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data-intensive systems in the microsecond era

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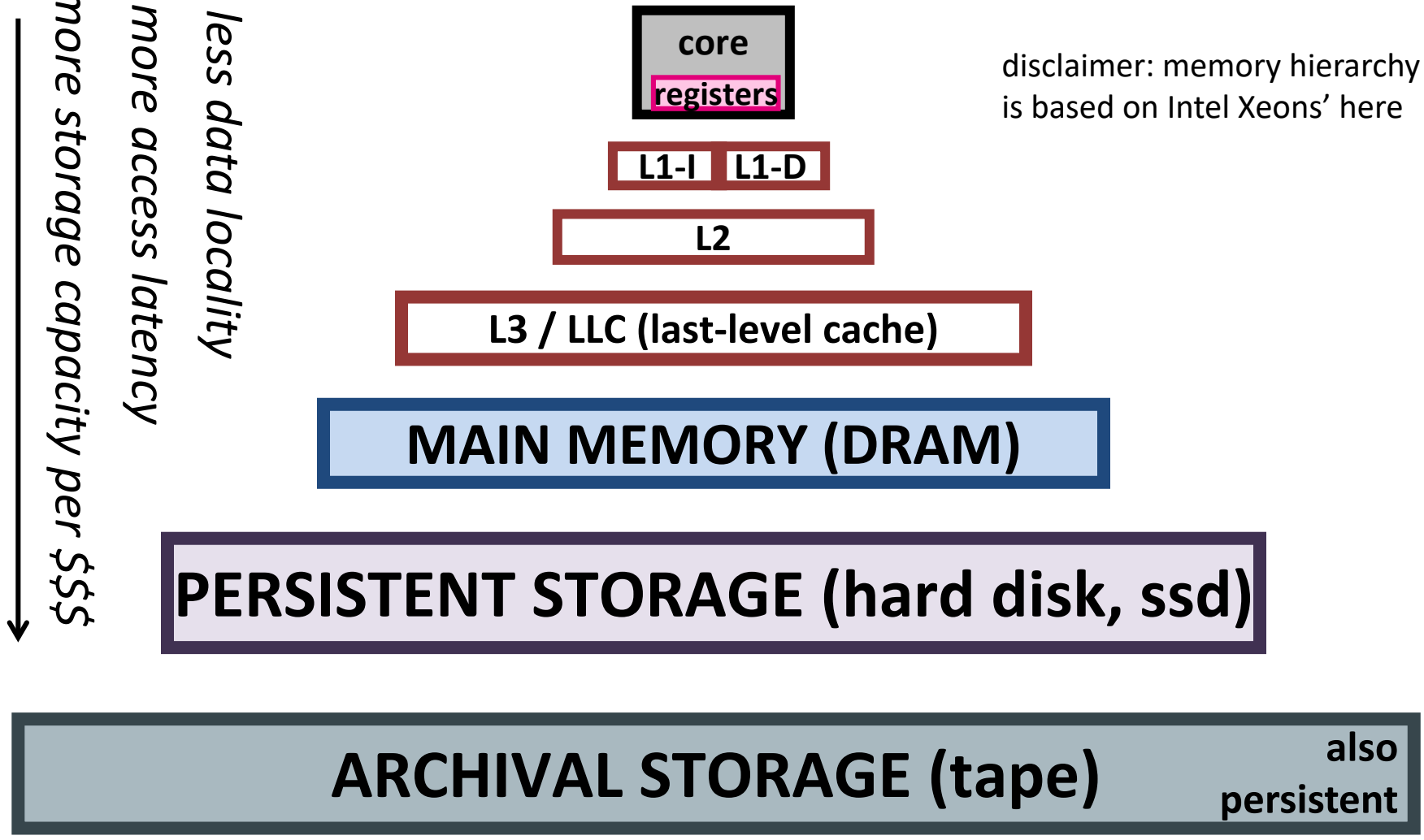
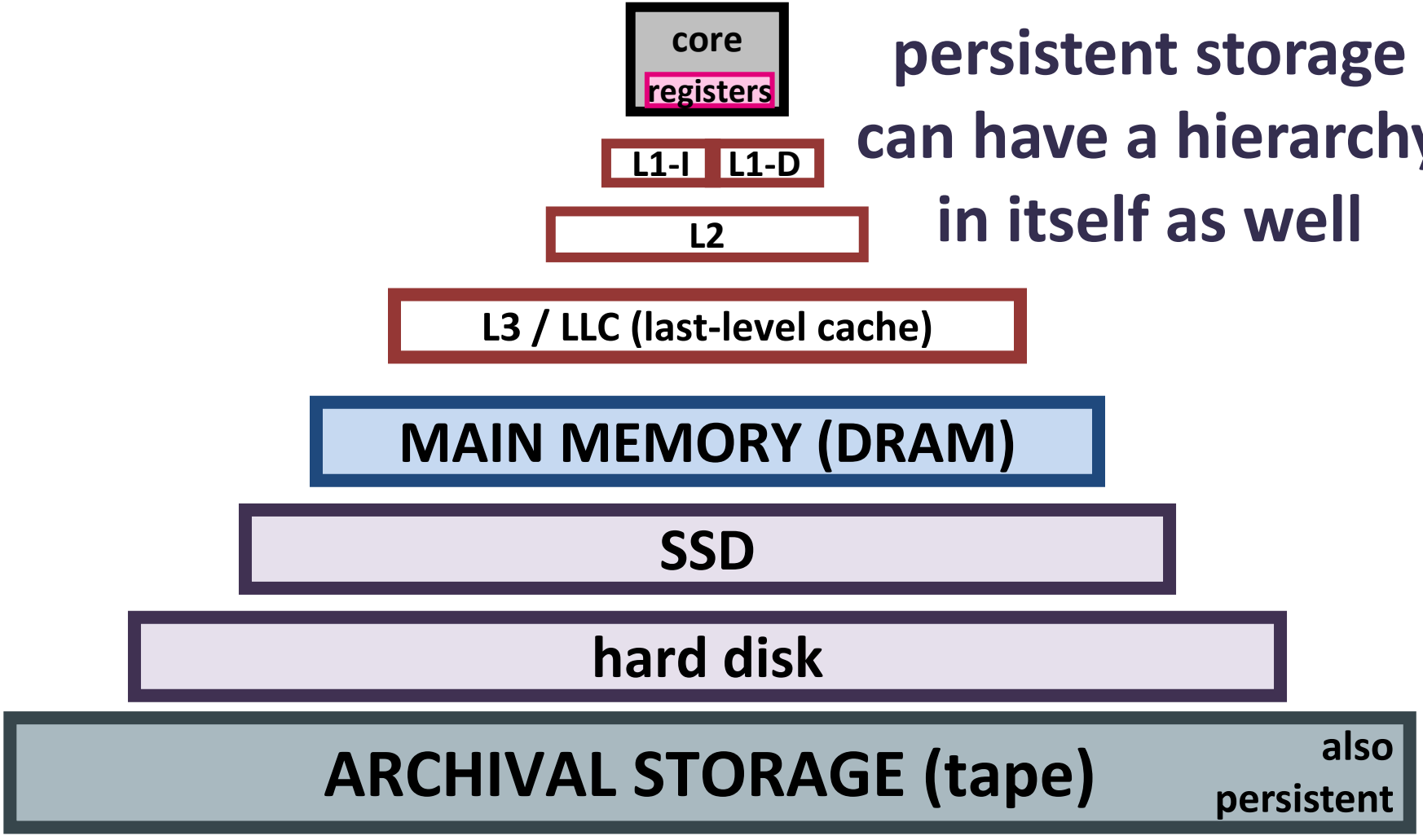
work done in collaboration with
Philippe Bonnet @ ITU

