Web search

Web data management and distribution

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Web Data Management and Distribution
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Outline

1. The World Wide Web
2. Web crawling
3. Web Information Retrieval
4. Web Graph Mining
5. Conclusion

Internet and the Web

Internet: physical network of computers (or hosts)

World Wide Web, Web, WWW: logical collection of hyperlinked documents

- static and dynamic
- public Web and private Webs
- each document (or Web page, or resource) identified by a URL

Uniform Resource Locators

`https://www.example.com:443/path/to/doc?name=foo&town=bar#`

scheme: `https` — hostname: `www.example.com` — port: `:443` — path: `path/to/doc` — query string: `?name=foo&town=bar` — f

- **scheme:** way the resource can be accessed; generally http or https
- **hostname:** domain name of a host (cf. DNS); hostname of a website may start with `www.`, but not a rule.
- **port:** TCP port; defaults: 80 for `http` and 443 for `https`
- **path:** logical path of the document
- **query string:** additional parameters (dynamic documents).
- **fragment:** subpart of the document

- Query strings and fragments optionals
- Empty path: root of the Web server
- Relative URIs with respect to a context (e.g., the URI above):

```
/titi  https://www.example.com/titi
tata   https://www.example.com/path/to/tata
```

(X)HTML

- Choice format for Web pages
- Dialect of SGML (the ancestor of XML), but seldom parsed as is
- HTML 4.01: most common version, W3C recommendation
- XHTML 1.0: XML-ization of HTML 4.01, minor differences
- Validation (cf `http://validator.w3.org/`). Checks the conformity of a Web page with respect to recommendations, for accessibility:
  - to all graphical browsers (IE, Firefox, Safari, Opera, etc.)
  - to text browsers (lynx, links, w3m, etc.)
  - to aural browsers
  - to all other user agents including Web crawlers
- Actual situation of the Web: tag soup

XHTML example

```
<!DOCTYPE html PUBLIC
"-//W3C//DTD XHTML 1.0 Strict//EN"
"http://www.w3.org/TR/xhtml1/DTD/xhtml1-strict.dtd">

<html xmlns="http://www.w3.org/1999/xhtml"
      lang="en" xml:lang="en">
  <head>
    <meta http-equiv="Content-Type"
          content="text/html; charset=utf-8" />
    <title>Example XHTML document</title>
  </head>
  <body>
    <p>This is a
      <a href="http://www.w3.org/">link to the
      <strong>W3C</strong>!</a></p>
  </body>
</html>
```

HTTP

- Client-server protocol for the Web, on top of TCP/IP
- Example request/response

```
GET /myResource HTTP/1.1
Host: www.example.com
```

```
HTTP/1.1 200 OK
Content-Type: text/html; charset=ISO-8859-1

<html>
  <head><title>myResource</title></head>
  <body><p>Hello world!</p></body>
</html>
```

- HTTPS: secure version of HTTP
  - encryption
  - authentication
  - session tracking

Features of HTTP/1.1

virtual hosting: different Web content for different hostnames on a single machine

login/password protection

content negociation: same URL identifying several resources, client indicates preferences

cookies: chunks of information persistently stored on the client

keep-alive connections: several requests using the same TCP connection

etc.

Outline

1. The World Wide Web
2. Web crawling
   - Discovering new URLs
   - Identifying duplicates
   - Crawling architecture
3. Web Information Retrieval
4. Web Graph Mining
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Web Crawlers

- crawlers, (Web) spiders, (Web) robots: autonomous user agents that retrieve pages from the Web
- Basics of crawling:
  1. Start from a given URL or set of URLs
  2. Retrieve and process the corresponding page
  3. Discover new URLs (cf. next slide)
  4. Repeat on each found URL
- No real termination condition (virtual unlimited number of Web pages!)
- Graph-browsing problem

  deep-first: not very adapted, possibility of being lost in robot traps

  breadth-first

  combination of both: breadth-first with limited-depth deep-first on each discovered website

Sources of new URLs

- From HTML pages:
  - hyperlinks `<a href="...">...</a>`
  - media `<img src="..."> <embed src="..."> <object data="...">`
  - frames `<frame src="..."> <iframe src="...">`
  - JavaScript links `window.open("...")`
  - etc.
- Other hyperlinked content (e.g., PDF files)
- Non-hyperlinked URLs that appear anywhere on the Web (in HTML text, text files, etc.): use regular expressions to extract them
- Referrer URLs
- Sitemaps [sit08]

Scope of a crawler

- Web-scale
  - The Web is infinite! Avoid robot traps by putting depth or page number limits on each Web server
  - Focus on important pages [APC03] (cf. lecture on the Web graph)
- Web servers under a list of DNS domains: easy filtering of URLs
- A given topic: focused crawling techniques [CvdBD99, DCL+00] based on classifiers of Web page content and predictors of the interest of a link.
- The national Web (cf. public deposit, national libraries): what is this? [ACMS02]
- A given Web site: what is a Web site? [Sen05]

A word about hashing

Definition

A hash function is a deterministic mathematical function transforming objects (numbers, character strings, binary. . .) into fixed-size, seemingly random, numbers. The more random the transformation is, the better.

Example

Java hash function for the `String` class:

$$\sum_{i=0}^{n-1} s_i \times 31^{n-i-1} \bmod 2^{32}$$

where s_i is the (Unicode) code of character i of a string s.

Identification of duplicate Web pages

Problem

Identifying duplicates or near-duplicates on the Web to prevent multiple indexing

trivial duplicates: same resource at the same canonized URL:

```
http://example.com:80/toto
http://example.com/titi/../toto
```

exact duplicates: identification by hashing

near-duplicates: (timestamps, tip of the day, etc.) more complex!

Near-duplicate detection

Edit distance. Count the minimum number of basic modifications (additions or deletions of characters or words, etc.) to obtain a document from another one. Good measure of similarity, and can be computed in $O(mn)$ where m and n are the size of the documents. But: does not scale to a large collection of documents (unreasonable to compute the edit distance for every pair!).

Shingles. Idea: two documents similar if they mostly share the same succession of k-grams (succession of tokens of length k).

Example

I like to watch the sun set with my friend.
My friend and I like to watch the sun set.

