Searching the World-Wide Web

Lecture 13

Challenges for Web Search

The World-Wide Web is…

- Distributed
- Volatile
- Huge
- Unstructured
- Redundant
- Of variable quality
- Heterogeneous
- Multilingual

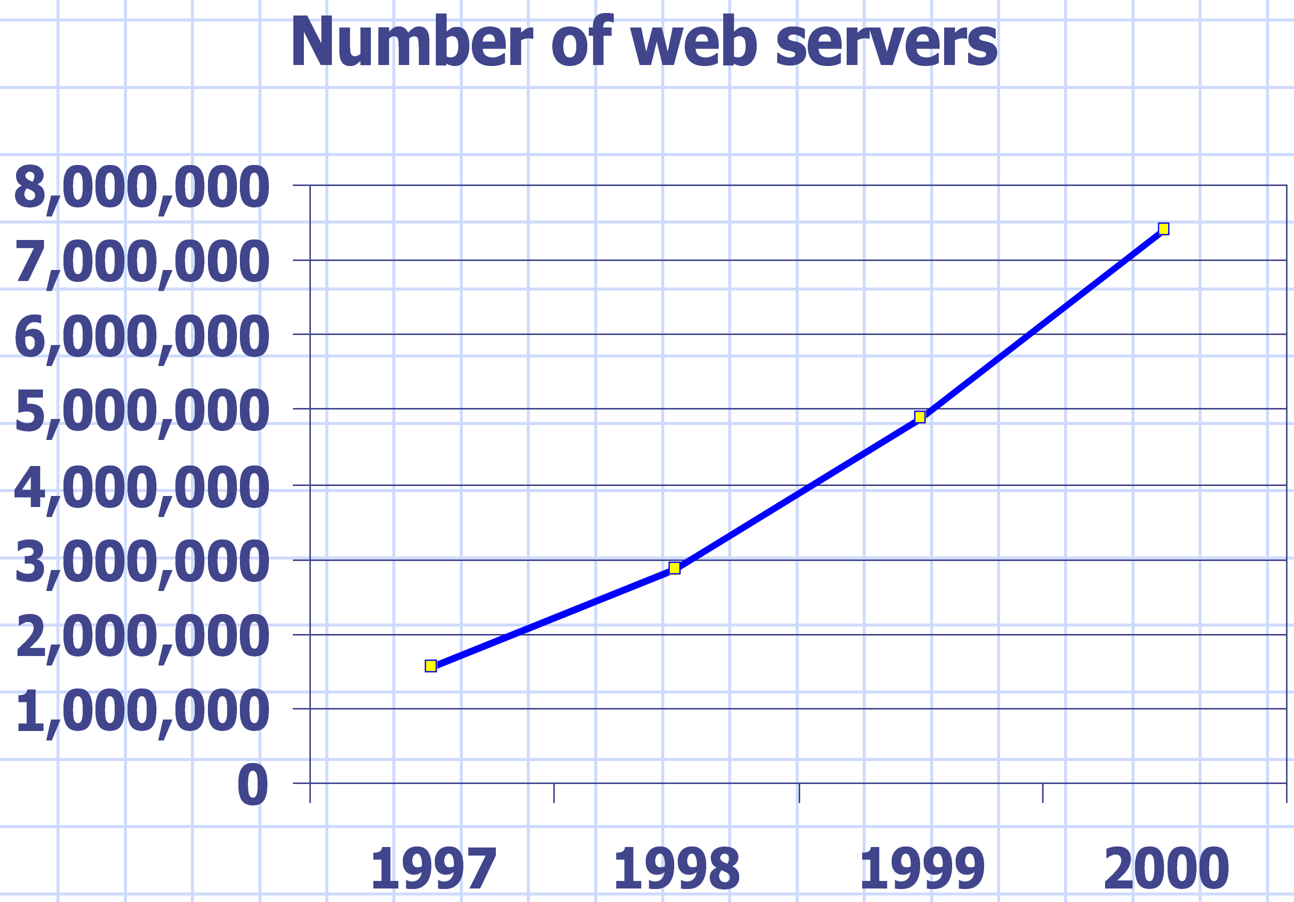
In an information system such as this,

- How should a user specify a query?
- How should he understand the results?

