8. Distributed Web-based Systems

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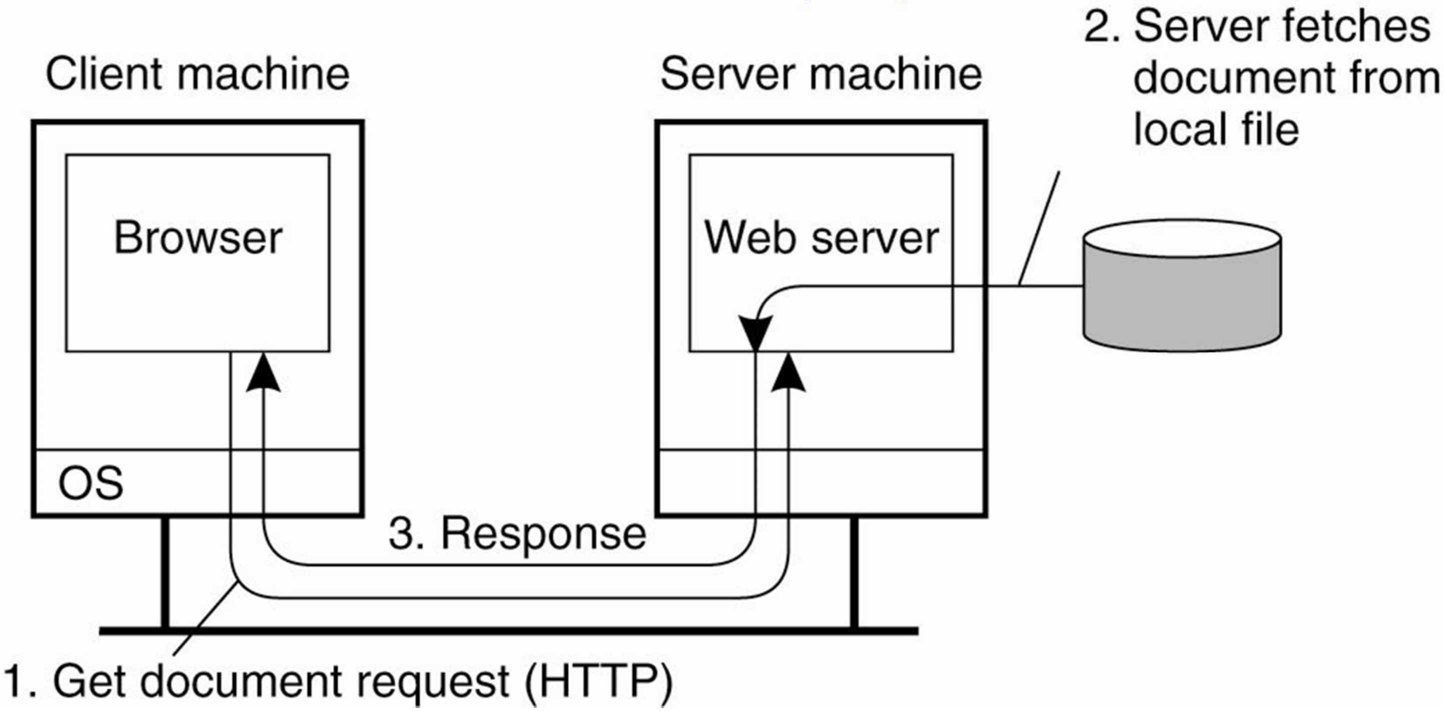
Contents

- **Architecture**
- Communication
- Naming
- Synchronization
- Consistency & replication
- Fault tolerance

Traditional Web-based systems

- The WWW is a huge client-server distributed system with millions of clients and servers
  - Server: host hyperlinked docs, run commands
  - Browser: retrieve and display docs

