

EECS251B

Advanced Digital Circuits and Systems

Lecture 2 – Building SoCs

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Tuesdays and Thursdays 9:30-11am

Cory 521

<https://github.com/ucb-bar/chipyard>



EE251B L02 CHIPIYARD

Stojanović Spring 2023

Announcements

- Assignment 1/Lab 1 will be posted on Fri

Assigned Reading

On an SoC generator

- A. Amid, et al, "Chipyard: Integrated design, simulation, and implementation framework for custom SoCs," IEEE Micro, 2020.

Project:

- UCIe Whitepaper

On transistor models:

- R.H. Dennard et al, "Design of ion-implanted MOSFET's with very small physical dimensions" IEEE Journal of Solid-State Circuits, April 1974.
 - Just the scaling principles
- C.G. Sodini, P.-K. Ko, J.L. Moll, "The effect of high fields on MOS device and circuit performance," IEEE Trans. on Electron Devices, vol. 31, no. 10, pp. 1386 - 1393, Oct. 1984.
- K.-Y. Toh, P.-K. Ko, R.G. Meyer, "An engineering model for short-channel MOS devices" IEEE Journal of Solid-State Circuits, vol. 23, no. 4, pp. 950-958, Aug. 1988.
- T. Sakurai, A.R. Newton, "Alpha-power law MOSFET model and its applications to CMOS inverter delay and other formulas," IEEE Journal of Solid-State Circuits, vol. 25, no. 2, pp. 584 - 594, April 1990.

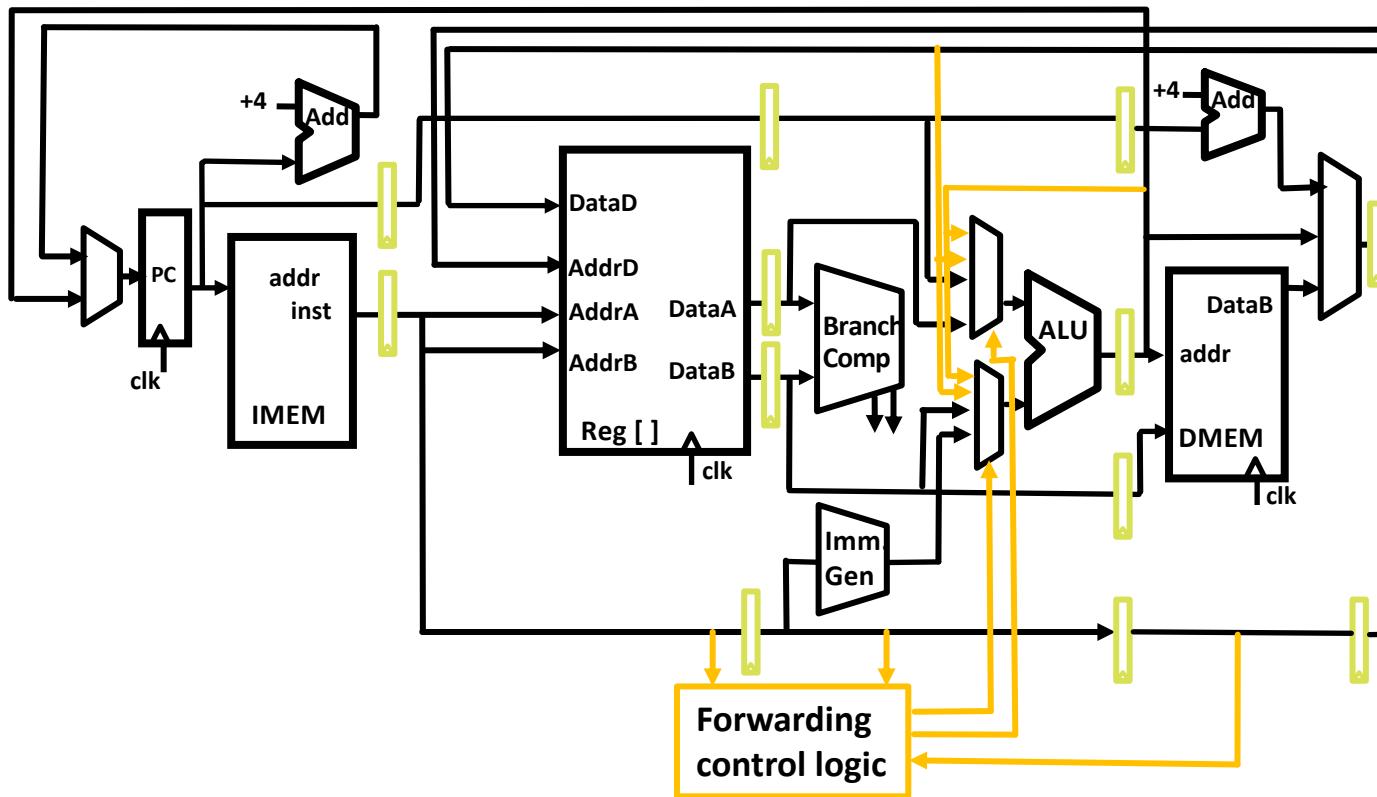
Outline

- SoC generator: Chipyard
 - Great starting point for SoC projects



RISC-V Processor Core

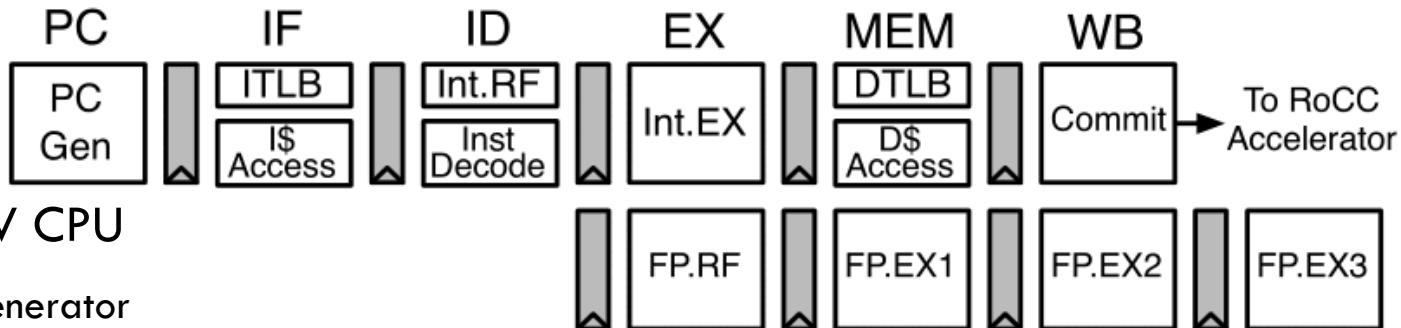
RISC-V Core



- Everyone has seen (or possibly designed) a 5-stage RISC-V (RV32I) core
- Needs memory (cache/scratchpad), co-processors, peripherals

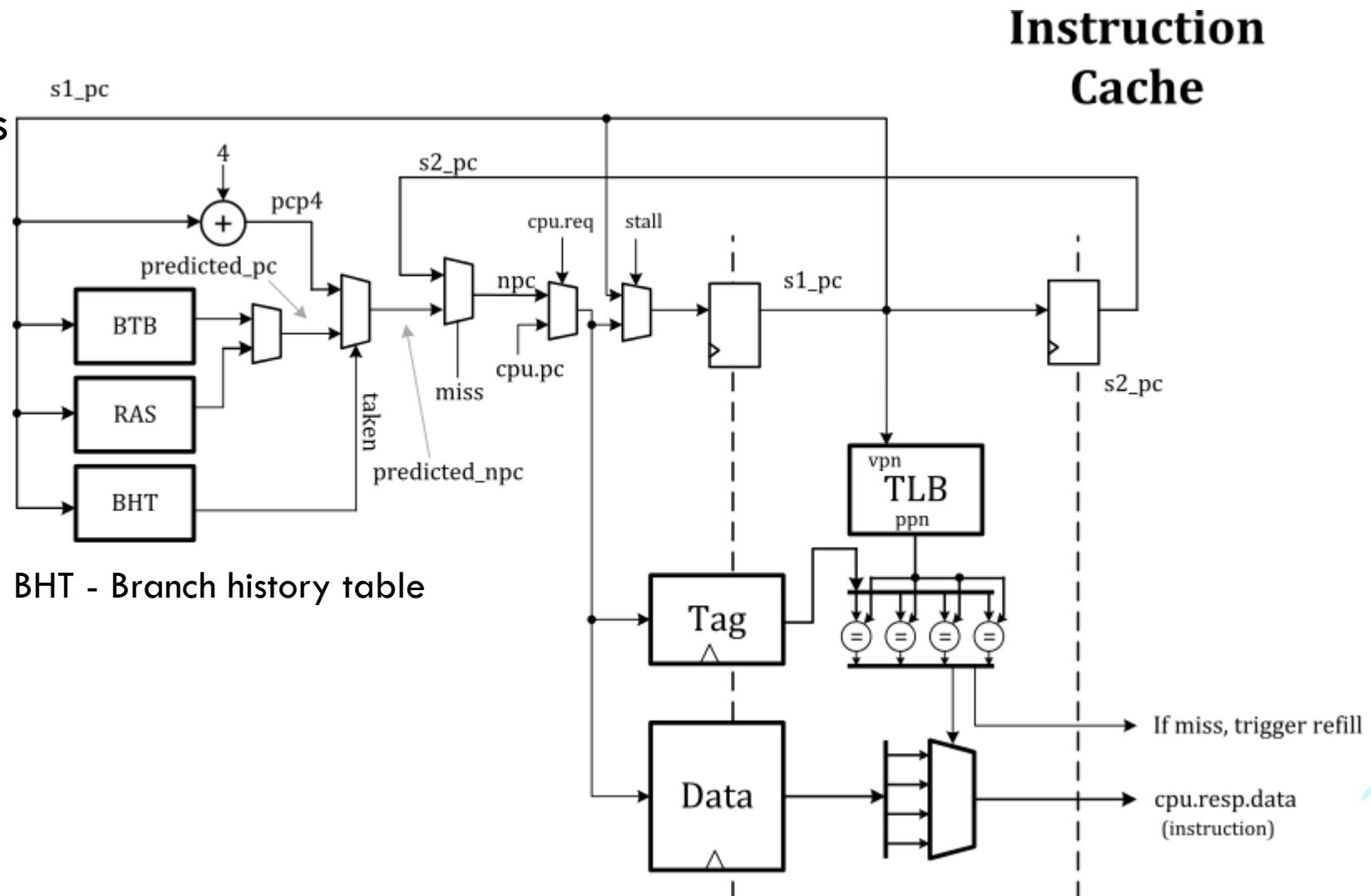
Rocket In-Order Core

- First open-source RISC-V CPU
 - Designed as a Chisel generator
- In-order, single-issue RV64GC core
 - Floating-point via Berkeley hardfloat library
 - RISC-V Compressed
 - Physical Memory Protection (PMP) standard
 - Supervisor ISA and Virtual Memory
- Boots Linux
- Supports Rocket Chip Coprocessor (RoCC) interface
- L1 I\$ and D\$
 - Caches can be configured as scratchpads



Inside Rocket

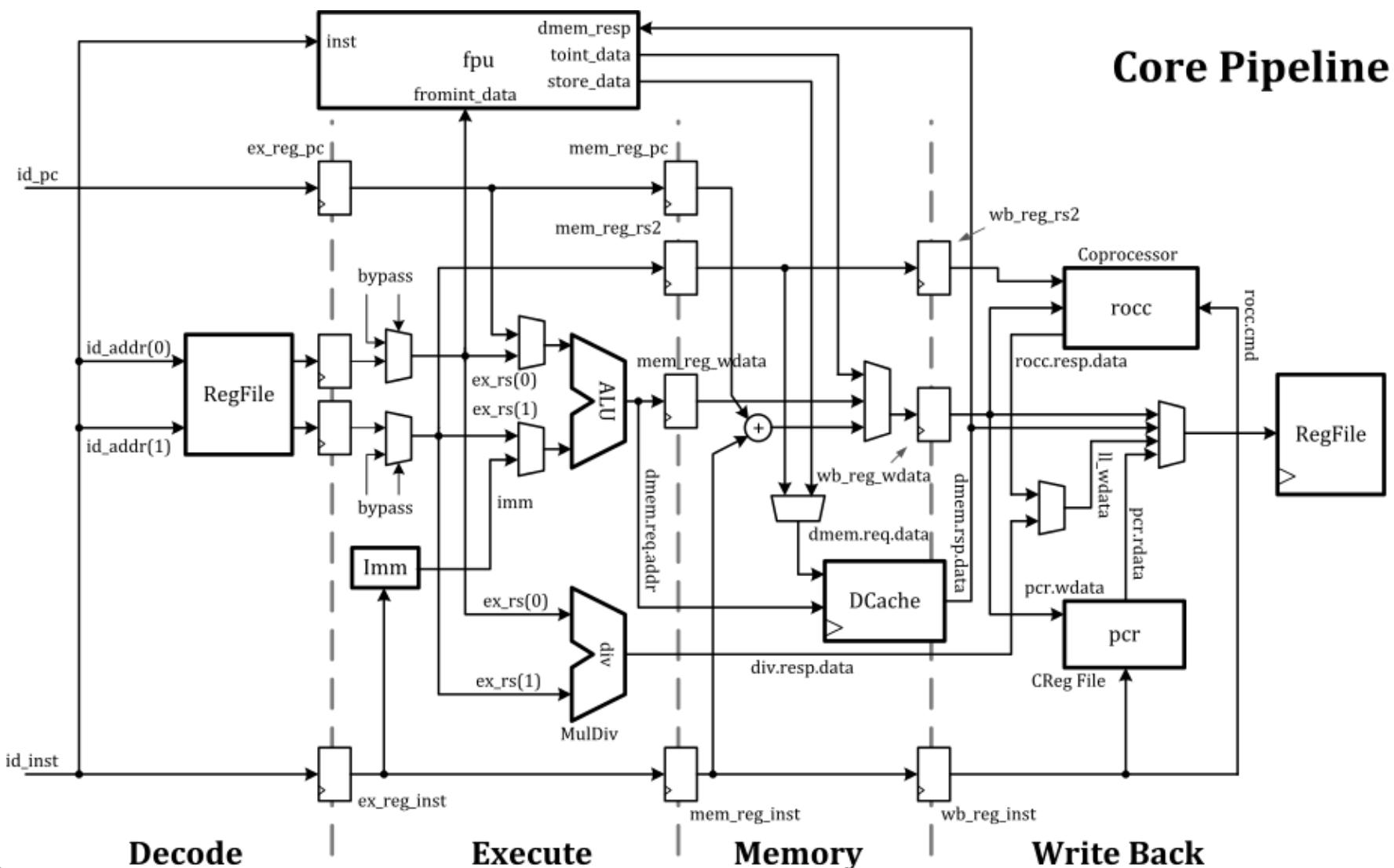
- Front-end
 - Fetches instructions from I\$



