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Assessing the Overhead of Offloading Compression Tasks

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Overview

In the context of compression accelerators, this work presents

- Part 1: Proposition and Implementation of multi-threaded benchmarks
- Part 2: Analysis of the systems performance while using the accelerator
- Part 3: Performance comparison of the accelerator and the CPU-only compression algorithms
- Part 4: Discussion
- Part 5: Conclusion and Outlook

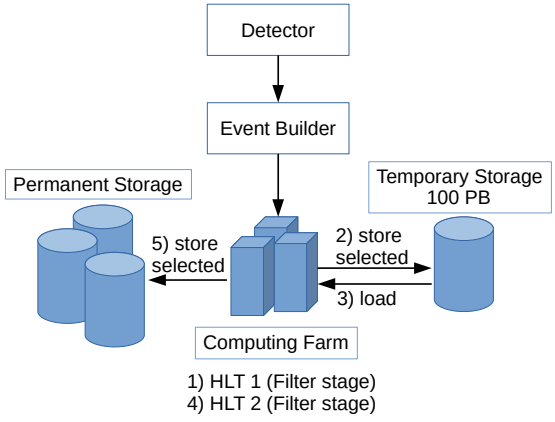
Motivation

CERN

- Upgrade from 2019 - 2021 to support higher luminosity

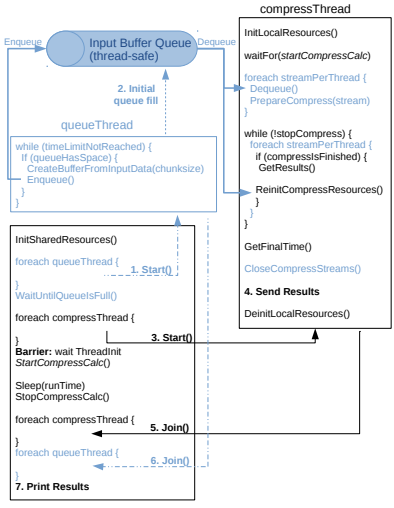
LHCb experiment upgrade

- Detector to compute farm bandwidth: from 60 GB/s to 5 TB/s
- 2 filter stages to filter interesting collisions (data transfer at 150 GB/s)
- 100 PB buffer in between the 2 filter stages



Part 1: Benchmarks

CPU Benchmark

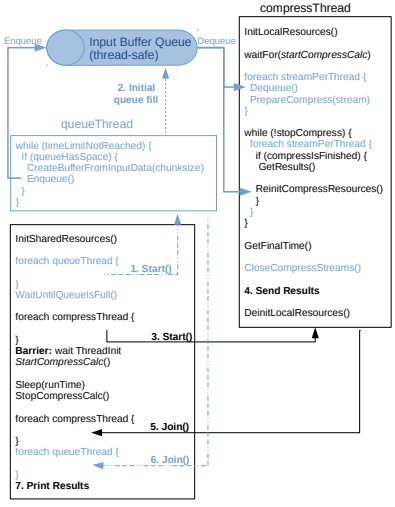


CPU-only compression benchmark

- `main` initializes and controls the threads
- `compressThread` executes compression

  Limitations due to RAM available
- Shared input data set for each NUMA-domain
- Private output buffer for each `compressThread`

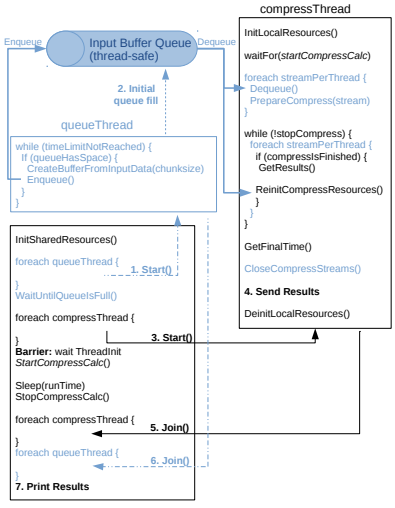
Accelerator Benchmark



Accelerator compression benchmark

- `queueThread` handels provisioning of data chunks
- One `compressThreads` coordinates multiple compression streams
- Uses busy-waiting to interact with the accelerator
- No internal NUMA-binding

Remarks about the Implementation



Measuring sustained throughput

- Time measured within the `compressThread`
- Coordinated by `main`
- Make sure: all threads are set-up before starting the compression and timing

Part 2: Performance Analysis of the Accelerator

Hardware

Server: Intel Xeon E5-2630 v4

- Dual-socket
- Real cores 20, threads per core 2
- 64 GB RAM, Max Memory Bandwidth per Socket 68.3 GB/s
- CentOS 7

