Software Routers: Click

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Slides used and adapted judiciously from COS-561, Advanced Computer Networks
At Princeton University

Goals for Today

- The Click Modular Router
  - E. Kohler, R. Morris, B. Chen, and M. F. Kaashoek. ACM Symposium on Operating Systems Principles (SOSP), December 1999, pages 217-23.

Click Motivation

- Flexibility
  - Add new features
  - Enable experimentation
- Openness
  - Allow users/researchers to build and extend
  - (In contrast to most commercial routers)
- Modularity
  - Simplify the composition of existing features
  - Simplify the addition of new features
- Speed/efficiency
  - Operation (optionally) in the operating system
  - Without the user needing to grapple with OS internals

Router as a Graph of Elements

- Large number of small elements
  - Each performing a simple packet function
  - E.g., IP look-up, TTL decrement, buffering
- Connected together in a graph
  - Elements inputs/outputs snapped together
  - Beyond elements in series to a graph
  - E.g., packet duplication or classification
- Packet flow as main organizational primitive
  - Consistent with data-plane operations on a router
  - (Larger elements needed for, say, control planes)

Click Elements: Push vs. Pull

- Packet hand-off between elements
  - Directly inspired by properties of routers
  - Annotations on packets to carry temporary state
- Push processing
  - Initiated by the source end
  - E.g., when an unsolicited packet arrives (e.g., from a device)
- Pull processing
  - Initiated by the destination end
  - E.g., to control timing of packet processing (e.g., based on a timer or packet scheduler)

Click Language

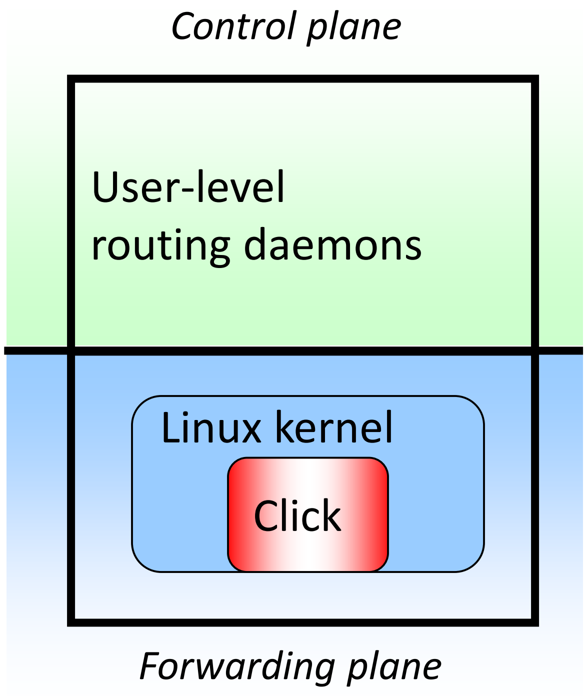
- Declarations
  - Create elements
- Connections
  - Connect elements

```
src :: FromDevice(eth0);
ctr :: Counter;
sink :: Discard;

src -> ctr;
ctr -> sink;
```

- Compound elements
  - Combine multiple smaller elements, and treat as single, new element to use as a primitive class
- Language extensions through element classes
  - Configuration strings for individual elements
  - Rather than syntactic extensions to the language

