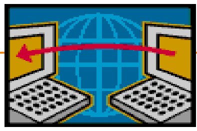

DNS and the Web

EE122 Fall 2012

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http://inst.eecs.berkeley.edu/~ee122/

Materials with thanks to Jennifer Rexford, Ion Stoica, Vern Paxson and other colleagues at Princeton and UC Berkeley

Announcements

- Midterm on Thursday
  - Closed book
  - Crib sheet: 2-sided, 8pt font minimum.
- Midterm will **not** cover details from today's lecture
  - **You should know role basic concepts and roles**
    - o DNS resolves names to addresses
    - o Differences between names and addresses
    - o HTTP retrieves content, is app-layer protocol
    - o Content is named relative to hosts
    - o ……..
- **Review on Tuesday**

Today: DNS and Web

- How many people already know how they work?
- Today is not about the details of these mechanisms, but about what roles they fulfill
  - Section will fill in the details….

DNS

Naming

- Internet has one global system of addressing: IP
  - By explicit design
- And one global system of naming: DNS
  - Almost by accident, naming was an afterthought
- At the time, only items worth naming were hosts
  - A mistake that causes many painful workarounds
- Everything is now named relative to a host
  - Content is most notable example (URL structure)

Logical Steps in Using Internet

- Person has name of entity she wants to access
  - Content, host, etc.
- Invokes an application to perform relevant task
  - Using that name (e.g., www.cnn.com)
- App invokes DNS to translate name to address
  - E.g. 157.166.255.18
- App invokes transport protocol to contact host
  - Using address as destination

Addresses vs Names

- Scope of relevance:
  - App/user is primarily concerned with names
  - Network is primarily concerned with addresses
- Frequency:
  - Name ➔ address lookup once (or get from cache)
  - Address ➔ physical port lookup on each packet
- When moving a host to a different subnet:
  - The address changes
  - The name does not change
- When moving content to a differently named host
  - Name and address both change! **(should it?)**

Relationship Betw'n Names/Addresses

- Addresses can change underneath
  - Move www.cnn.com to 4.125.91.21
  - Humans/Apps should be unaffected
- Name could map to multiple IP addresses
  - www.cnn.com to multiple replicas of the Web site
  - Enables
    - o Load-balancing
    - o Reducing latency by picking nearby servers
- Multiple names for the same address
  - E.g., aliases like www.cnn.com and cnn.com
  - Mnemonic stable name, and dynamic canonical name
    - o Canonical name = actual name of host

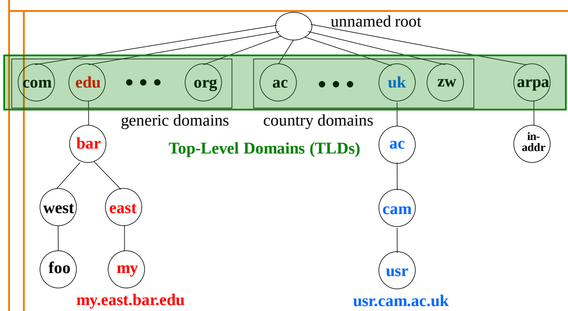
Mapping from Names to Addresses

- Originally: per-host file /etc/hosts
  - SRI (Menlo Park) kept master copy
  - Downloaded regularly
  - Flat namespace
- Single server not resilient, doesn't scale
  - Adopted a distributed hierarchical system
- Two intertwined hierarchies:
  - Infrastructure: hierarchy of DNS servers
  - Naming structure: www.cnn.com

Domain Name System (DNS)

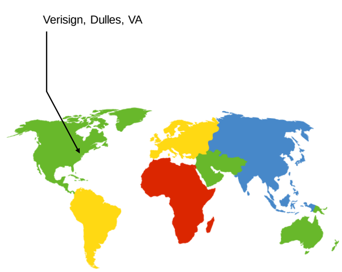
- Top of hierarchy: Root
  - Location hardwired into other servers
- Next Level: Top-level domain (TLD) servers
  - .com, .edu, etc.
  - Managed professionally
- Bottom Level: Authoritative DNS servers
  - Actually do the mapping
  - Can be maintained locally or by a service provider

Distributed Hierarchical Database



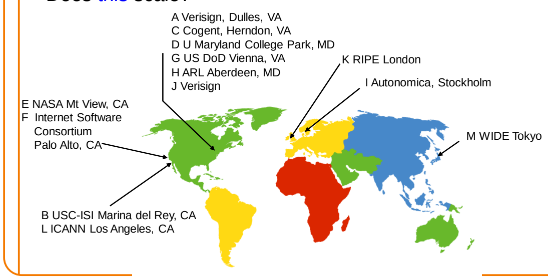
DNS Root

- Located in Virginia, USA
- How do we make the root scale?



