Zstd & LZ4

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Background: Compression algorithms comparisons

- As part of the DIANA/HEP to improve ROOT-based analysis, we have continued work in comparing compression algorithms. For this update, we include:
    - **LZ4:** lossless data compression algorithm that is focused on compression and decompression speed.
    - **ZSTD**: Relatively new algorithm in the LZ77 family, notable for its highly performant reference implementation and versatility.
    - **ZLIB / Cloudflare**: Update on work to include Cloudflare patches in ROOT.
- We will be comparing algorithms based on three metrics:
    - **Compression ratio:** The original size (numerator) compared with the compressed size (denominator), measured in unitless data as a size ratio of 1.0 or greater.
    - **Compression speed:** How quickly we can make the data smaller, measured in MB/s of input data consumed.
    - **Decompression speed:** How quickly we can reconstruct the original data from the compressed data, measured in MB/s for the rate at which data is produced from compressed data.

Testing setup - Software

- Performance numbers based on modified ROOT test "Roottest-io-compression-make" with 2000 events (unless noted).
- Branches:
  - https://github.com/oshadura/root/tree/latest-zlib-cms-cloudflare (latest cloudflare zlib, ported into ROOT Core)
  - https://github.com/oshadura/root/tree/brian-zstd (B.Bockelman's ZSTD integration with CMake improvements)
  - https://github.com/oshadura/root/tree/zstd-default (branch enabling ZSTD as default, used only for testing purposes)
  - https://github.com/oshadura/roottest/tree/zstd-allcompressionlevels (roottest compression test with extended cases presented here, covering all zlib and zstd compression level)
- We are trying to measuring the ROOT-level performance - numbers include all overheads (serialization / deserialization, ROOT library calls, etc).

Testing setup - Hardware

- Platforms utilized:
  - **Intel Laptop**: Intel Haswell Core i7 + SSD
  - **Intel Server**: Intel Haswell Xeon-E5-2683
  - **AARCH64neon Server:** Aarch64 ThunderX
  - **AARCH64neon+crc32 Server**: Aarch64 HiSilicon's Hi1612 processor (Taishan 2180). Includes CRC32 intrinsic instruction.
- Tests were repeated multiple times to give a sense of performance variability.

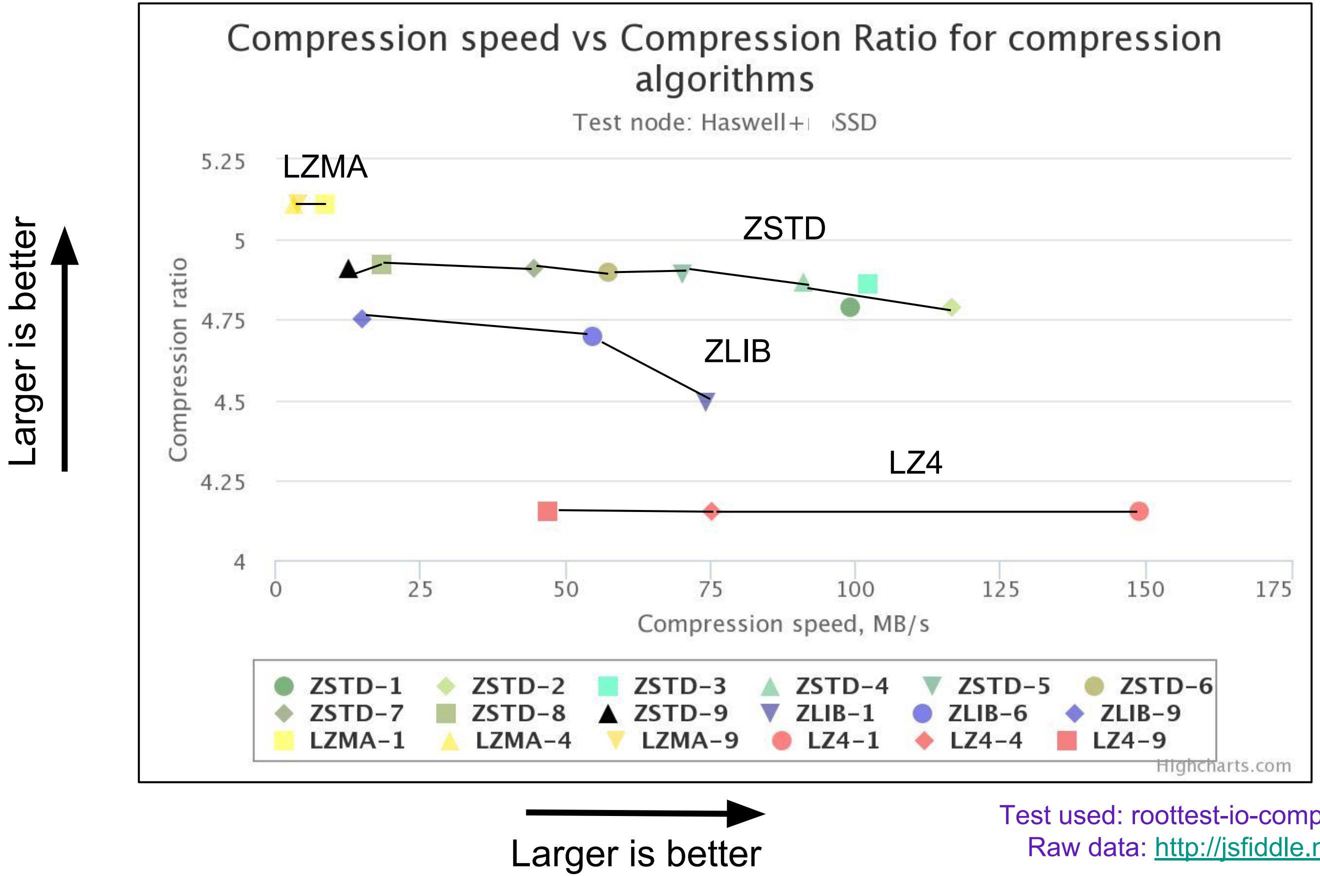
ZSTD

https://github.com/facebook/zstd.git

ZSTD Background

- Given ZSTD performance claims on their website (facebook.github.io/zstd/), we should expect:
  - **Better than ZLIB in all metrics**: compression speed, decompression speed, and compression ratio.
  - Like all LZ77 variants, **decompression speed should be constant regardless of compression level**.
  - High dynamic range in tradeoff between compression speed and compression ratio.
  - Does not achieve compression ratio of LZMA.
  - Does not achieve decompression speed of LZ4.

