TECHNISCHE UNIVERSITÄT DRESDEN

DRESDEN concept

Maximilian Knespel, Holger Brunst
Technische Universität Dresden

Rapidgzip: Parallel Decompression and Seeking in Gzip Files Using Cache Prefetching

HPDC' 23

ZIH
Center for Information Services & High Performance Computing

Motivation

Accessing huge datasets, e.g., from academictorrents.com:

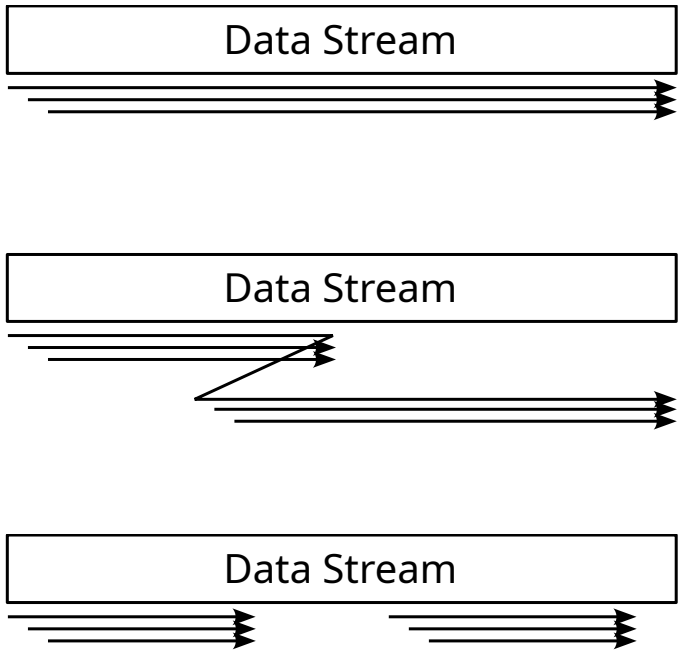
- **wikidata-20220103-all.json.gz:** gzip-compressed JSON, 109 GB, 1.4 TB uncompressed
- **ImageNet21K:** gzip-compressed TAR archive, 1.2 TB, 14 million images averaging 9 KiB.

Solutions:

- ratarmount : **R**andom **a**ccess **TAR mount**.
  Make (huge) archives' contents available via FUSE.
- rapidgzip, indexed_bzip2: Backends for ratarmount for parallel decompression and fast seeking inside compressed gzip and bzip2 files.
  They also offer command line tools for parallelized decompression.

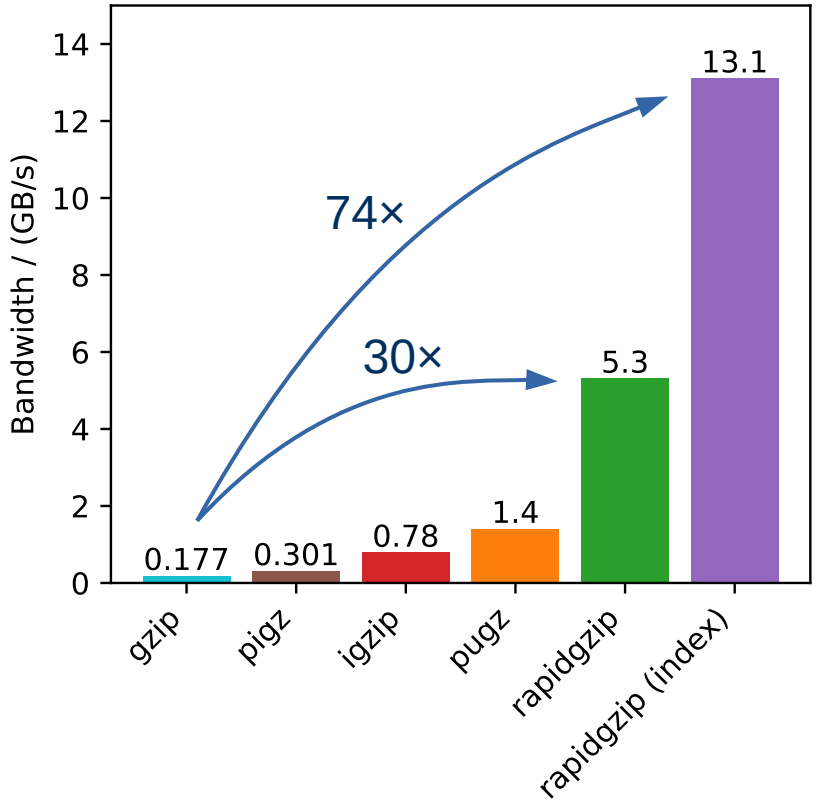
Requirements

- Parallelize gzip decompression
  - Without additional metadata
  - After any seeking
  - For concurrent accesses at two offsets
- Decompress all kinds of gzip files
- Enable fast backward and forward seeking
  - After the index has been created
  - While the index has only been partially created
- Usable as a (Python-)library



Introducing rapidgzip

- rapidgzip: **R**andom **a**ccess **p**arallel (**i**ndexed) **d**ecompression for **gzip** files
- Parallel decompression of gzip files
- Decompression is faster and less memory intensive with an existing index
- The index enables seeking without having to start decompression from the file beginning
- Header-only C++ library with Python bindings:
  `> pip install rapidgzip`
- Also a has a command line interface that can be used as a drop-in replacement for decompression:
  `gzip -d → rapidgzip -d`
- Not for compression
- https://github.com/mxmlnkn/rapidgzip



Decompression benchmarks on a 12 GB FASTQ file using 64 cores of an AMD EPYC 7702 @ 2.0 GHz processor.

Tools Overview

- 1992: `gzip` by Jean-loup Gailly and Mark Adler 

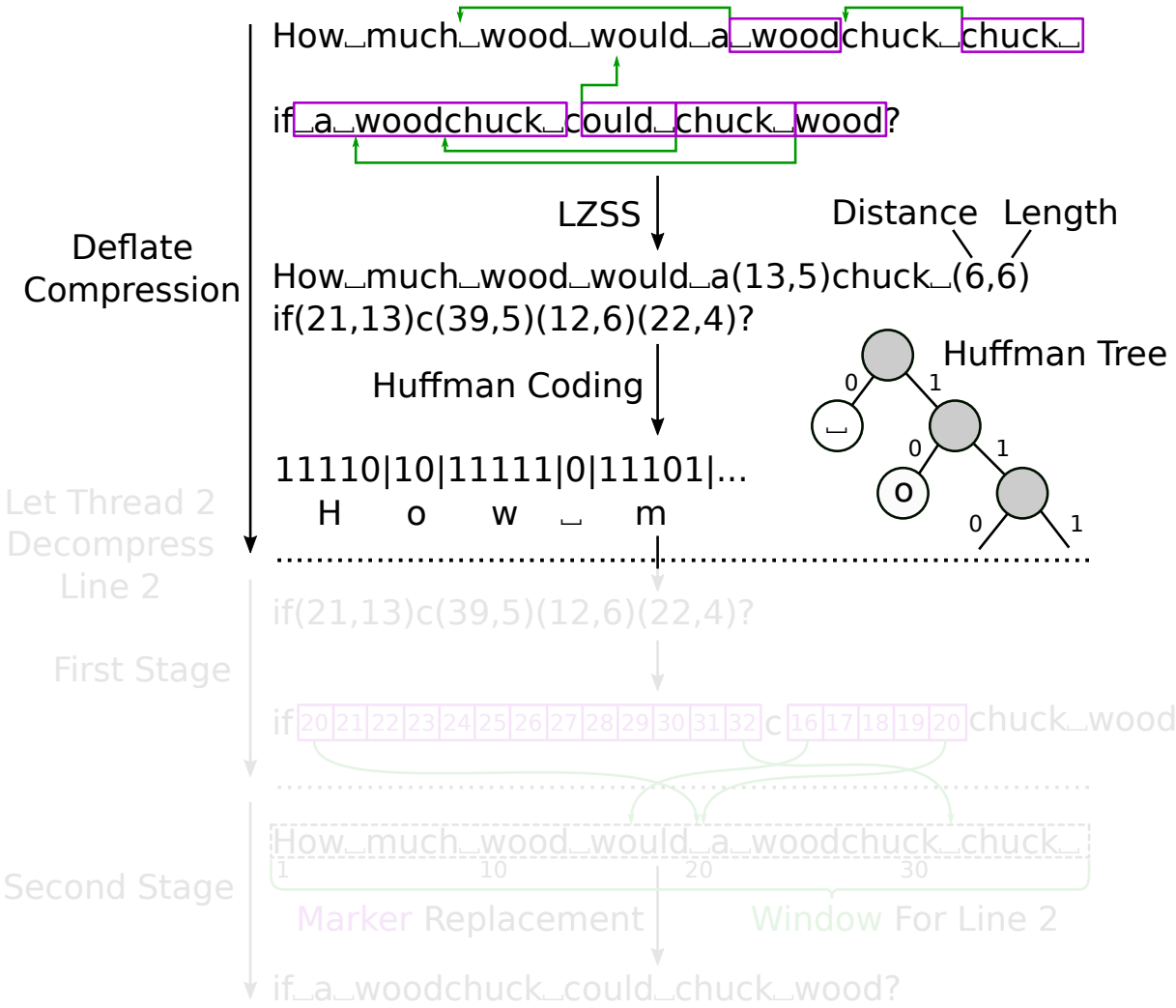
- 2005: zlib/examples/zran.c example by Mark Adler 

