Western Digital

A Tail of Latency, IOPs, & IO Priority

Adam Manzanares, Filip Blagojevic, Cyril Guyot

adam.manzanares@wdc.com

You want what from my HDD?

- Capacity -> Here is a 12 TB HDD
- Low $/TB -> Here is a 12 TB HDD

- IOPs – 200 4k Rand Read IOPs at QD 32
- Throughput – 243 MB/s
- Better tail latency – lets work together

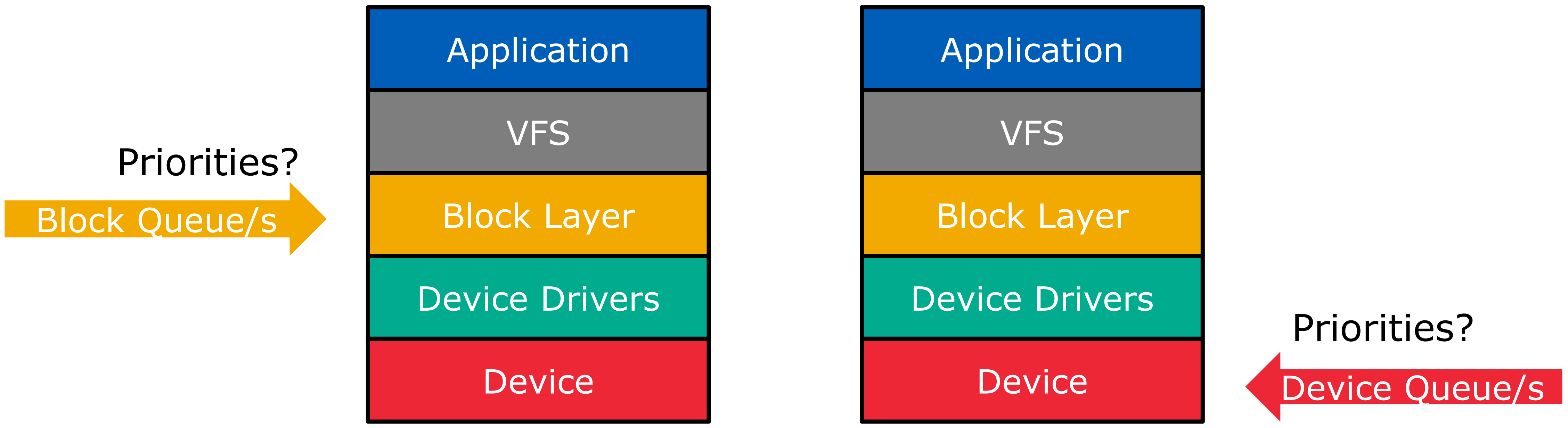
Single actuator arm

How do we enable each other?

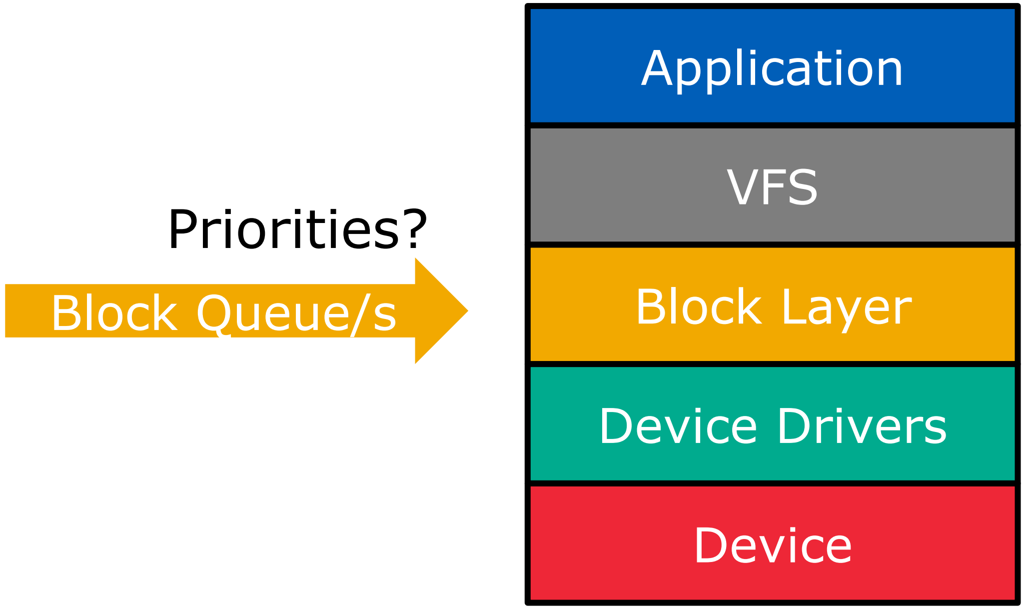
- HDD is peripheral
  - Under management by OS
  - Well defined interface for OS to HDD communication
    - SATA, SCSI
- Application runs on OS
  - Well defined interface to storage
    - File System, Block Access
- Let's deliver application semantics to the HDD
  - What, How, and Why