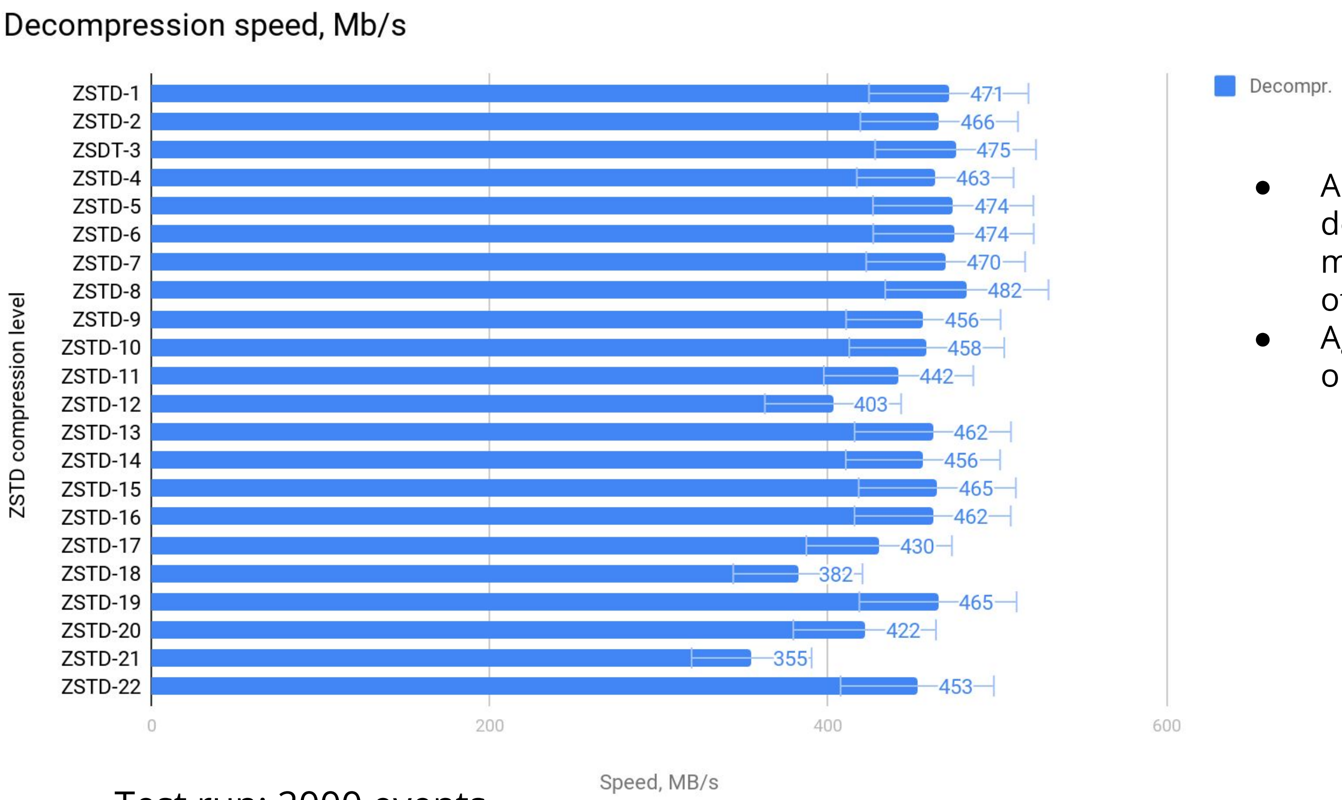
Write Tests - Write Speed and Compression Ratio



- Largely validates our expectations for compression!
- Note there is some performance noise between ZSTD-1 and ZSTD-2. Not understood.
- **NOTE**: Compression ratios are flatter than expected. Will do cross-comparisons with LHC files in a future follow-up.

Test used: roottest-io-compression-make with 2000 events
Raw data: http://jsfiddle.net/oshadura/yzusyhco/show/

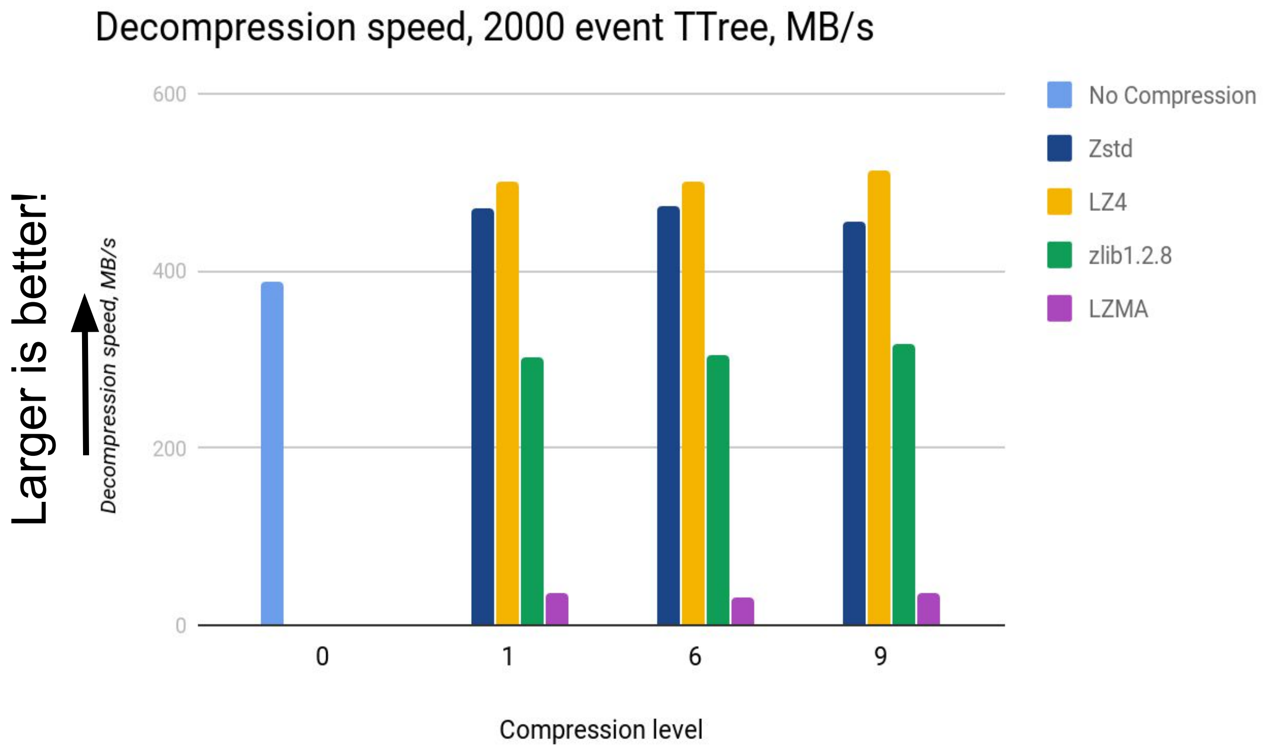
ZSTD - Read Speed Tests (Intel Laptop)



- As expected, decompression rates are mostly identical, regardless of compression level.
- Again, some curious outliers.

