# Block I/O Layer Tracing: *blktrace*

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# Introduction

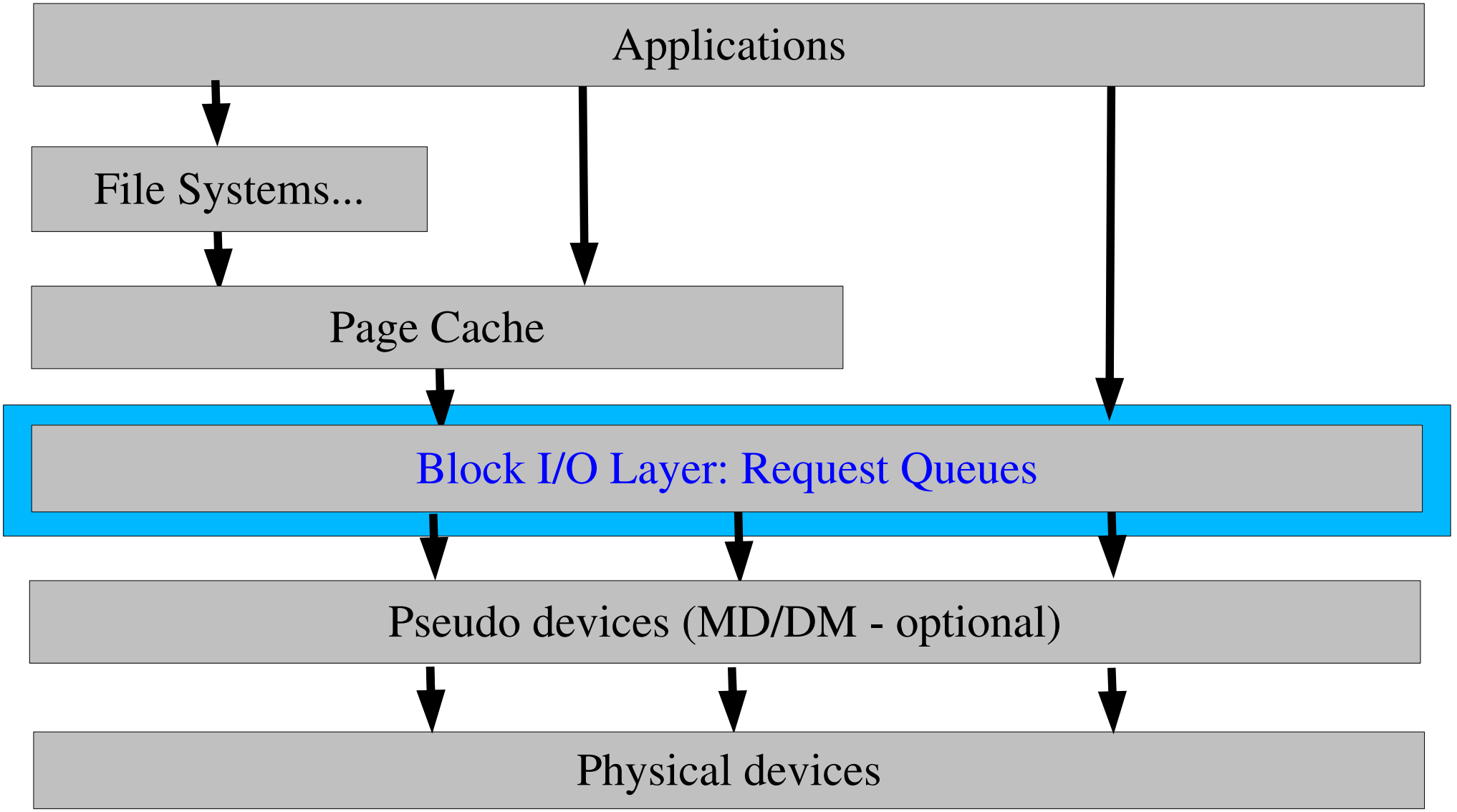
- Blktrace – overview of a new Linux capability
  - Ability to see what's going on inside the block I/O layer
    - “You can't count what you can't measure”
  - Kernel implementation
  - Description of user applications
- Sample Output & Analysis

# Problem Statement

- Need to know the specific operations performed upon ***each*** I/O submitted into the block I/O layer

- Who?
  - Kernel developers in the I/O path:
    - Block I/O layer, I/O scheduler, software RAID, file system, ...
  - Performance analysis engineers – *HP OSLO S&P*...

