The Wikipedia Goggle

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https://goggle.columbia.lol/

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The Wikipedia Goggle

The **Wikipedia Goggle** is a search engine for the English Wikipedia, using a trigram index and Google's original PageRank, implemented in modern C++.

Basics of a search engine

Offline:

- 1. Indexing
  - Pre-process data into efficient data structures for querying and ranking

Online:

- 2. Information retrieval
  - Retrieve all documents matching a query
- 3. Ranking
  - Rank retrieved documents depending on query

Now do it in < 100 ms! - You need good data structures!

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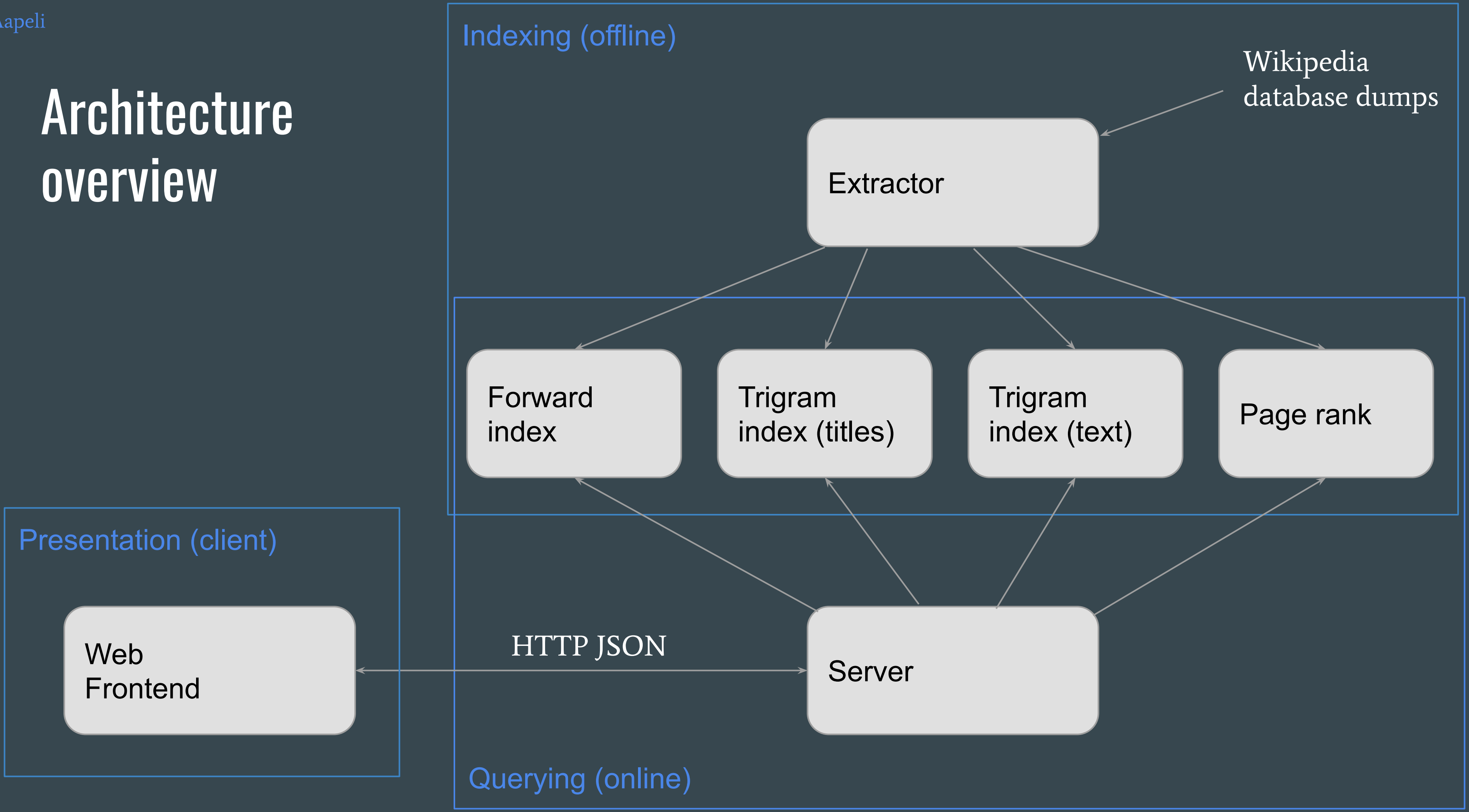
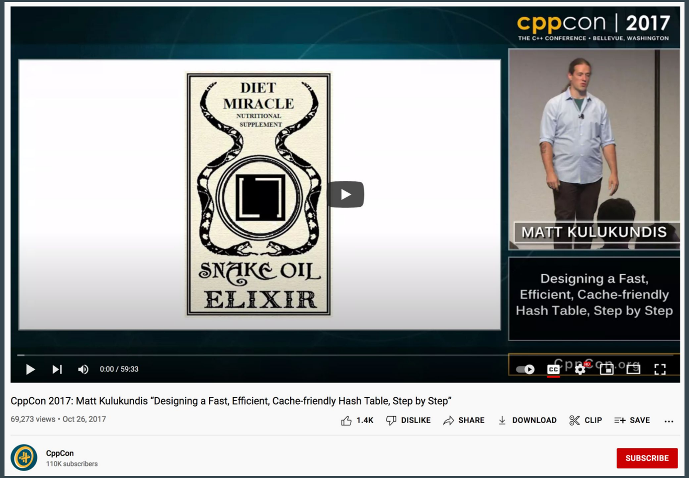
Architecture overview