Test run: 2000 events
TTree-roottest-io-compression-make

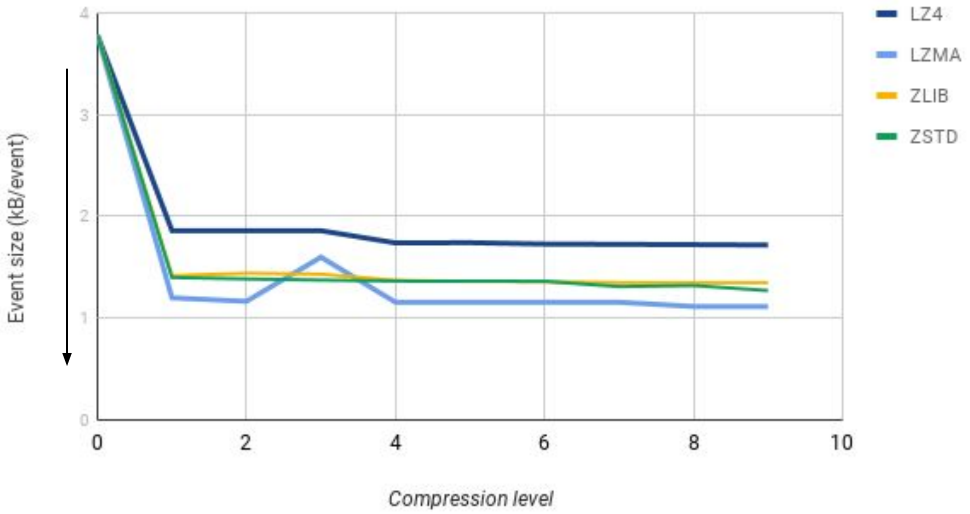
Read Speed - Compare across algorithms

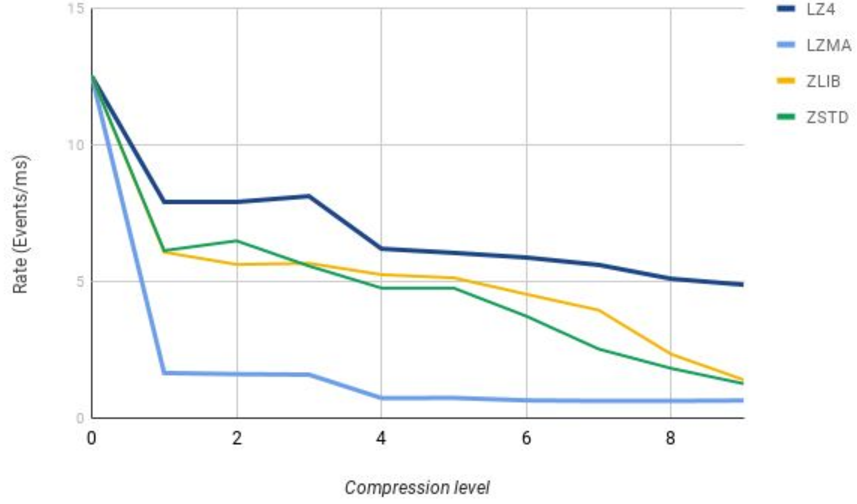


- At the current compression ratios, reading with decompression for LZ4 and ZSTD is actually faster than reading decompressed: significantly less data is coming from the IO subsystem.
- We know LZ4 is significantly faster than ZSTD on standalone benchmarks: likely bottleneck is ROOT IO API.

ZSTD - LHCB

LHCB B2ppKK2011_md_noPIDstrip.root (22920 entries)





ZLIB-cloudflare

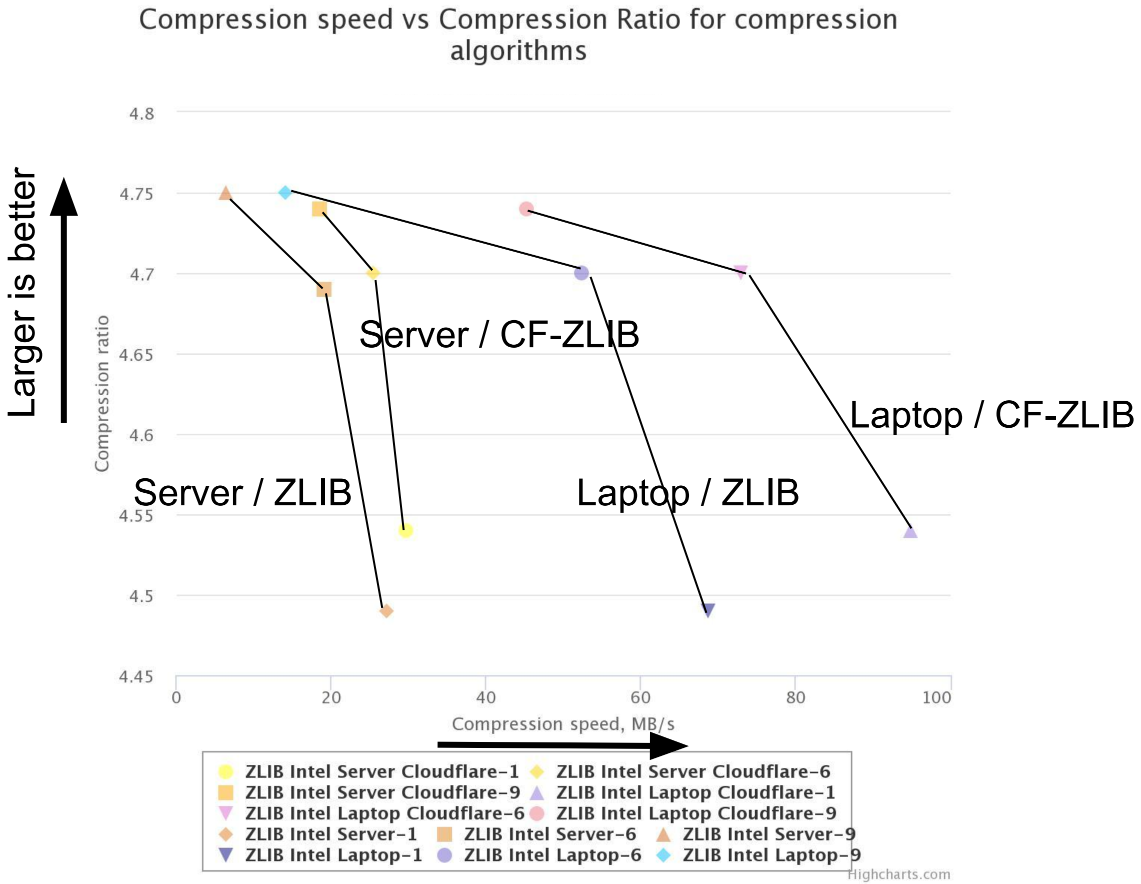
ZLIB Progress

- We have been trying to land the Cloudflare ZLIB (“CF-ZLIB”) patches into ROOT.
- ZLIB current version is 1.2.11; CF-ZLIB is based on 1.2.8.
  - Difference between 1.2.11 and 1.2.8 are mostly for build systems, bug fixes, and regression fixes in parts of the library unrelated to ROOT.
  - Rebasing Cloudflare to 1.2.11 proved very difficult. Decided to stay on 1.2.8.
- In addition to CloudFlare patches, we have added:
  - “Fat library”: When intrinsics are not available at runtime, switch to base implementation.
  - Build improvements: Now builds on ARM and Windows.
  - adler32 optimization: CloudFlare only optimizes CRC32; ROOT uses adler32.
- Here, we compare CF-ZLIB with upstream ZLIB.

