x-search: A C++ library for fast external string search

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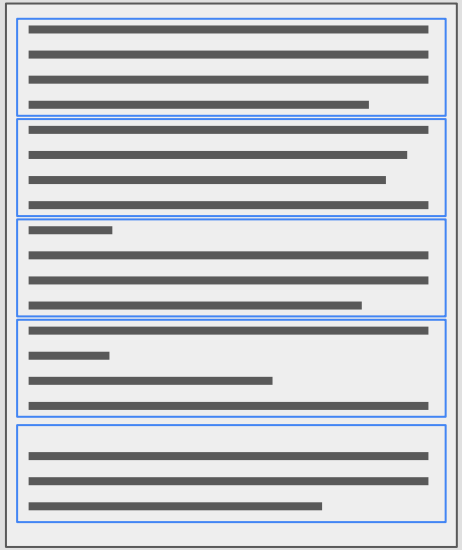
Why External String Search?

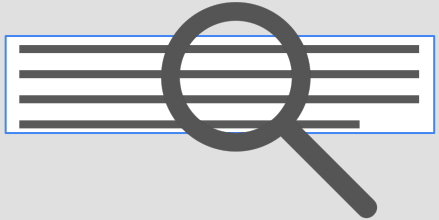
Information Retrieval

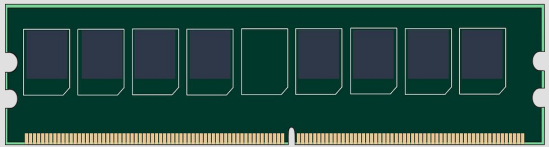
Natural Language Processing

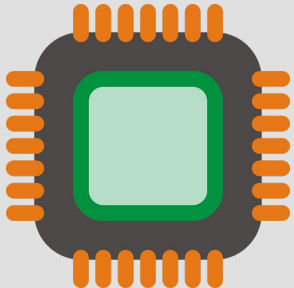
Bioinformatics

Problem









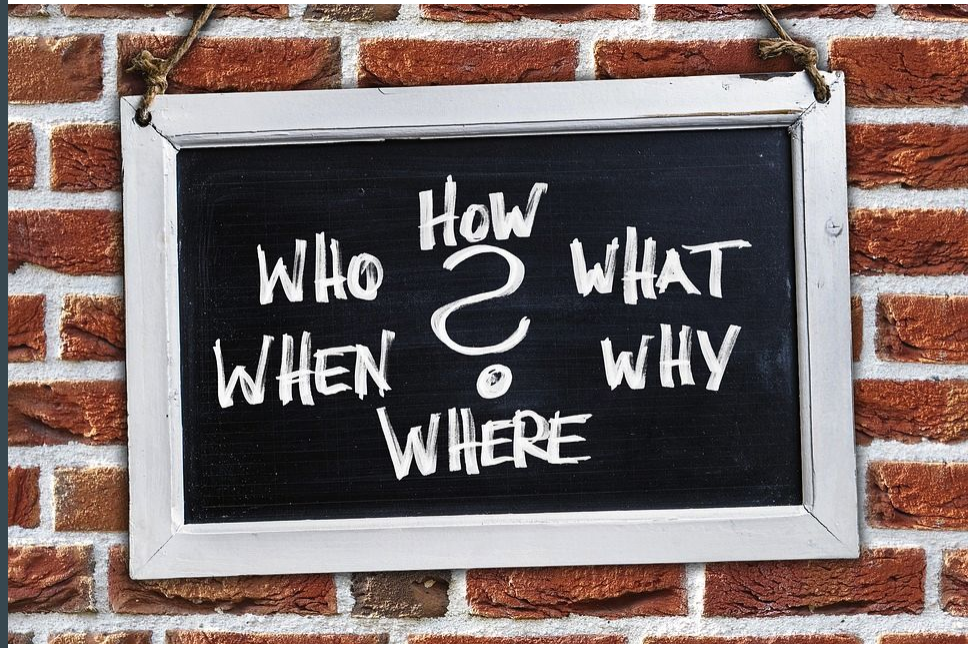
GNU grep Comes Short in Different Terms

- No library
- No multi-thread support for searching a single file
- No direct preprocessing supported
- License issues

Aims for this Thesis

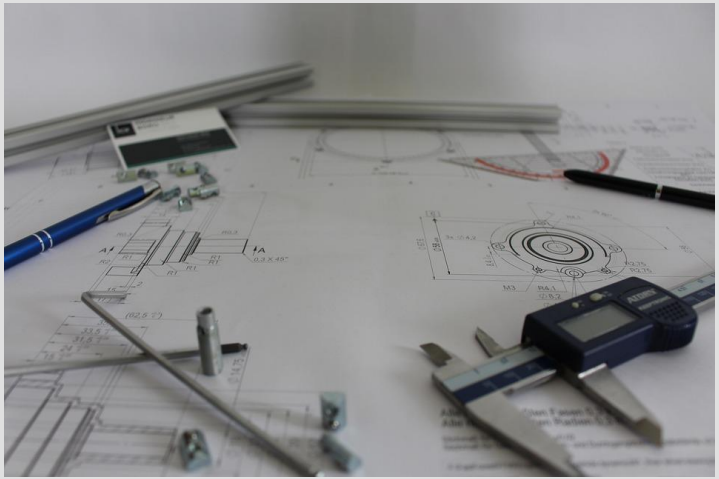
- Implement a C++ library
- Support multi-threading
- Support preprocessing (compression)
- Be faster than GNU grep

Questions?