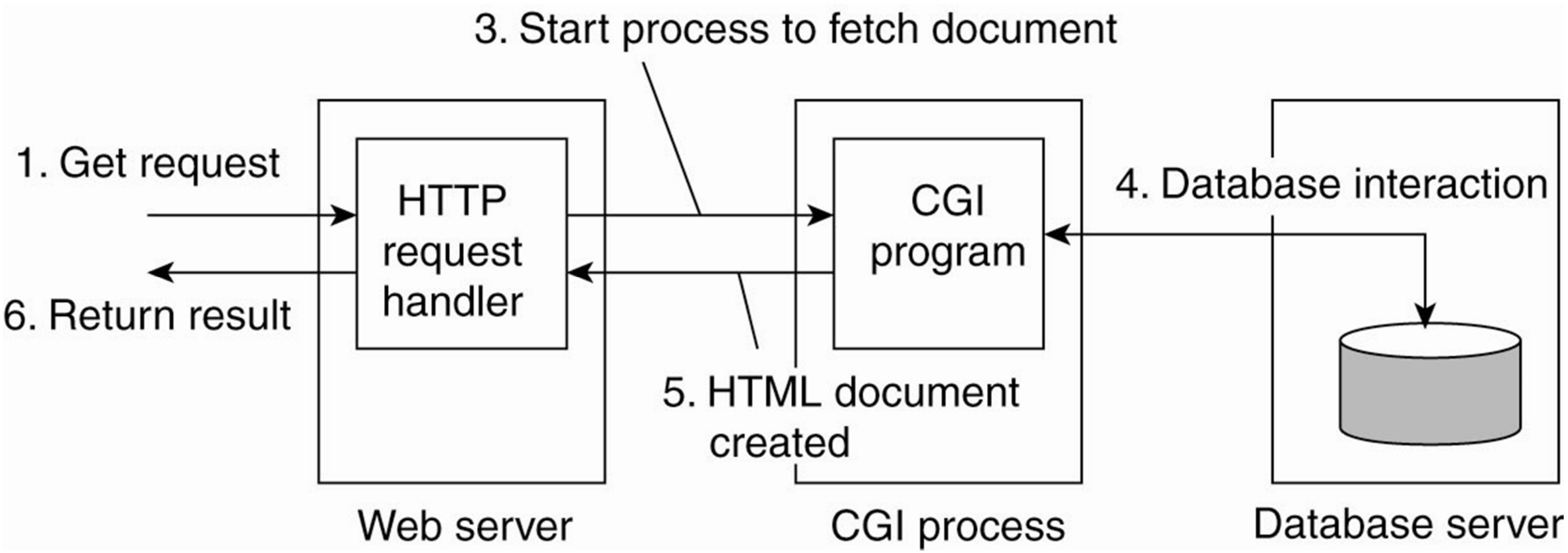


Traditional Web-based systems

- Documents can be:
  - Plain text
  - HTML: HyperText Markup Language
    - Most common
    - Allows embedding of links to other documents
  - XML: Extensible Markup Language
    - More flexible (i.e. it contains the names, types and structure of the data elements within it)
  - Images, Audio, Video
  - Applications (e.g. PDF, PS)
- Can include <u>scripts</u> that execute in the client

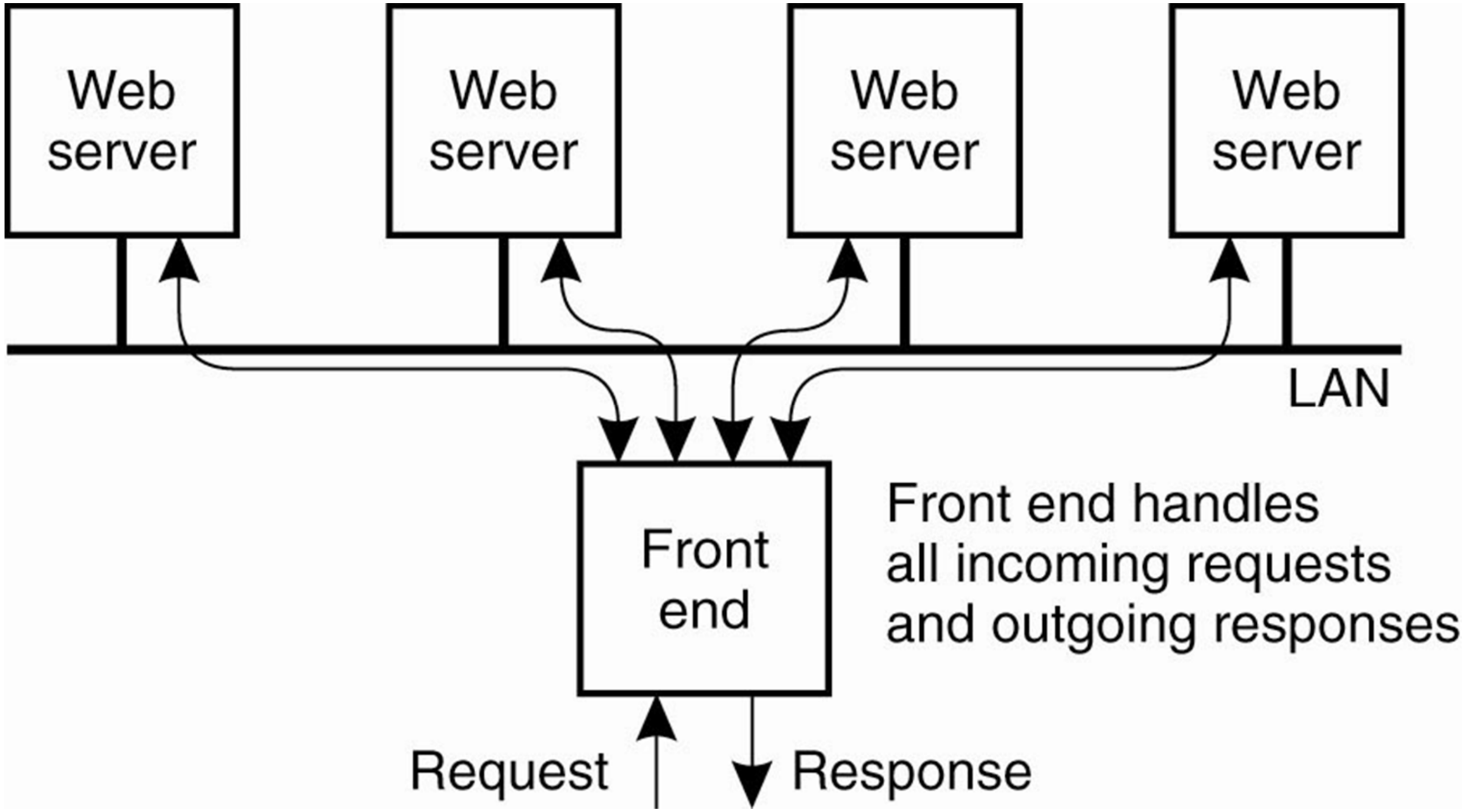
Multitiered architectures

- Common Gateway Interface (CGI)
  - Server runs a program taking user data as input
  - CGIs evolved to **servlets** and **JSPs**
- This has lead to <u>three-tiered architectures</u>



