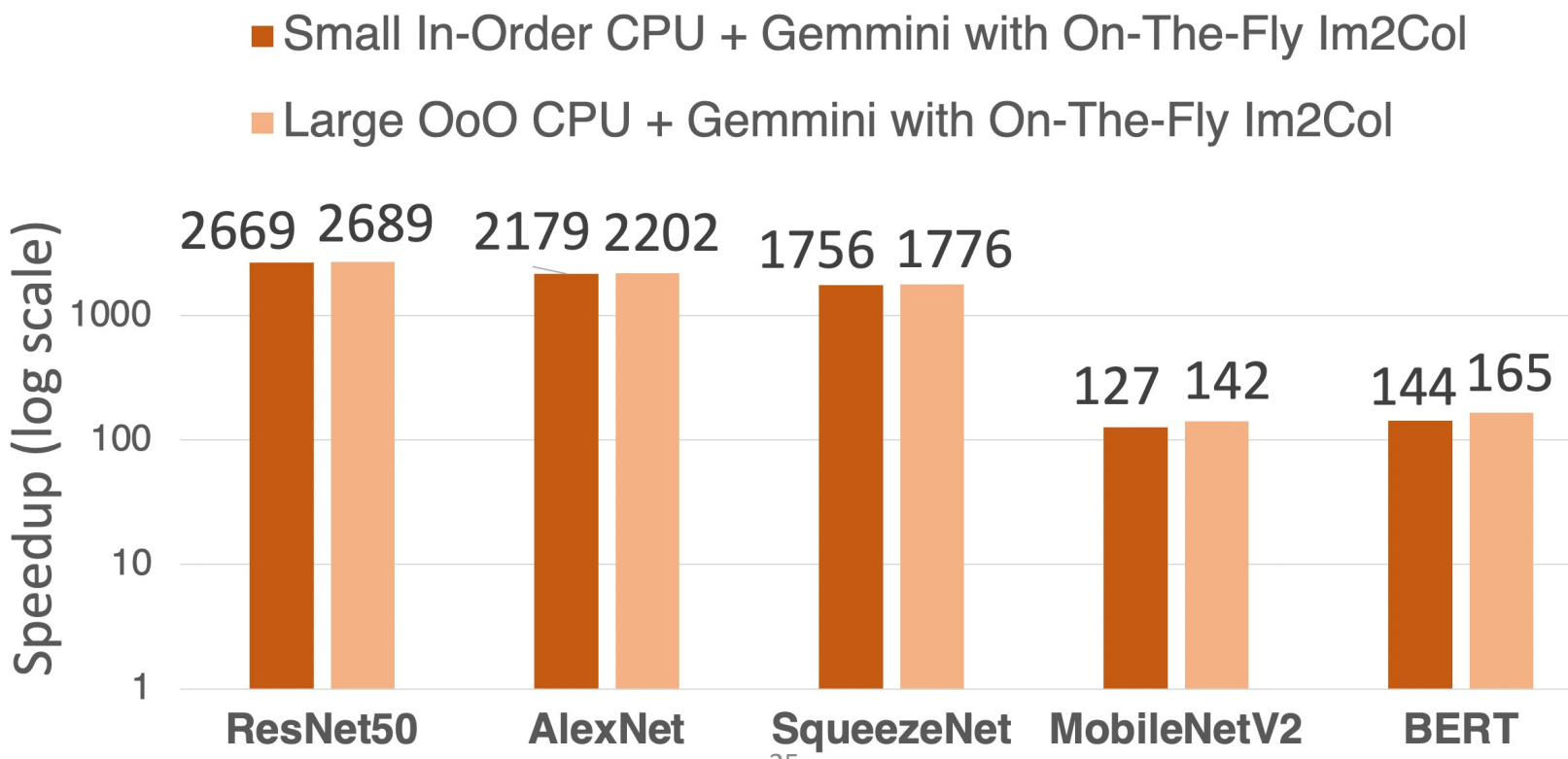
Performance: Evaluating Host CPUs

- "Im2col" runs on CPU, matmuls run on Gemmini



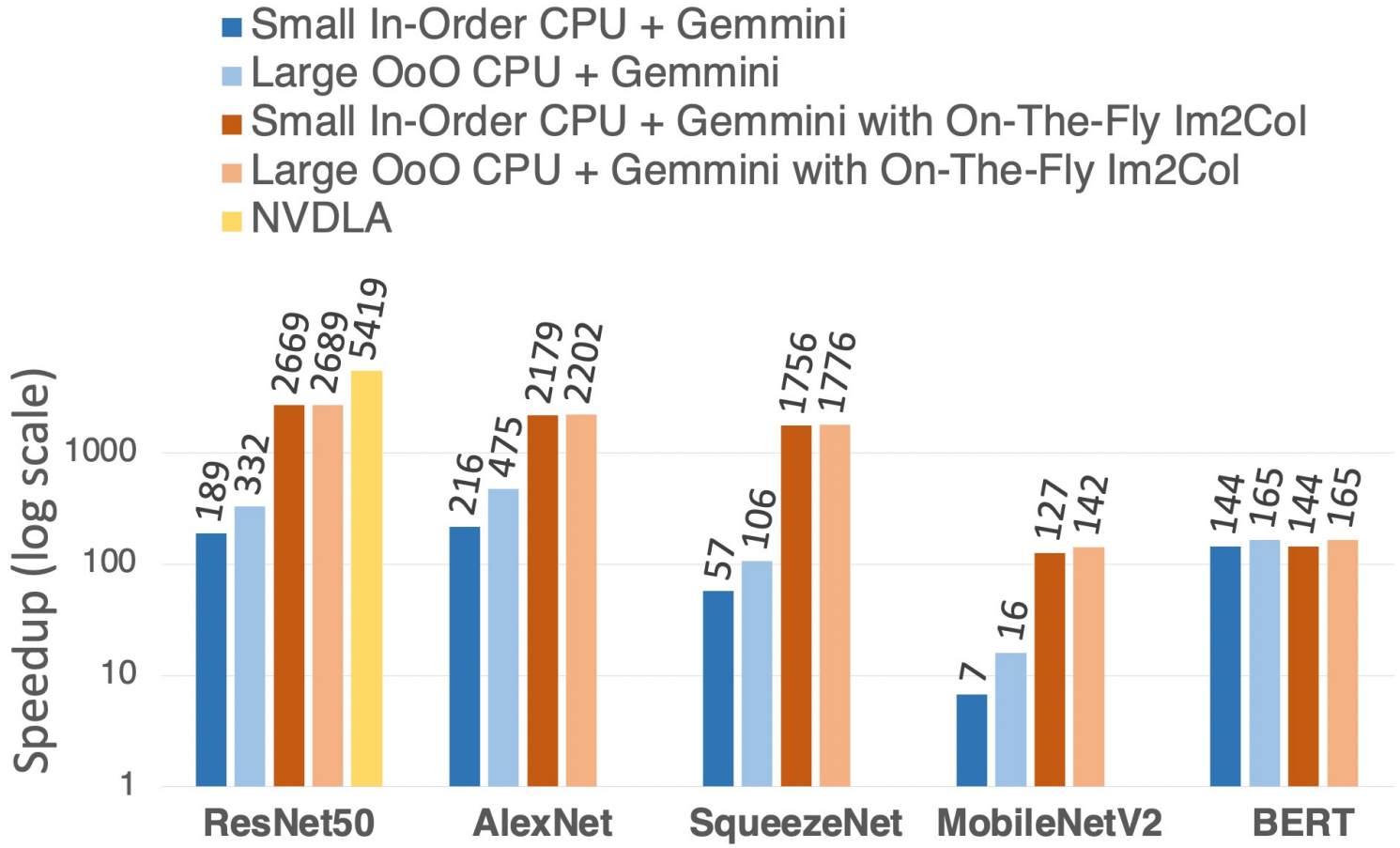
Performance: Evaluating Optional Functional Units

- "Im2col" and matmuls both run on Gemmini



Performance: Overall

- DNNs:
  - ResNet50: 40.3 FPS
  - AlexNet: 79.3 FPS
  - MobileNet: 18.7 FPS
  - BERT: 167x speedup
- **About 80% as fast as NVDLA**

