Reaping the performance of fast NVM storage with uDepot

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FAST'19

Key-Value (KV) stores

- Many applications require low-latency high-throughput KV storage
  - Flash-based SSDs not performant enough
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- DRAM is not getting cheaper

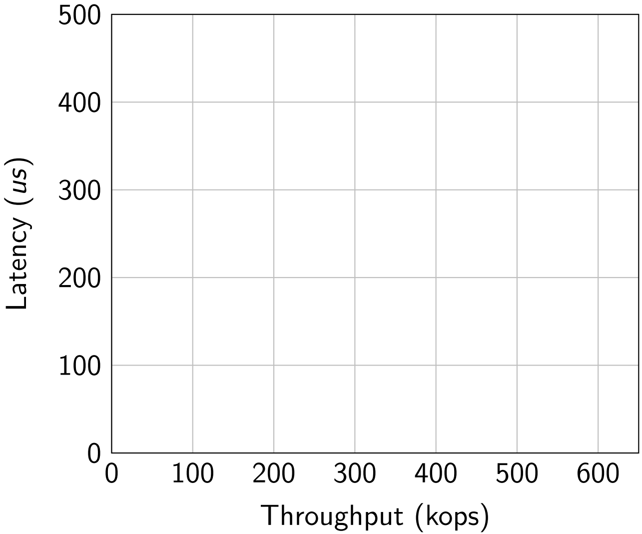
Fast NVM Devices

(FNDs)

- new class of SSDs
  - Intel Optane (3DXP)
  - Samsung Z-SSD (Z-NAND)

- An order of magnitude better performance than Flash SSDs
- Significantly cheaper than DRAM
  - \$1.25 vs \$10 per GiB (Intel Optane)
  - smaller TCO (number of machines, energy, etc.)

10GiB network vs Flash SSD vs FND SSD



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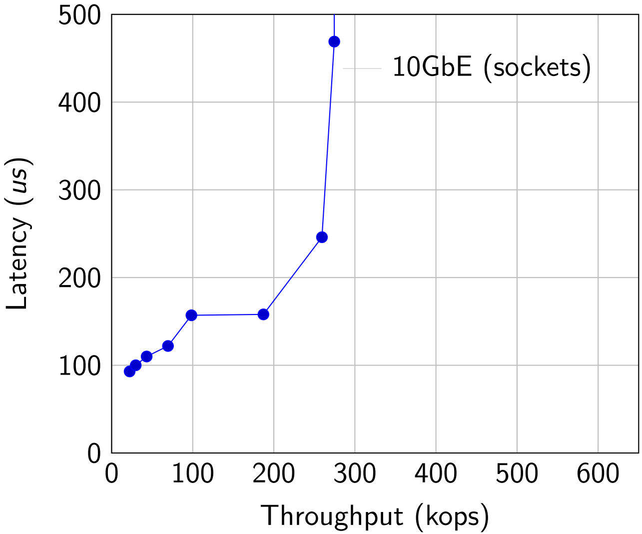

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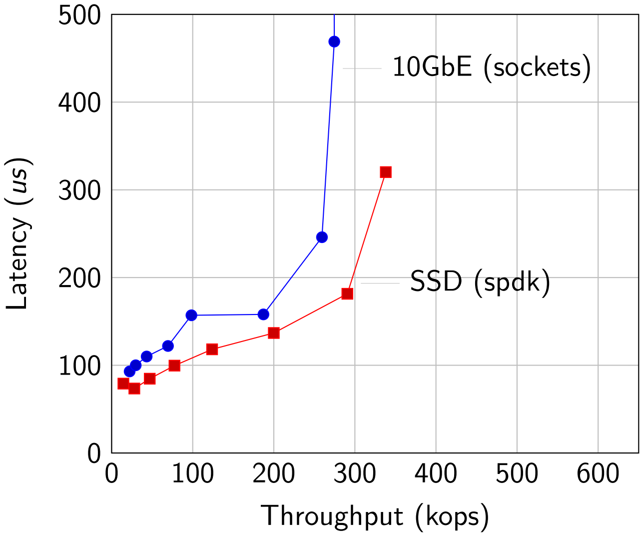

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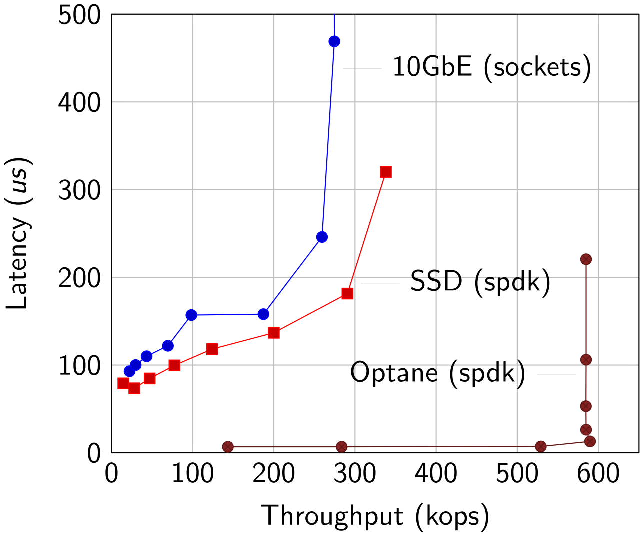

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- *SSD*: SPDK `perf`: 4KiB RDs (Flash NVMe)
- *Optane*: SPDK `perf`: 4KiB RDs ($\approx$ 0.6Mops/sec, $\approx$ 10us)

→ Storage no longer the bottleneck!