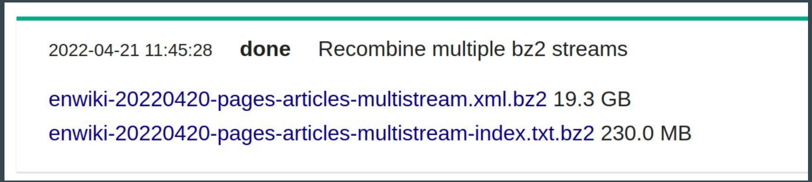


Dependencies

- Googly stuff:
  - Bazel - build system
  - Abseil - hash maps, flags, etc
  - googlelog + googletest + googlebench
  - LevelDB - persistent key-value storage
  - Protocol buffers - structured data serialization (cf. flats by Bjarne)
- Non-G stuff
  - rapidxml by Marcin Kalicinski: http://rapidxml.sourceforge.net/
  - bzip2 by Julian Seward: https://sourceware.org/bzip2/
  - httplib by Yuji Hirose: https://github.com/yhirose/cpp-httplib
  - JSON escape code from @vog (SE): https://stackoverflow.com/a/33799784 :)



Dump extraction & pre-processing


2022-04-21 11:45:28 **done** Recombine multiple bz2 streams

enwiki-20220420-pages-articles-multistream.xml.bz2 19.3 GB
enwiki-20220420-pages-articles-multistream-index.txt.bz2 230.0 MB

- Input: ~20 GB bzip2 “multistream” XML + “index.txt” file
- Output: cleaned up documents

1. Extract chunk boundaries from “index.txt” file
2. Read each chunk, decompress (bzip2)
3. Parse XML (rapidxml)
4. Extract wiki id, title, text, links (set)
5. Strip text of extra markup, etc
6. Ignore special pages (talk, templates, categories, etc)

Indexing as-we-go overview

(I’ll talk about each individually)

- Trigram index for titles -> id
- Trigram index for text body -> id
- Forward index for id -> doc
- Some “magic” page goodness measurements (for a basis of PageRank)
- Hash map of target -> list of backlinks

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Trigram indexes: principles

- **Reverse index** for text -> id
- Split text into trigrams (triplets of characters)
- a-z + space gives 27^3 ~ 20k trigrams
- For each trigram, store list of ids

To query:

- Get trigrams for query
- Intersect list of ids of these trigrams
- Lossy: find query in result

Implemented as

array of trigram_id -> std::vector<doc_id>

Indexing

```
hello world
```

Trigrams

```
"__h", "_he", "hel",
"ell", "llo", "lo_",
"o__", "o_w", "__w",
"_wo", "wor", "orl",
"rld", "ld_", "d__"
```

Querying

```
hello -> "__h", "_he",
         "hel", "ell",
         "llo", "lo_",
         "o__"
```

Now find all docs that contain **all** of these trigrams

Forward index (DocIndex)

