CC5212-1

PROCESAMIENTO MASIVO DE DATOS
OTOÑO 2019

Lecture 7

Information Retrieval: Crawling & Indexing

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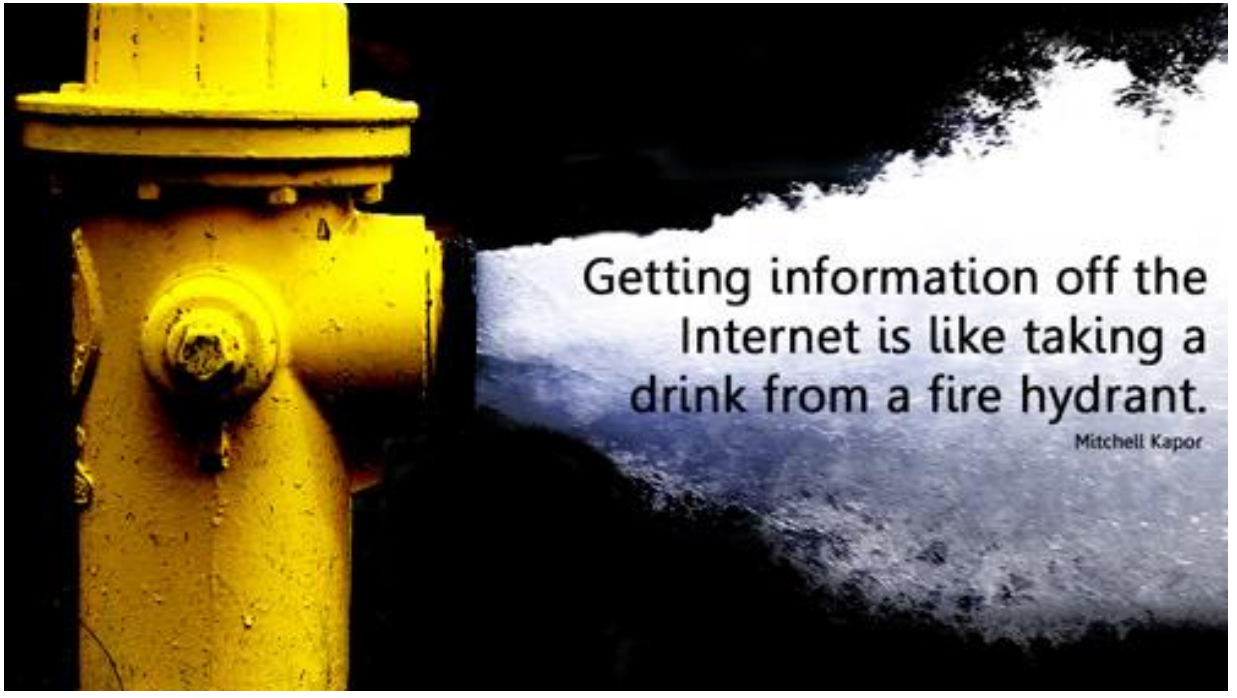
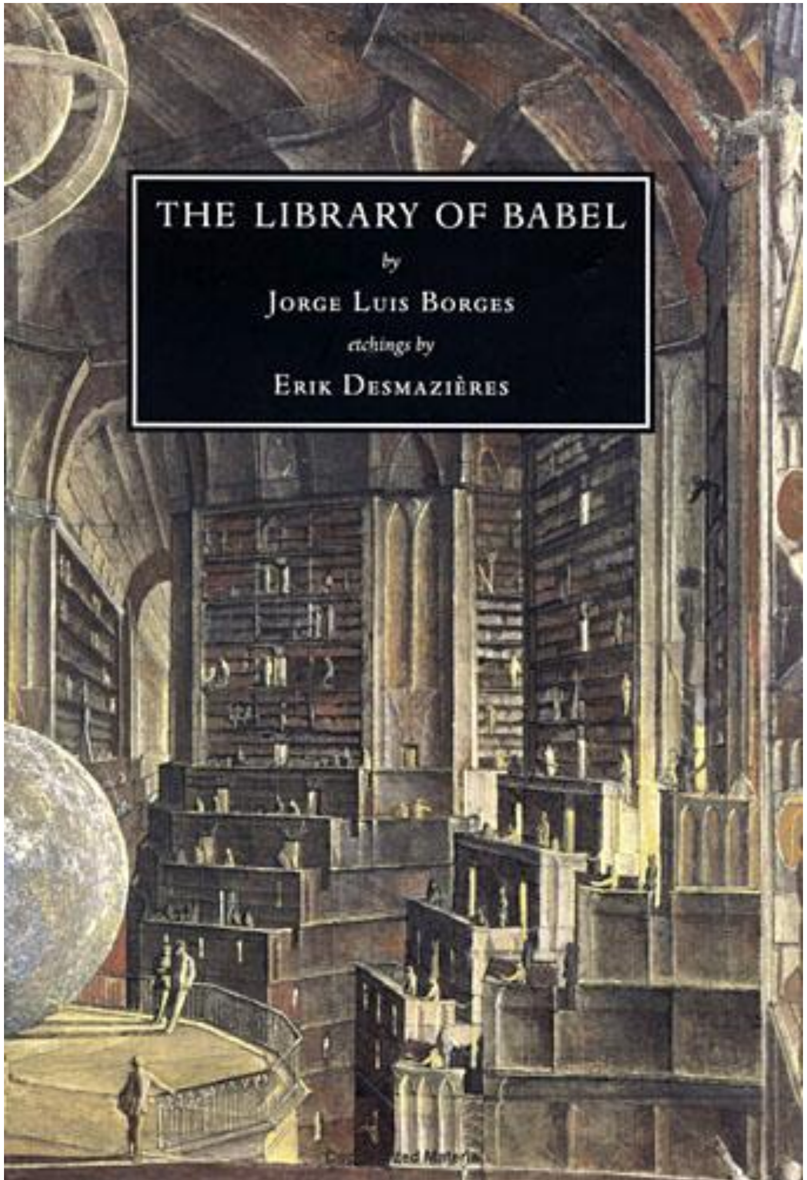
MapReduceBase
HDFS
grunt
replicas
Pig
replication
Sort
Hive
Rack-awareness
MapReduce
Partitioner
JobNode
JobTracker
ChunkServer
GFS
chunks
Hadoop
Reporter
Mapper
Writable
Shuffle
NameNode
Pipelined-reads
Reducer
Combiner
WritableComparable
DataNode
SecondaryNameNode

MANAGING TEXT DATA

Information Overload



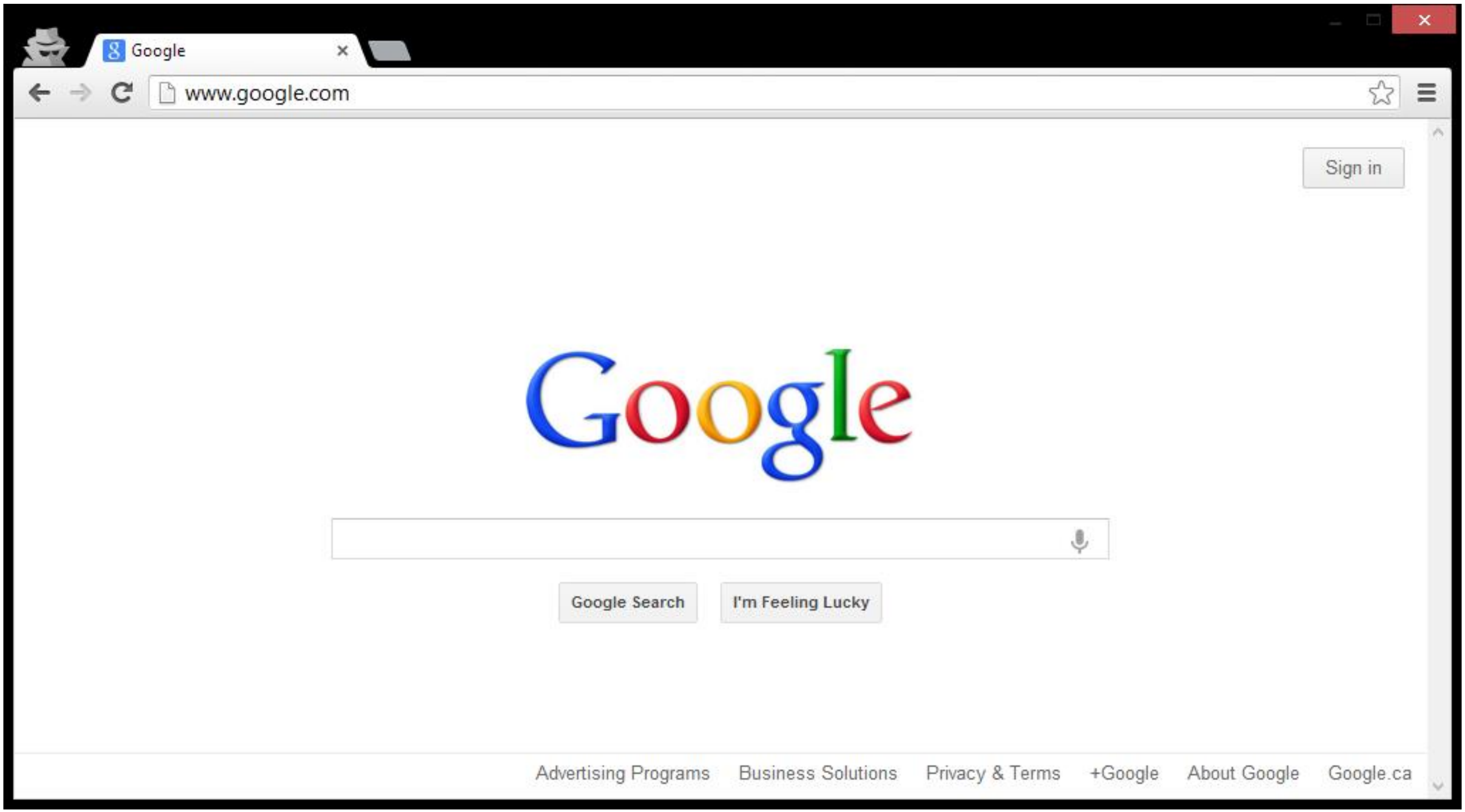
If we didn't have search …



- Contains all books with
  - 25 unique characters
  - 80 characters per line
  - 40 lines per page
  - 410 pages
  - 410 x 40 x 80 = 1,312,000 chars
  - $25^{1,312,000}$ books
- Would contain any book imaginable
  - Including a book with the location of useful books ;)

