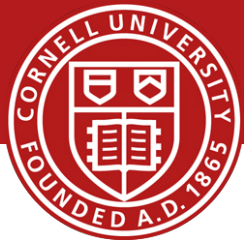

Software Routers: NetMap

Hakim Weatherspoon

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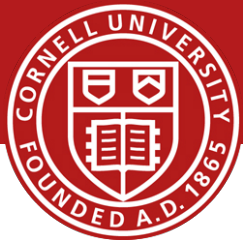
CS 5413: High Performance Systems and Networking

October 8, 2014

Slides from the “NetMap: A Novel Framework for Fast Packet I/O” at the USENIX Annual Technical Conference (ATC), June 2012.

Goals for Today



- Gates Data Center and Fractus tour

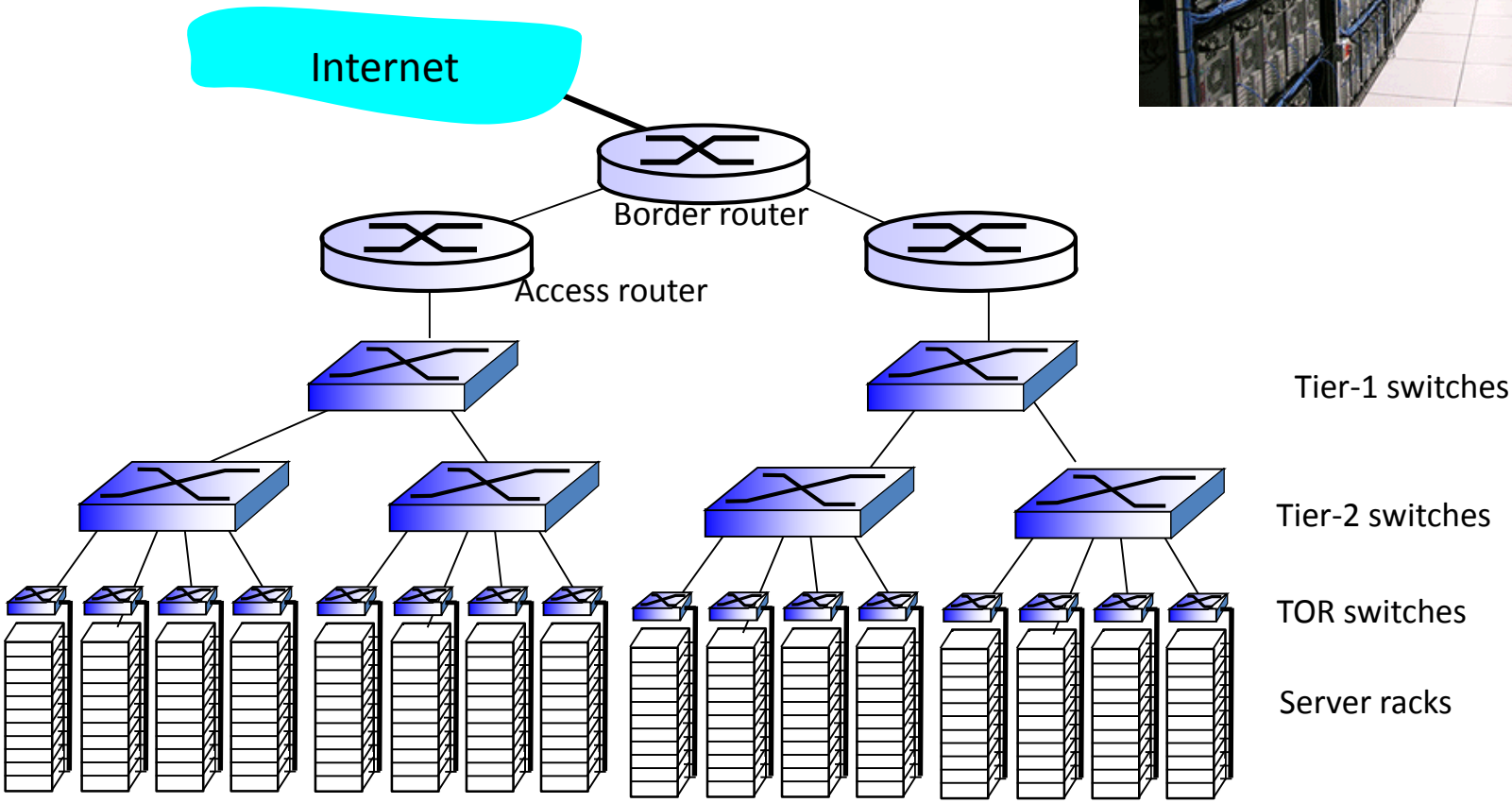
- NetMap: A Novel Framework for Fast Packet I/O
  - L. Rizzo. USENIX Annual Technical Conference (ATC), June 2012, pages 101-112.

