The Past, Present, and Future of Software Defined Networking

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BISmark

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What if we could change the *network* as easily as applications?

TCP/IP Header in Lego Format.

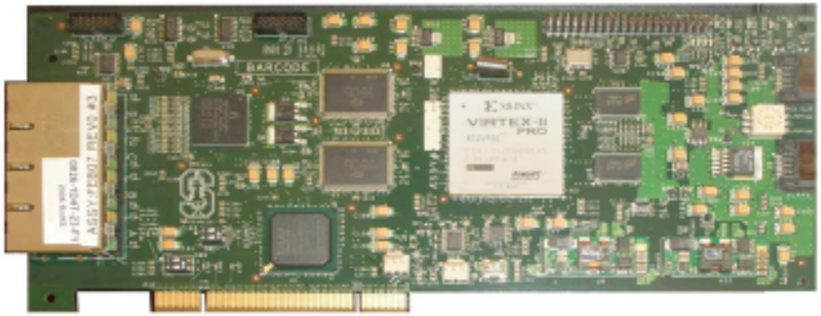
Now, We Can: Software-Defined Networking

- **Before:** Network devices closed, proprietary

- **Now:** A single software program can control the behavior of entire networks.

OpenFlow

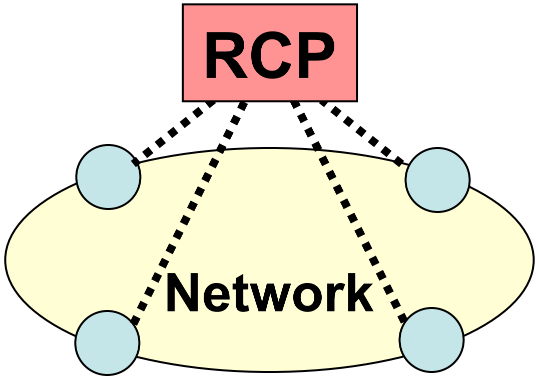
geni
Exploring Networks
of the Future



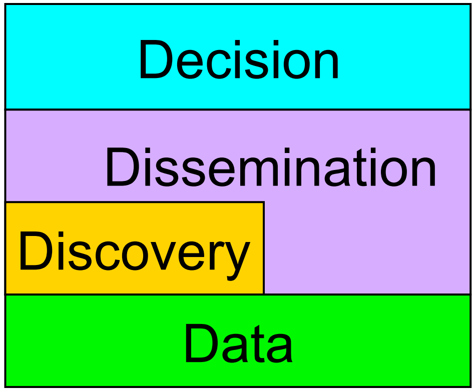
Software-Defined Networking

- Distributed configuration is a bad idea
- **Instead:** *Control* the network from a logically centralized system