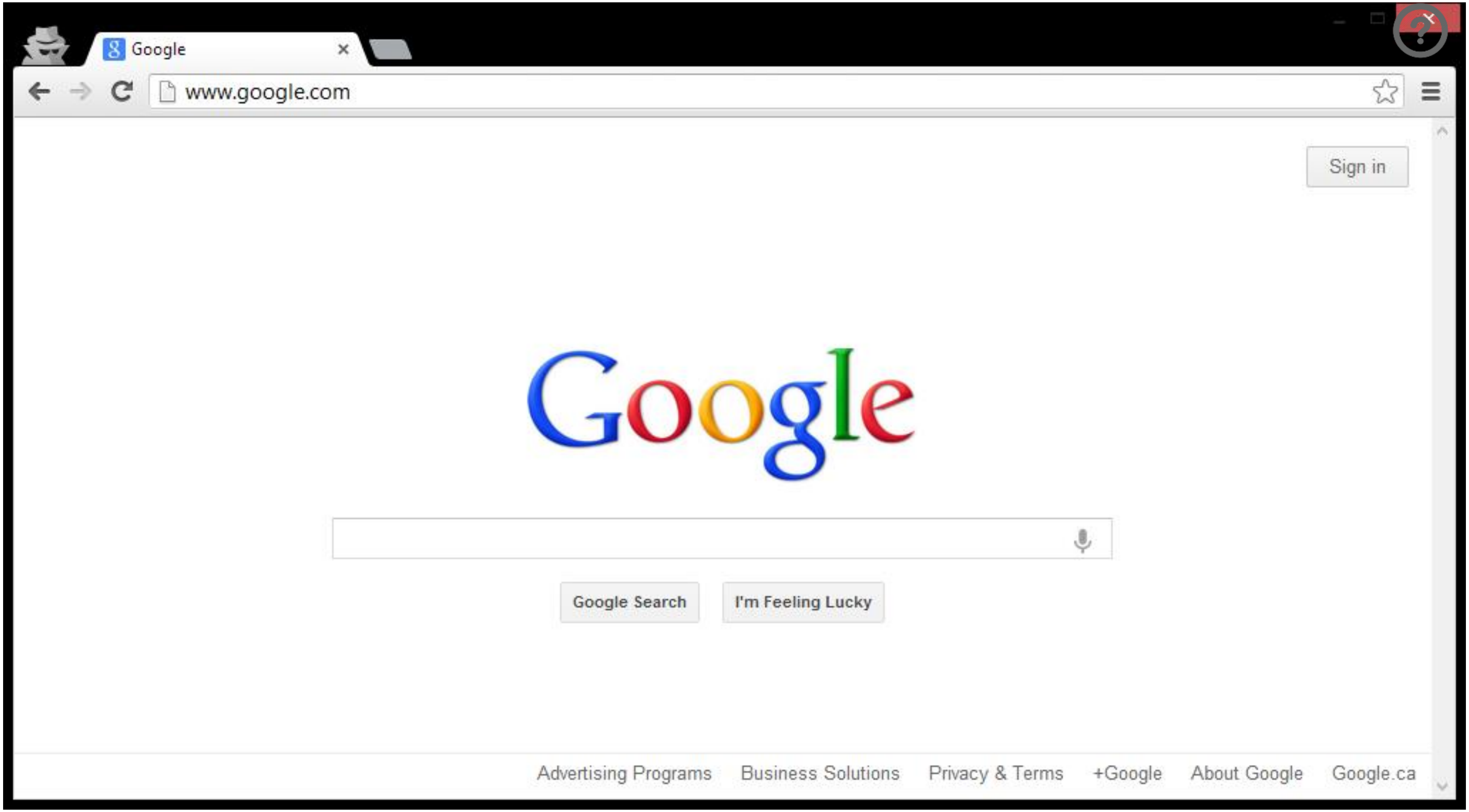
All information = Zero information

The book that indexes the library

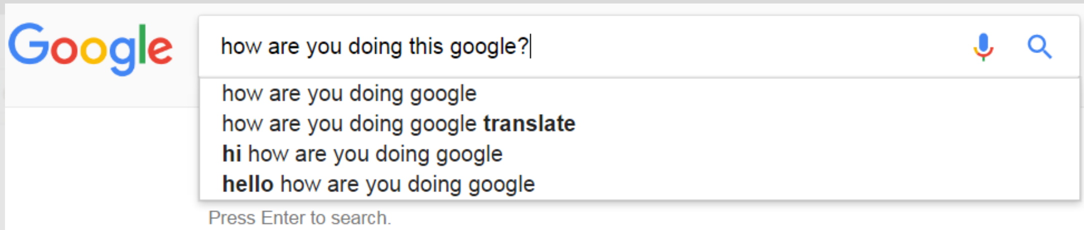


Web Search/Retrieval

Building Google Web-search



Building Google Web-search



What processes/algorithms does Google need to implement Web search?

Crawling

1. Parse links from webpages
2. Schedule links for crawling
3. Download pages, GOTO 1

Indexing

1. Parse keywords from webpages
2. Index keywords to webpages
3. Manage updates

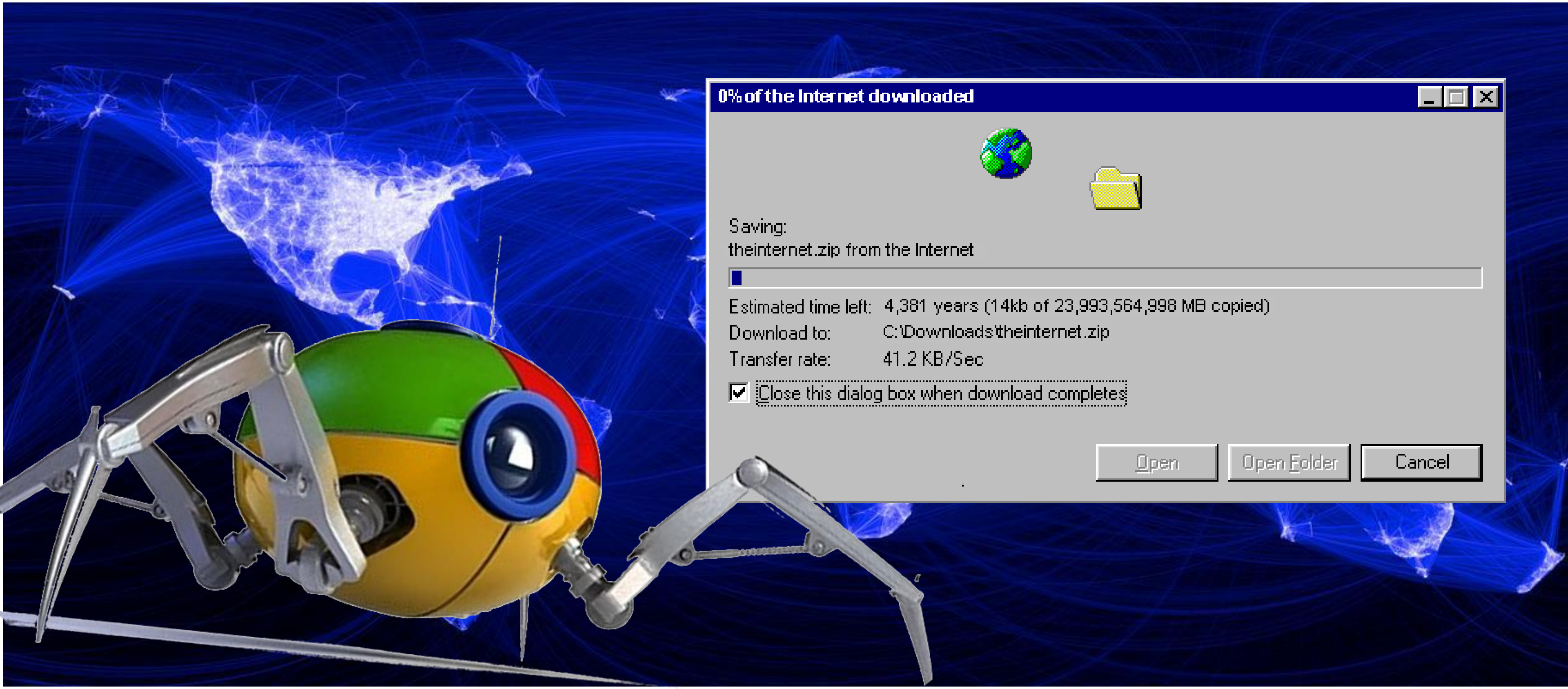
Ranking

1. How relevant is a page? (TF-IDF)
2. How important is it? (PageRank)
3. How many users clicked it?

…

Information Retrieval: Crawling

How does Google know about the Web?



Crawling

Download the Web. ☺

```
crawl(list seedUrls)
    frontier_i = seedUrls
    while(!frontier_i .isEmpty())
        new list frontier_i+1
        for url : frontier_i
                page = downloadPage(url)
                frontier_i+1.addAll(extractUrls(page))
                store(page)
        i++
```

What’s missing? ?

Crawling: Avoid Cycles

Download the Web. ☺

```
crawl(list seedUrls)
    frontier_i = seedUrls
    new set urlsSeen
    while(!frontier_i .isEmpty())
        new list frontier_i+1
        for url : frontier_i
                page = downloadPage(url)
                urlsSeen.add(url)
                frontier_i+1.addAll(extractUrls(page).removeAll(urlsSeen))
                store(page)
        i++
```

Performance? ?

Crawling: Avoid Cycles

Download the Web. ☺

```
crawl(list seedUrls)
    frontier_i = seedUrls
    new set urlsSeen
    while(!frontier_i .isEmpty())
        new list frontier_i+1
        for url : frontier_i
                page = downloadPage(url)
                urlsSeen.add(url)
                frontier_i+1.addAll(extractUrls(page).removeAll(urlsSeen))
                store(page)
        i++
```

Performance?

Crawling: Avoid Cycles

Download the Web. ☺

```
C:\Users\Aidan>ping twitter.com

Pinging twitter.com [199.16.156.198] with 32 bytes of data:
Reply from 199.16.156.198: bytes=32 time=118ms TTL=50
Reply from 199.16.156.198: bytes=32 time=120ms TTL=50
Reply from 199.16.156.198: bytes=32 time=120ms TTL=50
Reply from 199.16.156.198: bytes=32 time=125ms TTL=50

Ping statistics for 199.16.156.198:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 118ms, Maximum = 125ms, Average = 120ms

C:\Users\Aidan>
```

page = downloadPage(url)

- Majority of time spent waiting for connection
- Disk/CPU usage will be near 0
- Bandwidth will not be maximised

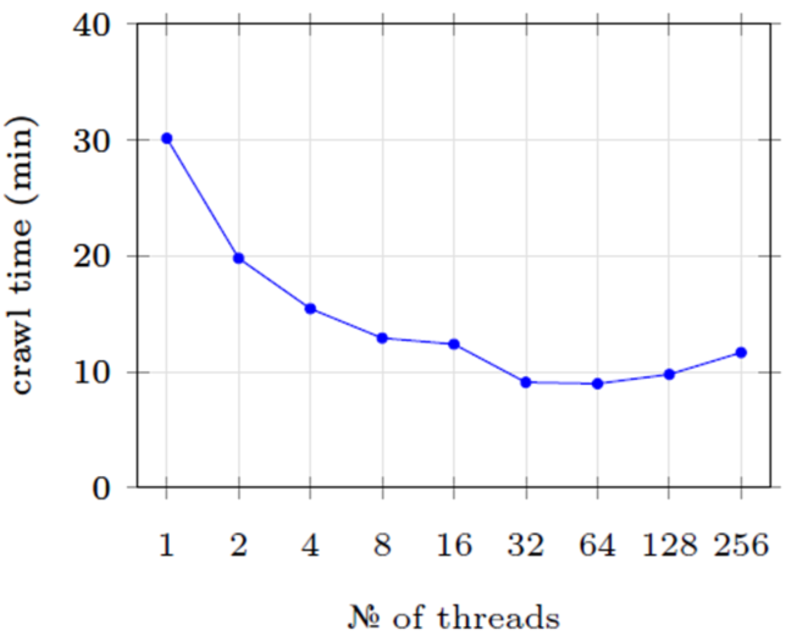
Performance?

