Postgres vs. filesystems

Tomas Vondra

FOSDEM February 3-4, 2024

https://postgres.land/talks/

EDB

Agenda

- Postgres relies on OS filesystems.
    - I/O scheduling, buffered I/O (page cache)
    - Why does it rely on OS, actually?
    - Good or bad? (Dis)advantages? Alternatives?
- evaluation of current (Linux) filesystems
    - ext4, xfs, btrfs, zfs
    - some basic benchmark numbers
    - problems and recommendations
- Future of Postgres I/O (maybe)
    - direct I/O, async I/O (next talk by Andres Freund)

Test cases

- filesystem: ext4, xfs, btrfs, zfs
- LVM vs. btrfs/zfs
- snapshots?
- compression?
- ...

Executive summary

- prefer a mature supported filesystem
  - supported by your distribution & support provider
  - new filesystems are great for research, not for production
- use recent kernels (very important - bugs, ...)
  - numbers will be from 6.3.9
  - bugs, performance improvements, hardware support

Executive summary

- ext4/xfs differences are "relatively small"
  - +10% is nice, but not a go / no-go matter (tuning?)
  - buying better hardware is likely "cheaper"
  - DB tuning easily makes up for this difference
- zfs / btrfs if you actually use advanced stuff
  - but maybe it's simpler to just use LVM ?

Reliance on OS

Michael W Lucas[1]

16 Jun · @mwl@io.mwl.io

Computers are like onions. Everything is layers built on layers, and every layer makes you cry. #sysadmin

19:54 · Jun 16, 2023

1,159 boosts 96 favorites

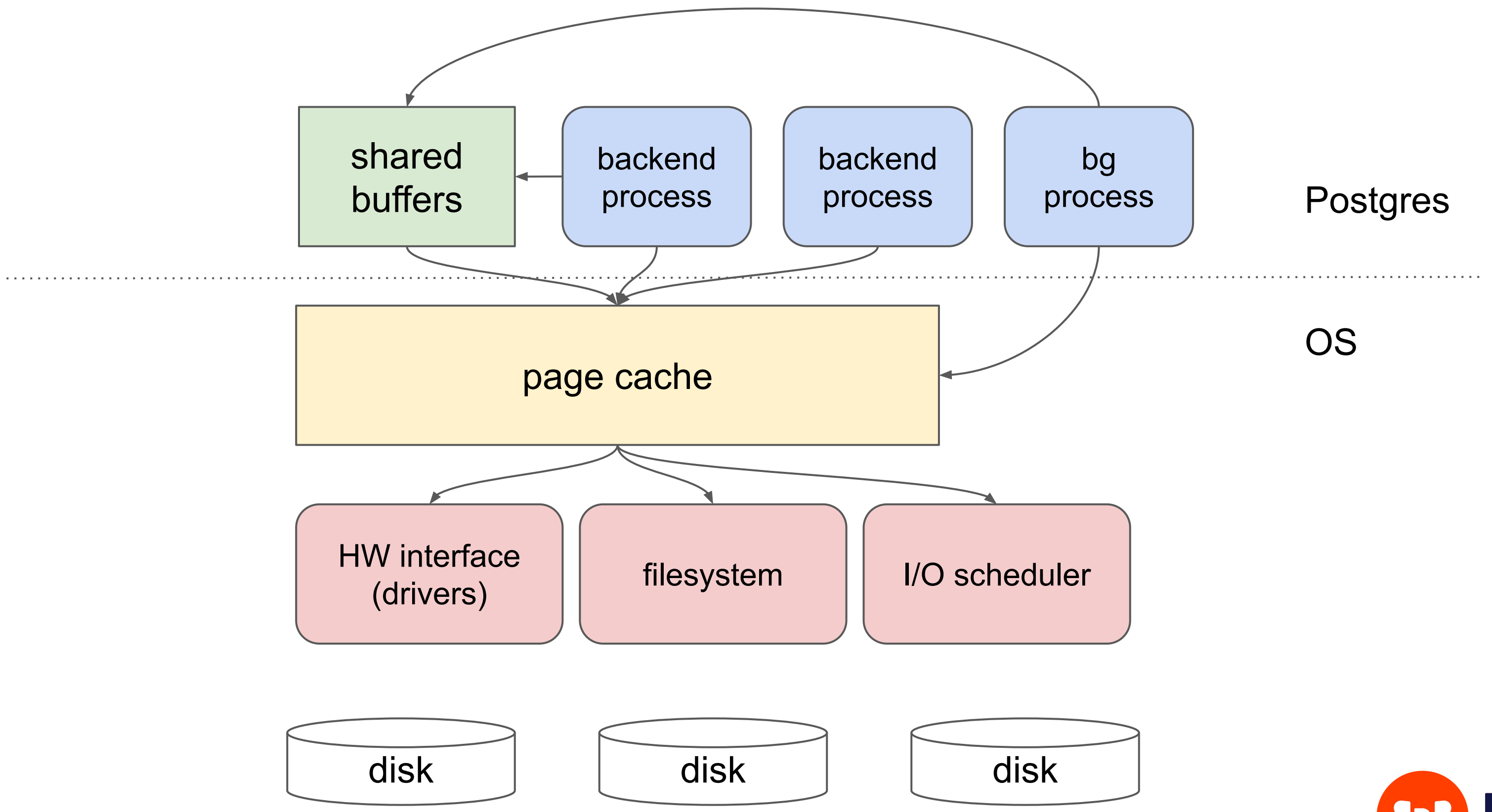
EDB

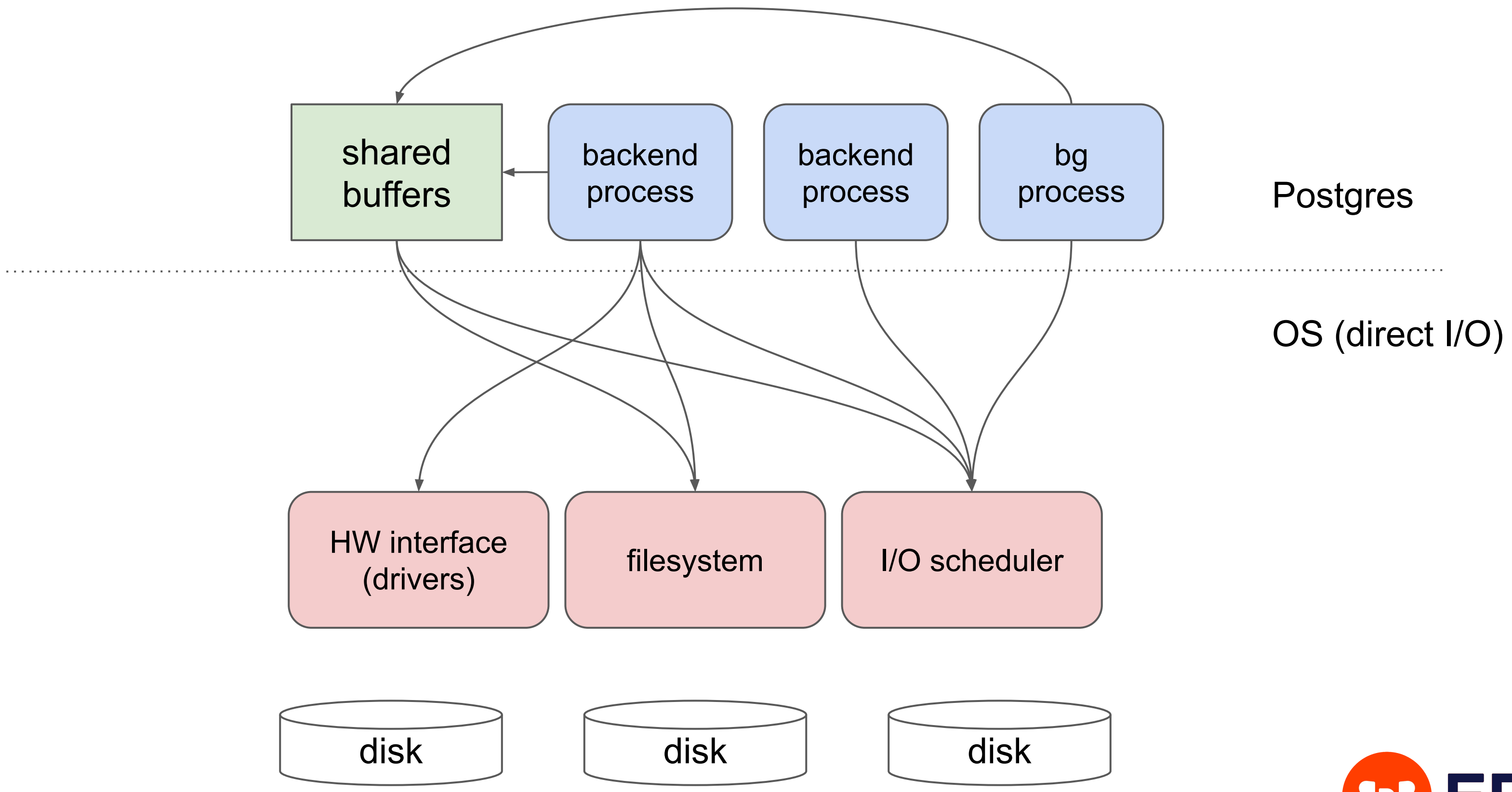
Postgres is a database ...

- storing / accessing data the whole point
- but the low-level stuff is left to the OS
  - OS implements filesystems, provides POSIX interface
- low-level stuff is responsibility of the OS
  - I/O scheduling, caching, sync/async, prefetching (*)
  - handling storage errors (*)

Postgres is a database ...

