The Web
Servers + Crawlers

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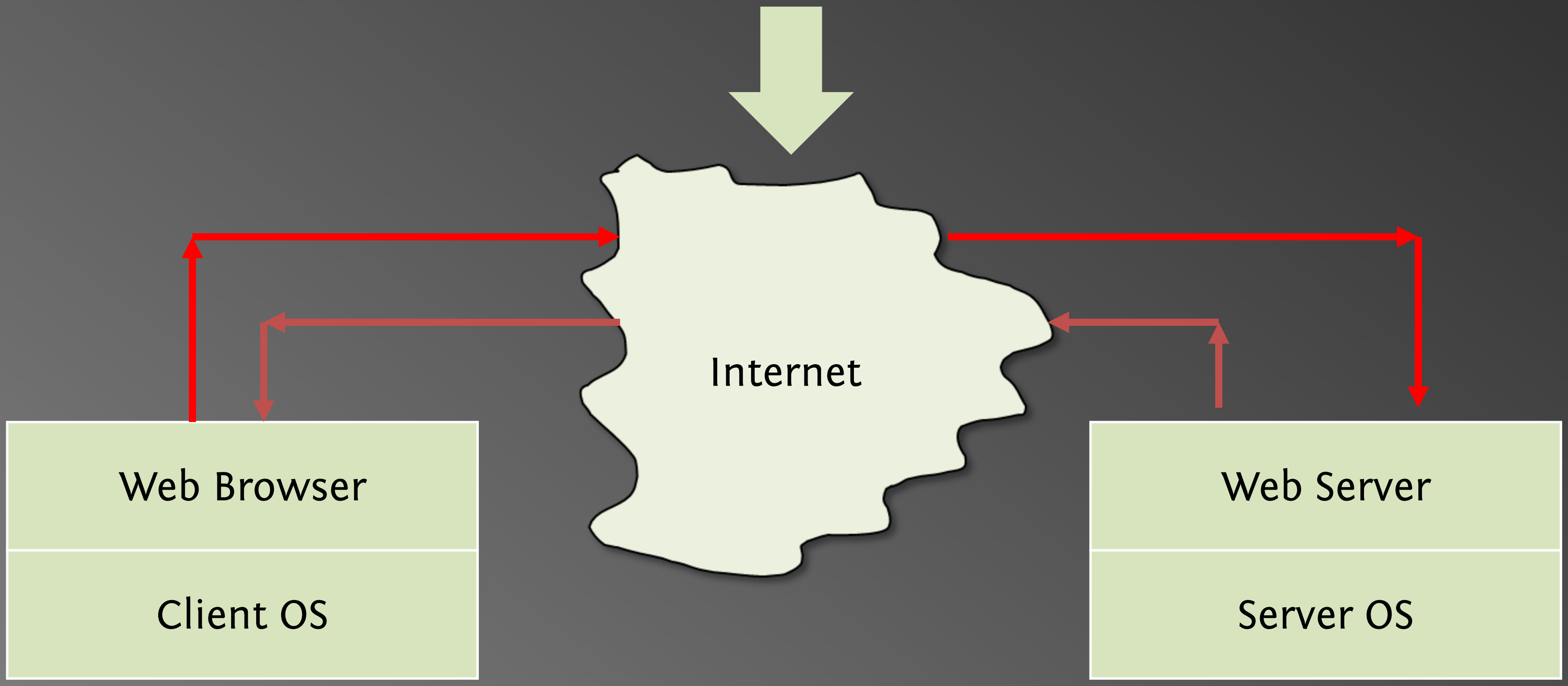
With slides from Dan Weld & Oren Etzioni

Story so far…

- We've assumed we have the text
  - Somehow we got it
  - We indexed it
  - We classified it
  - We extracted information from it

- But how do we get to it in the first place?

Connecting on the WWW



What happens when you click?

- Suppose
  - You are at **www.yahoo.com/index.html**
  - You click on **www.grippy.org/mattmarg/**
- Browser uses DNS => IP addr for *www.grippy.org*
- Opens TCP connection to that address
- Sends HTTP request:

Request

```
Get /mattmarg/ HTTP/1.0
User-Agent: Mozilla/2.0 (Macintosh; I; PPC)
Accept: text/html; */*
Cookie: name = value
Referer: http://www.yahoo.com/index.html
Host: www.grippy.org
Expires: …
If-modified-since: ...
```

Request Headers

HTTP Response

Status

HTTP/1.0 200 Found
Date: Mon, 10 Feb 1997 23:48:22 GMT
Server: Apache/1.1.1 HotWired/1.0
Content-type: text/html
Last-Modified: Tues, 11 Feb 1999 22:45:55 GMT

Image/jpeg, ...

- One click => several responses

- HTTP1.0: new TCP connection for each elt/page
- HTTP1.1: KeepAlive - several requests/connection

Response Status Lines

- 1xx Informational
- 2xx Success
  - 200 Ok
- 3xx Redirection
  - 302 Moved Temporarily
- 4xx Client Error
  - 404 Not Found
- 5xx Server Error

HTTP Methods

- GET
  - Bring back a page
- HEAD
  - Like GET but just return headers
- POST
  - Used to send data to server to be processed (e.g. CGI)
  - Different from GET:
    - A block of data is sent with the request, in the body, usually with extra headers like **Content-Type**: and **Content-Length**:
    - Request URL is not a resource to retrieve; it's a program to handle the data being sent
    - HTTP response is normally program output, not a static file.
- PUT, DELETE, ...

Logging Web Activity

- Most servers support “common logfile format” or “extended logfile format”

```
    127.0.0.1 - frank [10/Oct/2000:13:55:36 -0700] "GET /apache_pb.gif
HTTP/1.0" 200 2326
```

- Apache lets you customize format
- Every HTTP event is recorded
  - Page requested
  - Remote host
  - Browser type
  - Referring page
  - Time of day
- Applications of data-mining logfiles ??

