FPGA Prototyping

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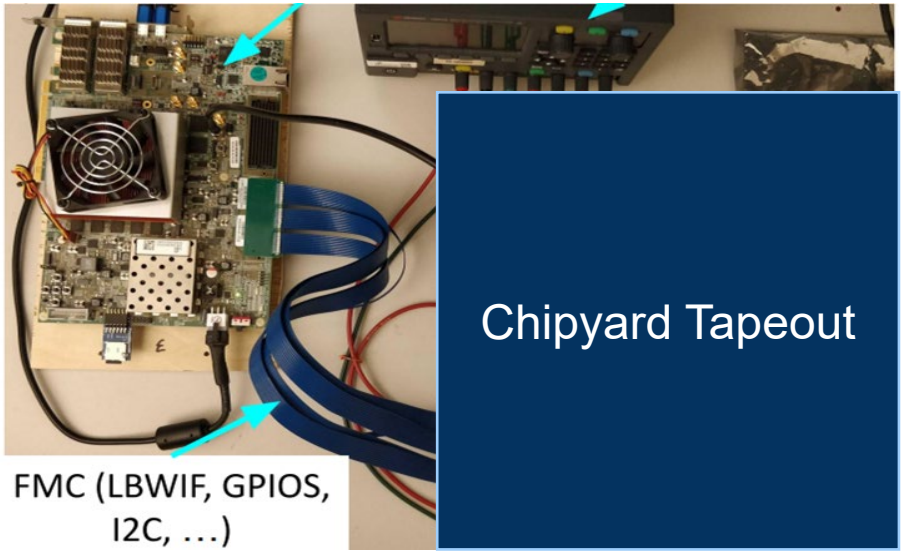
Slides adapted from Abraham Gonzalez

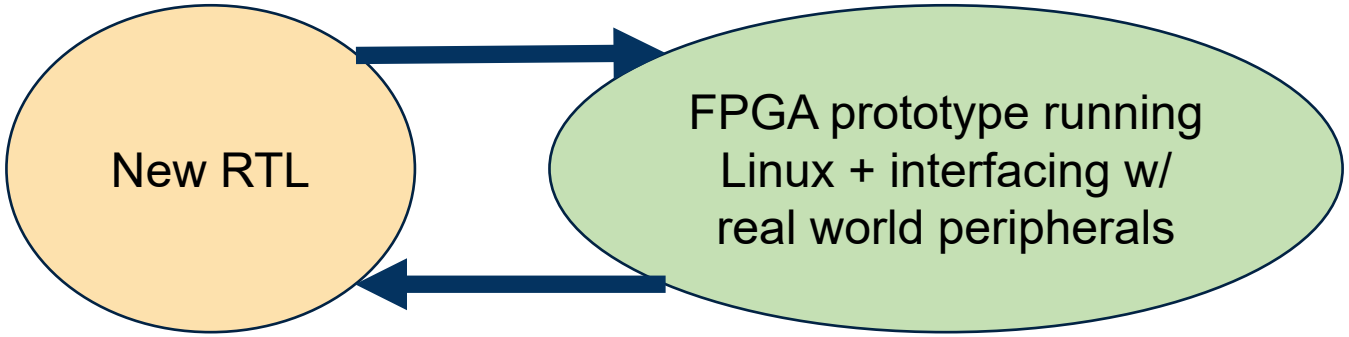
Berkeley Architecture Research

CHIPYARD

Motivation

- FPGAs are a powerful tool!
- Many people have off the shelf FPGAs
- Chipyard use cases for FPGAs
  - HW simulation – Use FireSim!
  - Interact with the real-world peripherals
  - Tapeout bringup platform

