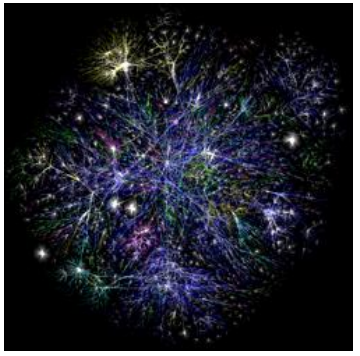
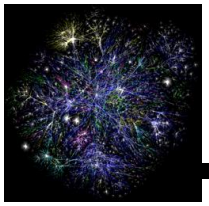
Information Networks

Searching on the Web

The anatomy of a search engine

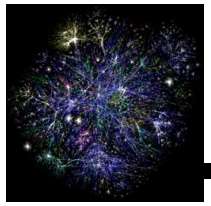
Lecture 7



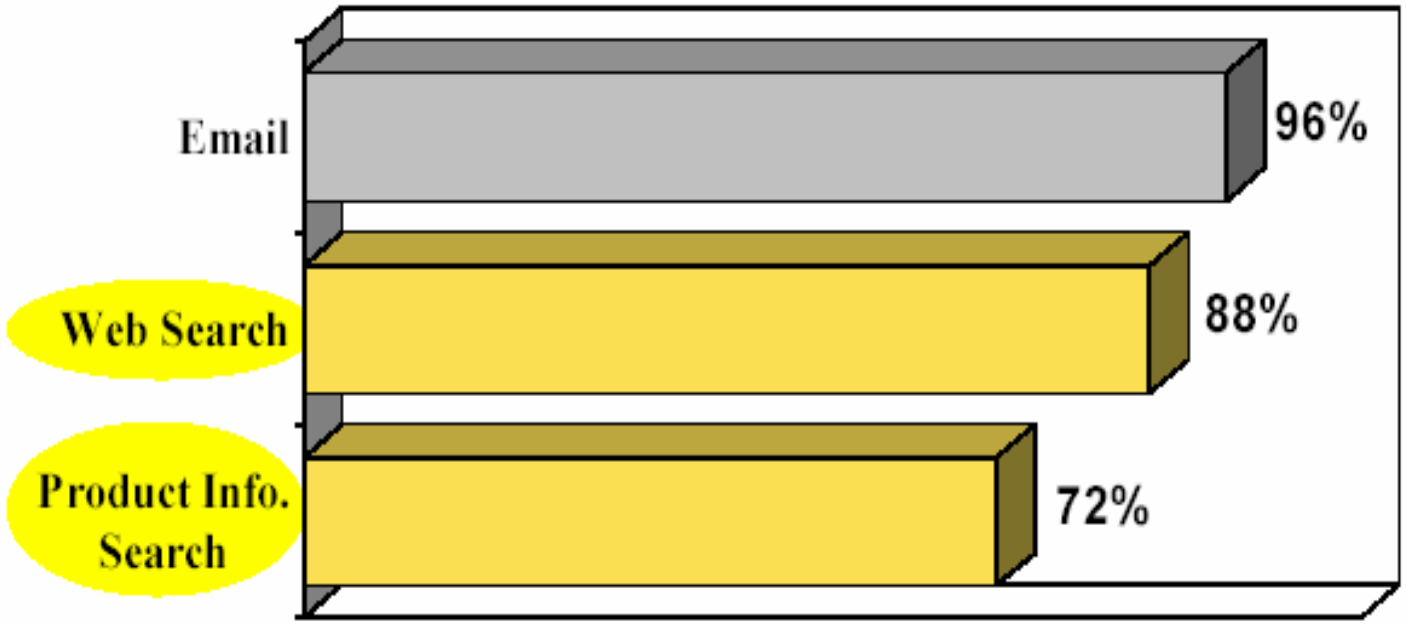


Why Web Search?

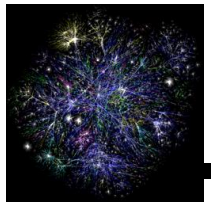
- Search is the main motivation for the development of the Web
  - people post information because they want it to be found
  - people are conditioned to searching for information on the Web (“Google it”)
  - The main tool is text search
    - directories cover less than 0.05% of the Web
    - 13% of traffic is generated by search engines
- Great motivation for academic and research work
  - Information Retrieval and data mining of massive data
  - Graph theory and mathematical models
  - Security and privacy issues



Top Online Activities

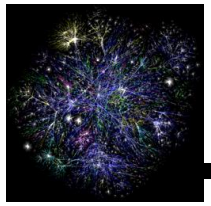


Feb 25, 2003: >600M queries per day



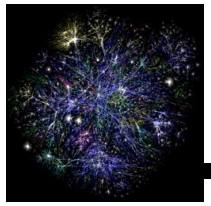
Outline

- Web Search overview
  - from traditional IR to Web search engines
- The anatomy of a search engine
  - Crawling, Duplicate elimination, indexing

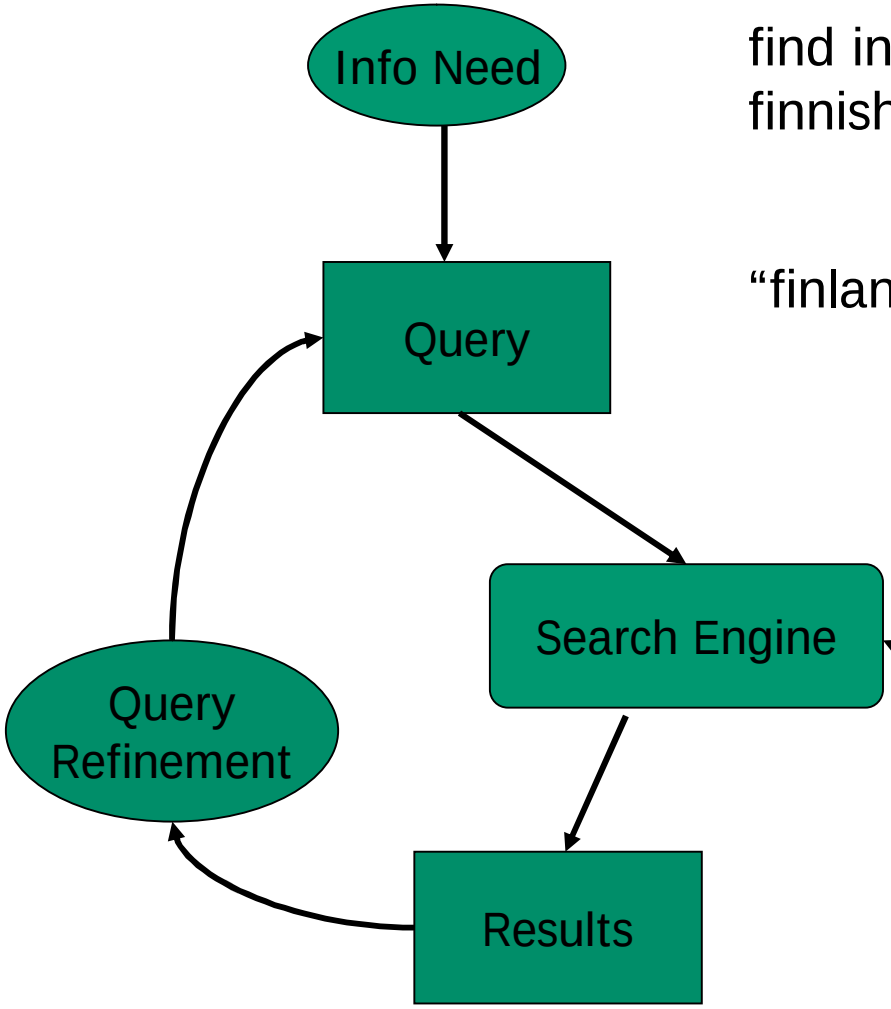


… not so long ago

- Information Retrieval as a scientific discipline has been around for the last 40-50 years
- Mostly dealt with the problem of developing tools for librarians for finding relevant papers in scientific collections



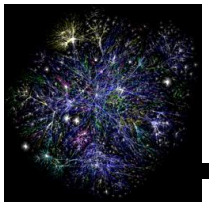
Classical Information Retrieval



find information about finnish train schedule

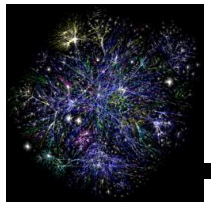
“finland train schedule”

Goal: Return the documents that best satisfy the user’s information need



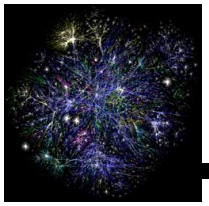
Classical Information Retrieval

- Implicit Assumptions
  - fixed and well structured corpus of manageable size
  - trained cooperative users
  - controlled environment



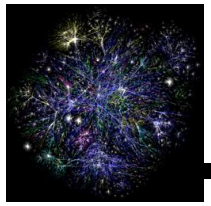
Classic IR Goal

- Classic Relevance
  - For each query Q and document D assume that there exists a relevance score S(D,Q)
    - score average over all users U and contexts C
  - Rank documents according to S(D,Q) as opposed to S(D,Q,U,C)
    - Context ignored
    - Individual users ignored

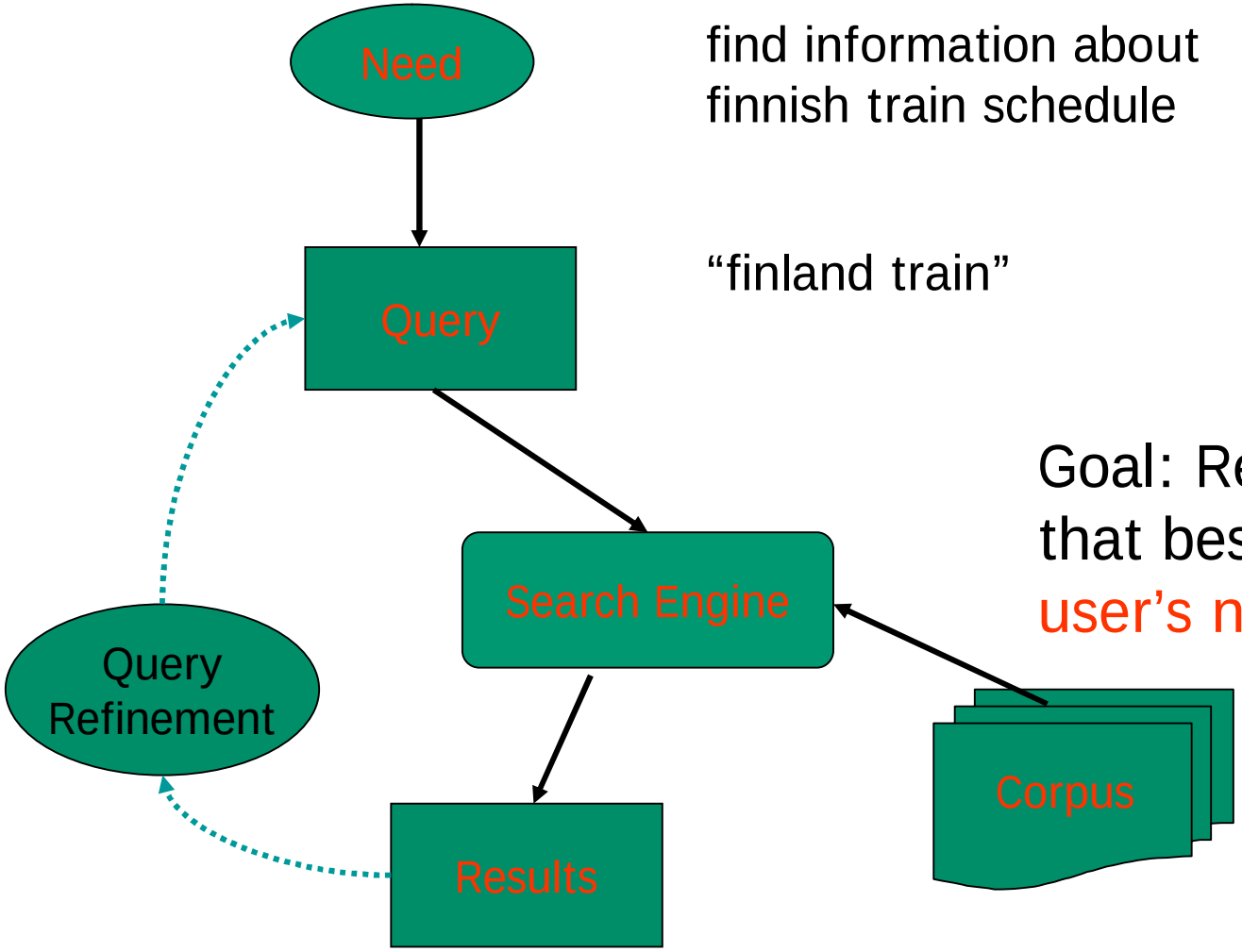


IR Concepts

- Models
  - Boolean model: retrieve all documents that contain the query terms
    - rank documents according to some term-weighting scheme
  - Term-vector model: docs and queries are vectors in the term space
    - rank documents according to the cosine similarity
  - Term weights
    - tf × idf : (tf = term frequency, idf = log of inverse document frequency – promote rare terms)
- Measures
  - Precision: percentage of relevant documents over the returned documents
  - Recall: percentage of relevant documents over all existing relevant documents