  - Shows how to resume decompression in the middle of a gzip stream
- 2007: `pigz` (**p**arallel **i**mplementation of **gz**ip) by Mark Adler 

  - Compresses in parallel
- 2008: Blocked GNU Zip Format (BGZF) and the command line tool `bgzip`, part of HTSlib
  - Compresses in parallel to gzip files with additional metadata
  - Can decompress files containing such metadata in parallel
  - James K. Bonfield and others, "HTSlib: C library for reading/writing high-throughput sequencing data", *GigaScience*, Volume 10, Issue 2, February 2021
- 2016: indexed_gzip: Python module for random access based on zran.c
- 2019: `pugz`
  - Can decompress gzip-compressed files in parallel if it only contains characters 9–126
  - Kerbiriou, Maël, and Rayan Chikhi. "Parallel decompression of gzip-compressed files and random access to DNA sequences." 2019 IEEE International Parallel and Distributed Processing Symposium Workshops (IPDPSW). IEEE, 2019.

→ What makes parallel decompression so difficult?

Deflate Compression



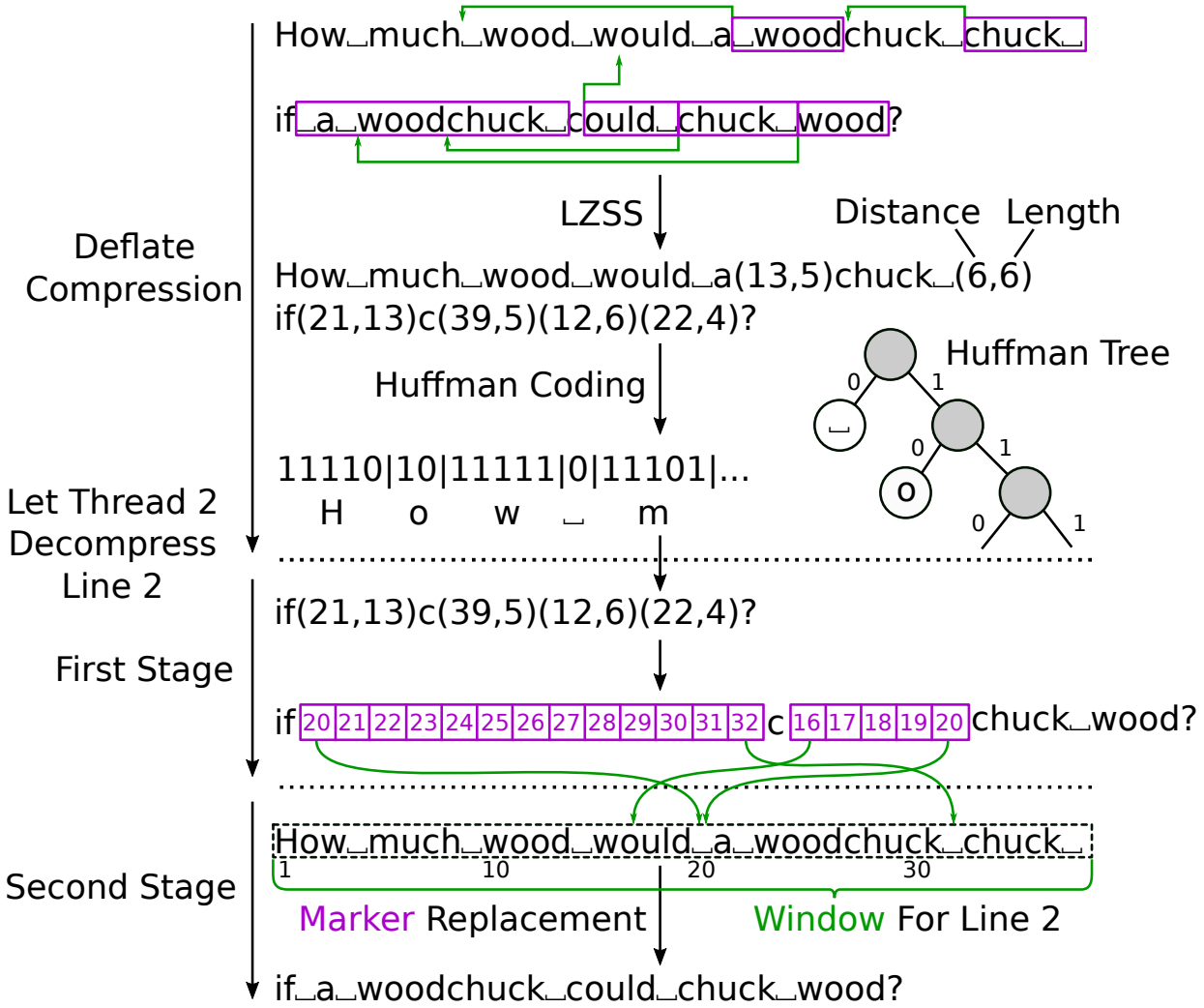
Challenges for Parallel Decompression:

- Find deflate block start offsets in bit stream
- Handling references to unknown data

→ Two-Staged Decompression as introduced by Kerbiriou and Chikhi (2019)

- Non-resolvable references result in markers that get resolved in the second stage after the 32 KiB window has become known

Parallelized Deflate Decompression



Challenges for Parallel Decompression:

- Find offsets in bit stream to start decompression from
- **Handling references to unknown data**

→ Two-Staged Decompression as introduced by Kerbiriou and Chikhi (2019)

