Data Containers

The Need For Compression

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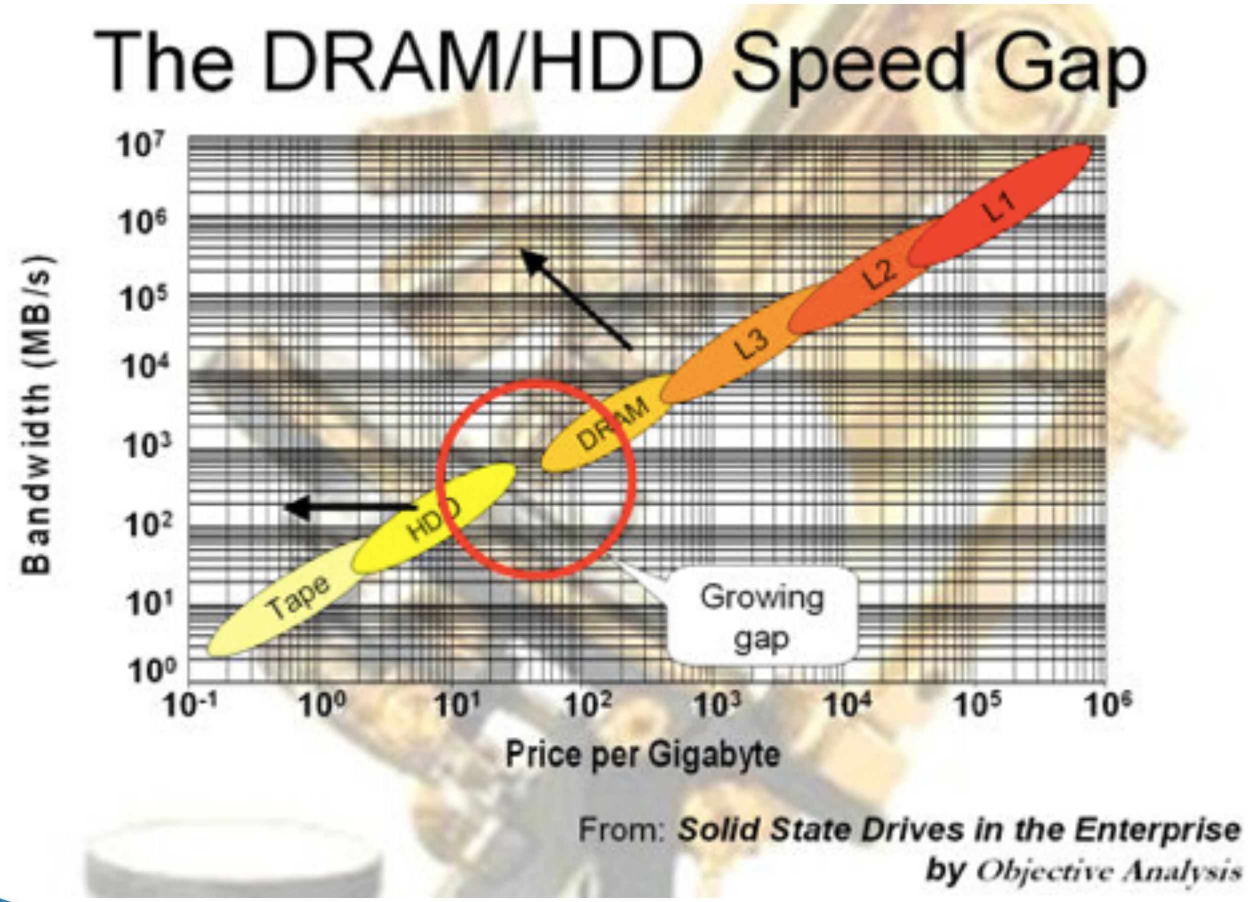
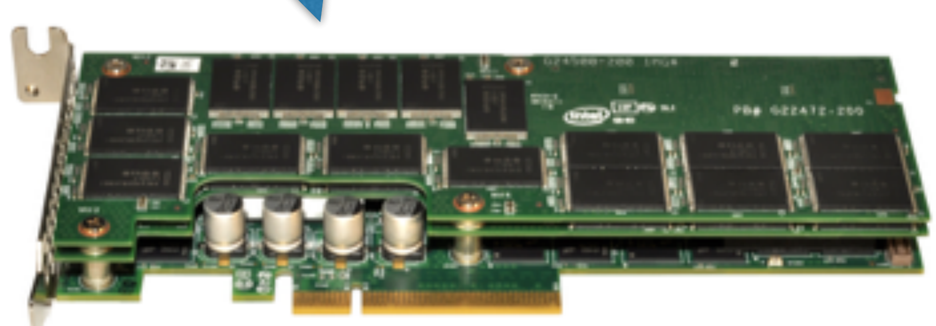
Goals

- Provide hints on where computer storage is headed
- Introduce compression as a way to alleviate the I/O bottleneck
- Get in contact with known (and less know) data containers, exposing advantages and disadvantages

Trends in Computer Storage

The growing gap between DRAM and HDD is facilitating the introduction of new SDD devices





PCIe SSD

M.2 SSD

BGA SSD

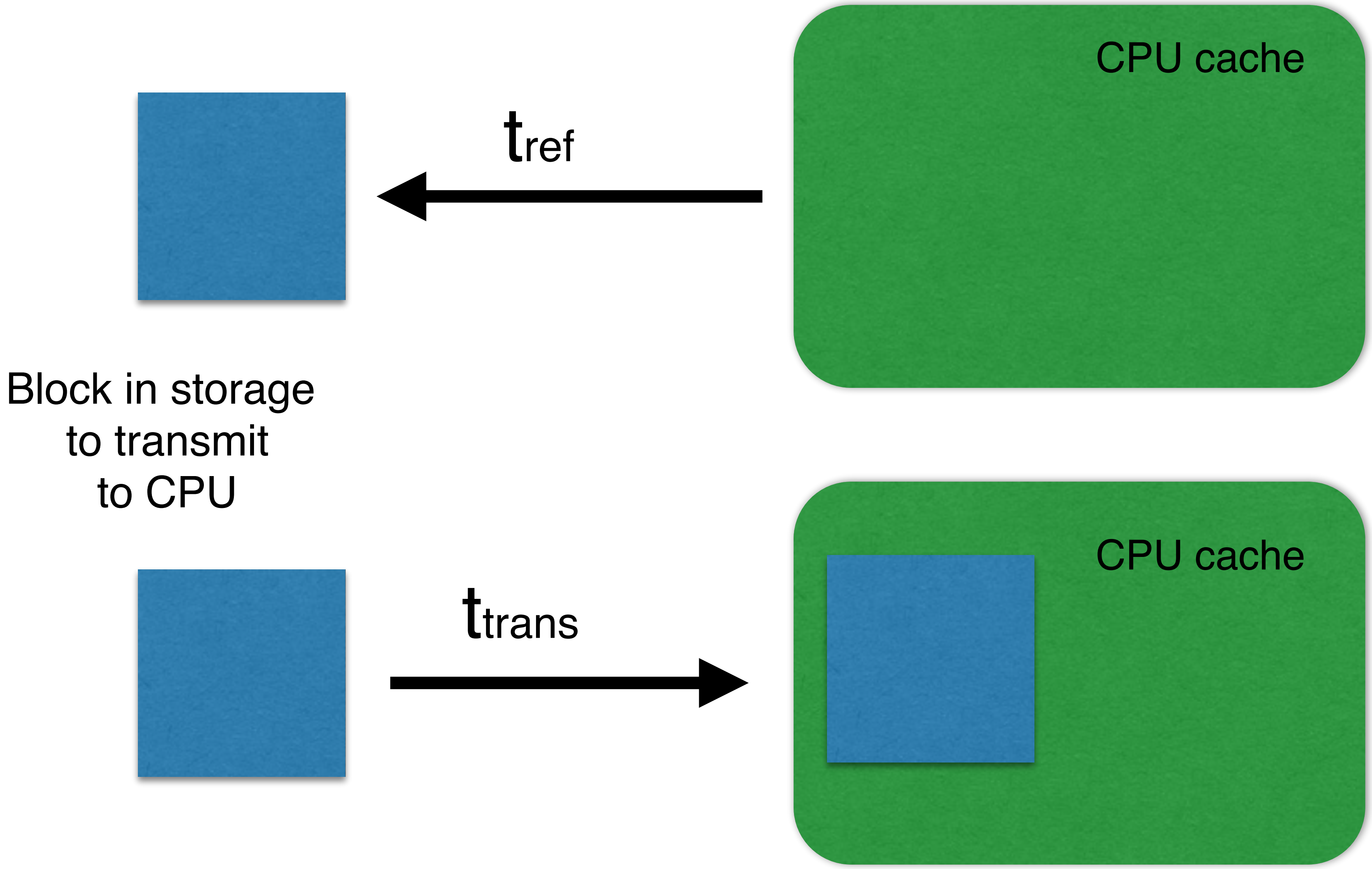
Latency Numbers Every Programmer Should Know

```
Latency Comparison Numbers
--------------------------
L1 cache reference                           0.5 ns
Branch mispredict                            5   ns
L2 cache reference                           7   ns                      14x L1 cache
Mutex lock/unlock                           25   ns
Main memory reference                      100   ns                      20x L2 cache, 200x L1 cache
Read 4K randomly from memory             1,000   ns     0.001 ms
Compress 1K bytes with Zippy             3,000   ns
Send 1K bytes over 1 Gbps network       10,000   ns     0.01 ms
Read 4K randomly from SSD*             150,000   ns     0.15 ms
Read 1 MB sequentially from memory     250,000   ns     0.25 ms
Round trip within same datacenter      500,000   ns     0.5  ms
Read 1 MB sequentially from SSD*     1,000,000   ns     1    ms  4X memory
Disk seek                           10,000,000   ns    10    ms  20x datacenter roundtrip
Read 1 MB sequentially from disk    20,000,000   ns    20    ms  80x memory, 20X SSD
Send packet CA->Netherlands->CA    150,000,000   ns   150    ms
```