2004



2005

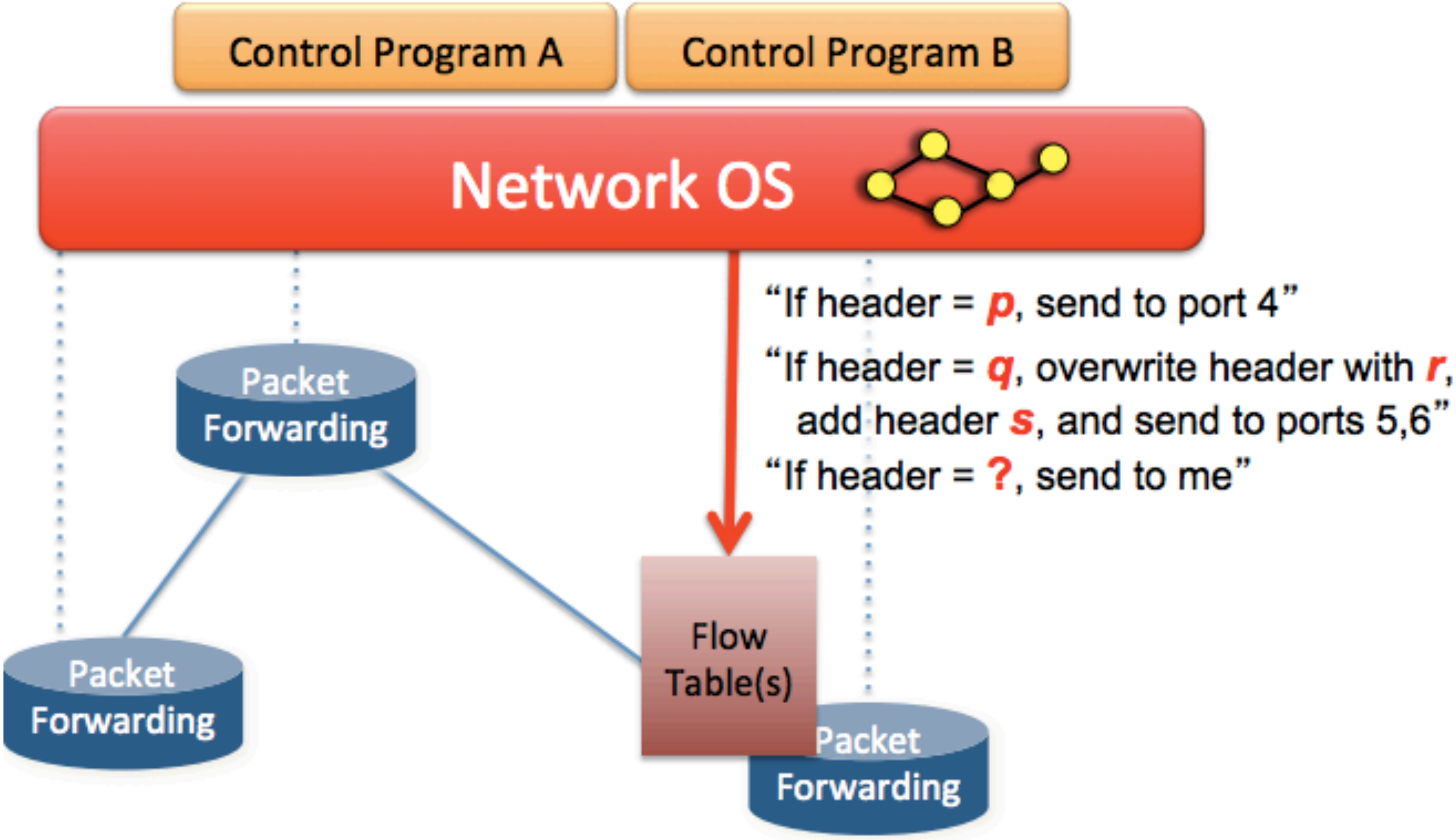


2008

OpenFlow

Feamster *et al*. The Case for Separating Routing from Routers. *Proc. SIGCOMM FDNA*, 2004
Caesar *et al.* Design and implementation of a Routing Control Platform. *Proc NSDI*, 2005

SDN Forwarding Abstraction



Control Program A

Control Program B

Network OS

Packet Forwarding

Packet Forwarding

Flow Table(s)

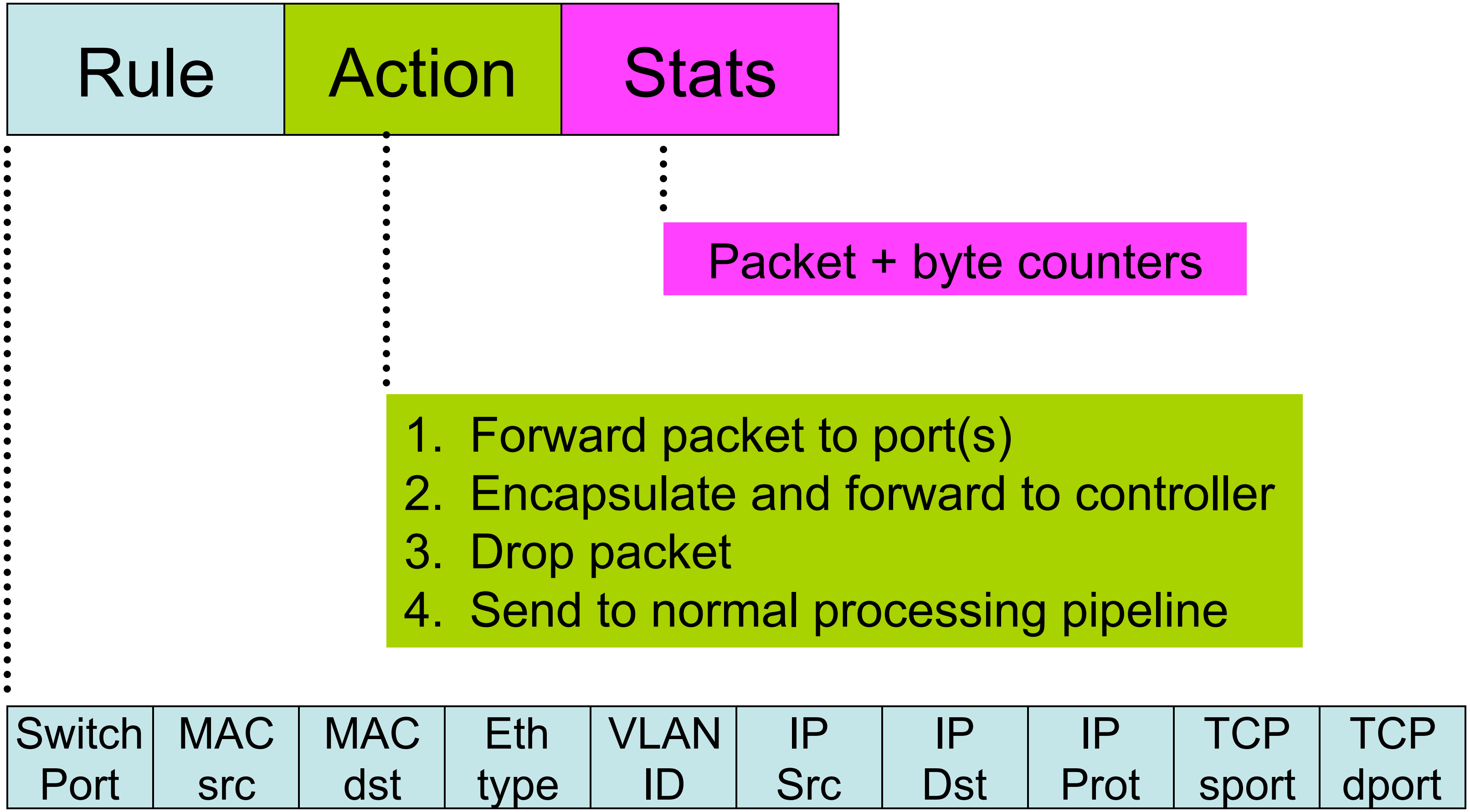
Packet Forwarding

"If header = *p*, send to port 4"

"If header = *q*, overwrite header with *r*, add header *s*, and send to ports 5,6"

"If header = ?, send to me"