Measuring the Web

- Between Fall 1998 and Summer 1999…
  - 40M computers connected to the Internet
  - 2.4-3M web servers
  - >200 countries, >100 languages
  - 200-350M web pages
    - 2-5Kb, 5-15 hyperlinks
    - Most links are local
    - Most pages <u>not</u> pointed to by external servers
  - Formats: HTML, GIF, JPEG, ASCII, Postscript
    - Images average 14Kb
  - 5Kb * 300M = 1.5 terabytes of text on the Web

Growth of the Web



In 2002...

- 162M hosts on the Internet
  - (July 2002, ISC Internet Domain Survey)
- 36M web servers (surveyed?)
  - (Sep 2002, Netcraft)
- Not many recent peer-reviewed surveys
- Growth may be much faster since 2000

The Internet Archive

- http://www.archive.org/
- Crawls from Alexa and Compaq
- 4 billion pages (40TB) in 2001
- In 2002, 100TB and growing at 12TB/month
- Access
  - The Wayback Machine
  - Researcher access via remote login

Definitions from Graph Theory

- Graph: set of nodes and edges between them
  - graphs can be undirected or directed
  - **In-degree:** # edges pointing to a node
  - **Out-degree:** # edges pointing out of a node
- Diameter
  - Maximum over all ordered pairs (u,v) of the shortest path from u to v
- Connected Component
  - a set of nodes in an undirected graph which are reachable from each other
  - **Strongly Connected Component (SCC):** directed

Power Laws on the Web

- Power Law distributions
  - $P(i) \propto 1/i^k$, for small positive values of k
  - Zipf's Law: a power law for ranks
- Power laws describe many things…
  - vocabulary, economics, sociological models, nucleotide sequences
- Including web phenomena
  - access statistics
  - # times users at a single site access particular pages
  - in/out-degree of web pages

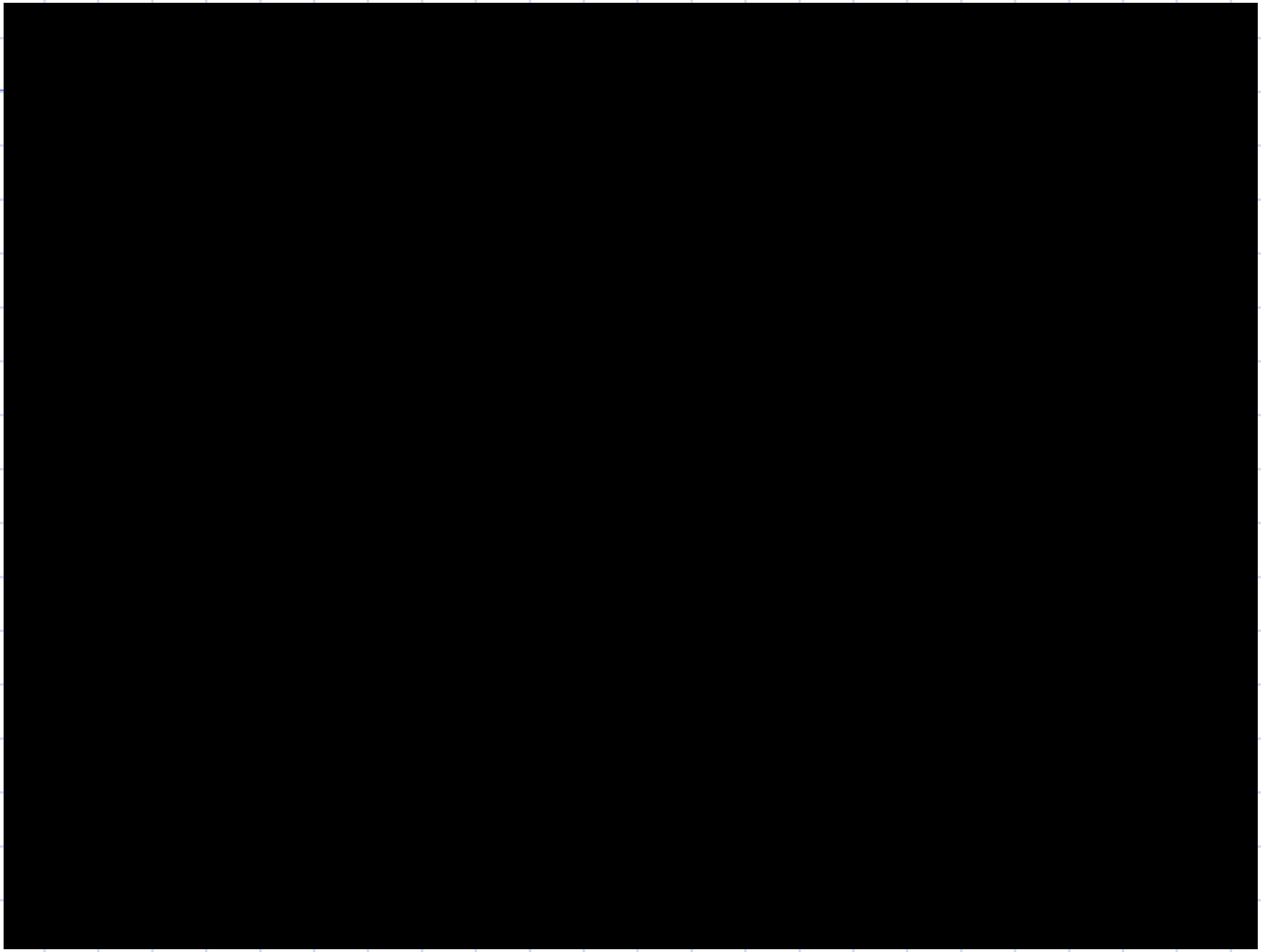
“Graph Structure in the Web”