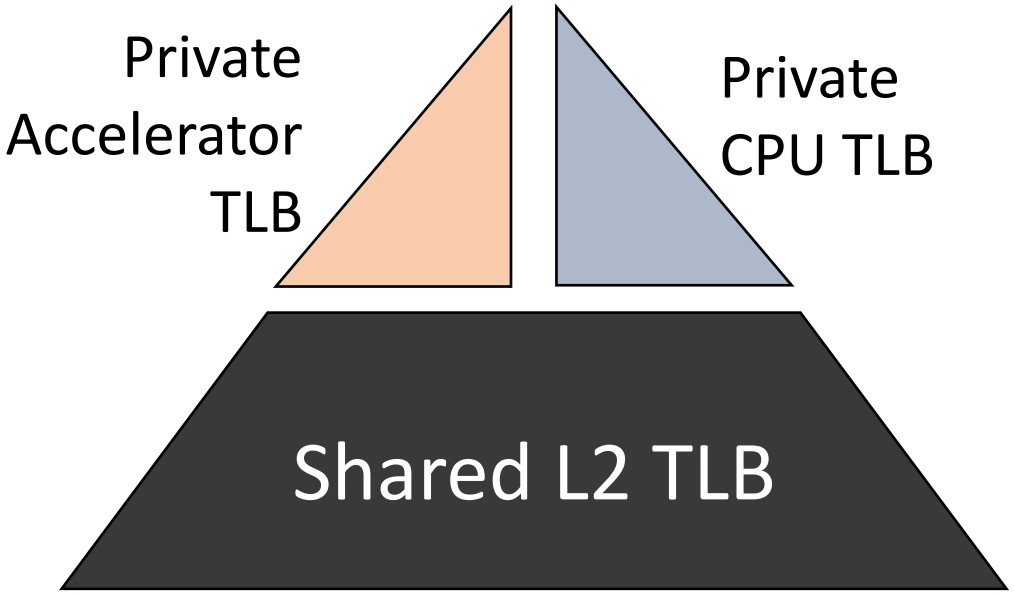


How Does the Full System and Full Stack Affect Performance?

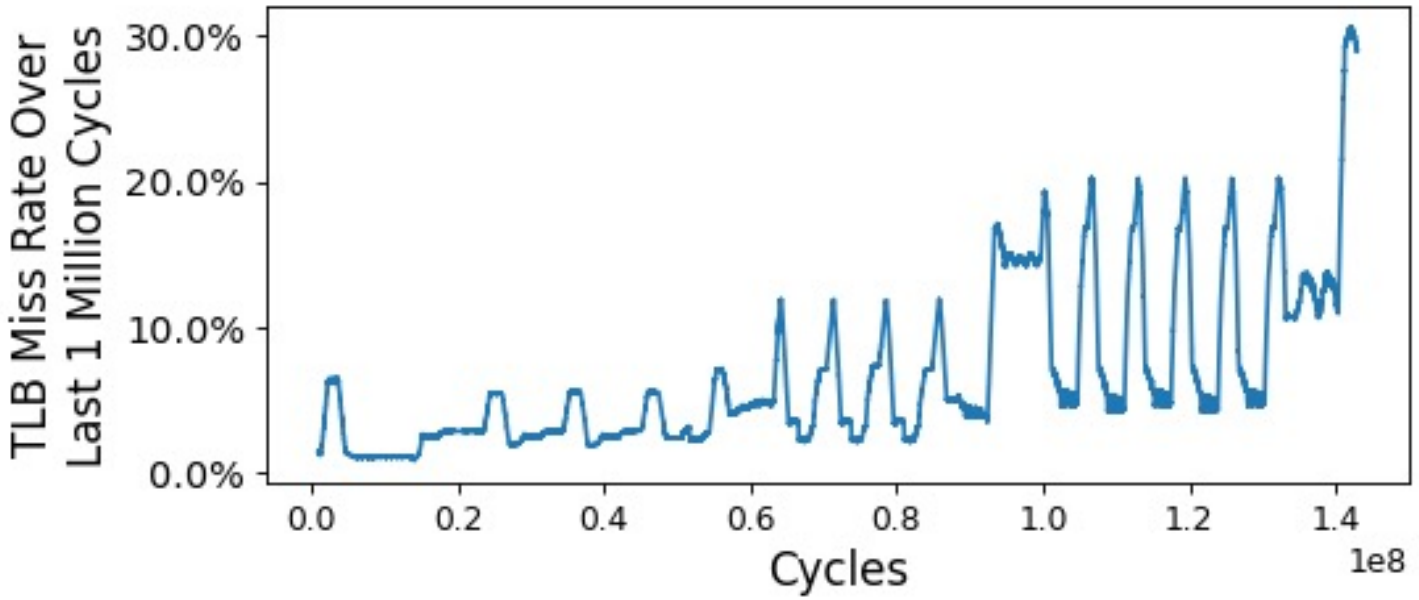
Case Study: How Does Virtual Memory Affect DNN Accelerator Performance?