- is this a good idea?
- historical reasons
  - limited developer capacity, outside of project focus
- would it even be possible to do "custom" stuff?
  - a lot of supported platforms / different behavior
  - storage hardware changes a lot / quickly
- filesystems do innovate too
  - immediate benefit thanks to that (snapshots, ...)


shared buffers
backend process
backend process
bg process
Postgres
OS
page cache
HW interface (drivers)
filesystem
I/O scheduler
disk
disk
disk
EDB



shared buffers
backend process
backend process
bg process
Postgres
OS (direct I/O)
HW interface (drivers)
filesystem
I/O scheduler
disk
disk
disk

Problem #1: error handling

- POSIX is great!
  - but it doesn't guarantee the same behavior everywhere
- what happens after an I/O error during fsync?
- fsync gate (~2018)
  - problems with reporting / handling fsync failures
  - who gets the error with multiple file descriptors?
    (everyone? old/new descriptors?)
  - fs-specific behavior - some throw away the dirty data / mark as clean
  - should be "fine" in new kernels (handled in a no-data-loss way)

Problem #2: lack of visibility

- the OS does great general-purpose scheduling
- the database knows more about the workload, could do better
- example A: it knows what can be done in the background
  - less sensitive I/O, acceptable to delay in favor of user stuff
  - flushing WAL / checkpoints, ...
- example B: prefetching
  - OS has to guess which block will be need next (depends on indexes, ...)
  - we already to explicit posix_fadvise() in a couple places to prefetch async

rule #1 - use recent kernel

- old kernels have all kinds of issues
- bugs
  - fsyncgate (but probably other issues)
  - occasional (performance) regression
- inefficiency
  - general improvements everywhere
  - significant improvements in some filesystems (e.g. BTRFS)
- OK, regressions exist too ...

Benchmarks / stress tests

https://github.com/tvondra/fsbench-results

When not under load, all filesystems perform great.

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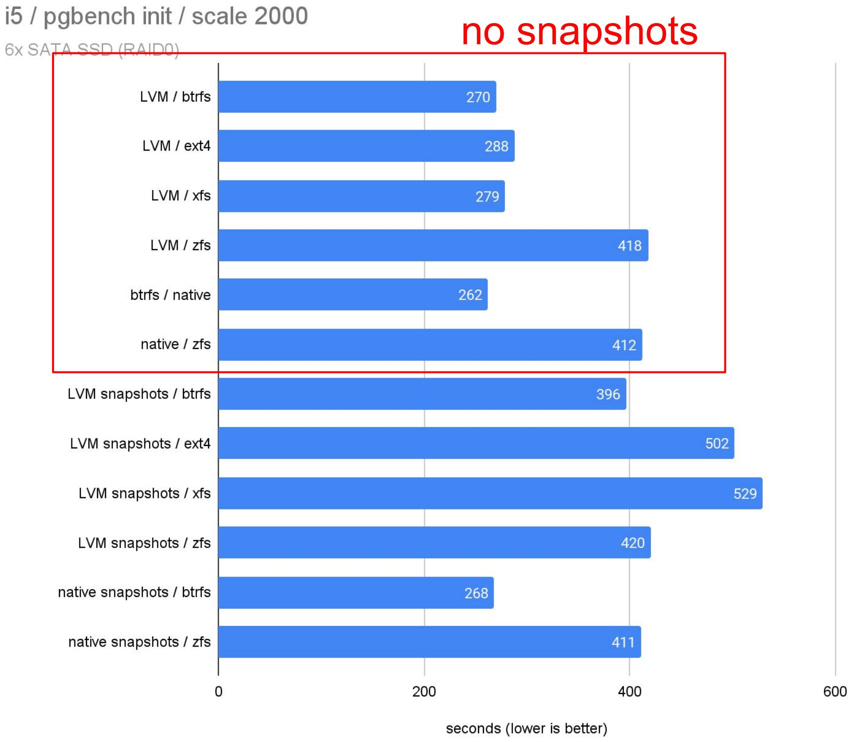
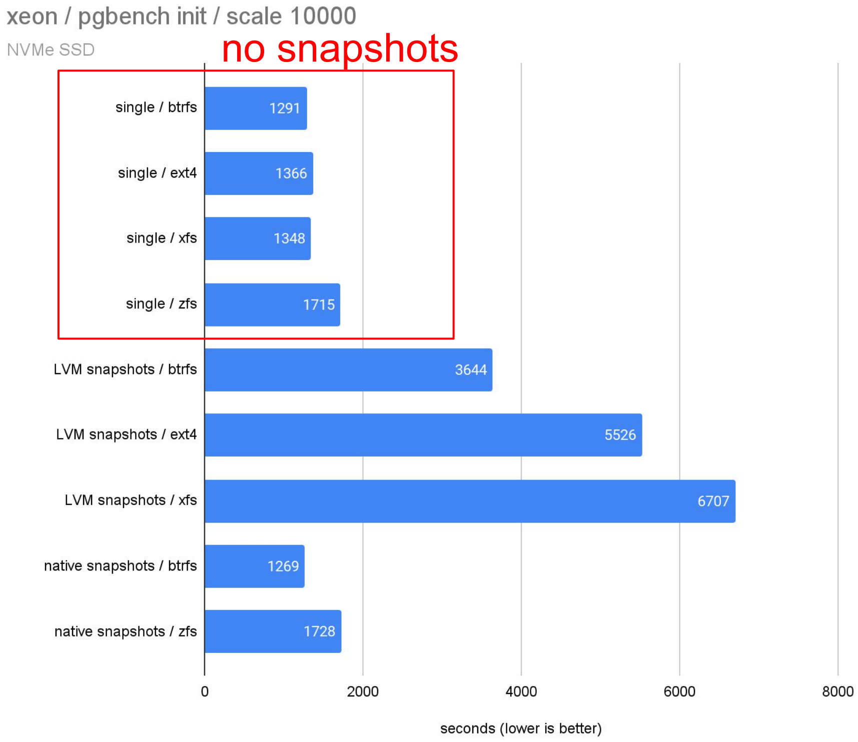
;-)

Stress tests are not realistic

- all filesystems have some sort of maintenance / cleanup
  - intended to happen in the background (no disruption)
- stress test = designed to saturate the system
  - do as many transactions as possible
- typical production workload is not 100%
  - aim for ~75% and then consider upgrade
  - makes some of the charts look worse than reality (latency)
- also hardware and configuration-dependent
  - different RAID levels, ZIL/SLOG, ...

Bulk load (COPY into table)





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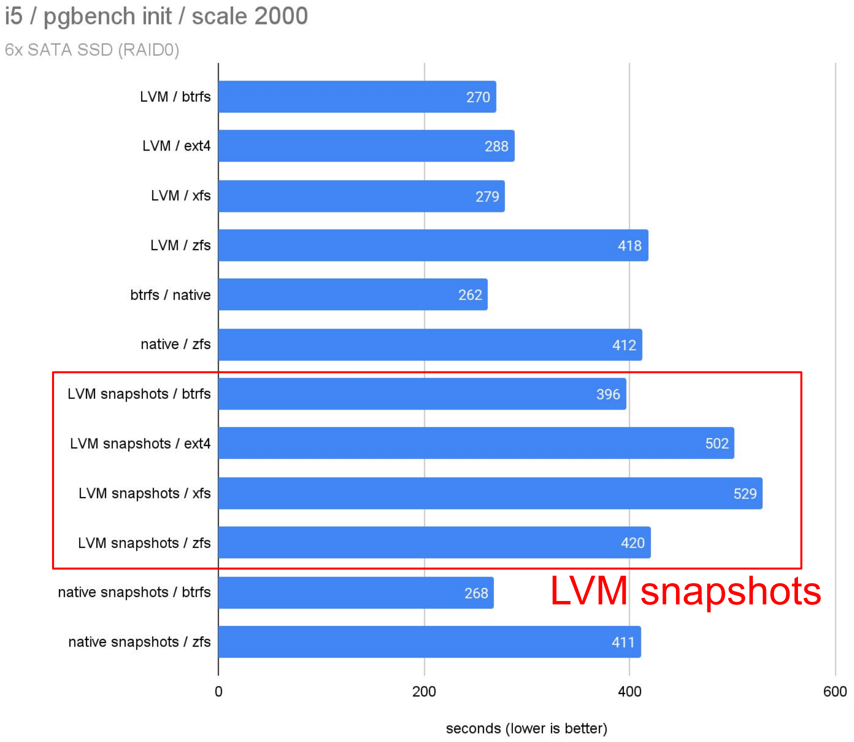