DNS Root Servers

- 13 root servers (see http://www.root-servers.org/)
  - Labeled A through M
- Does this scale?



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DNS Root Servers

- 13 root servers (see http://www.root-servers.org/)
  - Labeled A through M
- Replication via any-casting (localized routing for addresses)

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Refresher course on anycast

- Routing finds shortest paths to destination
- If several locations are given the same address, then the network will deliver the packet to the closest location with that address
- This is called "anycast"
  - But no modification of routing is needed for this….

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Was Hierarchy Necessary?

- Two aspects of hierarchy:
  - Name resolution: walk up/down hierarchy
  - Name allocation: control over namespace partitioned
- How to handle both without hierarchy?
  - **Any ideas?**
- Resolution: Google
  - scalable key-value store
- Allocation:
  - Statistically unique names (random)

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Using DNS

- Two components
  - Local DNS servers
  - Resolver software on hosts
- Local DNS server ("default name server")
  - Usually near the endhosts that use it
  - Local hosts configured with local server (e.g., /etc/resolv.conf) or learn server via DHCP
- Client application
  - Extract server name (e.g., from the URL)
  - Do **gethostbyname()** to trigger resolver code

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Many of you have complained….

- …that applications knowing addresses is a violation of layering
- What do people think?
- My opinion:
  - Layers are highly modular abstractions
  - Implementations are not very modular
    - o Violate modularity in several places. This is one of them.
- *Applications handling addresses as bags of bits is ok, but "understanding addresses" is not*

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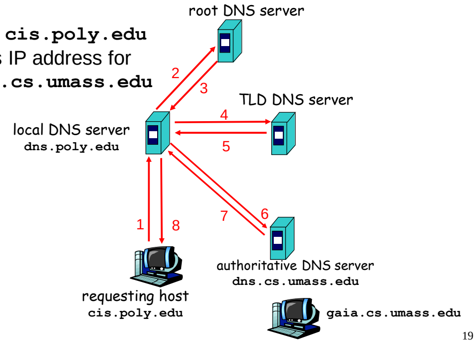
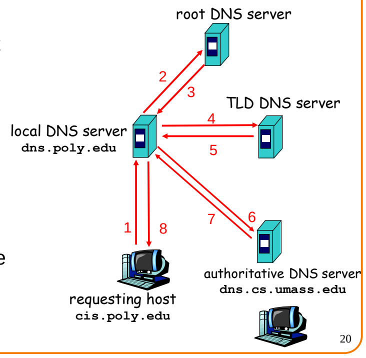
How Does Resolution Happen?

Host at **cis.poly.edu** wants IP address for **gaia.cs.umass.edu**



Recursive vs. Iterative Queries

- Recursive query
  - Ask server to get answer for you
  - E.g., request 1 and response 8
- Iterative query
  - Ask server who to ask next
  - E.g., all other request-response pairs



DNS Caching

- Performing all these queries takes time
  - And all this before actual communication takes place
  - E.g., 1-second latency before starting Web download
- Caching can greatly reduce overhead
  - The top-level servers very rarely change
  - Popular sites (e.g., www.cnn.com) visited often
  - Local DNS server often has the information cached
- How DNS caching works
  - DNS servers cache responses to queries
  - Responses include a "time to live" (TTL) field
  - Server deletes cached entry after TTL expires

Negative Caching

- Remember things that don't work
  - Misspellings like *www.cnn.comm* and *www.cnnn.com*
  - These can take a long time to fail the first time
  - Good to remember that they don't work
  - … so the failure takes less time the next time around
- But: negative caching is optional
  - And not widely implemented

DNS Resource Records

DNS: distributed DB storing resource records (RR)