OpenFlow 1.0 Flow Table Entry



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

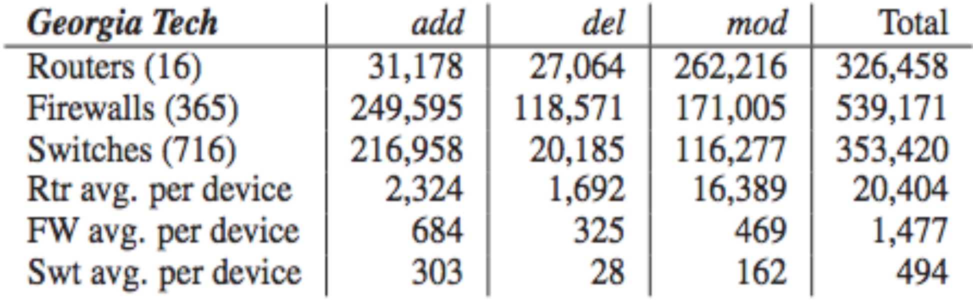
Software Defined Network *Management*

- Software defined networking (SDN) makes it easier for network operators to evolve network capabilities

- Can SDN also help network operators manage their networks, once they are deployed?
  - Home networks
  - Campus/Enterprise networks

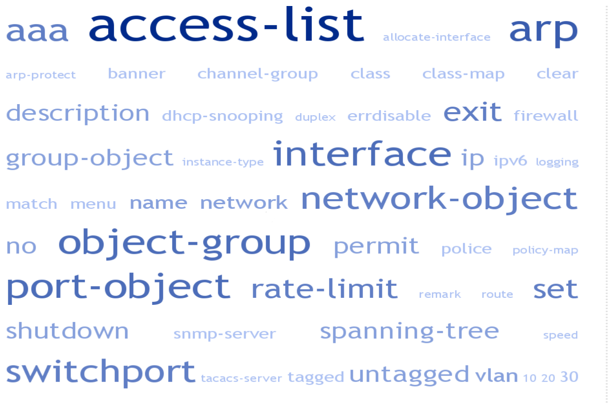
Big Problem: Configuration Changes Frequently

- Changes to the network configuration occur daily
  - **Errors are also frequent**



Georgia Tech	*add*	*del*	*mod*	Total
Routers (16)	31,178	27,064	262,216	326,458
Firewalls (365)	249,595	118,571	171,005	539,171
Switches (716)	216,958	20,185	116,277	353,420
Rtr avg. per device	2,324	1,692	16,389	20,404
FW avg. per device	684	325	469	1,477
Swt avg. per device	303	28	162	494

- Operators must determine
  - **What will happen** in response to a configuration change
  - Whether the configuration is **correct**

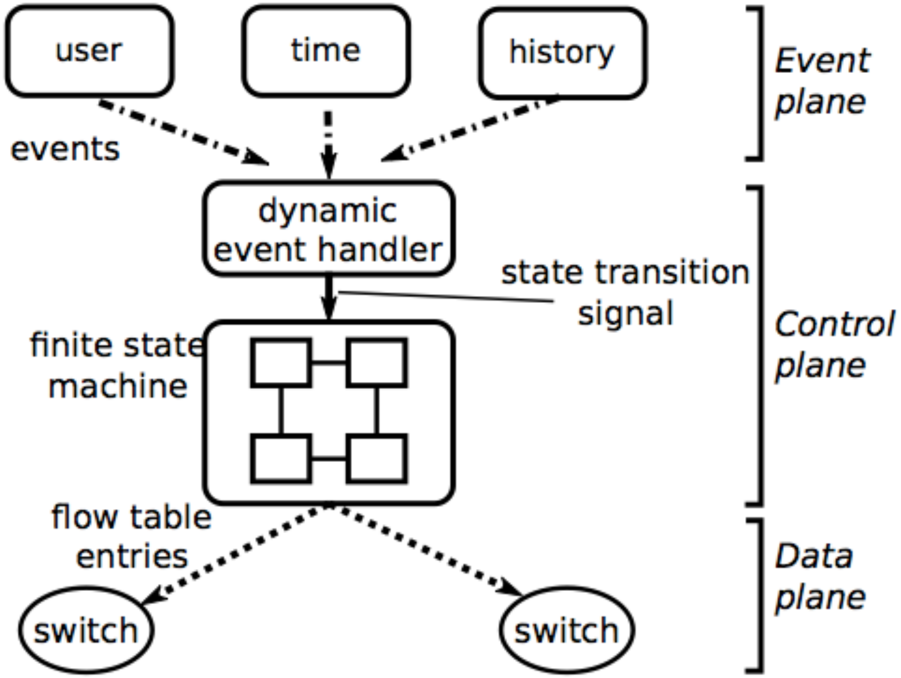


But, Network Configuration is Really Just Event Processing!

- Rate limit all Bittorrent traffic between the hours of 9 a.m. and 5 p.m.
- Do not use more than 100 GB of my monthly allocation for Netflix traffic
- If a host becomes infected, re-direct it to a captive portal with software patches
- …

Lithium: Event-Based Network Control

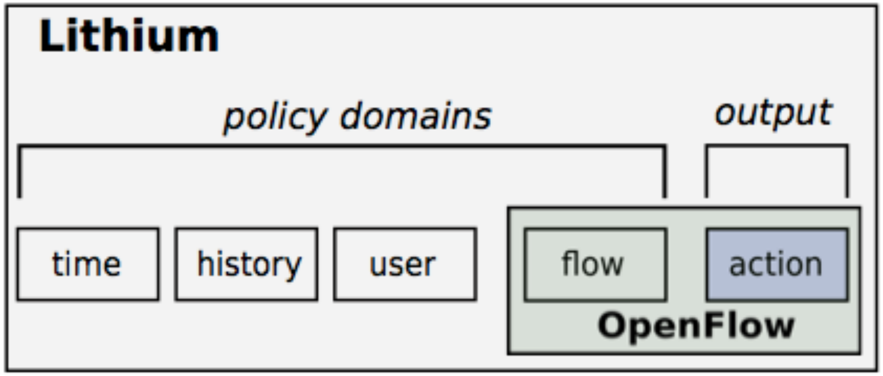
Main Idea: Express network policies as event-based programs.

