PASTE: Fast End System Networking with netmap

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Code: https://github.com/micchie/netmap/tree/stack

This talk is about:

What are problems with current network stack?

How do we solve it?

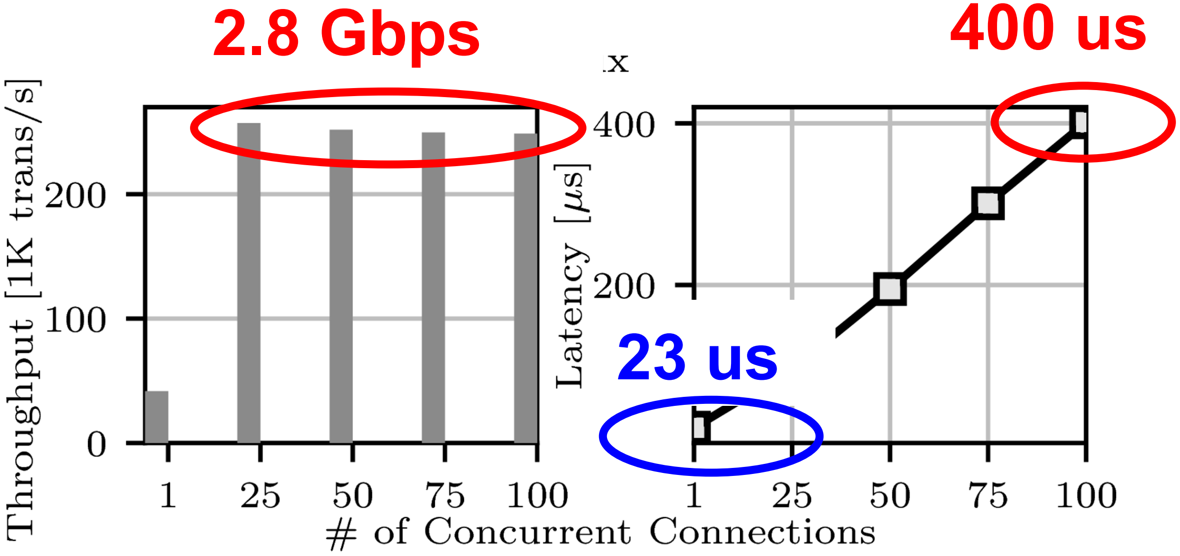
This talk is **NOT** about:

User-space network stack is awesome

Problem 1: Current socket API is slow

Request (1400B) and response (64B) over HTTP and TCP

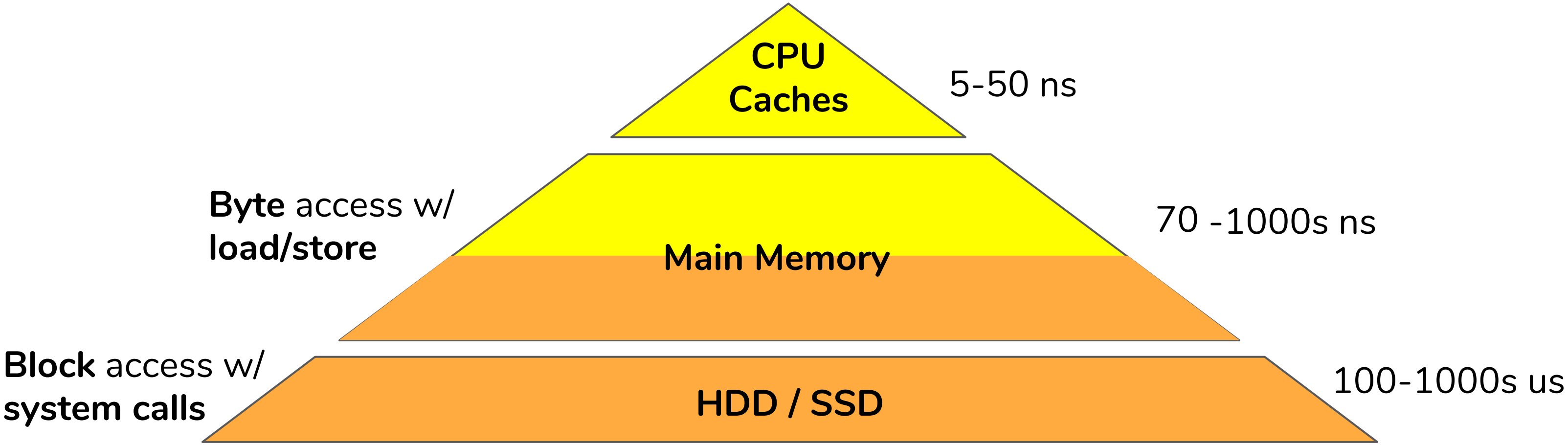
```
n = kevent(fds)
for (i=0; i<n; i++) {
    read(fds[i], buf);
    ...
    write(fds[i], res);
}
```



Server has Xeon 2640v4 2.4 Ghz (uses only 1 core) and Intel X540 10 GbE NIC
Client has Xeon 2690v4 2.6 Ghz and runs `wrk` HTTP benchmark tool