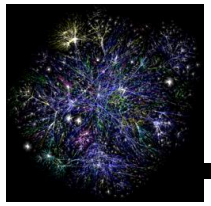
Web Search



find information about finnish train schedule

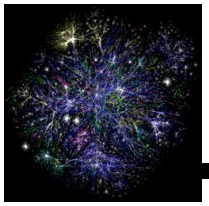
“finland train”

Goal: Return the results that best satisfy the user’s need



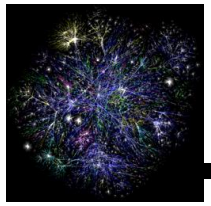
The need behind the query

- Informational – learn about something (~40%)
  - “colors of greek flag”, “haplotype definition”
- Navigational – locate something (~25%)
  - “microsoft”, “Jon Kleinberg”
- Transactional – do something (~35%)
  - Access a service
    - “train to Turku”
  - Download
    - “earth at night”
  - Shop
    - “Nicon Coolpix”



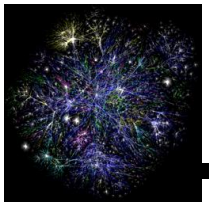
Web users

- They ask a lot but they offer little in return
  - Make ill-defined queries
    - short (2.5 avg terms, 80% <3 terms – AV, 2001)
    - imprecise terms
    - poor syntax
    - low effort
  - Unpredictable
    - wide variance in needs/expectations/expertise
  - Impatient
    - 85% look one screen only (mostly “above the fold”)
    - 78% queries not modified (one query per session)
- …but they know how to spot correct information
  - follow “the scent of information”…

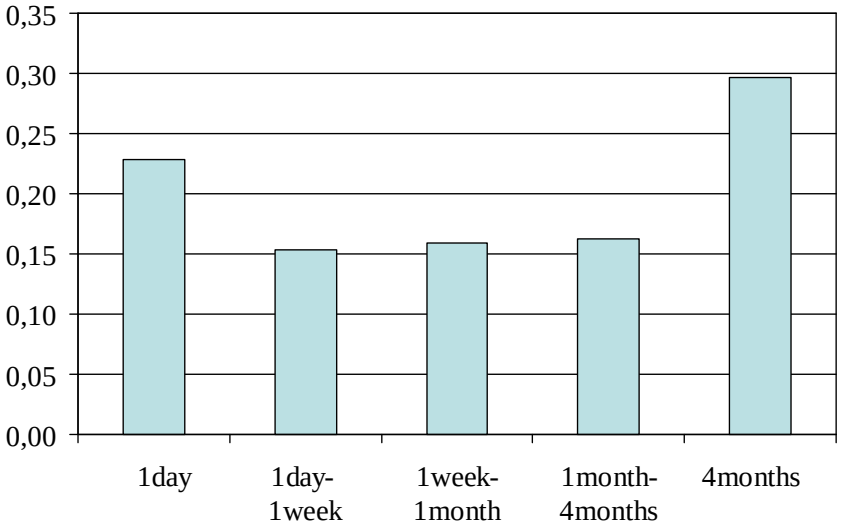


Web corpus

- Immense amount of information
  - 2005, Google: 8 Billion pages
  - fast growth rate (double every 8-12 months)
  - Huge Lexicon: 10s-100s millions of words
- Highly diverse content
  - many different authors, languages, encodings
  - highly un-structured content
- Static + Dynamic (“the hidden Web”)
- Volatile
  - crawling challenge

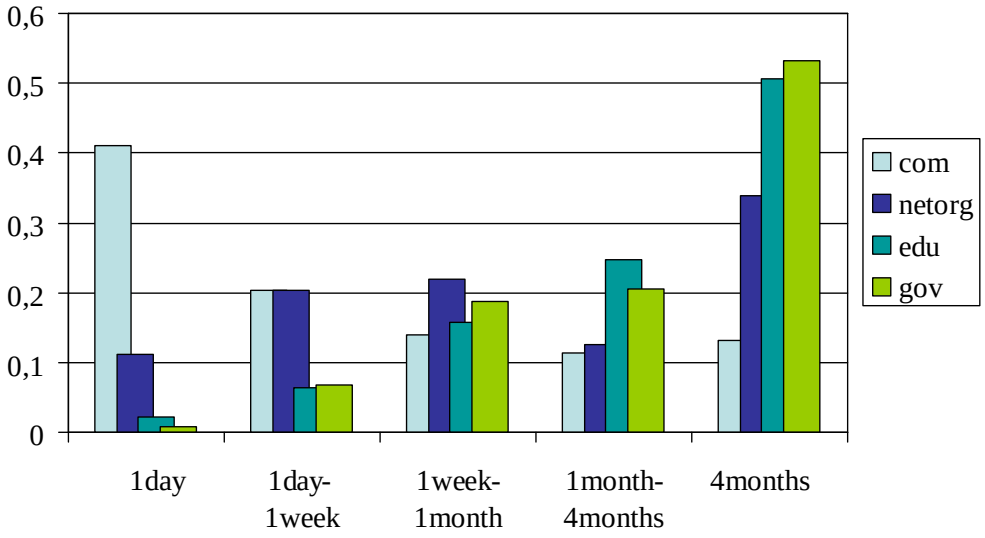


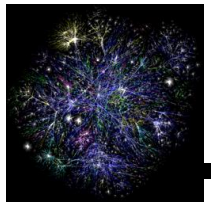
Rate of change [CGM00]



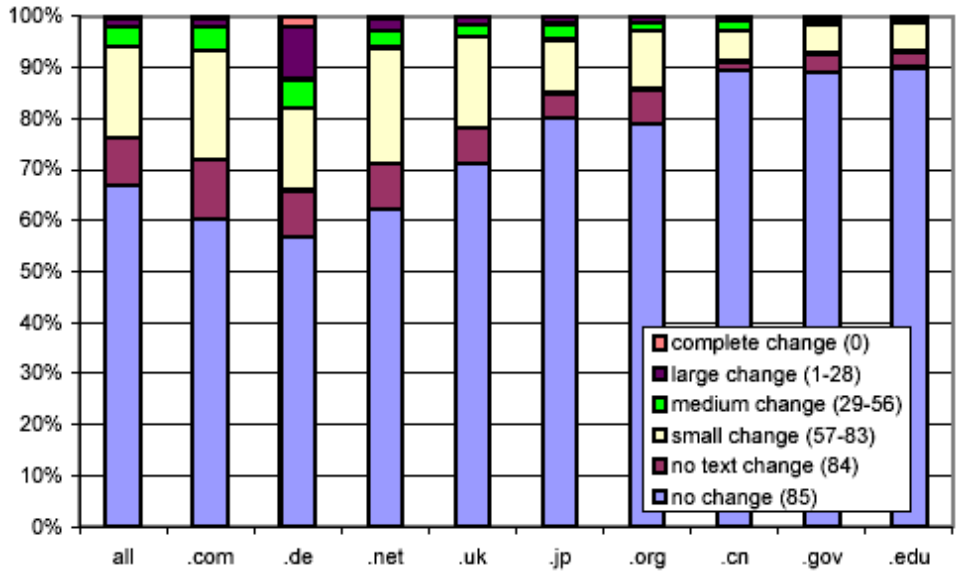
average rate of change

average rate of change per domain



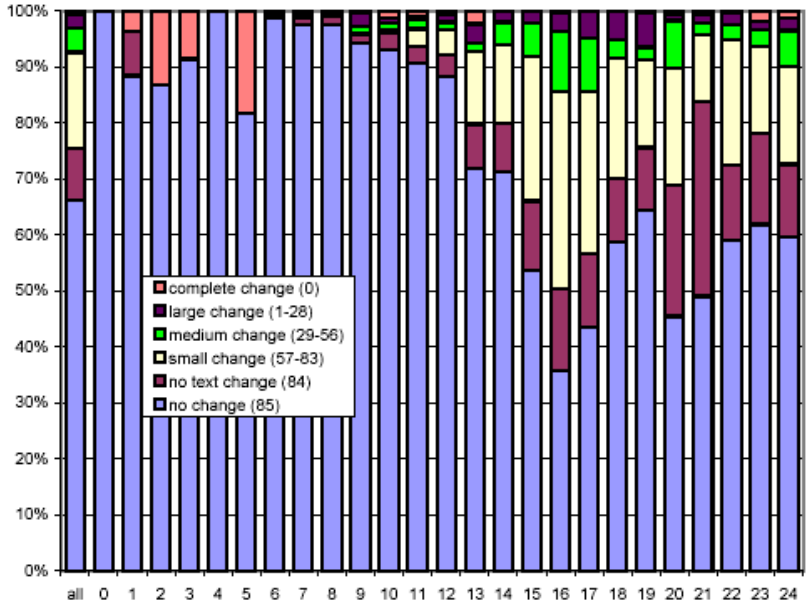


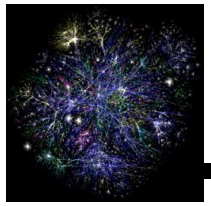
Rate of Change [FMNW03]



Rate of change per domain. Change between two successive downloads

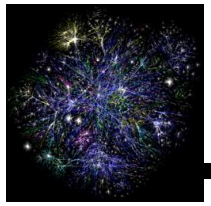
Rate of change as a function of document length





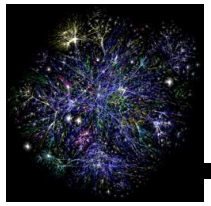
Other corpus characteristics

- Links, graph topology, anchor text
  - this is now part of the corpus!
- Significant amount of duplication
  - ~30% (near) duplicates [FMN03]
- Spam!
  - 100s of million of pages
  - Add-URL robots



Query Results

- Static documents
  - text, images, audio, video,etc
- Dynamic documents (“the invisible Web”)
  - dynamic generated documents, mostly database accesses
- Extracts of documents, combinations of multiple sources
  - www.googlism.com



Googlism

Googlism

Googlism.com will find out what Google.com thinks of you, your friends or anything! Search for your name here or for a good laugh check out some of the popular Googlisms below.