- Our Example Today
  - Binary priority to the HDD
  - 12 TB SATA HDD Supports NCQ Priority
- Linux Supports IOPriority
  - Not so fast
  - Priority used for One Particular Block Scheduler
  - Priority Is Not Passed To The Drive
- This talk discusses
  - Why Priority To The Device Is Important
  - What We Did to Get Priority To The Device
  - Results

Where To Handle Priority In The IO Stack



Block Layer Priorities



PROS

- No support needed from device
- Flexibility in implementation
  - Scheduler can be modified rather easily
  - Linux source code is available

Cons

- Request makes it to device
  - Priority no longer exists
- Devices may have large queue sizes
  - Your high priority request can be delayed significantly
- Implemented by time slicing
  - High priority requests could be significantly delayed
    - Before hitting the device queue

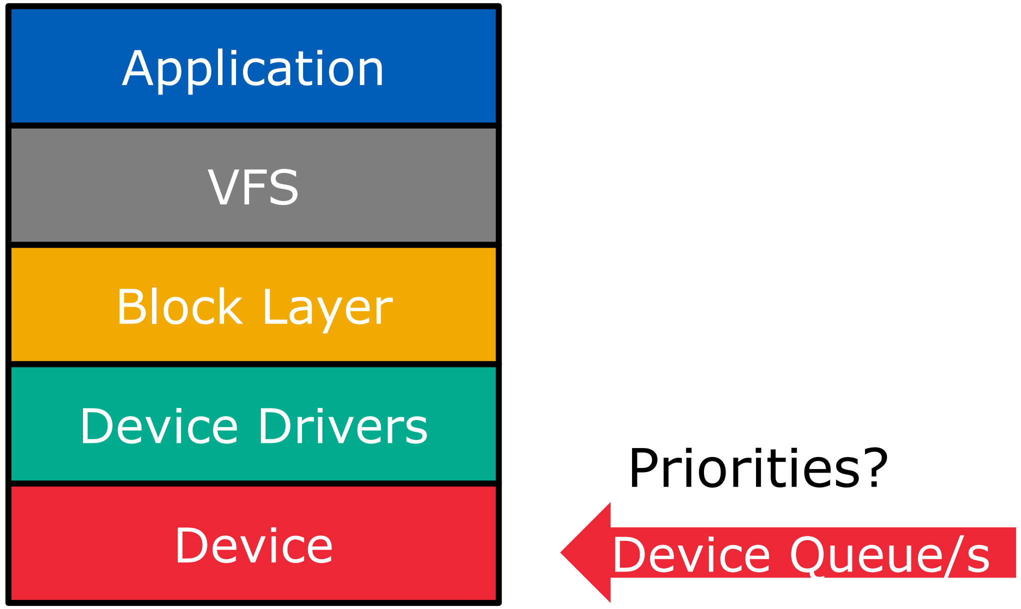
Device Priorities

PROS

- Device will service high priority requests first
  - Should improve latency
- Block layer scheduler irrelevant?
  - Hints of this with NVMe