(typical) storage hierarchy



disclaimer: memory hierarchy is based on Intel Xeons' here

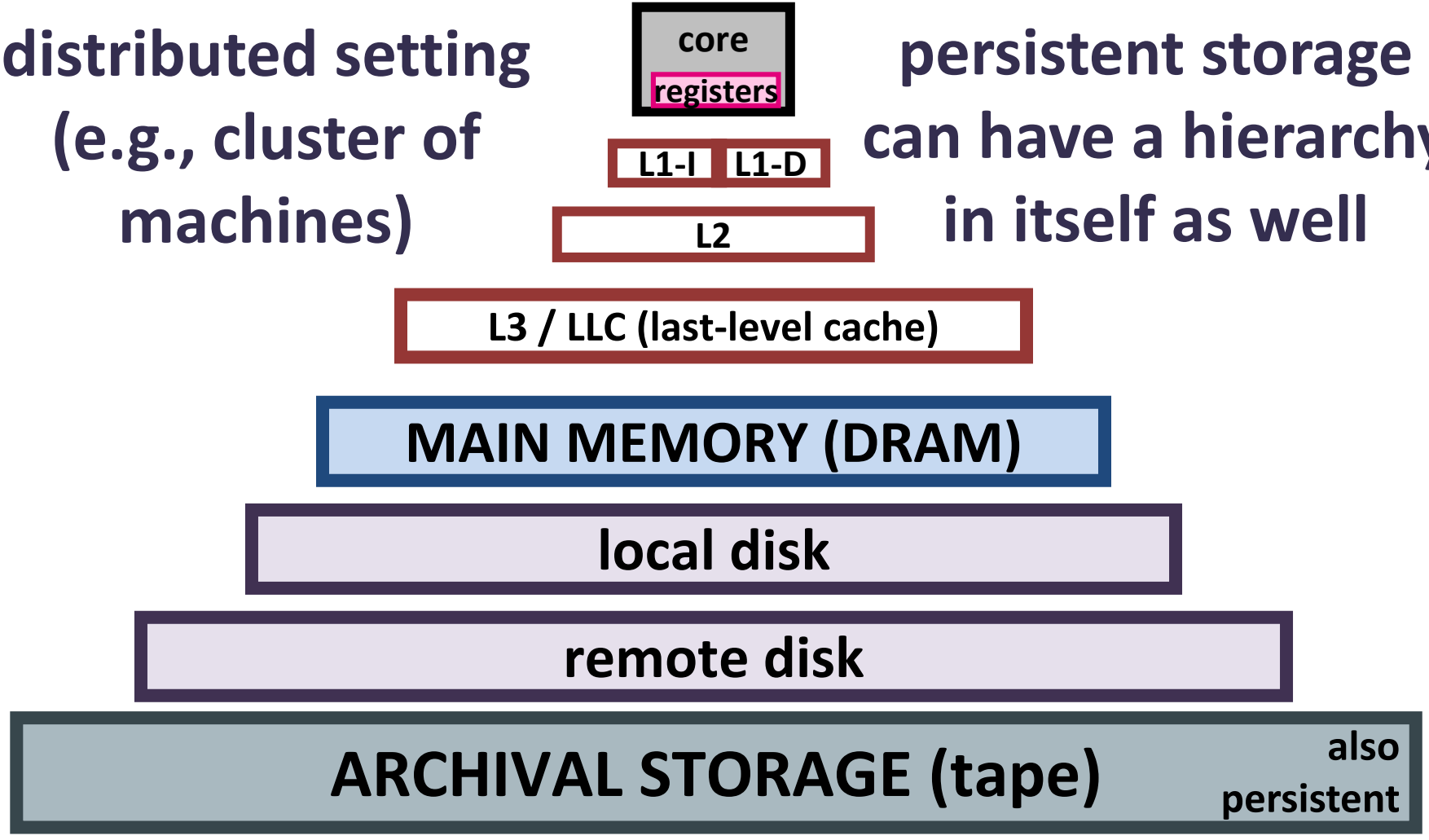
(typical) storage hierarchy



persistent storage can have a hierarchy in itself as well

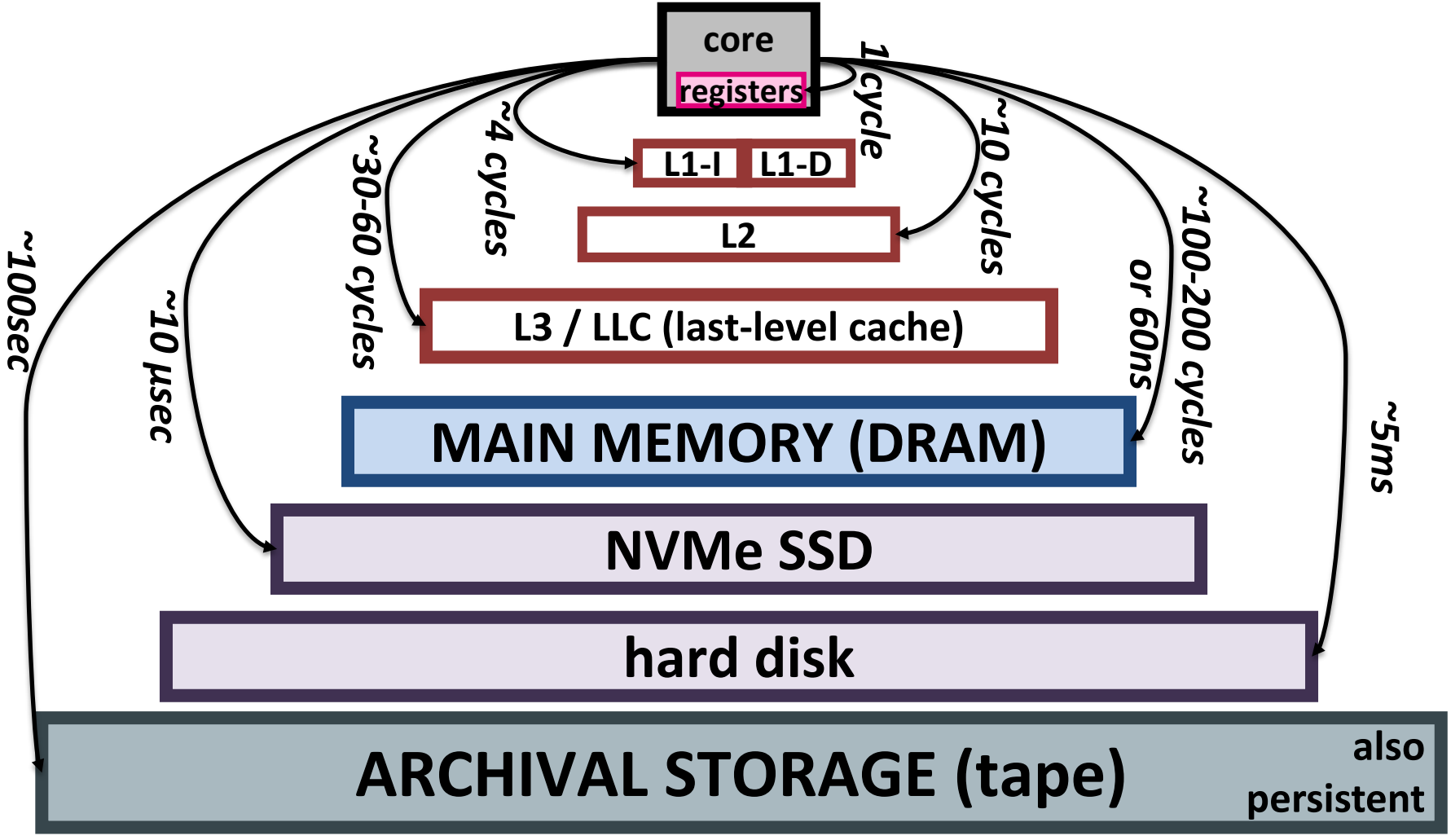
(typical) storage hierarchy

distributed setting (e.g., cluster of machines)



persistent storage can have a hierarchy in itself as well

latency to fetch data

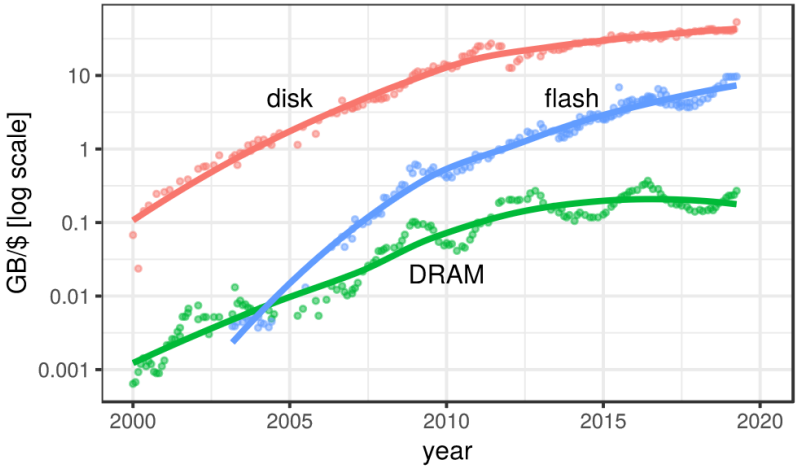


why focus on SSDs in this talk?

