



Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

Processamento e Recuperação de Informação

Web Retrieval and Link Analysis

Departamento de Engenharia Informática
Instituto Superior Técnico

1º Semestre
2018/2019



Bibliography

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- Bing Liu, Web Data Mining: Exploring Hyperlinks, Contents, and Usage Data, 2nd edition. Chapter 7.
- Christopher D. Manning, Prabhakar Raghavan and Hinrich Schütze, Introduction to Information Retrieval, Cambridge University Press. Chapters 19 and 21.
- Ricardo Baeza-Yates, Berthier Ribeiro-Neto, Modern Information Retrieval, 2nd edition. Chapter 11.



Outline

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

1 Web IR vs. Traditional IR

2 The Web as a Graph

3 Social Network Analysis

4 Link Analysis and Link-based Ranking

5 PageRank

6 HITS

7 Web Spamming



Traditional IR

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

Traditional IR systems:

- Worth of a document regarding a query is intrinsic to the document.
- Documents are self-contained units
- Documents are descriptive and truthful



Web IR

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

The **World Wide Web** is a shifting universe

- Indefinitely growing and changing
- Non-textual content
- Invisible keywords
- Web spam
- Documents are not self-complete
- Most web queries 2 words long
- **Hyperlinked**

Many features are included in a web similarity formula

- Ranking functions evaluate the reputation of pages, and different types of content within each page



Outline

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

1 Web IR vs. Traditional IR

2 The Web as a Graph

3 Social Network Analysis

4 Link Analysis and Link-based Ranking

5 PageRank

6 HITS

7 Web Spamming



The Web as a Graph

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- The Web is an hyperlink graph
 - Evolves organically,
 - No central coordination,
 - Yet shows global and local properties
 - An example of a **social network**



Graph structure of the Web

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

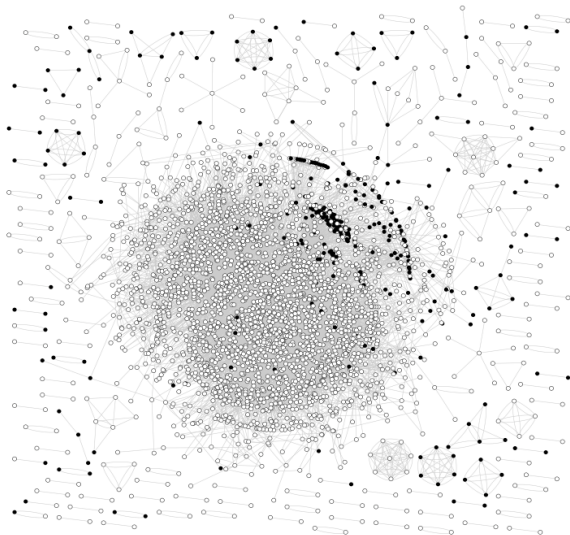
Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming



Web Spam detection using the web topology (Castillo et al. 2006)



Graph structure of the Web

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

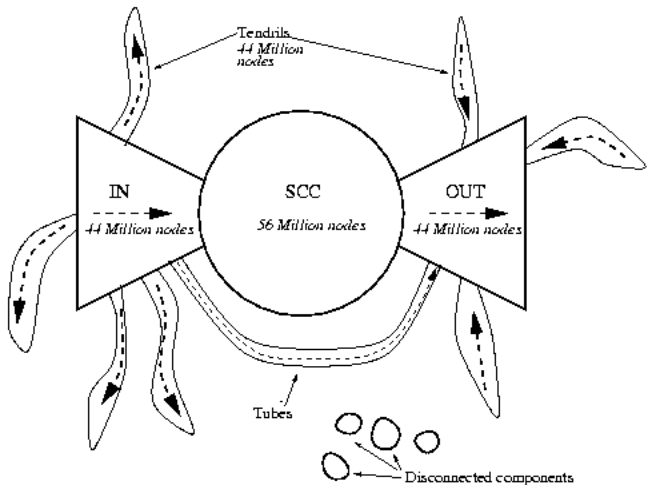
Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming



The Bow tie model (Broder et al., 2000)



A More Detailed View

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

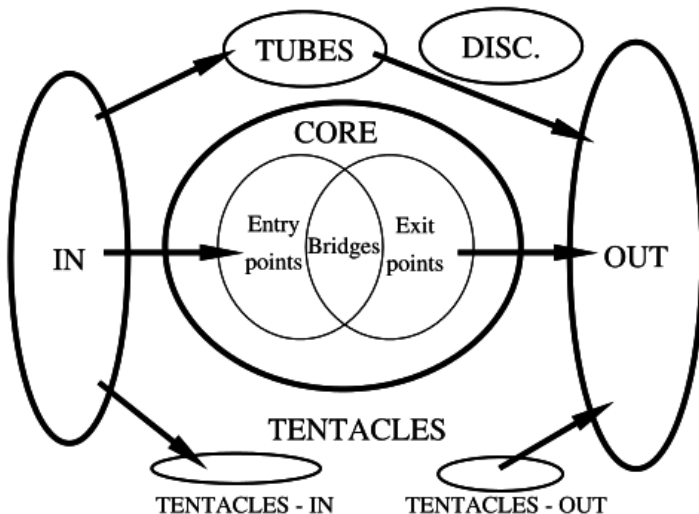
Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming



A study for link based web page ranking (Baeza-Yates & Castillo, 2001)



A More Recent View (cont.)

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- **Bridges:** sites in CORE that can be reached directly from the IN component and that can reach directly the OUT component
- **Entry points:** sites in CORE that can be reached directly from the IN component but are not in Bridges
- **Exit points:** sites in CORE that reach the OUT component directly, but are not in Bridges
- **Normal:** sites in CORE not belonging to the previously defined sub-components



Outline

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

1 Web IR vs. Traditional IR

2 The Web as a Graph

3 Social Network Analysis

4 Link Analysis and Link-based Ranking

5 PageRank

6 HITS

7 Web Spamming



Social Network Analysis

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- Social studies based on computing properties related to **connectivity and distances in graphs**
- Well established, long before the Web
- Example applications:
 - Epidemiology
 - Identifying a few nodes to be removed to significantly increase average path length between pairs of nodes
 - Citation analysis
 - Identifying influential or central papers
 - Identifying influential or central people



Finding influential researchers: H-index

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

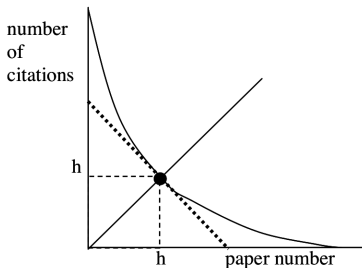
HITS

Web
Spamming

J.E. Hirsch, *An index to quantify an individual's scientific research output*, 2005 (available [here](#))

Definition

Index = h if h papers have at least h citations each, and the remaining papers have no more than h citations each.



Example: <http://www.cs.ucla.edu/~palsberg/h-number.html>



Graph Centrality

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- Degree centrality of v
 - Number of edges incident to v
 - Directed graphs: in-degree and out-degree centrality
- Betweenness centrality:

$$C(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}$$

where $\sigma_{st} = \#$ shortest paths from s to t (through v)

Example: <http://onearmedman.com/research/swineflu24>



Topic similarity using Co-citation

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- Documents v and w are said to be **co-cited** by u if a document u cites documents v and w
- If E is the document citation matrix
 - $E^T E$ is the **co-citation index matrix**
 - Indicator of relatedness between every v and w
- Example use: clustering
 - Using above pair-wise relatedness measure in a clustering algorithm