Solution

Simple Usage



High Level Viewport

x-search: Basic Usage

```
0  // basic_grep.cpp
1  #include “xsearch/xsearch.h”
2  #include <iostream>
3
4  int main(int argc, char** argv) {
5    auto searcher = xs::extern_search<xs::lines>(argv[1], argv[2], false, 1);
6    for (auto const& line : *searcher->getResult()) {
7      std::cout << line << '\n';
8    }
9  }
```

```
$ basic_grep pattern /path/to/file
```

A Pipeline as Base-Construct

- Reading from file

- Compression
- Decompression

- Substring search

Result
`xs::Result`

Managing partial results provided by the ReturnProcessor

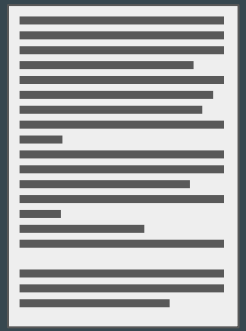
Preprocessing

Reading Data in Chunks
`xs::DataProvider`

Compression
`xs::InplaceProcessor`

Write (Meta) Data
`xs::ReturnProcessor`
`xs::Result`

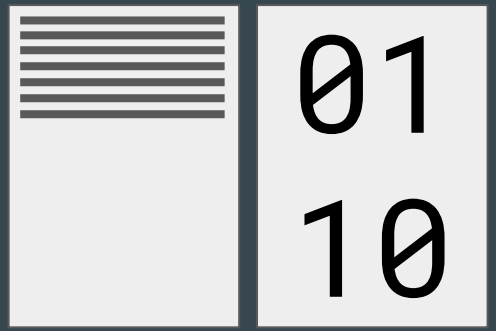
Each chunk ends with a new line character



Compress chunks using

- LZ4
- LZ4 HC
- ZSTD

- Write metadata to a metafile
- Write compressed data to a file



Searching a Preprocessed File

Read Data in Chunks
`xs::DataProvider`

Decompression
`xs::InplaceProcessor`

Search
`xs::ReturnProcessor`

Collect Search Results
`xs::Result`

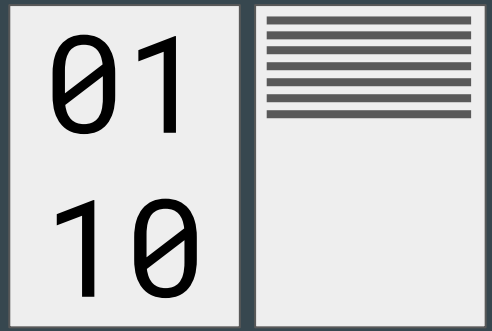
Read Metadata and chunks from input file

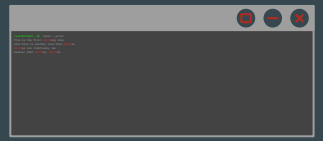
Decompress read chunks

Search according to the specified settings

- Literal
- Regex
- Ignore case

Provide results according to the specified result type





```
std::vector<T>
```

Input — Processing — Output

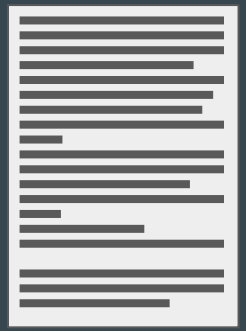
Searching a plain Text File

Read Data in Chunks
`xs::DataProvider`

Search
`xs::ReturnProcessor`

Collect Search Results
`xs::Result`

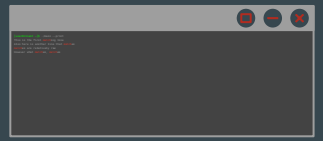
Each chunk ends with a new line character



Search according to the specified settings

- Literal
- Regex
- Ignore case

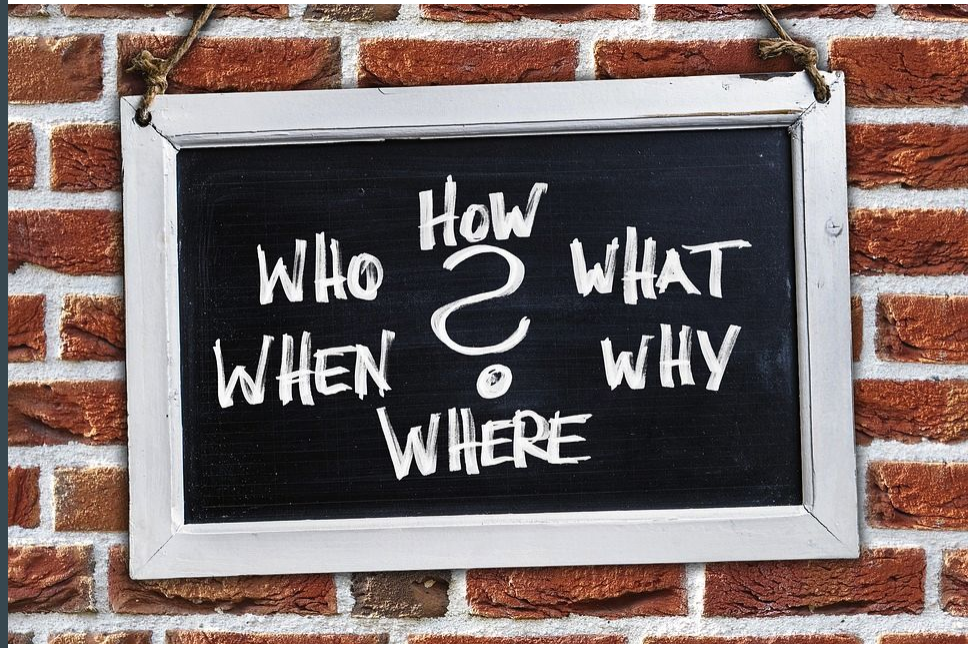
Provide results according to the specified result type



```
std::vector<T>
```

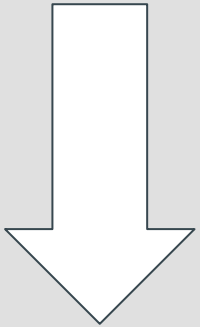
Input — Processing — Output

Questions?