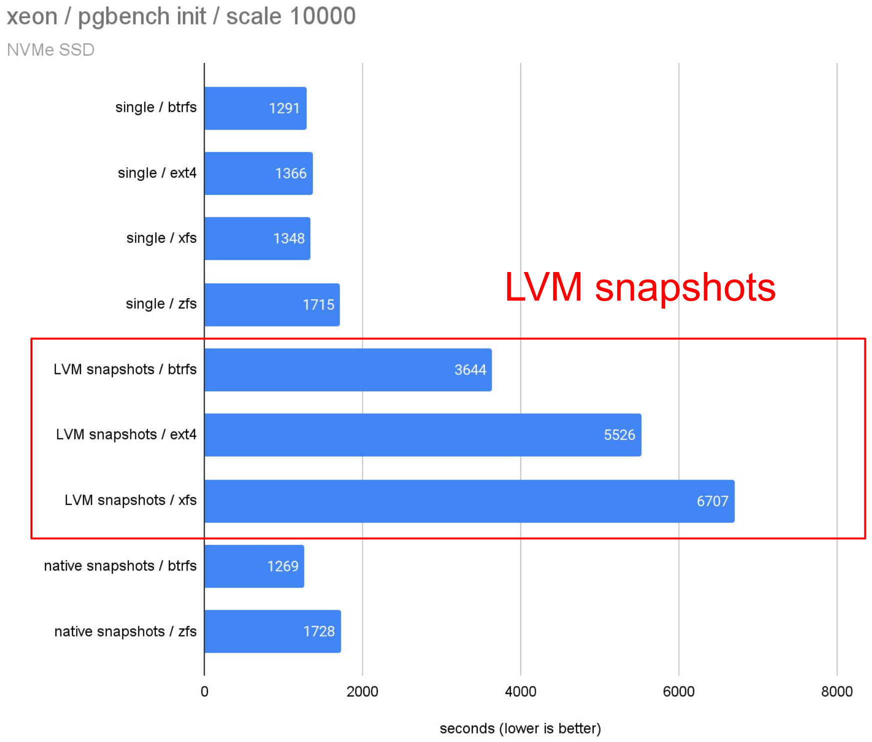

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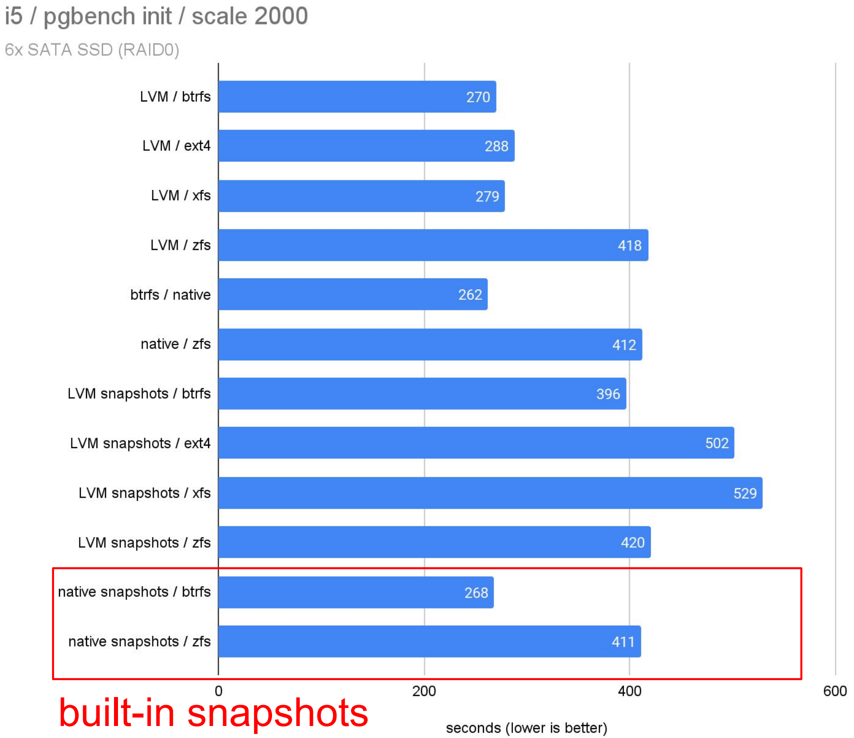

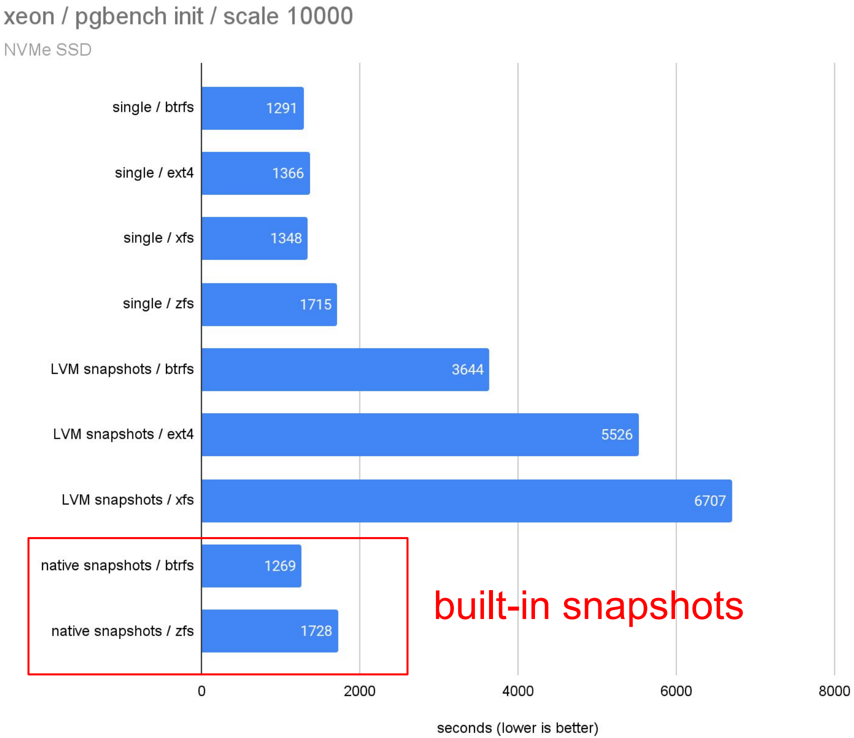

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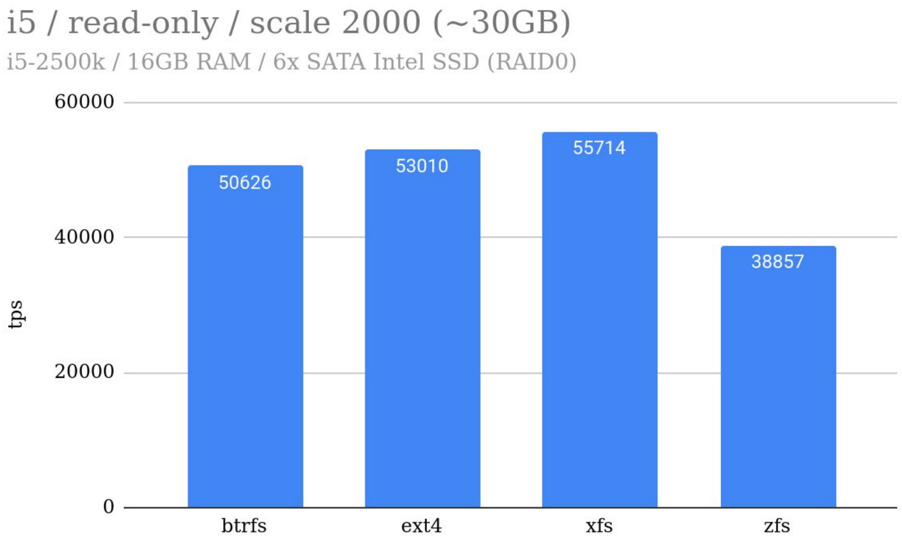
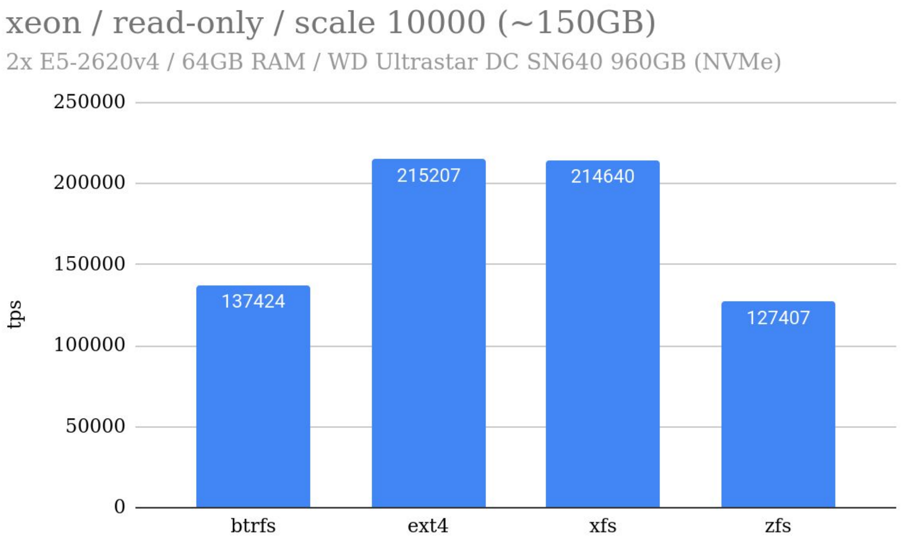
OLTP (pgbench, read-only)