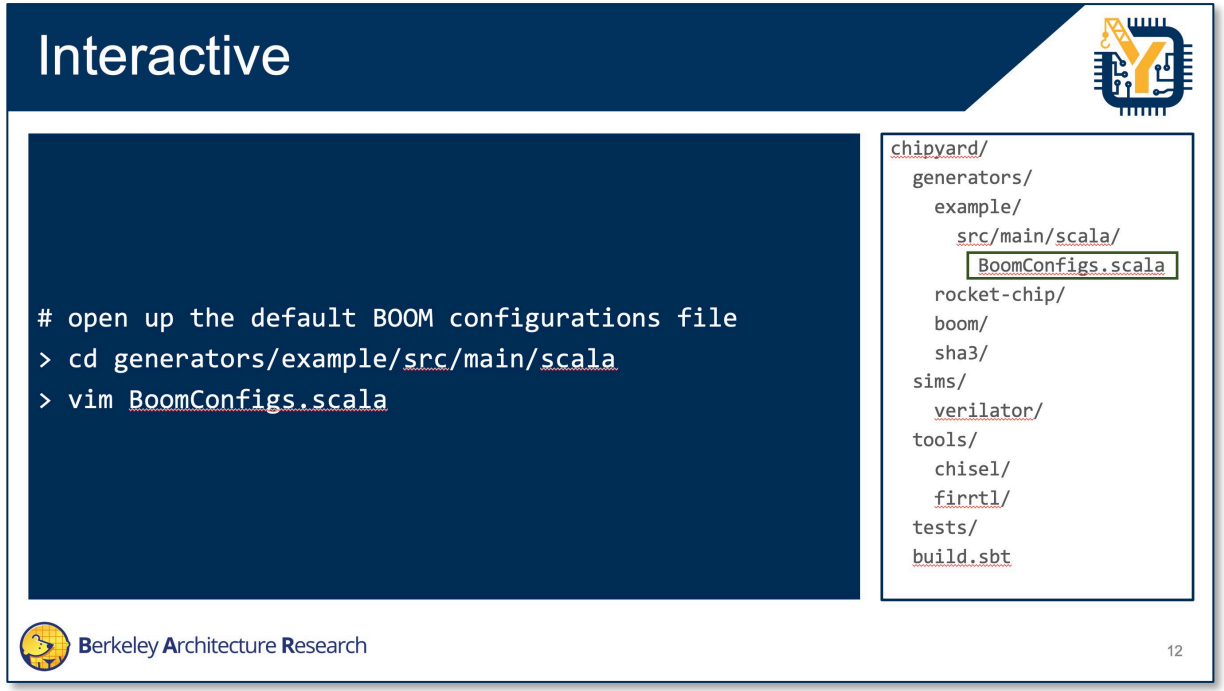


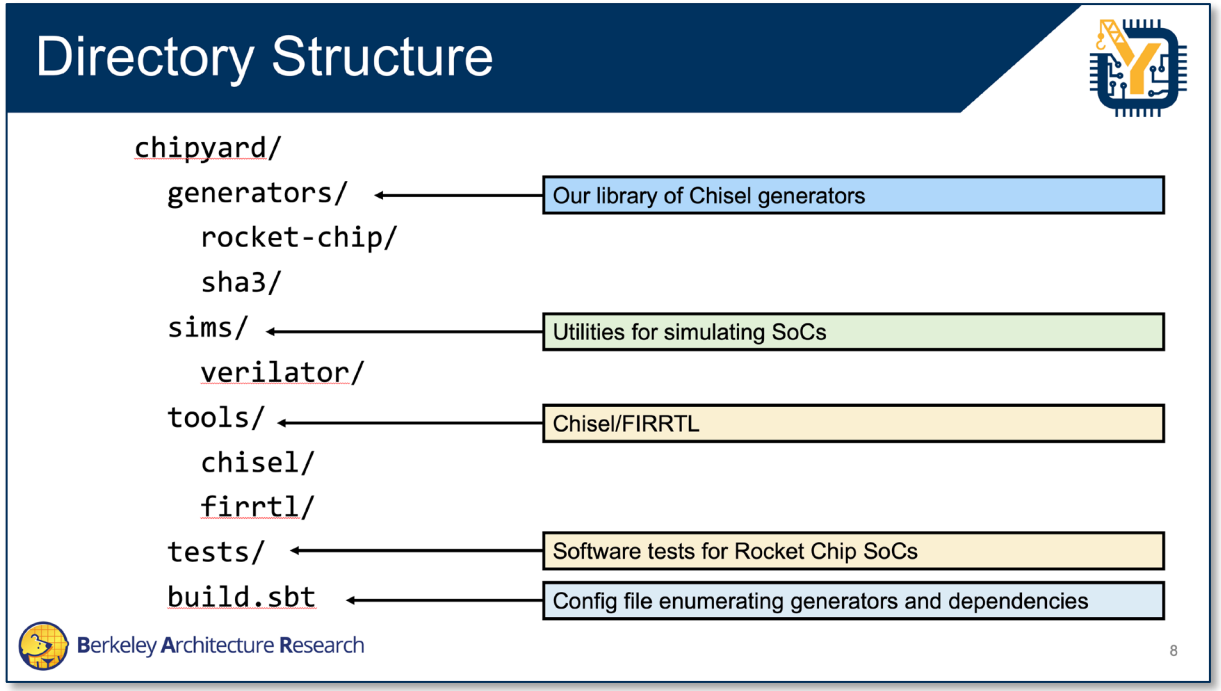


Goals

- Understand the basics of generating a bitstream
- Overview of the two supported platforms
- Example: Build and run Linux on a VCU118 FPGA w/ BOOM!
  - Build a pre-configured BOOM bitstream
  - Build Linux binary and start the prototype run
  - Interact with Linux!

How things will work





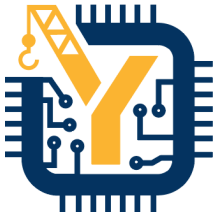
Interactive Slide

"Follow Along"

Explanation Slide

"What's happening?"