Source: Jeff Dean and Peter Norvig (Google), with some additions

http://www.eecs.berkeley.edu/~rcs/research/interactive_latency.html

Reference Time vs Transmission Time



$t_{ref} \sim= t_{trans}$ => optimizes memory access

Not All Storage Layers Are Created Equal

Memory: t_{ref}: 100 ns / t_{trans} (**1 KB**): ~100 ns

Solid State Disk: t_{ref}: 10 us / t_{trans} (**4 KB**): ~10 us

Mechanical Disk: t_{ref}: 10 ms / t_{trans} (**1 MB**): ~10 ms

The slower the media, the larger the block that is worth to transmit

But essentially, a blocked data access is mandatory for speed!

We Need More Data Blocking In Our Infrastructure!

- Not many data containers leveraging the blocking technique exist yet, but a handful (e.g. HDF5, bcolz or zarr) do

- With blocked access we can use persistent media (disk) as it is ephemeral (memory) and the other way around -> independency of media!

- **No silver bullet**: we won’t be able to find a single container that makes everybody happy; it’s all about tradeoffs

Can We Get Better Bandwidth Than Hardware Allows?

Compression for Random & Sequential Access in SSDs

Performance Specification	Incompressible Data	Compressible Data
Sequential Write Bandwidth (Mbp/s)	235	520
Sequential Read Bandwidth (Mbp/s)	550	550
Random Write (IOPS)	16,500 (65MB/s)	60,000 (240MB/s)
Random Read (IOPS)	46,000 (180MB/s)	50,000 (200MB/s)

3. Source: *Intel® Solid-State Drive 520 Series Product Specification*; Random reads based on 4KB Queue Depth 32

- Compression does help performance!

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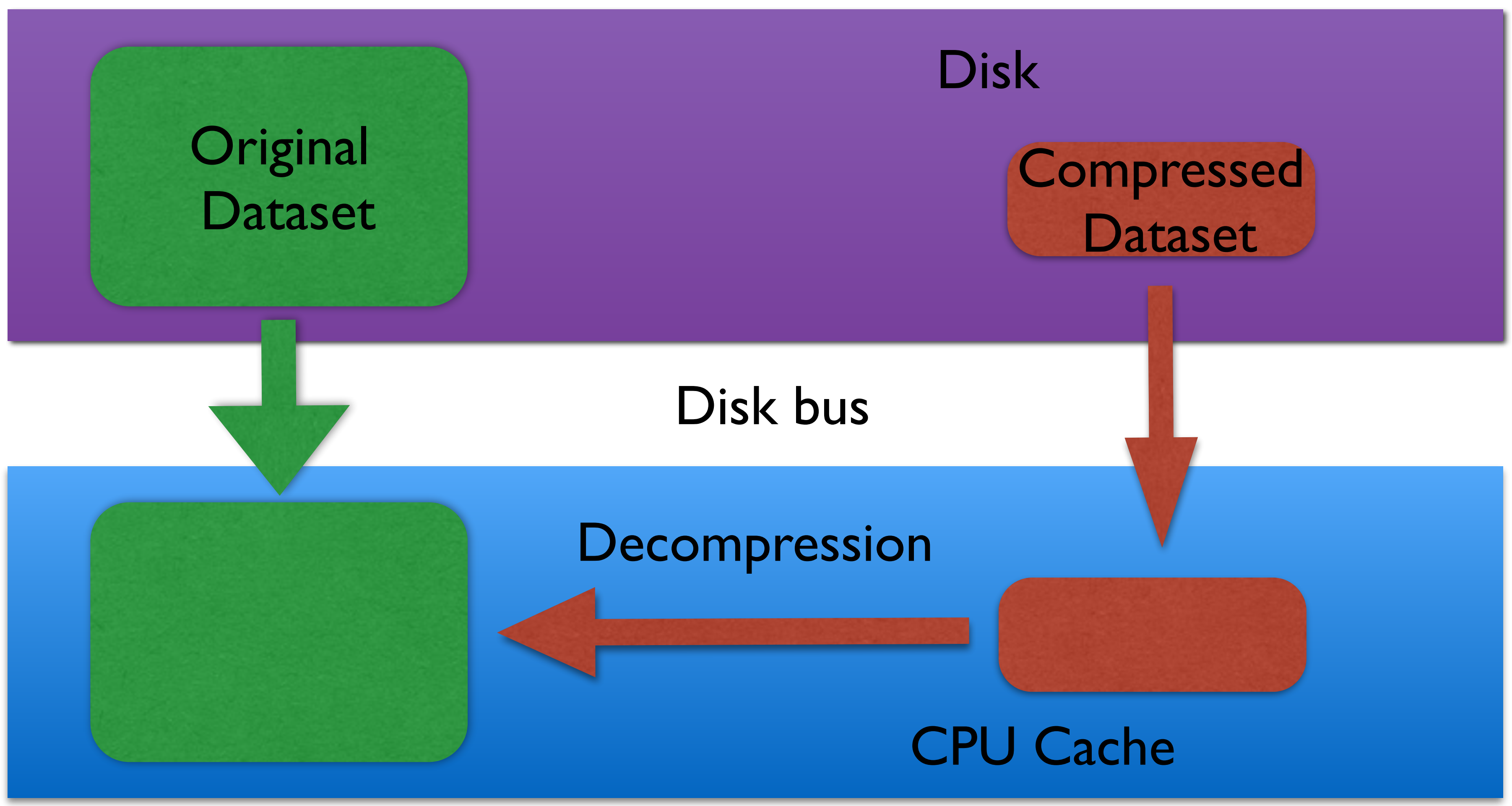
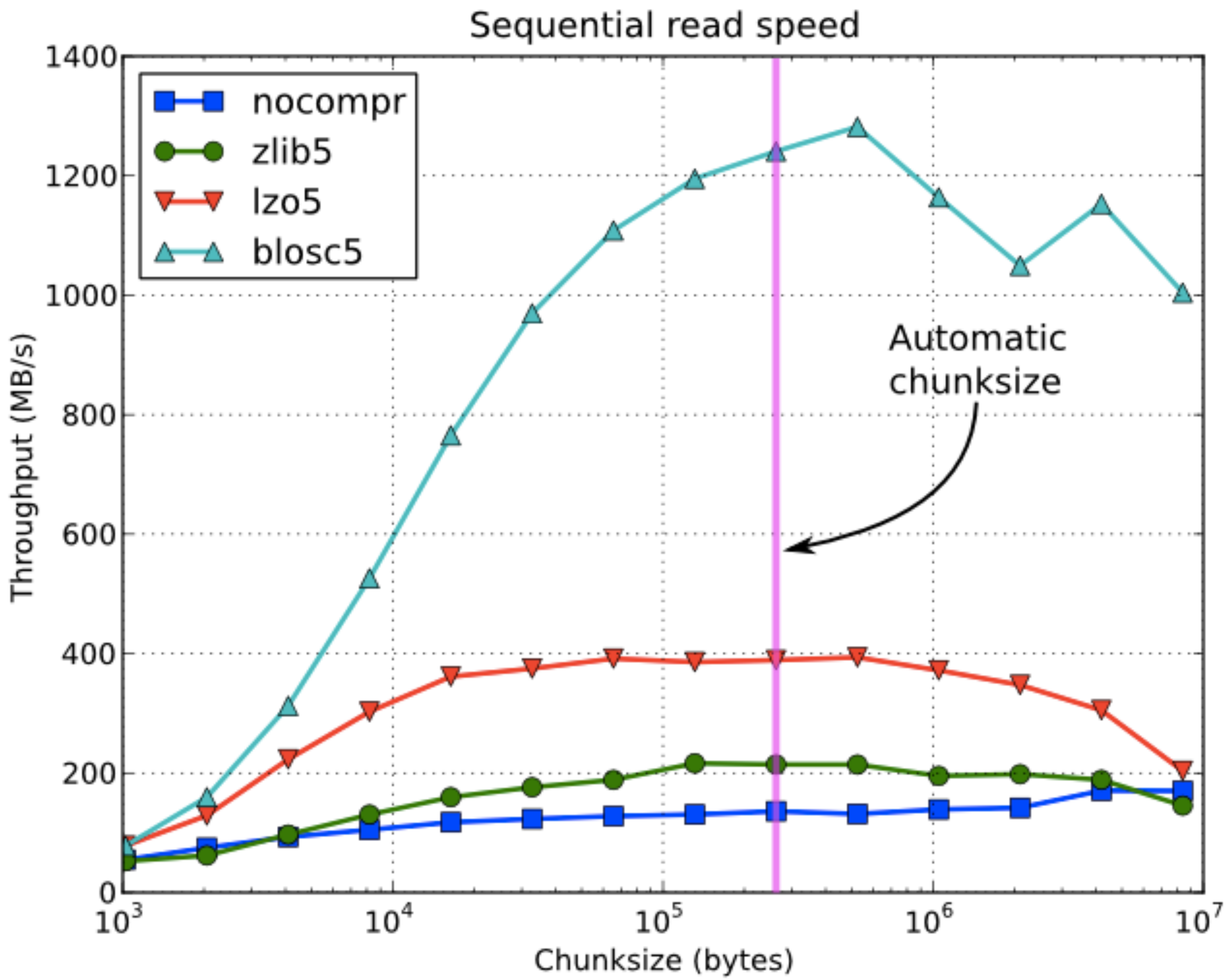
- Compression does help performance!
- However, limited by SATA bandwidth