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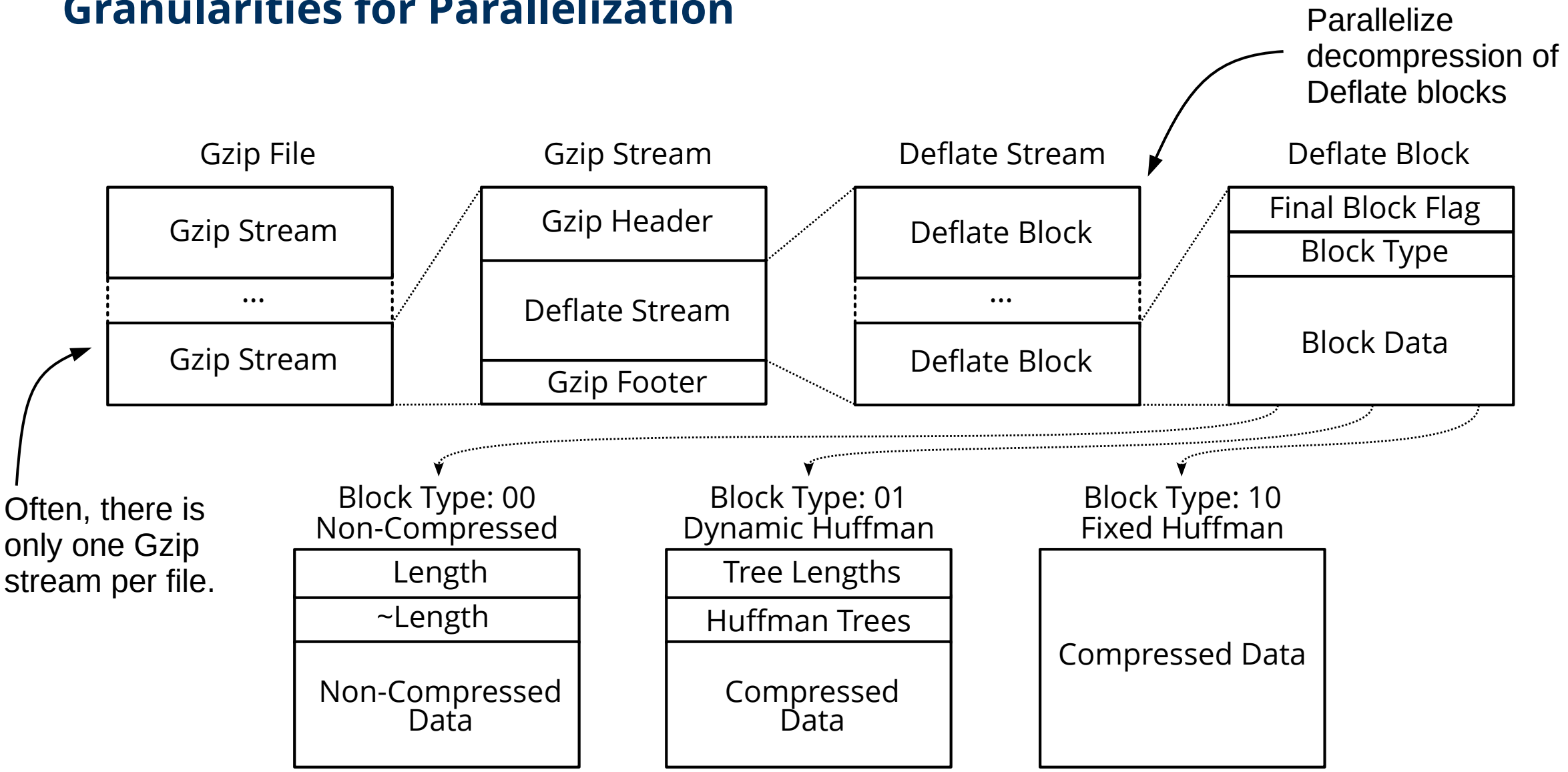
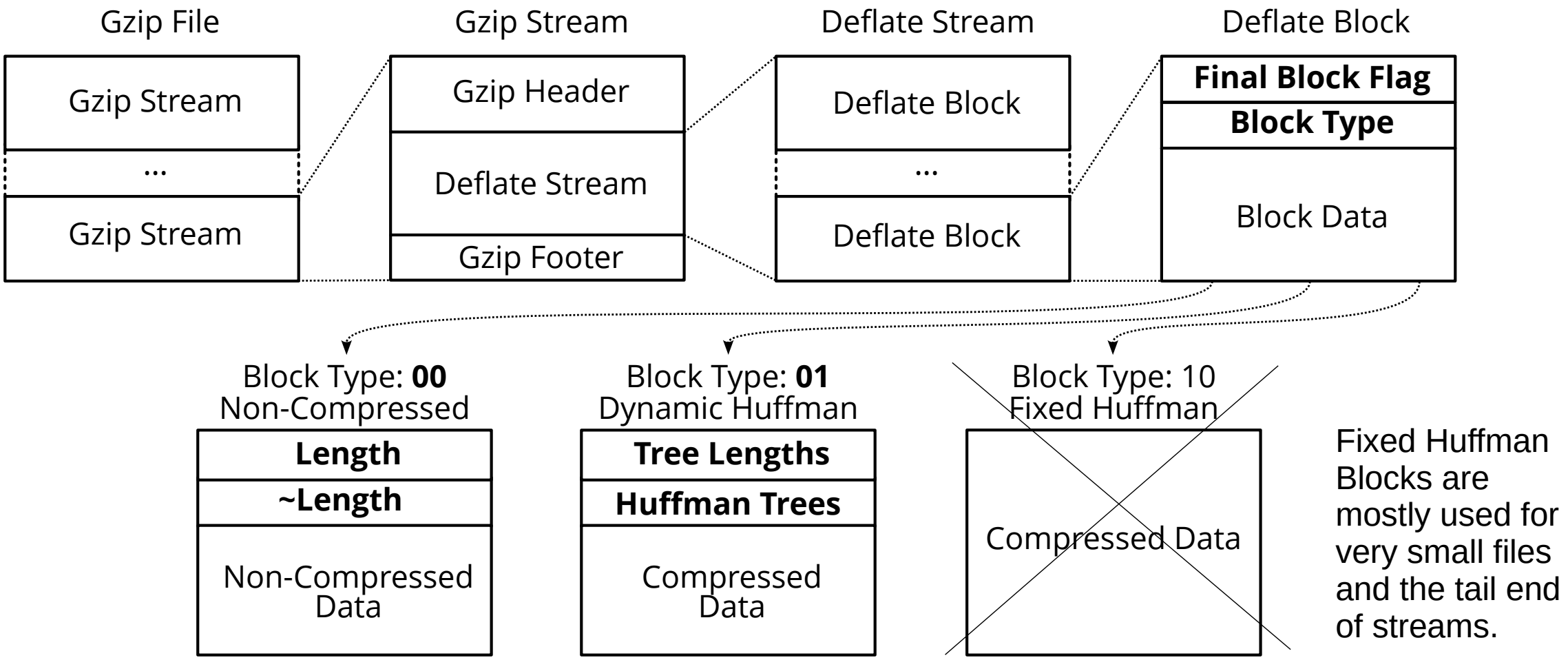
Granularities for Parallelization



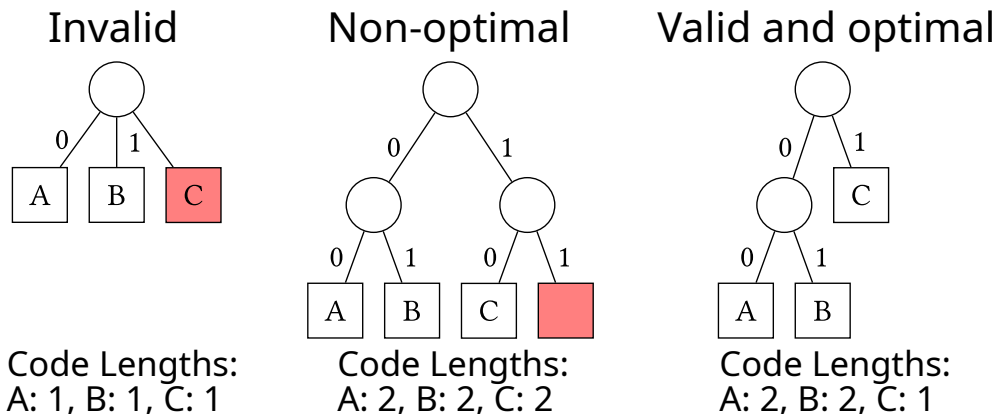
Redundancies that Help in Finding Deflate Blocks



Fixed Huffman Blocks are mostly used for very small files and the tail end of streams.

How Often Will Valid-Looking Block Headers be Found in Random Data?