$S =${i like, like to, my friend, set with, sun set, the sun, to watch, watch the, with my}
$T =${and i, friend and, i like, like to, my friend, sun set, the sun, to watch, watch the}

Hashing shingles to detect duplicates [BGMZ97]

- Similarity: Jaccard coefficient on the set of shingles:

$$J(S,T) = \frac{|S \cap T|}{|S \cup T|}$$

- Still costly to compute! But can be approximated as follows:
  1. Choose N different hash functions
  2. For each hash function h_i and each set of shingles $S_k = \{s_{k1} \dots s_{kn}\}$, store $\phi_{ik} = \min_j h_i(s_{kj})$
  3. Approximate $J(S_k, S_l)$ as the proportion of ϕ_{ik} and ϕ_{il} that are equal
- Possibly to repeat in a hierarchical way with super-shingles (we are only interested in very similar documents)

Crawling ethics

- Standard for robot exclusion: robots.txt at the root of a Web server [Kos94].

```
User-agent: *
Allow: /searchhistory/
Disallow: /search
```

- Per-page exclusion (*de facto* standard).

```
<meta name="ROBOTS" content="NOINDEX,NOFOLLOW">
```

- Per-link exclusion (*de facto* standard).

```
<a href="toto.html" rel="nofollow">Toto</a>
```

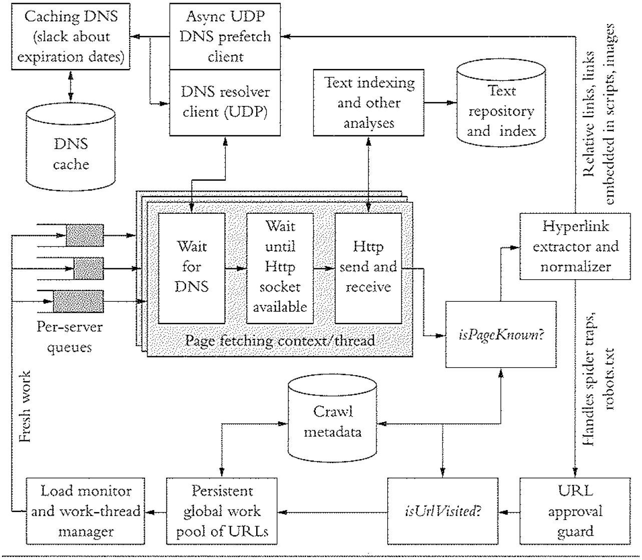
- Avoid Denial Of Service (DOS), wait 100ms/1s between two repeated requests to the same Web server

Parallel processing

Network delays, waits between requests:

- Per-server queue of URLs
- Parallel processing of requests to different hosts:
  - multi-threaded programming
  - asynchronous inputs and outputs (`select`, classes from `java.util.concurrent`): less overhead
- Use of keep-alive to reduce connexion overheads

General Architecture [Cha03]



Refreshing URLs

- Content on the Web changes
- Different change rates:

  online newspaper main page: every hour or so
  published article: virtually no change

- Continuous crawling, and identification of change rates for adaptive crawling:
  - `If-Last-Modified` HTTP feature (not reliable)
  - Identification of duplicates in successive request

Outline

1. The World Wide Web
2. Web crawling
3. Web Information Retrieval
   - Text Preprocessing
   - Inverted Index
   - Answering Keyword Queries
   - Building inverted files
   - Clustering
   - Other Media
4. Web Graph Mining
5. Conclusion

Information Retrieval, Search

Problem

How to index Web content so as to answer (keyword-based) queries efficiently?

Context: set of text documents

d_1 The jaguar is a New World mammal of the Felidae family.

d_2 Jaguar has designed four new engines.

d_3 For Jaguar, Atari was keen to use a 68K family device.

d_4 The Jacksonville Jaguars are a professional US football team.

d_5 Mac OS X Jaguar is available at a price of US \$199 for Apple's new "family pack".

d_6 One such ruling family to incorporate the jaguar into their name is Jaguar Paw.

d_7 It is a big cat.

Text Preprocessing

Initial text preprocessing steps

- Number of optional steps
- Highly depends on the application
- Highly depends on the document language (illustrated with English)

Language Identification

How to find the language used in a document?

- Meta-information about the document: often not reliable!
- Unambiguous scripts or letters: not very common!

한글
カタカナ
ދިވެހި
Għarbi
þorn

Language Identification

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  Respectively: Korean Hangul, Japanese Katakana, Maldivian Dhivehi, Maltese, Icelandic
- Extension of this: frequent characters, or, better, frequent *k*-grams
- Use standard machine learning techniques (classifiers)

Tokenization

Principle

Separate text into tokens (words)

Not so easy!

- In some languages (Chinese, Japanese), words not separated by whitespace
- Deal consistently with acronyms, elisions, numbers, units, URLs, emails, etc.
- Compound words: *hostname*, *host-name* and *host name*. Break into two tokens or regroup them as one token? In any case, lexicon and linguistic analysis needed! Even more so in other languages as German.

Usually, remove punctuation and normalize case at this point

Tokenization: Example

- d_1 the$_1$ jaguar$_2$ is$_3$ a$_4$ new$_5$ world$_6$ mammal$_7$ of$_8$ the$_9$ felidae$_{10}$ family$_{11}$
- d_2 jaguar$_1$ has$_2$ designed$_3$ four$_4$ new$_5$ engines$_6$
- d_3 for$_1$ jaguar$_2$ atari$_3$ was$_4$ keen$_5$ to$_6$ use$_7$ a$_8$ 68k$_9$ family$_{10}$ device$_{11}$
- d_4 the$_1$ jacksonville$_2$ jaguars$_3$ are$_4$ a$_5$ professional$_6$ us$_7$ football$_8$ team$_9$
- d_5 mac$_1$ os$_2$ x$_3$ jaguar$_4$ is$_5$ available$_6$ at$_7$ a$_8$ price$_9$ of$_{10}$ us$_{11}$ \$199$_{12}$ for$_{13}$ apple's$_{14}$ new$_{15}$ family$_{16}$ pack$_{17}$
- d_6 one$_1$ such$_2$ ruling$_3$ family$_4$ to$_5$ incorporate$_6$ the$_7$ jaguar$_8$ into$_9$ their$_{10}$ name$_{11}$ is$_{12}$ jaguar$_{13}$ paw$_{14}$
- d_7 it$_1$ is$_2$ a$_3$ big$_4$ cat$_5$

Stemming

Principle

Merge different forms of the same word, or of closely related words, into a single stem

- Not in all applications!
- Useful for retrieving documents containing *geese* when searching for *goose*
- Various degrees of stemming
- Possibility of building different indexes, with different stemming

Stemming schemes (1/2)

Morphological stemming.

- Remove bound morphemes from words:
  - plural markers
  - gender markers
  - tense or mood inflections
  - etc.
- Can be linguistically very complex, cf:
  Les poules du couvent couvent.
  [The hens of the monastery brood.]
- In English, somewhat easy:
  - Remove final -s, -'s, -ed, -ing, -er, -est
  - Take care of semiregular forms (e.g., -y/-ies)
  - Take care of irregular forms (mouse/mice)
- But still some ambiguities: cf stocking, rose

Stemming schemes (2/2)

Lexical stemming.

