Information Retrieval on the Web

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Based on Chapters 19, 20 and 21 from Introduction to Information Retrieval, Manning, C. et al. (2008)
Based on Chapters 11 and 12 from Modern Information Retrieval (2nd Edition), Baeza-Yates, R. et al. (2010)

Outline

- ➔ Overview of Information Retrieval on the Web
- ➔ Web Crawling
- ➔ Web Ranking
- ➔ Link Analysis
  - ➔ PageRank
  - ➔ HITS

Information Retrieval on the Web

The World Wide Web

- ➔ The web is unprecedented in many ways:
  - ➔ Unprecedented in scale (size and change);
  - ➔ Unprecedented in lack of central coordination;
  - ➔ Unprecedented in the diversity of users' backgrounds and needs.
- ➔ Two types of challenges:
  - ➔ Data: distribution, size, volatility, quality, unstructured, duplicates.
  - ➔ Interaction: user needs; relevance; diversity of users.

Information Access on the Web

- Early projects of making information discoverable on the web fell into two categories.
- **Full-text index search engines**, e.g. Altavista, Excite, Infoseek
  - Use keyword-based search supported by inverted indexes and ranking mechanisms;
- **Directories / Taxonomies**, e.g. Yahoo!, Open Directory Project
  - Navigate through a hierarchical tree of category labels.
  - Problems: mostly manual categorization (high cost and not scalable); mismatch between editors' and users' idea of how to organize a given node.

Web Search Challenges

- ➔ Decentralization of content publication (the web biggest innovation) means that there is no central point that keeps track of what exists, what was changed, or deleted.
- ➔ What is the size of the web?
- ➔ Content is created massively and in diverse forms
  - ➔ Diversity of languages and dialects;
  - ➔ Diversity of formats, i.e. structure, color, size, …;
  - ➔ Quality, i.e. truths, lies, contradictions, …;
  - ➔ Intent, i.e. legitimate, spam, search engine manipulation;

Web Characteristics

- ➔ The Web can be modeled as a graph.
- ➔ Web pages point to, and are pointed by, other pages.
- ➔ Links to other pages (out-links) usually include an "anchor text".
- ➔ The number of in-links to a page is called the in-degree.
- ➔ Studies of web characteristics and dynamics is an area of research.
- ➔ Early research suggests that the directed graph connecting web pages has a bowtie shape.

Web Graph

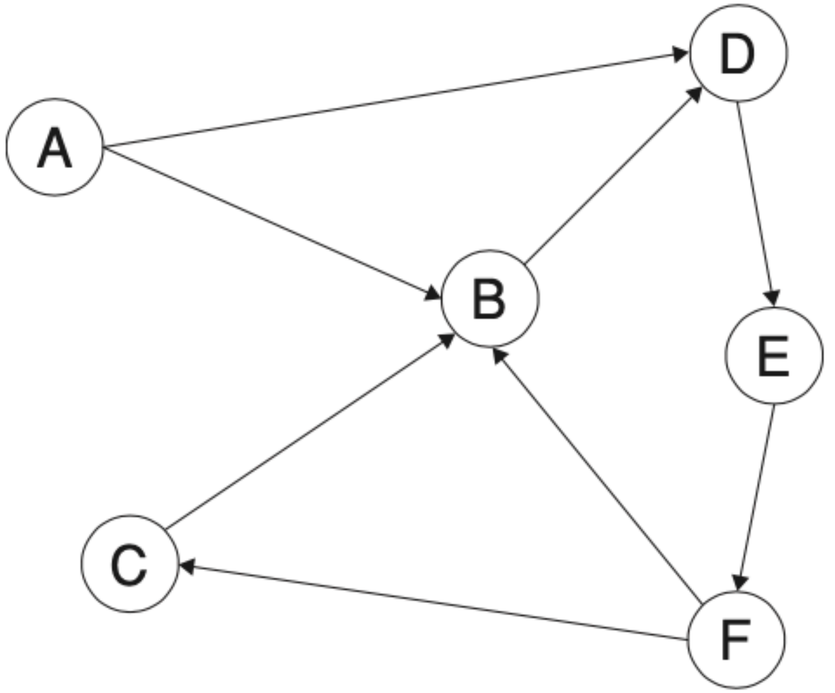

Figure 19.3 A sample small web graph. In this example we have six pages labeled A through F. Page B has in-degree 3 and out-degree 1. This example graph is not strongly connected: There is no path from any of pages B through F to page A.

Image from Introduction to Information Retrieval, Manning, C. et al. (2008)