Compression Accelerator: AHA378

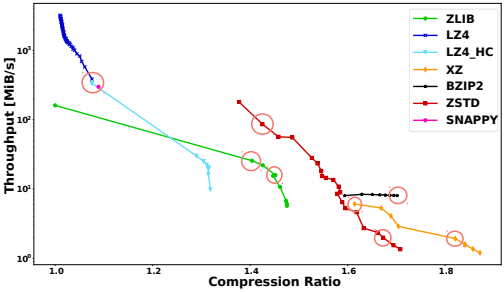
- Up to 80 Gb/s
- 4 FPGAs;
- Half-size, double-width PCI Gen3
- Compression algorithms
  - Lzs
  - Deflate, gzip, zlib

Data Sets

	Compression Corpora	
enwik9	1 GB	English Wikipedia from 2006
proteins	200 MB	Protein data of the Pizza & Chili corpus
silesia	203 MB	Multiple different files tarred into a single file
calgary	3.1 MB	Most famous compression corpora tarred into a single file
	150 MB	Calgary multiplied to conform with benchmark requirements
	High Energy Physics Data	
ATLAS	4.1 GB	Proton-Proton Collisions
ALICE	1 GB	Lead-Lead Collisions
LHCb	4.9 GB	Proton-Proton Collisions

Compression Algorithms

- bzip2 level 9
- lz4(_hc) level 2
- snappy
- xz level 5
- zlib level 2 and level 4
- zStandard (zstd) level 2 and level 21



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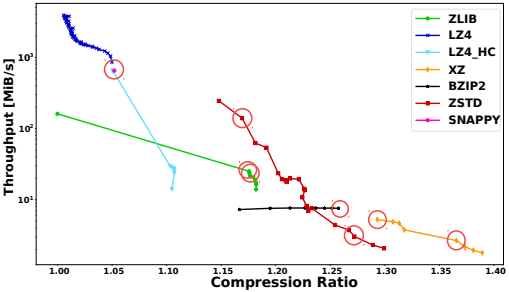
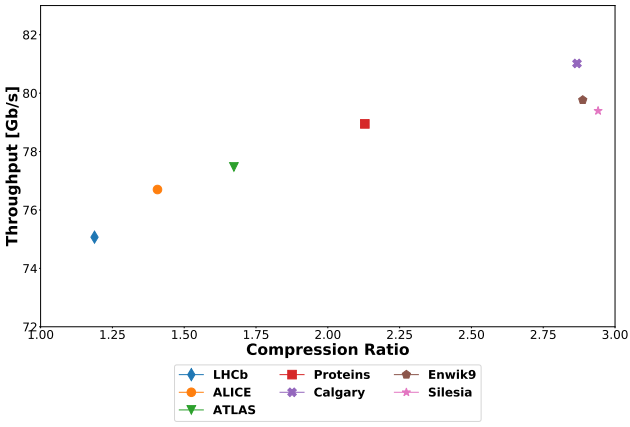


LHCb

Accelerator Results

Best Configuration: 2 MB chunk size, 500 queue elements, 3 `queueThread`, 4 `compressThreads`, 12 compression streams

- Memory bandwidth 22-30 Gb/s
- Power consumption: CPU 58 W, RAM 7 W

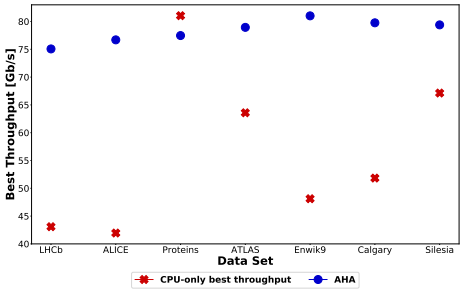


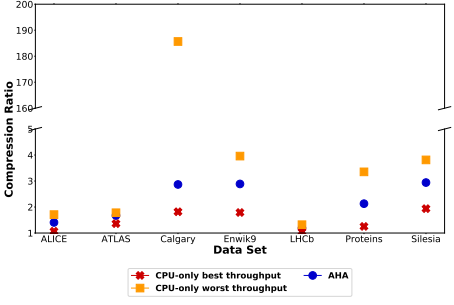
Part 3: Performance Comparison of accelerator vs CPU-only Algorithms