# Block I/O Layer (simplified)



# iostat

- The iostat utility *does* provide information pertaining to request queues associated with specifics devices
  - Average I/O time on queue, number of merges, number of blocks read/written, ...
- However, it does *not* provide detailed information on a per-I/O basis

# Blktrace – to the rescue!

- Developed and maintained by Jens Axboe (block I/O layer maintainer)
  - My additions included adding threads & utility splitting, DM remap events, blkrawverify utility, binary dump feature, testing, kernel/utility patches, and documentation.
- Low-overhead, configurable kernel component which emits ***events*** for specific operations performed on each I/O entering the block I/O layer
- Set of tools which extract and format these events

However, *blktrace* is **not** an analysis tool!

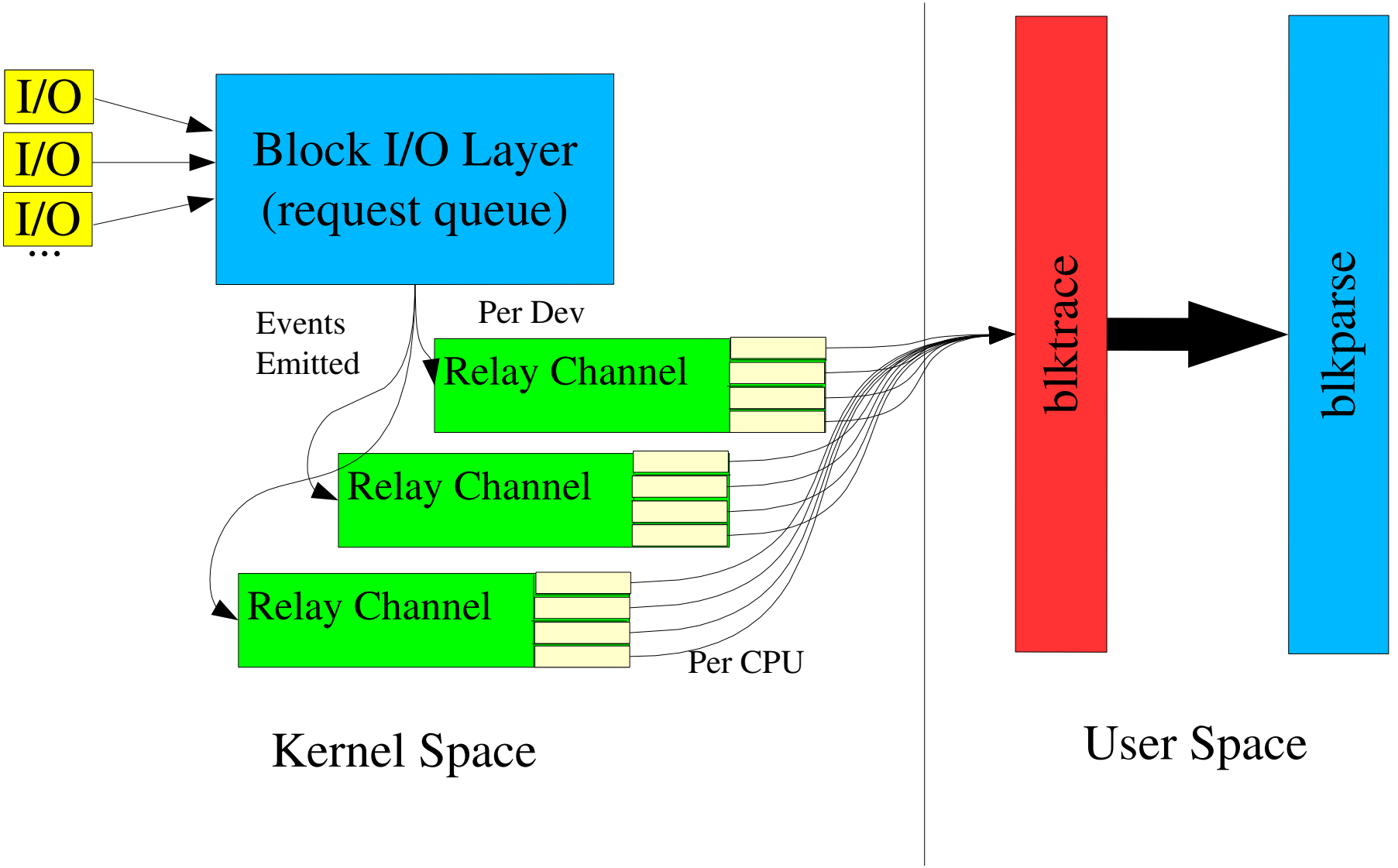
# Feature List

- Provides detailed block layer information concerning individual I/Os
- Low-overhead kernel tracing mechanism
  - Seeing less than 2% hits to application performance in relatively stressful I/O situations
- Configurable:
  - Specify 1 or more physical or logical devices (including MD and DM (LVM2))
  - User-selectable events – can specify filter at event acquisition and/or when formatting output
- Supports both “live” and “playback” tracing

# Events Captured

- Request queue entry allocated
- Sleep during request queue allocation
- Request queue insertion
- Front/back merge of I/O on request queue
- Re-queue of a request
- Request issued to underlying block dev
- Request queue plug/unplug op
- I/O split/bounce operation
- I/O remap
  - MD or DM
- Request completed