How things will work



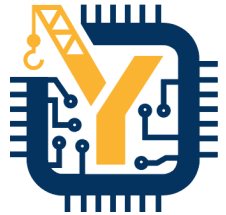
```
# command 1
> echo “Chipyard Rules!”

# command 2
> do_this arg1 arg2
```

Terminal Section

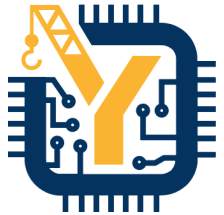
```
// SOME COMMENT HERE
class SmallBoomConfig extends Config(
  new WithTop ++
  new WithBootROM ++
  new boom.common.WithSmallBooms ++
  new boom.common.WithNBoomCores(1) ++
  new freechips.rocketchip.system.BaseConfig)
```

Inside-a-File Section



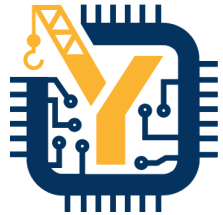
Getting Started

Prerequisites



- Vivado installed and on your PATH
  - Tested with 2018.3 but should work for some other versions
- Fully setup Chipyard
  - All submodules initialized
  - A toolchain installed
- Basic understanding of Vivado
  - How to load a bitstream
  - How to connect to an FPGA

Example

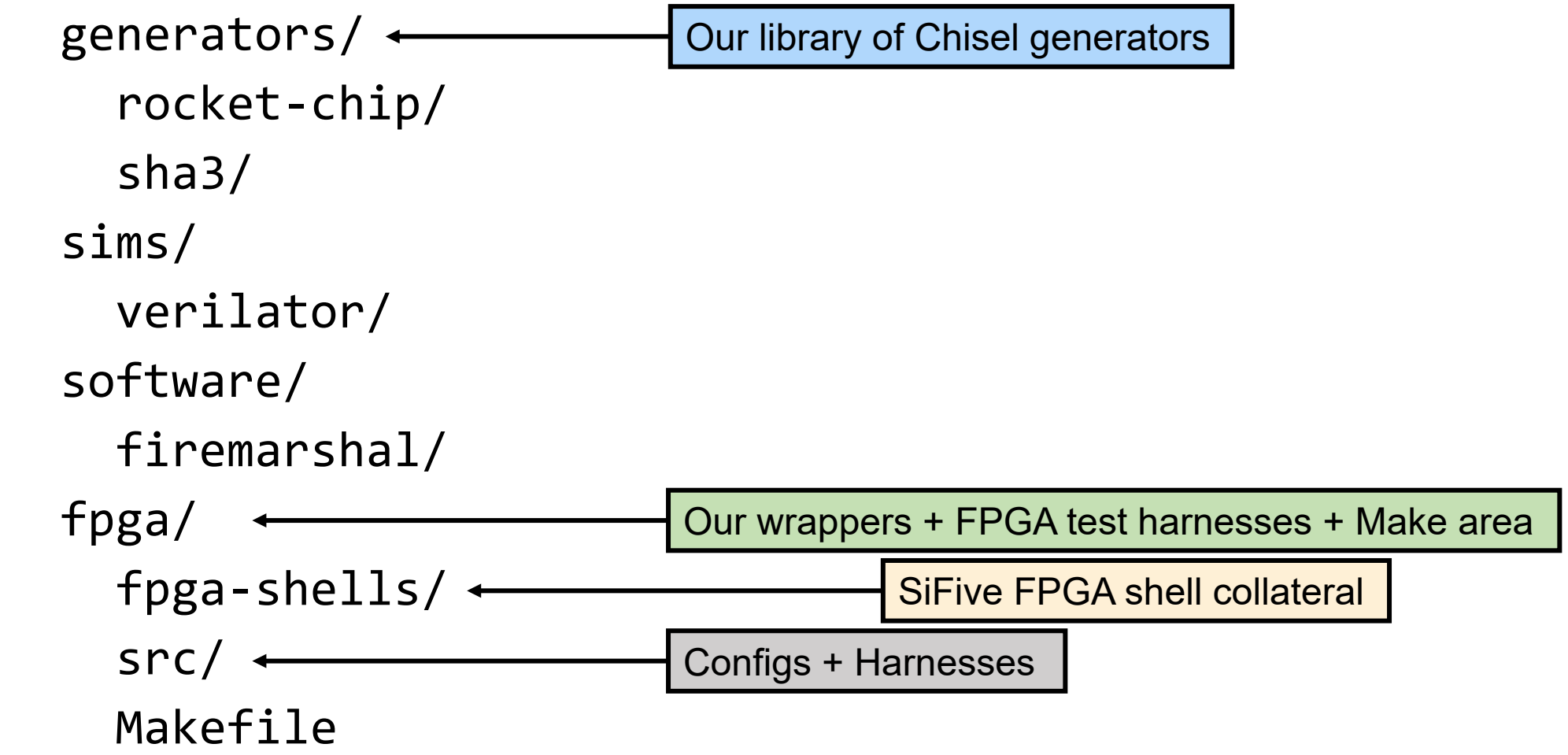


```
# return to Chipyard
> cd ~/chipyard
> ls

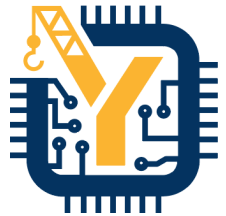
# setup the repo to build fpga images
> ./scripts/init-fpga.sh
```