<https://www.cl.cam.ac.uk/~jrrk2/docs/tagged-memory-v0.1/rocket-core/>

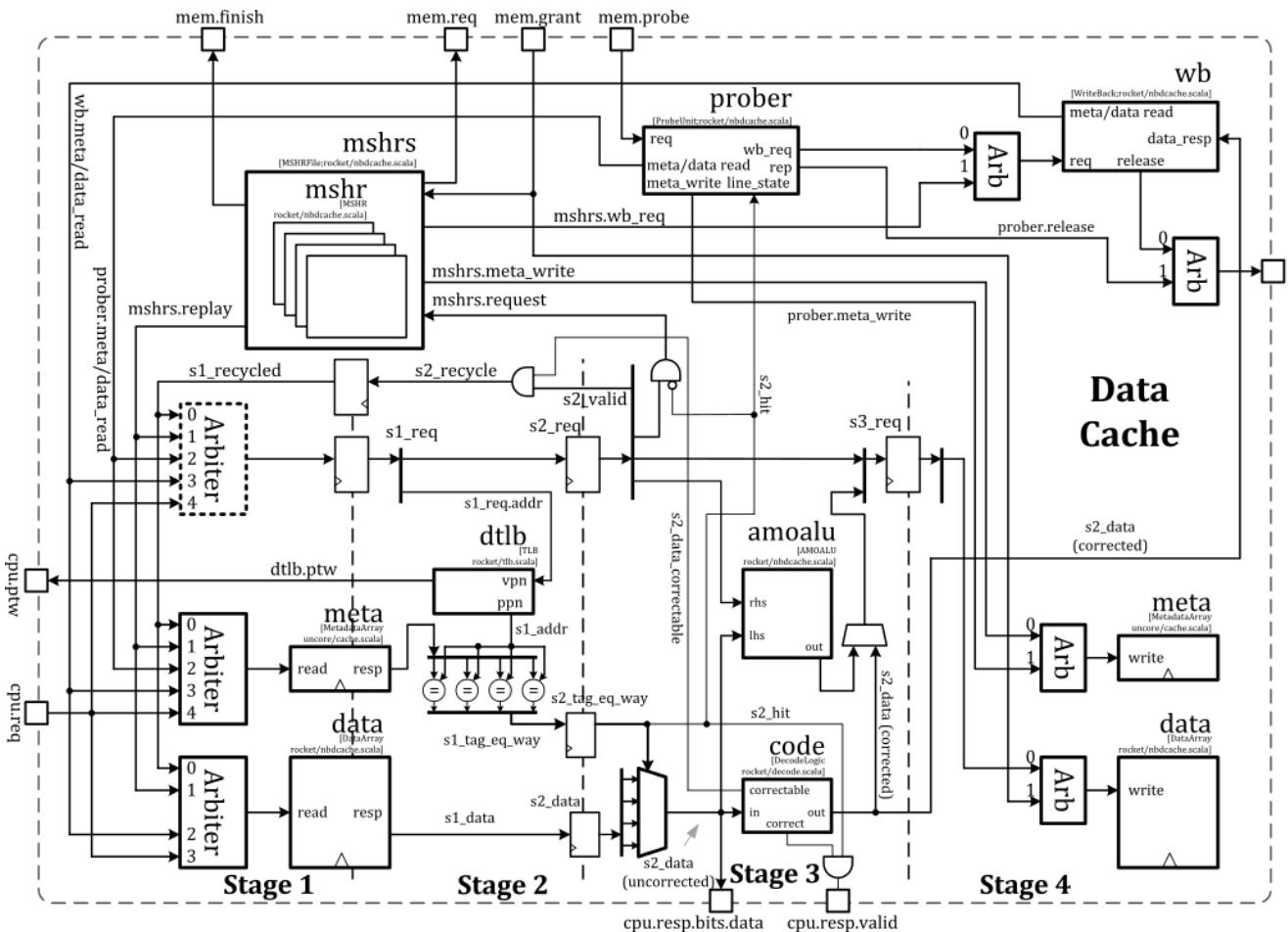
Rocket Pipeline

- 1 integer ALU/IMUL/IDIV + optional FPU



Data Cache

- L1 cache (can be configured as write-through or write-back)



To Build an SoC

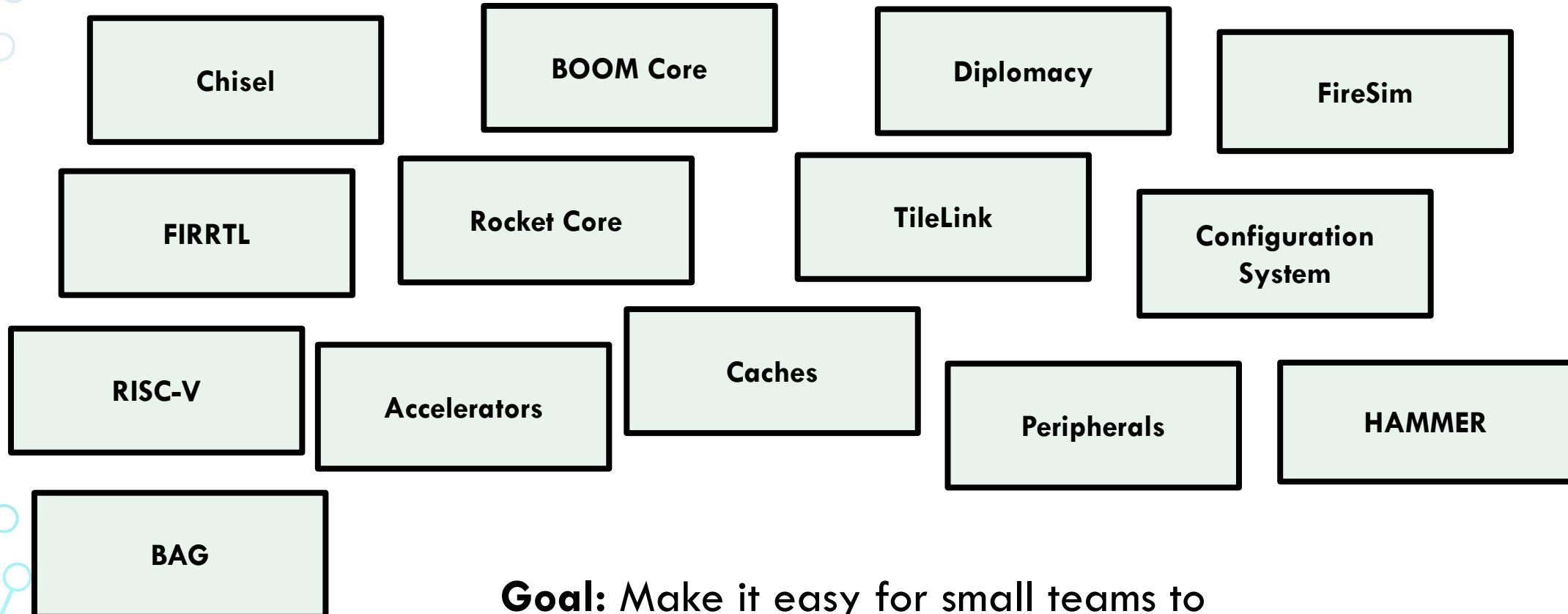
- Processor Cores (Rocket, BOOM, ...)
- Memory System (L1, L2 w/coherence protocol, ...)
- Interconnect (TileLink/TileLink2)
- Custom blocks (comms, imaging, ...)
- Standard Perihperhal devices
 - JTAG
 - SPI
 - I2C
 - BootROM
 - ...



Chipyard: SoC Generator

Open ISA (RISC-V) key to enabling the Open-Source Ecosystem!

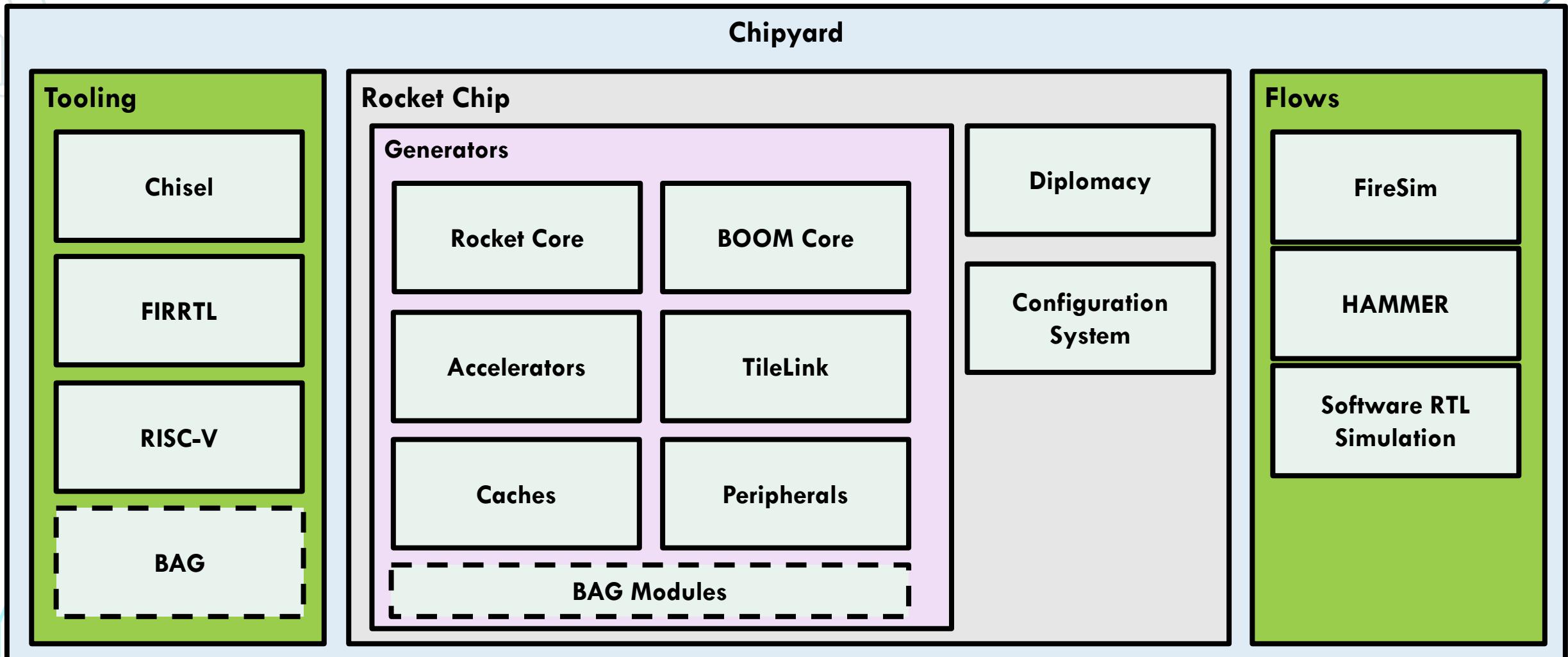
- Many open source components:



Goal: Make it easy for small teams to
design, integrate, simulate,
validate workload performance and tape-out a custom SoC

Need a way to express many needs in a configurable format -> a new language - CHISEL