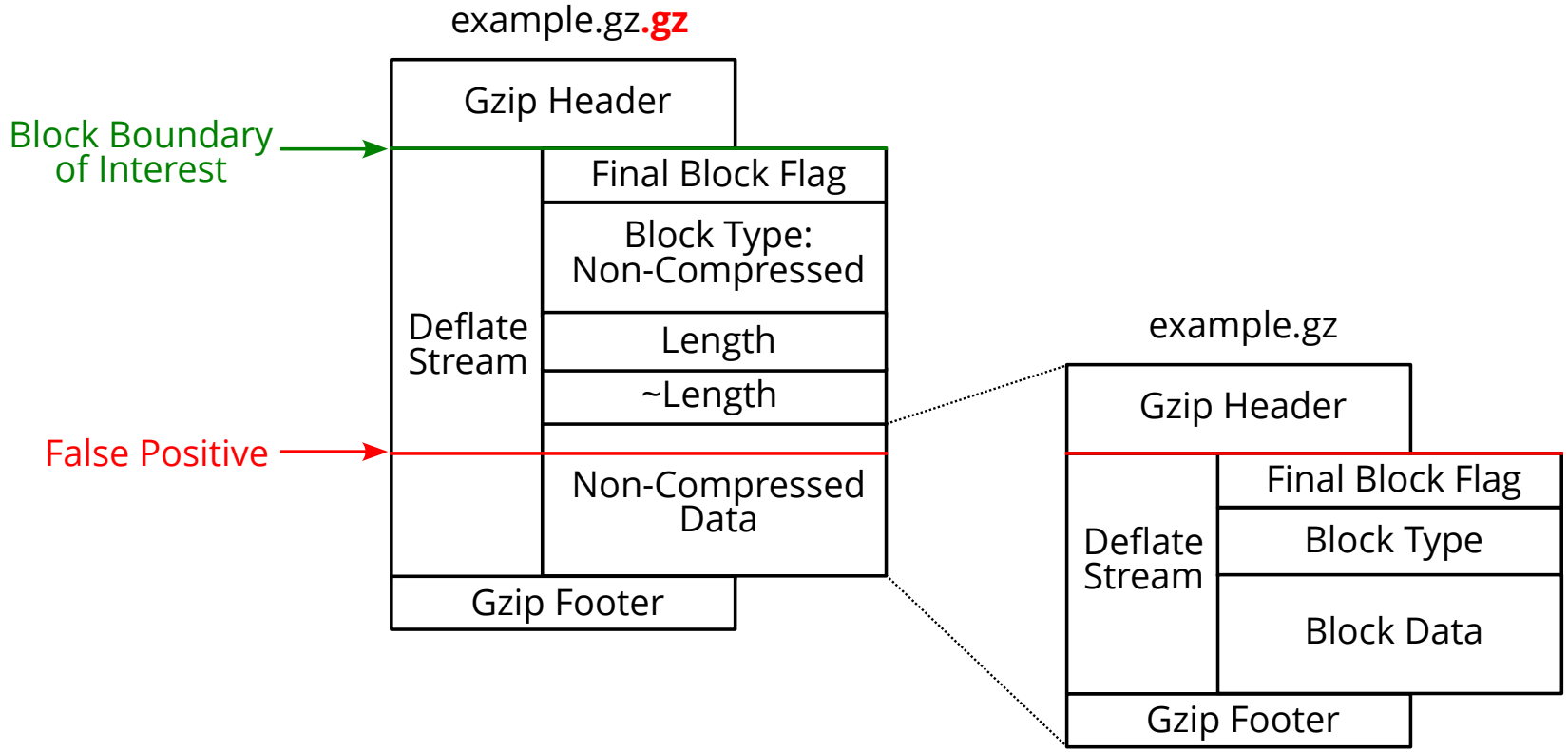
- **Deflate Blocks with Fixed Huffman codings:** Ignore because they are rare
- **Non-Compressed Deflate blocks:** Look for 16-bit lengths and their one's complement
  → *1 false positive per 525 kB*
- **Deflate Blocks with Dynamic Huffman codings:**
  Look for valid Deflate block headers and valid and optimal Huffman codings.
  ~200 offsets pass this test given 1 Tbits of random data → *1 false positive per 625 MB*



- **Pugz** reduces false positives further by checking that the decompressed data only contains characters in the range 9-126, an assumption made for FASTQ files

False Positives Can Be Crafted Using Non-Compressed Blocks

Example: Consider a gzip file that is compressed a second time.