Wrapper around `git submodule init` to clone the necessary FPGA collateral

Directory Structure



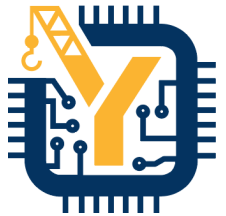
FPGA-Shells



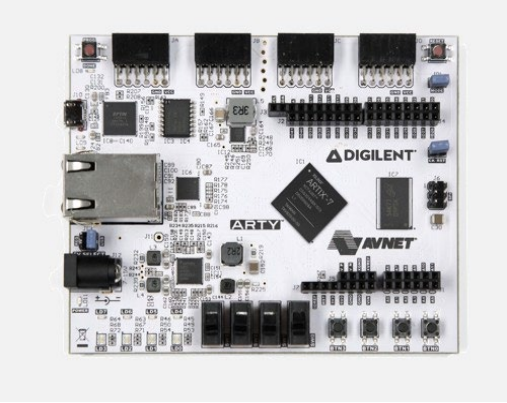
- Provided by SiFive
  - But extended and built upon by ADEPT students
  - Used in the SiFive Freedom platform
- Connects Rocket Chip SoCs to FPGAs
- Contains board and peripheral support
- Current FPGA support
  - VCU118
  - Arty A7

```
chipyard/
  generators/
    rocket-chip/
    boom/
    sha3/
  sims/
    verilator/
  fpga/
    fpga-shells/
    src/
  tools/
    chisel/
    firrtl/
  tests/
  build.sbt
```

Chipyard supported boards



Xilinx Arty



- Artix7 FPGA fits TinyRocketConfig
- UART, JTAG, QSPI flash for BootROM
- No backing DDR (yet), so does not boot Linux

Xilinx VCU118

- Ultrascale FPGA fits large Rocket and BOOM configs
- UART, JTAG, DDR backing memory, SDCard boot BootROM
- Boots Linux

```
chipyard/
  generators/
    rocket-chip/
    boom/
    sha3/
  sims/
    verilator/
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    fpga-shells/
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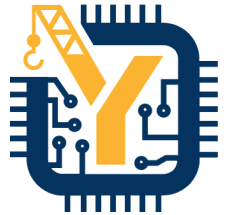
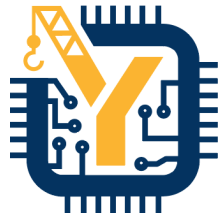


Build a VCU118 bitstream

Bitstreams



- Building a bitstream is similar to building a simulator binary in `sims/*` but in `fpga/`
  - Converts Chisel to Verilog
  - Runs Verilog through Vivado to create a bitstream
- Target a specific configuration + FPGA

```
# build the BOOM config bitstream for VCU118
> make SUB_PROJECT=vcu118 CONFIG=BoomVCU118Config
bitstream
```

```
chipyard/
  generators/
    rocket-chip/
    boom/
    sha3/
  sims/
    verilator/
  fpga/
    fpga-shells/
    src/
  tools/
    chisel/
    firrtl/
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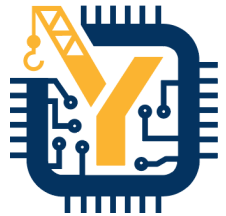
  build.sbt
```

Bitstreams



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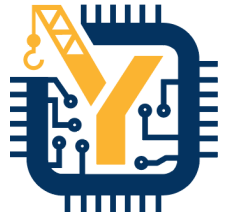
  - Converts Chisel to Verilog
  - Runs Verilog through Vivado to create a bitstream
- Target a specific configuration + FPGA