Evaluation

x-search



xs grep

Dataset

- OpenSubtitles2016
  - 9.3 GiB
  - 337’845’355 lines

Pattern

- Literal: “`Sherlock`”
  - 13’645

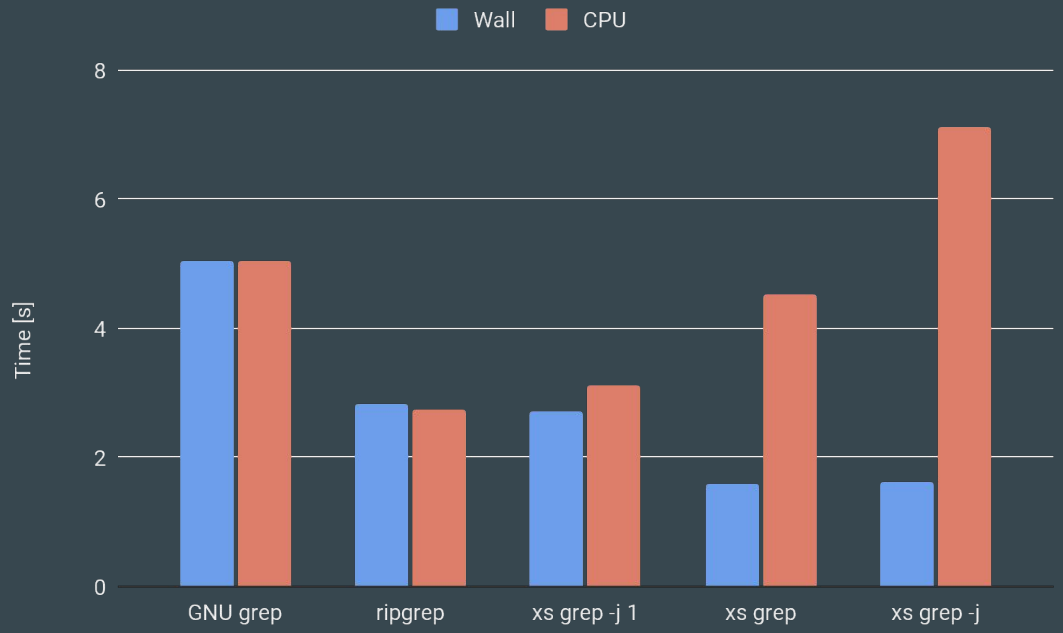
Benchmark Metrics

- Wall Time
- CPU Time

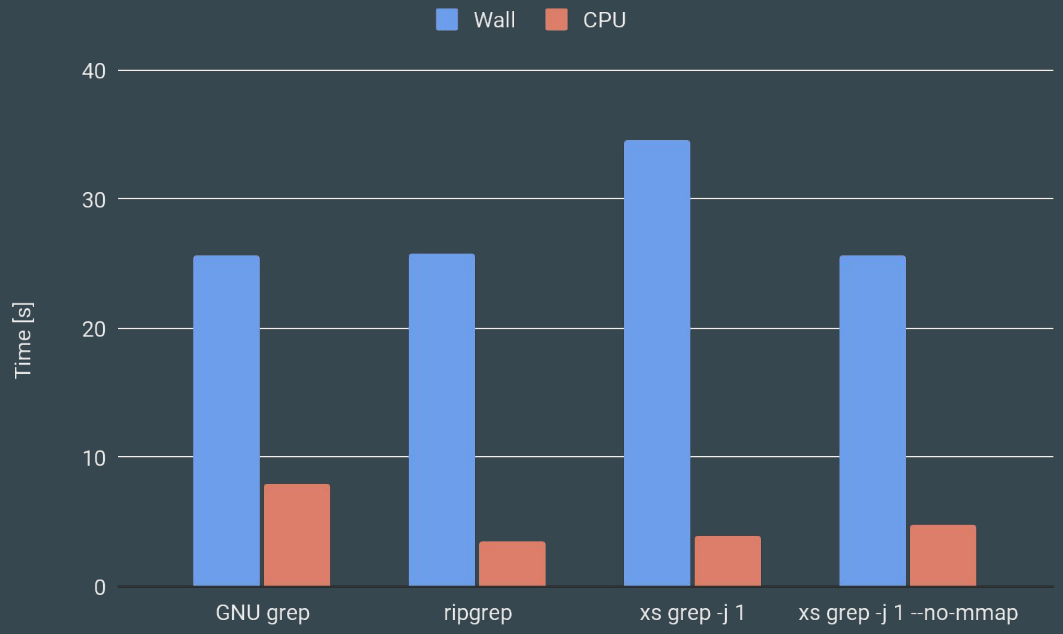
Hardware

- RAID0 NVMe SSD
- HDD

Reading from SSD

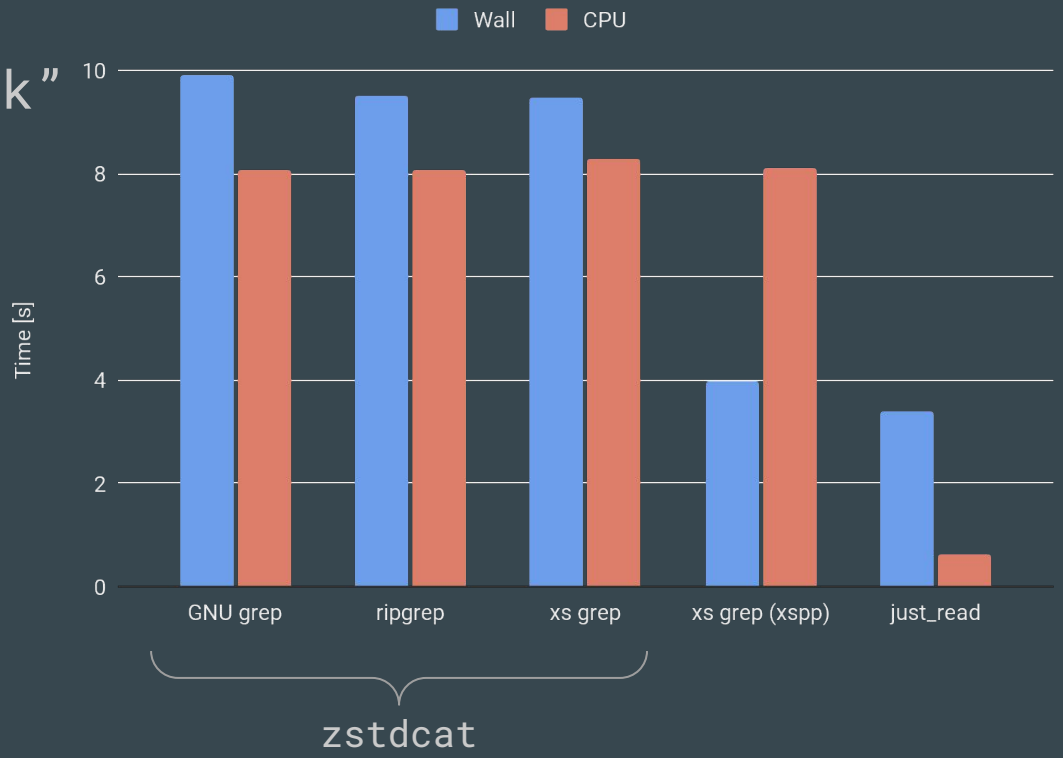


Reading from HDD

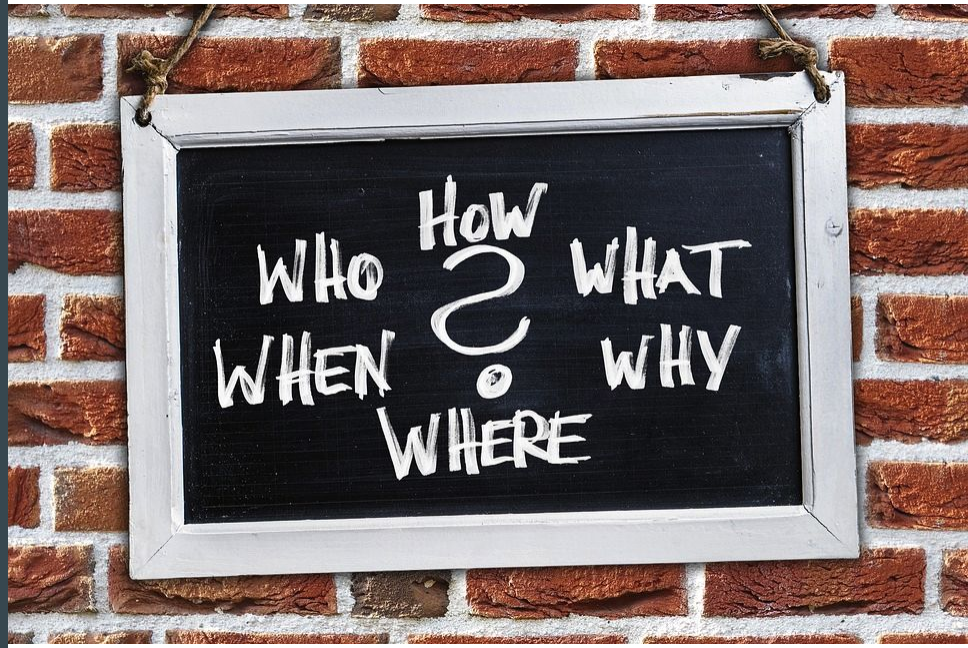


Reading from HDD: Compressed Input

Pattern	“Sherlock”
data.txt	9.3G
data.zst	1.5G
data.xs.zst	1.5G
data.xs.meta	9.6M



Questions?



What else can x-search do?

```
auto searcher = xs::extern_search<T>(...);
```

1. Supporting different search results (T)
    - xs::lines
    - xs::count
    - xs::count_lines
    - xs::match_byte_offsets
    - xs::line_byte_offsets
    - xs::line_indices

What else can x-search do?

```
auto searcher = xs::extern_search<T>(...);
```

1. Supporting different search results (T)
2. Controlling the searcher
   - `searcher.join()`: Wait for the search to finish
   - `searcher.stop()`: Force stop the searcher
   - `searcher.getResult()->begin()`: Access results live

What else can x-search do?

```
auto searcher = xs::extern_search<T>(...);
```

1. Supporting different search results (T)
2. Controlling the searcher
3. Accessing search results

What else can x-search do?

```
auto searcher = xs::extern_search<T>(...);
```

1. Supporting different search results (T)
2. Controlling the searcher
3. Accessing Search Results
4. Providing an extended API
    - Implement custom DataProvider-, InplaceProcessor- and ReturnProcessor-Tasks
    - Implement custom Result-Types

xs grep: A GNU grep-like command line search tool

- Single pattern and single file input
- Command-Line-Options:
  - `-F [--fixed-string]`
  - `-i [--ignore-case]`
  - `-o [--only-matching]`
  - `-n [--line-number]`
  - `-b [--byte-offset]`
  - `-c [--count]`