➔ except for SSDs, each layer stayed almost stable the last decade in terms of latency

- improvements on SSD internals
- from SAS/SATA to PCIe
- linux block IO improvements e.g., multiqueue

source: Haas et al., CIDR 2020



➔ improved price/capacity

➔ led to several SSD-optimized data systems

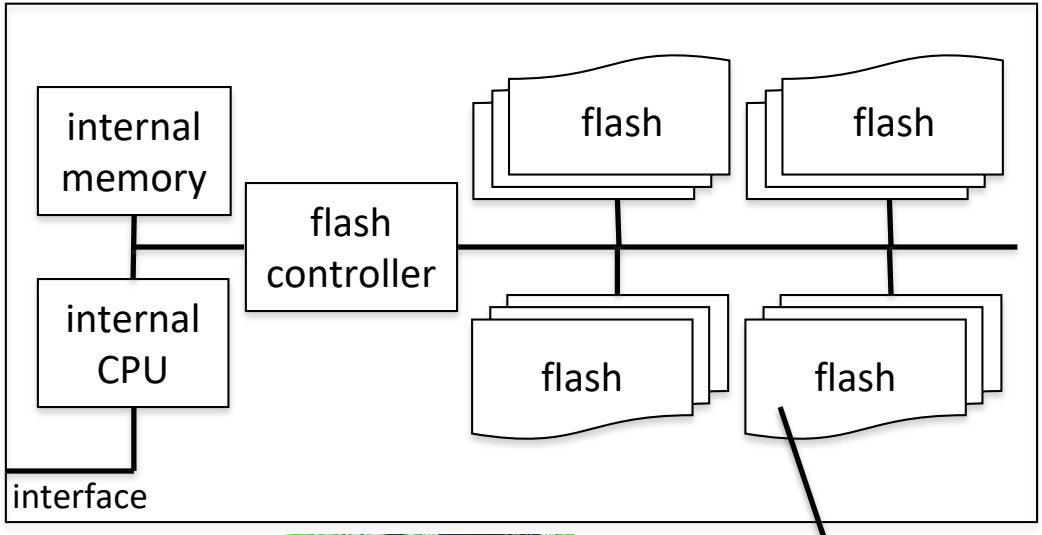
- RocksDB, BwTree, DANA, Umbra …

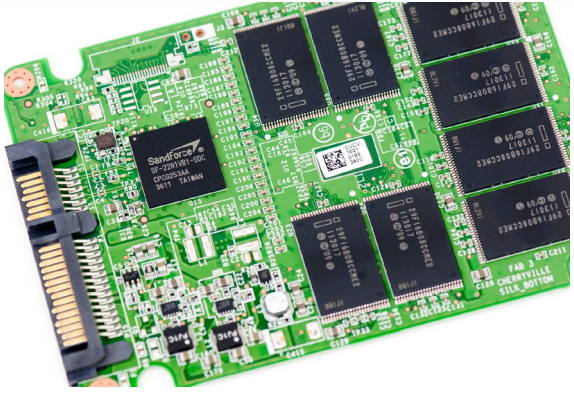
data management increasingly shifts from pure in-memory optimized to SSD-optimized!

agenda

- SSD internals & state of affairs today
- emerging SSD & computational storage landscape

solid-state disk (SSD)





interconnected flash chips

hard disk compatible API

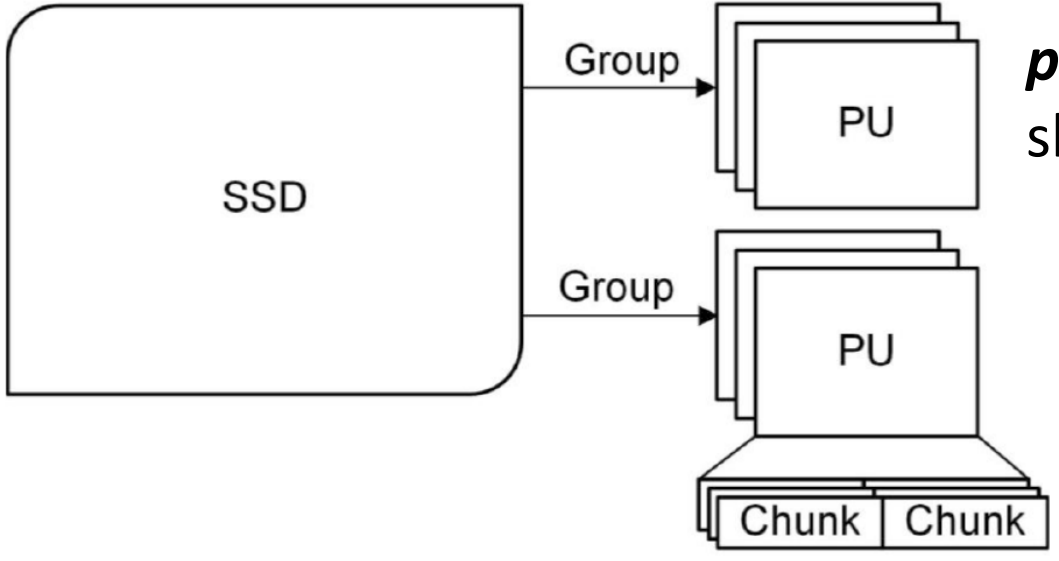
compared to hard disks

- efficient random access
- internal parallelism

device geometry

figure & components based on open-channel SSDs

isolation across ***group***s for parallel requests
each group has their own submission / completion queue



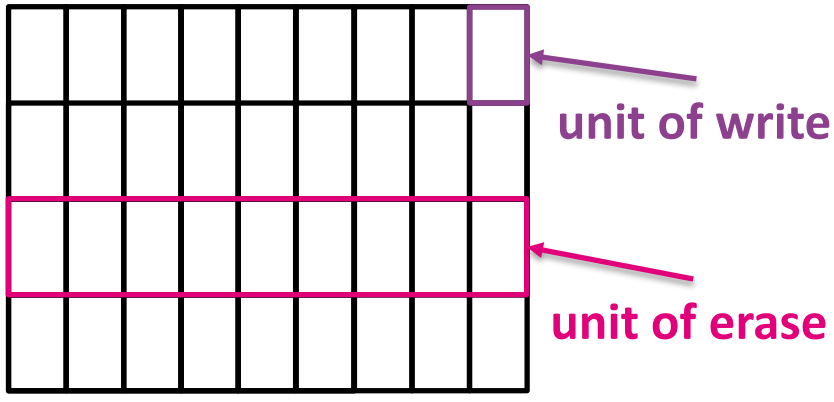
parallel units within a group share that group's queues

parallel units has ***chunks***, which are composed of ***sectors*** (= unit of read)

logical blocks ➔ multiples of sectors & unit of write

very different & complex internally compared to hard-disks

flash chips



flash translation layer (FTL) hides the internal complexities of flash chips from end-users

