# Reinventing the Internet: Platforms for Innovations

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# Key Takeaways

❖ **Big changes on the horizon**

  – Internet will look very different in five to ten years

❖ **Big changes means big opportunities**

  – For researchers, Research & Education Networks, & other stakeholders

  – **If we don't take the lead, we will get results we will not like**

❖ **Stanford Clean Slate Program**

  – Reinvent Internet by creating platforms for innovations

❖ **OpenFlow Network Platform**

  – Open the Internet infrastructure for innovations

❖ **OpenFlow as architecture concept**

  – Old concepts new context – still potential for big impact
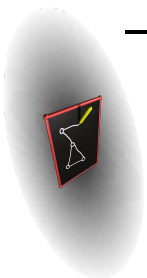
# Persistent Problems: Making Internet Infrastructure Worse

*"... in the thirty-odd years since its invention, new uses and abuses, ..., are pushing the Internet into realms that its original design neither anticipated nor easily accommodates."*
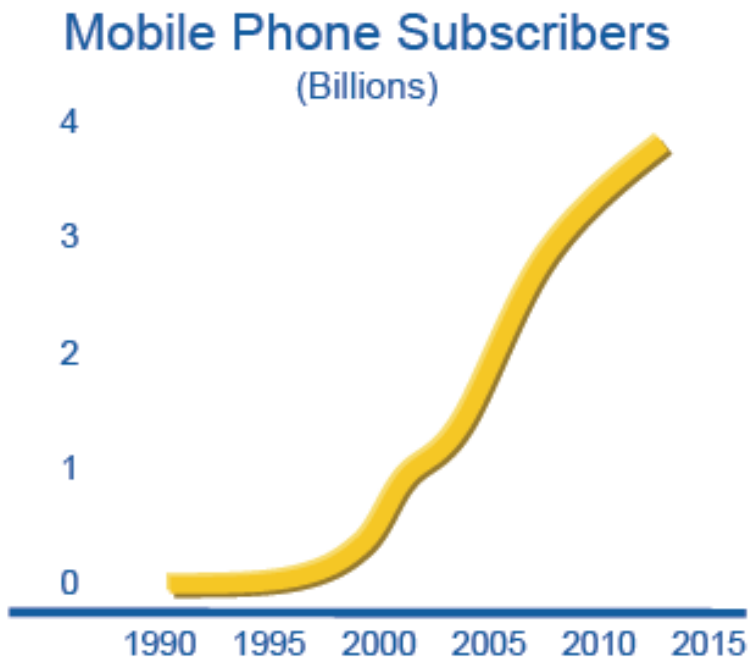
*"Freezing forevermore the current architecture would be bad enough, but in fact the situation is deteriorating."*

**Overcoming Barriers to Disruptive Innovation in Networking, NSF Workshop Report, 05.**

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# Revolution in Mobile Computing
## *Millions → Billions*



Mobile Phone Subscribers (Billions)



