Teaching Networking Hardware

Stanford High Performance Network Group

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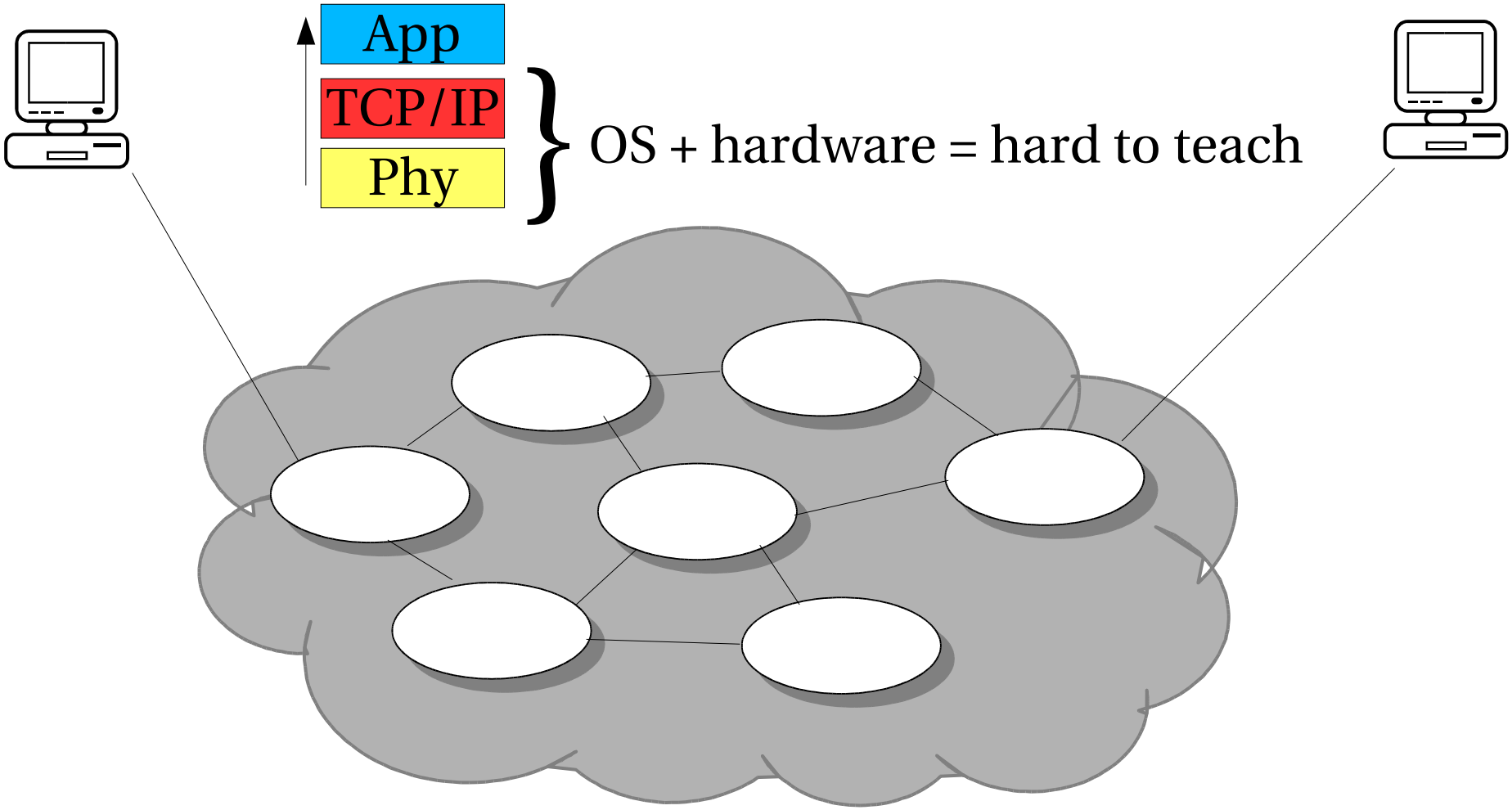
Motivation

(networking hardware experience needed in classroom)

- Many students go to work in the networking industry
  - complex hardware-software systems
  - high speed, asynchronous network environments
- Undergraduate (and graduate) hardware classes typically focus on processor design
  (… how many graduating students design processors?)
- Want to create practical, useful environment for developing working network systems