Fractus Cloud

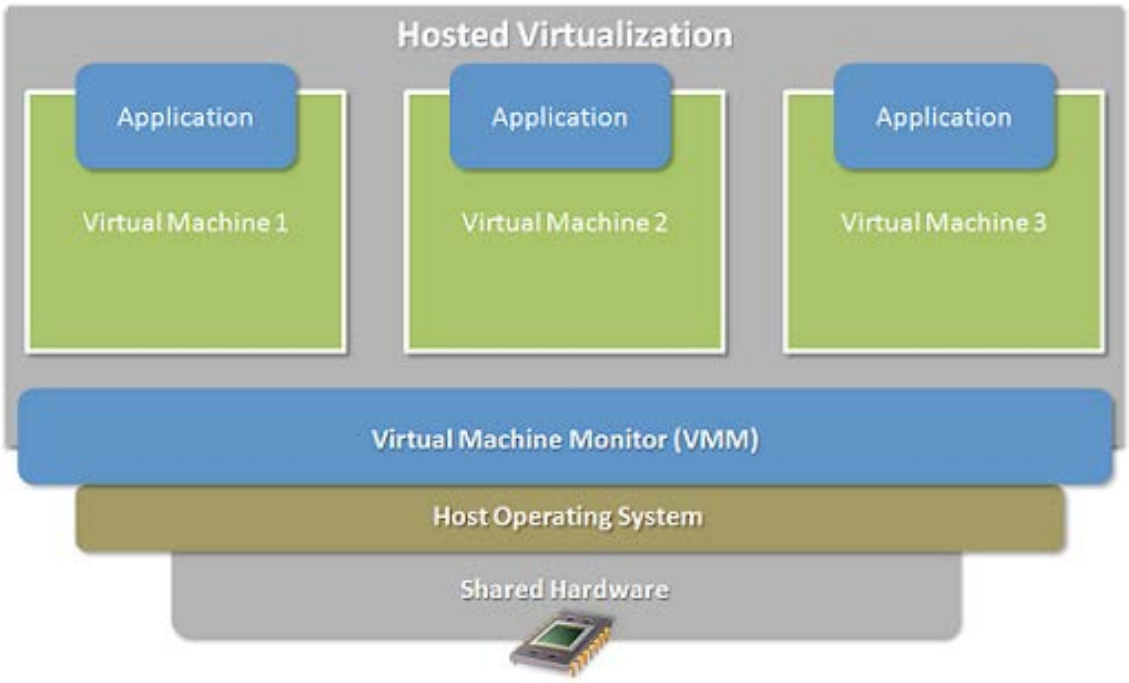
Production-side and Experimental side

- 1 rack of 19 machines each
- Network
  - 1x HP 10/100 Mb management switch
  - 1x Top-of-Rack switch: Dell Force10 10 Gb Ethernet data switch
    - Contains a bonded pair of 40 Gb links to the research rack (80 Gb total)
- Servers
  - 2x 8-core Intel Xeon E5-2690 2.9 GHz CPUs (16 cores/32 threads total)
  - 96 GB RAM
  - A bonded pair of 10 Gb Ethernet links (20 Gb total)
  - 4x 900 GB 10k RPM SAS drives in RAID 0

Fractus Cloud

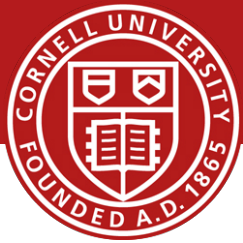


Fractus Cloud – Production-side



- Multiple virtual machines on one physical machine
- Applications run unmodified as on real machine
- VM can migrate from one computer to another

Goals for Today



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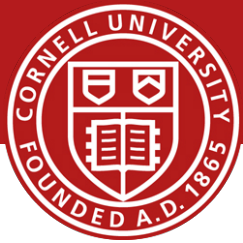
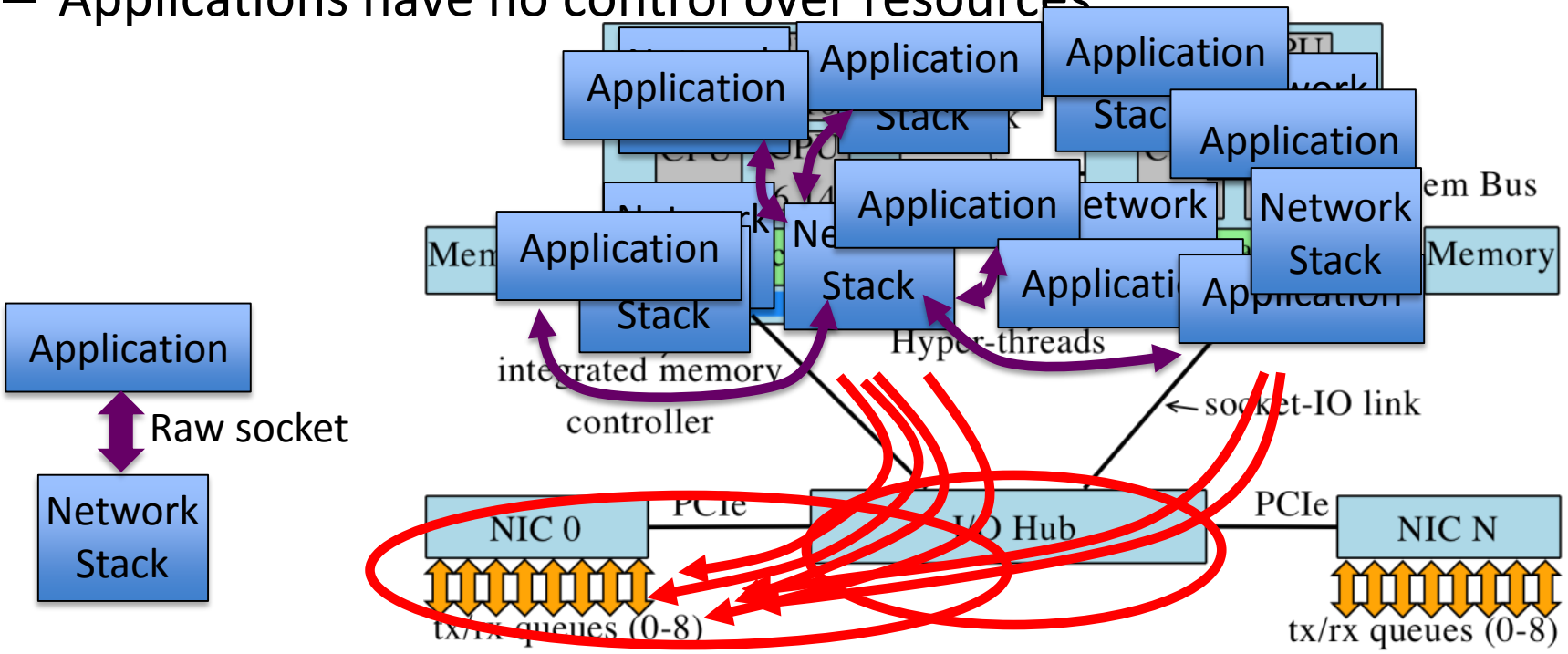
Direct Packet I/O Options