"By the way, its a wicked site good stuff." - Andrew Thompson

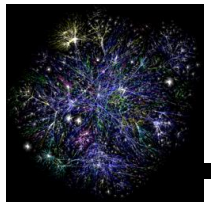
Googlism! Who What Where When

Googlism for: tsaparas

tsaparas is president and ceo of prophecy entertainment inc
tsaparas is the only person who went to the college of the holy cross
tsaparas is to be buried in thessaloniki this morning following his death late on thursday night at the age of 87

Googlism for: athens

athens is the home of the parthenon
athens is the capital of greece and the country's economic
athens is 'racing against time'
athens is a hometown guy



The evolution of Search Engines

- First Generation – text data only
  - word frequencies, tf × idf

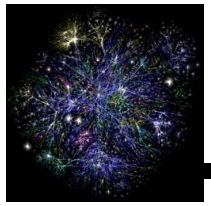
1995-1997: AltaVista
Lycos, Excite

- Second Generation – text and web data
  - Link analysis
  - Click stream analysis
  - Anchor Text

1998 - now : Google leads the way

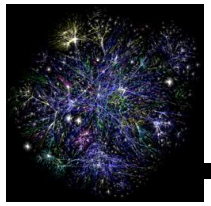
- Third Generation – the need behind the query
  - Semantic analysis: what is it about?
  - Integration of multiple sources
  - Context sensitive
    - personalization, geographical context, browsing context

Still experimental



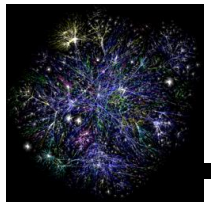
First generation Web search

- Classical IR techniques
  - Boolean model
  - ranking using tf × idf relevance scores
- good for informational queries
- quality degraded as the web grew
- sensitive to spamming



Second generation Web search

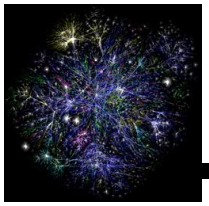
- Boolean model
- Ranking using web specific data
  - HTML tag information
  - click stream information (DirectHit)
    - people vote with their clicks
  - directory information (Yahoo! directory)
  - anchor text
  - link analysis



Link Analysis Ranking

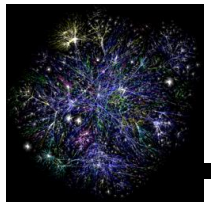
- Intuition: a link from q to p denotes endorsement
  - people vote with their links
- Popularity count
  - rank according to the incoming links
- PageRank algorithm
  - perform a random walk on the Web graph. The pages visited most often are the ones most important.

$$PR(p) = \alpha \sum_{q \to p} \frac{PR(q)}{|F(q)|} + (1-\alpha)\frac{1}{n}$$



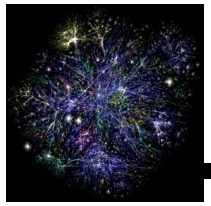
Second generation SE performance

- Good performance for answering navigational queries
  - “finding needle in a haystack”
- … and informational queries
  - e.g “oscar winners”
- Resistant to text spamming
- Generated substantial amount of research
- Latest trend: specialized search engines



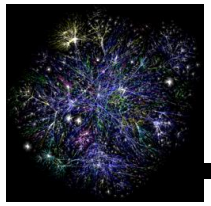
Result evaluation

- recall becomes useless
- precision measured over top-10/20 results
- Shift of interest from “relevance” to “authoritativeness/reputation”
- ranking becomes critical



Second generation spamming

- Online tutorials for "search engine persuasion techniques"
  - "How to boost your PageRank"
- Artificial links and Web communities
- Latest trend: "Google bombing"
  - a community of people create (genuine) links with a specific anchor text towards a specific page. Usually to make a political point



Google Bombing

Google™ Advanced Search Preferences Language Tools Search Tips

"miserable failure" Google Search

Search: the web pages from Canada

Web | Images | Groups | Directory | News

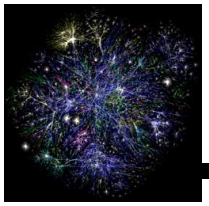
Searched the web for **"miserable failure"**. Results **1** - **10** of about

Biography of President George W. Bush
Home > President > Biography President George W. Bush En Español.
George W. Bush is the 43rd President of the United States. He ...
Description: Biography of the president from the official White House web site.
Category: Kids and Teens > School Time > ... > Bush, George Walker
www.whitehouse.gov/president/gwbbio.html - 29k - Cached - Similar pages

Biography of Jimmy Carter
Home > History & Tours > Past Presidents > Jimmy Carter. Jimmy Carter.
Jimmy Carter aspired to make Government "competent and compassionate ...
Description: Short biography from the official White House site.
Category: Society > History > ... > Presidents > Carter, James Earl
www.whitehouse.gov/history/presidents/jc39.html - 36k - Cached - Similar pages

Michael Moore.com
February 11, 2004 (67th anniversary of the Great Flint Sit-Down Strike) An Open
Letter from Michael Moore to George "I'ma War President!" Bush. Dear Mr. Bush,. ...
Description: Official site of the gadfly of corporations, creator of the film Roger and Me and the television show...
Category: Arts > People > M > Moore, Michael
www.michaelmoore.com/ - 47k - 4 Mar 2004 - Cached - Similar pages

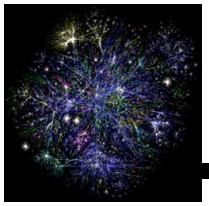
Michael Moore.com
I'll Be Voting For Wesley Clark / Good-Bye Mr. Bush - by Michael Moore.
Many of you have written to me in the past months asking, "Who ...
www.michaelmoore.com/index_real.php - 44k - Cached - Similar pages



Google Bombing

- Try also the following
  - “weapons of mass destruction”
  - “french victories”

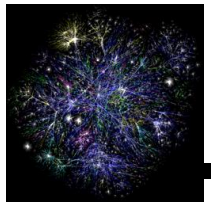
- Do Google bombs capture an actual trend?
- How sensitive is Google to such bombs?



Spamming evolution

- Spammers evolve together with the search engines. The two seem to be intertwined.

Adversarial Information Retrieval



Third generation Search Engines: an example

Google

Advanced Search Preferences Language Tools Search Tips

haplotype definition [Google Search]

Search: the web pages from Canada

Web | Images | Groups | Directory | News

Searched the web for **haplotype definition**. Results **1 - 10**

Tip: To get dictionary definitions for your search terms, click on the underlined search term(s) in the blue bar above your search

Web Definition: **Haplotype** - A way of denoting the collective genotype of a number of closely linked loci on a chromosome.
www.ornl.gov/TechResources/Human_Genome/glossary/glossary_h.html - More definitions

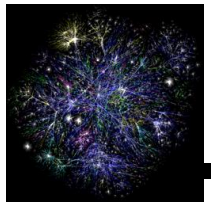
HAPLOTYPE definition

Home/H/HA/**HAPLOTYPE**. Medical Dictionary Search Engine. Advertise on this site! A service of health-link-net.com. Browse Dictionary Alphabetically. **...**
www.books.md/H/dic/haplotype.php - 11k - Cached - Similar pages

SimWalk2: **Haplotype** Exchange Format **Definition**

Back to SimWalk2 Overview. SimWalk2: **Haplotype** Exchange Format **Definition**. An example **Haplotype** Exchange Format (HEF) file: _____ **...**
watson.hgen.pitt.edu/docs/SW2_HEFdef.html - 12k - Cached - Similar pages

The need behind the query



Third generation Search Engines: another example

Google™ Advanced Search Preferences Language Tools Search Tips

iraq war [Google Search]

Search: (•) the web ( ) pages from Canada

Web | Images | Groups | Directory | News

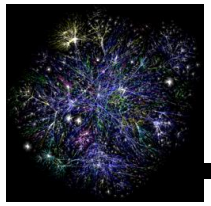
Searched the web for **iraq war**. Results **1** - **10**

Category: Regional > Middle East > ... > History > Iran-Iraq War

News: Blair's defence of the **Iraq war** - The Times (subscription) - 13 hours ago
Iraq War Amputees Get New Limbs, New Life - Los Angeles Times (subscription) - 16 hours ago
Defence chief's **Iraq war** concern - BBC News - 23 hours ago
Try Google News: Search news for **iraq war** or browse the latest headlines

Cost of **War**

... To the right you will find a running total of the amount of money spent by the US Government to finance the **war** in **Iraq**. **...** Cost of the **War** in **Iraq**. 0. **...**
Description: A running total of the amount of money spent by the US Government to finance the **war**, based on estimates...
Category: Society > Issues > ... > Specific Conflicts > Iraq
costofwar.com/ - 5k - Cached - Similar pages



Third generation Search Engines: another example

Google

Advanced Search Preferences Language Tools Search Tips

the answer to life the universe and e | Google Search

Search: the web pages from Canada

The following words are very common and were not included in your search: **the to the**. [de

The **"AND"** operator is unnecessary -- we include all search terms by default. [details]

Web | Images | Groups | Directory | News

Searched the web for **the answer to life the universe and everything**. Results **1 - 10** o

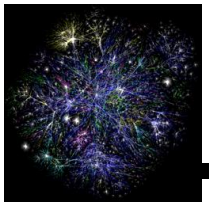
the answer to life the universe and everything = 42

More about calculator.

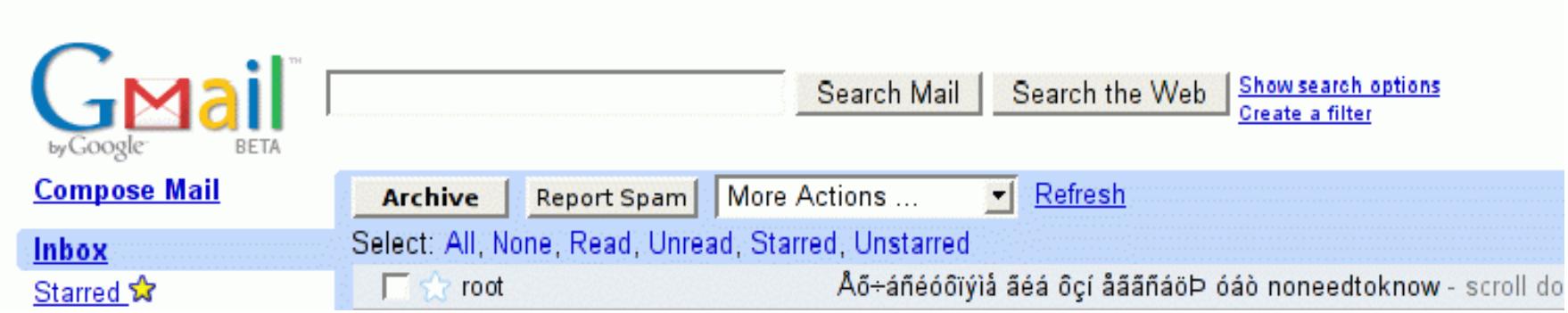
The **Answer** to **Life**, the **Universe**, and **Everything** - Wikipedia

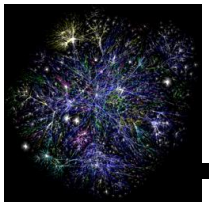
... Google has recently added a calculator function to its search engine, which contains a formula for the question **answer** to **life** the **universe** and **everything**. ...

en2.wikipedia.org/ wiki/The Answer to Life, the Universe, and Everything - 17k - Cached - Similar pages



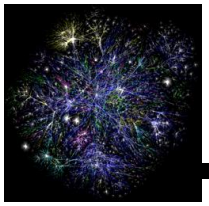
Integration of Search and Mail?





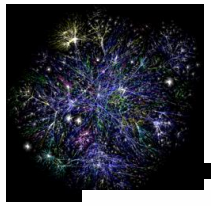
The future of Web Search?