- Merge lexically related terms of various parts of speech, such as *policy*, *politics*, *political* or *politician*
- For English, Porter's stemming [Por80]; stem *university* and *universal* to *univers*: not perfect!
- Possibility of coupling this with lexicons to merge (near-)synonyms

Phonetic stemming.

- Merge phonetically related words: search despite spelling errors!
- For English, Soundex [US 07] stems *Robert* and *Rupert* to *R163*. Very coarse!

Stemming Example

- d_1 the$_1$ jaguar$_2$ be$_3$ a$_4$ new$_5$ world$_6$ mammal$_7$ of$_8$ the$_9$ felidae$_{10}$ family$_{11}$
- d_2 jaguar$_1$ have$_2$ design$_3$ four$_4$ new$_5$ engine$_6$
- d_3 for$_1$ jaguar$_2$ atari$_3$ be$_4$ keen$_5$ to$_6$ use$_7$ a$_8$ 68k$_9$ family$_{10}$ device$_{11}$
- d_4 the$_1$ jacksonville$_2$ jaguar$_3$ be$_4$ a$_5$ professional$_6$ us$_7$ football$_8$ team$_9$
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- d_6 one$_1$ such$_2$ rule$_3$ family$_4$ to$_5$ incorporate$_6$ the$_7$ jaguar$_8$ into$_9$ their$_{10}$ name$_{11}$ be$_{12}$ jaguar$_{13}$ paw$_{14}$
- d_7 it$_1$ be$_2$ a$_3$ big$_4$ cat$_5$

Stop Word Removal

Principle

Remove uninformative words from documents, in particular to lower the cost of storing the index

determiners: *a*, *the*, *this*, etc.

function verbs: *be*, *have*, *make*, etc.

conjunctions: *that*, *and*, etc.

etc.

Stop Word Removal Example

- d_1 jaguar$_2$ new$_5$ world$_6$ mammal$_7$ felidae$_{10}$ family$_{11}$
- d_2 jaguar$_1$ design$_3$ four$_4$ new$_5$ engine$_6$
- d_3 jaguar$_2$ atari$_3$ keen$_5$ 68k$_9$ family$_{10}$ device$_{11}$
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- d_6 one$_1$ such$_2$ rule$_3$ family$_4$ incorporate$_6$ jaguar$_8$ their$_{10}$ name$_{11}$ jaguar$_{13}$ paw$_{14}$
- d_7 big$_4$ cat$_5$

Structure of an inverted index

Assume D a collection of (text) documents. Create a matrix M with one row for each document, one column for each token. Initialize the cells at 0.

Create the content of M: scan D, and extract for each document d the tokens t that can be found in d (preprocessing); put 1 in $M[d][t]$

Invert M: one obtains the inverted index. Term appear as rows, with the list of document ids or *posting list*.

Problem: storage of the whole matrix is not feasible.

Inverted Index construction

After all preprocessing, construction of an inverted index:

- Index of all terms, with the list of documents where this term occurs
- Small scale: disk storage, with memory mapping (cf. `mmap`) techniques; secondary index for offset of each term in main index
- Large scale: distributed on a cluster of machines; hashing gives the machine responsible for a given term
- Updating the index is costly, so only batch operations (not one-by-one addition of term occurrences)

Inverted Index Example

family	d_1, d_3, d_5, d_6
football	d_4
jaguar	$d_1, d_2, d_3, d_4, d_5, d_6$
new	d_1, d_2, d_5
rule	d_6
us	d_4, d_5
world	d_1
…	

Note:

- the length of an inverted (posting) list is highly variable – scanning short lists first is an important optimization.
- *entries* are homogeneous: this gives much room for compression.

Index size matters

We want to index a collection of 1M emails. The average size of an email is 1,000 bytes and each email contains an average of 100 words. The number of distinct terms is 200,000.

1. size of the collection; number of words?
2. how many lists in the index?
3. we make the (rough) assumption that 20% of the terms in a document appear twice; a document appears in how many lists on average ?
4. how many entries in a list?
5. we represent document ids as 4-bytes unsigned integers, what is the index size ?

Storing positions in the index

- phrase queries, NEAR operator: need to keep position information in the index
- just add it in the document list!

family	$d_1\,/\,11,\ d_3\,/\,10,\ d_5\,/\,16,\ d_6\,/\,4$
football	$d_4\,/\,8$
jaguar	$d_1\,/\,2,\ d_2\,/\,1,\ d_3\,/\,2,\ d_4\,/\,3,\ d_5\,/\,4,\ d_6\,/\,8+13$
new	$d_1\,/\,5,\ d_2\,/\,5,\ d_5\,/\,15$
rule	$d_6\,/\,3$
us	$d_4\,/\,7,\ d_5\,/\,11$
world	$d_1\,/\,6$
...	

$\Rightarrow$ so far, ok for Boolean queries: find the documents that contain a set of keywords; reject the other.

Ranked search

Boolean search does not give an accurate result because it does not take account of the relevance of a document to a query.

If the search retrieves dozen or hundreds of documents, the most relevant must be shown in top position!

The quality of a result with respect to relevance is measured by two factors:

$$precision = \frac{|relevant| \cap |retrieved|}{|retrieved|}$$

$$recall = \frac{|relevant| \cap |retrieved|}{|relevant|}$$

Weighting terms occurrences

Relevance can be computed by giving a weight to term occurrences.

- Terms occurring frequently in a given document: more relevant.
  The *term frequency* is the number of occurrences of a term t in a document d, divided by the total number of terms in d (normalization)

$$\mathrm{tf}(t,d) = \frac{n_{t,d}}{\sum_{t'} n_{t',d}}$$

  where $n_{t',d}$ is the number of occurrences of t' in d.

- Terms occurring rarely in the document collection as a whole: more informative
  The *inverse document frequency* (idf) is obtained from the division of the total number of documents by the number of documents where t occurs, as follows:

$$\mathrm{idf}(t) = \log \frac{|D|}{\left|\{d' \in D \,|\, n_{t,d'} > 0\}\right|}.$$

TF-IDF Weighting

The inverted is extended by adding Term Frequency—Inverse Document Frequency weighting

$$\mathrm{tfidf}(t, d) = \frac{n_{t,d}}{\sum_{t'} n_{t',d}} \cdot \log \frac{|D|}{\left|\{d' \in D \,\middle|\, n_{t,d'} > 0\}\right|}$$

$n_{t,d}$	number of occurrences of t in d
D	set of all documents

Documents (along with weight) are stored in decreasing weight order in the index

TF-IDF Weighting Example

family	d_1 / 11 / .13, d_3 / 10 / .13, d_6 / 4 / .08, d_5 / 16 / .07
football	d_4 / 8 / .47
jaguar	d_1 / 2 / .04, d_2 / 1 / .04, d_3 / 2 / .04, d_4 / 3 / .04, d_6 / $8 + 13$ / .04, d_5 / 4 / .02
new	d_2 / 5 / .24, d_1 / 5 / .20, d_5 / 15 / .10
rule	d_6 / 3 / .28
us	d_4 / 7 / .30, d_5 / 11 / .15
world	d_1 / 6 / .47

...