Leveraging Compression Straight To CPU

Less data needs to be transmitted to the CPU



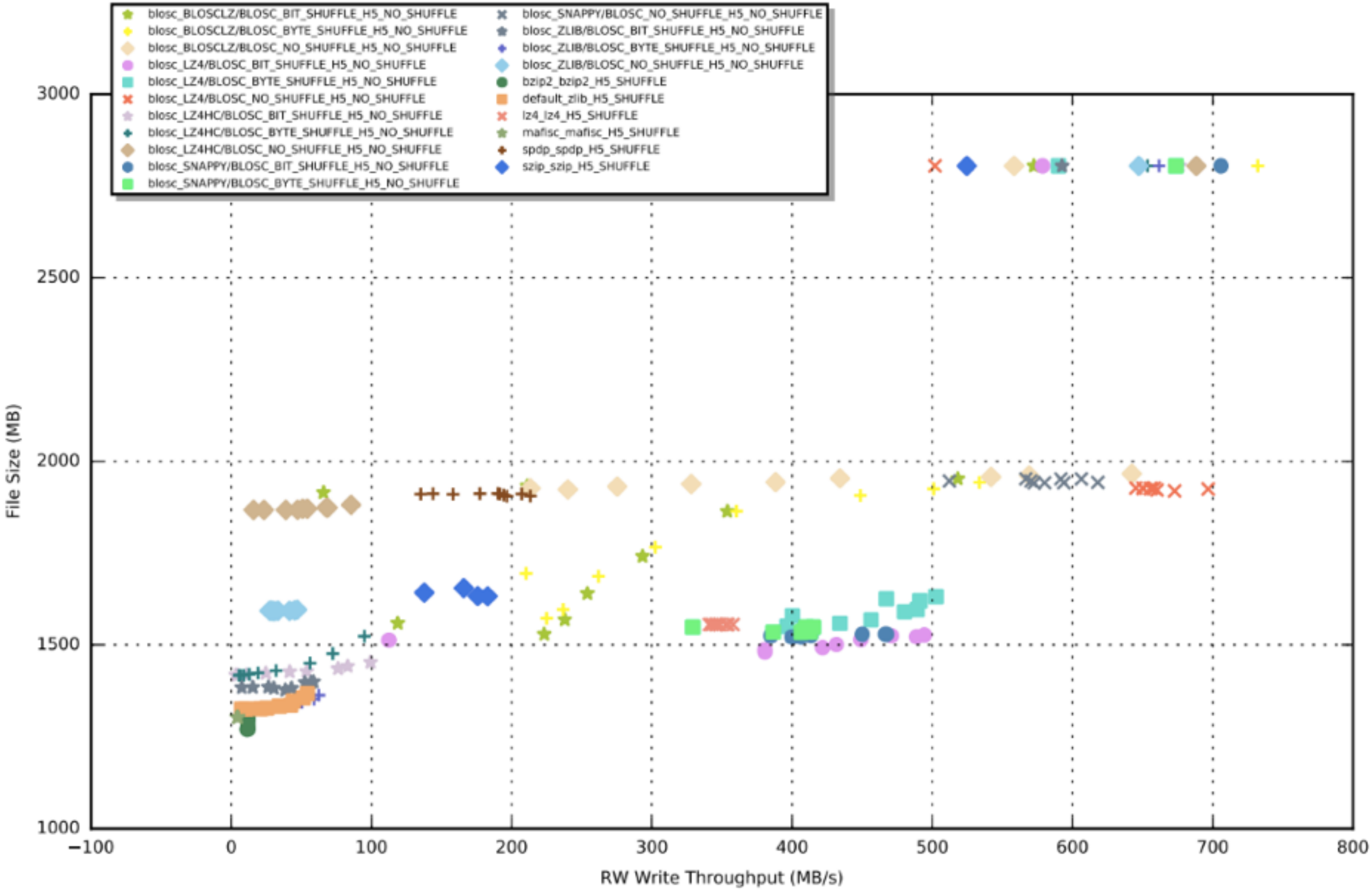
Transmission + decompression faster than direct transfer?



When we have a fast enough compressor
we can get rid of the limitations of the bus bandwidth.