Democratization of computing
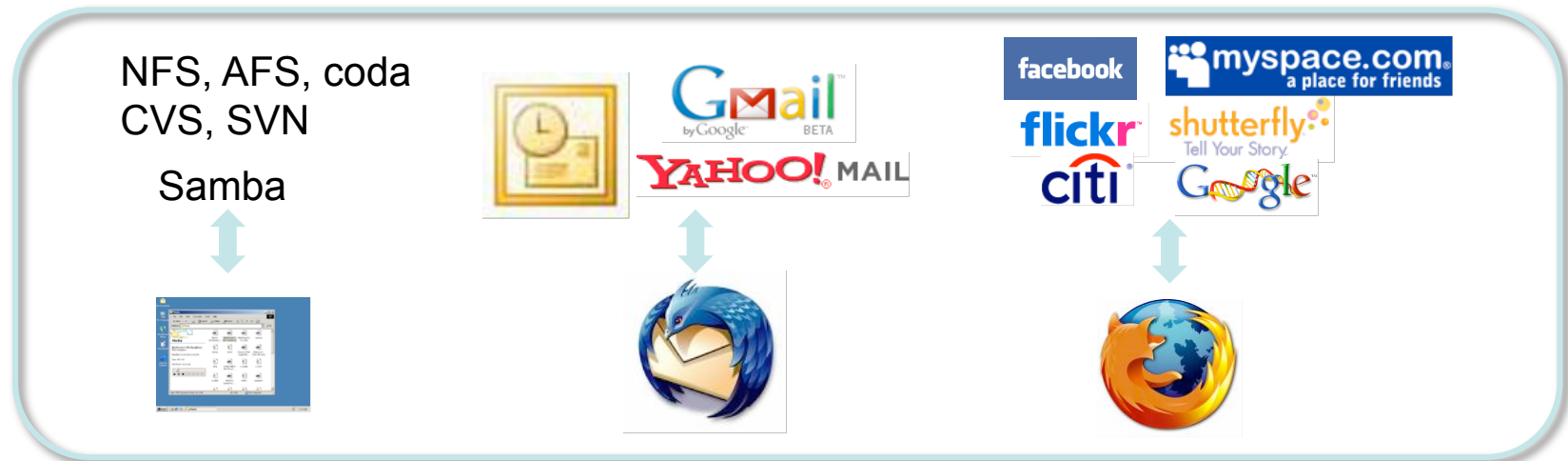


Entirely new uses of mobile computing

Power-limitation of handheld ⇨ computation will move to the cloud

Need to back up and refresh our lost data ⇨ data will move to the cloud

4

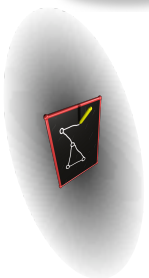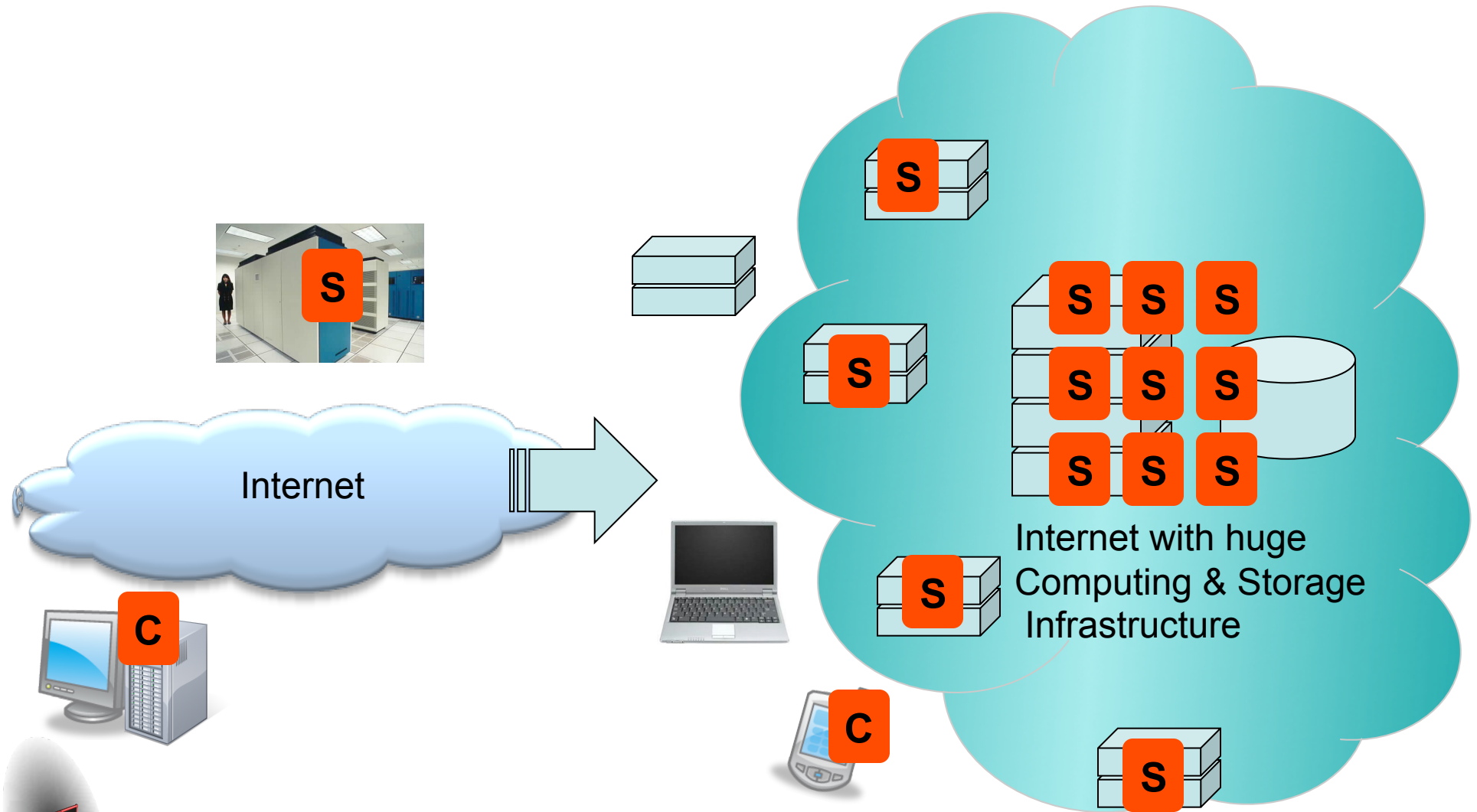# We are Losing Control of Our Data

NFS, AFS, coda
CVS, SVN

Samba

Our data

❖ moving into the cloud

❖ "owned" by applications => users losing control

❖ difficult to share among applications

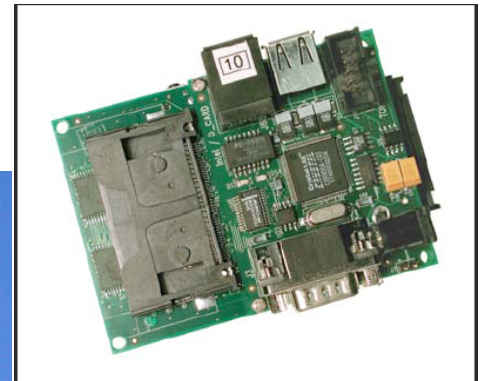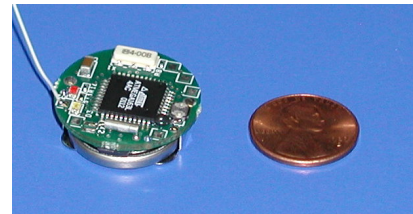❖ leakage a serious problems

Trends to accelerate unless checked…

5

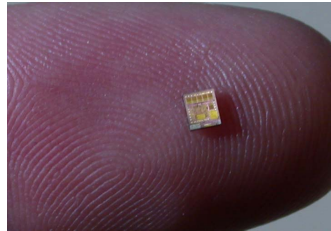# Computing and Storage Moving Into the Cloud



Internet

Internet with huge Computing & Storage Infrastructure

6

# Cyber-Physical World

**New Machines**

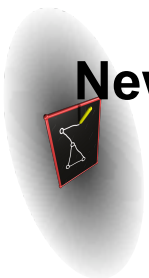

**New Environments**
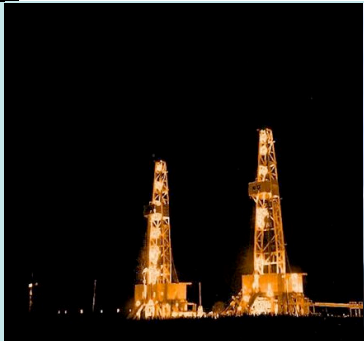**New Applications**



**New Scale**

**Billion to trillion devices!**

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# Network Centric Critical Infrastructures

**Transportation**

**Essential Utilities**

**Internet Architecture is NOT robust enough to support these**

communications

...nking & Finance

GOVERNMENT SERVICES
FEDERAL
STATE
LOCAL
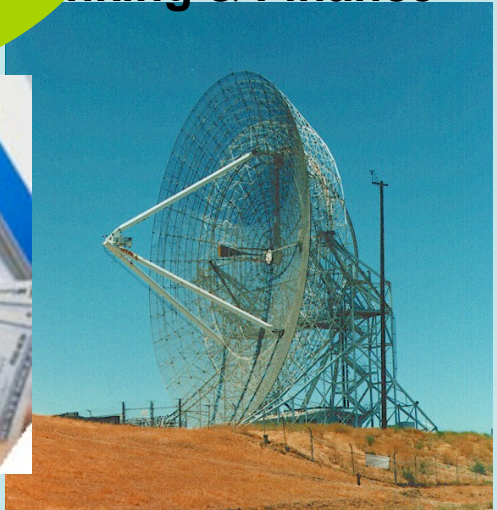
# Big Changes Represent Big Opportunities

