Web search

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. Hot Topics
6. 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

$$\underbrace{\texttt{https}}_{\text{scheme}}\texttt{://}\underbrace{\texttt{www.example.com}}_{\text{hostname}}\underbrace{\texttt{:443}}_{\text{port}}\texttt{/}\underbrace{\texttt{path/to/doc}}_{\text{path}}\underbrace{\texttt{?name=foo\&town=bar}}_{\text{query string}}\underbrace{\texttt{\#para}}_{\text{fragment}}$$

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 connexions: several requests using the same TCP connexion

etc.

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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 index the corresponding page
  3. Discover hyperlinks (<a> elements)
  4. Repeat on each found link
- 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

Identification of duplicated 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.) identification by hashing of sequences of n successive tokens (n-grams)

Crawling ethics

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

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

- Per-page exclusion.

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

- 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`): less overhead
- Use of keep-alive to reduce connexion overheads

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

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1. The World Wide Web
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3. Web Information Retrieval
   - Text Preprocessing
   - Inverted Index
   - Answering Keyword Queries
   - Clustering
   - Other Media
4. Web Graph Mining
5. Hot Topics

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)

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

Stemming schemes (1/2)

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$_9$

d_5 mac$_1$ os$_2$ x$_3$ jaguar$_4$ be$_5$ available$_6$ at$_7$ a$_8$ price$_9$ of$_{10}$ us$_{11}$ \$199$_{12}$ for$_{13}$ apple$_{14}$ new$_{15}$ family$_{16}$ pack$_{17}$

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$_6$
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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$_5$

Inverted Index

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 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
...	

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	$d_1/6$
...	

TF-IDF Weighting

- Some term occurrences have more weight than others:
  - Terms occurring frequently in a given document: more relevant
  - Terms occurring rarely in the document collection as a whole: more informative
- Add Term Frequency—Inverse Document Frequency weighting to occurrences;

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

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

- Store documents (along with weight) 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	$d_1/6/.47$
...	

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

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

Problem

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

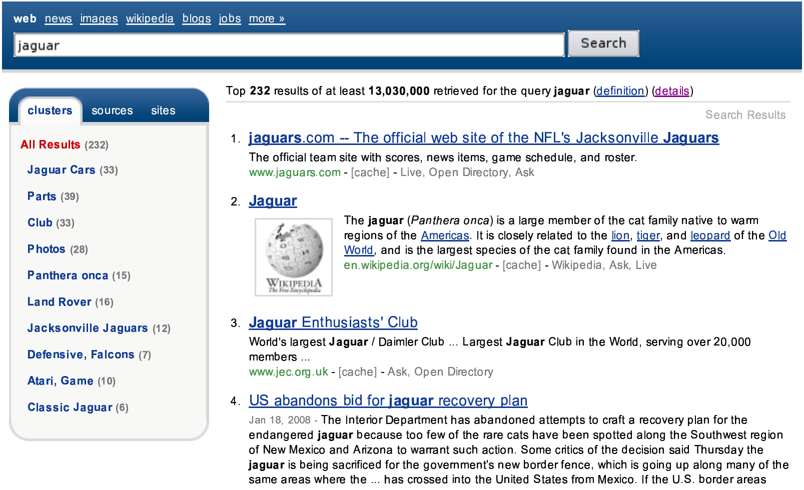
Notations:

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

Fagin's Threshold Algorithm [FLN03]

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.

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 tfidf(t,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
  - Musipedia: look for a partition by whistling a tune
  - Image search from a similar image

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- PageRank
- HITS
- Spamdexing

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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

PageRank (Google's Ranking [BP98])

Idea

Important pages are pages pointed to by important pages.

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

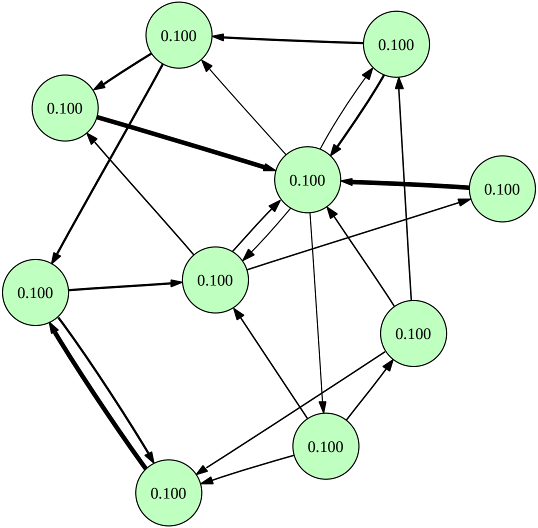
Definition (Tentative)