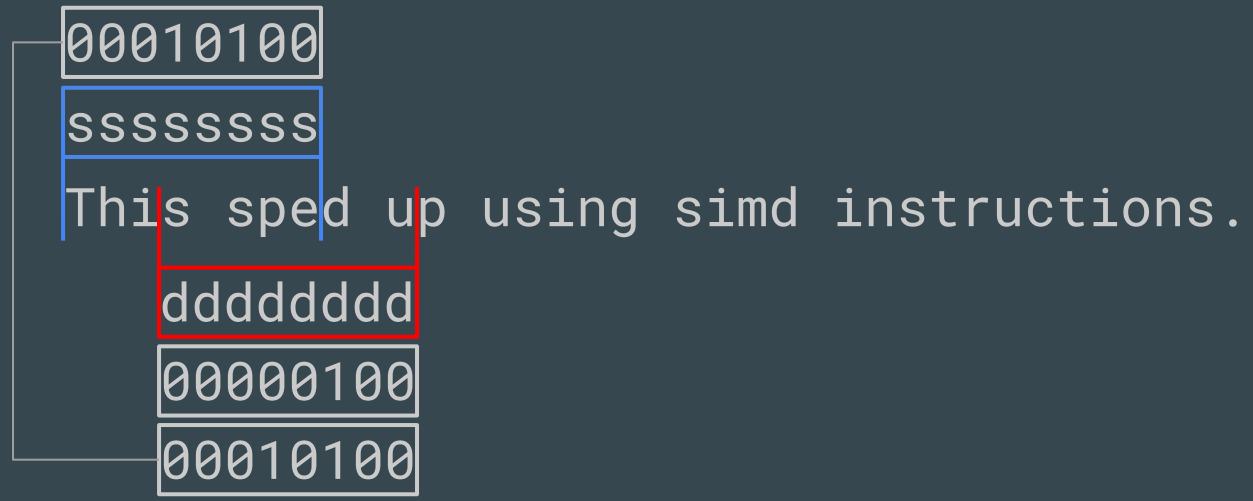
  } GNU grep equivalents

  - `-j [--threads]`
  - `--max-readers`
  - `-m [--metafile]`
  - `--no-mmap`

  } Additional arguments

SIMD Substring Search Algorithm

Pattern: “simd”

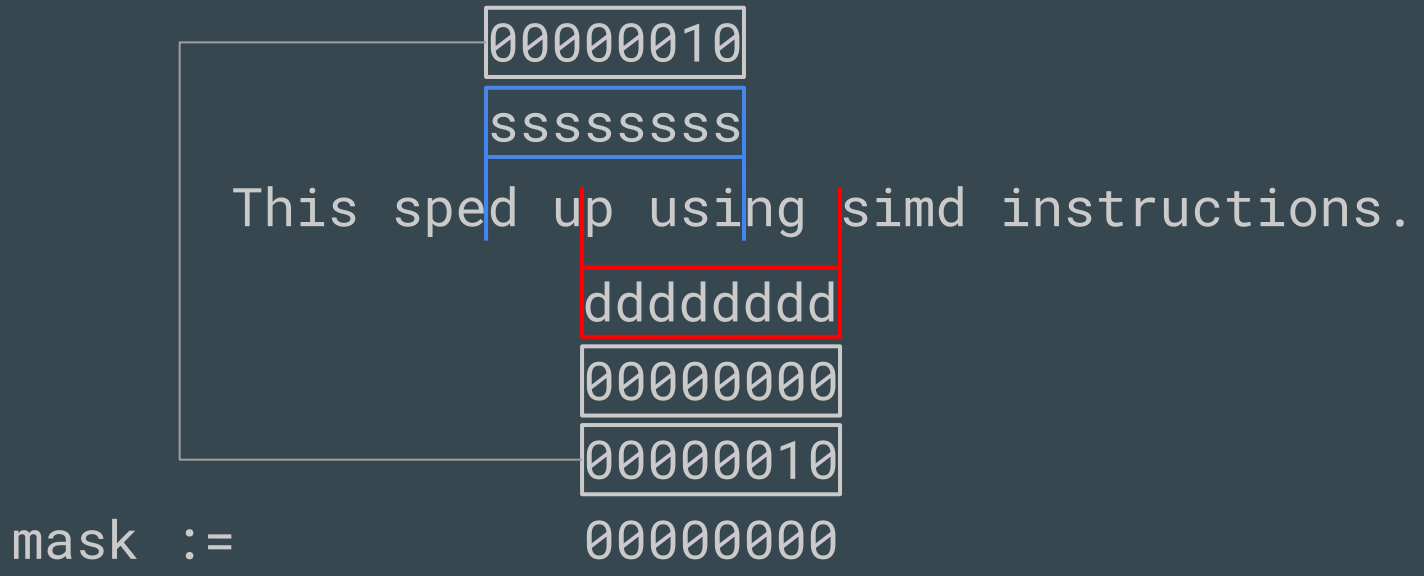


mask := 00000100

```
memcmp(data + __builtin_ctz(mask) + 1, pattern + 1, 2)
```

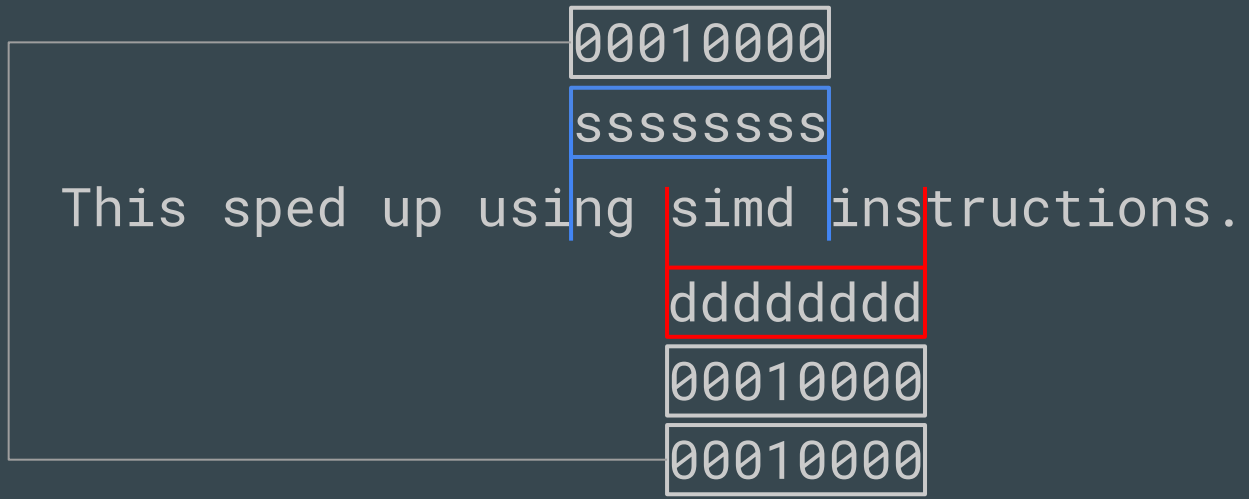
SIMD Substring Search Algorithm

Pattern: “simd”