KV store for ~~DRAM~~ FNDs

- reduced cost
- equivalent performance to DRAM KV store (at least, under commodity networks)

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- Built for slower devices
  (e.g., use synchronous IO)
- Data structures with inherent IO amplification
  (LSM- or B-trees)
- Cache data in DRAM, limiting scalability
- Rich feature set (e.g., transactions, snapshots)

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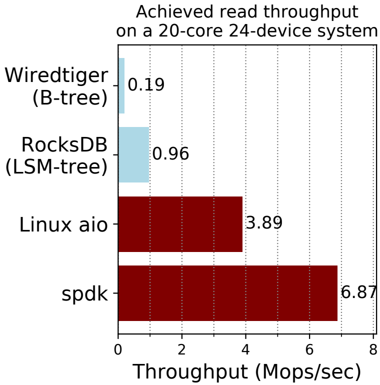

uDepot: a KV store for FNDs

Deliver the performance of FNDs to the application

- minimize IO amplification
- scalability (cores, devices, capacity)
- bottom-up approach
  - basic interface: `GET`, `PUT`, `DEL` on variable-sized keys and values.

uDepot architecture

uDepot architecture

Index kept in DRAM

Index

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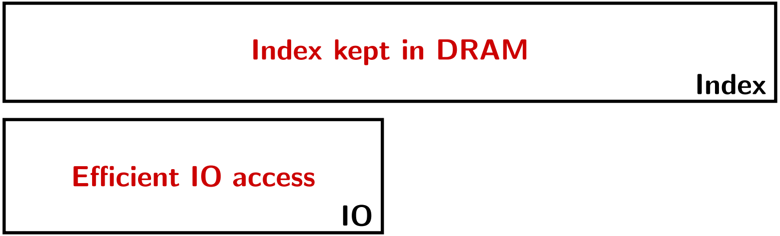

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Efficient IO access

IO

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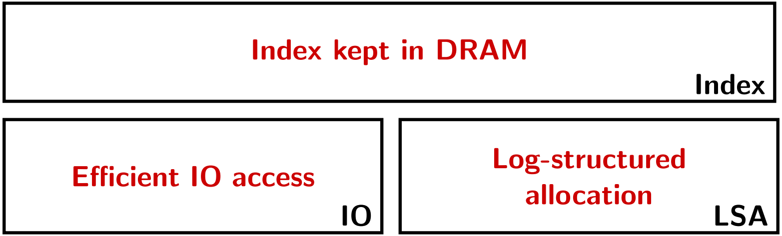

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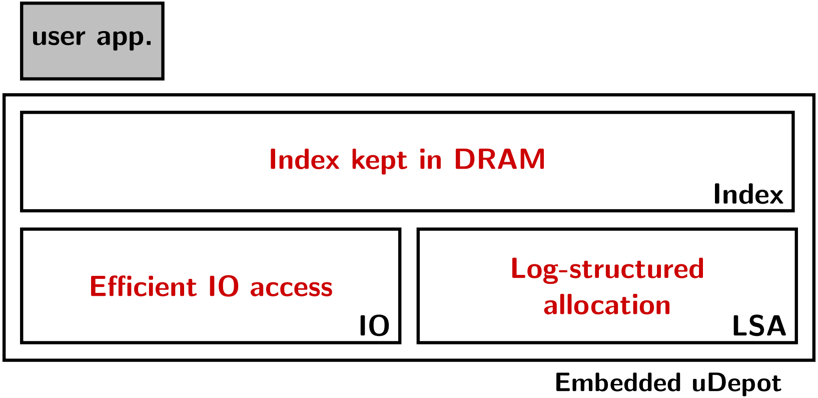

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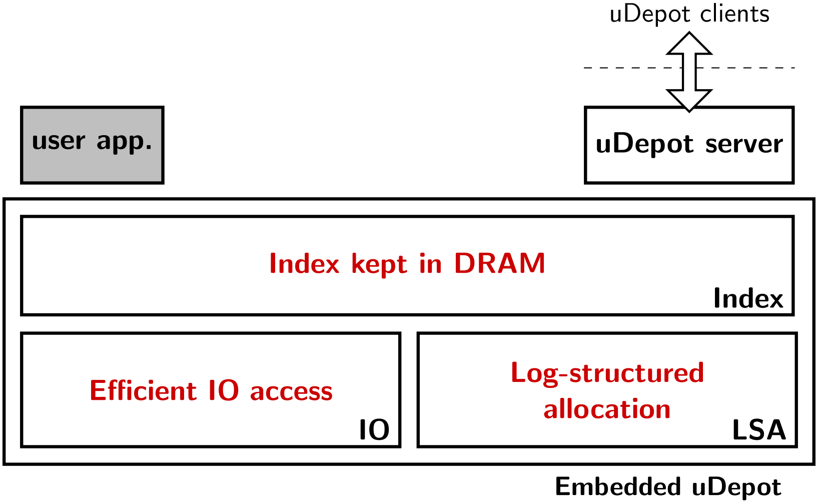

uDepot clients

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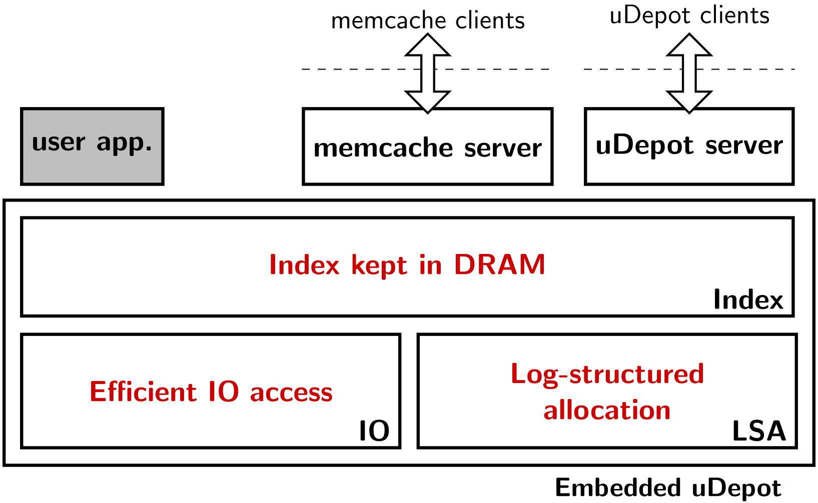