```
# build the BOOM config bitstream for VCU118
> make SUB_PROJECT=vcu118 CONFIG=BoomVCU118Config bitstream
```

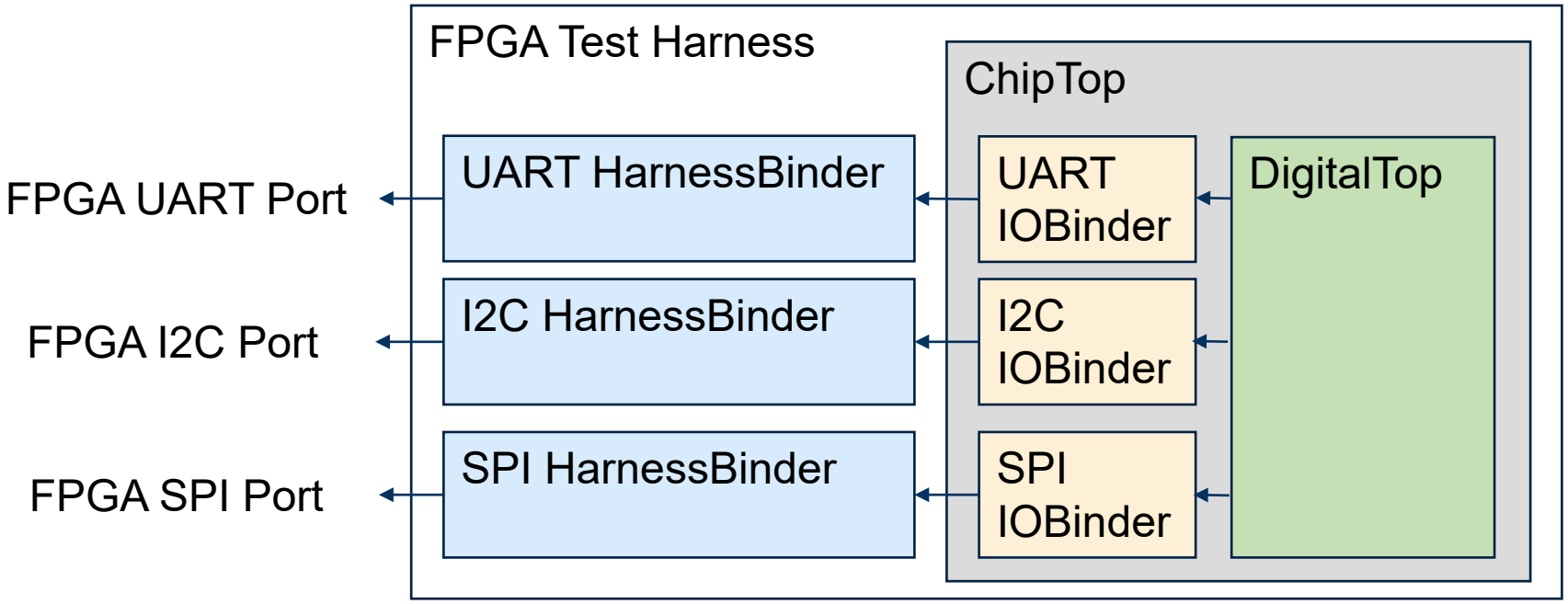
This will take a loooong time! It is generating the Verilog, and passing it to Vivado to create the bitstream

```
chipyard/
  generators/
    rocket-chip/
    boom/
    sha3/
  sims/
    verilator/
  fpga/
    fpga-shells/
    src/
  tools/
    chisel/
    firrtl/
  tests/
  build.sbt
```



In the meantime…

Anatomy of an FPGA prototype




```
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  generators/
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    sha3/
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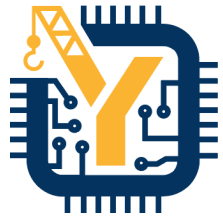
    src/main/scala/vcu118/
      Configs.scala
  tools/
    chisel/
    firrtl/
  tests/
  build.sbt
```

- HarnessBinders connect ChipTop IOs to FPGA specific ports given by FPGA-Shells
- TestHarness is associated with FPGA platform

View of the config



```
class WithVCU118Tweaks extends Config(
  new WithUART ++
  new WithSPISDCard ++
  new WithDDRMem ++
  new WithUARTIOPassthrough ++
  new WithSPIIOPassthrough ++
  new WithTLIOPassthrough ++
  new WithDefaultPeripherals ++
  new chipyard.config.WithTLBackingMemory ++
  new WithSystemModifications ++
  new chipyard.config.WithNoDebug ++
  new freechips.rocketchip.subsystem.WithoutTLMonitors ++
  new freechips.rocketchip.subsystem.WithNMemoryChannels(1))

class BoomVCU118Config extends Config(
  new WithFPGAFrequency(50) ++
  new WithVCU118Tweaks ++
  new chipyard.MegaBoomConfig)
```

Default Chipyard configuration

```
chipyard/
  generators/
    rocket-chip/
    boom/
    sha3/
  sims/
    verilator/
  fpga/
    fpga-shells/
    src/main/scala/vcu118/
      Configs.scala
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```

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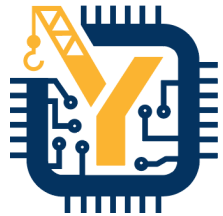

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class BoomVCU118Config extends Config(
  new WithFPGAFrequency(50) ++
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```

Set FPGA frequency in MHz

```
chipyard/
  generators/
    rocket-chip/
    boom/
    sha3/
  sims/
    verilator/
  fpga/
    fpga-shells/
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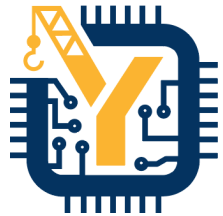

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  new WithDefaultPeripherals ++
  new chipyard.config.WithTLBackingMemory ++
  new WithSystemModifications ++
  new chipyard.config.WithNoDebug ++
  new freechips.rocketchip.subsystem.WithoutTLMonitors ++
  new freechips.rocketchip.subsystem.WithNMemoryChannels(1))

class BoomVCU118Config extends Config(
  new WithFPGAFrequency(50) ++
  new WithVCU118Tweaks ++
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```

Link this configuration with the upper configuration fragment

```
chipyard/
  generators/
    rocket-chip/
    boom/
    sha3/
  sims/
    verilator/
  fpga/
    fpga-shells/
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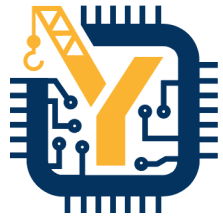