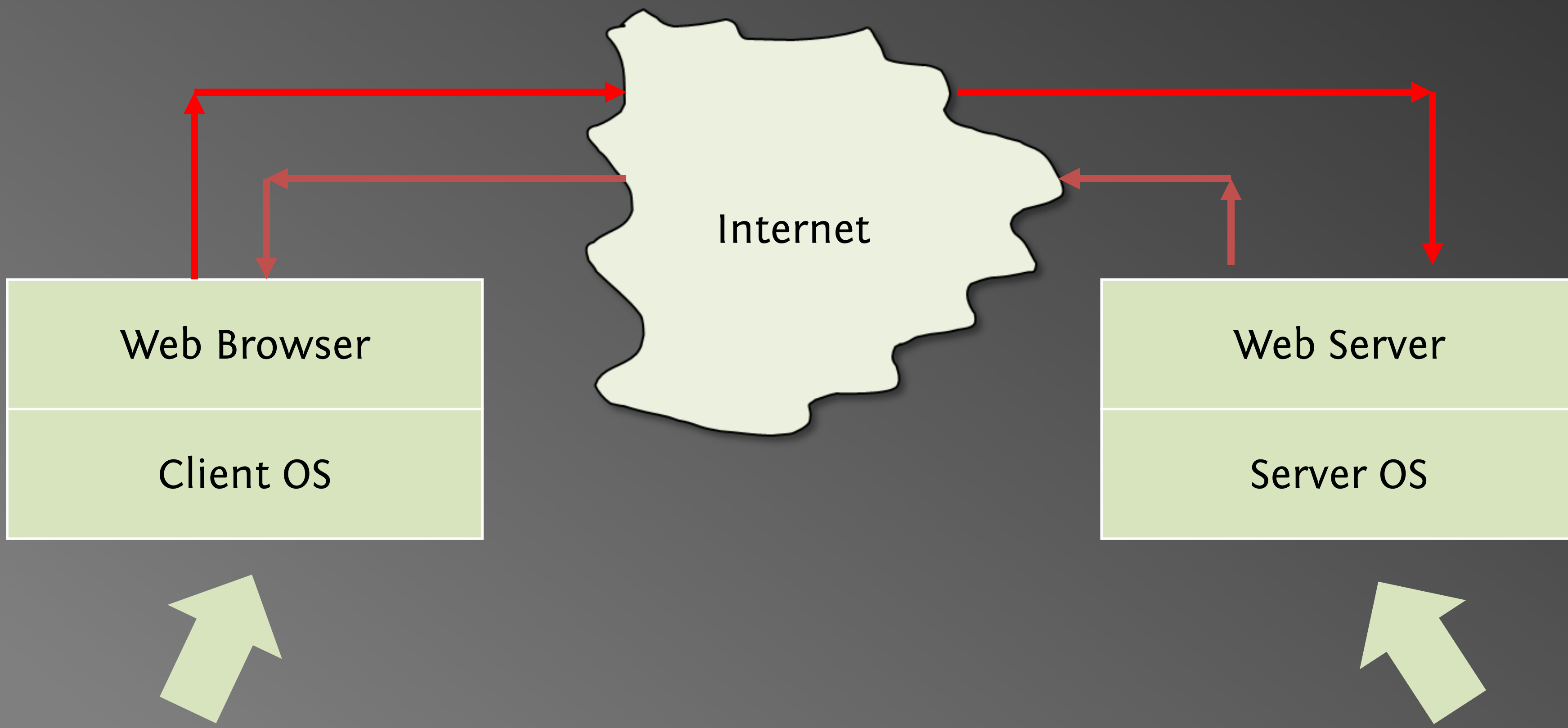
Cookies

- Small piece of info
  - Sent by server as part of response header
  - Stored on disk by browser; returned in request header
  - May have expiration date (deleted from disk)
- Associated with a specific domain & directory
  - Only given to site where originally made
  - Many sites have multiple cookies
  - Some have multiple cookies per page!
- Most Data stored as name=value pairs
- See
  - **C:\Program Files\Netscape\Users\default\cookies.txt**
  - **C:\WINDOWS\Cookies**

HTTPS

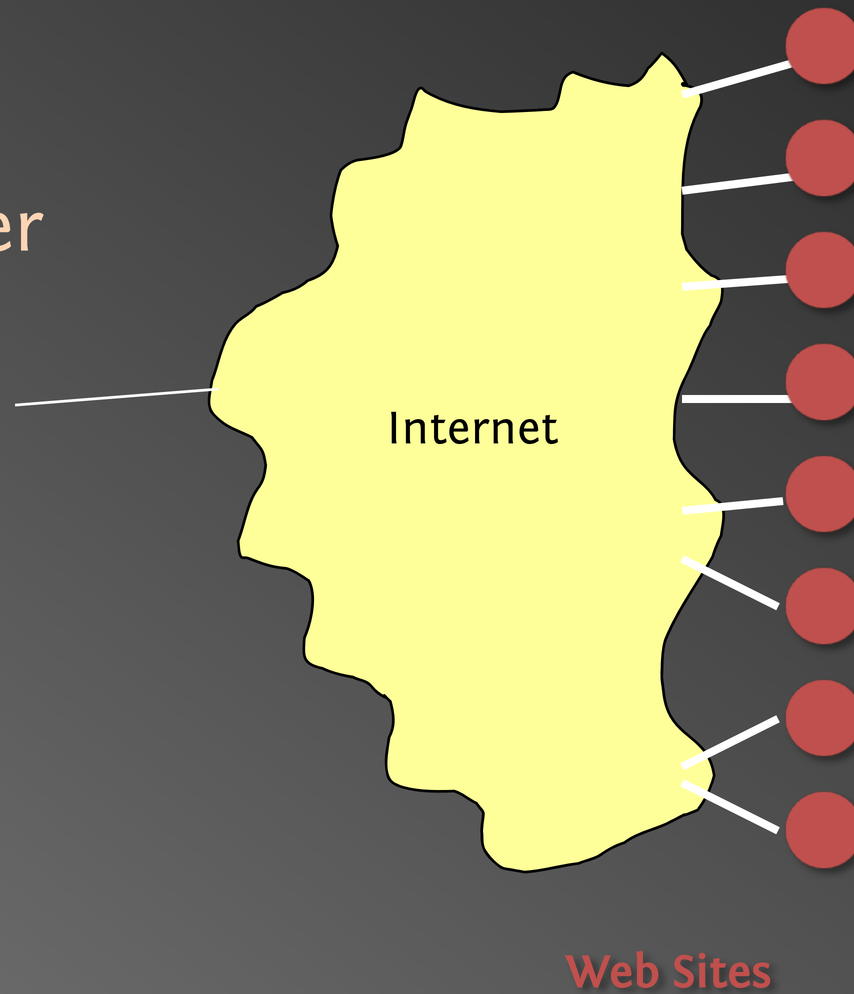
- Secure connections
- Encryption: SSL/TLS
- Fairly straightforward:
  - Agree on crypto protocol
  - Exchange keys
  - Create a shared key
  - Use shared key to encrypt data
- Certificates

Connecting on the WWW

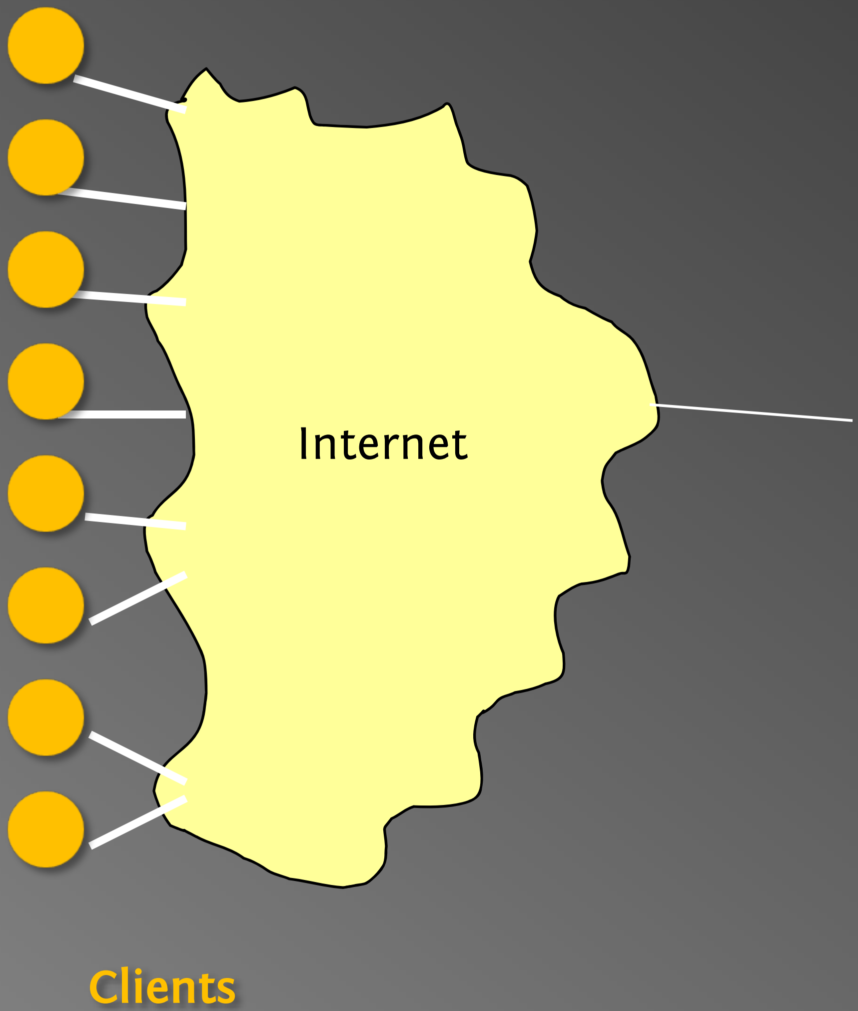


Client-Side View

- Content rendering engine
  - Tags, positioning, movement
- Scripting language interpreter
  - Document object model
  - Events
  - Programming language itself
- Link to custom Java VM
- Security access mechanisms
- Plugin architecture + plugins



Server-Side View



- Database-driven content
- Lots of Users
  - Scalability
  - Load balancing
- Often implemented with cluster of PCs
- 24x7 Reliability
- Transparent upgrades

Trade-offs in Client/Server Arch.

