Zero Copy Rx with io_uring

Pavel Begunkov and David Wei

Meta

Agenda

01 Problem statement

02 io_uring primer

03 Design

04 Preliminary results

05 Status + future work

06 Questions + discussions

01 Problem statement

Linux networking Rx overheads

- Memory and PCIe bandwidth bottlenecks
- Memcpy CPU overheads

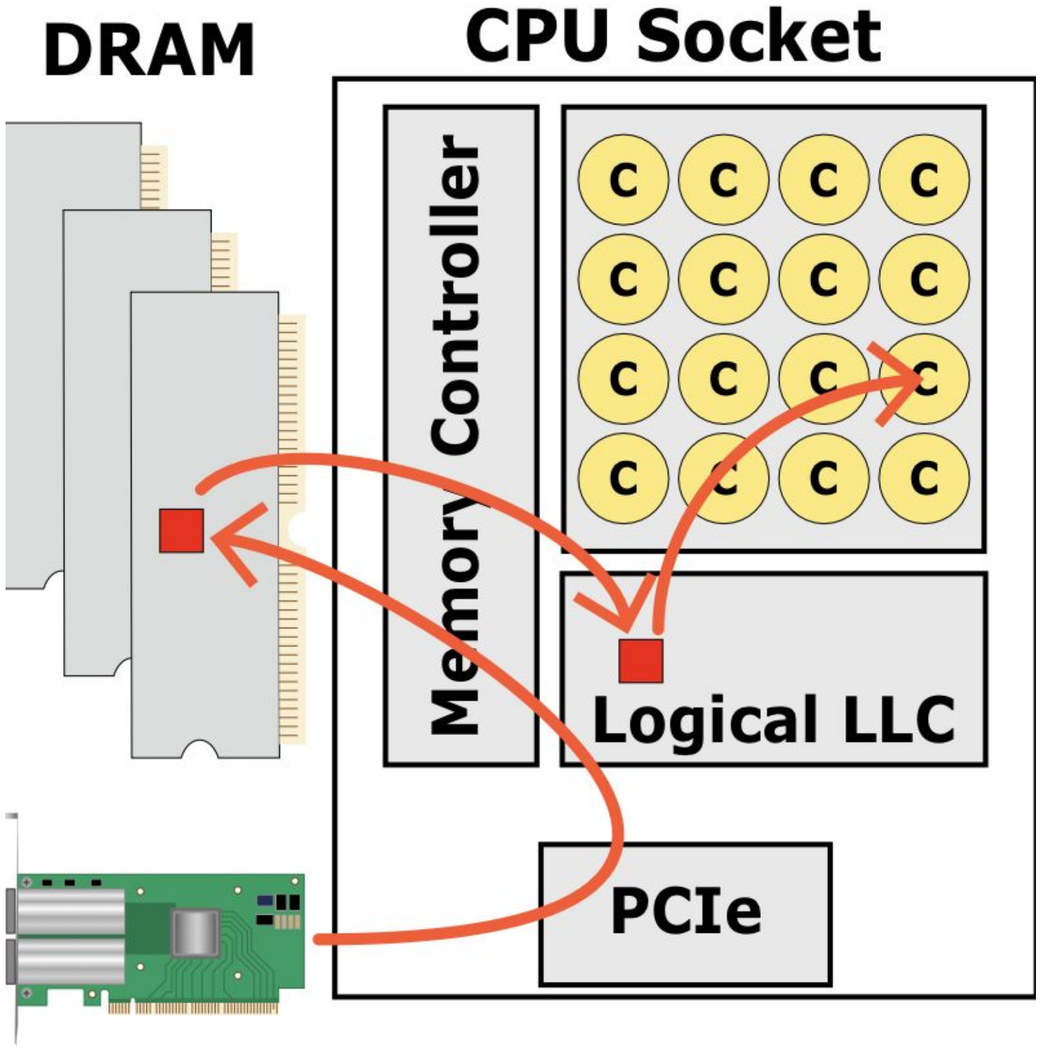
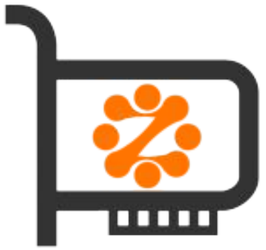


Image credit: A Farshin, A Roozbeh, G Q Maguire Jr., D Kostić. Reexamining Direct Cache Access to Optimize I/O Intensive Applications for Multi-hundred-gigabit Networks.

Kernel bypass

- High throughput! Low latency!
- **But** libraries and applications *expect* kernel networking stack
- Re-architecting an entire system around kernel bypass is expensive



DPDK

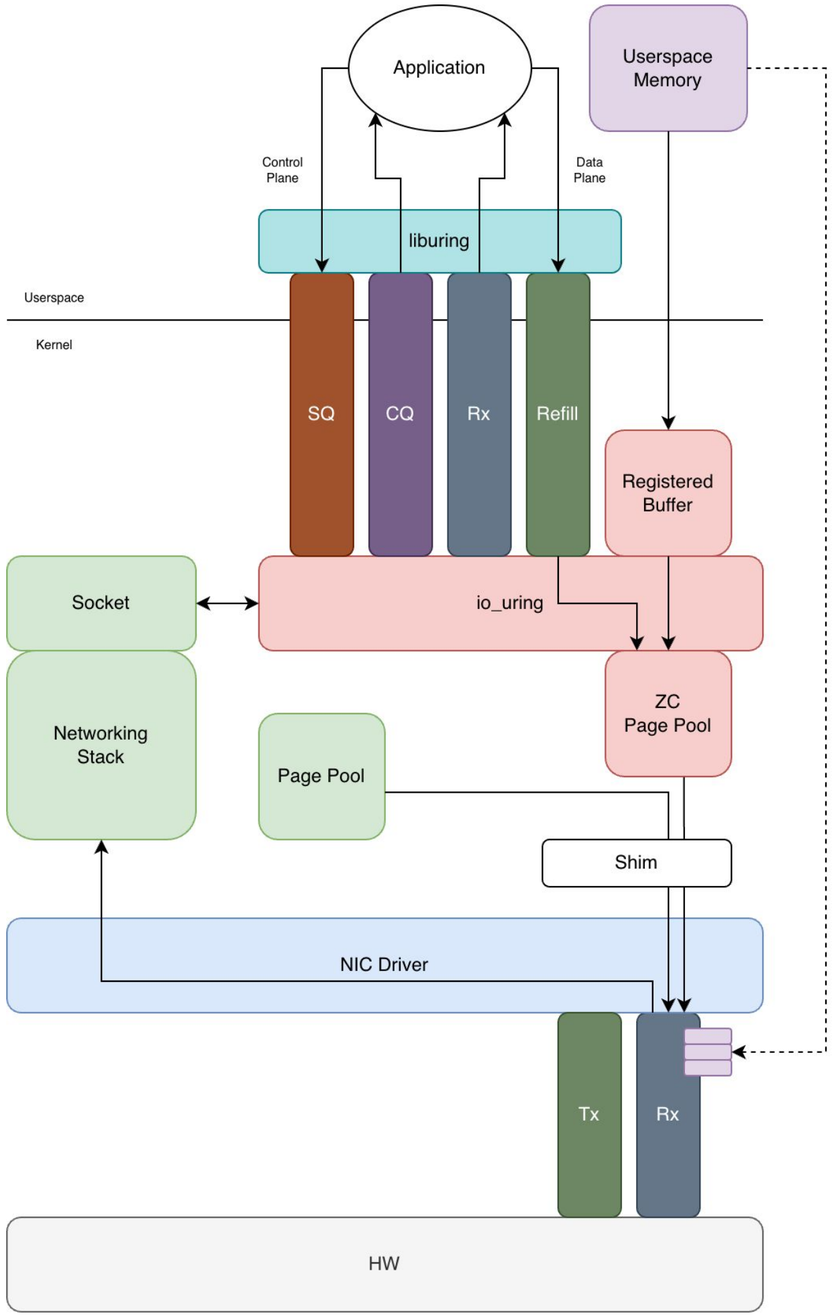
eBPF

AF_XDP

RoCE™

Proposal

- Hybrid solution
  - Standard control plane using kernel networking stack
  - Fast ZC Rx data plane using io_uring
- Two parts:
  - sk_buffs with page frags pointing to userspace pages end up in sockets
  - Read from socket using io_uring