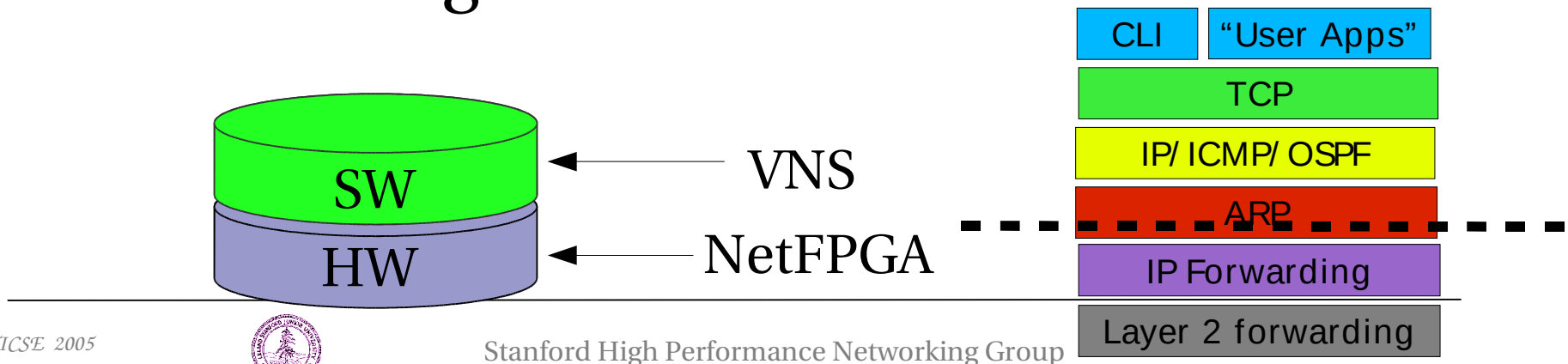
Motivation

(cool stuff in networks is hard to get to)



(The Punchline)
CS344: Advanced Projects in Networks

- Students design routers in hardware and software
- Teams of 1 hardware student, 1 software student
- Routers must route live Internet traffic
- All routers must interoperate on a complex topology
- Students then get to "show off"

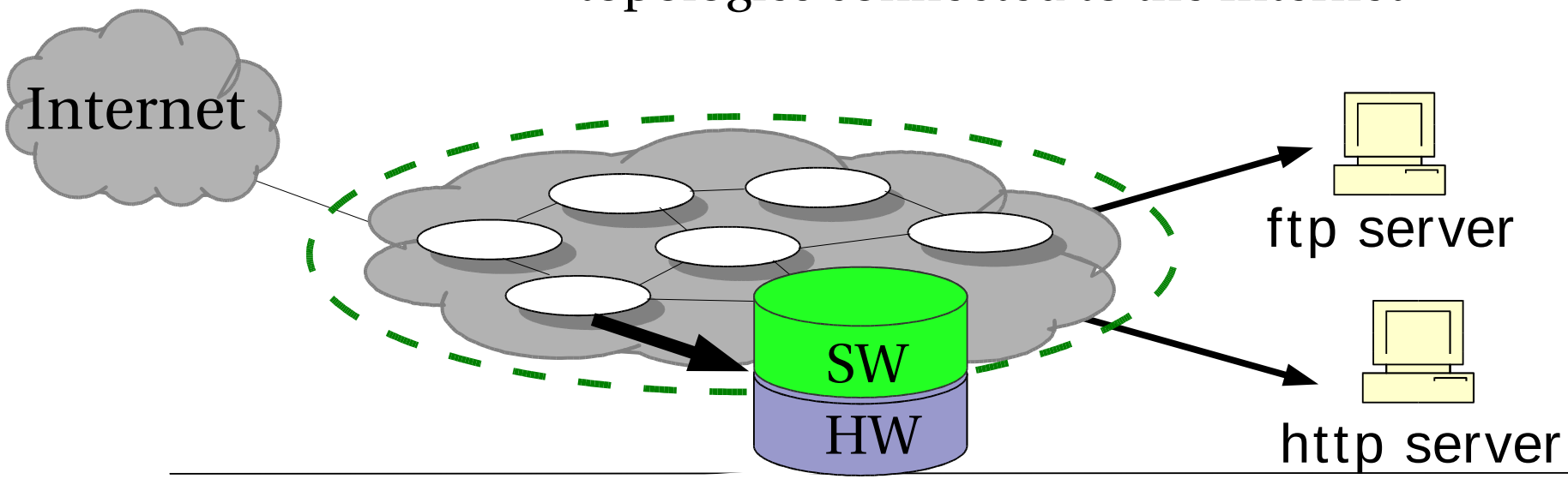


Presentation Overview
(a bit late)

- Technologies developed to support class
  - NetFPGA
  - VNS
- Class Overview
- Experiences in Classroom (2004, 2005)
- Looking Ahead

Course Tools

- **NetFPGA :** a programmable 8-port Ethernet device that can be programmed and tested remotely
- **VNS:** Allows user space processes to participate as routers on the Internet
- **VNS + NetFPGA :** Used to develop, test and deploy hardware+software routers on arbitrary topologies connected to the Internet