SIMD Substring Search Algorithm

Pattern: “simd”



mask :=

```
memcmp(data + __builtin_ctz(mask) + 1, pattern + 1, 2)
```

Data Characteristics

Size	9.3 GiB
Number of Lines	337’845’355

	Bytes per Line
Mean	29.5
Min	1
25% Quartile	14
50% Quartile	24
75% Quartile	38
Max	26’586

Pattern Characteristics

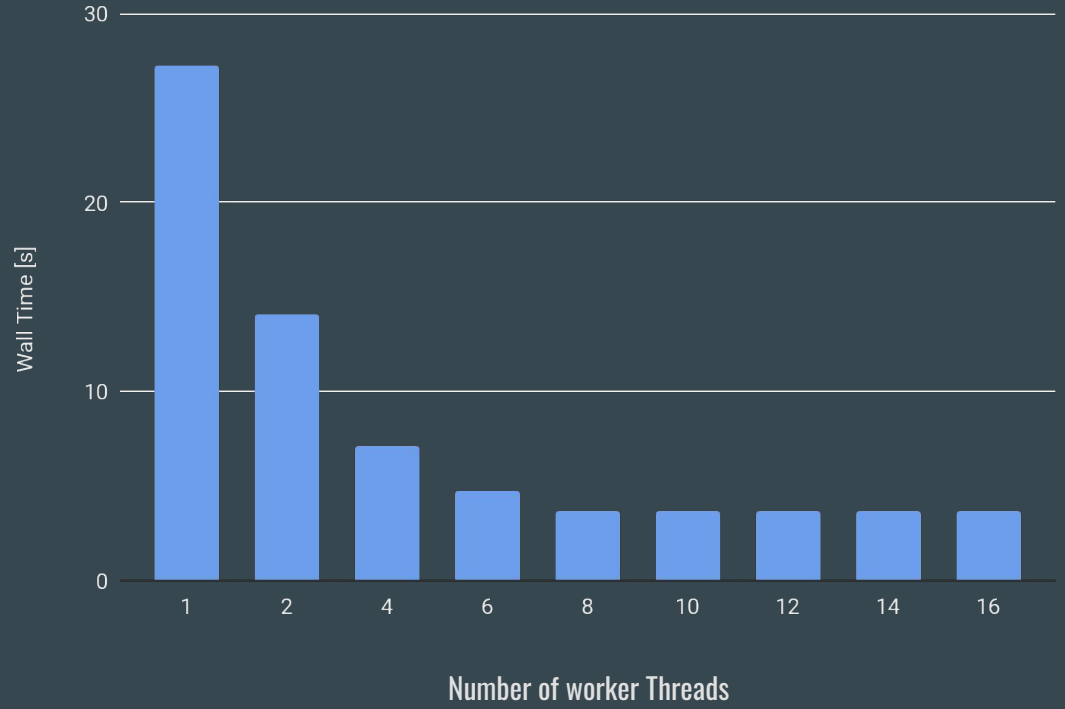
Pattern	Matching Lines	% of Lines
“Sherlock”	13’645	0.004
“ [sS][A-Za-z]*[Kk] ”	1’079’731	0.320

Thread Management

Pattern:

“ `[Ss][A-Za-z]*[Kk]` ”

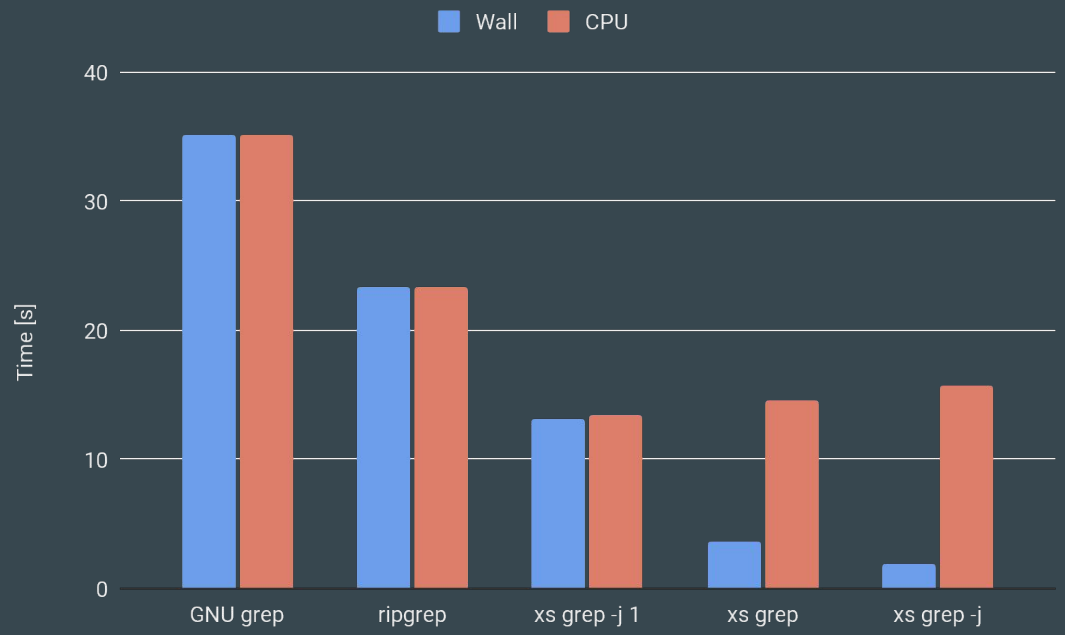
Reading from RAM cache



Reading from SSD

Pattern:

“ [Ss][A-Za-z]*[Kk] ”