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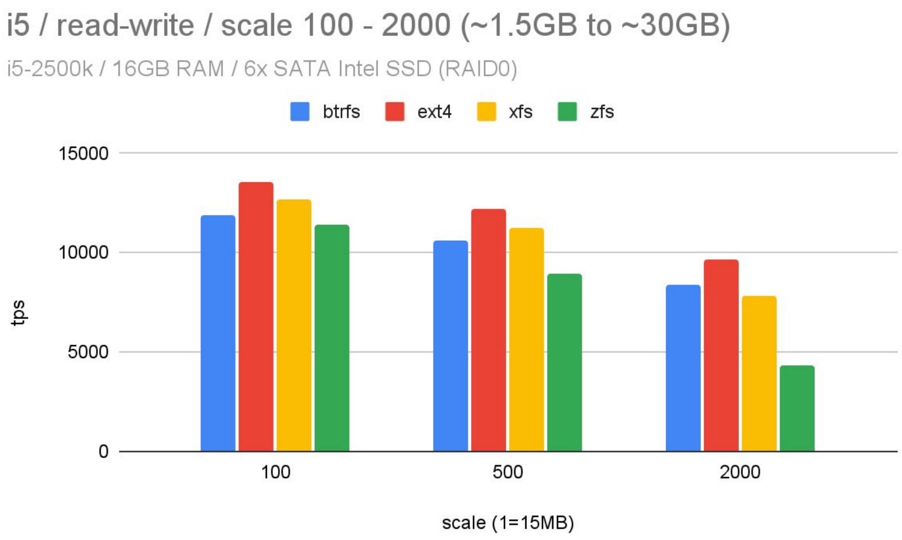
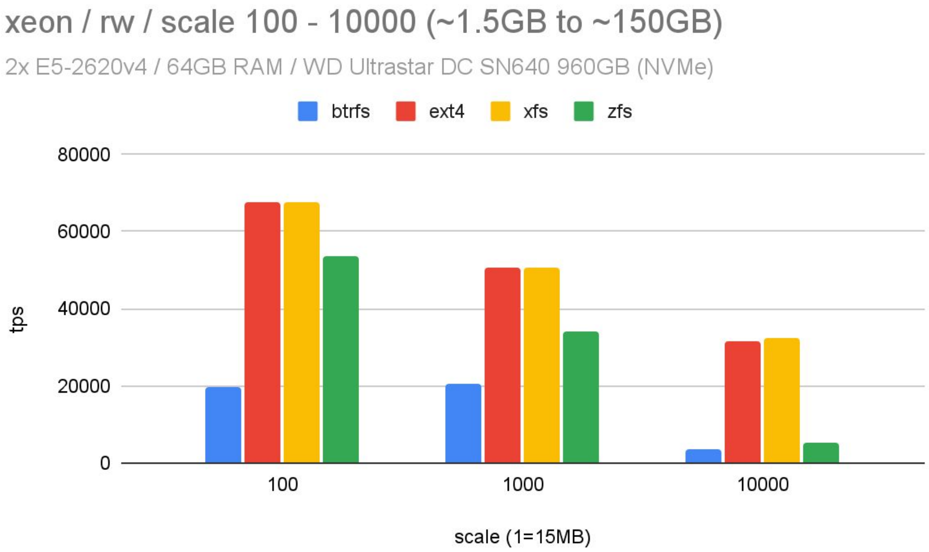
OLTP (pgbench, read-write)

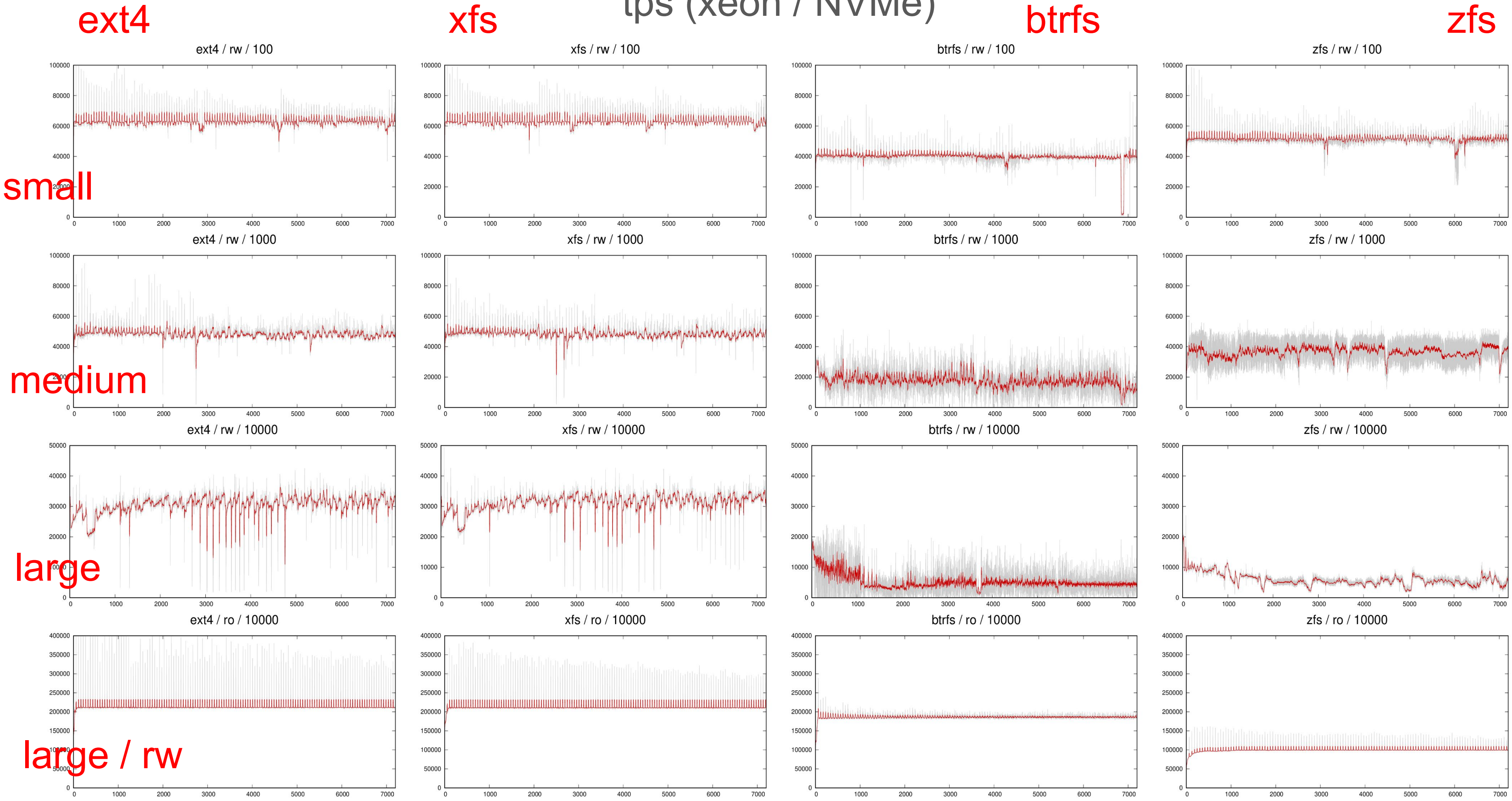




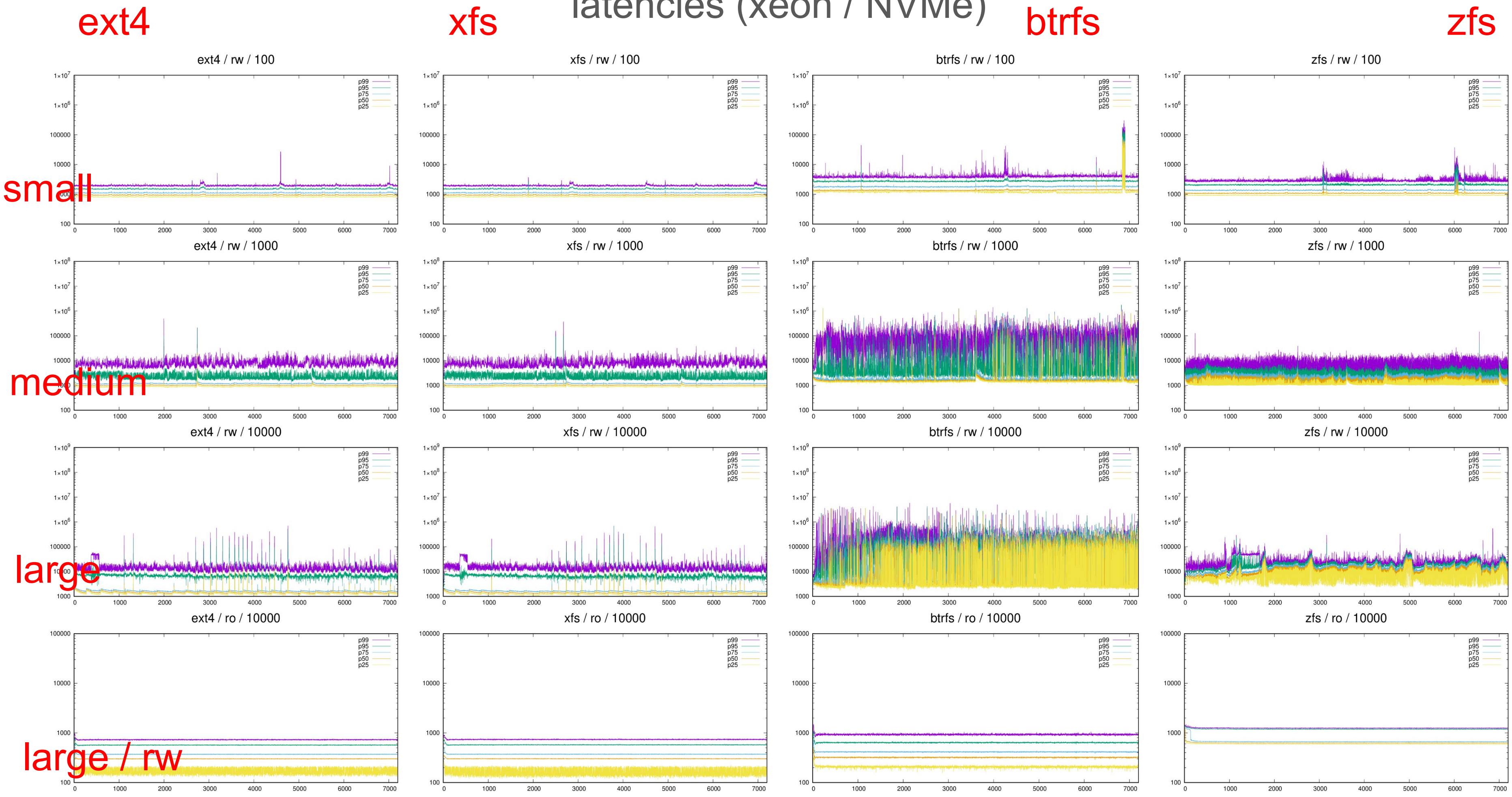
https://postgres.land/talks/

But throughput does not tell the whole story ...

