Speeding up VM's I/O sharing host's io_uring queues with guests

KVM Forum 2020

Stefano Garzarella <sgarzare@redhat.com>

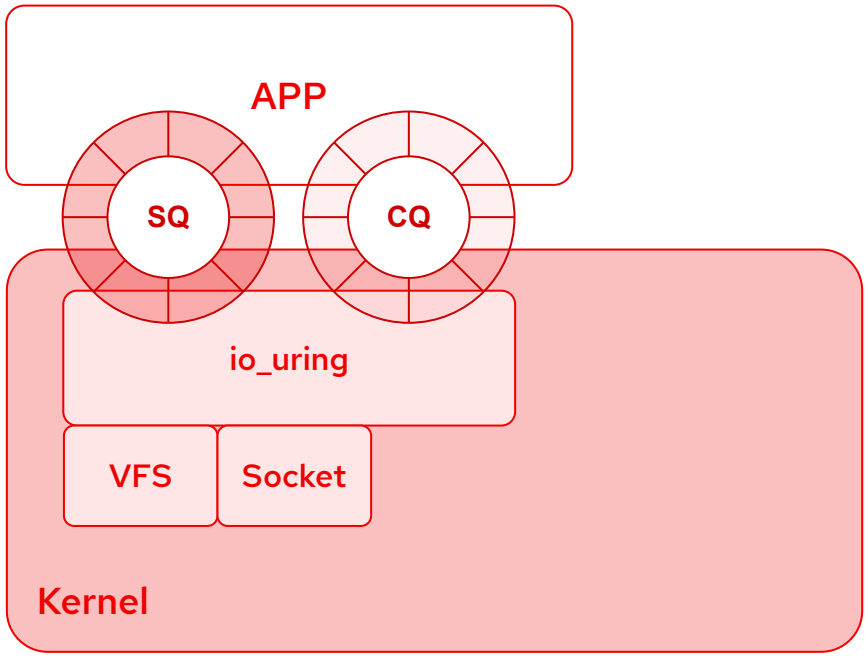
Senior Software Engineer @ Red Hat

Red Hat

Agenda

- io_uring overview
  - system calls
  - queues
  - resources registration
  - polling
- QEMU and io_uring
  - virtio block with io_uring backend
- io_uring passthrough
- vhost-blk
- vdpa-blk
- Next steps

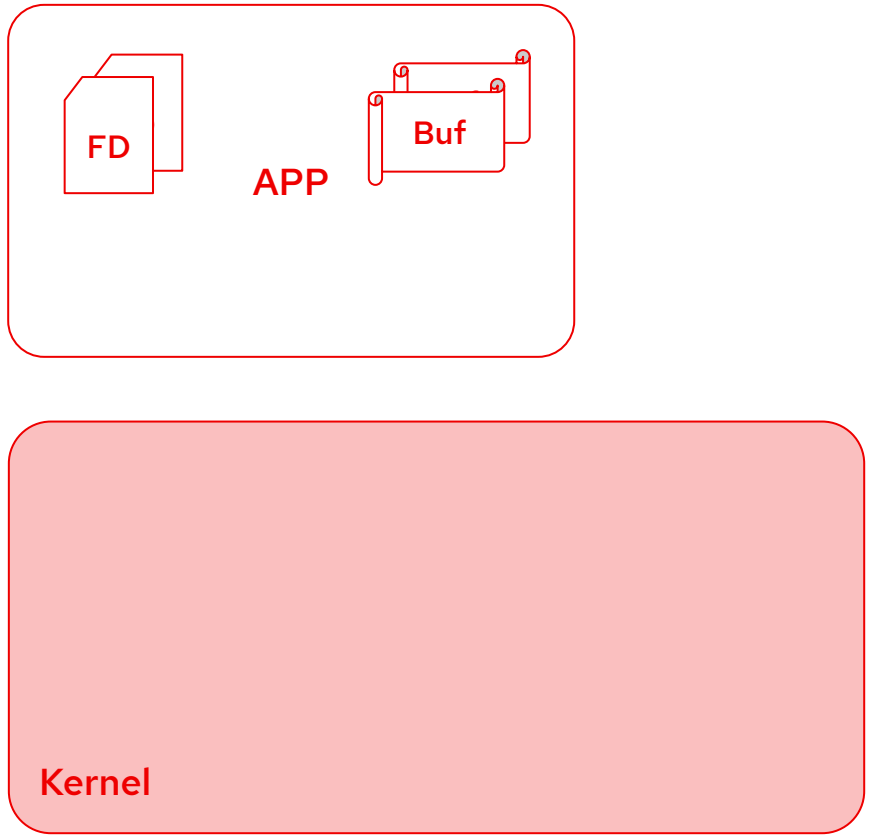
io_uring overview



- A new **Linux** interface for **asynchronous I/O**
  - Not only for block oriented I/O
- A **pair of rings** shared between kernel and application
  - Submission Queue (**SQ**)
  - Completion Queue (**CQ**)
- Three system calls
  - `io_uring_setup(2)`
  - `io_uring_register(2)`
  - `io_uring_enter(2)`