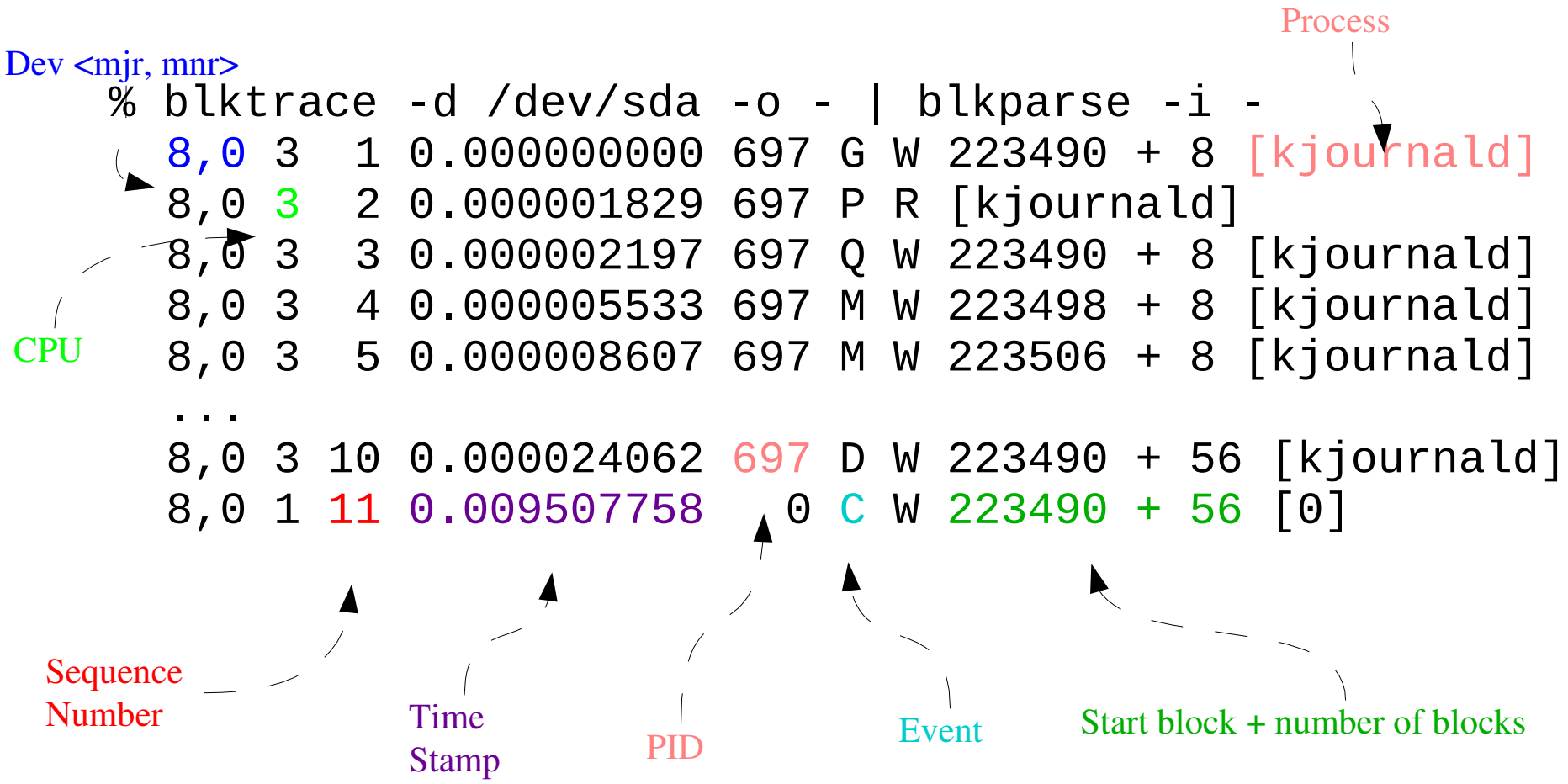
# *blktrace*: General Architecture



# *blktrace* Utilities

- *blktrace:* Device configuration, and event extraction utility
  - Store events in (long) term storage
  - Or, pipe to *blkparse* utility for live tracing
    - Also: networking feature to remote events for parsing on another machine
- *blkparse:* Event formatting utility
  - Supports textual or binary dump output

# *blktrace*: Event Output



# *blktrace*: Summary Output

Per CPU details

Writes submitted on

Writes completed on

Per device details

Avg throughput

```
CPU0 (sdao):
 Reads Queued:           0,        0KiB  Writes Queued:      77,382,    5,865MiB
 Read Dispatches:        0,        0KiB  Write Dispatches:    7,329,    3,020MiB
 Reads Requeued:         0              Writes Requeued:         6
 Reads Completed:        0,        0KiB  Writes Completed:        0,        0KiB
 Read Merges:            0              Write Merges:       68,844
 Read depth:             2              Write depth:            65
 IO unplugs:           414              Timer unplugs:         414
...
CPU3 (sdao):
 Reads Queued:         105,       18KiB  Writes Queued:      14,541,    2,578MiB
 Read Dispatches:       22,       60KiB  Write Dispatches:    6,207,    1,964MiB
 Reads Requeued:         0              Writes Requeued:     1,408
 Reads Completed:       22,       60KiB  Writes Completed:   12,300,    5,059MiB
 Read Merges:           83              Write Merges:       10,968