but knowing them can lead to smarter software design

cannot override a unit before erasing it first

garbage collection – for not used blocks so we can rewrite them

write amplification = data physically written / data logically written >= 1

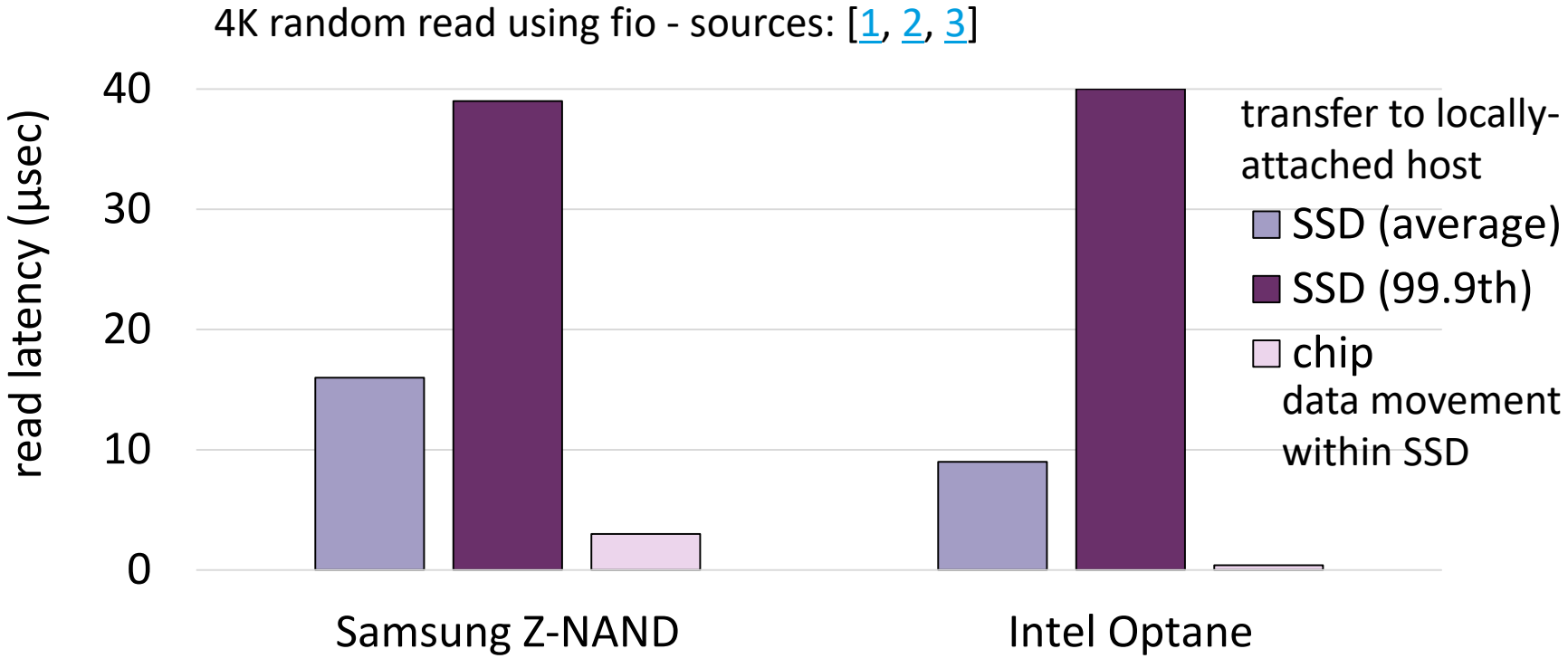
writing data might cause rewrites & garbage collection

wear leveling – some cells/blocks die over time

unpredictable read/write latencies

if a request gets stuck after a write triggering garbage collection

SSDs in the µsec era

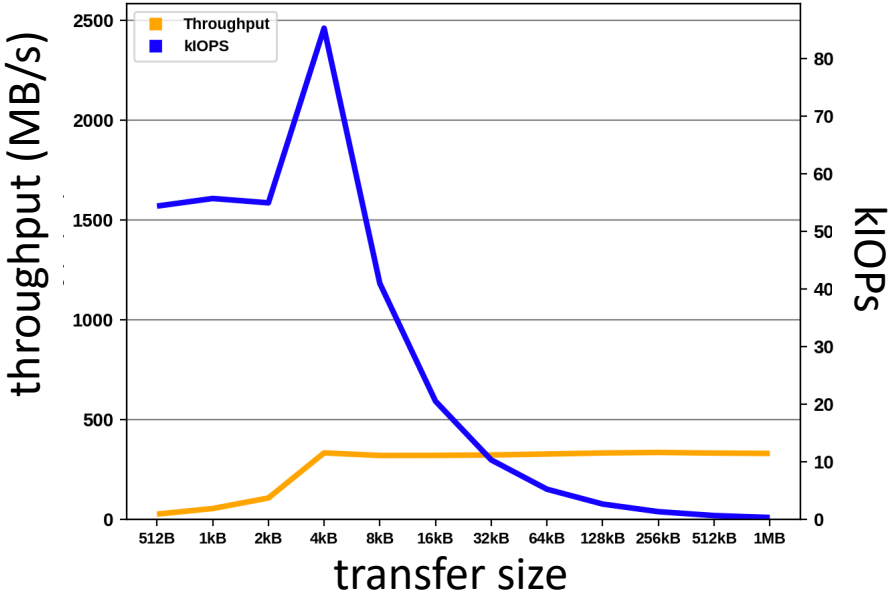


SSDs equipped with Z-NAND & Optane deliver at best 5x & 20x the read latency of the underlying storage chip, respectively.

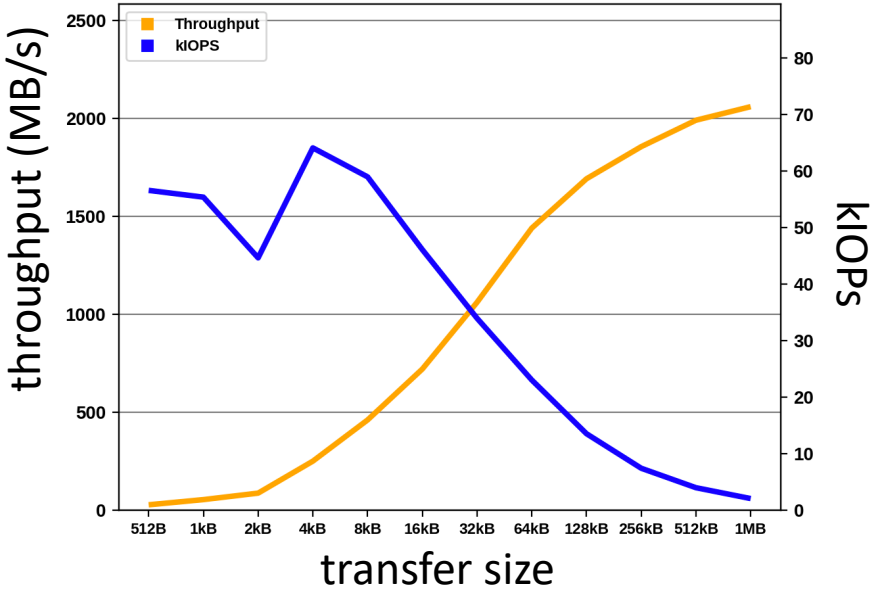
FTLs in the µsec era ..