02 io_uring primer

io_uring

- Rings shared between kernel and userspace
- Userspace submit requests into Submission Queue (SQ)
- Kernel posts completions into Completion Queue (CQ)
- Kick off work by entering kernel

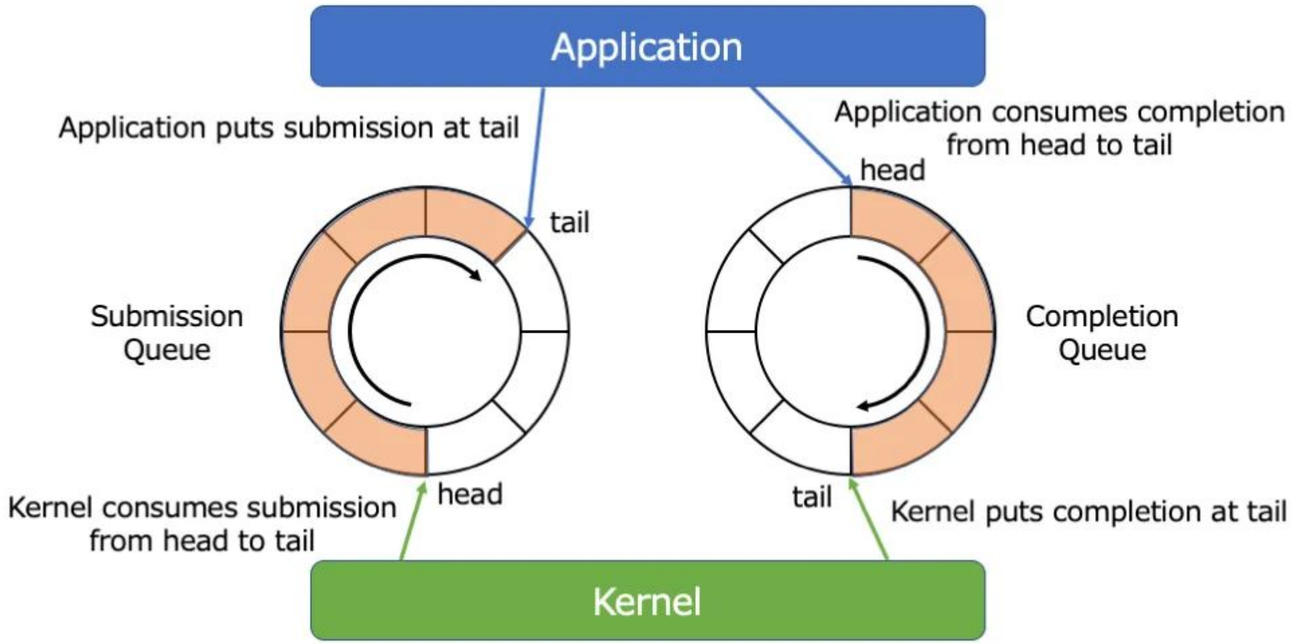


Image credit:
https://medium.com/nttlabs/rust-async-with-io-uring-db3fa2642dd4

Prepare request

```
struct io_uring_sqe *sqe;

sqe = io_uring_get_sqe(ring);

io_uring_prep_recv(sqe, sockfd, buf, len, flags);
```

Note this already moves the SQ tail

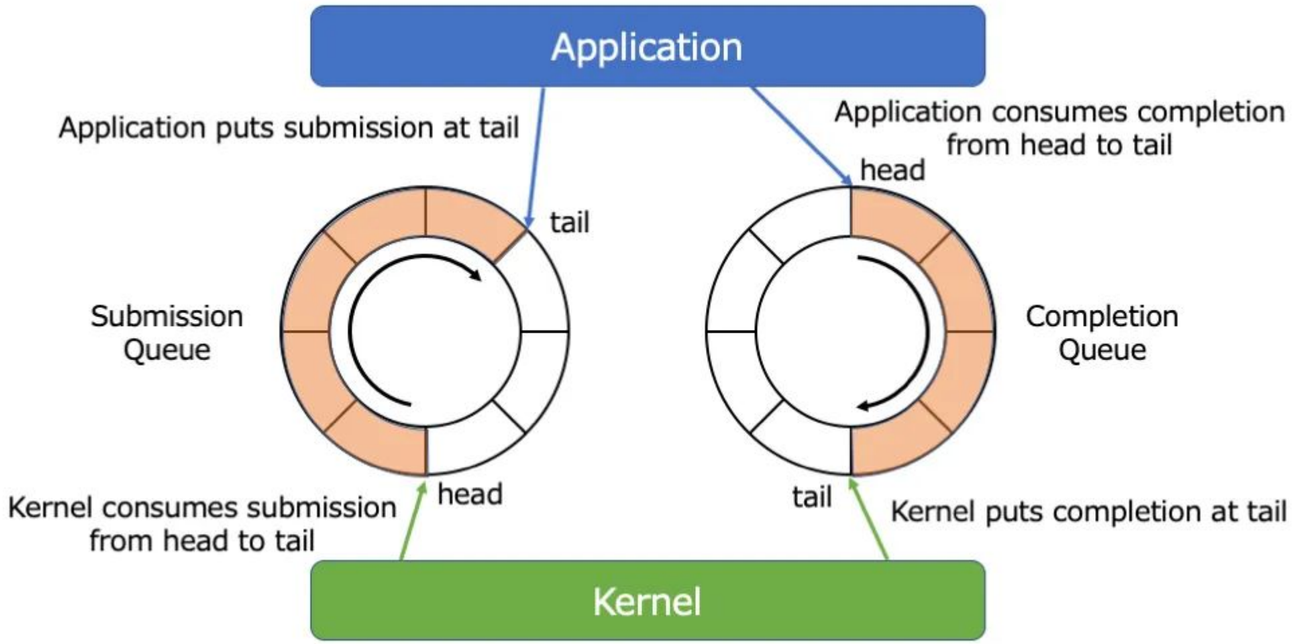


Image credit:
https://medium.com/nttlabs/rust-async-with-io-uring-db3fa2642dd4

Submit

```
io_uring_submit_and_wait(ring, nr_completions);
```

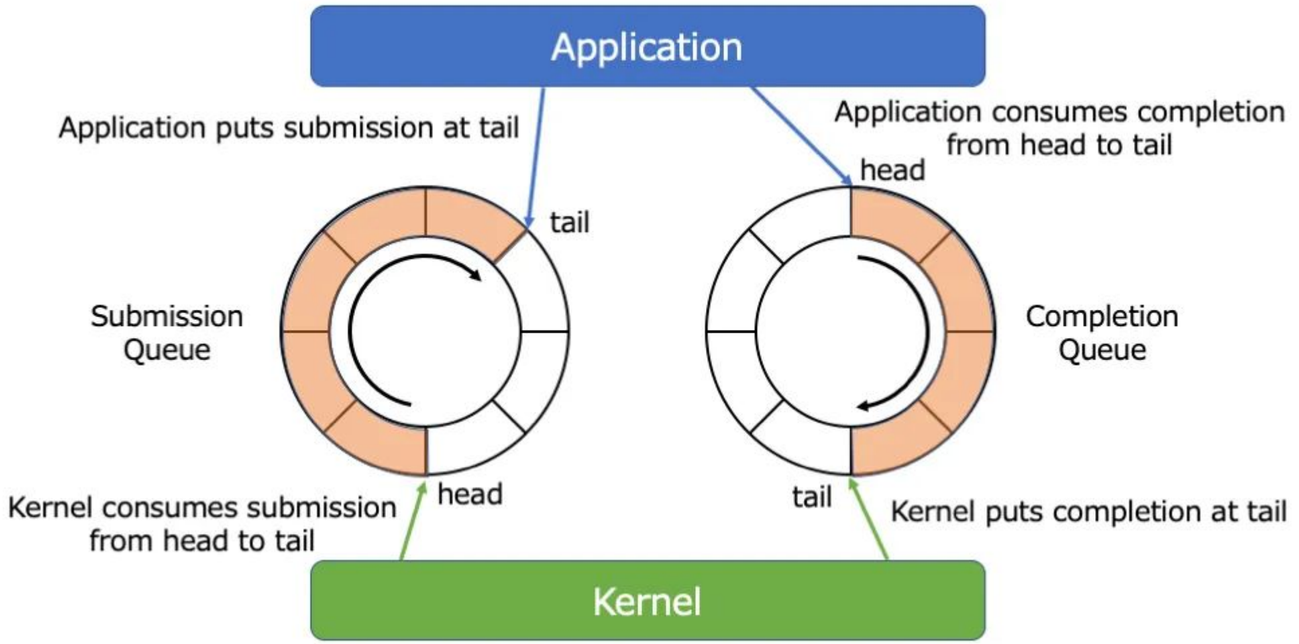


Image credit:
https://medium.com/nttlabs/rust-async-with-io-uring-db3fa2642dd4

Process completions

```
unsigned head;

int count = 0;

io_uring_for_each_cqe(ring, head, cqe) {
        // do stuff
        count++;
}

io_uring_cq_advance(ring, count);
```