Problem 2: Current stack cannot utilize Non-Volatile Main Memory efficiently

- Review: NVMMs offer fast, byte-addressable persistence



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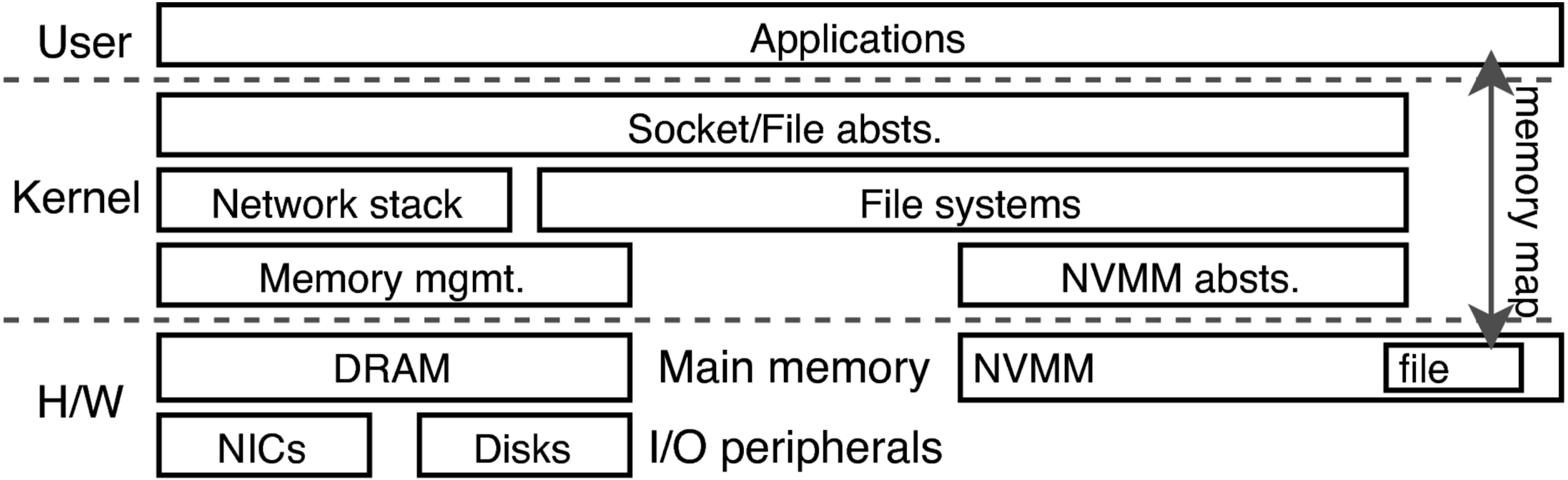
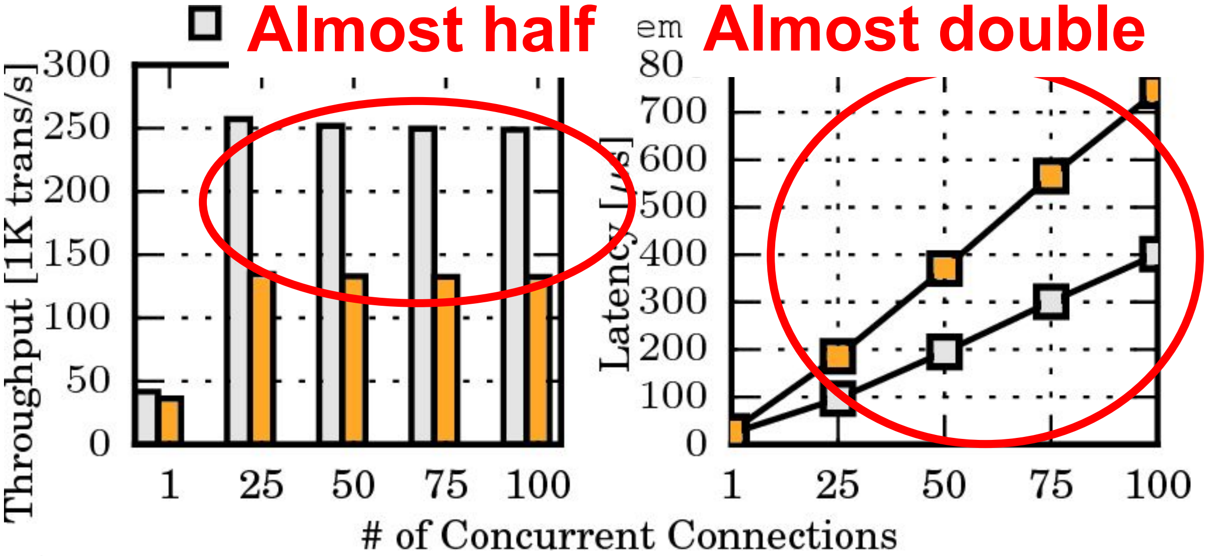


Problem 2: Current stack cannot utilize Non-Volatile Main Memory efficiently

Durable-write request (1400B) and response (64B) over HTTP and TCP

```
n = kevent(fds)
for (i=0; i<n; i++) {
  read(fds[i], buf);
  ...
  memcpy(nvmm, buf);
  clflush(nvmm);
  ...
  write(fds[i], res);
}
```



Server has Xeon 2640v4 2.4 Ghz
Client has Xeon 2690v4 2.6 Ghz and runs `wrk` HTTP benchmark tool

Summary

- Per-socket system call and I/O req. must be avoided
- Data copy (even to NVMM) must be avoided

Getting architecture right

How do we address these problems while preserving benefits offered by the current stack and socket API today?