- Good old sockets (BPF, raw sockets)
  - Flexible, portable, but slow

Direct Packet I/O options

- Good old sockets (BPF, raw sockets)
  - Flexible, portable, but slow
  - Raw socket: ***all*** traffic from ***all*** NICs to user-space
  - Too general, hence complex network stack
  - Hardware and software are loosely coupled
  - Applications have no control over resources



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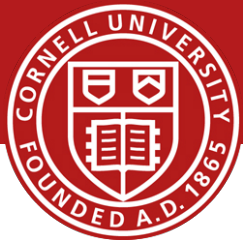

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  - Efficient, if mbufs/skbufs do not get in the way

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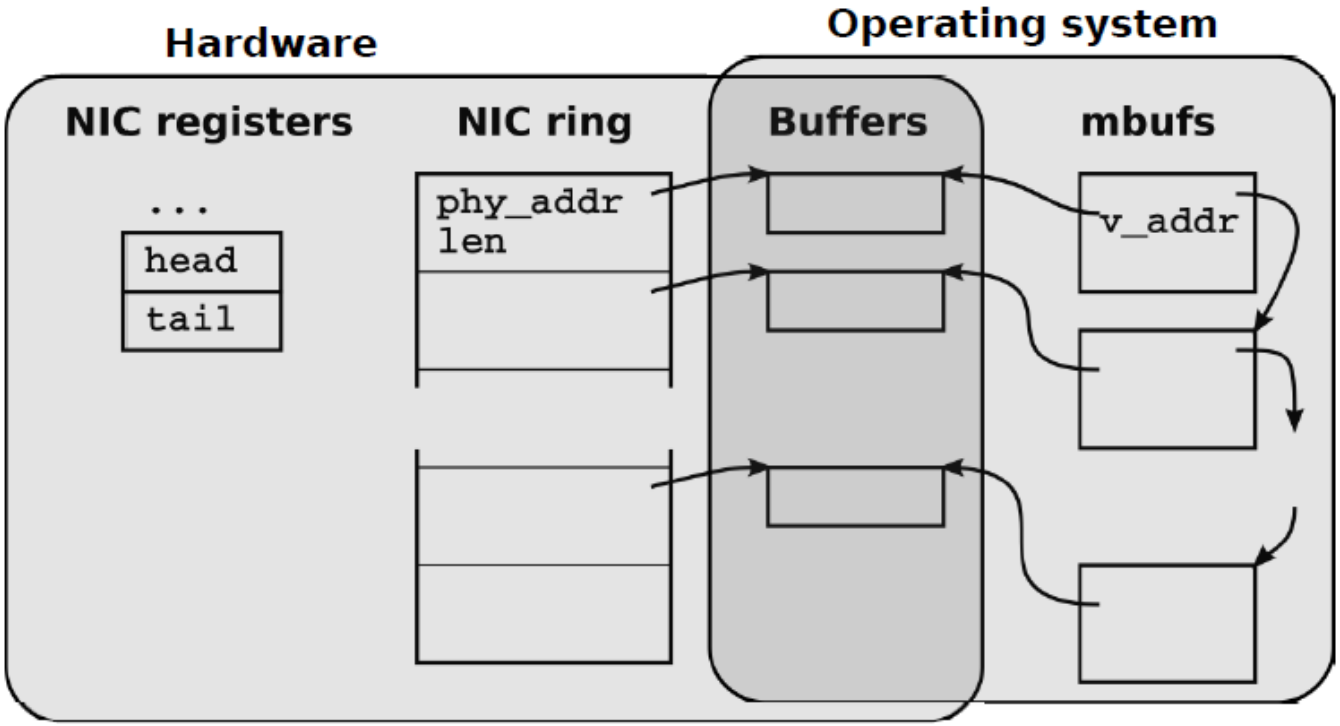
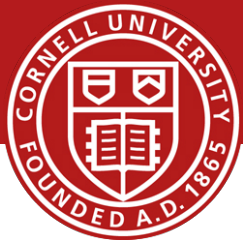


Direct Packet I/O Options



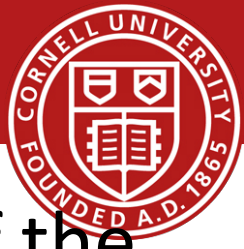
- Good old sockets (BPF, raw sockets)
  - Flexible, portable, but slow
- Memory mapped buffers (PF_PACKET, PF_RING)
  - Efficient, if mbufs/skbufs do not get in the way
- Run in the kernel (NETFILTER, PFIL, Netgraph, NDIS, Click)
  - Can be fast, especially if bypassing mbufs
- Custom Libraries (OpenOnLoad, Intel DPDK)
  - Vendor specific: Normally tied to vendor hardware
- Can we find a better (fast, safe, HW-independent) solution?