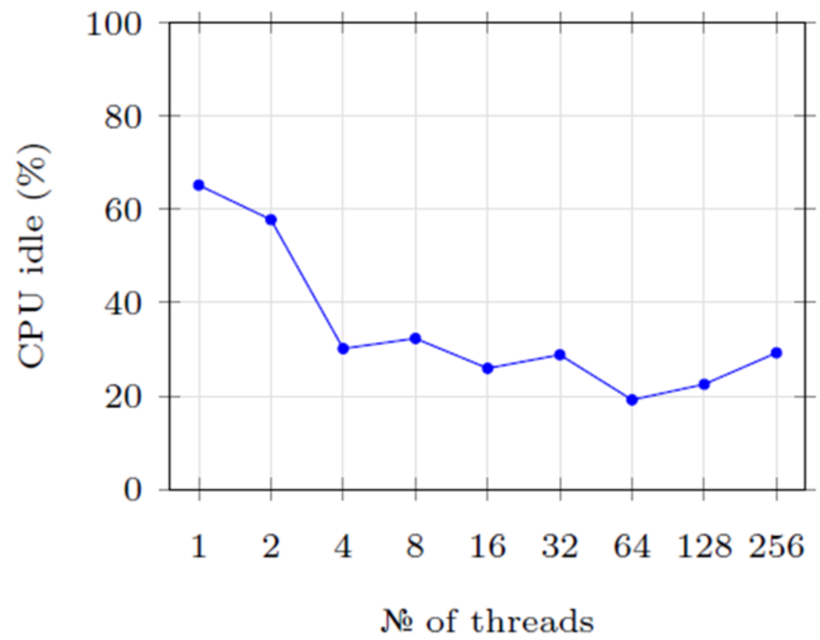
Crawling: Multi-threading Important

```
crawl(list seedUrls)
    frontier_i = seedUrls
    new set urlsSeen
    while(!frontier_i .isEmpty())
        new list frontier_i+1
        new list threads
        for url : frontier_i
                thread = new DownloadPageThread.run(url,urlsSeen,frontier_i+1)
                threads.add(thread)
        threads.poll()
        i++
DownloadPageThread: run(url,urlsSeen,frontier_i+1)
    page = downloadPage(url)
    synchronised: urlsSeen.add(url)
    synchronised: frontier_i+1.addAll(extractUrls(page).removeAll(urlsSeen))
    synchronised: store(page)
```

Crawling: Multi-threading Important

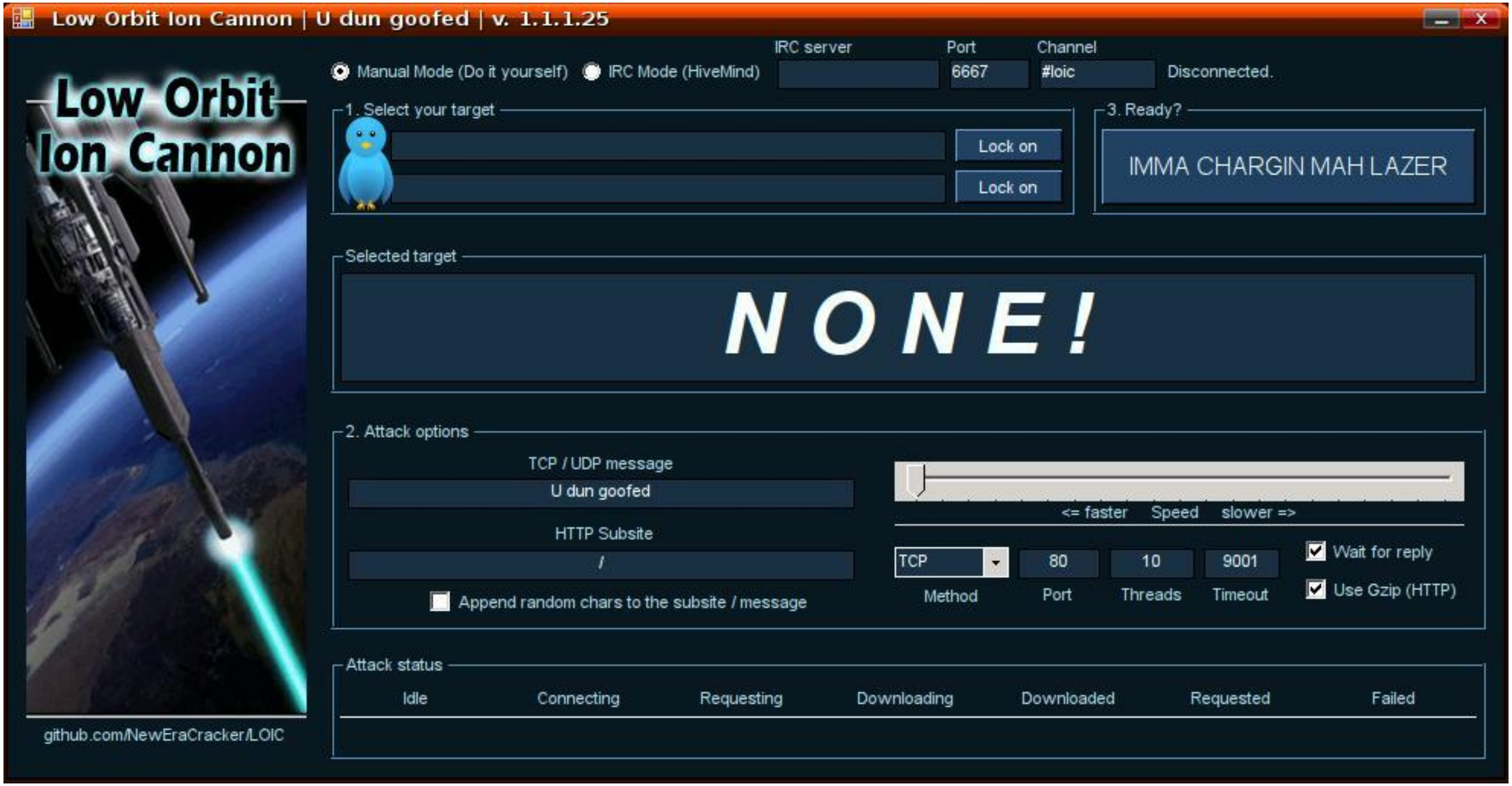
Crawl 1,000 URLs ...





Crawling: Important to be Polite!

(Distributed) Denial of Server Attack: (D)DoS



Crawling: Avoid (D)DoSing

- Christopher Weatherhead
- 18 months prison

… more likely your IP range will be banned

Crawling: Web-site Scheduler

```
crawl(list seedUrls)
    frontier_i = seedUrls
    new set urlsSeen
    while(!frontier_i .isEmpty())
        new list frontier_i+1
        new list threads
        for url : schedule(frontier_i) #maximise time between two pages on one site
                thread = new DownloadPageThread.run(url,urlsSeen,fronter_i+1)
                threads.add(thread)
        threads.poll()
        i++
DownloadPageThread: run(url,urlsSeen,frontier_i+1)
    page = downloadPage(url)
    synchronised: urlsSeen.add(url)
    synchronised: frontier_i+1.addAll(extractUrls(page) .removeAll(urlsSeen))
    synchronised: store(page)
```

Robots Exclusion Protocol

http://website.com/robots.txt

```
User-agent: *
Disallow: /
```

No bots allowed on the website.

```
User-agent: *
Disallow: /user/
Disallow: /main/login.html
```

No bots allowed in /user/ sub-folder or login page.

```
User-agent: googlebot
Disallow: /
```

Ban only the bot with “user-agent” googlebot.

Robots Exclusion Protocol (non-standard)

```
User-agent: googlebot
Crawl-delay: 10
```

Tell the googlebot to only crawl a page from this host no more than once every 10 seconds.

```
User-agent: *
Disallow: /
Allow: /public/
```

Ban everything but the /public/ folder for all agents

```
User-agent: *
Sitemap: http://example.com/main/sitemap.xml
```

Tell user-agents about your *site-map*

Site-Map: Additional crawler information

```xml
<?xml version="1.0" encoding="utf-8"?>
<urlset>
    <url>
        <loc>http://aidanhogan.com/</loc>
        <lastmod>2017-04-17</lastmod>
        <changefreq>weekly</changefreq>
        <priority>0.8</priority>
    </url>
    <url>
        <loc>http://aidanhogan.com/teaching/</loc>
        <lastmod>2017-04-04</lastmod>
        <changefreq>monthly</changefreq>
        <priority>0.5</priority>
    </url>
</urlset>
```

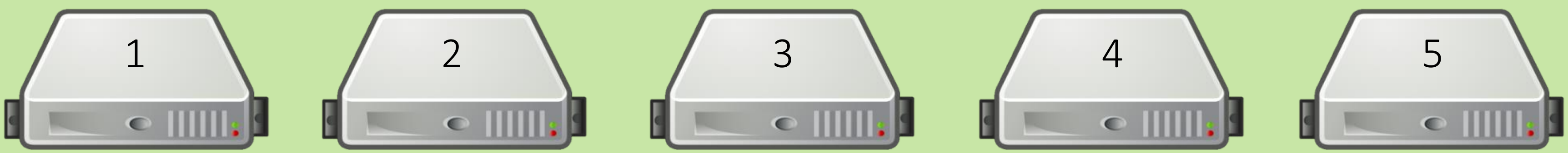
Crawling: Important Points

- Seed-list: Entry point for crawling
- Frontier: Extract links from current pages for next round
- Seen-list: Avoid cycles
- Threading: Keep machines busy
- Politeness: Don't annoy web-sites
  - Set delay between crawling pages on the same web-site
  - Stick to what's stated in the robots.txt file
  - Check for a site-map

Crawling: Distribution

How might we implement a distributed crawler?

```
for url : frontier_i-1
        map(url,count)
```



Similar benefits to multi-threading

What will be the bottleneck as machines increase?

Bandwidth or politeness delays

Crawling: All the Web?