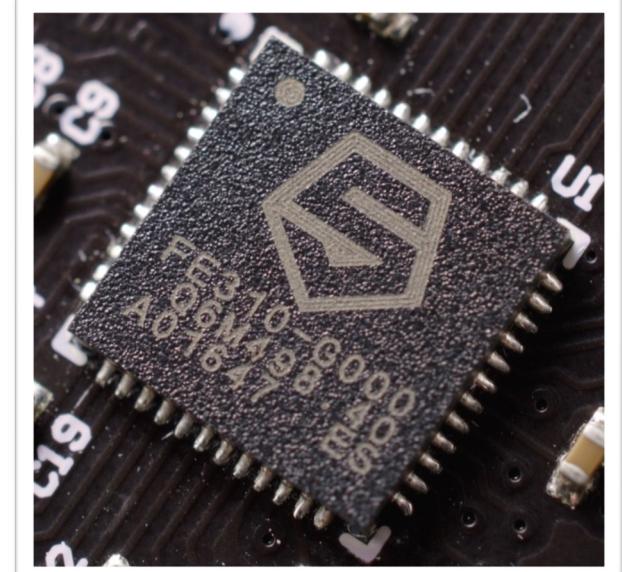
Chipyard



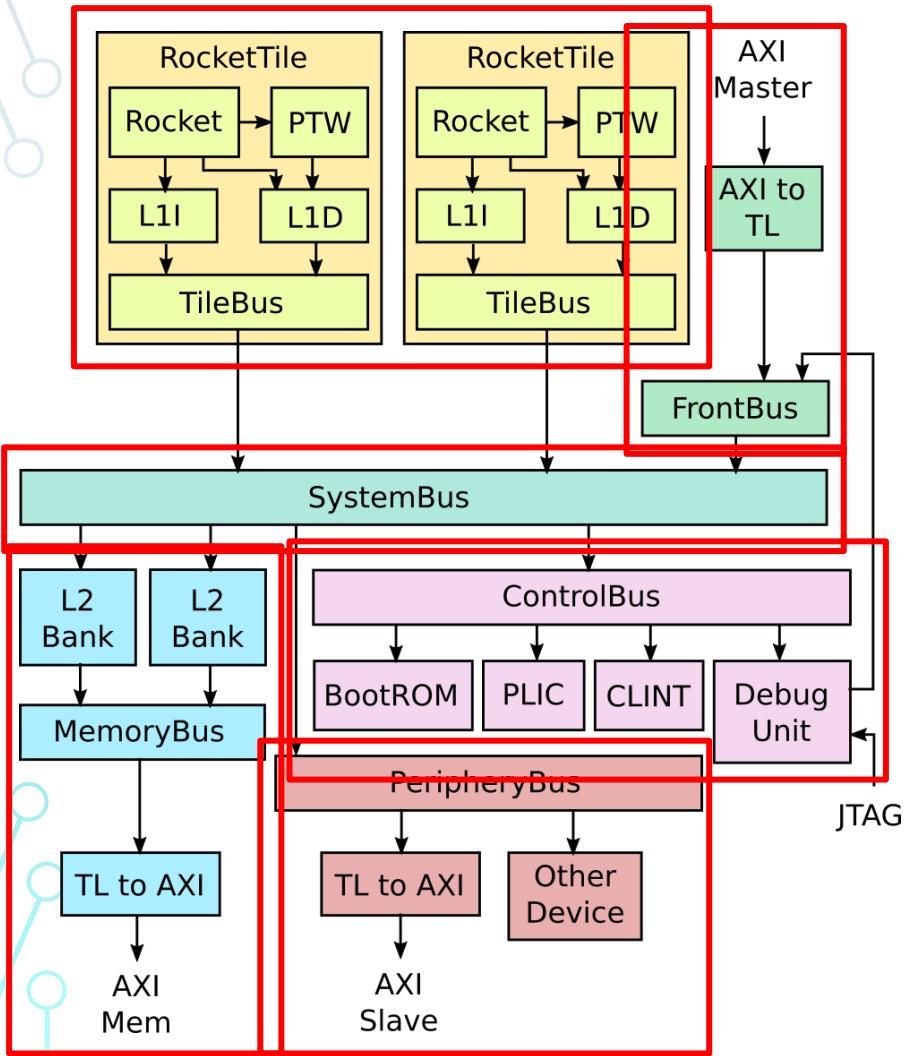
What is Rocket Chip?

- A highly parameterizable SoC generator
 - Replace default Rocket core w/ your own core
 - Add your own coprocessor
 - Add your own SoC IP to uncore
- A library of reusable SoC components
 - Memory protocol converters
 - Arbiters and Crossbar generators
 - Clock-crossings and asynchronous queues
- The largest open-source Chisel codebase
 - Scala allows advanced generator features
- Developed at Berkeley, now maintained by many
 - SiFive, CHIPS Alliance, UC Berkeley
- Perhaps not up to date with latest components, but making sure things work as configured

In industry: **SiFive Freedom E310**
(based on the Rocket Chip)



Structure of a Rocket Chip SoC



Tiles: unit of replication for a core

- CPU (Rocket, BOOM, Ariane)
- L1 Caches
- Page-table walker

L2 banks (contributed by SiFive):

- Receive memory requests

FrontBus:

- Connects to DMA devices

ControlBus:

- Connects to core-complex devices

PeripheryBus:

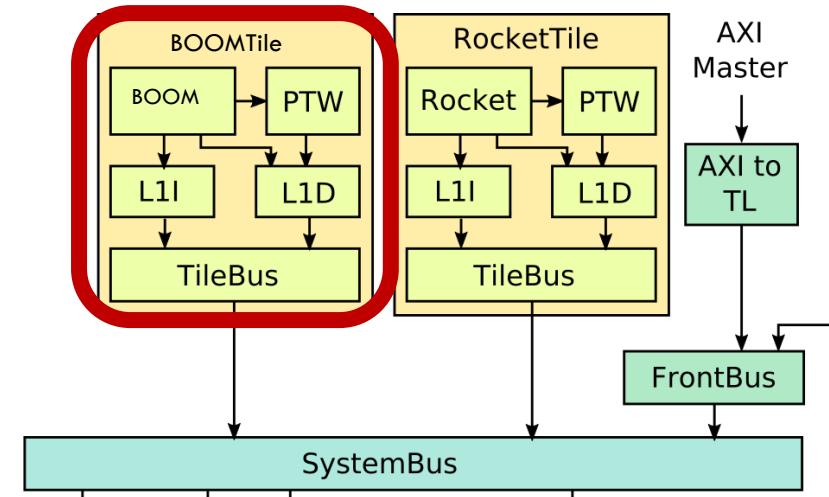
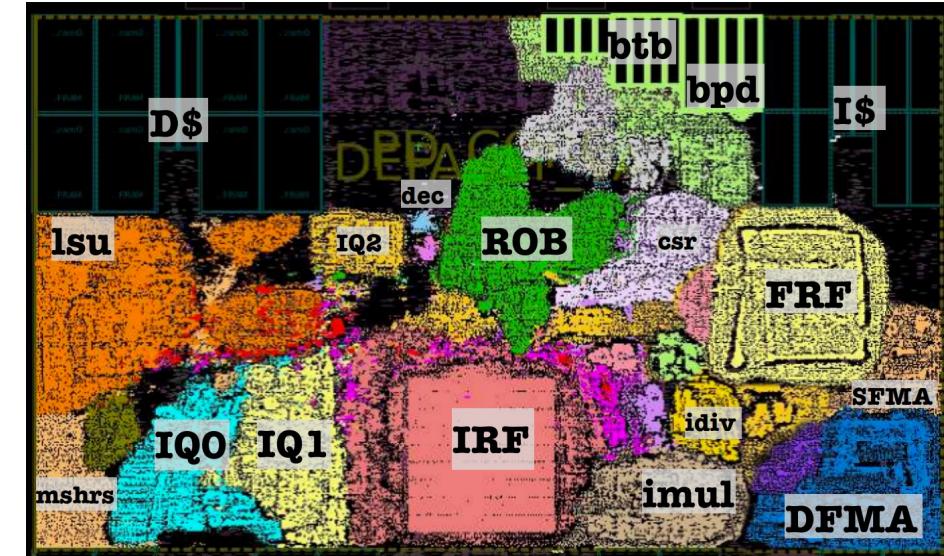
- Connects to other devices

SystemBus:

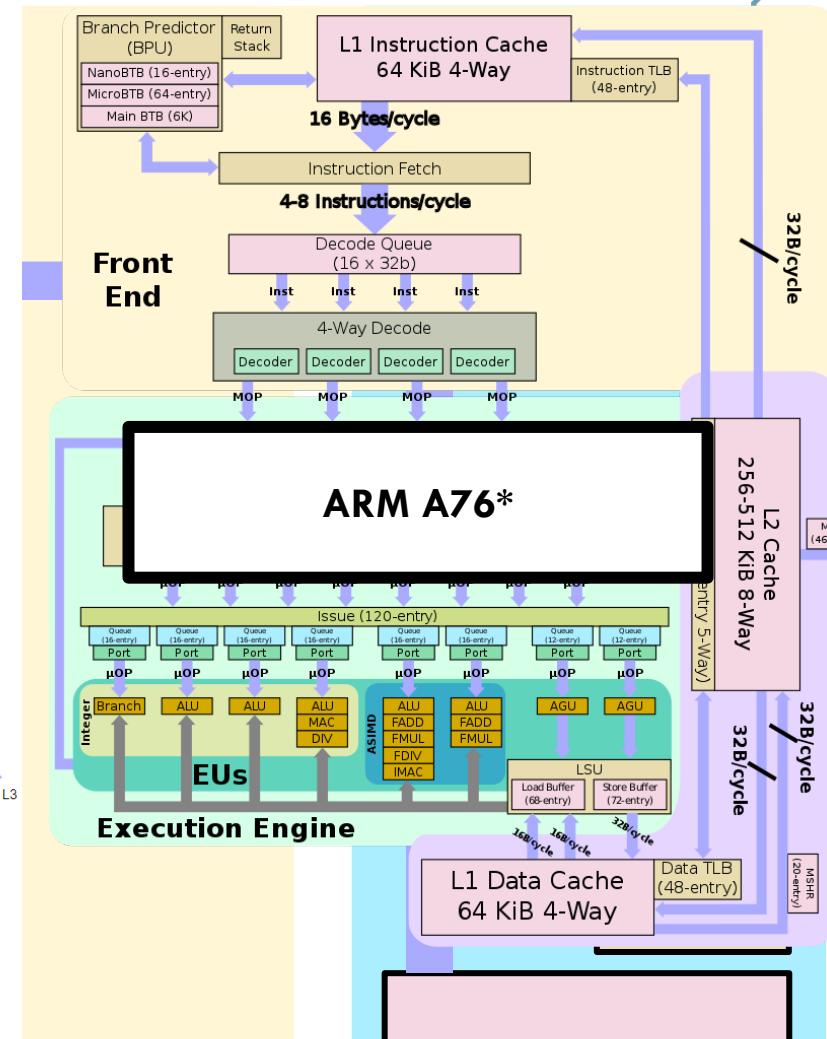
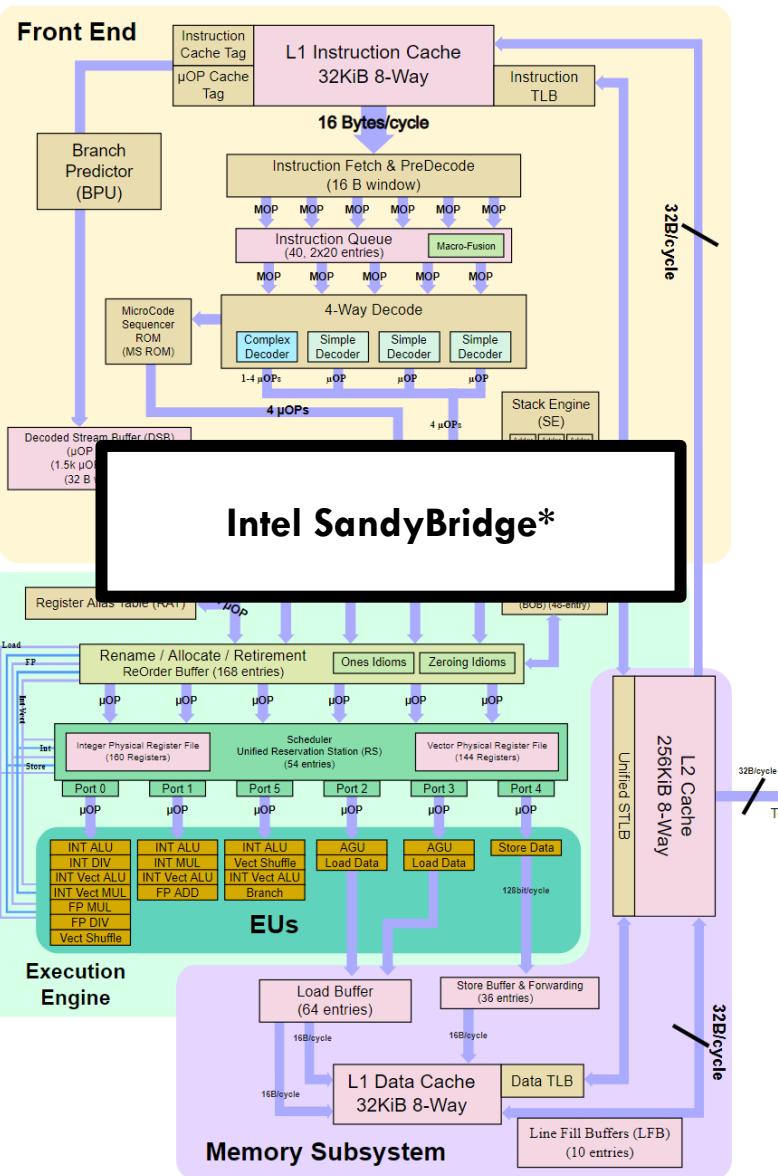
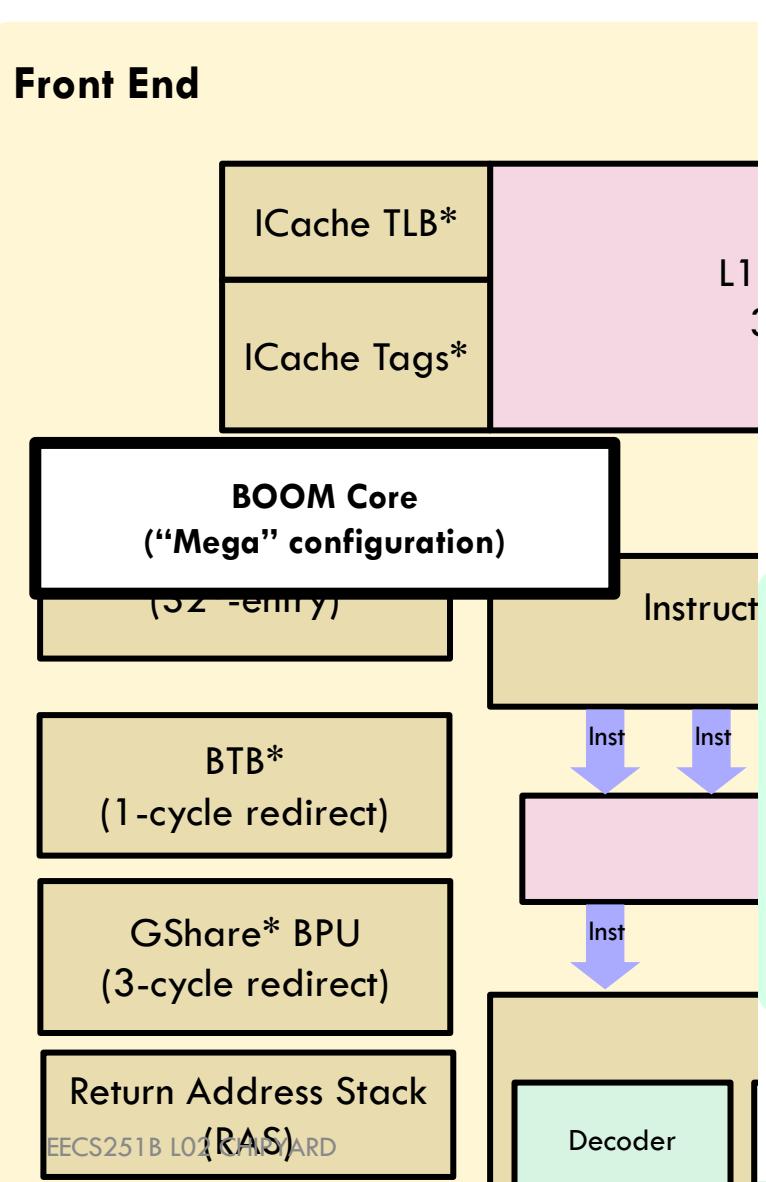
- Ties everything together