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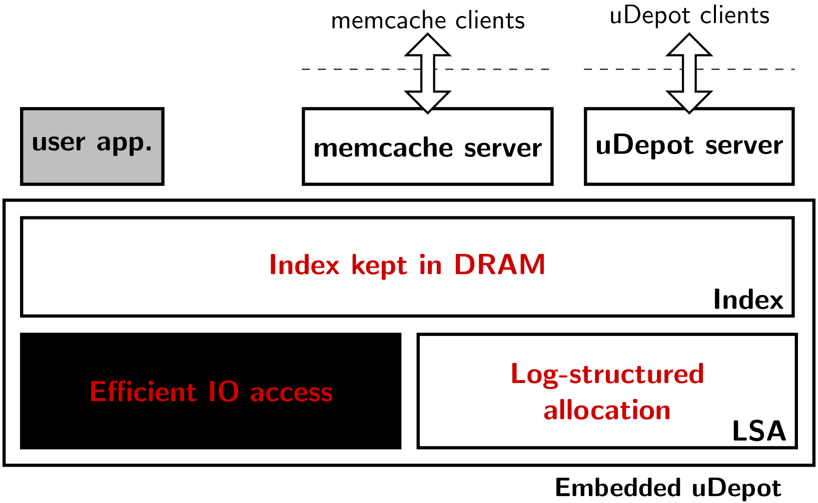
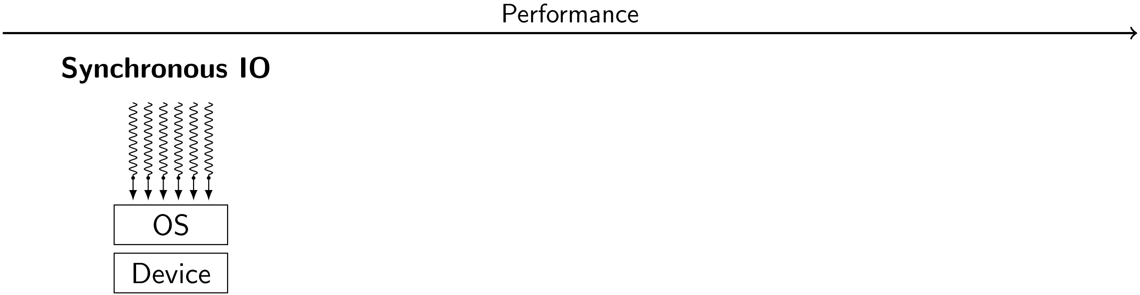


IO Facilities

Performance

IO Facilities



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- one thread per request
- syncronous (blocking) syscalls (e.g., `pread`)

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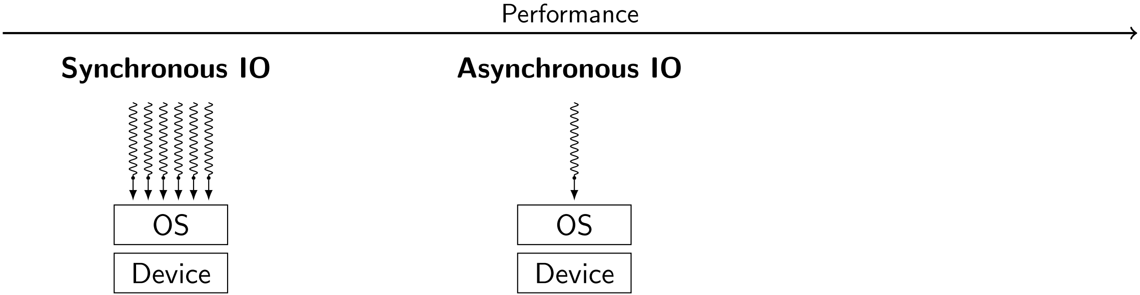

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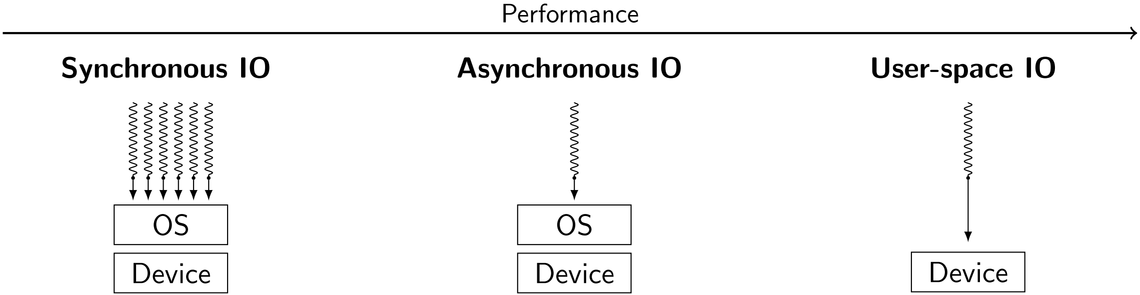

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- Polling instead of interrupts
- e.g., SPDK

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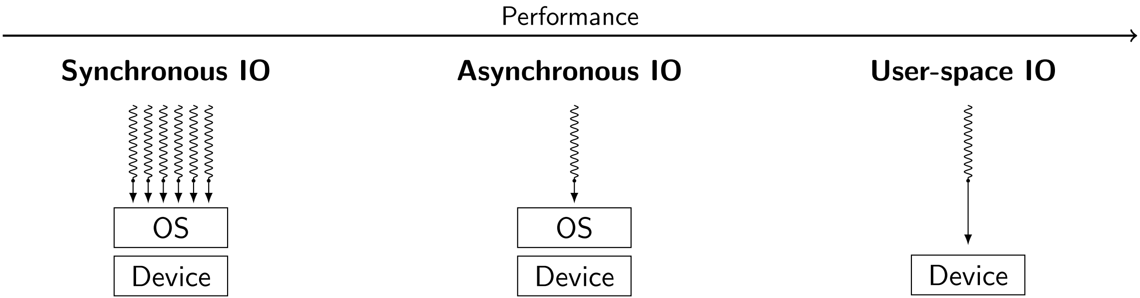