Exercise: take an entry, and check that the tf/idf value is indeed correct (take documents after stop-word removal).

Answering Boolean Queries

- Single keyword query: just consult the index and return the documents in index order.
- Boolean multi-keyword query

  (*jaguar* AND *new* AND NOT *family*) OR *cat*

  Same way! Retrieve document lists from all keywords and apply adequate set operations:

AND	intersection
OR	union
AND NOT	difference

- Global score: some function of the individual weight (e.g., addition for conjunctive queries)
- Position queries: consult the index, and filter by appropriate condition

Answering Top-k Queries

$$t_1 \text{ AND } \ldots \text{ AND } t_n$$

Problem

Find the top-k results (for some given k) to the query, without retrieving all documents matching it.

Notations:

- $s(t,d)$ weight of t in d (e.g., tfidf)
- $g(s_1,\ldots,s_n)$ monotonous function that computes the global score (e.g., addition)

Exercise

Consider the following documents:

1. d_1 = I like to watch the sun set with my friend.
2. d_2 = The Best Places To Watch The Sunset.
3. d_3 = My friend watches the sun come up.

Construct an inverted index with tf/idf weights for terms 'Best' and 'sun'. What would be the ranked result of the query 'Best and sun'?

Basic algorithm

First version of the top-k algorithm: the inverted file contains entries sorted on the document id. The query is

$$t_1 \text{ AND } \ldots \text{ AND } t_n$$

.

1. Take the first entry of each list; one obtains a tuple $T = [e_1, \ldots e_n]$;
2. Let d_1 be the minimal doc id in the entries of T: compute the global score of d_1;
3. For each entry e_i featuring d_1: advance on the inverted list L_i.

When *all* lists have been scanned: sort the documents on the global scores.

Not very efficient; cannot give the ranked result before a full scan on the lists.

The Threshold Algorithm

1. Let R be the empty list, and $m = +\infty$.
2. For each $1 \leq i \leq n$:
   1. Retrieve the document $d^{(i)}$ containing term t_i that has the next largest $s(t_i, d^{(i)})$.
   2. Compute its global score $g_{d^{(i)}} = g(s(t_1, d^{(i)}), \ldots, s(t_n, d^{(i)}))$ by retrieving all $s(t_j, d^{(i)})$ with $j \neq i$.
   3. If R contains less than k documents, or if $g_{d^{(i)}}$ is greater than the minimum of the score of documents in R, add $d^{(i)}$ to R.
3. Let $m = g(s(t_1, d^{(1)}), s(t_2, d^{(2)}), \ldots, s(t_n, d^{(n)}))$.
4. If R contains more than k documents, and the minimum of the score of the documents in R is greater than or equal to m, return R.
5. Redo step 2.

The TA, by example

q = "*new* OR *family*", and $k = 3$. We use inverted lists sorted on the weight.

family $d_1 / 11 / .13$, $d_3 / 10 / .13$, $d_6 / 4 / .08$, $d_5 / 16 / .07$

new $d_2 / 5 / .24$, $d_1 / 5 / .20$, $d_5 / 15 / .10$

...

Initially, $R = \varnothing$ and $\tau = +\infty$.

1. $d^{(1)}$ is the first entry in L_{family}, one finds $s(\text{new}, \text{d}_1) = .20$; the global score for d_1 is $.13 + .20 = .33$.
2. Next, $i = 2$, and one finds that the global score for d_2 is .24.
3. The algorithm quits the loop on i with $R = \langle [d_1, .33], [d_2, .24] \rangle$ and $\tau = .13 + .24 = .37$.
4. We proceed with the loop again, taking d_3 with score .13 and d_5 with score .17. $[d_5, .17]$ is added to R (at the end) and τ is now $.10 + .13 = .23$. A last loop concludes that the next candidate is d_6, with a global score of .08. Then we are done.

External Sort/Merge

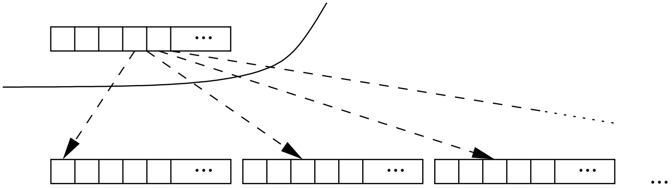
Building an inverted index from a document collection requires a sort/merge of the index entries.

- first extracts triplets $[d, t, f]$ from the collection;
- then sort the set of triplets on the term-docid pair $[t, d]$.
- contiguous inverted lists can be created from the sorted entries.

Note: ubiquitous operation; used in RDBMS for ORDER BY, GROUP BY, DISTINCT, and non-indexed joins.

First phase: sort

Repeat: fill the memory with entries; sort in memory (with quicksort); flush the memory in a “run”.

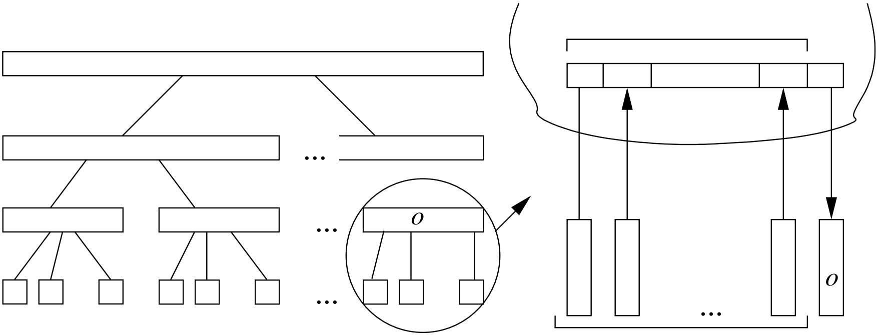


One obtains a list of sorted runs.

Cost: documents are read once; entries are written once.