Bowtie Shape of the Web

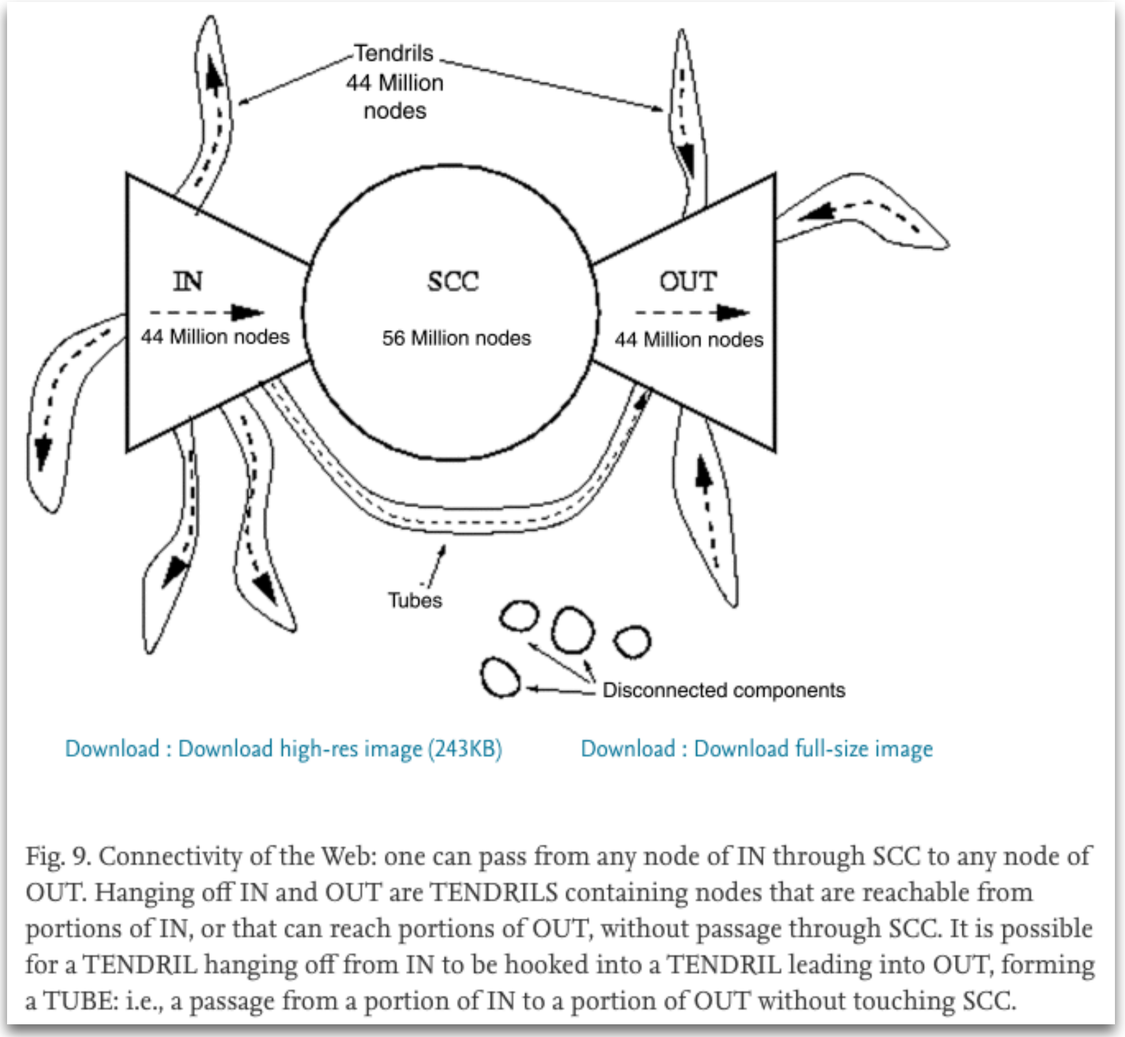

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Fig. 9. Connectivity of the Web: one can pass from any node of IN through SCC to any node of OUT. Hanging off IN and OUT are TENDRILS containing nodes that are reachable from portions of IN, or that can reach portions of OUT, without passage through SCC. It is possible for a TENDRIL hanging off from IN to be hooked into a TENDRIL leading into OUT, forming a TUBE: i.e., a passage from a portion of IN to a portion of OUT without touching SCC.

Image from Graph Structure in the Web, Broder et al. Computer networks (2000)

Web Spam

- ➔ There is a (high) commercial value associated with appearing on the top ranked results for a given search.
- ➔ Search engines must be resistant to manipulation attempts (high frequency!).
- ➔ For instance, a search engine whose scoring depends on the frequency of keywords, would be easy to manipulate by including numerous repetitions of selected keywords.
- ➔ This is called web spam, i.e. the manipulation of content on the web with the purpose of manipulating search engine rankings. Examples include: cloaking, link farms, link spam, click spam, etc.
- ➔ Topics in the sub-area of adversarial information retrieval.

Cloaking

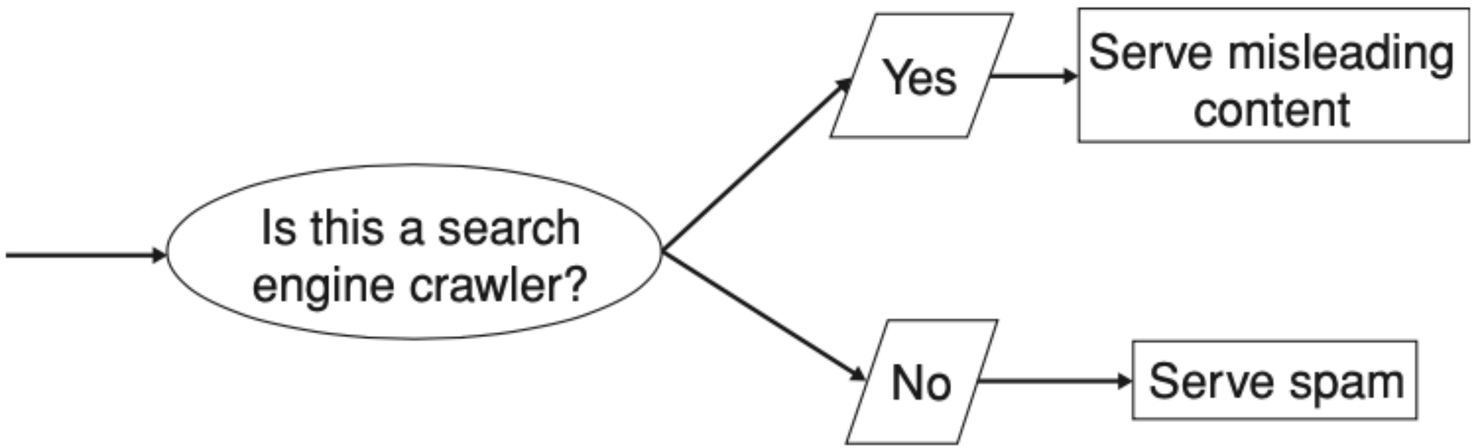

Figure 19.5 Cloaking as used by spammers.

Image from Introduction to Information Retrieval, Manning, C. et al. (2008)

"Mixed Motives in Search"

➔ Reflexion from Brin and Page in 1998.

8 Appendix A: Advertising and Mixed Motives

Currently, the predominant business model for commercial search engines is advertising. The goals of the advertising business model do not always correspond to providing quality search to users. For example, in our prototype search engine one of the top results for cellular phone is "The Effect of Cellular Phone Use Upon Driver Attention", a study which explains in great detail the distractions and risk associated with conversing on a cell phone while driving. This search result came up first because of its high importance as judged by the PageRank algorithm, an approximation of citation importance on the web [Page, 98]. It is clear that a search engine which was taking money for showing cellular phone ads would have difficulty justifying the page that our system returned to its paying advertisers. For this type of reason and historical experience with other media [Bagdikian 83], we expect that advertising funded search engines will be inherently biased towards the advertisers and away from the needs of the consumers.

Since it is very difficult even for experts to evaluate search engines, search engine bias is particularly insidious. A good example was OpenText, which was reported to be selling companies the right to be listed at the top of the search results for particular queries [Marchiori 97]. This type of bias is much more insidious than advertising, because it is not clear who "deserves" to be there, and who is willing to pay money to be listed. This business model resulted in an uproar, and OpenText has ceased to be a viable search engine. But less blatant bias are likely to be tolerated by the market. For example, a search engine could add a small factor to search results from "friendly" companies, and subtract a factor from results from competitors. This type of bias is very difficult to detect but could still have a significant effect on the market. Furthermore, advertising income often provides an incentive to provide poor quality search results. For example, we noticed a major search engine would not return a large airline's homepage when the airline's name was given as a query. It so happened that the airline had placed an expensive ad, linked to the query that was its name. A better search engine would not have required this ad, and possibly resulted in the loss of the revenue from the airline to the search engine. In general, it could be argued from the consumer point of view that the better the search engine is, the fewer advertisements will be needed for the consumer to find what they want. This of course erodes the advertising supported business model of the existing search engines. However, there will always be money from advertisers who want a customer to switch products, or have something that is genuinely new. But we believe the issue of advertising causes enough mixed incentives that it is crucial to have a competitive search engine that is transparent and in the academic realm.

http://infolab.stanford.edu/~backrub/google.html

Search Engines Economic Model

➔ In the early years, banner advertisements were used to support search engines operation, i.e. static banners. These banners are typically priced on a cost per mille (CPM) basis, i.e. cost per 1,000 impressions.

➔ Alternatively, commercial contracts can be set on a number of clicks basis — cost per click (CPC). The advertiser only pays when the searcher clicks on a search result.