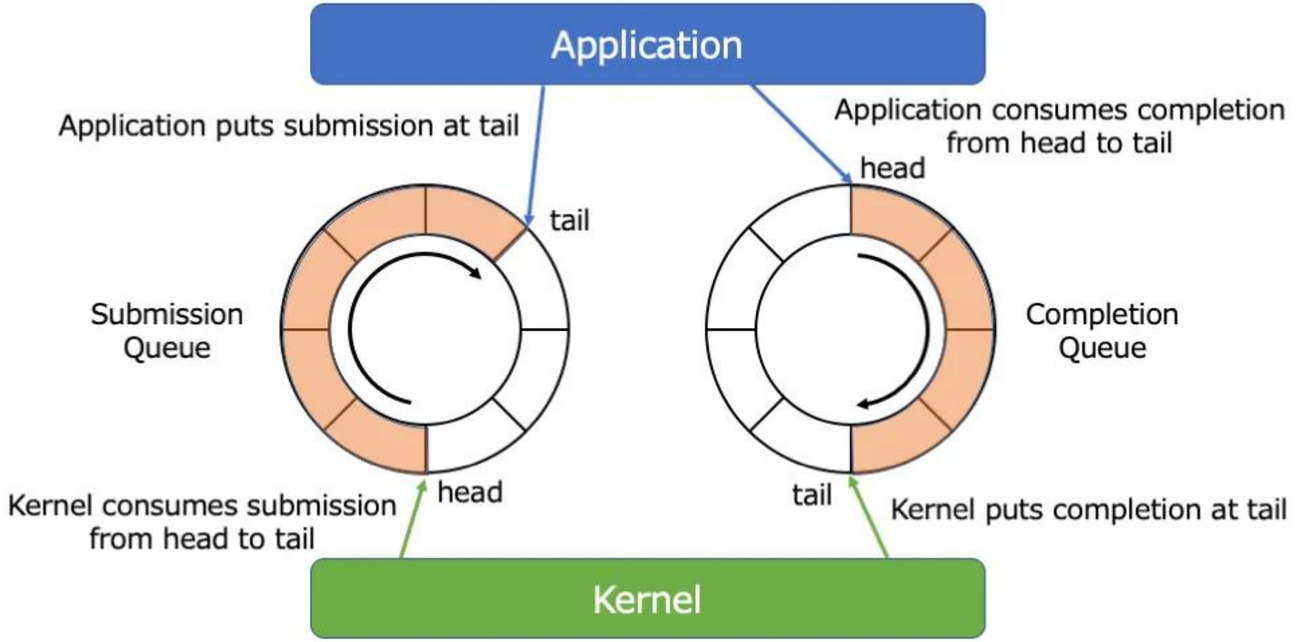
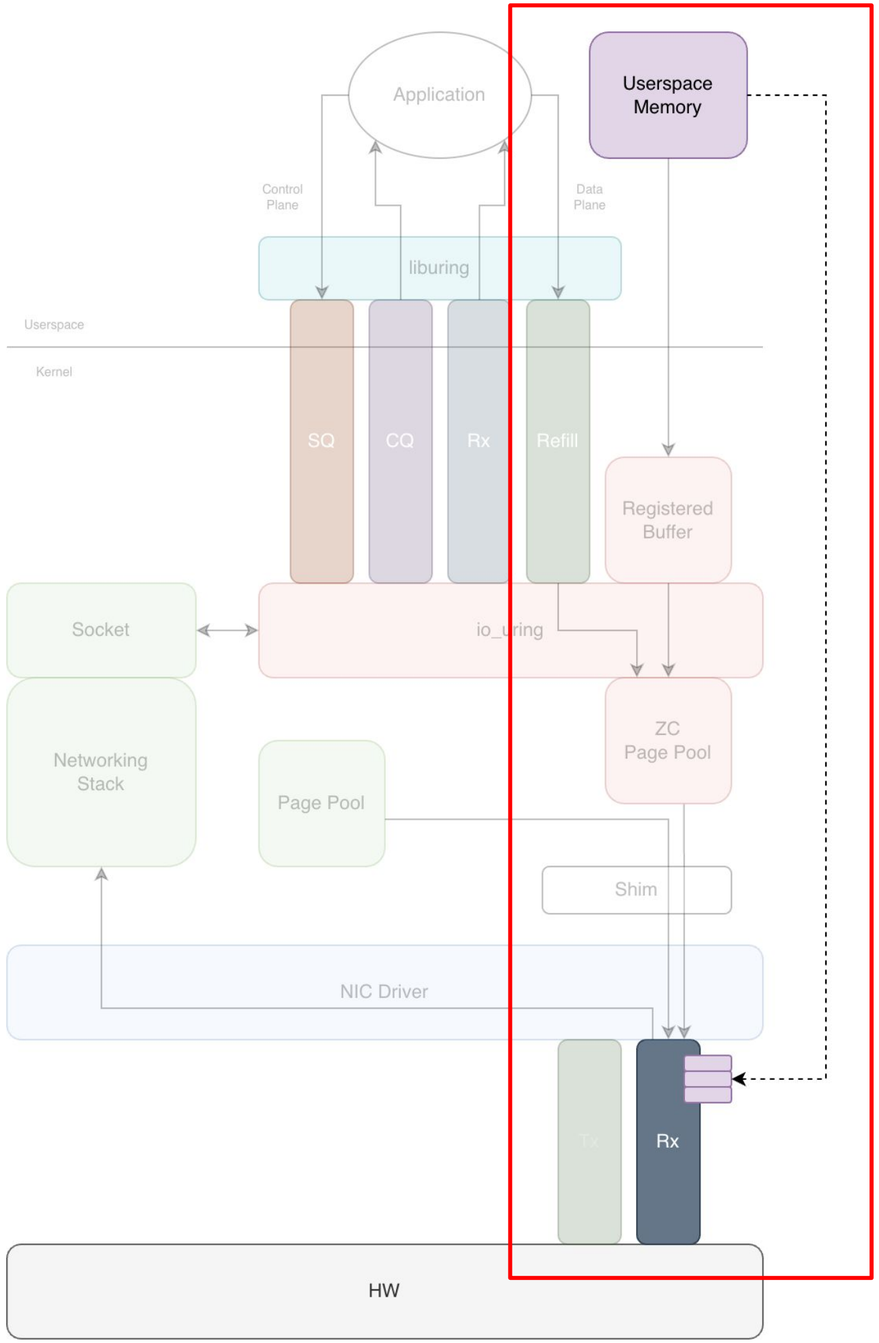


