Building an Internet Router with P4Pi

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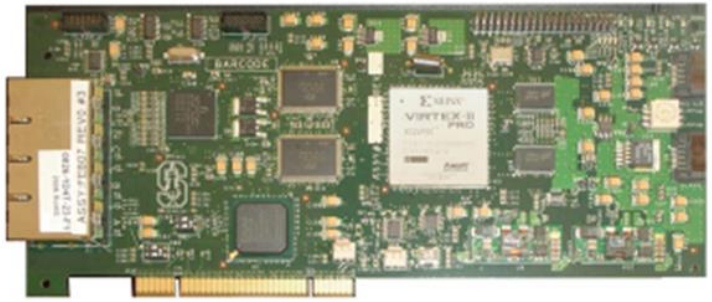
Teaching Computer Networks

- 2000: Computer networks courses are cool and popular!
- 2022: Computer networks – not as exciting, everyday commodity:
  "Do you mean the boring protocols' course?
  ... let me Google it on my phone"
- Hands on exercises are often based on socket programming

Goal: Engaging students to understand how networks work!

Building an Internet Router

- Introduced by McKeown at Stanford, 15 years ago
- Develop a complete IPv4 Router during a semester
- Running on NetFPGA, open source
- Used in multiple courses (Stanford CS344, Cambridge P33, Yale CPSC 435/535, …)



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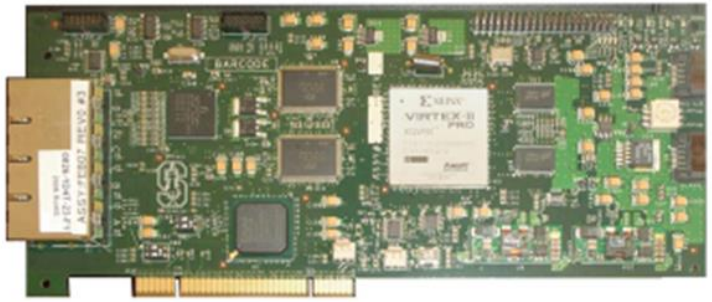
Limitations:

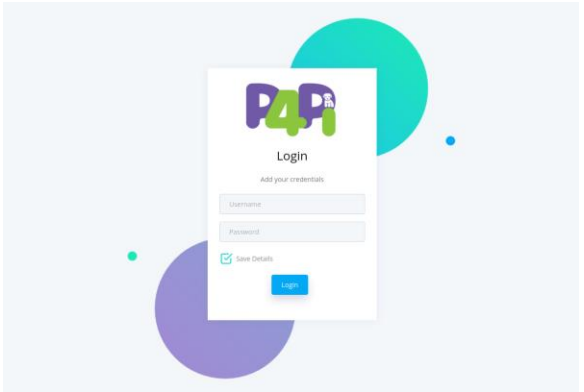
- Expensive!
  - e.g., 10x FPGA boards, PCs, NICs, …
- Requires FPGA design knowledge
- Significant load on the teaching team



– P4 on Raspberry Pi

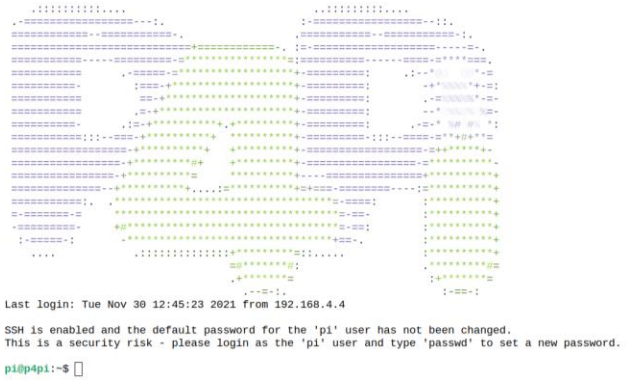
Raspberry Pi 4 model B

- 1.5GHz quad-core CPU
- 2.4 GHz and 5.0 GHz wireless
- 1x Gigabit Ethernet
- 2x USB 3.0; 2x USB 2.0



Web Interface

- *Cheap (under $100)*
- *No FPGA knowledge required*
- *Lots of online resources for Raspberry Pi and P4*