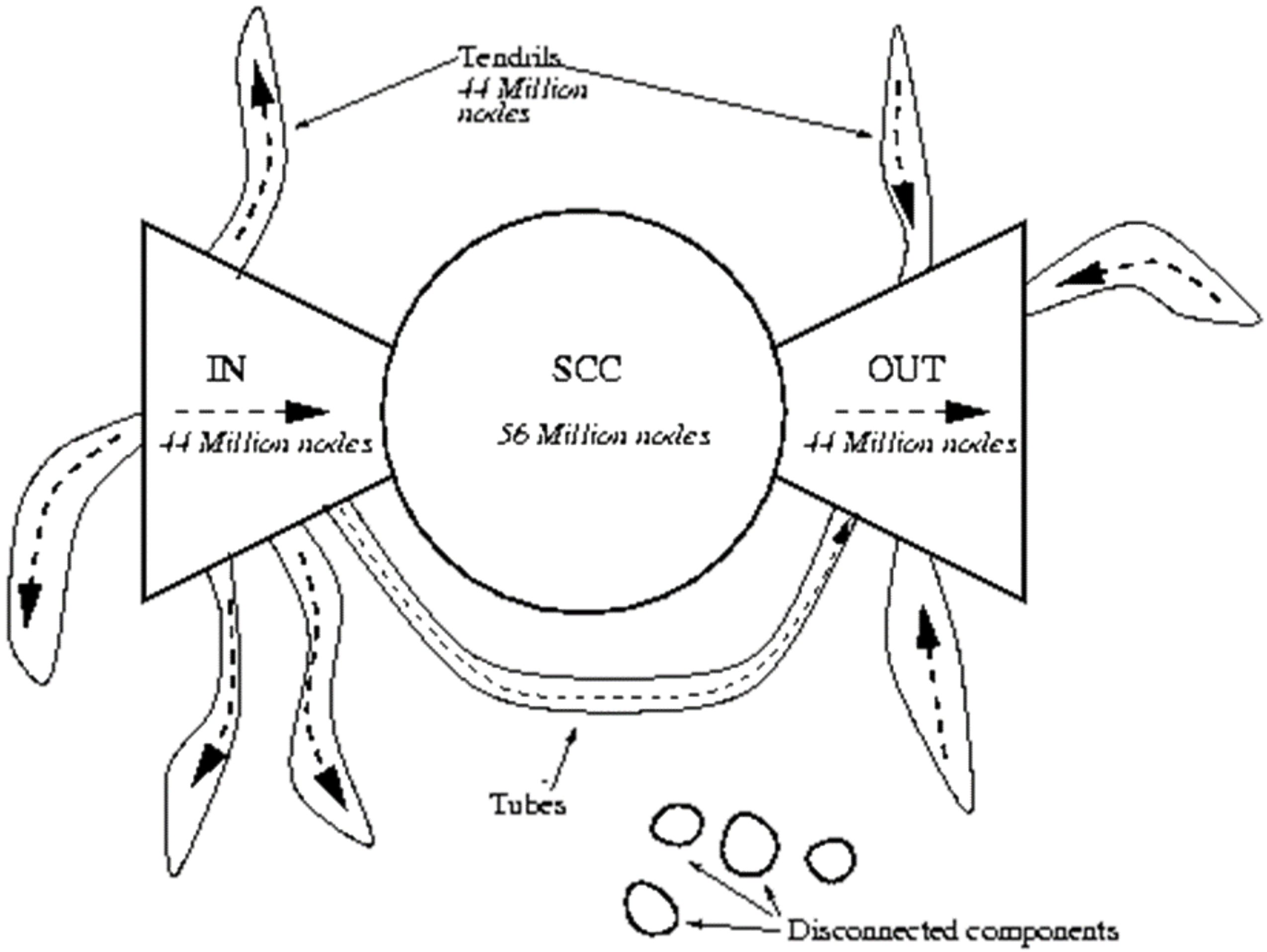
Can we crawl all the Web?

Crawling: All the Web?

Can ~~we~~ crawl all the Web?

Can Google crawl all the Web?

Crawling: Inaccessible (Bow-Tie)



Broder et al. "Graph structure in the web," Comput. Networks, vol. 33, no. 1-6, pp. 309–320,

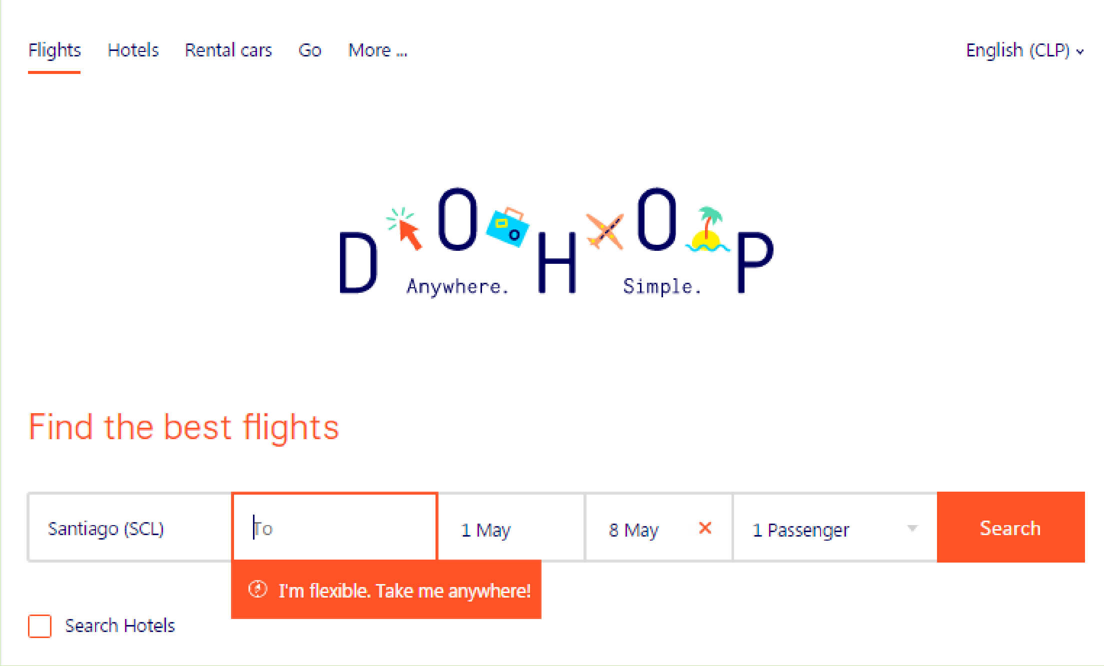
Crawling: Inaccessible (Deep Web)

What is the Deep Web?

Crawling: Inaccessible (Deep Web)

What is the Deep Web?

- Dynamically-generated content



Crawling: Inaccessible (Deep Web)

What is the Deep Web?

- Dynamically-generated content
- Password-protected

Crawling: Inaccessible (Deep Web)

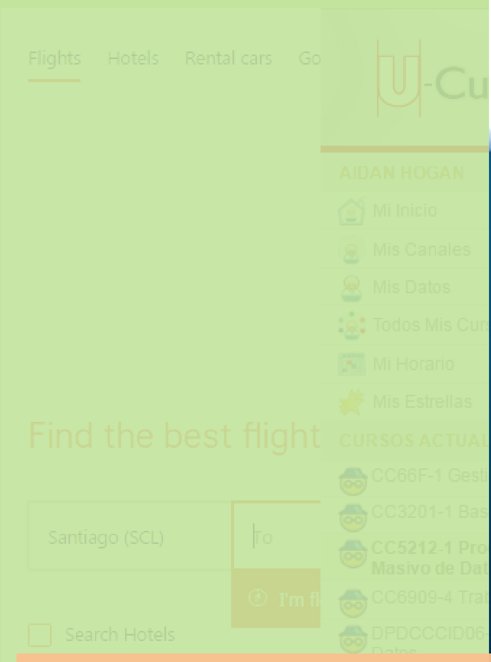
What is the Deep Web?

- Dynamically-generated content
- Password-protected
- Dark Web

Crawling: Inaccessible (Deep Web)

What is the Deep Web?

- Dynamically-gen
- Password-protec
- Dark Web



46% of statistics made up on the spot ⚠

Crawling: All the Web?

Can ~~we~~ crawl all the Web?

Can Google crawl all the Web?

Can Google crawl itself?

Apache Nutch

- Open-source crawling framework!
- Compatible with Hadoop!

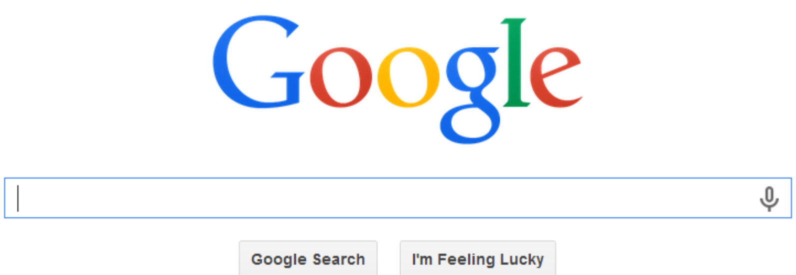
https://nutch.apache.org/

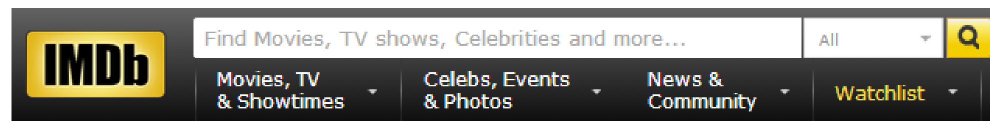
Information Retrieval: Inverted Indexing

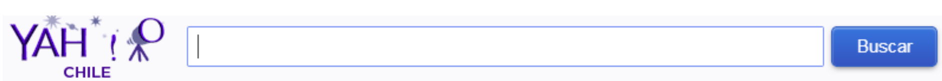
Inverted Index

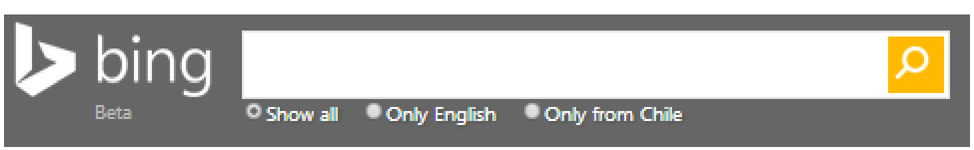
- Inverted Index: A map from words to documents
  - "Inverted" because usually documents map to words

Examples of applications?









Inverted Index: Example

1

en.wikipedia.org/wiki/Fruitvale_Station

Fruitvale Station

From Wikipedia, the free encyclopedia

Fruitvale Station is a 2013 American drama film written and directed by Ryan Coogler.

Inverted index:

Term List	Posting List
a	(1,2,…)
american	(1,5,…)
and	(1,2,…)
by	(1,2,…)
directed	(1,2,…)
drama	(1,16,…)
…	…

Inverted Index: Example Search

american drama

- AND: Intersect posting lists
- OR: Union posting lists
- PHRASE: ???