- Broder et al (2000), WWW9
- large-scale graph analysis of the Web
- two crawls from AltaVista
  - May 99: 203M pages, 1.5B links
  - Oct 99: 271M pages, 2.1B links
- Built on previous web characterizations
  - # links pointing to a page follows a power law
  - most pairs of pages separated by a handful of links (about 20)

Results of Broder et al

- Fraction of pages with in-degree i $\propto 1/i^{2.1}$
  - resembles other, smaller studies
  - small webs resemble large webs (fractal)
- Sizes of connected components also follow a power law
- Largest WCC 91%, Largest SCC 26%
- Examined connectivity of the web using breadth-first search with random starting points.

“Bow Tie” model of the Web



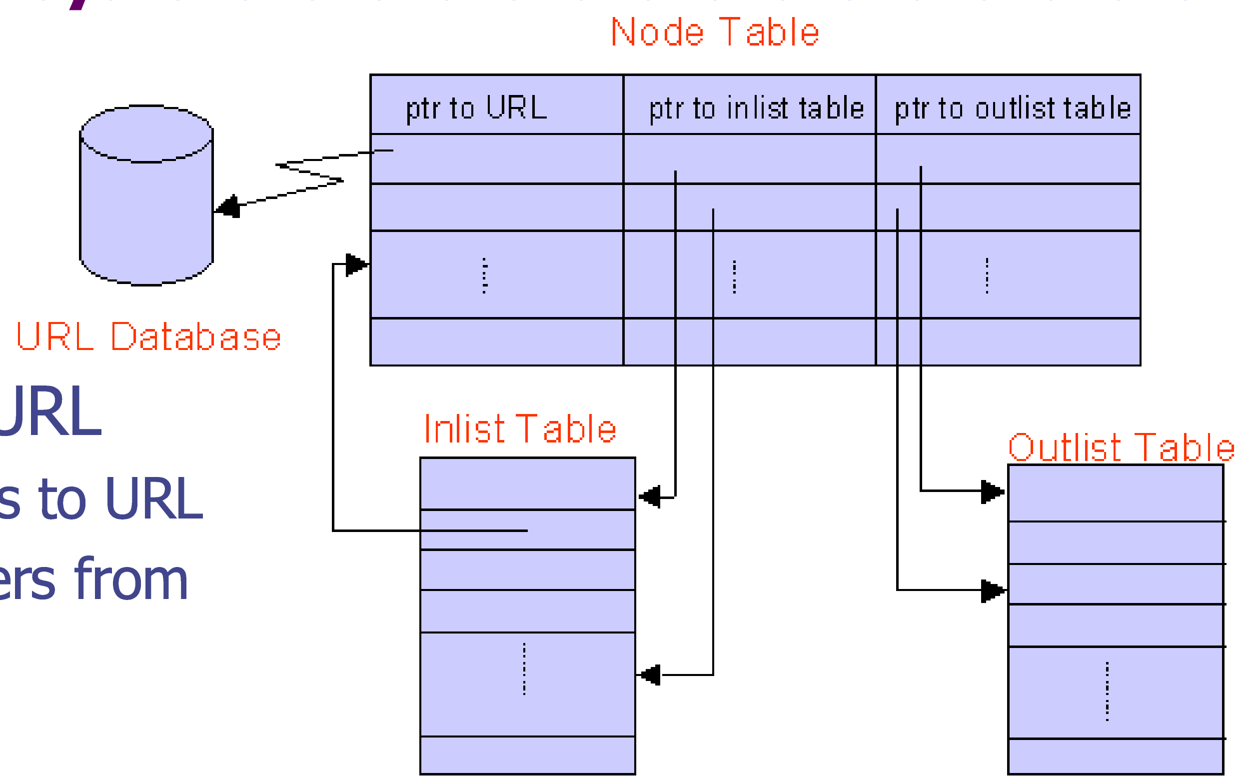
Paths and Connectivity

- Diameter of SCC is at least 28
  - whole web diameter is over 500
- Not all node pairs are connected
  - For random (u,v), P(path(u,v)) = 0.24
  - If a directed path exists, average length=16
  - Undirected paths, length = 6
- But the WWW in general is well-connected
