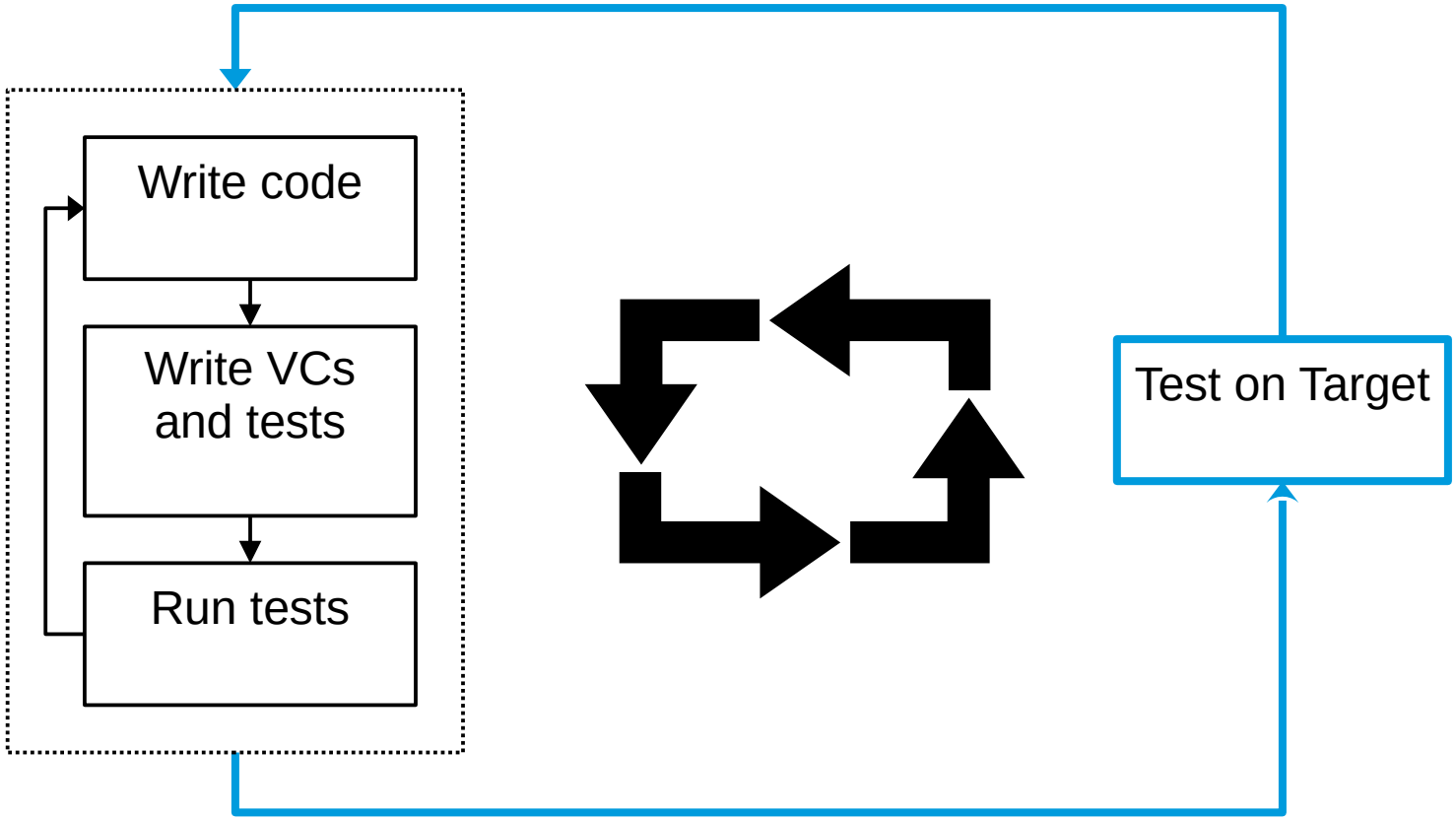
Using Cosimulation to Develop and Test Against Reference Systems

Or: Lazy People's Guide to Writing Test Benches

What do we usually do?



Why this sucks

- VHDL is awful for verification
- Verification components usually implement things that already exist (network protocols, busses, checksums, …)
- Takes a lot of time and money

So what can we do about it?