How should we implement PHRASE?

Inverted index:

Term List	Posting List
a	(1,2,…)
american	(1,5,…)
and	(1,2,…)
by	(1,2,…)
directed	(1,2,…)
drama	(1,16,…)
…	…

Inverted Index: Example

1

en.wikipedia.org/wiki/Fruitvale_Station

Fruitvale Station

From Wikipedia, the free encyclopedia

1 10 18 21 23 28 37 43 47 55 59 68 71 76

Fruitvale Station is a 2013 American drama film written and directed by Ryan Coogler.

Inverted index:

Term List	Posting List
a	(1,[21,96,103,…]), (2,[…]), …
american	(1,[28,123]), (5,[…]), …
and	(1,[57,139,…]), (2,[…]), …
by	(1,[70,157,…]), (2,[…]), …
directed	(1,[61,212,…]), (4,[…]), …
drama	(1,[38,87,…]), (16,[…]), …
…	…

Inverted Index: Flavours

Record-level inverted index:

Maps words to documents without positional information

Term List	Posting List
a	(1,2,…)
american	(1,5,…)
and	(1,2,…)
by	(1,2,…)
directed	(1,2,…)
drama	(1,16,…)
…	…

Word-level inverted index:

Additionally maps words with positional information

Term List	Posting List
a	(1,[21,96,103,…]), (2,[…]), …
american	(1,[28,123]), (5,[…]), …
and	(1,[57,139,…]), (2,[…]), …
by	(1,[70,157,…]), (2,[…]), …
directed	(1,[61,212,…]), (4,[…]), …
drama	(1,[38,87,…]), (16,[…]), …
…	…

Inverted Index: Word Normalisation

drama america

How can we solve this problem?

Inverted index:

Term List	Posting List
a	(1,[21,96,103,…]), (2,[…]), …
american	(1,[28,123]), (5,[…]), …
and	(1,[57,139,…]), (2,[…]), …
by	(1,[70,157,…]), (2,[…]), …
directed	(1,[61,212,…]), (4,[…]), …
drama	(1,[38,87,…]), (16,[…]), …
…	…

Inverted Index: Word Normalisation

drama america

How can we solve this problem?

Normalise words:

Stemming cuts the ends off of words using generic rules:

{ America , American , americas , americanise } → { america }

Inverted index:

Term List	Posting List
a	(1,[21,96,103,…]), (2,[…]), …
american	(1,[28,123]), (5,[…]), …
and	(1,[57,139,…]), (2,[…]), …
by	(1,[70,157,…]), (2,[…]), …
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{ America , American , americas , americanise } → { america }

Lemmatisation uses knowledge of the word to normalise:

{ better , goodly , best } → { good }

Inverted index:

Term List	Posting List
a	(1,[21,96,103,…]), (2,[…]), …
american	(1,[28,123]), (5,[…]), …
and	(1,[57,139,…]), (2,[…]), …
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{ better , goodly , best } → { good }

Synonym expansion

{ film , movie } → { movie }

Inverted index:

Term List	Posting Lists
a	(1,[21,96,103,...]), (2,[...]), ...
america	(1,[28,123]), (5,[...]), ...
and	(1,[57,139,...]), (2,[...]), ...
by	(1,[70,157,...]), (2,[...]), ...
directed	(1,[61,212,...]), (4,[...]), ...
drama	(1,[38,87,...]), (16,[...]), ...
...	...

Inverted Index: Word Normalisation

drama america

How can we solve this problem?

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{ better , goodly , best } → { good }

Synonym expansion

{ film , movie } → { movie }

- Language specific!
- Use same normalisation on query and document!

Inverted index:

Term List	Posting Lists
a	(1,[21,96,103,…]), (2,[…]), …
[illegible]	(1,[28,123]), (5,[…]), …
and	(1,[57,139,…]), (2,[…]), …
by	(1,[70,157,…]), (2,[…]), …
directed	(1,[61,212,…]), (4,[…]), …
drama	(1,[38,87,…]), (16,[…]), …
…	…

Inverted Index: Space

Record-level inverted index:

Maps words to documents without positional information

Term List	Posting List
a	(1,2,…)
american	(1,5,…)
and	(1,2,…)
by	(1,2,…)
directed	(1,2,…)
drama	(1,16,…)
…	…

Space? $\sum_{d \in D} \mathrm{U}(d)$ (sum of unique words in all docs)

Word-level inverted index:

Additionally maps words with positional information

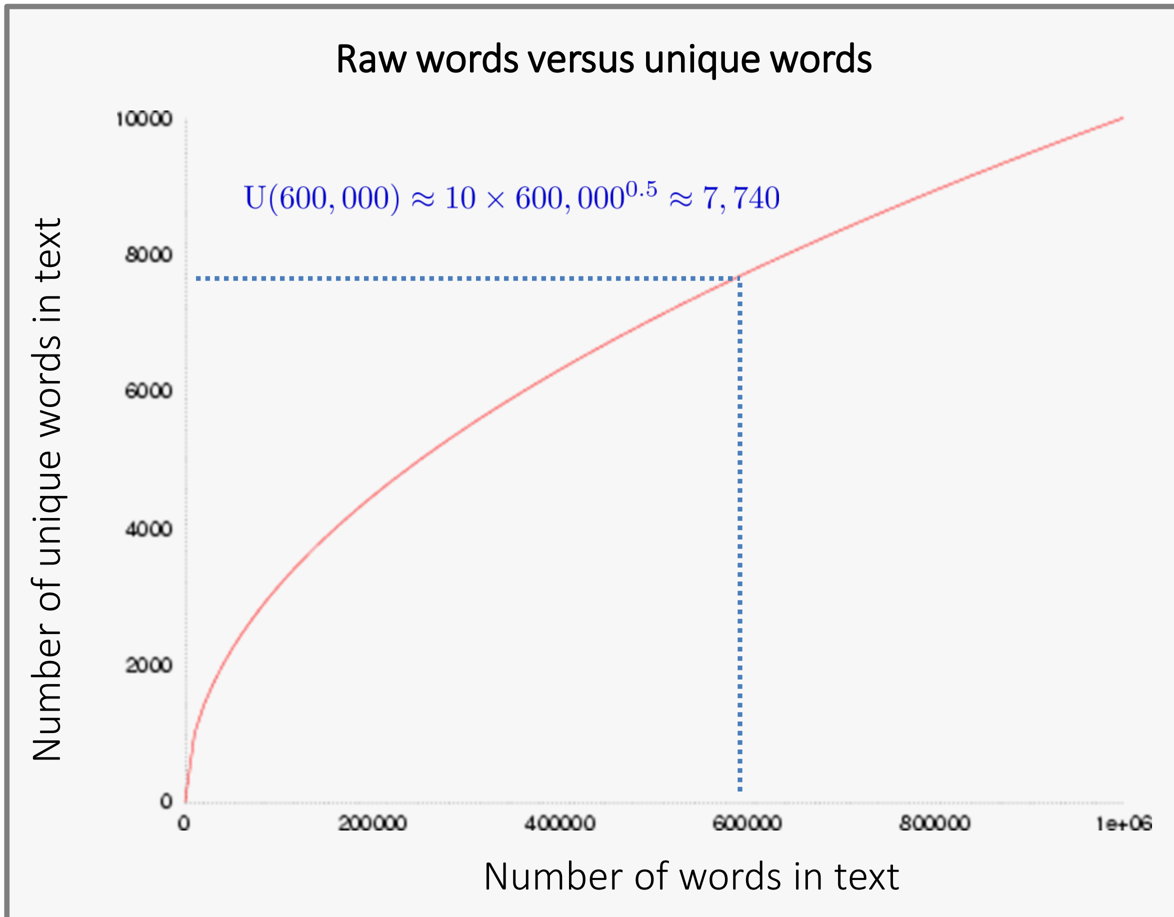
Term List	Posting List
a	(1,[21,96,103,…]), (2,[…]), …
american	(1,[28,123]), (5,[…]), …
and	(1,[57,139,…]), (2,[…]), …
by	(1,[70,157,…]), (2,[…]), …
directed	(1,[61,212,…]), (4,[…]), …
drama	(1,[38,87,…]), (16,[…]), …
…	…

Space? $\sum_{d \in D} \mathrm{W}(d)$ (sum of all word occurrences in all docs)

Inverted Index: Unique Words

Not so many unique words ...

- Heap's law: $\mathrm{U}(n) \approx K n^{\beta}$
- English text
  - K ∈ [10,100]
  - β ∈ [0.4,0.6]



Inverted Index: Space

$\mathrm{U}(d) \approx K \times \mathrm{W}(d)^{\beta}$ ⚠

Record-level inverted index:

Maps words to documents without positional information

Term List	Posting List
a	(1,2,…)
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Space? ? $\sum_{d \in D} \mathrm{U}(d)$ (sum of unique words in all docs)

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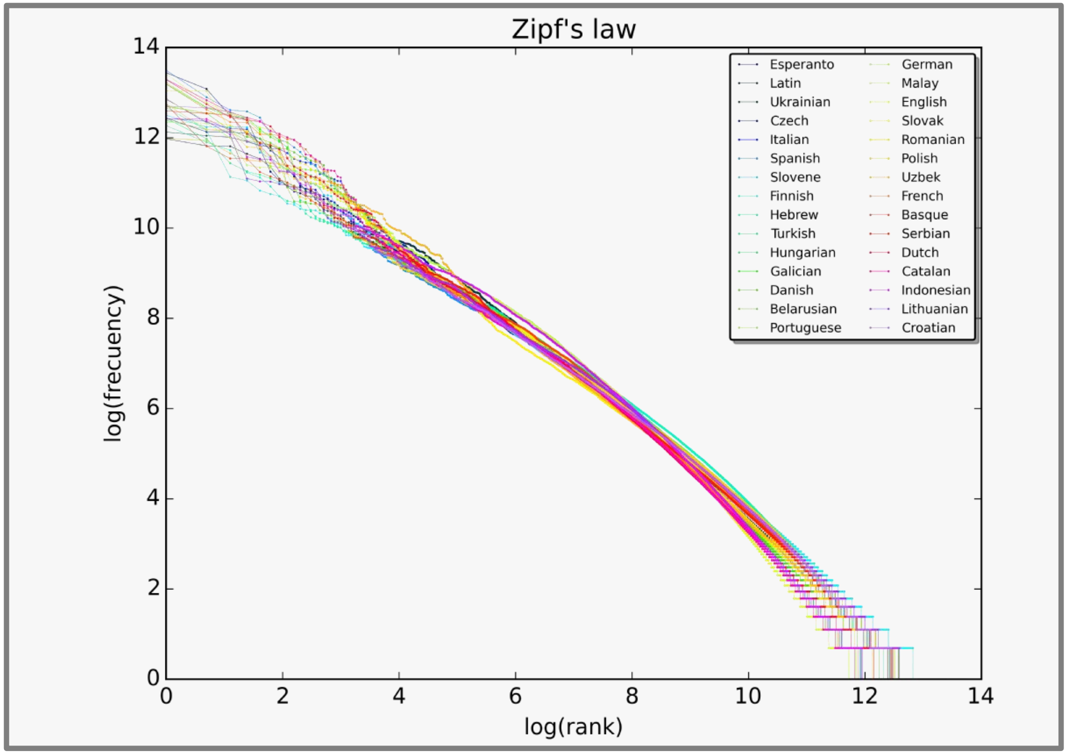
american	(1,[28,123]), (5,[…]), …
and	(1,[57,139,…]), (2,[…]), …
by	(1,[70,157,…]), (2,[…]), …
directed	(1,[61,212,…]), (4,[…]), …
drama	(1,[38,87,…]), (16,[…]), …
…	…