  - Even if nodes with in-degree > 5 are removed, it still contains a weak component of ~59M nodes.

Connectivity Server

- A fast, high-performance link database
- Input: a web crawl
- Creates database of hosts and URLs with all in-links and out-links
  - includes non-crawled URLs references more than five times
  - 10 bytes/URL, 3.4 bytes/link
- 465MHz Compaq Alpha server, 12GB RAM
- Each crawl fits in 9.5GB of disk

Connectivity Server Architecture



- Two lists per URL
  - inlist: pointers to URL
  - outlist: pointers from
- Heavy use of compression
  - front coding for URLs
  - integer coding for pointers

The "Indexable Web"

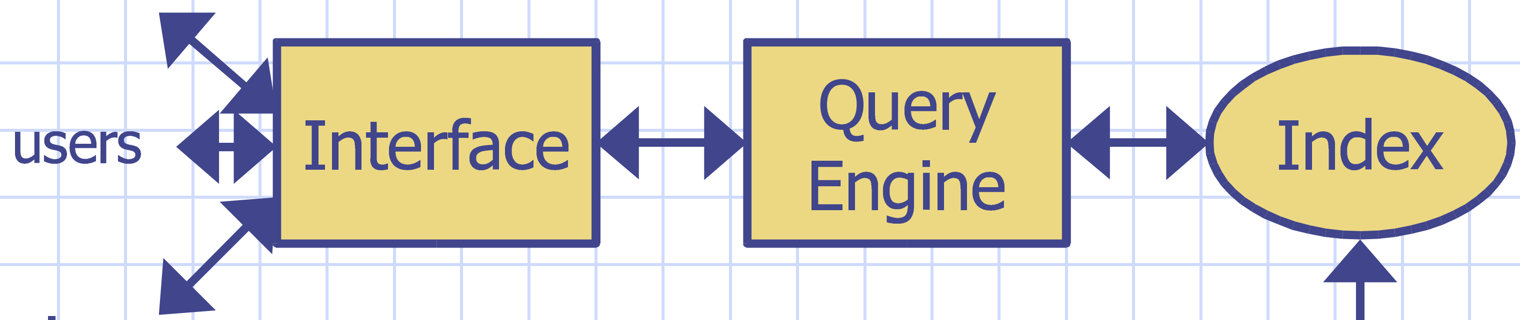
- Lawrence and Giles (1998)
- Estimated search engine coverage by carefully analyzing query results
- Lower bound on "indexable web": 320M pages
- Search engines index a small fraction of this
  - Their study found HotBot covered 34%, followed by AltaVista (28%),
    Northern Light (20%),
    Excite (14%),
    Infoseek (10%), and Lycos (3%)