RR format: `(name, value, type, ttl)`

- Type=A
  - **name** is hostname
  - **value** is IP address
- Type=NS
  - **name** is domain (e.g. foo.com)
  - **value** is hostname of authoritative name server for this domain
- Type=PTR
  - **name** is reversed IP quads
    - E.g. 78.56.34.12.in-addr.arpa
  - **value** is corresponding hostname
- Type=CNAME
  - **name** is alias name for some "canonical" name
    E.g., **www.cs.mit.edu** is really **eecsweb.mit.edu**
  - **value** is canonical name
- Type=MX
  - **value** is name of mailserver associated with **name**
  - Also includes a weight/preference

DNS Protocol

DNS protocol: *query* and *reply* messages, both with same *message format*

Message header:

- Identification: 16 bit # for query, reply to query uses same #
- Flags:
  - Query or reply
  - Recursion desired
  - Recursion available
  - Reply is authoritative
- Plus fields indicating size (0 or more) of optional header elements

16 bits	*16 bits*
Identification	Flags
# Questions	# Answer RRs
# Authority RRs	# Additional RRs
Questions (variable # of resource records)	
Answers (variable # of resource records)	
Authority (variable # of resource records)	
Additional information (variable # of resource records)	

Reliability

- DNS servers are replicated (primary/secondary)
  - Name service available if at least one replica is up
  - Queries can be load-balanced between replicas
- Usually, UDP used for queries **(why???)**
  - Need reliability: must implement this on top of UDP
  - Spec supports TCP too, but not always implemented
- Try alternate servers on timeout
  - Exponential backoff when retrying same server
- Same identifier for all queries
  - Don't care which server responds

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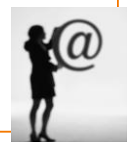
Inserting Resource Records into DNS

- Example: just created startup "FooBar"
- Get a block of address space from ISP
  - Say 212.44.9.128/25
- Register **`foobar.com`** at Network Solutions (say)
  - Provide registrar with names and IP addresses of your authoritative name server (primary and secondary)
  - Registrar inserts RR pairs into the **`com`** TLD server:
    - o (**`foobar.com`**, **`dns1.foobar.com`**, **`NS`**)
    - o (**`dns1.foobar.com`**, **`212.44.9.129`**, **`A`**)
- Put in your (authoritative) server **`dns1.foobar.com:`**
  - Type A record for **`www.foobar.com`**
  - Type MX record for **`foobar.com`**



DNS Measurements (MIT data from 2000)

- What is being looked up?
  - ~60% requests for A records
  - ~25% for PTR records
  - ~5% for MX records
  - ~6% for ANY records
- How long does it take?
  - Median ~100msec (but 90th percentile ~500msec)
  - 80% have no referrals; 99.9% have fewer than four
- Query packets per lookup: ~2.4
  - But this is misleading….

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DNS Measurements (MIT data from 2000)

- Does DNS give answers?
  - ~23% of lookups fail to elicit an answer!
  - ~13% of lookups result in NXDOMAIN (or similar)
    - o Mostly reverse lookups
  - Only ~64% of queries are successful!
    - o *How come the web seems to work so well?*
- ~ 63% of DNS packets in unanswered queries!
  - Failing queries are frequently retransmitted
  - 99.9% successful queries have ≤2 retransmissions

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Moral of the Story

- If you design a highly resilient system, many things can be going wrong without you noticing it!

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DNS Measurements (MIT data from 2000)

- Top 10% of names accounted for ~70% of lookups
  - Caching should really help!
- 9% of lookups are unique
  - Cache hit rate can never exceed 91%
- Cache hit rates ~ 75%
  - But caching for more than 10 hosts doesn't add much

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A Common Pattern…..

- Distributions of various metrics (file lengths, access patterns, etc.) often have two properties:
  - Large fraction of total metric in the top 10%
  - Sizable fraction (~10%) of total fraction in low values
- In an exponential distribution
  - Large fraction is in top 10%
  - But low values have very little of overall total
- Lesson: have to pay attention to both ends of dist.
- Here: caching helps, but not a panacea

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DNS and Security

- No way to verify answers
  - Opens up DNS to many potential attacks
  - DNSSEC fixes this
- Most obvious vulnerability: recursive resolution
  - Using recursive resolution, host must trust DNS server
  - When at Starbucks, server is under their control
  - And can return whatever values it wants
- More subtle attack: Cache poisoning
  - Those "additional" records can be anything!