Clustering with Co-citation

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

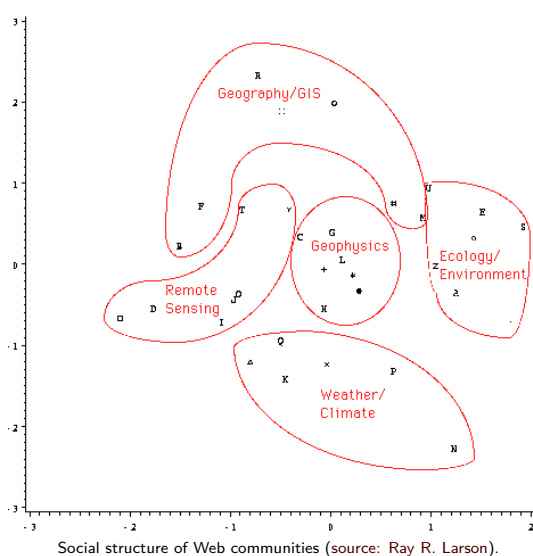
Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming





Outline

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- 1 Web IR vs. Traditional IR
- 2 The Web as a Graph
- 3 Social Network Analysis
- 4 Link Analysis and Link-based Ranking**
- 5 PageRank
- 6 HITS
- 7 Web Spamming



The Web as a Graph

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- Hypermedia is a graph of documents
- We can apply social network theory
 - Extensive research applying graph notions
 - Centrality and prestige
 - Co-citation
- Application: link analysis



Link Analysis

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

Three levels of analysis:

- **Macroscopic:** related to the structure of the Web at large
 - E.g. the bow tie structure analysis
- **Mesoscopic:** related to the properties of areas or regions of the Web
 - E.g. link-based ranking
- **Microscopic:** related to the statistical properties of links and individual nodes
 - E.g. link properties



Using Link Analysis

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

Main applications:

- Prioritize crawling
- Identify sub-structures on the Web graph, such as communities
- Infer relevance



Link-based Ranking Strategies

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

Goal: Leverage linkage information to address the *abundance problems* inherent in broad queries

Two pioneering algorithms:

- **PageRank**: Measure of prestige for every page on web
- **HITS**: Identify *hubs* and *authorities* in a query result



Link Model

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- Each page is a node **without any textual properties**
- Each hyperlink is an edge connecting two nodes (possibly with an edge weight)
- Some preprocessing procedure outside the scope of the algorithm may be used to choose what sub-graph of the Web to analyze



Outline

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- 1 Web IR vs. Traditional IR
- 2 The Web as a Graph
- 3 Social Network Analysis
- 4 Link Analysis and Link-based Ranking
- 5 PageRank**
- 6 HITS
- 7 Web Spamming



Overview

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- Pre-computes a **rank-vector**
 - Provides a-priori (offline) importance estimates for all pages on Web (i.e., probability distribution over pages)
 - Independent of the search query
- Prestige \approx In-degree
- But not all votes are worth the same
- Prestige of a page is **proportional to the sum of the prestige of citing pages**
- PageRank is **part of the ranking strategy adopted by Google**
 - At query time: **prestige scores** used in conjunction with query-specific IR scores



PageRank Algorithm

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

The algorithm:

- E is the *adjacency matrix* of the Web

$$E[u, v] = \begin{cases} 1 & \text{iff there is a link from } u \text{ to } v \\ 0 & \text{otherwise} \end{cases}$$

- The out-degree of node u is given by

$$N_u = \sum_v E[u, v]$$

- Start with an initial prestige vector $p_0[u]$
- Compute

$$p_{i+1}[v] = \sum_{(u,v) \in E} \frac{p_i[u]}{N_u}$$



Main Features

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- PageRank simulates a user **navigating randomly** on the Web
- At infinity, the probability of finding the user at any given page becomes stationary
- This process can be modeled by a **Markov chain**
 - stationary probability of being at each page can be computed
- This probability is a property of the graph
 - referred to as PageRank in the context of the Web