Opportunities for

❖ Research groups to shape future Internet

❖ Research and education networks

❖ Startups to create new product categories

❖ Incumbents to get into new markets and grow

❖ Newcomers to leapfrog

Otherwise incumbents will take it in directions we will not like

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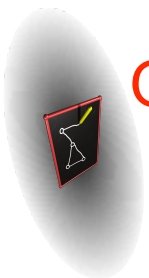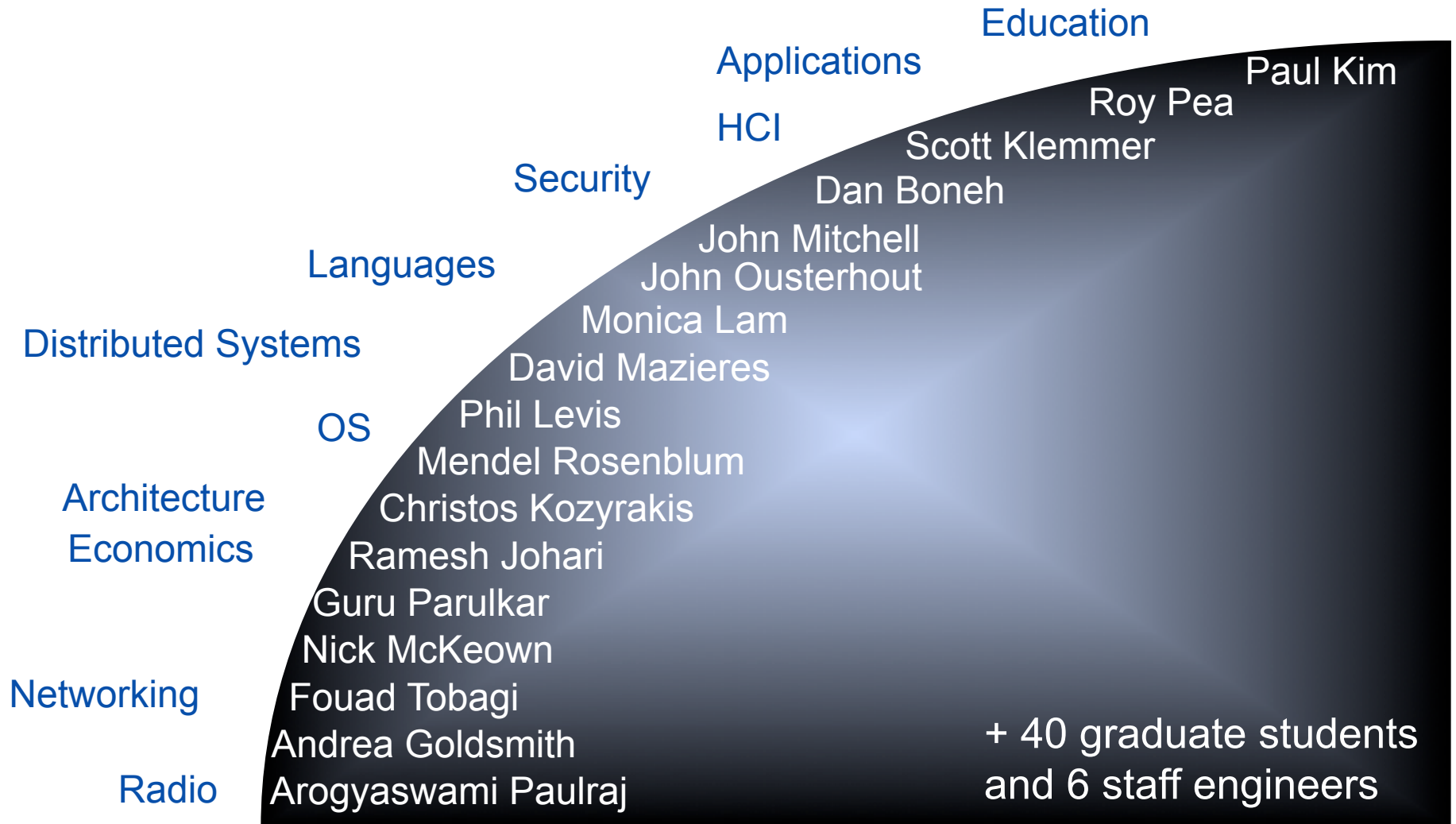# Stanford Clean Slate Team

Education

Applications

HCI

Security

Languages

Distributed Systems

OS

Architecture

Economics

Networking

Radio

Paul Kim
Roy Pea
Scott Klemmer
Dan Boneh
John Mitchell
John Ousterhout
Monica Lam
David Mazieres
Phil Levis
Mendel Rosenblum
Christos Kozyrakis
Ramesh Johari
Guru Parulkar
Nick McKeown
Fouad Tobagi
Andrea Goldsmith
Arogyaswami Paulraj

+ 40 graduate students
and 6 staff engineers

Departments of EE, CS, MS&E and School of Education
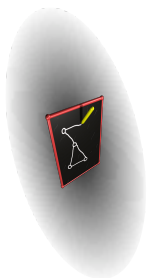
# Stanford Clean Slate Program

To reinvent Internet infrastructure and services

by creating key platforms for innovations and
deploying and making them available to research
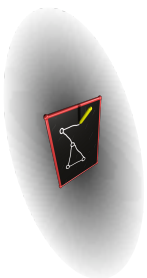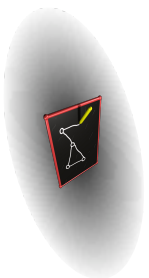and user communities

with emphasis on mobile computing

# The Big Picture
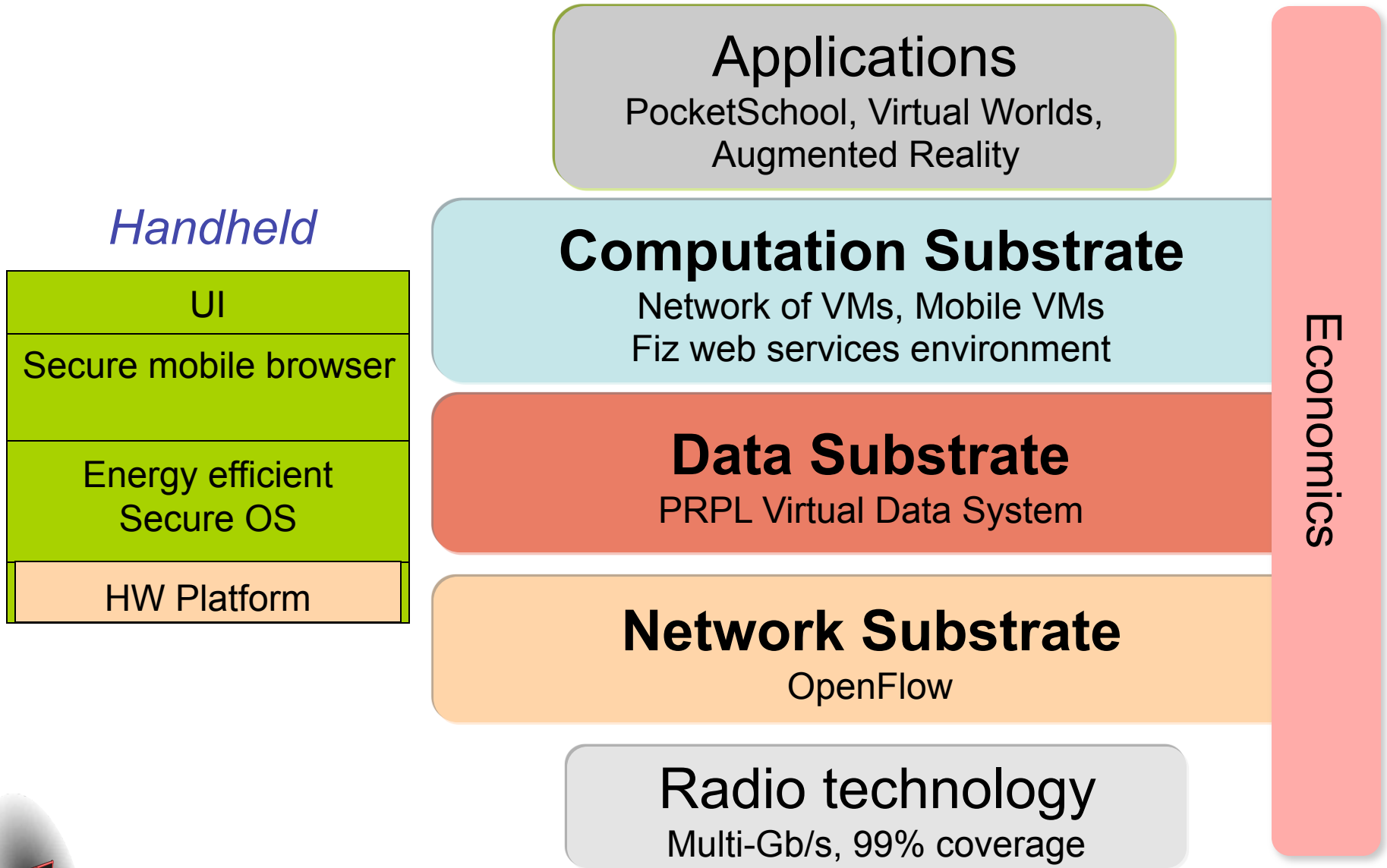
**Applications**
PocketSchool, Virtual Worlds,
Augmented Reality