➔ Current economic models are based on a (realtime) bidding paradigm, where advertisers bid on specific keywords and search engines show the ads based on the value of the bid.

➔ These results are known as sponsored search results, while the search engine’s "pure" rankings are known as algorithmic or organic results.

➔ Targeting ads to keywords is a basic targeting strategy. More sophisticated (and problematic) approaches can explore contextual or behavioral user data, e.g. location, navigation patterns, previous searches, etc.

www.google.com/search?q=lego&biw=1111&bih=850

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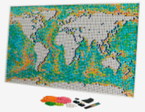
PROMOÇÃO



User Characteristics

- ➔ Web search users are not trained on how to write queries using the search operators offered by search engines.
- ➔ Studies in search user behavior show that users use between two or three keywords, search operators are rarely used, precision in the top results is highly valued, and lightweight result pages are preferred.
- ➔ Early research has shown that users' information needs can be grouped in three types:
  - ➔ Informational queries, i.e. seek general information about a topic. There is typically not a single source of relevant information. Users typically gather information from multiple web pages.
  - ➔ Navigational queries, i.e. seek the website or home page of a single entity. Users' expectations is to find a specific resource.
  - ➔ Transactional queries, i.e. preludes the user performing a transaction on the web, such as purchasing a product, downloading a file, or doing a reservation.

Signals for Web Ranking

- ➔ Hundreds of signals are used by search engines to estimate quality.
- ➔ Signals can be grouped by different dimensions:
  - ➔ Query-independent signals (static).
  - ➔ Query-dependent signals (dynamic).
  - ➔ Document-based signals (content or structural), e.g. HTML.
  - ➔ Collection-based signals, e.g. Links.
  - ➔ User-based signals, e.g. Clicks.

Web Search Engine Architecture

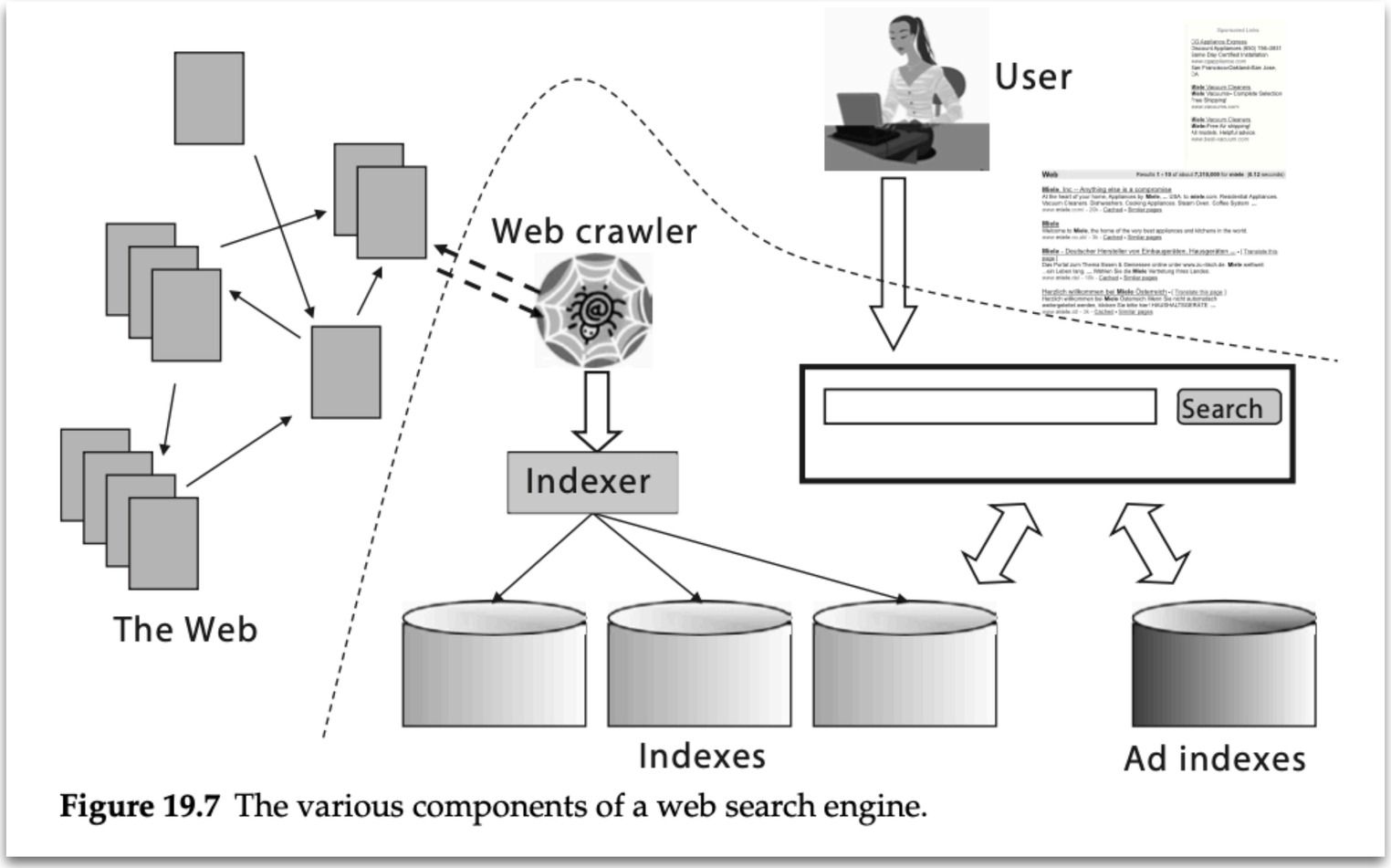
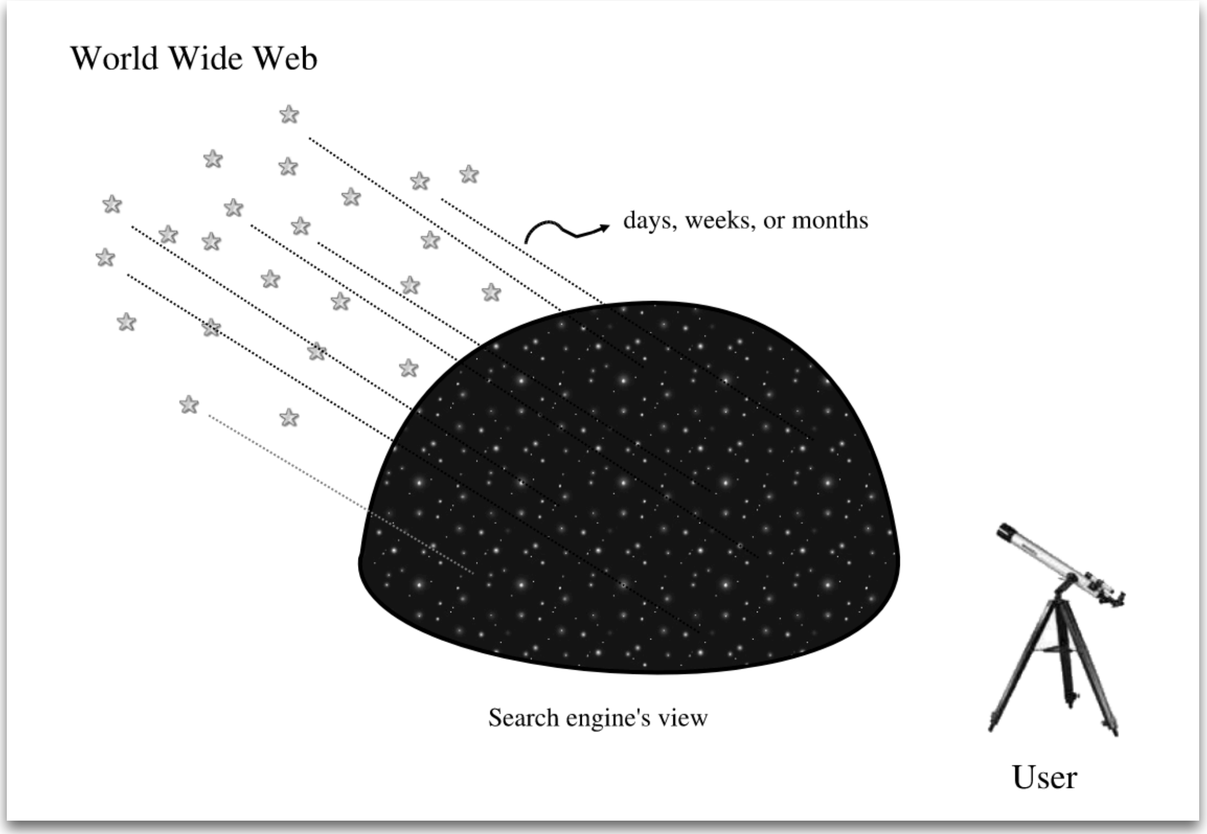