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

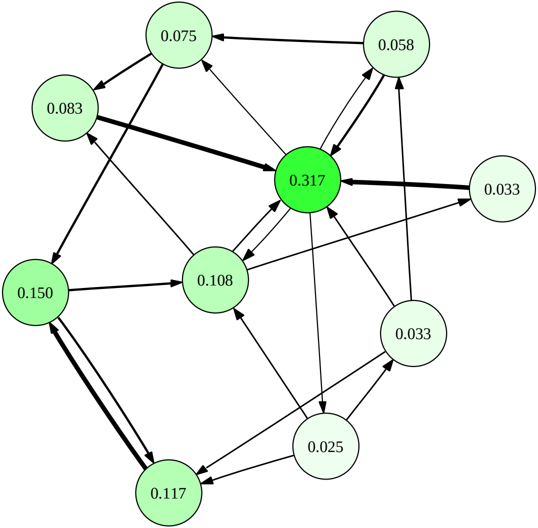
$$\mathrm{pr}(i) = \left(\lim_{k \to +\infty} (G^T)^k v \right)_i$$

where v is some initial column vector.

PageRank Iterative Computation



PageRank Iterative Computation



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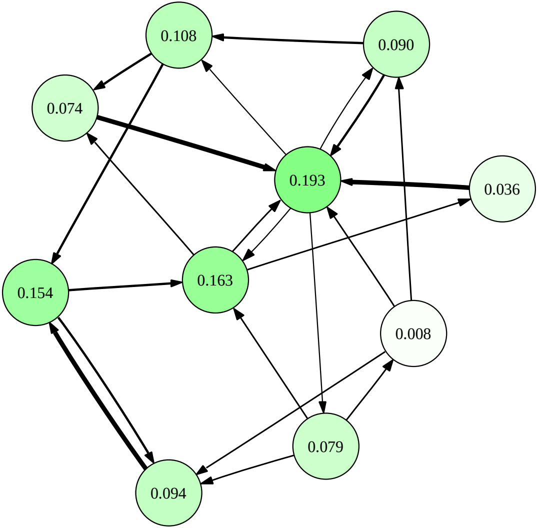

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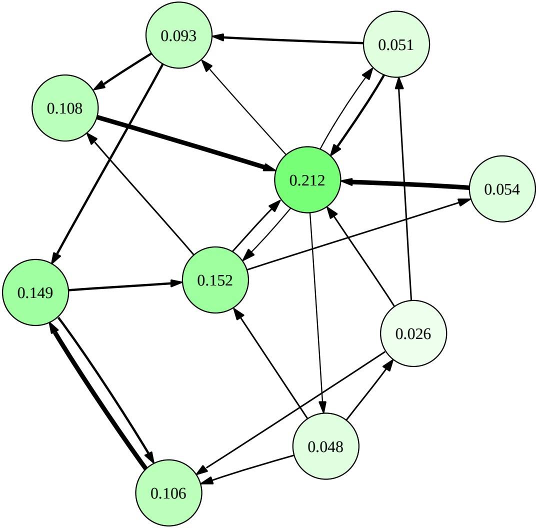

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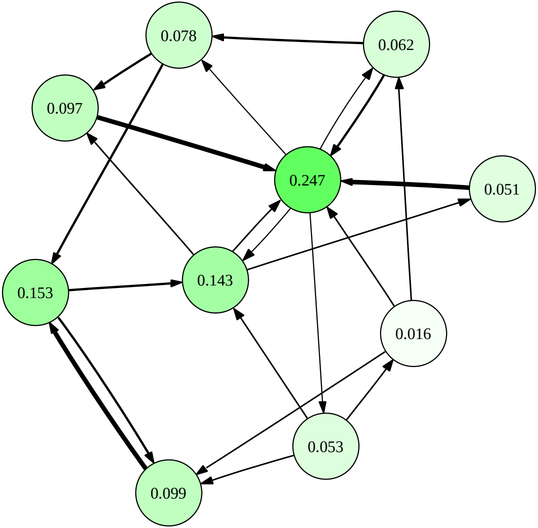

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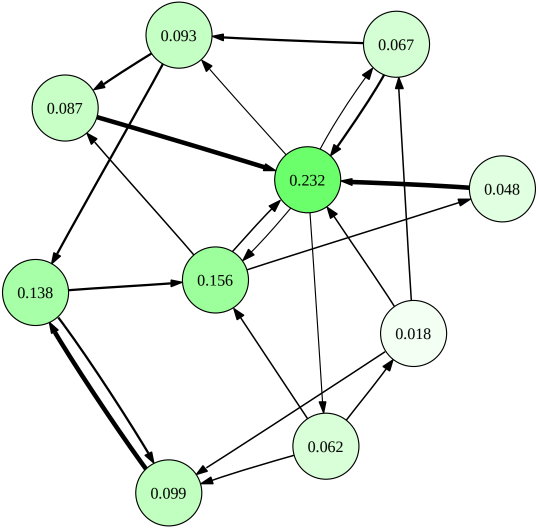