Convergence Conditions

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- Convergence to
 - stationary distribution of the normalized adjacency matrix L
 - PageRank vector p is principal eigenvector of L
- Convergence criteria
 - L is **irreducible**
 - there is a directed path from every node to every other node
 - L is **aperiodic**
 - for every node, there is no integer $k > 1$ that divides the length of every cycle that goes through the node
 - the reverse—periodic—means that a node is visited always after a regular nk number of steps ($n = 1, 2, 3, \dots$)



Problems of Convergence

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- Web graph is not strongly connected
 - Only a fourth of the graph is!
- Web graph is not aperiodic
 - There can be many periodic nodes in the Web graph



A simple fix

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- Two way choice at each node:
 - With a certain probability d ($0.1 < d < 0.2$), the surfer jumps to a random page on the Web
 - With probability $1 - d$ the surfer decides to choose, uniformly at random, an out-neighbor

$$p_{i+1}[v] = \frac{d}{N} + (1 - d) \sum_{(u,v) \in E} \frac{p_i[u]}{N_u}$$



PageRank architecture at Google

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- Ranking of pages more important than exact values of p
- Convergence of page ranks in 52 iterations for a crawl with 322 million links.
- Pre-compute and store the PageRank of each page.
 - PageRank independent of any query or textual content.
- Ranking scheme combines PageRank with textual match
 - Unpublished *learning-to-rank* approach
 - Many empirical parameters, human effort and regression testing.



Other Applications and Extensions

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- PageRank also used in other IR/IE applications (e.g., text summarization, keyword extraction, etc.)
- Many extensions proposed over the years
 - PageRank with edge weights:

$$p_{i+1}[v] = \frac{d}{N} + (1 - d) \sum_{(u,v) \in E} \frac{p_i[u] \times w(u, v)}{\sum_{(u,v') \in E} w(u, v')}$$

- Personalized PageRank:
- Topic-sensitive PageRank, etc.



Outline

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- 1 Web IR vs. Traditional IR
- 2 The Web as a Graph
- 3 Social Network Analysis
- 4 Link Analysis and Link-based Ranking
- 5 PageRank
- 6 HITS**
- 7 Web Spamming



HITS: Hypertext Induced Topic Selection

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- Relies on query-time processing
 - To select base set V_q of links for query q constructed by
 - selecting a sub-graph R from the Web (root set) relevant to the query
 - selecting any node u which neighbors any $r \in R$ via an inbound or outbound edge (expanded set)
 - To deduce **hubs** and **authorities** that exist in a sub-graph of the Web
- Every page u has two distinct measures of merit,
 - its hub score $h[u]$
 - its authority score $a[u]$
- Recursive quantitative definitions of hub and authority scores



Hubs and Authorities

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

Hub

A page is a good hub if it contains links to many good authority pages

Authority

A page is a good authority if it is pointed to by many good hubs

- Authority pages provide good content.
- Hub pages provide links to the pages with good content.



The HITS Algorithm

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

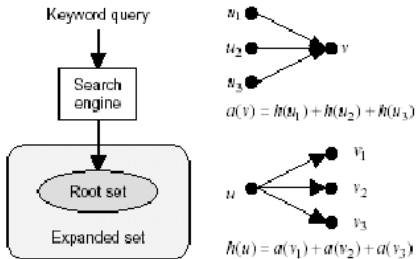
Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming



```

$$\vec{a} \leftarrow (1, \dots, 1)^T, \vec{h} \leftarrow (1, \dots, 1)^T$$

$$\text{while } \vec{h} \text{ and } \vec{a} \text{ change 'significantly' do}$$

$$\vec{h} \leftarrow E\vec{a}$$

$$\ell_h \leftarrow \|\vec{h}\|_1$$

$$\vec{h} \leftarrow \vec{h} / \ell_h$$

$$\vec{a} \leftarrow E^T \vec{h} = E^T E \vec{a}_0$$

$$\ell_a \leftarrow \|\vec{a}\|_1$$

$$\vec{a} \leftarrow \vec{a} / \ell_a$$

$$\text{end while}$$