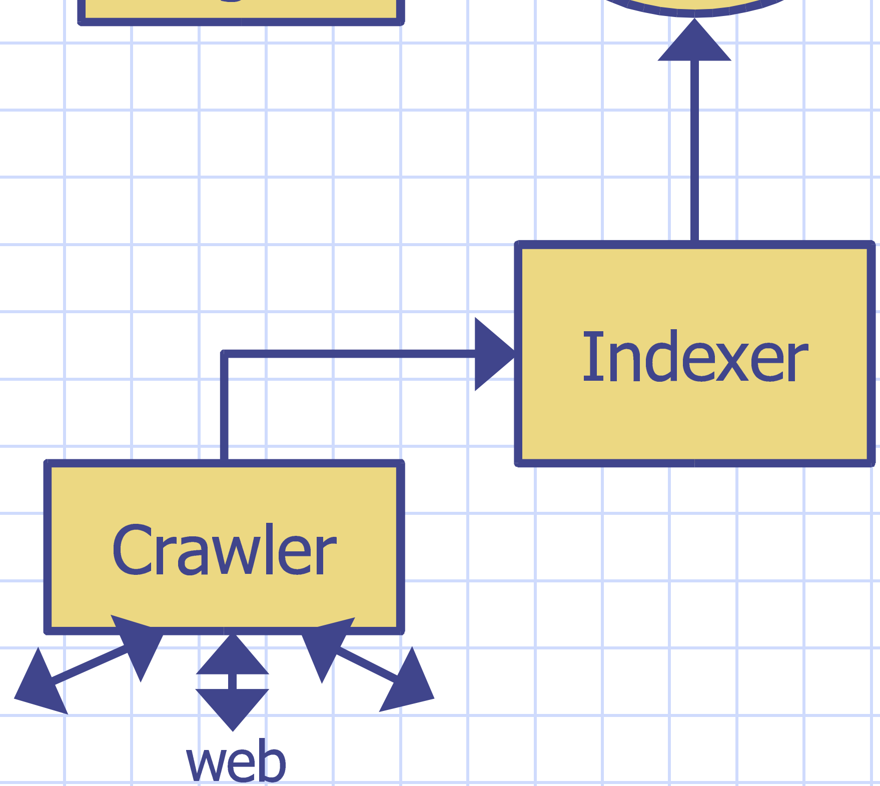
Searching the Web

start of Thursday lecture

- Collection is immense (multi-Terabyte)
  - queries must be answered without accessing the source text
  - alternative: store the text (a la Google)
    - It should be possible to decide what to store
    - Only keep the best pages?
  - alternative: search through the network
    - Too slow for "pure" searching
    - Might be optimized if we could search "best-first"