- Store document by id for avg O(1) lookup
- Earlier a hash map of id -> Document
- Later moved to rely only on LevelDB (next slide)

Data persistence in LevelDB as Protocol Buffers

- LevelDB: a fast on-disk key-value store
  - i.e. bytes key -> bytes value
  - Implemented as log-structured merge tree (LSM tree)
  - We use it as a giant on-disk hash map :)
- DocIndex: `docs/{id}`
- Titles: `trgm/titles/{trigram_ix}`
- Text body: `trgm/text/{trigram_ix}`
- Pagerank: `pr/pagerank`

```
message Doc {
  uint32 id = 1;
  uint32 wiki_id = 5;
  string title = 2;
  string text = 3;
  repeated string links = 4;
}
```

```
message TrigramVec {
  repeated uint32 docs = 1;
}
```

```
message PagerankVec {
  repeated float prs = 1;
}
```

So we don't need to re-index each startup.

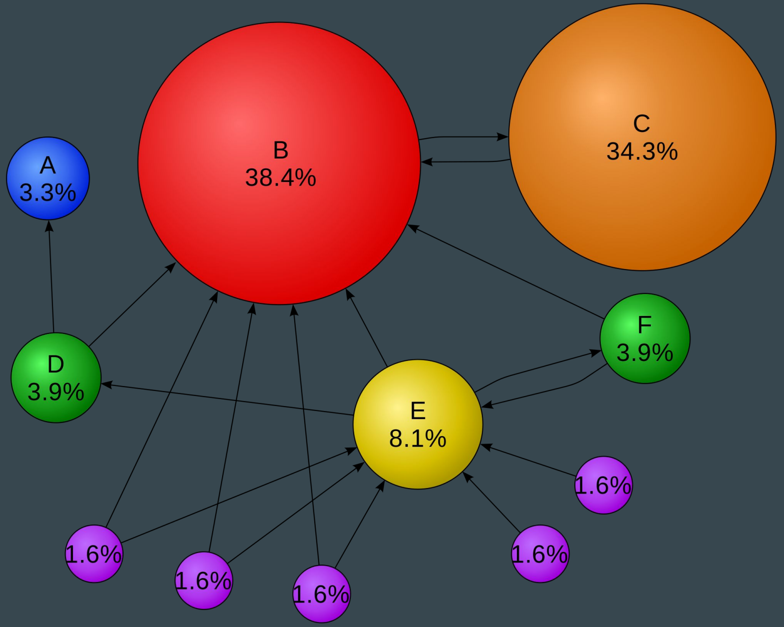
Illustration from “PageRank” on Wikipedia :)

PageRank: principles

Random (web) surfer model:

1. A user starts from a random page
2. Randomly clicks on a link on that page
3. With probability 1-d, stop and go back to 1.

PageRank is the steady-state prob. distribution of the page that the surfer is on. (Cf. Markov chains)



$$\boldsymbol{p} = (1-d)\boldsymbol{g} + d\boldsymbol{B}\boldsymbol{p}$$

- d is the dampening factor
- $\boldsymbol{g}$ is the “goodness” vector
- $\boldsymbol{p}$ is the page rank vector
- $\boldsymbol{B}$ is the transition matrix: $B_{ij} = 1/N_i$ if page i links to page j, and N_i is the number of links on page i

$$\boldsymbol{p} = ((1-d)\boldsymbol{I} + d\boldsymbol{B})\boldsymbol{p}$$

$$p_i = (1-d)g_i + d\sum_{j\in\mathcal{B}_i} \frac{p_j}{N_j}$$

PageRank: implementation

- Generate hash map of target -> backlinks
  - `absl::flat_hash_map<std::string, std::vector<std::string>>`
  - Need to go through and switch page titles to page ids to get:
  - `absl::flat_hash_map<int, std::vector<int>>`
- Power iteration using single precision floats (~40 MB)
- Page goodness:
  - Try to weed out "List of ..." pages
  - Surprising number of lists of dates, e.g. "December 30"
  - Try to avoid "stub" pages, favor some length
  - Basically comes down to page length + number of links and their ratios and counts

Surprisingly fast: ~2 min on full 10 million Wiki pages to < 1e-7 error!