Traditional Network Stack

- How slow is the traditional raw socket and host network stack?

File	Function/description	time ns	delta ns
user program	`sendto` system call	8	96
uipc_syscalls.c	`sys_sendto`	104	
uipc_syscalls.c	`sendit`	111	
uipc_syscalls.c	`kern_sendit`	118	
uipc_socket.c	`sosend`	—	
uipc_socket.c	`sosend_dgram` sockbuf locking, mbuf allocation, copyin	146	137
udp_usrreq.c	`udp_send`	273	
udp_usrreq.c	`udp_output`	273	57
ip_output.c	`ip_output` route lookup, ip header setup	330	198
if_ethersubr.c	`ether_output` MAC header lookup and copy, loopback	528	162
if_ethersubr.c	`ether_output_frame`	690	
ixgbe.c	`ixgbe_mq_start`	698	
ixgbe.c	`ixgbe_mq_start_locked`	720	
ixgbe.c	`ixgbe_xmit` mbuf mangling, device programming	730	220
–	on wire	950	

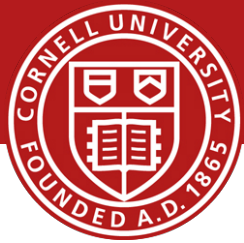
Traditional Network Stack



Significant amount of time spent at all levels of the stack

- The system call cannot be avoided (or can it?)
- Device programming is extremely expensive
- Complex mbufs are a bad idea
- Data copies and mbufs can be saved in some cases
- Headers should be cached and reused if possible

Motivation for a new design



Design Guidelines

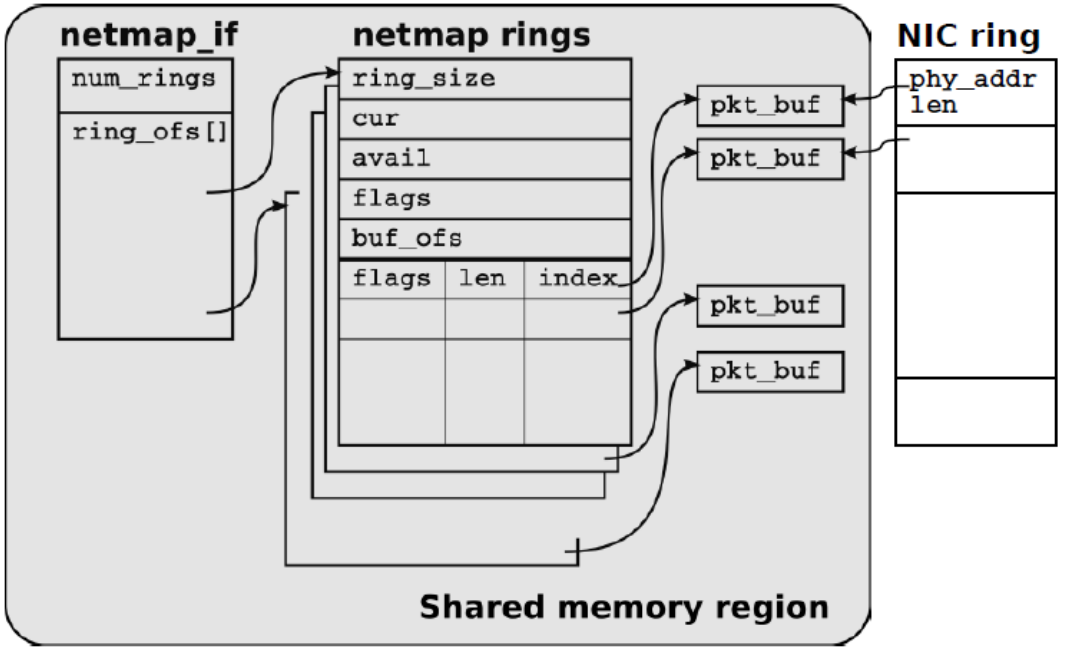
- No requirement/reliance on special hardware features
- Amortize costs over large batches (syscalls)
- Remove unnecessary work (copies, mbufs, alloc/free)
- Reduce runtime decisions (a single frame format)
- Modifying device drivers is permitted, as long as the code can be maintained

NetMap summary

Framework for raw packet I/O from userspace

- 65 cycles/packet between the wire in userspace
  - 14Mpps on one 900 MHz core
- Device and OS independent
- Good scalability with number of CPU frequency and number of cores
- **libpcap** emulation library for easy porting of applications

Netmap data structure and API



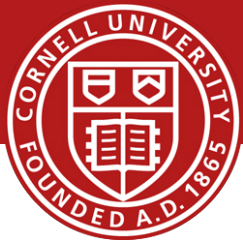
- **packet buffers**
  - Numbered and fixed size
- **netmap rings**
  - Device independent copy of NIC ring

  cur: current tx/rx position

  avail: available slots

  Ptrs stored as offsets or indexes (so not dependent of virtual mem)
- **netmap_if**
  - Contains references to all rings attached to an interface

