PostgreSQL-Consulting

data egret

Latest evolution of Linux IO stack, explained for database people

Ilya Kosmodemiansky (ik@dataegret.com)

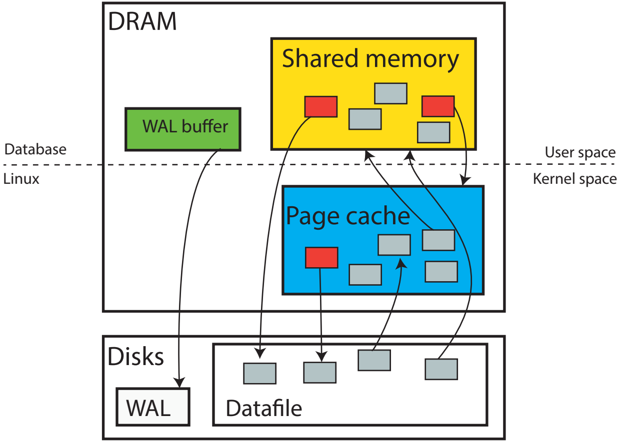
Why this talk

- Linux is a most common OS for databases
- Fast IO is essential for many workloads
- DBAs often run into IO problems
- Most of the information on topic is written by kernel developers (for kernel developers) or is checklist-style
- Last years Linux IO stack (re)development is very fast

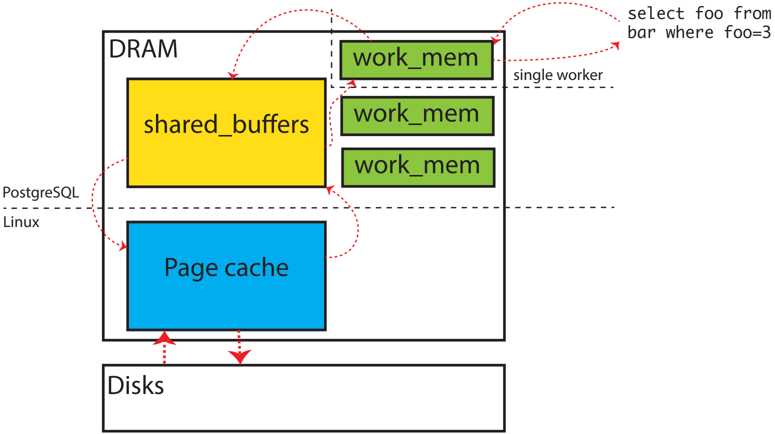
Bird eye view

- How a generic database or PostgreSQL interacts with IO
- Linux IO as we used to understand it
- What is new?

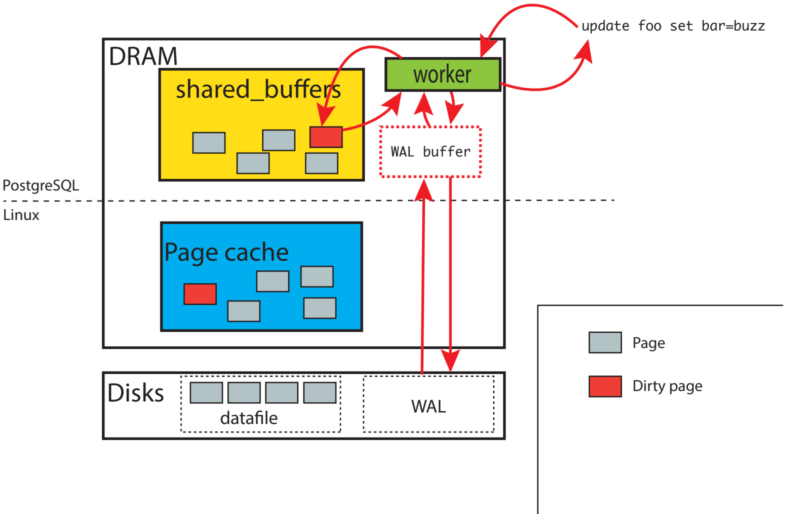
Well, typical database



It is easy, while read only



Writes add complexity



Key things about modern database workload

- Shared memory segment can be very large
- Keeping in-memory pages synchronized with disk generates huge IO
- WAL should be written fast and safe
- One and every layer of OS IO stack involved