Case Study: Virtual Memory for DNNs

Two-level TLB hierarchy

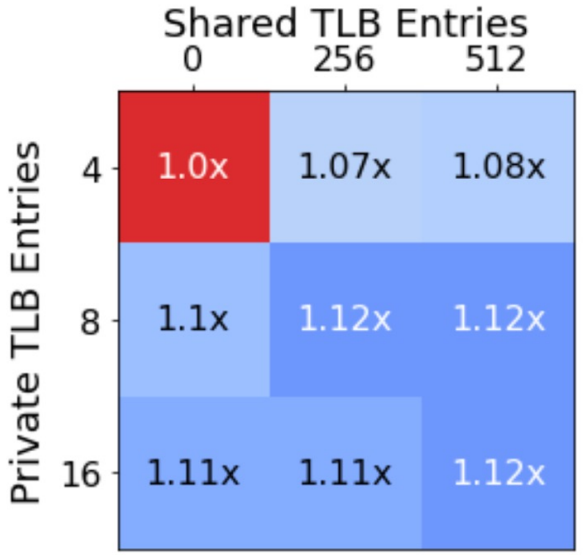


TLB Misses for ResNet50



Case Study: Virtual Memory for DNNs

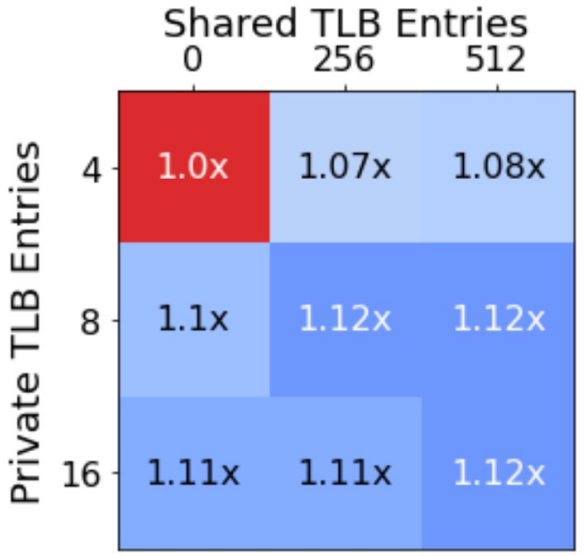
- Small private TLB much more impactful



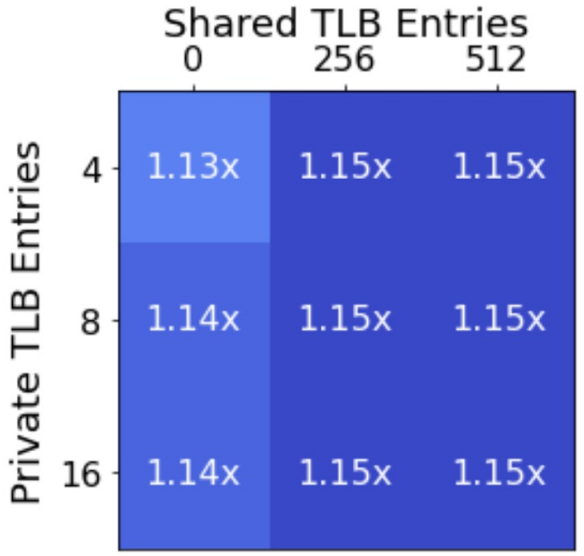
Without L0 TLB

Case Study: Virtual Memory for DNNs

- Small private TLB much more impactful
- Low-cost optimizations:
  - Single-entry L0 TLB filters out consecutive TLB requests to same page