- Compute on clients?
  - Complexity: Many different browsers
    - {Firefox, IE, Safari, …} × Version × OS
- Compute on servers?
  - Peak load, reliability, capital investment.

  \+ Access anywhere, anytime, any device

  \+ Groupware support (shared calendar, …)

  \+ Lower overall cost (utilization & debugging)

  \+ Simpler to update service

Dynamic Content

- We want to do more via an http request
  - E.g. we'd like to invoke code to run on the server.
- Initial solution: Common Gateway Interface (CGI) programs.
- Example: web page contains form that needs to be processed on server.

CGI Code

- CGI scripts can be in any language.
- A new process is started (and terminated) with each script invocation (overhead!).
- Improvement I:
  - Run some code on the client's machine
  - E.g., catch missing fields in the form.
- Improvement II:
  - Server APIs (but these are server-specific).

Java Servlets

- Servlets : applets that run on the server.
  - Java VM stays, servlets run as threads.
- Accept data from client + perform computation
- Platform-independent alternative to CGI.
- Can handle multiple requests concurrently
  - Synchronize requests - use for online conferencing
- Can forward requests to other servers
  - Use for load balancing

Java Server Pages (JSP)
Active Server Pages (ASP)

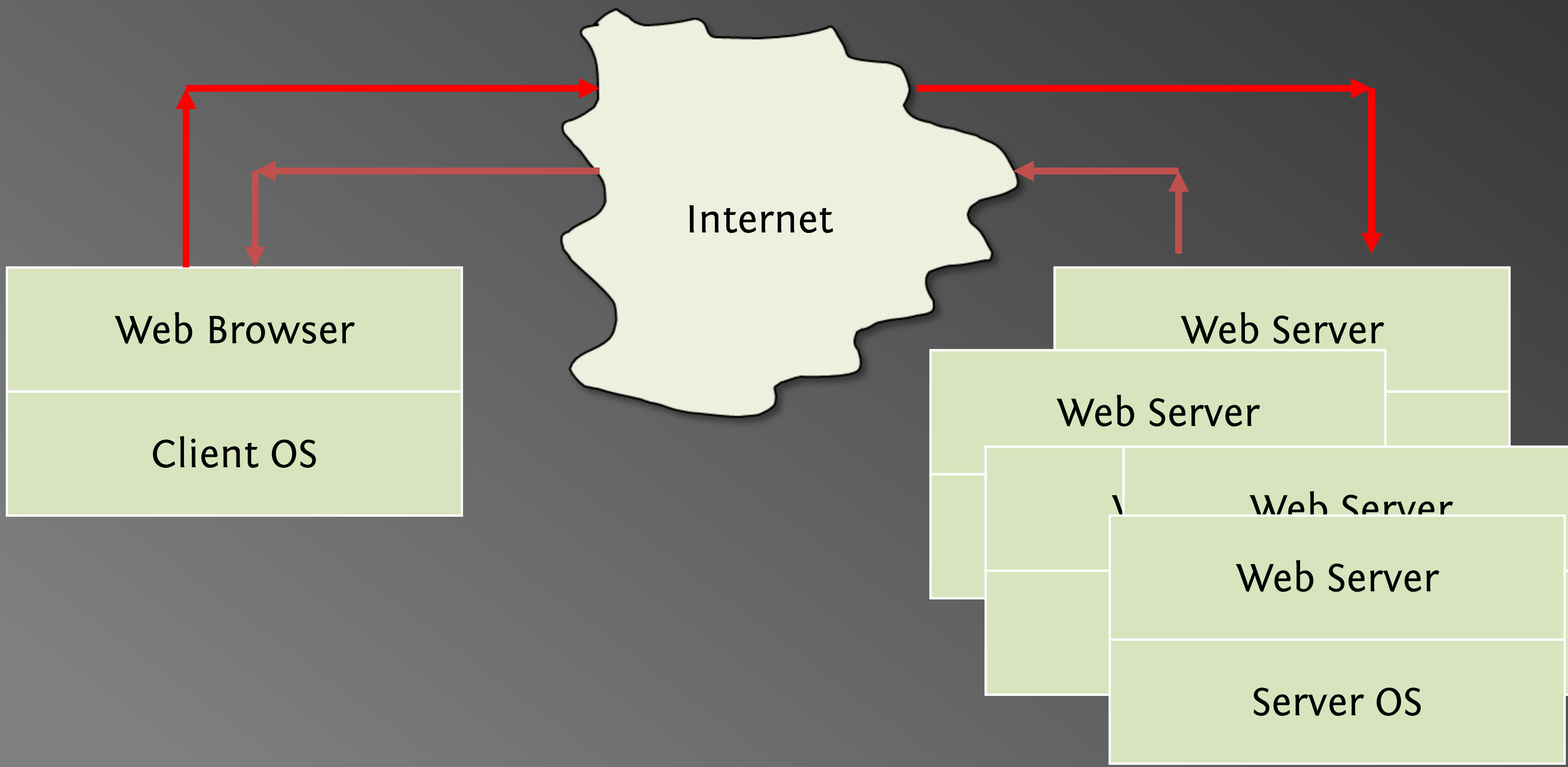
- Allows mixing static HTML w/ dynamically generated content
- JSP is more convenient than servlets for the above purpose
- More recently PHP (and Ruby on Rails, sort of) fall in this category

```
<html>

<head>
<title>Example #3</title>
</head>
<? print(Date("m/j/y")); ?>

<body>
</body>
</html>
```

AJAX

- Getting the browser to behave like your applications (caveat: Asynchronous)
- Client → Rendering library (Javascript)
  - Widgets
- Talks to Server (XML)
- How do we keep state?
- Over the wire protocol: SOAP/XML-RPC/etc.