Basic querying

1. Split query into trigrams
2. Compute intersection of all documents that contain all trigrams
3. Filter all returned documents (retrieved from DocIndex) using `string.find(query)`
4. Continue searching until we've found `page_length` documents

- We actually first search the title index, then search full body
- Indexes are sorted by page rank!

Optimization: setup

- Running on AMD Ryzen 7 5800X (32 MB L3 cache)
- 96 GB DDR4 RAM to build indexes! (Building peaks at ~60 GB RAM)
- ~45 GB disk for persistence, ~30 GB RAM once indexes built

- LLVM Clang 10.0.0-4ubuntu1
- Ubuntu 20.04.4 LTS

- Indexing: 50 min for full Wiki (~10 million pages)
- Page rank computation: ~2 min, to < 1e-7 error
- Search: depends on query

Optimization: the query planner

- Initially:
  - sorted docs
  - O(n^2) intersection, ~2.6 min!
- Binary search:
  - O(n log(n)), ~1.6 sec (100x speedup)
- “Early break”: < pl docs, > 80% docs
- “Smart query planner”, ~0.45 sec (350x speedup)
  - For large lists: sequential strategy
  - For small list with large one: binary search strategy
- Separated text body from metadata
- Last bit parallelized

Searching for “hello world” in full Wikipedia corpus

```cpp
std::vector<uint32_t> TrigramIndex::FindPossibleDocuments(
    const std::string_view& query,
    const std::unique_ptr<std::vector<float>>& pagerank,
    std::function<bool(uint32_t)> check_doc, size_t page_size) {
  auto trigrams = split_into_trigrams(query);
  std::sort(trigrams.begin(), trigrams.end(), [&](auto a, auto b) {
              return GetContainerAt(a).size() < GetContainerAt(b).size();
            });
  container_type remaining_docs{...};
  for (auto& ix : trigrams) {
    container_type& docs = GetContainerAt(ix);
    if (docs.size() > 0.8 * pagerank->size()) {
      LOG(INFO) << "More than 80\% docs for this trigram, breaking"; break;
    }
    if (remaining_docs.size() < page_size) {
      LOG(INFO) << "Less than page size docs, breaking"; break;
    }
    if (remaining_docs.size() > 1000 &&
        remaining_docs.size() > 0.05 * docs.size()) {
      LOG(INFO) << "Using sequential strategy";
      container_type intersection{};
      std::set_intersection(docs.begin(), docs.end(), remaining_docs.begin(),
                            remaining_docs.end(),
                            std::back_inserter(intersection), doc_order);
      remaining_docs = std::move(intersection);
    } else {
      LOG(INFO) << "Using binary search strategy";
      auto it = remaining_docs.begin();
      while (it != remaining_docs.end()) {
        if (!std::binary_search(docs.begin(), docs.end(), *it, doc_order)) {
          remaining_docs.erase(it);
        } else {
          ++it;
        }
      }
    }
  }
  std::vector<uint32_t> matches{};

  for (auto&& doc_id : remaining_docs) {
    if (check_doc(doc_id)) {
      matches.push_back(doc_id);
    }
    if (matches.size() >= page_size) break;
  }

  return matches;
}
```