Web server clusters

- Web servers can be clustered <u>transparently</u> to clients, improving performance & availability



Web server clusters

- The front end (a.k.a. Web switch) may get overloaded, so it must be carefully designed
- Various mechanisms impact its performance:

1. **Request routing**
   - Mechanisms to route incoming client requests to their selected target Web server
2. **Request dispatching**
   - Policies to select the Web server that is considered best suited to serve each client's request

Request routing

- Two architectures depending on the data flow between the client and the target server

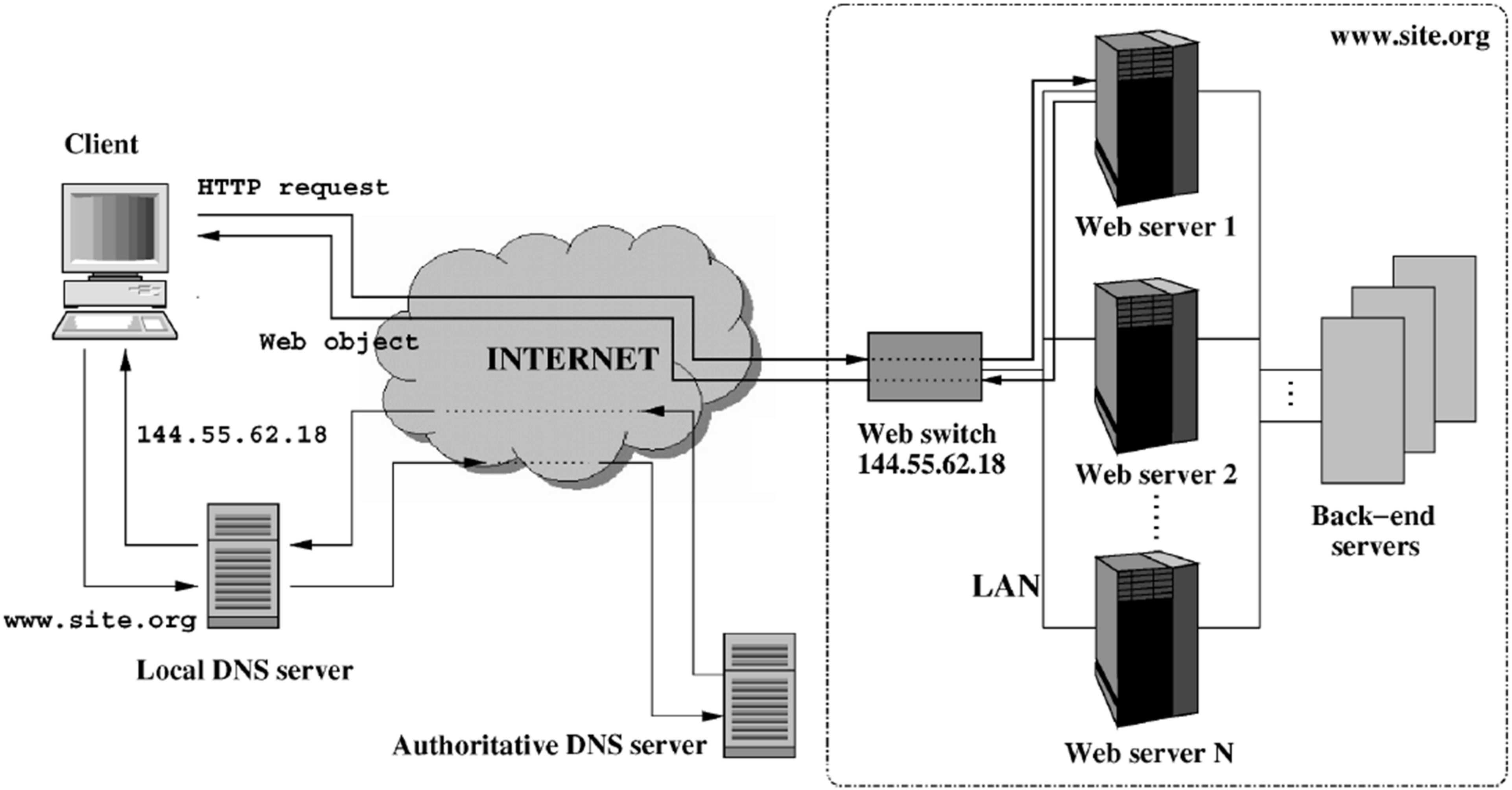
A. Two-way architecture

- – Both incoming requests and outgoing responses flow through the Web switch
- ↑ Simpler to implement