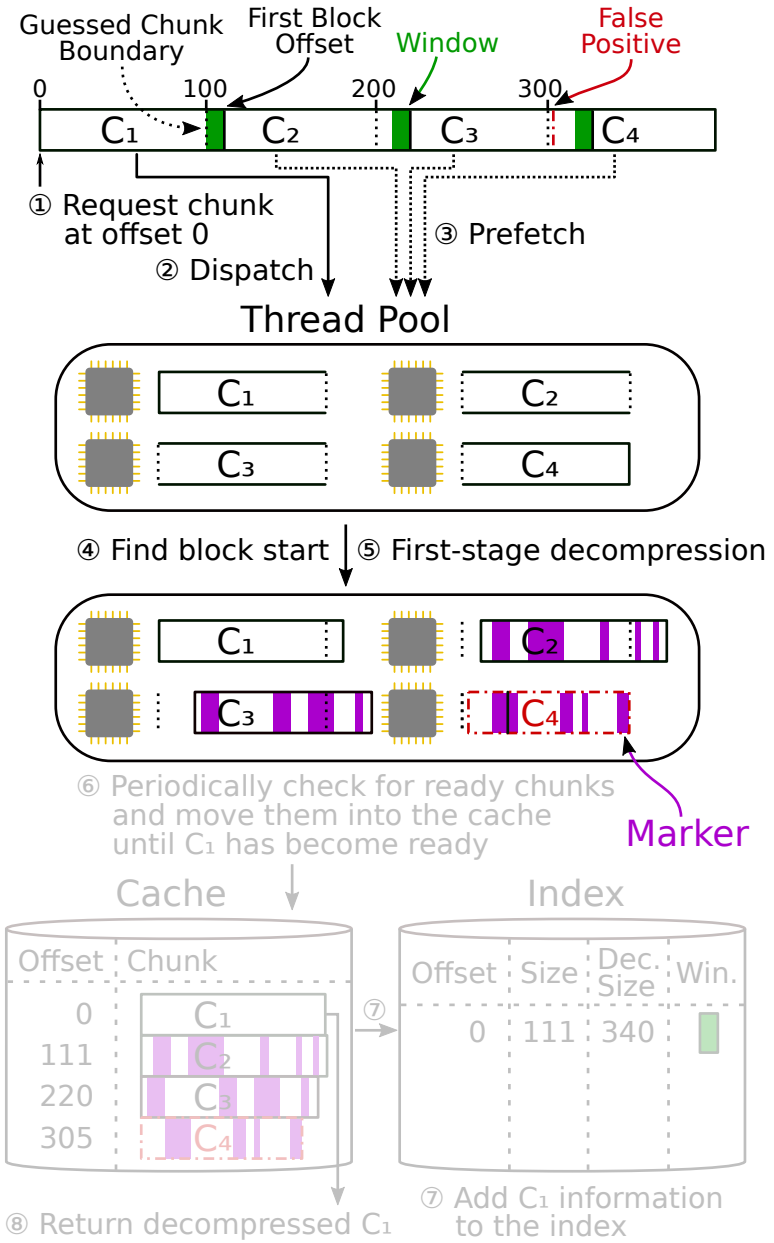


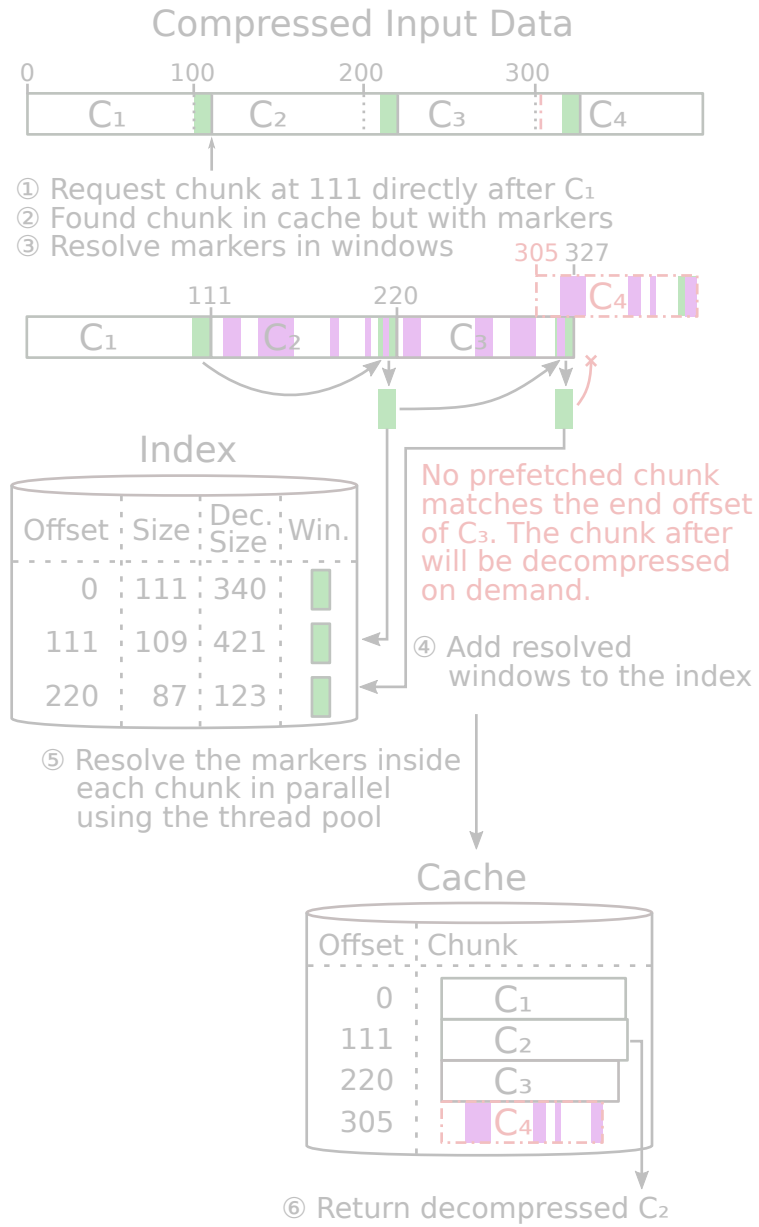
Sequences inside the compressed Block Data might be recognized as Deflate block headers

→ These cases need to be detected and handled

Implementation

- Prefetching to generate work that can be processed in parallel
- Thread pool for work balancing
- Cache to speed up seeking and concurrent decompression
- Use block offset as cache key to catch false positives
- On-demand cache fill to recover from errors





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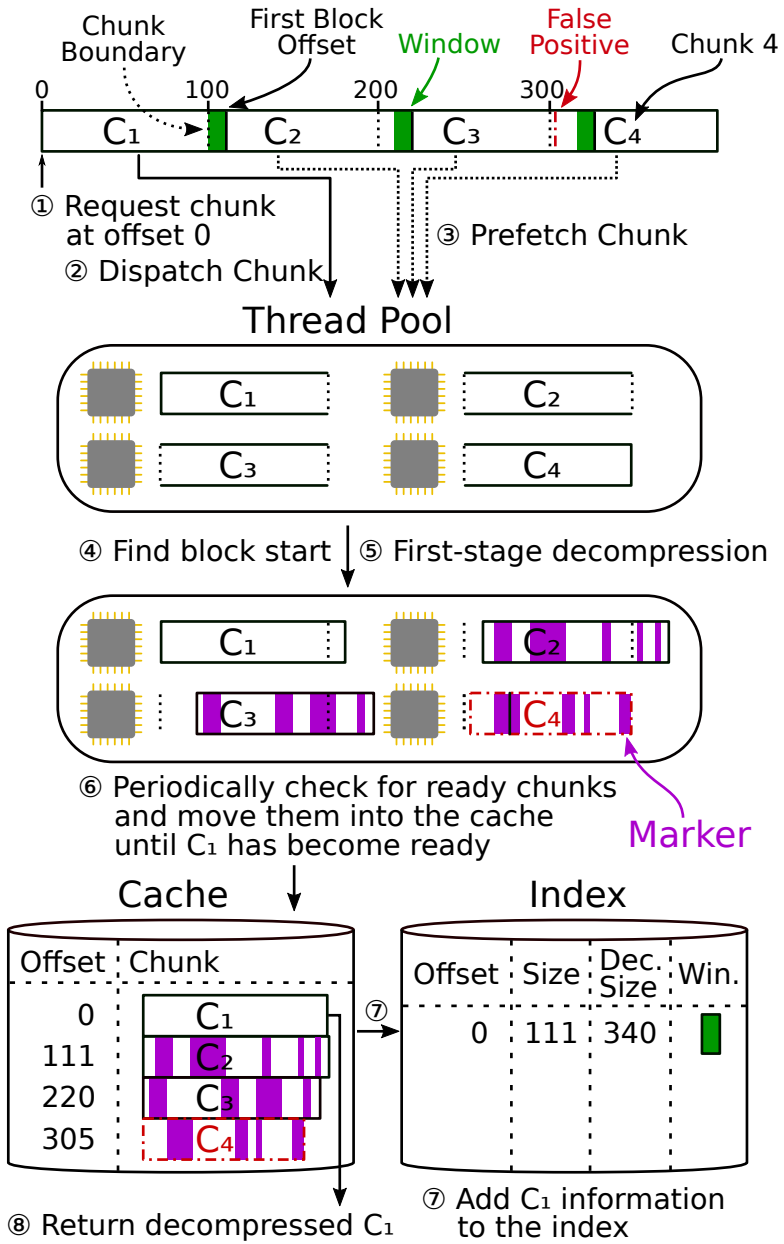