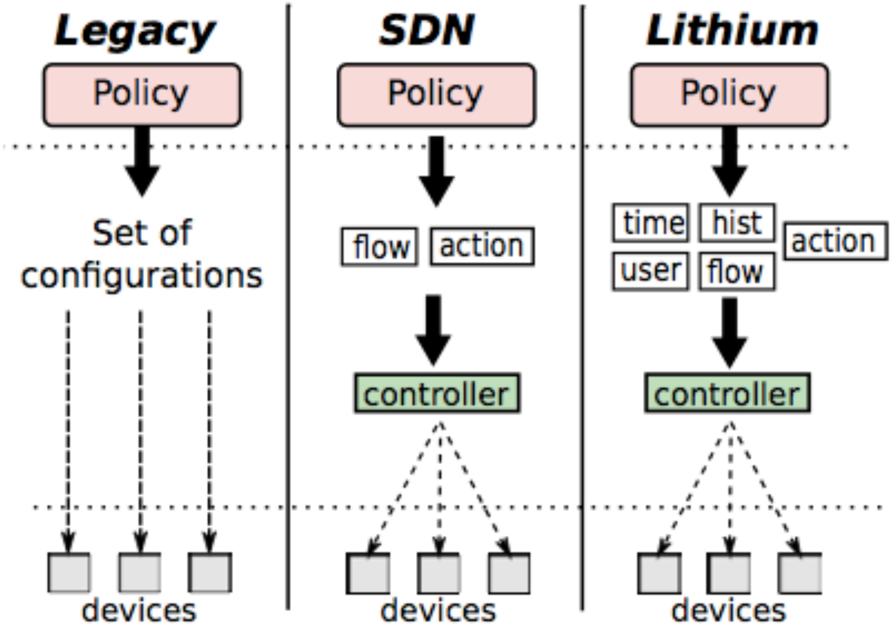


Resonance: Inference-Based Access Control for Enterprise Networks. Nayak, Reimers, Feamster, Clark. *ACM SIGCOMM Workshop on Enterprise Networks*. August 2009.

Extending the Control Model

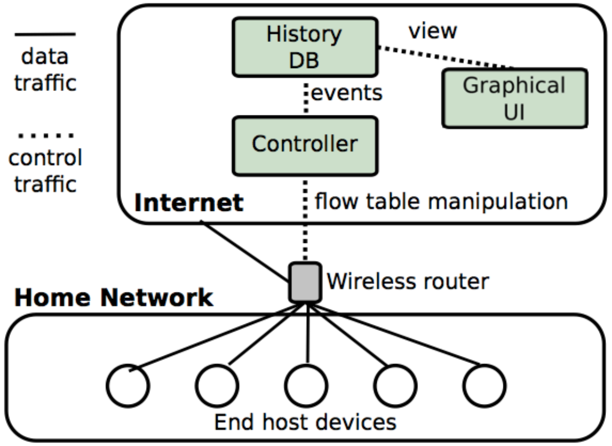
- OpenFlow only operates on flow properties
- Lithium **extends the control model** so that actions can be taken on **time**, **history**, and **user**