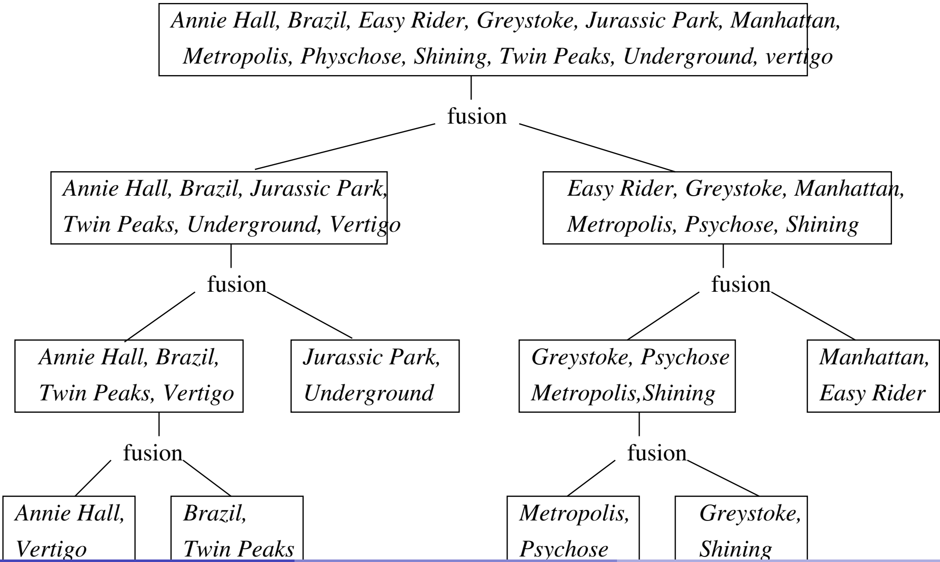
Second phase: merge

Group the runs and merge.



Cost: one read/write of all entries for each level of the merge tree.

Illustration with $M = 3$



Main parameter: the buffer size

Consider a file with 75 000 pages, 4Kb each, thus 307 MBs.

1. $M > 307Mo$: one read 307
2. $M = 2Mo$, (500 pages).
   1. the sort phase yields $\lceil \frac{307}{2} \rceil = 154$ runs.
   2. The merge phase requires 154 pages

   Total cost: $614 + 307 = 921$ MB.

NB : we must allocate a lot of memory to decrease the number of merge levels by one.

With few memory

$M = 1Mo$, 250 pages.

1. sort phase: 307 runs.
2. Merge the 249 first runs; then the 58 remaining. One obtains F_1 and F_2.
3. Second merge of F_1 and F_2.

Total cost: $1\,228 + 307 = 1\,535$ MBs.

NB : important performance loss between 2 MBs and 1 MBs ().

Exercise

Assume that a page holds only two records. Explain the sort-merge algorithm on the following dataset with a 4-pages buffers.

```
3 Allier;   36 Indre    18 Cher    75 Paris     39 Jura
9 Ariï£¡ge;   81 Tarn     11 Aude    12 Aveyron  25 Doubs
73 Savoie   55 Meuse    15 Cantal 51 Marne     42 Loire
40 Landes 14 Calvados 30 Gard    84 Vaucluse 7 Ardï£¡che
```

Same question with a 3-pages buffer.

Compression of inverted lists

Without compression, an inverted index with positions and weights may be large than the documents collection!

Compression is essential. The gain must be higher than the time spent to compress.

Key to compression in inverted lists: documents are ordered by id:

$$[87; 273; 365; 576; 810].$$

First step: use *delta-coding*:

$$[87; 186; 92; 211; 234].$$

Exercise: what is the minimal number of bytes for the first list? for the second?

Variable bytes encoding

Idea: encode integers on 7 bits ($2^7 = 128$); use the leading bit for termination.

Let $v = 9$, encoded on one byte as 10000101 (note the first bit set to 1).

Let $v = 137$.

1. the first byte encodes $v' = v \bmod 128 = 9$, thus $b = 10000101$ just as before;
2. next we encode $v/128 = 1$, in a byte $b' = 00000001$ (note the first bit set to 0).

137 is therefore encoded on two bytes:

$$00000001\ 10000101.$$

Compression ratio: typically 1/4 to 1/2 of the fixed-length representation.

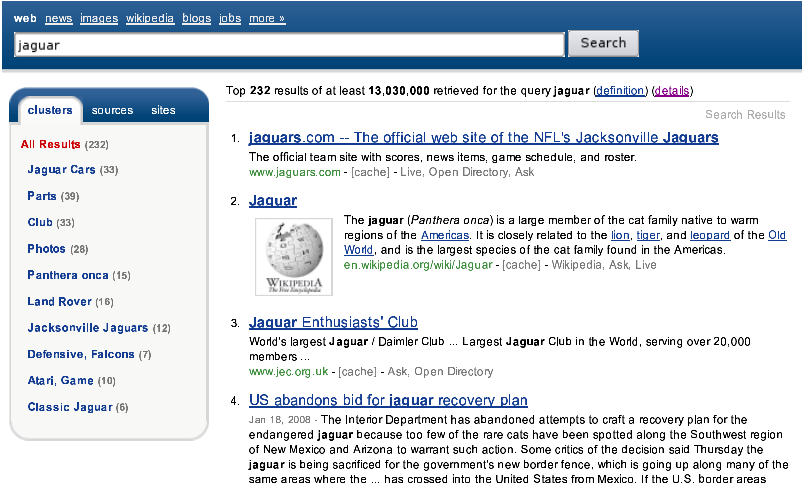
Exercise

The inverted list of a term *t* consists of the following document ids:

$$[345; 476; 698; 703].$$

Apply the VByte compression technique to this sequence. What is the amount of space gained by the method?

Clustering Example



Cosine Similarity of Documents

- Document Vector Space model:

terms	dimensions
documents	vectors
coordinates	weights

  (The projection of document d along coordinate t is the weight of t in d, say $\mathrm{tfidf}(\mathrm{t}, \mathrm{d})$)

- Similarity between documents d and d': cosine of these two vectors

$$\cos(d, d') = \frac{d \cdot d'}{\|d\| \times \|d'\|}$$

$d \cdot d'$	scalar product of d and d'
$\|d\|$	norm of vector d

- $\cos(d, d) = 1$
- $\cos(d, d') = 0$ if d and d' are orthogonal (do not share any common term)

Agglomerative Clustering of Documents

1. Initially, each document forms its own cluster.
2. The similarity between two clusters is defined as the maximal similarity between elements of each cluster.
3. Find the two clusters whose mutual similarity is highest. If it is lower than a given threshold, end the clustering. Otherwise, regroup these clusters. Repeat.

Remark

Many other more refined algorithms for clustering exist.

Indexing HTML

- HTML: text + meta-information + structure
- Possibly: separate index for meta-information (title, keywords)
- Increase weight of structurally emphasized content in index
- Tree structure can also be queried with XPath or XQuery, but not very useful on the Web as a whole, because of tag soup and lack of consistency.