Results Comparison I

CPU-only benchmark best configuration: 40 `compressThreads`, 150 MB chunk size

- Accelerator was compared to zlib level 2. zlib level 4 was not selected because
  - Only 7% better compression ratio
  - But 13 - 37% decrease in throughput
- zstd level 2 compression ratio was close to zlib level 2, but 2 - 3x higher throughput





best: snappy or lz4

worst: zstd level 21 and xz

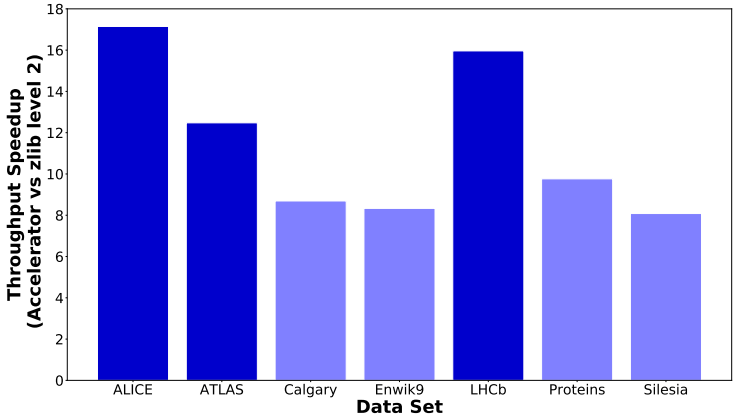
Result Comparison II

- CPU power consumption: 72 - 103 W (TDP 105 W)
- RAM power consumption: 4 W (zlib level 2) - 11 W (xz level 5)

- **Highest CPU power consumption**: zlib level 2 and zstd level 2 (99 - 103 W)
  - This is 40-45 W more than the accelerator
- **RAM power consumption**
  - Accelerator had 2x the memory bandwidth for 7 W compared to CPU-only algorithms
  - For CPU-only algorithms: to get same memory bandwidth 9 W are needed

Result Comparison III

The accelerator had a 8-17x higher throughput than zlib level 2



Part 4: Discussion

Discussion I

- Throughput variation between data sets: 7% accelerator vs 42% CPU-only
  - Higher accelerator throughput possible if PCI Gen4?
  - NUMA binding very important for stable performance
- Related Works (Calgary Corpus, Harmonic mean compression ratio)
  - FPGAs
    - Abdelfattah et al.[1]: 2.17 with 24 Gb/s
    - Qiao et al.[2]: 2.03 with 80 Gb/s
    - AHA378: 2.81 with 80 Gb/s
  - CPU-only algorithms
    - snappy: 1.85 with 53 Gb/s
    - zlib level 2: 2.65 with 9.3 Gb/s
    - zstd level 2: 2.76 with 22 Gb/s
    - zstd level 21: 3.26 with 13 Gb/s
    - xz level 5: 3.38 with 0.58 Gb/s
- Limitations
  - The server did not provide enough reliable performance counter to do further analyses

[1] https://doi.org/10.1145/2664666.2664670; [2] https://doi.org/10.1109/FCCM.2018.00015

Discussion II

For system integration it is important to understand underlying requirements to not degrade the accelerator's performance

- Accelerator needed only 10% of the CPU compute resources (4 `compressThreads`)
- Accelerator needed 80% of memory bandwidth of one socket
  - Note: In general, software utilizing two sockets will not have twice the amount of memory bandwidth available compare to a single socket
- Most compatible tasks for collocation
  - NUMA binding important to prevent unnecessary cross-NUMA-domain communication
  - Best choice: Tasks which have a big computation, but small memory footprint
  - Preferable, utilizing compression as a post-processing step, so that the data already resides in memory

Discussion III

- Benchmark used busy waiting
  - → Interrupt-based implementation might reduce further resource requirements

Accelerators and API Documentation

- Other accelerator tested: Intel QuickAssist 8970
  - Up to 100 Gb/s; ASIC; half-size, double-width PCI Gen3
  - Does encryption and compression
  - Compression algorithms: deflate, gzip, zlib
  - ↯ Not further pursued because of significant performance and stability issues
- AHA378
  - Good documentation, but must be thoroughly read to get good performance
    - → Accelerator access memory via DMA!
  - Examples allow to get a good performance in reasonable time

Part 5: Conclusion and Outlook

Conclusion

- Insights of integration costs of accelerators
  - NUMA binding is important
  - Measuring time is not so straight-forward in multi-threaded environments
- Accelerator vs zlib level 2
  - 80% less CPU resources
  - 8-17x higher throughput
- Commercially available compression accelerators are a realistic option
- The work on CPU-only compression algorithms can be used to select the right algorithm for the right task

Outlook

- Implement interrupt-based communication with the accelerator
- Measuring collocation performance with different CPU workloads

→ Hypothesis: Is it possible to have a generic *optimal performance* policy for co-scheduling accelerator and CPU workloads with little parameterization effort?