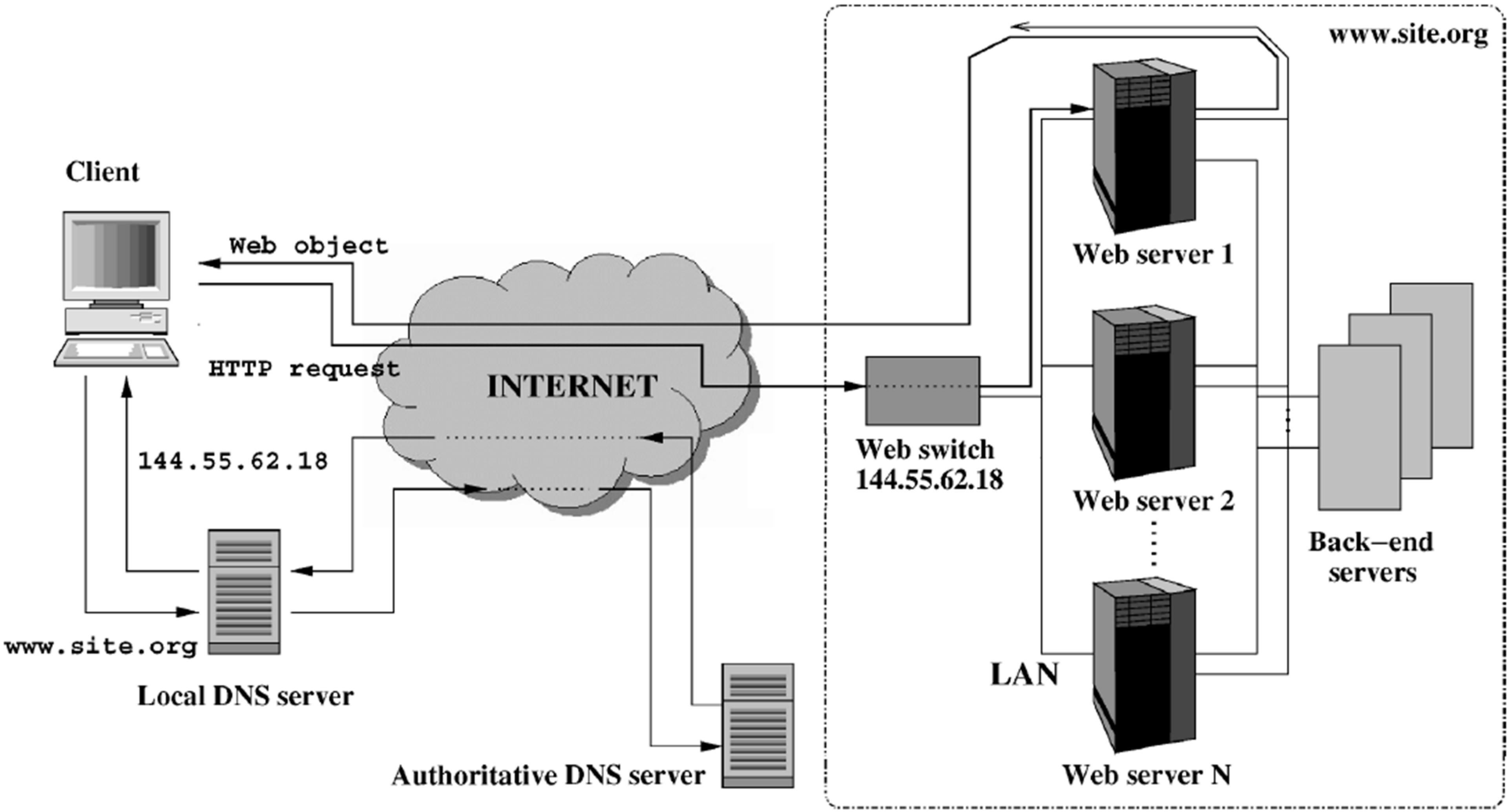
B. One-way architecture

- – Only incoming requests flow through the switch
- – The target server responds directly to the client
- ↑ More efficient