Figure 19.7 The various components of a web search engine.

Image from Introduction to Information Retrieval, Manning, C. et al. (2008)

Web Crawling



Crawling the Web, in a certain way, resembles watching the sky in a clear night: the star positions that we see reflects the state of the stars at different times

From Modern Information Retrieval, Baeza-Yates, R. et al. (2010)

Web Crawling

- Web crawling is the process by which pages are gathered from the web.
- The goal is to discover as quickly and as efficiently as possible quality web pages.
- Features a crawler **must** provide:
  - robustness in face of problems, unexpected content, or traps,
  - politeness to web hosts.
- Features a crawler **should** provide: execute in a distributed fashion, scalable, efficient use of resources, bias towards good quality pages, freshness depending on page change rate, and extensible to cope with innovations on the web.
- Industry standards: robots.txt (robotstxt.org); sitemap protocol (sitemaps.org).

Politeness

- ➔ A crawler would ideally use all the available resources to obtain the collection
- ➔ However, crawlers should fulfill **politeness**
  - ➔ That is, a crawler cannot overload a web site with HTTP requests;
  - ➔ That implies that a crawler should wait a small delay between two requests to the same web site.
- ➔ A crawler that is impolite may be banned by the hosting provider.
- ➔ Three basic rules for web crawler operation:
  - ➔ A crawler must identify itself as such, and must not pretend to be a regular user.
  - ➔ A crawler must obey the robots exclusion protocol (robots.txt).
  - ➔ A crawler must keep a low bandwidth usage in a given web site.
- ➔ Example crawler behavior:
  - ➔ Google Crawler https://developers.google.com/search/docs/crawling-indexing/googlebot

Robot Exclusion Protocol (1)

- The robot exclusion protocol involves three types of exclusion:
  - server-wide, page-wise exclusions, and cache exclusions.
- **Server-wide exclusion** instructs about directories that should not be crawled.
  - These exclusions are defined via the robots.txt file located at the root.
  - All crawlers should not download the directory /data/private.
    - `User-agent: *`
    - `Disallow: /data/private`
- Examples:
  - https://sigarra.up.pt/robots.txt
  - https://facebook.com/robots.txt

Robot Exclusion Protocol (2)

➔ **Page-wise exclusion** is done by the inclusion of meta tags directly on in the pages.

➔ Meta tags are part of the HTML standard.

➔ This example indicates that crawlers should neither index this page, not follow links contained on it.

- `<meta name="robots" content="noindex,nofollow" />`

➔ **Cache exclusion** is used to instruct search engines not to show the user a local cached copy of the page.

- `<meta name="robots" content="nocache" />`

Applications of Web Crawling

- A web crawler can be used to
  - create an index covering broad topics (general web search);
  - create an index covering specific topics (vertical web search);
  - archive content (archiving, backup);
  - analyze web sites for extracting aggregate statistics (characterization, analytics);
  - keep copies or replicate web content (mirroring);
  - web site analysis.

Taxonomy of Crawling

➔ Crawlers assign different importance to issues such as freshness, quality, and volume.

➔ Crawlers can be classified according to these three axes.