Centralized Search Engines





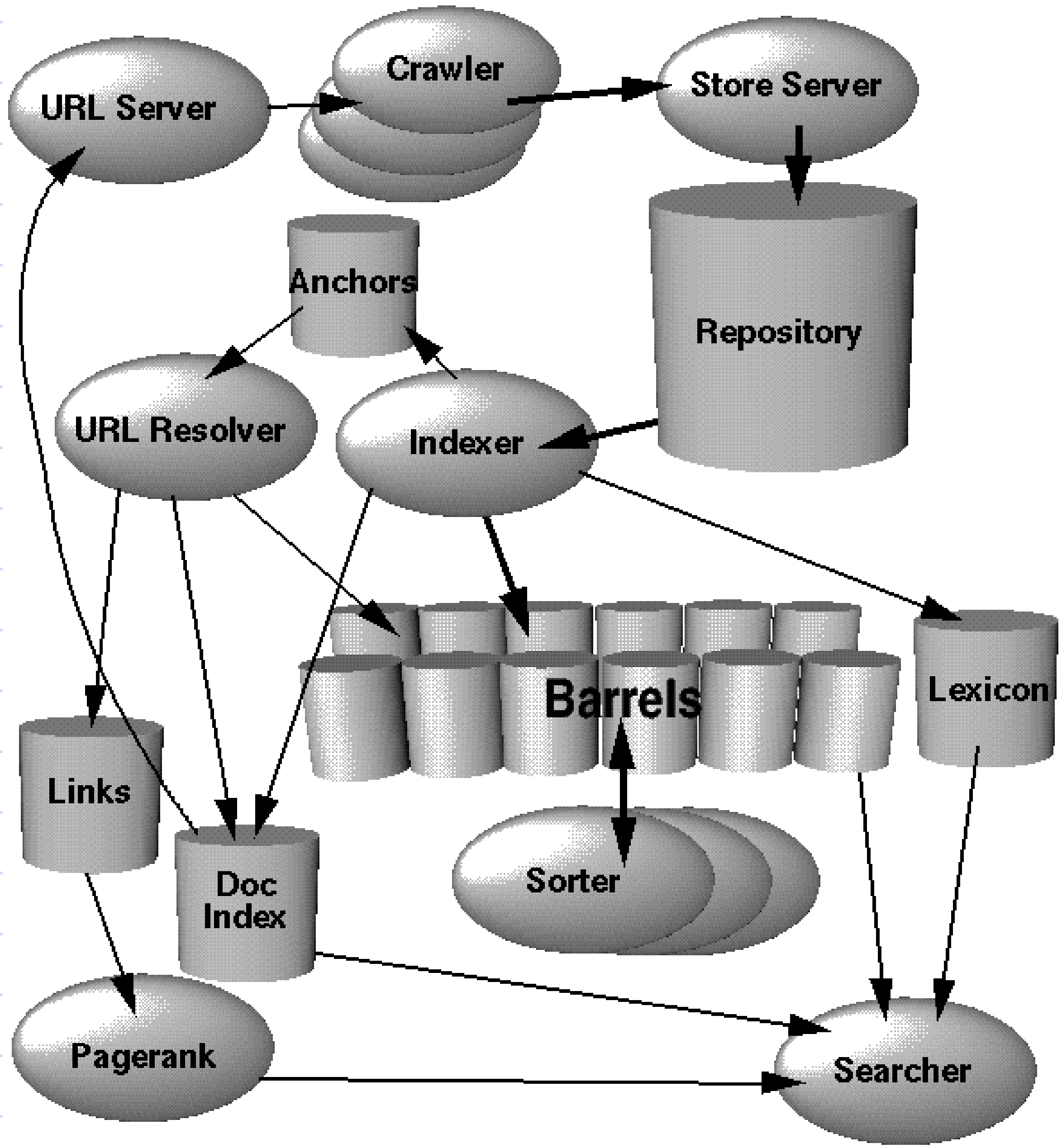
- Crawler
  - Fetches web pages
  - Culls links
  - Prioritizes links (usually BFS variant)
- Indexed at main server

AltaVista Architecture

- Circa 1998
  - 20 multiprocessor machines
  - 130 GB RAM, 500 GB disk (probably low)
- Query engine uses 75% of resources
- O($100M) in hardware costs

Google

- Full-text index
  - terms sorted into barrels for merging
- Link database
  - URLs, in/out links
- Parallel crawl approach
  - 100 pages/sec



Distributed Search Engines

- Idea: coordinate among several web servers
- **Harvest**: gatherers and brokers
  - Gatherer collects and extracts information from one or more web servers
  - Brokers provide indexing and query interface
    - Receive info from one or more Gatherers
    - Updates indices
    - Can also filter information and send to other brokers
  - Also features caching and replication agents

CARROT

- Cooperative Agent-based Routing and Retrieval of Text
- Individual search engines manage their own collections
- Broker agents gather metadata from the SEs that describe their collection
  - e.g. a centroid, or vector of document freqs
- Broker routes an incoming query based on similarity to metadata