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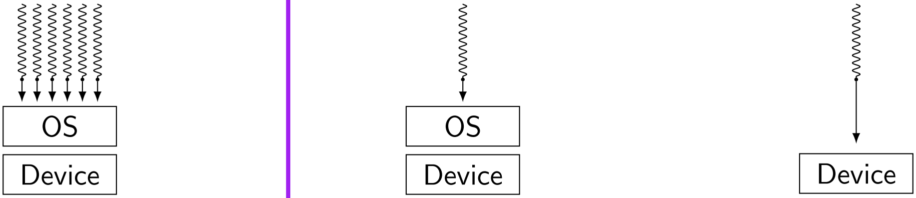

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TRT: a run-time system for async IO

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- progammer-friendly
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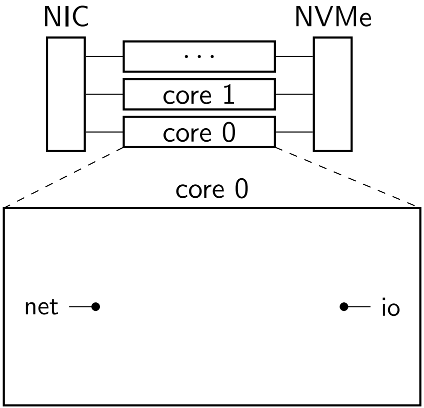

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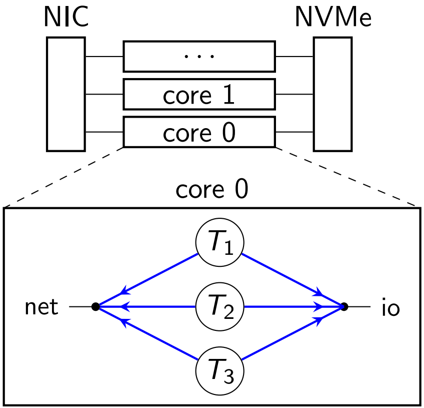

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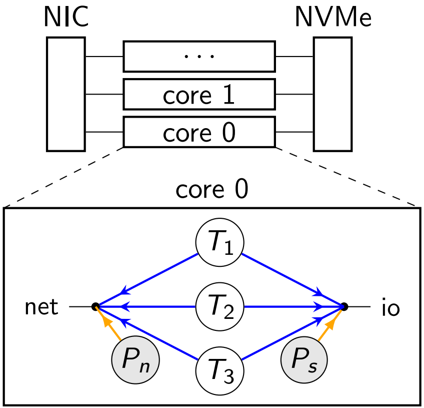

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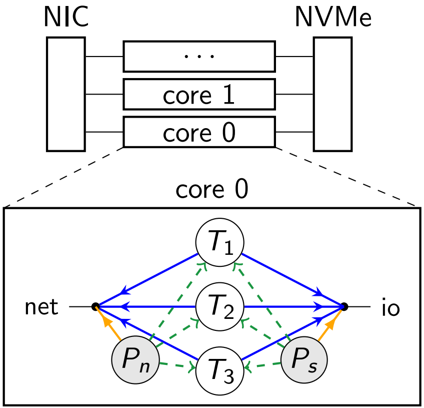

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Pollers notify tasks - - ›

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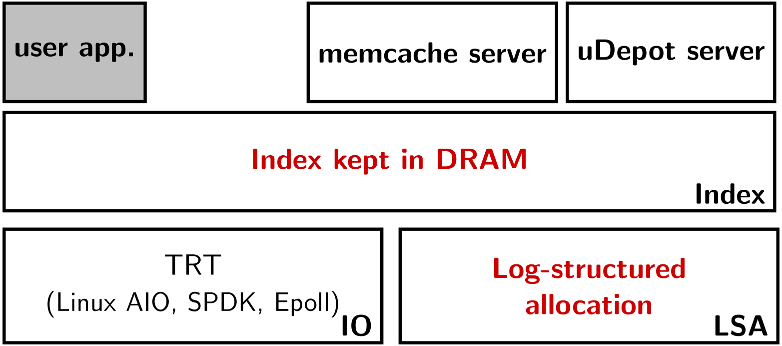

user app.

memcache server

uDepot server

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TRT

(Linux AIO, SPDK, Epoll)

IO

Log-structured allocation

LSA

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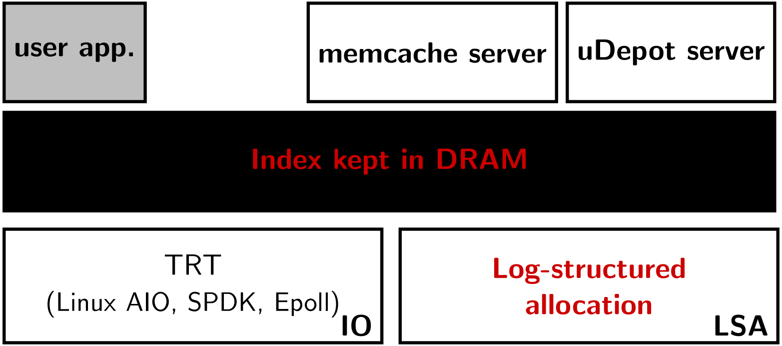