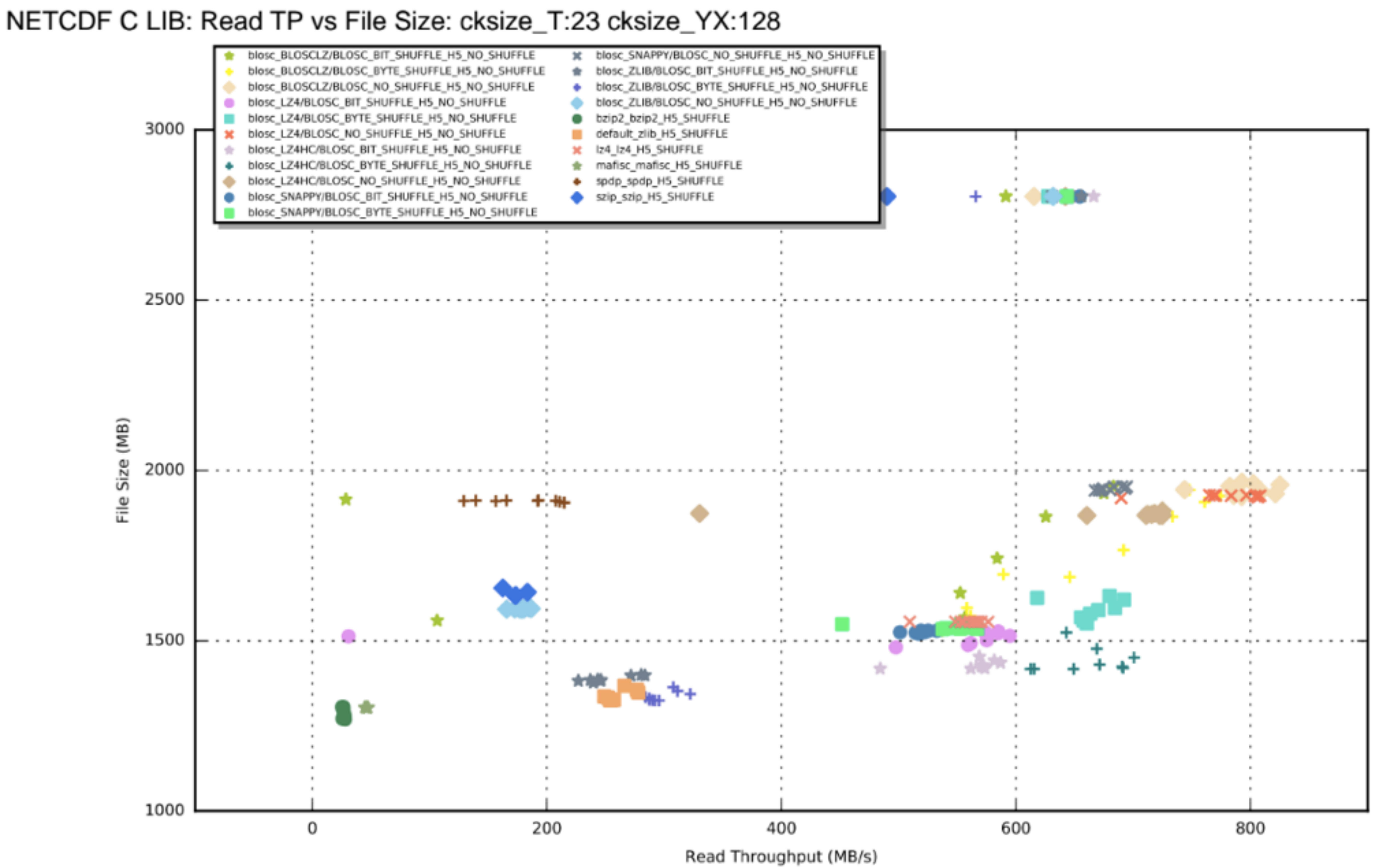
How to get maximum compression performance?

NETCDF C LIB: Write TP vs File Size cksize_T:23 cksize_YX:128



Thanks to: Rui Yang, Pablo Larraondo (NCI Australia)

Example with actual data (satellite images):
Blosc compression does not degrade I/O performance



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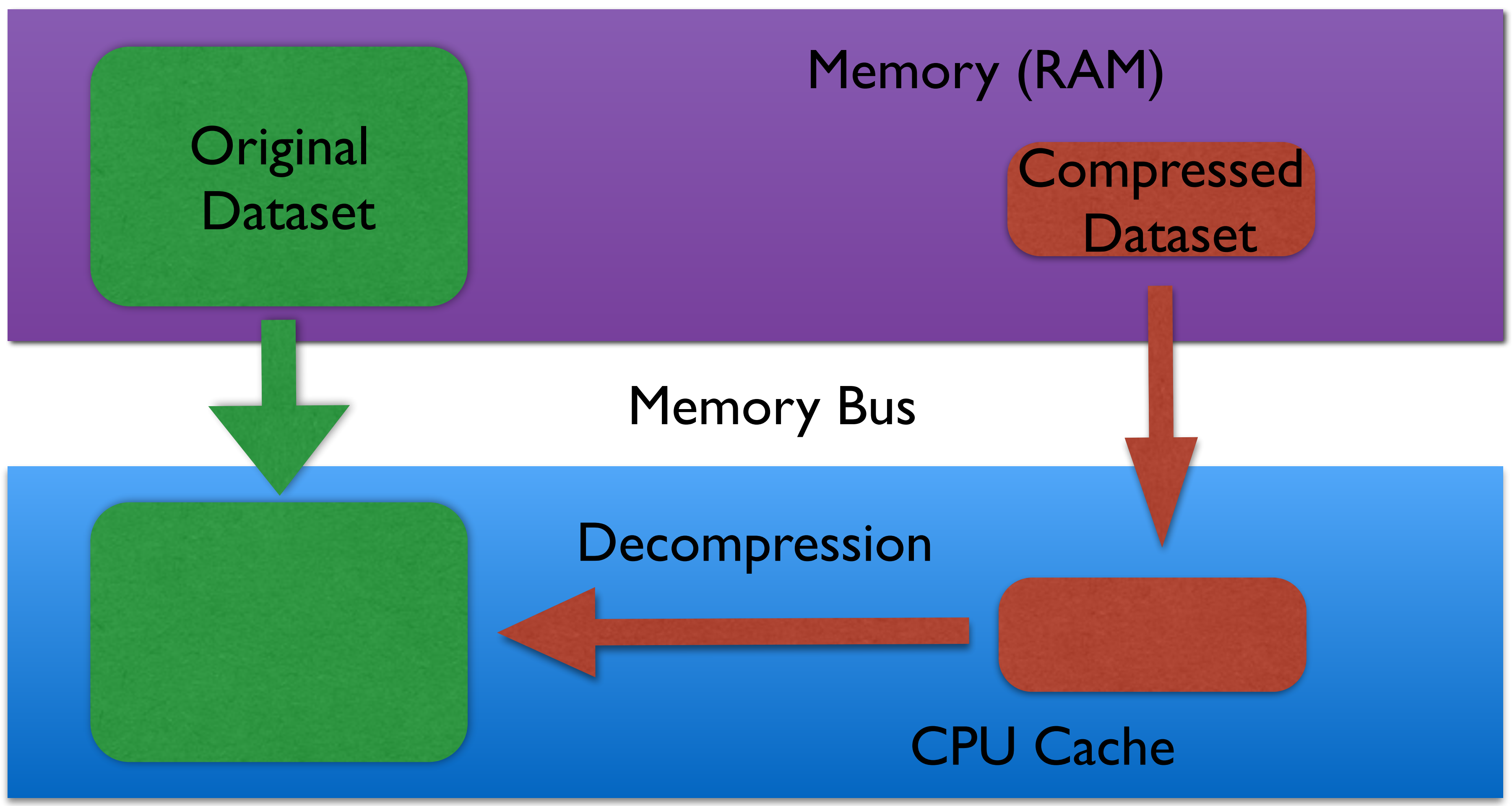
Reading satellite images: Blosc decompression accelerates I/O

Can CPU-based Compression Alleviate The Memory Bottleneck?

Improving RAM Speed?

Less data needs to be transmitted to the CPU



Transmission + decompression faster than direct transfer?