**Computation Substrate**
Network of VMs, Mobile VMs
Fiz web services environment

**Data Substrate**
PRPL Virtual Data System

**Network Substrate**
OpenFlow

Radio technology
Multi-Gb/s, 99% coverage

*Handheld*

UI

Secure mobile browser

Energy efficient
Secure OS

HW Platform

Economics

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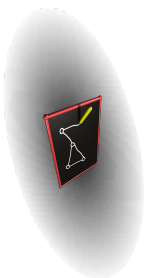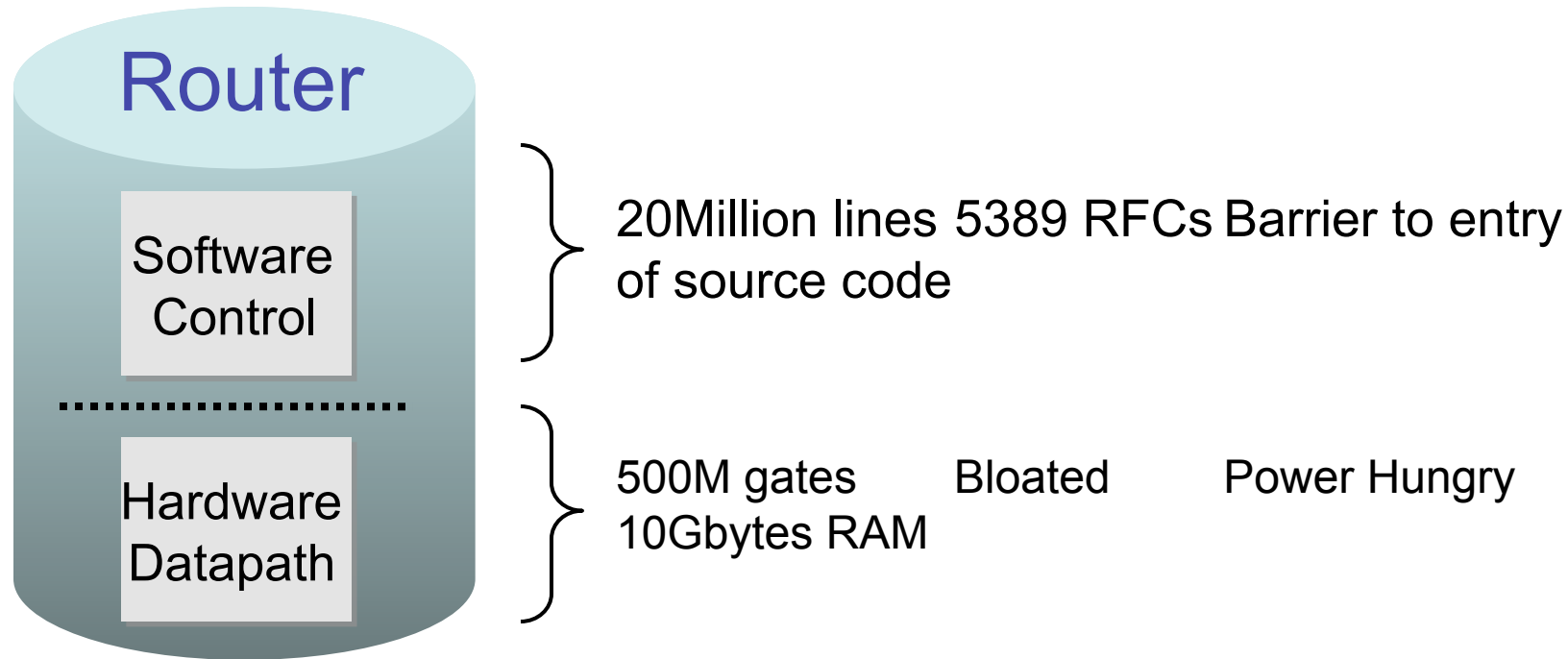– Old concepts new context

13
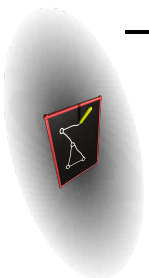
Internet has many problems

Plenty of evidence and documentation

Internet's "root cause problem"

It is Closed for Innovations

# Why Internet Closed for Innovations?

**Router**

Software Control

Hardware Datapath

20Million lines 5389 RFCs Barrier to entry of source code

500M gates       Bloated       Power Hungry
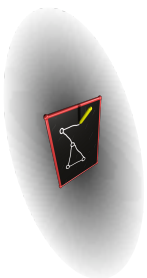10Gbytes RAM
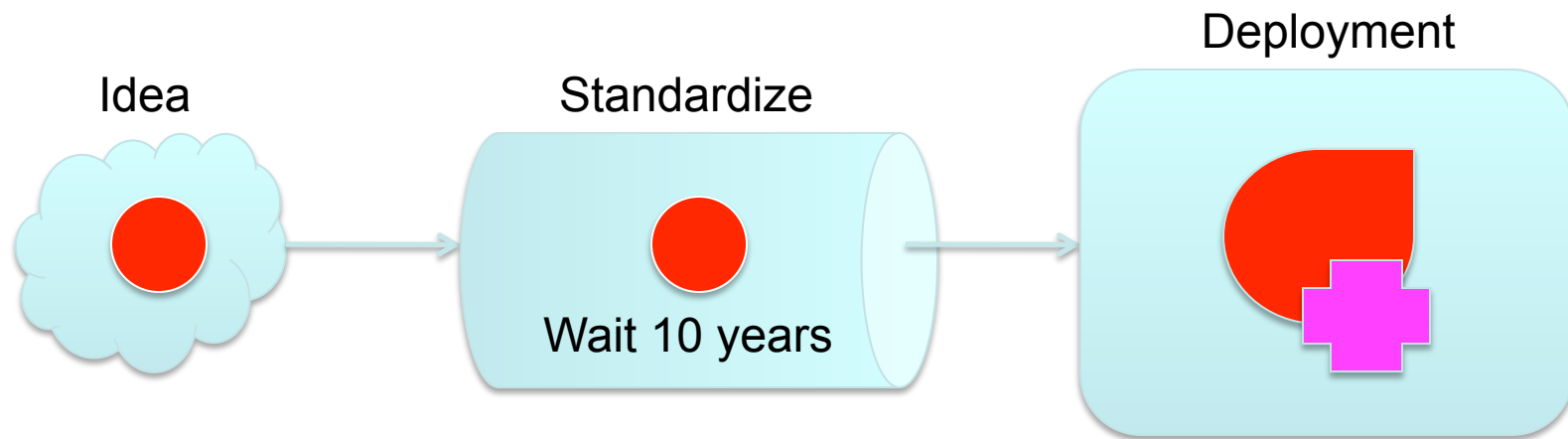
Many complex functions baked into the infrastructure