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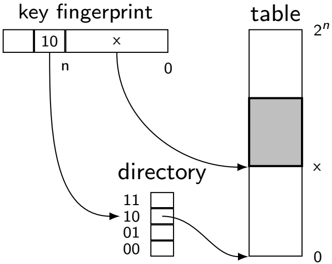
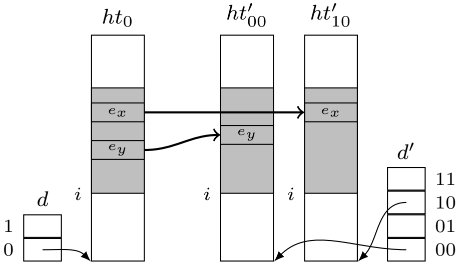
uDepot index

- Two-level hopscotch hash table
  - directory + tables
- 8 byte hash entry (cf. 6-byte for FAWN, FlashStore)
  - maintain KV size in the entry
  - larger storage addresses
- high-performance, scalable
- efficient resizing



Growing the uDepot index



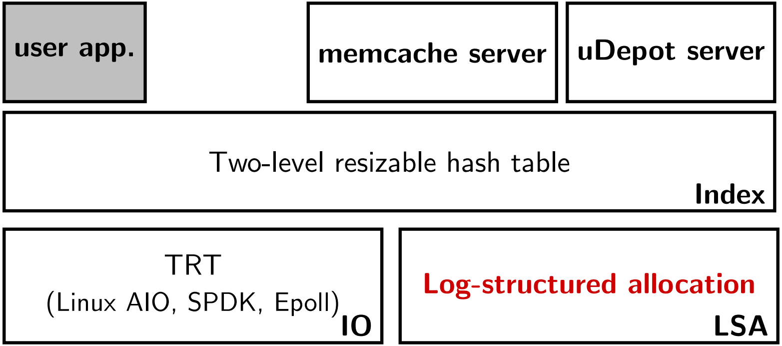
Operations:

- double the size of the directory
- migrate entries to new tables

Minimal disruption

- **unobstructed reads**
- **no IO required**: information in the hash entry to reconstruct the fingerprint
- **incremental**: each operation migrates a bounded number of entries

uDepot architecture



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Two-level resizable hash table

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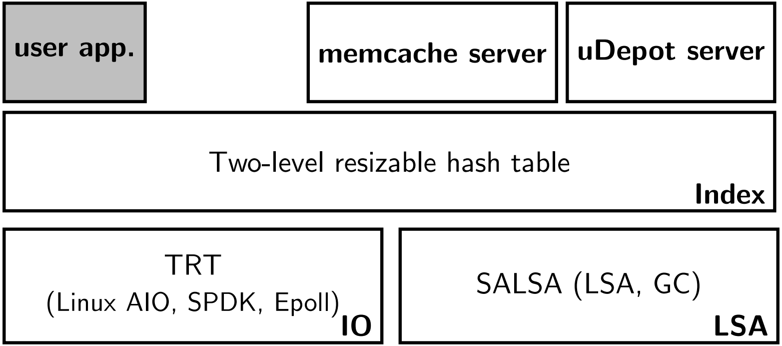

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(Linux AIO, SPDK, Epoll)

IO

SALSA (LSA, GC)

LSA

Evaluation

1. Performance of uDepot index (with and without resize)
2. Embedded uDepot performance vs device performance
3. uDepot server vs other NVMe stores (Aerospike, ScyllaDB)
4. uDepot memcache vs DRAM-based memcache implementations

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Experiment

- vs libcuckoo (better performance, see paper)
- Here: How is tail latency affected by the grow operation?
- ubench: perform 50M (no grow) and 1B (4 grows) inserts and lookups

uDepot index latency

percentile	lookup/50M	lookup/1B	insert/50M	insert/1B
50%	0.2 µs	0.3 µs	0.2 µs	0.4 µs
99%	1.1 µs	1.2 µs	0.6 µs	1.0 µs
99.9%	1.9 µs	2.0 µs	1.6 µs	9.2 µs
99.99%	11.0 µs	8.9 µs	7.5 µs	1168.0 µs

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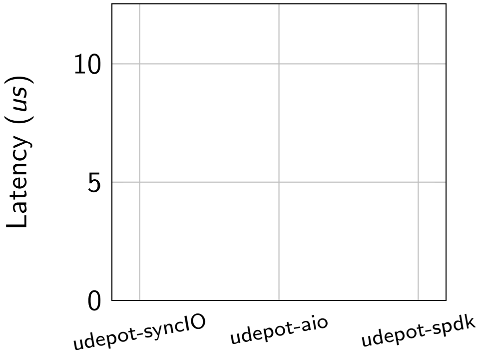
Experiment

- uDepot ubench: perform 10M uDepot `PUTs` and `GETs`
    - multiple backends (how different backends behave)
- vs. dev ubench: `fio` and SPDK `perf`
- same workload: 4KiB

Embedded uDepot: Efficiency (1 core / 1 Optane)

GET: median latency for qd=1



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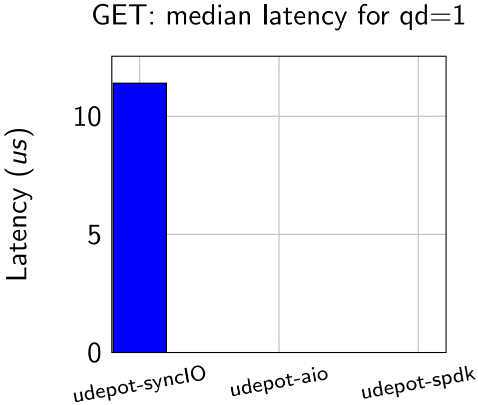

