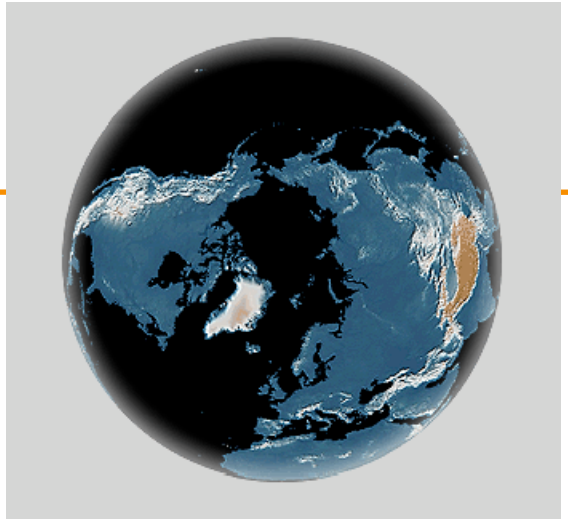


Web Content Delivery

Reading: Section 9.1.2 and 9.4.3

Acknowledgments: Lecture slides are from Computer networks course thought by Jennifer Rexford at Princeton University. When slides are obtained from other sources, a a reference will be noted on the bottom of that slide. A full list of references is provided on the last slide.

Outline: Web Content Distribution

- Main ingredients of the Web
  - URL, HTML, and HTTP
  - HTTP: the protocol and its stateless property
- Web Systems Components
  - Clients
  - Servers
  - DNS (Domain Name System)
- Interaction with underlying network protocol: TCP
- Scalability and performance enhancement
  - Server farms
  - Web Proxy
  - Content Distribution Network (CDN)

Web History

- Before the 1970s-1980s
  - Internet used mainly by researchers and academics
  - Log in remote machines, transfer files, exchange e-mail
- Internet growth and commercialization
  - 1988: ARPANET gradually replaced by the NSFNET
  - Early 1990s: NSFNET begins to allow commercial traffic
- Initial proposal for the Web by Berners-Lee in 1989
- Enablers for the success of the Web
  - 1980s: Home computers with graphical user interfaces
  - 1990s: Power of PCs increases, and cost decreases

Main ingredients of the Web

- URL
  - Denotes the global unique location of the web resource
  - Formatted string

    e.g., http://www.sharif.edu/index.html

    Protocol for communicating with server (e.g., http)

    Name of the server (e.g., www.sharif.edu)

    Name of the resource (e.g., index.html)
- HTML
  - Actual content of web resource, represented in ASCII

Main ingredients of the Web: HTML

- HyperText Markup Language (HTML)
  - Format text, reference images, embed hyperlinks
  - Representation of hypertext documents in ASCII format
  - Interpreted by Web browsers when rendering a page
- Web page
  - Base HTML file
  - referenced objects (e.g., images), Each object has its own URL
- Straight-forward and easy to learn
  - Simplest HTML document is a plain text file
  - Automatically generated by authoring programs

Main ingredients of the Web

- URL
  - Denotes the global unique location of the web resource
  - Formatted string

    e.g., http://www.sharif.edu/index.html

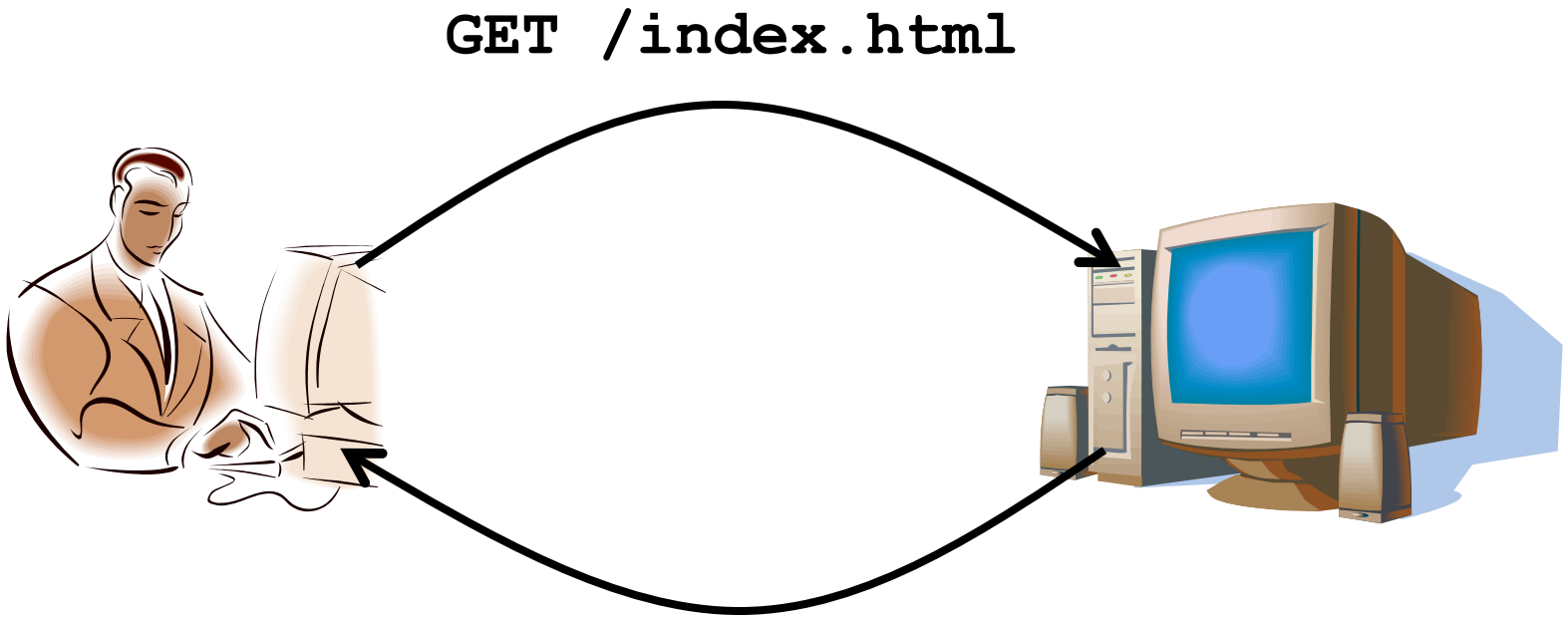
    Protocol for communicating with server (e.g., http)

    Name of the server (e.g., www.sharif.edu)

    Name of the resource (e.g., index.html)
- HTML
  - Actual content of web resource, represented in ASCII
- HTTP
  - Protocol for client/server communication

Main ingredients of the Web: HTTP

- Client program
  - E.g., Web browser
  - Running on end host
  - Requests service
- Server program
  - E.g., Web server
  - Provides service



Outline: Web Content Distribution

- Main ingredients of the Web
  - URL, HTML, and HTTP
  - HTTP: the protocol and its stateless property
- Web Systems Components
  - Clients
  - Servers
  - DNS (Domain Name System)
- Interaction with underlying network protocol: TCP
- Scalability and performance enhancement
  - Server farms
  - Web Proxy
  - Content Distribution Network (CDN)

HTTP Example: Request and Response Message


```
GET /courses/archive/spring08/ce443/ HTTP/1.1
Host: www.ce.sharif.edu
User-Agent: Mozilla/4.03
<CRLF>
```