BOOM: The Berkeley Out-of-Order Machine

- Superscalar RISC-V OoO core
- Fully integrated in Rocket Chip ecosystem
- Open-source
- Described in Chisel
- Parameterizable generator
- Taped-out ([BROOM](#); VLSI'18)
 - Updated: <https://boom-core.org/>
- Full RV64GC ISA support
 - FP, RVC, Atomics, PMPs, VM, Breakpoints, RoCC
 - Runs real OS's, software
- Drop-in replacement for Rocket
- Architecture similar to state-of-the-art CPUs
 - Performance heavily dependent on the physical design



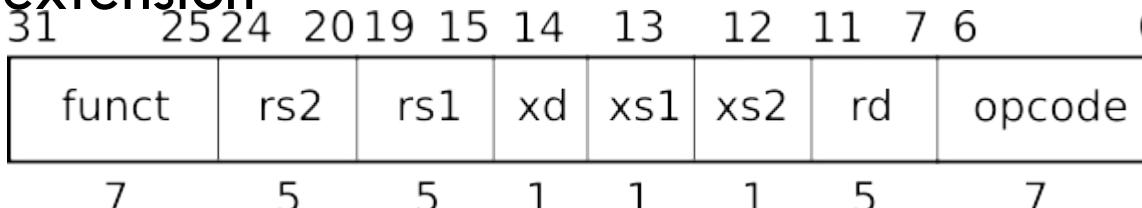
BOOM Microarchitecture



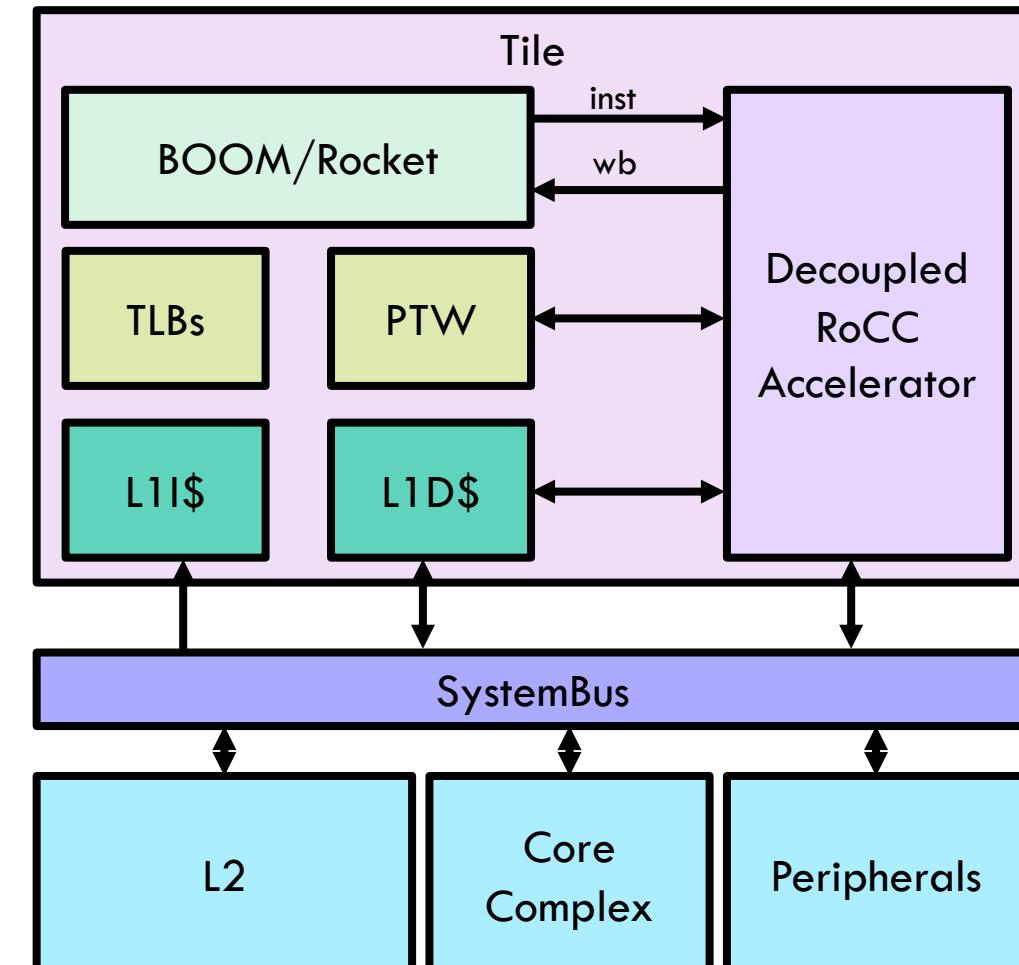
*Block diagram from WikiChip

RoCC Accelerators

- **RoCC:** Rocket Chip Coprocessor
- Execute custom RISC-V instructions for a custom extension

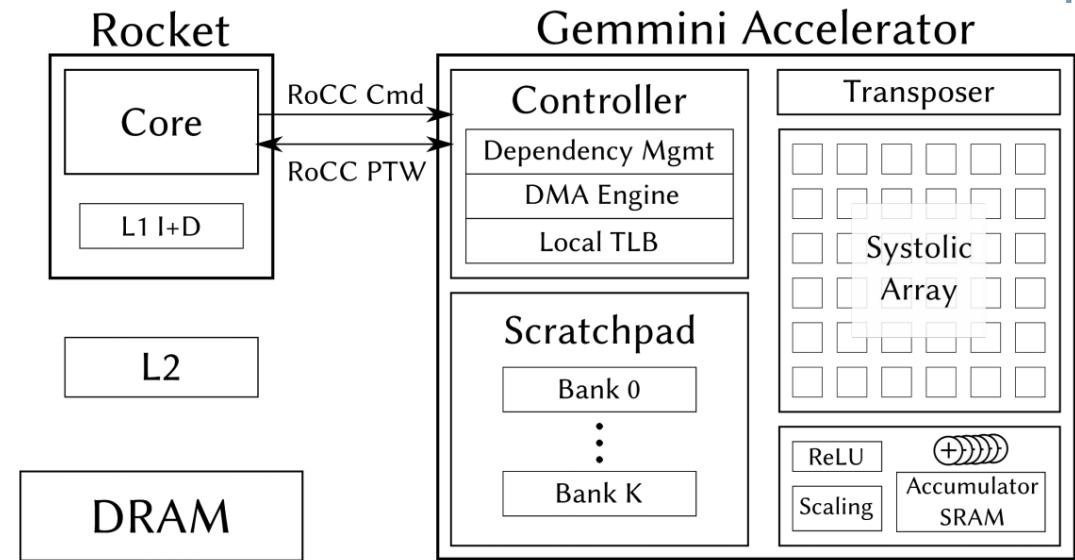


- Examples of RoCC accelerators
 - Vector accelerators
 - Memcpy accelerator
 - Machine-learning accelerators (Gemmini, NVDLA)
 - See the second part of the tutorial!
 - Java GC accelerator



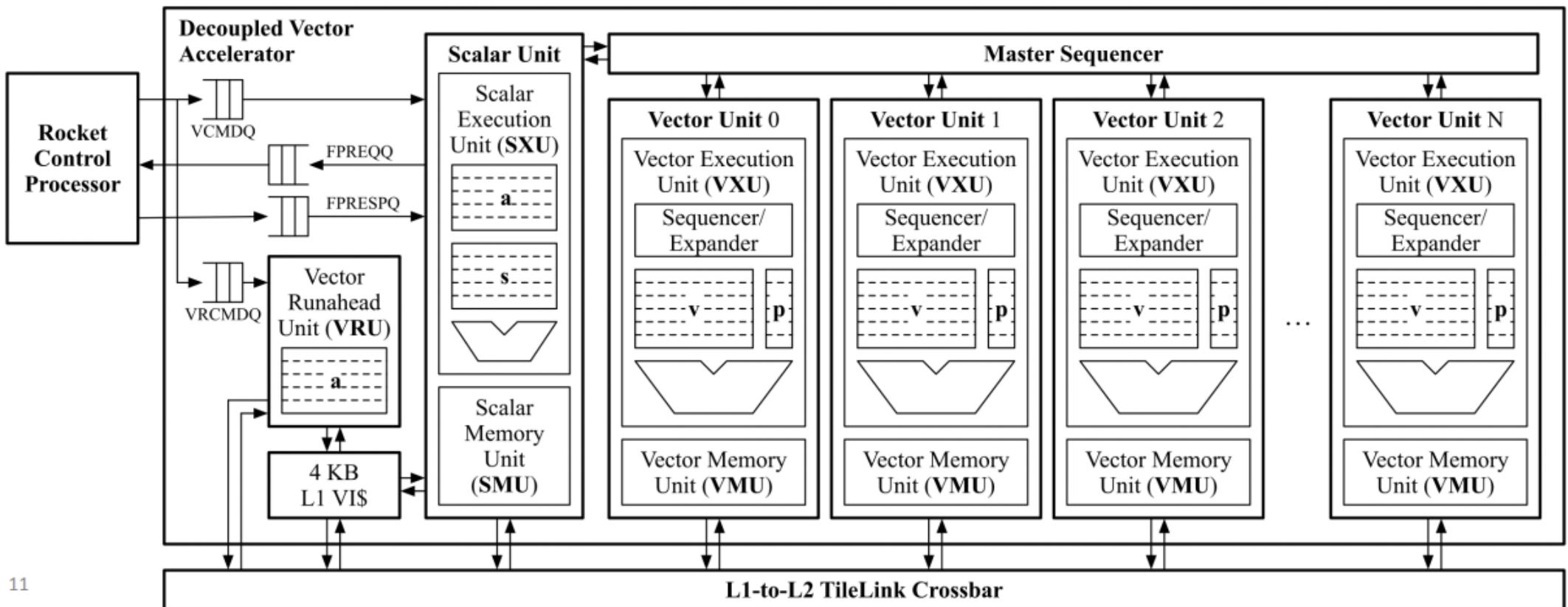
Gemmini: A Systolic(ish) Generator

- Systolic Array Accelerator
- Fully configurable
 - Dataflow – Output/Weight Stationary
 - Dimensions
 - Bitwidths/Datatypes
 - Pipeline Depth
 - Memory capacity
 - Memory banking
 - Memory Bus Width



Hwacha: A Vector Accelerator

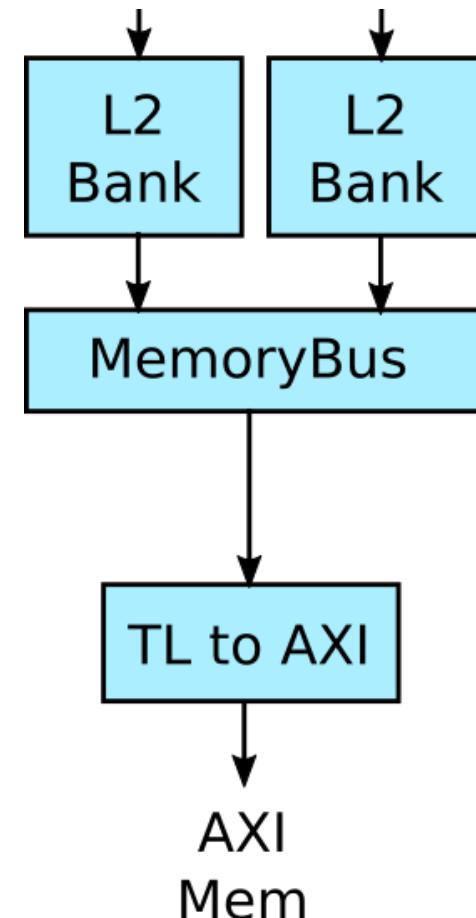
- Configurable access/execute decoupled vector architecture*