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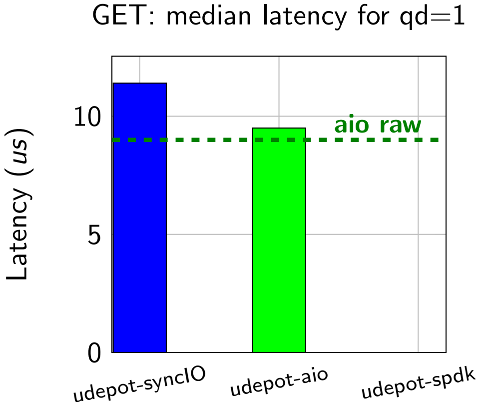

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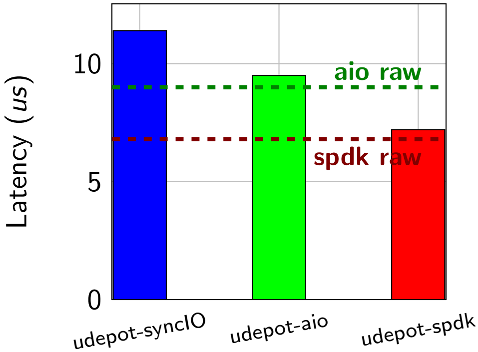

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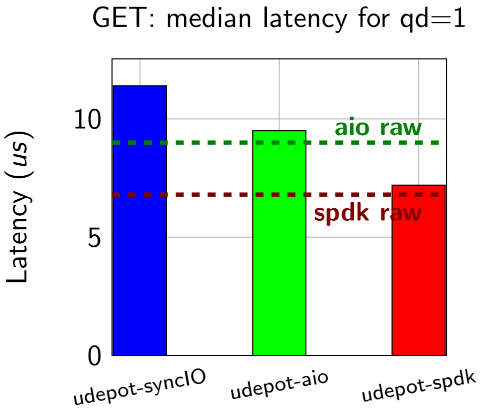

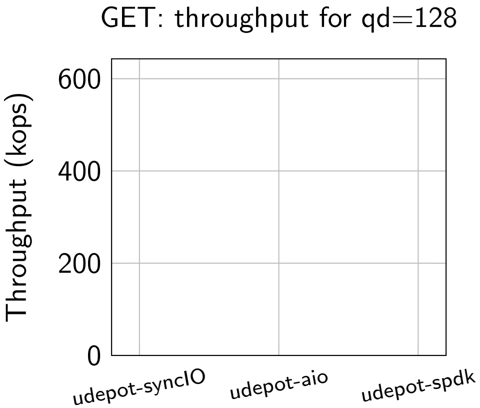

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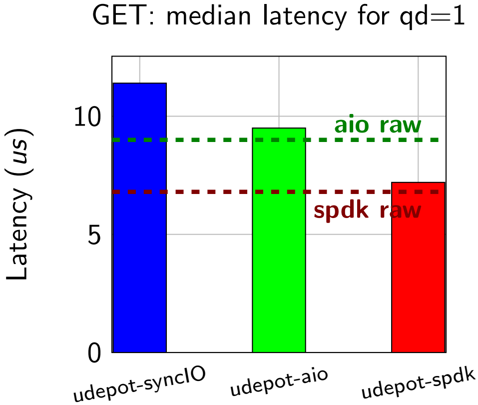

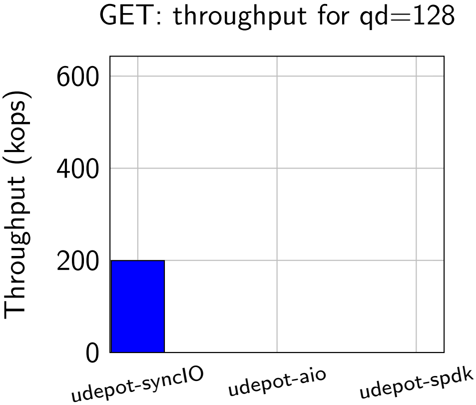

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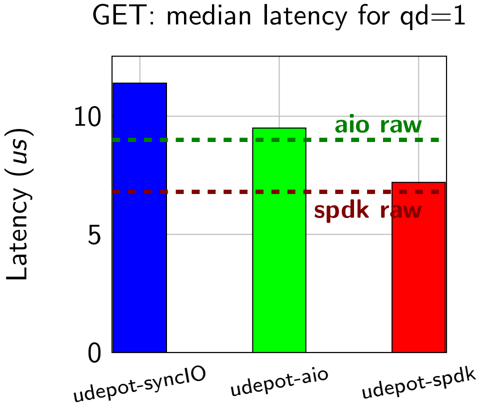

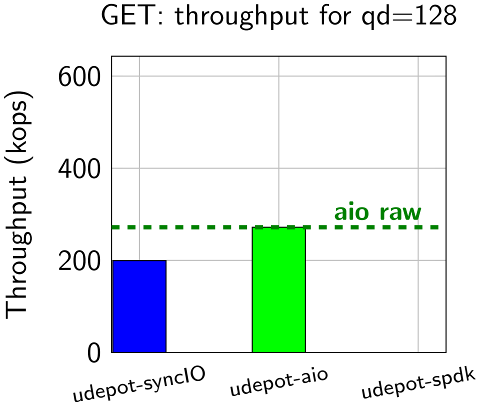

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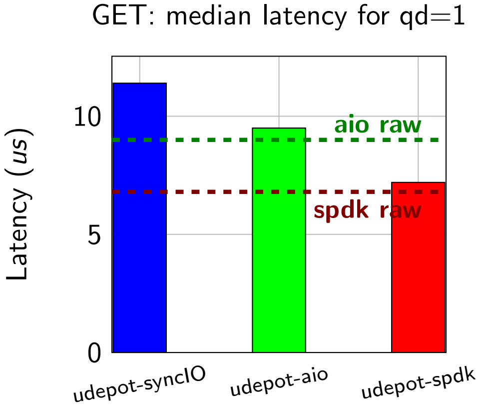