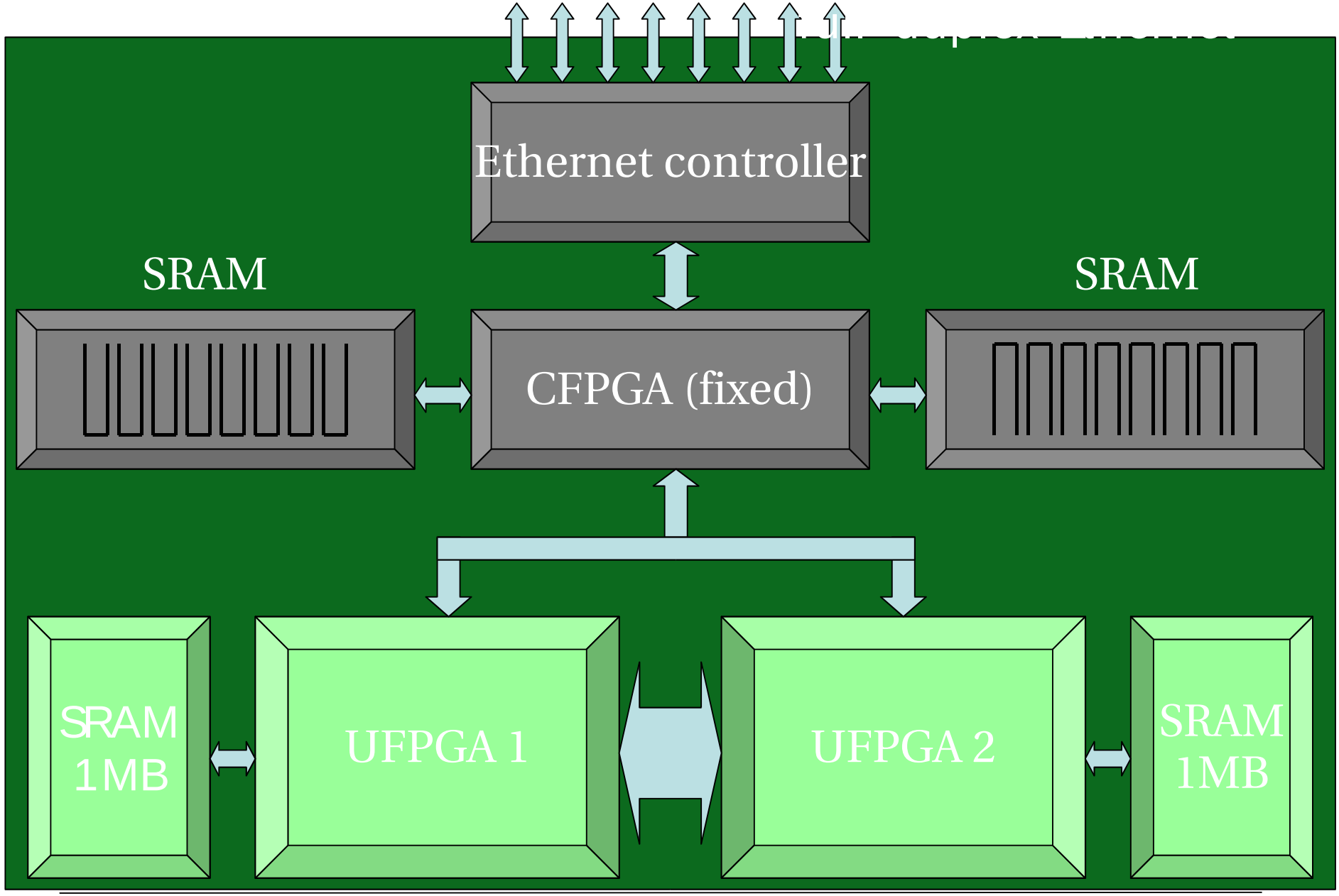


NetFPGA

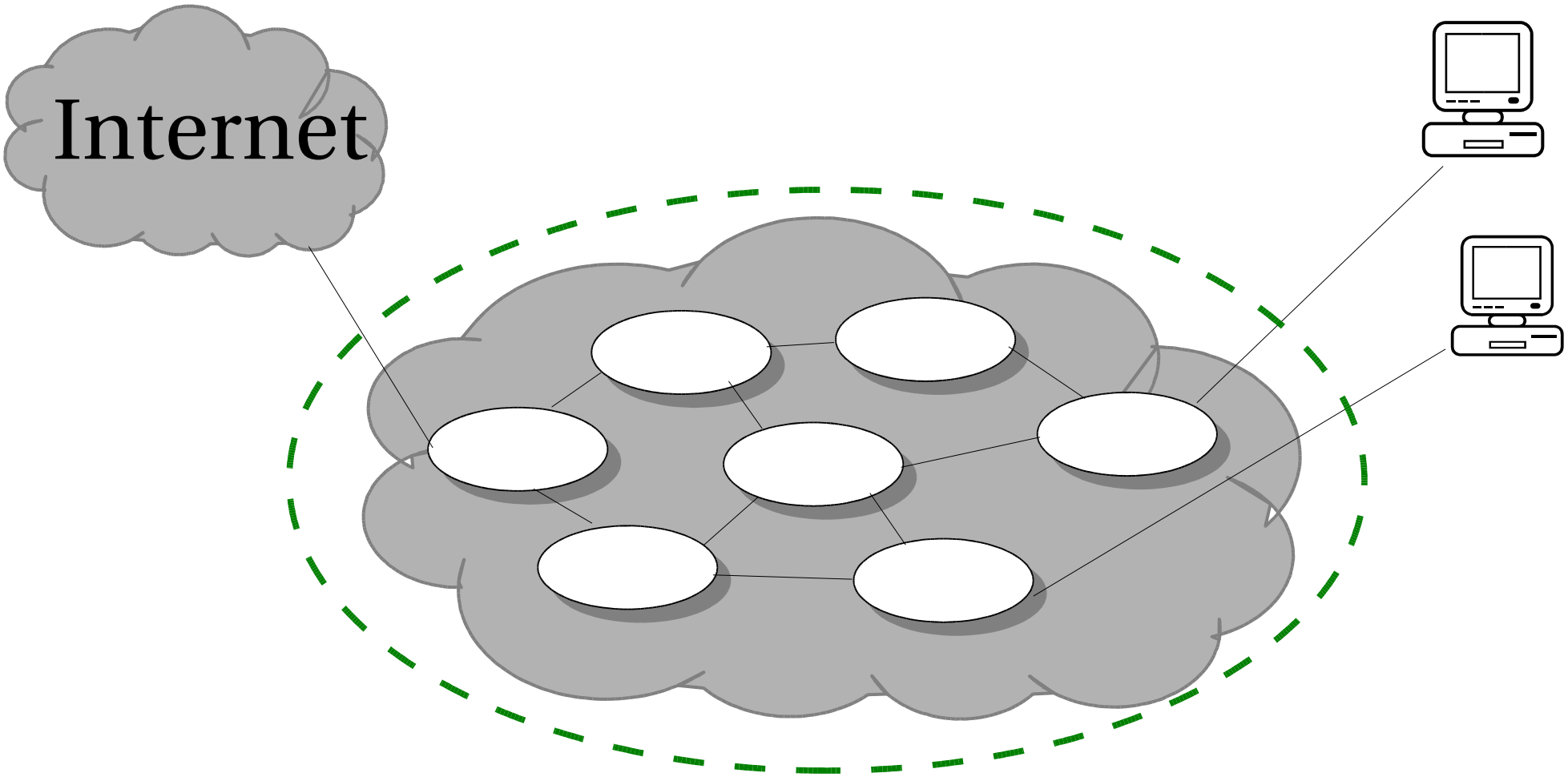
- Programmable Network device
- Each board contains three FPGAs and an 8-port Ethernet controller.
- A suite of scripts that invoke the various design tools (industry standard)
- Libraries to make it easy to create verification scripts that run in simulation environment as well as on the actual hardware.
- A web interface for remotely downloading and running the designs.