Image credit:
https://medium.com/nttlabs/rust-async-with-io-uring-db3fa2642dd4

03 Design

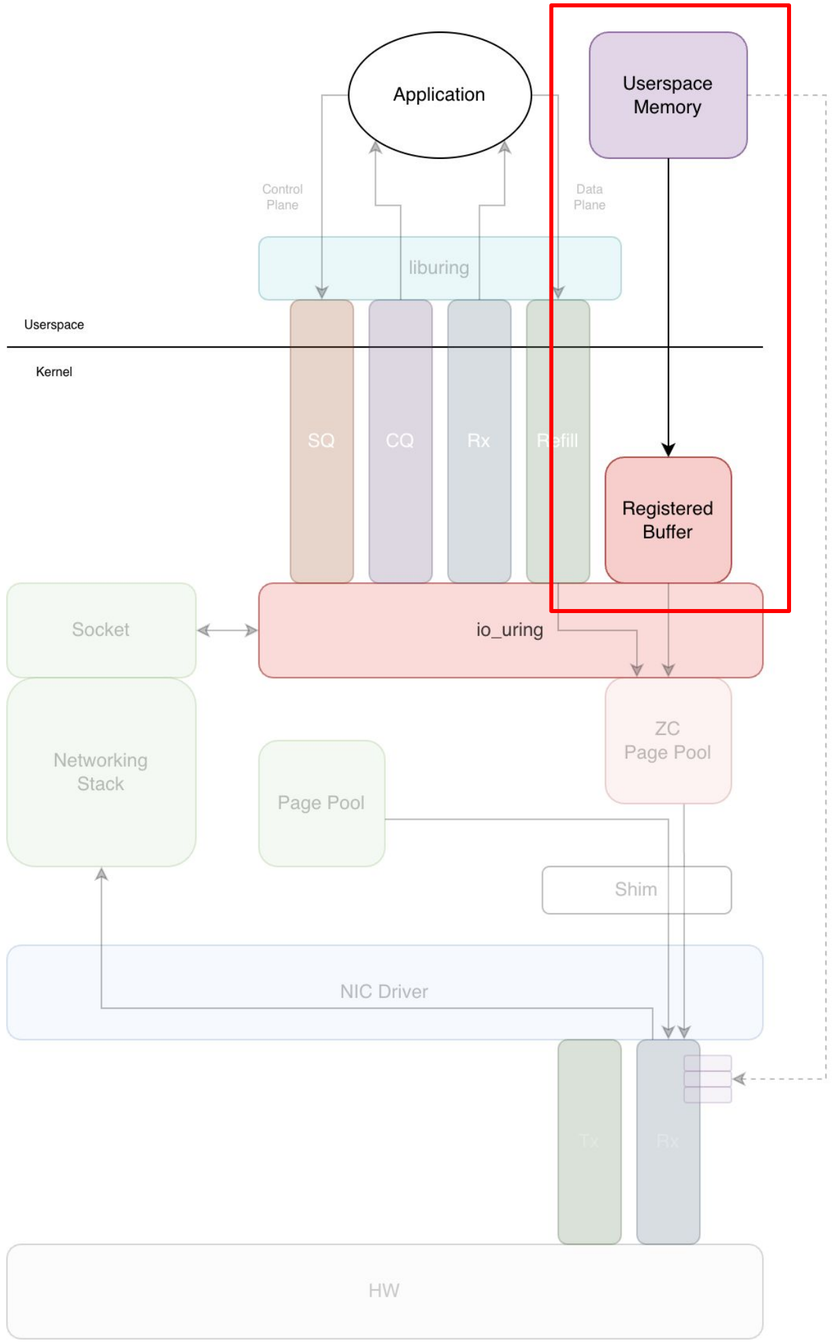
Buffer management

- sk_buffs with page frags pointing to userspace pages end up in sockets
- To do this:
  - Fill hardware Rx queue filled with *userspace* pages



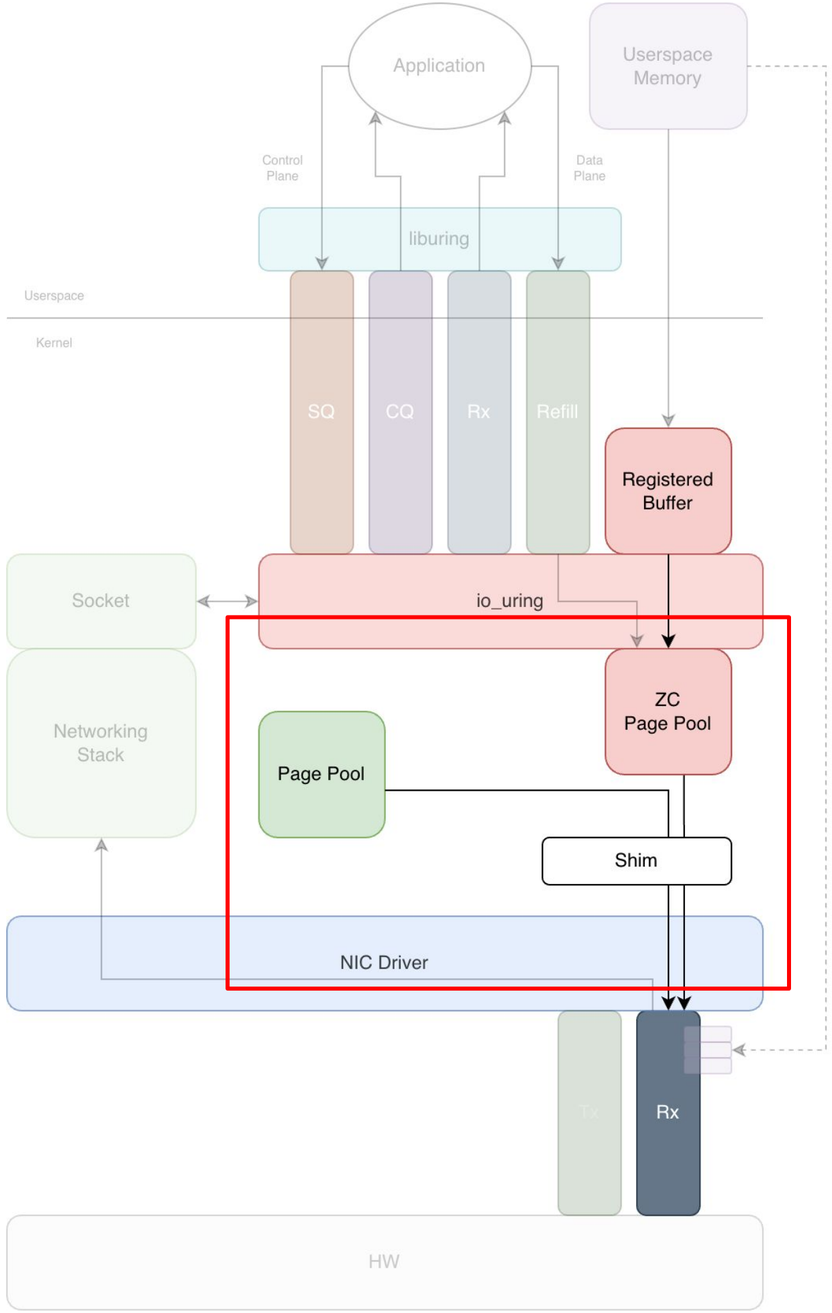
Buffer management: registration

- Register userspace memory with io_uring
- Pin pages
- struct bio_vec bvec[]



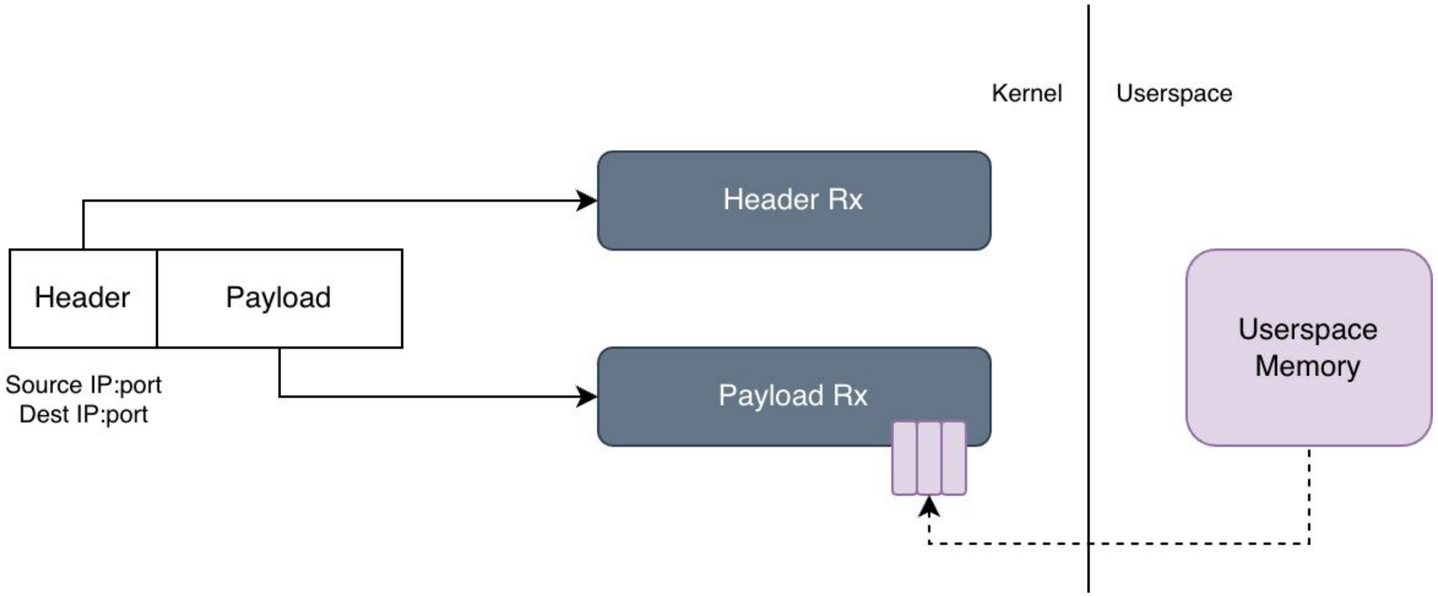
Buffer management: fill HW Rx queue

- Page pool evolving to become generic allocator for NICs
- Add ZC page pool “inspired” by page pool
- Thin shim layer + driver changes