 Read depth:             2              Write depth:            65
 IO unplugs:           287              Timer unplugs:         287

Total (sdao):
 Reads Queued:         105,       18KiB  Writes Queued:      92,546,    8,579MiB
 Read Dispatches:       22,       60KiB  Write Dispatches:   13,714,    5,059MiB
 Reads Requeued:         0              Writes Requeued:     1,414
 Reads Completed:       22,       60KiB  Writes Completed:   12,300,    5,059MiB
 Read Merges:           83              Write Merges:       80,246
 IO unplugs:           718              Timer unplugs:         718

Throughput (R/W): 0KiB/s / 39,806KiB/s
Events (sdao): 324,011 entries
Skips: 0 forward (0 -   0.0%)
```

# *blktrace*: Event Storage Choices

- Physical disk backed file system
  - *Pros*: large/permanent amount of storage available; supported by all kernels
  - *Cons*: potentially higher system impact; may negatively impact devices being watched (if storing on the same bus that other devices are being watched on...)
- RAM disk backed file system
  - *Pros*: predictable system impact (RAM allocated at boot); less impact to I/O subsystem
  - *Cons*: limited/temporary storage size; removes RAM from system (even when not tracing); may require reboot/kernel build
- TMPFS
  - *Pros*: less impact to I/O subsystem; included in most kernels; only utilizes system RAM while events are stored
  - *Cons*: limited/temporary storage; impacts system predictability – RAM "removed" as events are stored – could affect application being "watched"