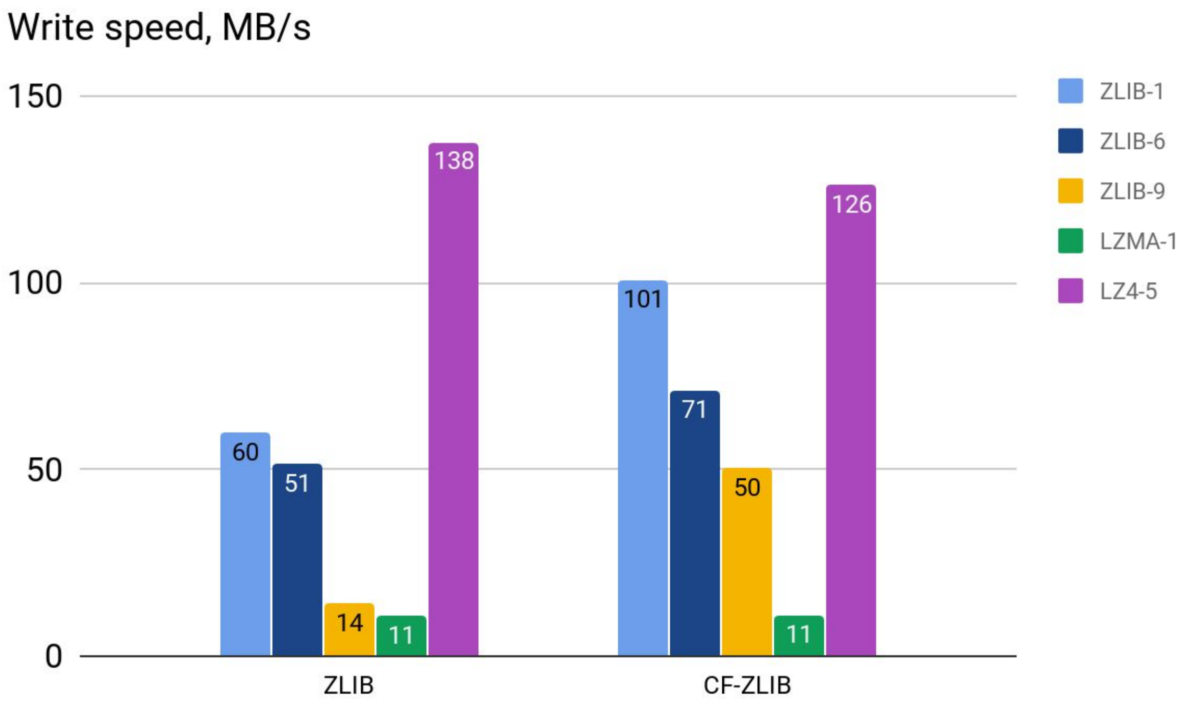
Cloudflare ZLIB vs ZLIB - Intel Laptop/Intel Server (http://jsfiddle.net/oshadura/npp670kr/show)

Note: small dynamic range for y-axis.

The CF-ZLIB compression ratios *do* change because CF-ZLIB uses a different, faster hash function.



Compression write speed (Intel Laptop)

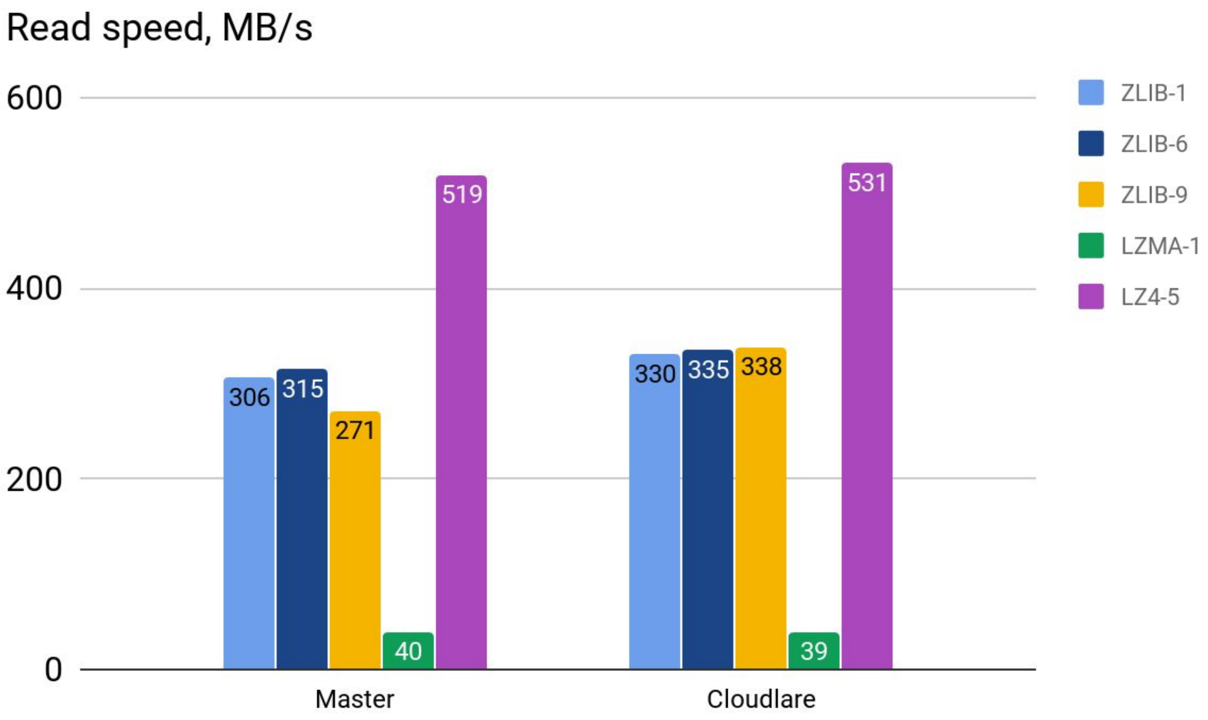


Reductions in speed:

- ZLIB-1: -40%
- ZLIB-6: -28%
- ZLIB-9 -72%

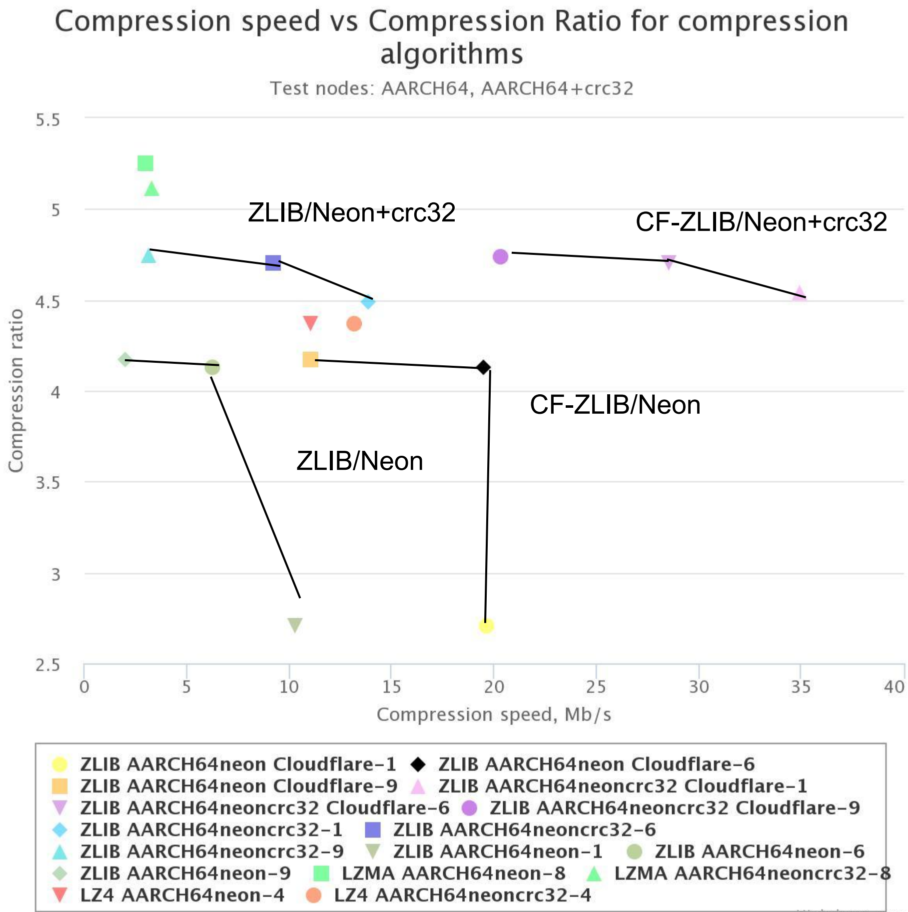
CF-ZLIB-9 is the same speed as ZLIB-6.

Read speed (Intel Laptop)



Small improvement of CloudFlare's version ~ 7%.

Cloudflare zlib vs zlib -AARCH64+CRC32 HiSilicon's Hi1612 processor (Taishan 2180) http://jsfiddle.net/oshadura/qcwsx9y4/show



- Significant improvements for aarch64 with with Neon/CRC32
- Improvement for zlib Cloudflare comparing to master for:
  - ZLIB-1/Neon+crc32: -31%
  - ZLIB-6/Neon+crc32: -36%
  - ZLIB-9/Neon +crc32-9: -69%
  - ZLIB-1/Neon: -10%
  - ZLIB-6/Neon: -10%
  - ZLIB-9/Neon: -50%

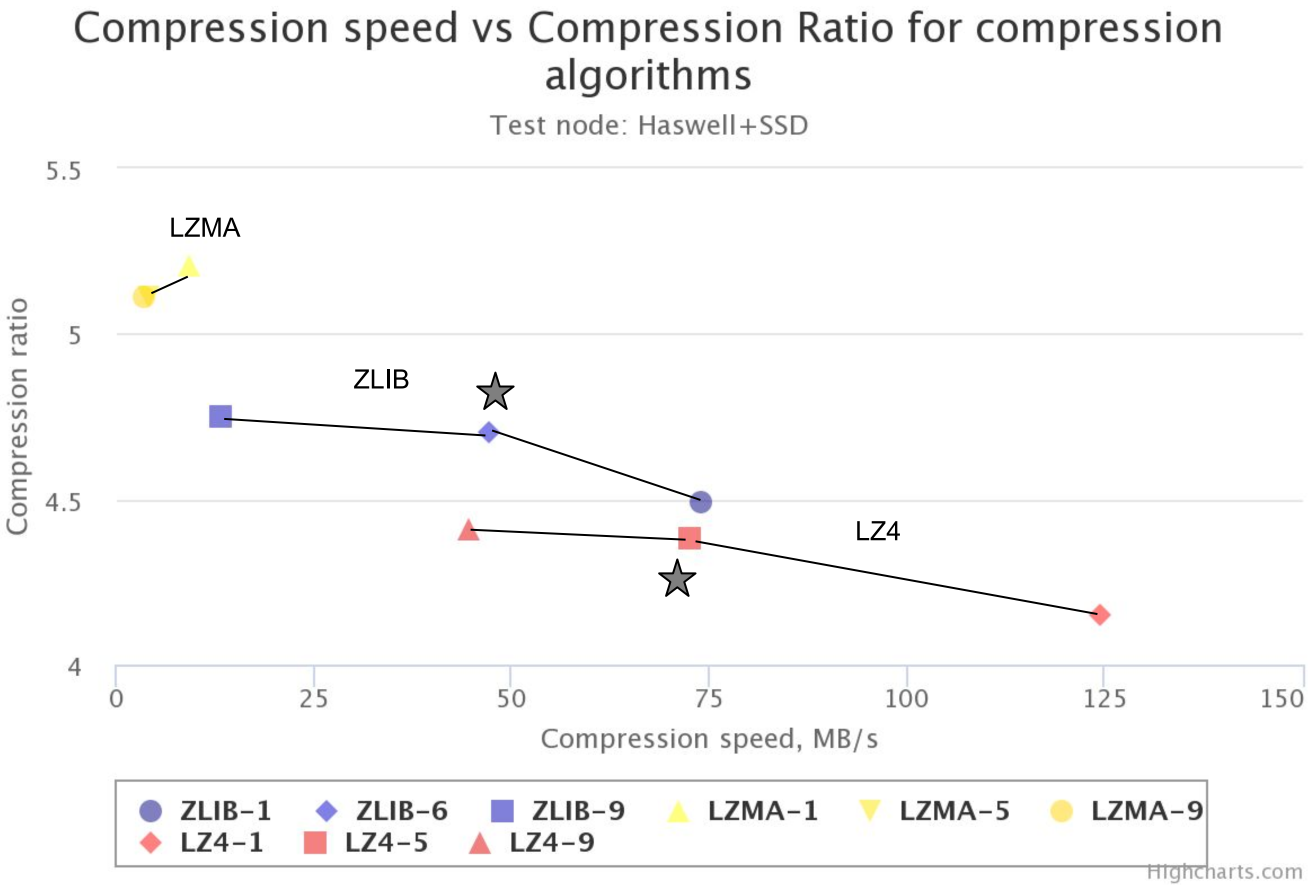
Lz4 - Extremely Fast Compression algorithm http://www.lz4.org)