			'Sherlock'			' [sS][A-Za-z]*[kK] '		
			Wall (s)	CPU (s)	Wall (%)	Wall (s)	CPU (s)	Wall (%)
Cached Read	Threads	1	0.938	0.938	**100.0**	27.270	27.276	**100.0**
		2	0.548	1.046	**171.2**	14.082	27.944	**193.7**
		4	0.408	1.438	**229.9**	7.134	28.492	**382.3**
		8	0.426	2.786	**220.2**	3.654	29.054	**746.3**
		16	0.434	2.790	**216.1**	3.696	29.376	**737.8**
	mmap	yes	0.424	1.450	**100.0**			
		no	1.680	2.786	**25.2**			
SSD Read	Threads	1	2.734	3.122	**100.0**	28.876	29.168	**100.0**
		2	1.888	3.542	**144.8**	15.028	30.254	**192.1**
		4	1.612	4.624	**169.6**	7.662	30.816	**376.9**
		8	1.624	7.376	**168.3**	4.002	31.902	**721.5**
		16	1.632	7.164	**167.5**	4.020	32.048	**718.3**
	mmap	yes	1.604	4.498	**100.0**			
		no	3.512	4.574	**45.7**			
HDD Read	Threads	1	34.526	4.188	**100.0**	41.642	28.792	**100.0**
		2	37.534	4.198	**92.0**	45.736	43.178	**91.0**
		4	37.842	3.944	**91.2**	37.044	53.766	**112.4**
		8	37.868	4.196	**91.2**	36.216	57.380	**115.0**
		16	37.834	4.194	**91.3**	36.054	57.736	**115.5**
	mmap	yes	37.472	4.134	**100.0**			
		no	25.674	4.940	**146.0**			

		Cached Read								
		`'Sherlock'`			`'She[r ]lock'`			`' [sS][A-Za-z]*[kK] '`		
		Wall	CPU	Wall %	Wall	CPU	Wall %	Wall	CPU	Wall %
Line	ripgrep	0.836	0.830	**100.0**	1.262	1.256	**100.0**	21.166	21.162	**100.0**
	GNU grep	3.206	3.204	**26.1**	3.930	3.926	**32.1**	33.032	33.026	**64.1**
	xs grep -j 1	0.956	0.964	**87.4**	1.108	1.120	**113.9**	11.314	11.324	**187.1**
	xs grep	0.424	1.458	**197.2**	0.436	1.504	**289.4**	3.022	12.068	**700.4**
	xs grep -j	0.450	2.808	**185.8**	0.442	2.816	**285.5**	1.554	12.280	**1362.0**
Line Number	ripgrep	1.102	1.092	**100.0**	1.526	1.522	**100.0**	21.292	21.286	**100.0**
	GNU grep	5.832	5.828	**18.9**	6.542	6.538	**23.3**	35.924	35.916	**59.3**
	xs grep -j 1	3.886	3.900	**28.4**	4.080	4.092	**37.4**	14.944	14.956	**142.5**
	xs grep	1.286	4.726	**85.7**	1.296	4.758	**117.7**	3.882	15.484	**548.5**
	xs grep -j	0.894	6.144	**123.3**	0.894	6.158	**170.7**	2.010	15.822	**1059.3**
Ignore Case	ripgrep	1.472	1.466	**100.0**	2.468	2.462	**100.0**	21.150	21.146	**100.0**
	GNU grep	13.042	13.040	**11.3**	13.236	13.234	**18.6**	35.374	35.368	**59.8**
	xs grep -j 1	2.216	2.224	**66.4**	11.796	11.806	**20.9**	27.384	27.392	**77.2**
	xs grep	1.714	6.436	**85.9**	3.078	12.184	**80.2**	7.106	28.358	**297.6**
	xs grep -j	1.770	13.146	**83.2**	1.598	12.432	**154.4**	3.632	28.794	**582.3**

		SSD Read								
		`'Sherlock'`			`'She[r ]lock'`			`' [sS][A-Za-z]*[kK] '`		
		Wall	CPU	Wall %	Wall	CPU	Wall %	Wall	CPU	Wall %
Line	ripgrep	2.840	2.760	**100.0**	3.272	3.202	**100.0**	23.384	23.324	**100.0**
	GNU grep	5.054	5.038	**56.2**	5.798	5.784	**56.4**	35.182	35.164	**66.5**
	xs grep -j 1	2.730	3.118	**104.0**	2.894	3.284	**113.1**	13.224	13.422	**176.8**
	xs grep	1.608	4.538	**176.6**	1.614	4.550	**202.7**	3.598	14.630	**649.9**
	xs grep -j	1.626	7.112	**174.7**	1.630	7.406	**200.7**	1.978	15.736	**1182.2**
Line Number	ripgrep	3.174	3.106	**100.0**	3.576	3.504	**100.0**	23.628	23.572	**100.0**
	GNU grep	7.708	7.694	**41.2**	8.424	8.410	**42.5**	37.786	37.770	**62.5**
	xs grep -j 1	5.788	6.174	**54.8**	5.960	6.330	**60.0**	16.940	17.216	**139.5**
	xs grep	2.102	7.946	**151.0**	2.164	8.072	**165.2**	4.556	18.336	**518.6**
	xs grep -j	1.790	12.190	**177.3**	1.766	11.834	**202.5**	2.494	19.760	**947.4**
Ignore Case	ripgrep	3.496	3.428	**100.0**	4.484	4.422	**100.0**	23.402	23.340	**100.0**
	GNU grep	14.928	14.912	**23.4**	15.002	14.988	**29.9**	37.438	37.422	**62.5**
	xs grep -j 1	4.288	4.664	**81.5**	13.610	13.904	**32.9**	28.866	29.160	**81.1**
	xs grep	2.704	10.094	**129.3**	3.618	14.692	**123.9**	7.654	30.806	**305.7**
	xs grep -j	2.720	21.18	**128.5**	1.990	15.790	**225.3**	3.994	31.814	**585.9**