Cons

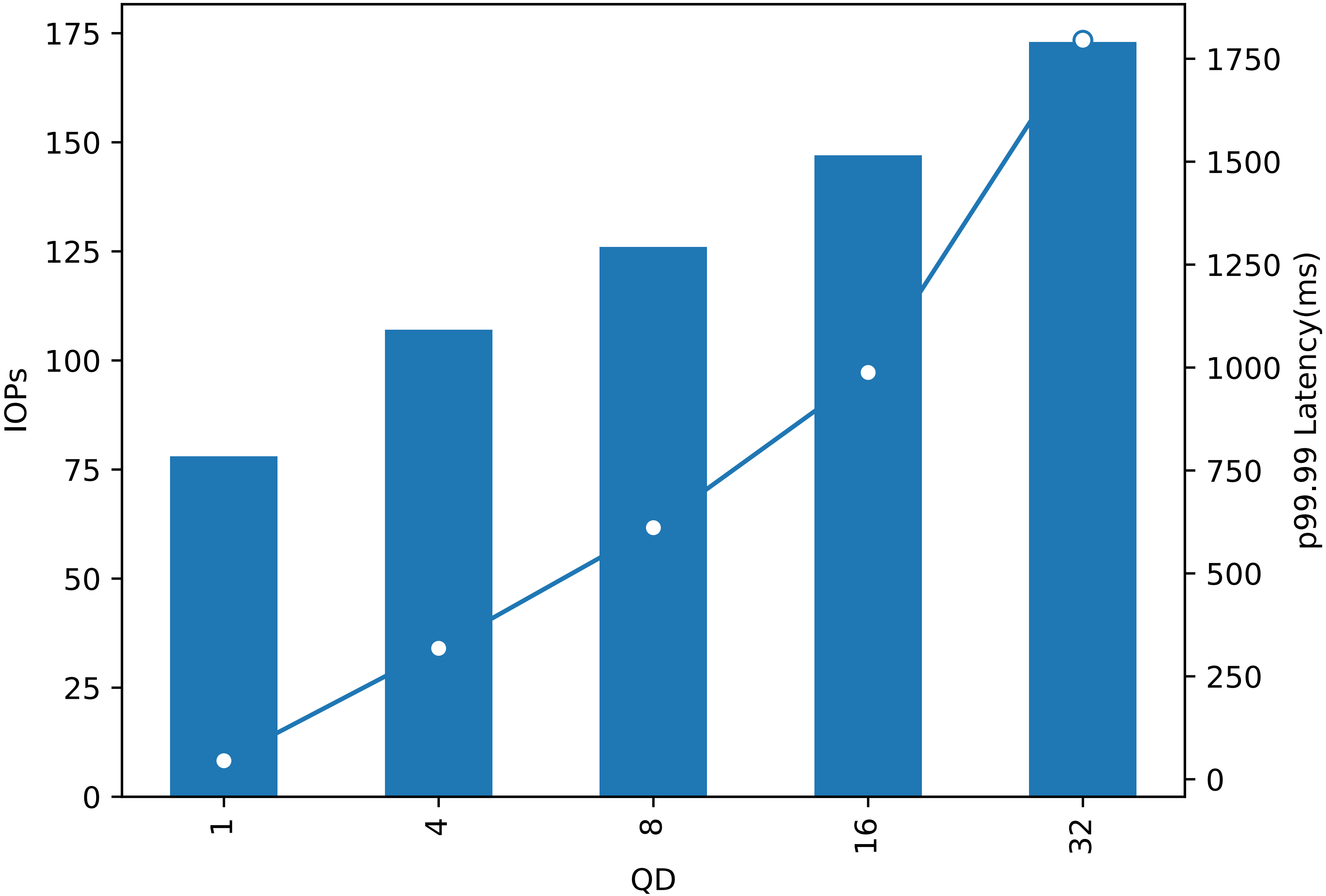
- Device must support priority
- What does device do with priority?
  - This can not be changed easily
  - Most don’t have access to FW



SATA NCQ & Priority

- Serial Advanced Technology Attachment
  - BUS protocol for HDD to host communication
- Native Command Queuing
  - SATA feature that defines mechanism for multiple outstanding IOs between host and device
  - Currently supports 31 outstanding commands
- Drive is allowed to reorder commands
  - Achieves better throughput
  - User loses control of when a particular IO is completed.
- NCQ Supports Priority Bit In Read and Write NCQ commands
- What does the drive do with prioritized NCQ commands?