LZ4: previous tests

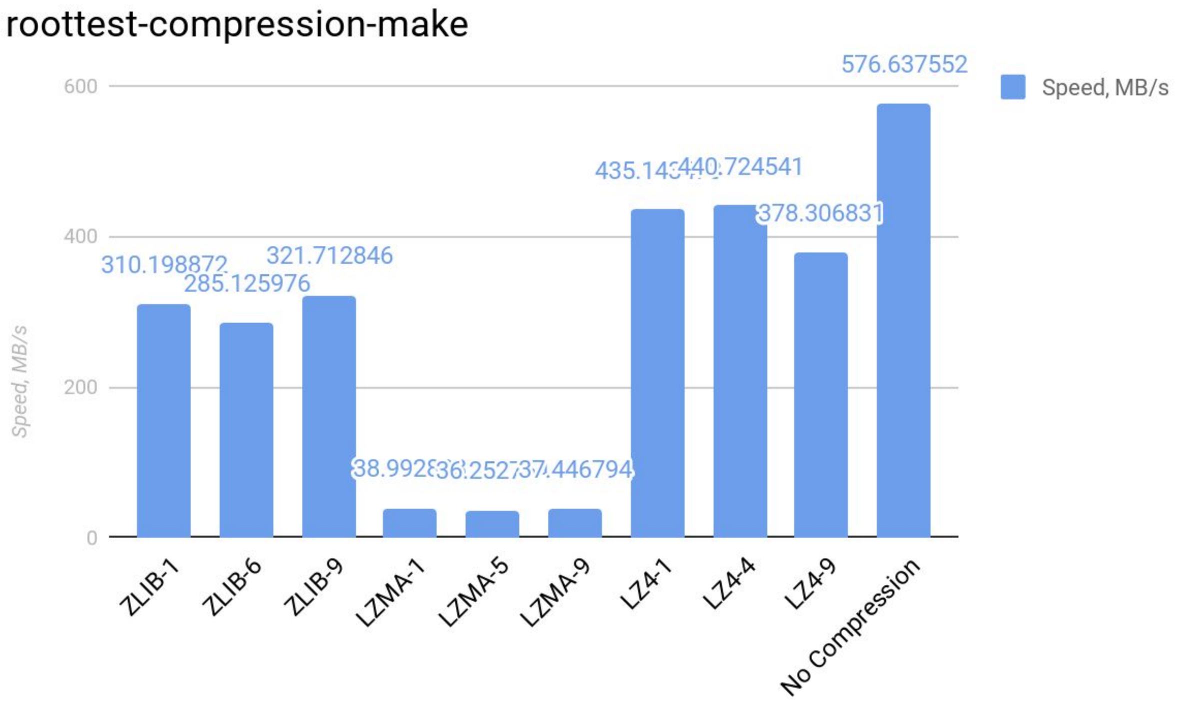
- Winter ROOT I/O Workshop: https://indico.fnal.gov/event/15154
  - https://indico.fnal.gov/event/15154/contribution/8/material/slides/0.pdf (Jim Pivarsky)

During spring ROOT I/O workshop was recommended to turn on the LZ4 compression algorithm as a default with compression level 4

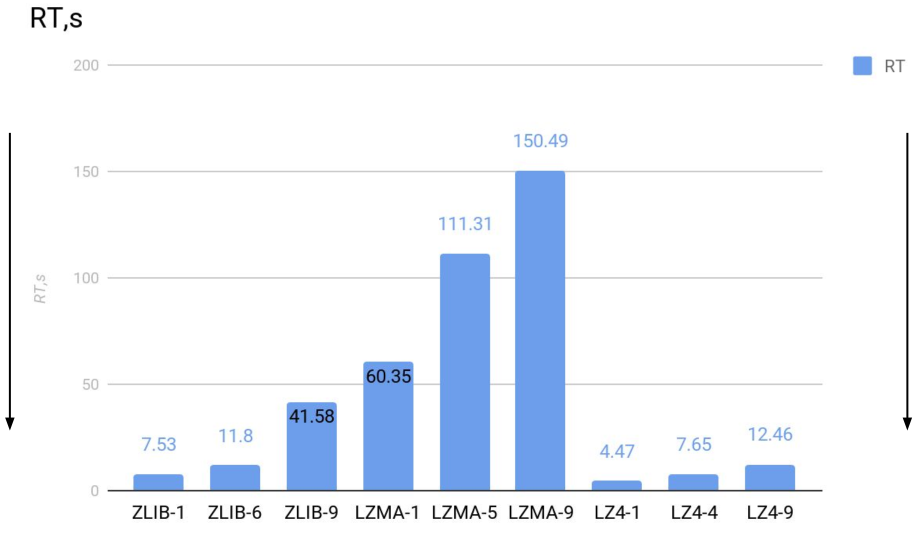
Roottest-compression-test: compression test



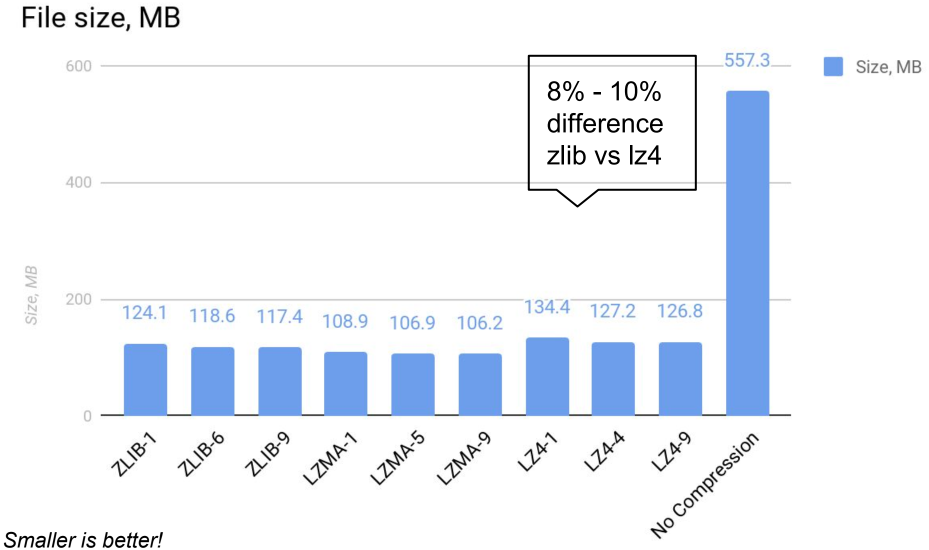
Roottest-compression-test: decompression test



Roottest-compression-test: compression RT and compressed size comparison



Smaller is better!