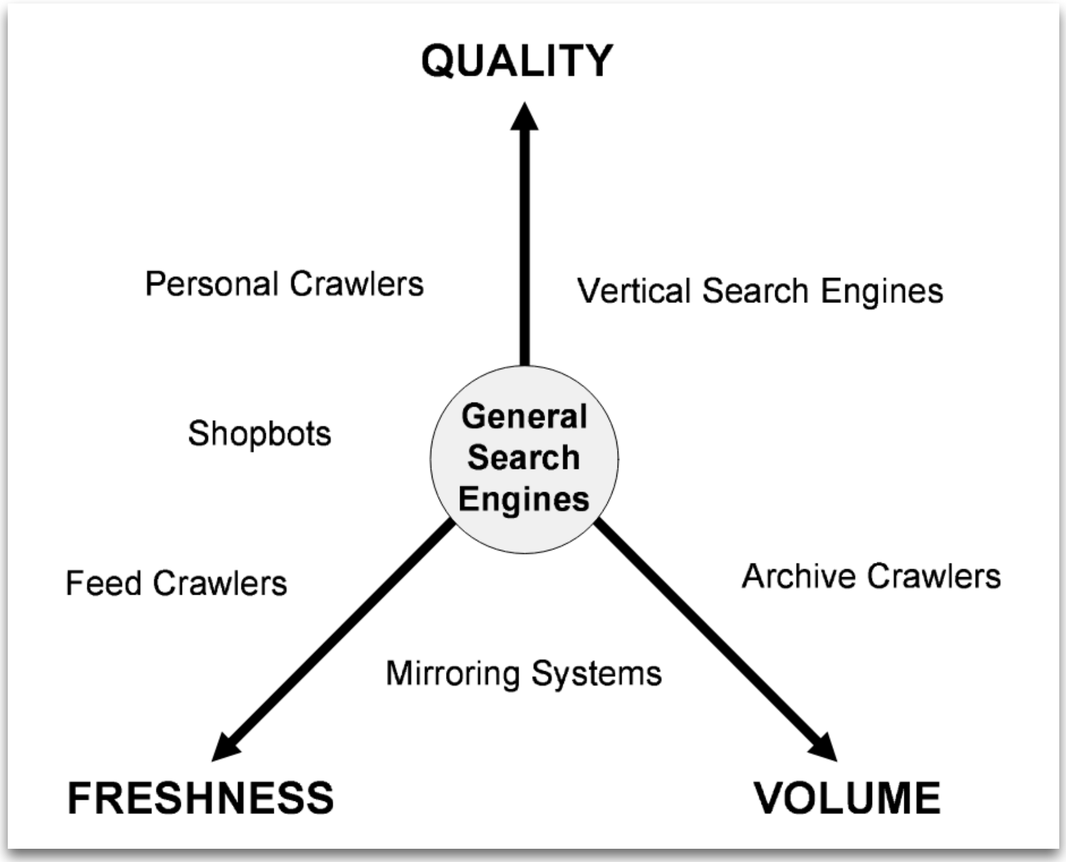
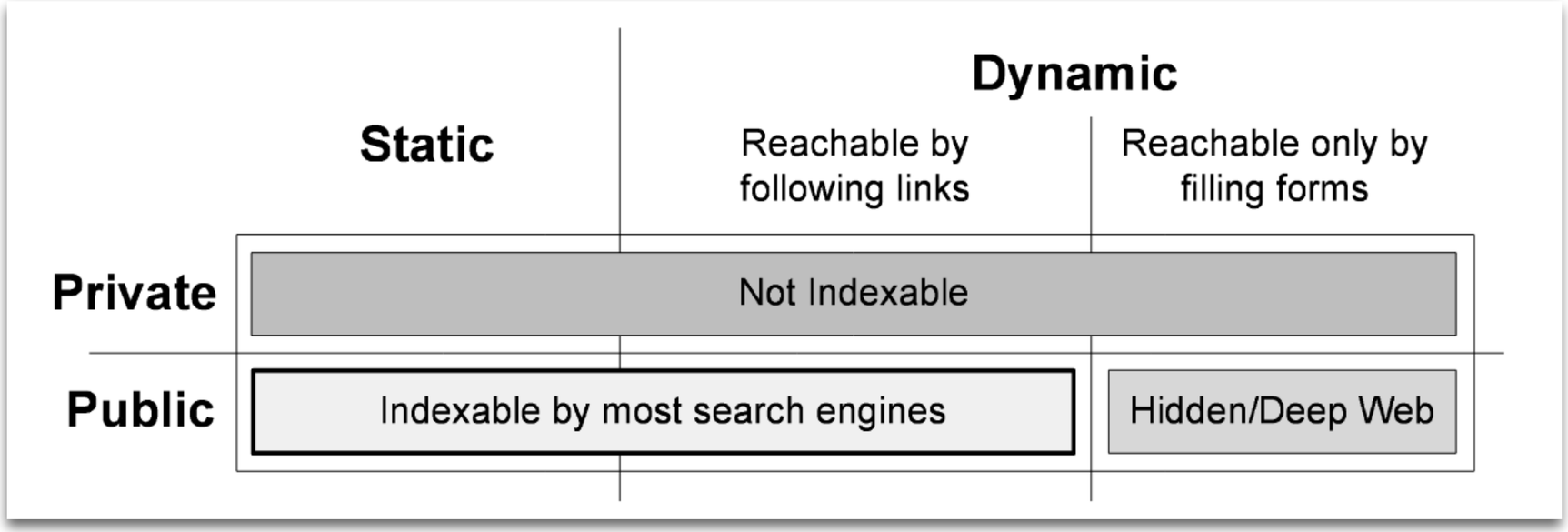


Image from Modern Information Retrieval, Baeza-Yates, R. et al. (2010)

Taxonomy of Web Pages



Web Crawling Process

- ➔ The crawler starts with a set of **seed pages**,
  - ➔ these are downloaded, parsed, and scanned for new links.
- ➔ The links to pages that have not yet been downloaded are added to a central queue for download later (URL frontier).
- ➔ The crawler selects a new page for download and the processes is repeated:
  - ➔ until a stop criterion is met.
  - ➔ considering an established update / refresh policy.

Web Crawler Architecture

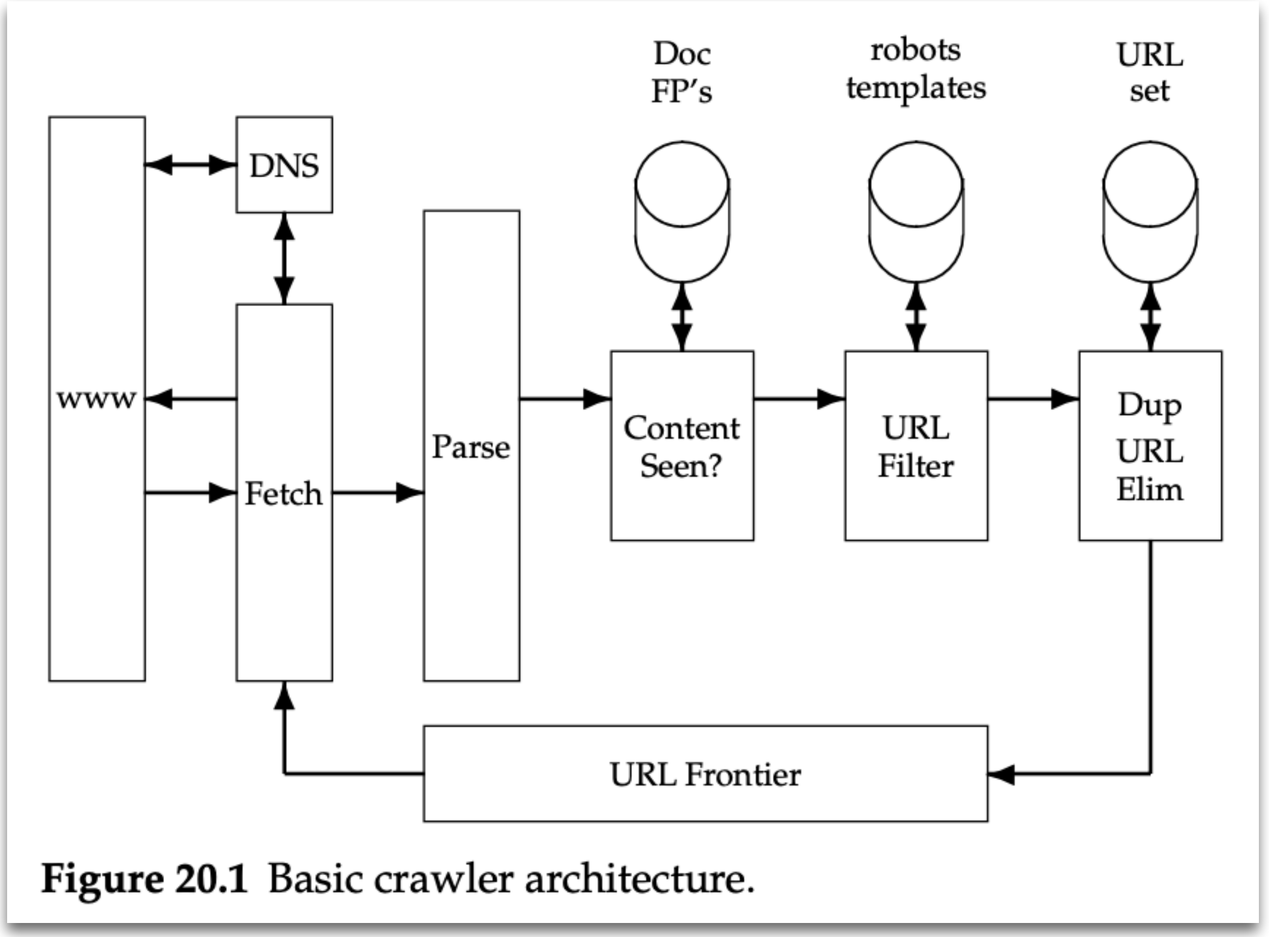


Figure 20.1 Basic crawler architecture.