Modular software forwarding plane: Click modular router

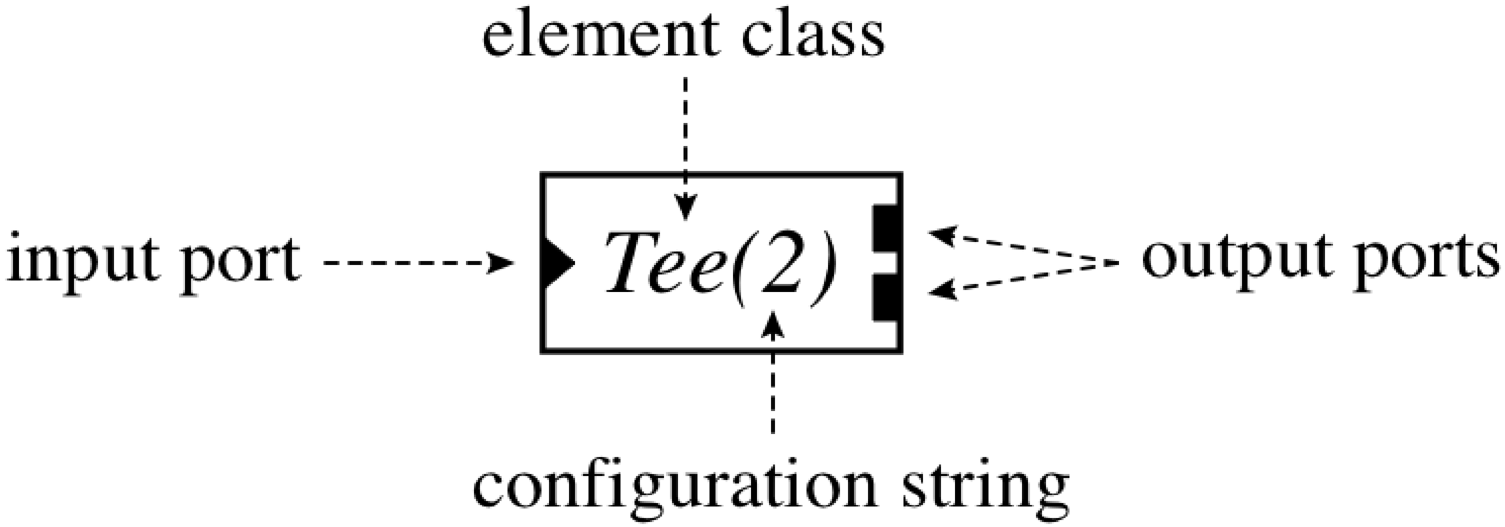


- Elements
  - Small building blocks, performing simple operations
  - Instances of C++ classes
- Packets traverse a directed graph of elements

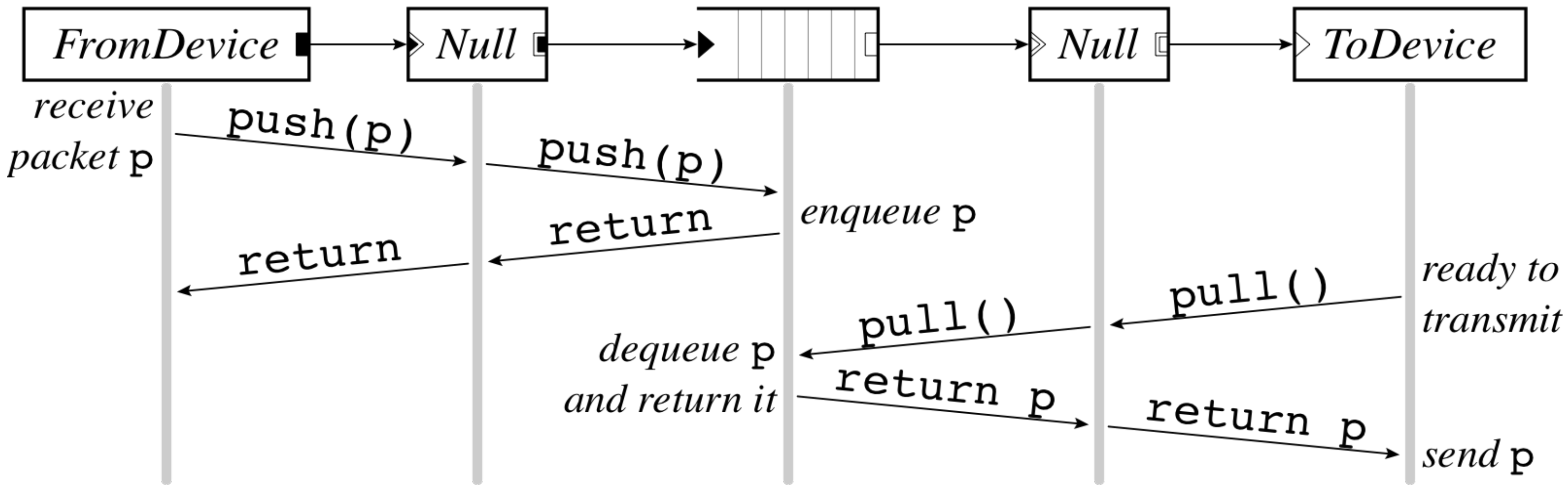
```
FromDevice(eth0)->CheckIPHeader(14)
 ->IPPrint->Discard;
```