random writes- source: AnandTech

Samsung SSD with Z-NAND

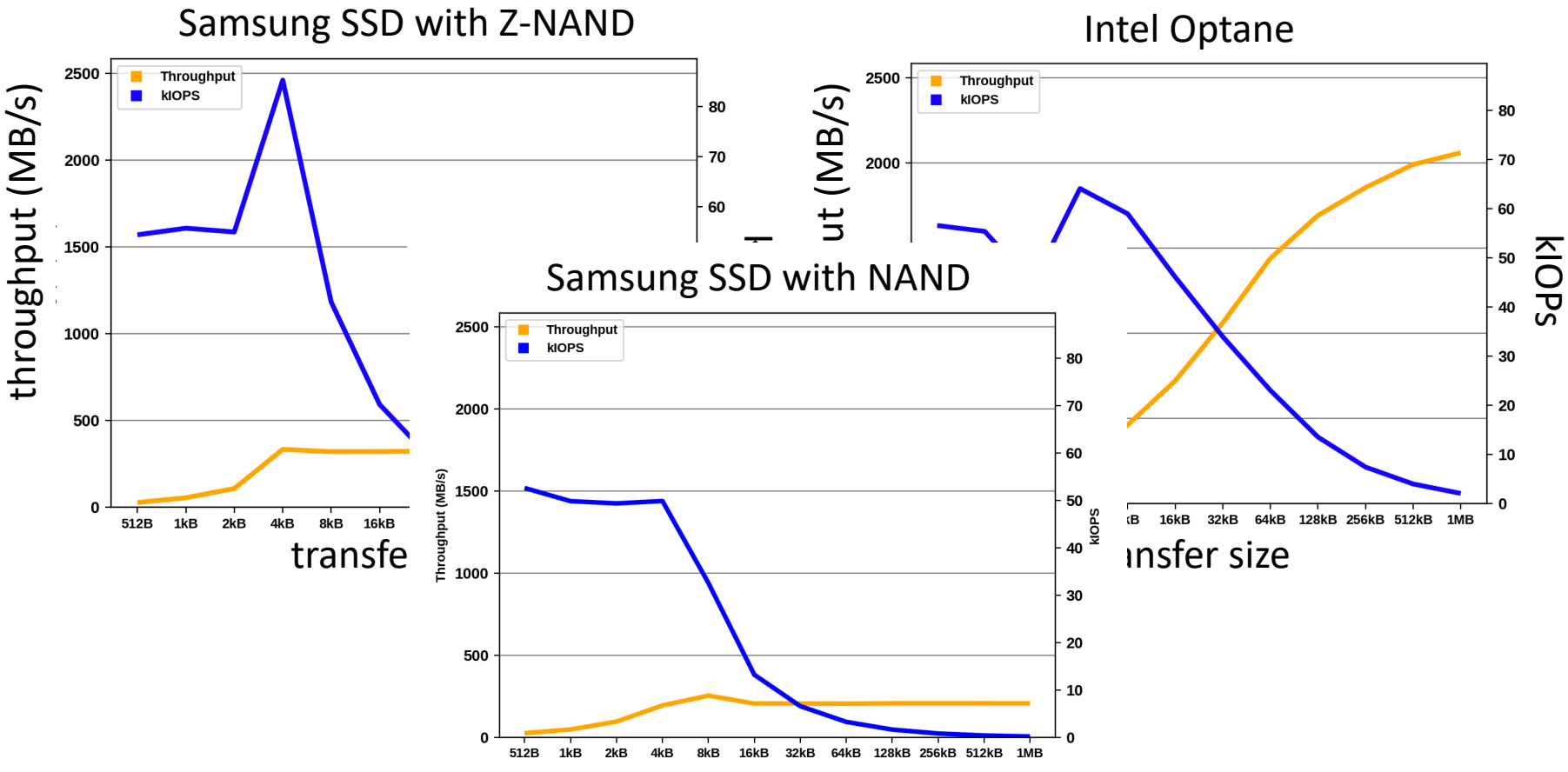


Intel Optane



FTLs in the µsec era ..

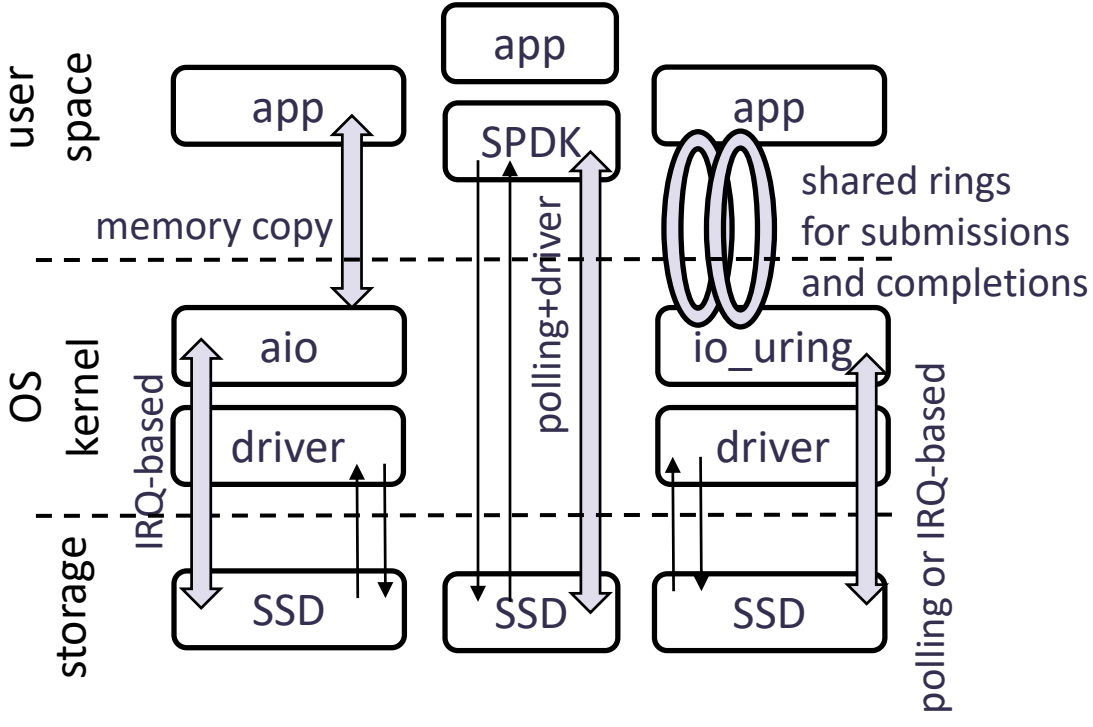
random writes- source: AnandTech

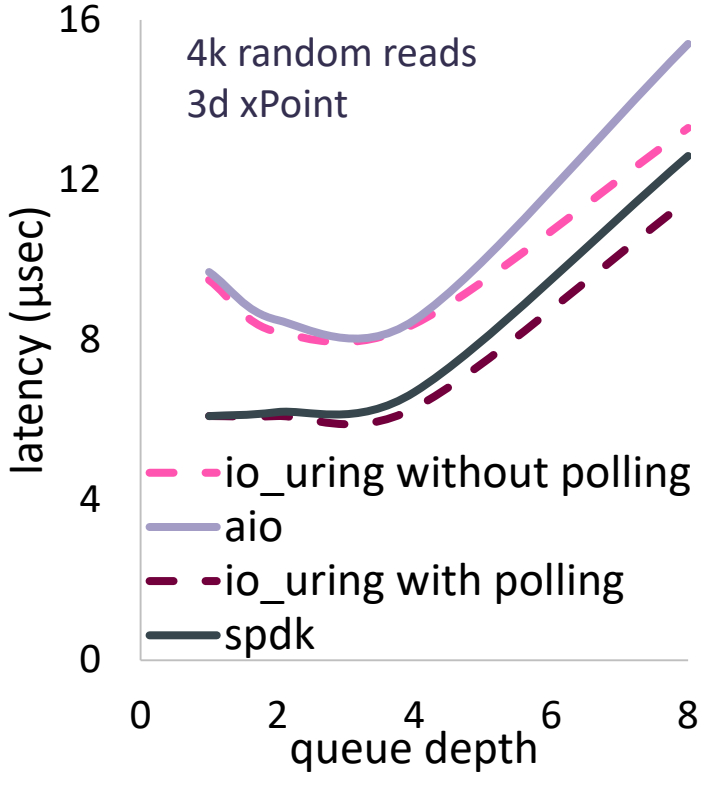


… have drastic impact on throughput!

linux IOs in the µsec era

sources: Faster IO through io_uring & Efficient I/O with io_uring & J.Axboe





separation of control & data plane in linux now, POSIX out

zero copy & minimized synchronization overhead

the benefits of fast storage wasted by
- data movement overheads
(from device to host & across network)
- black-box generic flash-translation layers
- multitude of software layers

how do we prevent these?

agenda

- SSD internals & state of affairs today
- emerging SSD & computational storage landscape

computational storage

back when I was a kid

Put Everything in Future (Disk) Controllers (it's not "if", it's "when?")