Red Hat

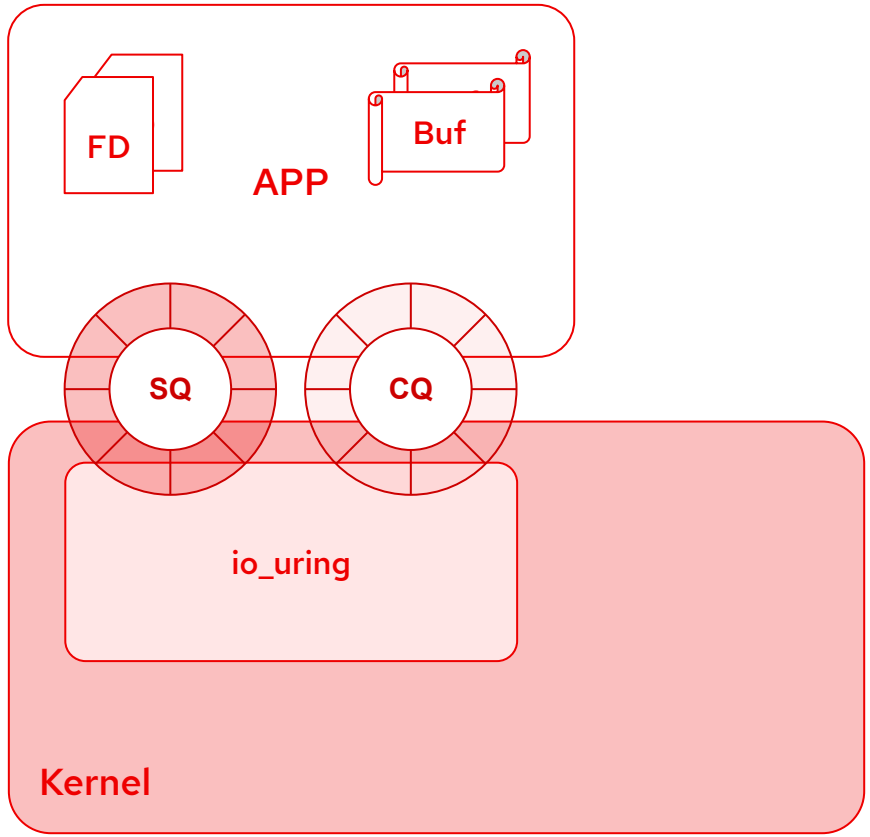
io_uring system calls



Red Hat

io_uring system calls

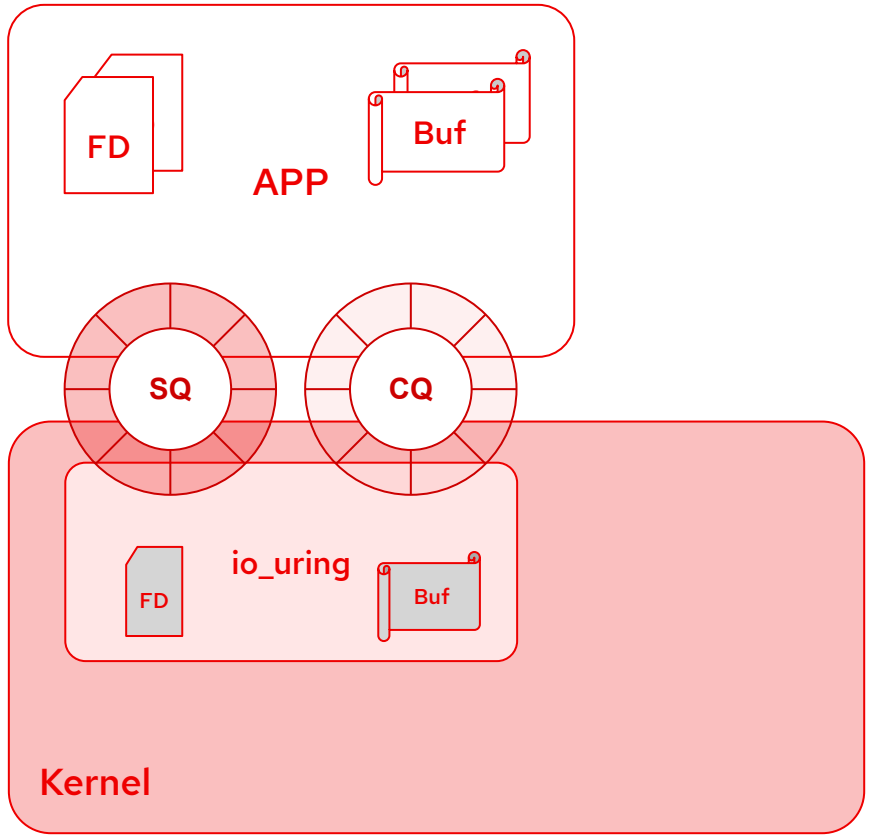
- **`io_uring_setup(2)`**
  - setup a context for performing asynchronous I/O



Red Hat

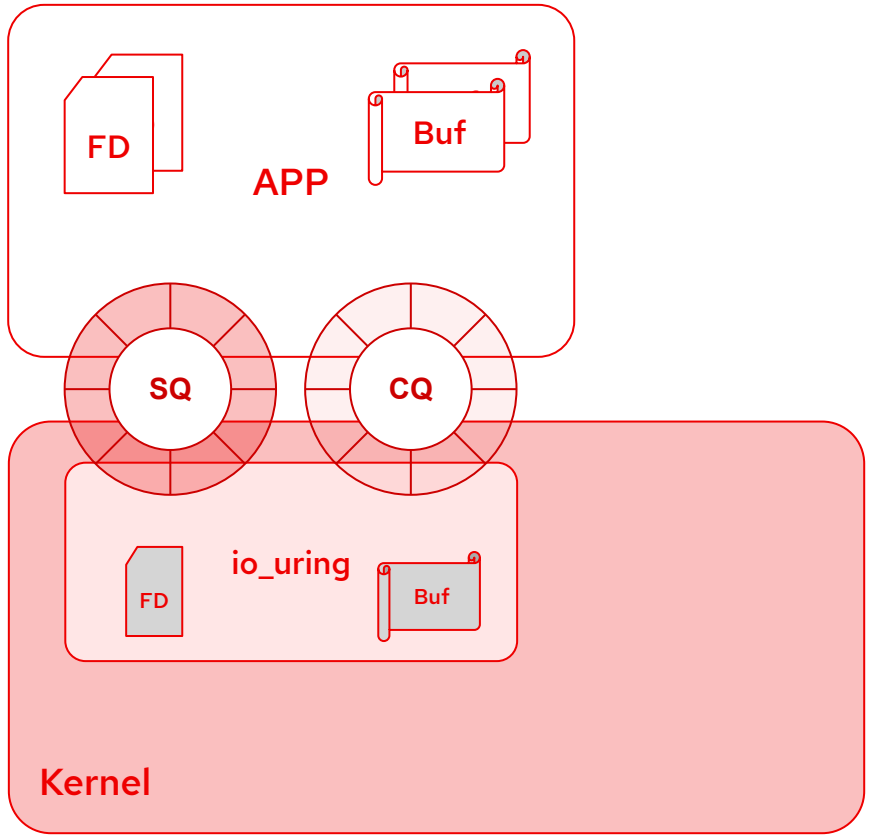
io_uring system calls

- **`io_uring_setup(2)`**
  - setup a context for performing asynchronous I/O
- **`io_uring_register(2)`**
  - registers resources (e.g. user buffers, files, eventfd, personality, restrictions) in the context



io_uring system calls

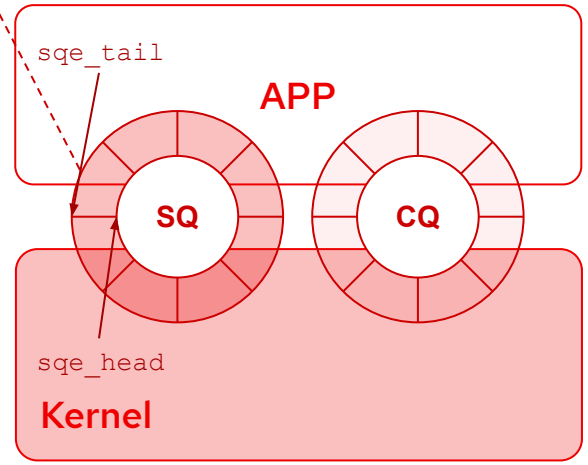
- **`io_uring_setup(2)`**
  - setup a context for performing asynchronous I/O
- **`io_uring_register(2)`**
  - registers resources (e.g. user buffers, files, eventfd, personality, restrictions) in the context
- **`io_uring_enter(2)`**
  - initiate and/or complete asynchronous I/O
  - single system call
    - submit new operations to do
    - reap operations result



Red Hat

Submission and Completion Queues

SQE
opcode
flags
fd
addr
off
...
user_data

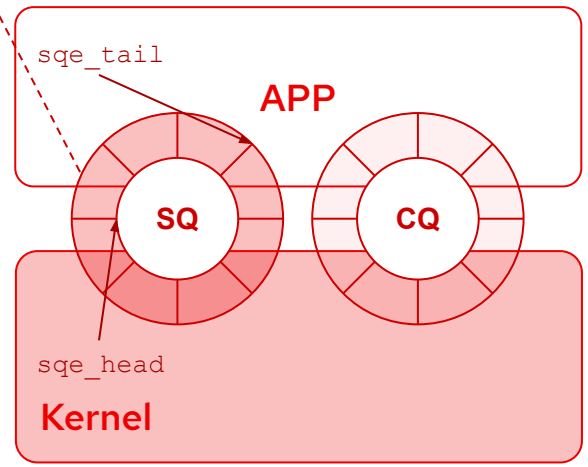


- **Submission Queue (SQ)**
  - Application
    - produces SQEs (SQ Entry)
      - operation to do (opcode)

Red Hat

Submission and Completion Queues

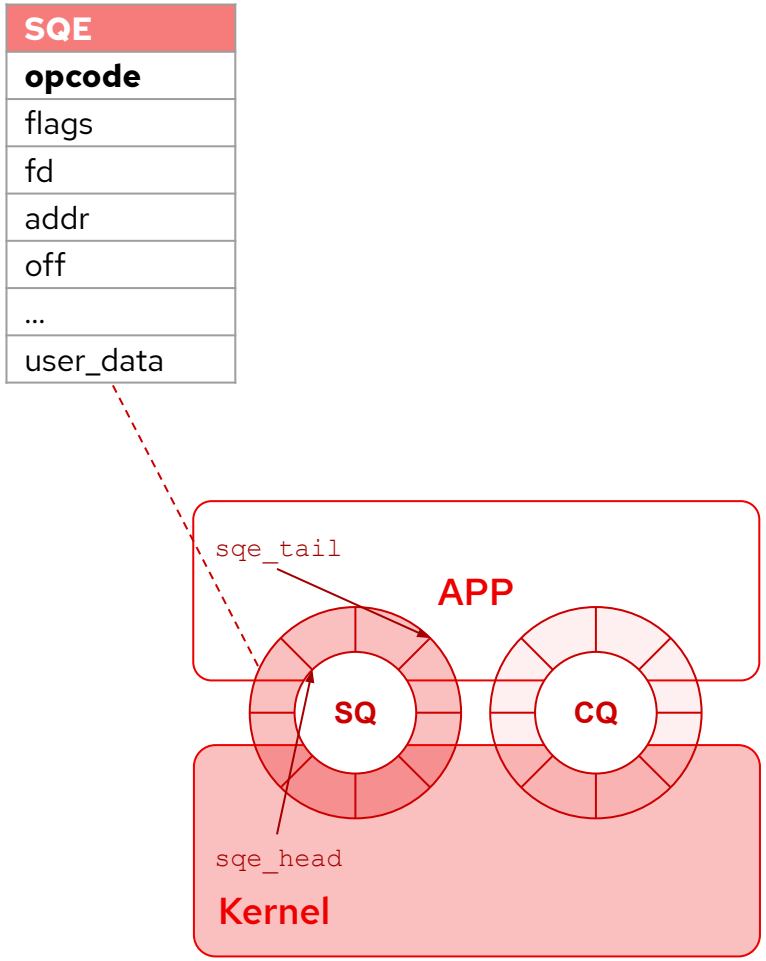
SQE
opcode
flags
fd
addr
off
...
user_data