* Not based on RV-V (adopted in '22)

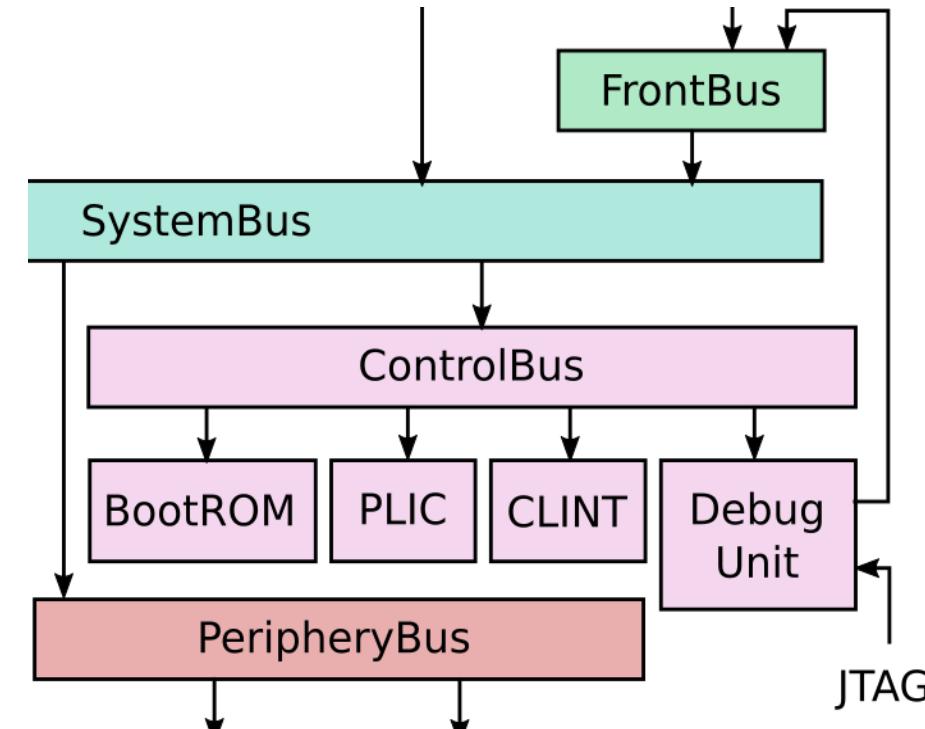
L2 Cache and Memory System

- Multi-bank shared L2
 - SiFive's open-source IP
 - Fully coherent
 - Configurable size, associativity
 - Supports atomics, prefetch hints
- Non-caching L2 Broadcast Hub
 - Coherence w/o caching
 - Bufferless design
- Multi-channel memory system
 - Conversion to AXI4 for compatible DRAM controllers



Core Complex Devices

- BootROM
 - First-stage bootloader
 - DeviceTree
- PLIC
- CLINT
 - Software interrupts
 - Timer interrupts
- Debug Unit
 - DMI
 - JTAG

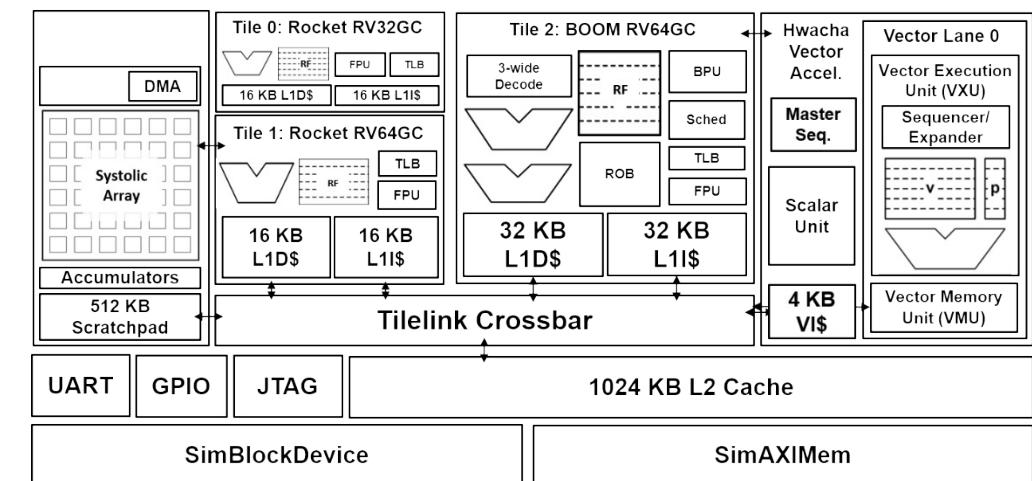
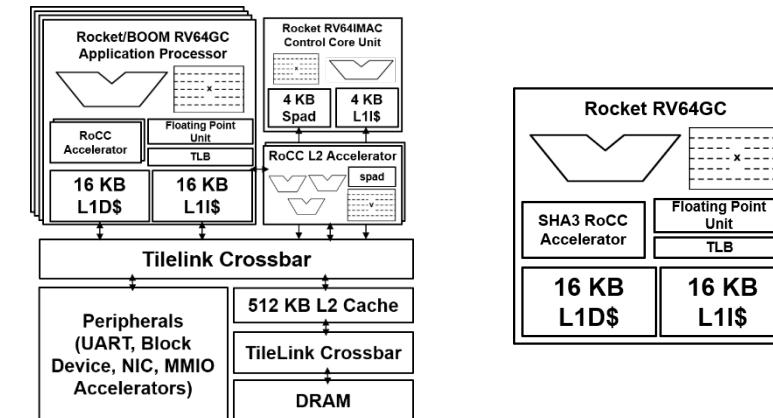


Other Chipyard Blocks

- **Hardfloat:** Parameterized Chisel generators for hardware floating-point units
- **IceNet:** Custom NIC for FireSim simulations
- **SiFive-Blocks:** Open-sourced Chisel peripherals
 - GPIO, SPI, UART, etc.
- **TestchipIP:** Berkeley utilities for chip testing/bringup
 - Tethered serial interface
 - Simulated block device
- **SHA3:** Educational SHA3 RoCC accelerator
 - Lab

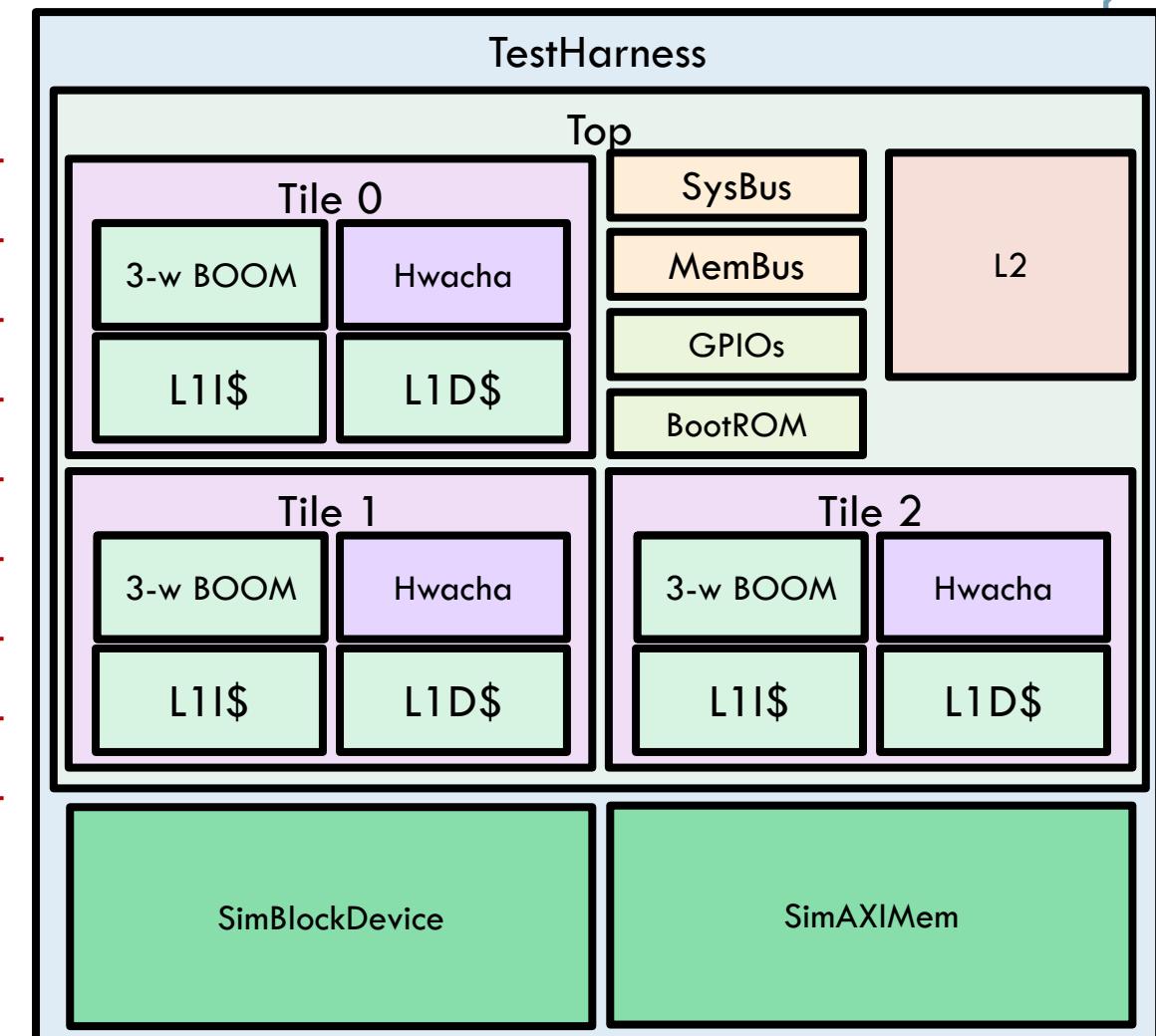
Customization – from very simple to very complex SoCs

- Cores and controllers: Intra-core Rocket/BOOM configurations
 - Control core / PMU as an example
- Simple RoCC accelerators
 - SHA3 as an ‘instructional’ demo
- Complex RoCC accelerators
 - Hwacha and Gemmini as examples
- MMIO Tilelink accelerators
- Peripherals



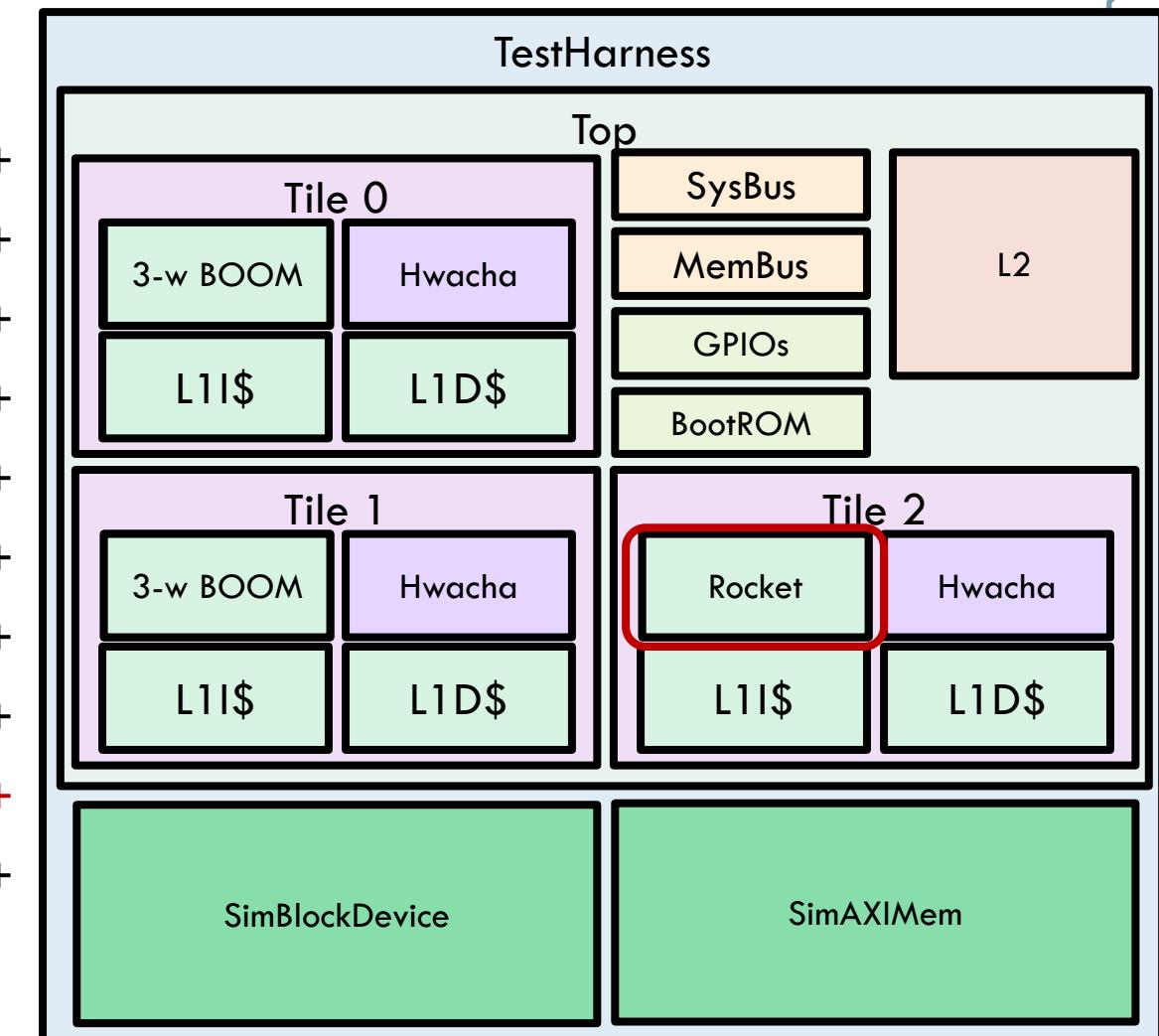
Rocket Chip Configuration

```
class MyCustomConfig extends Config(  
    new WithExtMemSize((1<<30) * 2L)  
    new WithBlockDevice  
    new WithGPIO  
    new WithBootROM  
    new hwacha.DefaultHwachaConfig  
    new WithInclusiveCache(capacityKB=1024)  
    new boom.common.WithLargeBooms  
    new boom.system.WithNBoomCores(3)  
    new WithNormalBoomRocketTop  
    new rocketchip.system.BaseConfig)
```