Web Search Interfaces

- Most query interfaces are spare
  - Implicit AND or OR among search terms
  - Users don't know logical view of text
  - Most engines provide an "advanced" search feature
    - Boolean expressions, phrases, proximity operators, wildcard globs, regular expressions
- Results pages also don't give much information

User query behavior

Measure	Average	Range
# words	2.35	0-393
# operators	0.41	0-958
Repetitions of each query	3.97	1-1.5 million
Queries/user session	2.02	1-173,325
Results screens/query	1.39	1-78,496

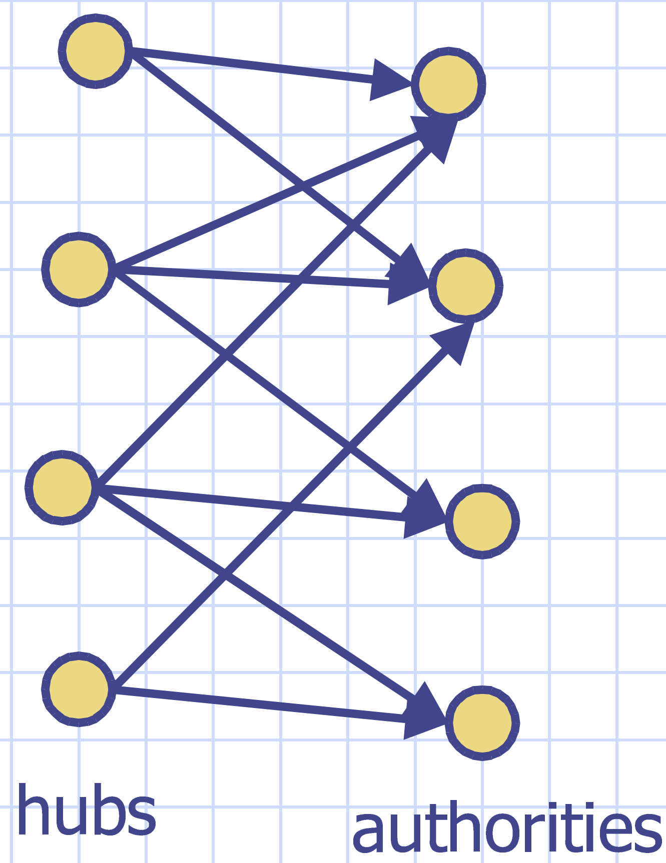
- 25% of users query with a single word
- 15% restrict to a prespecified topic
- 80% don’t modify the query after first retrieval
- 85% only look at first results page
- 64% of queries are unique

Ranking Web Pages

- Traditional models
  - vector space, probabilistic, etc.
  - operate on text only
- Hyperlink models
  - link structure, anchor text
- Hard to assess performance of engines
  - proprietary algorithms
  - complicated engineering
  - but in general they are using known ideas

HITS Algorithm (Kleinberg 97)

- Hypertext Induced Topic Search
- How to identify good pages?
  - Authoritative pages are pointed to by many other pages
  - Hub pages point to many pages
- Identifies good hubs and authorities
- Recommends those as best results.



HITS Algorithm (1)

- Find a focused subgraph $S\sigma$ of the web
  - Should be relatively small
  - Should be rich in pages relevant to the user's query
  - Should contain many good authorities
- To make the focused subgraph:
  - Fetch top t pages from a textual engine: $R\sigma$
  - Expand $R\sigma$ with
    - all pages pointed to by a page in $R\sigma$
    - some pages which point to pages in $R\sigma$ (max d per page)
    - don't add pages with URLs within same domain name
  - Return as $S\sigma$

Finding Hubs and Authorities

- Now subgraph contains
  - authorities pointed to by initial ranked list
  - good connectivity among results
- How to determine authorities?
  - Simple: order by in-degree
  - Confuses authorities with unversally popular pages (large in-degree, but lack relevance to topic)

Refining the Authority Concept

- Sets of authorities on a topic have
  - high in-degree for all authorities
  - significant overlap in the sets of pages that point to them
- These hubs point to multiple relevant authorities
- Mutually reinforcing relationship
  - a good hub points to many good authorities
  - a good authority is a page pointed to by many good hubs