# *blktrace*: Analysis *Aid*

- As noted previously, *blktrace* does not analyze the data; it is responsible for storing and formatting events
- Need to develop post-processing analysis tools
  - Can work on formatted output or binary data stored by *blktrace* itself
  - Example: *btt* – block trace timeline

# Practical *blktrace*

- Here at HP OSLO S&P, we are investigating I/O scalability at various levels
  - Including the efficiency of various hardware configurations and the effects on I/O performance caused by software RAID (MD and DM)
- *blktrace* enables us to determine scalability issues within the block I/O layer and the overhead costs induced when utilizing software RAID

# Life of an I/O *(simplified)*

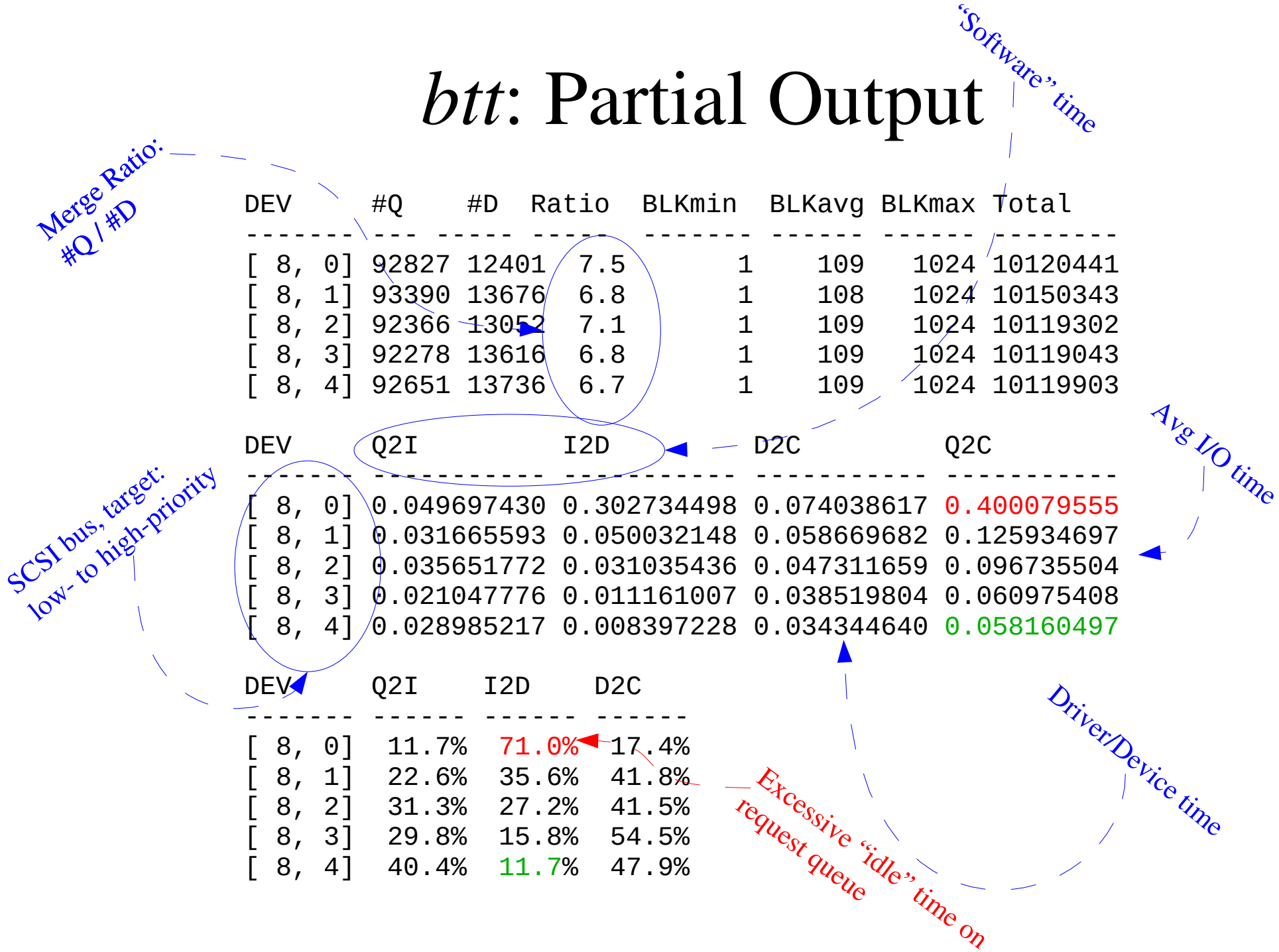
- I/O enters block layer – it can be:
  - Remapped onto another device (MD, DM)
  - Split into 2 separate I/Os (alignment, size, ...)
  - Added to the request queue
  - Merged with a previous entry on the queue