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Cache Poisoning

- Suppose you are a Bad Guy and you control the name server for foobar.com. You receive a request to resolve www.foobar.com and reply:

```
;; QUESTION SECTION:
;www.foobar.com.                 IN      A

;; ANSWER SECTION:
www.foobar.com.         300      IN      A        212.44.9.144

;; AUTHORITY SECTION:
foobar.com.             600      IN      NS       dns1.foobar.com.
foobar.com.             600      IN      NS       google.com.

;; ADDITIONAL SECTION:
google.com.             5        IN      A        212.44.9.155
```

Evidence of the attack disappears 5 seconds later!

A foobar.com machine, *not* google.com

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The Web

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The Web – Precursor

Ted Nelson

- **1967**, Ted Nelson, Xanadu:
  - A world-wide publishing network that would allow information to be stored not as separate files but as connected literature
  - Owners of documents would be automatically paid via electronic means for the virtual copying of their documents
- Coined the term "Hypertext"
  - Influenced research community
    - o Who then missed the web…..

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The Web – History

Tim Berners-Lee

- Physicist trying to solve real problem
  - Distributed access to data
- World Wide Web (WWW): a distributed database of "pages" linked through Hypertext Transport Protocol (HTTP)
  - First HTTP implementation - 1990
    - o Tim Berners-Lee at CERN
  - HTTP/0.9 – 1991
    - o Simple GET command for the Web
  - HTTP/1.0 –1992
    - o Client/Server information, simple caching
  - HTTP/1.1 - 1996

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Why Didn't CS Research Invent Web?

HTML is precisely what we were trying to PREVENT— ever-breaking links, links going outward only, quotes you can't follow to their origins, no version management, no rights management.

– Ted Nelson

Academics get paid for being clever, not for being right.

–Don Norman

Why So Successful?

- What do the web, youtube, fb have in common?
  - The ability to self-publish
- Self-publishing that is easy, independent, free
- No interest in collaborative and idealistic endeavor
  - People aren't looking for Nirvana (or even Xanadu)
  - People also aren't looking for technical perfection
- Want to make their mark, and find something neat
  - Two sides of the same coin, creates synergy
  - "Performance" more important than dialogue….

Web Components

- Infrastructure:
  - Clients
  - Servers
  - Proxies
- Content:
  - Individual objects (files, etc.)
  - Web sites (coherent collection of objects)
- Implementation
  - HTML: formatting content
  - URL: naming content
  - HTTP: protocol for exchanging content

HTML: HyperText Markup Language

- A *Web page* has:
  - Base HTML file
  - Referenced objects (*e.g.*, images)
- HTML has several functions:
  - Format text
  - Reference images
  - Embed *hyperlinks* (HREF)

URL Syntax

protocol://hostname[:port]/directorypath/resource

protocol	http, ftp, https, smtp, rtsp, *etc.*
hostname	DNS name, IP address
port	Defaults to protocol's standard port *e.g.* http: 80 https: 443
directory path	Hierarchical, reflecting file system
resource	Identifies the desired resource Can also extend to program executions: http://us.f413.mail.yahoo.com/ym/ShowLetter?box=%40B%40Bulk&MsgId=2604_1744106_29699_1123_1261_0_28917_3552_1289957100&Search=&Nhead=f&YY=31454&order=down&sort=date&pos=0&view=a&head=b

HyperText Transfer Protocol (HTTP)

- Request-response protocol
- Reliance on a global namespace
- Resource *metadata*
- *Stateless*
- ASCII format

% telnet www.icir.org 80
GET /jdoe/ HTTP/1.0
<blank line, i.e., CRLF>

Steps in HTTP Request

- HTTP Client initiates TCP connection to server
  - SYN
  - SYNACK
  - ACK
- Client sends HTTP request to server
  - Can be piggybacked on TCP's ACK
- HTTP Server responds to request
- Client receives the request, terminates connection
- TCP connection termination exchange

How many RTTs for a single request?