Optimization: the query planner

Searching for “hello world” in full Wikipedia corpus

```
I20220430 08:29:18.675081 2385008 trigram.cc:102] Have trigrams:
I20220430 08:29:18.675088 2385008 trigram.cc:104] Have trigram: lo , size: 1140260
I20220430 08:29:18.675096 2385008 trigram.cc:104] Have trigram: rld, size: 1909386
I20220430 08:29:18.675101 2385008 trigram.cc:104] Have trigram: orl, size: 2135213
I20220430 08:29:18.675107 2385008 trigram.cc:104] Have trigram: hel, size: 2212559
I20220430 08:29:18.675114 2385008 trigram.cc:104] Have trigram: o w, size: 2346584
I20220430 08:29:18.675122 2385008 trigram.cc:104] Have trigram: llo, size: 2511270
I20220430 08:29:18.675127 2385008 trigram.cc:104] Have trigram: ell, size: 3421354
I20220430 08:29:18.675133 2385008 trigram.cc:104] Have trigram: wor, size: 3811003
I20220430 08:29:18.675139 2385008 trigram.cc:104] Have trigram: ld , size: 3932145
I20220430 08:29:18.675145 2385008 trigram.cc:104] Have trigram:  wo, size: 4183474
I20220430 08:29:18.675153 2385008 trigram.cc:104] Have trigram:  he, size: 4539906
I20220430 08:29:18.675158 2385008 trigram.cc:104] Have trigram:   h, size: 6196546
I20220430 08:29:18.675164 2385008 trigram.cc:104] Have trigram:   w, size: 6270405
I20220430 08:29:18.675170 2385008 trigram.cc:104] Have trigram: o  , size: 6332643
I20220430 08:29:18.675177 2385008 trigram.cc:104] Have trigram: d  , size: 6402039
I20220430 08:29:18.675182 2385008 trigram.cc:104] Have trigram:    , size: 6487373
I20220430 08:29:18.675648 2385008 trigram.cc:167] After trigram lo , have 1140260 docs left, took 0 ms
I20220430 08:29:18.675658 2385008 trigram.cc:136] Using sequential strategy
I20220430 08:29:18.727077 2385008 trigram.cc:167] After trigram rld, have 503364 docs left, took 51 ms
I20220430 08:29:18.727115 2385008 trigram.cc:136] Using sequential strategy
I20220430 08:29:18.754030 2385008 trigram.cc:167] After trigram orl, have 502055 docs left, took 26 ms
I20220430 08:29:18.754060 2385008 trigram.cc:136] Using sequential strategy
I20220430 08:29:18.781070 2385008 trigram.cc:167] After trigram hel, have 350714 docs left, took 27 ms
I20220430 08:29:18.781106 2385008 trigram.cc:136] Using sequential strategy
I20220430 08:29:18.812491 2385008 trigram.cc:167] After trigram o w, have 282096 docs left, took 31 ms
I20220430 08:29:18.812526 2385008 trigram.cc:136] Using sequential strategy
I20220430 08:29:18.838678 2385008 trigram.cc:167] After trigram llo, have 252016 docs left, took 26 ms
I20220430 08:29:18.838707 2385008 trigram.cc:136] Using sequential strategy
I20220430 08:29:18.869164 2385008 trigram.cc:167] After trigram ell, have 245368 docs left, took 30 ms
I20220430 08:29:18.869196 2385008 trigram.cc:136] Using sequential strategy
I20220430 08:29:18.901517 2385008 trigram.cc:167] After trigram wor, have 245346 docs left, took 32 ms
I20220430 08:29:18.901551 2385008 trigram.cc:136] Using sequential strategy
I20220430 08:29:18.935571 2385008 trigram.cc:167] After trigram ld , have 244661 docs left, took 34 ms
I20220430 08:29:18.935601 2385008 trigram.cc:136] Using sequential strategy
I20220430 08:29:18.978783 2385008 trigram.cc:167] After trigram  wo, have 244540 docs left, took 43 ms
I20220430 08:29:18.978821 2385008 trigram.cc:136] Using sequential strategy
I20220430 08:29:19.019239 2385008 trigram.cc:167] After trigram  he, have 243699 docs left, took 40 ms
I20220430 08:29:19.019270 2385008 trigram.cc:127] More than 80% docs for this trigram, breaking
I20220430 08:29:19.019274 2385008 trigram.cc:175] Matched 243699 docs in 344 ms
I20220430 08:29:19.019296 2385008 trigram.cc:192] About to check docs with 32 threads
I20220430 08:29:19.137099 2385008 trigram.cc:220] Had to check 1245 docs before finding 1 in 117 ms
I20220430 08:29:19.138181 2385008 goggle.cc:329] Searched for "hello world" with page size 10
I20220430 08:29:19.138200 2385008 goggle.cc:330] Took 465 ms
```

```cpp
std::vector<uint32_t> TrigramIndex::FindPossibleDocuments(
    const std::string_view& query,
    const std::unique_ptr<std::vector<float>>& pagerank,
    std::function<bool(uint32_t)> check_doc, size_t page_size) {
  auto trigrams = split_into_trigrams(query);
  std::sort(trigrams.begin(), trigrams.end(), [&](auto a, auto b) {
              return GetContainerAt(a).size() < GetContainerAt(b).size();
            });
  container_type remaining_docs{...};
  for (auto& ix : trigrams) {
    container_type& docs = GetContainerAt(ix);
    if (docs.size() > 0.8 * pagerank->size()) {
      LOG(INFO) << "More than 80\% docs for this trigram, breaking"; break;
    }
    if (remaining_docs.size() < page_size) {
      LOG(INFO) << "Less than page size docs, breaking"; break;
    }
    if (remaining_docs.size() > 1000 &&
        remaining_docs.size() > 0.05 * docs.size()) {
      LOG(INFO) << "Using sequential strategy";
      container_type intersection{};
      std::set_intersection(docs.begin(), docs.end(), remaining_docs.begin(),
                            remaining_docs.end(),
                            std::back_inserter(intersection), doc_order);
      remaining_docs = std::move(intersection);
    } else {
      LOG(INFO) << "Using binary search strategy";
      auto it = remaining_docs.begin();
      while (it != remaining_docs.end()) {
        if (!std::binary_search(docs.begin(), docs.end(), *it, doc_order)) {
          remaining_docs.erase(it);
        } else {
          ++it;
        }
      }
    }
  }
  std::vector<uint32_t> matches{};

  for (auto&& doc_id : remaining_docs) {
    if (check_doc(doc_id)) {
      matches.push_back(doc_id);
    }
    if (matches.size() >= page_size) break;
  }

  return matches;
}
```