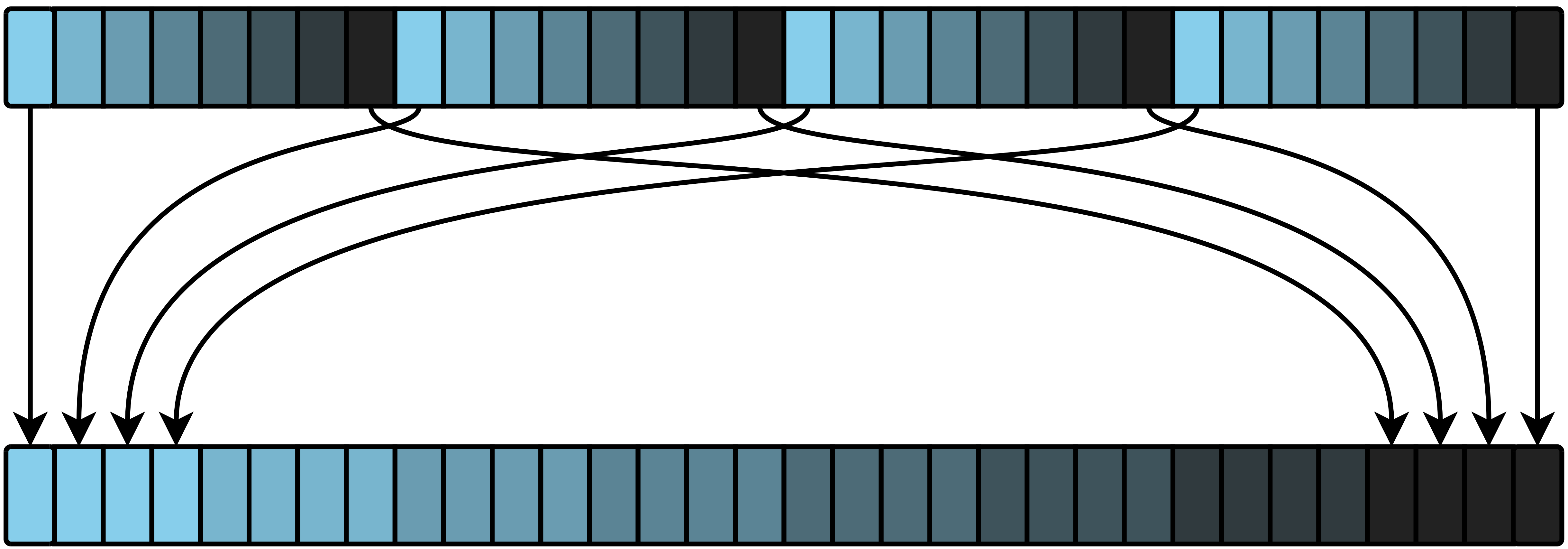
We can try, but certain conditions must be met

- We must follow the principles we have seen:
    - Data Containers leveraging the blocking technique (better cache usage)
    - Using (extremely fast) compression per every block

Principles of Blosc

- Split data chunks in blocks internally (better cache utilization)
- Supports Shuffle and BitShuffle filters
- Uses parallelism at two levels:
  - Use multicores (multithreading)
  - Use SIMD in Intel/AMD processors (SSE2, AVX2) and ARM (NEON)

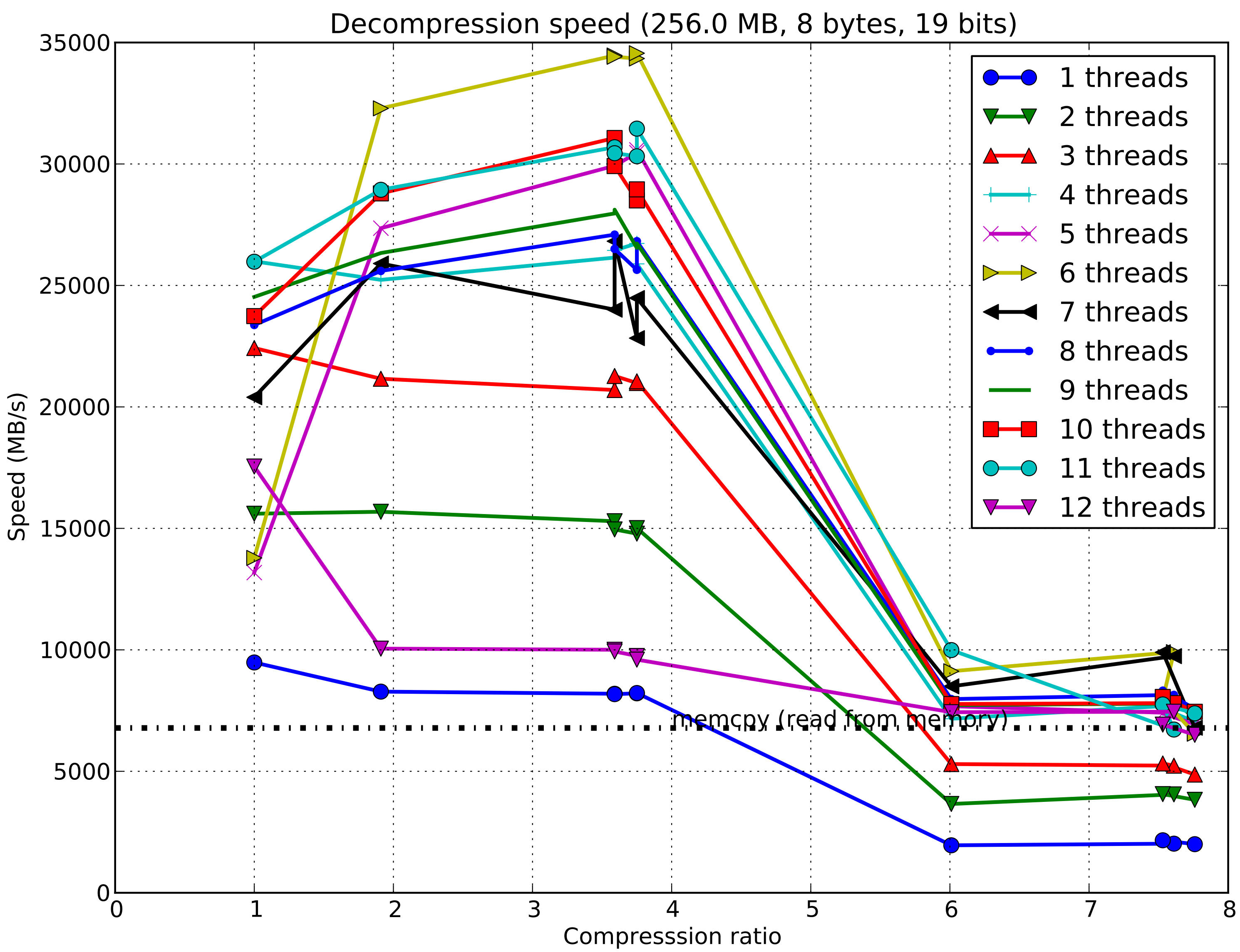
The Shuffle filter



- Shuffle works at byte level, and works well for integers or floats that vary smoothly