QD vs IOPs & Tail Latency



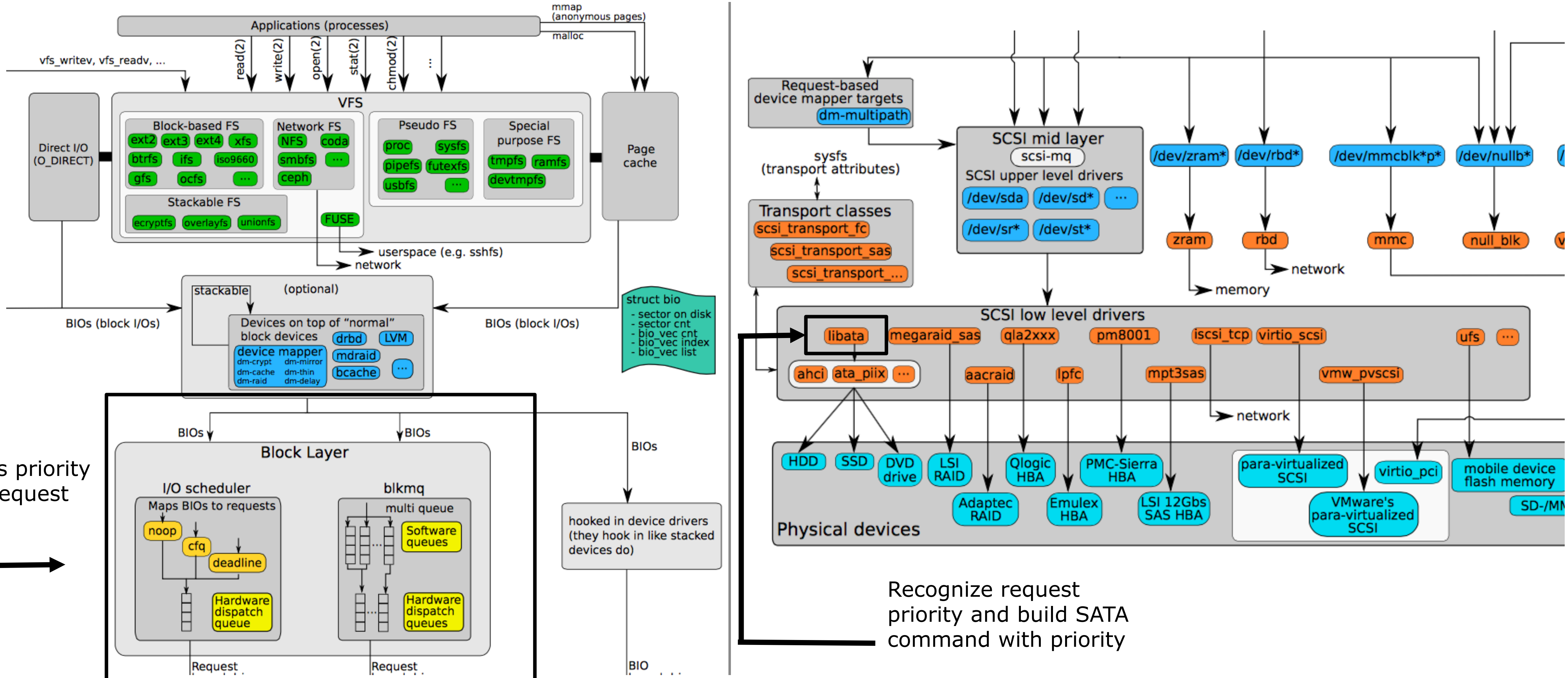
How Are IO Priorities Used In Linux Currently

- System call exists to set IO priorities
  - ioprio_set
  - Priority info currently only used by CFQ scheduler
  - Set in kernel io context which is associated with a process, process group, or user
  - ionice utility can be used
- User Space IO Converted to BIO in Kernel
  - read(), write(), pread(), pwrite() … eventually generate BIO inside of the kernel
- BIO mapped to a request
  - Request queues are managed by block schedulers
- Request structure
  - Has a priority field
  - IO context only relevant if CFQ scheduler is used
- Request based device drivers convert requests to device specific commands
  - May be a layered path to device, SCSI to libata, SCSI to mpt3 SAS, …
- CFQ Scheduler
  - Creates queues based on priority classes
  - Time slices across these queues

What we Want to Do, Why, and How

- IO priorities passed to the drive
  - Not just to the CFQ scheduler, allowing use of all kernel schedulers
  - Make sure common request submission pathways pass IO priority information to devices.
- Drive level priority should enable finer grained control
  - Currently, priorities not passed to drive
    - Low priority IO equivalent to high priority IO at the drive
  - Guarantees high priority IO is respected in the drive queues
- Grab priority from IO context
  - Done when BIO is converted to request
  - Request has an io priority field
    - System call does not set this field
- Lower layer leverages request priority
  - Libata builds ata commands with high priority
  - mpt3sas (Broadcom HBAs) flag command as being high priority
    - HBA correctly builds high priority SATA command
  - MicoSemi HBAs TBD
- Libata
  - Recognize IO priority in SCSI command and build SATA command with priority information