Is it any good?

- When it works well
- When it doesn’t work well
- Ranking trick
- Probably not good in general for full text search of large documents
- Great for title search

Katie

Ideal

Anarchism

From Wikipedia, the free encyclopedia

For other uses, see Anarchism (disambiguation).

"Anarchist" and "Anarchists" redirect here. For other uses, see Anarchist (disambiguation).

Not to be confused with Anarchy.

Anarchism is a political philosophy and movement that is sceptical of authority and rejects all involuntary, coercive forms of hierarchy.[1] Anarchism calls for the abolition of the state, which it holds to be unnecessary, undesirable, and harmful. As a historically left-wing movement, placed on the farthest left of the political spectrum, it is usually described alongside communalism and libertarian Marxism as the libertarian wing (libertarian socialism) of the socialist movement, and has a strong historical association with anti-capitalism and socialism.

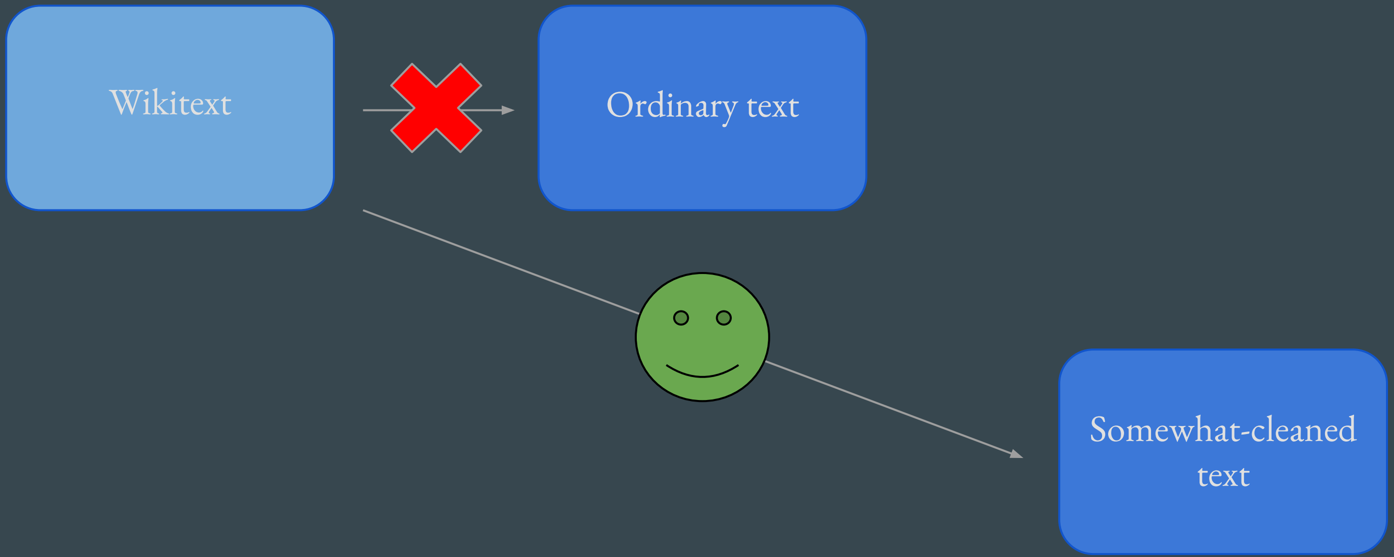
```
{{short description|Political philosophy and movement}}
{{other uses}}
{{redirect2|Anarchist|Anarchists|other uses|Anarchist (disambiguation)}}
{{distinguish|Anarchy}}
{{pp-semi-indef}}
{{good article}}
{{use British English|date=August 2021}}
{{use dmy dates|date=August 2021}}
{{anarchism sidebar}}
{{basic forms of government}}
'''Anarchism''' is a [[political philosophy]] and [[Political movement|movement]] that is sceptical of [[authority]] and rejects all
involuntary, coercive forms of [[Social hierarchy|hierarchy]].{{sfn|Suissa|2019b|ps=: "...as many anarchists have stressed, it is not
government as such that they find objectionable, but the hierarchical forms of government associated with the nation state."}} Anarchism
calls for the abolition of the [[State (polity)|state]], which it holds to be unnecessary, undesirable, and harmful. As a historically
[[left-wing]] movement, placed on the farthest left of the [[political spectrum]], it is usually described alongside [[Communalism
(Bookchin)|communalism]] and [[libertarian Marxism]] as the [[libertarian]] wing ([[libertarian socialism]]) of the [[socialist movement]],
and has a strong historical association with [[anti-capitalism]] and [[socialism]].
```