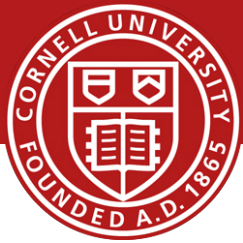
Protection



Rely on standard OS mechanism

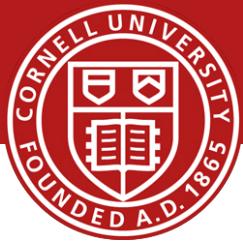
- The NIC is not exposed to the userspace
- Kernel validates the netmap ring before using its contents
- Cannot crash the kernel or trash other processes memory

Data Ownership



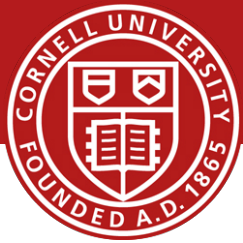
- No races between kernel and user
- Global fields, and [**cur**…**cur**+**avail**-1]:
  - Owned by the application, updated during system calls
- other slots/buffers
  - Owned by the kernel
- Interrupt handler never touches shared memory regions

NetMap API



- Access
  - open: returns a file descriptor (fd)
  - ioctl: puts an interface into netmap mode
  - mmap: maps buffers and rings into user address space
- Transmit (TX)
  - Fill up to **avail** bufs, starting at slot **cur**
  - **ioctl(fd, NIOCTXSYNC)** queues the packets
- Receive (RX)
  - **ioctl(fd, NIOCTXSYNC)** reports newly received packets
  - Process up to **avail** bufs, starting at **cur**
- poll()/select()

NetMap API



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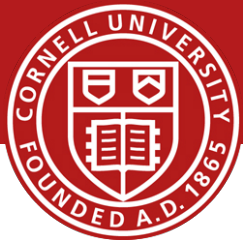
- Receive (RX)
  - **ioctl(fd, NIOCTXSYNC)** reports
  - Process up to **avail** bufs, startir
- poll()/select()

```
fds.fd = open("/dev/netmap", O_RDWR);
strcpy(nmr.nm_name, "ix0");
ioctl(fds.fd, NIOCREG, &nmr);
p = mmap(0, nmr.memsize, fds.fd);
nifp = NETMAP_IF(p, nmr.offset);
fds.events = POLLOUT;
for (;;) {
  poll(fds, 1, -1);
  for (r = 0; r < nmr.num_queues; r++) {
    ring = NETMAP_TXRING(nifp, r);
    while (ring->avail-- > 0) {
      i = ring->cur;
      buf = NETMAP_BUF(ring, ring->slot[i].buf_index);
      ... store the payload into buf ...
      ring->slot[i].len =  ... // set packet length
      ring->cur = NETMAP_NEXT(ring, i);
    }
  }
}
```

Multiqueue/multicore support

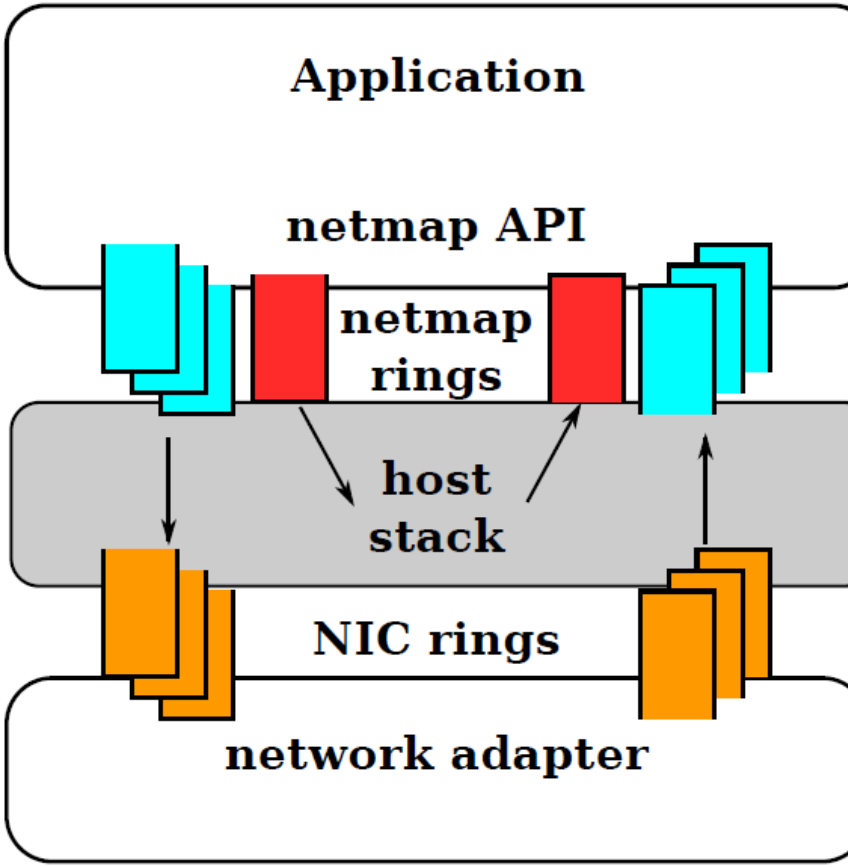


- One netmap ring per physical NIC ring
- By default, the **fd** is bound to all NIC rings, but
  - ioctl can restrict the binding to a single NIC ring pair
  - multiple **fd**'s can be bound to different rings on the same card
  - The **fd**'s can be managed by different threads
  - Threads mapped to cores with **pthread_setaffinity()**

