A Hands-On Environment for Teaching Networks

Stanford High Performance Network Group

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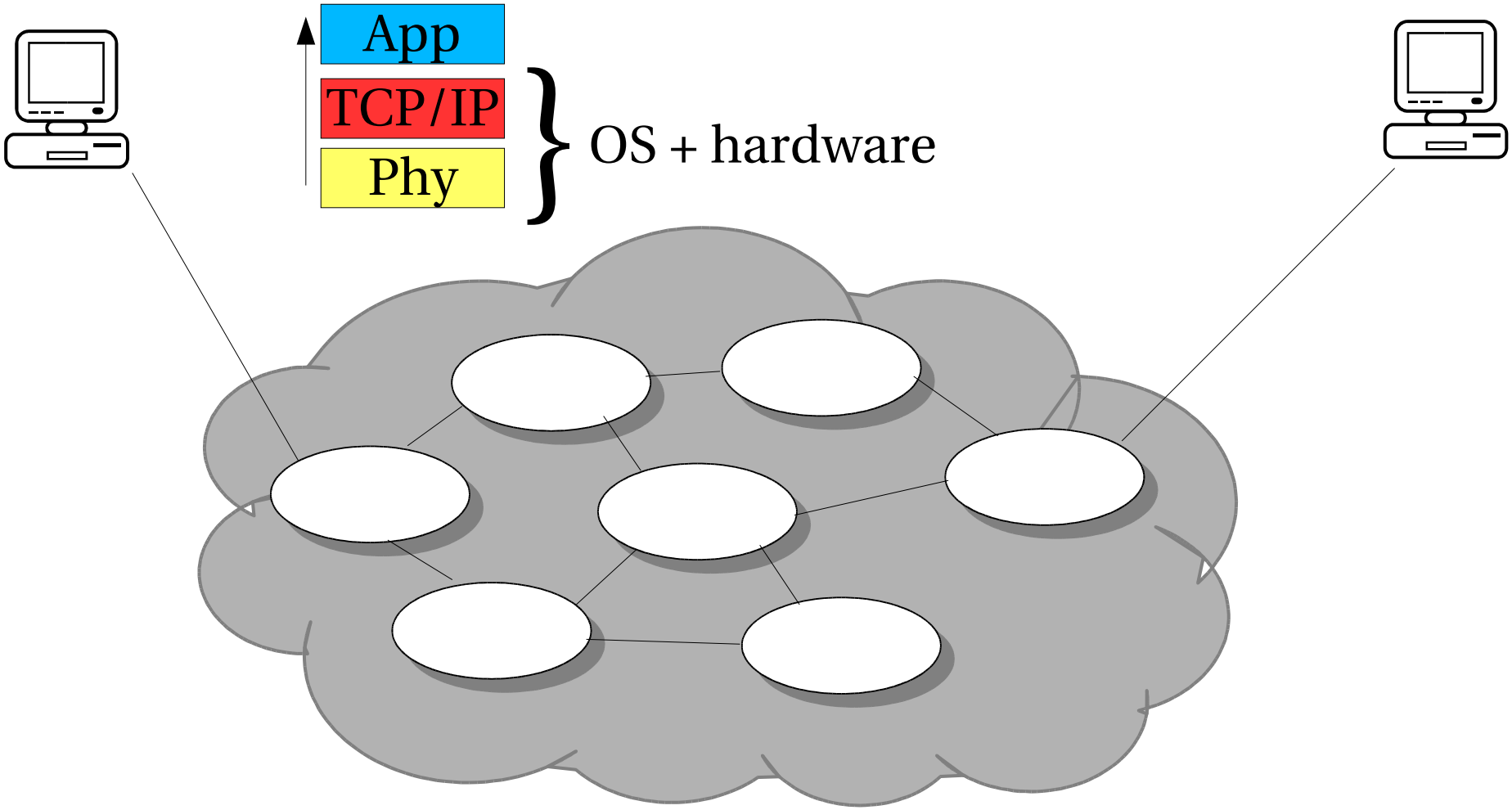
Presentation Outline

- The problem
- Our approach
- Application in the classroom
- Experiences in the classroom

Problem Overview:
Motivation



Problem Overview:

Motivation

"How can you teach router implementation to a large undergraduate class?"

Problem Overview:

Provide Router per Student?

(dedicated hardware)

- Obvious resource constraints
- Difficult to set up/manage
- Complicated development environment

Problem Overview:

Use Network Simulator?

- No access to real Internet traffic/Synthetic
- Specialized development environment
  - Learning curve
  - Non-standard scripting interfaces (we want C!)

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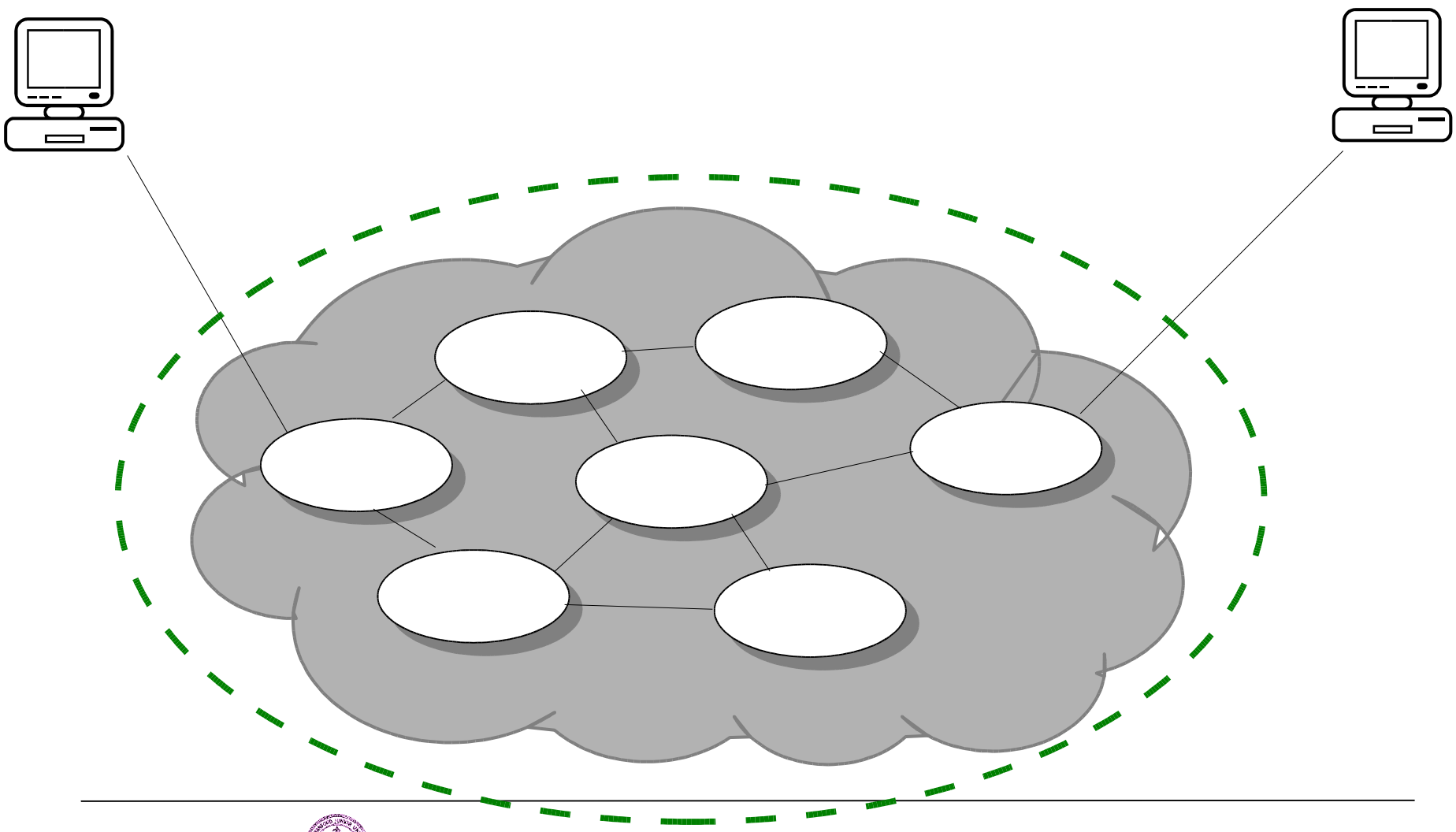
Our Apprach:

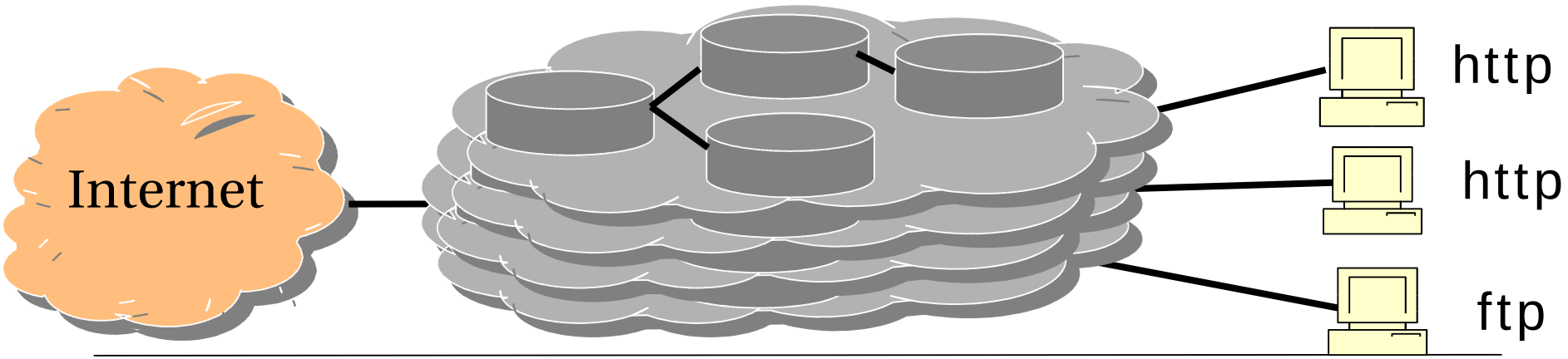
Virtualize the Network



Virtual Network System:

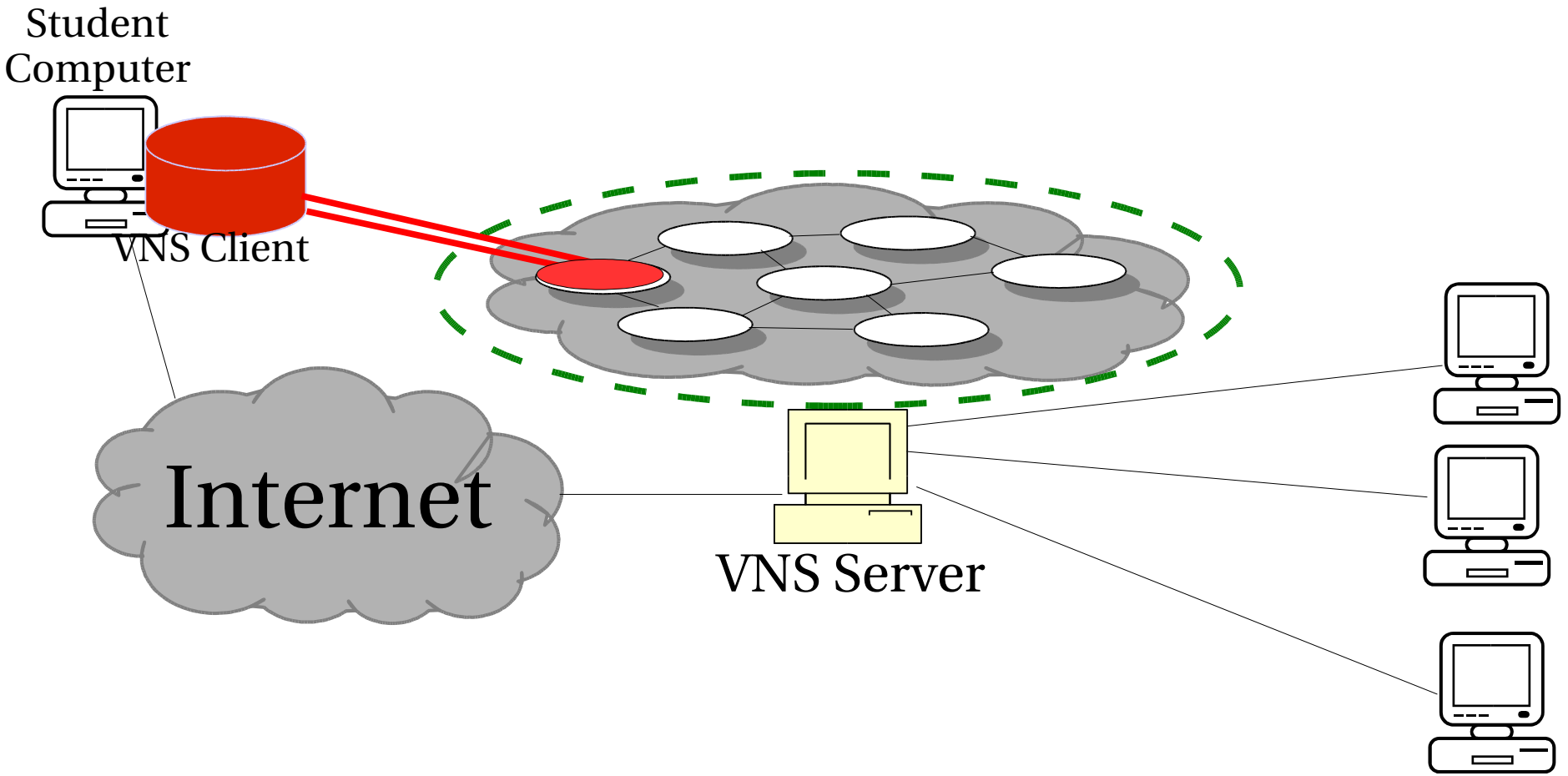
Why Don't We ....