Reality

String cleaning measurements

We started out quite optimistic!

Then we realized just how slow regex – or linear scans – can be in practice.



Katie

String cleaning measurements

Measurements: runtime using Bazel run & using 1/1000th of total dump

Trade-off between tractable pre-processing time and quality of search results

- ParseXml w/ link extraction & removal of non-alphabetical characters:
  - 113281 ms averaged across 3 runs
  - A single for loop – O(n)
- ParseXml w/ link extraction & tolower():
  - 44886 ms averaged across 3 runs
  - A single for auto loop – O(n)
- ParseXml w/ link extraction & ad hoc regex:
  - 78k – 100k ms for a single document
  - Will not do.

Future improvements

- *Nothing. Goggle is perfect the way it is.*
- Remove extra markup instead of just ignoring it

V0.8: we extract and clean (by hand) 1k wiki pages and are able to do a basic trigram search on them, returning results in arbitrary order through a command line interface

V1.0: code to extract and clean a wikipedia dump, then search all wiki pages, returning results in arbitrary order through a web interface

v1.2: Allow for fuzzy search or basic regex search

References

- The Anatomy of a Large-Scale Hypertextual Web Search Engine, Sergey Brin, Larry Page, available at http://infolab.stanford.edu/~backrub/google.html
- The PageRank Citation Ranking: Bringing Order to the Web. Page, Lawrence and Brin, Sergey and Motwani, Rajeev and Winograd, Terry, available at http://ilpubs.stanford.edu:8090/422/
- PostgreSQL docs on Trigra

“Latency numbers every programmer should know”

```
memory:
sequential read (MT): 41 GB/s
sequential read (64B): 22 GB/s (2.7 ns)
sequential write (64B): 15 GB/s (4 ns)
random read (64B): 2.8 GB/s (20 ns)
random write (64B): 2.6 GB/s (22 ns)

disk:
sequential read (64KB): 7 GB/s (8 µs)
sequential write (fsync) (8KB): 4 MB/s (1.8 ms)
sequential write (no fsync) (8KB): 1.4 GB/s (5 µs)
sequential read (io uring) (2MB): 3.9 GB/s (506 µs)
random read (8KB): 600 MB/s (13 µs)

other:
mutexes per second: 17,531,612 (57 ns)
sha256 (64B): 150 MB/s (409 ns)
crc32 (64B): 3.6 GB/s (16 ns)
siphash (64B): 3.0 GB/s (19 ns)
tcp echo on localhost (64KB): 4.5 GB/s (13 µs)
```