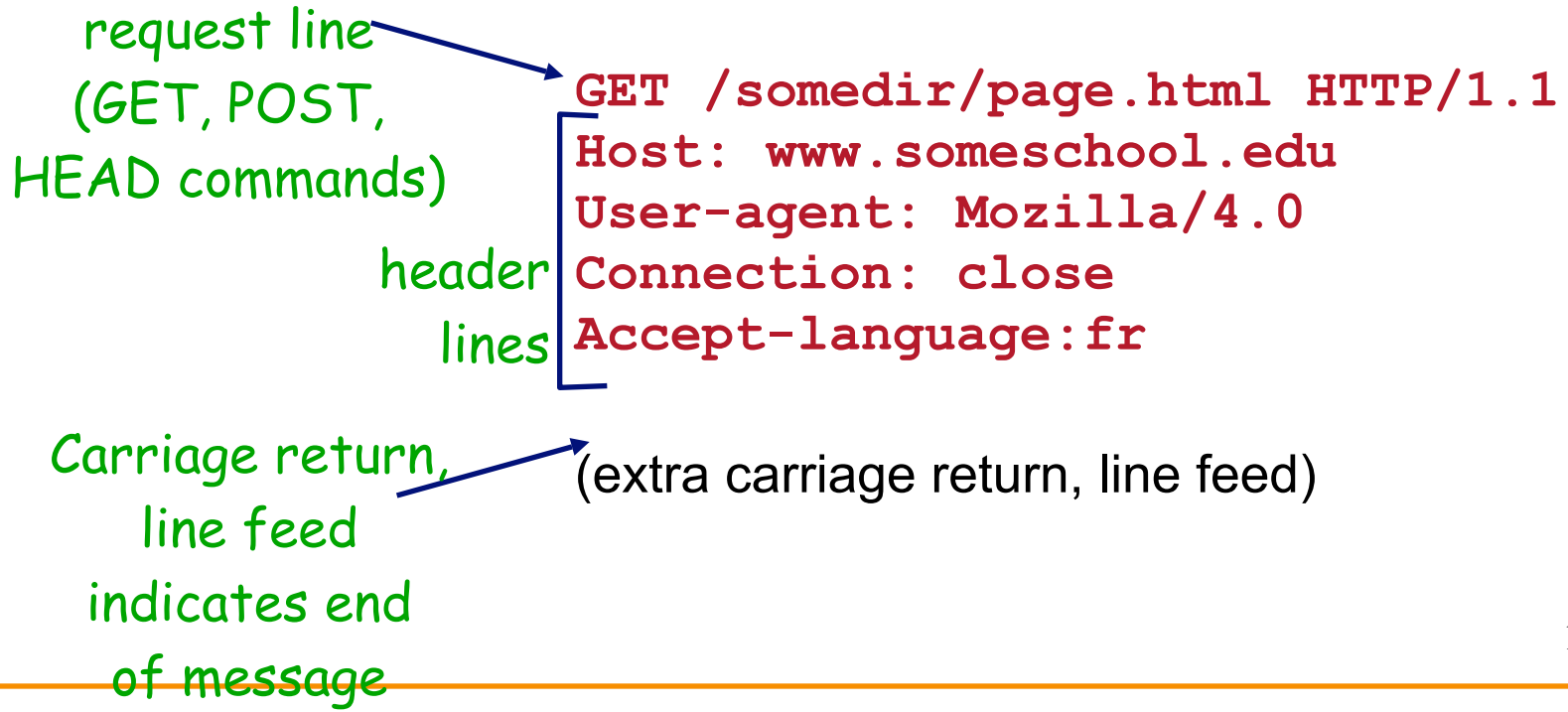
Request

Response

```
HTTP/1.1 200 OK
Date: Mon, 6 Feb 2006 13:09:03 GMT
Server: Netscape-Enterprise/3.5.1
Last-Modified: Mon, 6 Feb  2006 11:12:23 GMT
Content-Length: 21
<CRLF>
Site under construction
```

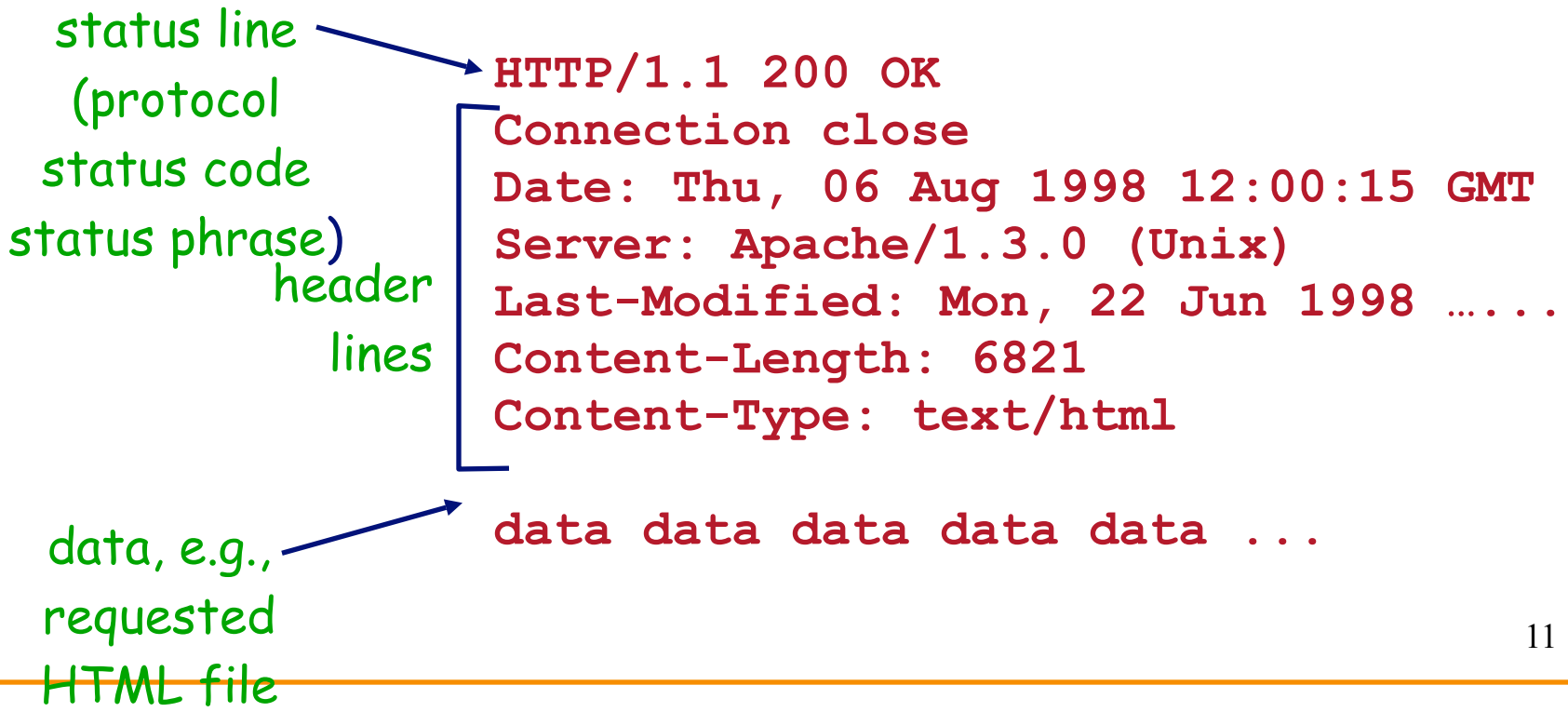
HTTP Request Message

- Request message sent by a client
  - Request line: method, resource, and protocol version
  - Request headers: provide information or request
  - Body: optional data (e.g., to "POST" data to the server)