NetFPGA Board

NetFPGA Board

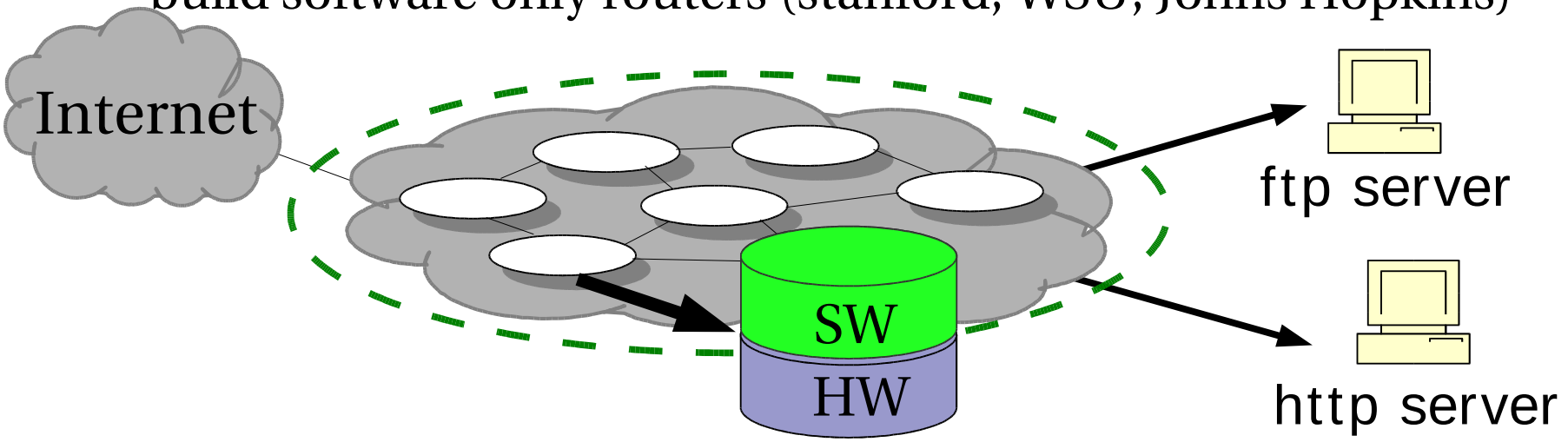


Virtual Network System (emulate network topologies)