Jim Gray

http://www.research.Microsoft.com/~Gray

Acknowledgements:
Dave Patterson explained this to me a year ago
Kim Keeton
Erik Riedel
Catharine Van Ingen
Helped me sharpen these arguments

1

Basic Argument for x-Disks

- Future disk controller is a super-computer.
  - 1 bips processor
  - 128 MB dram
  - 100 GB disk plus one arm
- Connects to SAN via high-level protocols
  - RPC, HTTP, DCOM, Kerberos, Directory Services,….
  - Commands are RPCs
  - management, security,….
  - Services file/web/db/… requests
  - Managed by general-purpose OS with good dev environment
- Move apps to disk to save data movement
  - need programming environment in controller

Jim Gray, NASD Talk, 6/8/98
http://jimgray.azurewebsites.net/jimgraytalks.htm

= computation on the IO path

computational storage

back when I joined ITU

8-core ARMv8 processor

32GB DRAM

2TB+ of NVM via M.2 slots

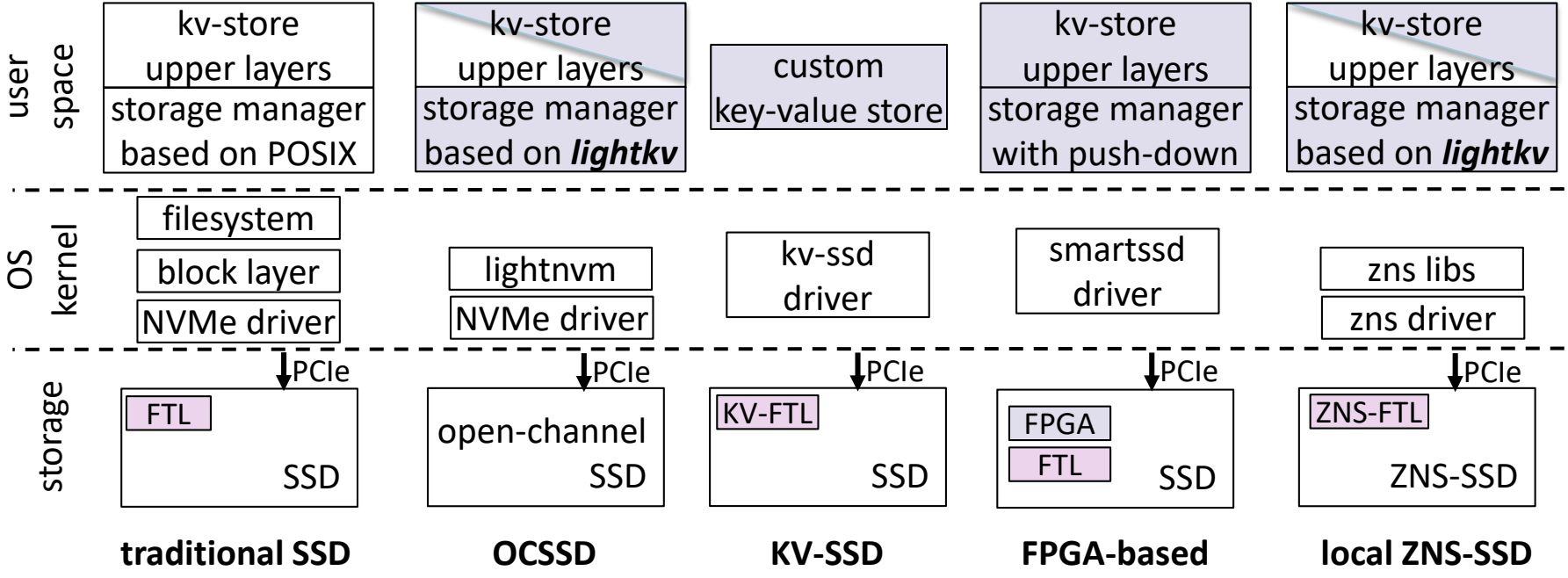
4x 10Gb Ethernet

Dragon Fire Card (DFC)
https://github.com/DFC-OpenSource/

- Future disk controller is a super-computer.
  - 1 bips processor
  - 128 MB dram
  - 100 GB disk plus one arm

SSD landscape – local

kv-store needs to change when you start app-specific storage management & pushing functionality down!



traditional SSD — **black-box**

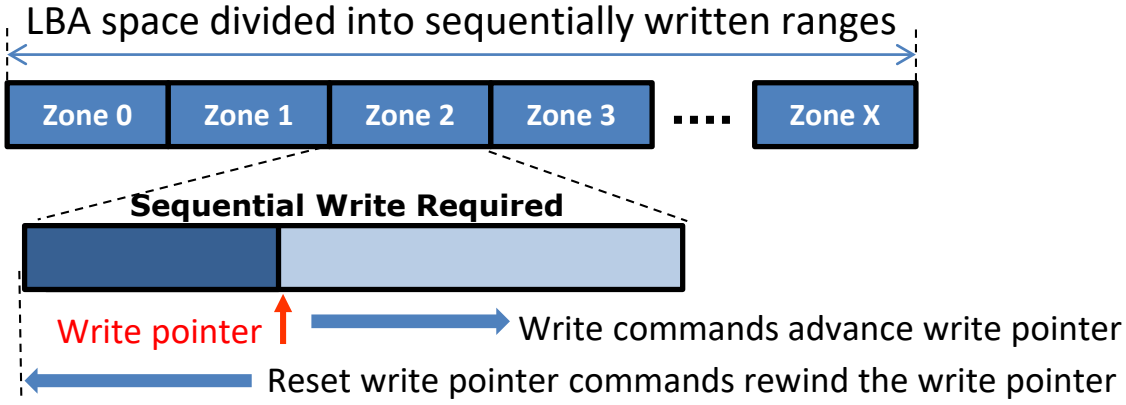
OCSSD — **app-specific, no comp. storage**

KV-SSD — **static custom**

FPGA-based storage controller — **generic FTL**

local ZNS-SSD — **similar to OCSSD, less customizable**

zoned namespaces (ZNS)

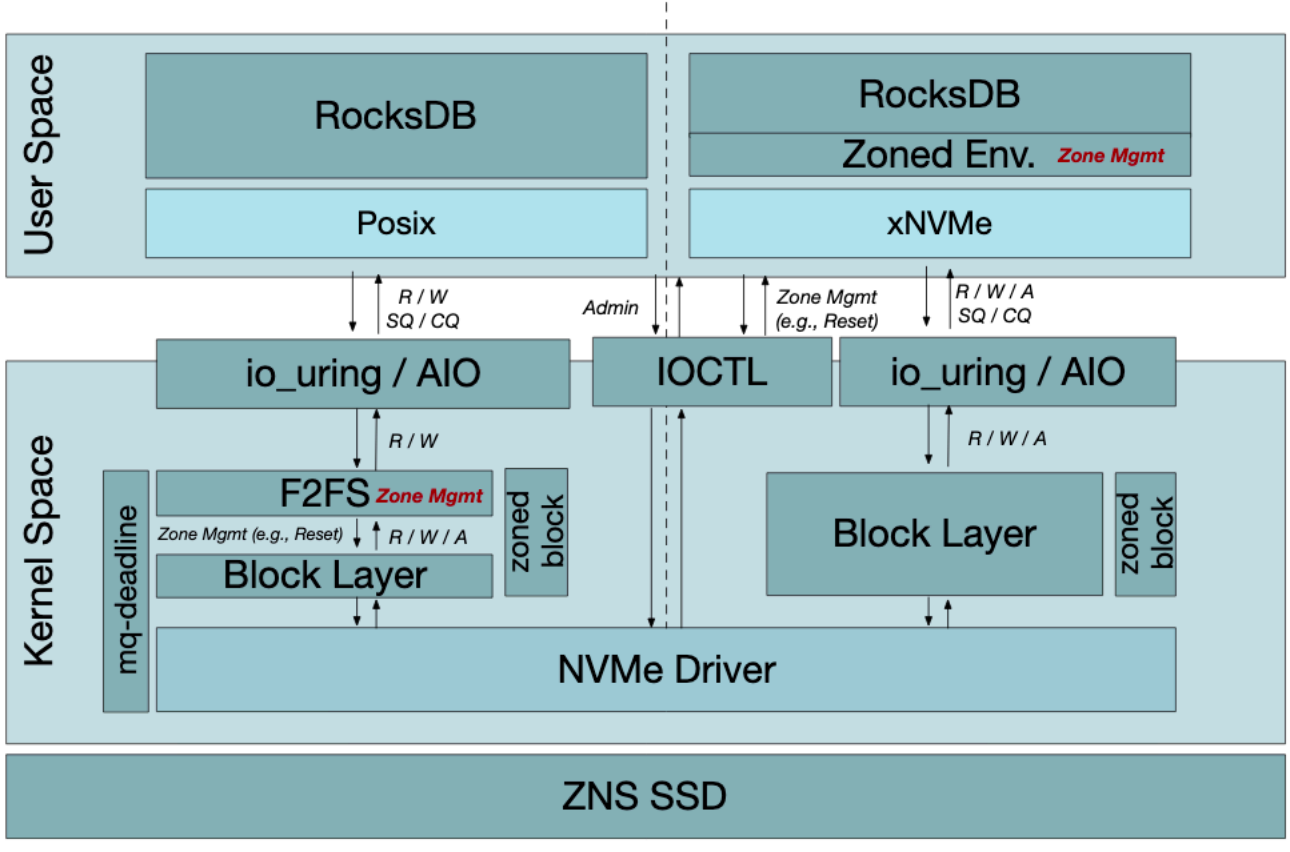


mode	host managed	host aware
host responsibility	explicit zone transition write command, write pointer per zone	implicit zone transition append command at large queue depth
SSD responsibility	zone placement I/O scheduling	zone placement, I/O scheduling sequential writes within a zone

with ZNS, FTL specialization is possible, but without control over data placement or I/O scheduling