Indexing Multimedia Content

- Basic approach: index text from context of the media
  - surrounding text
  - text in or around the links pointing to the content
  - filenames
  - associated subtitles (hearing-impaired track on TV)
- Elaborate approach: index and search the media itself, with the help of speech recognition and sound, image, and video analysis
  - TrackID, Shazam: identify a song played on the radio
  - Musipedia: look for music by whistling a tune, `http://www.musipedia.org/`, `http://www.midomi.com/`
  - Image search from a similar image, `http://images.google.com/`, Google Goggles
  - Voxalead, `http://voxaleadnews.labs.exalead.com/`

Outline

1 The World Wide Web

2 Web crawling

3 Web Information Retrieval

4 Web Graph Mining
- PageRank
- HITS
- Spamdexing

5 Conclusion

The Web Graph

The World Wide Web seen as a (directed) graph:

Vertices: Web pages

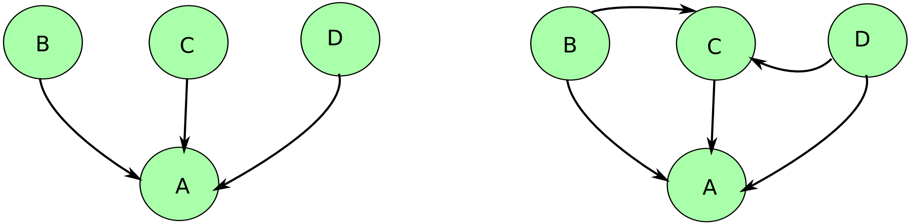
Edges: hyperlinks

Same for other interlinked environments:

- dictionaries
- encyclopedias
- scientific publications
- social networks

Let's start with simple examples

The *PageRank* (PR) of page *i* is the Probability that a surfer following the random walk has arrived on *i* at some distant given point in the future.

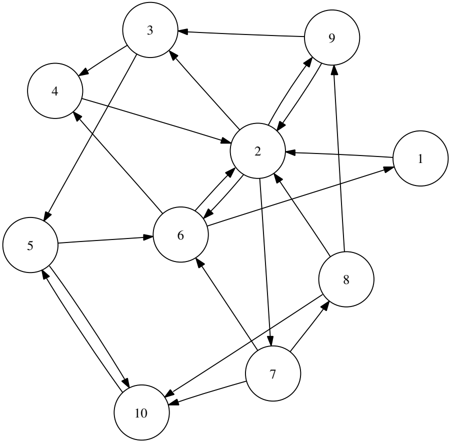


Left part: $PR(A) = PR(B) + PR(C) + PR(D)$

Right part?

Assume that the initial PR of each page is 0.25: what is the PR after one iteration? Two iterations?

The example graph



The transition matrix

$$\begin{cases} g_{ij} = 0 & \text{if there is no link between page } i \text{ and } j; \\ g_{ij} = \frac{1}{n_i} & \text{otherwise, with } n_i \text{ the number of outgoing links of page } i. \end{cases}$$

$$G = \begin{pmatrix}
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \frac{1}{4} & 0 & 0 & \frac{1}{4} & \frac{1}{4} & 0 & \frac{1}{4} & 0 \\
0 & 0 & 0 & \frac{1}{2} & \frac{1}{2} & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \frac{1}{2} & 0 & 0 & 0 & \frac{1}{2} \\
\frac{1}{3} & \frac{1}{3} & 0 & \frac{1}{3} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \frac{1}{3} & 0 & \frac{1}{3} & 0 & \frac{1}{3} \\
0 & \frac{1}{3} & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{3} & \frac{1}{3} \\
0 & \frac{1}{2} & \frac{1}{2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0
\end{pmatrix}$$

PageRank (Google's Ranking [BP98])

Idea

Important pages are pages pointed to by important pages.

PageRank simulates a random walk by iterately computing the PR of each page, represented as a vector v.

Initially, v is set using a uniform distribution ($v[i] = \frac{1}{|v|}$).

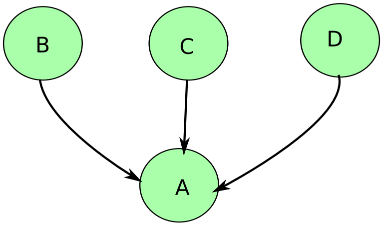
Definition (Tentative)

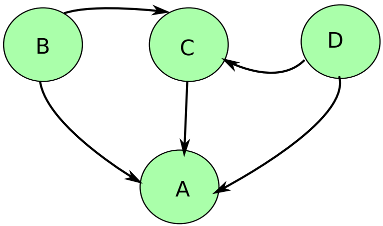
Probability that the surfer following the random walk in G has arrived on page i at some distant given point in the future.

$$\text{pr}(i) = \left(\lim_{k \to +\infty} (G^T)^k v \right)_i$$

where v is some initial column vector.

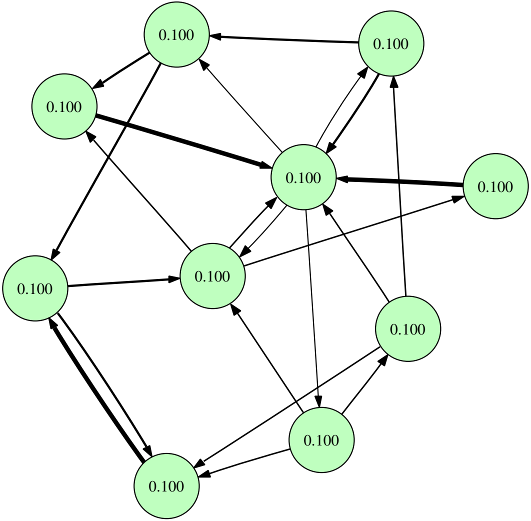
Exercise



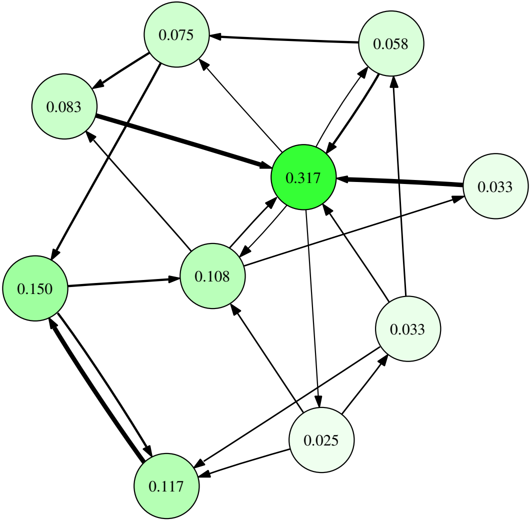


Model the simple examples with transition matrix, and apply PageRank, assuming an initial uniform distribution.