Connecting on the WWW



Tiered Architectures

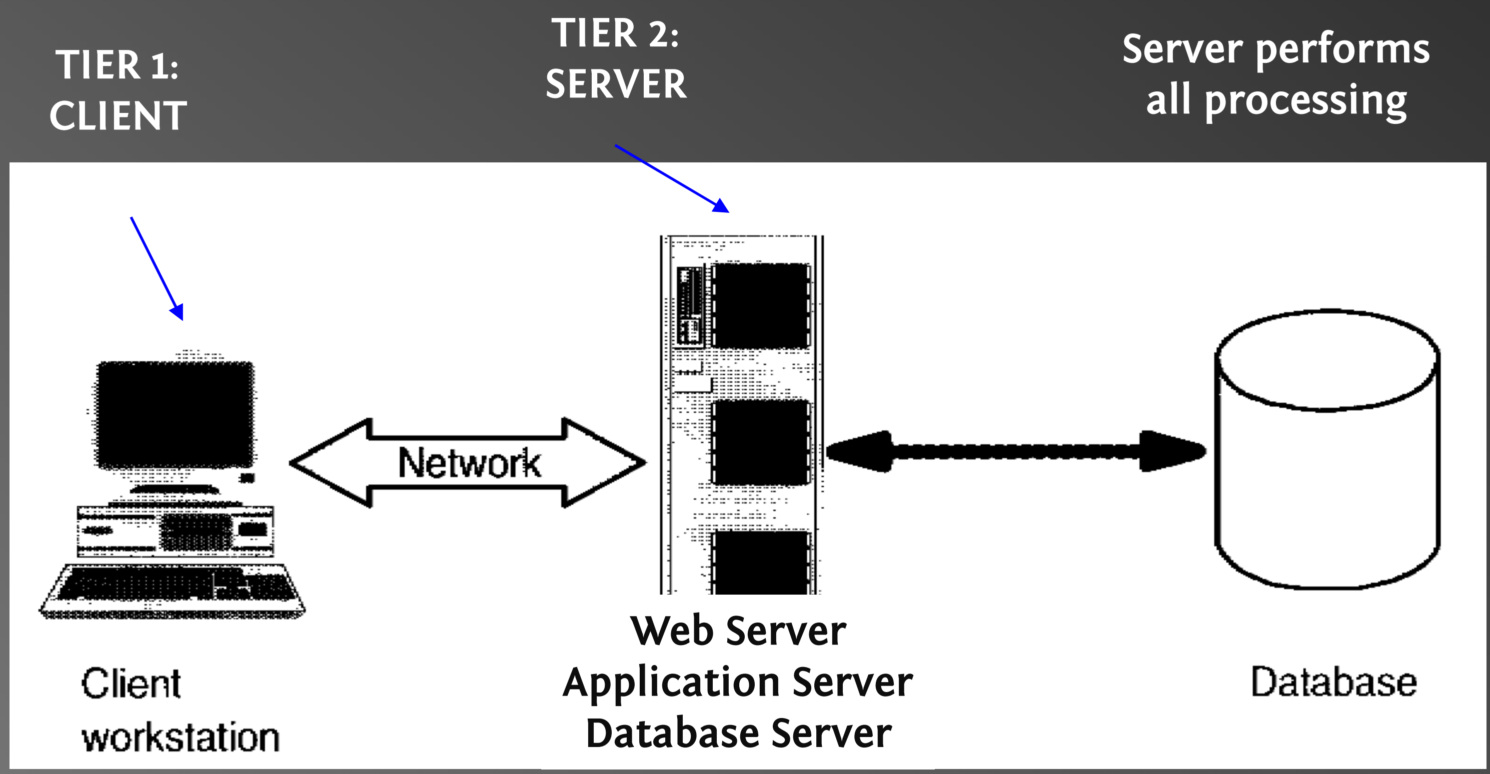
1-tier = dumb terminal → smart server.

2-tier = client/server.

3-tier = client/application server/database.

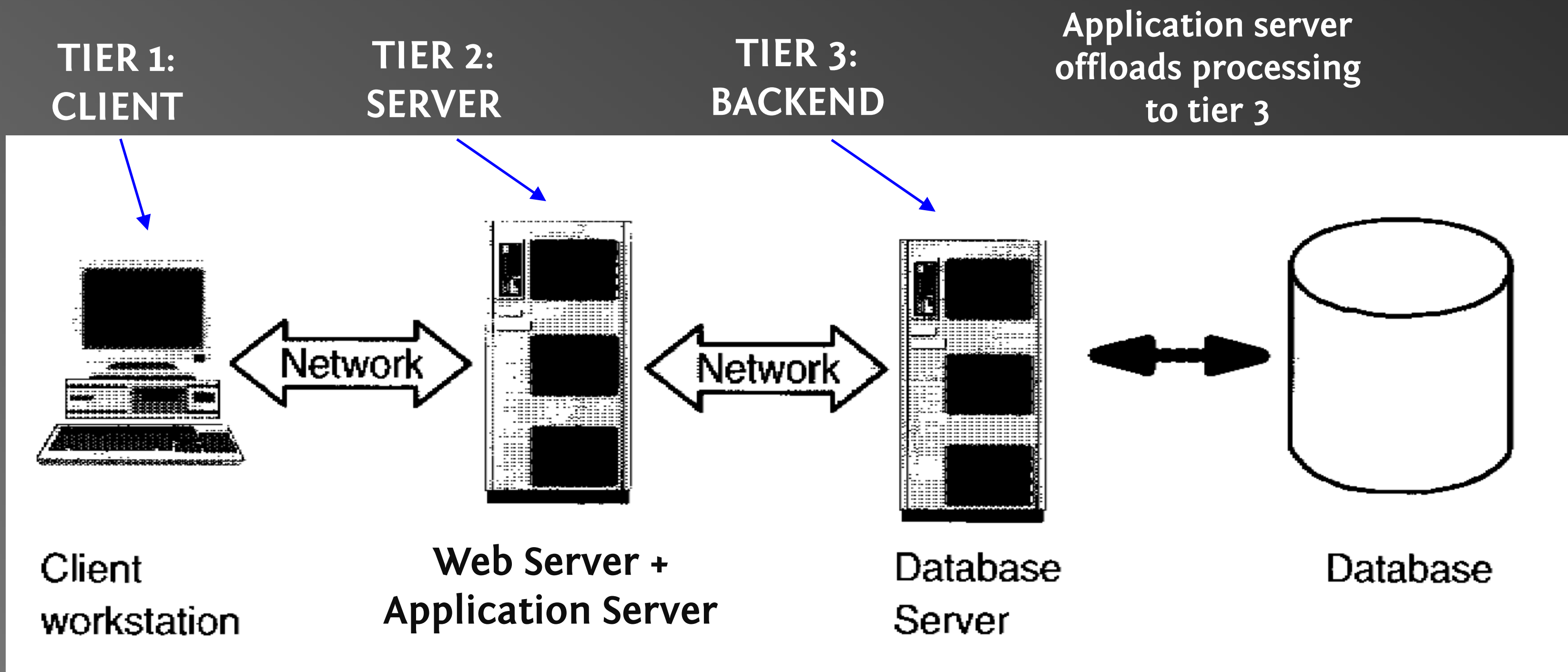
- Why decompose the server?

Two-Tier Architecture



Server does too much work. Weak Modularity.