Space? ? $\sum_{d \in D} \mathrm{W}(d)$ (sum of all word occurrences in all docs)

Inverted Index: Common Words

Many occurrences of few words
/ Few occurrences of many words

- Zipf's law
- In English text:
  - "the" 7%
  - "of" 3.5%
  - "and" 2.7%
  - 135 words cover half of all occurrences



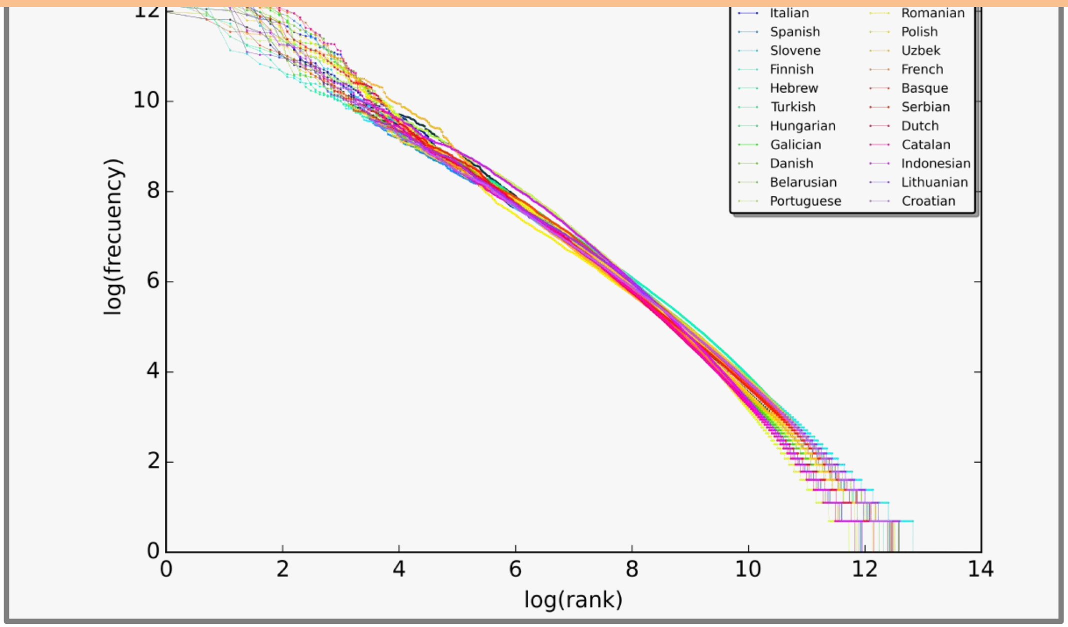
Zipf's law: *the most popular word will occur twice as often as the second most popular word, thrice as often as the third most popular word, n times as often as the n-most popular word.*

Inverted Index: Common Words

Many occurrences of few words / Few occurrences of many words

Expect long posting lists for common words ⚠

- In English text:
  - “the” 7%
  - “of” 3.5%
  - “and” 2.7%
  - 135 words cover half of all occurrences



Zipf’s law: *the most popular word will occur twice as often as the second most popular word, thrice as often as the third most popular word, n times as often as the n-most popular word.*

Inverted Index: Common Words

- Perhaps implement stop-words?
  - Most common words contain least information

```
the drama in america
```

Inverted Index: Common Words

- Perhaps implement stop-words?
- Perhaps implement block-addressing?

Fruitvale Station is a 2013 American drama film written and directed by Ryan Coogler.

Block 1 Block 2

What is the effect on phrase search?

Small blocks ~ okay
Big blocks ~ not okay

Term List	Posting List
a	(1,[1,…]), (2,[…]), …
american	(1,[1,…]), (5,[…]), …
and	(1,[2, …]), (2,[…]), …
by	(1,[2, …]), (2,[…]), …
…	…