- Write in a language that was intended for writing software
- Reuse existing / reference implementations
- Even has the advantage of using proven-in-use code
  - Possibly even the actual application target

Example: Ethernet

- Need: MAC, IP, ARP, TCP, HTTP, …
- Wouldn’t it be nice if we could just

```
test:~$ curl http://fpga/test
```

and have all that work already done for us?

Well, we can: Python + Cocotb

- Just a way to write test benches for VHDL designs in Python
- But:
  - **Writing in Python is like giving our test bench superpowers**

Back to Ethernet: What can we do?

- Python allows us to tap a real network card!

```
self.macdev=socket.socket(..., socket.SOCK_RAW, ...)
self.macdev.bind((“eth0”, 0))
```

- Now just forward every packet to VHDL

```
r = self.macdev.recv(2000)
await self.eth_tx.send(ETH_HEAD + r)
```

- And vice versa:

```
frame = await self.eth_rx.queue.get()
self.macdev.send(frame)
```

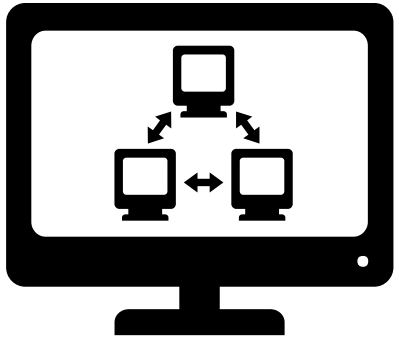
How to script real hardware?

- **We don’t!** We just create a separate environment for the test

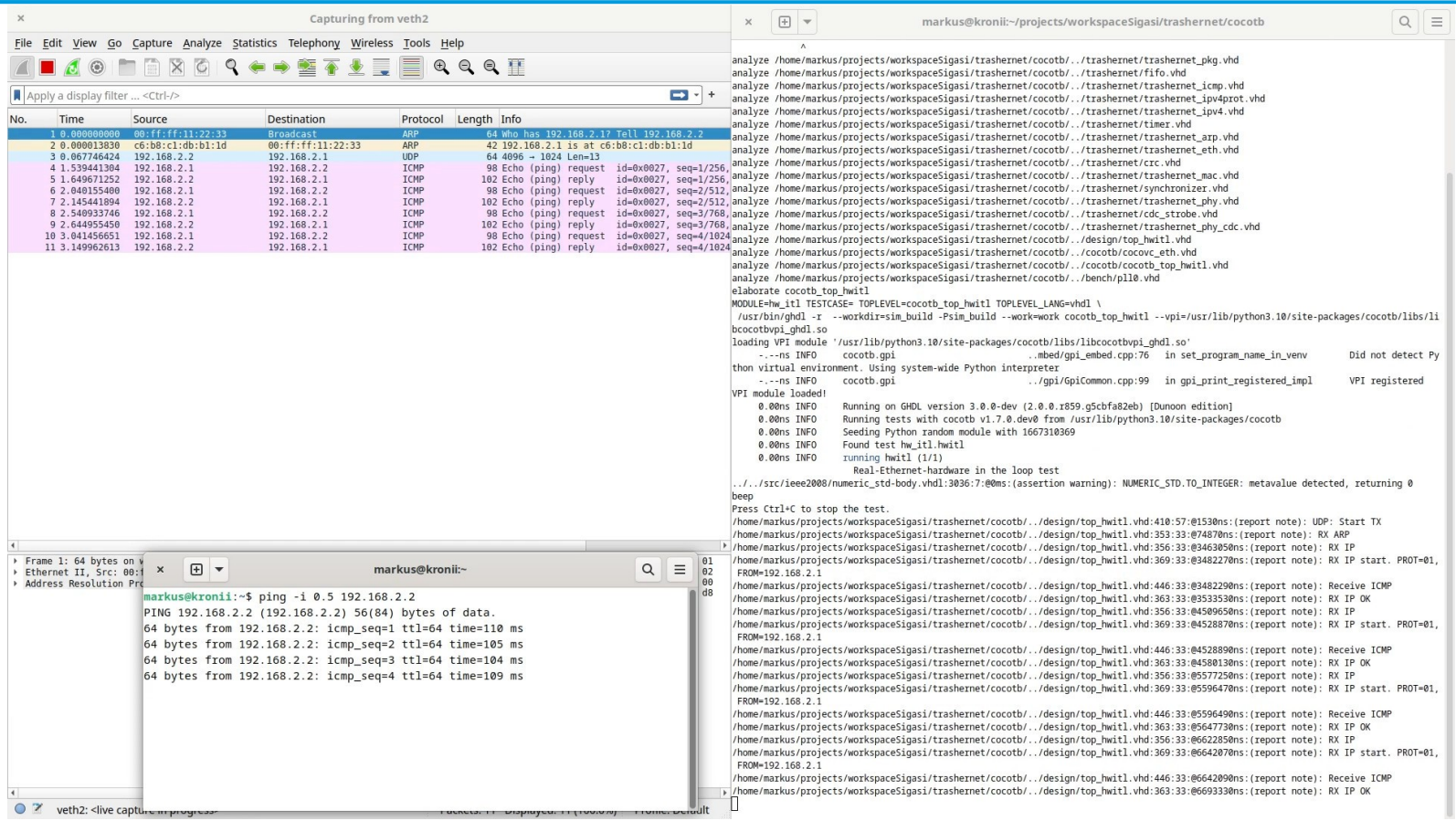
```
ip link add dev veth1 type veth peer name veth2
ip link set up veth1
ip link set up veth2
ip addr add 192.168.2.1/24 dev veth1
ip link set promisc on dev veth2
```