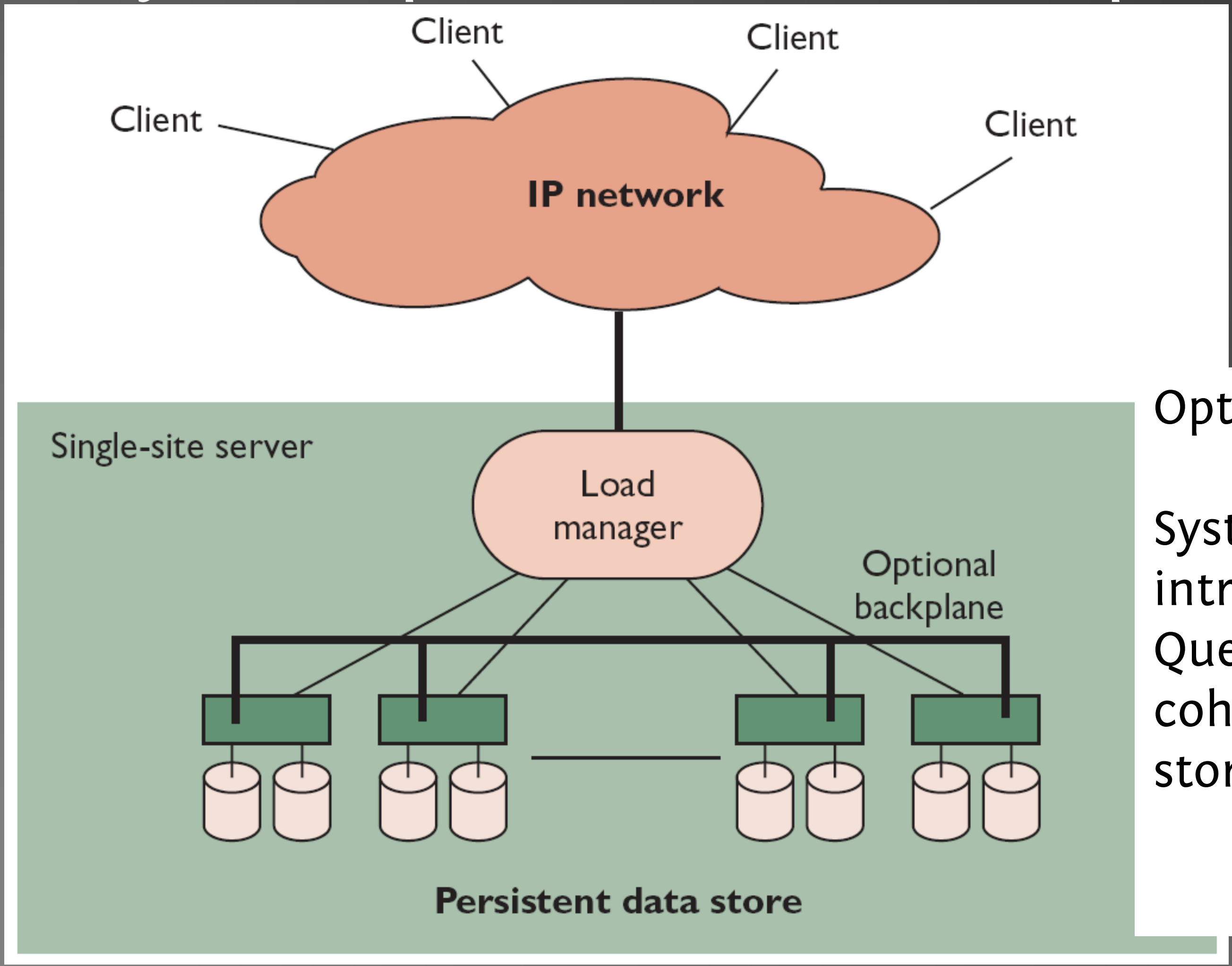
Three-Tier Architecture



Using 2 computers instead of 1 can result in a ***huge increase*** in simultaneous clients.
Depends on % of CPU time spent on database access.
While DB server waits on DB, Web server is busy!

Getting to 'Giant Scale'

- Only real option is cluster computing



Optional Backplane:

System-wide network for intra-server traffic: Query redirect, coherence traffic for store, updates, …

From: Brewer *Lessons from Giant-Scale Services*

Assumptions

- Service provider has limited control
  - Over clients, network
- Queries drive system
  - HTTP Get
  - FTP
  - RPC
- Read Mostly
  - Even at Amazon, browsing >> purchases

From: Brewer *Lessons from Giant-Scale Services*

Cluster Computing: Benefits

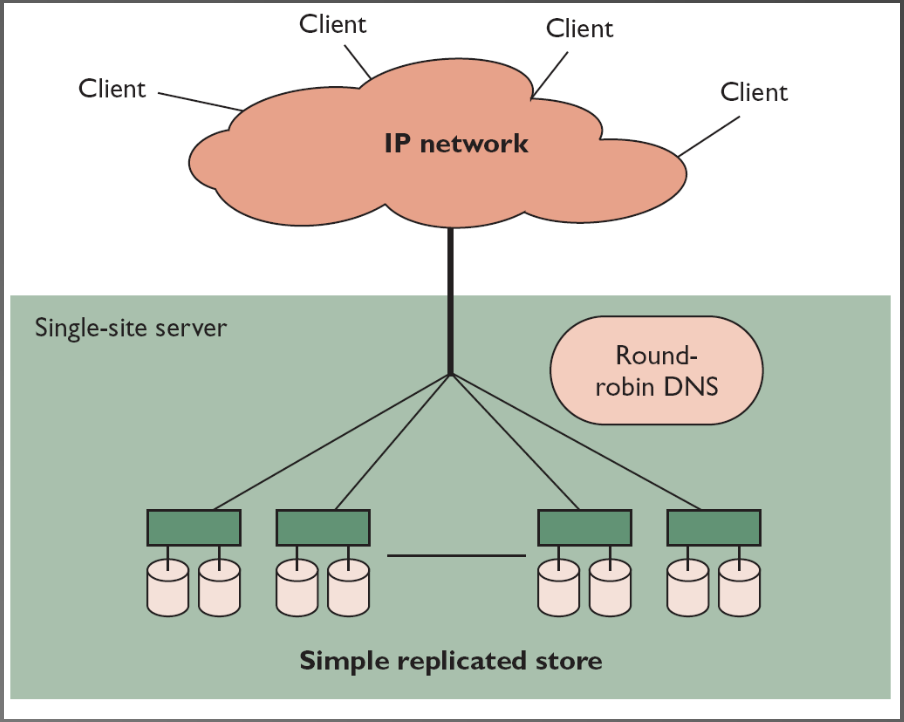
- Absolute Scalability
  – Large % of earth population may use service!
- Incremental Scalability
  – Can add / replace nodes as needed
  – Nodes ~5x faster / 3 year depreciation time
  – Cap ex $$ *vs.* cost of rack space / air cond
- Cost & Performance
  – But no alternative for scale; hardware cost << ops
- Independent Components
  – Independent faults help reliability

From: Brewer *Lessons from Giant-Scale Services*

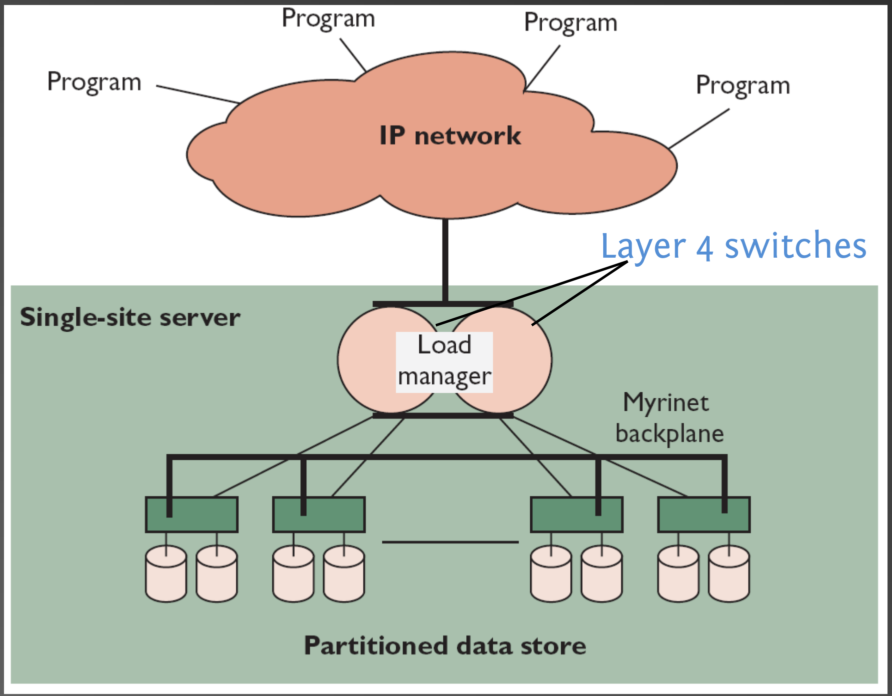
Load Management

- Round-Robin DNS
  - Problem: doesn't hide failed nodes
- Layer 4 switch
  - Understand TCP, port numbers
- Layer 7 (application layer) switch
  - Understand HTTP; Parse URLs at wire speed!
  - Use in pairs (automatic failover)
- Custom front-ends
  - Service-specific layer 7 routers in software
- Smart client end-to-end
  - Hard for WWW in general. Used in DNS, Cell roaming

Case Studies



Simple Web Farm



Search Engine Cluster

Inktomi (2001) Supports programs (not users) Persistent data is partitioned across servers: ⇑ capacity, but ⇓ data loss if server fails

From: Brewer *Lessons from Giant-Scale Services*

High Availability

- Essential Objective
- Phone network, railways, water system
- Challenges
  - Component failures
  - Constantly evolving features
  - Unpredictable growth

From: Brewer *Lessons from Giant-Scale Services*

Typical Cluster

- Extreme symmetry
- Internal disks
- No monitors
- No visible cables
- No people!