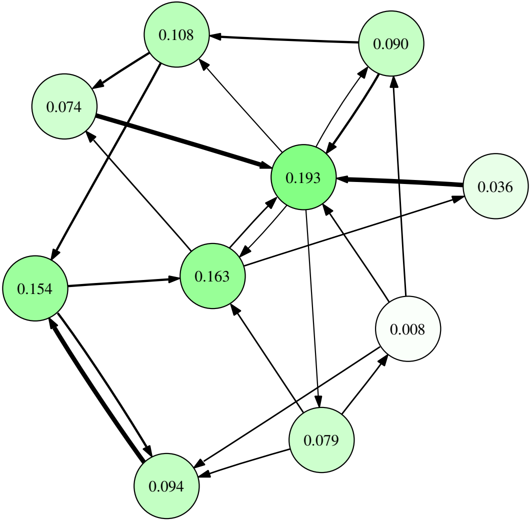
PageRank Iterative Computation



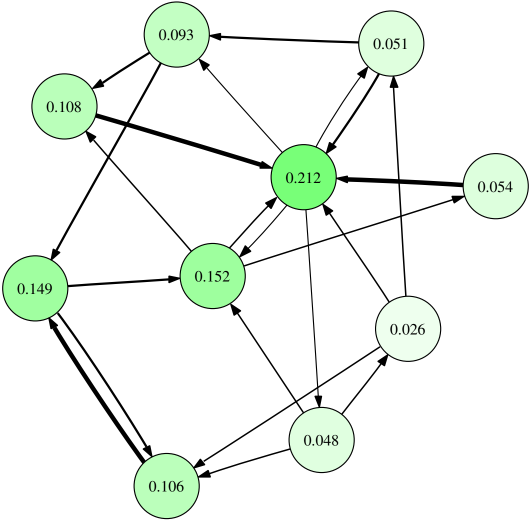
PageRank Iterative Computation



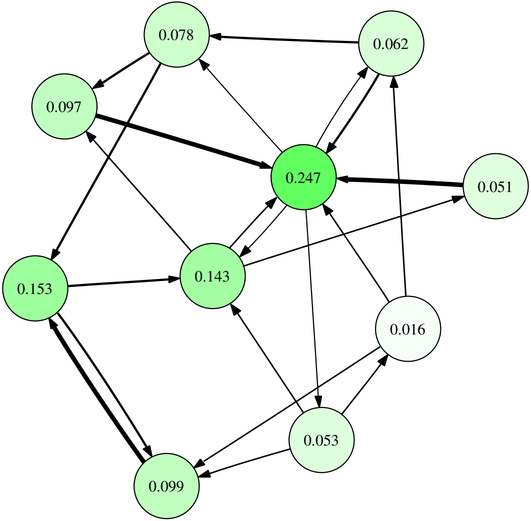
PageRank Iterative Computation



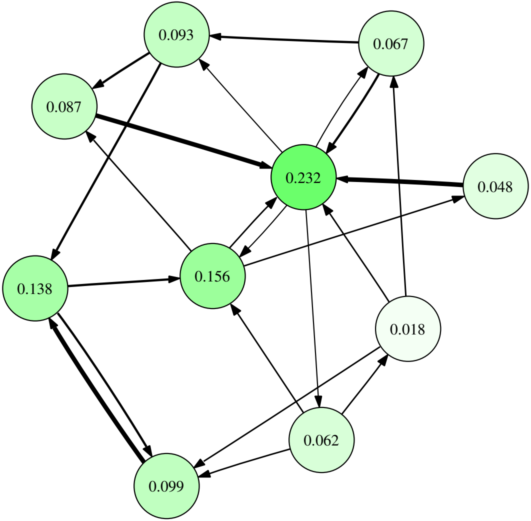
PageRank Iterative Computation



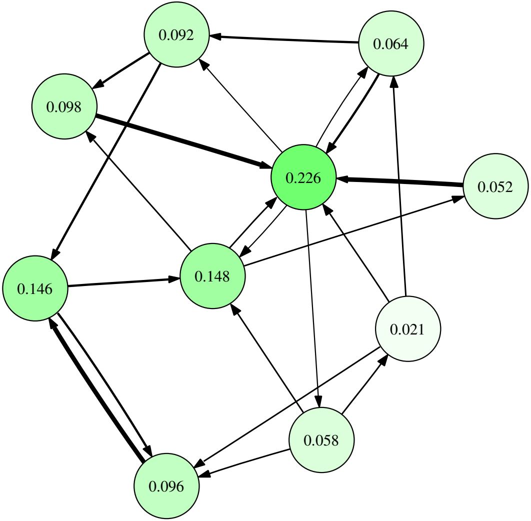
PageRank Iterative Computation



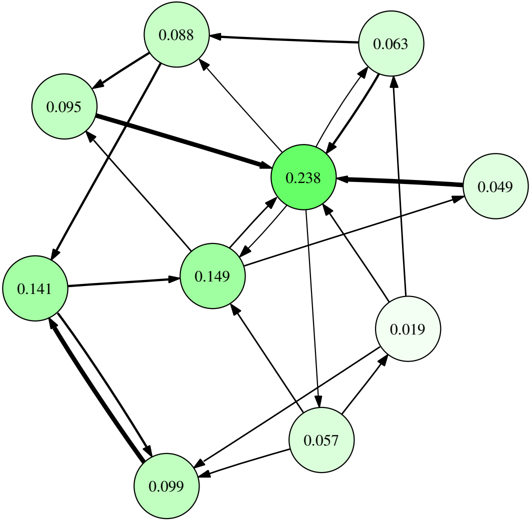
PageRank Iterative Computation



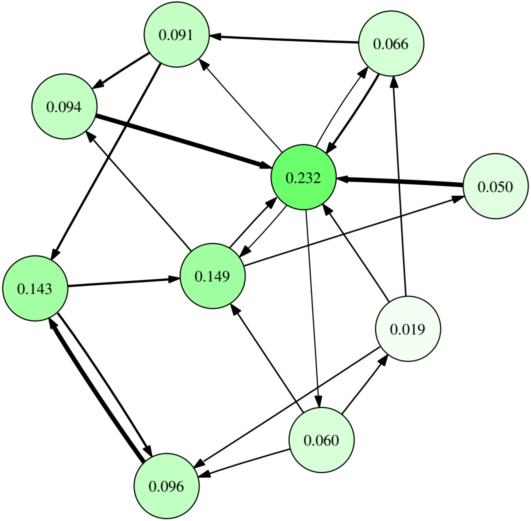
PageRank Iterative Computation



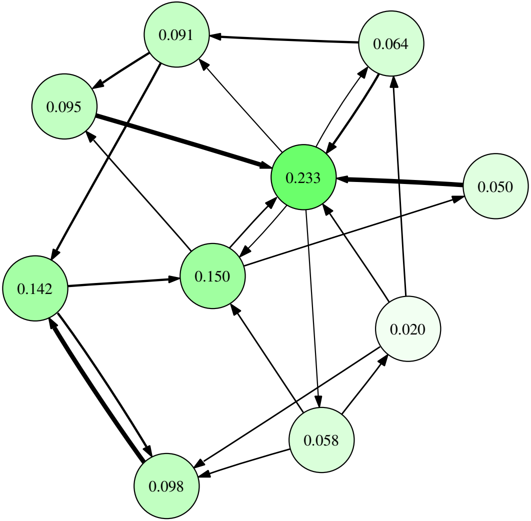
PageRank Iterative Computation



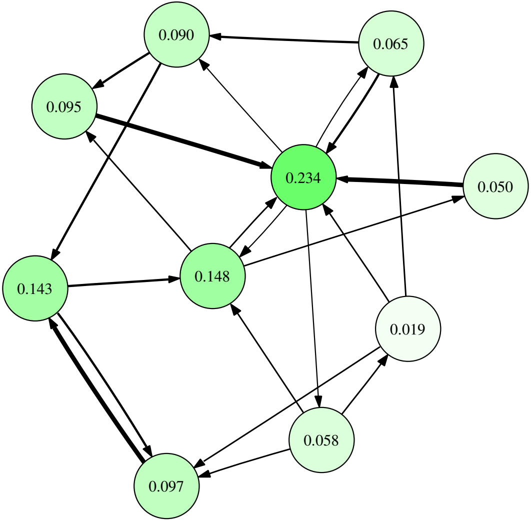
PageRank Iterative Computation



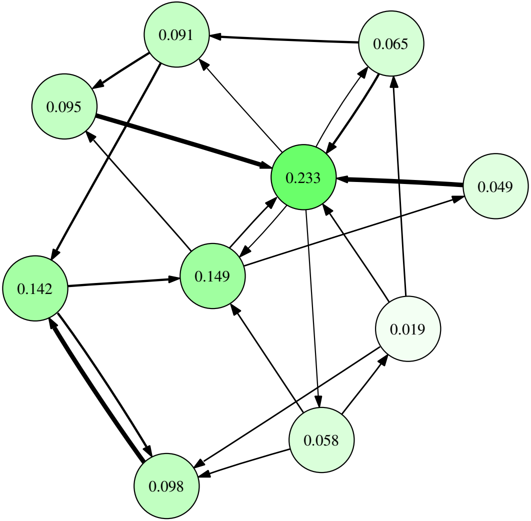
PageRank Iterative Computation



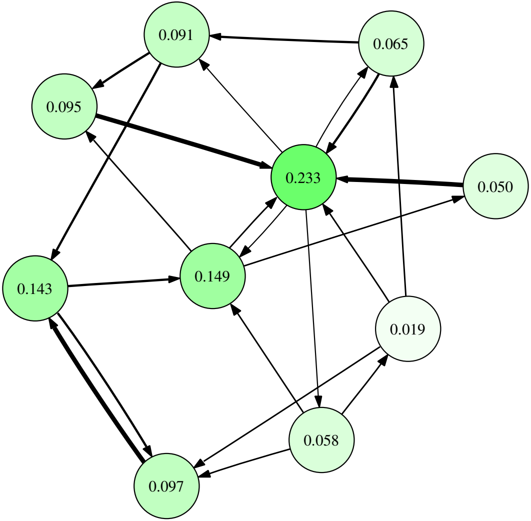
PageRank Iterative Computation



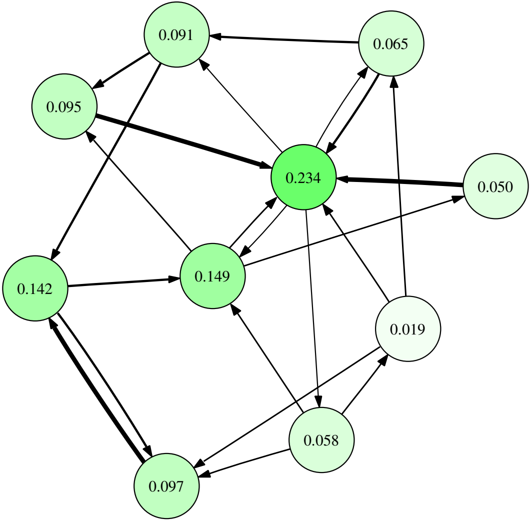
PageRank Iterative Computation



PageRank Iterative Computation



PageRank Iterative Computation



PageRank With Damping

May not always converge, or convergence may not be unique.

To fix this, the random surfer can at each step randomly jump to any page of the Web with some probability d ($1 - d$: damping factor).

$$\mathrm{pr}(i) = \left(\lim_{k \to +\infty} ((1-d)G^T + dU)^k v \right)_i$$

where U is the matrix with all $\frac{1}{N}$ values with N the number of vertices.

Using PageRank to Score Query Results

- PageRank: global score, independent of the query
- Can be used to raise the weight of important pages:

$$\text{weight}(t, d) = \text{tfidf}(t, d) \times \text{pr}(d),$$

- This can be directly incorporated in the index.

HITS (Kleinberg, [Kle99])

Idea

Two kinds of important pages: hubs and authorities. Hubs are pages that point to good authorities, whereas authorities are pages that are pointed to by good hubs.

G' transition matrix (with 0 and 1 values) of a subgraph of the Web. We use the following iterative process (starting with a and h vectors of norm 1):

$$\begin{cases} a := \frac{1}{\|G'^T h\|} G'^T h \\ h := \frac{1}{\|G' a\|} G' a \end{cases}$$