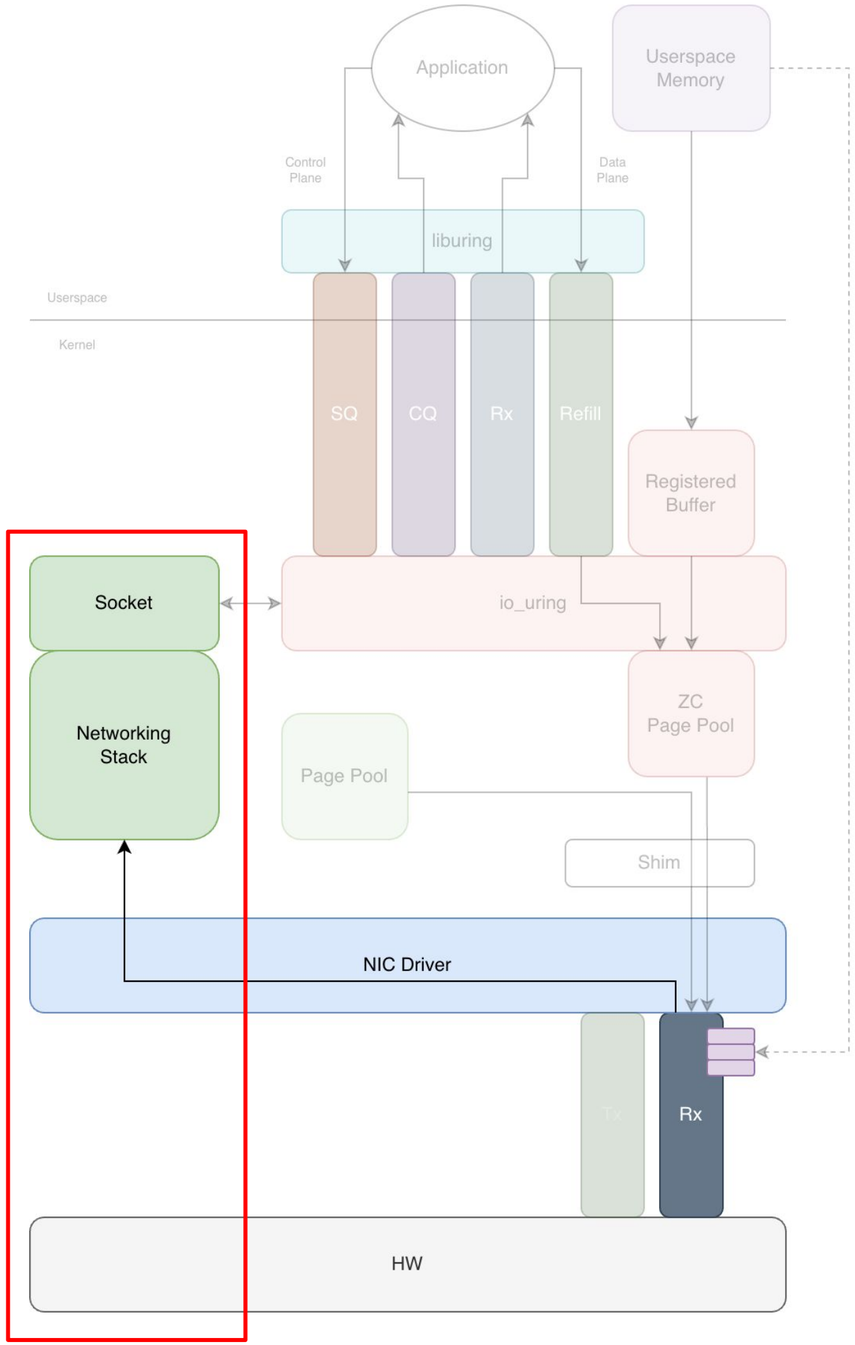
Header splitting + flow steering

- Only want payload
  - Header splitting
- Only want our specific application flows to hit our ZC hardware Rx queues
  - Flow steering
  - RSS



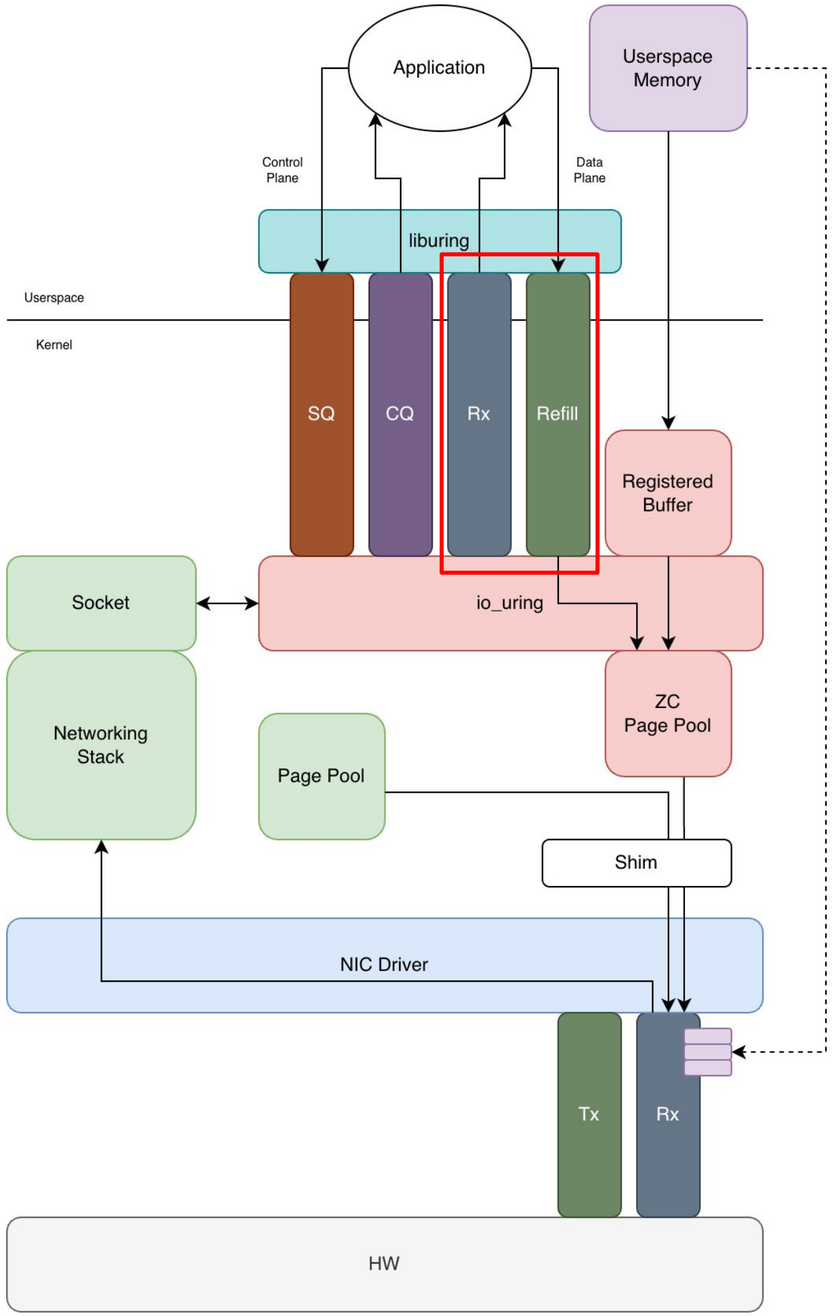
Kernel network stack

- Hardware side fully set up
- Hard IRQs
- Softirq - NAPI poll
- Construct sk_buffs
  - Marked as ZC Rx
  - Page frags → userspace pages
- Goes through networking stack