- There is also support for a BitShuffle filter that works at bit level

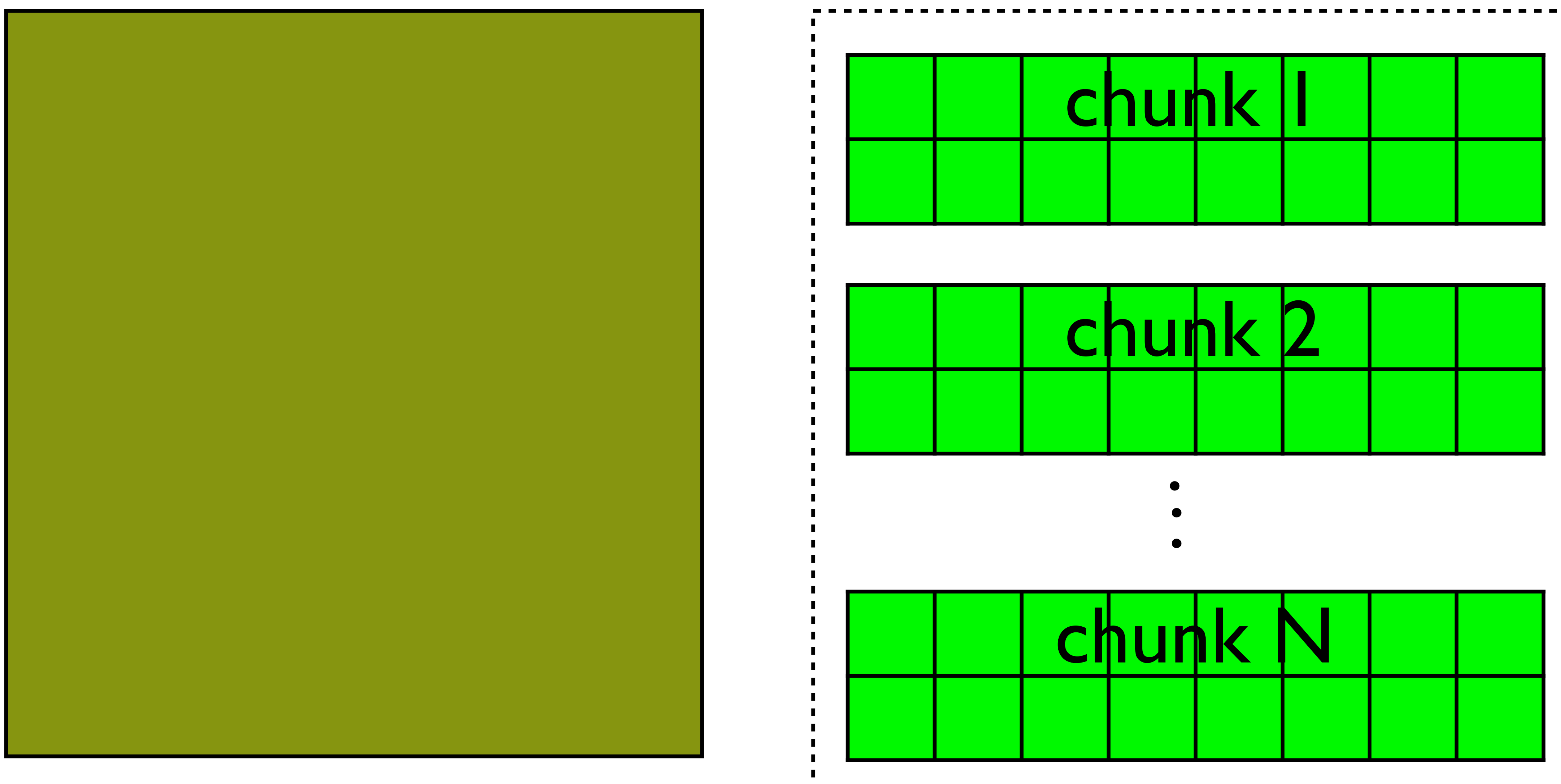
Blosc: Compressing Faster Than *memcpy()*