Two-way architecture

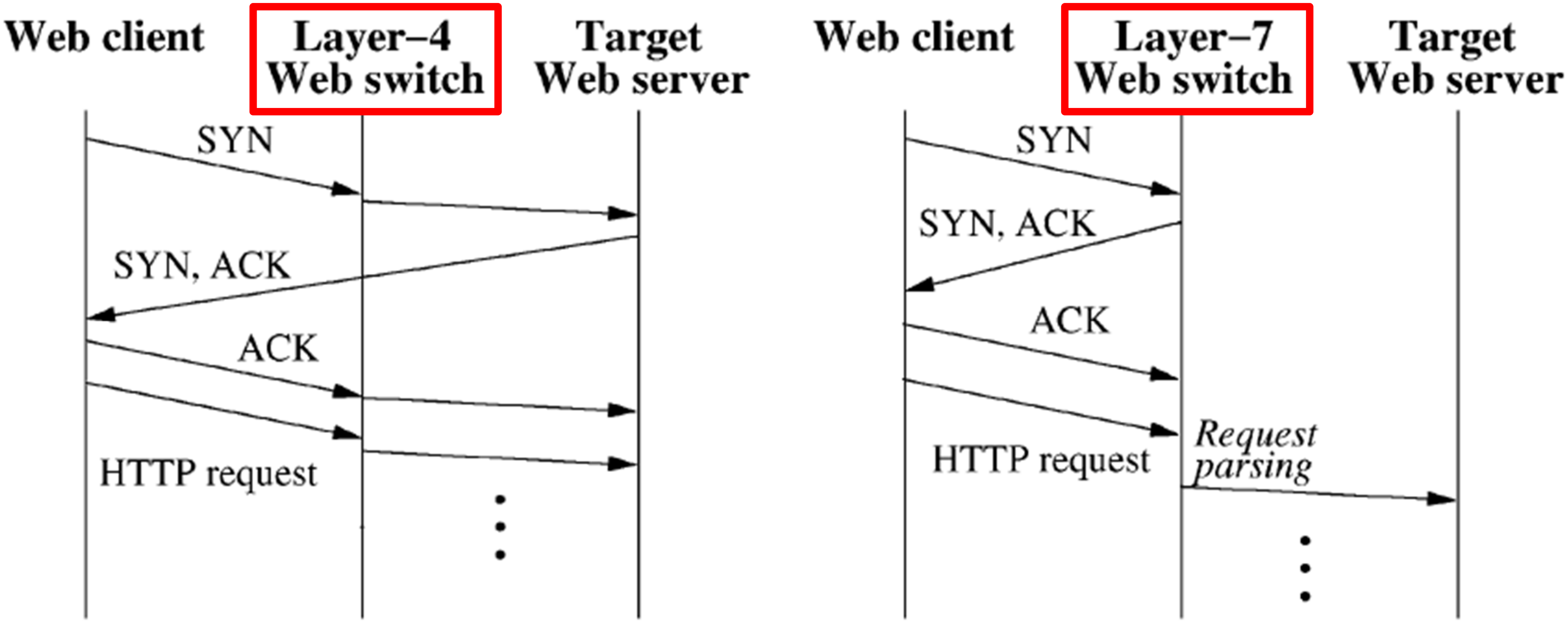


One-way architecture



Request routing

- Two types of switches depending on the OSI protocol stack layer at which the Web switch routes inbound packets to the target server



Layer-4 request routing

a) Packet rewriting
   - Switch (or target server) rewrites the destination / source addresses of inbound / outbound packets with the IP of the target server / web switch

b) Packet tunneling
   - Switch tunnels inbound packets to target server by encapsulating them within other IP packets

c) Packet forwarding
   - Switch forwards inbound packets to the target server through its MAC address (all nodes share now the same IP address)

Layer-7 request routing

a) TCP gateway
   – Switch runs a proxy at the application layer that mediates between the client and the target server

b) TCP splicing
   – Switch runs a proxy at the network layer that splices together the client-switch and the switch-server TCP connections

c) TCP hand-off
   – Switch hands off its TCP connection with the client to the target server, which uses it to communicate directly with the client

Request dispatching

- Request routing has also a big impact on dispatching policies due to the kind of information available at the Web switch

A. Content-blind dispatching (Layer-4 routing)
   - ↑ Efficient
   - ↓ Simple policies

B. Content-aware dispatching (Layer-7 routing)
   - ↑ Sophisticated policies: better profit of caching, better load sharing
   - ↓ Less efficient: higher demand on the front end

Content-blind request dispatching

A. Static algorithms
   - Do not consider any state information
     - Efficient & easy to implement (↑) but naïve decisions (↓)
   - e.g. Random and Round-Robin algorithms

B. Dynamic algorithms
   - Consider client and/or server state information
     - Better decisions (↑) but overhead to collect state (↓)
   - e.g. Least Loaded: assign request to the server with the fewest active connections
   - e.g. Client Affinity: assign consecutive requests from the same client to the same server