Smaller is better!

GeneROOT experience with compression algorithms (Fons Rademaker)

Results was tested on genomics files used for testing ROOT I/O that contain 10% of a human genome. The files contain exact the same data, only the ROOT compression algorithm differs. For each algorithm, compression level 1 was used. The code to work with these files is in: https://github.com/GeneROOT/ramtools.

The following observations can be made:

- LZ4 is almost 2x the LZMA file size and 30% larger than the ZLIB version.

- Running the viewing script (reads in a region all 11 columns, i.e. a range of alignment records) we see that:

The LZ4 file, while bigger, is just as fast scanning 5400000 records as the ZLIB file. There is no reason to use LZ4, except to waste space.

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In these measurements, it was not taken in account compression speed and compression levels..

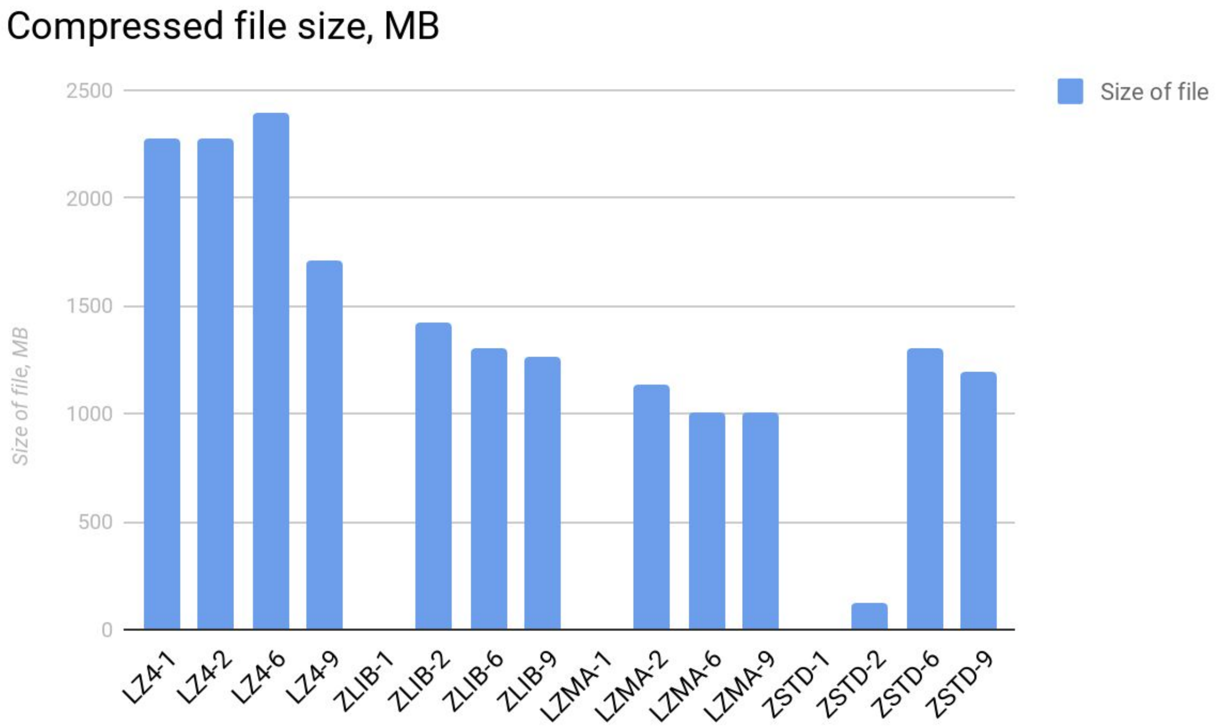
Browsing files with GeneROOT/ramtools.git

- All files are identical (I got access to the full collection of files)
- **Baskets in compressed files are very small!**
- Files are translated from SAM format data to ROOT data format

```
H0E3UALXX:5:1101:5441428:0   147   7   9644968   60   150M   =   9644807   -311
CAACACGATATTATTAACTATATTCACAATAAACCCACGTGCACTGATGGTAGGAATGTAAATTGATACAGCCCTTATGAGGTGGTTGTTTTTACTCCTTTTTTGTGTTTGTGTATGAAATTCTTATTCAAT
GAAAGAAAAGAGTGTATG
JJJJFJFJJJJFJJJJJJJFJJFJJJJJJJJJJJJJFJJJJJJJJFFJJJJJJJJJJJJJJFJJJFJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJFJJJJJJJJJJJJJFJFJJAFFFFF
NM:i:0   MD:Z:150   AS:i:150   XS:i:21   RG:Z:id   MC:Z:150M   MQ:i:60
```