Image from Introduction to Information Retrieval, Manning, C. et al. (2008)

Near-Duplicate Detection

- ➔ A large percentage of content on the web are near-duplicates, i.e. differing only in small parts. Standard duplicate detection methods do not work, e.g. fingerprinting.
- ➔ Crawlers need to decide if new pages are duplicates of existing content and if pages being revisited have changed since last visit, e.g. estimate change rate.
- ➔ Common solution: obtain shingles of k size from web pages; compare shingles from two pages to determine if they are near-duplicates. The more shingles in common, the more similar are the pages.
- ➔ Example of k=4 shingles for the text: [these are red and blue roses]
  - ➔ [these are red and], [are red and blue], [red and blue roses]

Open Source Crawlers

➔ Heritrix, Internet Archive (Java), https://github.com/internetarchive/heritrix3

➔ Nutch, Apache (Java), https://nutch.apache.org

➔ Scrapy, (Python), https://github.com/scrapy/scrapy

Web Ranking

Web Ranking

- ➔ Ranking is the most complex and most important function of a search engine.
- ➔ First challenge, implement an evaluation process:
  - ➔ Devise an adequate process of evaluating the ranking in terms of relevance of results.
  - ➔ Such evaluation is necessary to fine tune the ranking function.
- ➔ Second challenge, identify quality content:
  - ➔ Collect and combine evidence of quality from different signals.
- ➔ Third challenge, avoid, prevent and manage web spam.
- ➔ Four challenge, define a ranking function and compute it.

Ranking Signals

- ➔ Signals can be organized in different types.
- ➔ Content signals
  - ➔ related to the text itself.
  - ➔ consider HTML semantics (headings, sections, links).
- ➔ Structural signals
  - ➔ related to the link structure of the web.
  - ➔ can be textual (e.g. anchor text), or related to the links (e.g. number).
- ➔ Usage signals
  - ➔ related to the feedback provided by the users (e.g. clicks).
  - ➔ other usage signals include geographical location, technological context, temporal context.

Ranking Signals

➔ Signals can also be distinguished according to other dimensions.

- ➔ User-dependent, depend on the user’s characteristics.
- ➔ Query-dependent, depend on the user’s query.
- ➔ Document-dependent, depend on a single document.
- ➔ Collection-dependent, depend on information from the complete collection.

➔ The characteristics of each signal will impact its computation.

Learning to Rank

- ➔ Given dozens or hundreds of signals, how to combine them in a ranking function?
- ➔ Traditional approaches rely on manual selection of signals and respective weights, depending on domain knowledge.
- ➔ Modern approaches are based on machine learning techniques to
  - ➔ learn the ranking of the results.
  - ➔ Given a query Q, different training data can be used:
    - ➔ pointwise, a set or relevant pages for Q.
    - ➔ pairwise, a set of pairs of relevant pages indicating the ranking relation between the two pages.
    - ➔ listwise, a set of ordered relevant pages.

Link Analysis

Link-based Signals

- Links are one of the distinctive features of a collection of web documents.
- Base assumption: the number of hyperlinks pointing to a page provides a measure of its popularity and quality.
- Link-based ranking algorithms build on the assumption that an hyperlink from page A to page B represents an endorsement of page B, by the creator of page A.
- Two classic algorithms: PageRank and HITS.
  - PageRank, Larry Page and Sergey Brin (1996)
  - HITS, Jon Kleinberg (1997)

PageRank

➔ The PageRank of a node is a value between 0 and 1.

➔ It is a query-independent value computed offline that only depends on the structure of the web graph.

➔ The algorithms models a random surfer who begins at a web page and, at each step, randomly chooses between the out-links to move to the next page. If the random surfer executes this "forever", he will visit some pages more frequently than others. The PageRank value of a page represents this probability.

$$PR(a) = \frac{q}{T} + (1 - q) \sum_{i=1}^{n} \frac{PR(p_i)}{L(p_i)}$$

PageRank Illustration

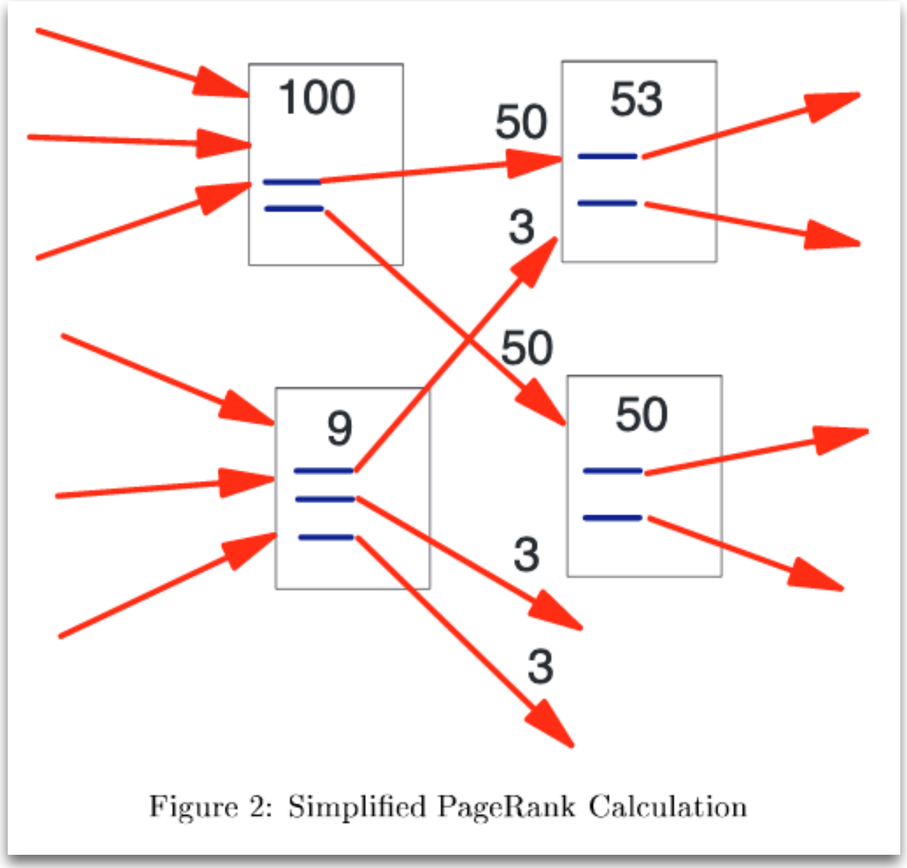


Figure 2: Simplified PageRank Calculation

From: "The PageRank Citation Ranking: Bringing Order to the Web" (1998) http://ilpubs.stanford.edu:8090/422/

Hyperlink Induced Topic Search (HITS)

➔ Query-dependent algorithm.