Inverted Index: Common Words

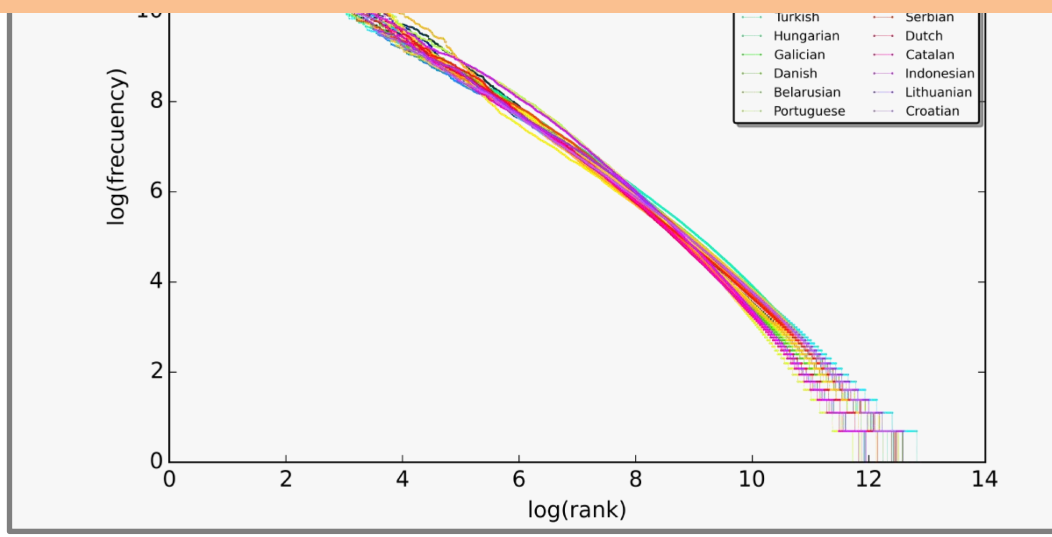
Many occurrences of few words

/ Few occurrences of many words

Expect long posting lists for common words ⚠

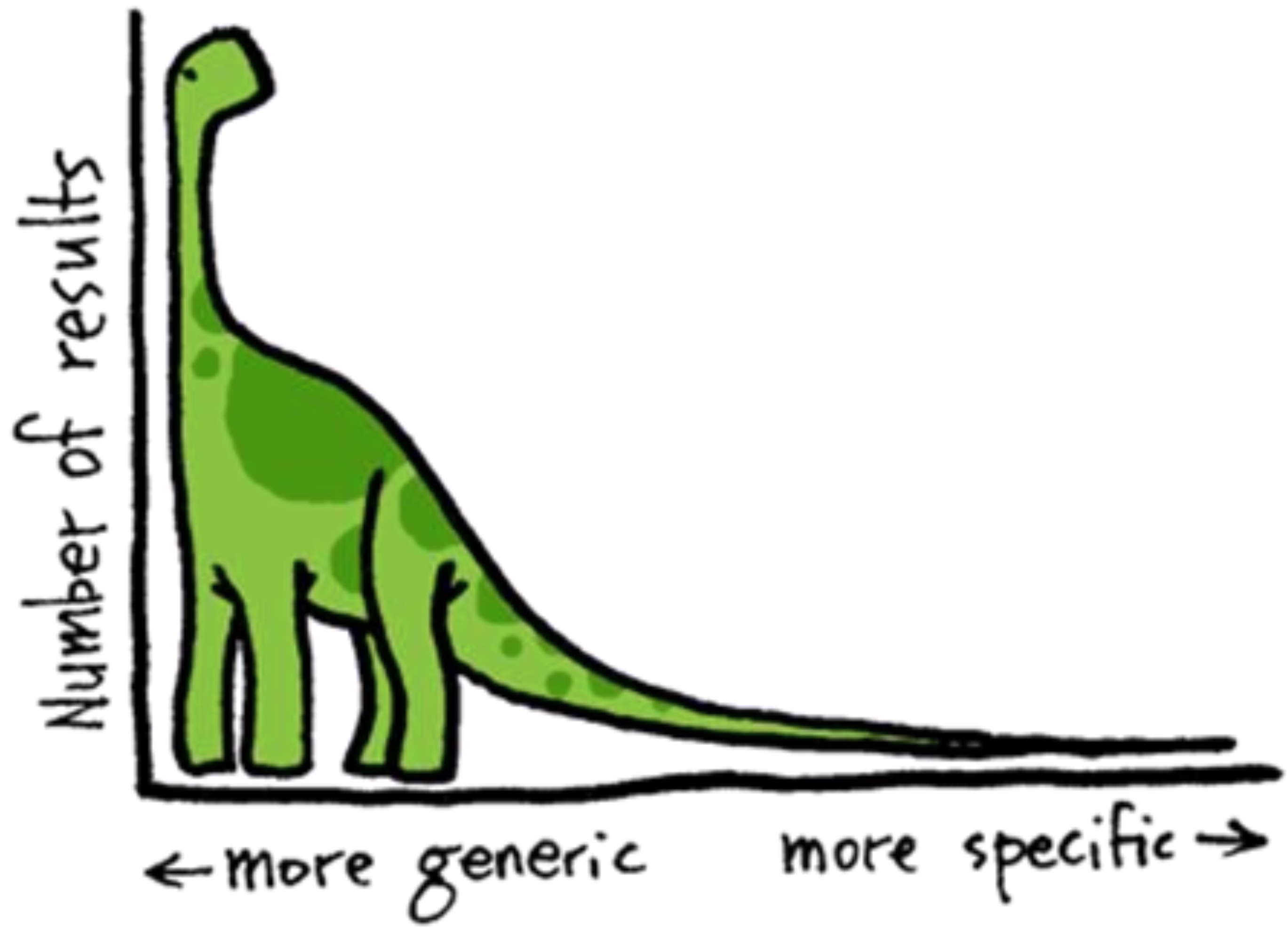
Expect more queries with common words

- “the” 7%
- “of” 3.5%
- “and” 2.7%
- 135 words cover half of all occurrences

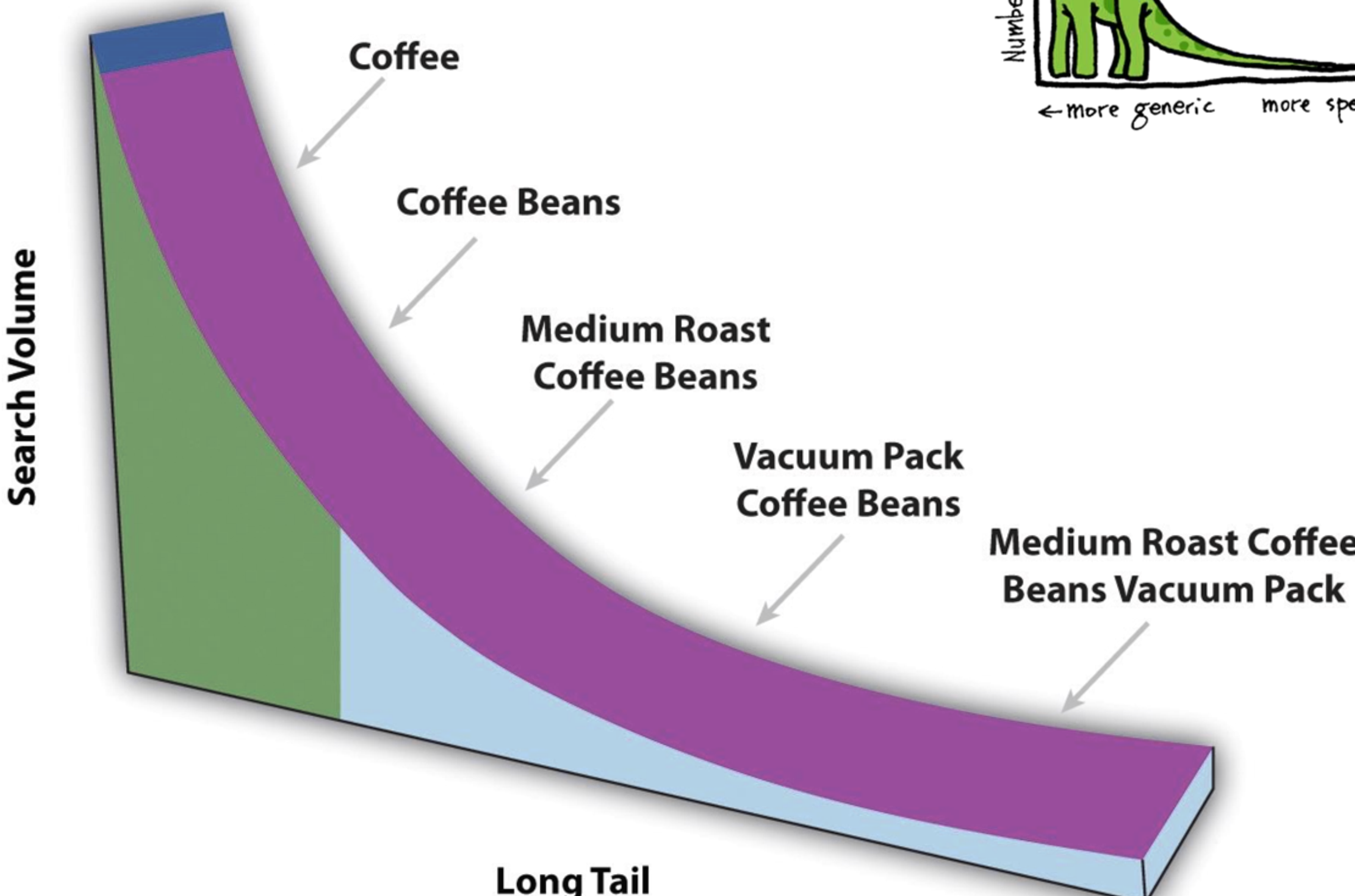


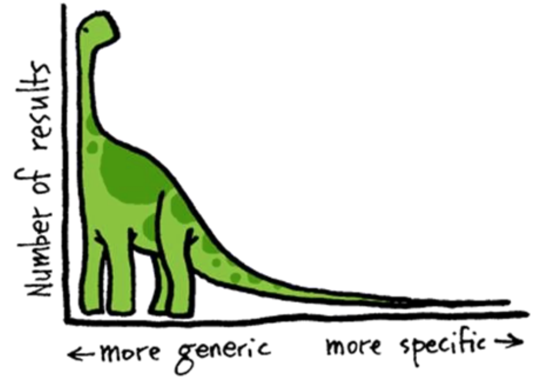
Zipf’s law: *the most popular word will occur twice as often as the second most popular word, thrice as often as the third most popular word, n times as often as the n-most popular word.*

The Long Tail of Search



The Long Tail of Search

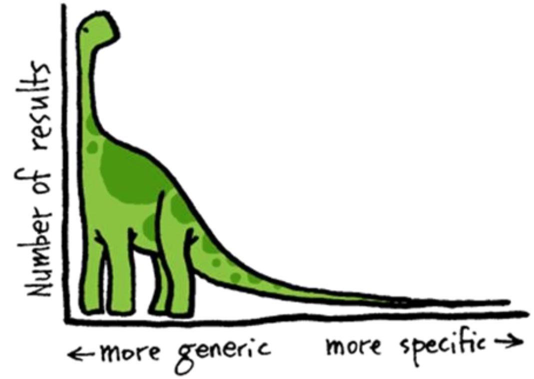




How to optimise for this?

Caching for common queries like “coffee”

If interested …



Anatomy of the Long Tail: Ordinary People with Extraordinary Tastes

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ABSTRACT

The success of "infinite-inventory" retailers such as Amazon.com and Netflix has been ascribed to a "long tail" phenomenon. To wit, while the majority of their inventory is not in high demand, in aggregate these "worst sellers," unavailable at limited-inventory competitors, generate a significant fraction of total revenue. The long tail phenomenon, however, is in principle consistent with two fundamentally different theories. The first, and more popular hypothesis, is that a majority of consumers consistently follow the crowds and only a minority have any interest in niche content; the second hypothesis is that everyone is a bit eccentric, consuming both popular and specialty products. Based on examining extensive data on user preferences for movies, music, Web search, and Web browsing, we find overwhelming support for the latter theory. However, the observed eccentricity is

Categories and Subject Descriptors

J.4 [**Computer Applications**]: Social and Behavioral Sciences

General Terms

Economics, Measurement

Keywords

Long tail, infinite inventory

1. INTRODUCTION

The explosion of electronic commerce has opened the door to so-called "infinite-inventory" retailers, such as Amazon.com, Netflix, and the iTunes Music Store, which offer an order of

Search Implementation

- Vocabulary keys:
  - Hashing: O(1) lookups (assuming ideal hashing)
    - no range queries
    - relatively easy to update (though rehashing expensive!)
  - Sorting/B-Tree: O(log(u)) lookups, u unique words
    - range queries
    - tricky to update (standard methods for B-trees)
  - Tries: O(l) lookups, l length of the word
    - range queries, compressed, auto-completion!
    - referencing becomes tricky (on disk)

Tries? (in class)

Memory Sizes

- Term list (vocabulary keys) small:
  - Often will fit in memory!
- Posting lists larger:
  - On disk / Hot regions cached

Term List	Posting List
a	(1,[21,96,103,…]), (2,[…]), …
american	(1,[28,123]), (5,[…]), …
and	(1,[57,139,…]), (2,[…]), …
by	(1,[70,157,…]), (2,[…]), …
directed	(1,[61,212,…]), (4,[…]), …
drama	(1,[38,87,…]), (16,[…]), …
…	…

Compression techniques

- Numeric compression important

Term List	Posting List
country	(1), (2), (3), (4), (6), (7), …
…	…

Compression techniques: High Level

- Interval indexing
  - Example for record-level indexing
    - Could also be applied for block-level indexing, etc.

Term List	Posting List
country	(1), (2), (3), (4), (6), (7), …
…	…

Term List	Posting List
country	(1-4), (6-7),
…	…

Compression techniques: High Level

- Gap indexing
  – Example for record-level indexing
    - Could also be applied for block-level indexing, etc.

Term List	Posting List
country	(1), (3), (4), (8), (9), …
…	…

Term List	Posting Lists
country	(1), 2, 1, 4, 1
…	…

Benefit? Repeated small numbers easier to compress!

Compression techniques: Bit Level

- Variable length coding: bit-level techniques
- For example, Elias γ (gamma) encoding
  - Assumes many small numbers

$2\lfloor \log_2(z) \rfloor + 1$ bits

z: integer to encode	n = $\lfloor \log_2(z) \rfloor$ coded in unary	a zero marker	next n binary numbers	final Elias γ code
1	0			0
2	1	0	0	100
3	1	0	1	101
4	11	0	00	11000
5	11	0	01	11001
6	11	0	10	11010
7	11	0	11	11011
8	111	0	000	1110000
…	…	…	…	…

Can you decode "0100001100011100001 1001"? ? <1,2,1,1,4,8,5>

Compression techniques: Bit Level

- Variable length coding: bit-level techniques
- For example, Elias δ (delta) encoding
  - Better for some distributions

$\lfloor \log_2(z) \rfloor + 2\lfloor \log_2(\lfloor \log_2(z) \rfloor + 1) \rfloor + 1$ bits

z: integer to encode	$\lfloor \log_2(z) \rfloor + 1$ coded in Elias γ	next $\lfloor \log_2(z) \rfloor$ binary numbers	final Elias δ code
1	0		0
2	100	0	1000
3	100	1	1001
4	101	00	10100
5	101	01	10101
6	101	10	10110
7	101	11	10111
8	11000	000	11000000
…	…	…	…

Can you decode "01100000011001011001001"? ? <1,9,3,1,17>

Compression techniques: Bit Level

- Previous methods “non-parametric”
  - Don’t take an input value
- Other compression techniques parametric:
  - for example, Golomb-*3* code:

z: integer to encode	*n* = ⌊(*z-1*)/3⌋ coded in unary	zero separator	remainder	final Golomb-3 code
1	0		0	00
2	0		10	010
3	0		11	011
4	1	0	0	100
5	1	0	10	1010
6	1	0	11	1011
7	11	0	0	1100
8	11	0	10	11010
…	…		…	…

Comparison

- Small values

z: integer de entrada	código Elias γ	código Elias δ	código Golomb-3
1	0	0	00
2	100	1000	010
3	101	1001	011
4	11000	10100	100
5	11001	10101	1010
6	11010	10110	1011
7	11011	10111	1100
8	1110000	11000000	11010

- Larger values

z: integer de entrada	código Elias γ	código Elias δ	código Golomb-3
100	1111110100100	10110100100	1111111...101
…			**…**

Compression techniques: Byte Level

- Use variable length byte codes
- Use last bit of byte to indicate if the number ends

- For example:

00100100	10100010	00000101	00100100

18	81	274

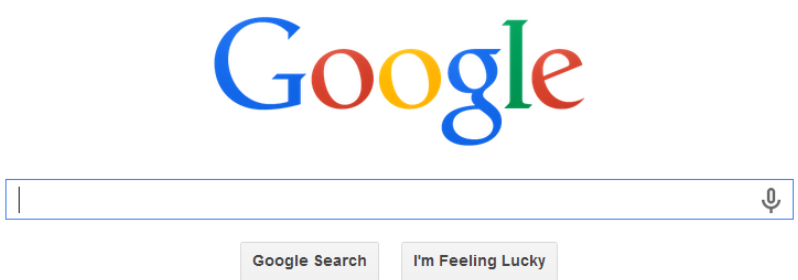
Other Optimisations

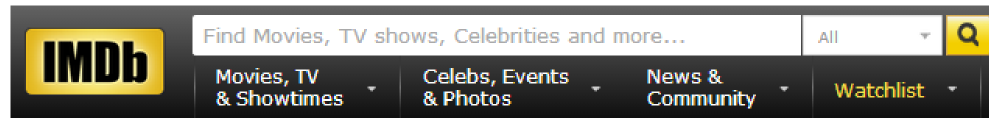
- Top-Doc: Order posting lists to give likely "top documents" first: good for top-*k* results
- Selectivity: Load the posting lists for the most rare keywords first; apply thresholds
- Sharding: Distribute over multiple machines

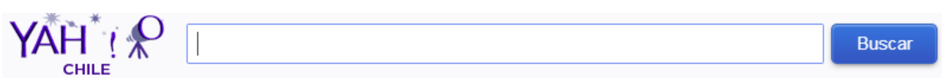
How to distribute? (in class)

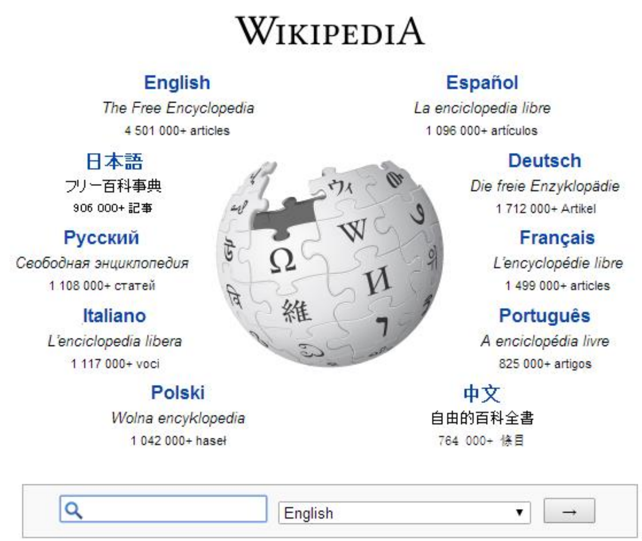
Extremely Scalable/Efficient

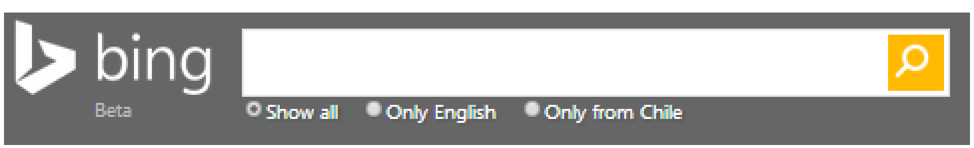
When engineered correctly ☺







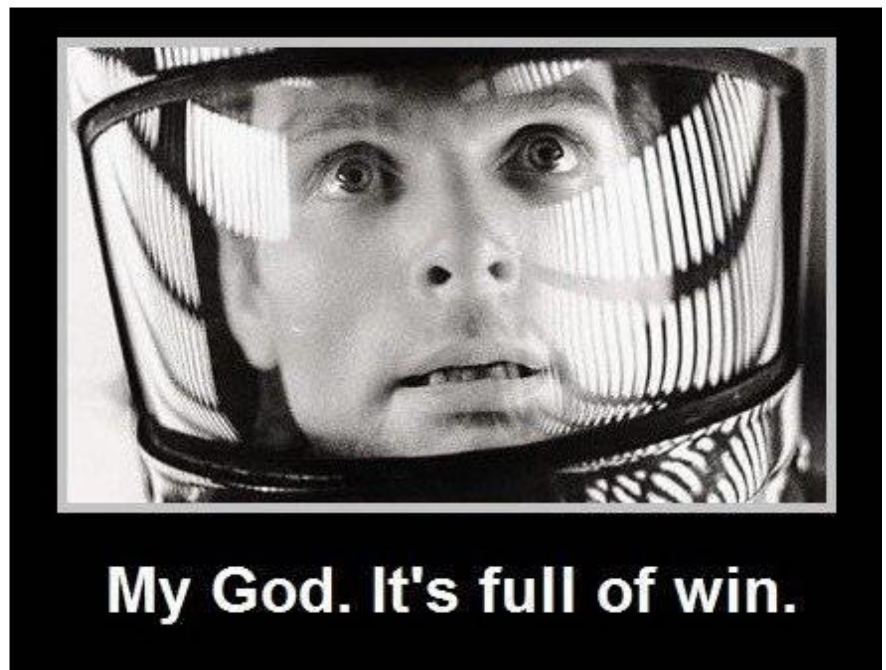




Lucene: Text Indexing

Apache Lucene

- Inverted Index
  - They built one so you don't have to!
  - Open Source in Java



Apache Lucene

Lucene

- Inverted Index
  - Re-used in other well-known projects

Apache Solr

elasticsearch

Doug Cutting (above) & Mike Cafarella (below)

Lucene™

nutch

hadoop

Class Projects

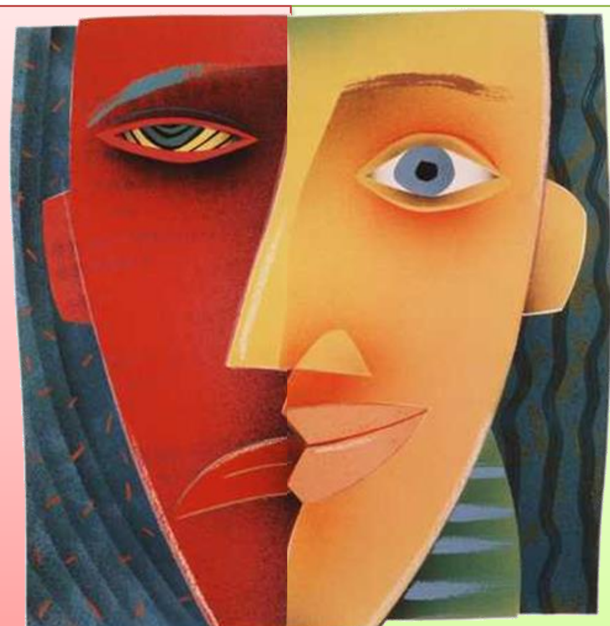
Course Marking

- 55% for Weekly Labs (~5% a lab!)
- 15% for Class Project
- 30% for 2x Controls

Assignments each week

Controls

Working in groups



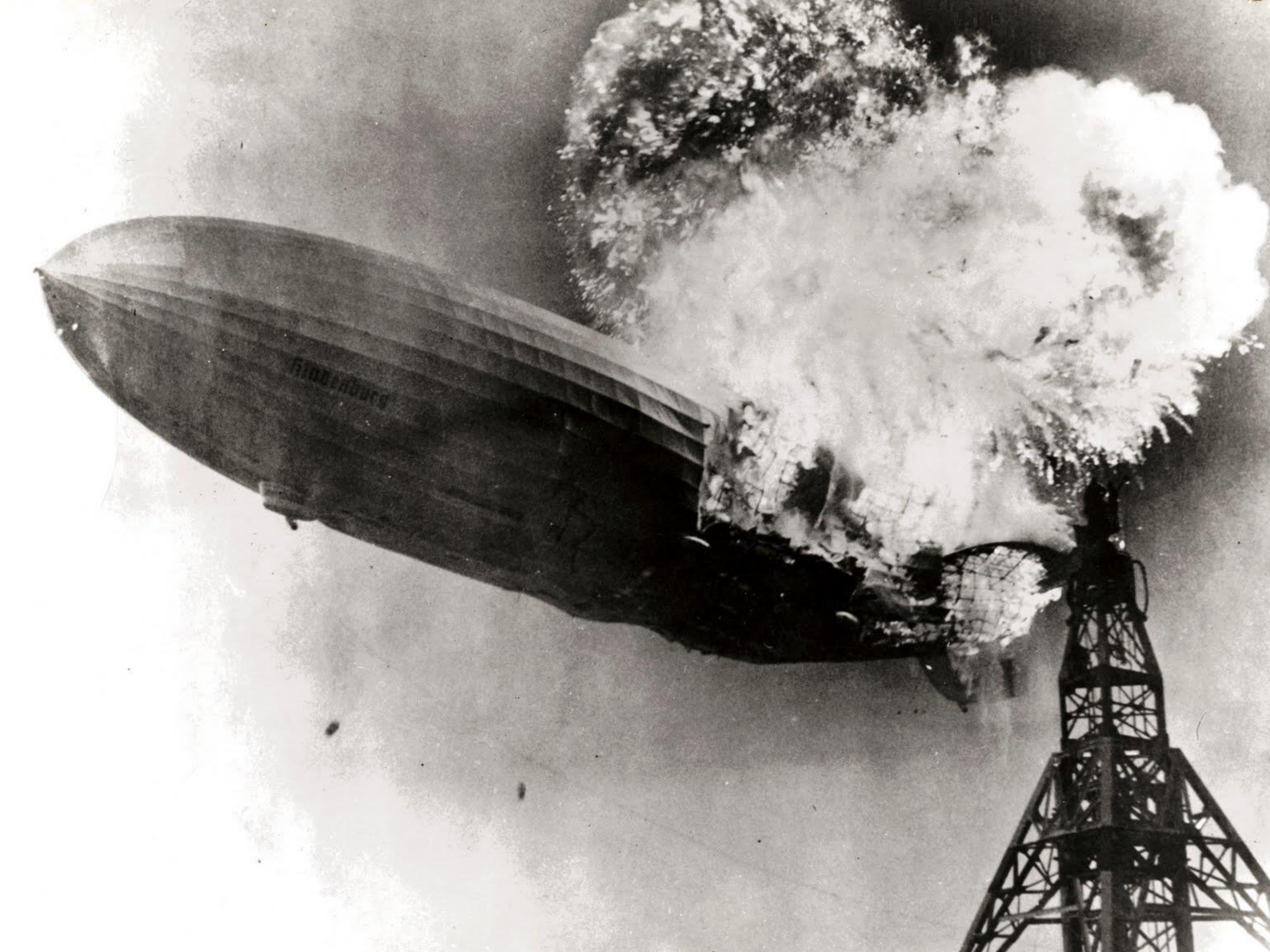
Hands-on each week!

No final exam!

Working in groups!

Class Project

- Done in threes
- Goal: Use what you've learned to do something cool/fun (hopefully)
- Expected difficulty: A bit more than a lab's worth
  - But without guidance (can extend lab code)
- Marked on: Difficulty, appropriateness, scale, good use of techniques, presentation, coolness, creativity, value
  - Ambition is appreciated, even if you don't succeed
- Process:
  - Start thinking up topics / find interesting datasets!
- Deliverables: 4 minute presentation & short report



Questions?