Areas Of Kernel Modified



Pass priority to request

Recognize request priority and build SATA command with priority

https://www.thomas-krenn.com/en/wiki/Linux_Storage_Stack_Diagram

Some Block Layer Code

```
static blk_qc_t blk_queue_bio(struct request_queue *q, struct bio *bio)
```

Function takes bio and places it on a request queue.
Eventually makes a call to:

```
static struct request *__get_request(struct request_list *rl, int op,int op_flags,
                                     struct bio *bio, gfp_t gfp_mask)
```

Which gets a free request and initializes it. We added a call to the following in __get_request:

```
static inline void blk_rq_set_prio(struct request *rq, struct io_context *ioc)

{
        if (ioc)
                rq->ioprio = ioc->ioprio;
}
```

Some Libata Code

```
@@ -1755,6 +1756,8 @@ static unsigned int ata_scsi_rw_xlat(struct ata_queued_cmd *qc)

{
        struct scsi_cmnd *scmd = qc->scsicmd;
        const u8 *cdb = scmd->cmnd;
+       struct request *rq = scmd->request;
+       int class = IOPRIO_PRIO_CLASS(req_get_ioprio(rq));
```

```
 int ata_build_rw_tf(struct ata_taskfile *tf, struct ata_device *dev, u64 block, u32 n_block,
                     unsigned int tf_flags,
-                     unsigned int tag)
+                     unsigned int tag, int class)
 {
         tf->flags |= ATA_TFLAG_ISADDR | ATA_TFLAG_DEVICE;
         tf->flags |= tf_flags;
@@ -785,6 +786,12 @@ int ata_build_rw_tf(struct ata_taskfile *tf, struct ata_device *dev,
         tf->device = ATA_LBA;
         if (tf->flags & ATA_TFLAG_FUA)
                 tf->device |= 1 << 7;
+
+                if (dev->flags & ATA_DFLAG_NCQ_PRIO) {
+                        if (class == IOPRIO_CLASS_RT)
+                                tf->hob_nsect |= ATA_PRIO_HIGH << ATA_SHIFT_PRIO;
+                }
```

But My HDD is Not Connected Through AHCI

- We have tested and completed patches to enable priority when using a couple of Broadcom HBAs
- Changes merged into 4.10
- Investigating how to get this done with MicroSemi HBAs
- HBA Vendors Contact Us