*OSPF, BGP, multicast, differentiated services, Traffic Engineering, NAT, firewalls, MPLS, redundant layers, …*

# Process of (Lack of) Innovation

Idea

Standardize

Deployment

Wait 10 years

◆ Equipment vendors own the process

◆ Equipment closed

◆ Almost no technology transfer from research

◆ Not good for equipment vendors either
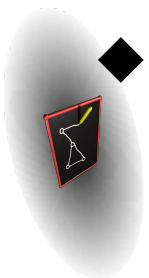
# Imagine Internet Infrastructure

That continuously evolves &

Is under the control of the users,
owners and their applications &

Is open to public scrutiny

# OpenFlow: Enable Innovations "within" the Infrastructure
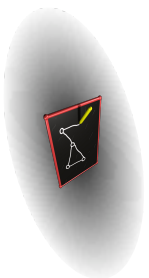


*OpenFlow Switch specification*

**OpenFlow Switch**

sw — Secure Channel

hw — Flow Table

OpenFlow Protocol SSL

PC — Controller

Net Services

API

- Add/delete flow entries
- Encapsulated packets
- Controller discovery
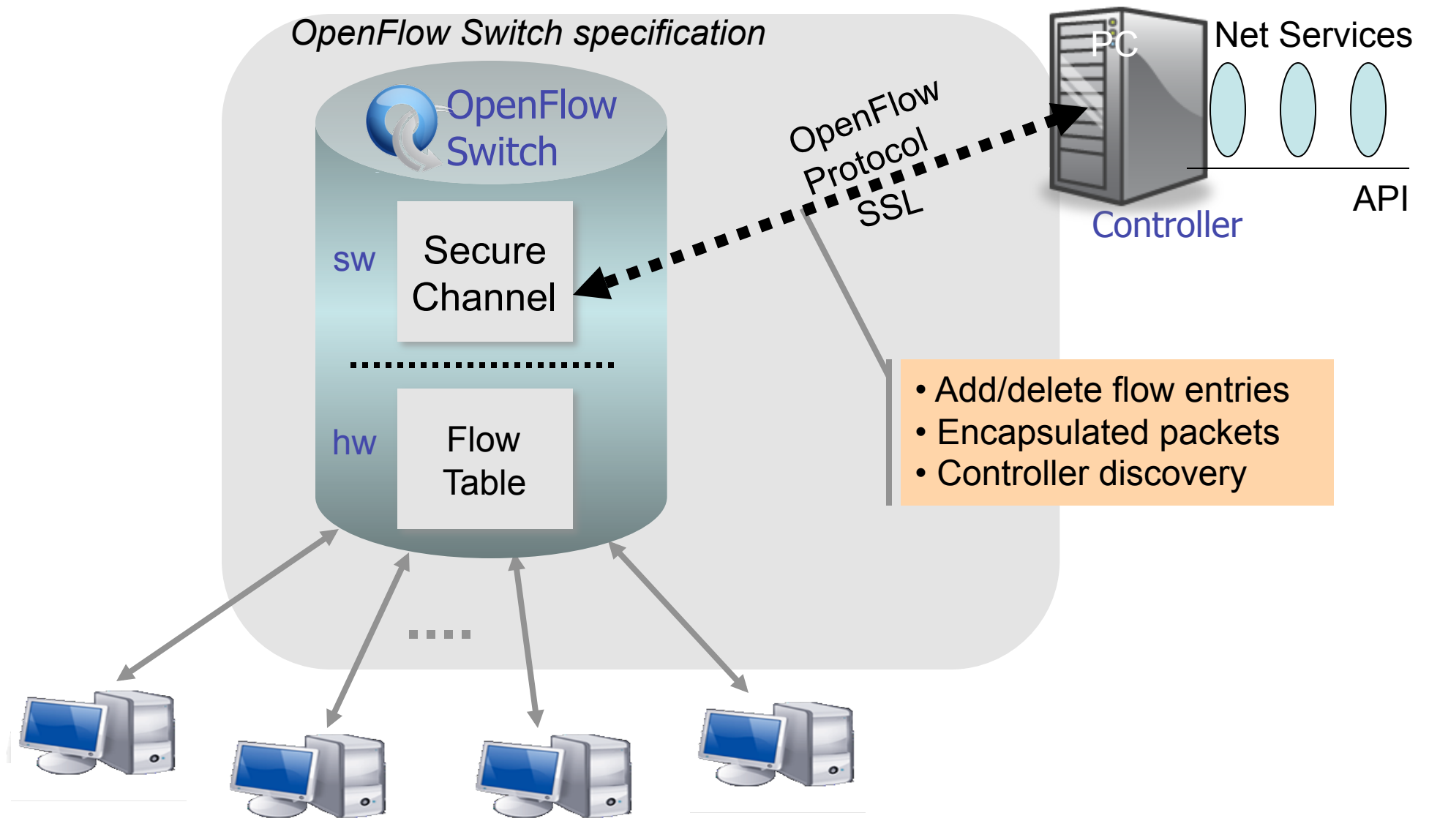
# Example Network Services

- ❖ Static "VLANs"
- ❖ New routing protocol: unicast, multicast, multipath, load-balancing
- ❖ Network access control
- ❖ Home network manager
- ❖ Mobility manager
- ❖ Energy manager
- ❖ Packet processor (in controller)
- ❖ IPvX
- ❖ Network measurement and visualization
- ❖ …
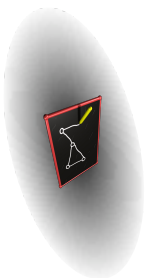
# Virtualized OpenFlow Substrate