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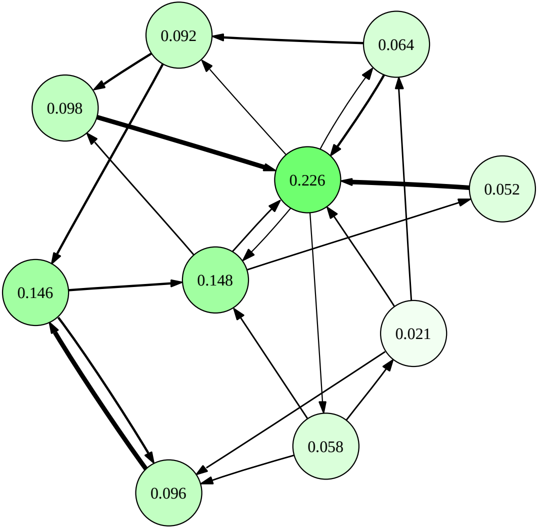

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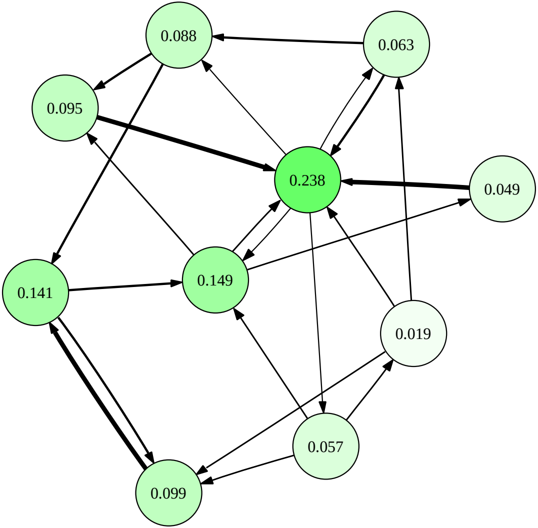

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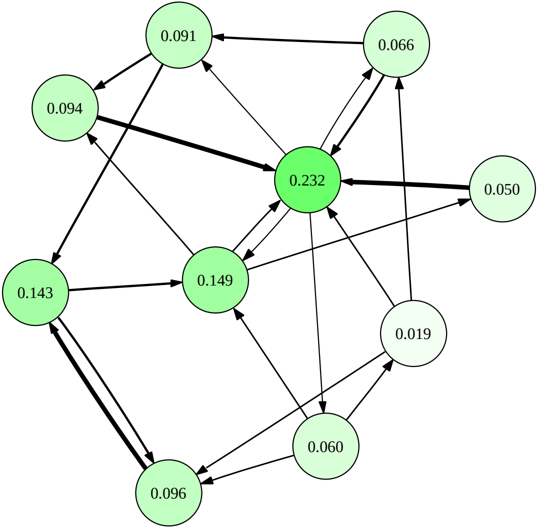

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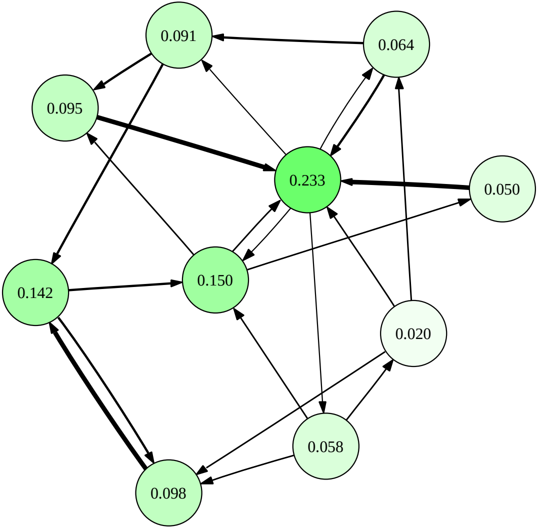

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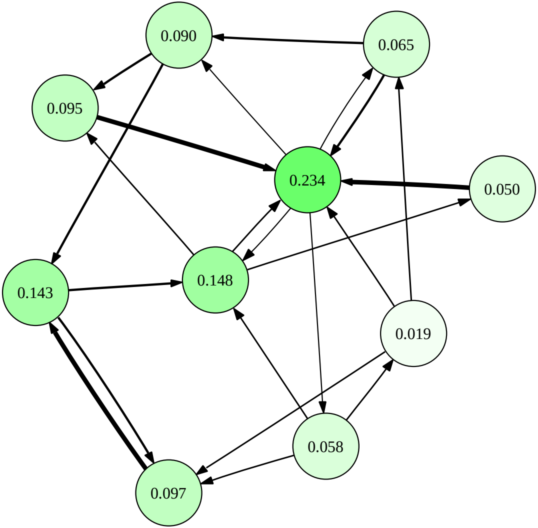