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```

Add IOBinders

```
chipyard/
  generators/
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    boom/
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  sims/
    verilator/
  fpga/
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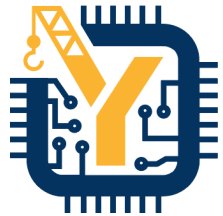

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Add HarnessBinders

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  generators/
    rocket-chip/
    boom/
    sha3/
  sims/
    verilator/
  fpga/
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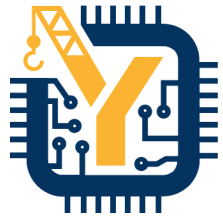

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```

Setup params for UART/SPI peripherals and DDR

```
chipyard/
  generators/
    rocket-chip/
    boom/
    sha3/
  sims/
    verilator/
  fpga/
    fpga-shells/
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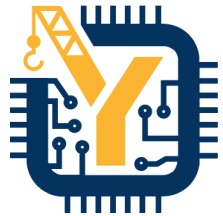

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  new WithVCU118Tweaks ++
  new chipyard.MegaBoomConfig)
```

Setup buses, use SDCard bringup bootrom, set memory size, and more

```
chipyard/
  generators/
    rocket-chip/
    boom/
    sha3/
  sims/
    verilator/
  fpga/
    fpga-shells/
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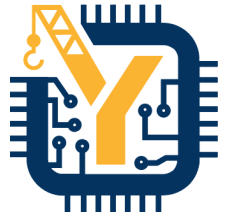
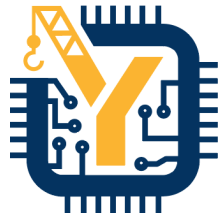


Building Linux for FPGA prototypes

Using FireMarshal to build Linux



- Later in the tutorial we will go into more depth on FireMarshal
  - A unified workload generation tool used across Chipyard

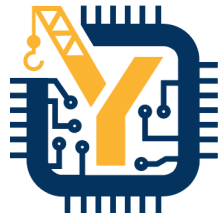
```
# navigate to firemarshal (assuming pre-setup)
> cd chipyard/software/firemarshal

# configure firemarshal for fpga prototypes
> echo "board-dir : 'boards/prototype'" > marshal-config.yaml

# build linux with initramfs
> ./marshal -v -d build br-base.json
```

```
chipyard/
  generators/
    rocket-chip/
    boom/
    sha3/
  sims/
    verilator/
  fpga/
    fpga-shells/
    src/
  software/
    firemarshal/
  tests/
  build.sbt
```

Using FireMarshal to build Linux



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  - A unified workload generation tool used across Chipyard

```
# navigate to firemarshal (assuming pre-setup)
> cd chipyard/software/firemarshal

# configure firemarshal for fpga prototypes
> echo "board-dir : 'boards/prototype'" > marshal-config.yaml

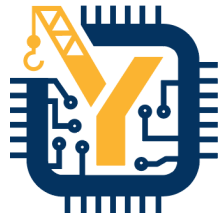
# build linux with initramfs
> ./marshal -v -d build br-base.json

> ls images/
```

All collateral will be located in the `images/` area of the `firemarshal/` directory

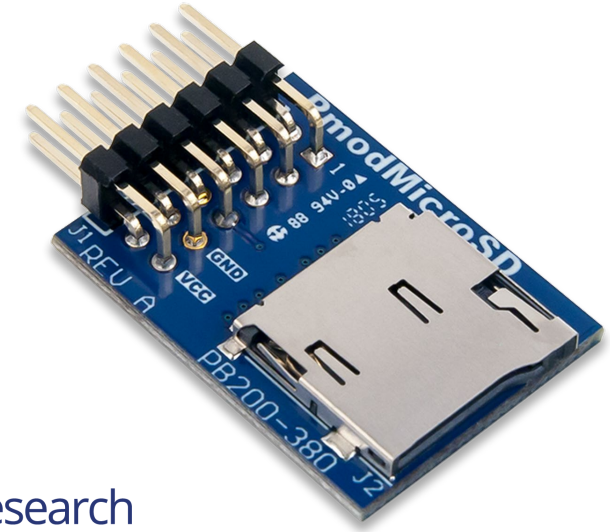
```
chipyard/
  generators/
    rocket-chip/
    boom/
    sha3/
  sims/
    verilator/
  fpga/
    fpga-shells/
    src/
  software/
    firemarshal/
    sts/
    ild.sbt
```

Putting Linux onto VCU118 SDCard



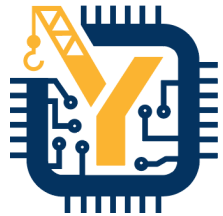
- By default the VCU118 platform loads binaries from a PMOD SDCard
- We need to flatten (i.e. remove the DRAM offset) of the output binary before loading it into SDCard

```
# flatten output linux binary to load on SDCard
> ./marshal -v -d install –t prototype br-base.json
```




```
chipyard/
  generators/
    rocket-chip/
    boom/
    sha3/
  sims/
    verilator/
  fpga/
    fpga-shells/
    src/
  software/
    firemarshal/
  tests/
  build.sbt
```