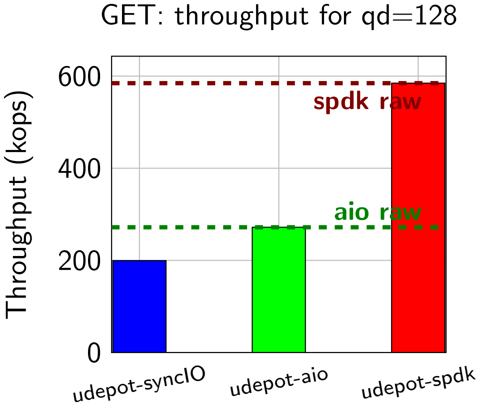

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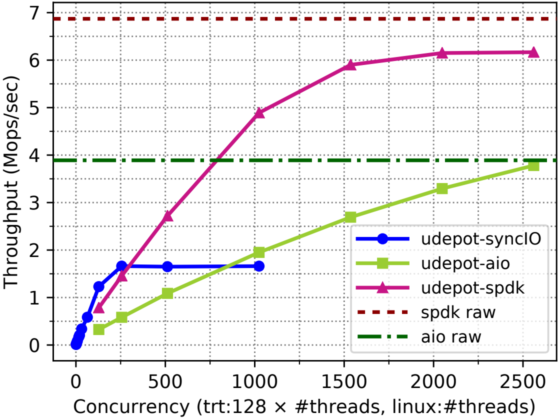
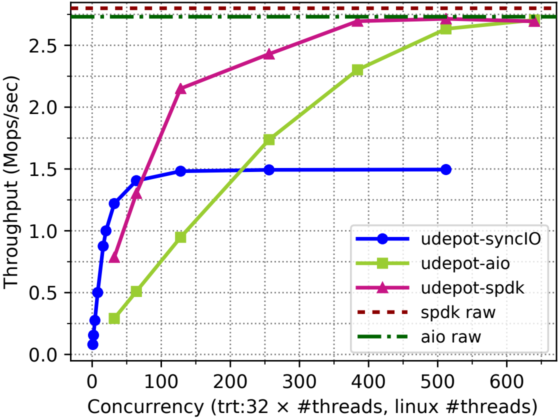


GETs



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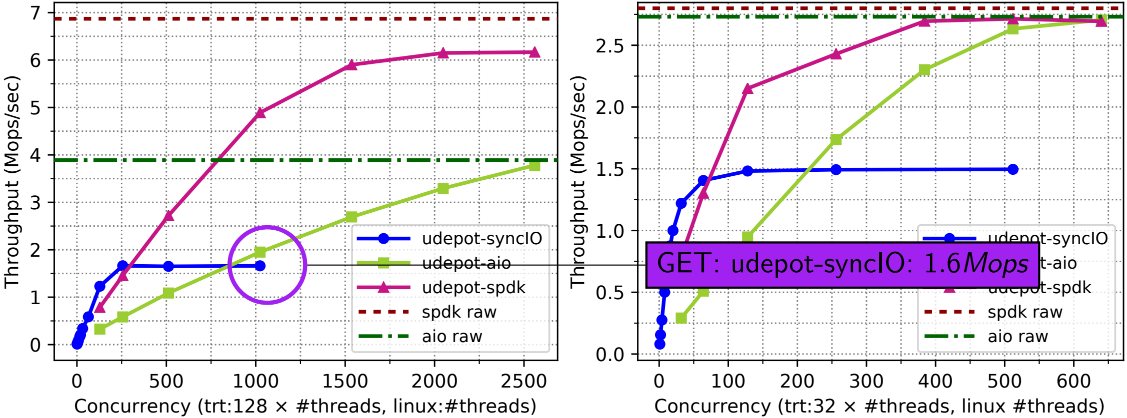
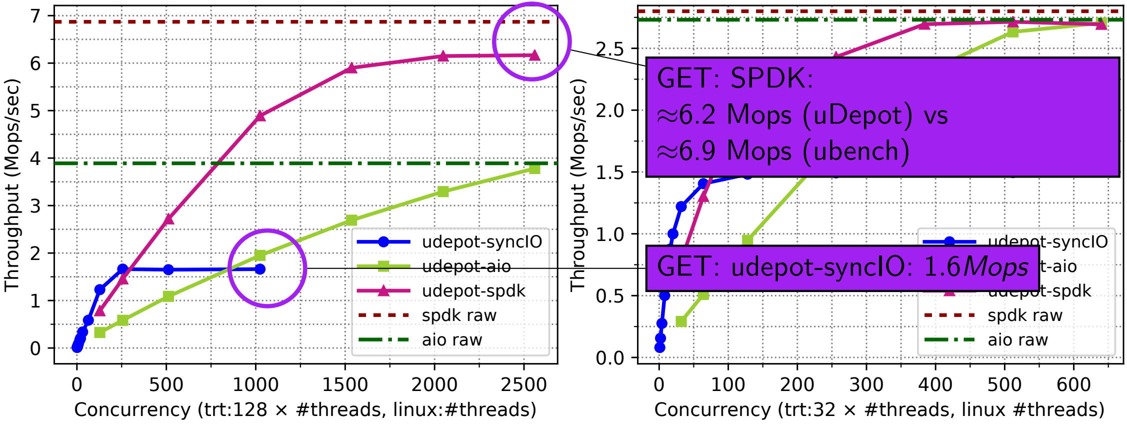


GETs

PUTs

GET: udepot-syncIO: 1.6$Mops$

Embedded uDepot: Scalability (20 cores, 24 Flash NVMes)



GETs

PUTs

GET: SPDK:
≈6.2 Mops (uDepot) vs
≈6.9 Mops (ubench)

GET: udepot-syncIO: 1.6*Mops*

Evaluation

1. ~~Performance of uDepot index (with and without resize)~~
2. ~~Embedded uDepot performance vs device performance~~
3. uDepot server vs other NVMe stores (Aerospike, ScyllaDB)
4. uDepot memcache vs DRAM-based memcache implementations