EPIC

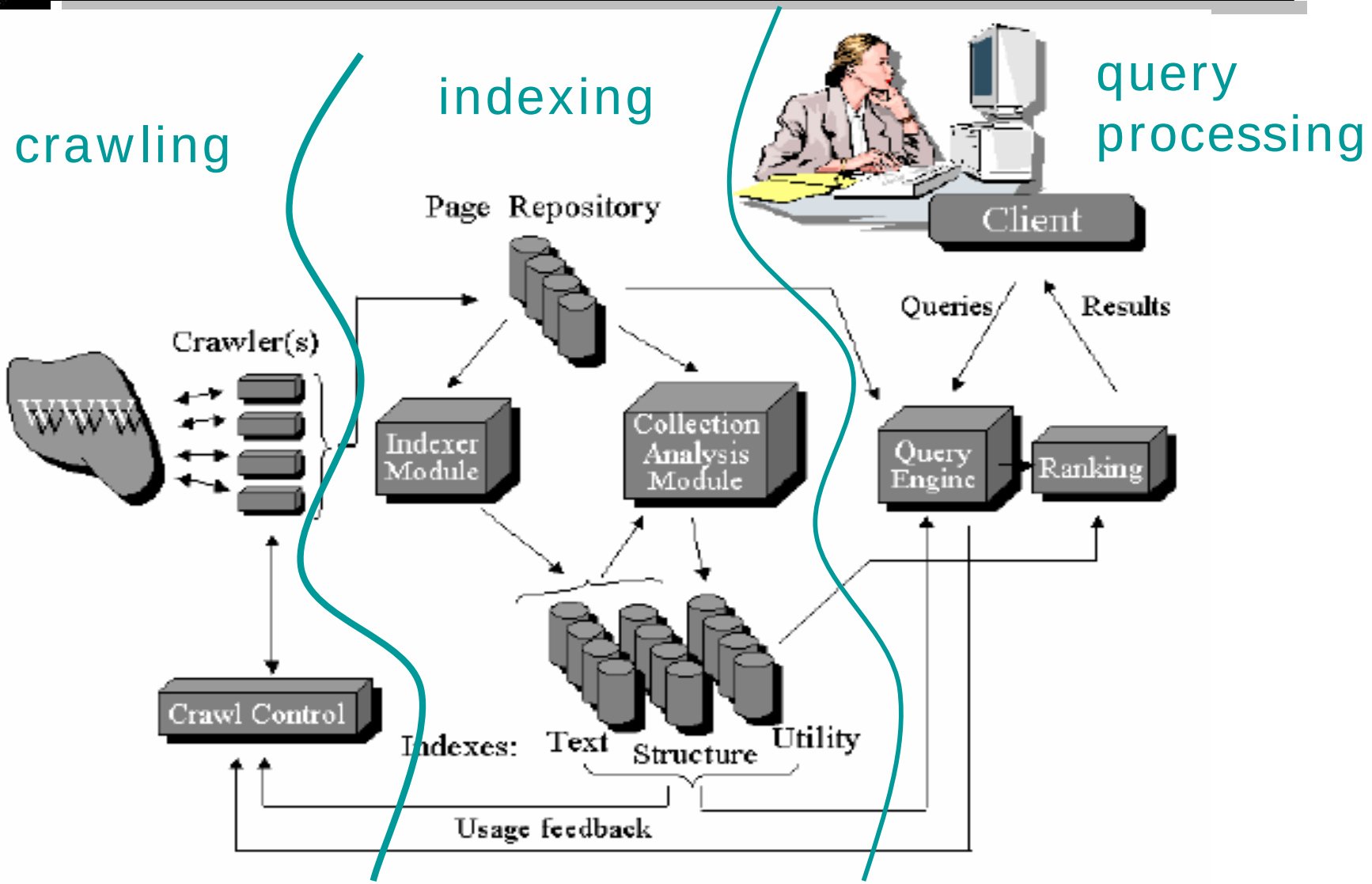


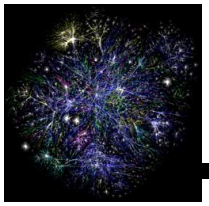
Outline

- Web Search overview
  - from traditional IR to Web search engines
- The anatomy of a search engine
  - Crawling, Duplicate elimination, Indexing



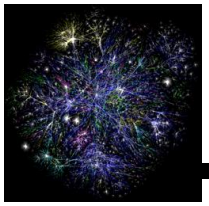
The anatomy of a Search Engine





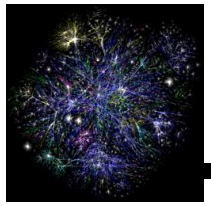
Crawling

- Essential component of a search engine
  - affects search engine quality
- Performance
  - 1995: single machine – 1M URLs/day
  - 2001: distributed – 250M URLs/day
- Where do you start the crawl from?
  - directories
  - registration data
  - HTTP logs
  - etc…



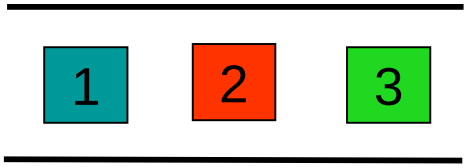
Algorithmic issues

- Politeness
  - do not hit a server too often
- Freshness
  - how often to refresh and which pages?
- Crawling order
  - in which order to download the URLs
- Coordination between distributed crawlers
- Avoiding spam traps
- Duplicate elimination
- Research: focused crawlers

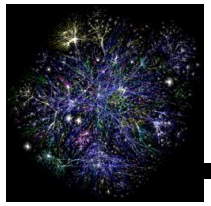


Poor man’s crawler

- A home-made small-scale crawler



start with a queue of URLs to be processed



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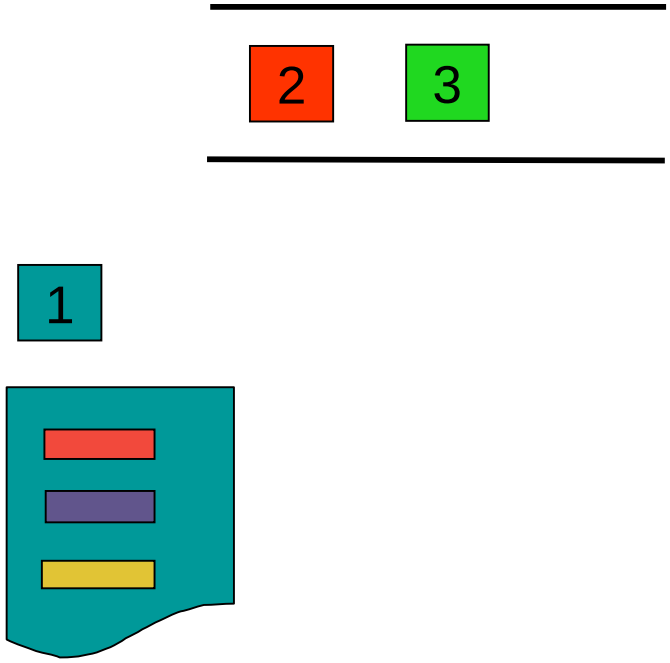

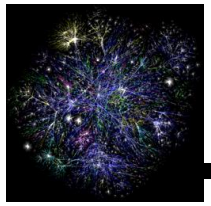

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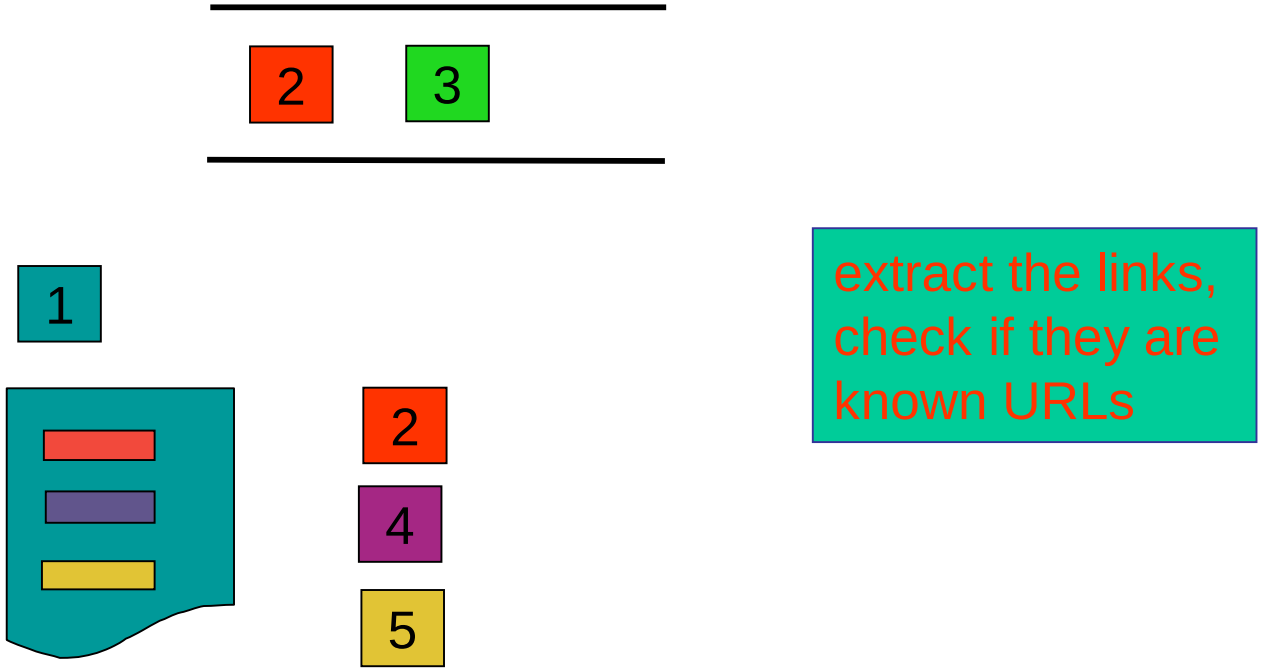

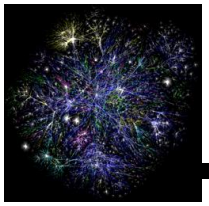

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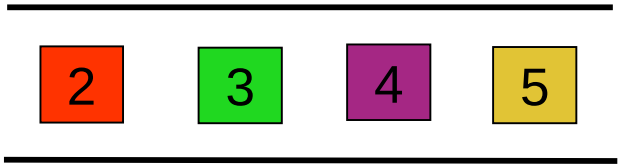
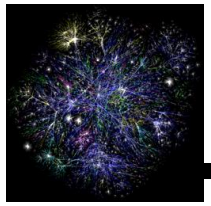


adj list

1: 2 4 5

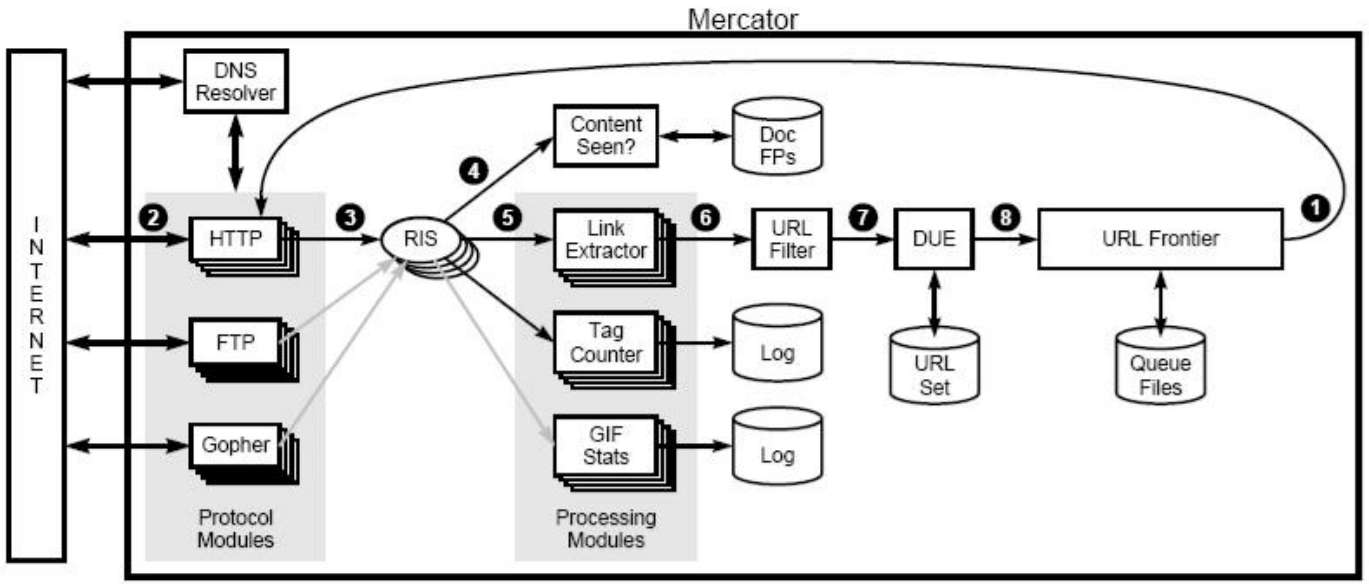
store to adjacency list
add new URLs to queue

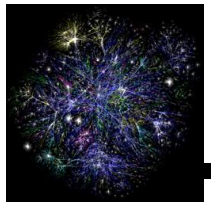
index textual content



Mercator Crawler [NH01]