- Start with a machine between the Internet and some servers
- .. have it emulate a network topology
- .. make that multiple network topologies



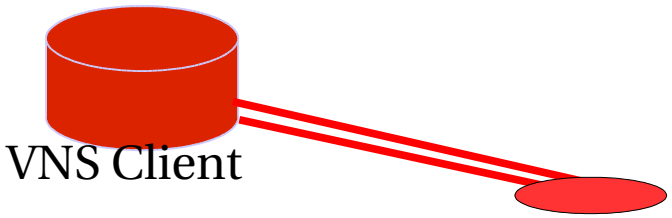
Our Apprach:

Virtual Network System



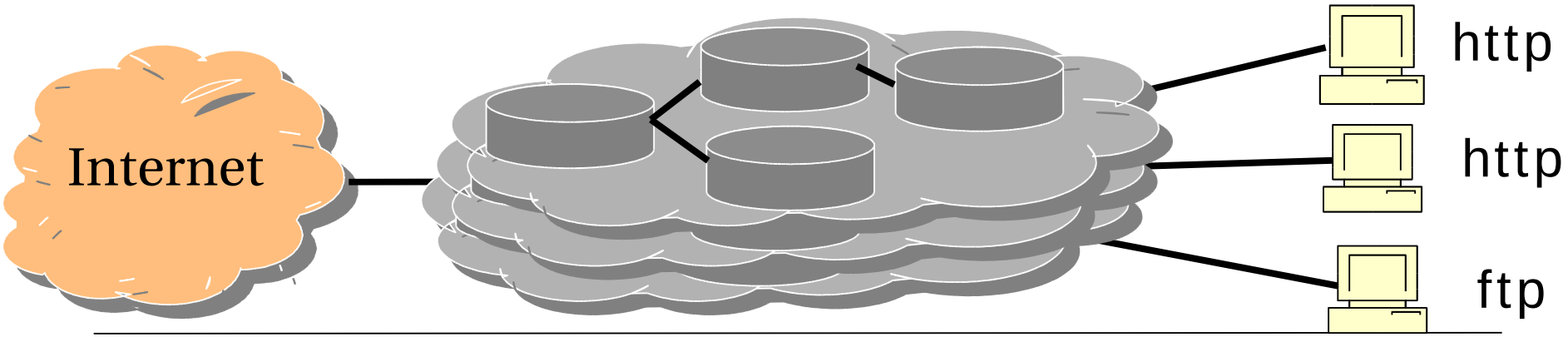
Virtual Network System:
Client Library

- Reserve a virtual host on a given topology
- Read a packet from a specified interface
- Write a packet to a specified interface
- Bindings in C/C++/Java/Python

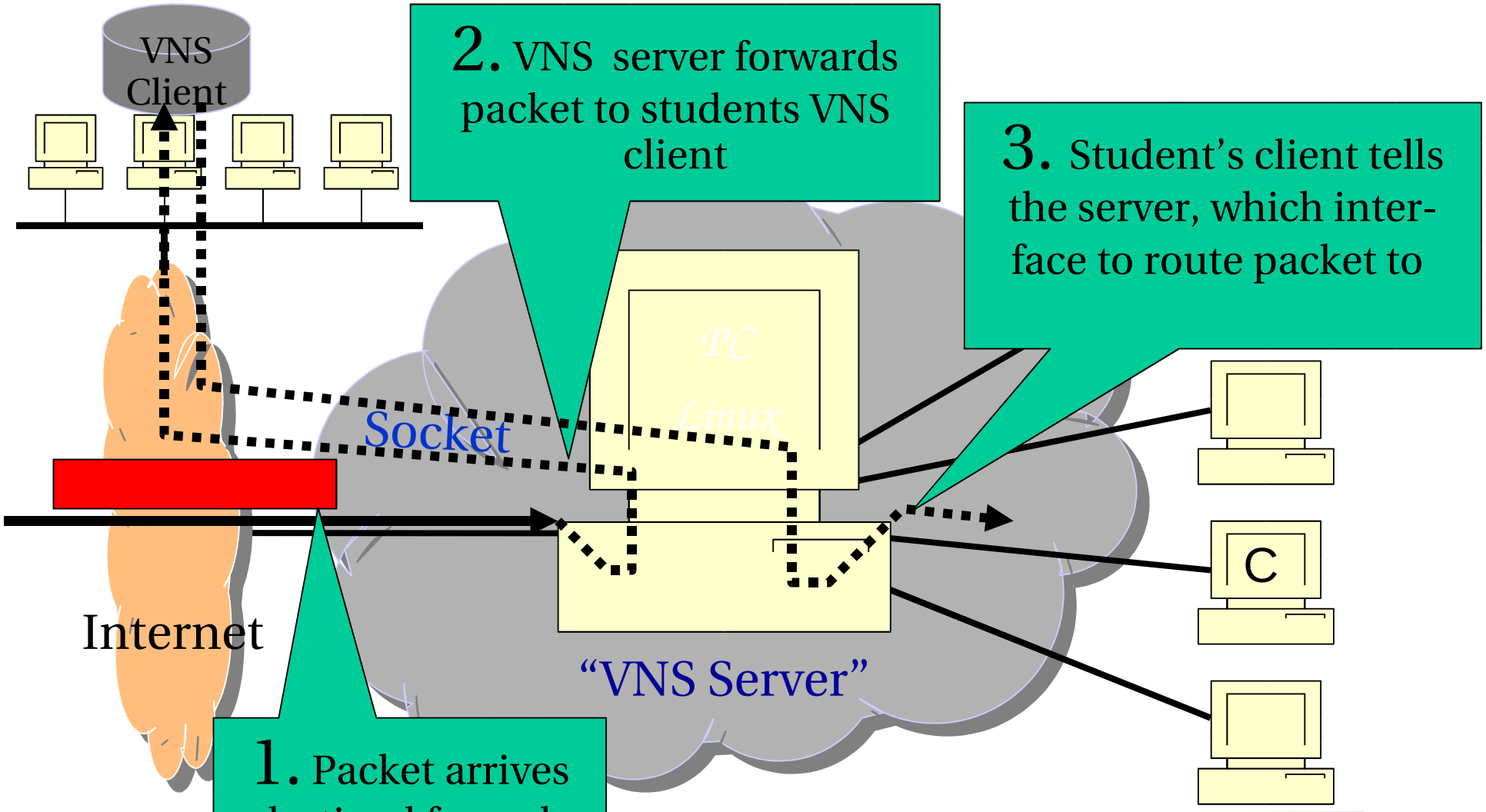


Virtual Network System:
Result?

- Each student has their own topology
- Students can develop from anywhere
- Access to live traffic
- Can interact with hosts on Internet
- Can support 1000's of students



Virtual Network System:
Packet Forwarding



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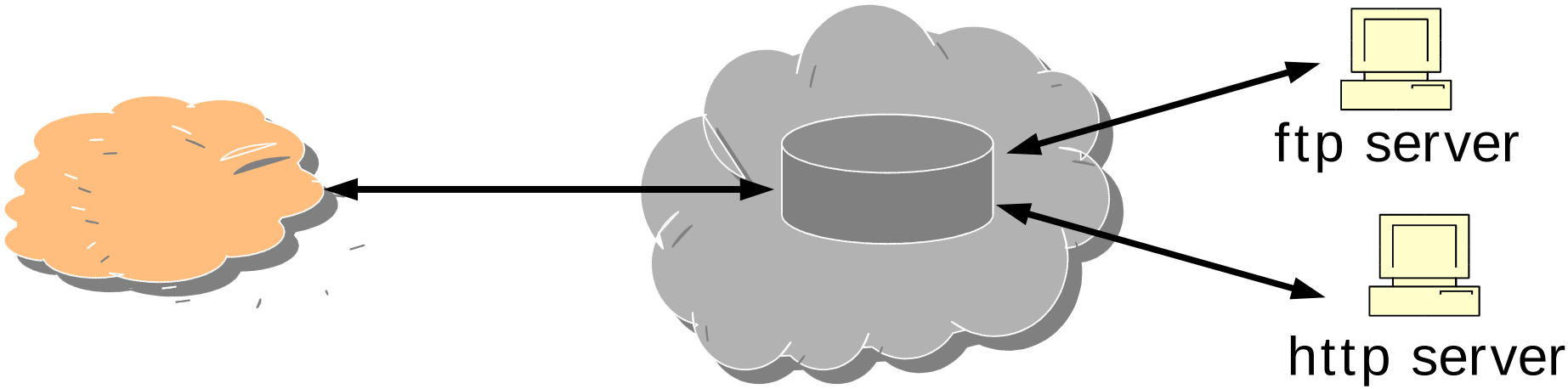
Virtual Network System:

VNS in the Classroom

- Projects
  - Building a functional router
  - Building the full networking stack
  - Building a hardware/software router
- Demonstrating networking concepts

Example Assignment : Software Router

- Each student gets their own topology
- Single router attached to Internet and application servers



Software Router

- Handle ARP
  - request/response
  - cache/queue of packets pending responses
- Support various ICMP types
  - ECHO (ping)
  - Time Exceeded (traceroute)
  - Port Unreach
  - Host Unreach
- Forward correctly from static routing table
- IP header checksum

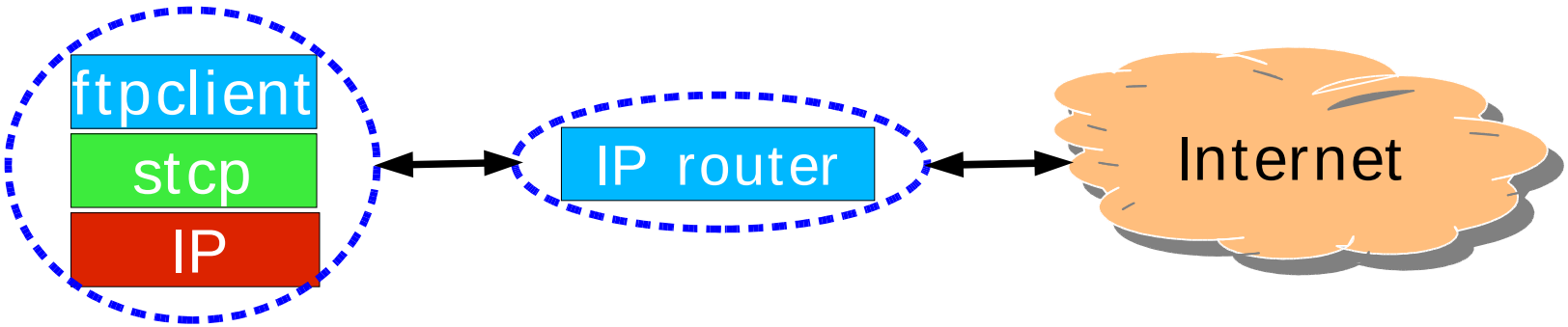
Software Router: Code Complexity

- Typically around 1,000 lines of code
- No-threads required
- Project takes 2 weeks – 1 month
- Roughly 30 hours of work

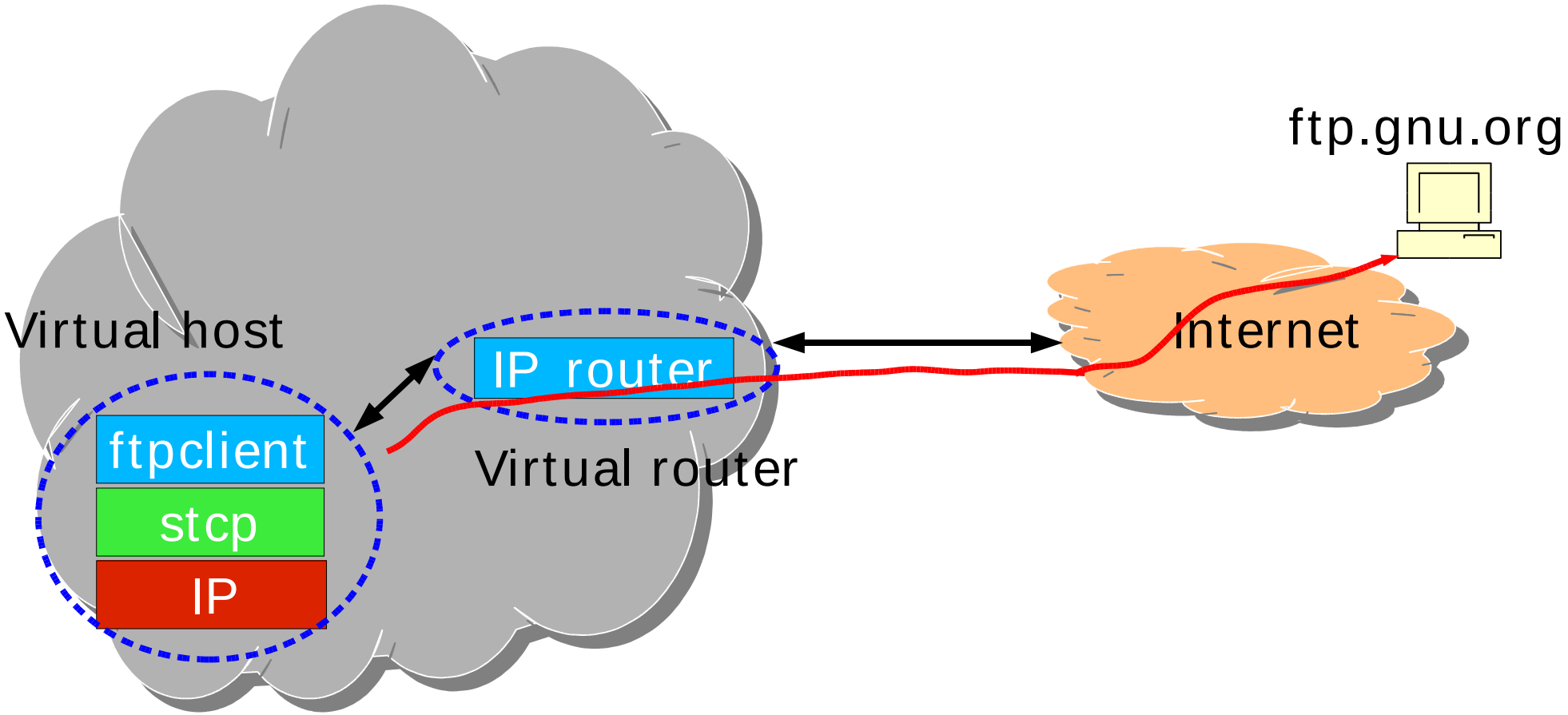
VNS in Practice:

Building a Full Network Stack

- All components of the networking stack
- Combination of three projects
  - Ftp client
  - Software router
  - TCP compatible transport layer (STCP)



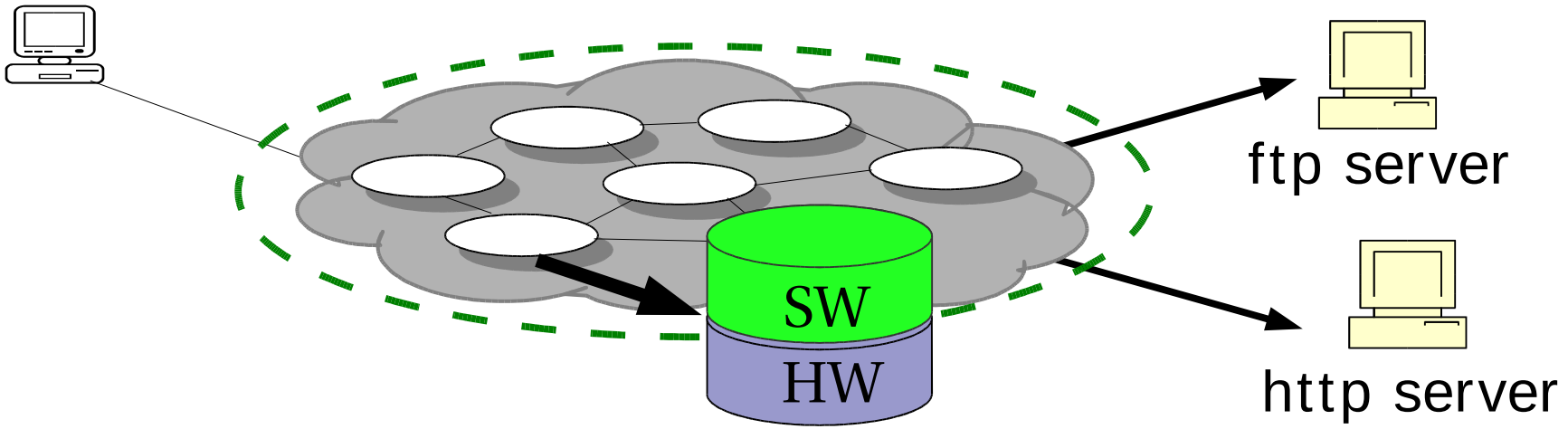
VNS in Practice:
Full Network Stack



VNS in Practice:

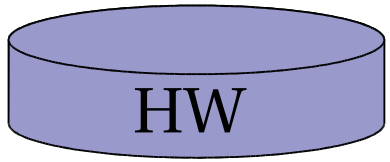
Building an Integrated Software/Hardware Router

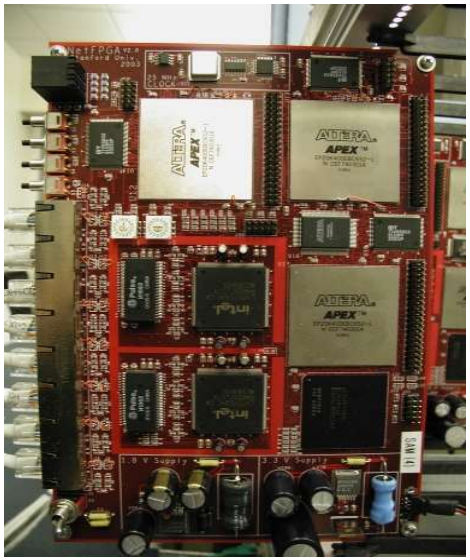
- Full router in hardware and software
- Managed via CLI
- Hardware forwarding path
- Router – router protocol
- Must inter-operate with other students



VNS in Practice:
Hardware, NetFPGA

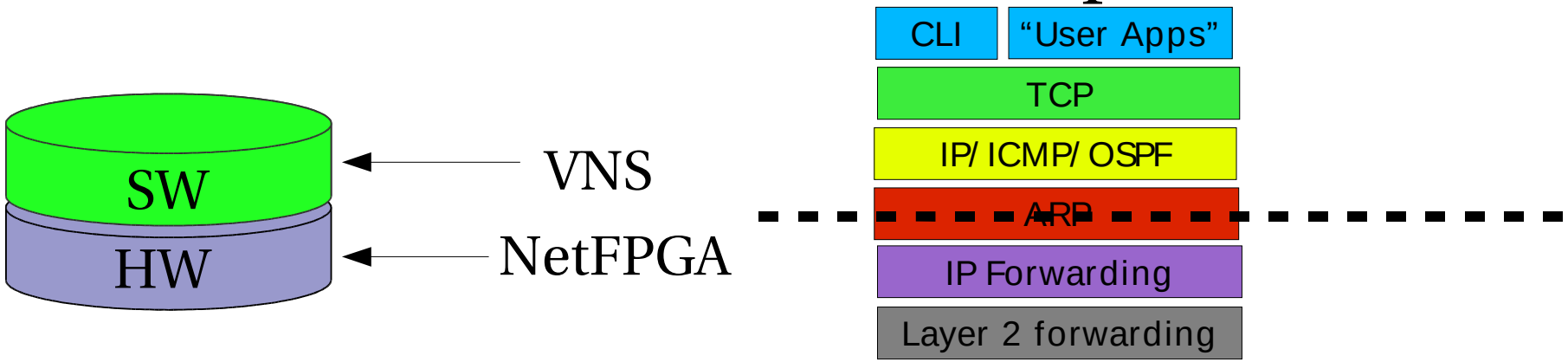
- Network programmable FPGA
- Basically a programmable, 8 port network device
- Provides facilities for handling communication paths to/from network
- Students use Verilog
- Works with VNS





VNS in Practice:
Software

- Software runs as “CPU” for hardware through VNS
- Integrated TCP stack
- User applications
- Simplified OSPF variant
- Controls hardware via 'control packets'



VNS in Practice:
Other Projects

- Simplified link-state routing protocol
- Open ended router design
- Security (Conceptual)
  - ssh man in the middle
  - tcp session hijack
  - Traffic poisening/redirection
  - etc.

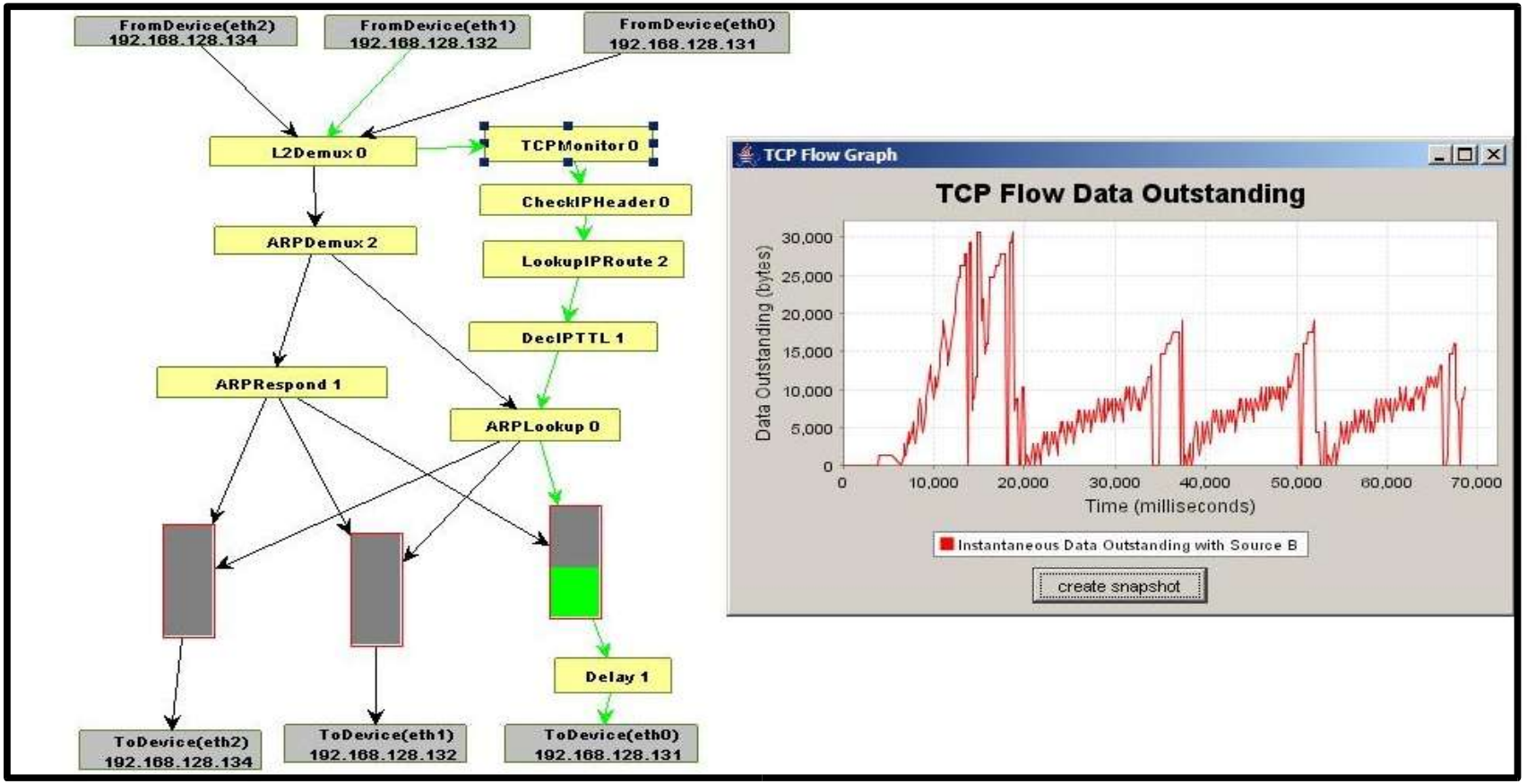
VNS in Practice:
Classroom Demonstrations