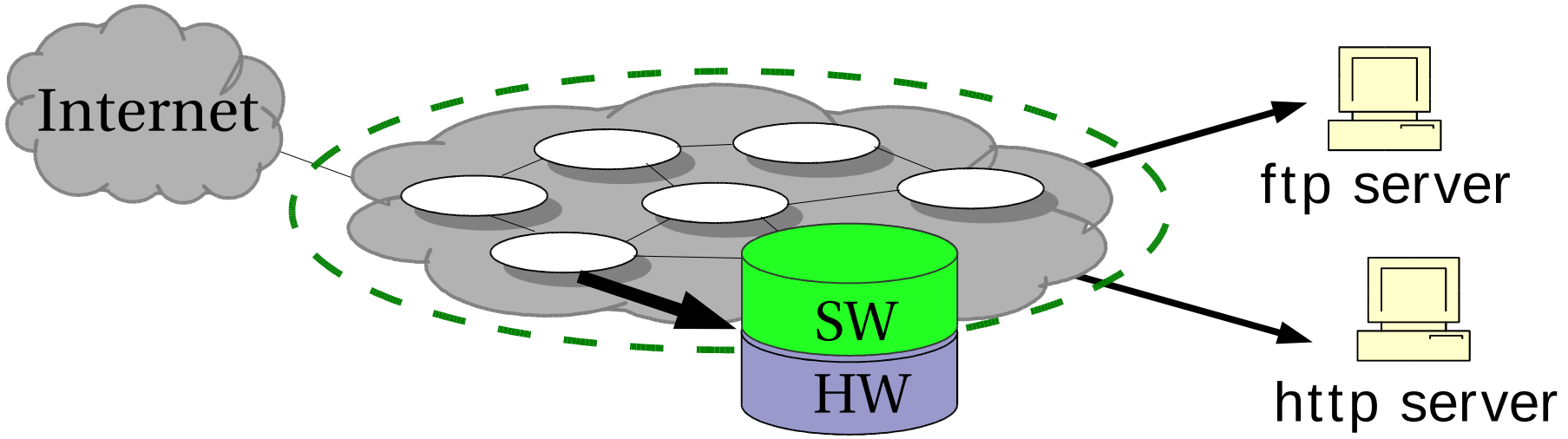
Virtual Network System

- Maps NetFPGA boards into complex networks connected to the Internet
- Allows students to write software "cpu" for boards as user space programs (in C)
- Connect standard servers (e.g. Linux + apache)
- Currently used in undergraduate networking courses to build software only routers (stanford, WSU, Johns Hopkins)