➔ Starts with the answer set (e.g. pages containing the keywords).

➔ Computes two scores for each page: authority score and hub score.

  ➔ Pages with many links pointing to them are called authorities.

  ➔ Pages with many outgoing links are called hubs.

$$H(p) = \sum_{u \in S \mid p \to u} A(u) \,, \qquad A(p) = \sum_{v \in S \mid v \to p} H(v)$$

HITS Illustration

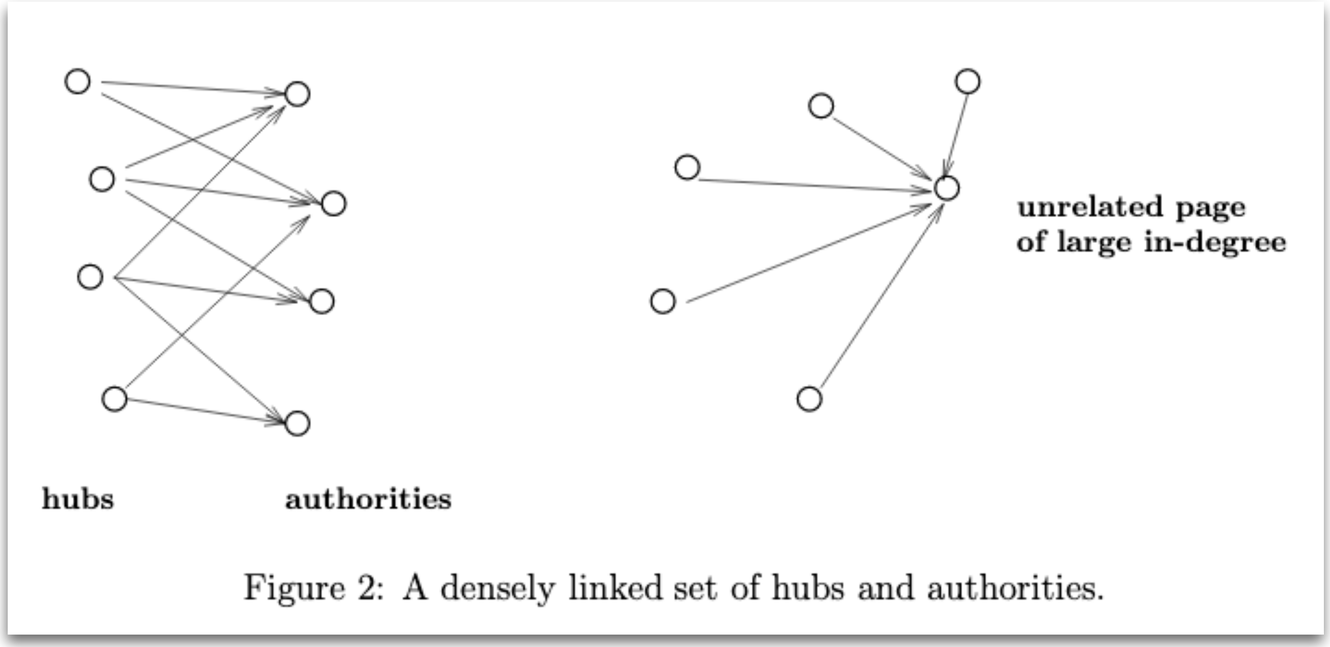


Figure 2: A densely linked set of hubs and authorities.

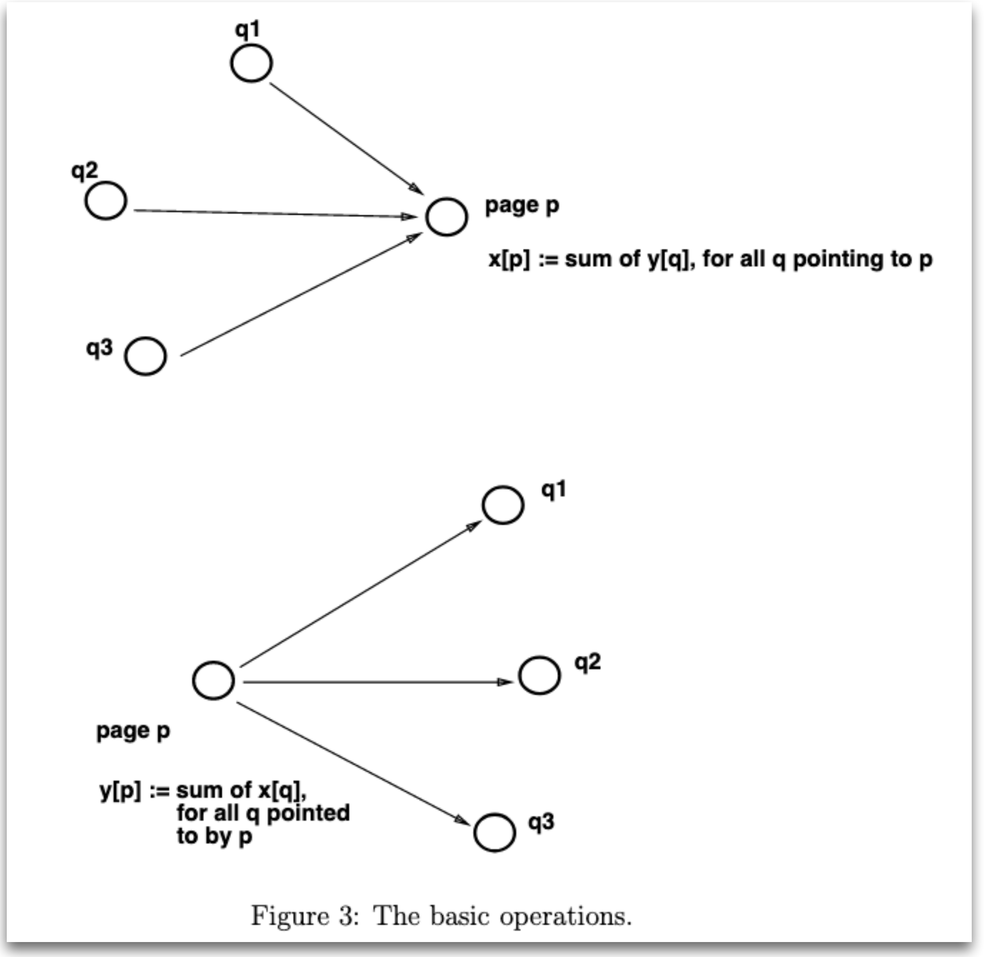


Figure 3: The basic operations.