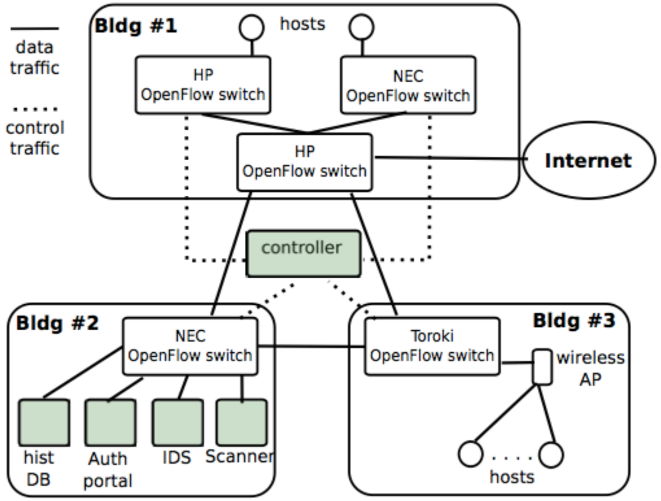




Two Real-World Deployments

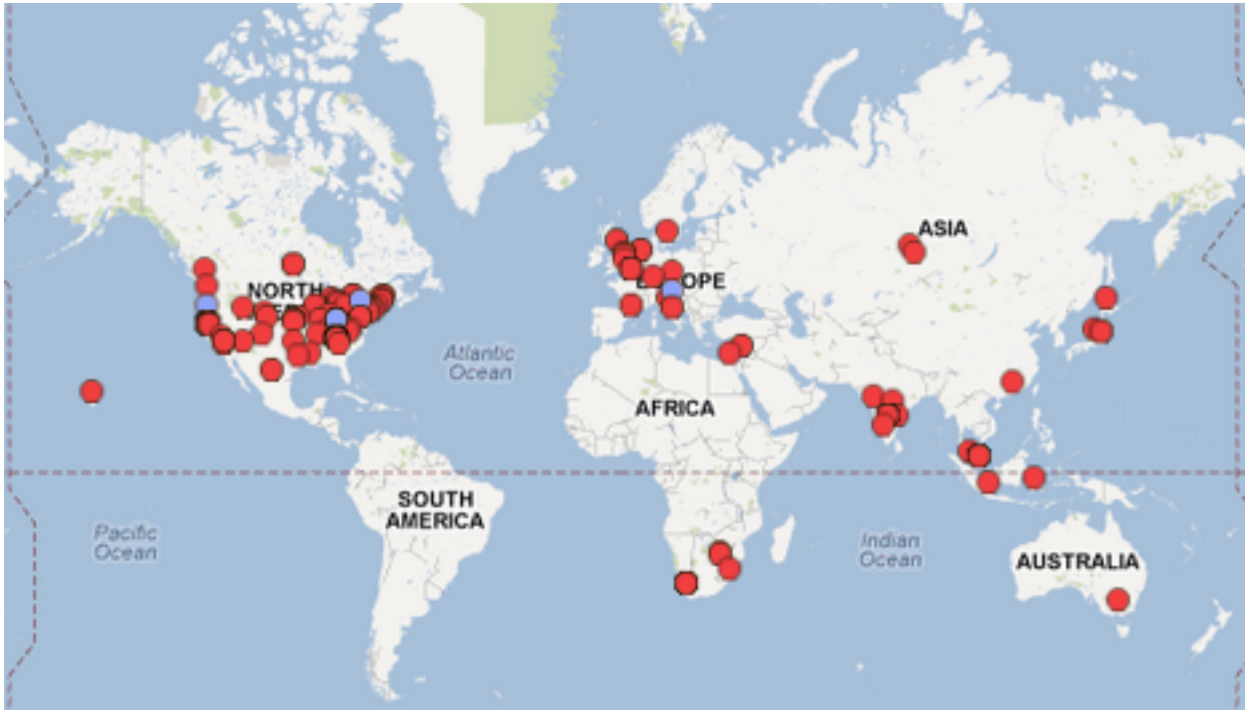
- **Usage control in home networks**
  - Implementation of user controls (e.g., usage cap management, parental controls) in home networks
  - **Today:** Not possible
  - **With SDN:** Intuitive, simple
- **Access control in enterprise networks**
  - Re-implementation of access control on the Georgia Tech campus network
  - **Today:** Complicated, low-level
  - **With SDN:** Simpler, more flexible





Frontier #1: SDN @ Home

- Better monitoring and management of home and access networks
- **Deployment:** 225 Routers in ~30 countries



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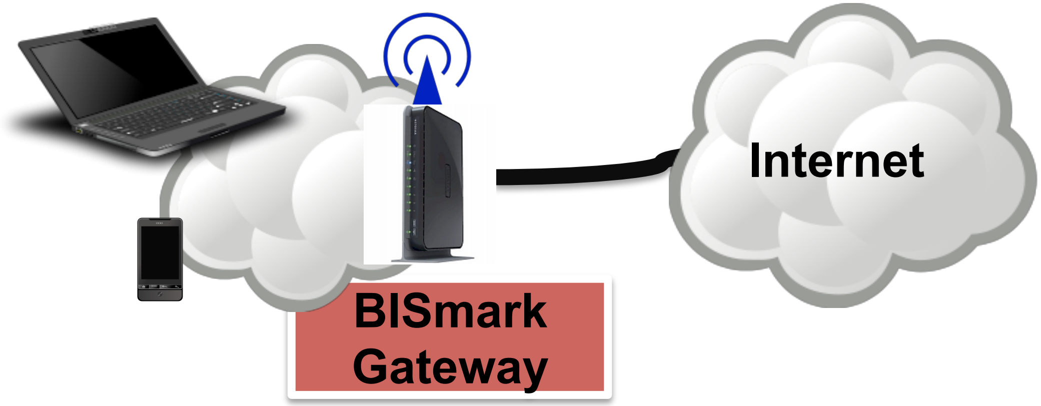
Vision: Better Home Networks

- **Monitoring and Measurement**
  - ISP performance
  - Wireless characteristics and interference
  - Traffic use inside the home
  - Security
  - Human activity patterns

- **Control (with Software Defined Networking)**
  - Usage cap management (ongoing w/HCI researchers)
  - Traffic prioritization (e.g., ensure file sharing does not clobber critical traffic)
  - Parental controls

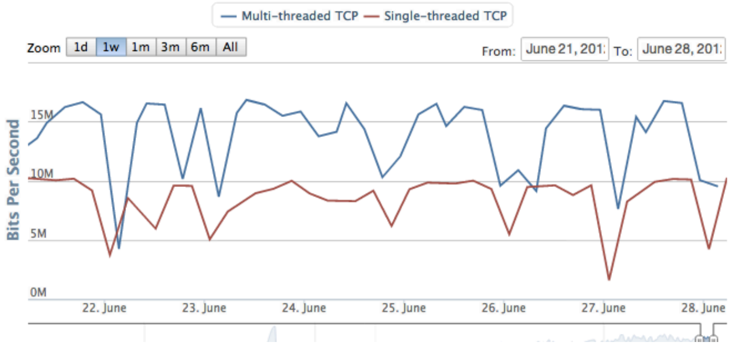
Better Visibility & Control



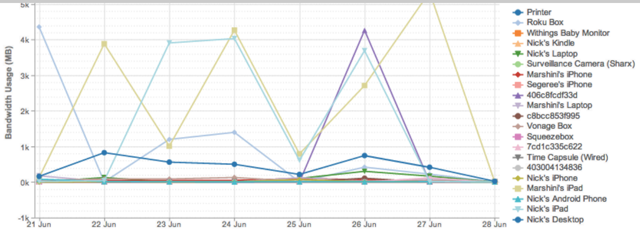
- Better visibility: Continuous performance monitoring
  - Network and application-level monitoring