NetMap and Host Stack

Netmap Mode

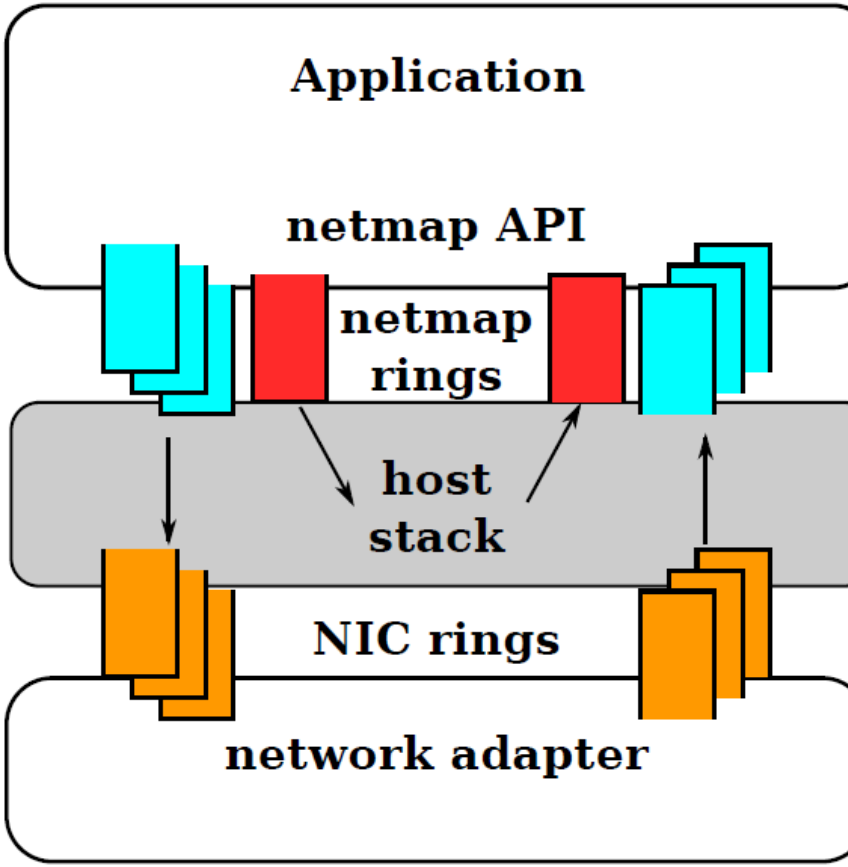
- Data path
  - Normal path between NIC and host stack is removed
- Control path
  - OS believes NIC is still there
  - Ifconfig, ioctl, etc still work



NetMap and Host Stack

Netmap Mode

- Data path
  - Packets from NIC end up in netmap ring
  - Packets from TX netmap ring are sent to the NIC
- Control path
  - OS believes NIC is still there
  - Ifconfig, ioctl, etc still work



Zero copy

- Zero-copy forwarding by swapping buffer indexes

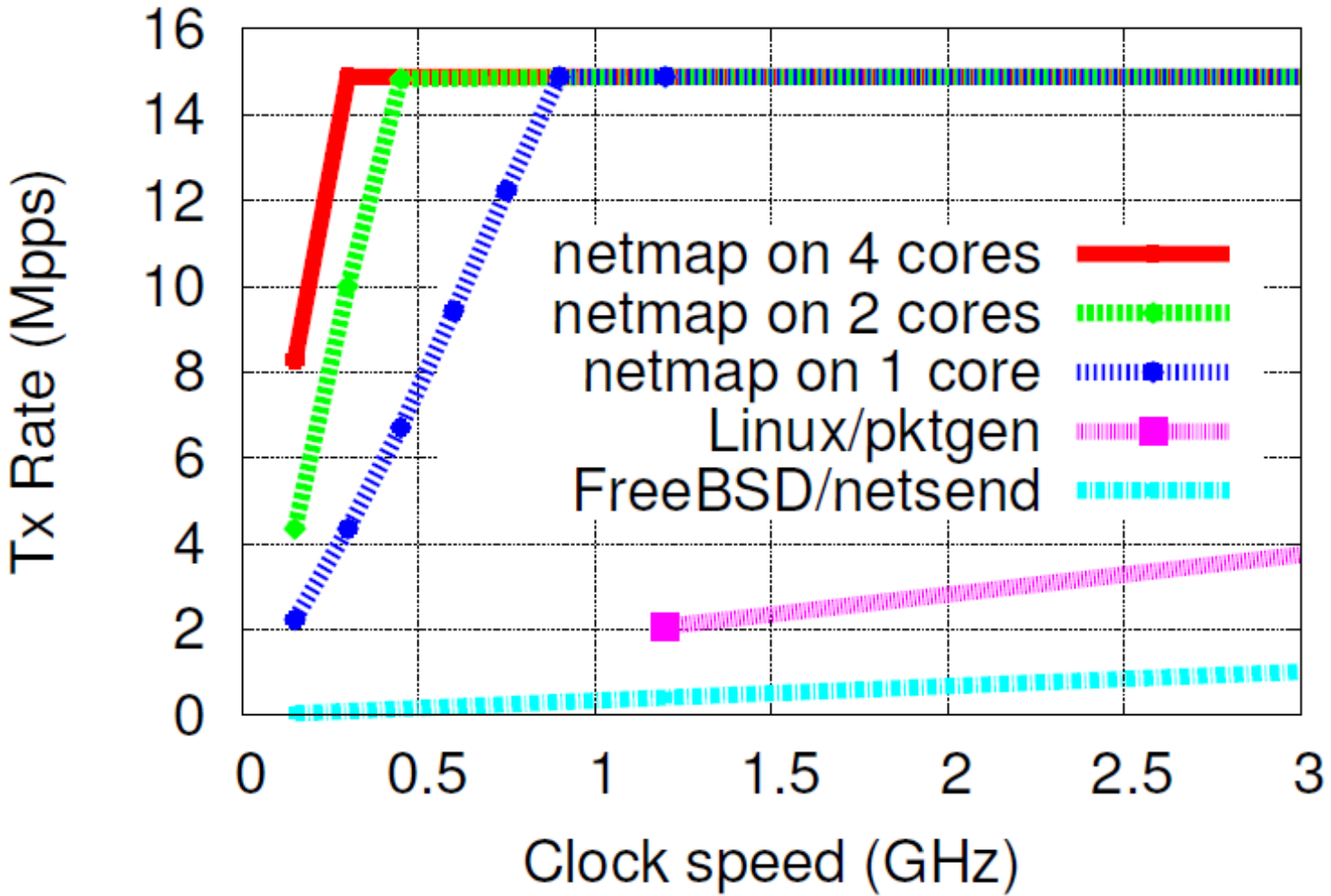
```
...
src = &src_nifp->slot[i]; /* locate src and dst slots */
dst = &dst_nifp->slot[j];
/* swap the buffers */
tmp = dst->buf_index;
dst->buf_index = src->buf_index;
src->buf_index = tmp;
/* update length and flags */
dst->len = src->len;
/* tell kernel to update addresses in the NIC rings */
dst->flags = src->flags = BUF_CHANGED;
...
```