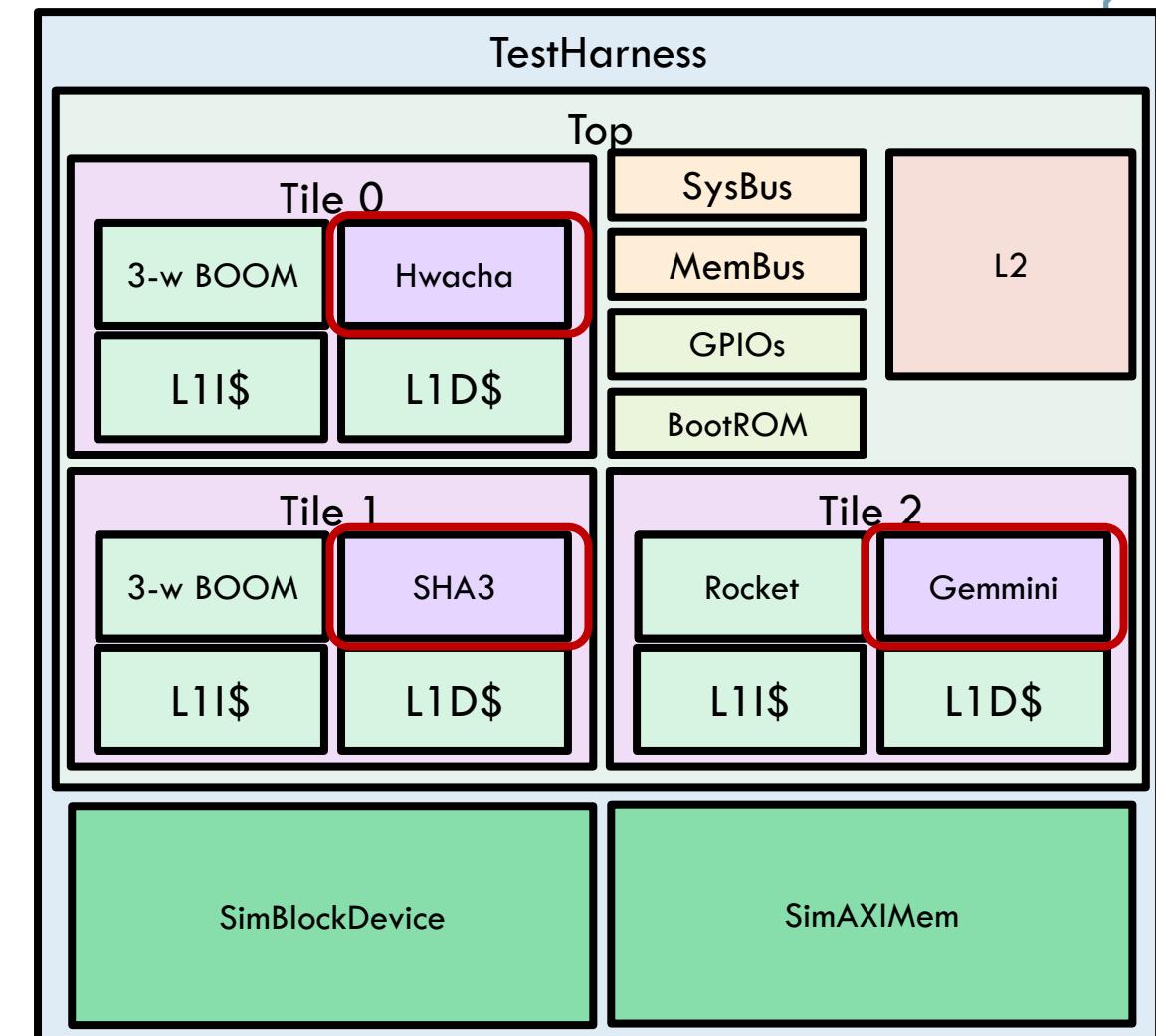
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    new boom.system.WithNBoomCores(2)  
    new rocketchip.subsystem.WithNBigCores(1)  
    new WithNormalBoomRocketTop  
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```



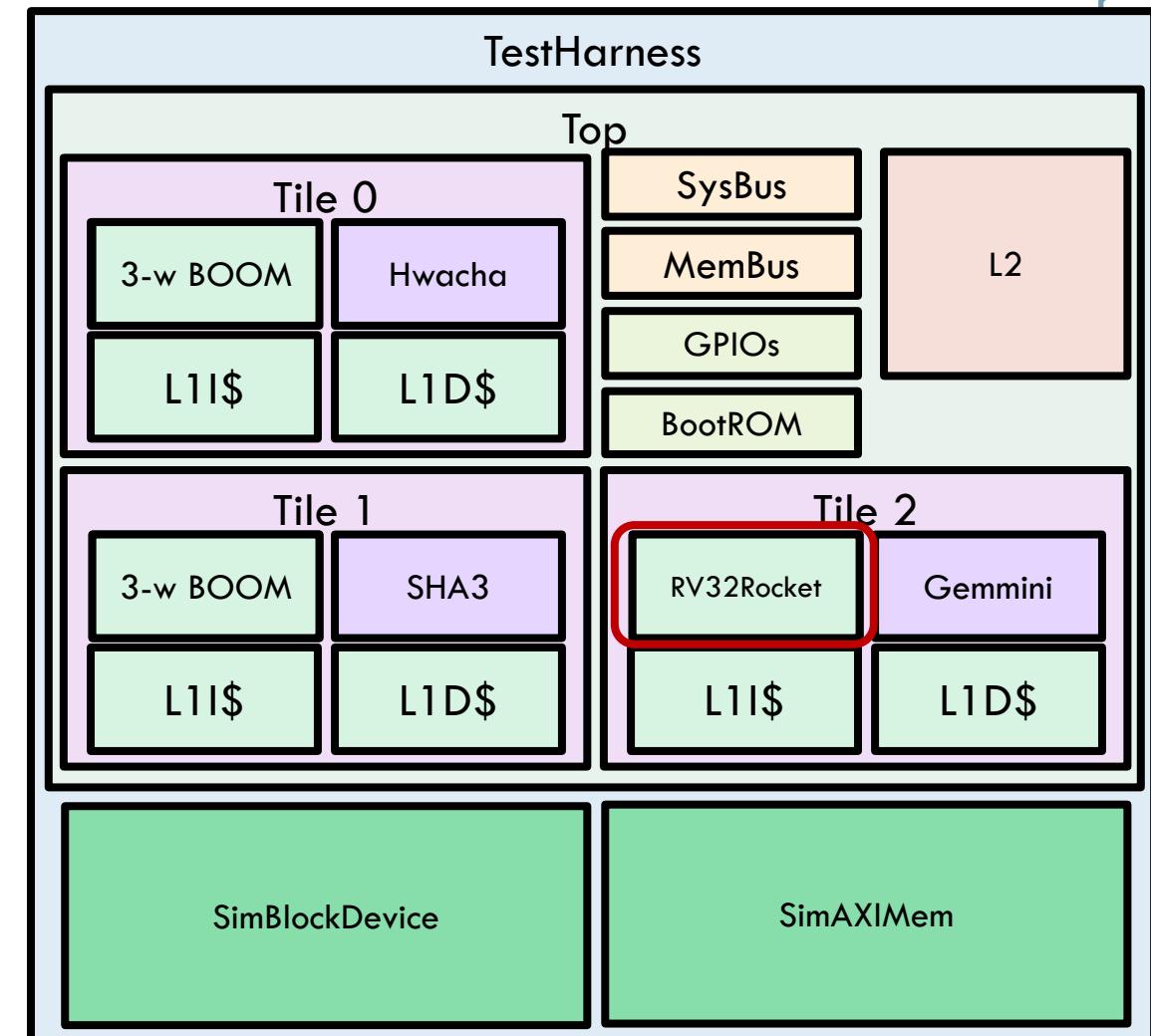
Rocket Chip Configuration

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    new WithBlockDevice
    new WithGPIO
    new WithBootROM
    new WithMultiRoCCGemmini(2)
    new WithMultiRoCCSha3(1)
    new WithMultiRoCCHwacha(0)
    new WithInclusiveCache(capacityKB=1024)
    new boom.common.WithLargeBooms
    new boom.system.WithNBoomCores(2)
    new rocketchip.subsystem.WithNBigCores(1)
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```