SSH

Building an Internet Router

Part I: Data Plane

Students implement the data plane in P4

- IP Routing table
- Local IP address table
- ARP table
- L2 forwarding table

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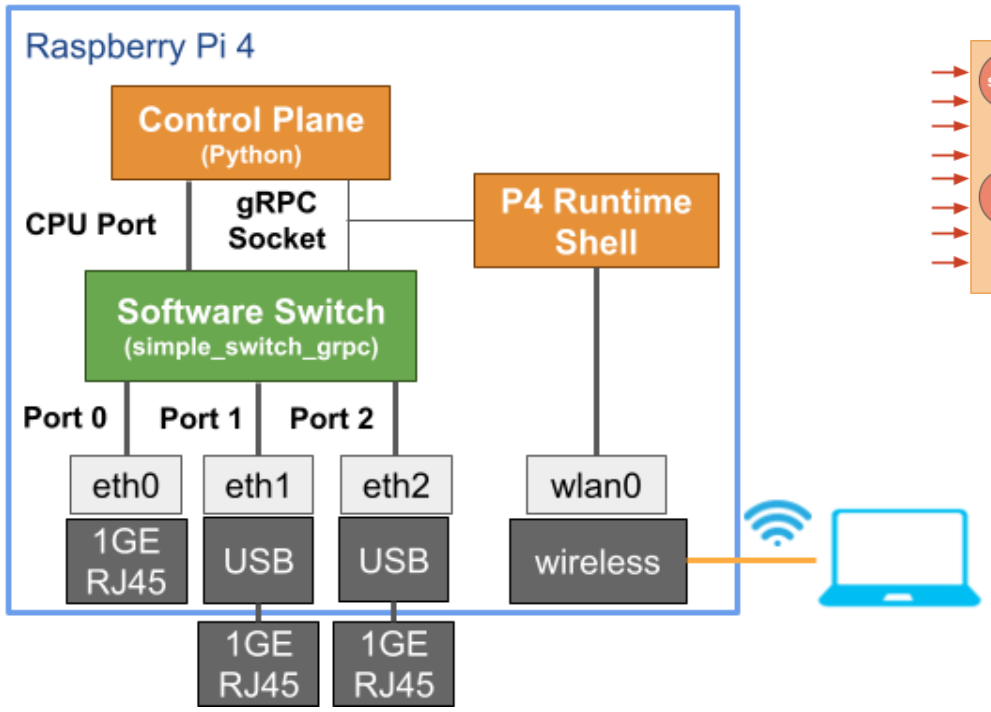
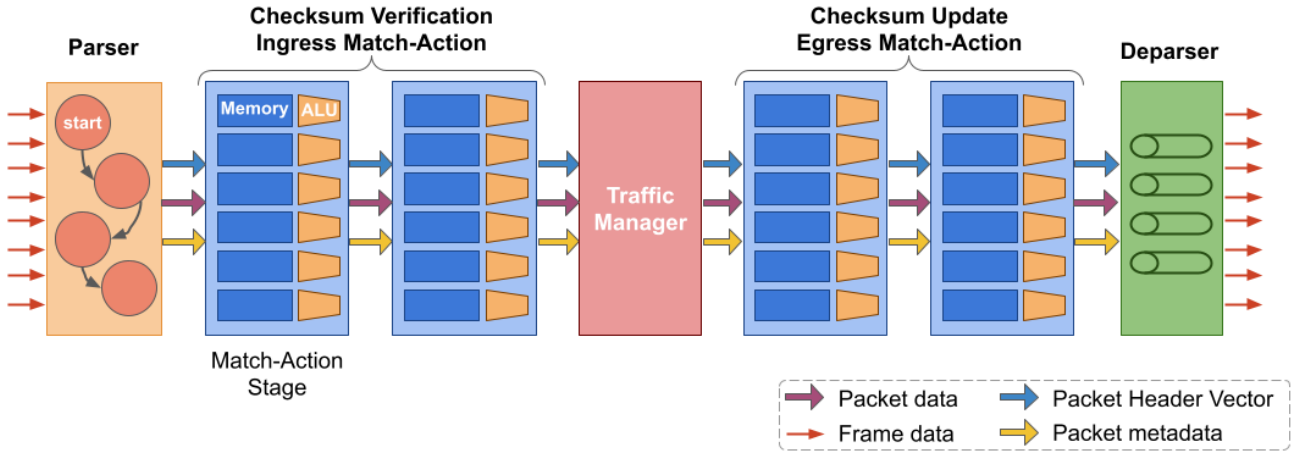
Part II: Control Plane