- Offsite management
- Contracts limit
  - Δ Power
  - Δ Temperature

From: Brewer *Lessons from Giant-Scale Services*
Images from Zillow talk

Availability Metrics

- Traditionally: Uptime
  - Uptime = (MTBF – MTTR)/MTBF
- Phone system ~ "Four or Five Nines"
  - Four nines means 99.99% reliability
  - I.e. less than 60 sec downtime / week
- How improve uptime?
  - Measuring "MTBF = 1 week" requires > 1 week
  - Measuring MTTR much easier
  - New features reduce MTBF, but not MTTR
  - ***Focus on MTTR***; just best effort on MTBF

From: Brewer *Lessons from Giant-Scale Services*

Yield

- Queries completed / queries offered
  - Numerically similar to uptime, but
  - Better match to user experience
  - (Peak times are much more important)

Harvest

- **Data available / complete data**
  - Fraction of services available
    - E.g. Percentage of index queried for Google
    - Ebay seller profiles down, but rest of site ok

Architecture

- What do faults impact? Yield? Harvest?
- Replicated systems

  Faults → reduced capacity (hence, yield @ high util)
- Partitioned systems

  Faults → reduced harvest

  Capacity (queries / sec) unchanged

- DQ Principle $\exists$ physical bottleneck

  Data/Query $\times$ Queries/Sec = Constant

From: Brewer *Lessons from Giant-Scale Services*

Using DQ Values

- Measurable, Tunable
- Absolute Value Irrelevant
  - Relative value / changes = predictable!

- Methodology
  1. Define DQ value for service
  2. Target workload & load generator
  3. Measure for hardware × software × DB size
     Linearity: small cluster (4 nodes) predict perf for 100
  4. Plan: capacity/traffic; faults; replic/part;

From: Brewer *Lessons from Giant-Scale Services*

Graceful Degradation

- Too expensive to avoid saturation
- Peak/average ratio
  - 1.6x - 6x or more
  - Moviefone: 10x capacity for Phantom Menace
    - Not enough…
- Dependent faults (temperature, power)
  - Overall DQ drops ***way*** down

- Cutting harvest by 2 doubles capacity…

From: Brewer *Lessons from Giant-Scale Services*

Admission Control (AC) Techniques

- Cost-Based AC
  - Denying an expensive query allows 2 cheap ones
  - Inktomi
- Priority-Based (Value-Based) AC
  - Stock trades *vs.* quotes
  - Datek
- Reduced Data Freshness

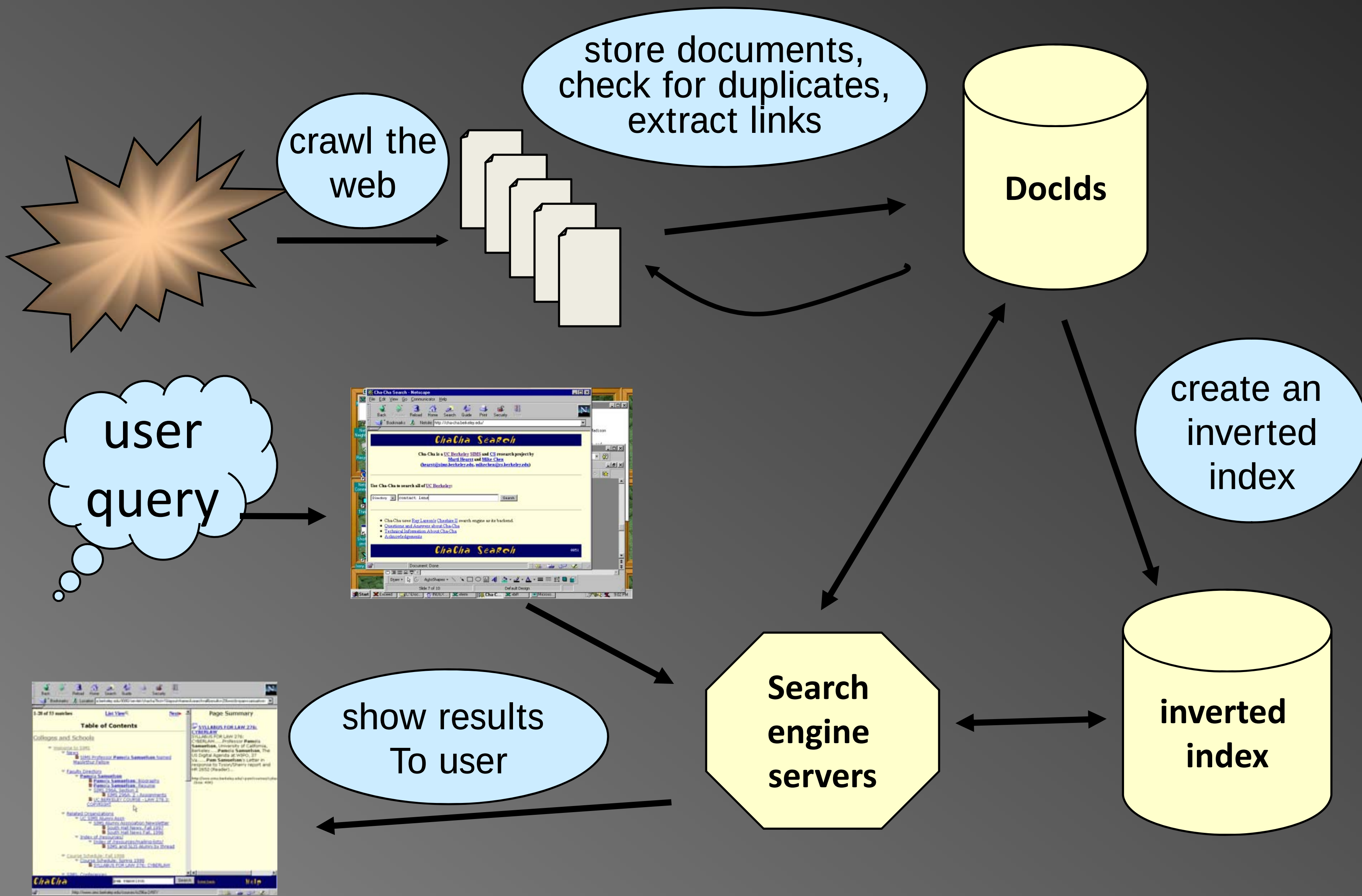
From: Brewer *Lessons from Giant-Scale Services*

Managing Evolution

- Traditional Wisdom
  - “High availability = minimal change”
- Internet: continuous growth, ⇑ features
  - Imperfect software (memory leaks, intermit bugs
- Acceptable quality
  - Target MTBF; low MTTR; no cascading failures
  - Maintenance & upgrades = controlled failures