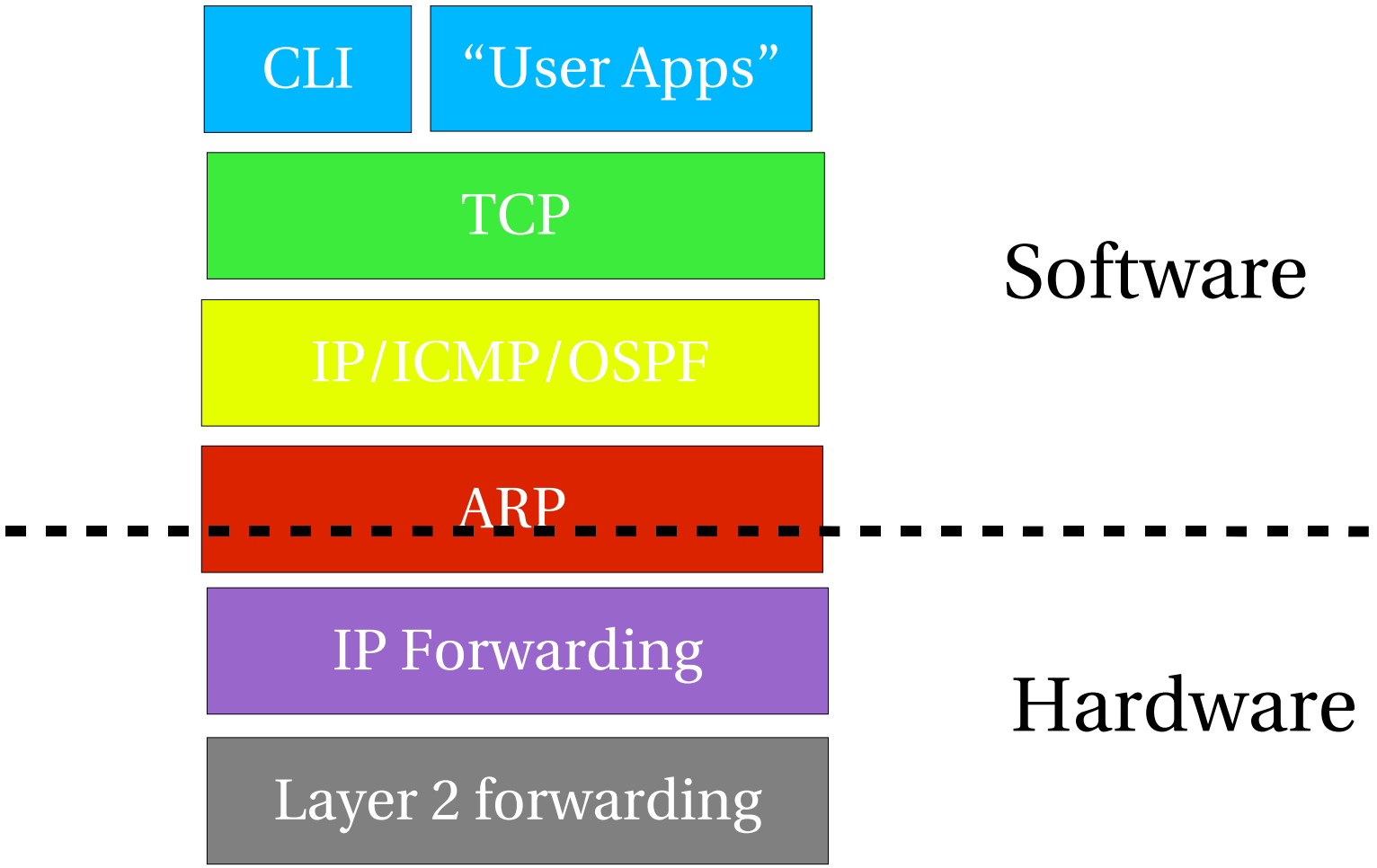


VNS + NetFPGA =

- Build hardware-software routers on the Internet
- Each team can have an isolated topology or multiple teams can connect to the same topology (interoperation)
- Entire design and development process can be done remotely (e.g. Remote University)
(students never have to see an actual NetFPGA board!)



CS344: Building an Internet Router



CS344: Building an Internet Router

- Build full router in hardware and software (6 weeks)
  - Route live Internet traffic
  - Managed via CLI
  - Generate forwarding tables using OSPF-like protocol
  - Converge in complex topology after link failure
- Inter-operate with all other routers in class on complex network topology
- Open-ended design component (build something neat) (2 weeks)
- Comprehensive design, implementation and testing documentation

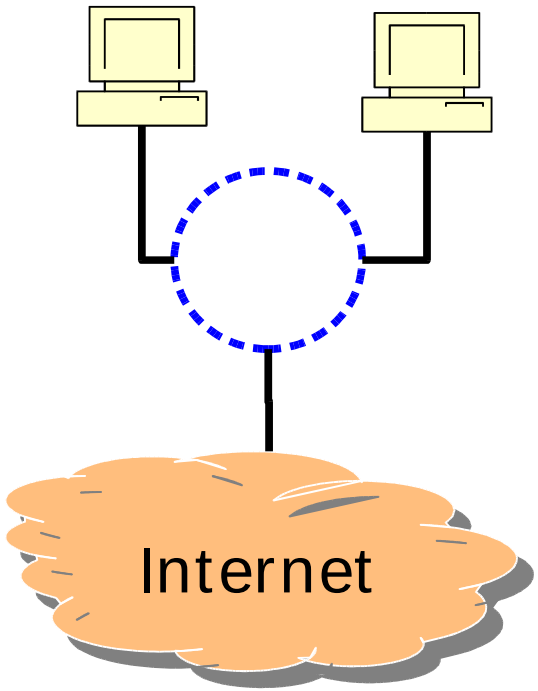
Hardware Requirements

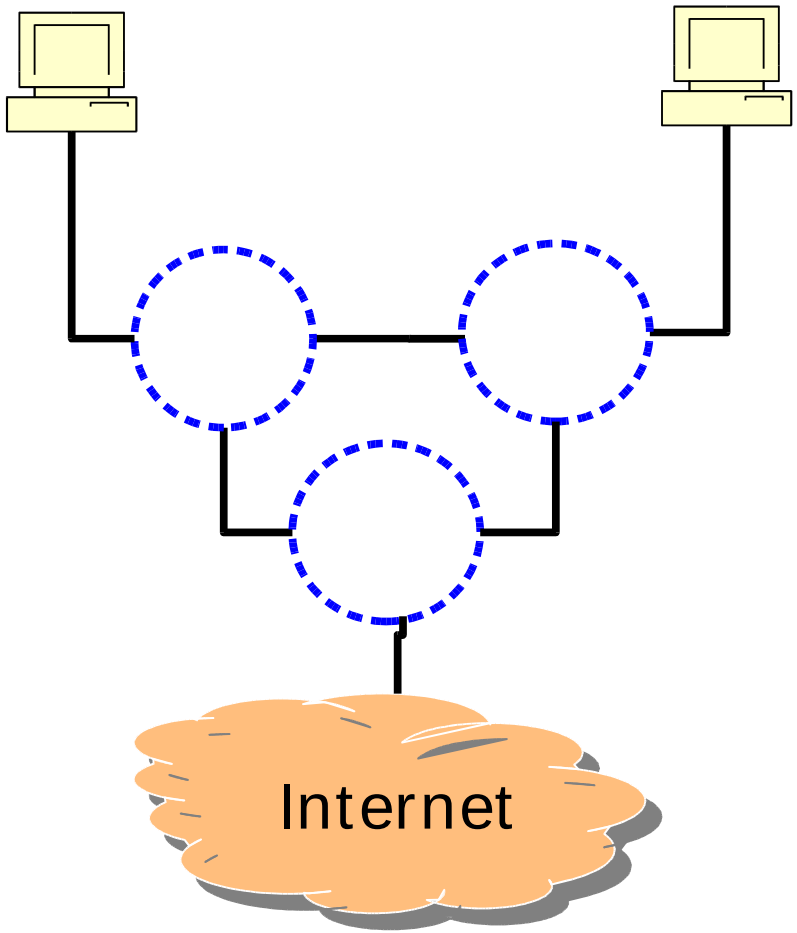
- Layer-2 switching
- Protocol decoding
- ARP cache lookup
- Forwarding
  - Longest prefix match
  - Decrement ttl
  - Calculate IP checksum
- Handle read/write register packets from software