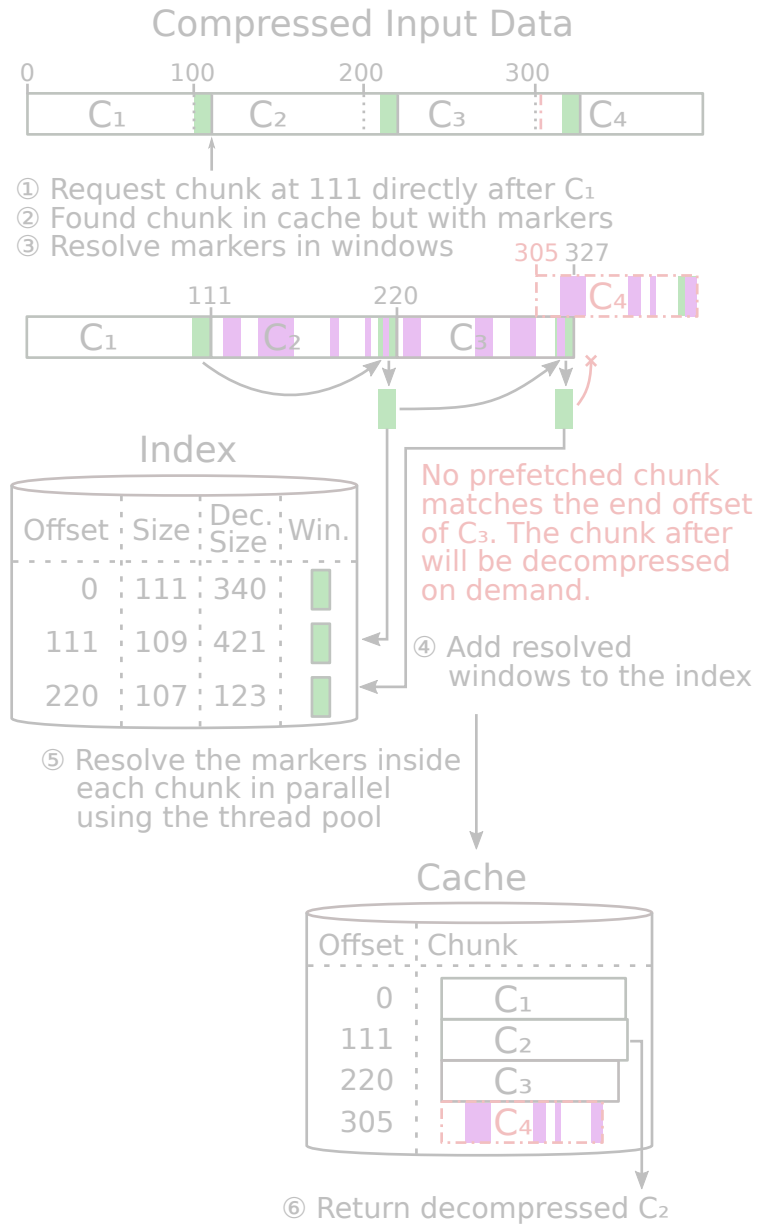

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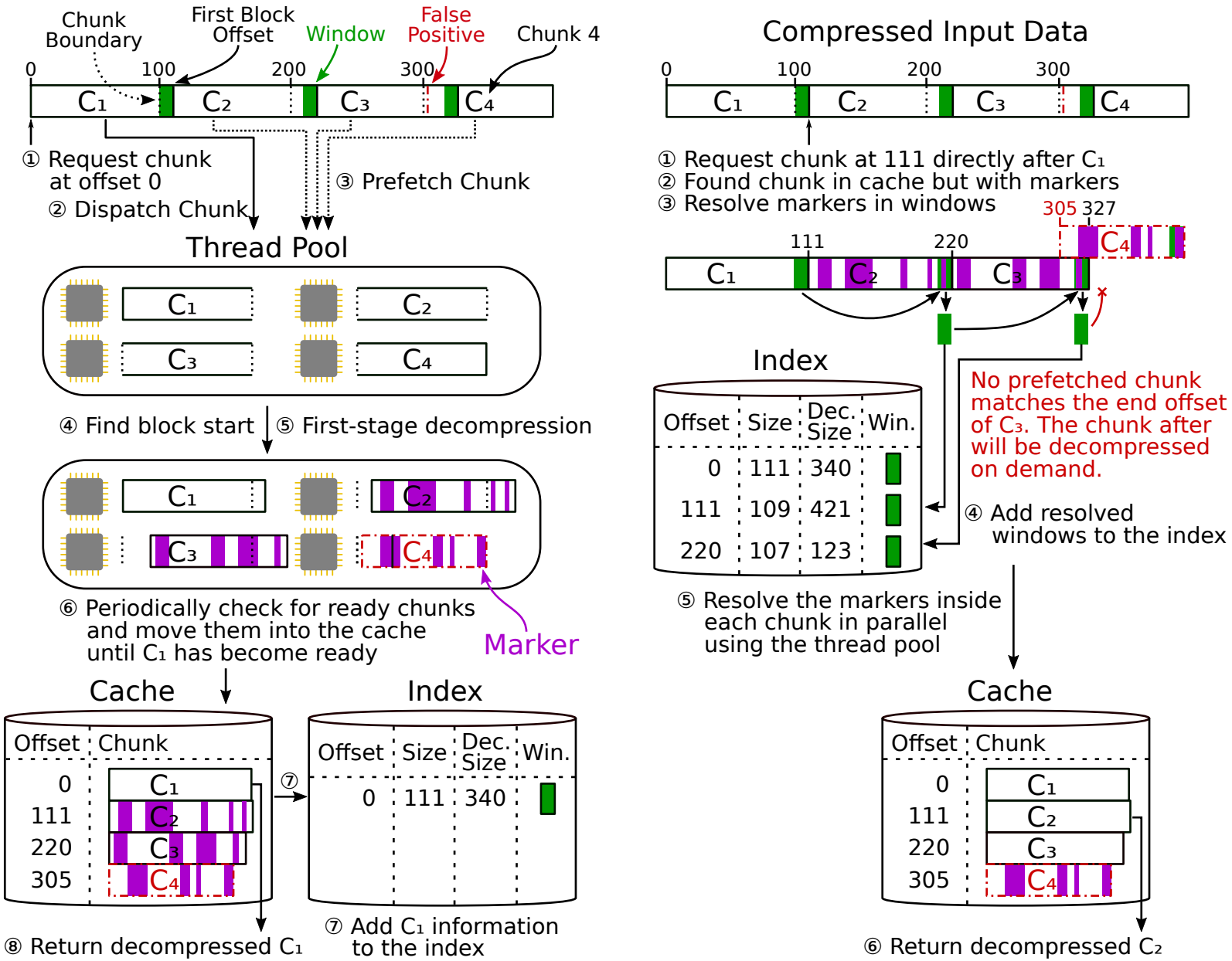


Optimal Chunk Size

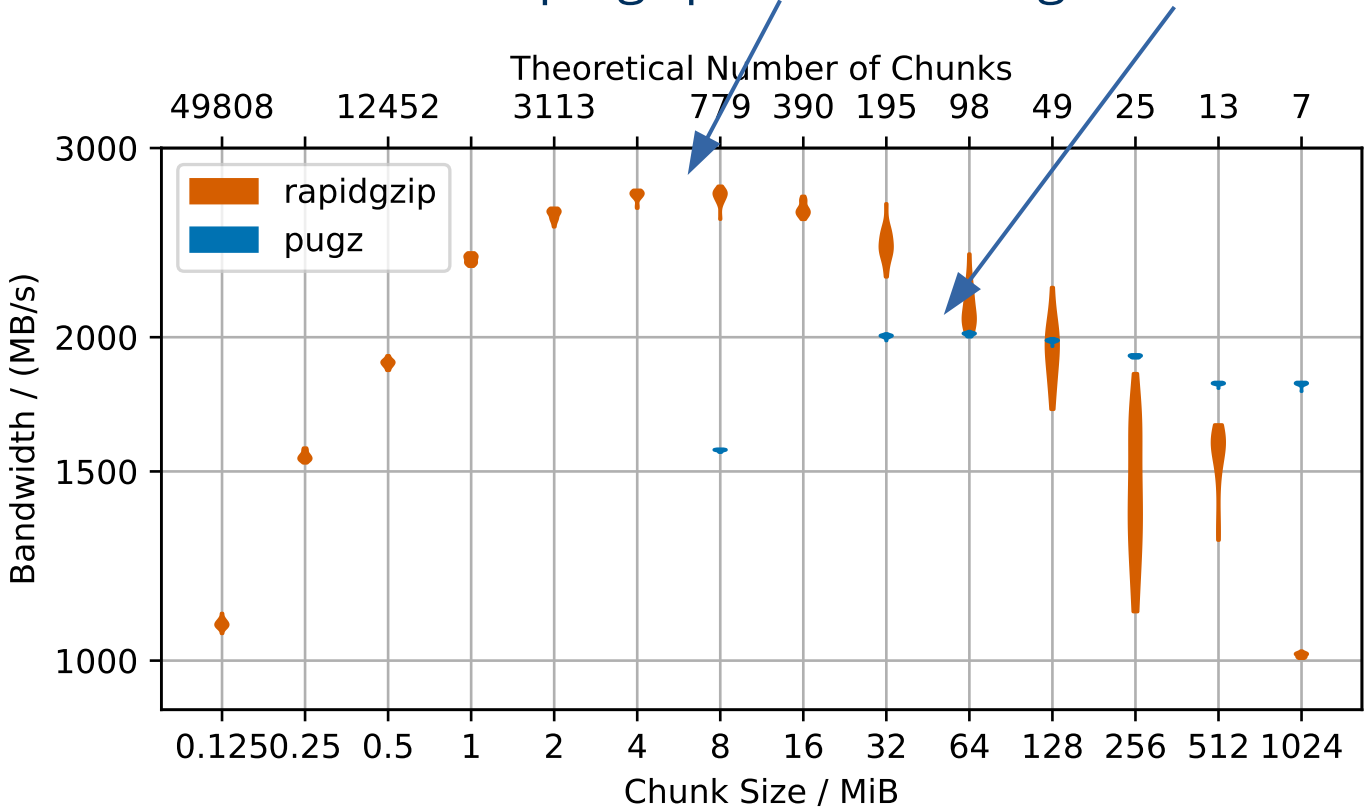
- For smaller chunk sizes, the block finder overhead leads to worse performance
- Larger chunk sizes lead to work balancing issues and also might adversely affect the cache behavior and allocation speed