- **Submission Queue (SQ)**
  - Application
    - produces SQEs (SQ Entry)
      - operation to do (opcode)
    - updates `sqe_tail`
    - invokes `io_uring_enter(2)`

Red Hat

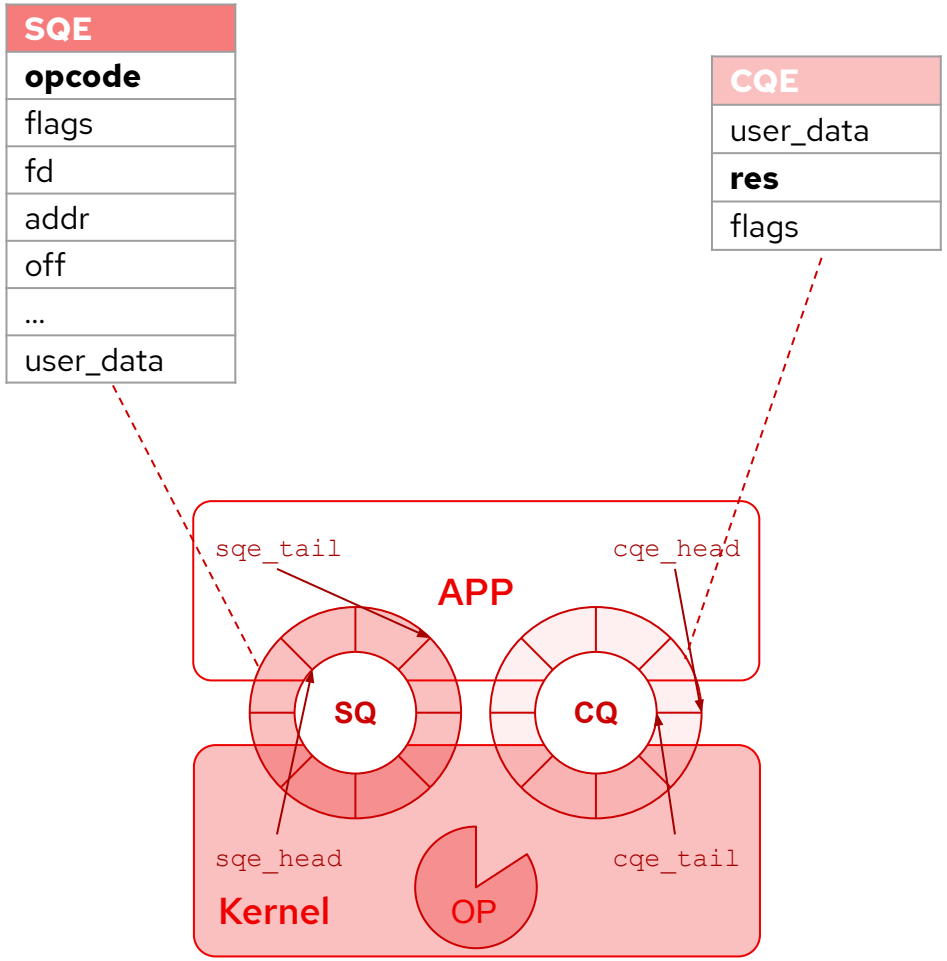
Submission and Completion Queues



- **Submission Queue (SQ)**
  - Application
    - produces SQEs (SQ Entry)
      - operation to do (opcode)
    - updates `sqe_tail`
    - invokes `io_uring_enter(2)`
  - Kernel
    - consumes SQEs
    - updates `sqe_head`

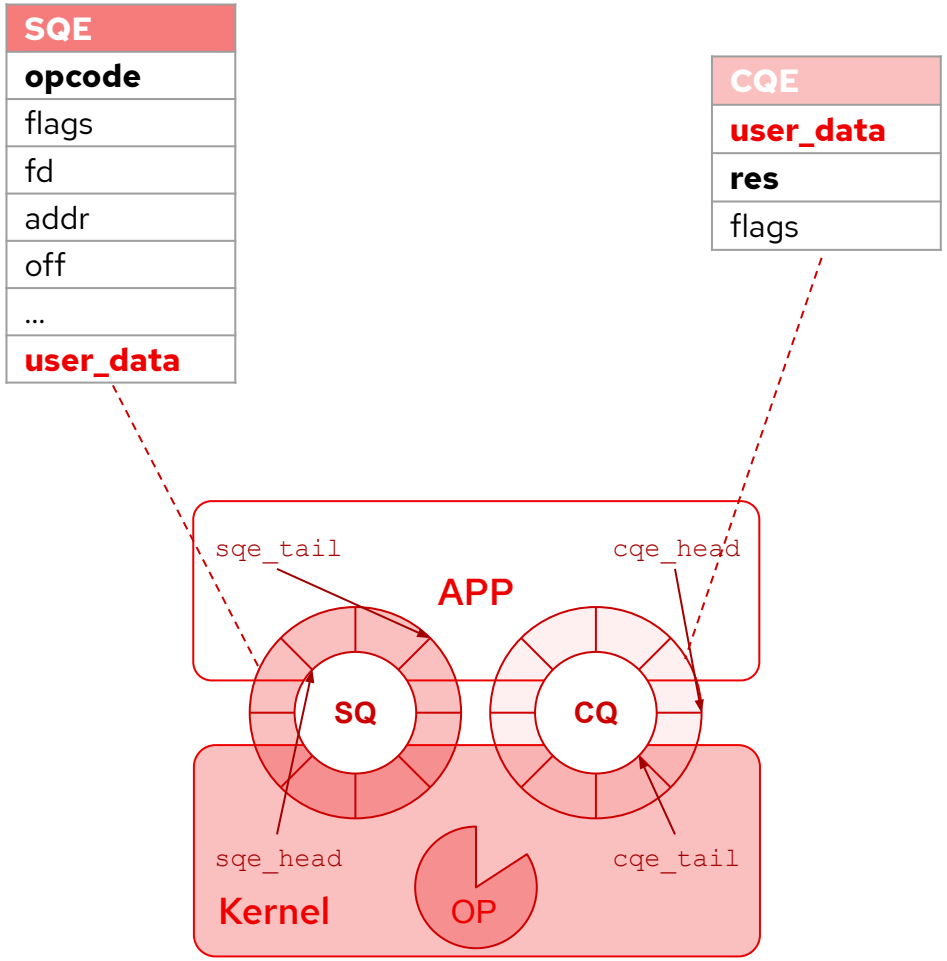
Red Hat

Submission and Completion Queues



- **Submission Queue (SQ)**
  - Application
    - produces SQEs (SQ Entry)
      - operation to do (opcode)
    - updates `sqe_tail`
    - invokes `io_uring_enter(2)`
  - Kernel
    - consumes SQEs
    - updates `sqe_head`
- Kernel processes the operation