How to set IO Priorities In Applications

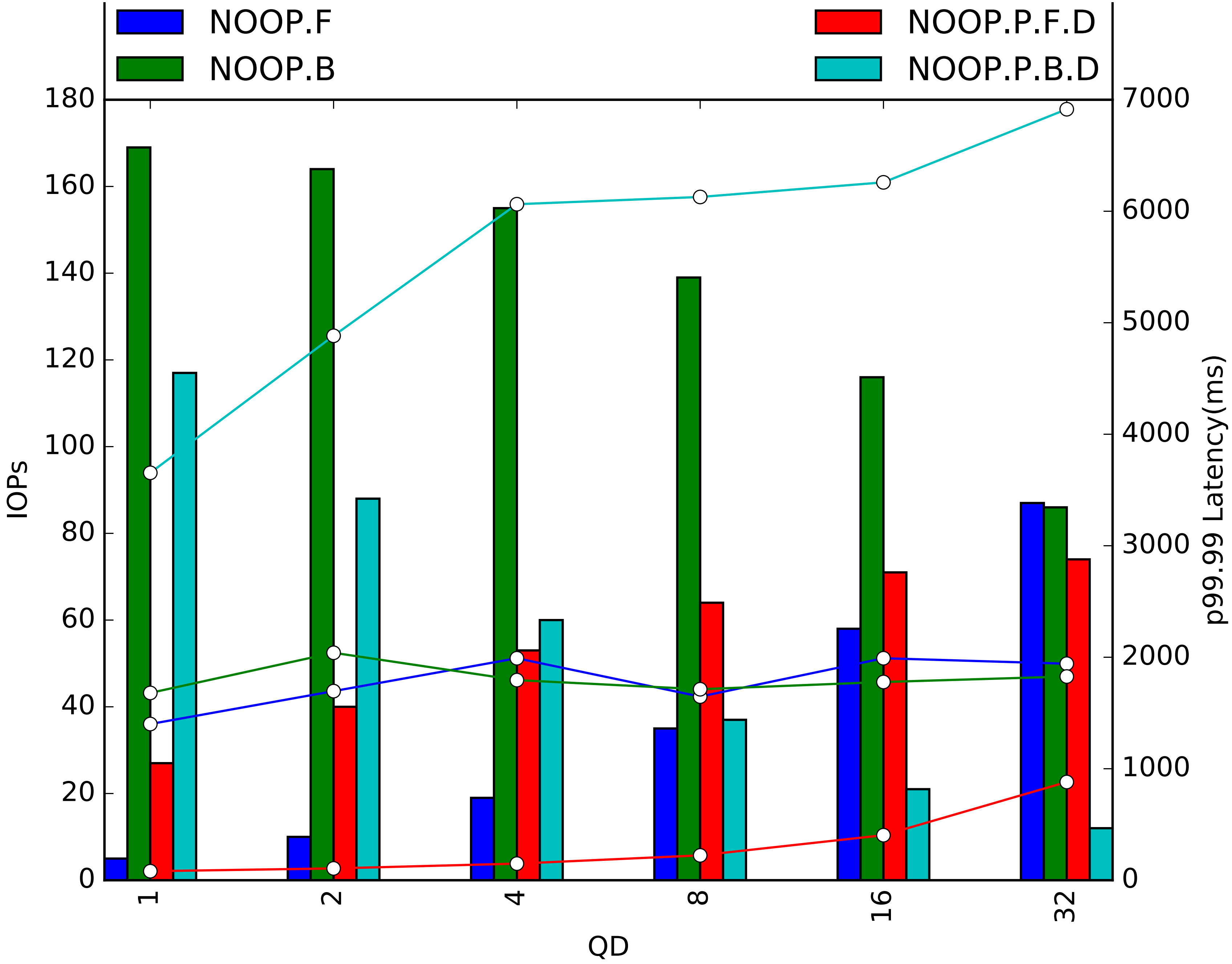
- Turn on sata ncq priority support
  - SATA
    - /sys/devices/pci0000:00/0000:00:1f.2/ata8/host7/target7:0:0/7:0:0:0/ncq_prio_enable
  - MPT3SAS
    - /sys/device/*/sas_ncq_prio_enable
- ionice
  - Linux Utility
  - set/get process I/O scheduling class and priority
  - Use process id, process group id, or a user id
- ioprio_set, ioprio_get
  - Systems calls to get/set scheduling class and priority
  - https://www.kernel.org/doc/Documentation/block/ioprio.txt
- Do you want a quick test with fio
  - Use the prioclass and prio arguments

```
sudo fio --ioengine=libaio --iodepth=1 --rw=randread --bs=4k --direct=1 --numjobs=1
--time_based --runtime=300 --filename=/dev/sdb --randrepeat=0 --prioclass=1 --prio=7
```