    *All I/Os end up on a request queue at some point*
- At some later time, the I/O is issued to a device driver, and submitted to a device
- Later, the I/O is completed by the device, and its driver

# *btt*: Life of an I/O

- Q2I – time it takes to process an I/O *prior* to it being inserted or merged onto a request queue
  - Includes split, and remap time
- I2D – time the I/O is “idle” on the request queue
- D2C – time the I/O is “active” in the driver and on the device
- Q2I + I2D + D2C = Q2C
  - Q2C: Total processing time of the I/O

# *btt*: Partial Output

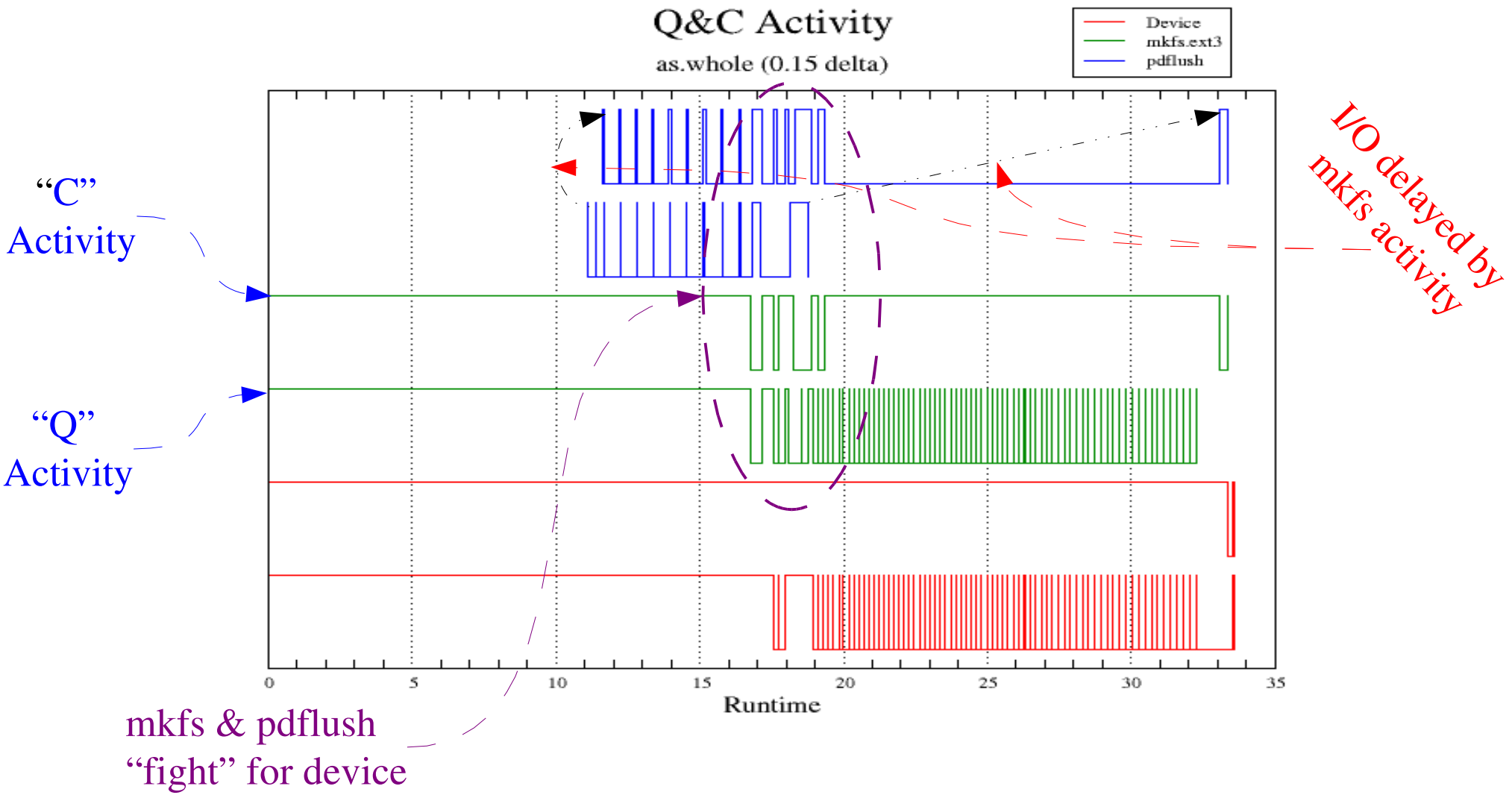



```
DEV      #Q    #D  Ratio  BLKmin  BLKavg BLKmax Total
-------- ----- ----- ----- ------- ------ ------ --------
[ 8,  0] 92827 12401   7.5       1    109   1024 10120441
[ 8,  1] 93390 13676   6.8       1    108   1024 10150343
[ 8,  2] 92366 13052   7.1       1    109   1024 10119302
[ 8,  3] 92278 13616   6.8       1    109   1024 10119043
[ 8,  4] 92651 13736   6.7       1    109   1024 10119903

DEV      Q2I          I2D          D2C          Q2C
-------- ------------ ------------ ------------ ------------
[ 8,  0] 0.049697430 0.302734498 0.074038617 0.400079555
[ 8,  1] 0.031665593 0.050032148 0.058669682 0.125934697
[ 8,  2] 0.035651772 0.031035436 0.047311659 0.096735504
[ 8,  3] 0.021047776 0.011161007 0.038519804 0.060975408
[ 8,  4] 0.028985217 0.008397228 0.034344640 0.058160497

