# COMP 102: Excursions in Computer Science
## Lecture 12: Searching the Web

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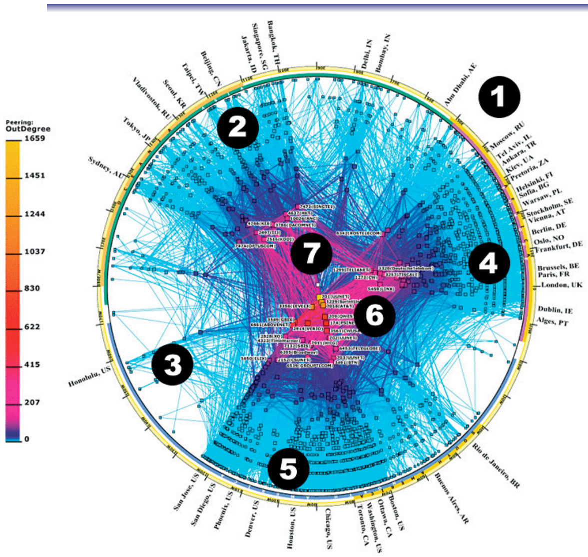
# The most interesting graph in town!



"Information moving through cyberspace travels in tiny packets that hopscotch around the world.

This graph shows data from a two-week stretch in April 2005, Tracking packets from hub to hub and country to country."

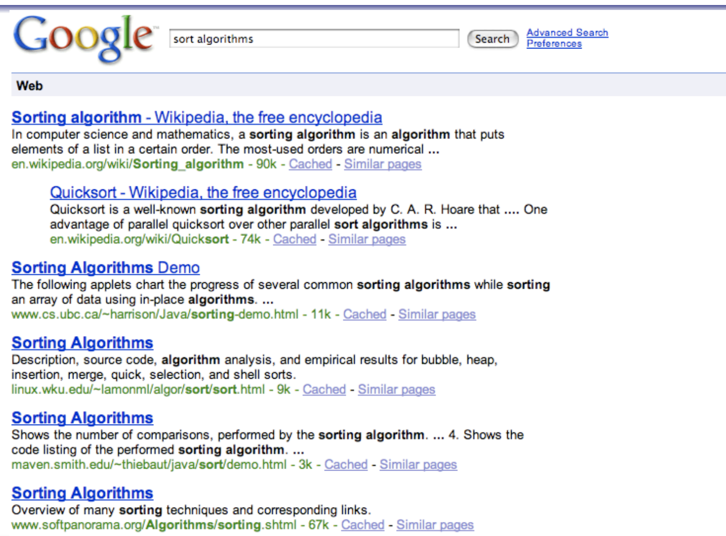
*http://discovermagazine.com/2006/oct/map-internet-servers*

# The Web as a Graph

- What is the structure of the web?
  - A directed graph G: {N, E}.
  - Nodes correspond to web pages, composed of text and hypertext.
  - Edges correspond to hyperlinks.



# How do search engines do it?



## Internet search

- Goal of a web search engine:
  - **Crawl** and **index** the web efficiently.
  - Produce satisfying **search results** to human queries.

- Main components required to achieve this:
  1. Web crawling -> exploring the graph
  2. Indexing -> storing nodes
  3. Searching -> finding a target node



## Exploring the graph: Web crawling

- A program to explore the web in a systematic way.

- We know 3 methods for exploring a graph:
  - Breadth-first search, Depth-first search, Best-first search

- Similar ideas apply here, but there are complicating factors!
  - Large size of the graph
  - Content of nodes change over time
  - Nodes are added/removed, so structure of the graph changes also.

## Web crawling strategies

- We need a **selection strategy**, to decide order in which pages are explored.
- We need a **re-visit strategy**, to decide when to re-visit nodes.
- Let's do these two things separately.



## Node selection strategy

- There are **many, many** nodes. Need to prioritize them somehow.
- Key idea: prioritize them in terms of **importance**.
- What makes a page important?
  - Intrinsic quality ("authority")
  - Popularity (# visits)
  - Connectivity (# links to it)
- Let's say we get a number *Score(n)*, that tells us the importance of webpage *n*. (We'll get back to how we calculate this later.)

## A new algorithm for exploring a graph

- Assume you have a list of candidate nodes to explore.
- Algorithm:
  - Get a starting node from somewhere.
  - Add its neighbours to the list of candidate nodes.
  - Pick the candidate node with highest score.
  - Add its neighbours to the list of candidate nodes.
  - Continue until no more unexplored nodes.
- This is our old friend **Best-first-search**.

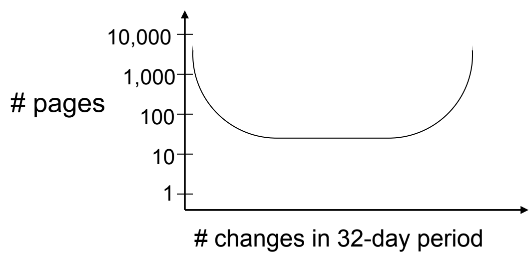


## Re-visit strategy

- Once in a while, we need to re-visit nodes. How should we do this?
- Two possible strategies:
  - Re-visit all pages with the same frequency (e.g. once a month)
    **Uniform strategy**
  - Re-visit more often pages that change more frequently.
    **Proportional strategy**
- Which is best?

## Choosing a re-visit strategy

- Surprisingly, the uniform strategy is best!
- Why?






