Application Layer: The Web & HTTP

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The Web: Precursor

Ted Nelson

- **1967, Ted Nelson, Project 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 data

- **Coined the term "Hypertext"**

The Web: History

Tim Berners-Lee

- World Wide Web (WWW): A distributed database of "pages" linked through the Hypertext Transport Protocol (HTTP)
  - First implementation - 1990
    - Tim Berners-Lee at CERN
  - HTTP/0.9 - 1991
    - Simple GET command for the Web
  - HTTP/1.0 - 1992
    - Client/server information, simple caching
  - HTTP/1.1 - 1996
  - HTTP/2 - 2015

Web Components

- **Infrastructure:**
  - Clients
  - Servers
- **Content:**
  - URL: naming content
  - HTML: formatting content
- **Protocol for exchanging information: HTTP**

Uniform Resource Locator (URL)

`protocol://host-name[:port]/directory-path/resource`

- Extend the idea of hierarchical hostnames to include anything in a filesystem
  - *http://cpsc.yale.edu/people/anurag-khandelwal/myfile.txt*
- Extend to program executions as well…
  - *http://us.f413.mail.yahoo.com/ym/ShowLetter?box=%40B%40Bulk&Msgld=2604_1744106_29699_1123_1261_0_28917_3552_1289957100&Search=&Nhead=f&YY=31454&order=down&sort=date&pos=0&view=a&head=b*
  - Server-side processing can be incorporated in the name

Uniform Resource Locator (URL)

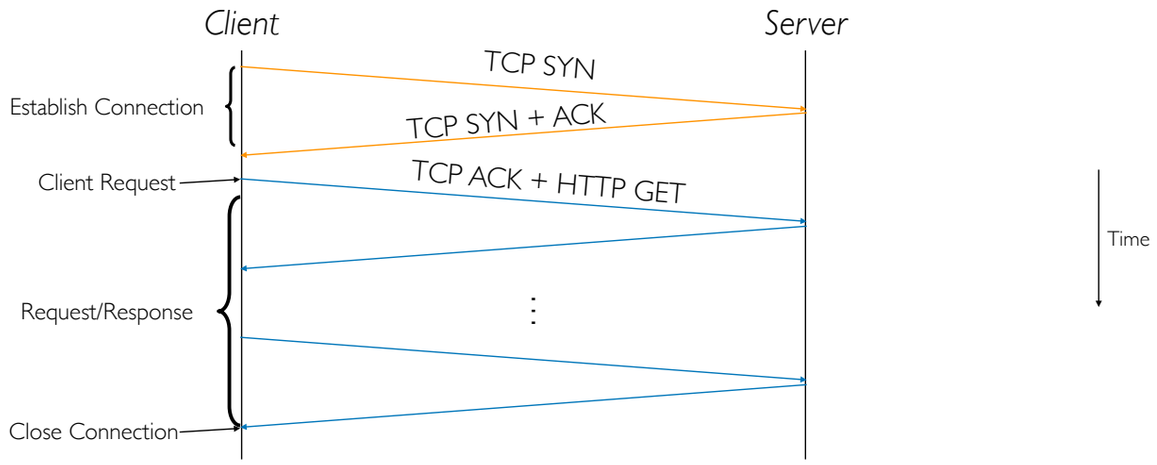
`protocol://host-name[:port]/directory-path/resource`

- `protocol`: http, ftp, https, smtp, rtsp, etc.
- `host-name`: DNS name, IP address
- `port`: defaults to protocol's standard port; e.g., http: 80, https: 443
- `directory-path`: hierarchical, reflecting filesystem
- `resource`: identifies the desired resource

Hyper Text Transfer Protocol (HTTP)