# OpenFlow Deployment Model: Enterprsie and WAN Backbones
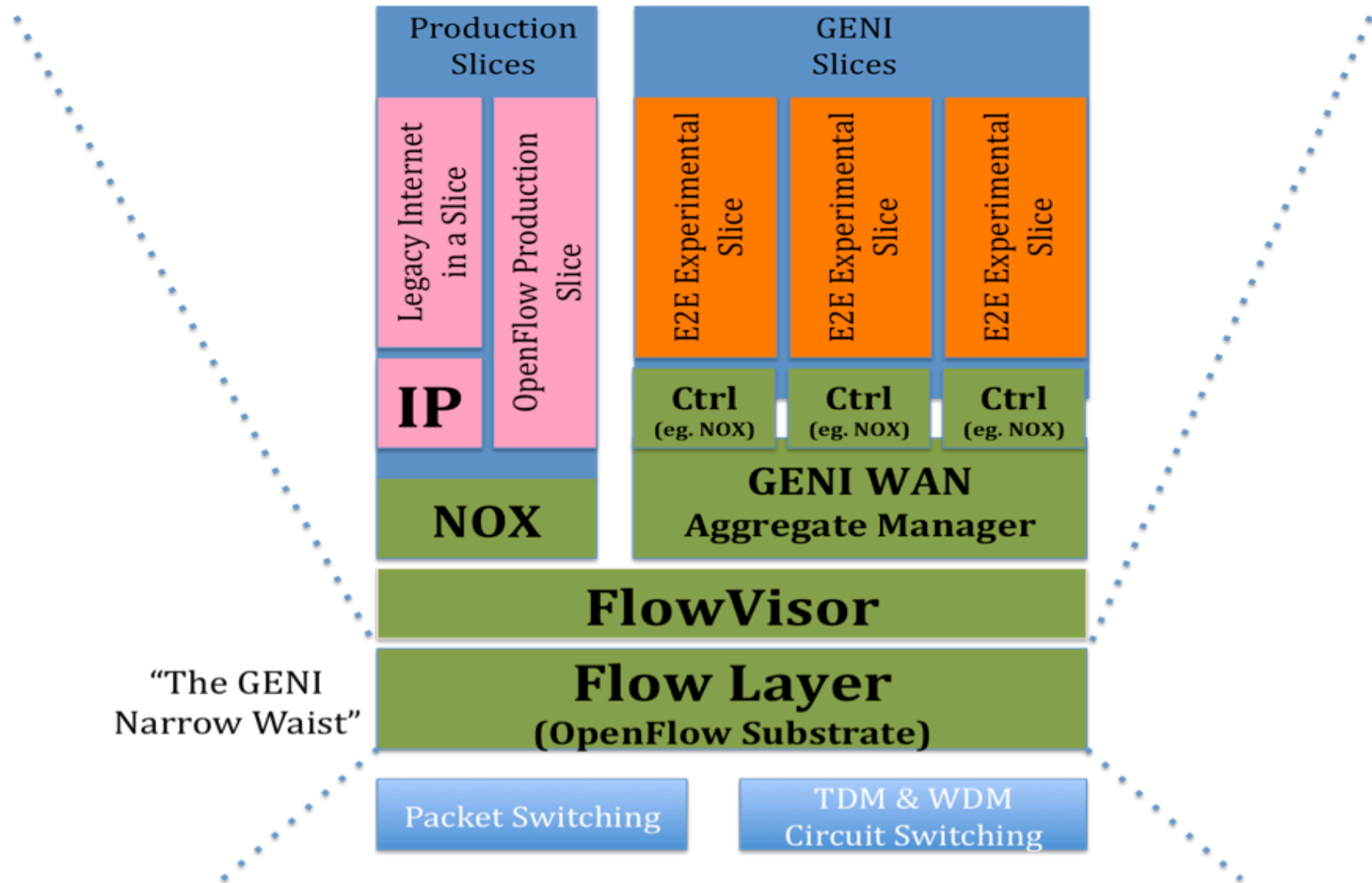
# OpenFlow Deployments

## Research and Production Deployments
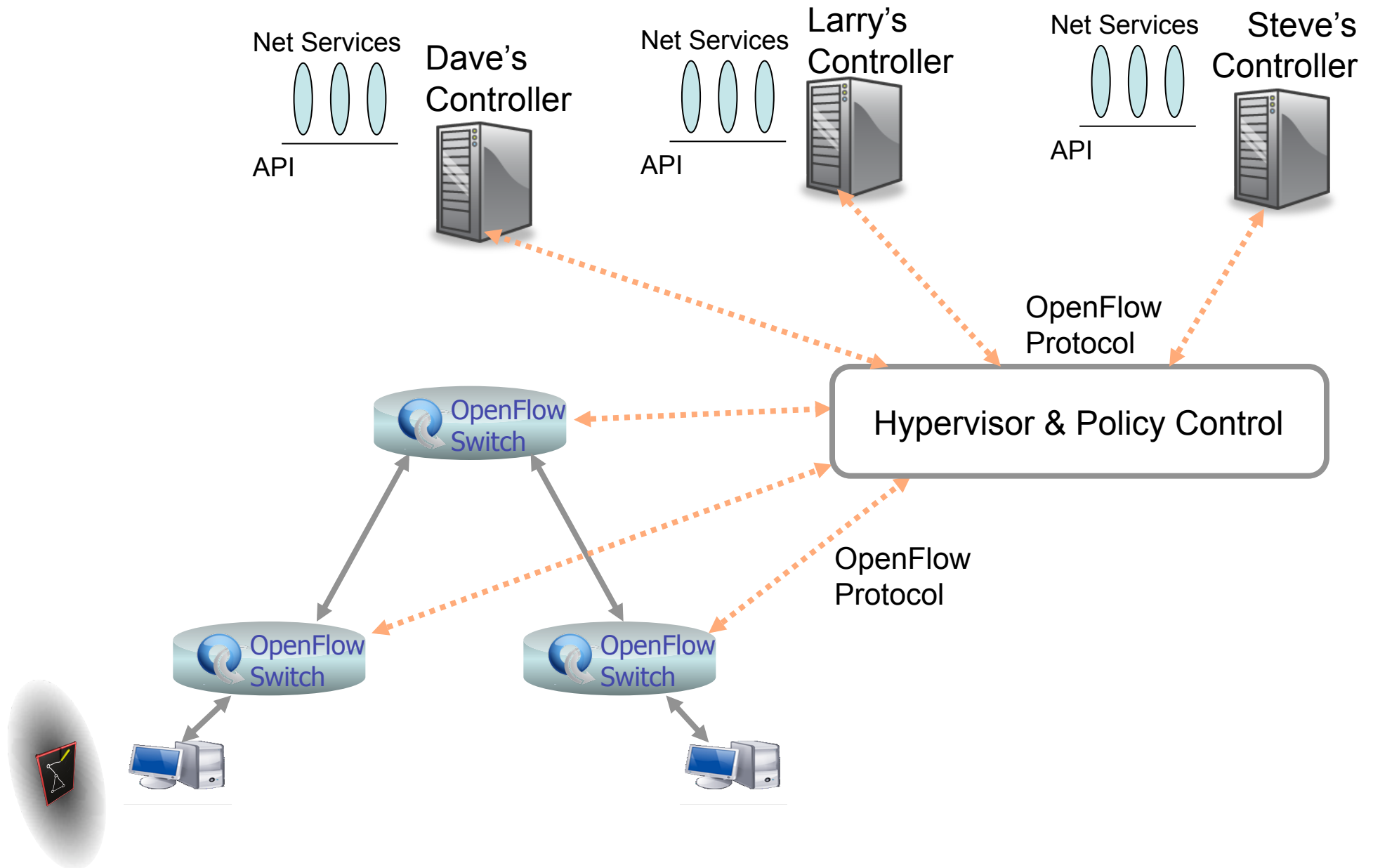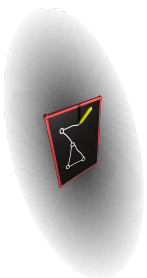## on commercial hardware
Juniper, HP, Cisco, NEC, (Quanta)

❖ Stanford Deployments
- Wired: CS Gates building, EE CIS building, EE Packard building (soon)
- WiFi: 100 OpenFlow APs across SoE
- WiMAX: OpenFlow service in SoE

❖ Other deployments
- Internet2
- JGN2plus, Japan
- 10-15 research groups have switches
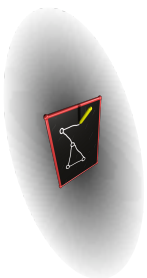
# Our Approach

1. Define the substrate
   - ✓ Define the OpenFlow feature
   - ✓ Add to commercial switches, routers, APs and basestations
2. Deploy on college campuses
3. Deploy in national networks
4. Deploy in enterprise networks

OpenFlow…
- ✓ Puts control into the hands of users, owners and applications
- ✓ Allows continued evolution of the network
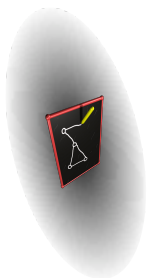
# Many Open Questions!