•Kohler, E., Morris, R., Chen, B., Jannotti, J., Kaashoek, M. F., *The click modular router*, ACM Trans. Comput. Syst. 18, 3 (Aug. 2000)
•Andrea Bianco, Robert Birke, Davide Bolognesi, Jorge M. Finochietto, Giulio Galante, Marco Mellia, *Click vs. Linux: Two Efficient Open-Source IP Network Stacks for Software Routers,* HPSR 2005

Elements

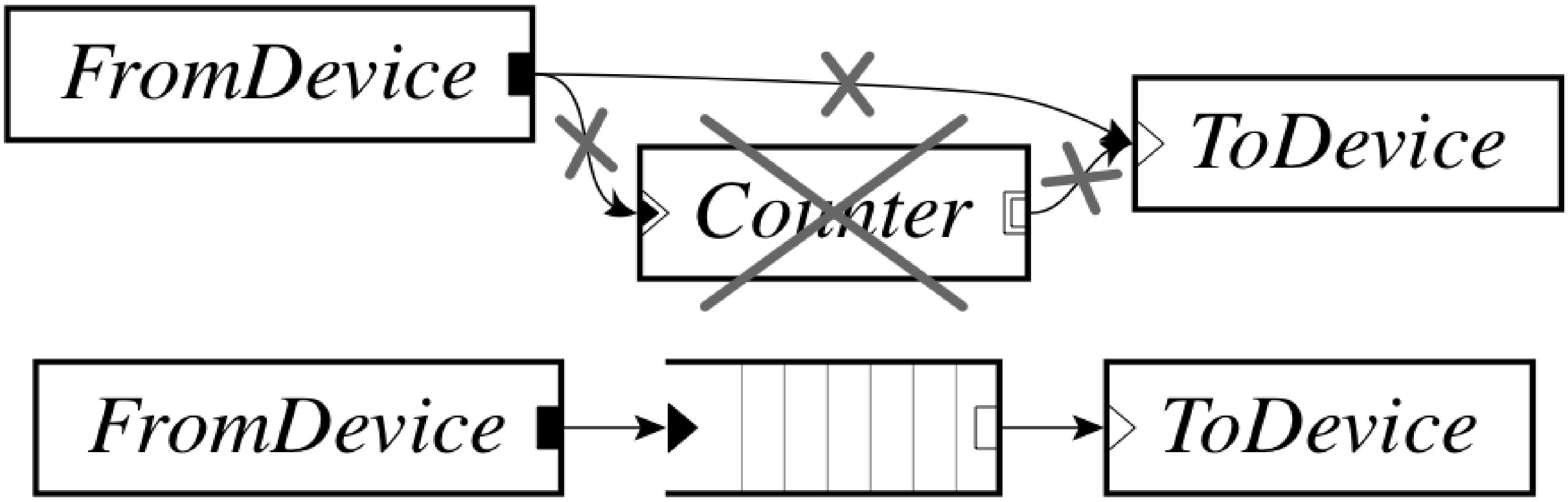

element class
input port
Tee(2)
output ports
configuration string

Push and Pull



- Push connection
  - Source pushes packets downstream
  - Triggered by event, such as packet arrival
  - Denoted by filled square or triangle
- Pull connection
  - Destination pulls packets from upstream
  - Packet transmission or scheduling
  - Denoted by empty square or triangle
- Agnostic connection
  - Becomes push or pull depending on peer
  - Denoted by double outline