## What next?

- Main components required to build a search engine:
  - Web crawling -> exploring the graph
  - Indexing -> storing nodes
  - Searching -> finding a target node

# Web indexing

- Indexing is a method to store information collected during crawling.
- Need a BIG array to store web pages: ⇒**The Repository**

  **What goes in this array?**

Array:

| document ID | length | URL | webpage (compressed) |
|---|---|---|---|
| | | | |



# Indexing all explored webpages

- Documents in the array are sorted by document ID.
  - **Problem 1**: Given a URL, how do we retrieve the right document?
  - **Problem 2**: Given a new document (with its URL), how do we pick its document ID?
- Could just use the order in which it was explored.
  - Easy to generate this document ID (just keep a counting variable).
  - Hard to retrieve later (need to search the whole array!)
- Instead: Use a special program that converts URL to document ID.
  - Easy to generate this document ID.
  - Same program is applied to address to retrieve document given its URL.
- Apply binary search to look through the array and find the correct row.

## Indexing the words

- **Problem 3**: Given a set of keywords, how do we retrieve webpages with those words?
- Need another big array to store words: ⇒**The Lexicon**

Array:

| word | documents that contain that word (by document ID) |
|---|---|
| aardvark | 00110100 10100011 11100111 … |



## What next?

- Main components required to build a search engine:
  - Web crawling -> exploring the graph
  - Indexing -> storing nodes
  - Searching -> finding a target node
- Goal: Return the webpages which contain the given query words.

## Idea #1: Starting with something simple

- Web pages returned should contain the query words!
- Easy! Use the lexicon to find all the pages that contain the query words.
- Problem: Too many pages returned.



## Idea #2: Need to prioritize!

- Prioritize pages in terms of **importance** (as we did for web crawling).
- How do we assess importance?
  - Webpage authors tend link to good pages.
  - Good sites (I.e. "authorities") are cited by many other sites.
    - These should get high priority.
    - Prefer webpages with many "in" edges.
  - Good sites are cited by authorities.
    - These should also get high priority.
    - Prefer webpages with "in" links from authorities.
  - Some websites link to many others
    - These are generally less useful, and so should get lower priority.
    - Exclude webpages with many "out" edges.
- Need to incorporate all these ideas!

# Calculating the "score" of a webpage

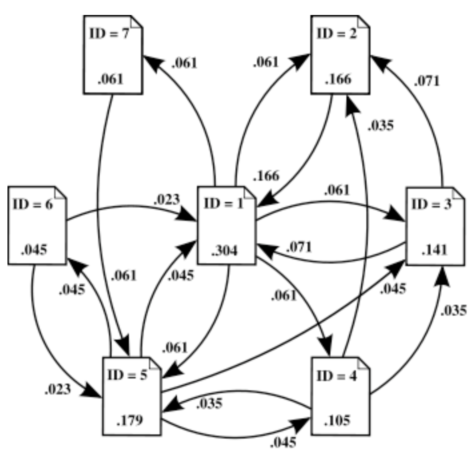
- Assume each website gets an importance score ⇒ **its PageRank**
- The PageRank is based on the actual graph structure, not on an actual query (this will come later).
  - Let PR(n) be the PageRank of node n.
  - Let C(n) be the number of links "out" of node n.
  - Let $w_1$, $w_2$, …, $w_k$ be the pages that have "in" links to n.

$$PR(n) = \frac{PR(w_1)}{C(w_1)} + \frac{PR(w_2)}{C(w_2)} + \ldots + \frac{PR(w_k)}{C(w_k)}$$

- We have a system of N linear equations with N unknowns (N = #webpages).
  - Use linear algebra (numerical approximation, not Gaussian elimination) to solve this system of equations.



# Example of PageRank Calculation




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

## Using PageRank for web crawling

- Recall the Best-first-search algorithm:
  - Get a starting node from somewhere.
  - Add it's neighbours to the list of candidate nodes.
  - Pick the candidate node with highest score.
  - Add it's neighbours to the list of candidate nodes.
  - Continue until no more unexplored nodes.
- Use PageRank to order the list of candidate nodes.
  - Keep the list in sorted order at all times.
  - Every time you need to add a node, search the list of candidate nodes (e.g. using binary search) to find the spot in the list where to insert the new candidate webpage.



## Using PageRank to answer queries

- Search the Lexicon for all webpages containing the query words.
- Using the Document ID, extract the content of these webpages from the Repository.
- Sort these pages in decreasing order of their PageRank.

## Manipulating the PageRank

- Popular activity! Why?
  - Higher PageRank = more traffic!

- How?
  - Bribery
  - Collusion
  - Many different ways!



## Manipulating PageRank by Bribing an Authority

- How do we do this?
  - Place a link to your webpage on an “authority” page.
  - However if the “authority” page has too many “out” links, it’s own PageRank is reduced, and it becomes less useful.
  - Pay an appropriate amount (based on the authority’s PageRank) to have a link from the authority to your webpage.
  - There’s a whole economy for buying and selling links.

## Manipulating PageRank by Collusion

- What is collusion?

  *A secret agreement between two or more parties for a fraudulent, illegal, or deceitful purpose.*

- How does this concern PageRank?
  - A web designer creates many new webpages.
  - The designer then creates links between these webpages, so each has many "in" links.



## A few more general comments

- Most ranking systems are vulnerable to manipulation.

- Users often have incentives to cheat.

  E.g. Study of eBay has shown that buyers are willing to pay an extra 8% to buy from a seller with a high reputation.

- Many search engine companies spend substantial resources trying to outsmart such people.

## Take-home message

- Concepts to understand:
  - Web crawling and the best-first search algorithm
  - PageRank (the main ideas that come into the equation, not necessarily how to solve the system of equations.)
  - The Repository and the Lexicon: their role and their content
- Understand the role of basic searching and sorting algorithms in the web.
- **Midterm**: Tuesday Oct.18, in class.
  Closed book. No calculators/dictionaries. All material up to lecture 13.