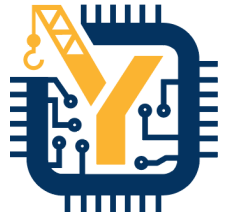
Putting Linux onto VCU118 SDCard



- Next, we need to put the binary onto a pre-setup SDCard
  - Contains 2 partitions; one to store the binary, one to store a filesystem to access from the DUT
  - SDCard setup instructions: chipyard.readthedocs.io/en/1.5.0/Prototyping/VCU118.html#setting-up-the-sdcard

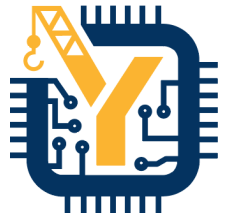
```
# move flattened binary to SDCard 1st partition (/dev/sdc1 an ex)
> sudo dd if=$PWD/images/br-base-bin-nodisk-flat of=/dev/sdc1
```

```
chipyard/
  generators/
    rocket-chip/
    boom/
    sha3/
  sims/
    verilator/
  fpga/
    fpga-shells/
    src/
  software/
    firemarshal/
  tests/
  build.sbt
```



Programming the FPGA and Running Linux

Last steps

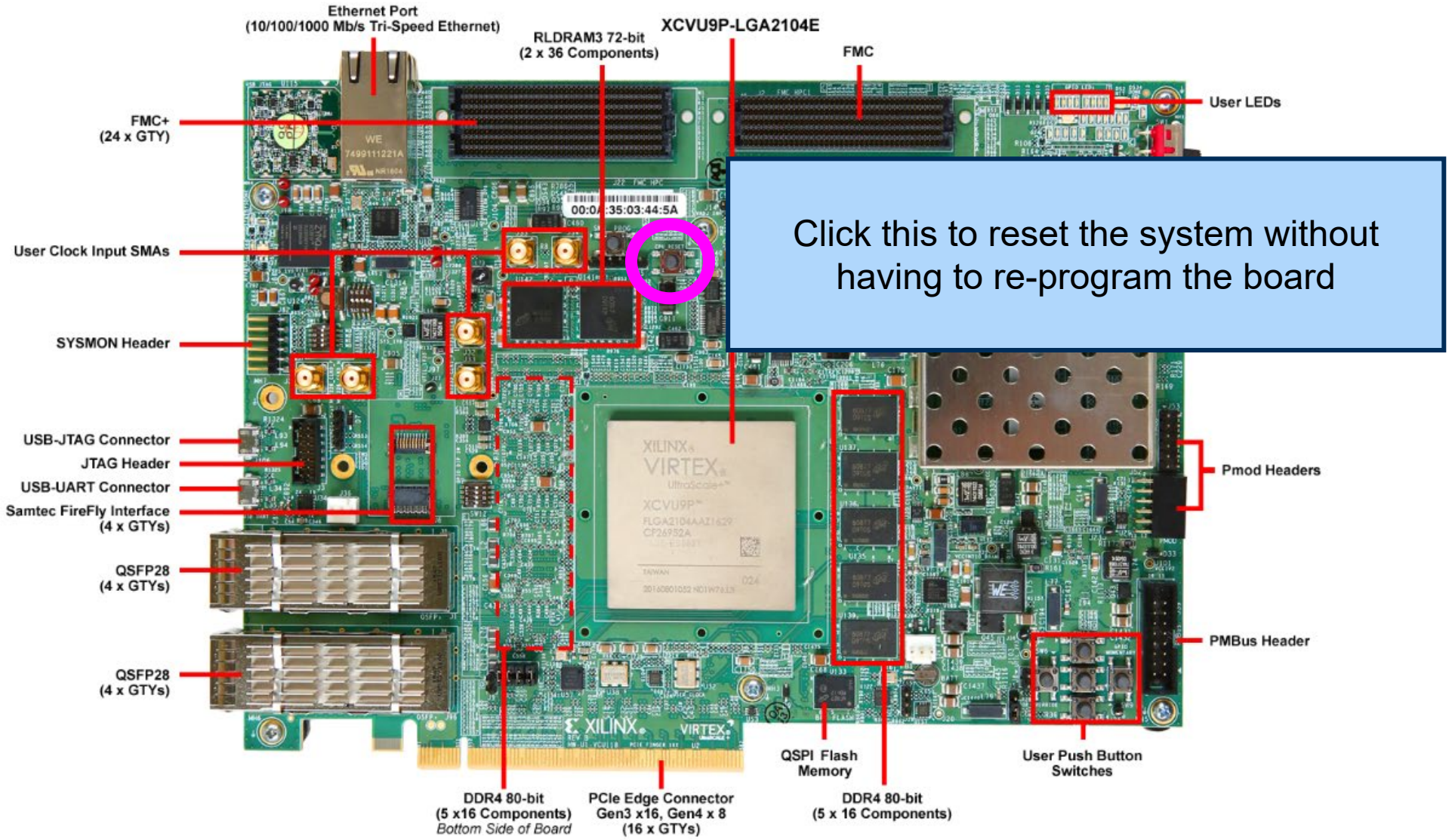


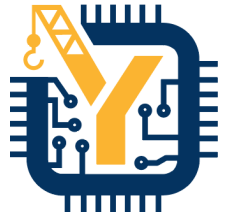
- Use Vivado to program the FPGA with the bitstream
  - Either can use GUI or CLI