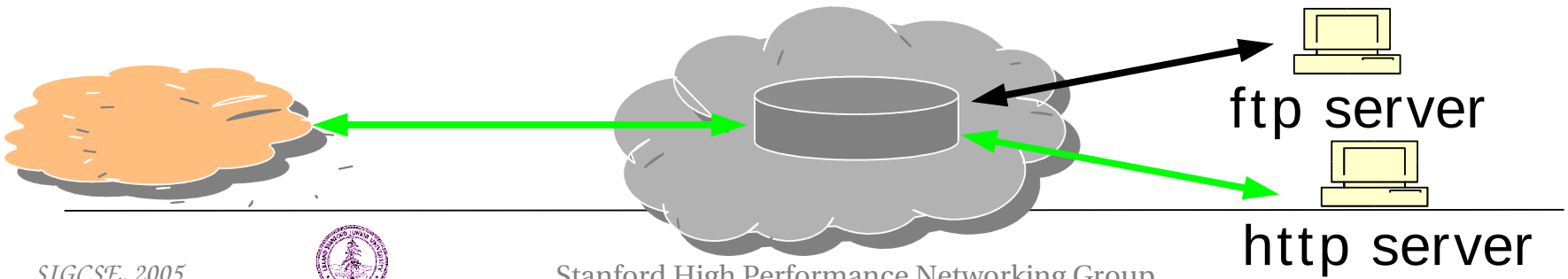
- Want to visualize network concepts
  - TCP congestion window over time
  - Router buffer occupancies
- "View" inside operating router
- Real-time inspection of protocol stack

VNS in Practice:
Clack

- GUI Router (Java applet)
- Build router out of visual components
- Allows real time visualization
  - tcp flows
  - tcp sawtooth
  - queue sizes etc
- Useful for teaching/demoing
- Work in progress ...
- http://yuba.stanford.edu/vns/clack

VNS in Practice:
Clack





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- Experience in the classroom

Experiences in the Classroom

- Stanford
  - Introductory Networking Course (3 years)
    (router, stcp, full network stack)
  - Graduate course in router design (2 years
    (Integrated hardware router)
- Johns Hopkins
  - upper level networking protocols course (2 years)
    (router, OSPF)
- WSU
  - introductory networking course (1 year)
    (router)
- Over 1500 students
- Create remote teaching lab

Student Feedback

- Overwhelmingly positive (anonymous formal evaluations)
- Hard but very rewarding
- Many requests for access after projects are finished
- Many students experiment with more complex functionality (NAT, VPN, firewalls, web-servers, QOS etc.)

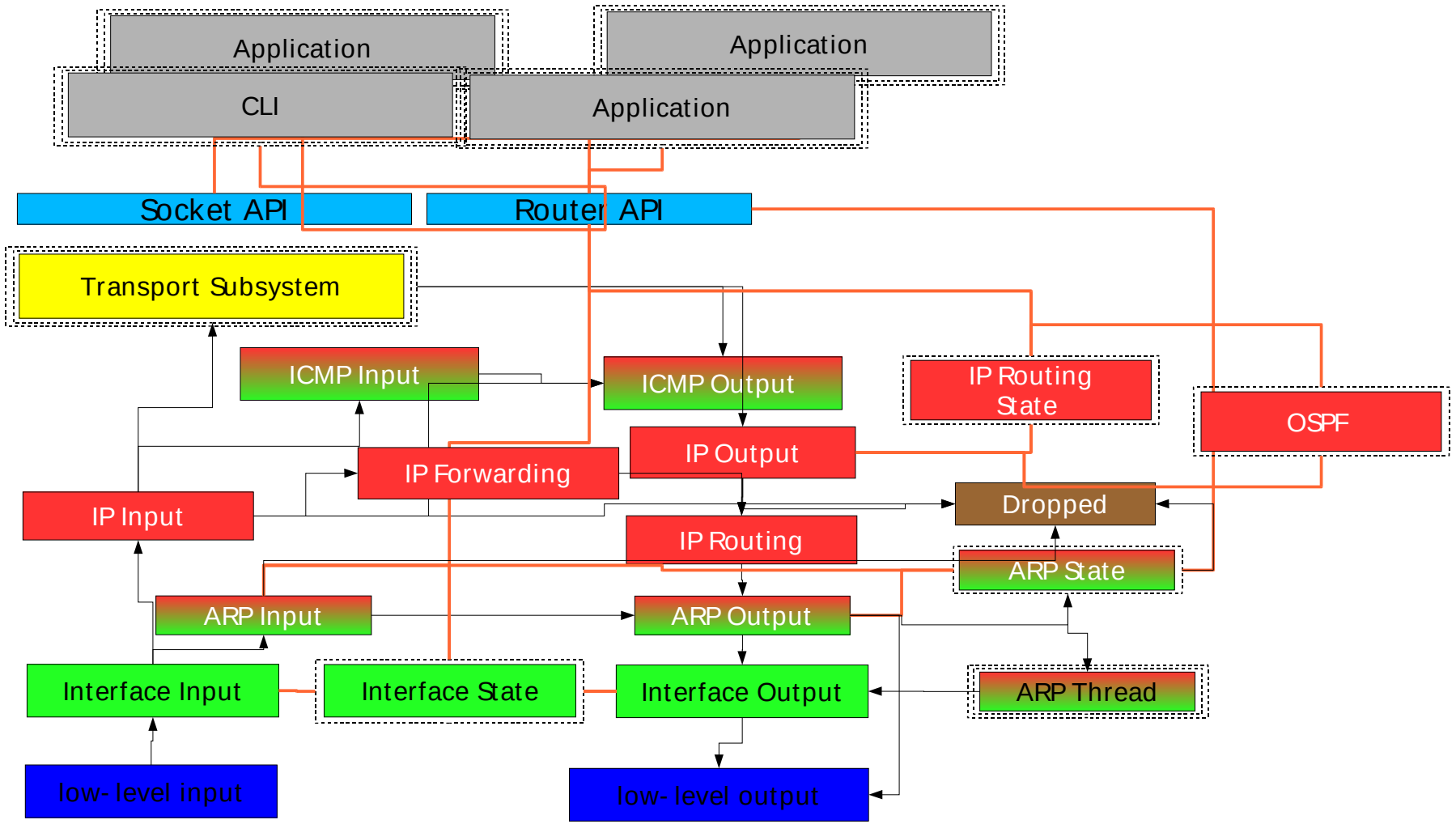
Teacher Feedback

- Very positive
- Both pilot schools will continue using
- Have been excited to contribute project ideas/extensions