Students implement the control plane in python

- Pee-Wee OSPF Protocol
  - Simplified OSPFv2
  - HELLO Packets
  - Link State Update Packets
  - Topology Database

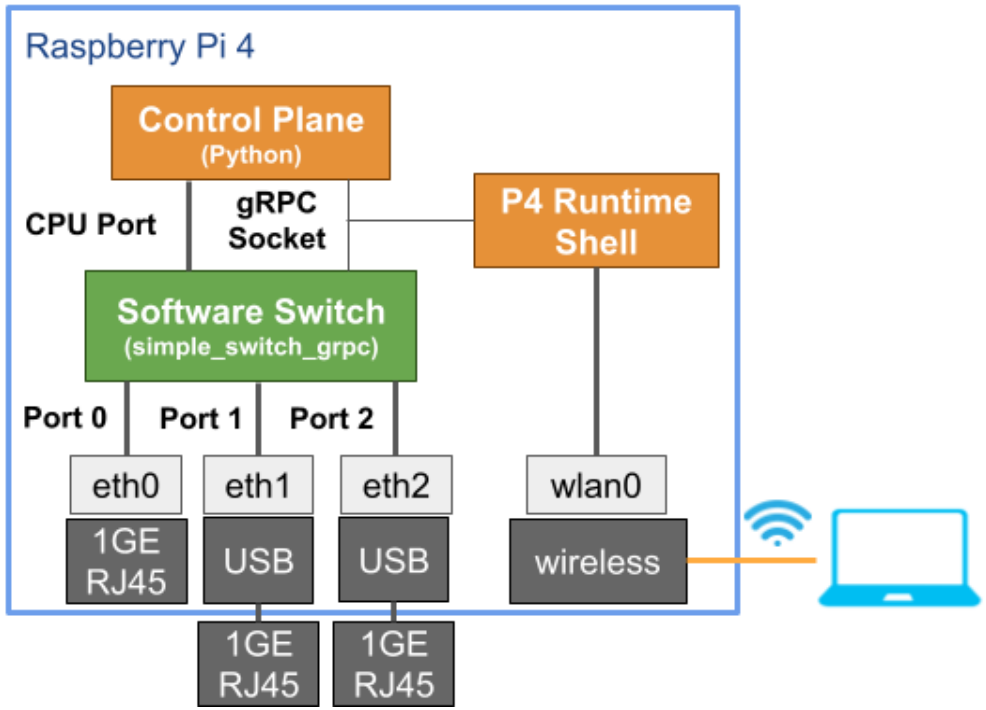
Router Architecture on P4Pi





- Architecture: v1model
- P4 Compiler: p4c-bm2-ss
- P4 Target: simple_switch_grpc