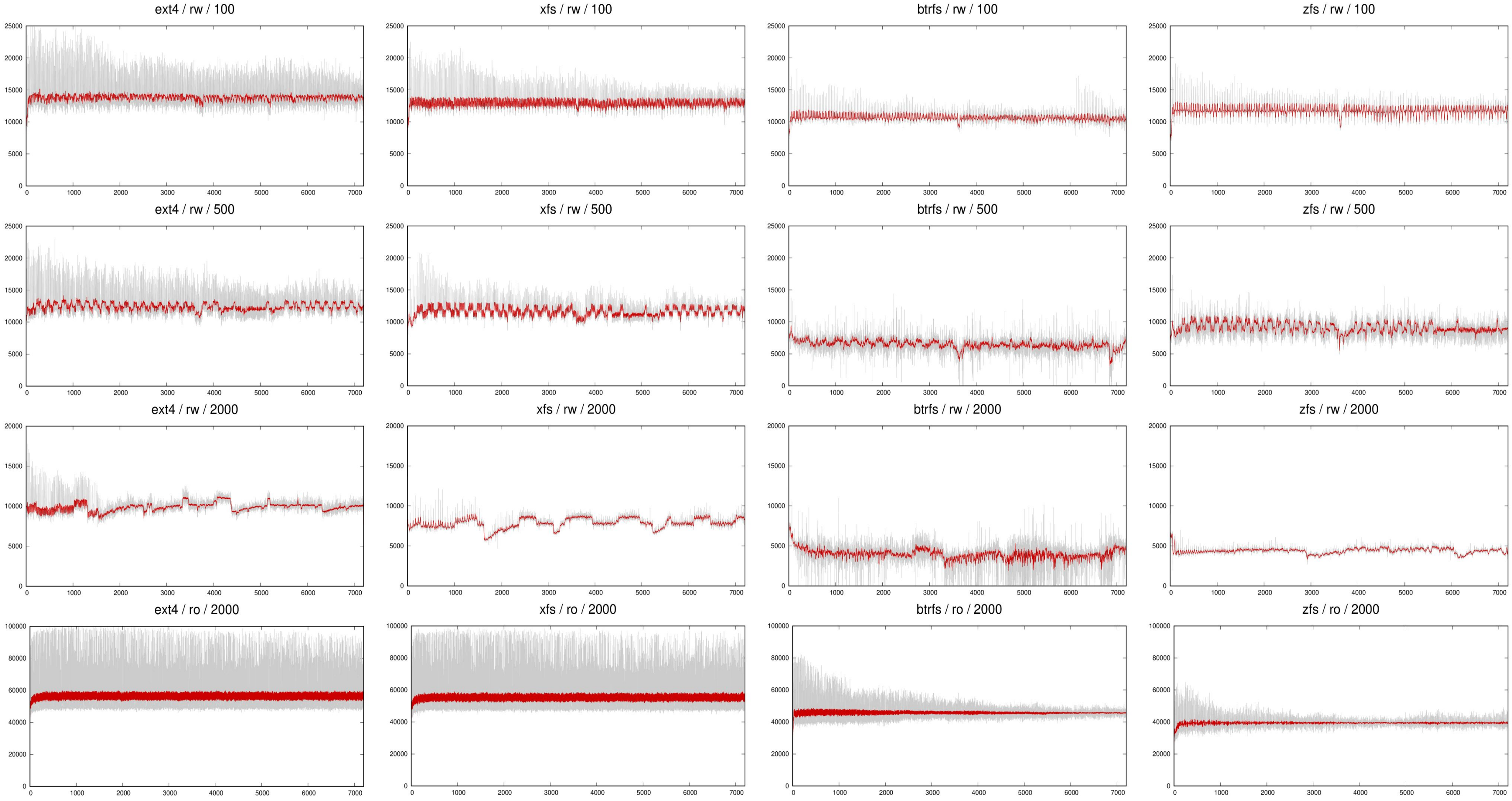
tps (xeon / NVMe)



latencies (xeon / NVMe)



tps (i5 / SATA SSD)



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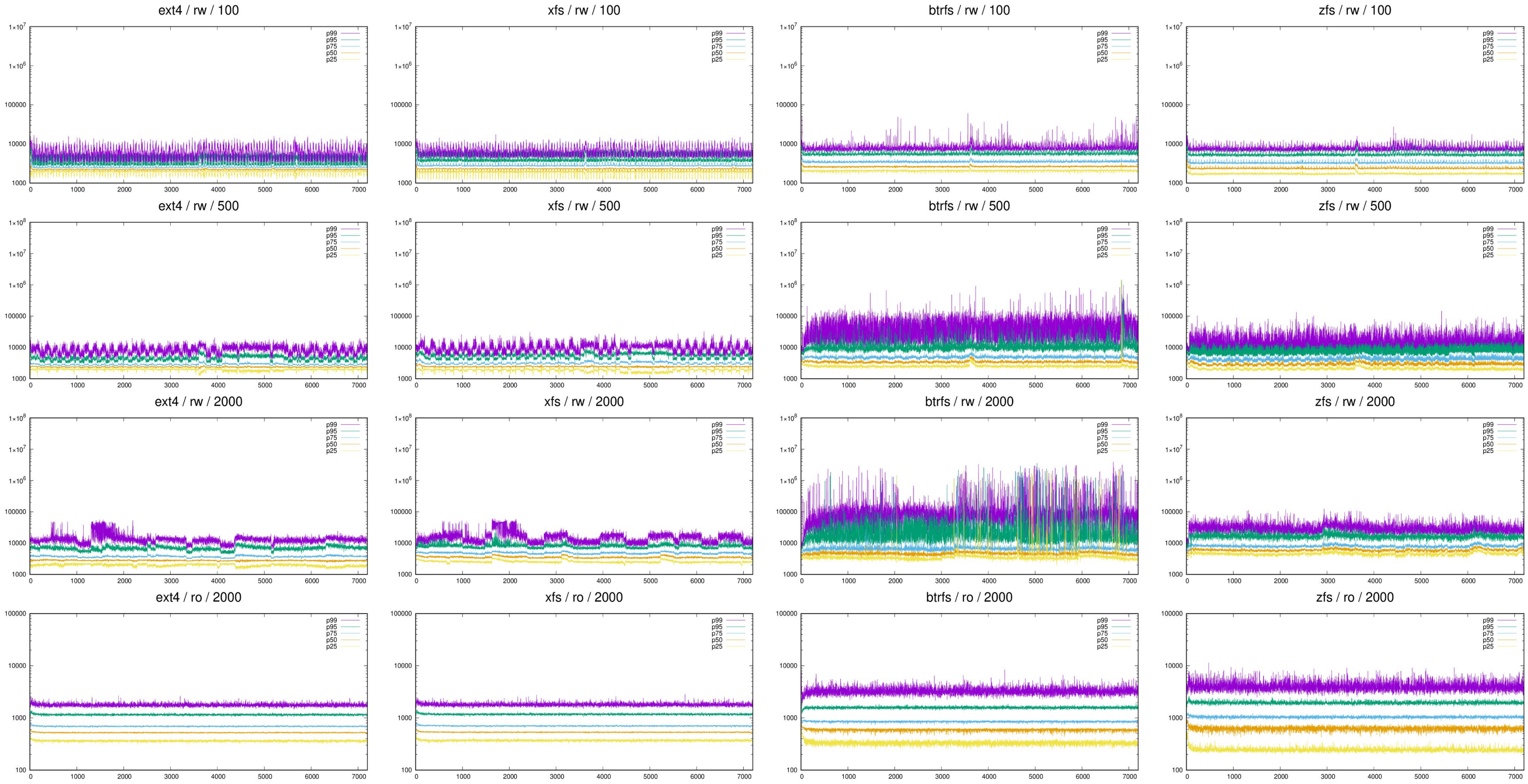
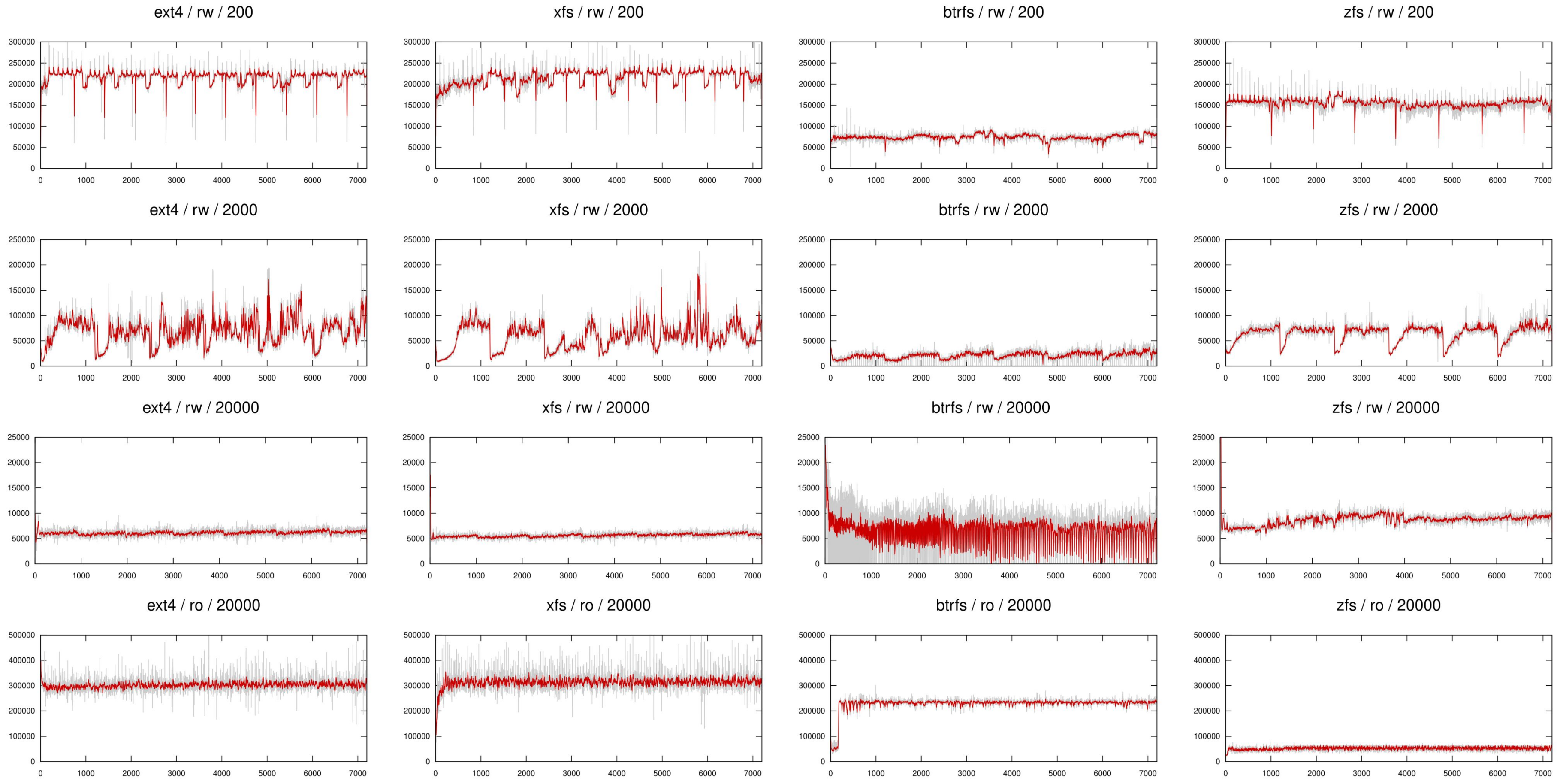