From: "Authoritative Sources in a Hyperlinked Environment" (1999) https://www.cs.cornell.edu/home/kleinber/auth.pdf

Anchor Text as a Signal

➔ The text used in HTML anchors, i.e. links, is called anchor text.

➔ Faculty of Engineering of the University of Porto

➔ Represents a description from "others" about a given web page.

➔ The collection of all anchor texts can be explored with standard IR techniques, and incorporated as an additional features in an inverted index.

➔ Important feature for image search.

➔ See "Google bombing", https://en.wikipedia.org/wiki/Google_bombing

References

➔ Sergey Brin and Lawrence Page, The anatomy of a large-scale hypertextual Web search engine. Comput. Netw. ISDN Syst. 30, 1-7 (April 1998), http://infolab.stanford.edu/~backrub/google.html

➔ Ricardo Baeza-Yates, Berthier Ribeiro-Neto, Modern Information Retrieval: The Concepts and Technology behind Search

- ➔ Chapter 11: Web Retrieval + Slides for Chapter 11: Web Retrieval
- ➔ Slides for Chapter 12: Web Crawling

➔ Christopher D. Manning, Prabhakar Raghavan and Hinrich Schütze, Introduction to Information Retrieval

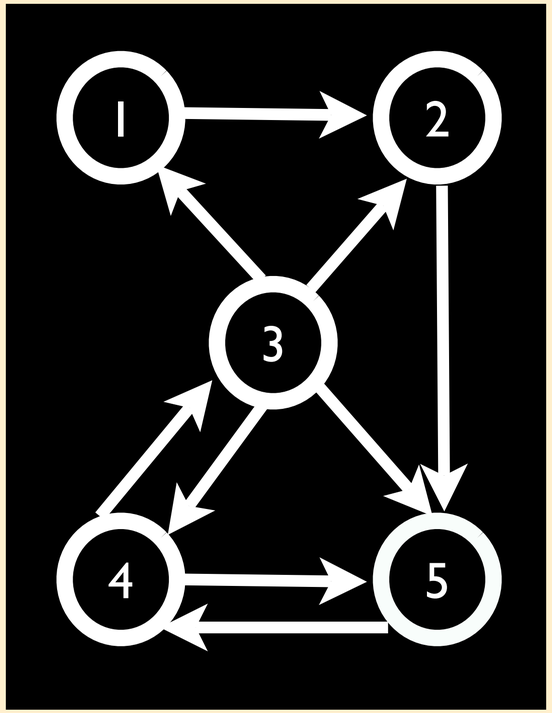
- ➔ Chapter 19: Web search basics
- ➔ Chapter 20: Web crawling and indexes
- ➔ Chapter 21: Link analysis

Exercises

PageRank and HITS

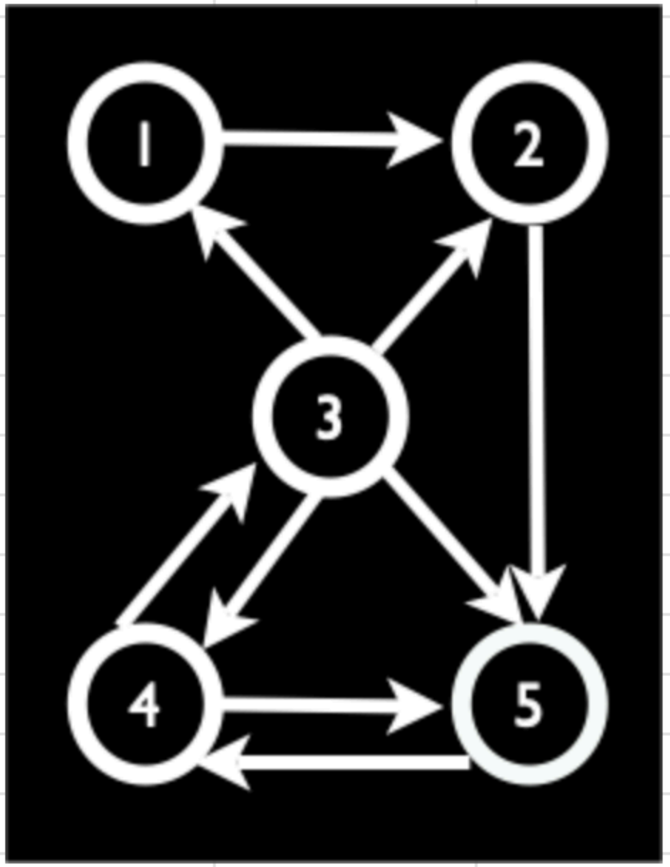
➔ Rank all nodes according to their PageRanks score.

➔ Rank all nodes according to their HITS Authority and Hub scores.



PageRank

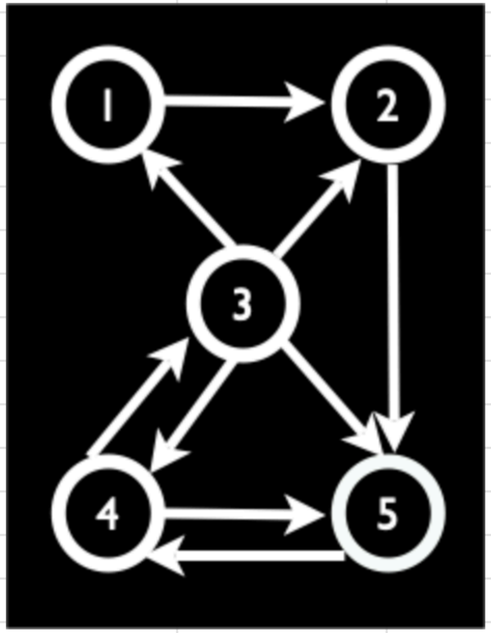
- ➔ $PR_1 = PR_3 / 4$
- ➔ $PR_2 = PR_1 / 1 + PR_3 / 4$
- ➔ $PR_3 = PR_4 / 2$
- ➔ ....



PageRank Score		
	Iteration 1	2
P1	0.2	0.050
P2	0.2	0.250
P3	0.2	0.100
P4	0.2	0.250
P5	0.2	0.350
sum		1.000
error		0.500

HITS

- ➔ $Auth_1$ = (Hub_3) / SUM(All Hub Votes)
- ➔ $Auth_2$ = (Hub_1 + Hub_3) / SUM(All Hub Votes)
- ➔ $Auth_3$ = (Hub_4) / SUM(All Hub Votes)
- ➔ ...
- ➔ Hub_1 = ($Auth_2$) / SUM(All Auth Votes)
- ➔ Hub_2 = ($Auth_5$) / SUM(All Auth Votes)
- ➔ Hub_3 = ($Auth_1$ + $Auth_2$ + $Auth_4$ + $Auth_5$) / SUM(All Auth Votes)
- ➔ ....



Authority scores		
	Iteration 1	**2**
P1	1	0.111
P2	1	0.222
P3	1	0.111
P4	1	0.222
P5	1	0.333
sum		9
Hub scores		
	Iteration 1	**2**
P1	1	0.105
P2	1	0.158
P3	1	0.421
P4	1	0.211
P5	1	0.105
sum		2.111
convergence		8.000000