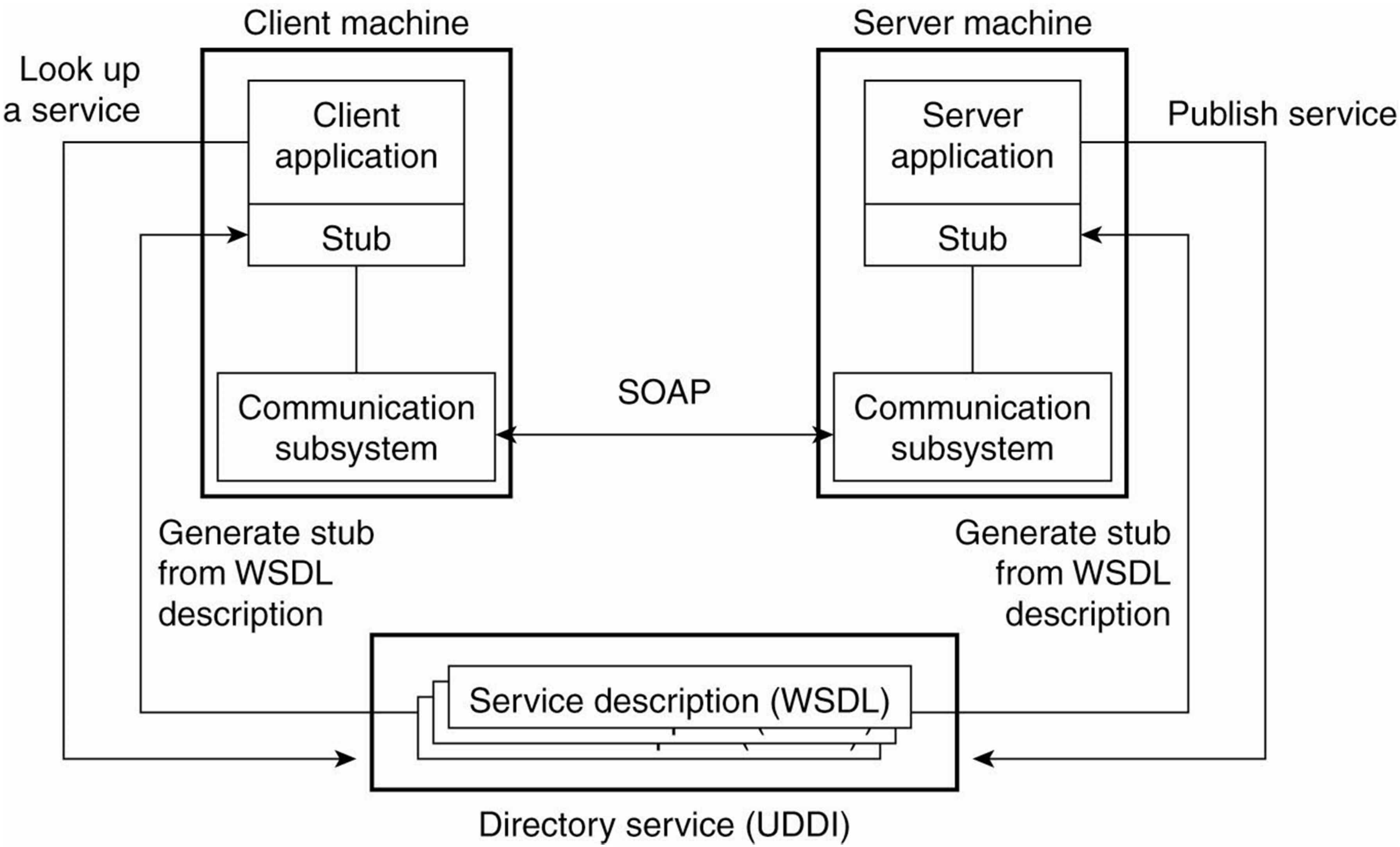
Content-aware request dispatching

A. Dynamic algorithms
   - Consider client and/or server state information
   - e.g. Cache Affinity: partition data among servers and assign clients based on the data they access
   - e.g. Load Sharing: assign clients to balance load among servers (based on the size of requested file or the expected impact on the server resources)
   - e.g. employ specialized servers for certain type of requests (e.g. multimedia, streaming)
   - e.g. Client Affinity: avoid the limitations of the IP address identification by using individual client identifiers, such as cookies and SSL identifiers

Web Services

- Go beyond simple user-site interaction and offer **services** to remote applications
  - Communication using <u>Internet standards</u>
- Web Services components
  - A standard way for communication (SOAP)
  - A uniform data representation and exchange mechanism (XML)
  - A standard meta language to describe the services offered (WSDL)
  - A mechanism to register and locate WS-based applications (UDDI)

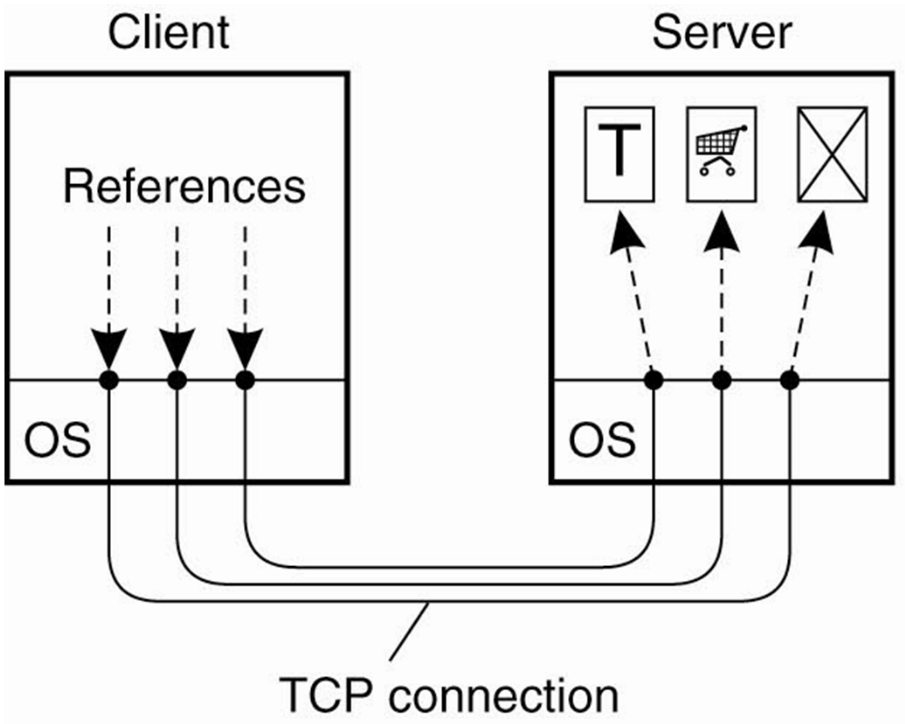
Web Services



Contents

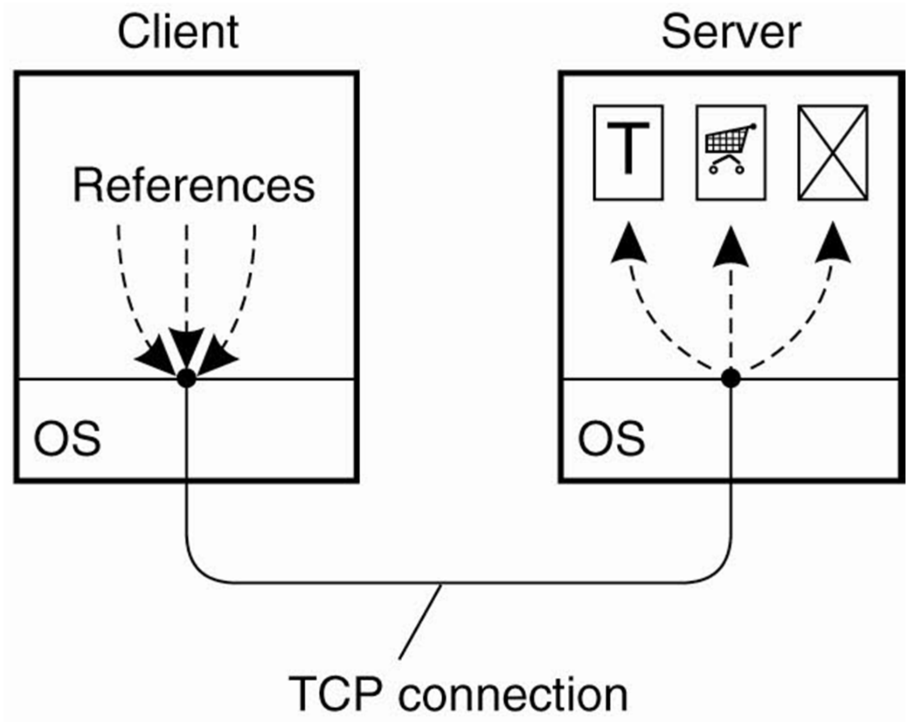
HyperText Transfer Protocol (HTTP)