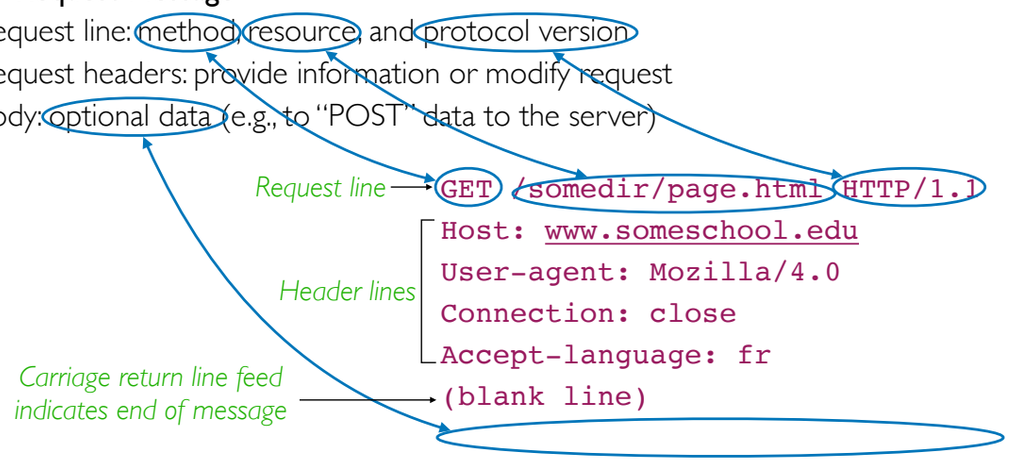
- **Client-server architecture**
  - Server is "always on" and "well known"
  - Clients initiate contact to server
- **Synchronous request/reply protocol**
  - Runs over TCP, port 80
- **ASCII format**
- **Stateless**

Steps in HTTP Request/Response



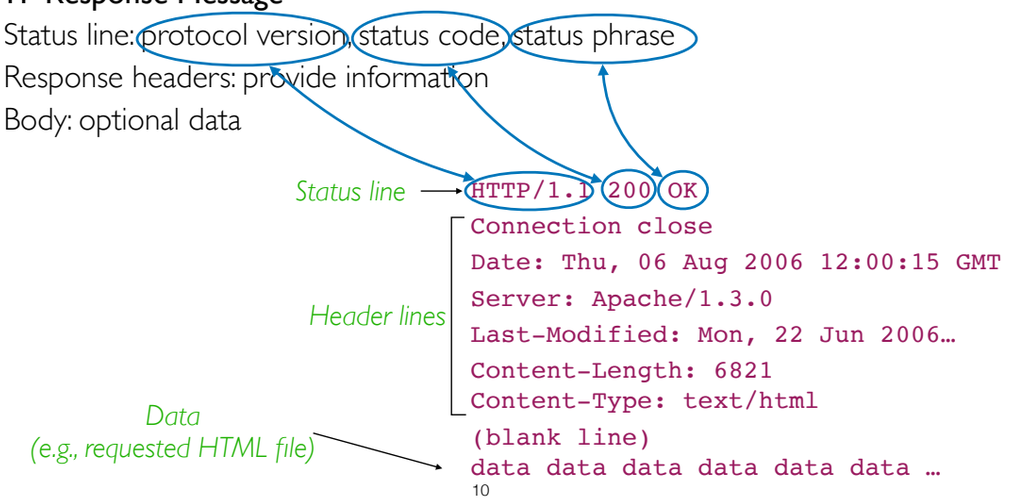
Client-to-Server Communication

- **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)



Server-to-Client Communication

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



Questions?

HTTP is *Stateless*

- **Each request-response treated independently**
  - Servers *not* required to retain state from clients
  - Pros vs cons?

- **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 information
  - e.g., Shopping cart, user profiles, usage tracking, …

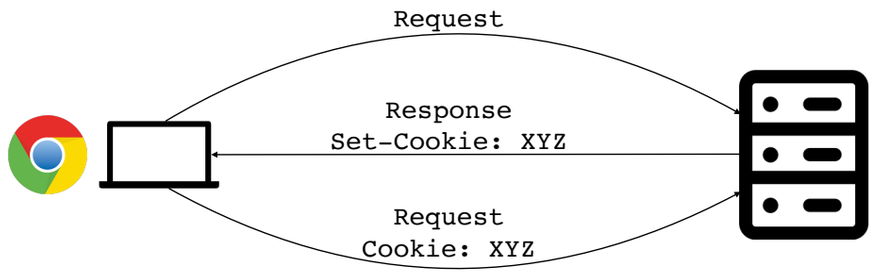
Question

- How does a stateless protocol keep state?