HTTP Response Message

- Response message sent by a server
  - Status line: protocol version, status code, status phrase
  - Response headers: provide information
  - Body: optional data



HTTP: Request Methods and Response Codes

- Request methods include
  - GET: return current value of resource, …
  - HEAD: return the meta-data associated with a resource
  - POST: update a resource, provide input to a program, …
  - Etc.
- Response code classes
  - 1xx: informational (e.g., “100 Continue”)
  - 2xx: success (e.g., “200 OK”)
  - 3xx: redirection (e.g., “304 Not Modified”)
  - 4xx: client error (e.g., “404 Not Found”)
  - 5xx: server error (e.g., “503 Service Unavailable”)

HTTP is a Stateless Protocol

- Stateless
  - Each request-response exchange treated independently
  - Clients and servers not required to retain state
- Statelessness to improve scalability
  - Avoids need for the server to retain info across requests
  - Enables the server to handle a higher rate of requests

Outline: Web Content Distribution

- Main ingredients of the Web
  - URL, HTML, and HTTP
  - HTTP: the protocol and its stateless property
- Web Systems Components
  - Clients
  - Servers
  - DNS (Domain Name System)
- Interaction with underlying network protocol: TCP
- Scalability and performance enhancement
  - Server farms
  - Web Proxy
  - Content Distribution Network (CDN)

Web Systems Components

- Clients
  - Send requests and receive responses
  - Browsers, spiders, and agents
- Servers
  - Receive requests and send responses
  - Store or generate the responses
- DNS (Domain Name System)
  - Distributed network infrastructure
  - Transforms site name -> IP address
  - Direct clients to servers

Web Browser

- Generating HTTP requests
  - User types URL, clicks a hyperlink, or selects bookmark
  - User clicks “reload”, or “submit” on a Web page
  - Automatic downloading of embedded images
- Layout of response
  - Parsing HTML and rendering the Web page
  - Invoking helper applications (e.g., Acrobat, PowerPoint)
- Maintaining a cache
  - Storing recently-viewed objects
  - Checking that cached objects are fresh

Typical Web Transaction

- User clicks on a hyperlink
  - http://www.cnn.com/index.html
- Browser learns the IP address of the server
  - Invokes gethostbyname(www.cnn.com)
  - And gets a return value of 64.236.16.20
- Browser establishes a TCP connection
  - Selects an ephemeral port for its end of the connection
  - Contacts 64.236.16.20 on port 80
- Browser sends the HTTP request
  - "GET /index.html HTTP/1.1
    Host: www.cnn.com"

Typical Web Transaction (Continued)

- Browser parses the HTTP response message
  - Extract the URL for each embedded image
  - Create new TCP connections and send new requests
  - Render the Web page, including the images
- Opportunities for caching in the browser
  - HTML file
  - Each embedded image
  - IP address of the Web site

Web Systems Components

- Clients
  - Send requests and receive responses
  - Browsers, spiders, and agents
- Servers
  - Receive requests and send responses
  - Store or generate the responses
- DNS (Domain Name System)
  - Distributed network infrastructure
  - Transforms site name -> IP address
  - Direct clients to servers

Web Server

- Web site vs. Web server
  - Web site: collections of Web pages associated with a particular host name
  - Web server: program that satisfies client requests for Web resources
- Handling a client request
  - Accept the TCP connection
  - Read and parse the HTTP request message
  - Translate the URL to a filename
  - Determine whether the request is authorized
  - Generate and transmit the response

Web Server: Generating a Response

- Returning a file
  - URL corresponds to a file (e.g., /www/index.html)
  - … and the server returns the file as the response
  - … along with the HTTP response header
- Returning meta-data with no body
  - Example: client requests object "if-modified-since"
  - Server checks if the object has been modified
  - … and simply returns a "HTTP/1.1 304 Not Modified"
- Dynamically-generated responses
  - URL corresponds to a program the server needs to run
  - Server runs the program and sends the output to client

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: returning the correct content
  - www.foo.com/index.html vs. www.bar.com/index.html
  - How to differentiate when both are on same machine?
- Solution: multiple servers on the same machine
  - Run multiple Web servers on the machine
  - Have a separate IP address for each server

    OR
  - Use the HTML header

Hosting: Multiple Machines Per Site

- Replicating a popular Web site
  - Running on multiple machines to handle the load
  - … and to place content closer to the clients
- Problem: directing client to a particular replica
  - To balance load across the server replicas
  - To pair clients with nearby servers
- Solution:
  - Takes advantage of Domain Name System (DNS)

Web Systems Components

- Clients
  - Send requests and receive responses
  - Browsers, spiders, and agents
- Servers
  - Receive requests and send responses
  - Store or generate the responses
- DNS (Domain Name System) and the Web
  - Distributed network infrastructure
  - Transforms site name -> IP address
  - Direct clients to servers

DNS Query in Web Download

- User types or clicks on a URL
  - E.g., http://www.cnn.com/2006/leadstory.html
- Browser extracts the site name
  - E.g., www.cnn.com
- Browser calls gethostbyname() to learn IP address
  - Triggers resolver code to query the local DNS server
- Eventually, the resolver gets a reply
  - Resolver returns the IP address to the browser
- Then, the browser contacts the Web server
  - Creates and connects socket, and sends HTTP request

Multiple DNS Queries

- Often a Web page has embedded objects
  - E.g., HTML file with embedded images
- Each embedded object has its own URL
  - … and potentially lives on a different Web server
  - E.g., http://www.myimages.com/image1.jpg
- Browser downloads embedded objects
  - Usually done automatically, unless configured otherwise
  - Requires learning the address for www.myimages.com

When are DNS Queries Unnecessary?