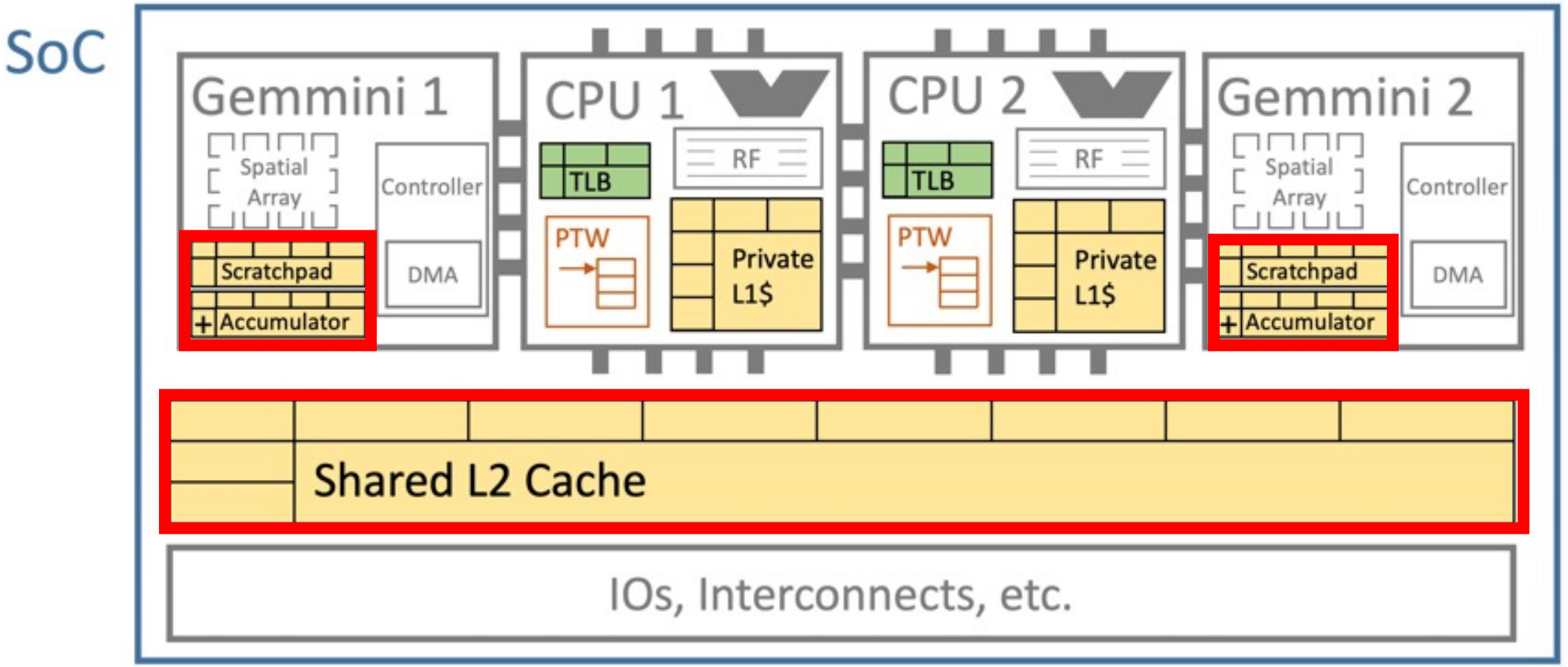
Without L0 TLB



With L0 TLB

Case Study: Memory Partitioning Schemes for Multi-Accelerator SoCs

Case Study: Memory Partitioning

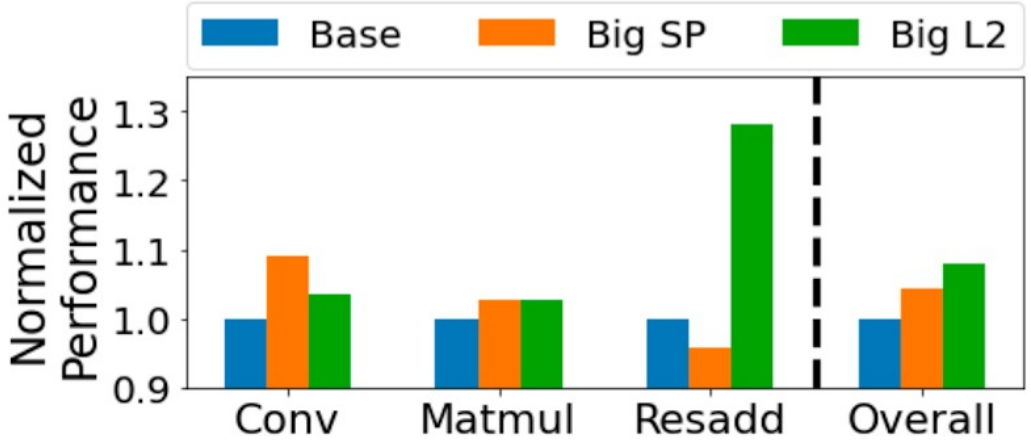


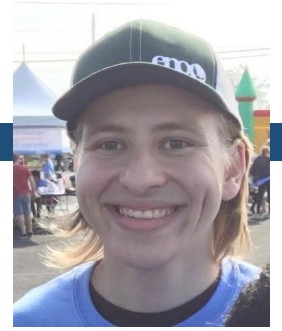
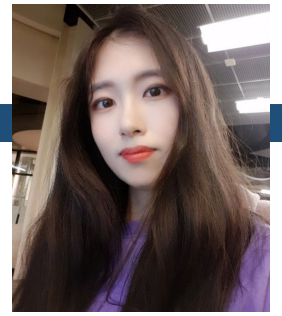
Case Study: Memory Partitioning

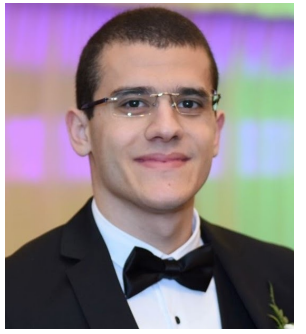
- Single core
  - Private scratchpad more helpful
  - Much better for convs

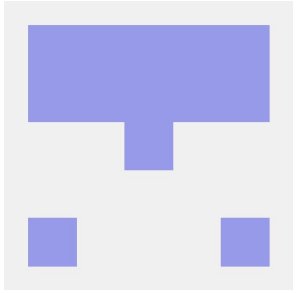
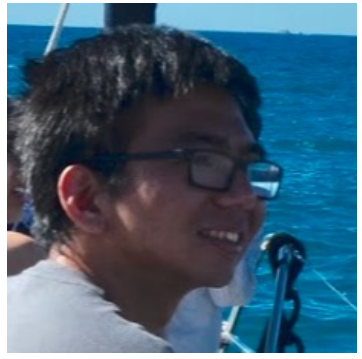
Case Study: Memory Partitioning

- Single core
  - Private scratchpad more helpful
  - Much better for convs
- Dual core
  - Shared L2 more helpful
  - Much better for residual additions





Conclusion

- Gemmini is:
  - Full-system
  - Full-stack
- Enables DSE and hardware/software co-design
  - Layer composition vs. memory partitioning
  - Virtual address translation design
- Open-source!
  - github.com/ucb-bar/gemmini

DARPA

Funded by DARPA RTML program
(contract FA8650-20-2-7006)

Acknowledgements

This research was, in part, funded by the U.S. Government under the DARPA RTML program (contract FA8650-20-2-7006). The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the U.S. Government.