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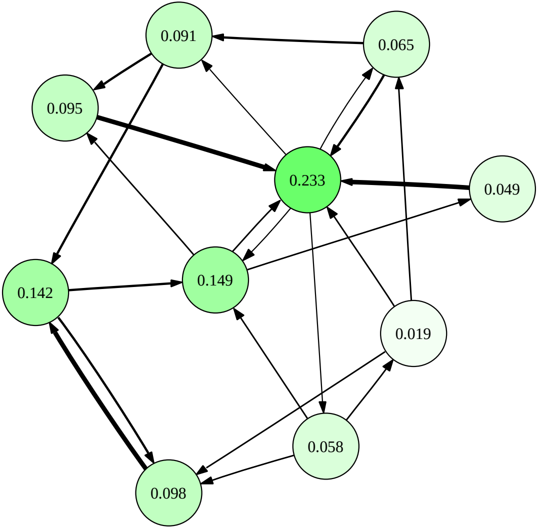

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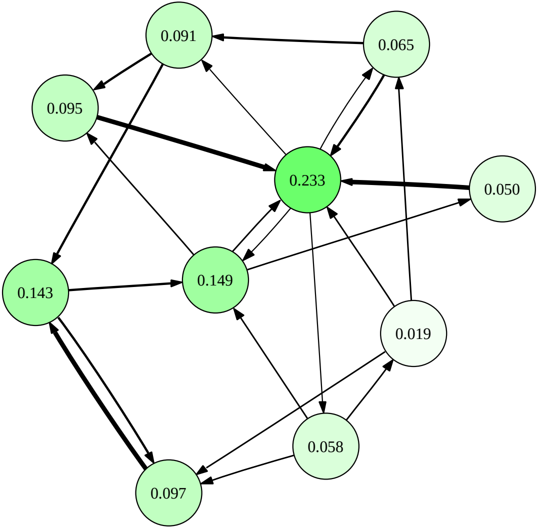

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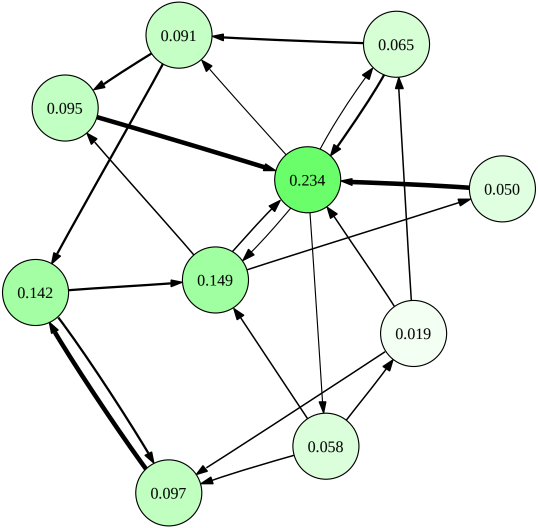

PageRank With Damping

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:

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

- 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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   - Semantic Web
   - Web 2.0
   - Deep Web
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Querying the Semantic Web

Definition

Semantic Web: extension of the current Web, where human-readable content is annotated with machine-readable descriptions

- RDF to describe objects, and graphs of relationships between objects
- RDFS and OWL to express schemata and ontologies
- SPARQL to query semantic Web sources
- Problem: no uniformity in schemata and ontologies on the Web
  $\Rightarrow$ integration needed

Web 2.0

Definition

Web 2.0: buzzword about:

- rich dynamic interfaces, especially with the help of AJAX (Asynchronous JavaScript and XML) technologies: GMail, Google Suggest
- user-editable content, collaborative work and social networks: blogs, Wikipedia, MySpace, Facebook
- aggregation of content from multiple sources and personalization: Netvibes, Yahoo! Pipes

Interesting issues:

- application of graph mining techniques to the graph of social network websites
- mashups for aggregating content from multiple sources on the Web

The Deep Web

Definition

Deep Web (or hidden Web, or invisible Web): part of Web content that lies in online databases, typically queried through HTML forms, and is not usually accessible by following hyperlinks

- Huge amount of information (maybe 500 more than on the surface Web?): *Yellow pages* directories, information from the US *Census bureau*, weather or geolocation services
- Extensional (siphoning) or intensional (understanding services) approaches

Outline

1. The World Wide Web
2. Web Crawling
3. Web Information Retrieval
4. Web Graph Mining
5. Hot Topics
6. 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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