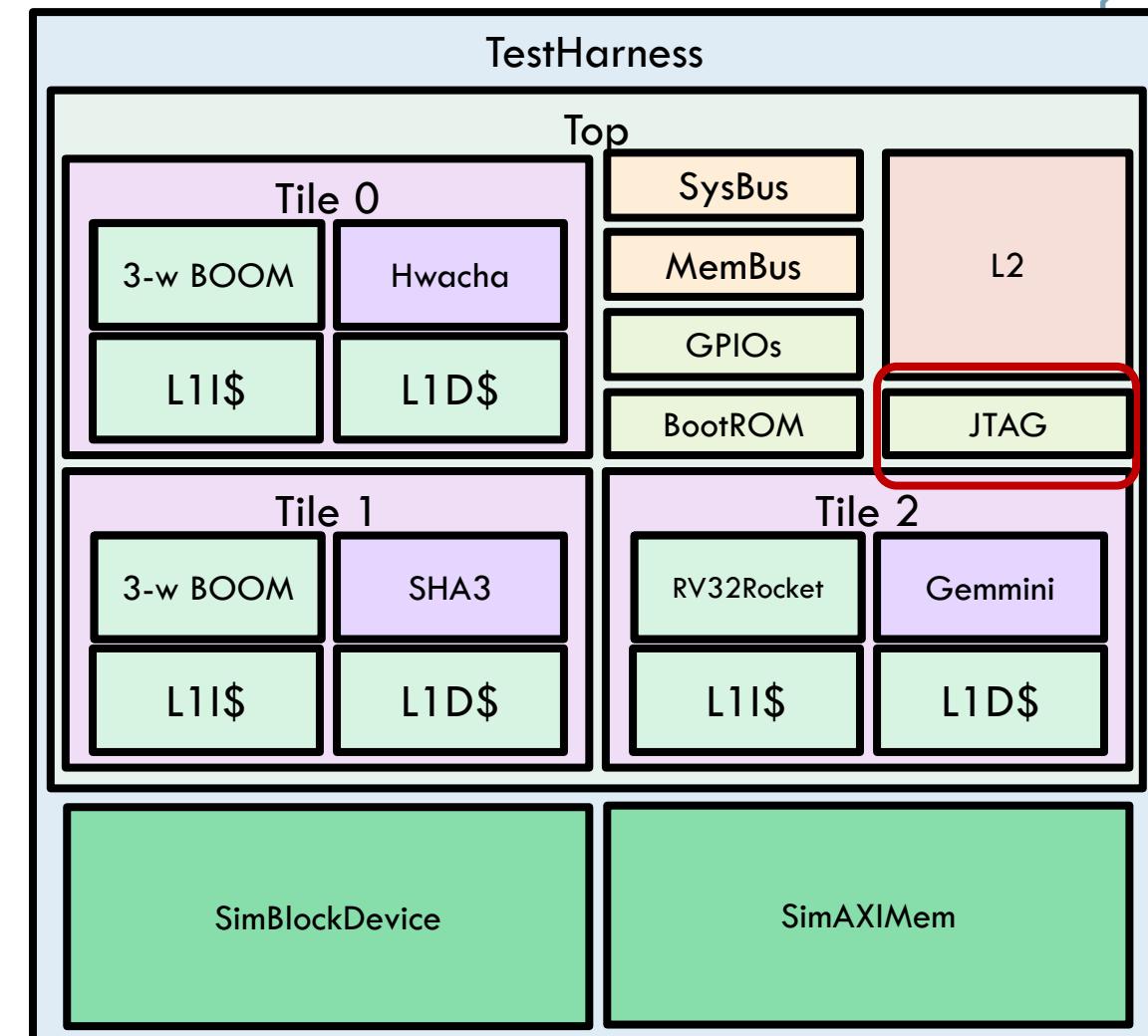
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    new WithBootROM  
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    new WithMultiRoCCSha3(1)  
    new WithMultiRoCCHwacha(0)  
    new WithInclusiveCache(capacityKB=1024)  
    new boom.common.WithLargeBooms  
    new boom.system.WithNBoomCores(2)  
    new rocketchip.subsystem.WithRV32  
    new rocketchip.subsystem.WithNBigCores(1)  
    new WithNormalBoomRocketTop  
    new rocketchip.system.BaseConfig)
```



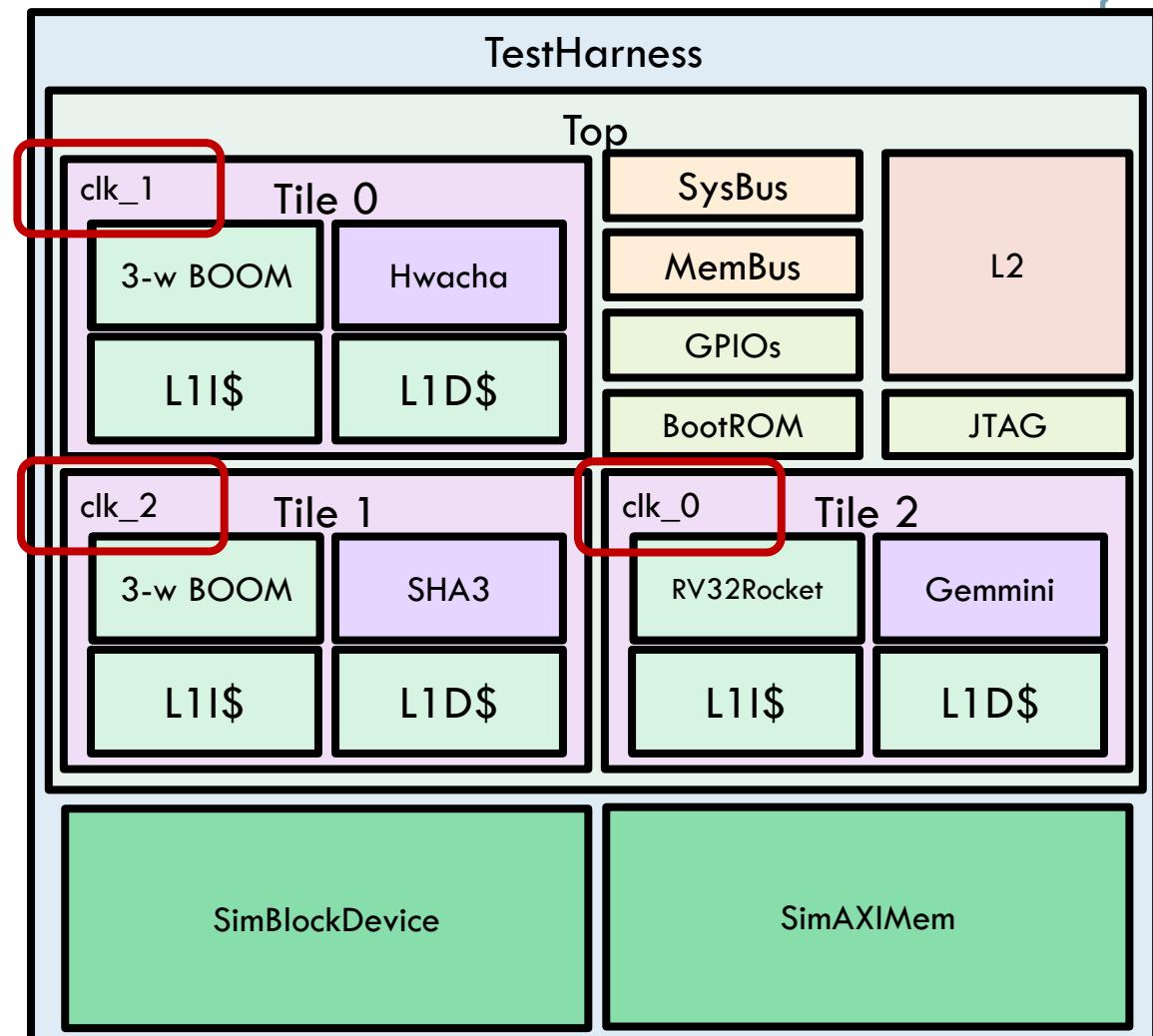
Rocket Chip Configuration

```
class MyCustomConfig extends Config  
    new WithExtMemSize((1<<30) * 2L)          ++  
    new WithBlockDevice                         ++  
    new WithGPIO                                ++  
    new WithJtagDTM                            ++  
    new WithBootROM                            ++  
    new WithMultiRoCCGemmini(2)                 ++  
    new WithMultiRoCCSha3(1)                     ++  
    new WithMultiRoCCHwacha(0)                  ++  
    new WithInclusiveCache(capacityKB=1024)     ++  
    new boom.common.WithLargeBooms             ++  
    new boom.system.WithNBoomCores(2)            ++  
    new rocketchip.subsystem.WithRV32           ++  
    new rocketchip.subsystem.WithNBigCores(1)++  
    new WithNormalBoomRocketTop                ++  
    new rocketchip.system.BaseConfig)
```

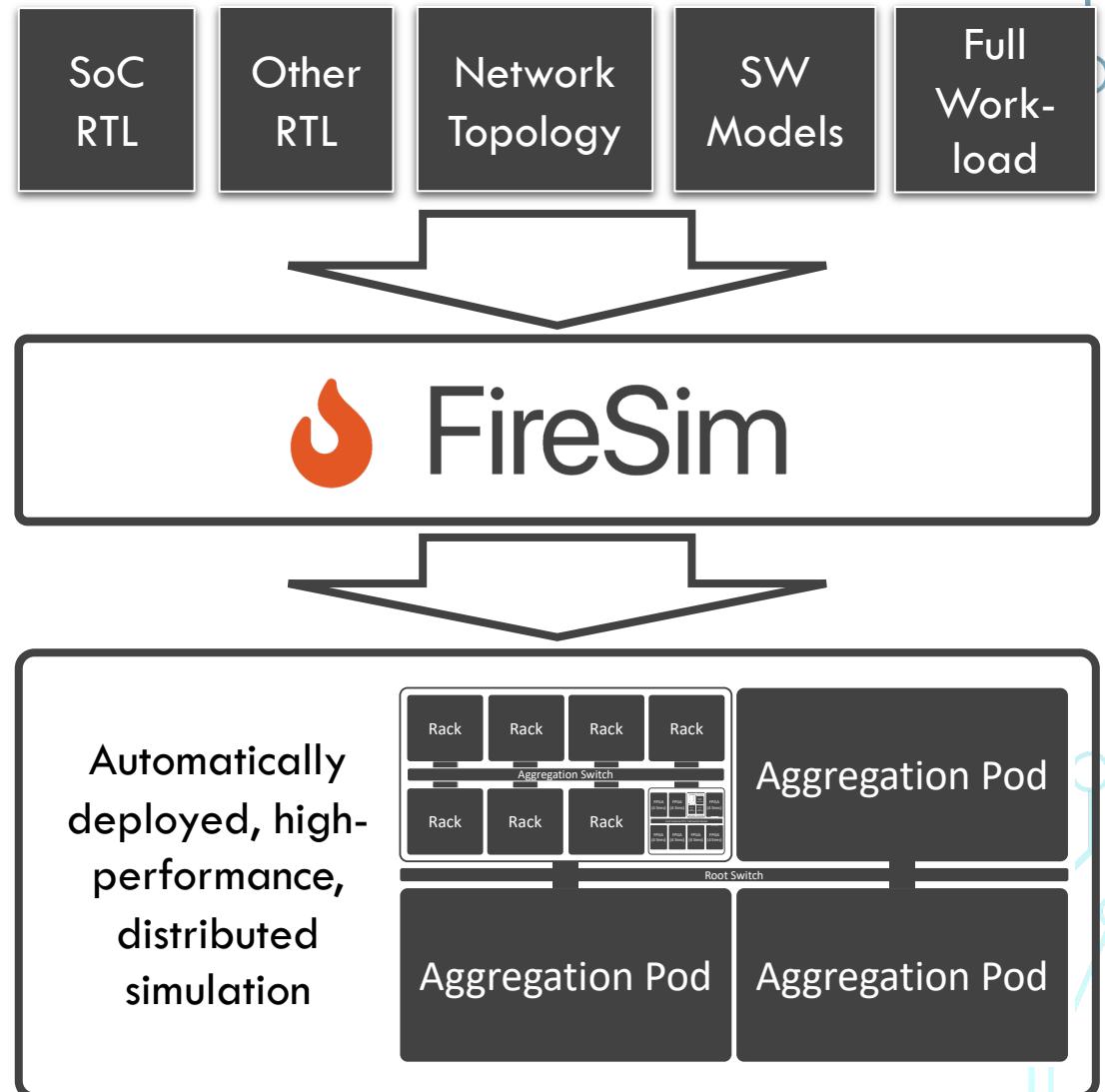


Rocket Chip Configuration