- Browser is configured to use a proxy
  - E.g., browser sends all HTTP requests through a proxy
  - Then, the proxy takes care of issuing the DNS request
- Requested Web resource is locally cached
  - E.g., cache has http://www.cnn.com/2006/leadstory.html
  - No need to fetch the resource, so no need to query
- Resulting IP address is locally cached
  - Browser recently visited http://www.cnn.com
  - So, the browser already called *gethostbyname()*
  - … and may be locally caching the resulting IP address

Directing Web Clients to Replicas

- Simple approach: different names
  - www1.cnn.com, www2.cnn.com, www3.cnn.com
  - But, this requires users to select specific replicas
- More elegant approach: different IP addresses
  - Single name (e.g., www.cnn.com), multiple addresses
  - E.g., 64.236.16.20, 64.236.16.52, 64.236.16.84, …
- Authoritative DNS server returns many addresses
  - And the local DNS server selects one address
  - Authoritative server may vary the order of addresses

Clever Load Balancing Schemes

- Selecting the "best" IP address to return
  - Based on server performance
  - Based on geographic proximity
  - Based on network load
  - …
- Example policies
  - Round-robin scheduling to balance server load
  - U.S. queries get one address, Europe another
  - Tracking the current load on each of the replicas

Outline: Web Content Distribution

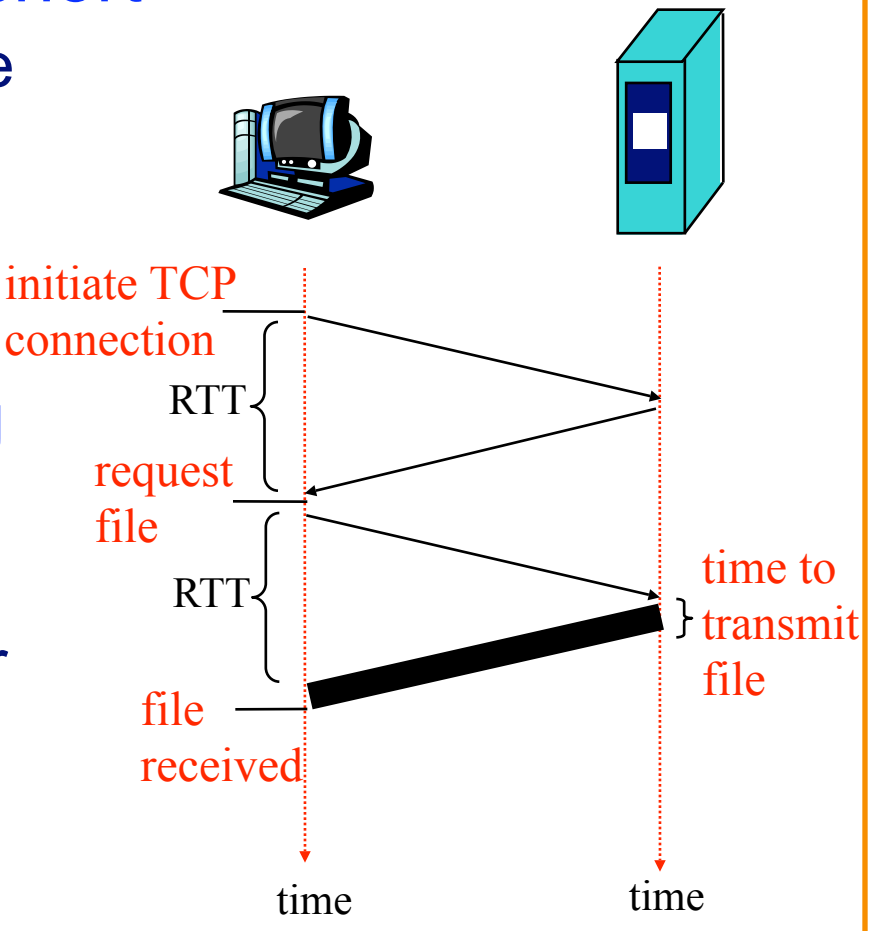
- Main ingredients of the Web
  - URL, HTML, and HTTP
  - HTTP: the protocol and its stateless property
- Web Systems Components
  - Clients
  - Servers
  - DNS (Domain Name System)
- Interaction with underlying network protocol: TCP
- Scalability and performance enhancement
  - Server farms
  - Web Proxy
  - Content Distribution Network (CDN)

TCP Interaction: Multiple Transfers

- Most Web pages have multiple objects
  - E.g., HTML file and multiple embedded images
- Serializing the transfers is not efficient
  - Sending the images one at a time introduces delay
  - Cannot start retrieving second images until first arrives
- Parallel connections
  - Browser opens multiple TCP connections (e.g., 4)
  - … and retrieves a single image on each connection
- Performance trade-offs
  - Multiple downloads sharing the same network links
  - Unfairness to other traffic traversing the links

TCP Interaction: Short Transfers

- Most HTTP transfers are short
  - Very small request message (e.g., a few hundred bytes)
  - Small response message (e.g., a few kilobytes)
- TCP overhead may be big
  - Three-way handshake to establish connection
  - Four-way handshake to tear down the connection