tps (epyc / 4 x NVMe)



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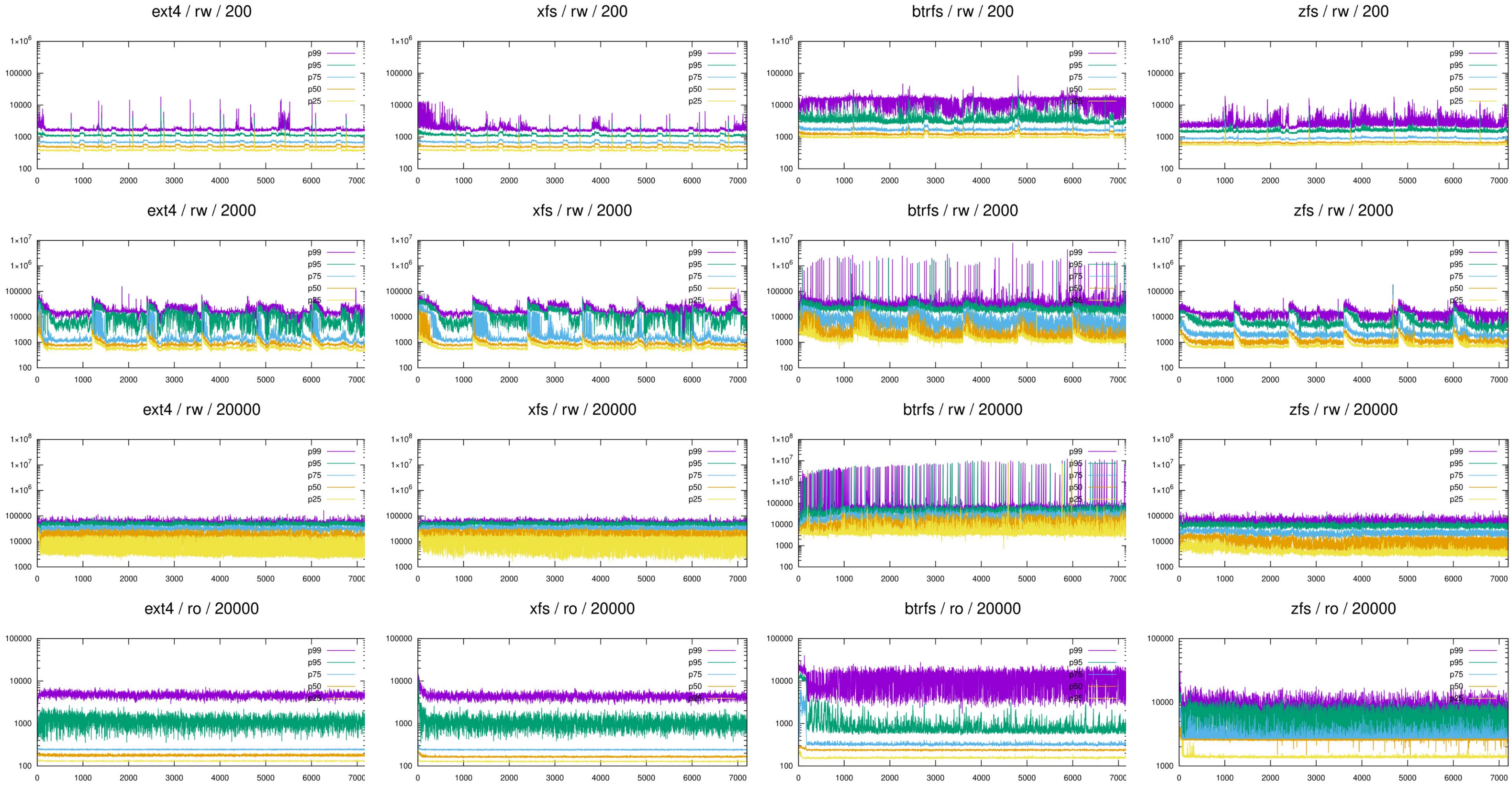
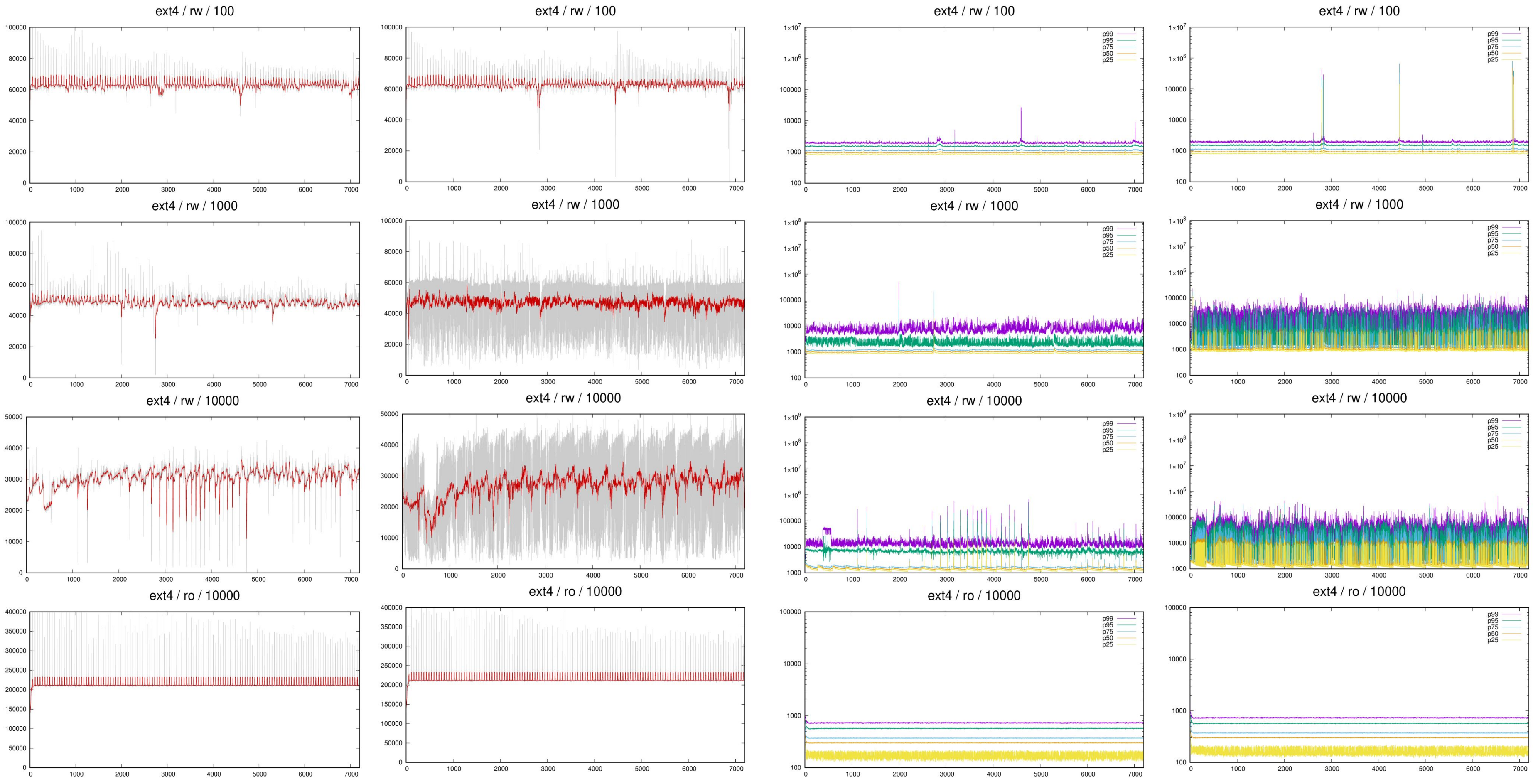


More important ...