PASTE

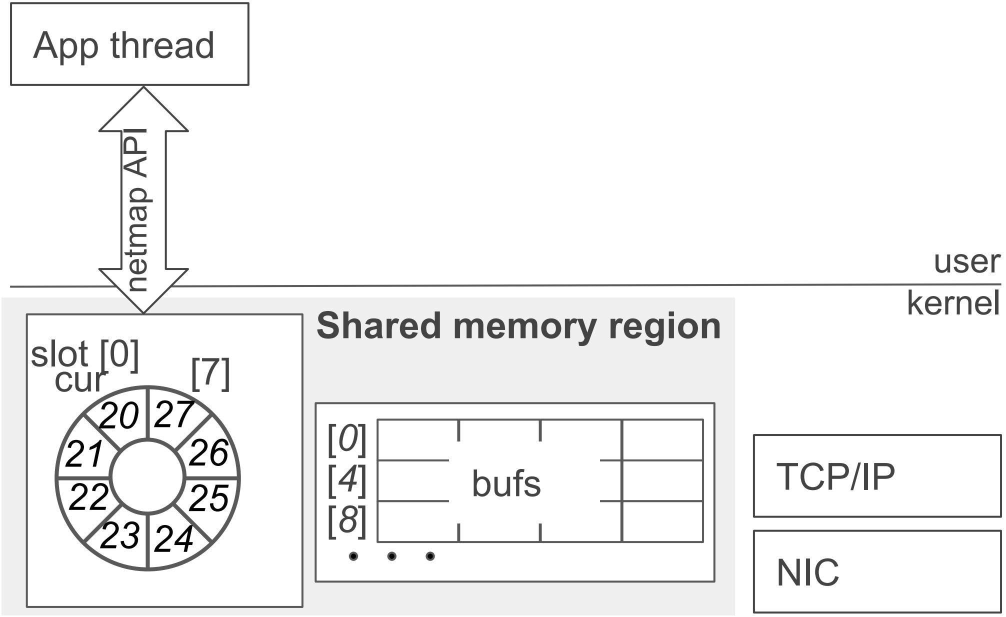
- Scalable, flexible end system networking architecture
  - True zero copy (even to NVMM)
  - System call and I/O batching across multiple sockets
  - Support for kernel TCP/IP
  - Protocol independence
  - Blocking and busy polling
  - Protection

What we benefit from socket API today

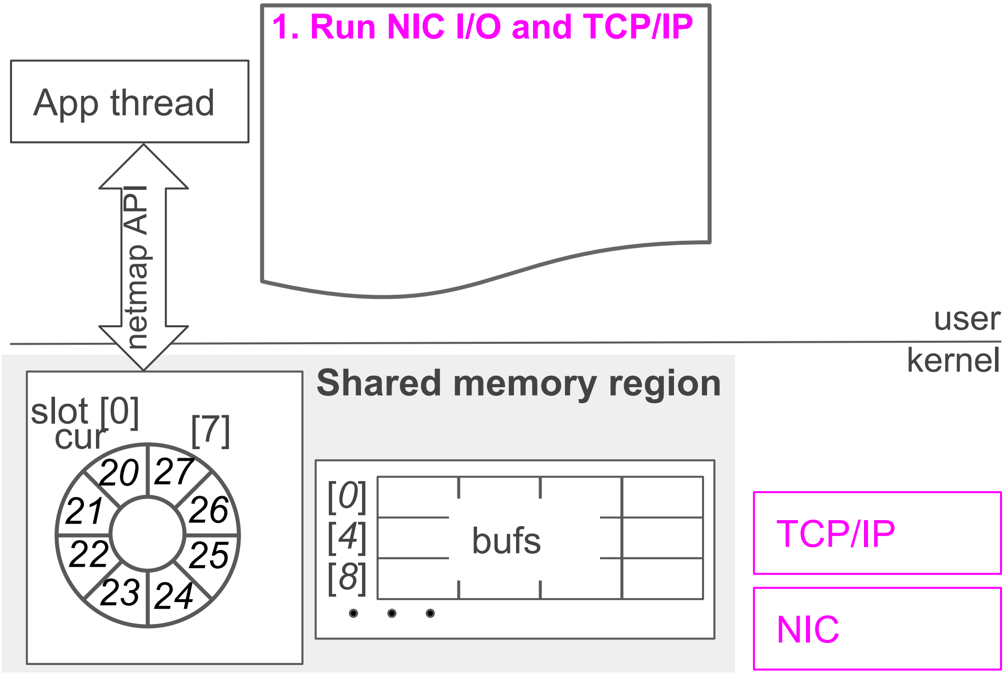
PASTE building blocks

- Two netmap extensions:
  - ***stack*** port
    - integrates the kernel TCP/IP implementation
    - same level of abstraction with pipe and vale ports
  - ***extmem*** subsystem
    - supports arbitrary (user virtual address) memory region for netmap objects
    - `mmap()`-ed file in NVMM can be used