Benchmark	Bandwidth / (MB/s)
DBF zlib	0.1234 ± 0.0003
DBF custom deflate	3.403 ± 0.007
Pugz block finder	11.3 ± 0.7
DBF skip-LUT	18.26 ± 0.03
DBF rapidgzip	43.1 ± 1.1
NBF	301.8 ± 0.5
Marker replacement	1254 ± 6

3.8×

DBF … Dynamic Block Finder
NBF … Non-Compressed Block Finder

Optimal chunk sizes: Rapidgzip: 4-8 MiB, Pugz: 32-64 MiB

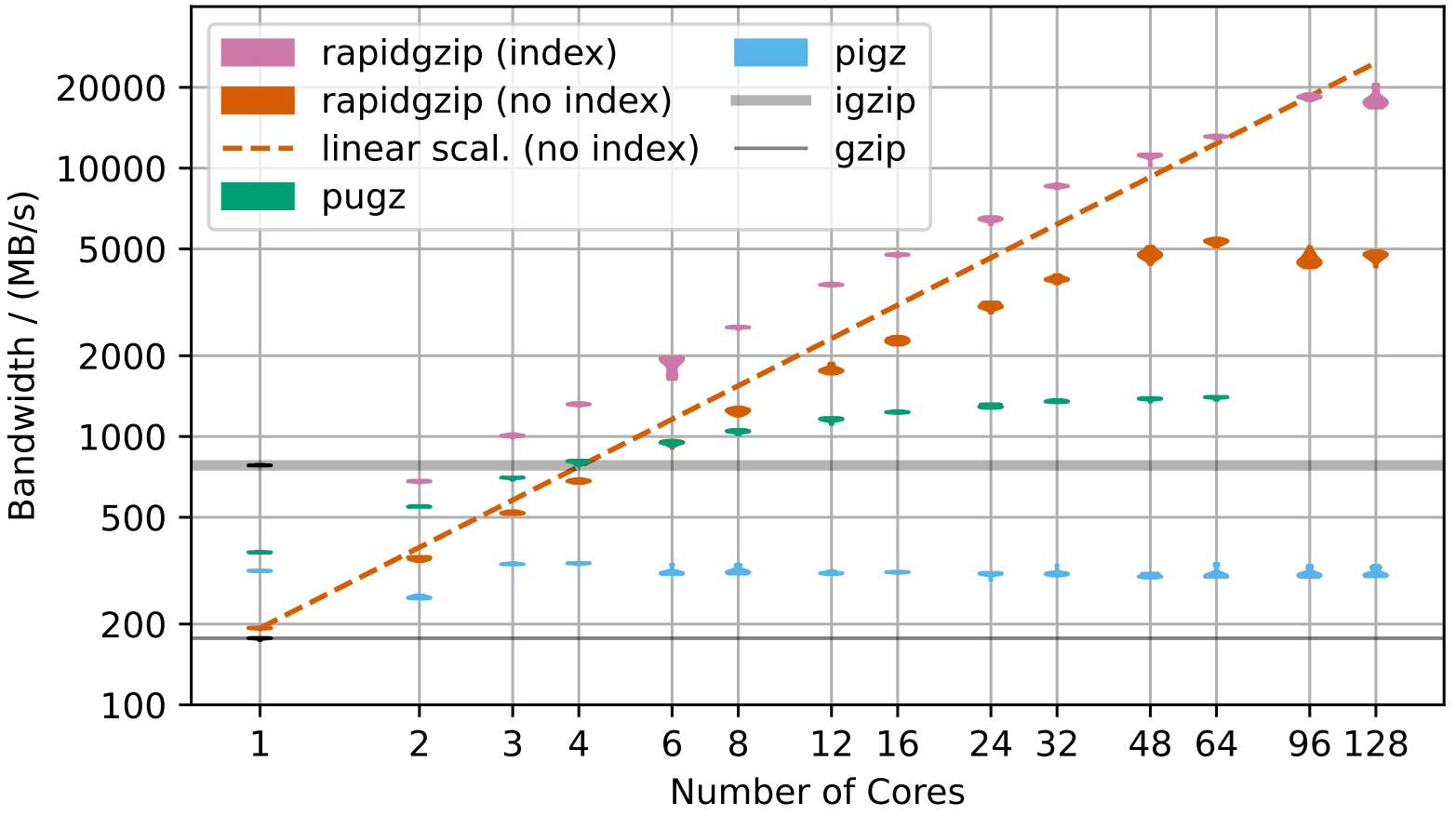


Decompression bandwidth using 16 cores and a 6.08 GiB test file, which decompresses to 8 GiB.

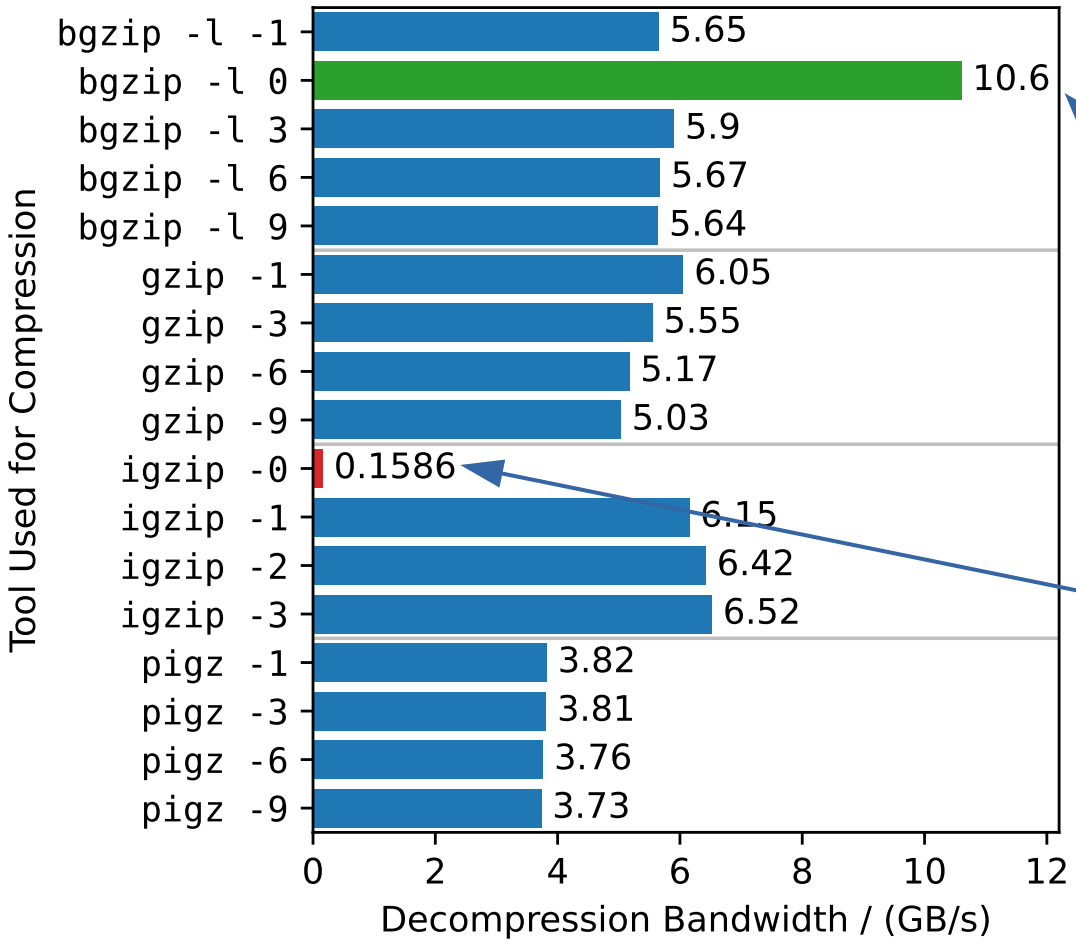
Decompression Benchmark: FASTQ File

Weak-scaling and writing the results to /dev/null

- `gzip` is the slowest, half as slow as zlib-based `pigz`
- `rapidgzip` with an index scales up to 20 GB/s, without an index up to 5 GB/s
- `pugz` tops out at 1.4 GB/s and crashes for 96+ cores
- `igzip` by Intel shows leading single-core performance
- `pigz` does not parallelize