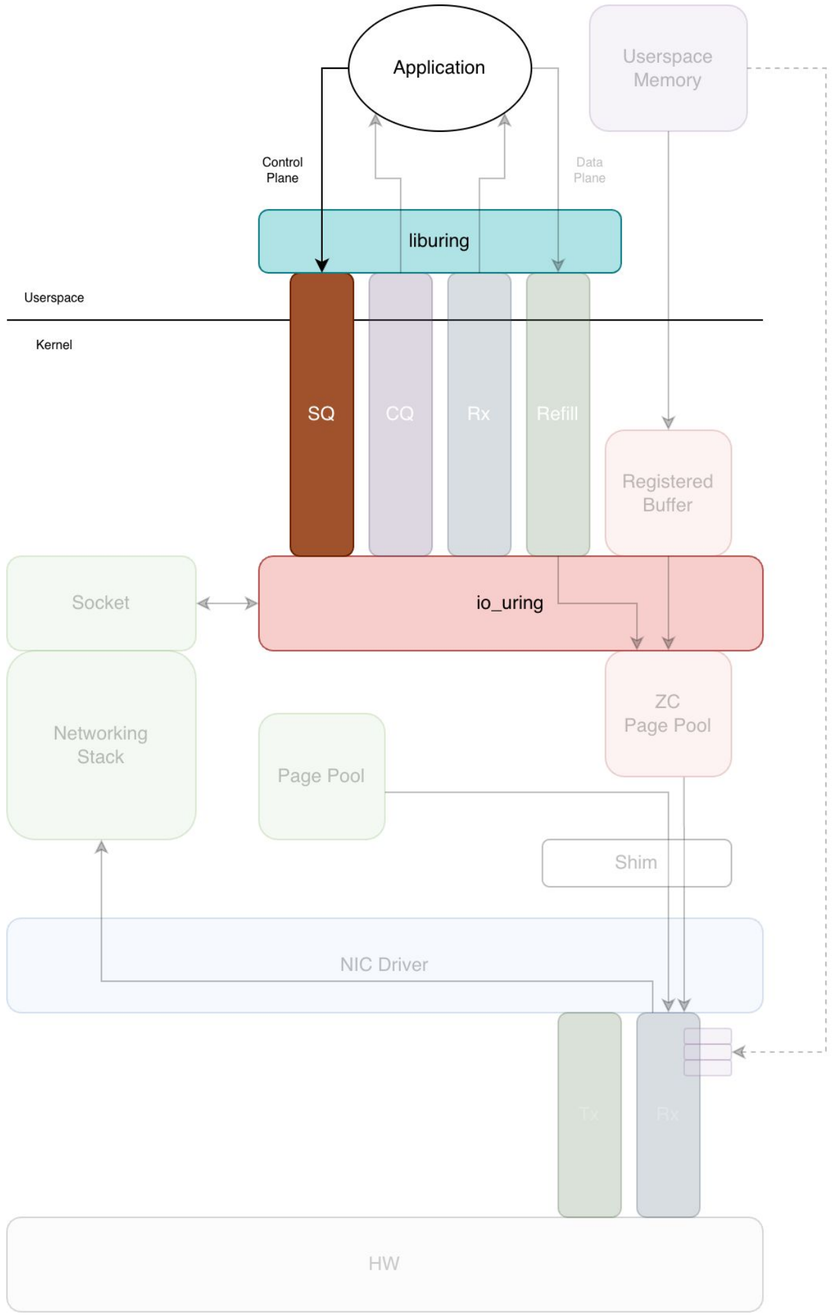
More rings

- Add two new shared ringbufs to io_uring:
  - Rx queue
  - Refill queue
- One pair per hardware Rx queue



Userspace: submit request

- Submit ZC receive request to io_uring
- Get SQE, prep, and submit

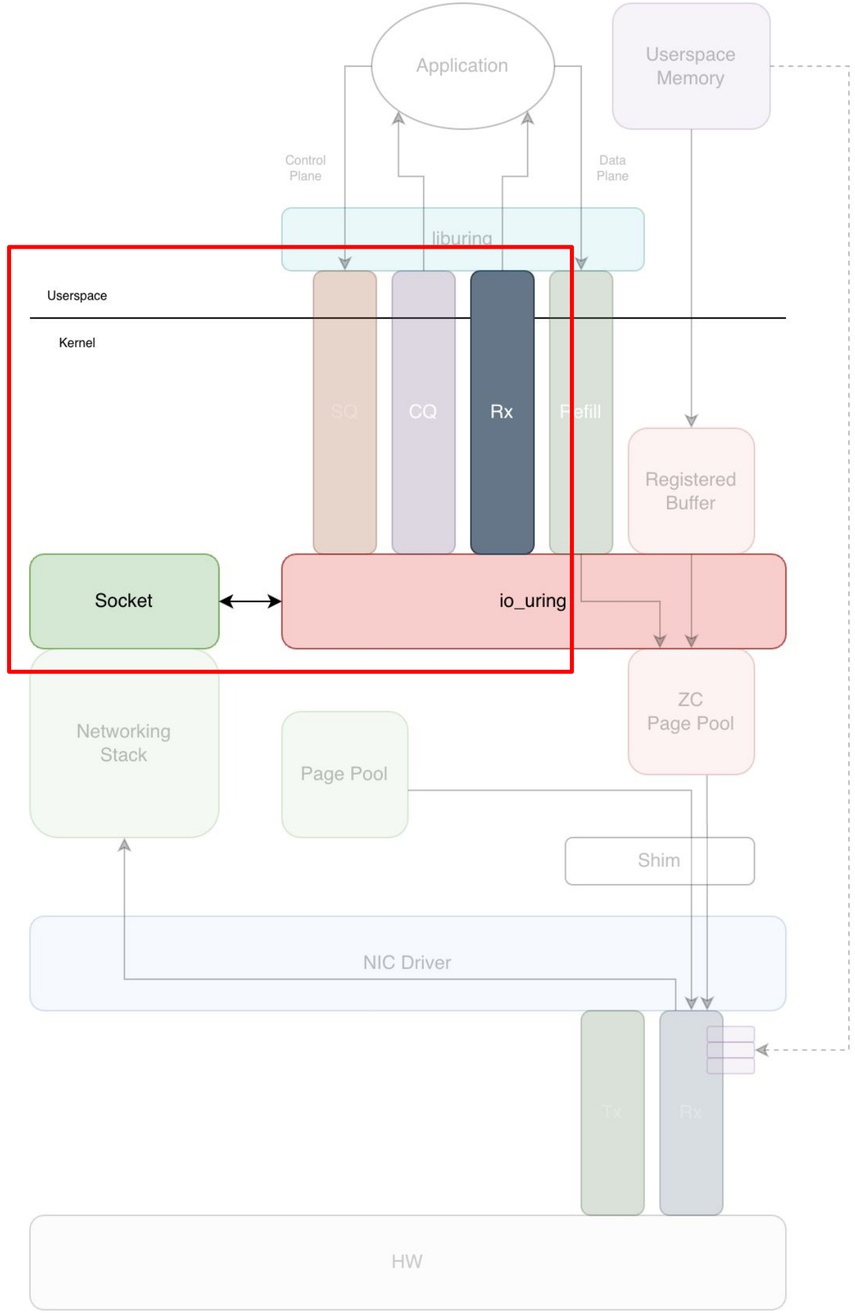


io_uring:

read socket

- Handle ZC receive request
- Read sk_buffs from socket
- No copy - payload already in userspace
- Post one ZC Rx queue entry per skb page frag