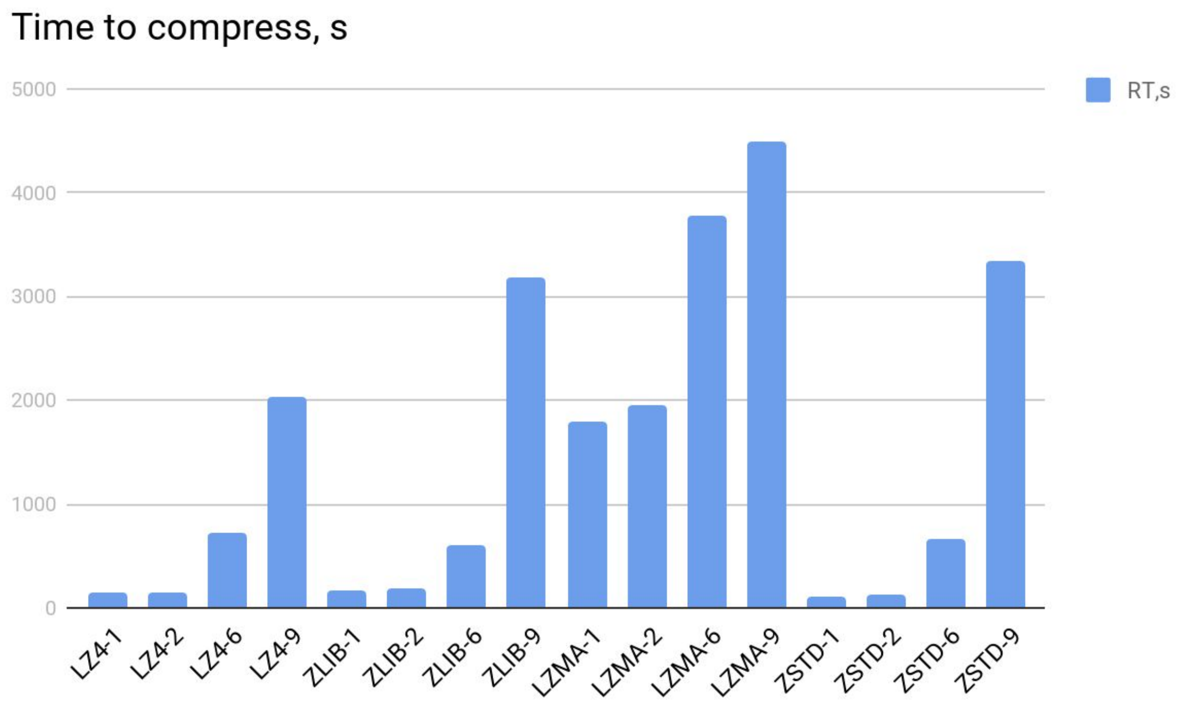
```
H0E3UALXX:2:1117:4842492:0   147   7   9645026   60   16S134M   =   9644775   -385
AAAGCTACCACTATGCTAAATTGATACAGCCCTTATGAGGTGGTTGTTTTTACTCCTTTTTTGTGTTTGTGTATGAAATTCTTATTCAATGAAAGAAAAGAGTGTATGATTCATTTGAAAGAAAGCATGACT
CCATTTGTCCTGTACAGC
-----7---F--<----A-<<7-A<-AA-<-F7A--7--F7<FAFAF<AF<FFFJAJFFJA<JF7JJFAJ-FJ<FJFFFJJFJFFJJ-FFF<FJFF7FJJFJJFJJFJAJ<FJFJJFJJFJJJFJJJJA<FJJJAA<FFFJFJAJFAFAA   NM:i:0
MD:Z:134   AS:i:134   XS:i:21   RG:Z:id   MC:Z:146M4S   MQ:i:60
```

Writing GeneROOT files with different compression



Seems to be a “corner case” for LZ4...

Writing GeneROOT files with different compression



Suggestions: to use ROOT recommended compression levels

ZLIB	6
LZMA	7-8
LZ4	4 [ROOT Winter I/O Workshop]
ZSTD	Still not validated

This is recommended compression levels, defined after step-by-step evaluation of performance of compression algorithms used ROOT

LZ4 and zlib-cloudflare - next steps

- LZ4: enable in a ROOT (expected in next development release)
    - Check LZ4 1.8.1 with possibility to use compression algorithm dictionaries
- ZLIB-cloudflare: merge into ROOT builtins
- LZ4 & ZLIB-cloudflare: extend rootbench.git with compression tests (artificial and LHC datasets)

ZSTD - next steps:

- Follow-up with a wider corpus of inputs (e.g., LHCb ntuples, CMS NANOAOD).
- These tests indicate ZSTD would be a versatile addition to ROOT compression formats.
- Worthwhile to explore read rates for LZ4-vs-ZSTD: can we show cases where reading LZ4 is more significantly faster?
- ZSTD has an additional promising mode where the compression dictionary can be reused between baskets.
    - Facebook reports dictionary reuse provides massive improvements over baseline ZSTD for compression / decompression speeds and compression ratio when compressing small buffers (ROOT's use case!).
    - Naive tests did not bear out this claim: however, Facebook tested against a text-based corpus while we have binary data.
    - Needs investigation.

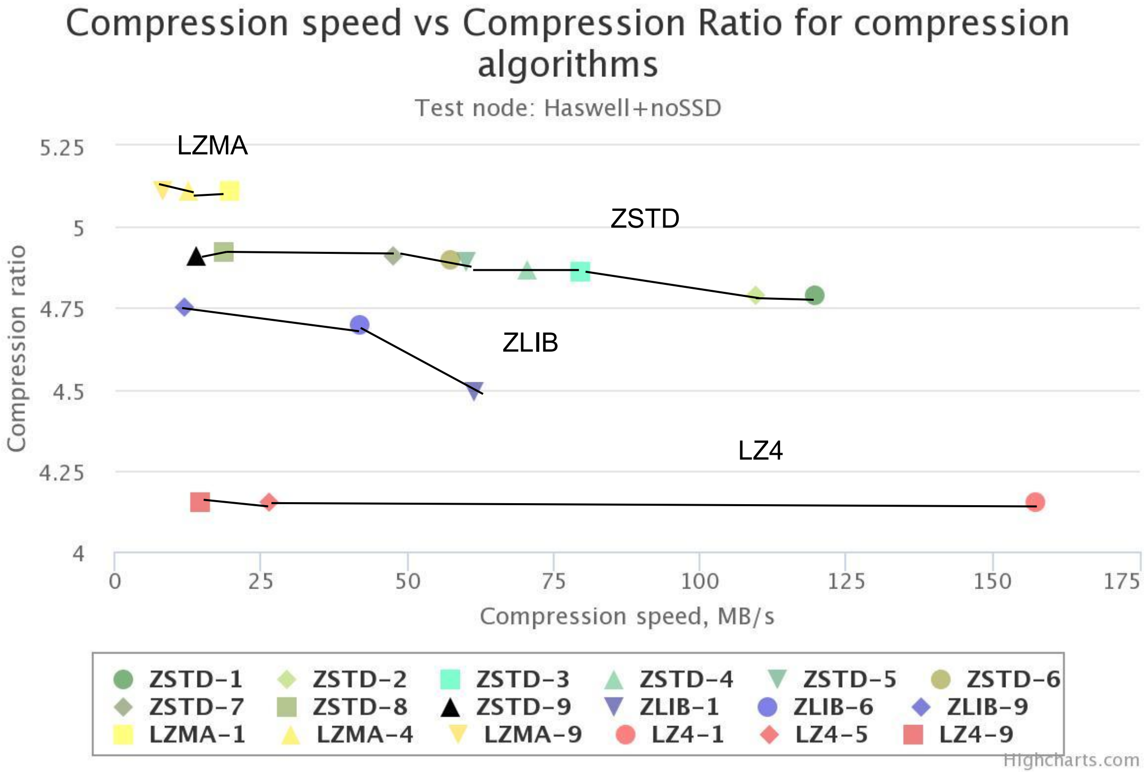
Thank you for your attention!

Backup Slides

ZSTD - Haswell x 56core - no SSD

https://jsfiddle.net/oshadura/af6xt4n1/view

Larger is better



ZLIB-NG

- Fork of ZLIB, cleaning up and merging patches.
- Drop support of 16-bit platforms, ancient compilers
- Merged with all optimizations from Intel and Cloudflare. Supports more architectures than those forks.
- More actively developed.
- Check it out: https://github.com/Dead2/zlib-ng/tree/develop
    - Worth watching! Perhaps not enough history to make the jump yet...