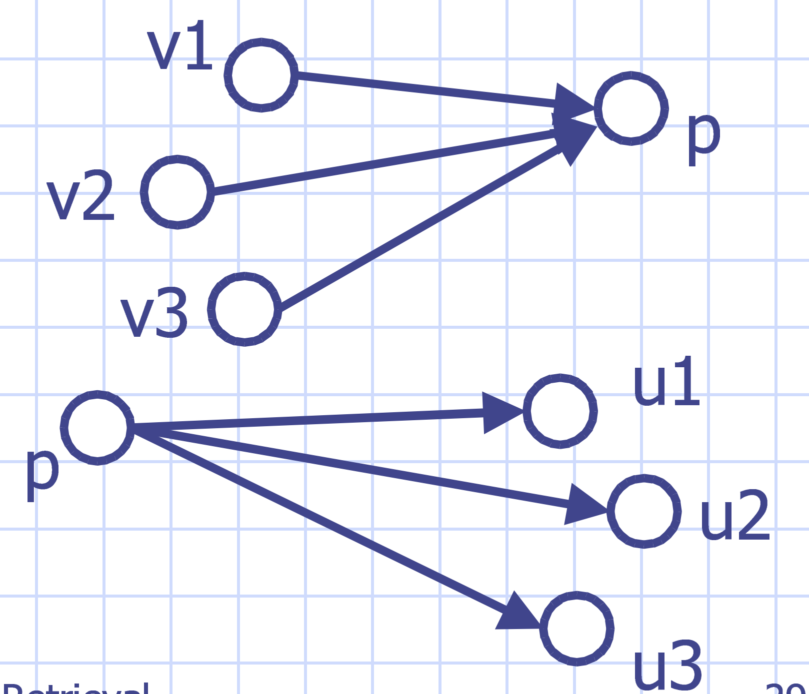
HITS Algorithm (2)

- H(p) = hub value of node p
- A(p) = authority value of node p
  - Initialize H(p) and A(p) to (1,1,1,…,1)

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

$$H(p) = \sum_{u \in S \mid p \to u} H(u)$$

normalize A(p) and H(p) after each iteration



Convergence of HITS

- Typically, 20 iterations is sufficient for the largest elements of H(p) and A(p) to be stable
- If M is the adjacency matrix of subgraph
  - H(p) and A(p) converge to the principal eigenvectors of MM^T and M^TM, respectively
  - These are the also first columns of U and V from the singular value decomposition of M

HITS example

- (java) Authorities

.328	http://www.gamelan.com/	Gamelan
.251	http://java.sun.com/	JavaSoft home
.190	http://www.digitalfocus.com/ digitalfocus/faq/howdoi.html	The Java Developer: HowDoI
.190	http://lightyear.ncsa.uiuc.edu/ ~srp/java/javabooks.html	The Java Book Pages
.183	http://sunsite.unc.edu/javafaq/ javafaq.html	comp.lang.java FAQ

HITS example (2)

- ("search engines") Authorities

.346	http://www.yahoo.com/	Yahoo!
.291	http://www.excite.com/	Excite
.239	http://www.mckinley.com/	Welcome to Magellan!
.231	http://www.lycos.com/	Lycos Home Page
.231	http://www.altavista.digital.com/	AltaVista: Main Page

- Can also be used to find "similar" pages
  - "Find top t pages pointing to p."

PageRank (Brin and Page, 98)

- Consider a user browsing randomly
  - Will follow a random link on a page with uniform chance (1-q)
  - May get bored, jump to an unlinked page (q)
  - Never uses the "back" button
- Similar to a Markov chain
  - can use to compute the probability of browsing to any page.

PageRank formula

- $C(a)$ = out-degree of page a
- $p_1 \ldots p_n$ – pages pointing to page a
- $PR(a) = q + (1-q)\Sigma_{i=1..n} PR(p_i)/C(p_i)$
  - compute iteratively as in HITS
  - precomputed over all pages in the index
  - q is typically 0.15
  - converges to principal eigenvector of link matrix
- Underlying ranking formula used by Google

What are the implications of…

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