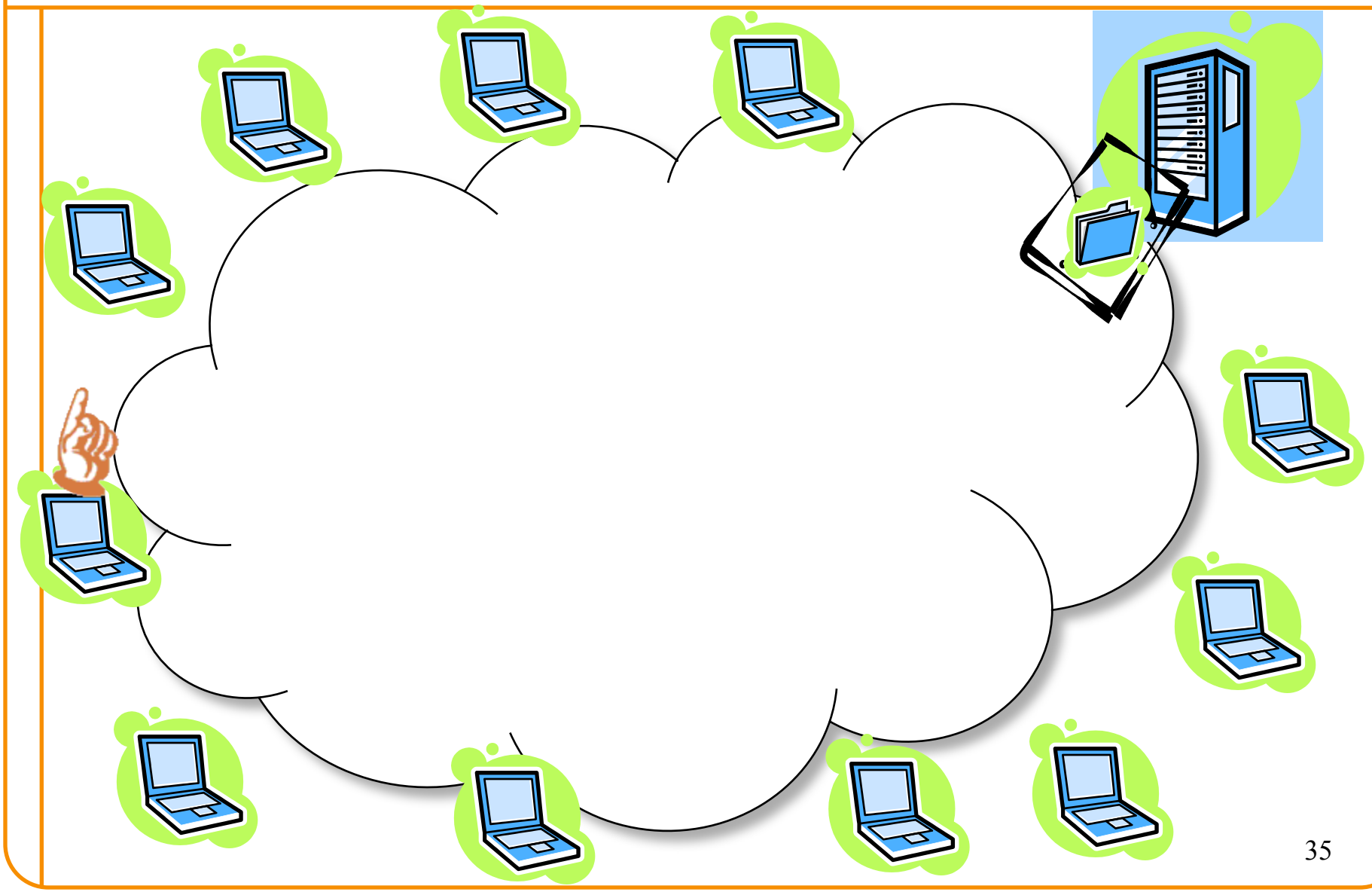
TCP Interaction: Short Transfers

- Round-trip time estimation
  - Maybe large at the start of a connection (e.g., 3 seconds)
  - Leads to latency in detecting lost packets
- Congestion window
  - Small value at beginning of connection (e.g., 1 MSS)
  - May not reach a high value before transfer is done
- Detecting packet loss
  - Timeout: slow ☹
  - duplicate ACK
    - requires many packets in flight
    - which doesn't happen for very short transfers ☹

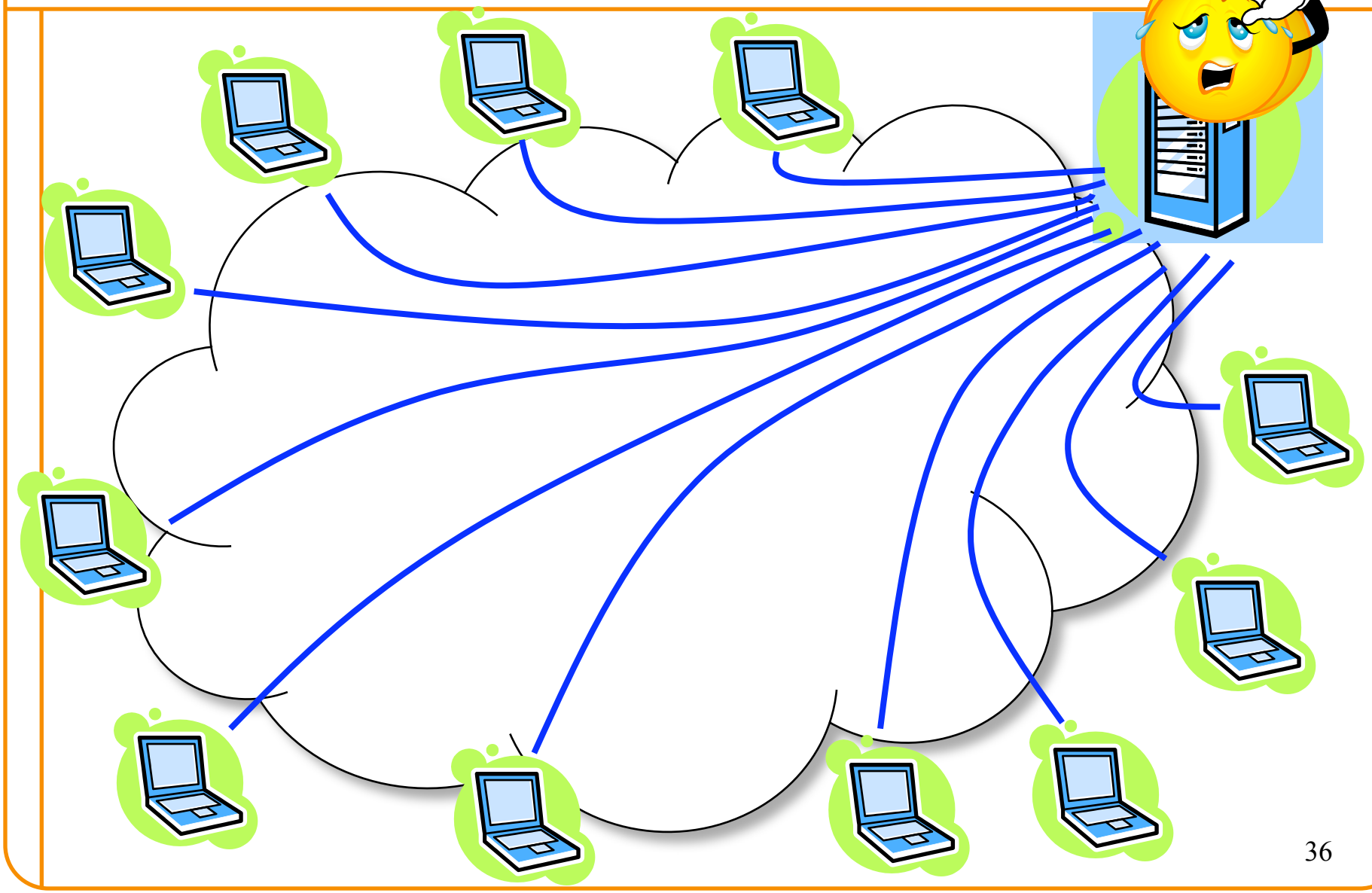
TCP Interaction: Persistent Connections

- Handle multiple transfers per connection
  - Maintain the TCP connection across multiple requests
  - Either the client or server can tear down the connection
  - Added to HTTP after the Web became very popular
- Performance advantages
  - Avoid overhead of connection set-up and tear-down
  - Allow TCP to learn a more accurate RTT estimate
  - Allow the TCP congestion window to increase