Converges under some technical assumptions to authority and hub scores.

Using HITS to Order Web Query Results

1. Retrieve the set D of Web pages matching a keyword query.
2. Retrieve the set D^* of Web pages obtained from D by adding all linked pages, as well as all pages linking to pages of D.
3. Build from D^* the corresponding subgraph G' of the Web graph.
4. Compute iteratively hubs and authority scores.
5. Sort documents from D by authority scores.

Less efficient than PageRank, because local scores.

Spamdexing

Definition

Fraudulent techniques that are used by unscrupulous webmasters to artificially raise the visibility of their website to users of search engines

Purpose: attracting visitors to websites to make profit.

Unceasing war between spamdexers and search engines

Spamdexing: Lying about the Content

Technique

Put unrelated terms in:

- meta-information (`<meta name="description">`, `<meta name="keywords">`)
- text content hidden to the user with JavaScript, CSS, or HTML presentational elements

Countertechnique

- Ignore meta-information
- Try and detect invisible text

Link Farm Attacks

Technique

Huge number of hosts on the Internet used for the sole purpose of referencing each other, without any content in themselves, to raise the importance of a given website or set of websites.

Countertechnique

- Detection of websites with empty or duplicate content
- Use of heuristics to discover subgraphs that look like link farms

Link Pollution

Technique

Pollute user-editable websites (blogs, wikis) or exploit security bugs to add artificial links to websites, in order to raise its importance.

Countertechnique

`rel="nofollow"` attribute to <a> links not validated by a page's owner

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5 Conclusion

What you should remember

- The inverted index model for efficient answers of keyword-based queries.
- The threshold algorithm for retrieving top-k results.
- PageRank and its iterative computation.

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