- dirty page cache (kernel)
  - evicted by OS, can cause spikes in latency
  - reduce vm.dirty_background_bytes / vm.dirty_expire_centisecs
  - and/or set backend_flush_after (disabled by default)
- full_page_writes (PG)
  - necessary on most file systems (zfs exception)
  - possible source of massive write amplification
  - maybe increase max_wal_size (but has drawbacks too)
- zfs prefetch (read-ahead)?
  - pg_dump durations ~2x higher than other filesystems

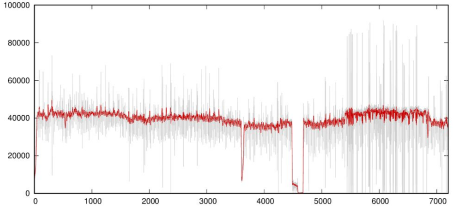
vm.dirty_background_bytes = 32MB vs. 1GB



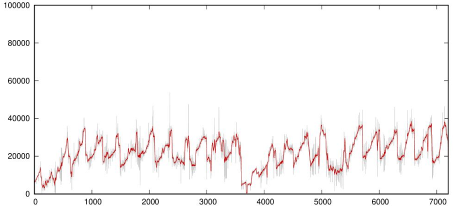
what about snapshots?

ext4 / LVM

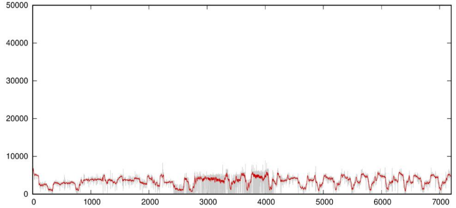
ext4 / rw / 100



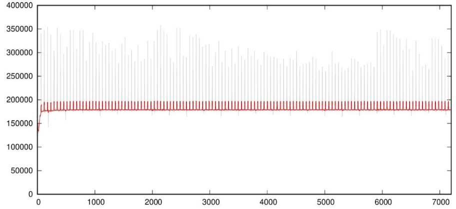
ext4 / rw / 1000



ext4 / rw / 10000

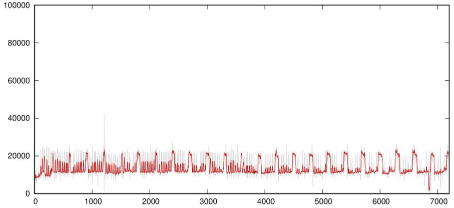


ext4 / ro / 10000

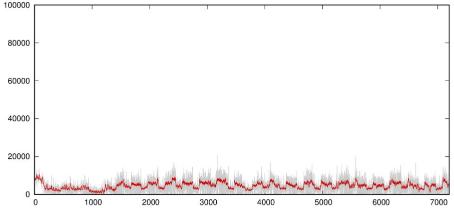


btrfs / LVM

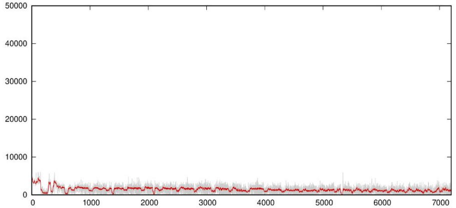
btrfs / rw / 100



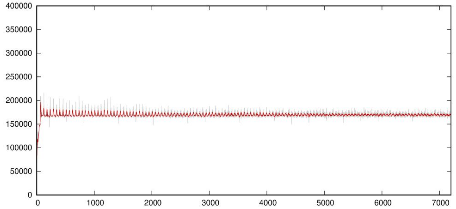
btrfs / rw / 1000



btrfs / rw / 10000

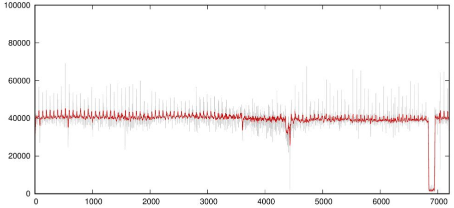


btrfs / ro / 10000

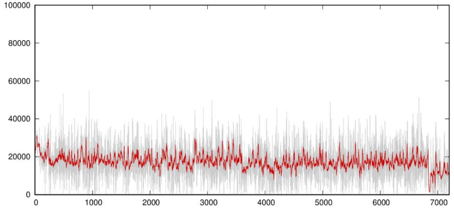


btrfs / native

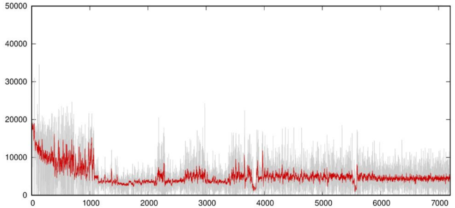
btrfs / rw / 100



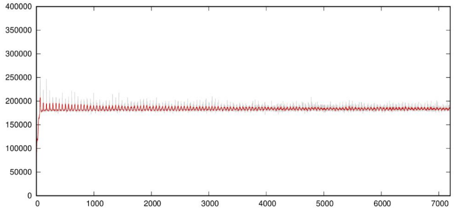
btrfs / rw / 1000



btrfs / rw / 10000

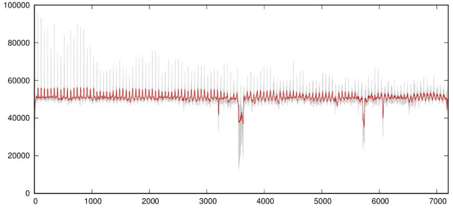


btrfs / ro / 10000