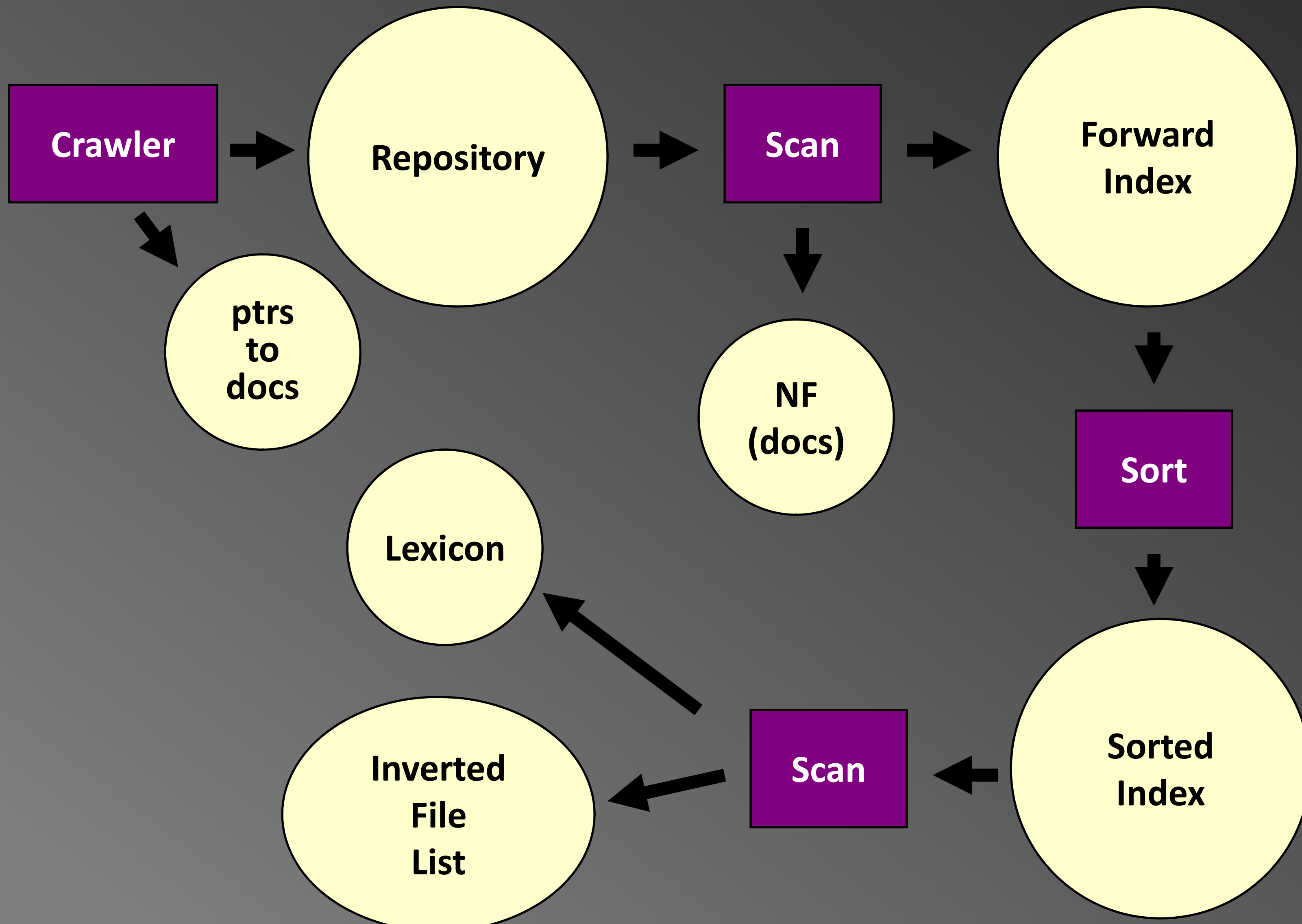
CRAWLERS…

Standard Web Search Engine Architecture



Slide adapted from Marti Hearst / UC Berkeley]

How Inverted Files are Created



Search Engine Architecture

- Crawler (Spider)
  - Searches the web to find pages. Follows hyperlinks.
    Never stops
- Indexer
  - Produces data structures for fast searching of all words in the pages
- Retriever
  - Query interface
  - Database lookup to find hits
    - 300 million documents
    - 300 GB RAM, terabytes of disk
  - Ranking, summaries
- Front End

Spiders

- 1000s of spiders
- Various purposes:
  - Search engines
  - Digital rights management
  - Advertising
  - Spam

Spiders (Crawlers, Bots)

- Queue := initial page URL_0
- Do forever
  - Dequeue URL
  - Fetch P
  - Parse P for more URLs; add them to queue
  - Pass P to (specialized?) indexing program

- Issues…
  - Which page to look at next?
    - keywords, recency, focus, ???
  - Avoid overloading a site
  - How deep within a site to go?
  - How frequently to visit pages?
  - Traps!

Crawling Issues

- Storage efficiency
- Search strategy
  - Where to start
  - Link ordering
  - Circularities
  - Duplicates
  - Checking for changes
- Politeness
  - Forbidden zones: robots.txt
  - CGI & scripts
  - Load on remote servers
  - Bandwidth (download what need)
- Parsing pages for links
- Scalability
- Malicious servers: SEOs

Robot Exclusion

- Person may not want certain pages indexed.
- Crawlers should obey Robot Exclusion Protocol.
  - But some don't
- Look for file robots.txt at highest directory level
  - If domain is www.ecom.cmu.edu, robots.txt goes in www.ecom.cmu.edu/robots.txt
- Specific document can be shielded from a crawler by adding the line:

  <META NAME="ROBOTS" CONTENT="NOINDEX">

Robots Exclusion Protocol

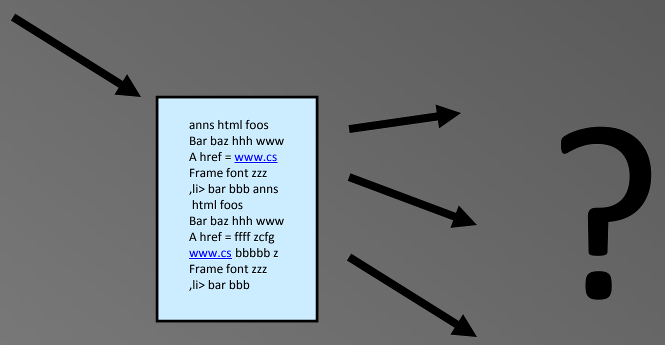
- Format of robots.txt
  - Two fields. User-agent to specify a robot
  - Disallow to tell the agent what to ignore
- To exclude all robots from a server:

  User-agent: *
  Disallow: /
- To exclude one robot from two directories:

  User-agent: WebCrawler
  Disallow: /news/
  Disallow: /tmp/
- View the robots.txt specification at http://info.webcrawler.com/mak/projects/robots/norobots.html

Outgoing Links?

- Parse HTML…
- Looking for…what?



Which tags / attributes hold URLs?