Push and pull violations



Handlers and Control Socket

- Access points for user interaction
  - Appear like files in a file system
  - Can have both read and write handlers
- Examples
  - Installing/removing forwarding-table entries
  - Reporting measurement statistics
  - Changing a maximum queue length
- Control socket
  - Allows other programs to call read/write handlers
  - Command sent as single line of text to the server
  - http://read.cs.ucla.edu/click/elements/controlsocket?s=llrpc

Example: EtherSwitch Element

- Ethernet switch
  - Expects and produces Ethernet frames
  - Each input/output pair of ports is a LAN
  - Learning and forwarding switch among these LANs
- Element properties
  - Ports: any # of inputs, and same # of outputs
  - Processing: push
- Element handlers
  - Table (read-only): returns port association table
  - Timeout (read/write): returns/sets TIMEOUT

http://read.cs.ucla.edu/click/elements/etherswitch

Implicit vs explicit queues

Implicit queue
- Used by STREAM, Scout, etc.
- Hard to control

Explicit queue
- Led to push and pull, Click's main idea
- Contributes to high performance

An Observation…

- Click is widely used
  – And the paper on Click is widely cited
- Click elements are created by others
  – Enabling an ecosystem of innovation

- Take-away lesson
  – Creating useful systems that others can use and extend has big impact in the research community
  – And brings tremendous professional value
  – Compensating amply for the time and energy ☺

Improving software router performance: exploiting parallelism

- Can you build a Tbps router out of PCs running Click?
  - Not quite, but you can get close
- RouteBricks: high-end software router
  - Parallelism across servers and cores
  - High-end servers: NUMA, multi-queue NICs
  - RB4 prototype
    - 4 servers in full mesh acting as 4-port (10Gbps/port) router
    - 4 × 8.75 = 35Gbps
  - Linearly scalable by adding servers (in theory)

•Dobrescu, M., Egi, N., Argyraki, K., Chun, B., Fall, K., Iannaccone, G., Knies, A., Manesh, M., and Ratnasamy, S. *RouteBricks: exploiting parallelism to scale software routers,* SOSP 2009

•Bolla, R. and Bruschi, R., *PC-based software routers: high performance and application service support*, PRESTO 2008

Improving software router performance: specialized hardware

NetFPGA

QuickTime™ and a
decompressor
are needed to see this picture.

Network processor

QuickTime™ and a
decompressor
are needed to see this picture.

•Jad Naous, Glen Gibb, Sara Bolouki, Nick McKeown, *NetFPGA: Reusable Router Architecture for Experimental Research,* PRESTO 2008
•Spalink, T., Karlin, S., Peterson, L., and Gottlieb, Y., *Building a robust software-based router using network processors,* SOSP 2001
•J. Turner, P. Crowley, J. Dehart, A. Freestone, B. Heller, F. Kuhms, S. Kumar, J. Lockwood, J. Lu, M.Wilson, C. Wiseman, D. Zar, *Supercharging PlanetLab – A High Performance, Multi-Application, Overlay Network Platform,* SIGCOMM 2007
•Tilman Wolf, *Challenges and applications for network-processor-based programmable routers*, IEEE Sarnoff Symposium, Princeton, NJ, Mar. 2006

Before Next time

- Project Progress
  - **Need to setup environment as soon as possible**
  - And meet with groups, TA, and professor
- Lab0b – Getting Started with Fractus
  - Use Fractus instead of Red Cloud
    - Red Cloud instances will be terminated and state lost
  - **Due Monday, Sept 29**

- ***Required review and reading for Friday, October 3***
  - RouteBrics

- Check piazza: http://piazza.com/cornell/fall2014/cs5413
- Check website for updated schedule