	File Size (GB)		HDD Read 'Sherlock' Wall	CPU	Wall %
Plain	9.3	ripgrep	25.810	3.462	**100.0**
		GNU grep	25.632	7.998	**100.7**
		xs grep	25.662	4.826	**100.6**
ZStandard	1.5	zstcat → ripgrep	9.518	8.068	**269.4**
		zstcat → GNU grep	9.922	8.058	**260.1**
		zstcat → xs grep	9.484	8.294	**272.1**
		xs grep (xspp)	3.976	8.116	**649.1**
LZ4	3.7	lz4cat → ripgrep	8.184	6.332	**315.4**
		lz4cat → GNU grep	13.096	7.896	**197.1**
		lz4cat → xs grep	8.228	7.586	**313.7**
		xs grep (xspp)	8.862	6.438	**291.2**
LZ4 HC	2.1	lz4cat → ripgrep	6.446	5.750	**400.4**
		lz4cat → GNU grep	11.614	6.680	**222.2**
		lz4cat → xs grep	7.102	7.040	**363.4**
		xs grep (xspp)	5.358	5.744	**481.7**

Benchmark Metrics

- Wall Time
- CPU Time

Scenario 0:

One Thread reads data from disk and writes the read data to standard out. The program runs 1 second.

- Wall: 1 seconds
- CPU: 0.1 seconds

Scenario 1:

Two threads simultaneously search two different patterns within a string. The program runs 1 second.

- Wall: 1 second
- CPU: 2 seconds

Boyer-Moore: Bad Character

```
Data:    this is a boyer-moore test!
Pattern: test|   |   |   |   ||       's' = 1
          test   |   |   |   ||       ' ' = 4
              test   |   |   ||       'a' = 4
                  test   |   ||       'y' = 4
                      test   ||       'm' = 4
                          test|       'e' = 2
                            test      ' ' = 4
                               test
```

t	0
e	2
s	1
other	pattern size: 4

Boyer-Moore: Good Suffix

```
Data:    reinesupersauersupesupersupe
Pattern: superrsupe   |     |
              supersupe    |
                       supersupe
                            supersupe
```

e	1
pe	10
upe	11
supe	12
rsupe	9
ersupe	10
persupe	11
upersupe	12

x-search: Basic Usage

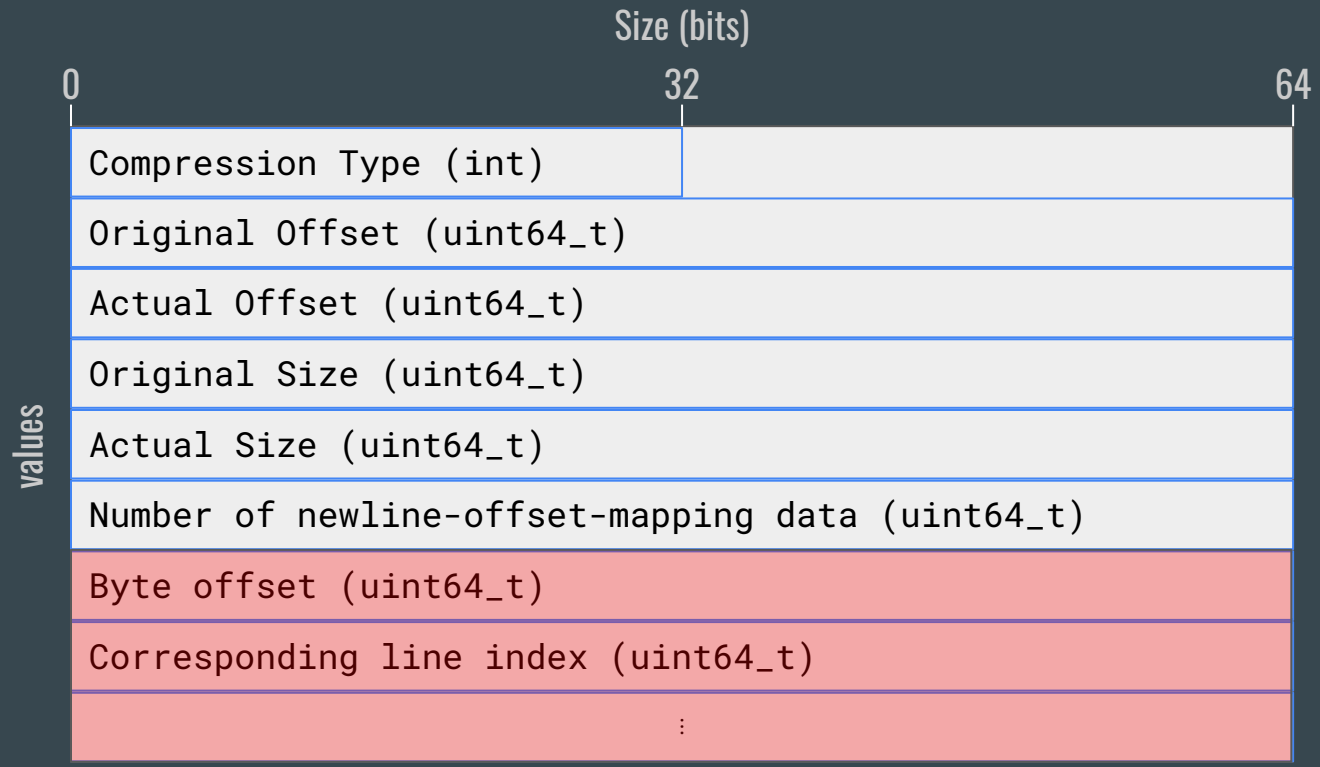
```
[lfreist@xps ~]$ time ./example_grep Sherlock data.txt

real   0m0.933s
user   0m0.640s
sys    0m0.320s


[lfreist@xps ~]$ time grep Sherlock data.txt

real   0m3.572s
user   0m2.626s
sys    0m0.869s
```

Metafile Structure



Appendix