PASTE in Action

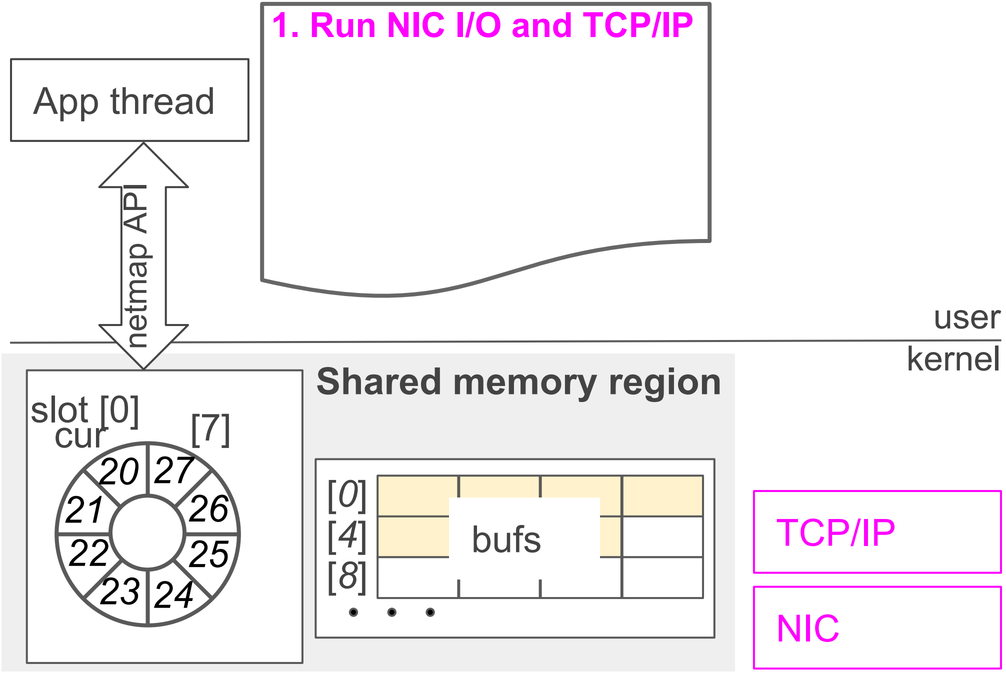


PASTE in Action



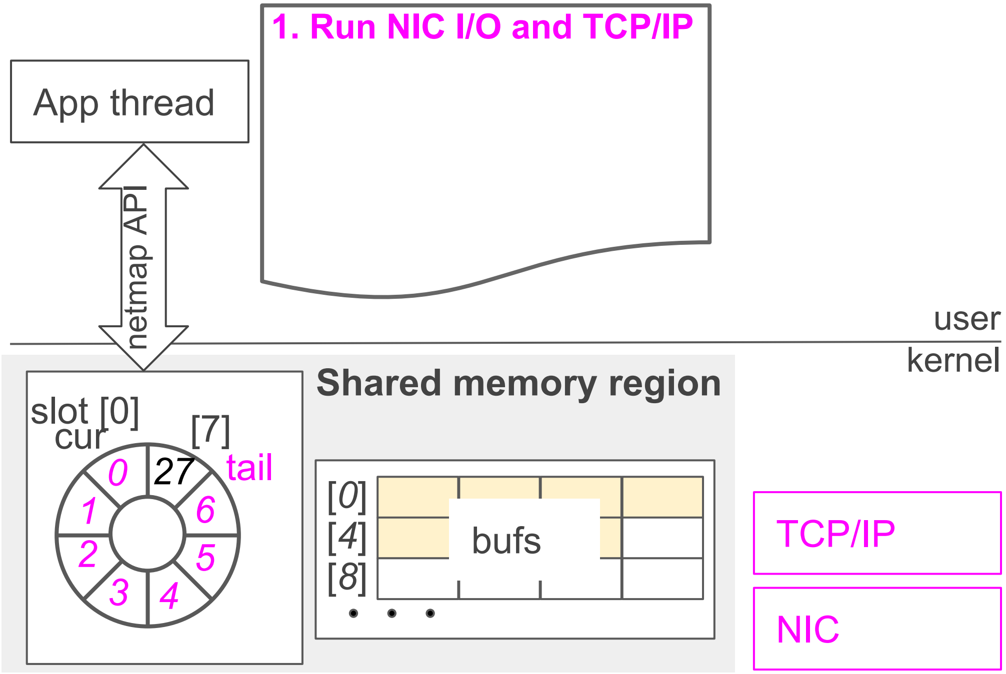
- `poll()` triggers NIC I/O and TCP/IP processing