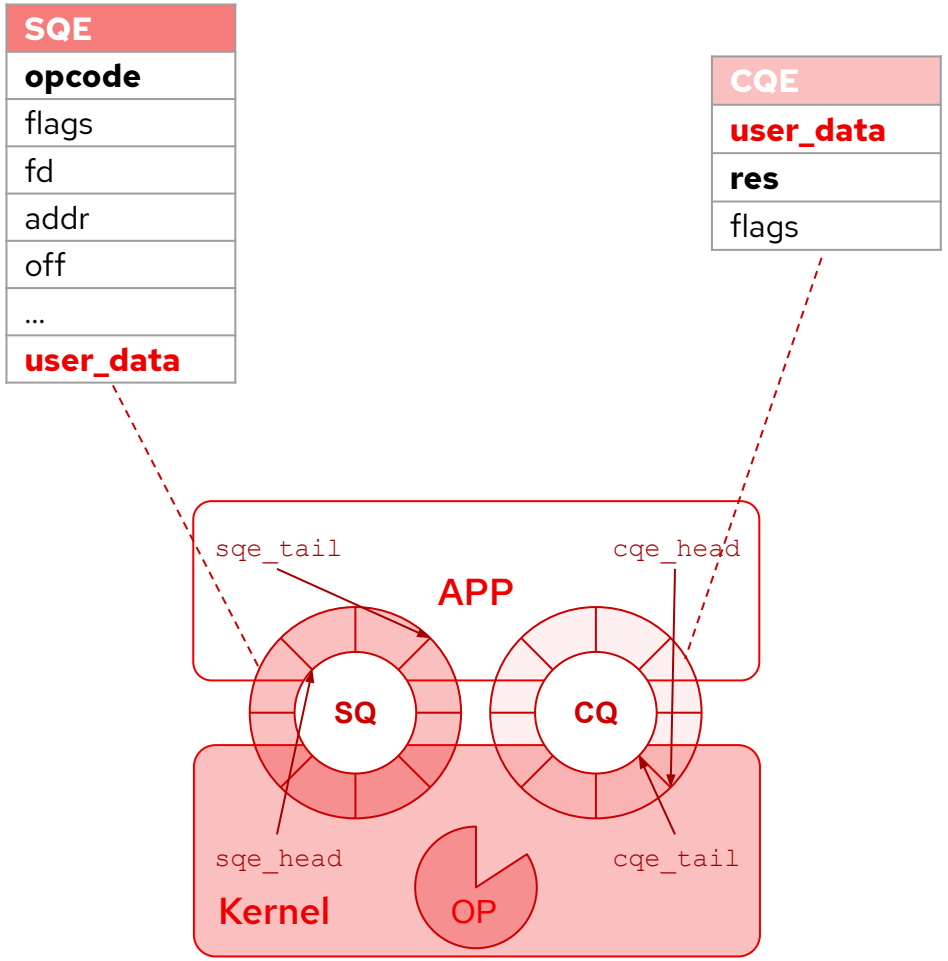
Submission and Completion Queues



- **Submission Queue (SQ)**
  - Application
    - produces SQEs (SQ Entry)
      - operation to do (opcode)
    - updates `sqe_tail`
    - invokes `io_uring_enter(2)`
  - Kernel
    - consumes SQEs
    - updates `sqe_head`
- Kernel processes the operation
- **Completion Queue (CQ)**
  - Kernel
    - produces CQEs (CQ entry)
      - operation result (res) and user_data
    - updates `cqe_tail`

Red Hat

Submission and Completion Queues

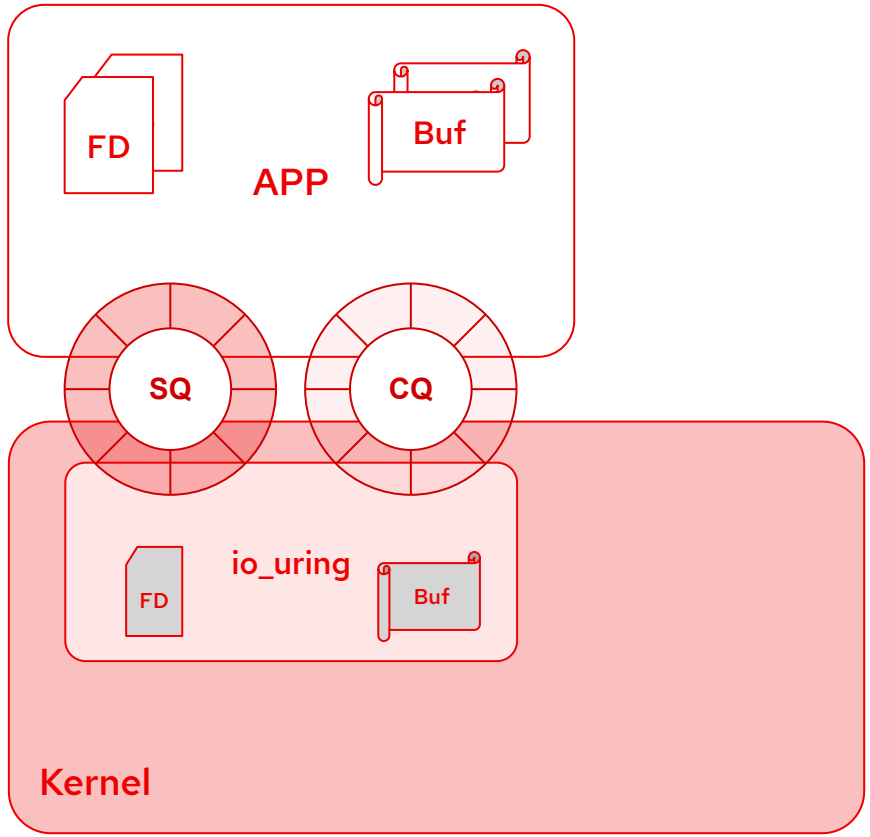


- **Submission Queue (SQ)**
  - Application
    - produces SQEs (SQ Entry)
      - operation to do (opcode)
    - updates `sqe_tail`
    - invokes `io_uring_enter(2)`
  - Kernel
    - consumes SQEs
    - updates `sqe_head`
- Kernel processes the operation
- **Completion Queue (CQ)**
  - Kernel
    - produces CQEs (CQ entry)
      - operation result (res) and user_data
    - updates `cqe_tail`
  - Application
    - consumes CQEs
    - updates `cqe_head`

Red Hat

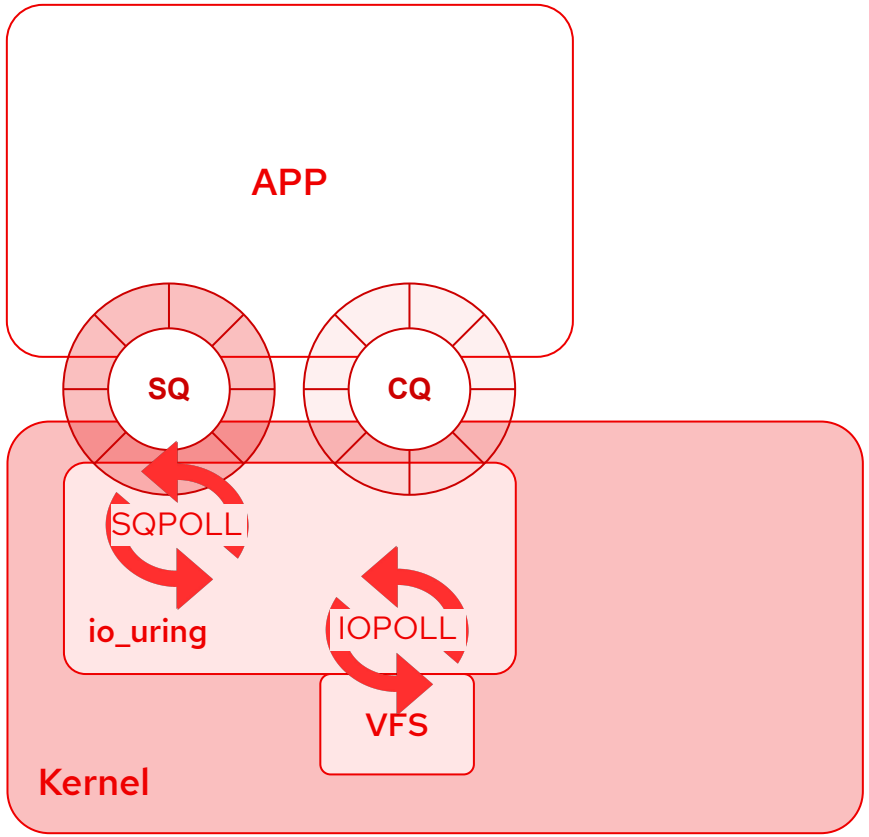
Resources registration

- `io_uring_register(2)` system call
  - register long term references to reduce per-I/O overhead
    - **user buffers**
    - **file descriptors**
  - register **eventfd** to receive notifications of completion requests
  - **probe** io_uring to get information about the opcodes supported
  - register **personality** to issue SQE with certain credentials
  - register **restrictions** to install feature allowlist
  - **enable** ring processing