- Simple client-server transfer protocol for communication in traditional web systems
- One resource per HTTP request
- Based on TCP
- HTTP v1.0 uses **non-persistent** connections
  - Each request needs setting up a separate TCP connection



HyperText Transfer Protocol (HTTP)

- HTTP v1.1 uses **persistent** connections
  - Same TCP connection can be used to issue several requests



- **Pipelining**: Client can also issue several requests in a row without waiting the response for the first

HyperText Transfer Protocol (HTTP)

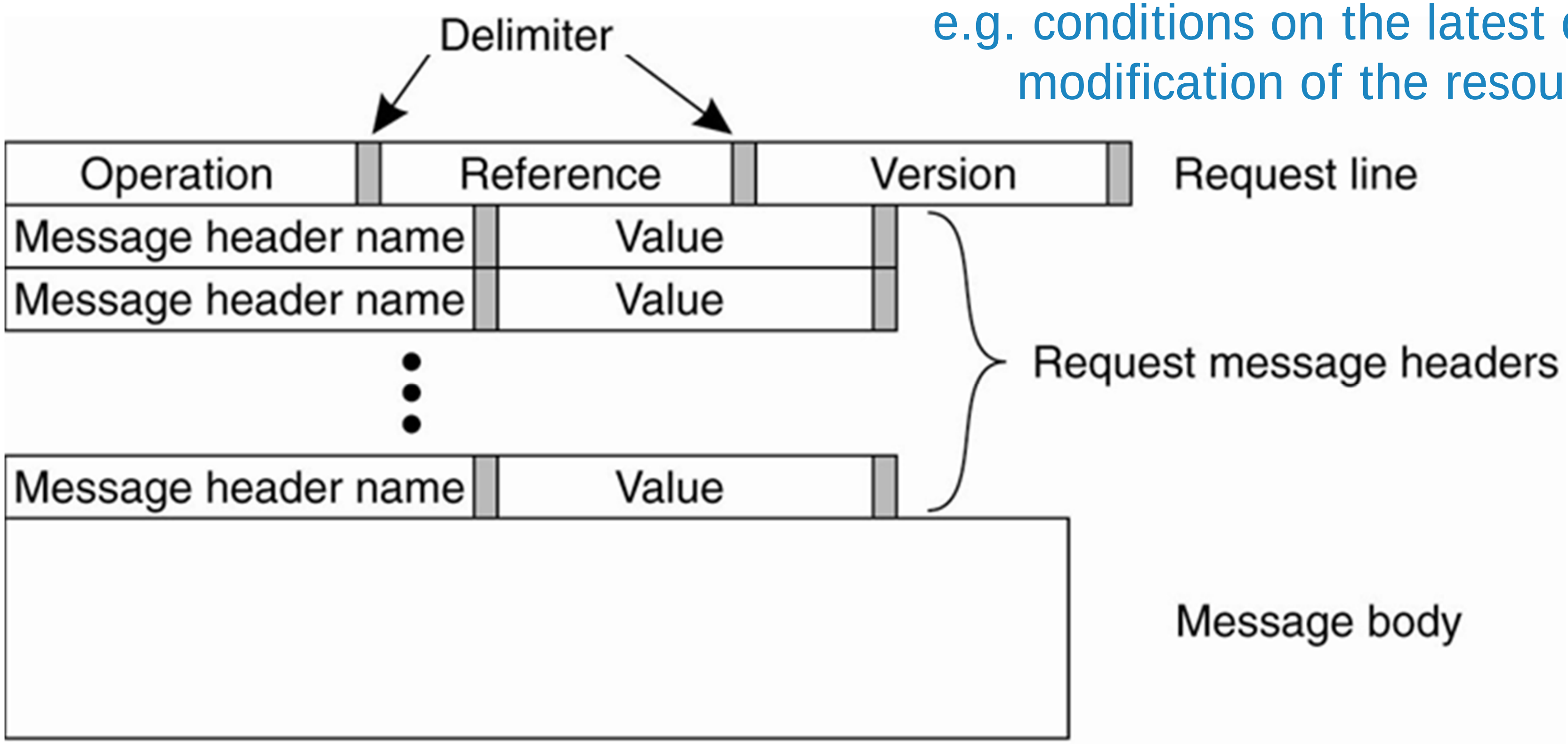
- Operations supported by HTTP

Operation	**Description**
Head	Request to return the header of a resource
Get	Request to return a resource to the client. Can be a document or the output of a program execution
Put	Request to store data as a resource
Post	Provide data that are to be handled by a resource
Delete	Request to delete a resource

HyperText Transfer Protocol (HTTP)