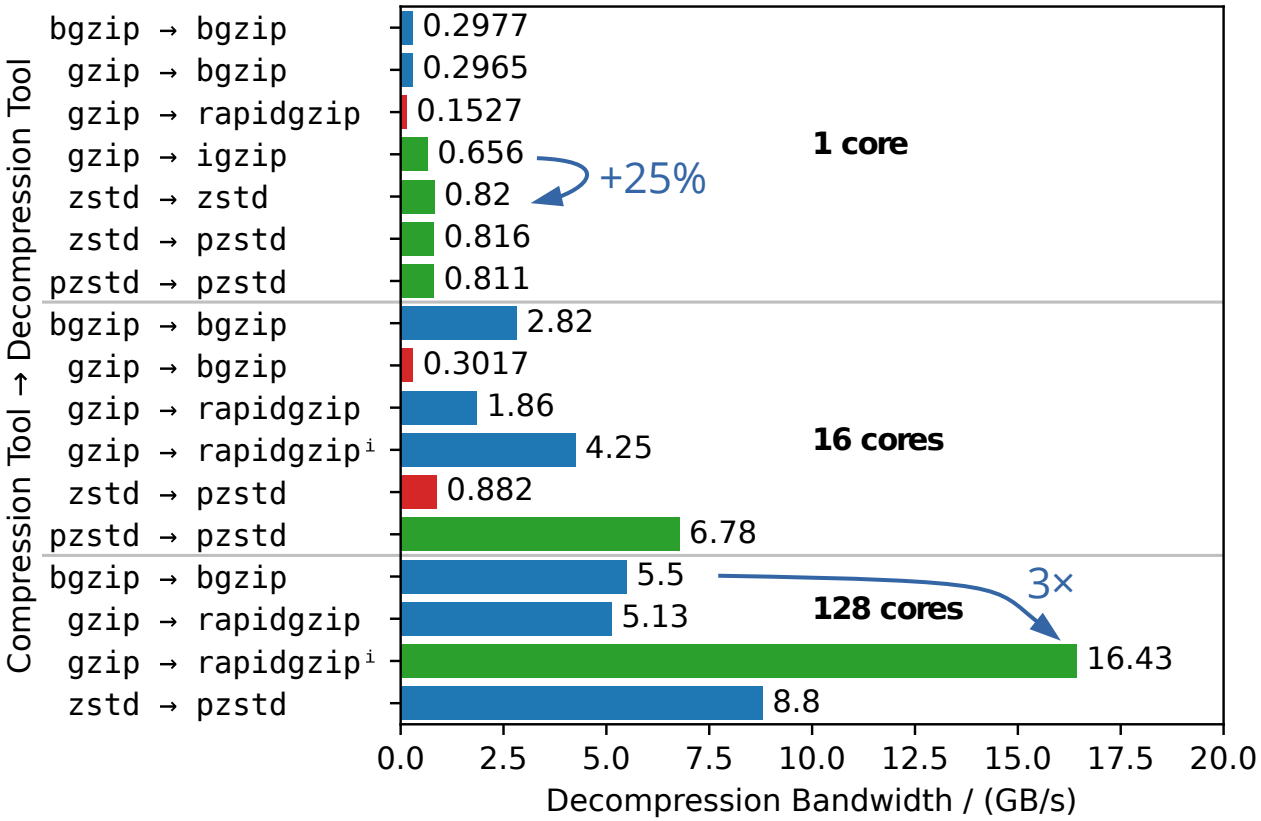
Benchmark: Various Gzip Compressors → Rapidgzip Decompression



- `rapidgzip` can parallelize decompression for gzip files produced with a wide variety of tools and compression levels
- Contains only Non-Compressed Deflate blocks so that decompression is reduced to a fast copy and some accounting
- Contains only a single Deflate block with Fixed Huffman coding and therefore cannot be parallelized

Benchmark: Competing File Formats

- `igzip` is surprisingly competitive to `zstd`
- `zstd` is the fastest in single-core decompression
- `bgzip` and `pzstd` can only decompress gzip/zstd files produced by themselves in parallel
- `zstd`-compressed (TAR) files are not eligible for random access and parallel decompression. `pzstd` is recommended instead to create multi-frame Zstandard files.
- Applying the `rapidgzip` approach to arbitrary Zstandard files might be infeasible because their window size is not limited to 32 KiB.



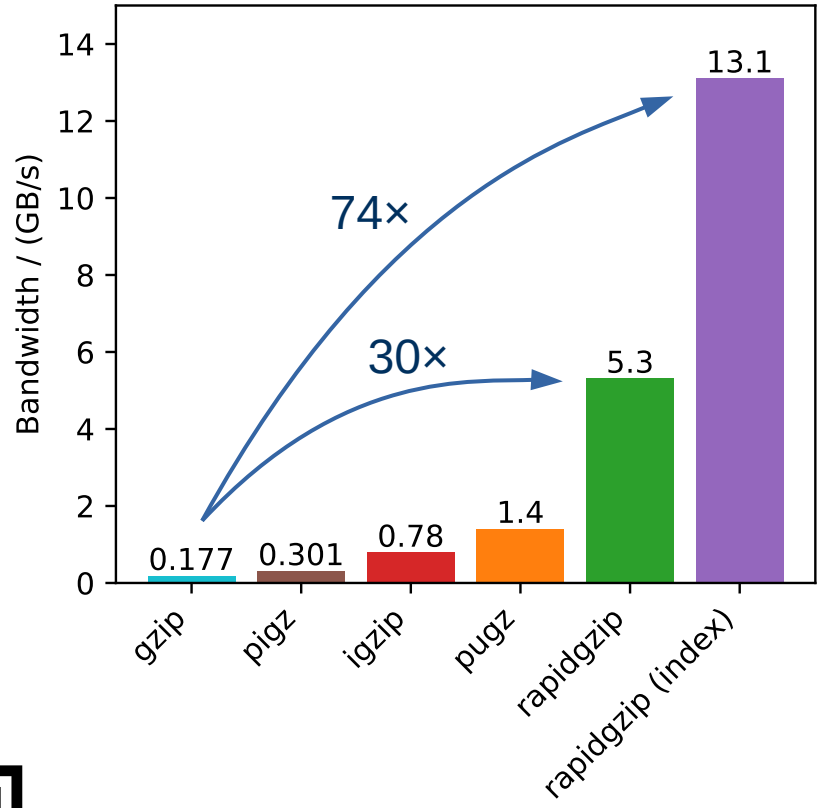
[i] rapidgzip decompression with an existing index

Improvements Since Submission

- High memory usage has been alleviated by limiting the decompressed chunk size
  Worst case (compression ratio ~1000)
  was: ~ 9 GB per thread
  now: **~ 200 MB per thread (configurable)**
- The Inflate implementation has been improved for high compression ratios
  → **25 % faster** for Silesia by using memcpy/memset for long references
- CRC32 computation has been added
  → The slice-by-16 algorithm has been implemented and parallelized using crc32_combine.
  Achieves **~ 4 GB/s per core** (**~ 6 % overhead** independent of parallelism)

Summary

- We have shown that the specialized approach for parallelized gzip decompression introduced by Kerbiriou and Chikhi (2019) can be generalized without affecting performance and stability.
- Our architecture achieves better performance, scales to more cores, adds robustness against false positives, and also increases versatility by adding fast seeking capabilities.
- An index is created internally on first time decompression and it can be exported and imported to speed up subsequent decompression and seeking.
- Can be used with ratarmount to mount .tar.gz archives.
- Available at https://github.com/mxmlnkn/rapidgzip



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