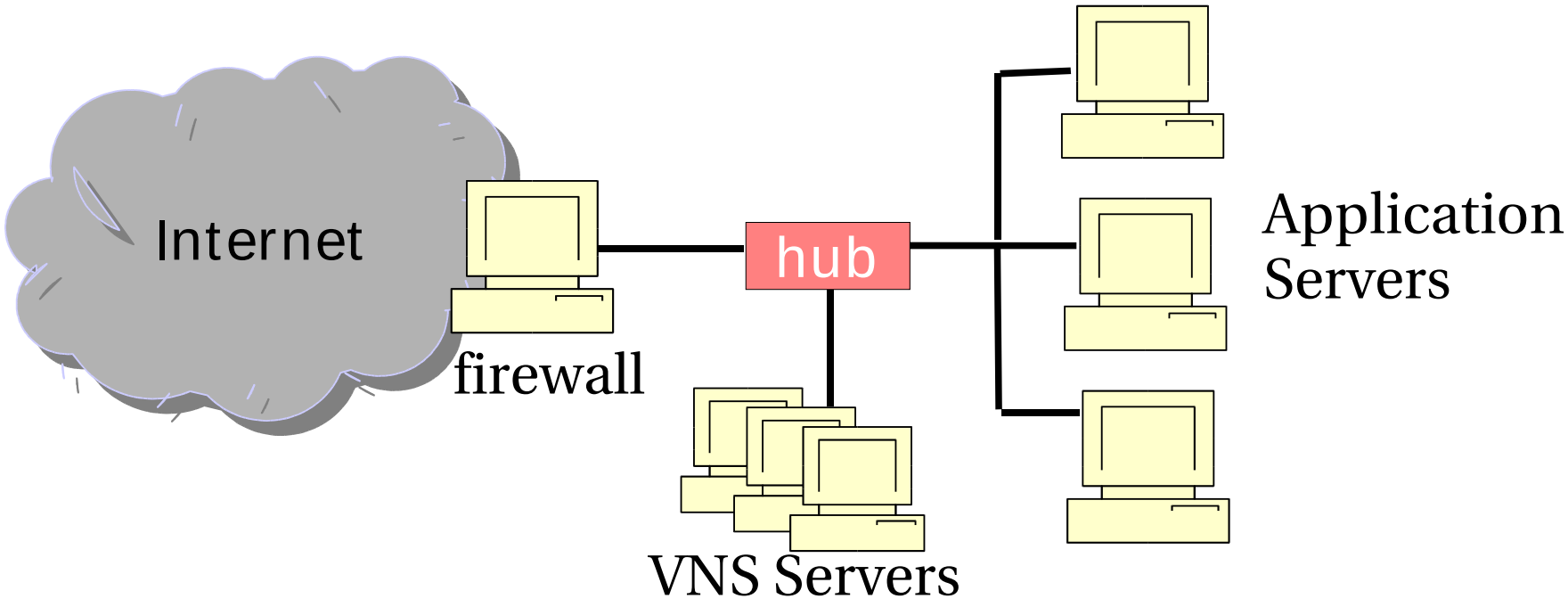
Plug

- Are looking to host more remote projects
- Provide full curriculum and support
- Collaboration with other projects?
- If you are interested, please contact us directly!
  - casado@cs.stanford.edu
  - http://yuba.stanford.edu/vns
  - http://yuba.stanford.edu/vns/clack/

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

Virtual Network System:
Physical Setup

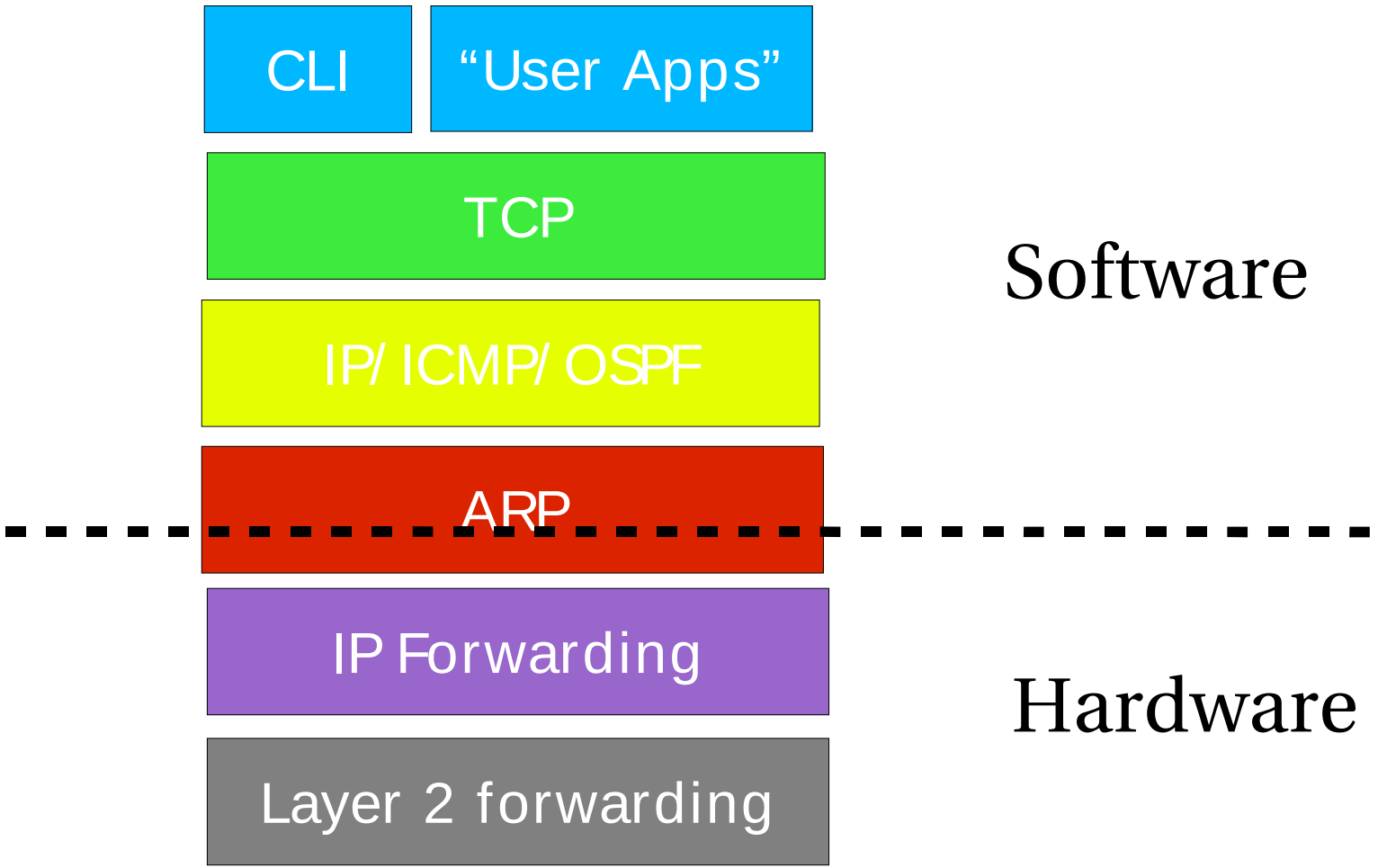


Problem Overview:

Requirements

- Route live Internet traffic
- Isolated network topology per student
- systems programming expertice not required
- Efficient use of hardware
- Support 1000s of students
- Support remote projects
- Safe

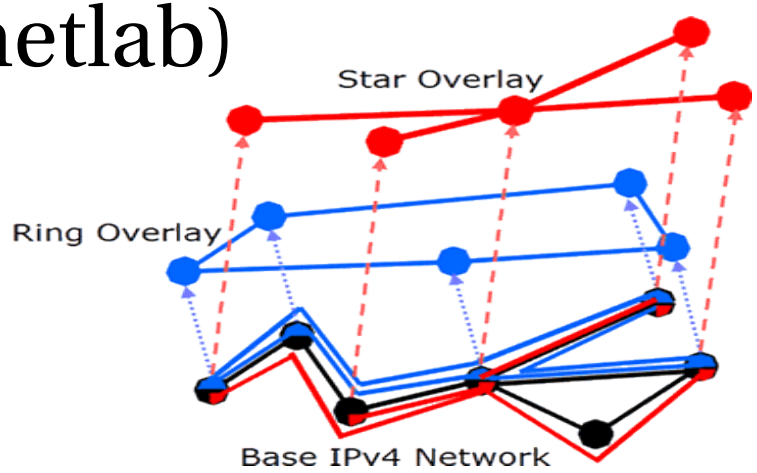
VNS in Practice:
Building a full router



Problem Overview:

Virtual Overlay Network?