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Round trips for an exchange

- **TCP SYN** ➔
- ← **TCP SYN-ACK**

First RTT (To Get TCP Started)

- **TCP ACK** ➔
- **HTTP REQUEST** ➔
- ← **HTTP RESPONSE**

Second RTT (To Get HTTP Response)

- **TCP FIN** ➔
- ← **TCP FIN-ACK**
- **TCP ACK** ➔

Third (and a half) RTT (To Close Down TCP Connection)

Typically this third RTT doesn't matter (because data is delivered)

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Client-to-Server Communication

- HTTP Request Message
  - Request line: method, resource, and protocol version
  - Request headers: provide information or modify request
  - Body: optional data (*e.g.,* to "POST" data to the server)

request line

header lines

```
GET /somedir/page.html HTTP/1.1
Host: www.someschool.edu
User-agent: Mozilla/4.0
Connection: close
Accept-language: fr
```

(blank line) ← **Not optional**

carriage return line feed **indicates end of message**

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Client-to-Server Communication

- Request *methods* include:
  - GET: Return current value of resource, run program, …
  - HEAD: Return the meta-data associated with a resource
  - POST: Update resource, provide input to a program, …
- *Headers* include:
  - Useful info for the server
    - o *e.g.* desired language

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Server-to-Client Communication

- HTTP Response Message
  - Status line: protocol version, status code, status phrase
  - Response headers: provide information
  - Body: optional data

status line (protocol, status code, status phrase)

header lines

```
HTTP/1.1 200 OK
Connection close
Date: Thu, 06 Aug 2006 12:00:15 GMT
Server: Apache/1.3.0 (Unix)
Last-Modified: Mon, 22 Jun 2006 ...
Content-Length: 6821
Content-Type: text/html
```

(blank line)

data *e.g.,* requested HTML file

```
data data data data data ...
```

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Server-to-Client Communication

- Response code classes
  - Similar to other ASCII app. protocols like SMTP

Code	Class	Example
1xx	Informational	100 Continue
2xx	Success	200 OK
3xx	Redirection	304 Not Modified
4xx	Client error	404 Not Found
5xx	Server error	503 Service Unavailable

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Different Forms of Server Response

- Return a file
  - URL matches a file (*e.g.,* /www/index.html)
  - Server returns file as the response
  - Server generates appropriate response header
- Generate response dynamically
  - URL triggers a program on the server
  - Server runs program and sends output to client
- Return meta-data with no body

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HTTP Resource Meta-Data

- Meta-data
  - Info *about* a resource, stored as a separate entity
- Examples:
  - Size of resource, last modification time, type of content
- Usage example: Conditional GET Request
  - Client requests object "`If-modified-since`"
  - If unchanged, "`HTTP/1.1 304 Not Modified`"
  - No body in the server's response, only a header

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HTTP is *Stateless*

- Each request-response treated independently
  - Servers *not* required to retain state
- **Good**: Improves scalability on the server-side
  - Failure handling is easier
  - Can handle higher rate of requests
  - Order of requests doesn't matter
- **Bad**: Some applications need persistent state
  - Need to uniquely identify user or store temporary info
  - *e.g.,* Shopping cart, user profiles, usage tracking, …

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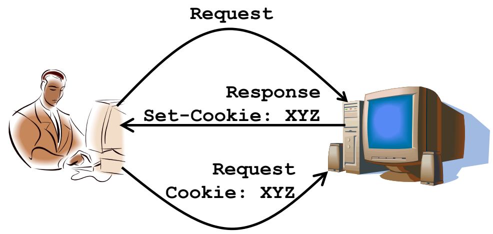
State in a Stateless Protocol:
Cookies

- *Client-side* state maintenance
  - Client stores small(?) state on behalf of server
  - Client sends state in future requests to the server
- Can provide authentication



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Performance Issues

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HTTP Performance

- Most Web pages have multiple objects
  - *e.g.,* HTML file and a bunch of embedded images
- How do you retrieve those objects (naively)?
  - *One item at a time*