What generates most of IO in case of PostgreSQL

- Keeping pages synchronized: checkpoints and other sync mechanisms
- Autovacuum can generate a lot of IO
- Cache refill
- Worker IO (Sorts and hashing, as well as worst-case fsyncs)

The main IO problem for databases for a long time was

- **How to maximize page throughput between memory and disks**
- Things involved:
  - Disks
  - Memory
  - CPU
  - IO Schedulers
  - Filesystems
  - Database itself
- IO problems for databases are not always only about disks

- **How to maximize page throughput between memory and disks**
- Things involved:
    - **Disks** - **because latency of this part was very significant**
    - Memory
    - CPU
    - IO Schedulers
    - Filesystems
    - Database itself
- IO problems for databases are not always only about disks

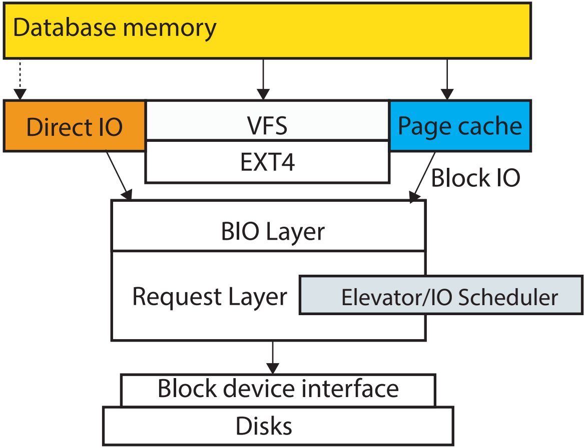
Throughput and latency

- Maximizing IO performance through maximizing throughput is easy up to certain moment
- Minimizing latency of IO usually is tricky
- With large adoption of proper SSDs, hardware latency dropped dramatically

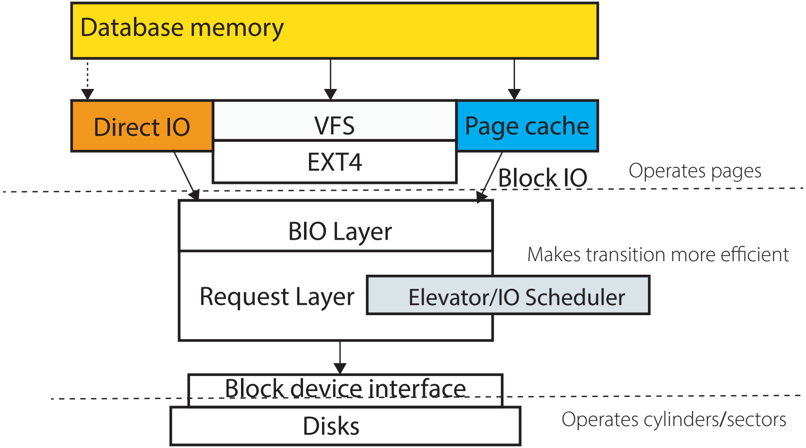
Because of high latency of rotating disks

- Database development was concentrated around maximization of throughput
- So did Linux kernel development
- Many rotating disks era IO optimization techniques are not that good for SSDs

IO stack (as it used to look like)



IO stack (as it used to look like)



Elevators: before 2.6 kernel

- **Linus Elevator** - the only one in times of 2.4
- *merging* and *sorting* request queues
- Had **lots** of problems