Red Hat

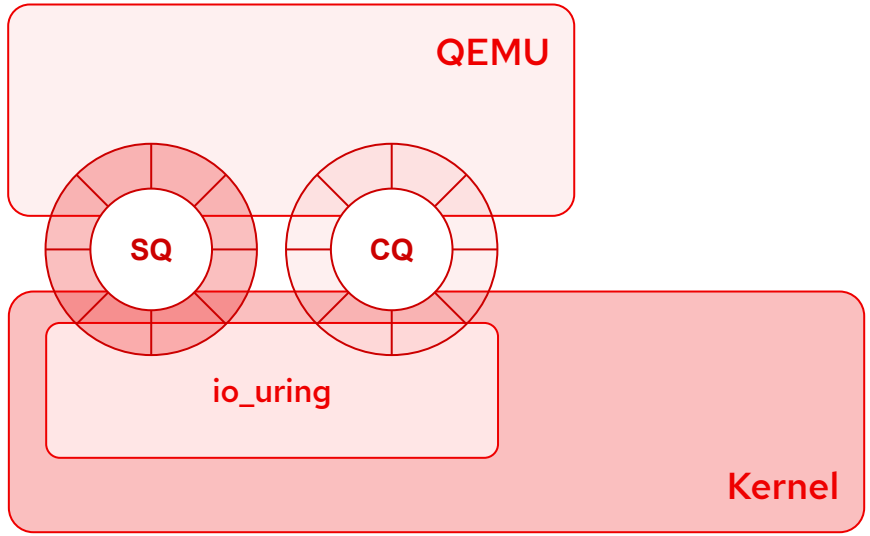
Polling



- **SQ polling**
  - `IORING_SETUP_SQPOLL` flag
  - kernel thread is created to perform submission queue polling
    - idle time is configurable
    - io_uring_enter() to wake up the kernel thread
  - Potentially application can submit and reap I/Os without doing a single system call
- **I/O polling**
  - `IORING_SETUP_IOPOLL` flag
  - busy-waiting for an I/O completion
    - opposed to getting notifications via an asynchronous IRQ
  - file system or block device must support polling

QEMU and io_uring

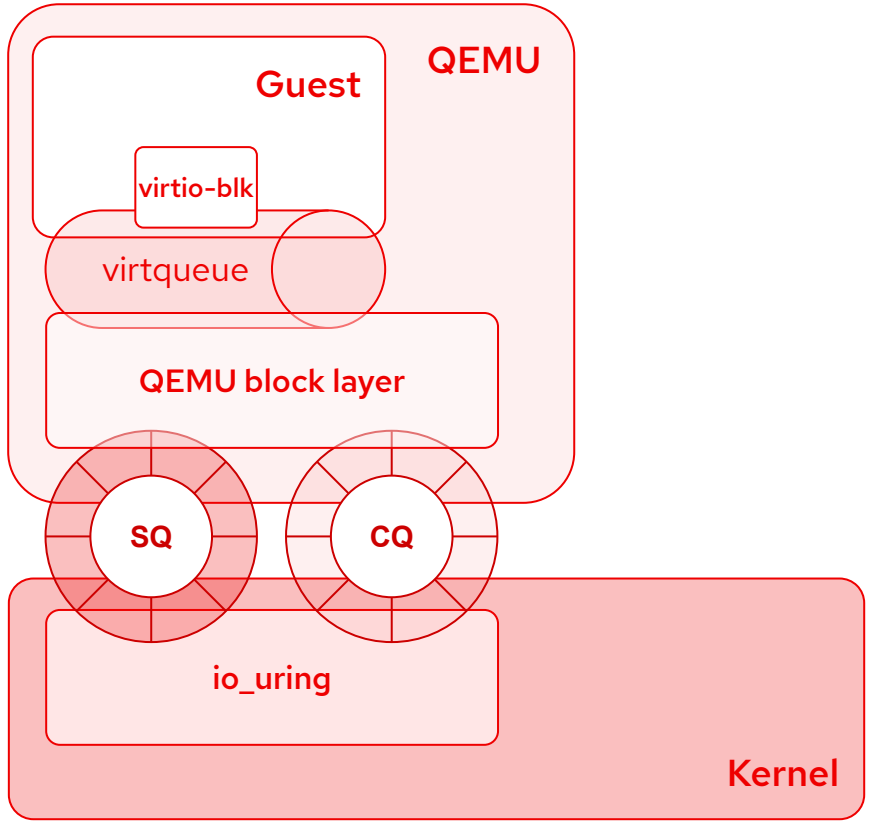
- QEMU 5.0 supports io_uring for Asynchronous I/O
- **AIO** engine
  - existing: thread, native (Linux AIO)
  - new: io_uring
    - **`-drive aio=io_uring`**
    - operations
      - `IORING_OP_WRITEV`
      - `IORING_OP_READV`
      - `IORING_OP_FSYNC`
- Developed by Aarushi Mehta, Julia Suvorova, and Stefan Hajnoczi



Red Hat

virtio block

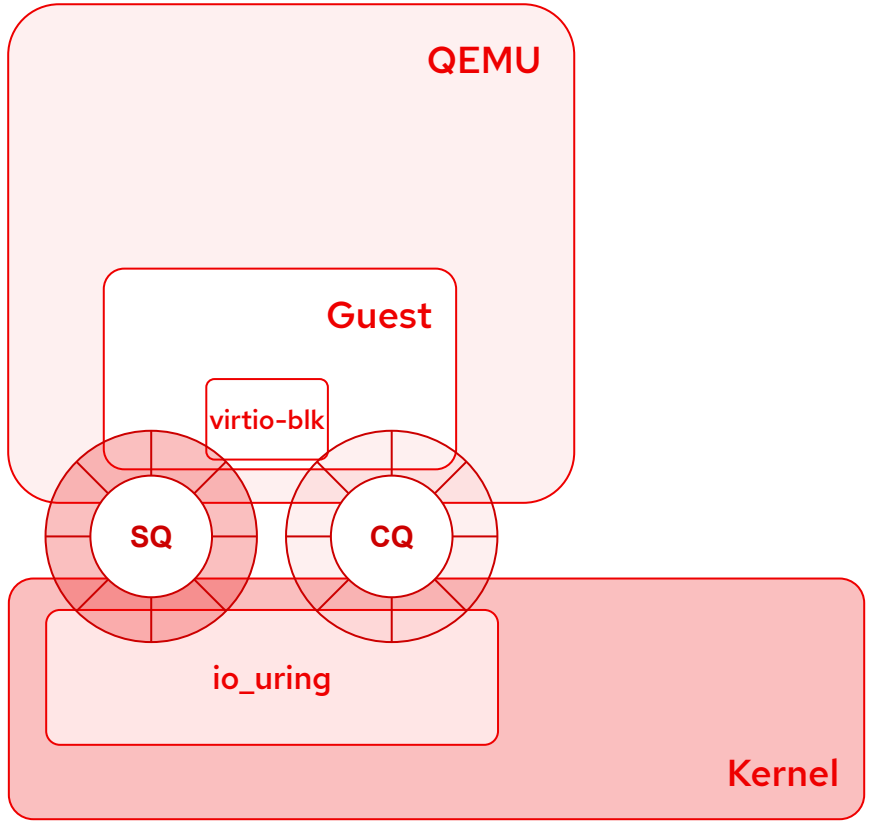
- Two communication channels
  - **virtqueue**
    - Guest kernel <-> QEMU
  - **io_uring queues (SQ, CQ)**
    - QEMU <-> Host kernel
- QEMU "translates" requests and responses between virtqueue and io_uring queues
- We can bypass the QEMU block layer if we are not using it's features (e.g. QCOW2)
  - **io_uring passthrough**