PASTE in Action



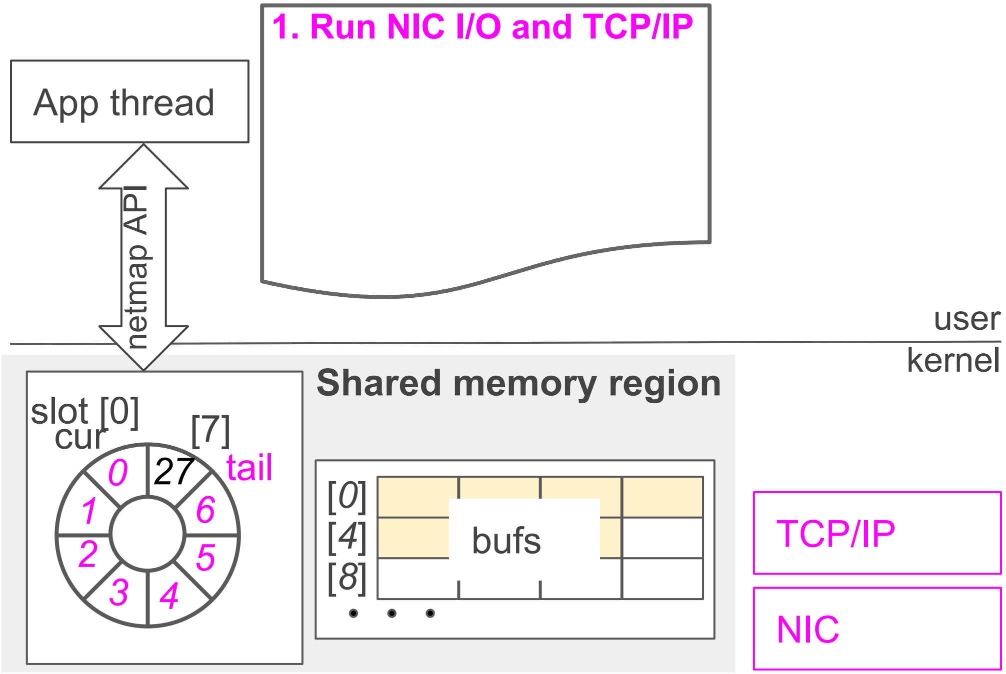
- Imagine 7 packets received

PASTE in Action



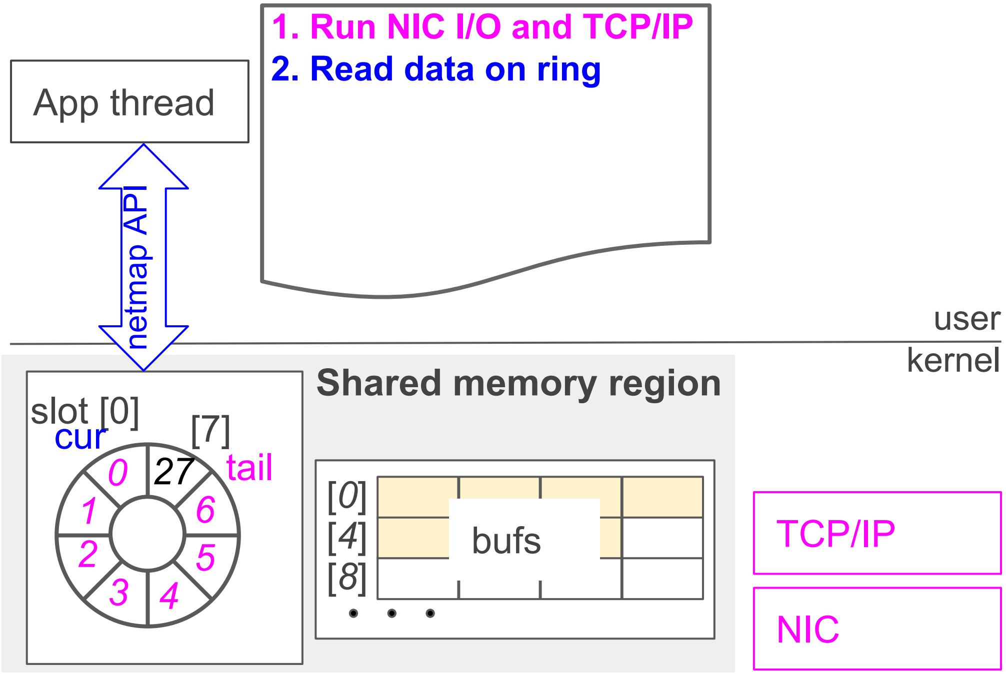
- They are in-order TCP segments, so the kernel set them to app ring slots
- Zero copy
  - swap with buffers in the current app ring
- Advance tail pointer to indicate new app data