Web Content Delivery



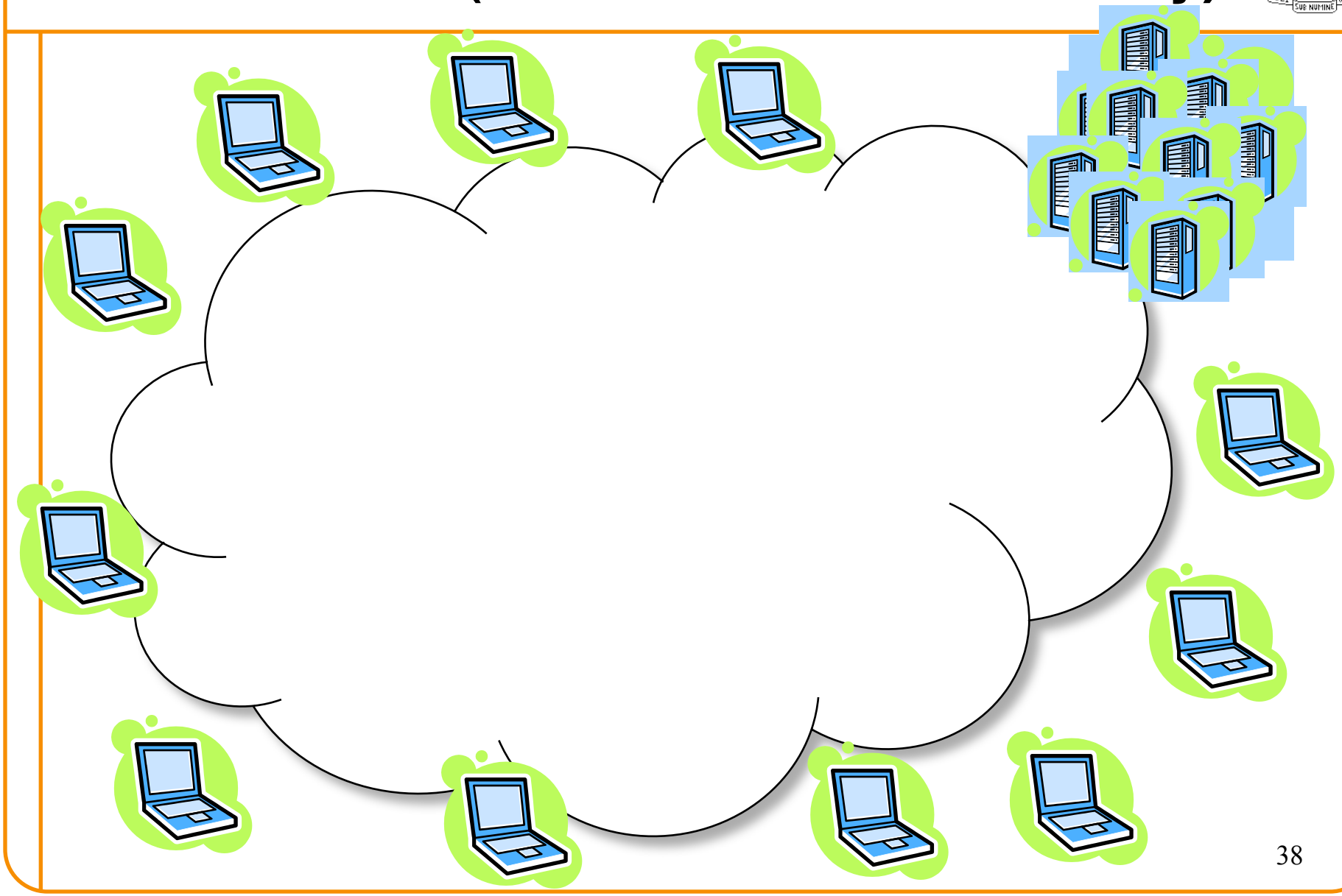
Scalability Limitation



Outline: Web Content Distribution

- Main ingredients of the Web
  - URL, HTML, and HTTP
  - HTTP: the protocol and its stateless property
- Web Systems Components
  - Clients
  - Servers
  - DNS (Domain Name System)
- Interaction with underlying network protocol: TCP
- Scalability and performance enhancement
  - Server farms
  - Proxy
  - Content Distribution Network (CDN)

Server Farms (motivated for scalability)



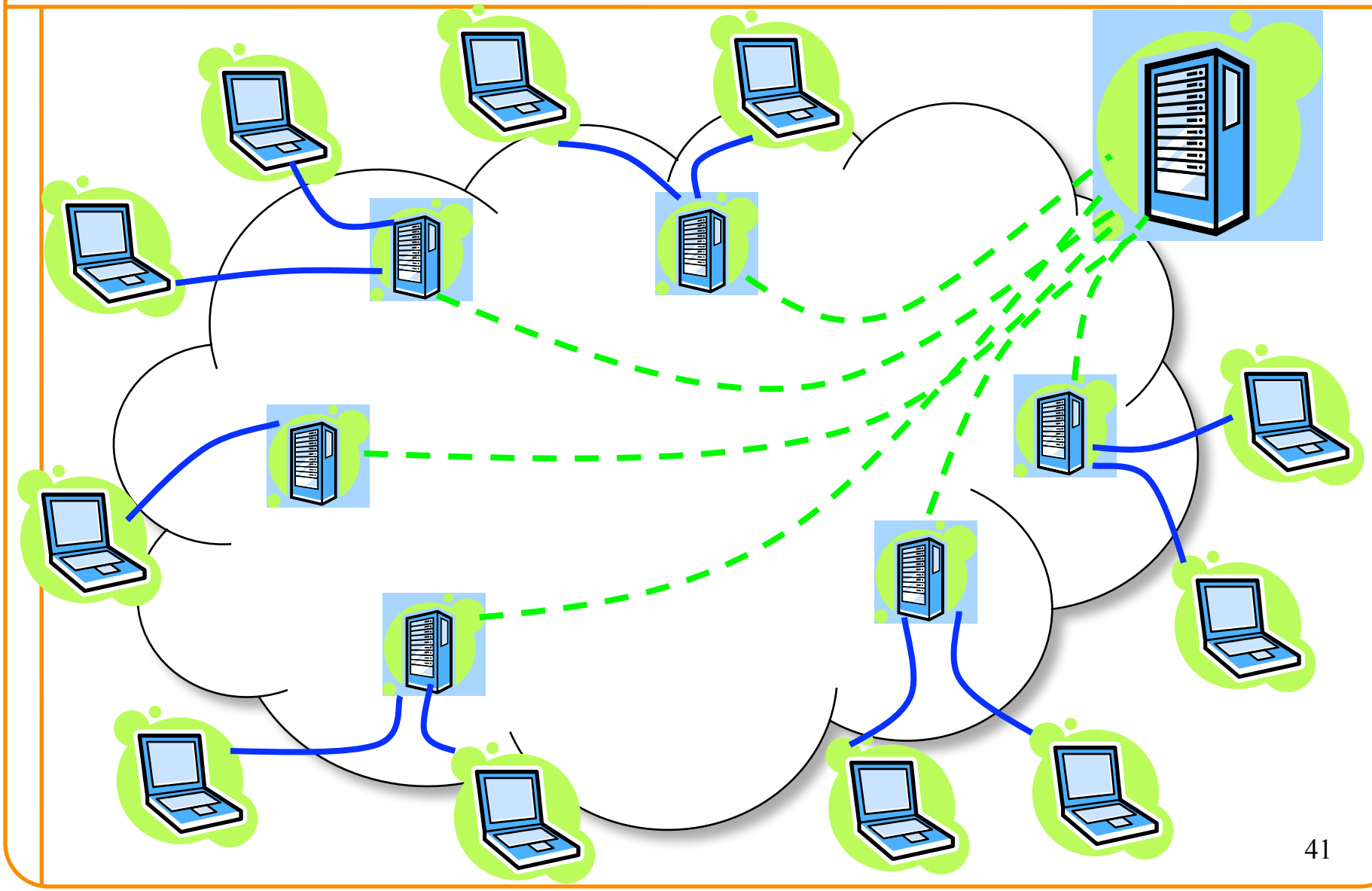
Server Farms

- Definition
  - a collection of computer servers to accomplish server needs far beyond the capacity of one machine.
  - Often have both a primary and backup server allocated to a single task (for fault tolerance)
- Web Farms
  - Common use of server farms is for web hosting