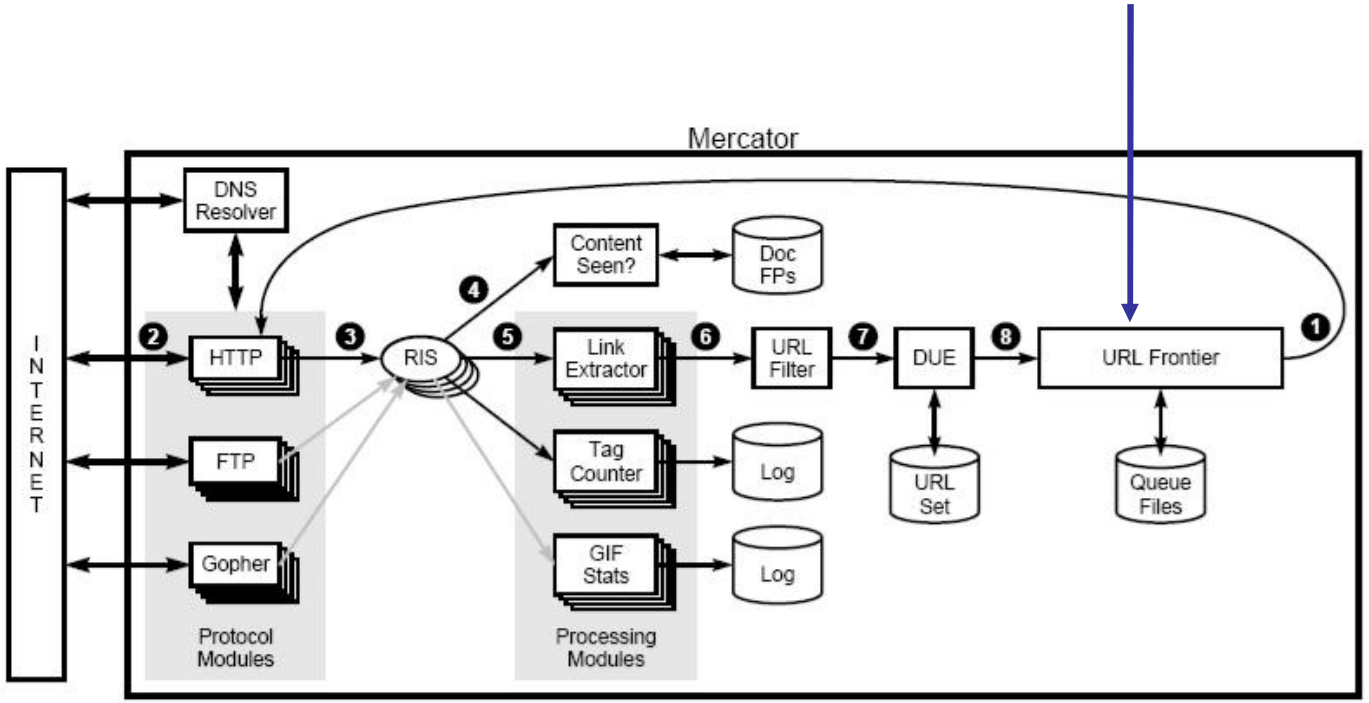
- Not much different from what we described

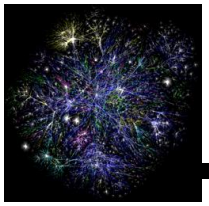




Mercator Crawler [NH01]

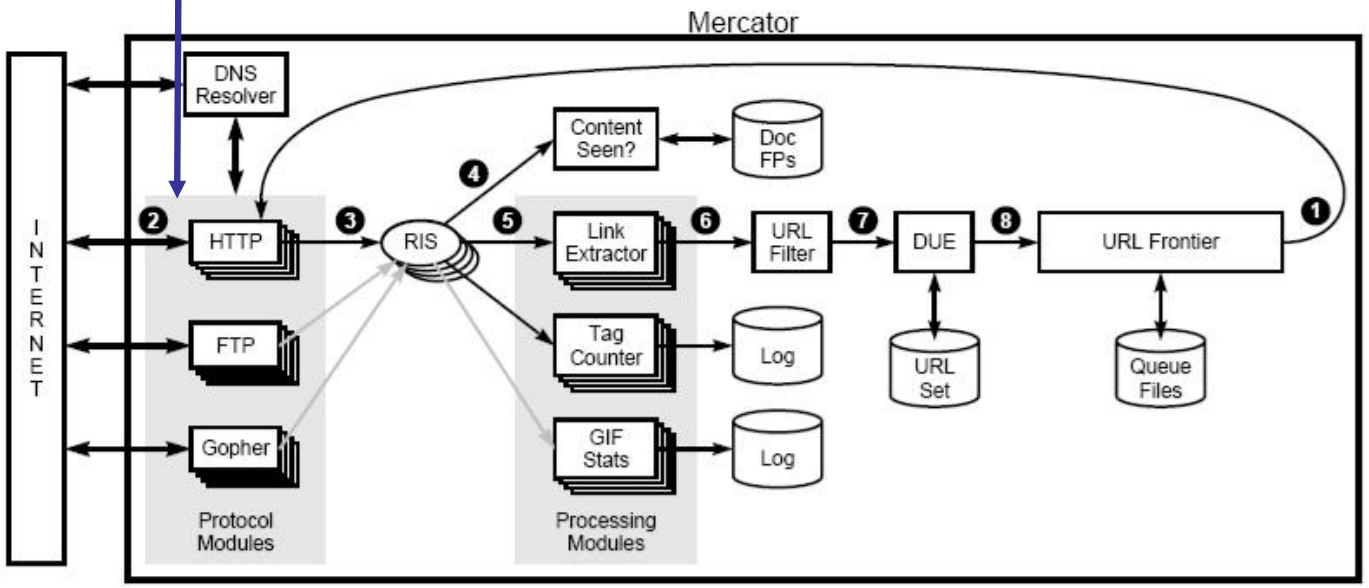
the next page to be crawled is obtained from the URL frontier

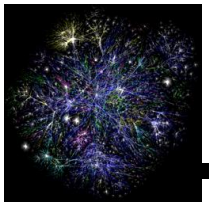




Mercator Crawler [NH01]

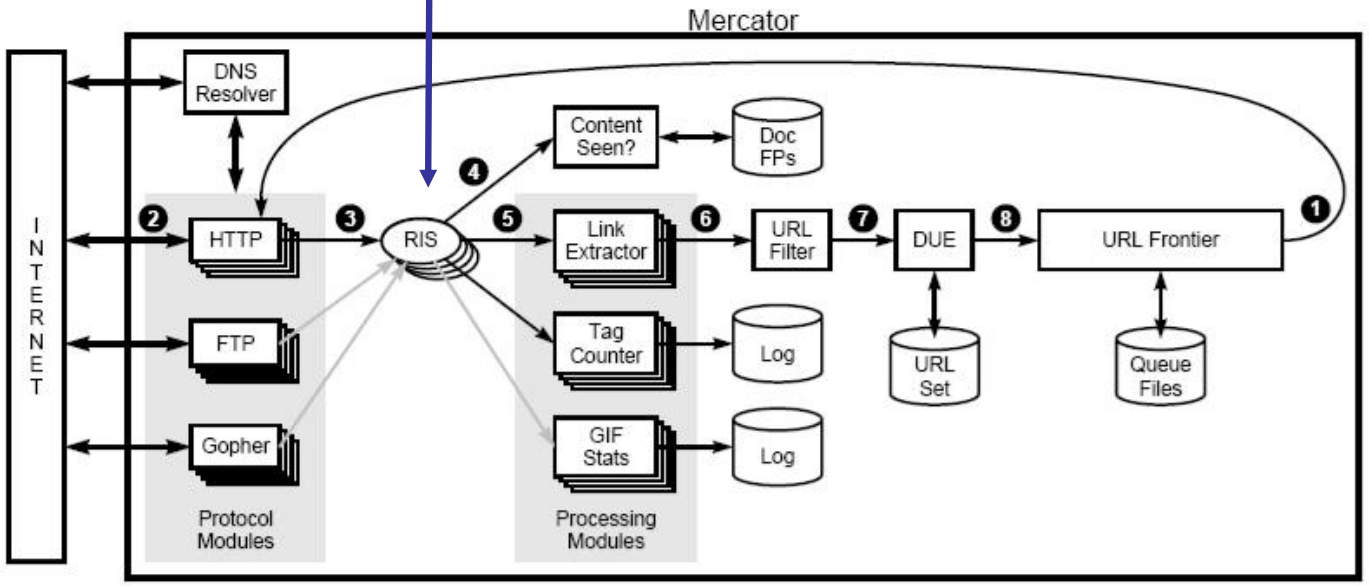
the page is fetched using the appropriate protocol

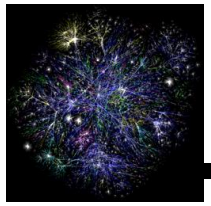




Mercator Crawler [NH01]

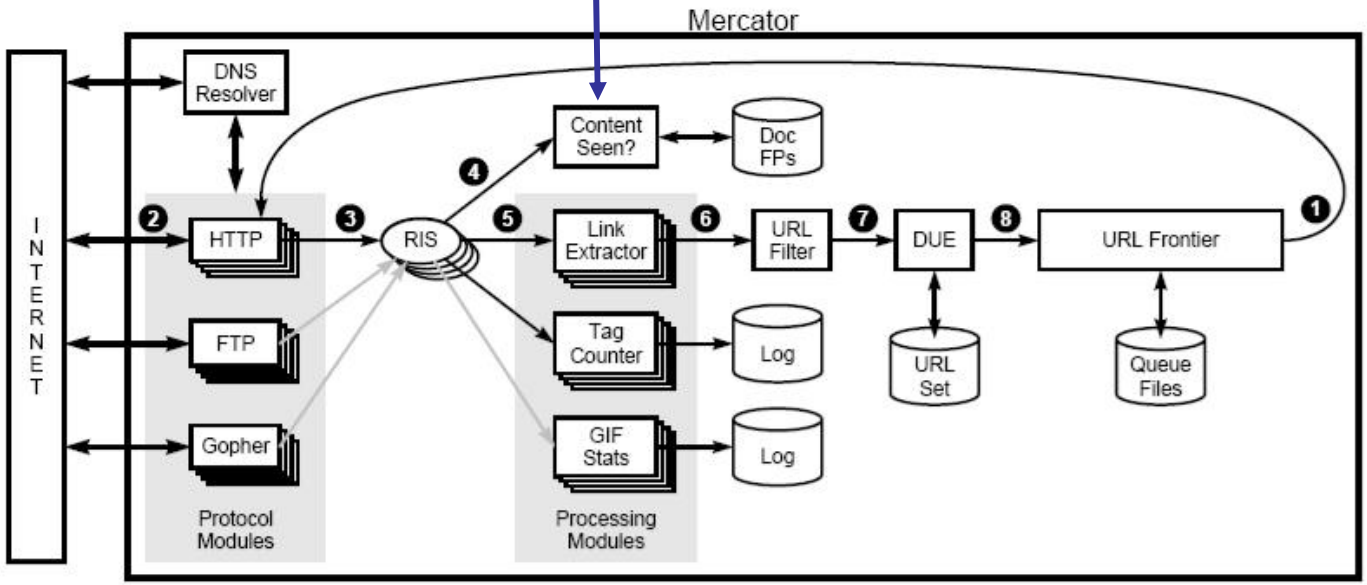
Rewind Input Stream: an IO abstraction

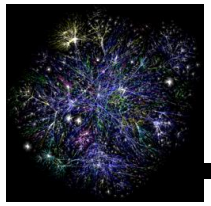




Mercator Crawler [NH01]

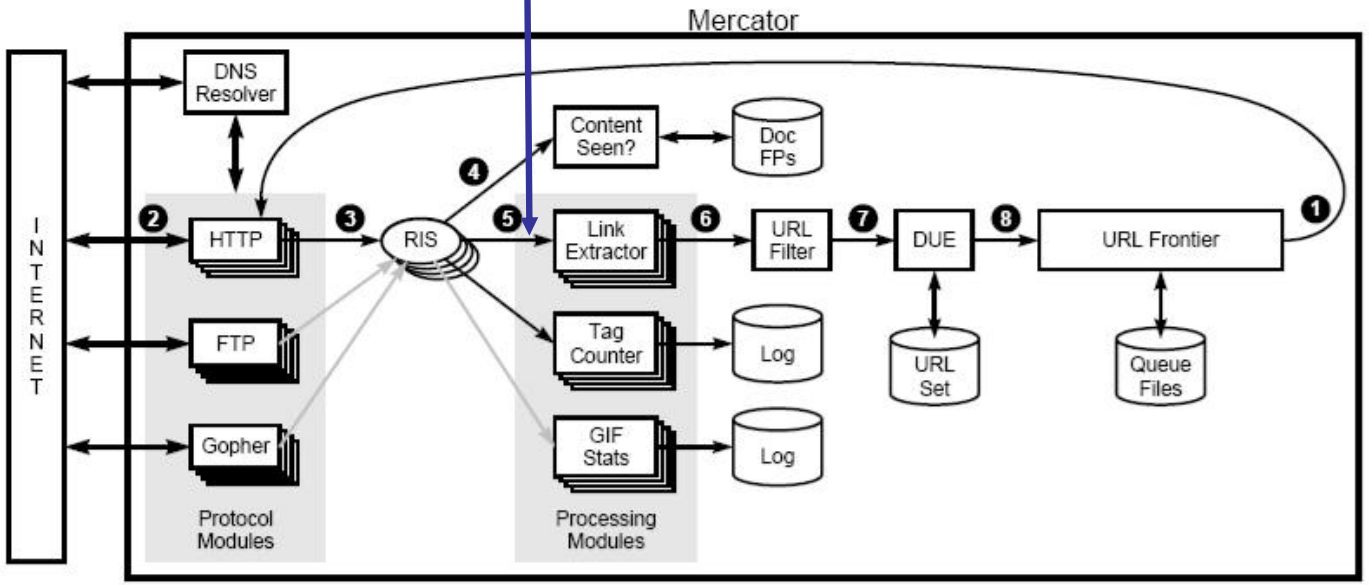
check if the content of the page has been seen before (duplicate, or near duplicate elimination)