1. Scalability of a controller

2. Load-balancing over redundant controllers

3. Federation, hierarchy and aggregation

4. Protecting the controller against DDOS

5. …

Our goal is to enable the research community to explore all these questions

OpenFlowSwitch.org

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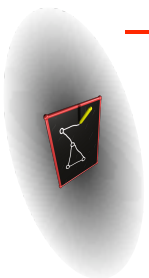
# OpenFlow: Architecture Concept

❖ Separate data from control

❖ Define a flow based data path
  – Very flexible and generalized flow abstraction
  – Delayer L1-L7

❖ Innovate with new network services in control plane
  – Give control of networks to providers, app developers, …
  – "Network capabilities as a service" model

❖ Unified control of circuit and packet networks

❖ Backward compatible
  – Easy to support in existing switches/routers and hosts
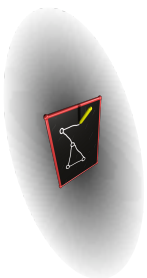
# Flow Table Entry
## OpenFlow Protocol

| Rule | Action | Stats |
|------|--------|-------|

**Packet + byte counters**

1. Forward packet to port(s)
2. Encapsulate and forward to controller
3. Drop packet
4. Send to normal processing pipeline

| Switch Port | MAC src | MAC dst | Eth type | VLAN ID | IP Src | IP Dst | IP Prot | TCP sport | TCP dport |
|-------------|---------|---------|----------|---------|--------|--------|---------|-----------|-----------|
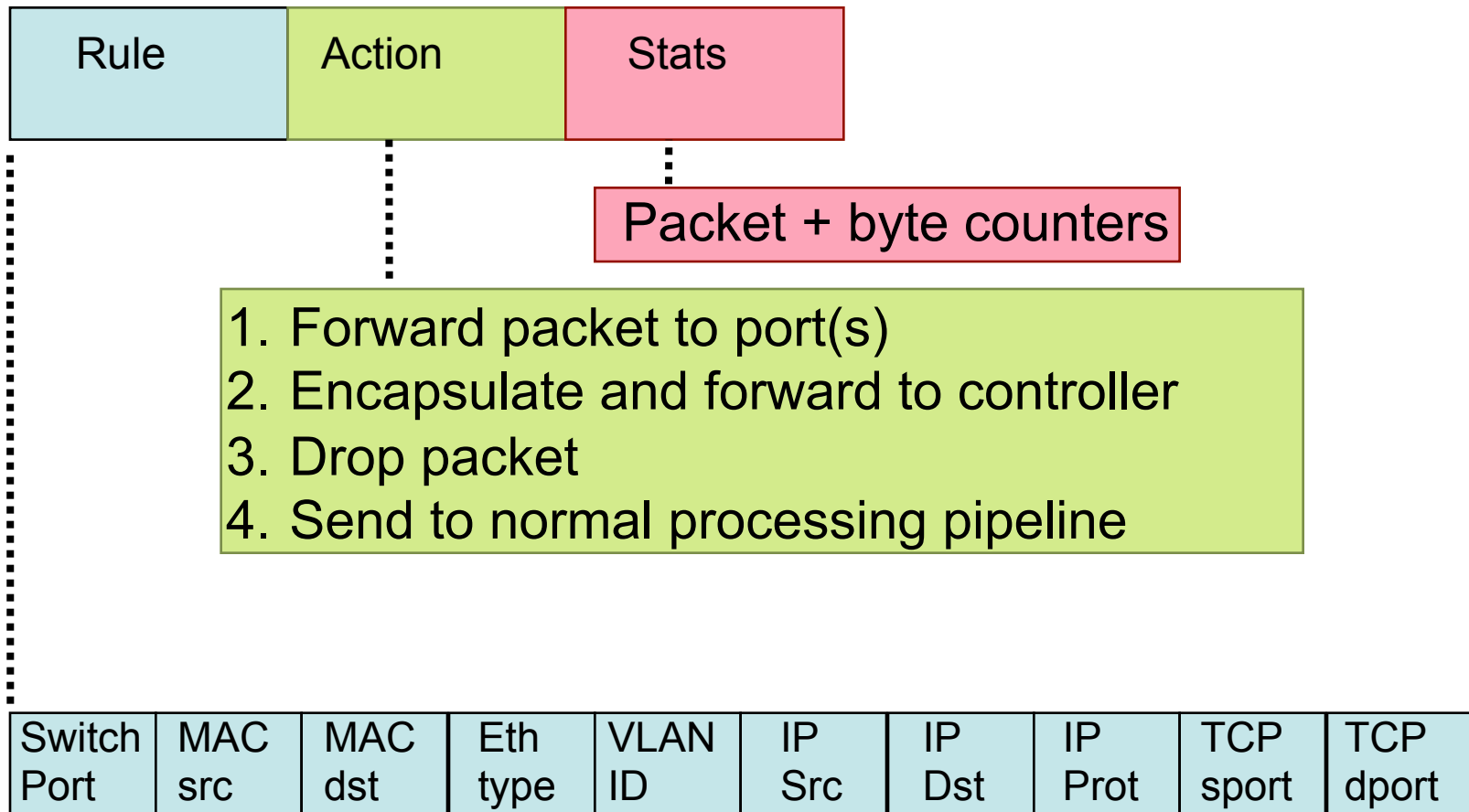
+ mask what fields to match
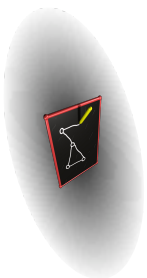
# Generalized Flexible Flow Definitions

Switching

| Switch Port | MAC src | MAC dst | Eth type | VLAN ID | IP Src | IP Dst | IP Prot | TCP sport | TCP dport | Action |
|---|---|---|---|---|---|---|---|---|---|---|
| * | * | 00:1f:.. | * | * | * | * | * | * | * | port6 |

Flow Switching

| Switch Port | MAC src | MAC dst | Eth type | VLAN ID | IP Src | IP Dst | IP Prot | TCP sport | TCP dport | Action |
|---|---|---|---|---|---|---|---|---|---|---|
| port3 | 00:2e.. | 00:1f.. | 0800 | vlan1 | 1.2.3.4 | 5.6.7.8 | 4 | 17264 | 80 | port6 |

Firewall

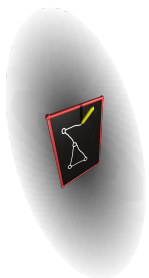| Switch Port | MAC src | MAC dst | Eth type | VLAN ID | IP Src | IP Dst | IP Prot | TCP sport | TCP dport | Forward |
|---|---|---|---|---|---|---|---|---|---|---|
| * | * | * | * | * | * | * | * | * | 22 | drop |
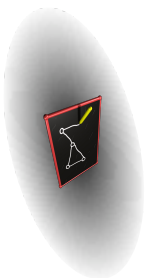
# Generalized Flexible Flow Definitions