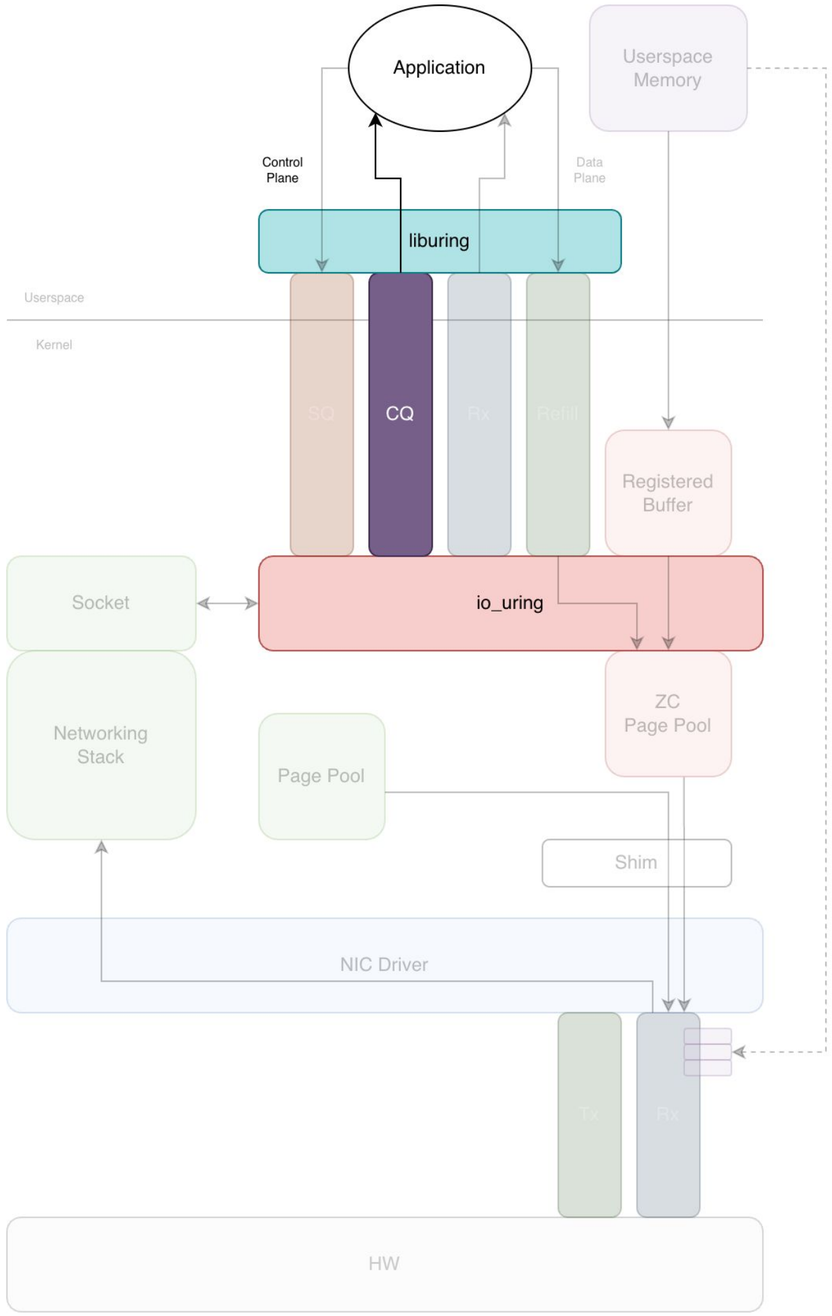
```
struct io_uring_rbuf_cqe {
        u32 off;
        u32 len;
        u16 region;
        u8 sock;
        u8 flags;
}
```



io_uring:

notify userspace

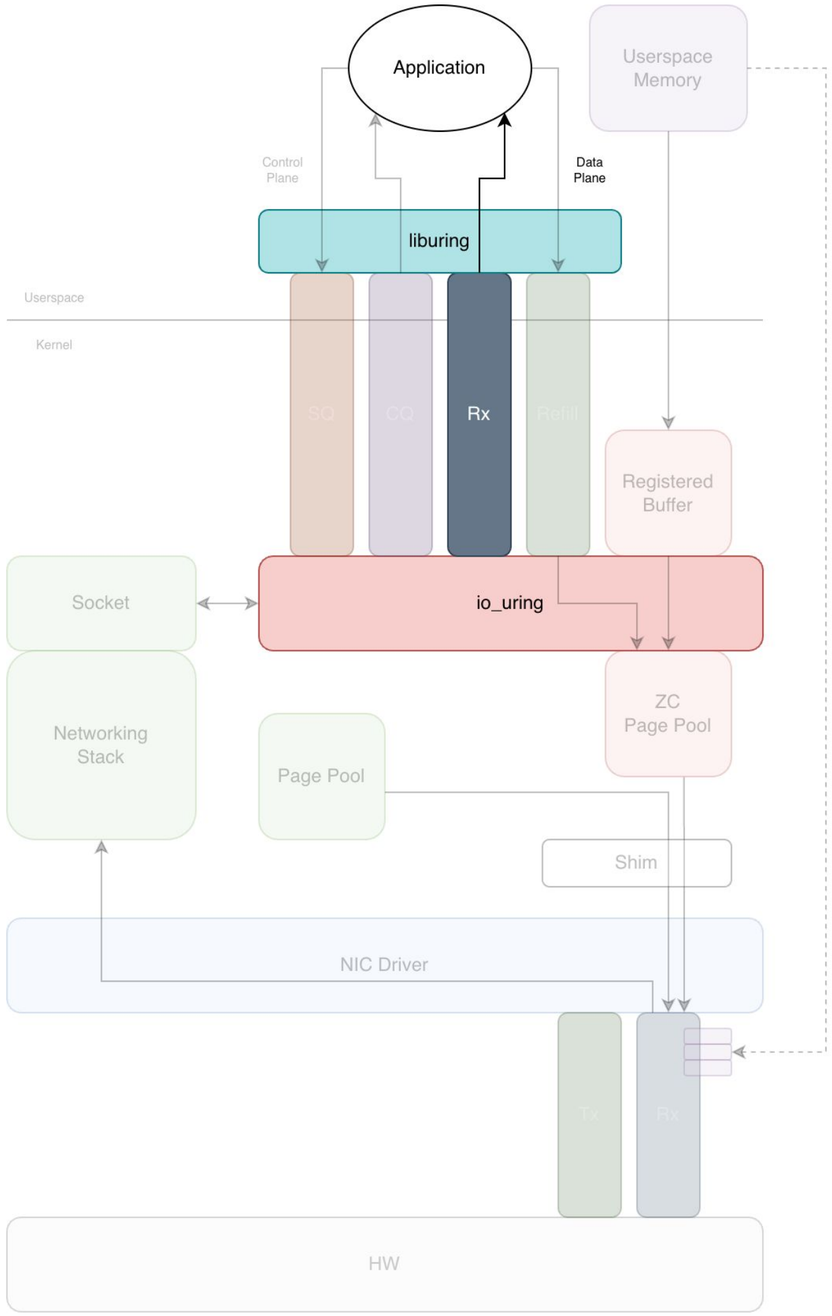
- Post completion event into CQ
- Tells userspace to go look at a ZC Rx queue



Userspace: read data

- Look at a ZC Rx queue
- Each entry tells user where the payload is relative to the registered memory region

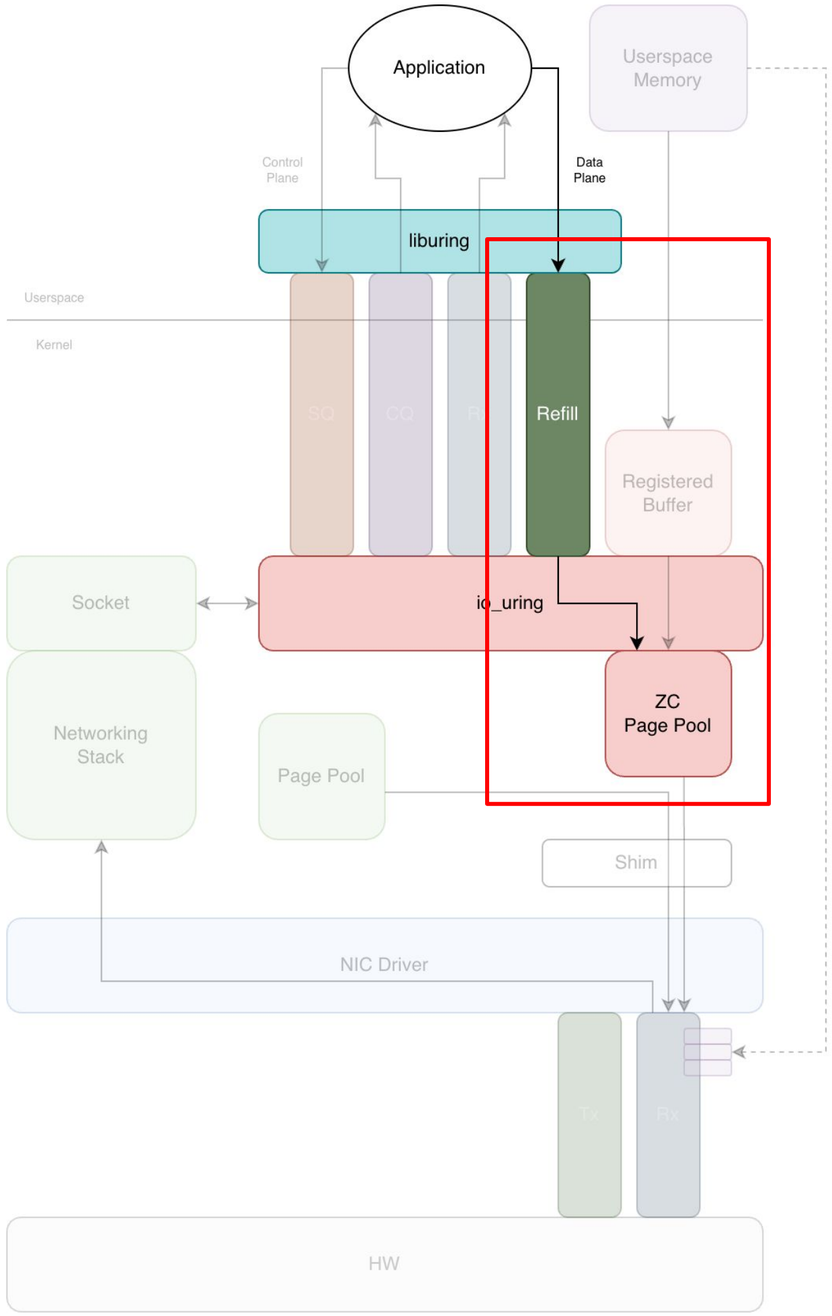
```
struct io_uring_rbuf_cqe {
        u32 off;
        u32 len;
        u16 region;
        u8 sock;
        u8 flags;
}
```