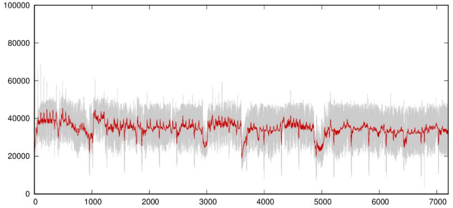


zfs / native

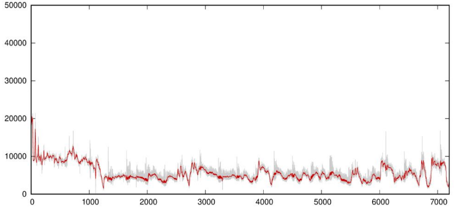
zfs / rw / 100



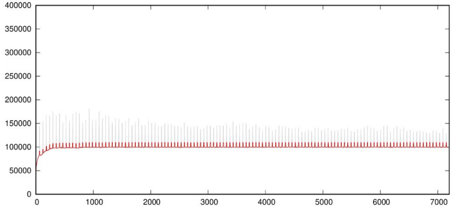
zfs / rw / 1000



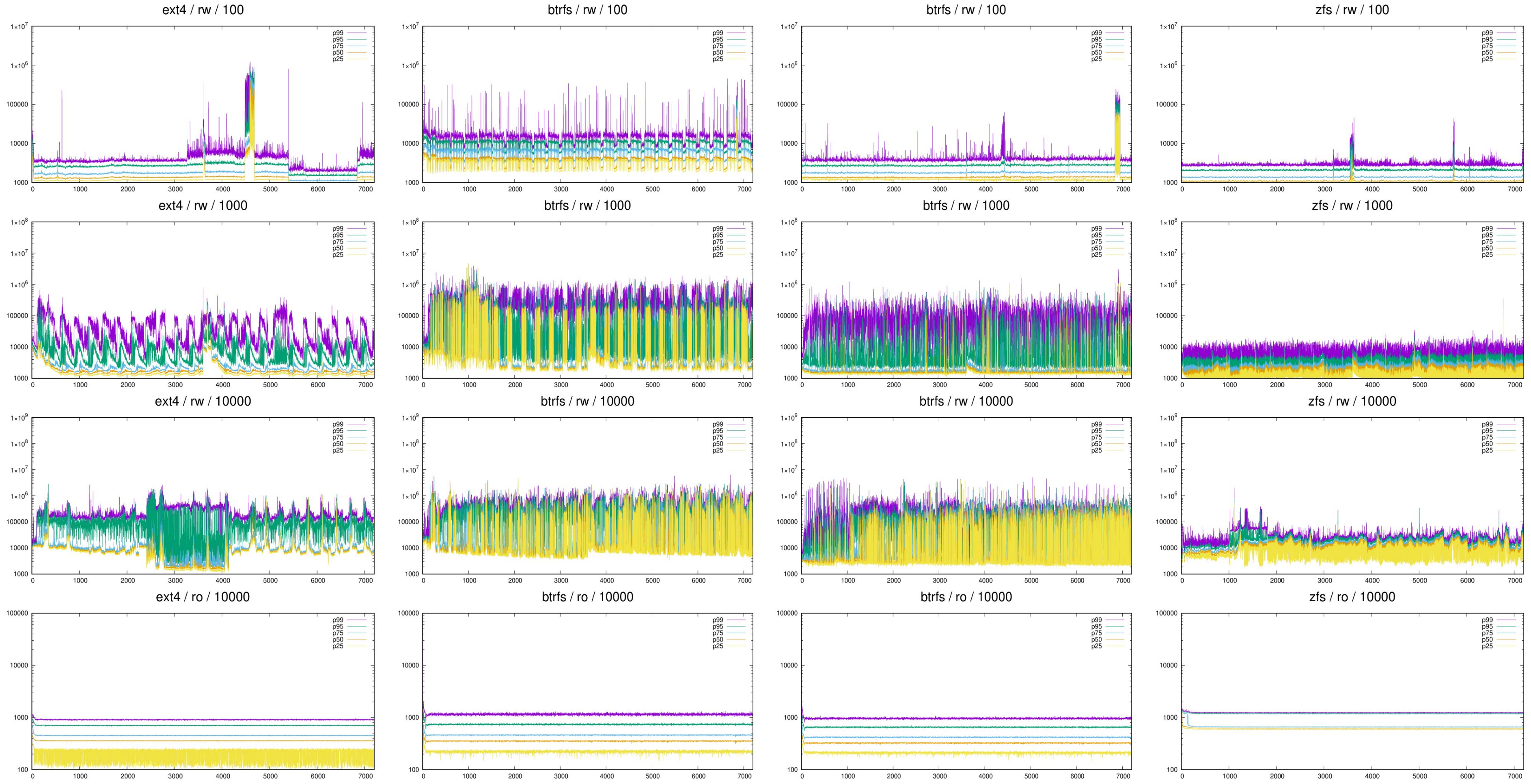
zfs / rw / 10000



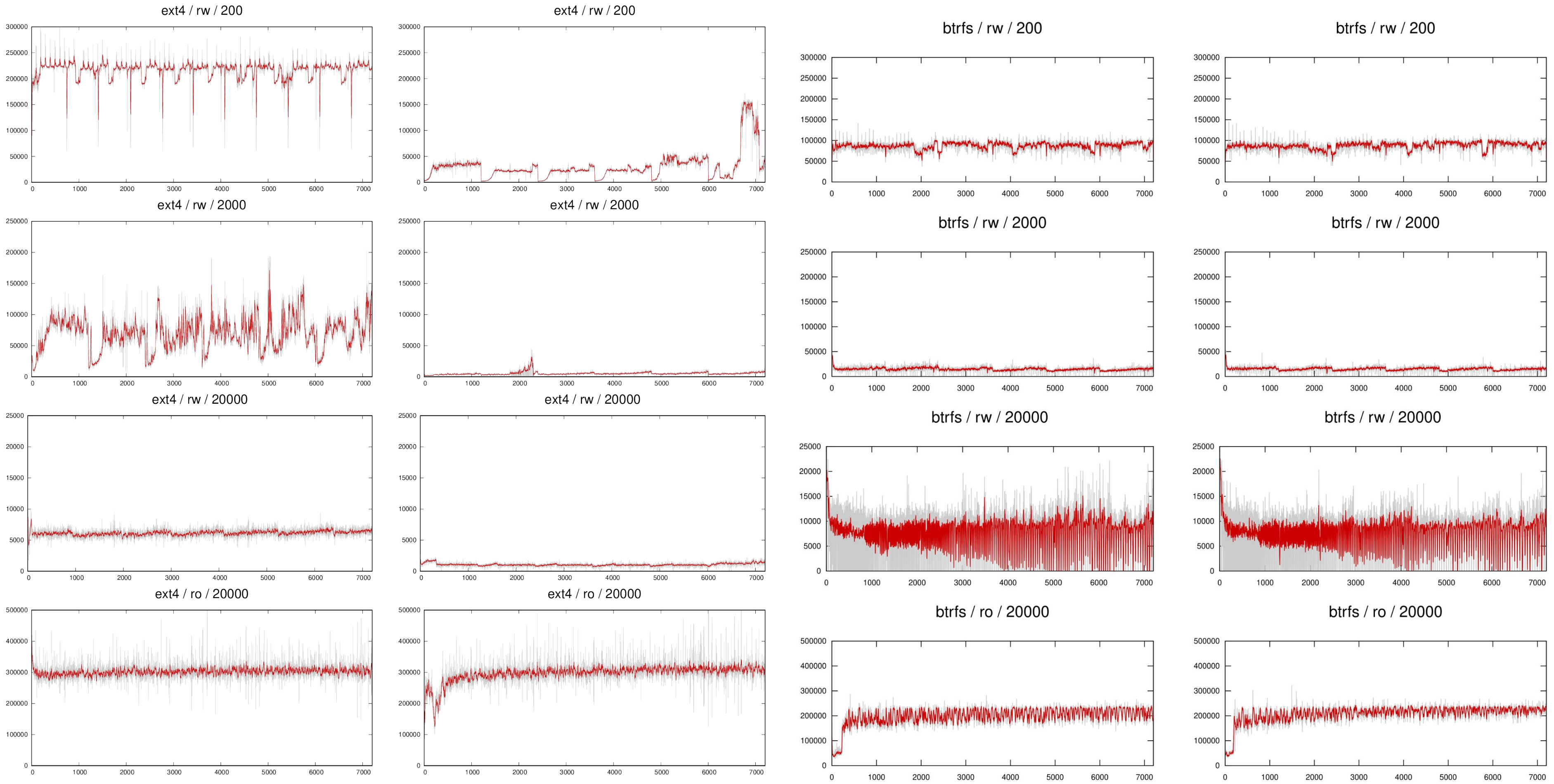
zfs / ro / 10000



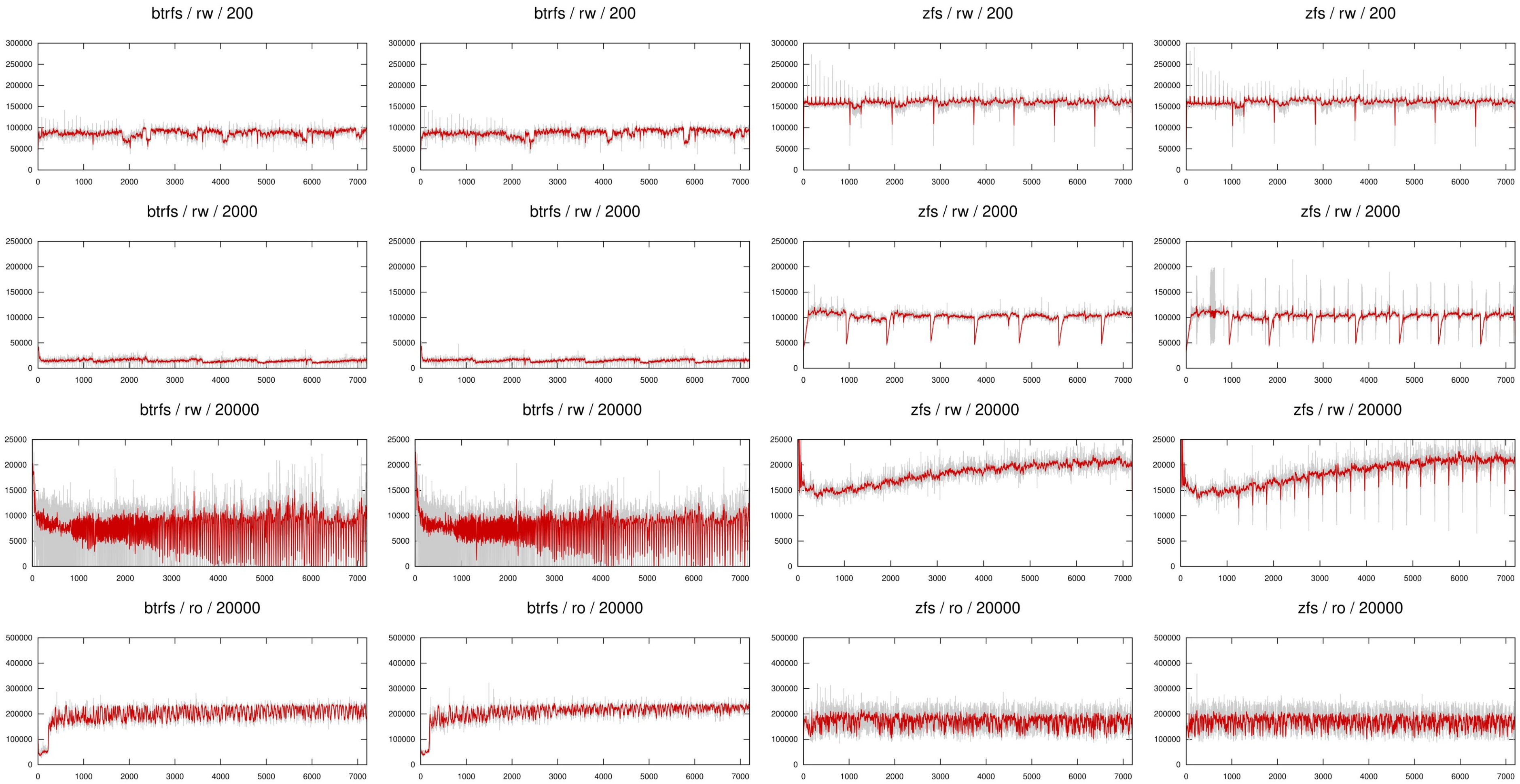
ext4 / LVM | btrfs / LVM | btrfs / native | zfs / native



ext4 / no snapshots | ext4 / LVM snapshots | btrfs / no snapshots | btrfs / snapshots



btrfs / no snapshots | btrfs / snapshots | zfs / no snapshots | zfs / snapshots



Questions

- how much more we could get from NVMe?
  - can we saturate NVMe for reads/writes?
  - not really, we're quite CPU heavy (cycles per I/O request)

- What Modern NVMe Storage Can Do, And How To Exploit It: High-Performance I/O for High-Performance Storage Engines Gabriel Haas, Viktor Leis, Technische Universität München https://www.vldb.org/pvldb/vol16/p2090-haas.pdf

Future tests

- different hardware / configuration
  - different behaviors on old vs. new hardware
  - LVM vs. mdraid + LVM
- what about many files?
  - large relations: 1TB relation is ~1000 files, partitioning
  - caching, but max_files_per_backend = 1000 (=> syscalls)
- different workloads
  - OLTP is heavy on random I/O, but fairly simple
  - OLAP or mixed (OLTP + OLAP) workload

Q & A