Outline: Web Content Distribution

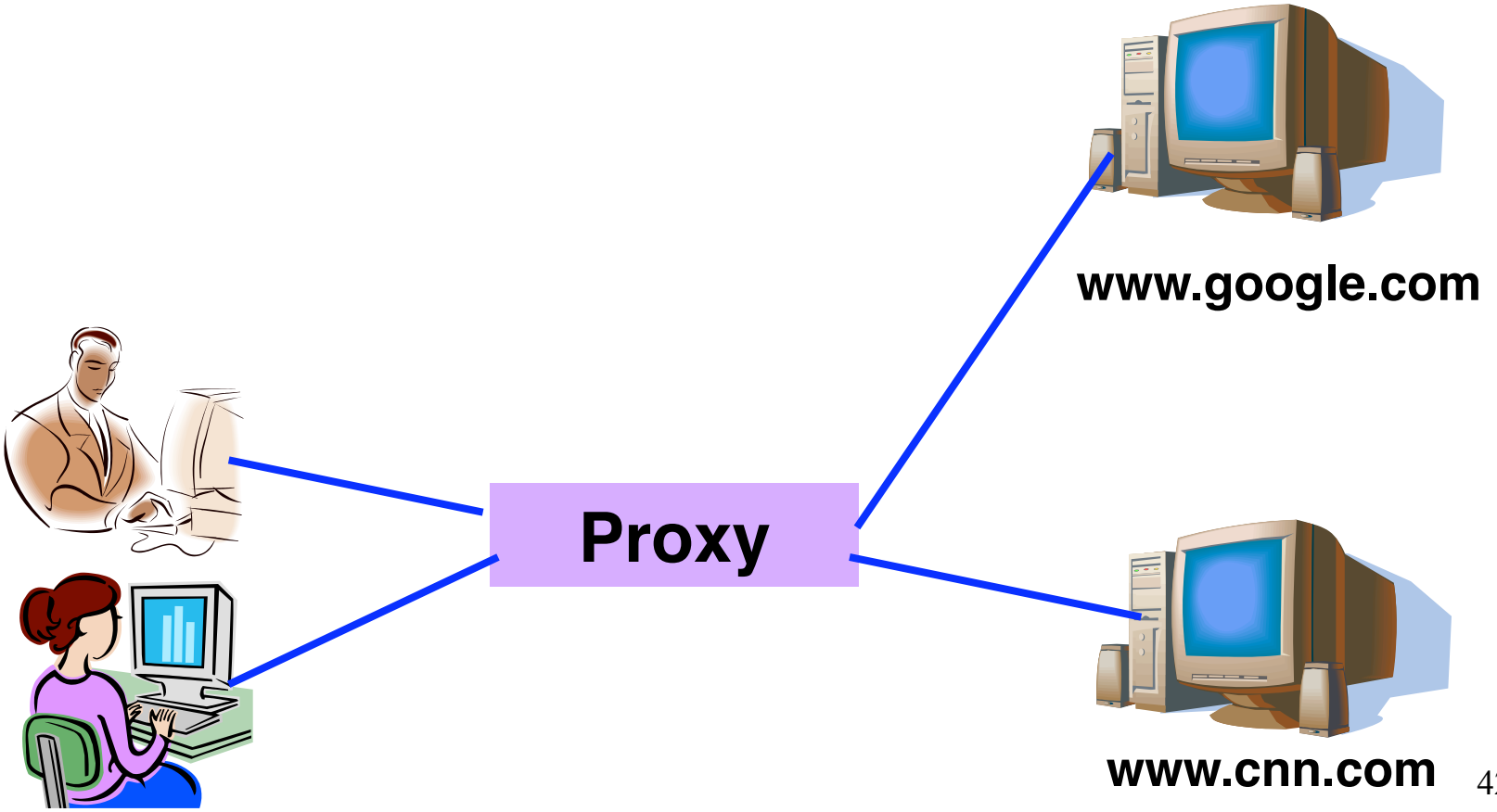
- Main ingredients of the Web
  - URL, HTML, and HTTP
  - HTTP: the protocol and its stateless property
- Web Systems Components
  - Clients
  - Servers
  - DNS (Domain Name System)
- Interaction with underlying network protocol: TCP
- Scalability and performance enhancement
  - Server farms
  - Web Proxy
  - Content Distribution Network (CDN)

Web Proxies



Web Proxies are Intermediaries

- Proxies play both roles
  - A server to the client
  - A client to the server



Proxy Caching

- Client #1 requests http://www.foo.com/fun.jpg
  - Client sends “GET fun.jpg” to the proxy
  - Proxy sends “GET fun.jpg” to the server
  - Server sends response to the proxy
  - Proxy stores the response, and forwards to client
- Client #2 requests http://www.foo.com/fun.jpg
  - Client sends “GET fun.jpg” to the proxy
  - Proxy sends response to the client from the cache
- Benefits
  - Faster response time to the clients
  - Lower load on the Web server
  - Reduced bandwidth consumption inside the network

Getting Requests to the Proxy

- Explicit configuration
  - Browser configured to use a proxy
  - Directs all requests through the proxy
  - Problem: requires user action
- Transparent proxy (or “interception proxy”)
  - Proxy lies in path from the client to the servers
  - Proxy intercepts packets en route to the server
  - … and interposes itself in the data transfer
  - Benefit: does not require user action

Other Functions of Web Proxies

- Anonymization
  - Server sees requests coming from the proxy address
  - … rather than the individual user IP addresses
- Transcoding
  - Converting data from one form to another
  - E.g., reducing the size of images for cell-phone browsers
- Prefetching
  - Requesting content before the user asks for it
- Filtering
  - Blocking access to sites, based on URL or content