Red Hat

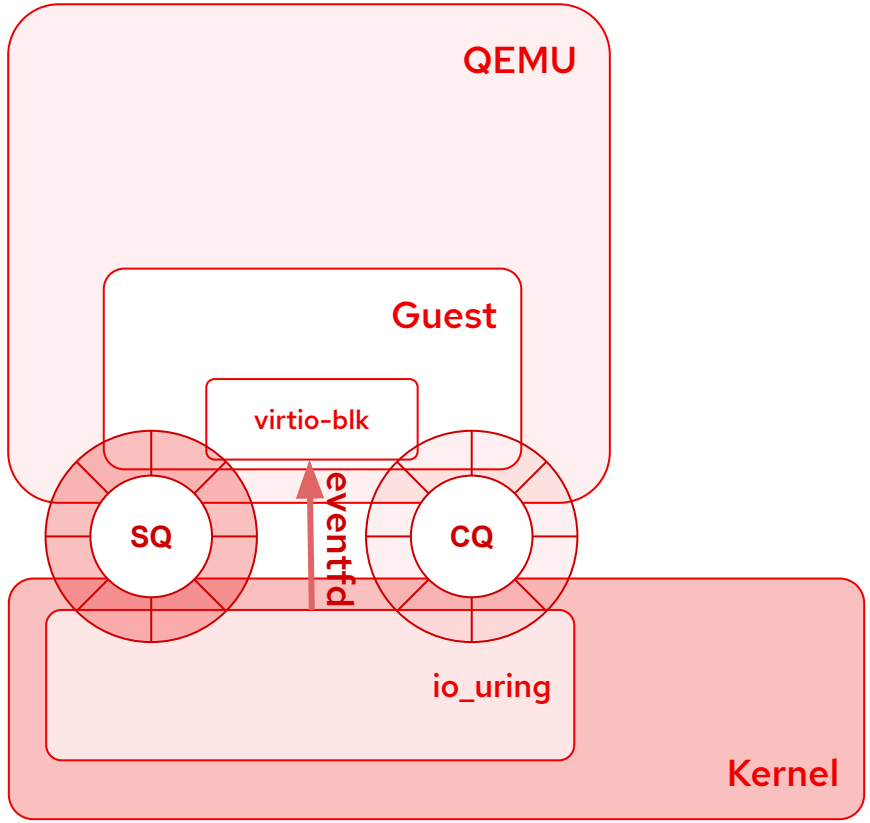
io_uring passthrough

- io_uring's **SQ/CQ** are **memory mapped** in the guest
- virtio-blk driver modified to use the "fast path"
  - handle io_uring's SQ/CQ
  - eventfd registered to inject interrupts (irqfd)
- **polling**
  - block io_poll in the guest driver to avoid IRQs in the guest
    - https://github.com/stefanha/linux/tree/virtio-blk-io_poll
    - modified to poll CQ
  - SQPOLL enabled in the host to avoid notification from the guest (vmexit)
  - IOPOLL enabled in the host to avoid IRQs in the host



io_uring changes for passthrough

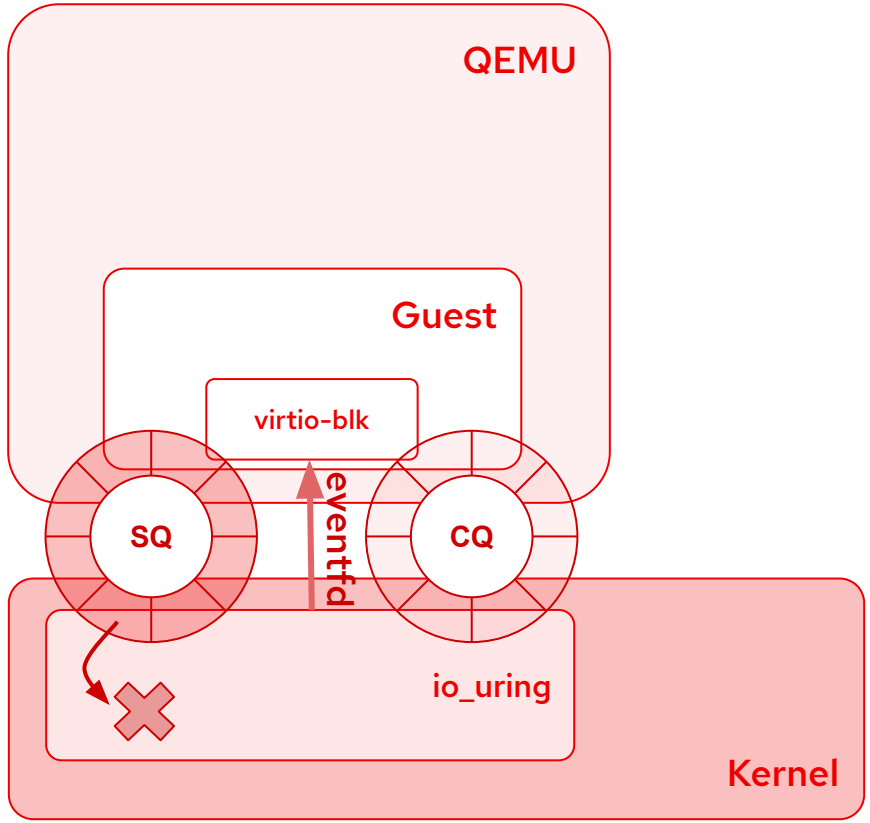
- eventfd disabling
  - merged upstream (Linux 5.8 - liburing 0.7)
  - patches
    - [PATCH v2 0/2] io_uring: add a CQ ring flag to enable/disable eventfd notification
      - https://lkml.org/lkml/2020/5/15/912



Red Hat

io_uring changes for passthrough

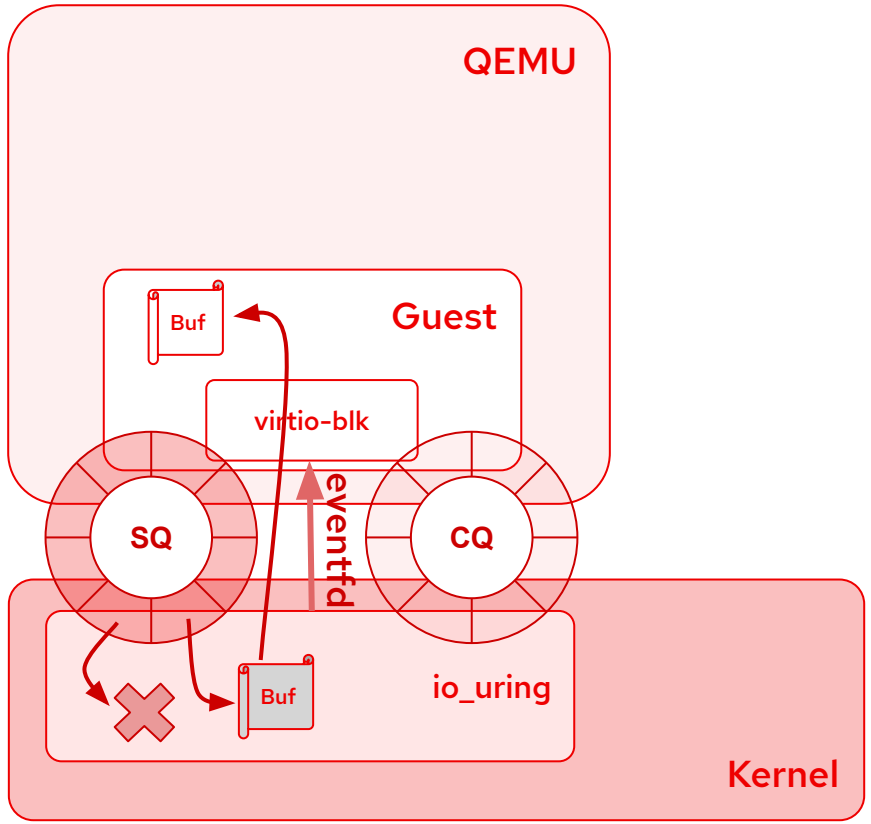
- eventfd disabling
  - merged upstream (Linux 5.8 - liburing 0.7)
  - patches
    - [PATCH v2 0/2] io_uring: add a CQ ring flag to enable/disable eventfd notification
      - https://lkml.org/lkml/2020/5/15/912
- restrictions
  - merged upstream (Linux 5.10 - liburing 0.8)
  - **Operations restrictions for io_uring**
    - https://lwn.net/Articles/826053/
  - patches
    - [PATCH v6 0/3] io_uring: add restrictions to support untrusted applications and guests
      - https://lkml.org/lkml/2020/8/27/826