- Better control: SDN
  - Control applications with simple programs and interfaces

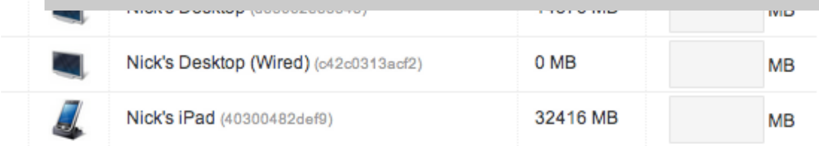
What is the network performance?



How do users use apps and devices?



Can we manage resource allocation ?



Nick's Desktop (Wired) (c42c0313acf2)	0 MB		MB
Nick's iPad (40300482def9)	32416 MB		MB

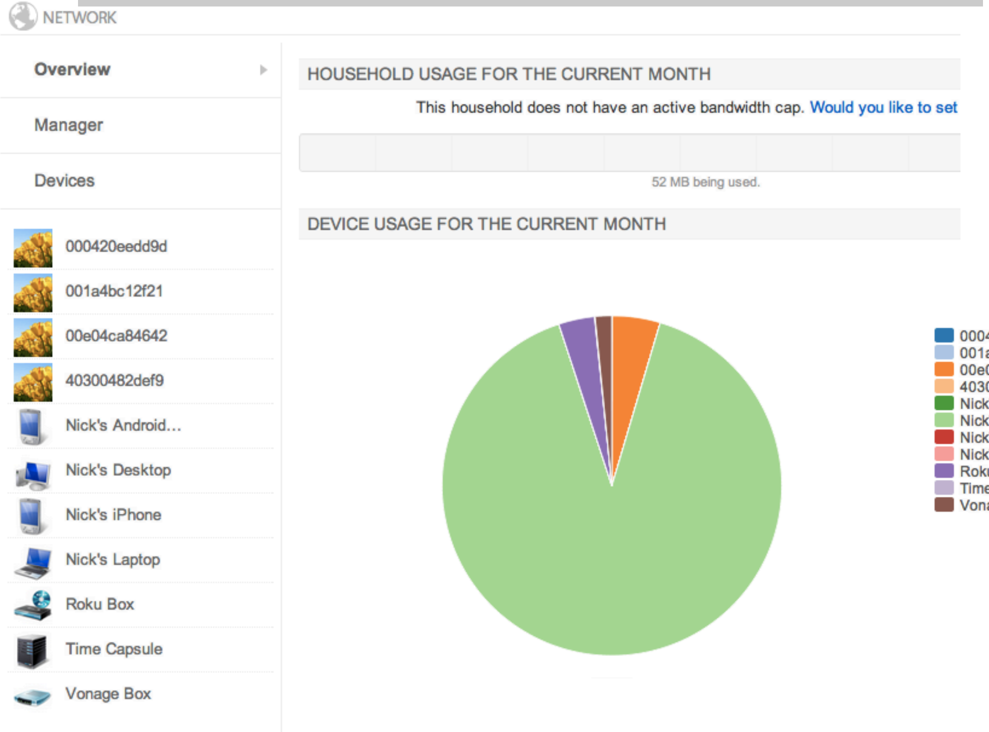
Usage Control in Home Networks

- Network management in homes is challenging
- One aspect of management: **usage control**
  - Usage cap management
  - Parental control
  - Bandwidth management

- **Idea:** Outsource network management/control
  - Home router runs OpenFlow switch
  - Usage reported to off-site controller
  - Controller adjusts behavior of traffic flows

Control: SDN + Intuitive Interfaces

Real-Time Monitoring and Control



NETWORK

- Overview
- Manager
- Devices
- 000420eedd9d
- 001a4bc12f21
- 00e04ca84642
- 40300482def9
- Nick's Android...
- Nick's Desktop
- Nick's iPhone
- Nick's Laptop
- Roku Box
- Time Capsule
- Vonage Box