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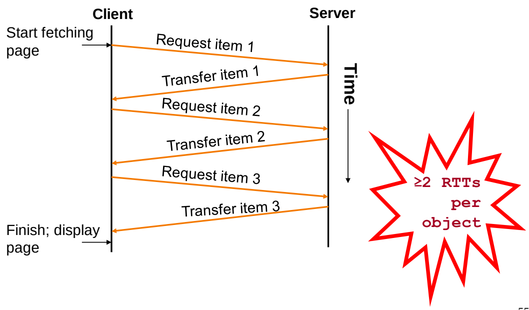
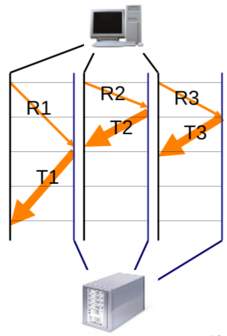
Fetch HTTP Items: Stop & Wait



Improving HTTP Performance:

Concurrent Requests & Responses

- Use multiple connections *in parallel*
- Does not necessarily maintain order of responses

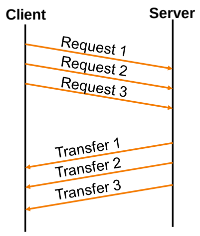


- Client = ☺
- Server = ☺
- Network = ☹ Why?

Improving HTTP Performance:

Pipelined Requests & Responses

- *Batch* requests and responses
  - Reduce connection overhead
  - Multiple requests sent in a single batch
  - Maintains order of responses
  - Item 1 always arrives before item 2
- How is this different from concurrent requests/responses?
  - Single TCP connection



Improving HTTP Performance:

Persistent Connections

- Enables multiple transfers per connection
  - Maintain TCP connection across multiple requests
  - Including transfers subsequent to current page
  - Client or server can tear down connection
- Performance advantages:
  - Avoid overhead of connection set-up and tear-down
  - Allow TCP to learn more accurate RTT estimate
  - Allow TCP congestion window to increase
  - i.e., leverage previously discovered bandwidth
- Default in HTTP/1.1

Scorecard: Getting n Small Objects

Time dominated by latency

- One-at-a-time: ~2n RTT
- Persistent: ~ (n+1)RTT
- M concurrent: ~2[n/m] RTT
- Pipelined: ~2 RTT
- Pipelined/Persistent: ~2 RTT first time, RTT later

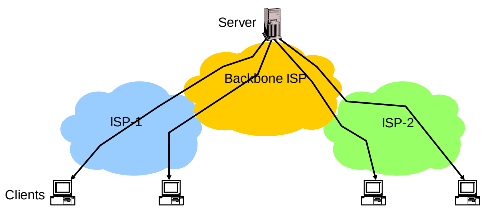
Scorecard: Getting n Large Objects

Time dominated by bandwidth

- One-at-a-time: ~ nF/B
- M concurrent: ~ [n/m] F/B
  - assuming shared with large population of users
  - and each TCP connection gets the same bandwidth
- Pipelined and/or persistent: ~ nF/B
  - The only thing that helps is getting more bandwidth..

Improving HTTP Performance:
Caching

- Many clients transfer same information
  - Generates redundant server and network load
  - Clients experience unnecessary latency



Improving HTTP Performance:
Caching: How

- Modifier to GET requests:
  - If-modified-since – returns "not modified" if resource not modified since specified time
- Response header:
  - Expires – how long it's safe to cache the resource
  - No-cache – ignore all caches; always get resource directly from server

Improving HTTP Performance:
Caching: Why

- Motive for placing content closer to client:
  - User gets better response time
  - Content providers get happier users
    - o Time is money, really!
  - Network gets reduced load
- Why does caching work?
  - Exploits *locality of reference*
- How well does caching work?
  - Very well, up to a limit
  - Large overlap in content
  - But many unique requests

Improving HTTP Performance:
Caching on the Client

Example: Conditional GET Request

- Return resource only if it has changed at the server
  - Save server resources!