PASTE in Action



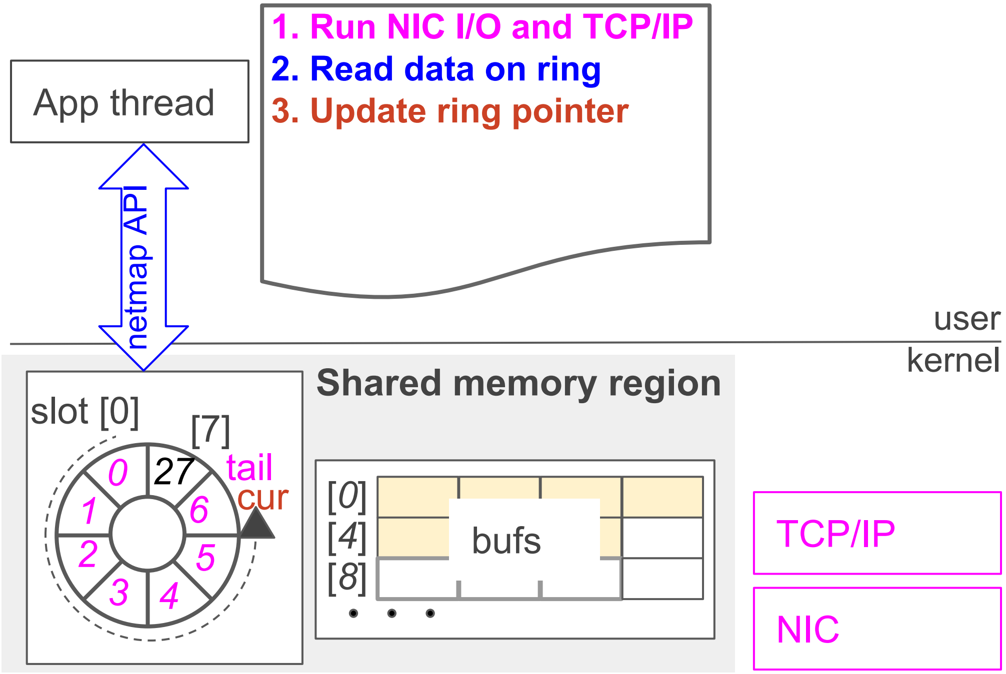
- `poll()` returns

PASTE in Action



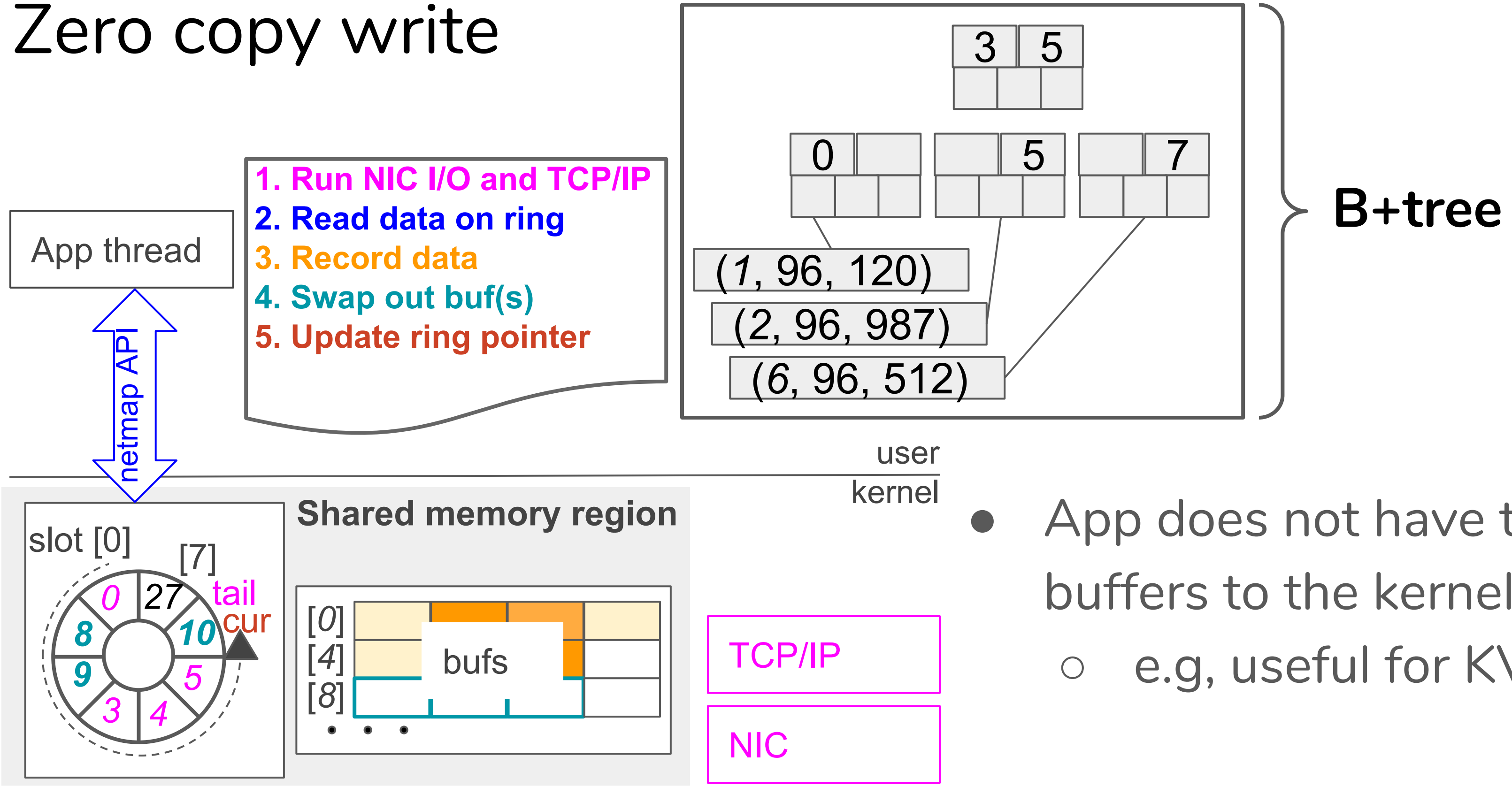
- App reads buffers in ring slots from `cur` to `tail`

PASTE in Action



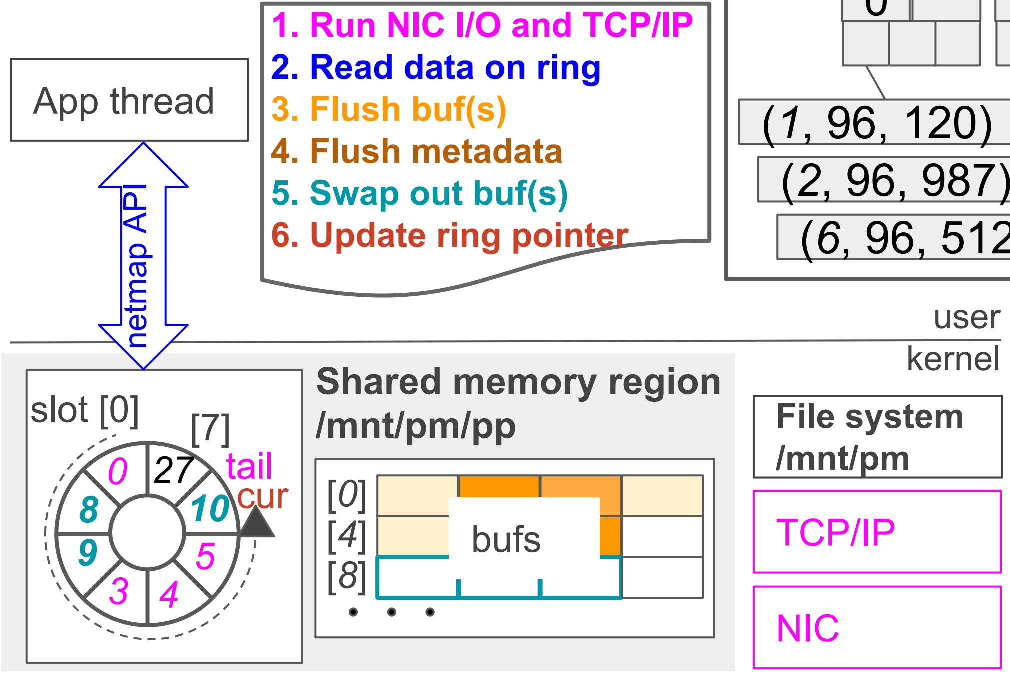
- App advances cur
  - Return buffers in slot 0-6 to the kernel at next poll()
    - Buffer indices are also 0-6 in this case