- Zero-copy also works with rings from/to host stack
  - Firewalls, NAT boxes, IDS mechanisms

Performance Results

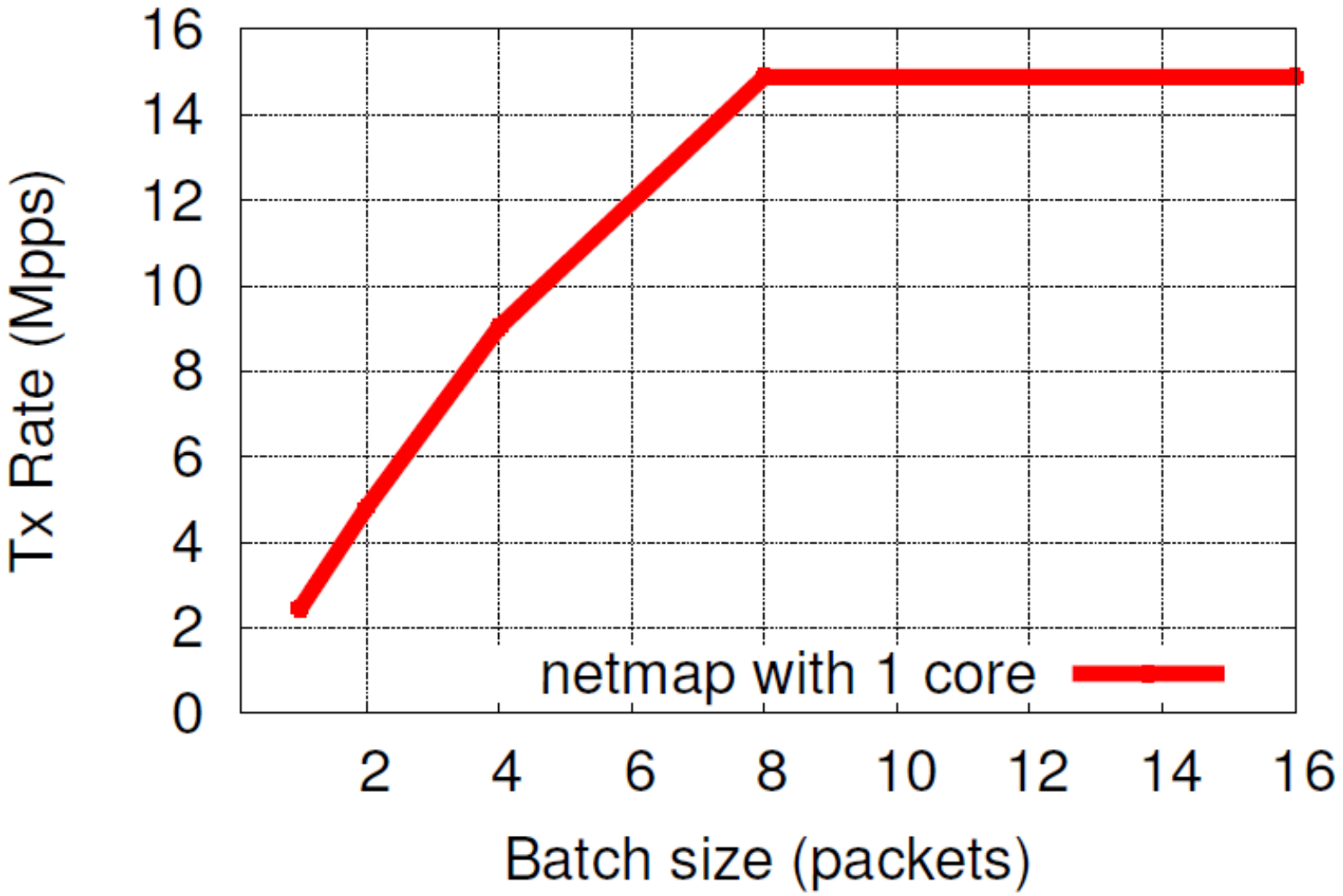
Performance Results

- TX tput vs clock speed and number of cores



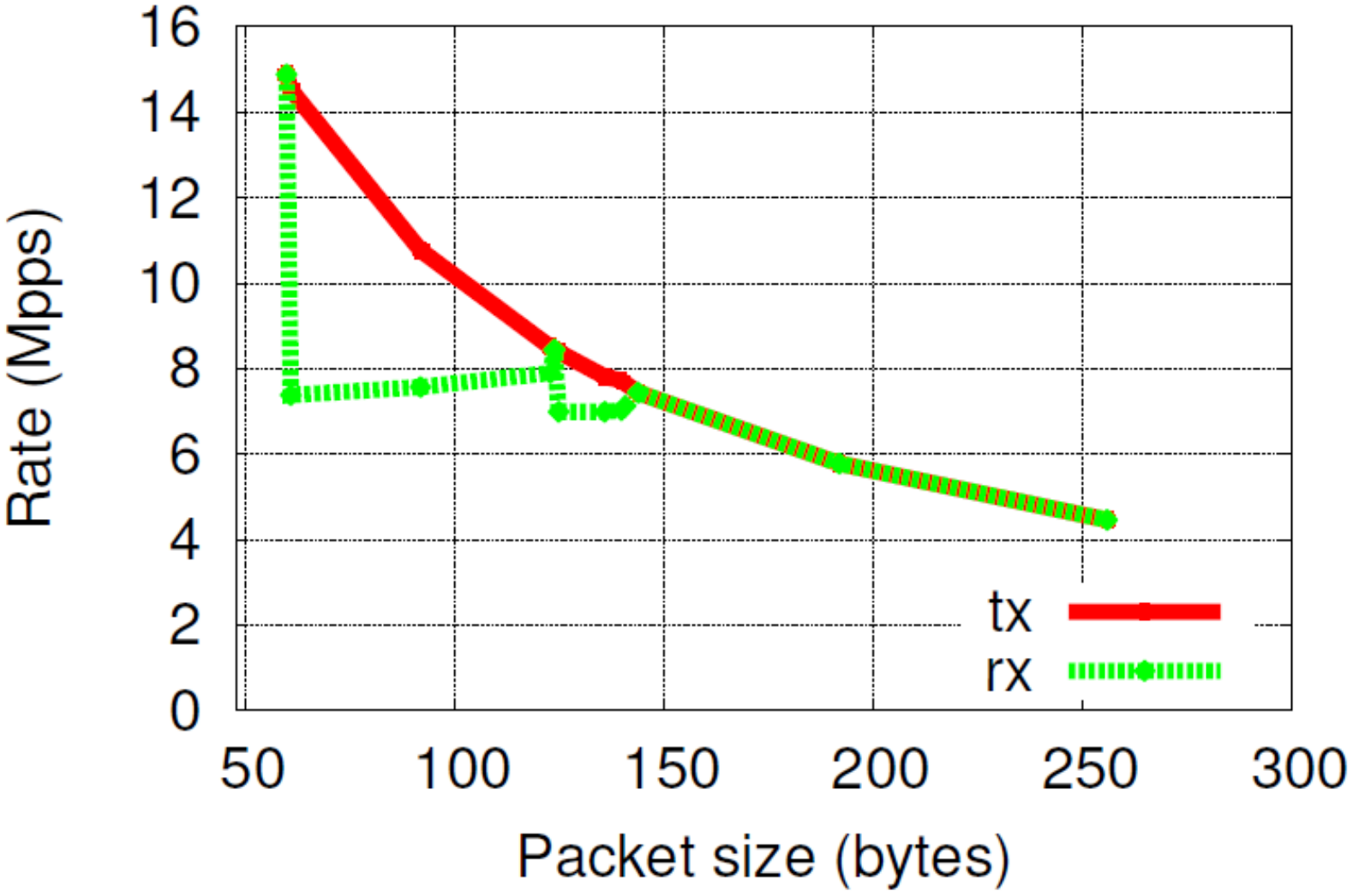
Performance Results

- TX tput vs burst size



Performance Results

- RX tput vs packet size



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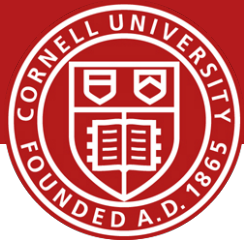

- Forwarding performance

Configuration	Mpps
netmap-fwd (1.733 GHz)	14.88
netmap-fwd + pcap	7.50
click-fwd + netmap	3.95
click-etherswitch + netmap	3.10
click-fwd + native pcap	0.49
openvswitch + netmap	3.00
openvswitch + native pcap	0.78
bsd-bridge	0.75

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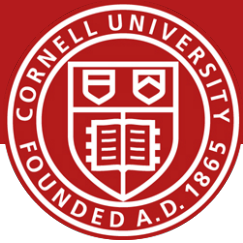
Before Next time



- Project Progress
  - **Need to setup environment as soon as possible**
  - And meet with groups, TA, and professor
- Lab3 – Packet filter/sniffer
  - **Due Thursday, October 16**
  - Use Fractus instead of Red Cloud

- ***Required review and reading for Friday, October 15***
  - "NetSlices: Scalable Multi-Core Packet Processing in User-Space", T. Marian, K. S. Lee, and H. Weatherspoon. *ACM/IEEE Symposium on Architectures for Networking and Communications Systems (ANCS)*, October 2012, pages 27-38.
  - http://dl.acm.org/citation.cfm?id=2396563
  - http://fireless.cs.cornell.edu/publications/netslice.pdf

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