Routing

| Switch Port | MAC src | MAC dst | Eth type | VLAN ID | IP Src | IP Dst | IP Prot | TCP sport | TCP dport | Action |
|---|---|---|---|---|---|---|---|---|---|---|
| * | * | * | * | * | * | 5.6.7.8 | * | * | * | port6 |

VLAN

| Switch Port | MAC src | MAC dst | Eth type | VLAN ID | IP Src | IP Dst | IP Prot | TCP sport | TCP dport | Action |
|---|---|---|---|---|---|---|---|---|---|---|
| * | * | * | * | vlan1 | * | * | * | * | * | port6, port7, port9 |

# OpenFlow and Circuit Switches

Packet Flows

| Switch Port | MAC src | MAC dst | Eth type | VLAN ID | IP Src | IP Dst | IP Prot | TCP sport | TCP dport | Action |
|---|---|---|---|---|---|---|---|---|---|---|

Exploit the cross-connect table in circuit switches

Circuit Flows

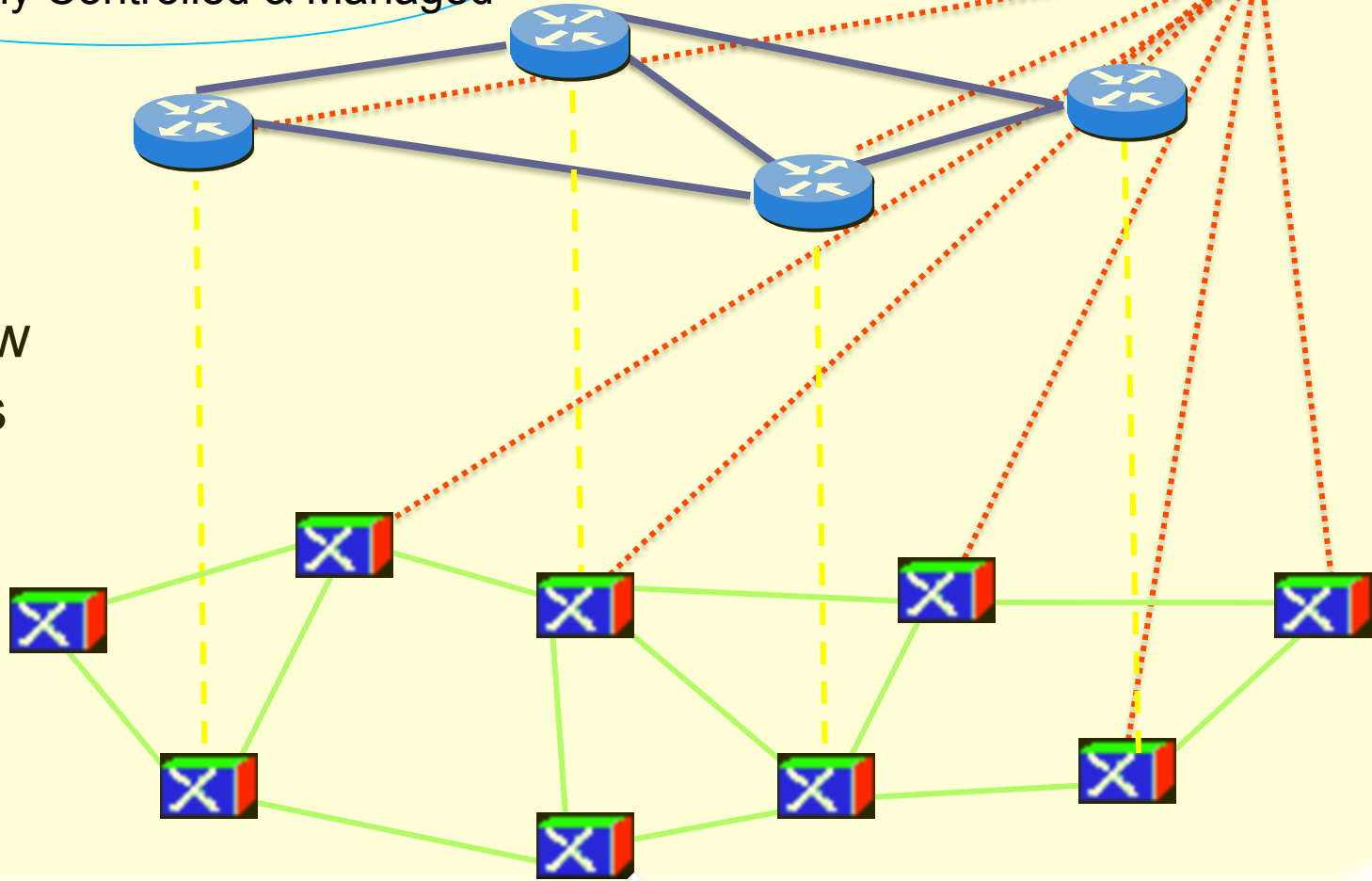| In Port | In Lambda | VCG | Starting Time-Slot | Signal Type | ⟷ | Out Port | Out Lambda | VCG | Starting Time-Slot | Signal Type |
|---|---|---|---|---|---|---|---|---|---|---|

# Flow abstraction applies to packet and circuits
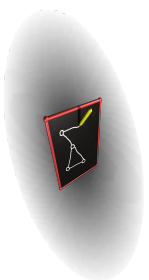
# Simple Unified Control Plane



Packet and Circuit Flows
Commonly Controlled & Managed

OpenFlow
Networks

… that switch at different granularities:  packet, time-slot, lambda & fiber

# OpenFlow: Old Concepts?

- ❖ Flow and separation of data and control
  - – Telephone nets, ATM, IntServe with RSVP, …
- ❖ Programmability and giving control to operators, app developers, users
  - – Active Networks, Programmable Networks
- ❖ Virtualization
  - – VPNs, Overlay Networks, Xbone, …
- ❖ Cross layer design
- ❖ Application level framing
- ❖ …

The Stanford Clean Slate Program                    http://cleanslate.stanford.edu
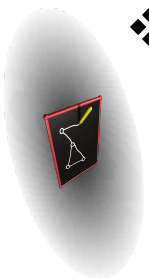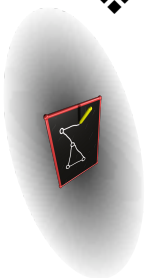
Carefully selected old concepts in a new context exploiting technology trends can be very powerful.
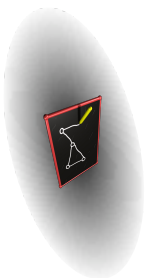
# Old Concepts New Context

- ❖ **Emphasis on enabling innovations**
  - – Different from many other architectures
  - – Allow choices and create a market place of ideas
- ❖ **Generalized definition of flow**
  - – Exploiting state of the art hardware capabilities
  - – L1-L7 de-layering
- ❖ **Centralization of control with servers/data centers**
  - – Programmability in server context for control path
  - – "Network capabilities as a service" model – not part of infrastructure
  - E.g., Routing, Mobility Management, Access Control, …
- ❖ **Virtualization of data and control paths**
- ❖ **Bring significant change with backward compatibility**

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  – Internet will look very different in five to ten years

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