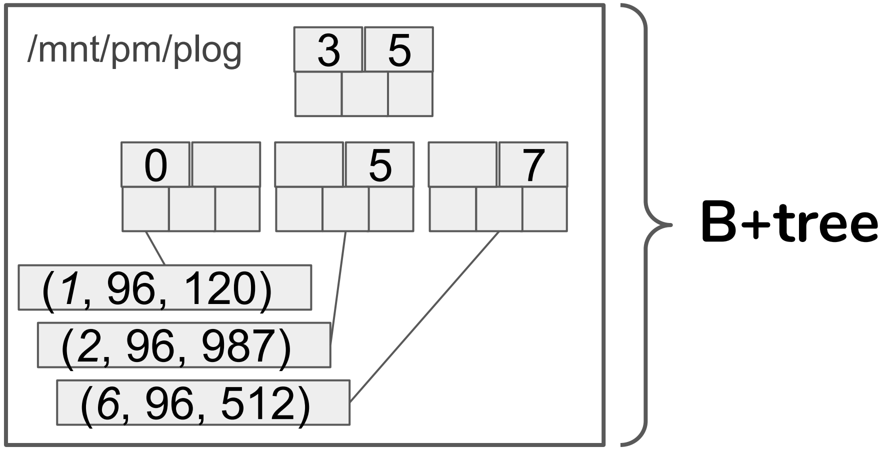
Zero copy write



- App does not have to return buffers to the kernel
  - e.g, useful for KVSes

Durable zero copy write





- `mmap()` a file on NVMM
  - /mnt/pm/pp
- Create netmap objects in it with extmem
- Create B+tree also in NVMM

How app code look like

```
nmd = nm_open("stack:0");
ioctl(nmd->fd,, "stack:em0");
s = socket();bind(s);listen(s);
int fds[2] = {nmd, s};
for (;;) {
  poll(fds, 2,);
  if (fds[1] & POLLIN)
    ioctl(nmd,, accept(fds[1]));
  if (fds[0] & POLLIN) {
    for (slot in nmd->rxring) {
      int fd = slot->fd;
      char *p = NETMAP_BUF(slot)
                   + slot->offset;
    }
  }
}
```

*use of extmem can be specified at nm_open()

What's going on in poll()

```
1.poll(app_ring)
-------------------------------------
3.mysoupcall (so) {
    mark_readable(so->so_rcv);
  }
```

netmap

```
  TCP/UDP/SCTP/IP impl.
```

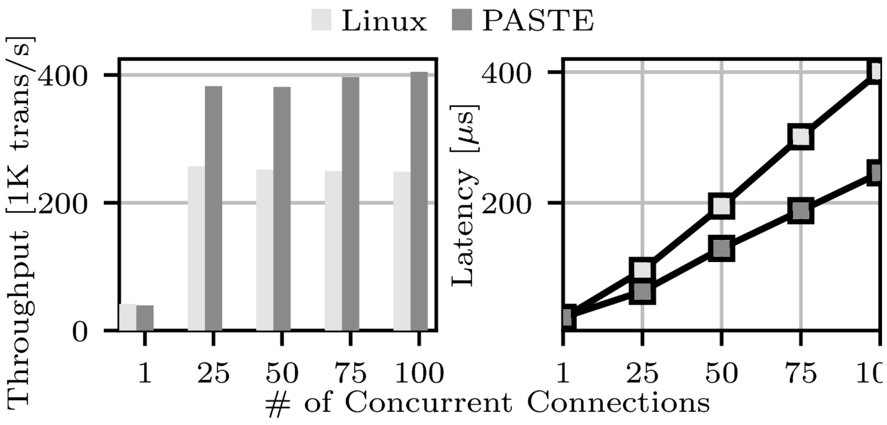
```
2.for (bufi in nic_rxring) {
    nmb = NMB(bufi);
    m = m_gethdr();
    m->m_ext.ext_buf = nmb;
    ifp->if_input(m);
}
4.for (bufi in readable) {
    set(bufi, fd(so), app_ring);
  }
```