Software Requirements

- ARP (request/response/cache)
- ICMP (echo, port unreach, ttl timeout)
- TCP Stack (provided)
- CLI
  - ping/traceroute
  - Similar to IOS
  - Manage interfaces, forwarding table etc.
- OSPF-like protocol
- Control hardware by reading writing registers using special packets

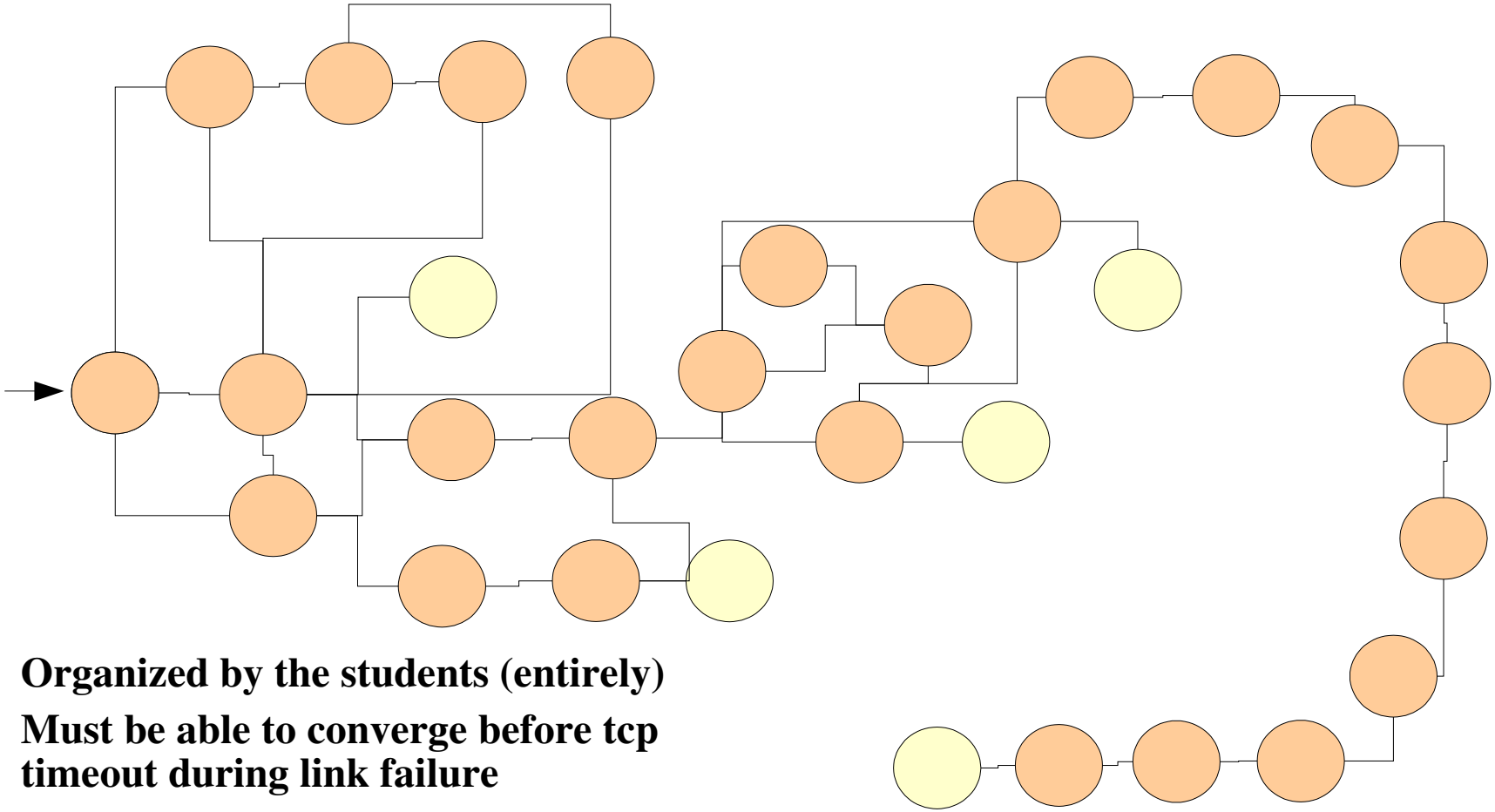
Topologies for Testing
(per team)





Plus any other requested topology
(popular during advanced functionality)

Interoperability



- **Organized by the students (entirely)**
- **Must be able to converge before tcp timeout during link failure**
- **For final test, we randomly sprinkle topology with students routers and see what happens!**

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Advanced Functionality

- Open-ended (almost anything goes)
- 2 requirements
  - Something neat
  - Hardware + software component
- Must consider hardware/software tradeoffs during design
- Present designs in front of panel of industry experts

Classroom Experience

- 2004: 7 students (3 teams)
- 2005: 18 students (6 teams)
- Only 1 team has failed to produce working router
- Software typically 12,000 – 20,000 lines of C
- Hardware 7,000 – 11,000 lines of verilog
- Easy week = 10 – 15 hours of work
- Hard week = 40 – 60 hours of work
- Student evaluations very positive
- Industry feedback very positive