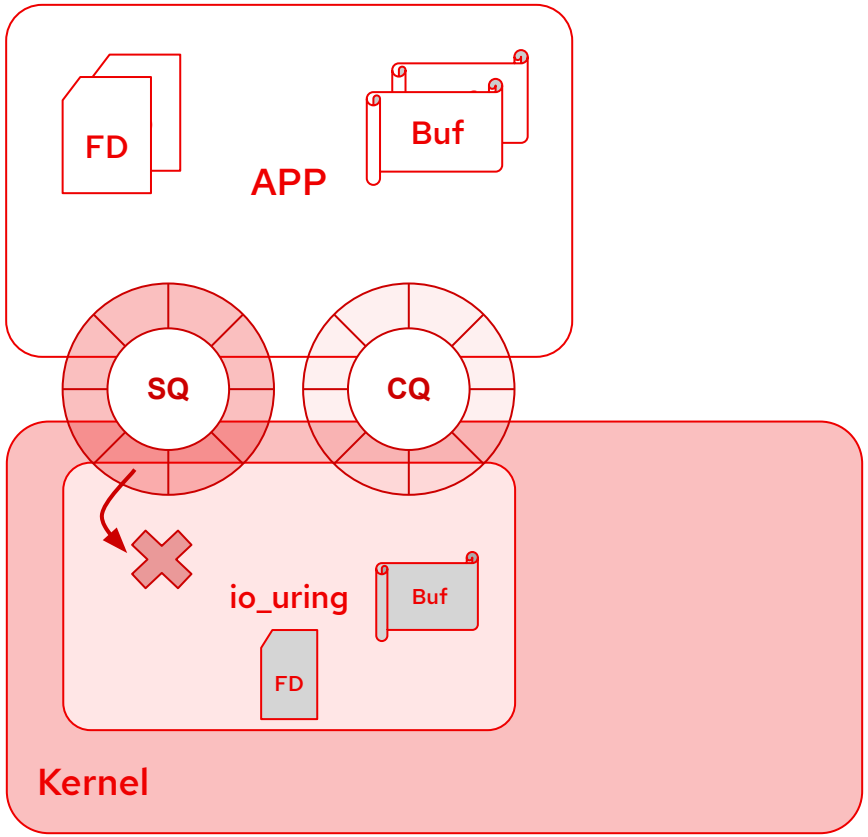
Red Hat

io_uring changes for passthrough

- eventfd disabling
  - merged upstream (Linux 5.8 - liburing 0.7)
  - patches
    - [PATCH v2 0/2] io_uring: add a CQ ring flag to enable/disable eventfd notification
      - https://lkml.org/lkml/2020/5/15/912
- restrictions
  - merged upstream (Linux 5.10 - liburing 0.8)
  - **Operations restrictions for io_uring**
    - https://lwn.net/Articles/826053/
  - patches
    - [PATCH v6 0/3] io_uring: add restrictions to support untrusted applications and guests
      - https://lkml.org/lkml/2020/8/27/826
- memory translation
  - Guest PA <-> Host VA
  - to do



io_uring restrictions

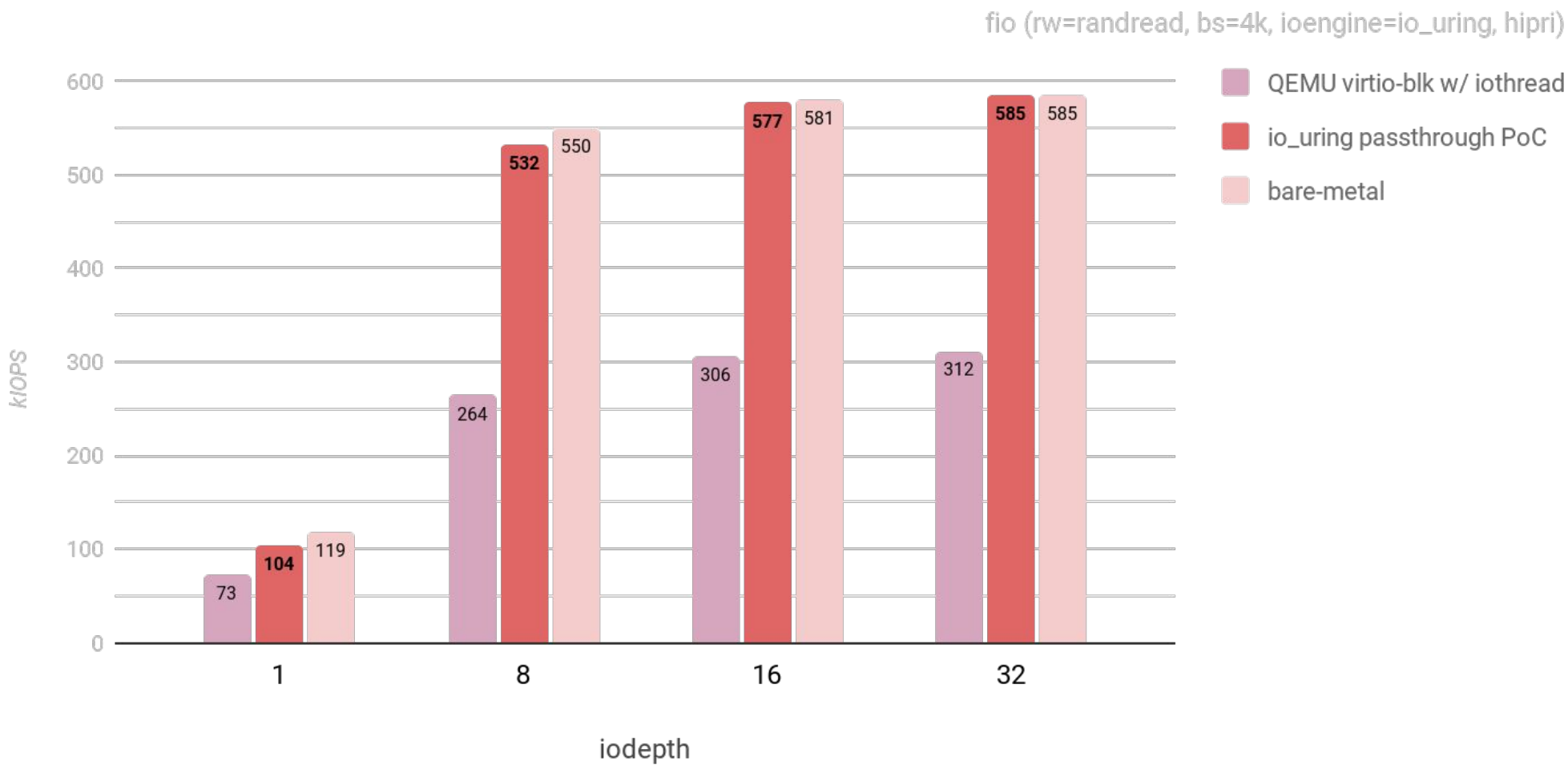


- Install feature **allowlist** on an io_uring context
  - only operations defined in the allowlist can be executed
  - new io_uring features do not accidentally become available
- How to install restriction?
  - using the new `io_uring_register(2)` opcode:

    `IOURING_REGISTER_RESTRICTIONS`
  - rings must start disabled (`IORING_SETUP_R_DISABLED`)
    - enabled with `IORING_REGISTER_ENABLE_RINGS`
- What we can restrict?
  - `io_uring_register(2)` op. codes
  - SQE op. codes
  - SQE flags for each operation
    - allowed
    - required