- Now we just use that for our tests

```
ping -I veth1 192.168.2.2
```



Demo time!


Capturing from veth2
File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help
Apply a display filter ... <Ctrl-/>
No. Time Source Destination Protocol Length Info
1 0.000000000 00:ff:ff:11:22:33 Broadcast ARP 64 Who has 192.168.2.17 Tell 192.168.2.2
2 0.000013830 c6:b8:c1:db:b1:1d 00:ff:ff:11:22:33 ARP 42 192.168.2.1 is at c6:b8:c1:db:b1:1d
3 0.067746424 192.168.2.2 192.168.2.1 UDP 64 4096 → 1024 Len=13
4 1.539441304 192.168.2.1 192.168.2.2 ICMP 98 Echo (ping) request id=0x0027, seq=1/256
5 1.649671252 192.168.2.2 192.168.2.1 ICMP 102 Echo (ping) reply id=0x0027, seq=1/256
6 2.040155400 192.168.2.1 192.168.2.2 ICMP 98 Echo (ping) request id=0x0027, seq=2/512
7 2.145441894 192.168.2.2 192.168.2.1 ICMP 102 Echo (ping) reply id=0x0027, seq=2/512
8 2.540933746 192.168.2.1 192.168.2.2 ICMP 98 Echo (ping) request id=0x0027, seq=3/768
9 2.644955450 192.168.2.2 192.168.2.1 ICMP 102 Echo (ping) reply id=0x0027, seq=3/768
10 3.041456651 192.168.2.1 192.168.2.2 ICMP 98 Echo (ping) request id=0x0027, seq=4/1024
11 3.149962613 192.168.2.2 192.168.2.1 ICMP 102 Echo (ping) reply id=0x0027, seq=4/1024
Frame 1: 64 bytes on w
Ethernet II, Src: 00:f
Address Resolution Pro
markus@kronii:~
markus@kronii:~$ ping -i 0.5 192.168.2.2
PING 192.168.2.2 (192.168.2.2) 56(84) bytes of data.
64 bytes from 192.168.2.2: icmp_seq=1 ttl=64 time=110 ms
64 bytes from 192.168.2.2: icmp_seq=2 ttl=64 time=105 ms
64 bytes from 192.168.2.2: icmp_seq=3 ttl=64 time=104 ms
64 bytes from 192.168.2.2: icmp_seq=4 ttl=64 time=109 ms
01
02
00
d8
markus@kronii:~/projects/workspaceSigasi/trashernet/cocotb
analyze /home/markus/projects/workspaceSigasi/trashernet/cocotb/../trashernet/trashernet_pkg.vhd
analyze /home/markus/projects/workspaceSigasi/trashernet/cocotb/../trashernet/fifo.vhd
analyze /home/markus/projects/workspaceSigasi/trashernet/cocotb/../trashernet/trashernet_icmp.vhd
analyze /home/markus/projects/workspaceSigasi/trashernet/cocotb/../trashernet/trashernet_ipv4prot.vhd
analyze /home/markus/projects/workspaceSigasi/trashernet/cocotb/../trashernet/trashernet_ipv4.vhd
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analyze /home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd
analyze /home/markus/projects/workspaceSigasi/trashernet/cocotb/../cocotb/cocovc_eth.vhd
analyze /home/markus/projects/workspaceSigasi/trashernet/cocotb/../cocotb/cocotb_top_hwitl.vhd
analyze /home/markus/projects/workspaceSigasi/trashernet/cocotb/../bench/pll0.vhd
elaborate cocotb_top_hwitl
MODULE=hw_itl TESTCASE= TOPLEVEL=cocotb_top_hwitl TOPLEVEL_LANG=vhdl \
/usr/bin/ghdl -r --workdir=sim_build -Psim_build --work=work cocotb_top_hwitl --vpi=/usr/lib/python3.10/site-packages/cocotb/libs/libcocotbvpi_ghdl.so
loading VPI module '/usr/lib/python3.10/site-packages/cocotb/libs/libcocotbvpi_ghdl.so'