Router Architecture on P4Pi

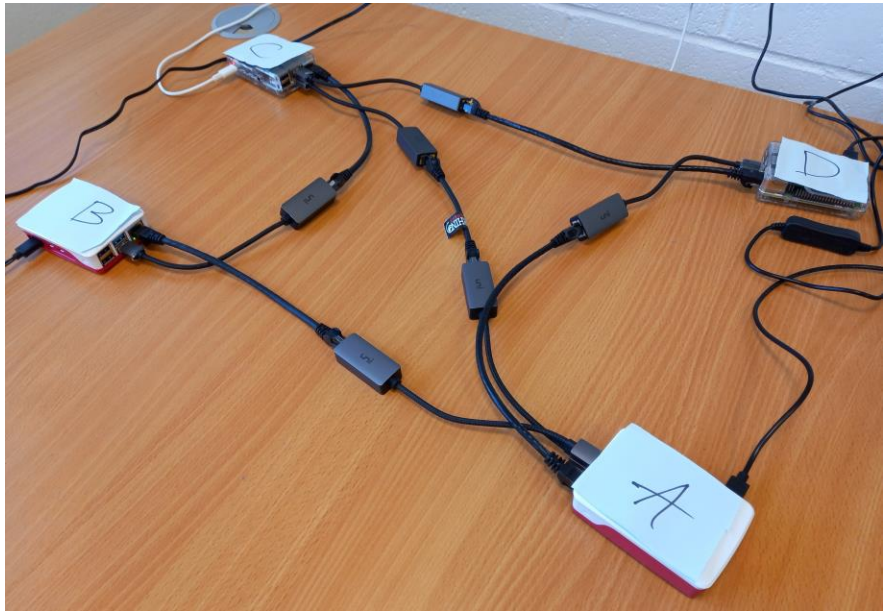


- Students develop the P4 data plane code and Python control plane code
  - Either on their laptop
    - Can test in the tutorials' environment
  - OR directly on P4Pi
- The router runs on P4Pi as any other project
- Use ssh to connect, configure and run

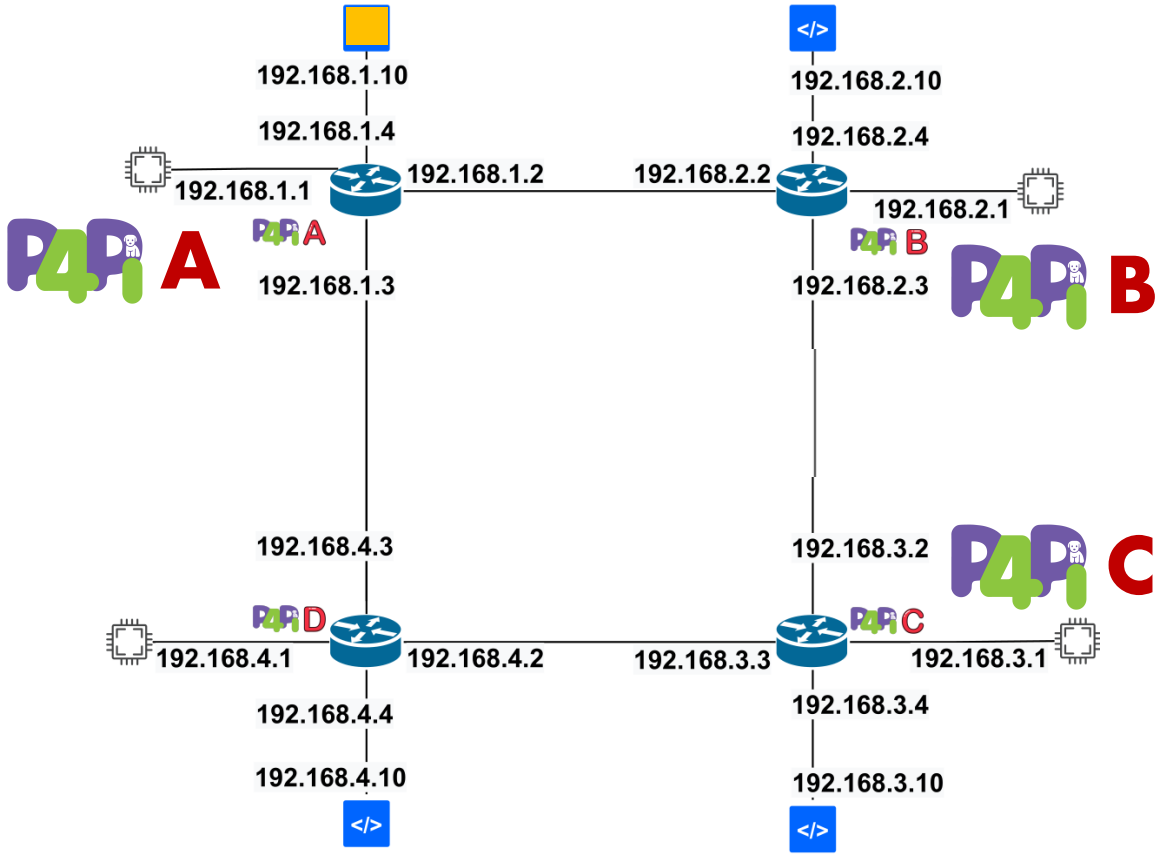
Testing is *FUN!*

- Stand alone tests:
  - Using P4Pi and laptop(s)
  - Test ARP, Ping, iperf, …

- Interoperability tests
  - Multiple students projects, multiple P4Pi platforms
  - What happens when you add new routers?
  - What happens when you disconnect cables?