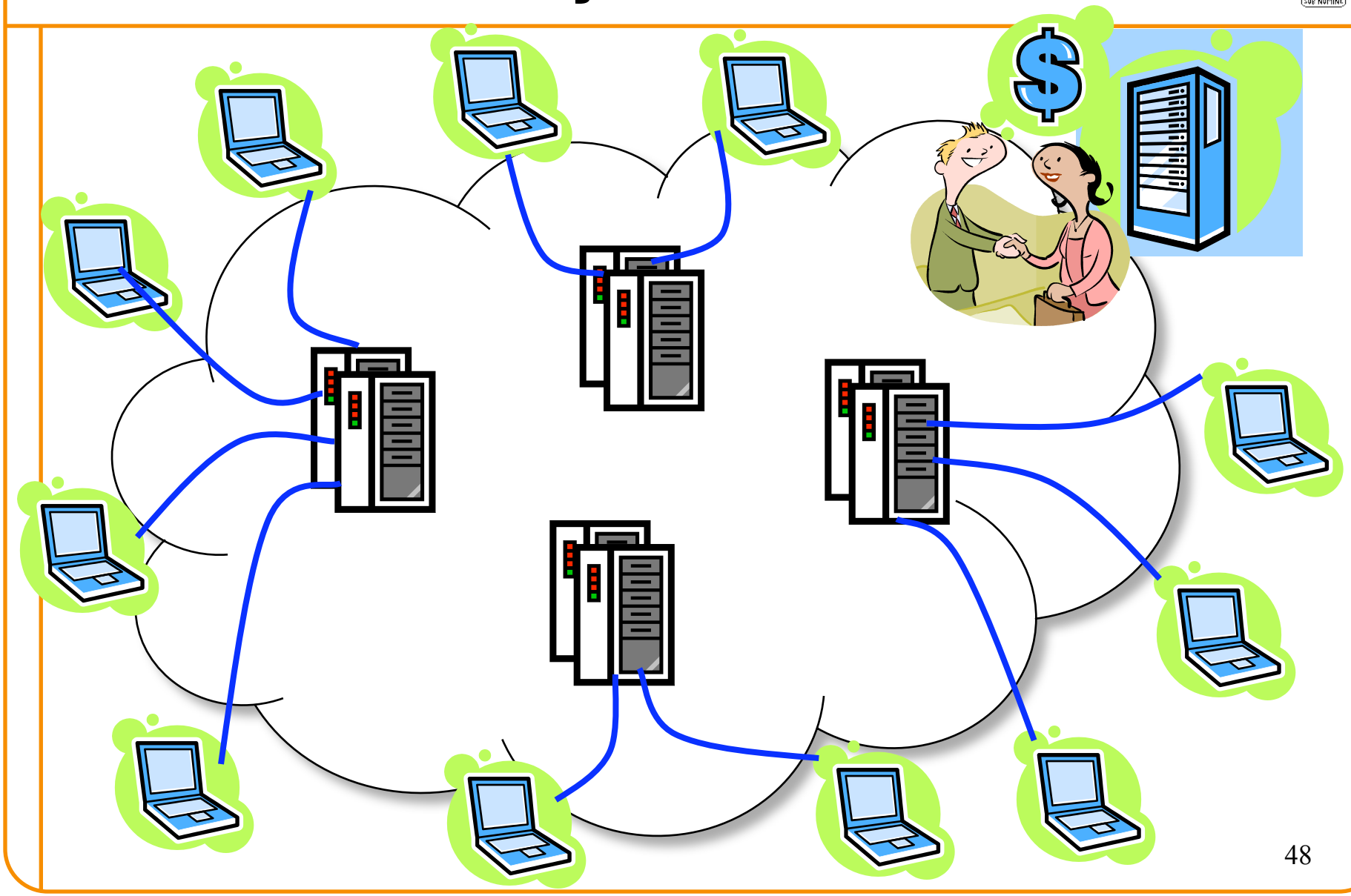
Outline: Web Content Distribution

- Main ingredients of the Web
  - URL, HTML, and HTTP
  - HTTP: the protocol and its stateless property
- Web Systems Components
  - Clients
  - Servers
  - DNS (Domain Name System)
- Interaction with underlying network protocol: TCP
- Scalability and performance enhancement
  - Server farms
  - Web Proxy
  - Content Distribution Network (CDN)

Motivation for CDN

- Providers want to offer content to consumers
  - Efficiently
  - Reliably
  - Securely
  - Inexpensively
- The server and its link can be overloaded
- Peering points between ISPs can be congested
- Alternative solution: Content Distribution Networks
  - Geographically diverse servers serving content from many sources

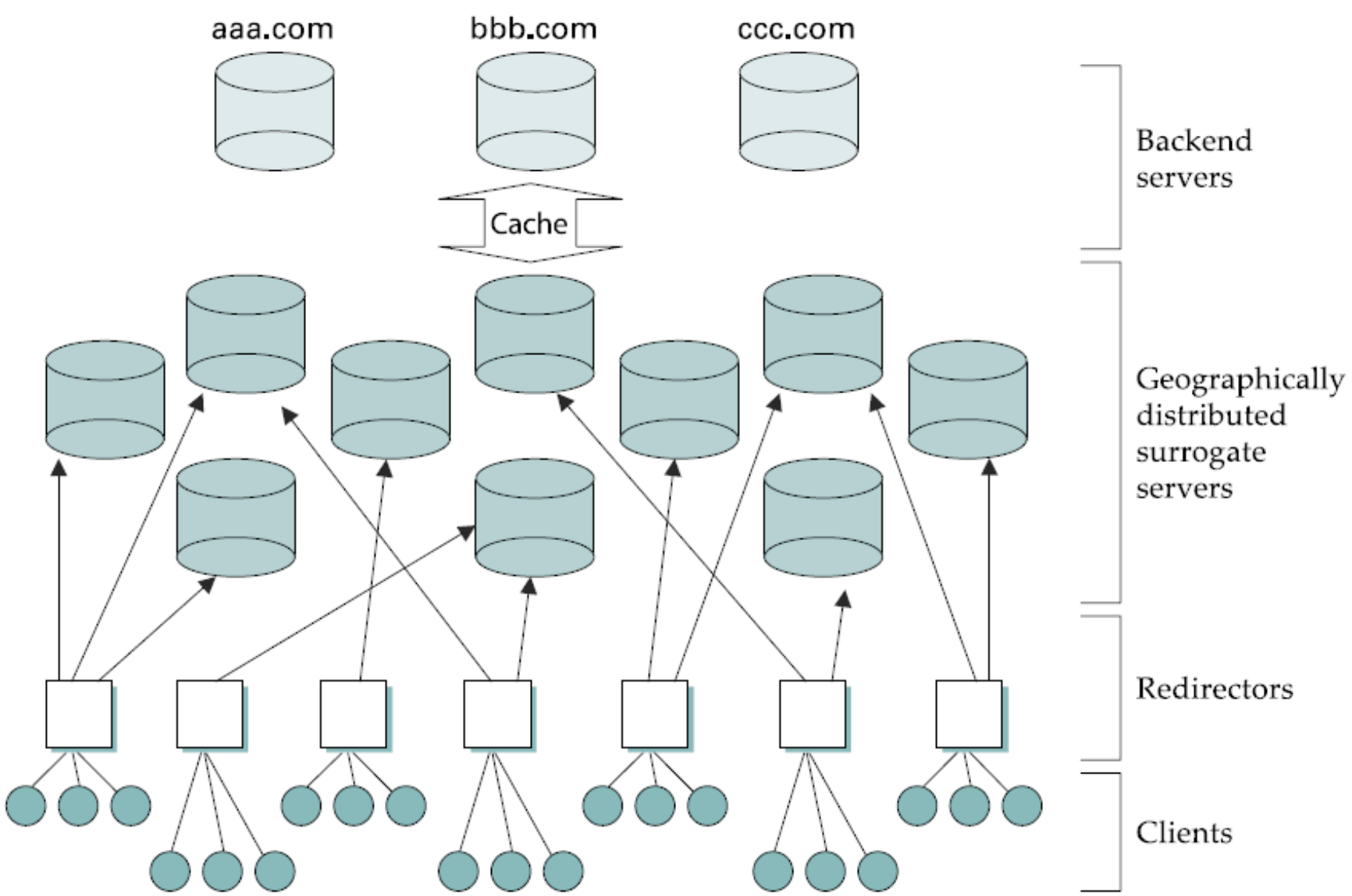
Content Delivery Networks



CDN Architecture

- Proactively replicate data by caching static pages
- Architecture
  - Backend servers
  - Geographically distributed surrogate servers
  - Redirectors (according to network proximity, balancing)
  - Clients
- Redirector Mechanisms
  - Augment DNS to return different server addresses
  - Server-based redirection: based on HTTP redirect feature

CDN Architecture



Summary: Web Content Distribution

- Protocols and Standards
  - URL, HTML, and HTTP
  - HTTP Interaction with underlying network protocol: TCP
- Systems Components: Client/Server
- Web interaction with DNS infrastructure
- Scalability and performance enhancement
  - Server farms: replication
  - Web Proxy: indirection
  - Content Distribution Network (CDN): indirection and replication
- Next Lecture on Translating Addresses
  - DNS, DHCP, and ARP