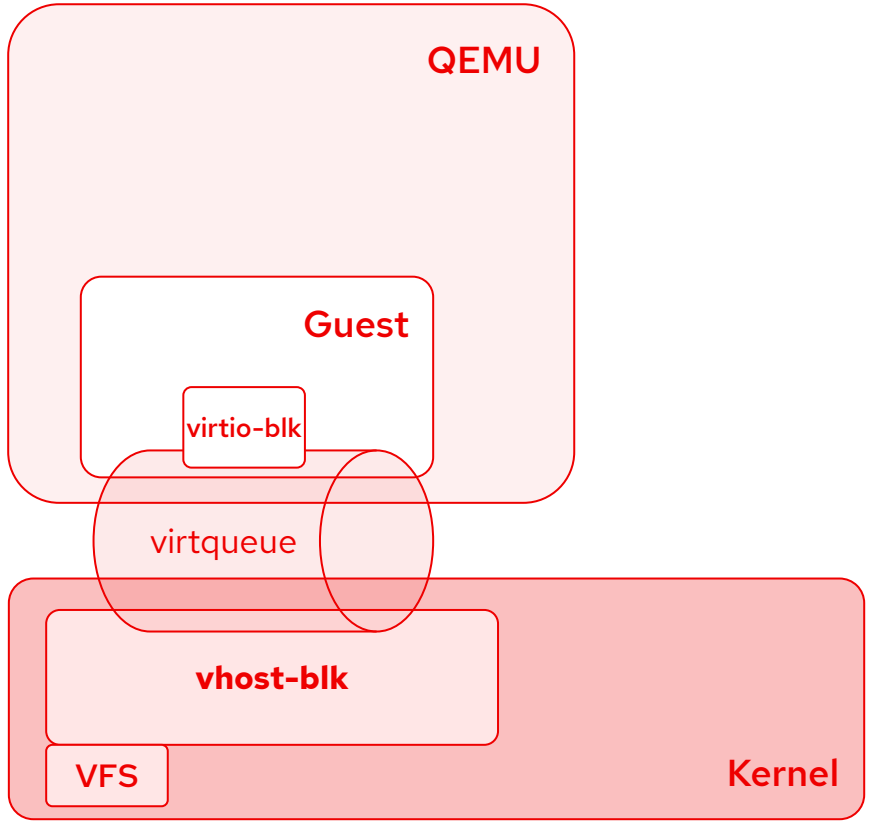
Red Hat

io_uring passthrough PoC performance

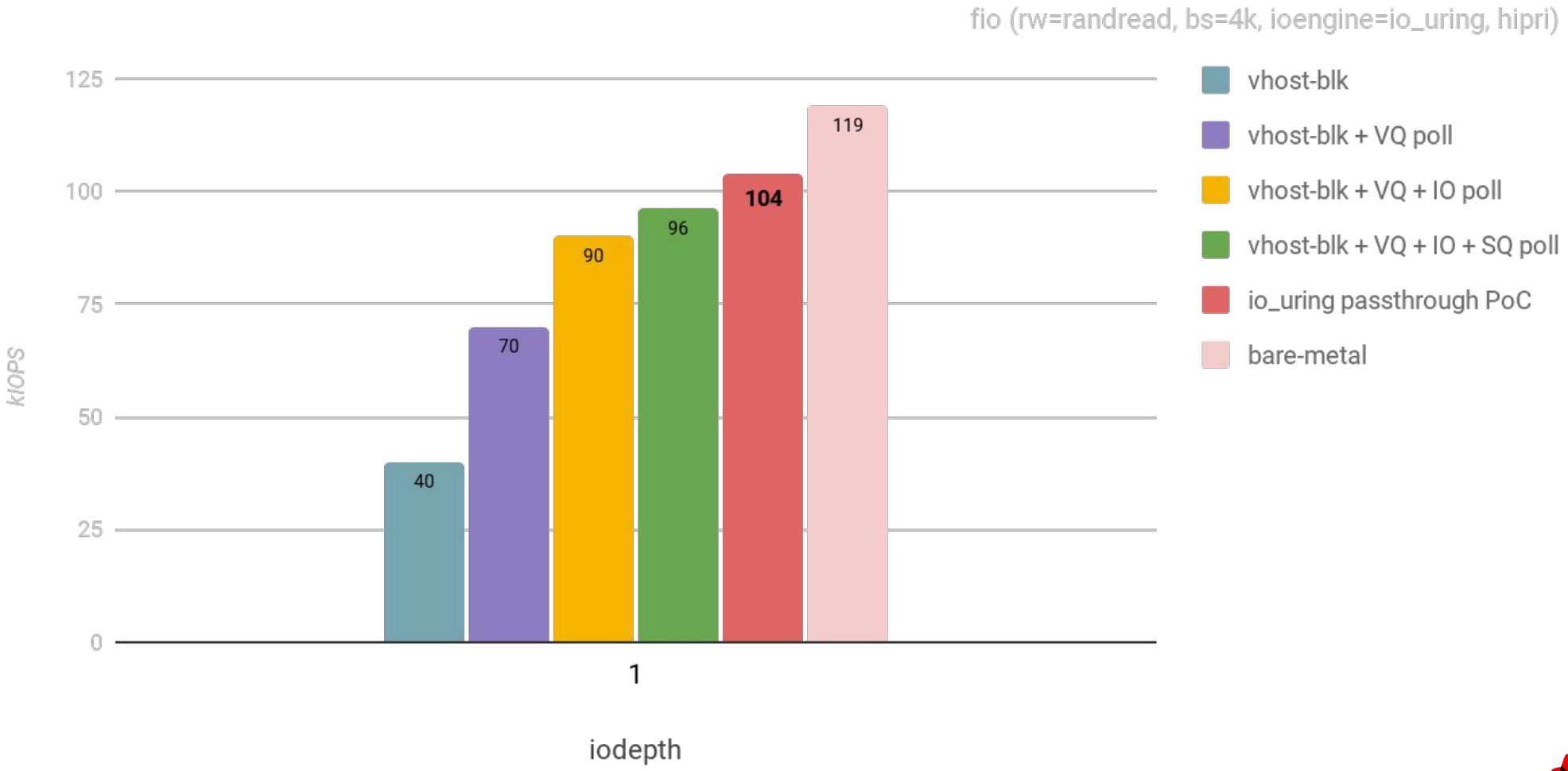


vhost block

- An alternative to io-uring passthrough to have a single communication channel
  - **virtqueue** shared between guest and host kernels
- Some implementations was published upstream but never merged
  - Asias He's **vhost-blk** [2012]
    https://lore.kernel.org/patchwork/patch/344823/
    - bio API
  - Vitaly Mayatskih's **vhost-blk** [2018]
    https://patchwork.kernel.org/cover/10665995/
    - VFS API
- vhost-blk improved adding polling
  - VQ polling
  - I/O polling



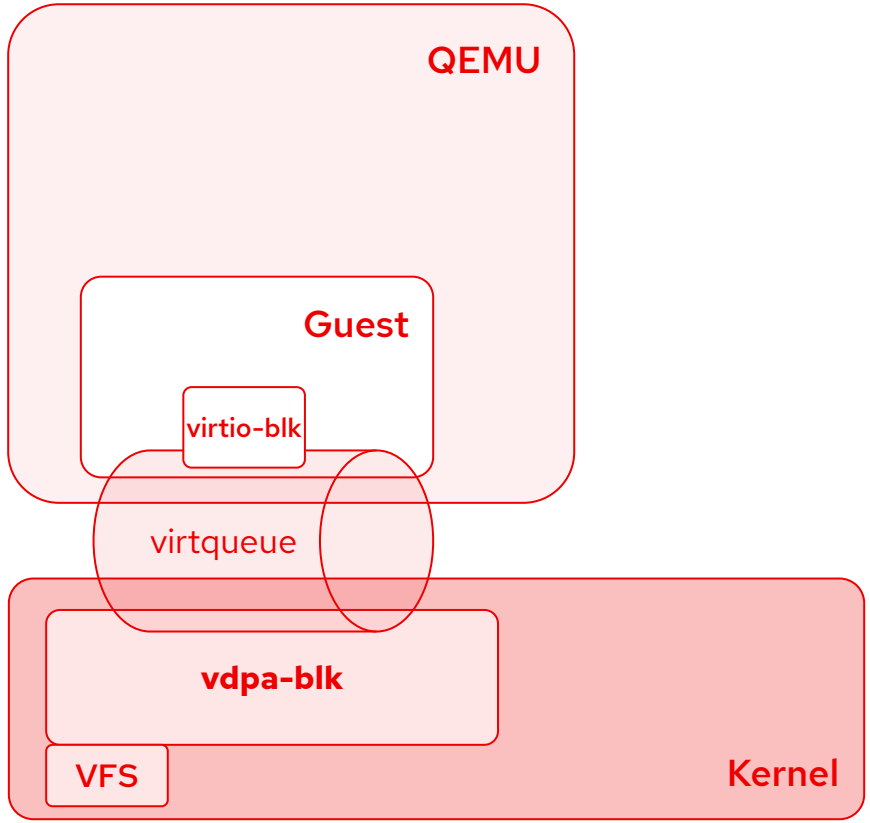
io_uring passthrough vs vhost-blk



Red Hat

vDPA block software device

- Similar to vhost-blk but using the new **vDPA** framework
  - virtio Data Path Acceleration
- PROs
  - **unified software stack** (host, guest, QEMU, hardware)
    - hardware implementation will be available
  - more control than vhost on device lifecycle
  - guest pages pinned
    - copy_in/to() not needed
- CONs
  - guest pages pinned
    - no memory overcommit
  - io-uring passthrough already supports IO polling, SQ polling, VFS integrations, etc.
- Work in progress



Next Steps

- vDPA-blk software device
  - simulator
  - QEMU support
  - Linux vDPA driver with VFS integration
- virtio-blk driver optimizations
  - blk io_poll upstream
- io-uring passthrough
  - memory translation

Thank you!

Stefano Garzarella <**sgarzare@redhat.com**>

Blog: https://**stefano-garzarella.github.io/**

IRC: **sgarzare** on #qemu irc.oftc.net

linkedin.com/company/red-hat

facebook.com/redhatinc

youtube.com/user/RedHatVideos

twitter.com/RedHat

Red Hat