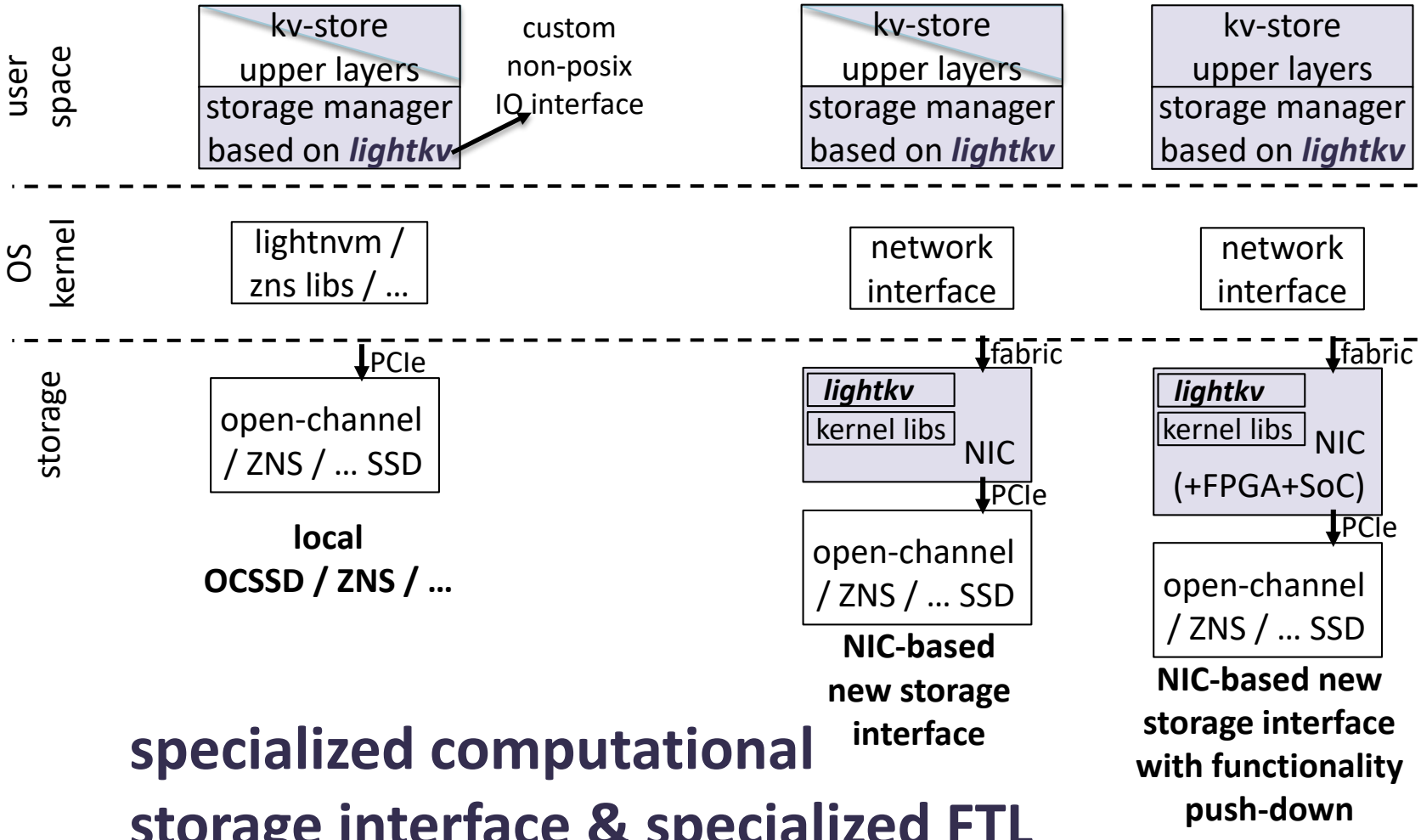
ZNS linux ecosystem

Javier Gonzalez video / slides



no block device, no dependence on POSIX IO

SSD landscape – disaggregated



specialized computational storage interface & specialized FTL

OpenSSD & Smart SSD

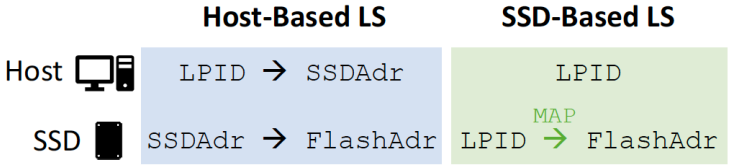
http://www.crz-tech.com/crz/article/daisy/

- Xilinx Zynq Ultrascale+ ZU17EG FPGA (XCZU17EG-xFFVC1760-E)
- Quad-core ARM Cortex-A53 MPCore up to 1.5GHz
- Dual-core ARM Cortex-R4 MPCore up to 600MHz
- PCIe Gen3 x16