bcolz: a Data Container that Leverages the Blocking Technique

NumPy container

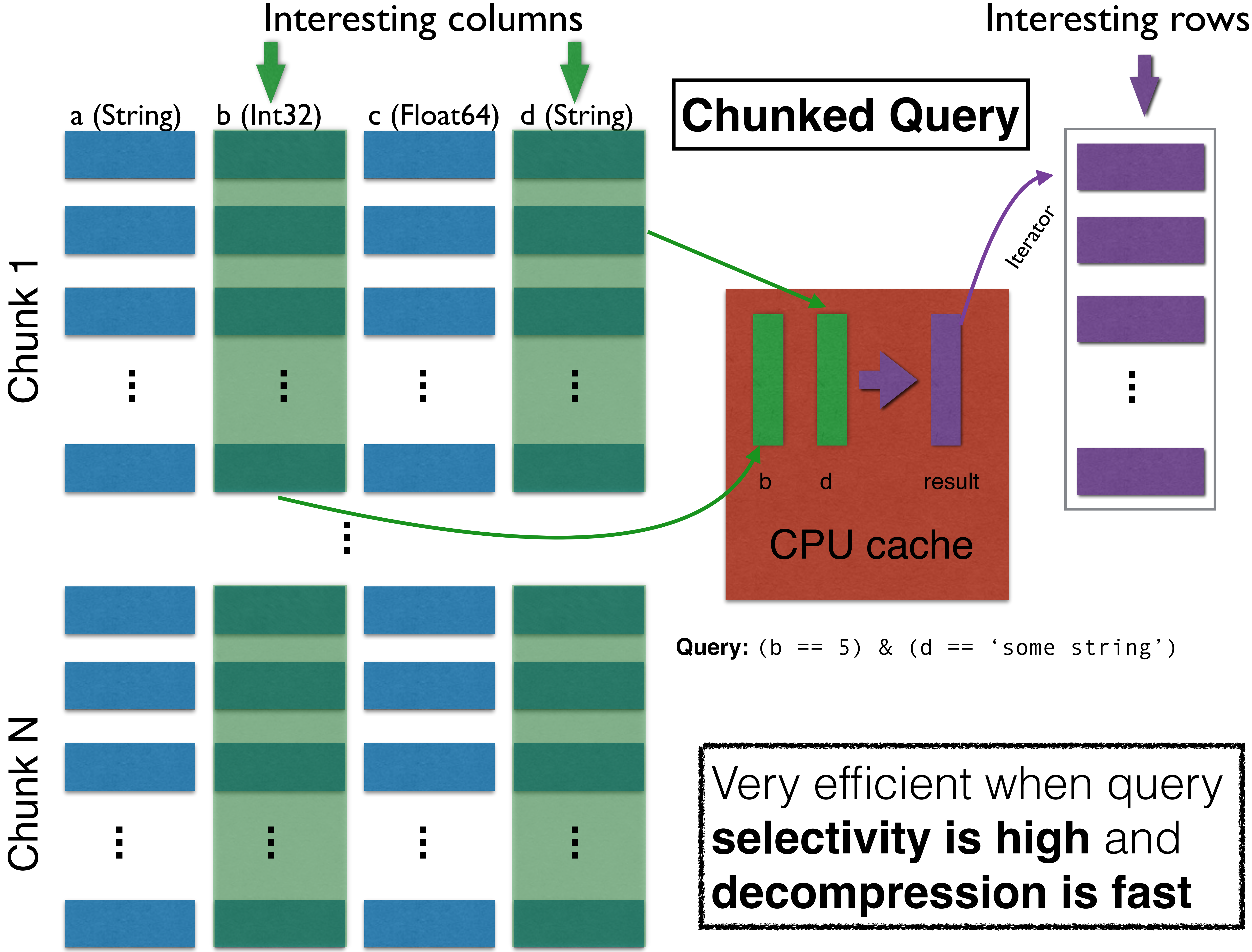
bcolz container



Contiguous memory

Discontiguous memory

Chunked Query

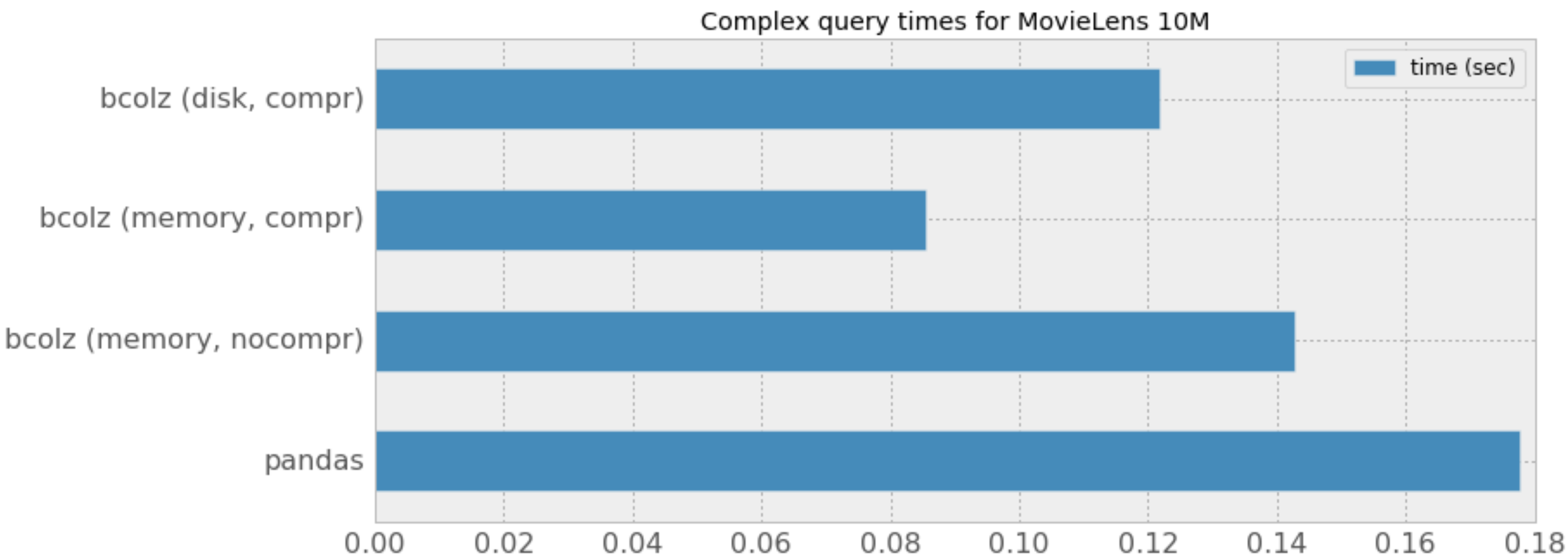


Query: `(b == 5) & (d == 'some string')`

Very efficient when query **selectivity is high** and **decompression is fast**

Query Times in `bcolz`

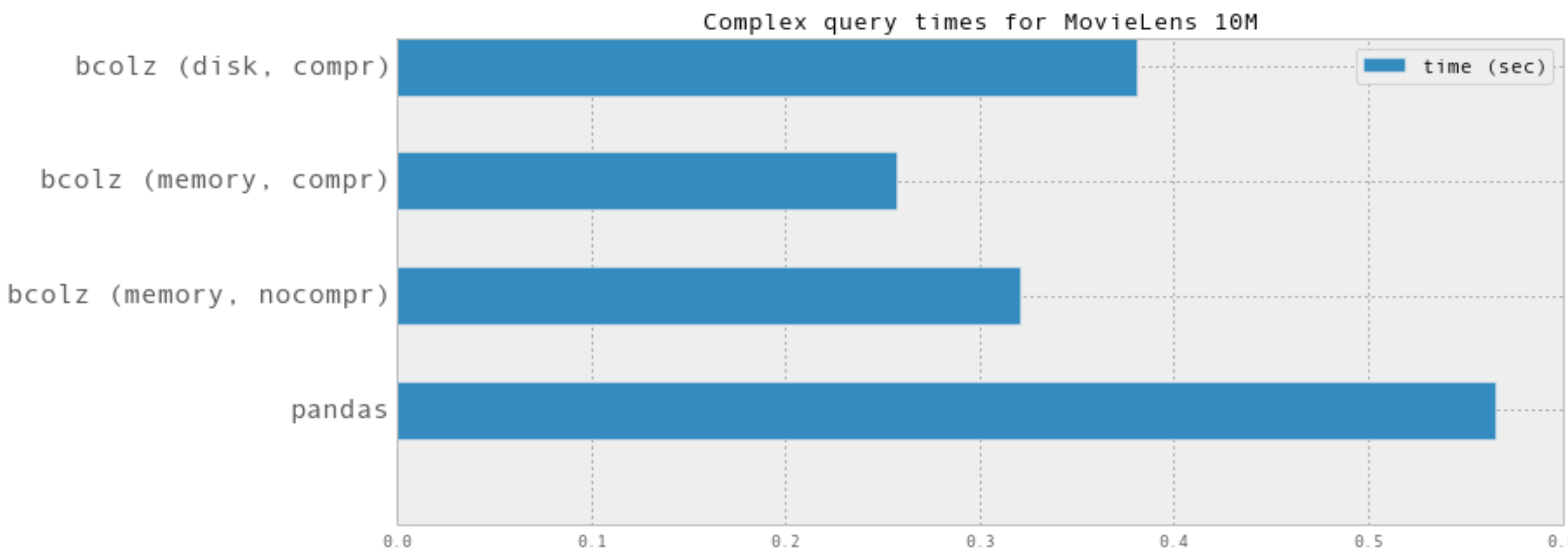
Recent server (Intel Xeon Skylake, 4 cores)
Compression **speeds** things up



Reference: https://github.com/Blosc/movielens-bench/blob/master/querying-ep14.ipynb

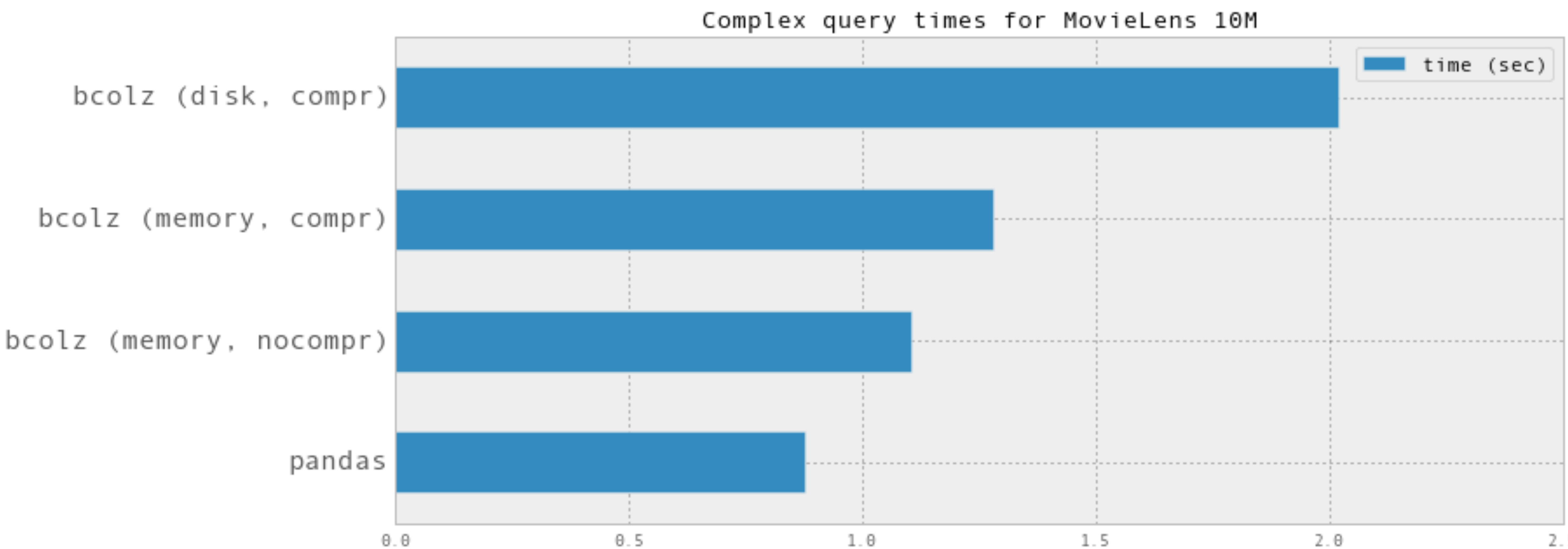
Query Times in `bcolz`

4-year old laptop (Intel Ivy-Bridge, 2 cores)
Compression still **speeds** things up