  - Bitstream - `fpga/generated-src/<NAME>/obj/*.bit`
- Plug in the SDCard and connect to the serial port
  - Might need to reset the DUT using CPU_RESET button

```
# connect to serial port (in this case called ttyUSB1)
> screen -S FPGA_UART_CONSOLE /dev/ttyUSB1 115200
```

```
chipyard/
  generators/
    rocket-chip/
    boom/
    sha3/
  sims/
    verilator/
  fpga/
    fpga-shells/
    src/
    generated-src/
  software/
    firemarshal/
  tests/
  build.sbt
```

Finding the CPU_RESET

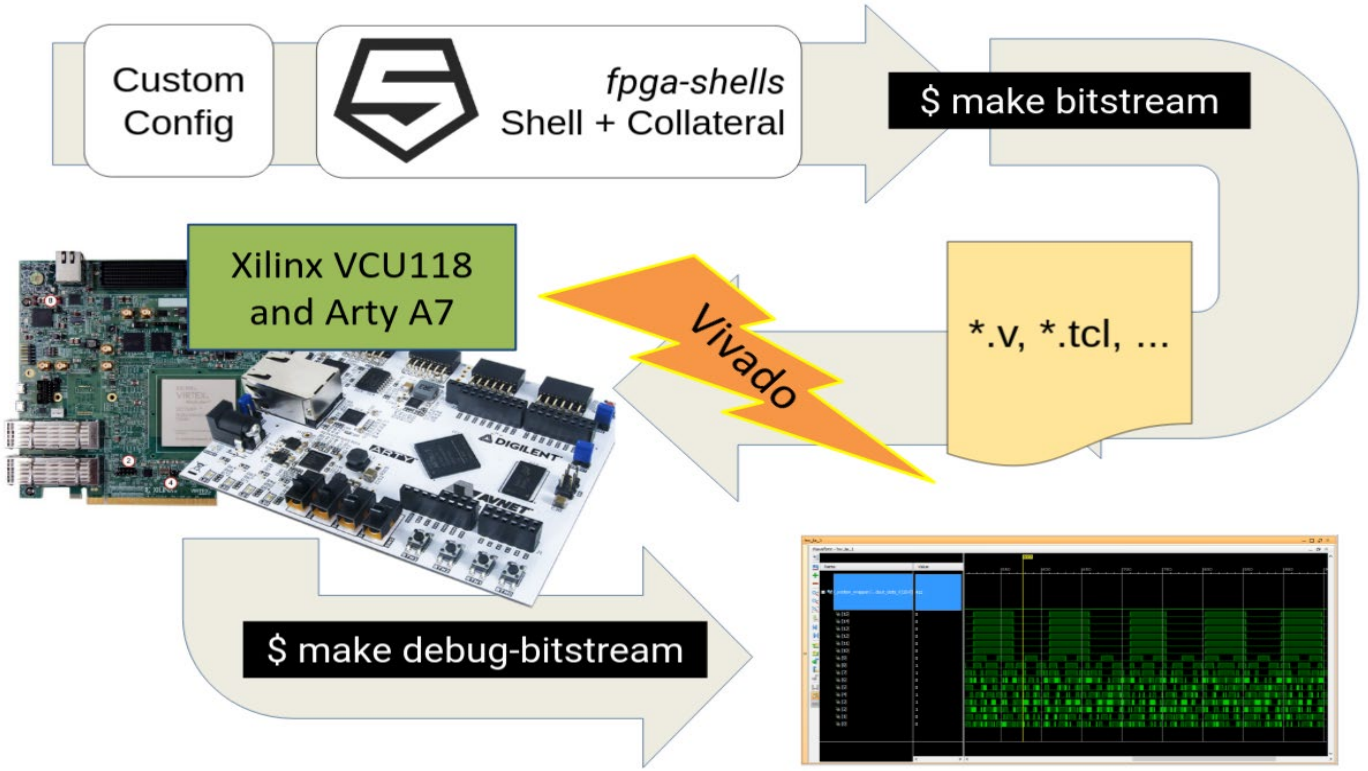


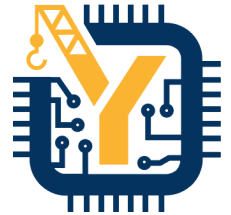


That’s it! Demo time!

Conclusion

- Future Updates
  - More FPGAs supported
  - Full behavior simulation of prototype at board level
  - More peripherals
  - Better SW support
- Used internally at Berkeley
  - Real world interaction
  - Bringup Platform
  - Education
  - Outreach!





Coming up…

FireSim Introduction