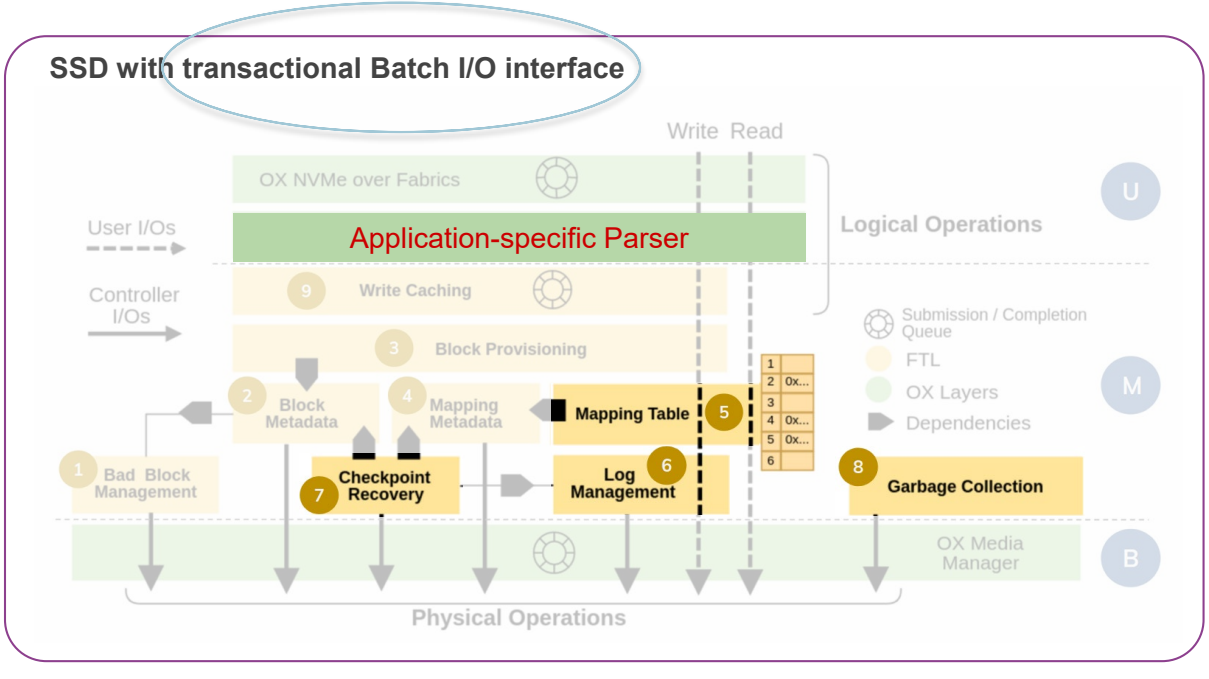
https://samsungatfirst.com/smartssd/

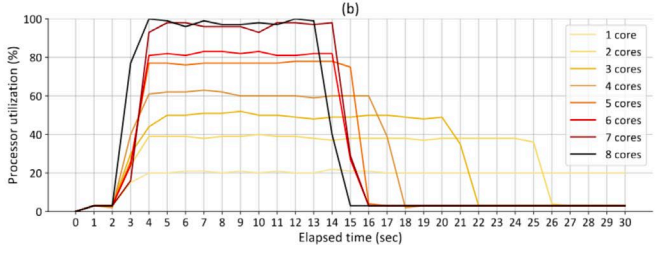
programming SSDs

The VLDB Journal 2021



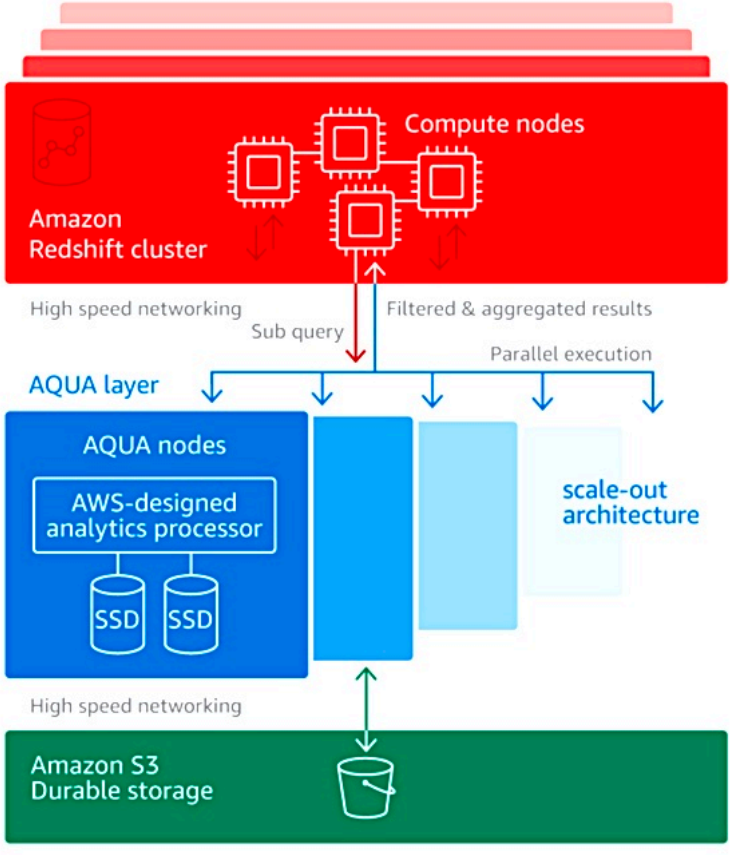
- Philippe Bonnet's team @ITU in collaboration with MSR
- programming a storage controller using OX framework on an OCSSD





BwTree-specific FTL!

AWS AQUA



Advanced Query Accelerator

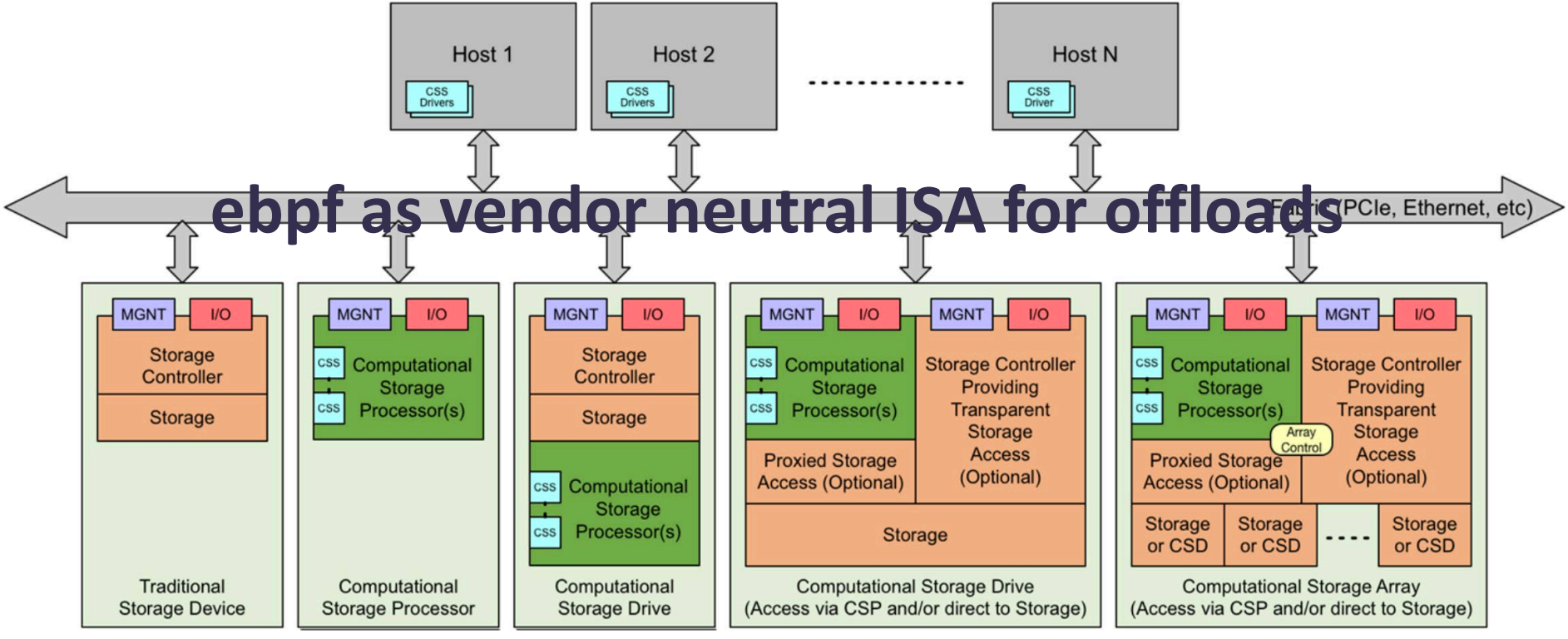
- near-data processing from AWS

(also called computational storage)

- announced in 2019
  (see video if interested)
- they are using SSDs and FPGAs at the AQUA layer
- goal: to reduce network traffic by reducing data movement

envisioned architectures

SNIA. Computational Storage Architecture and Programming Model. V0.5, Rev 1. Aug 2020



being standardized in NVMe (expected in 2022)

conclusion

- data management community increasingly shifts from pure in-memory optimized to SSD-optimized
- NVMe SSDs aren't a uniform class of devices
- expanding range of standardized storage interfaces (block, ZNS, KV, OCSSD)
  ➔ **the storage interface is a design choice**
- computational storage enables the definition of even more specialized storage interfaces

need for co-design of storage engine – FTL – SSD

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Data-Intensive Systems and Applications



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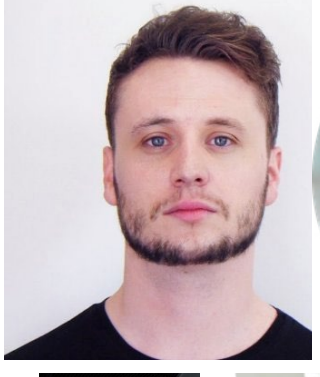
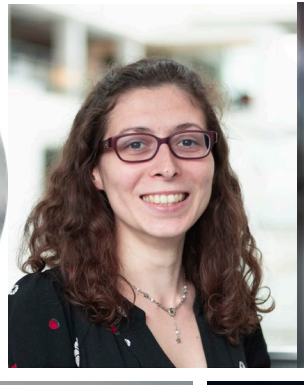
Zsolt István









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Check out vldb.org/2021

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