Anchor tag: …

Option tag: <option value=“URL”…> … </option>

Map: <area href=“URL” …>

Frame: <frame src=“URL” …>

Link to an image: <img src=“URL” …>

Relative path vs. absolute path: <base href= …>

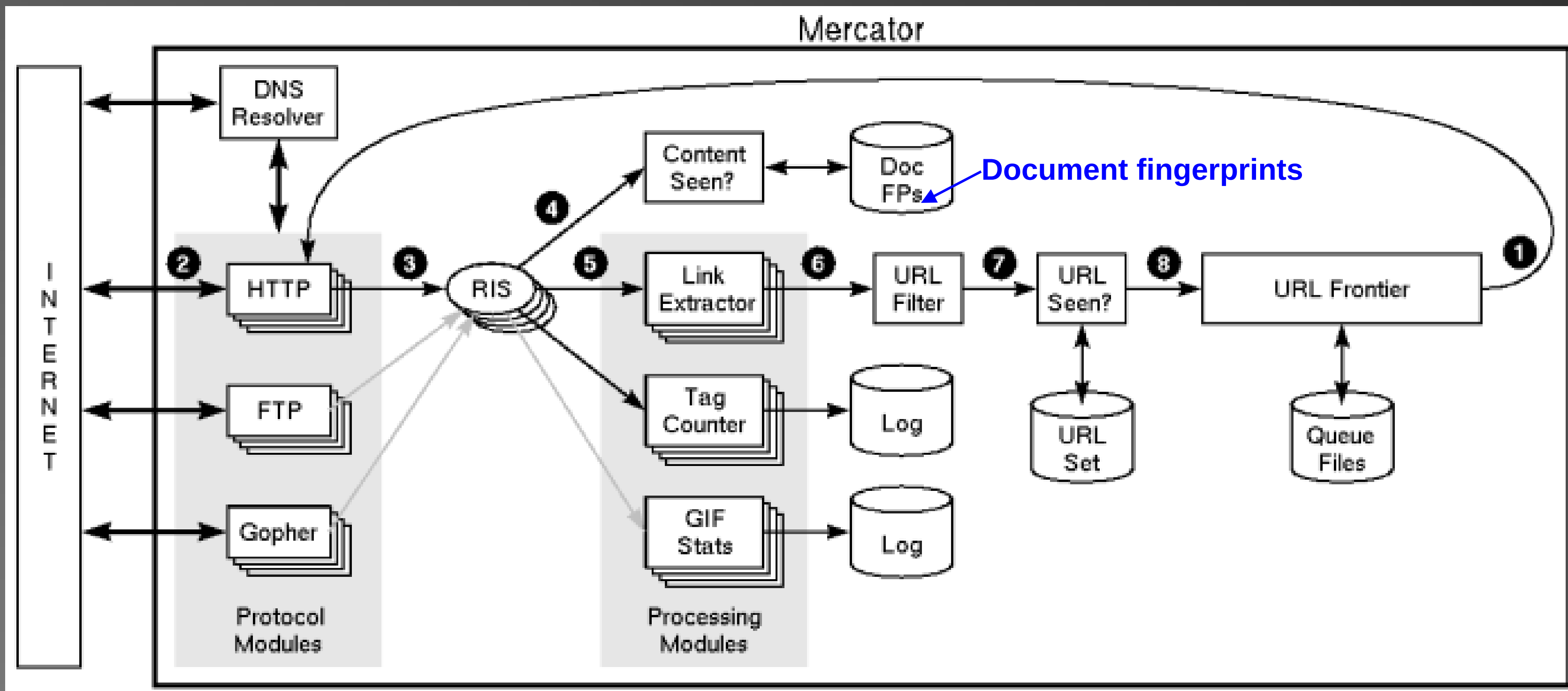
Bonus problem: Javascript

- In our favor: Search Engine Optimization

Web Crawling Strategy

- Starting location(s)
- Traversal order
  - Depth first (LIFO)
  - Breadth first (FIFO)
  - Or ???
- Politeness
- Cycles?
- Coverage?

Structure of Mercator Spider



1. Remove URL from queue
2. Simulate network protocols & REP
3. Read w/ RewindInputStream (RIS)
4. Has document been seen before? (checksums and fingerprints)
5. Extract links
6. Download new URL?
7. Has URL been seen before?
8. Add URL to frontier

URL Frontier (priority queue)

- Most crawlers do breadth-first search from seeds.
- Politeness constraint: don't hammer servers!
  - Obvious implementation: "live host table"
  - Will it fit in memory?
  - Is this efficient?
- Mercator's politeness:
  - One FIFO subqueue per thread.
  - Choose subqueue by hashing host's name.
  - Dequeue first URL whose host has NO outstanding requests.

Fetching Pages

- Need to support http, ftp, gopher, ...
  - Extensible!
- Need to fetch multiple pages at once.
- Need to cache as much as possible
  - DNS
  - robots.txt
  - Documents themselves (for later processing)
- Need to be defensive!
  - Need to time out http connections.
  - Watch for "crawler traps" (e.g., infinite URL names.)
  - See section 5 of Mercator paper.
  - Use URL filter module
  - Checkpointing!

Duplicate Detection

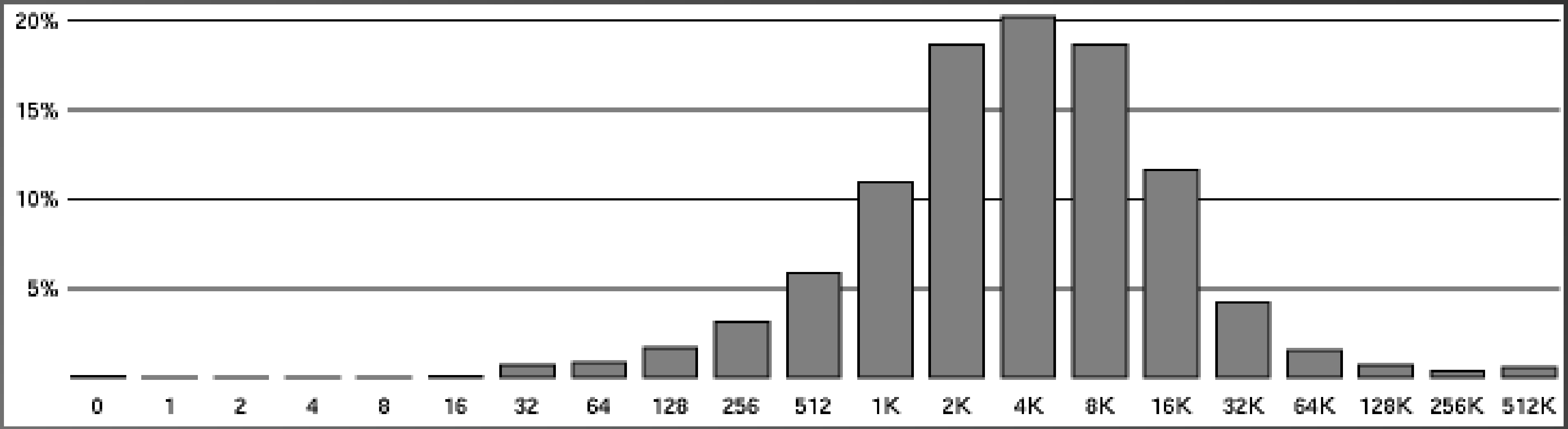
- URL-seen test: has this URL been seen before?
  - To save space, store a hash
- Content-seen test: different URL, same doc.
  - Supress link extraction from mirrored pages.
- What to save for each doc?
  - 64 bit “document fingerprint”
  - Minimize number of disk reads upon retrieval.

Nutch: A simple architecture

- Seed set
- Crawl
- Remove duplicates
- Extract URLs (minus those we've been to)
  - new frontier
- Crawl again
- Can do this with Map/Reduce architecture
  - How?

Mercator Statistics

HISTOGRAM OF DOCUMENT SIZES



Exponentially increasing size →

PAGE TYPE	PERCENT
text/html	69.2%
image/gif	17.9%
image/jpeg	8.1%
text/plain	1.5
pdf	0.9%
audio	0.4%
zip	0.4%
postscript	0.3%
other	1.4%

Advanced Crawling Issues

- Limited resources
  - Fetch most ***important*** pages first
- Topic specific search engines
  - Only care about pages which are ***relevant*** to topic

"Focused crawling"

- Minimize stale pages
  - Efficient re-fetch to keep index timely
  - How track the rate of change for pages?

Focused Crawling

- Priority queue instead of FIFO.
- How to determine priority?
  - Similarity of page to driving query
    - Use traditional IR measures
  - Backlink
    - How many links point to this page?
  - PageRank (Google)
    - Some links to this page count more than others
  - Forward link of a page
  - Location Heuristics
    - E.g., Is site in .edu?
    - E.g., Does URL contain ‘home’ in it?
  - Linear combination of above