netmap

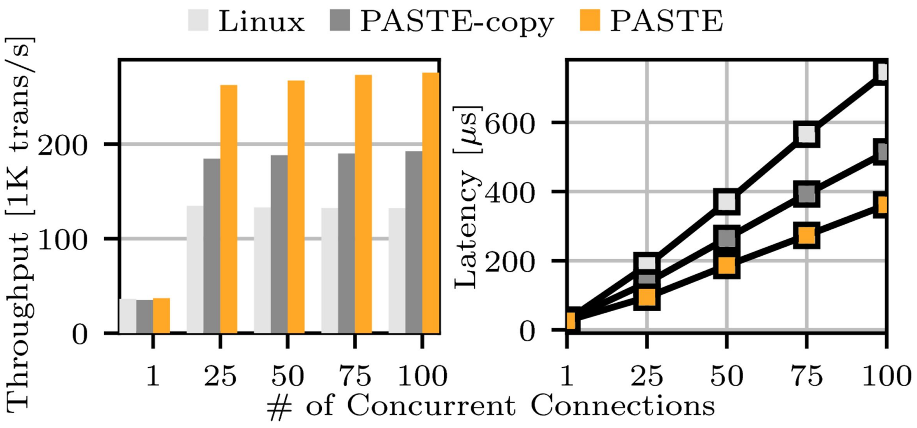
PASTE performance

Single CPU core

Don’t store data



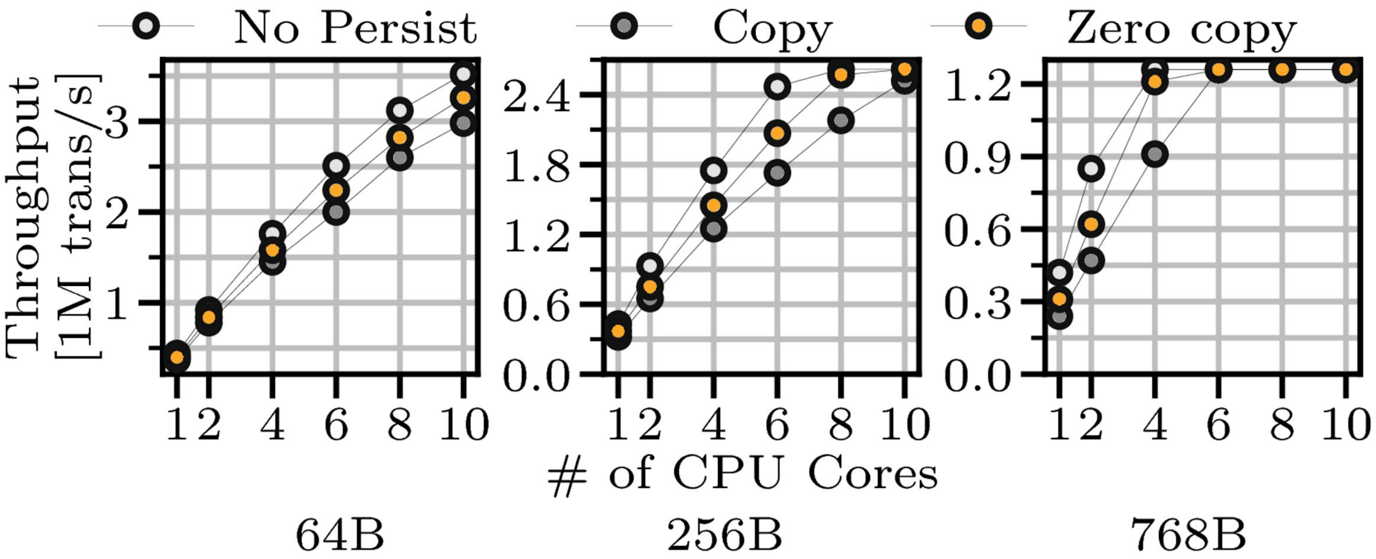
Store data in NVMM



Server has Xeon 2640v4 2.4 Ghz, Intel X540 10 GbE NIC and HPE NVDIMM
Client has Xeon 2690v4 2.6 Ghz and the sameNIC, and runs `wrk` HTTP benchmark tool

PASTE performance

Multiple CPU cores



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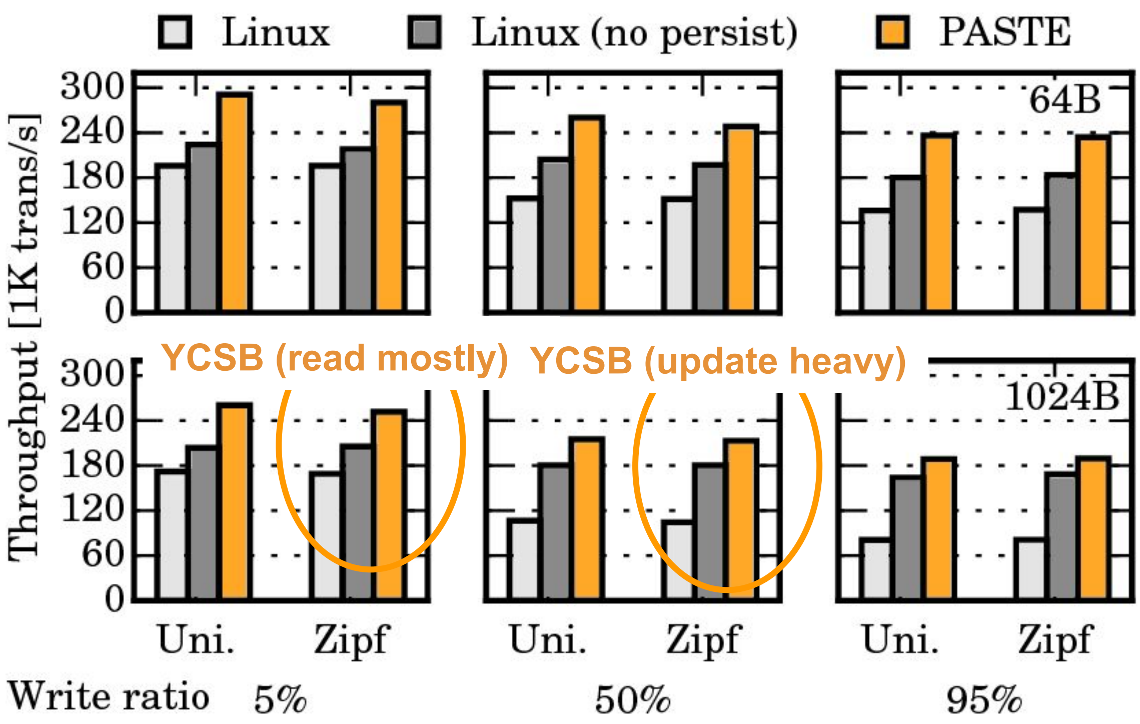
PASTE performance

Redis



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Changes needed in FreeBSD core

```
@@ -1101,6 +1101,8 @@ soclose(struct socket *so)
 drop:
        if (so->so_proto->pr_usrreqs->pru_close != NULL)
                (*so->so_proto->pr_usrreqs->pru_close)(so);
+       if (so->so_dtor != NULL)
+               so->so_dtor(so);

        SOCK_LOCK(so);
@@ -111,6 +111,7 @@ struct socket {

        int so_ts_clock;        /* type of the clock used for timestamps */
        uint32_t so_max_pacing_rate;    /* (f) TX rate limit in bytes/s */
+       void (*so_dtor)(struct socket *so); /* (a) optional destructor */
        union {
                /* Regular (data flow) socket. */
```

Summary

- PASTE integrates the kernel TCP/IP implementations and emerging NVMM with netmap API
- Status
  - In the process of upstreaming to netmap (w/ Giuseppe Lettieri)

Academic paper:
Michio Honda, Giuseppe Lettieri, Lars Eggert and Douglas Santry,
“PASTE: A Network Programming Interface for Non-Volatile Main Memory”, USENIX NSDI 2018
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