Classroom Experience

- Hardware/software students must learn how to communicate
- Interoperation is hard for students (many, many edge conditions)
- Design is really important … bad start = chaos later on
- Software bug fix = a few minutes
- Hardware bug fix = a few hours

Advanced Functionality

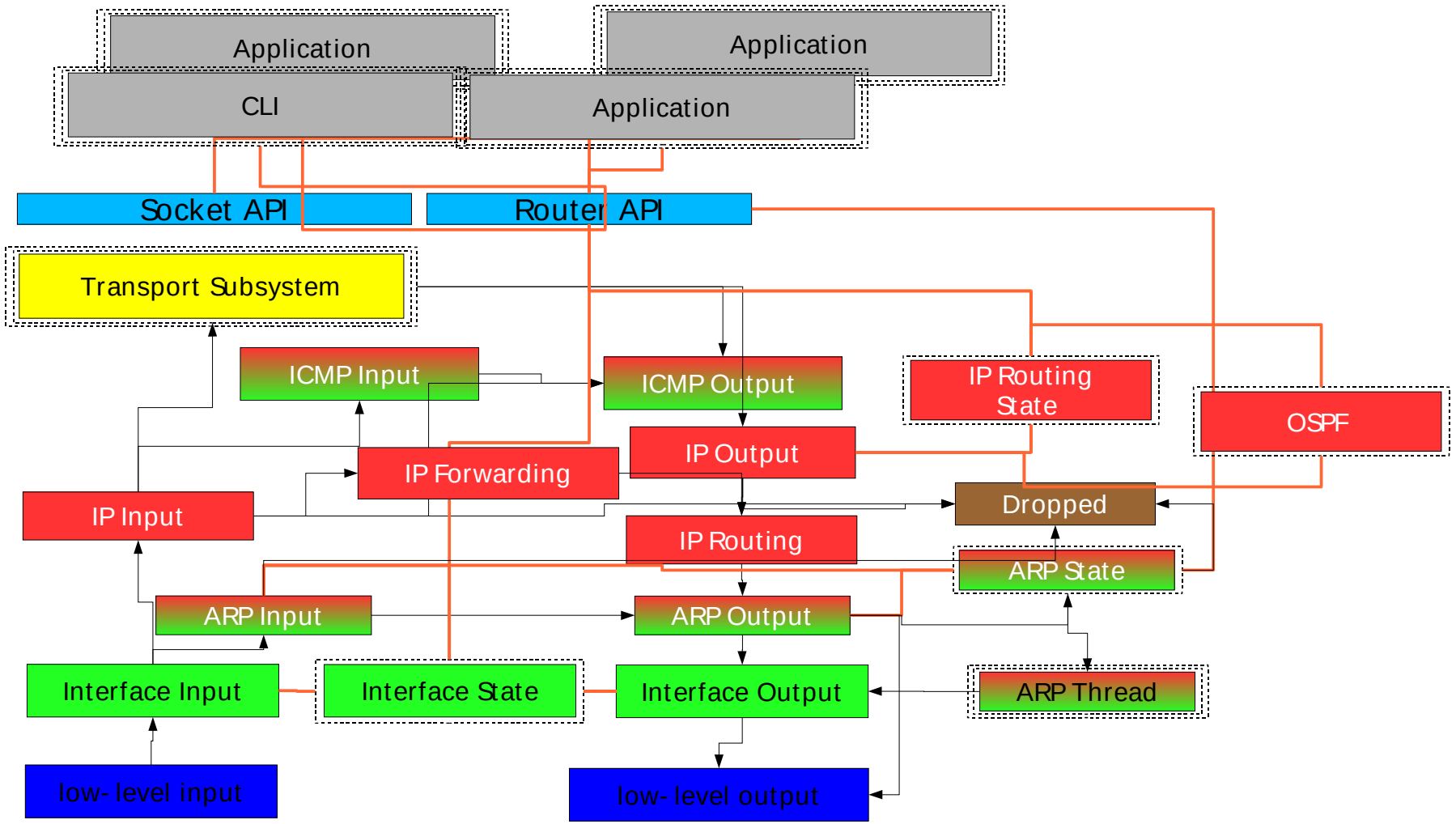
- MAC level encryption (DES)
- SSH man in the middle attack
- Intrusion Detection System
- Random Early Detection
- Token-based rate limiting
- Firewall
- NAT/VPN
- Distributed DNS cache

- Have really impressed industry panel

And Now …

- Developing NetFPGA2
  - PCI cards
  - 1 Gb/s
  - On board CPU
- Working on curriculum for introductory architecture course
- Would like to see NetFPGA used outside of Stanford
- If you are interested, please contact us directly!
  - casado@cs.stanford.edu
  - http://yuba.stanford.edu/vns
  - http://yuba.stanford.edu/netfpga

Thank You!


Application
Application
CLI
Application
Socket API
Router API
Transport Subsystem
ICMP Input
ICMP Output
IP Routing State
OSPF
IP Output
IP Forwarding
IP Input
Dropped
IP Routing
ARP State
ARP Input
ARP Output
Interface Input
Interface State
Interface Output
ARP Thread
low- level input
low- level output