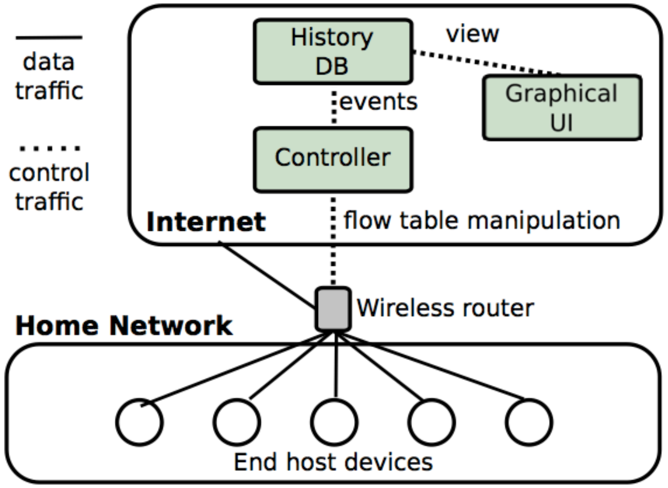
HOUSEHOLD USAGE FOR THE CURRENT MONTH

This household does not have an active bandwidth cap. Would you like to set

52 MB being used.

DEVICE USAGE FOR THE CURRENT MONTH

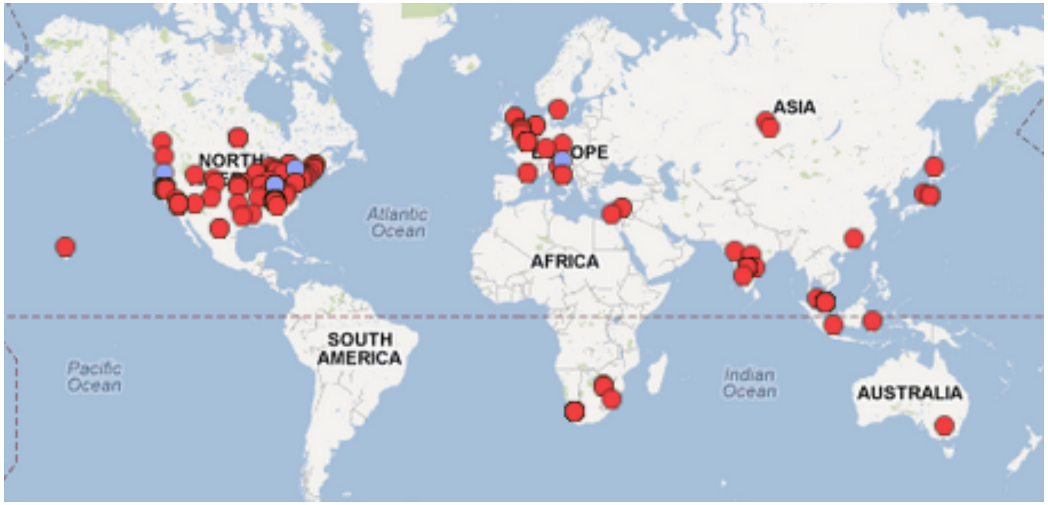
- 🟦 000420eedd9d
- 🟦 001a4bc12f21
- 🟧 00e04ca84642
- 🟧 40300482def9
- 🟩 Nick's Android Phone
- 🟩 Nick's Desktop
- 🟥 Nick's iPhone
- 🟥 Nick's Laptop
- 🟪 Roku Box
- 🟪 Time Capsule
- 🟫 Vonage Box



Joint work with Boris de Souza, Bethany Sumner, Marshini Chetty.

Deployment Status

- Over 225 routers deployed in home networks “in the wild”
- Collaboration with Measurement Lab on monitoring network performance from various regions and ISPs.
- Ongoing trials with several ISPs as part of private deployments



- Firmware
  - OpenWrt, with luci web interface
  - IPv6-capable
- Netgear 3800 router
  - Atheros chipset
  - MIPS processor, 16 MB flash, 64 MB RAM
  - Gigabit ethernet
  - 2.4 GHz *and* 5 GHz radio

Ongoing Extensions

- **More measurements:** Denser deployments (e.g., apartments)
- **Broader scope:** More measurements (e.g., integration with Tor’s OONI project)
- **Sensor fusion:** Tighter integration with other in-home, *in situ* sensing capabilities (e.g., phones)
- **Open programming interface:** Enable other researchers to perform measurements

Frontier #2: Policy Language

- Network policies
  - Are **dynamic**
  - Depend on **temporal conditions** defined in terms of external events

- Need a way to configure these policies **without resorting to general-purpose programming** of a network controller

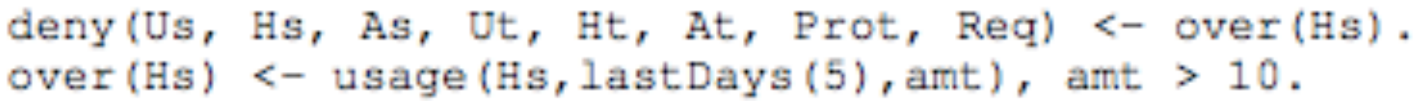
- Intuitive user interfaces can ultimately be built on top of this language

Language Design Goals

- **Declarative Reactivity:** Describing when events happen, what changes they trigger, and how permissions change over time.
- **Expressive and Compositional Operators:** Building reactive permissions out of smaller re-active components.
- **Well-defined Semantics:** Simple semantics, simplifying policy specification.
- **Error Checking & Conflict Resolution:** Leveraging well-defined, mathematical semantics.

The Need for Reactive Control

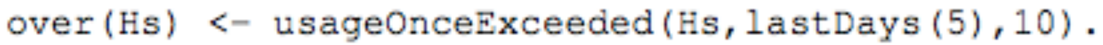
- Simple policies are doable in FML: “Ban the device if usage exceeds 10 GB in the last 5 days”



```
deny(Us, Hs, As, Ut, Ht, At, Prot, Req) <- over(Hs).
over(Hs) <- usage(Hs,lastDays(5),amt), amt > 10.
```