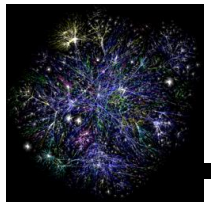




Mercator Crawler [NH01]

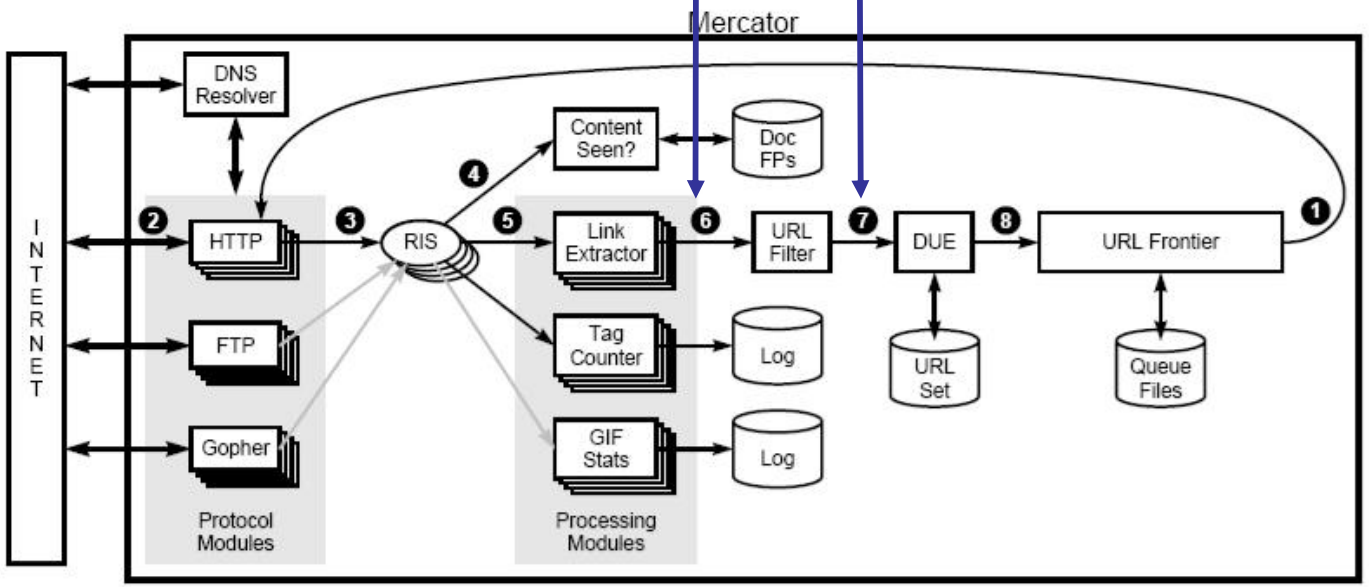
process the page (e.g. extract links)

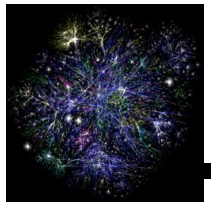




Mercator Crawler [NH01]

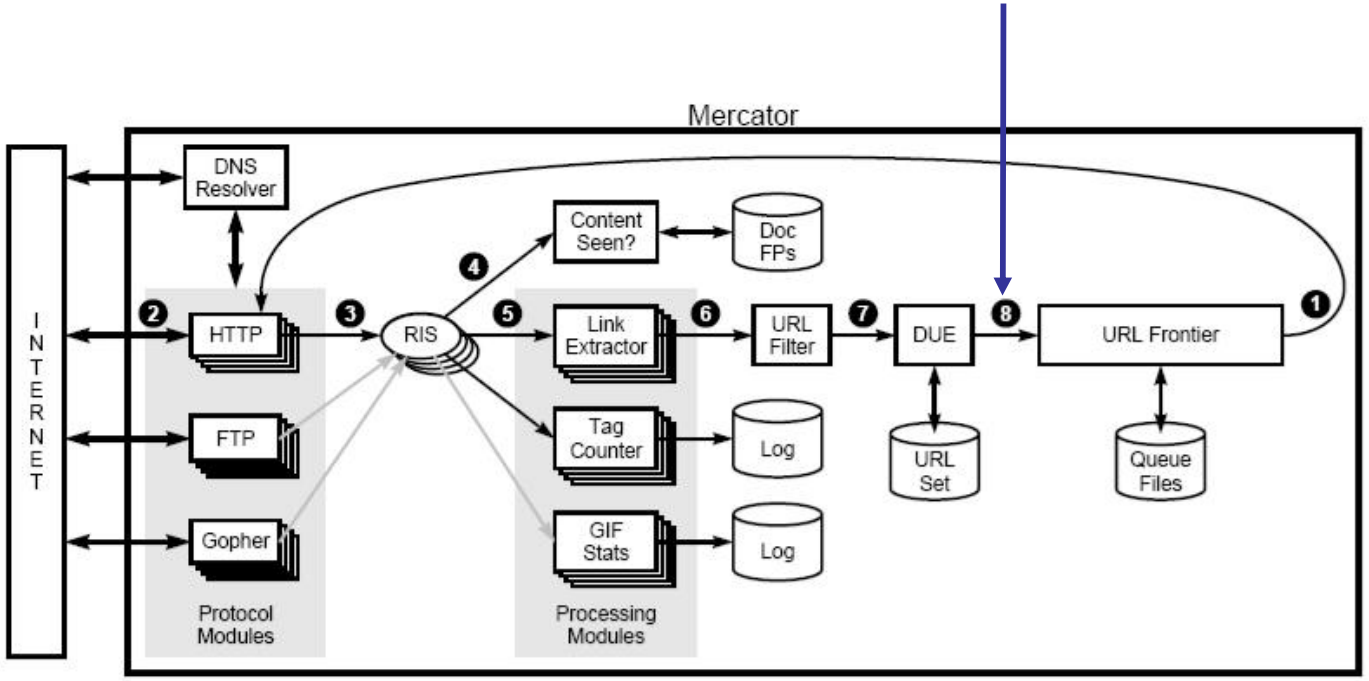
check if the links should be filtered out (e.g. spam) or if they are already in the URL set

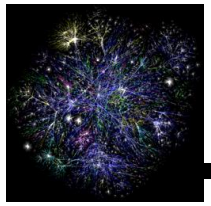




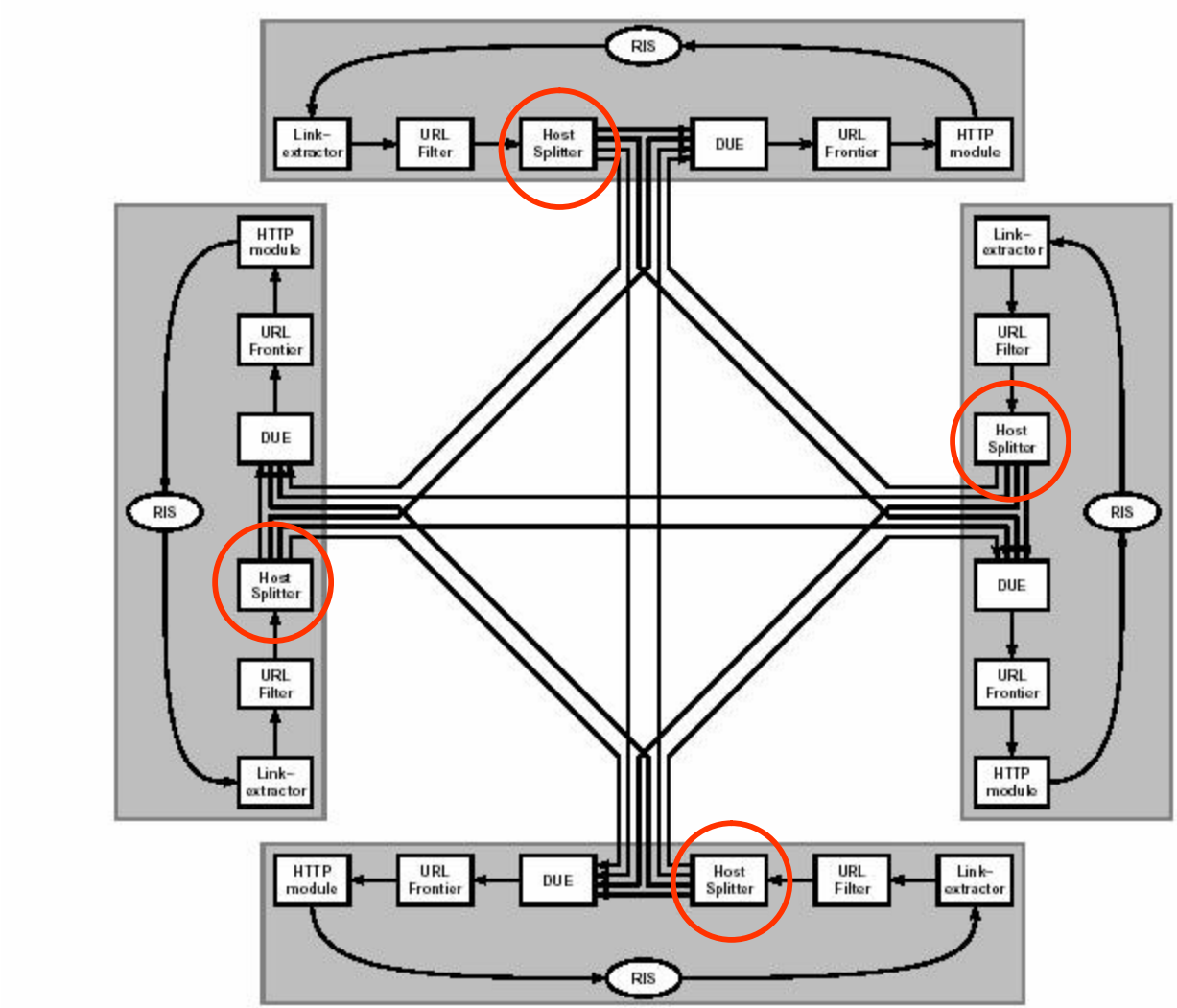
Mercator Crawler [NH01]

if not visited, add to the URL frontier, prioritized
(in the case of continuous crawling, you may add also the source page, back to the URL frontier)

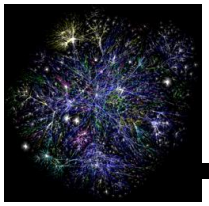




Distributed Crawling

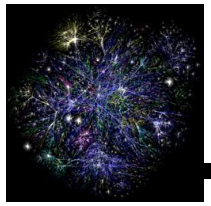


- Each process is responsible for a partition of URLs
- The Host Splitter assigns the URLs to the correct process
- Most links are local so traffic is small



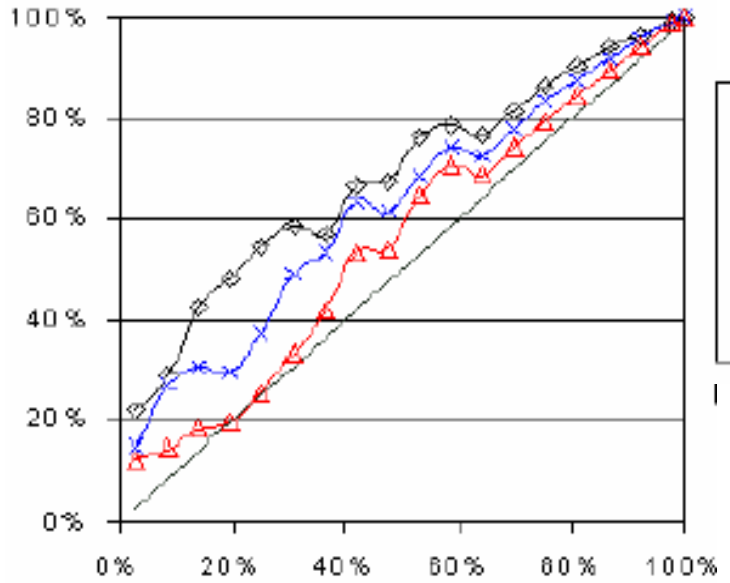
Crawling order

- Best pages first
  - possible quality measures
    - in-degree
    - PageRank
  - possible orderings
    - Breadth First Search (FIFO)
    - in-degree (so far)
    - PageRank (so far)
    - random