Userspace: return buffers

- Return buffers to ZC page pool via refill queue
- Eventually used by NIC driver to refill hardware Rx queue

```
struct io_uring_rbuf_rqe {
    u32 off;
    u32 len;
    u16 region;
}
```



04 Preliminary Results

MemBW

Broadcom BCM57504 NIC @ 25 Gbps link

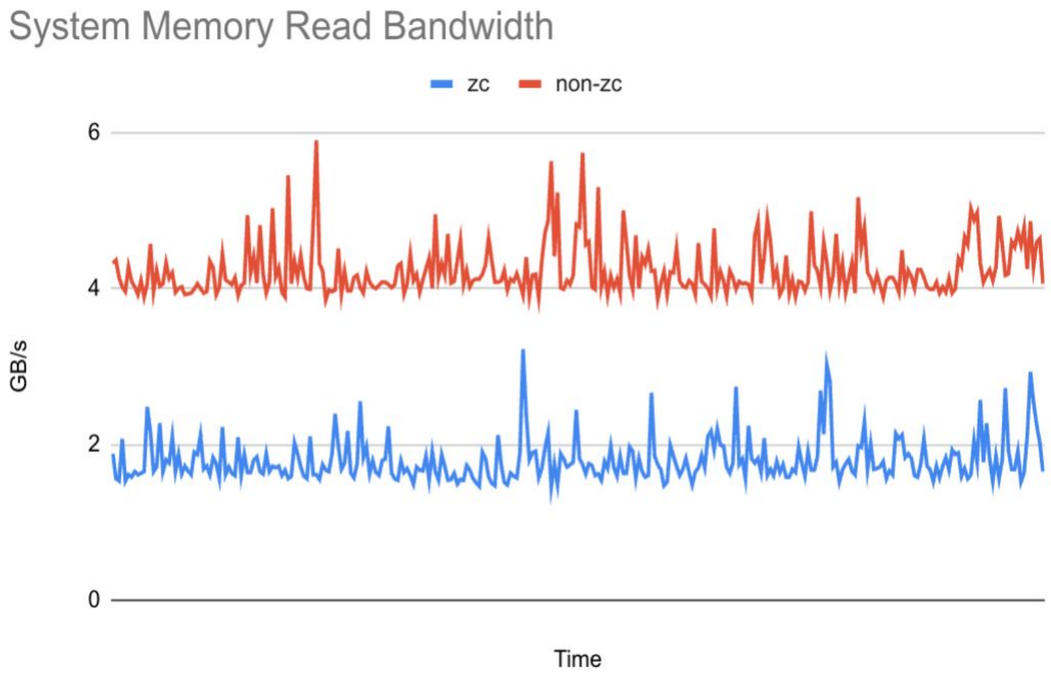
62 GB DRAM

iperf3 + io_uring + ZC Rx

AMD EPYC 7D13

iperf3

uProf



MemBW

Broadcom BCM57504 NIC @ 25 Gbps link

62 GB DRAM

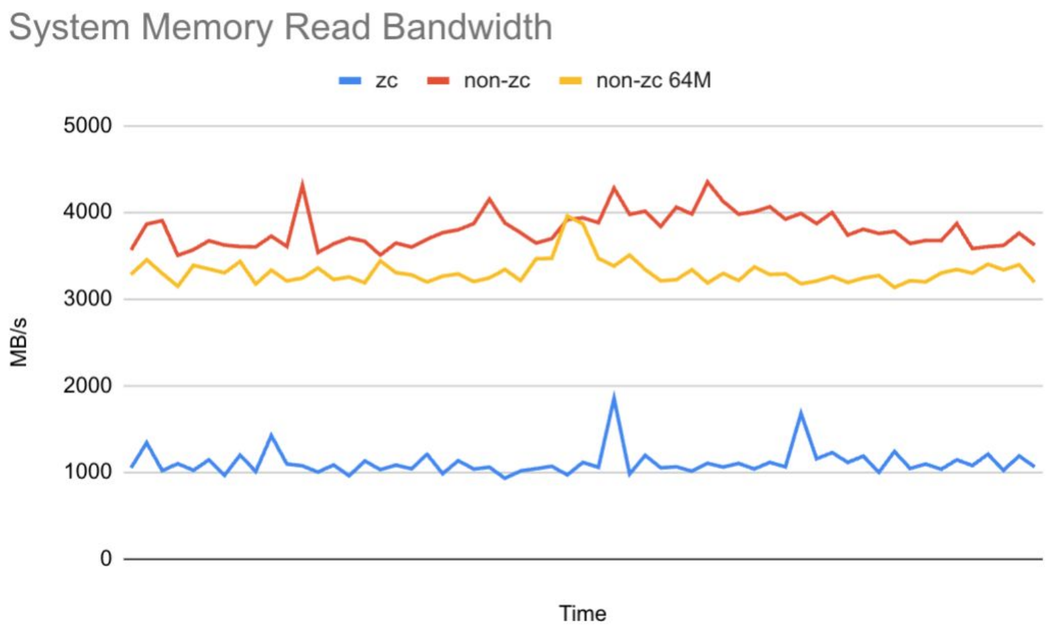
iperf3 + io_uring + ZC Rx

Intel Xeon Platinum 8321HC

iperf3

pcm-memory

DDIO is off



05 Status + future work

Status

- V2 RFC is on the mailing list (netdev + io-uring)
- Hacky veth support if you want to play with the API
- Broadcom bnxt hardware support
- Multi-socket
- Copy fallback

Future work

- Jakub Kicinski’s memory provider API
- Proper test device
  - netdevsim?
- Tying flow steering rules with socket
- Dynamic Rx queue reconfiguration
- Support GPU device memory
  - Using Google’s TCP devmem proposal

06 Questions + discussions


Meta

07 Appendix

Open questions

- Containers + VMs support?
- TLS + kTLS?
- HugePages?

Copy fallback

- What if we run out of userspace memory allocated for ZC Rx?
- Fill HW Rx queue with kernel pages - as before
- When io_uring ZC receive finds sk_buffs with page frags that are not ZC pages, copy into a page from refill queue

Handling errors

- How much to allocate ahead of time?
- What if it runs out?
- What if header splitting fails?
  - Split too little - header malformed
  - Split too much - payload included
- What if flow steering fails?
  - ZC Rx packet ends up in non-ZC Rx queue
  - Non-ZC Rx packet ends up in ZC Rx queue

Integrating ZC Rx well

- NIC → userspace memory is only one hop in a long end to end pipeline
- What if data needs to be modified after ZC Rx? Another copy…
- API need to expose fine control over the placement of data to satisfy constraints e.g. alignment
  - Hardware also needs to support this too