Request from client to server:

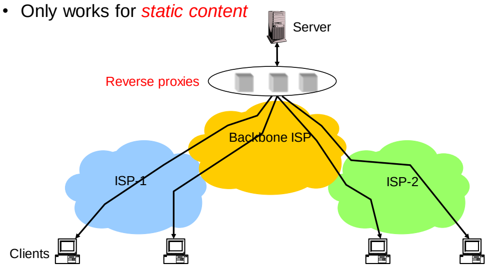
GET /~ee122/fa07/ HTTP/1.1
Host: inst.eecs.berkeley.edu
User-Agent: Mozilla/4.03
If-Modified-Since: Sun, 27 Aug 2006 22:25:50 GMT
<CRLF>

- How?
  - Client specifies "if-modified-since" time in request
  - Server compares this against "last modified" time of desired resource
  - Server returns "304 Not Modified" if resource has not changed
  - …. or a "200 OK" with the latest version otherwise

Improving HTTP Performance:
Caching with Reverse Proxies

Cache documents close to **server**
→ decrease server load

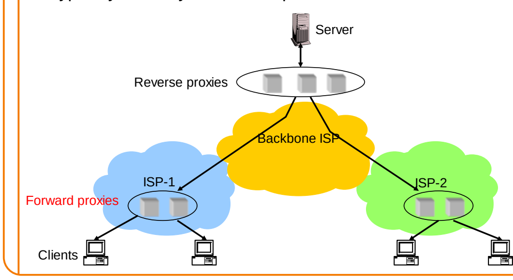
- Typically done by content providers
- Only works for *static content*



Improving HTTP Performance:
Caching with Forward Proxies

Cache documents close to **clients**
→ reduce network traffic and decrease latency

- Typically done by ISPs or corporate LANs



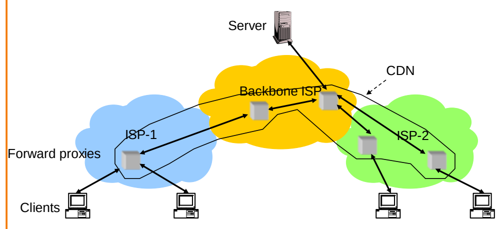
Improving HTTP Performance:

Caching w/ Content Distribution Networks

- Integrate forward and reverse caching functionality
  - One overlay network (usually) administered by one entity
  - *e.g.,* Akamai
- Provide document caching
  - **Pull:** Direct result of clients' requests
  - **Push:** Expectation of high access rate
- Also do some processing
  - Handle *dynamic* web pages
  - *Transcoding*

Improving HTTP Performance:

Caching with CDNs (cont.)



Improving HTTP Performance:

CDN Example – Akamai

- Akamai creates new domain names for each client content provider.
  - e.g., *a128.g.akamai.net*
- The CDN's DNS servers are authoritative for the new domains
- The client content provider modifies its content so that embedded URLs reference the new domains.
  - "Akamaize" content
  - e.g.: *http://www.cnn.com/image-of-the-day.gif* becomes *http://a128.g.akamai.net/image-of-the-day.gif*
- *Requests now sent to CDN's infrastructure…*

Hosting: Multiple Sites Per Machine

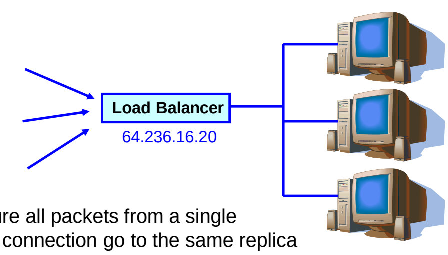
- Multiple Web sites on a single machine
  - Hosting company runs the Web server on behalf of multiple sites (*e.g.*, www.foo.com and www.bar.com)
- Problem: GET /index.html
  - www.foo.com/index.html or www.bar.com/index.html?
- Solutions:
  - Multiple server processes on the same machine
    - o Have a separate IP address (or port) for each server
  - Include site name in HTTP request
    - o Single Web server process with a single IP address
    - o Client includes "Host" header (*e.g.,* Host: www.foo.com)
    - o *Required header* with HTTP/1.1

Hosting: Multiple Machines Per Site

- Replicate popular Web site across many machines
  - Helps to handle the load
  - Places content closer to clients
- Helps when content isn't cacheable
- Problem: Want to direct client to particular replica
  - Balance load across server replicas
  - Pair clients with nearby servers

Multi-Hosting at Single Location

- Single IP address, multiple machines
  - Run multiple machines behind a single IP address



  - Ensure all packets from a single TCP connection go to the same replica

Multi-Hosting at Several Locations

- Multiple addresses, multiple machines
  - Same name but different addresses for all of the replicas
  - Configure DNS server to return different addresses