DEV      Q2I     I2D     D2C
-------- ------- ------- -------
[ 8,  0]   11.7%   71.0%   17.4%
[ 8,  1]   22.6%   35.6%   41.8%
[ 8,  2]   31.3%   27.2%   41.5%
[ 8,  3]   29.8%   15.8%   54.5%
[ 8,  4]   40.4%   11.7%   47.9%
```

# *btt*: Q&C Activity

- *btt* also generates “activity” data – indicating ranges where processes and devices are actively handling various events (block I/O entered, I/O inserted/merged, I/O issued, I/O complete, ...)
- This data can be plotted (e.g. xmgrace) to see patterns and extract information concerning anomalous behavior

# *btt*: I/O Scheduler Example



# btt: I/O Scheduler - Explained

- Characterizing I/O stack
- Noticed very long I2D times for certain processes
- Graph shows continuous stream of I/Os...
  - ...at the device level
  - ...for the *mkfs.ext3* process
- Graph shows significant lag for *pdflush* daemon
  - Last I/O enters block I/O layer around 19 seconds
  - But: last batch of I/Os aren't completed until 14 seconds later!
- Cause? Anticipatory scheduler – allows mkfs.ext3 to proceed, holding off pdflush I/Os

# Resources

- Kernel sources:
  - Patch for Linux 2.6.14-rc3 (or later, up to 2.6.17)
  - Linux 2.6.17 (or later) – built in
- Utilities & documentation (& kernel patches)
  - rsync://rsync.kernel.org/pub/scm/linux/kernel/git/axboe/blktrace.git
  - See documentation in *doc* directory
- Mailing list: linux-btrace@vger.kernel.org