State in a Stateless Protocol: Cookies

- *Client-side* state maintenance
  - Client store small state on behalf of server
  - Client sends state in future requests to the server

- Can provide authentication



Questions?

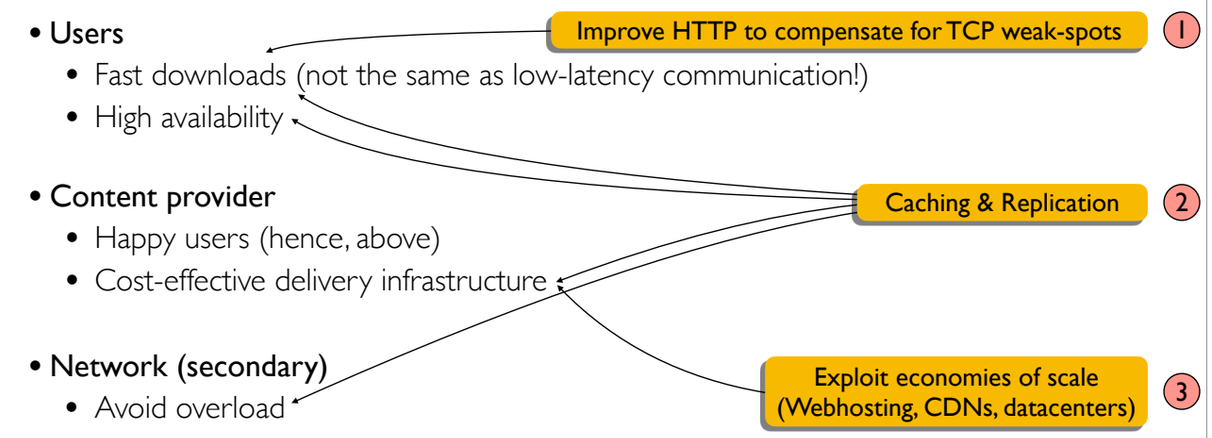
HTTP Performance Issues

Performance Goals

- **Users**
  - Fast downloads (not the same as low-latency communication!)
  - High availability
- **Content provider**
  - Happy users (hence, above)
  - Cost-effective delivery infrastructure
- **Network (secondary)**
  - Avoid overload

Solutions?

- **Users**
  - Fast downloads (not the same as low-latency communication!)
  - High availability
- **Content provider**
  - Happy users (hence, above)
  - Cost-effective delivery infrastructure
- **Network (secondary)**
  - Avoid overload



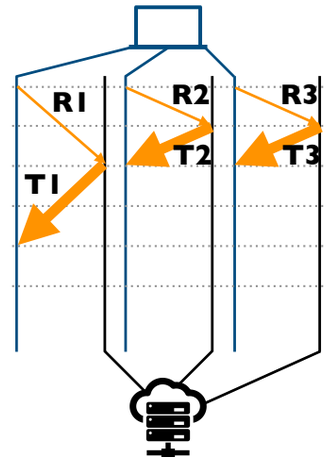
HTTP Performance on TCP

- Most webpages have multiple objects
  - e.g., HTML and a bunch of embedded images
- How do you retrieve those objects (naively)?
  - One object at a time
- New TCP connection per (small) object!

Improving HTTP Performance:

Concurrent Requests & Responses

- Use multiple connections *in parallel*
- Does not necessarily maintain order of responses
- Client: :)
- Content provider: :)
- Network: :((Why?)