```

https://en.wikipedia.org/wiki/HITS_algorithm



Some Issues

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- Does not work with non-existent, repeated, or automatically generated links
 - Solution: weigh each link based on surrounding content
- Topic diffusion
 - The result set might include pages that are not directly related to the query
 - One solution: associate a score with content of each page
 - This score is then combined with the link weight
 - Experiments show that recall and precision for first ten results increase significantly



PageRank vs. HITS

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- PageRank advantage over HITS
 - Query-time cost is low
 - HITS computes an eigenvector for every query
 - Less susceptible to localized link-spam
- HITS advantage over PageRank
 - HITS ranking is sensitive to query
 - HITS has notion of hubs and authorities



Outline

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- 1 Web IR vs. Traditional IR
- 2 The Web as a Graph
- 3 Social Network Analysis
- 4 Link Analysis and Link-based Ranking
- 5 PageRank
- 6 HITS
- 7 Web Spamming



Web Spamming

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

Activity of deliberately misleading a search engine by a website owner.

Deceivers try to understand how a ranking function computes, by changing the ranking of a page without changing its user-perceived value.

SEO - Search Engine Optimization:

A business activity that sometimes is legitimate, but often is not perceived as ethical.



Content Spamming

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

Attempt to affect the content-based ranking features

Places where to add spam terms:

- Title
- Meta-tags
- Body
- Anchor text
- URL

Techniques

- repeat some important terms

*the picture **mining** quality of the camera **mining**
is amazing*

- dumping of many unrelated terms

Tom Cruise



Link Spamming

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

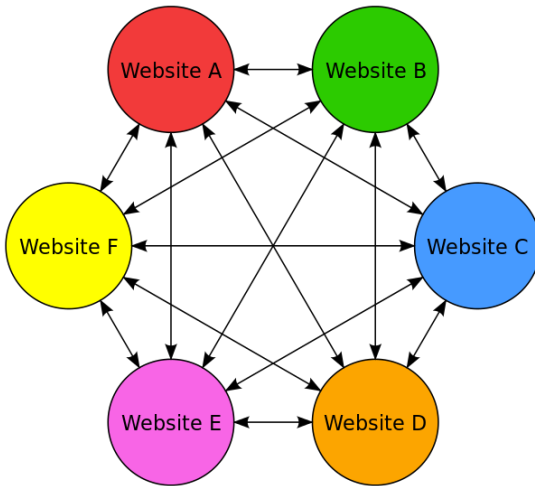
Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- out-link spamming
 - easy: pick popular websites from directories
- in-link spamming
 - Create a honey pot
 - Add links to web directories
 - Post links to user-generated content sites
 - Participate in a link exchange
 - Create a spam farm



http://en.wikipedia.org/wiki/Link_farm



Hiding Techniques

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

Content hiding: pick background white and font color also white

Cloaking: serve one page to normal clients and another to search engines

Redirection: redirect browser to another page (user sees one, search engine will crawl both)



URL Redirection

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

https://en.wikipedia.org/wiki/URL_redirection



Combating Spam

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

- Give higher weight to anchor text
- PageRank - assign authority to pages based on number and importance of links
- TrustRank - the good guys and the bad guys cluster together
- Learn from language features common in spam (longer titles, longer words, ...)
- Partition pages in blocks and compute PageRank on a block basis (instead of assigning a single PR value to each page), to defeat honeycombs and link exchanges
- ...an on-going process...



Click Farming

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

https://en.wikipedia.org/wiki/Click_farm



The Deep Web

Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming



[http://thehackernews.com/2012/05/
what-is-deep-web-first-trip-into-abyss.html](http://thehackernews.com/2012/05/what-is-deep-web-first-trip-into-abyss.html)



Processamento
e Recuperação
de Informação

Web IR vs.
Traditional IR

The Web as a
Graph

Social
Network
Analysis

Link Analysis
and
Link-based
Ranking

PageRank

HITS

Web
Spamming

Questions?