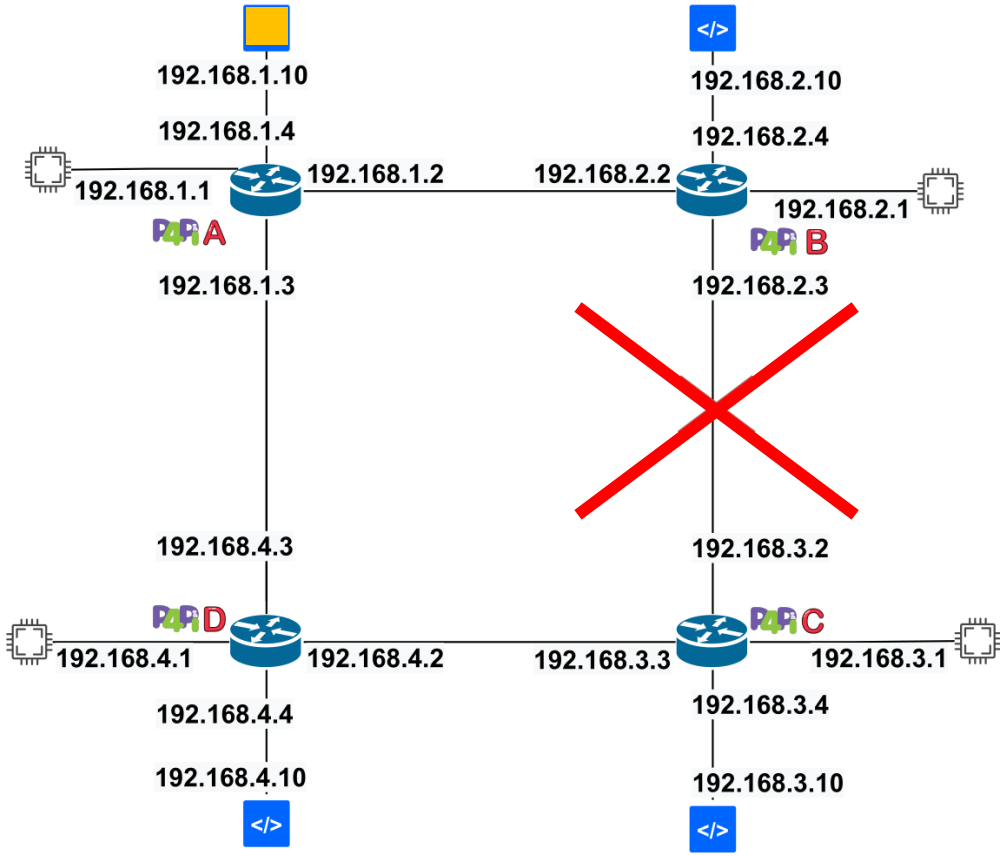


Example: Routing Loops



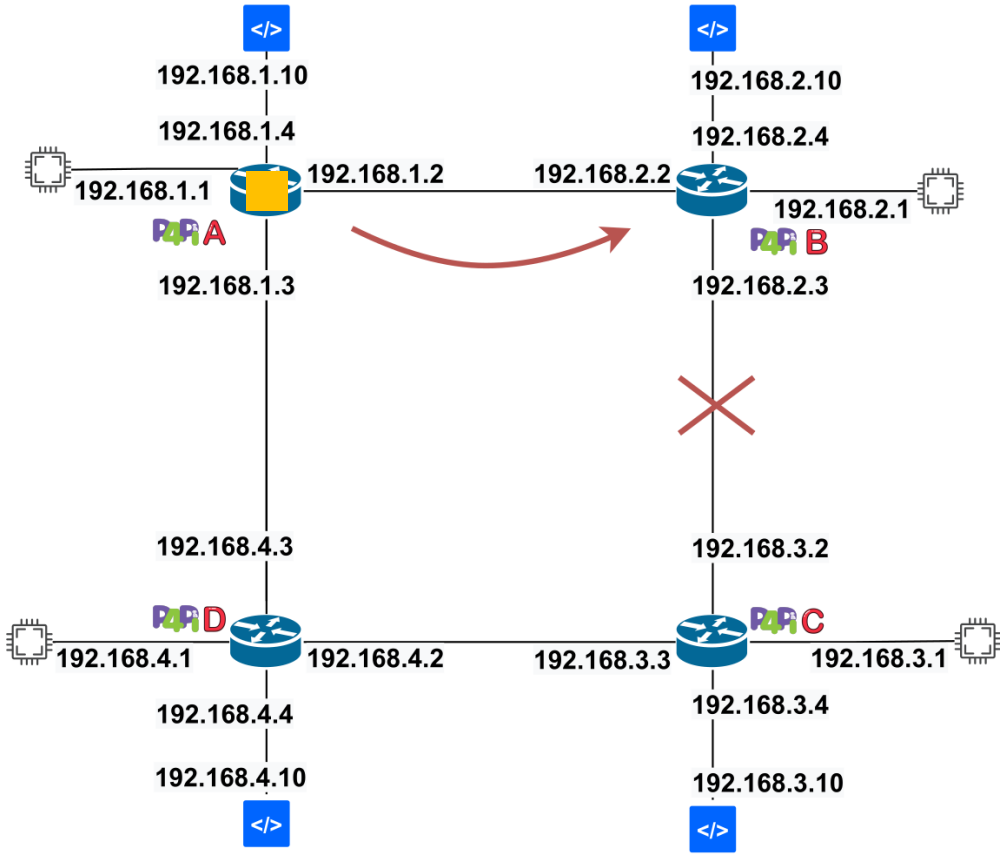
Initially A sends to C through B

Example: Routing Loops



The link breaks between B and C

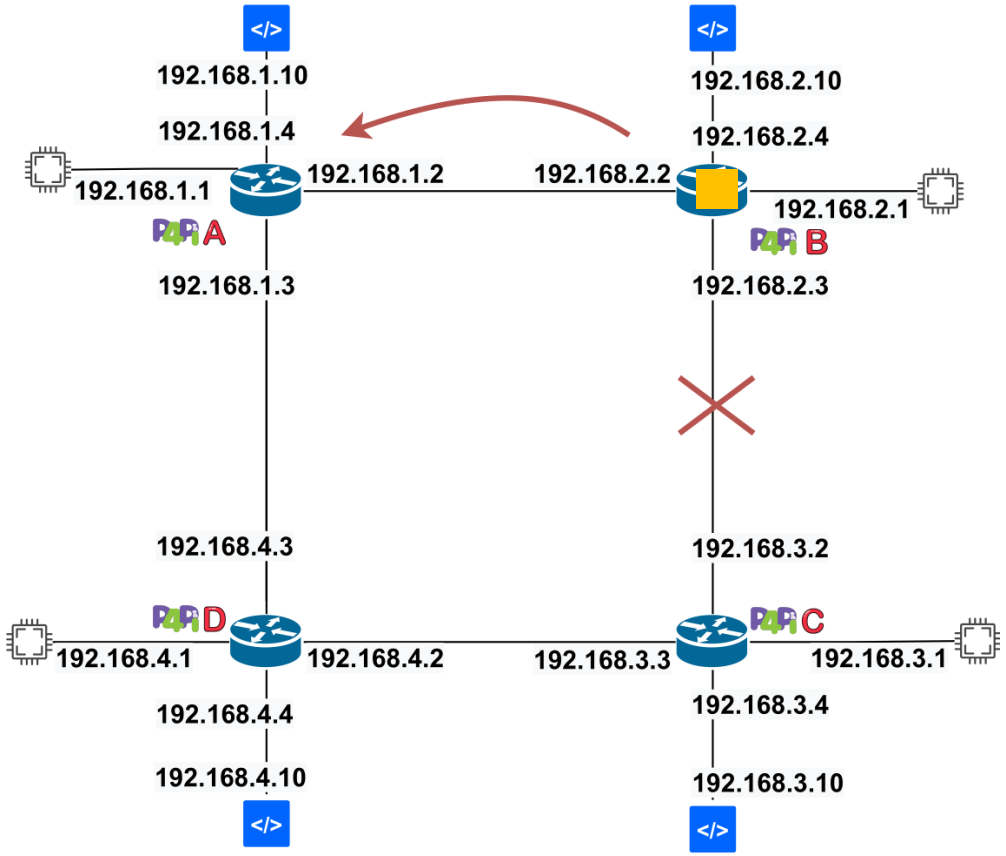
Example: Routing Loops



A is not aware that the link is broken

A sends a message to C through B

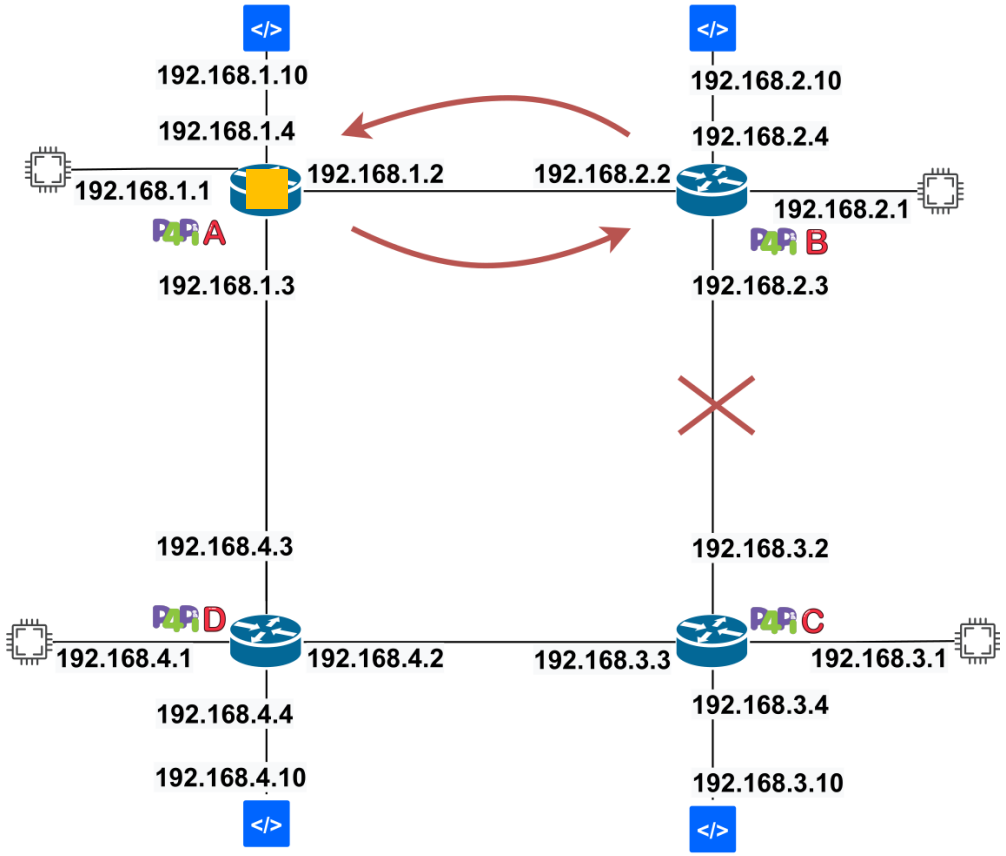
Example: Routing Loops



B knows that the new route to C is through A (and D)

B sends the message back to A

Example: Routing Loops



A is still not aware that the link is broken

A sends the message again to B

Will be fixed with the next periodic update
… or with manual update of the routing table

Summary

- Hands-on computer networks courses can be exciting!
- Building an Internet Router on P4Pi is:
  - Open source
  - Low cost
  - Starter code available on P4Pi repo
- The complexity (/length) of the exercise can be adjusted
- Students can test, interop, interact, engage, enjoy!

Community contributions to P4Pi are invited and appreciated

Questions?

P4Pi: https://github.com/p4lang/p4pi/

Building an Internet Router with P4Pi:
https://github.com/p4lang/p4pi/wiki/Building-an-Internet-Router-with-P4Pi