```
class MyCustomConfig extends Config(
    new WithExtMemSize((1<<30) * 2L)          ++
    new WithBlockDevice                         ++
    new WithGPIO                                ++
    new WithJtagDTM                            ++
    new WithBootROM                            ++
    new WithRationalBoomTiles                   ++
    new WithRationalRocketTiles                 ++
    new WithMultiRoCCGemmini(2)                ++
    new WithMultiRoCCSha3(1)                    ++
    new WithMultiRoCCHwacha(0)                  ++
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    new rocketchip.system.BaseConfig)
```



- FPGA-accelerated simulation on the Amazon EC2 public cloud
- Originally developed for cycle-exact architectural exploration of data-center clusters
- Not FPGA prototypes, rather FPGA-accelerated simulators
- Cloud FPGAs
 - Inexpensive, elastic supply of large FPGAs
 - Easy to collaborate with other researchers

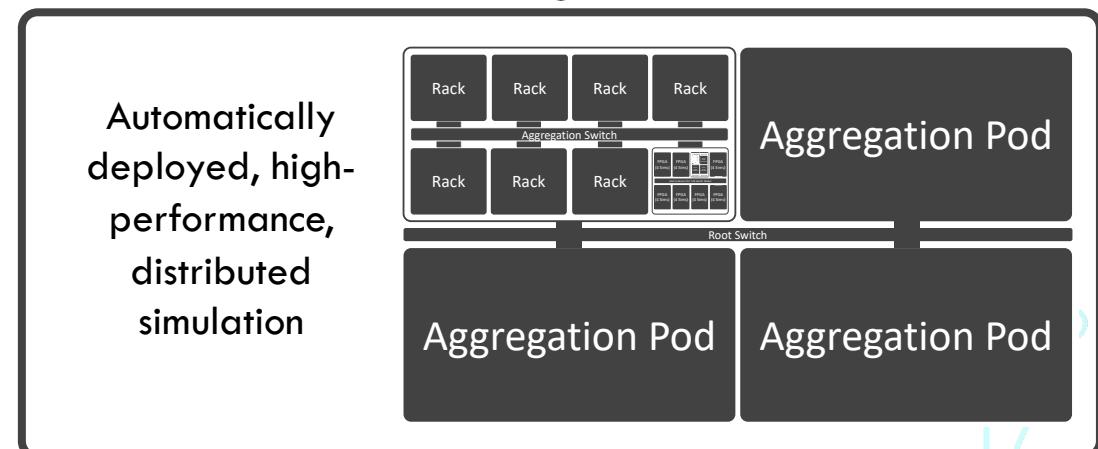
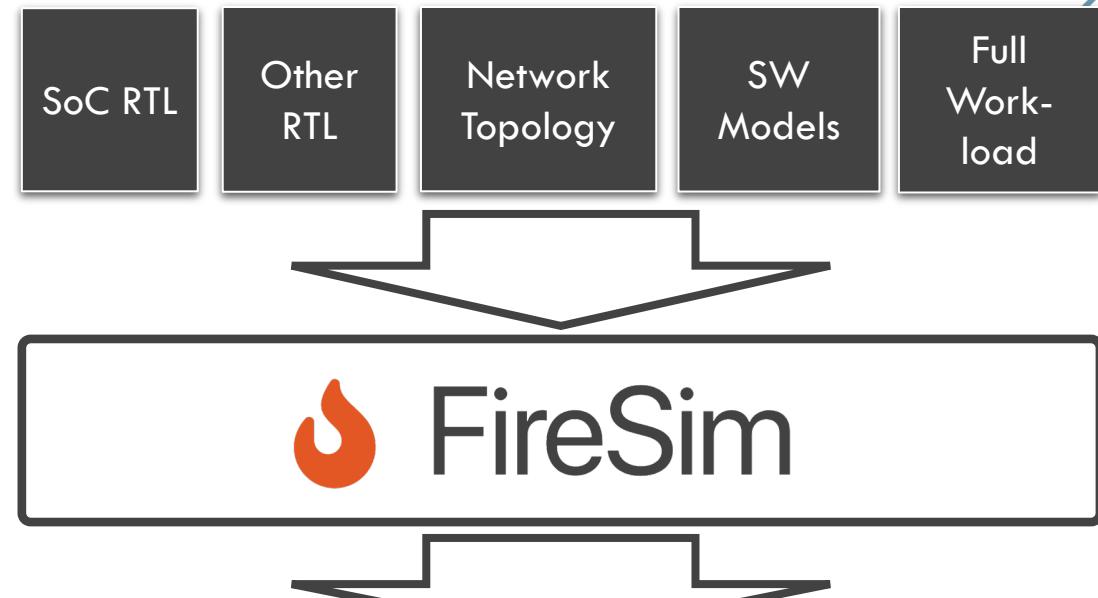
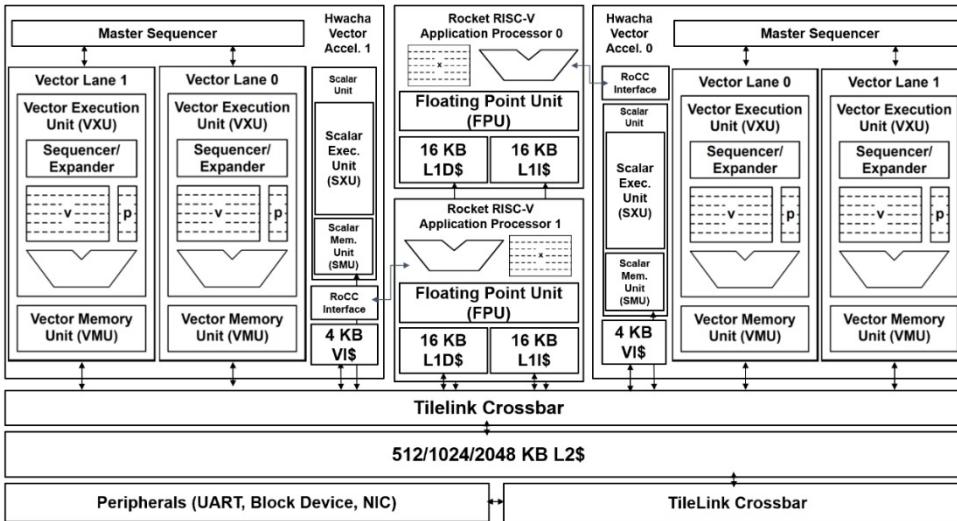


FireSim

- Cycle-exactly simulating large SoCs on cloud FPGAs @10s-100s of MHz
- Open-source: <https://firesim.org>
- Targets:
 - (1) Architecture evaluation
 - (2) Validate application on a pre-Si SoC

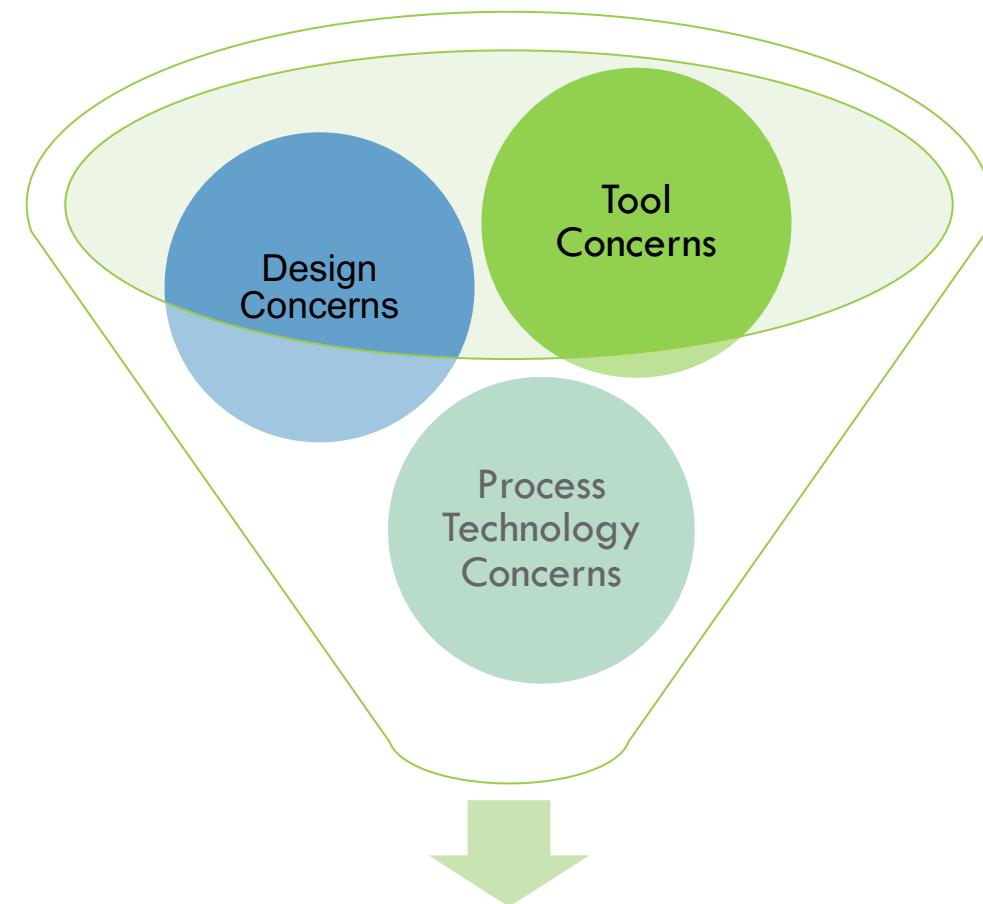
S. Karandikar, ISCA '18, IEEE Micro TopPicks '18, CARRV '19

Example of (2): PageRank on Rocket+Hwacha



Hammer

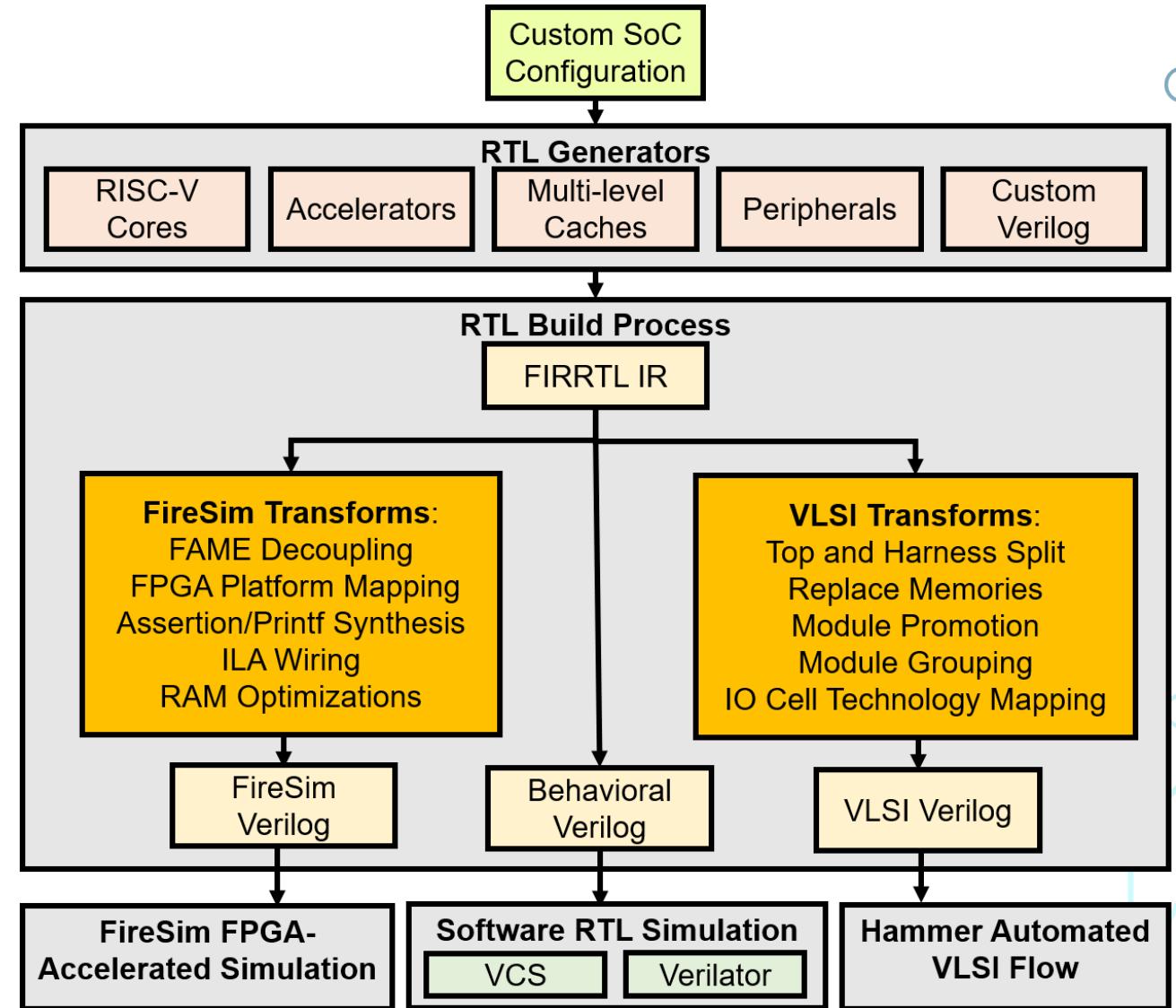
- Modular VLSI flow
 - Allow reusability
 - Allow for multiple “small” experts instead of a single “super” expert
 - Build abstractions/APIs on top
 - Improve portability
 - Improve hierarchical partitioning
- Three categories of flow input
 - Design-specific
 - Tool/Vendor-specific
 - Technology-specific



Customized TCL Script

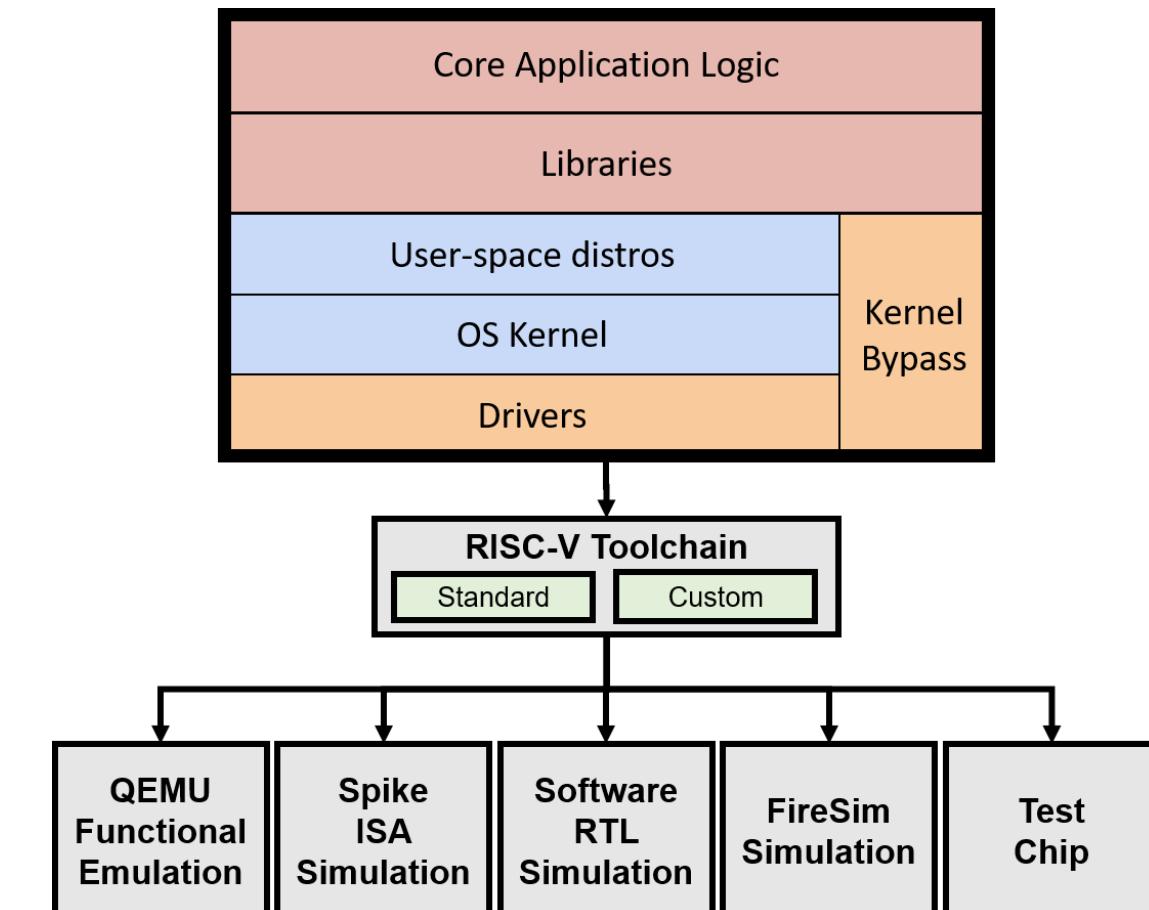
Simulation/Implementation Targets

- Custom hardware design is not just about generated IP blocks!
- Different collaterals for different simulation or implementation targets
 - Design cycle RTL simulation
 - Verification / validation
 - VLSI flow



Software

- Compatible standard RISC-V Tools versions
- ESP-Tools as a non-standard equivalent SW tools package with custom accelerator extensions (Hwacha, Gemmini)
- Improved BareMetal testing flow
 - Use libgloss and newlib instead of in-house syscalls
- FireMarshal workload management



Summary

- We will use Chipyard to generate a minimalist RISC-V SoC for logic design and circuits experiments
- Labs will exercise the design flow
- The projects will help expand this SoC template with chiplet interface

Next Lecture

- Chisel