Benchmark

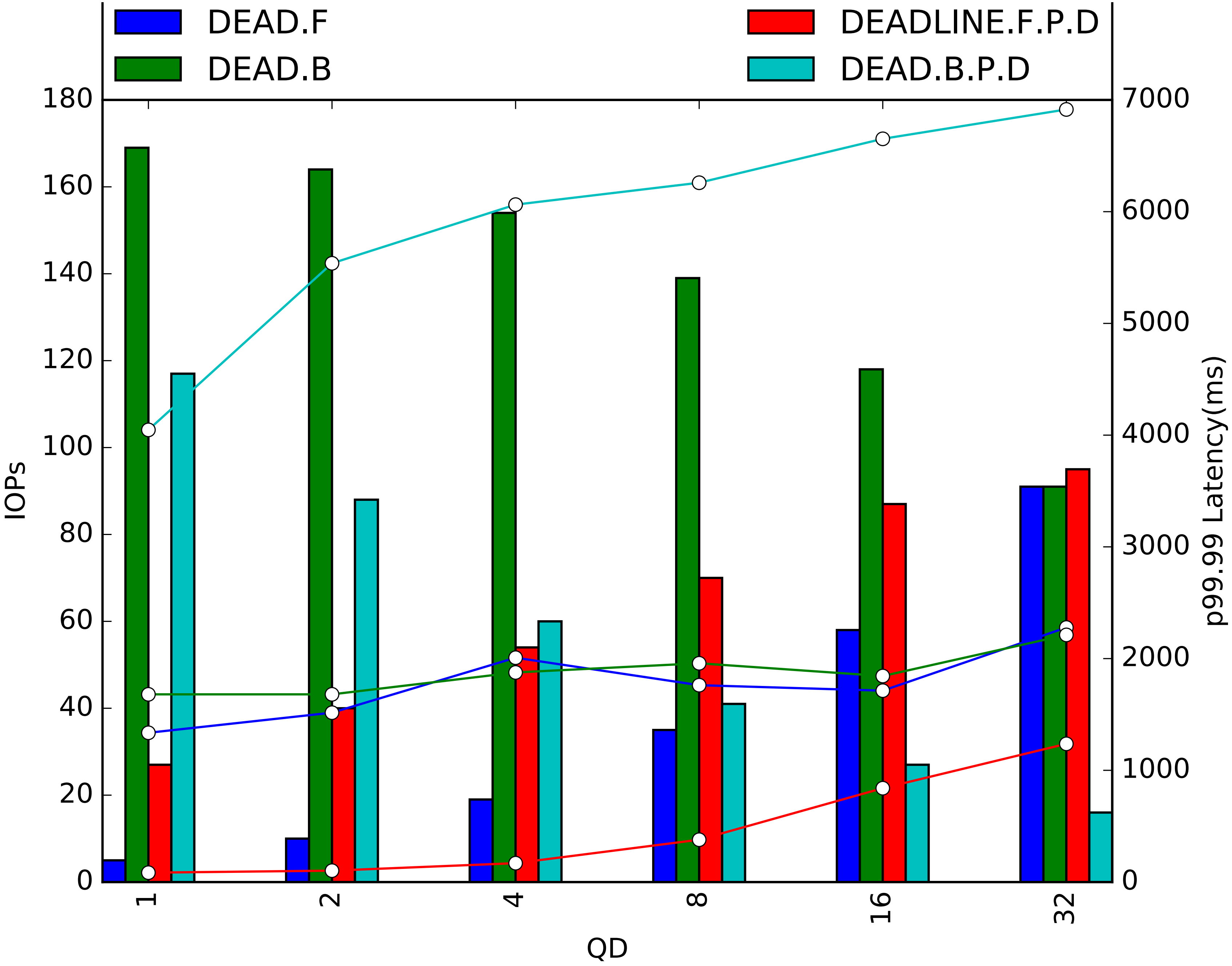
- Background IO
  - FIO Random Read
  - 4KiB Block Size
  - Run time = 5m
  - Queue Depth = 32
  - ioengine = libaio
- Foreground IO
  - FIO Random Read
  - 4KiB Block Size
  - Run time = 5m
  - ioengine = libaio
  - Queue Depth = {1,4,16,32}
- Schedulers used
  - Deadline with/without drive priority
  - NOOP with/without drive priority
  - CFQ with/without priority & CFQ with priority and drive priority