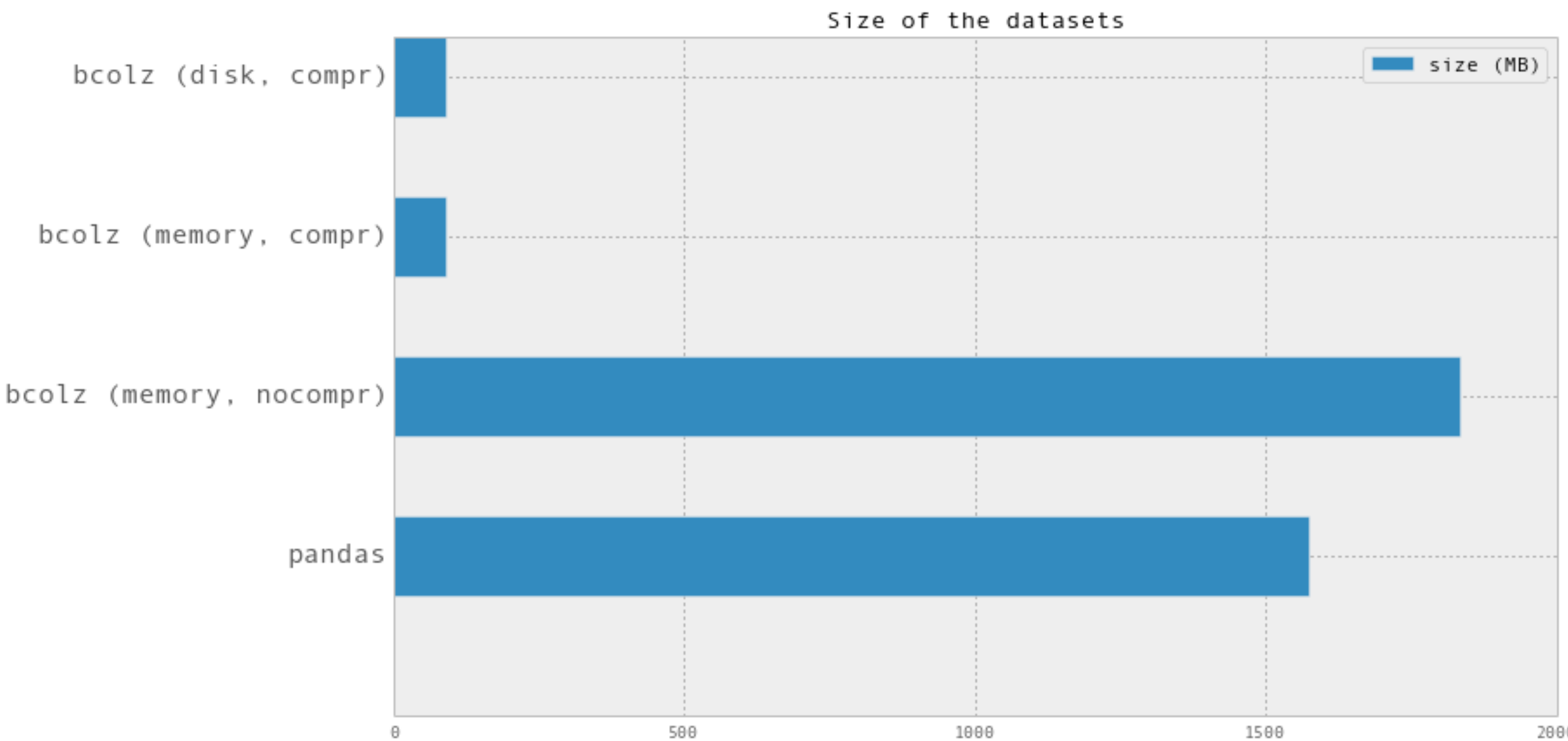


Query Times in `bcolz`

2010 laptop (Intel Core2, 2 cores)
Compression **slows** things down



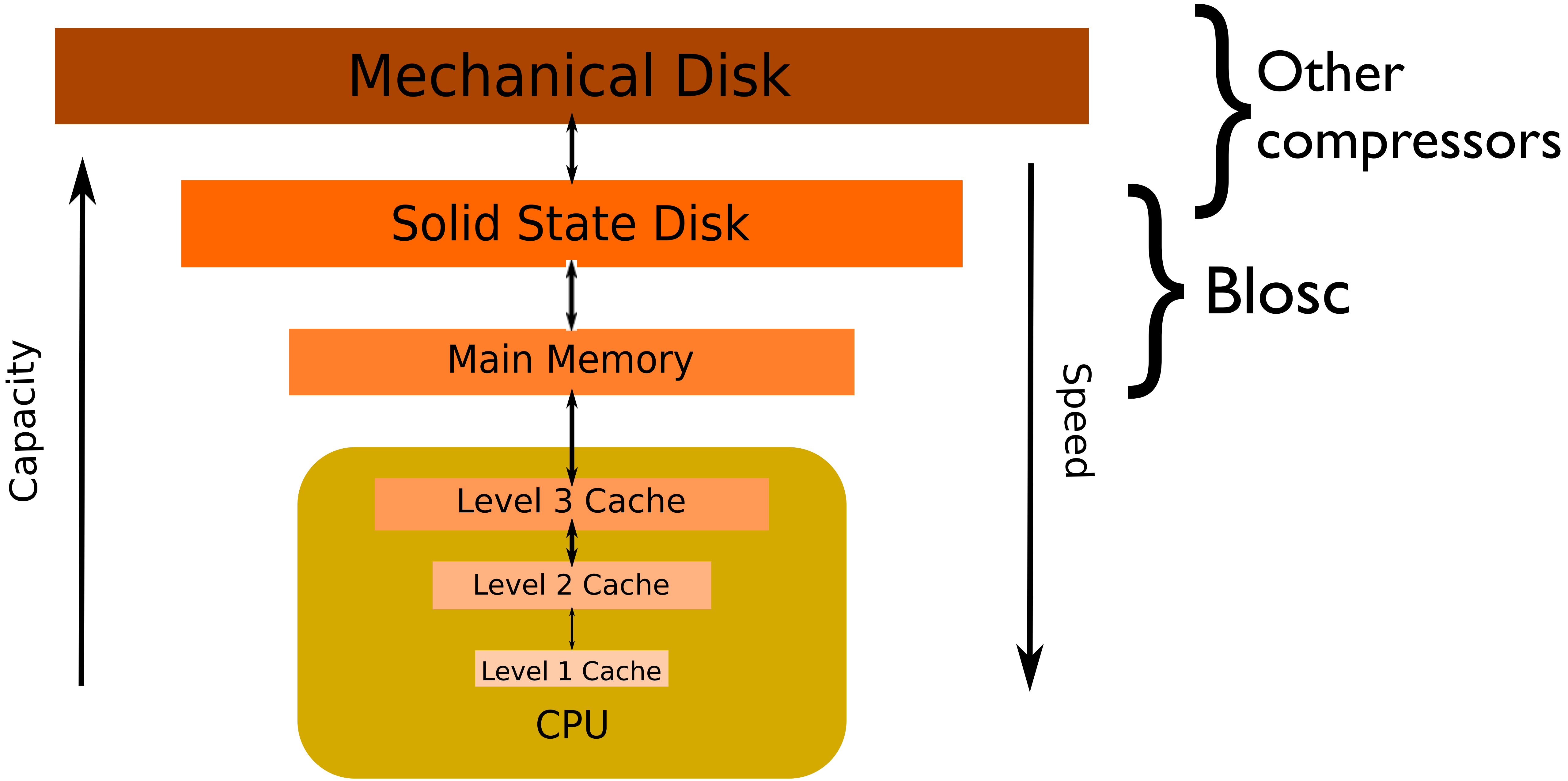
Sizes in `bcolz`



Do not forget compression main strength:

We can store more data while using same resources

Accelerating I/O With Blosc



“Blosc compressors are the fastest ones out there at this point; there is no better publicly available option that I'm aware of. That's not just ‘yet another compressor library’ case.”

— *Ivan Smirnov*
(advocating for Blosc inclusion in h5py)

Compression matters!

Take Away Messages

- Due to the evolution in computer architecture, compression can be effective for two reasons:
  - We can work with more data using the same resources.
  - We can reduce the overhead of compression to near zero, and even beyond than that!