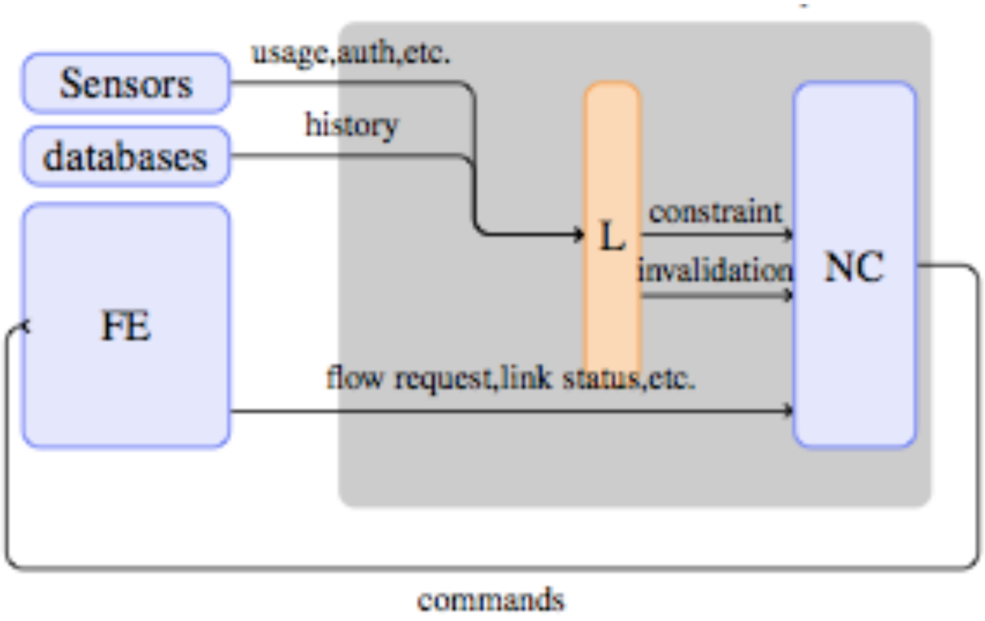
- But, adding **temporal predicates** is difficult!
  - “Remove the ban if usage drops below 10 GB.”
  - “Remove the ban when an administrator resets.”

- Each condition requires a new predicate.

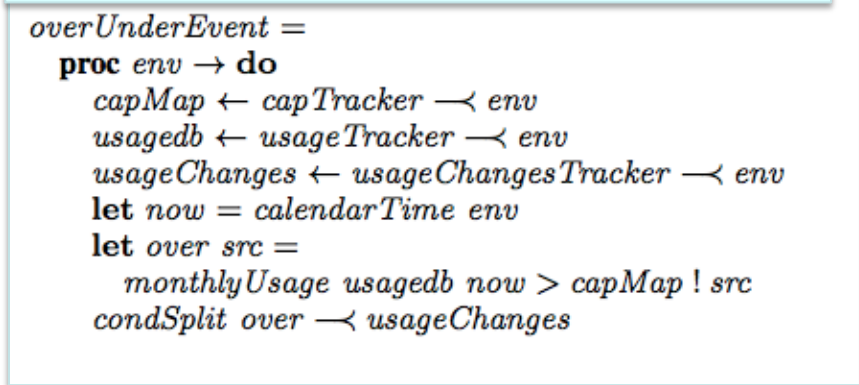


```
over(Hs) <- usageOnceExceeded(Hs,lastDays(5),10).
```

Procera: Programming Reactive, Event-Based Network Control

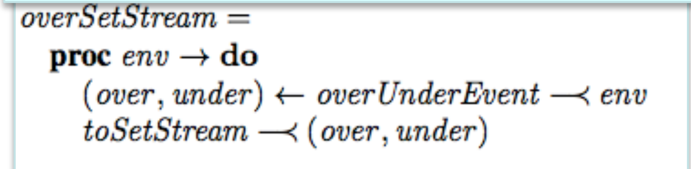


Define a signal function for a device going over (or under) the usage cap:



```
overUnderEvent =
  proc env → do
    capMap ← capTracker ⤙ env
    usagedb ← usageTracker ⤙ env
    usageChanges ← usageChangesTracker ⤙ env
    let now = calendarTime env
    let over src =
      monthlyUsage usagedb now > capMap ! src
    condSplit over ⤙ usageChanges
```

Define the set of devices over the cap:

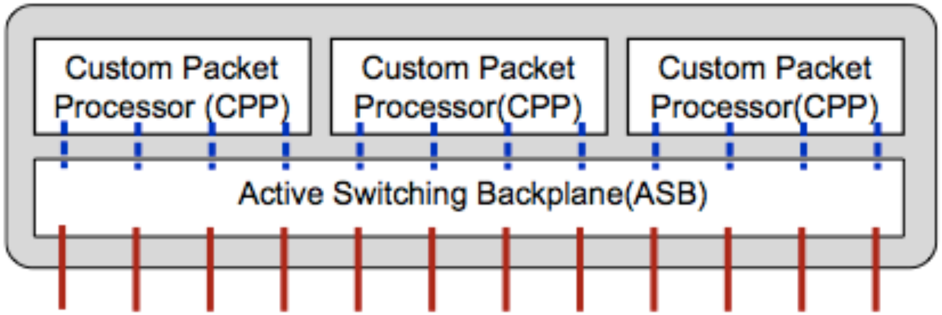


```
overSetStream =
  proc env → do
    (over, under) ← overUnderEvent ⤙ env
    toSetStream ⤙ (over, under)
```

- **Controller:** signal functions and a flow constraint function
- Receives **input signals** from environment
- Periodically updates a **flow constraint function** that controls the forwarding elements

Frontier #3: Custom Packet Processing

- Augment OpenFlow switches with **custom packet processors**
- **Device abstraction layer** to allow programmability of this substrate
  - Single device
  - Network wide
- **Applications**
  - Big data applications
  - On-the fly encryption, transcoding, classification
  - Selective deep packet inspection


Custom Packet Processor (CPP)
Custom Packet Processor(CPP)
Custom Packet Processor(CPP)
Active Switching Backplane(ASB)

Summary

- Software Defined Networking can simplify network monitoring and management, but we still need new control models.

- **Lithium:** Event-based network control
  - Deployment in two real-world settings

- Three frontiers
  - SDN at Home
  - Policy languages for SDN
  - Custom Packet Processing for SDN

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