NOOP Scheduler



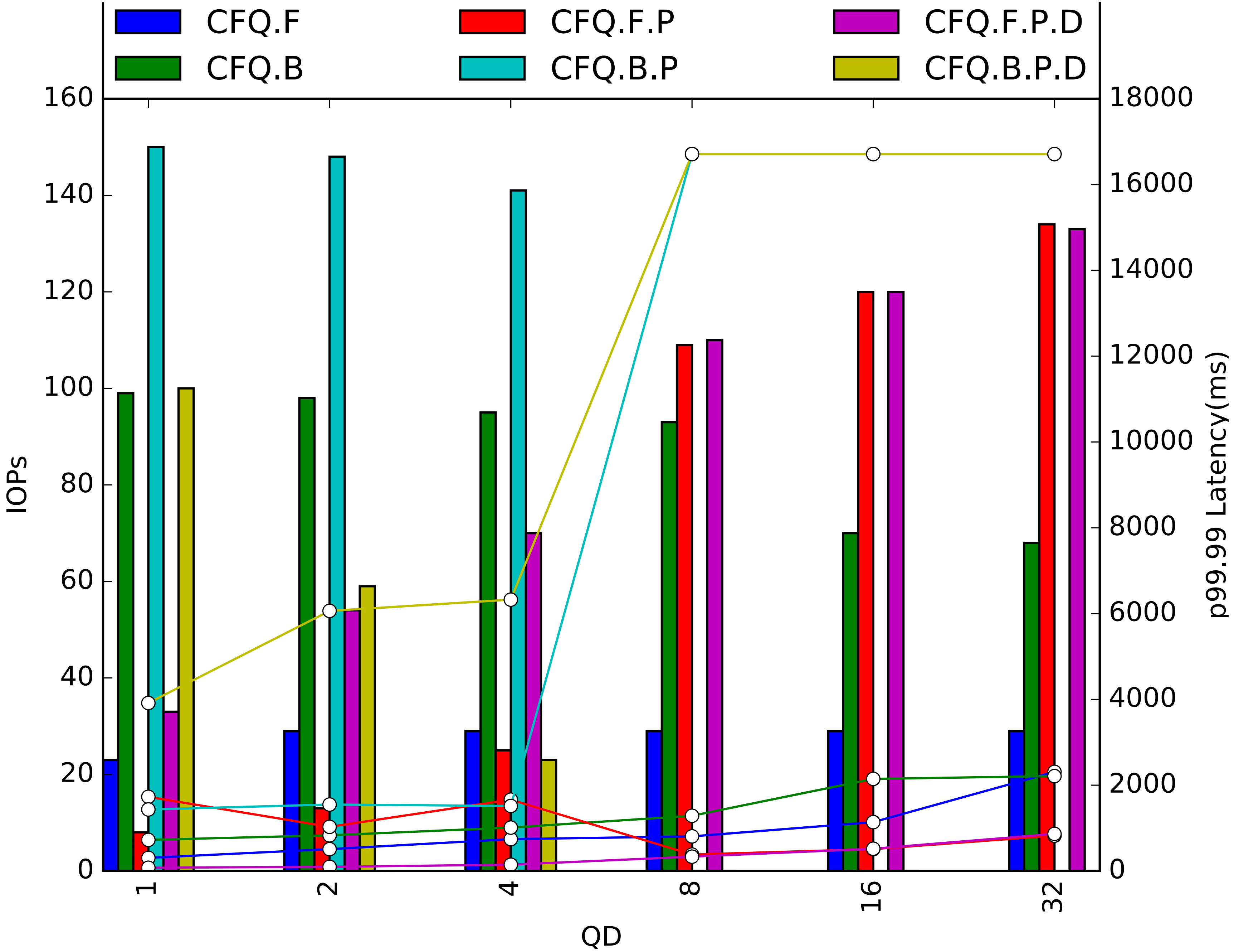
Western Digital.

Deadline Scheduler



Western Digital.

CFQ Scheduler



Some Kernel Files Modified

- block/blk-core.c
  - When request is initialized for a bio we now set the iopriority from the io context of the current process
- One block patch committed
  - 5dc8b362a2374d007bc0db649b7ab6a79dd32bda
- drivers/ata/libata-scsi.c
  - ata_scsi_rw_xlat()
    - grab request from scsi command, use this to get priority class
- Four libata/ahci patches committed
  - 8e061784b51ec4a4efed0deaafb5bd9725bf5b06
  - 84f95243b5439a20c33837075b88926bfa00c4ec
  - 4e647d960c510e0d5cd700058fb8ddd529c390ee
  - 9f56eca3aeeab699a7dbfb397661d2eca4430e94
- drivers/ata/libata-core.c
  - ata_build_rw_tf
    - Add priority class, if device supports priorities build ATA tf with high priority
  - ata_dev_config_ncq_prio
    - Check identify log page priority support
  - ata_id_has_ncq_prio
    - check if identify priority bit is set
  - added functions for adding a sysfs entry
  - also changed includes to ata device flag for indicating if prioritized commands should be used
- drivers/scsi/mpt3sas/*
  - HBA command set as high priority when request is set as high prio
  - sysfs entries to enable/disable feature
  - scsi probe functions to discover
- Once mpt3sas patch committed
  - 307d9075a02b696e817b775c565e45c4fa3c32f2

Future Directions

- How do schedulers/devices/priorities mix?
  - CFQ has some unexpected results
    - What causes this and can device priority help?
  - BFQ algorithms may be improved with priority
    - Currently looking into this
- How many priorities does an application need?
  - Currently high/regular
- Is a latency cut off a better mechanism to control tail latency?
- How does this work translate to distributed storage systems?
- Should repair priority be a function of the state of the cluster?
  - Enough redundancy low priority rebuild
  - High priority rebuild when necessary
- Do classes of users map cleanly into priorities?
- Will this be mapped onto NVMe devices using prioritized queues or using prioritized commands?

Thanks for your attention.

Any additional questions? Contact me at:

adam.manzanares@wdc.com