Crawling order [CGP98]

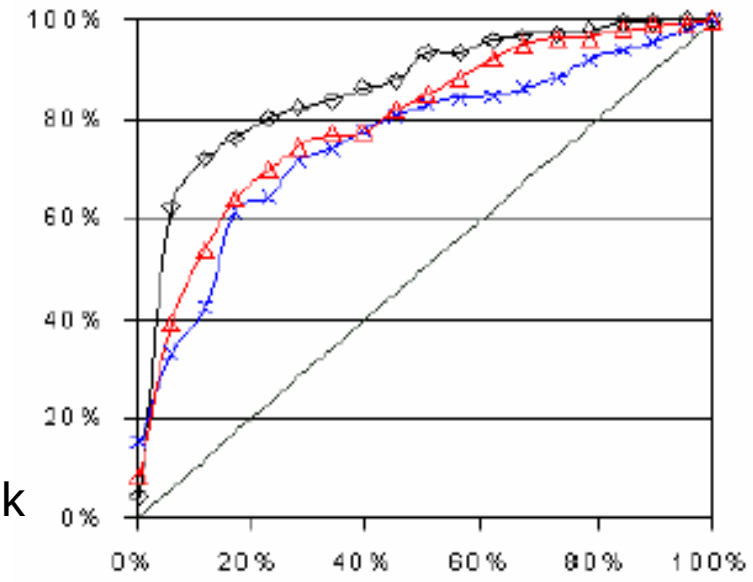
“hot” page = high in-degree

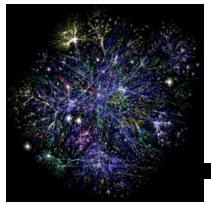


% of “hot” pages

percentage of pages crawled

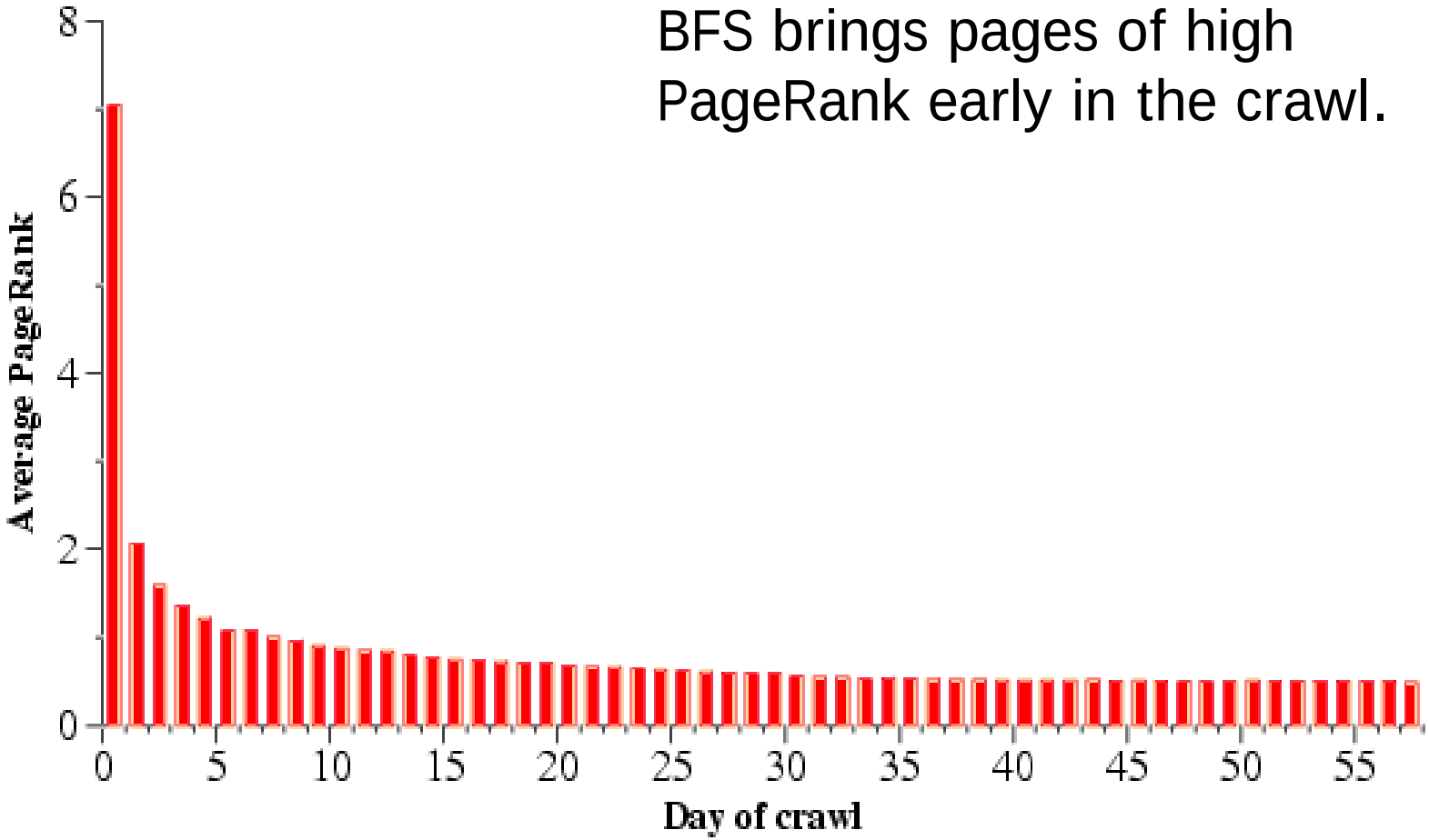
“hot page = high PageRank

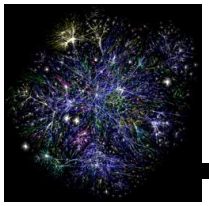




Crawling order [NW01]

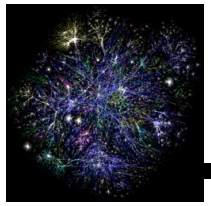
BFS brings pages of high PageRank early in the crawl.





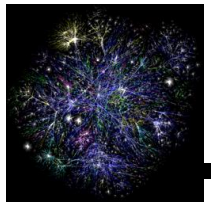
Duplication

- Approximately 30% of the Web pages are duplicates or near duplicates
- Sources of duplication
  - Legitimate: mirrors, aliases, updates
  - Malicious: spamming, crawler traps
  - Crawler mistakes
- Costs:
  - wasted resources
  - unhappy users



Observations

- Eliminate both duplicates and near duplicates
- Computing pairwise edit distance is too expensive
- Solution
  - reduce the problem to set intersection
  - sample documents to produce small sketches
  - estimate the intersection using the sketches



Shingling

- Shingle: a sequence of w contiguous words

a rose is a rose is a rose

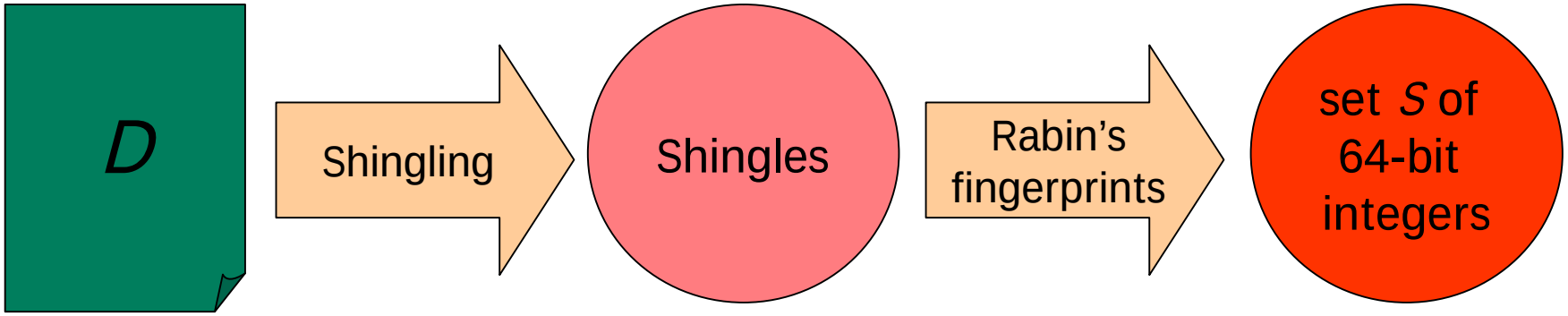
a rose is a

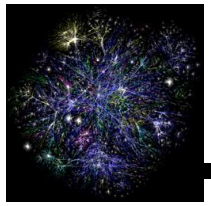
rose is a rose

is a rose is

a rose is a

rose is a rose





Rabin's fingerprinting technique

- Comparing two strings of size n

a = 10110
b = 11010

a=b?

O(n) too expensive!

f(a)=f(b)?

$$A = 1*2^4 + 0*2^3 + 1*2^2 + 1*2^1 + 0*2^0$$

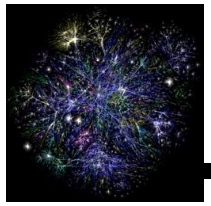
$$B = 1*2^4 + 1*2^3 + 0*2^2 + 1*2^1 + 0*2^0$$

f(a)= A mod p
f(b)= B mod p

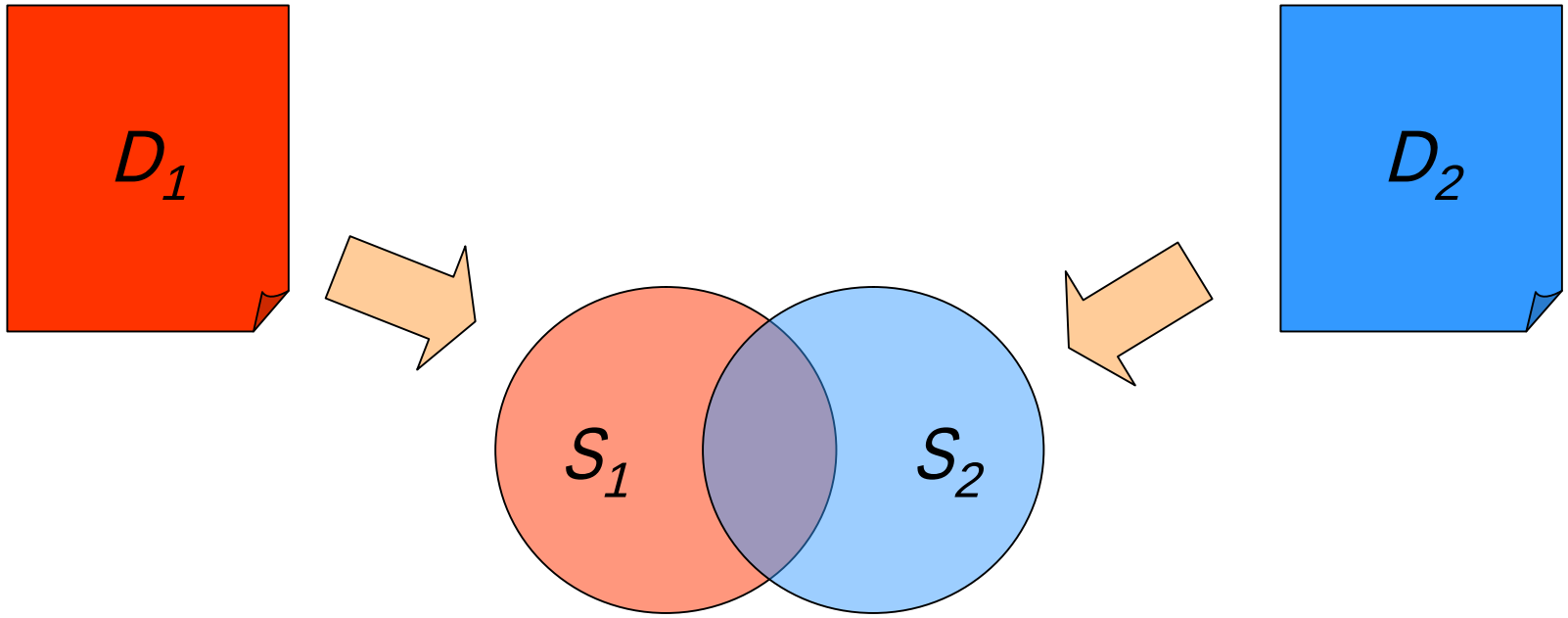
p = small random prime
size O(logn loglogn)