-.--ns INFO cocotb.gpi ..mbed/gpi_embed.cpp:76 in set_program_name_in_venv Did not detect Python virtual environment. Using system-wide Python interpreter
-.--ns INFO cocotb.gpi ../gpi/GpiCommon.cpp:99 in gpi_print_registered_impl VPI registered VPI module loaded!
0.00ns INFO Running on GHDL version 3.0.0-dev (2.0.0.r859.g5cbfa82eb) [Dunoon edition]
0.00ns INFO Running tests with cocotb v1.7.0.dev0 from /usr/lib/python3.10/site-packages/cocotb
0.00ns INFO Seeding Python random module with 1667310369
0.00ns INFO Found test hw_itl.hwitl
0.00ns INFO running hwitl (1/1)
Real-Ethernet-hardware in the loop test
../../src/ieee2008/numeric_std-body.vhdl:3036:7:@0ms:(assertion warning): NUMERIC_STD.TO_INTEGER: metavalue detected, returning 0
beep
Press Ctrl+C to stop the test.
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:410:57:@1530ns:(report note): UDP: Start TX
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:353:33:@74870ns:(report note): RX ARP
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:356:33:@3463050ns:(report note): RX IP
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:369:33:@3482270ns:(report note): RX IP start. PROT=01, FROM=192.168.2.1
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:446:33:@3482290ns:(report note): Receive ICMP
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:363:33:@3533530ns:(report note): RX IP OK
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:356:33:@4509650ns:(report note): RX IP
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:369:33:@4528870ns:(report note): RX IP start. PROT=01, FROM=192.168.2.1
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:446:33:@4528890ns:(report note): Receive ICMP
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:363:33:@4580130ns:(report note): RX IP OK
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:356:33:@5577250ns:(report note): RX IP
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:369:33:@5596470ns:(report note): RX IP start. PROT=01, FROM=192.168.2.1
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:446:33:@5596490ns:(report note): Receive ICMP
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:363:33:@5647730ns:(report note): RX IP OK
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:356:33:@6622850ns:(report note): RX IP
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:369:33:@6642070ns:(report note): RX IP start. PROT=01, FROM=192.168.2.1
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:446:33:@6642090ns:(report note): Receive ICMP
/home/markus/projects/workspaceSigasi/trashernet/cocotb/../design/top_hwitl.vhd:363:33:@6693330ns:(report note): RX IP OK

Let’s recap

- Save cost and time
- Get higher quality tests
- Have happy engineers

- **Profit!**

Additional resources

- Slides: https://notsyncing.net/?p=blog&b=2022.cocotb-hw-cosim
- Ethernet demo: https://git.notsyncing.net/fpga/trashernet
- Questions?
  - Markus (@*m42uko*) <markus@notsyncing.net>

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