Improving HTTP Performance:

Persistent Connections

- **Maintain TCP connection across multiple requests**
  - Including transfers after current page
  - Client or server can tear down connection

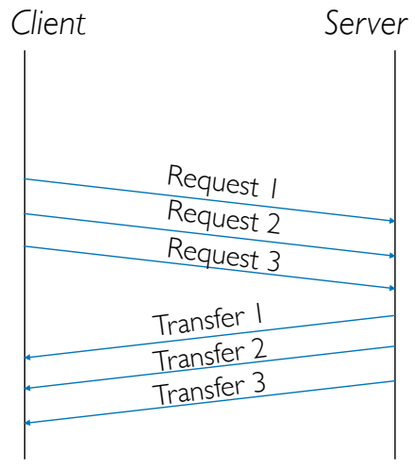
- **Performance advantages**
  - Avoid overhead of connection setup and teardown
  - Allow TCP to learn more accurate RTT estimate
  - Allow TCP congestion window to increase, i.e., leverage previously discovered bandwidth

- **Default in HTTP/1.1**

Improving HTTP Performance:

Pipelined Requests & Responses

- Batch requests & responses to reduce #of packets
- Multiple requests can be contained in 1 TCP segment



Scorecard: Getting *n* Small Objects

Time dominated by latency

- One-at-a-time:
- M concurrent:
- Persistent:
- Pipelined:
- Pipelined/Persistent:

Scorecard: Getting *n* Large Objects of Size *F*

Time dominated by bandwidth

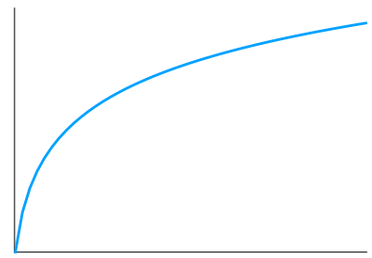
- One-at-a-time:
- M concurrent:
  - Assuming shared with large population of users
  - And each TCP connection gets the same bandwidth
- Pipelined and/or Persistent:
  - The only thing that helps is getting more bandwidth..

Questions?

Improving HTTP Performance:

Caching

- **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
    - *A universal story!*
    - *Effectiveness of caching grows logarithmically with size*



Improving HTTP Performance:

Caching: How

- Modifier to GET requests:
  - `If-modified-since` — returns "not modified" if resource not modified since specified time

> - Client specifies "if-modified-since" time in request
> - Server compares this against "last modified" time of resource
> - Server returns "not modified" if resource has not changed
> - … or an "OK" with the latest version otherwise

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 its safe to cache the resource
  - `No-cache` — ignore all caches; always get resource directly from server

Improving HTTP Performance:

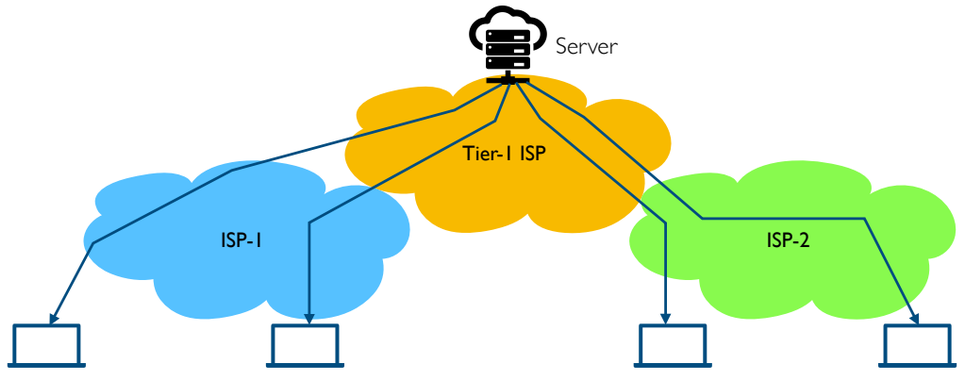
Caching: Where

- Options:
  - Client
  - Forward proxies
  - Reverse proxies
  - Content Distribution Network

Improving HTTP Performance:

Caching: Where

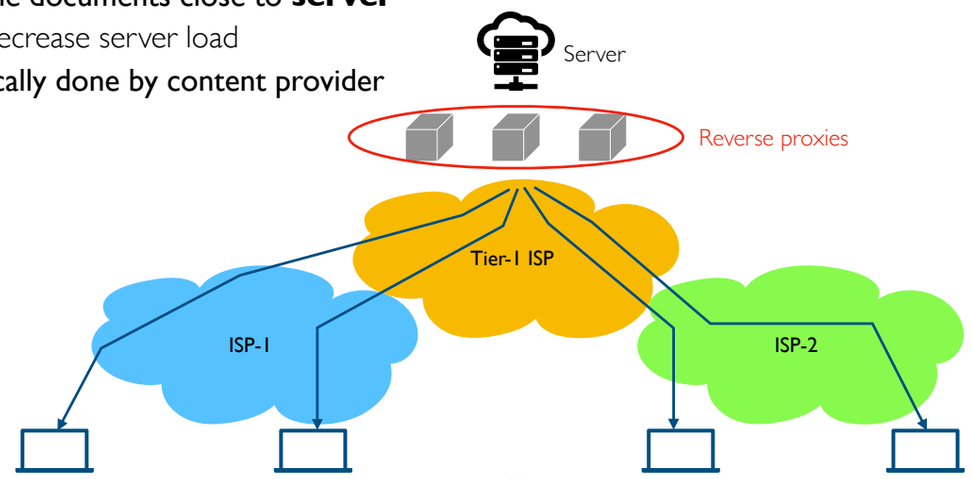
- **Baseline: many clients transfer same information**
  - Generate unnecessary server and network load
  - Clients experience unnecessary latency



Improving HTTP Performance:

Caching: Where

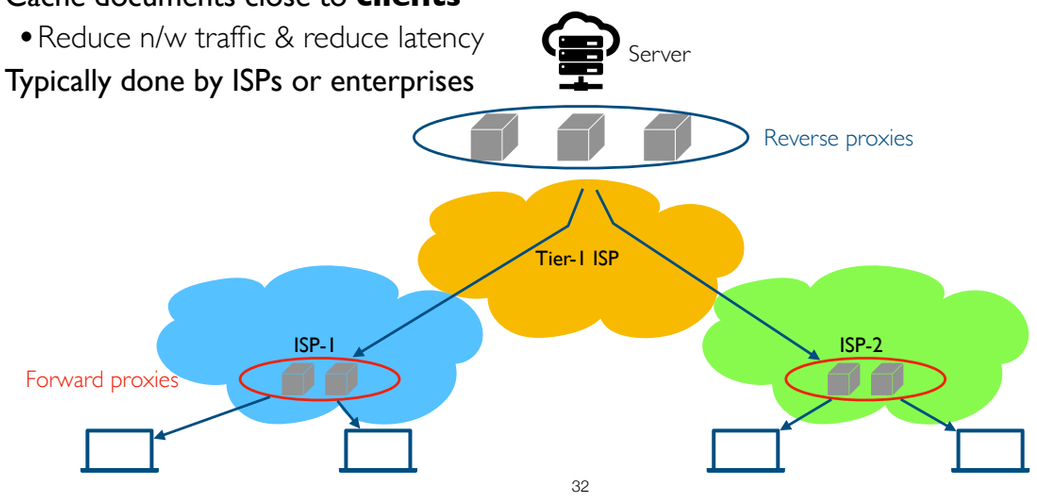
- Cache documents close to **server**
  - Decrease server load
- Typically done by content provider



Improving HTTP Performance:

Caching: Where

- Cache documents close to **clients**
  - Reduce n/w traffic & reduce latency
- Typically done by ISPs or enterprises



Improving HTTP Performance:

Replication

- **Replicate popular websites across many machines**
  - Spreads load on servers
  - 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
- **Common solution:**
  - DNS returns different addresses based on clients geo-location, server load, etc.