- if **a=b** then **f(a)=f(b)**

if **f(a)=f(b)** then **a=b** with high probability

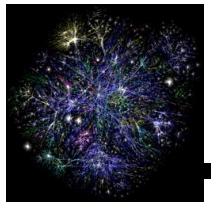


Defining Resemblance



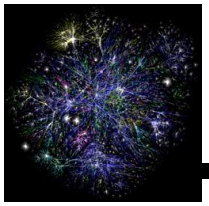
$$\text{reseblance} = \frac{|S_1 \cap S_2|}{|S_1 \cup S_2|}$$

Jaccard coefficient



Sampling from a set

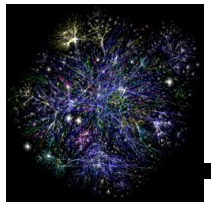
- Assume that $S \subset U$
  - e.g. $U = \{a,b,c,d,e,f\}$, $S=\{a,b,c\}$
- Pick uniformly at random a permutation σ of the universe U
  - e.g $\sigma=\langle d,f,b,e,a,c\rangle$
- Represent S with the element that has the smallest image under σ
  - e.g. $\sigma=\langle d,f,\mathbf{b},e,a,c\rangle$ $b = \sigma\text{-min}(S)$
- Each element in S has equal probability of being σ-min(S)



Estimating resemblance

- Apply a permutation σ to the universe of all possible fingerprints $U=[1...2^{64}]$
- Let $\alpha = \sigma\text{-min}(S_1)$ and $\beta = \sigma\text{-min}(S_2)$

$$\Pr(\alpha = \beta) = ?$$



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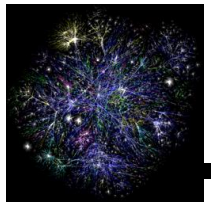
- Apply a permutation σ to the universe of all possible fingerprints $U=[1...2^{64}]$
- Let $\alpha=\sigma\text{-min}(S_1)$ and $\beta=\sigma\text{-min}(S_2)$

$$\Pr(\alpha=\beta)=\frac{|S_1\cap S_2|}{|S_1\cup S_2|}$$

- Proof:
  - The elements in $S_1\cup S_2$ are mapped by the same permutation σ.
  - The two sets have the same σ-min value if $\sigma\text{-min}(S_1\cup S_2)$ belongs to $S_1\cap S_2$



Example

Universe U = {a,b,c,d,e,f}

$S_1 = \{a,b,c\}$

$S_2 = \{b,c,d\}$

$S_1 \cap S_2 = \{b,c\}$

$S_1 \cup S_2 = \{a,b,c,d\}$

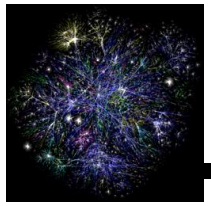
$\sigma(U) = \langle e,*,*,f,*,* \rangle$

We do not care where the elements e and f are placed in the permutation

$\sigma\text{-min}(S_1) = \sigma\text{-min}(S_2)$ if * is from {b,c}

The element in * can be any of the {a,b,c,d}

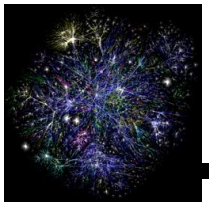
$$\Pr(\sigma - \min(S_1) = \sigma - \min(S_2)) = \frac{|\{b,c\}|}{|\{a,b,c,d\}|} = \frac{|S_1 \cap S_2|}{|S_1 \cup S_2|}$$



Filtering duplicates

- Sample k permutations of the universe $U=[1\ldots2^{64}]$
- Represent fingerprint set S as

  $S'=\{\sigma_1\text{-}min(S), \sigma_2\text{-}min(S),\ldots \sigma_k\text{-}min(S)\}$
- For two sets S_1 and S_2 estimate their resemblance as the number of elements S_1' and S_2' have in common
- Discard as duplicates the ones with estimated similarity above some threshold r



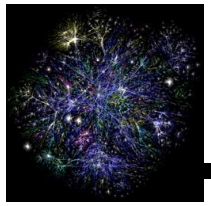
Why does this work?

- The probability that the two sets S_1' and S_2' agree on one of the permutations is

$$p = \frac{|S_1 \cap S_2|}{|S_1 \cup S_2|}$$

- The expected number of agreements on k trials is pk
- If the estimated similarity is above r then on expectation

$$\frac{|S_1 \cap S_2|}{|S_1 \cup S_2|} \geq \frac{r}{k}$$



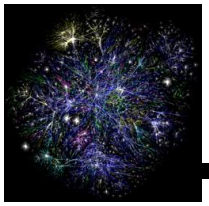
min-wise independent permutations

- Problem: There is no practical way to sample from the universe $U=[1\ldots2^{64}]$
- Solution: Sample from the (smaller) set of min-wise independent permutations [BCFM98]
- min-wise independent permutation σ

  for every set X

  for every element x of X

  x has equal probability of being the minimum element of X under σ

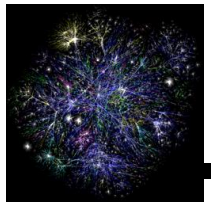


Other applications

- This technique has also been applied to other data mining applications
  - for example find words that appear often together in documents

	w1	w2	w3	w4
d1	1	0	1	1
d2	1	0	1	1
d3	0	1	0	1
d4	1	0	0	0
d5	1	1	1	0

w1 = {d1,d2,d4,d5}
w2 = {d3,d5}
w3 = {d1,d2,d3,d5}
w4 = {d1,d2,d3}



Other applications

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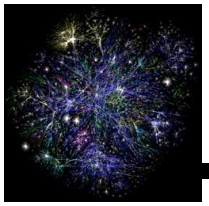
	w1	w2	w3	w4
d1	**1**	0	**1**	1
d2	**1**	0	**1**	**1**
d3	0	**1**	0	**1**
d4	1	0	0	0
d5	1	**1**	1	0

w1 = {d1,d2,d4,d5}
w2 = {d3,d5}
w3 = {d1,d2,d3,d5}
w4 = {d1,d2,d3}

w1 = {**d1,d2**}
w2 = {**d3**,**d5**}
w3 = {**d1**,**d2**}
w4 = {**d2**,**d3**}

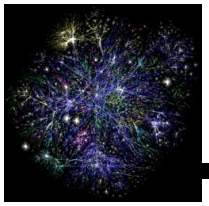
‹d3,d1,d5,d2,d4›

‹d2,d5,d4,d1,d3›



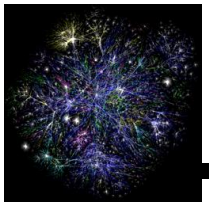
The indexing module

- Inverted Index
  - for every word store the doc ID in which it appears
- Forward Index
  - for every document store the word ID of each word in the doc.
- Lexicon
  - a hash table with all the words
- Link Structure
  - store the graph structure so that you can retrieve in nodes, out nodes, “sibling” nodes
- Utility Index
  - stores useful information about pages (e.g. PageRank values)



Google's Indexing module (circa 98)

- For a word w appearing in document D, create a hit entry
  - plain hit: [cap | font | position]
  - fancy hit: [cap | 111 | type | pos]
  - anchor hit: [cap | 111 | type | docID | pos]

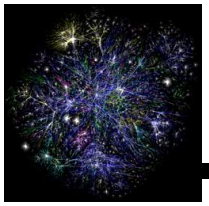


Forward Index

- For each document store the list of words that appear in the document, and for each word the list of hits in the document

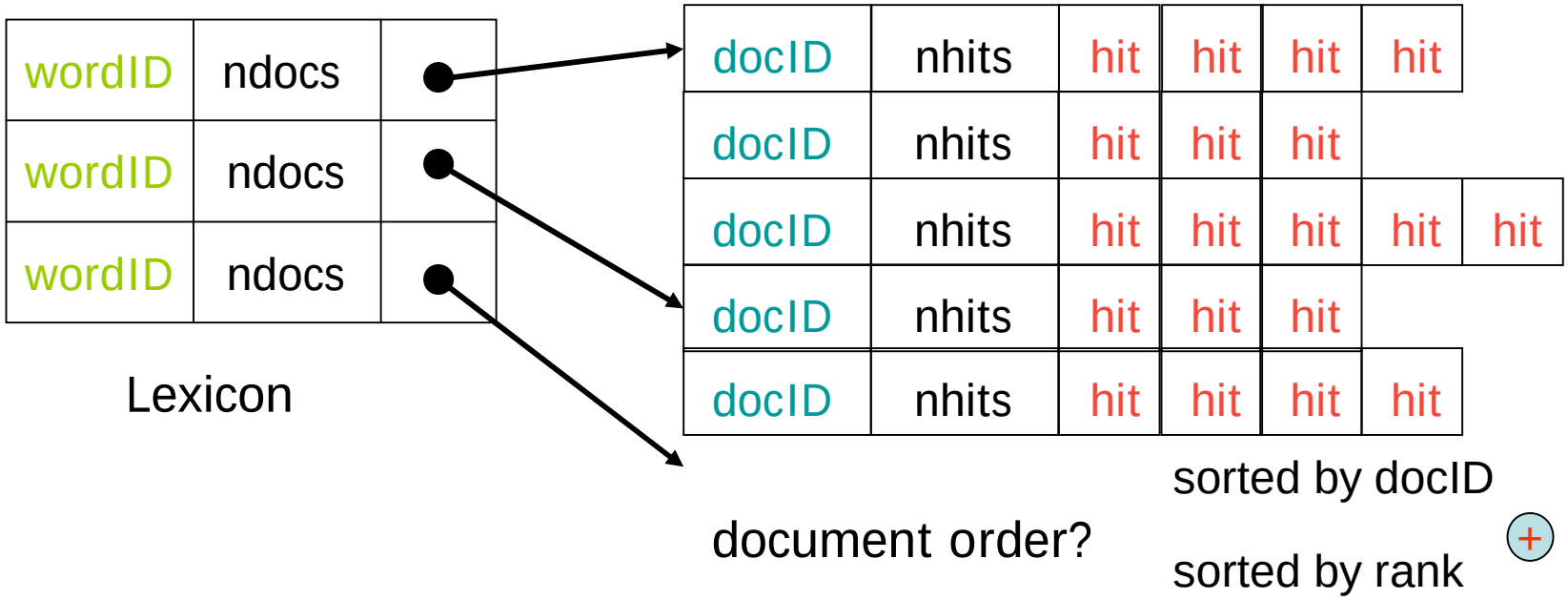
docID	wordID	nhits	hit	hit	hit	hit
	wordID	nhits	hit	hit	hit	
	NULL					
docID	wordID	nhits	hit	hit	hit	
	wordID	nhits	hit	hit	hit	hit	hit
	NULL					

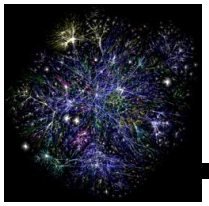
docIDs are replicated in different barrels that store specific range of wordIDs
This allows to delta-encode the wordIDs and save space



Inverted Index

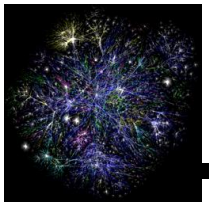
- For each word, the lexicon entry points to a list of document entries in which the word appears





Query Processing

- Convert query terms into wordIDs
- Scan the docID lists to find the common documents.
  - phrase queries are handled using the pos field
- Rank the documents, return top-k
  - PageRank
  - hits of each type × type weight
  - proximity of terms



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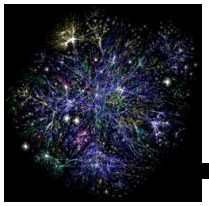

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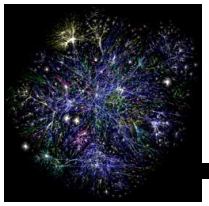

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