- No access to link layer (generally intended for network layer on up)
- Designed for dedicated research environment
- Often virtualize components of OS
- Normally have large scale deployment (X-bone, Planetlab)



Virtual Network System

- Many possible solutions
- None met our particular requirements
- Developed our own within the context of our introductory networking course

Virtual Network System:

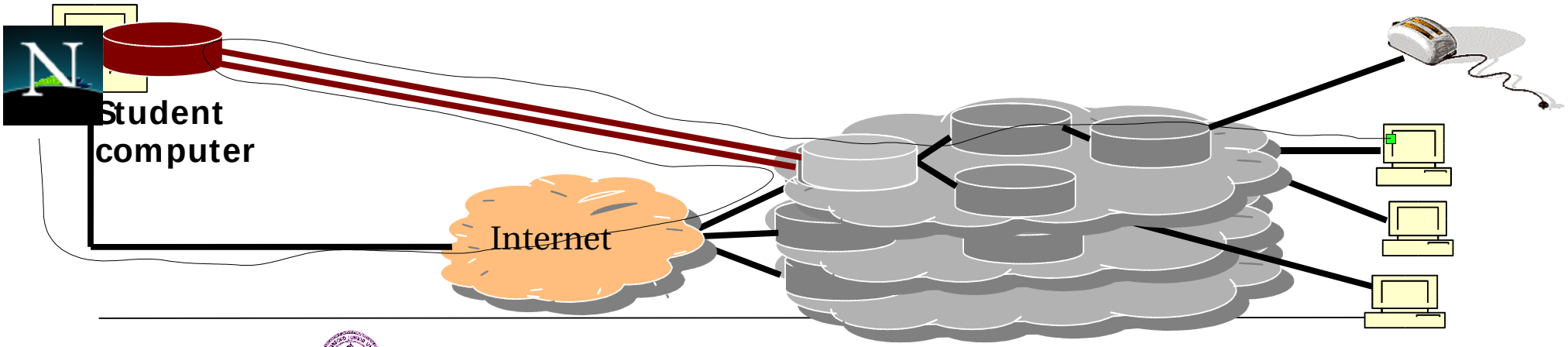
Transparency

- A challenge! more always better
- Provide tcpdump-compatible files for all packets seen by the router
  - Encourage students to use ethereal/tcpdump for debugging
  - Helps students find most errors
- Run mini-web-server showing which topologies/routers are reserved, number of packets services etc.
- Active area of exploration … (Especially for complex setups with integrated hardware)

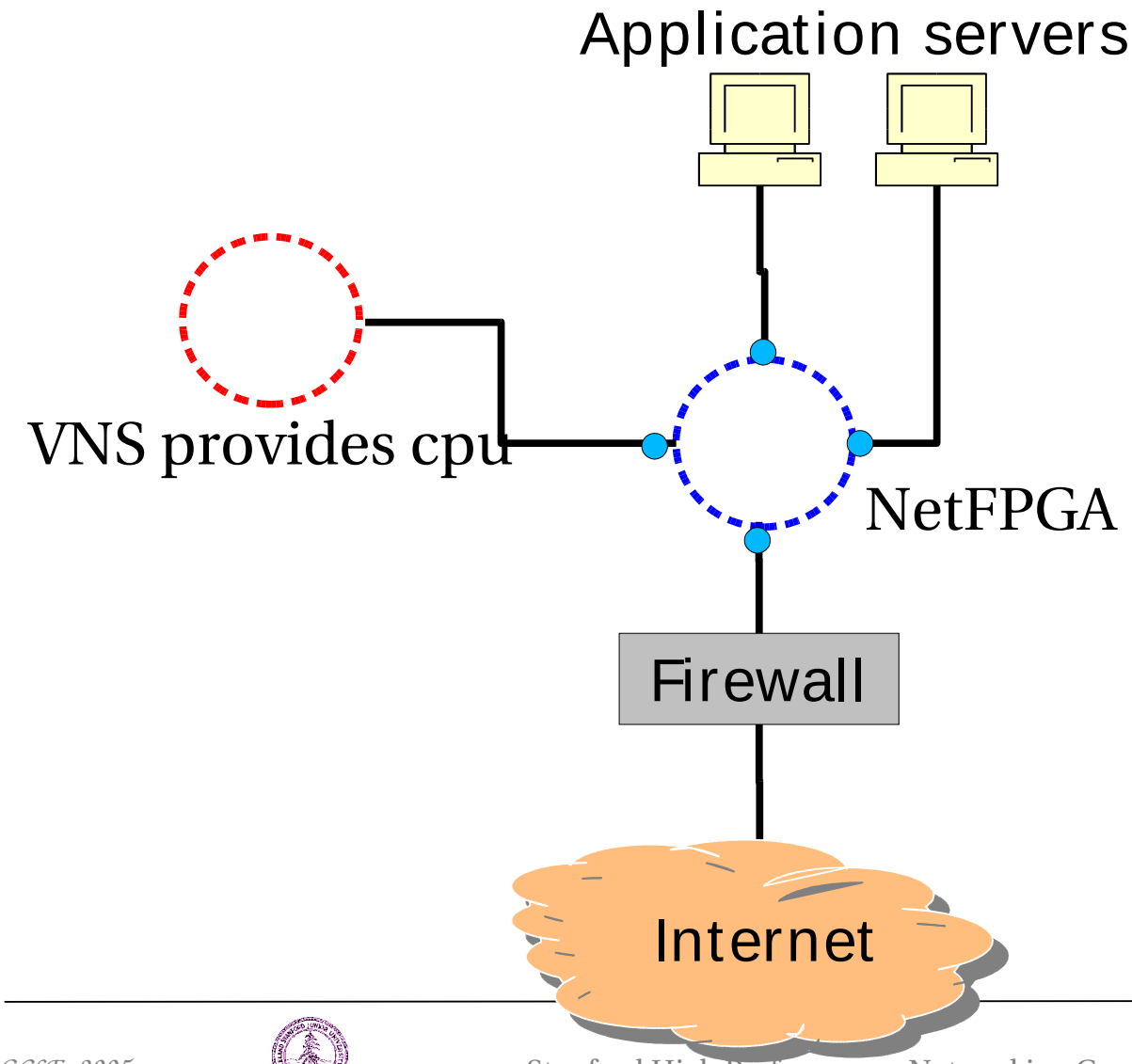
Virtual Network System:

Providing Student Access

- Students write user-level program (using provided api)
- Allow user-level program to send/receive packets as if it were on the topology
- Student's can then send real traffic to their server's on the topology



VNS in Practice:
Topology



VNS in Practice:
Software