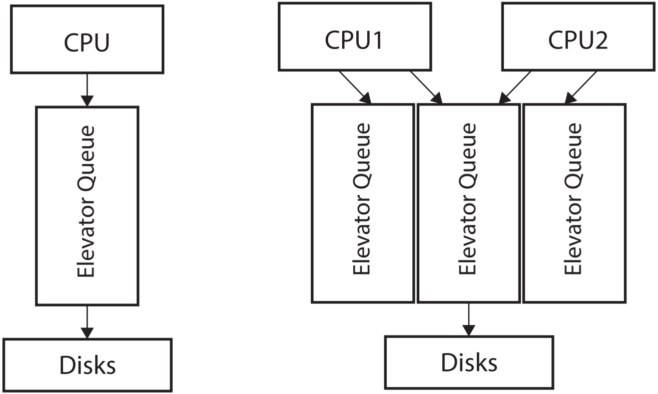
Elevators: between 2.6 and early 3.*

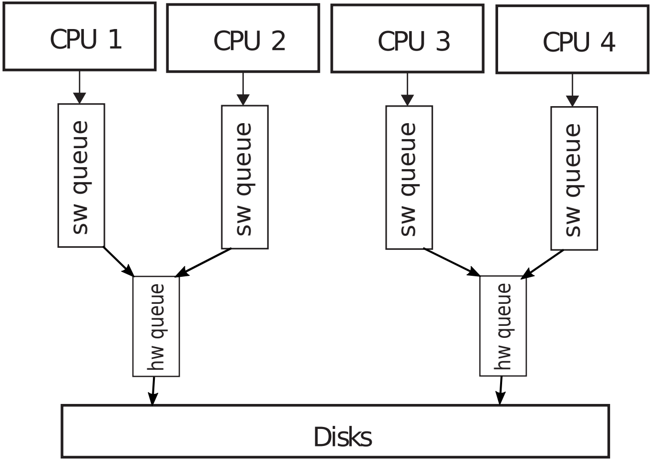
- **CFQ** - universal, default one
- **deadline** - rotating disks
- **noop** or **none** - then disks throughput is so high, that it can not benefit from keen scheduling
  - PCIe SSDs
  - SAN disk arrays

Elevators: 3.13 and newer

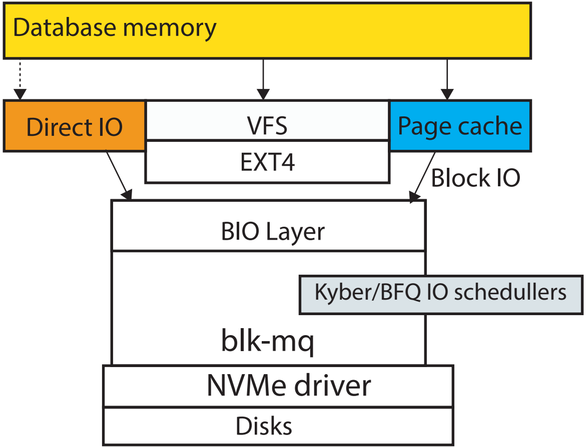
- Effectiveness of **noop** clearly shows ineffectiveness of others, or ineffectiveness of smart sorting as an approach
- **blk-mq** scheduler was merged into 3.13 kernel
- Much better deals with parallelism of modern SSD - basically separate IO queue for each CPU
- The best option for good SSDs right now
- **blk-mq and NVMe driver is actually more than scheduler, but a system aimed to substitute whole request layer**

Old approach to elevators




CPU 1
CPU 2
CPU 3
CPU 4
sw queue
sw queue
sw queue
sw queue
hw queue
hw queue
Disks

IO stack (with blk-mq)



Good diagram on Linux IO stack

- **https://www.thomas-krenn.com/en/wiki/Linux_Storage_Stack_Diagram**
- Regular updates
- Some things are difficult to draw, but it is a complex topic

Non Volatile Memory Express or NVMe

- Sets of standards, which helps to use modern SSDs more effectively
- For Linux it is first of all NVMe driver (or subsystem)
- Most common example of NVMe SSDs are PCIe NAND drives
- With NVMe v.5 (currently 3 is ready for production) can work up to 32GB/sec
- Are databases NVMe ready?

- IO polling
- New IO schedulers Kyber and BFQ (Kernel 4.12)
- IO tagging
- Direct IO improvements

- Currently PostgreSQL supports DirectIO only for WAL, but it is unusable on practice
- Requires a lots of development
- Very OS specific
- Allows to use specific things, like O_ATOMIC
- PostgreSQL is the only database, which is not using Direct IO

Questions?

ik@dataegret.com