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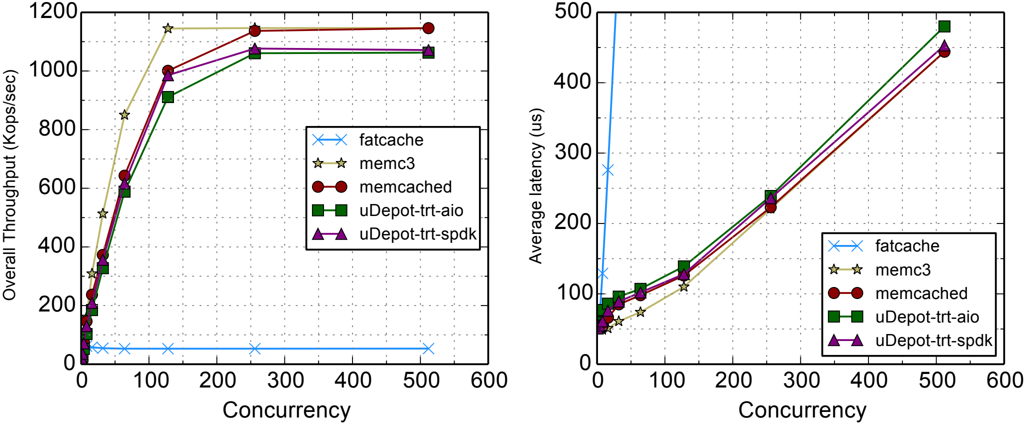
Experiment

- `memaslap` benchmark
- default workload: 1KiB objects, 10%/90% `PUT`/`GET`
- 2 Optane SSDs, 20 cores, 10GbE
- vs Memcached (expected performance), Memc3 (optimized memcached), Fatcache (tranditional SSD impl.)

uDepot memcache



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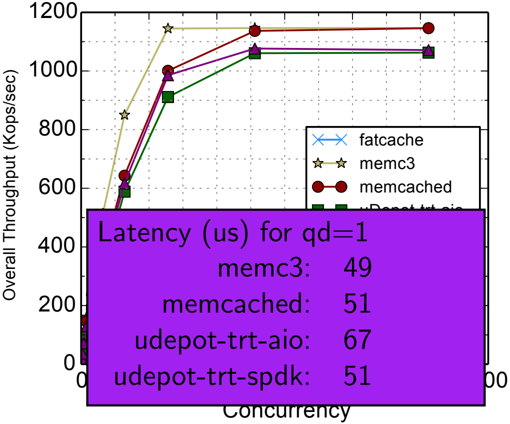
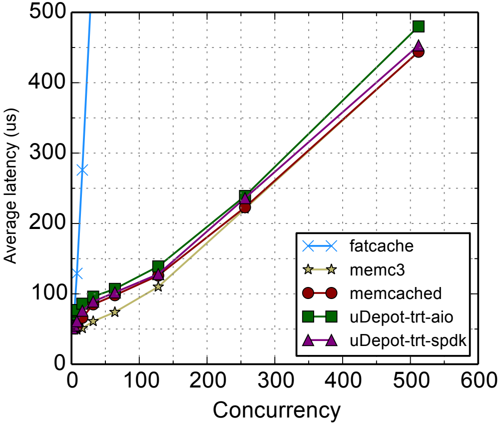
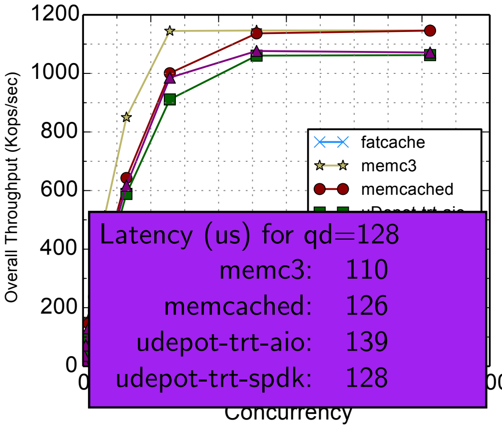


Latency (us) for qd=1

memc3:	49
memcached:	51
udepot-trt-aio:	67
udepot-trt-spdk:	51

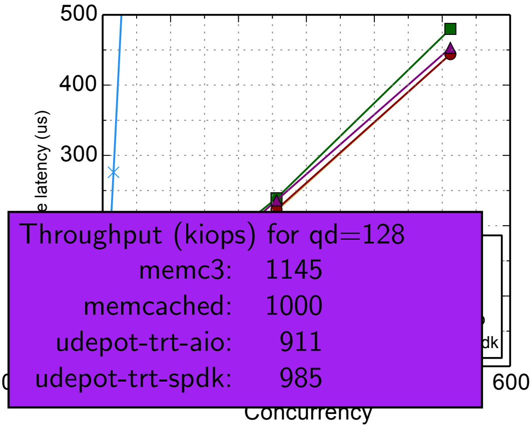


uDepot memcache



Latency (us) for qd=128

memc3:	110
memcached:	126
udepot-trt-aio:	139
udepot-trt-spdk:	128



Throughput (kiops) for qd=128

memc3:	1145
memcached:	1000
udepot-trt-aio:	911
udepot-trt-spdk:	985

Conclusions

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  - low latency, high throughput
  - uDepot memcache has comparable performance with DRAM memcache

Conclusions

- Fast NVMe devices offer an attractive cost-performance tradeoff between DRAM and Flash SSDs
  - They shift the bottleneck from the storage to the network
- uDepot: a KV store that delivers their performance
  - low latency, high throughput
  - uDepot memcache has comparable performance with DRAM memcache
- Experimental Cloud service based on uDepot memcache implementation
  - try it out (for free): `https://cloud.ibm.com/catalog/services/data-store-for-memcache`

Thank you! Questions?