- HTTP request message
  - Request message headers:

e.g. acceptable content types
e.g. acceptable document encoding
e.g. list of client's credentials
e.g. conditions on the latest date of modification of the resource

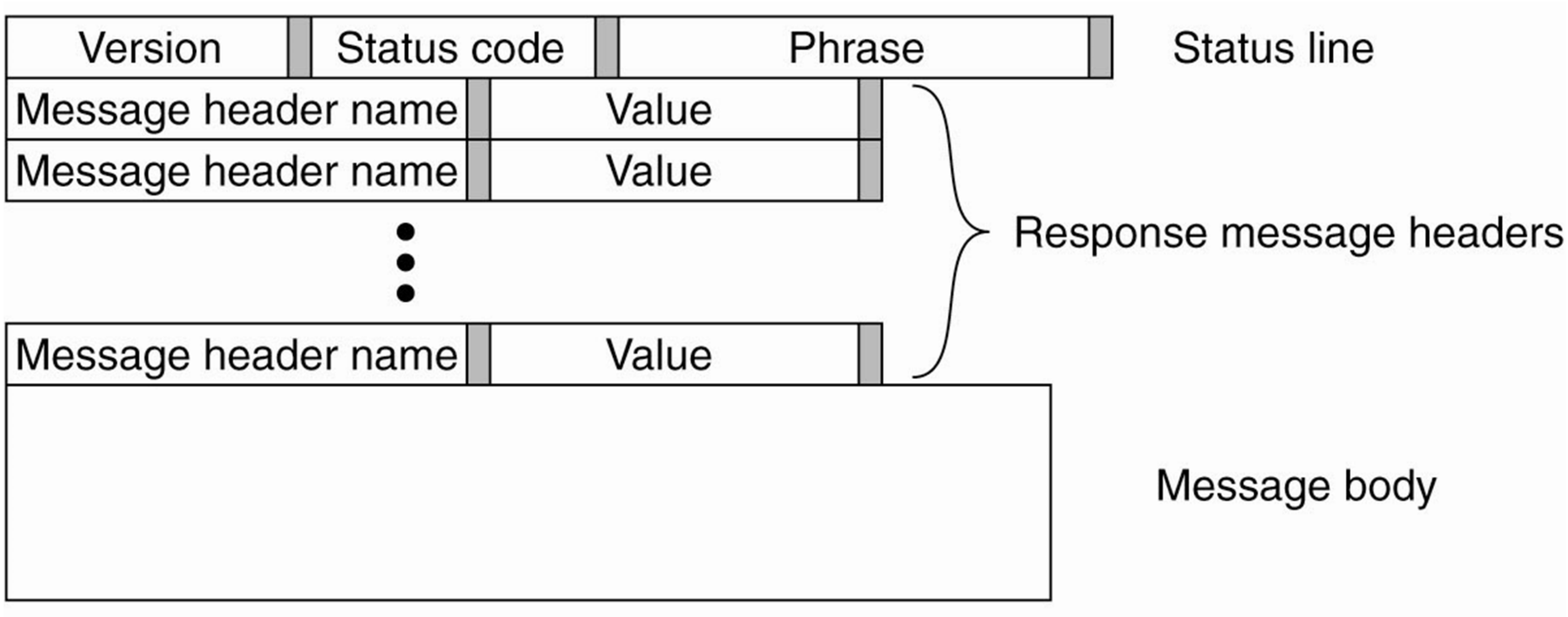


GET	http://www.dcs.qmul.ac.uk/index.html	HTTP/ 1.1		

HyperText Transfer Protocol (HTTP)

- HTTP response message
  - Response message headers:

e.g. time of last modification
e.g. response's expiration time
e.g. URL to redirect request



HTTP/1.1	200	OK		resource data

Simple Object Access Protocol

- SOAP is the standard protocol for communication between Web services
- Based on XML (extends XML-RPC)
  - ↑ XML allows self-describing data (portable)
  - ↓ Parsing overhead
  - ↓ Not meant to be read by human beings
- SOAP is platform independent, but bound to an underlying transfer protocol (a.k.a. carrier)
  - – Currently HTTP, SMTP
  - – Transfer protocol specifies the recipient's address

Simple Object Access Protocol

- SOAP message consists of two elements which are jointly put inside an Envelope
  1. Header (optional) contains information relevant for nodes along the path from sender to receiver
     - e.g. routing, authentication, transactions
  2. Body (mandatory) contains the actual message
- SOAP offers 2 different styles of interactions
  1. Document-style: Conversational mode of XML message exchange (placed directly in the body)
  2. RPC-style: XML representation of a method invocation-response

SOAP example: Request

```
GET /StockPrice HTTP/1.1
Host: www.stockquote.com
Content-Type: application/soap+xml; charset=utf-8
Content-Length: nnn
```

URI of XML schema for SOAP envelopes

URI of XML schema for the service description

```
<?xml version="1.0"?>
<env:Envelope xmlns:env="http://www.w3.org/2003/05/soap-envelope"
   xmlns:s="http://example.org/quotes">
   <env:Body>
     <s:GetStockQuote>
          <s:TickerSymbol>IBM</s:TickerSymbol>
     </s:GetStockQuote>
   </env:Body>
</env:Envelope>
```

SOAP example: Response

```
HTTP/1.1 200 OK
Content-Type: application/soap+xml; charset=utf-8
Content-Length: nnn
```

URI of XML schema for SOAP envelopes

URI of XML schema for the service description

```
<?xml version="1.0"?>
<env:Envelope xmlns:env="http://www.w3.org/2003/05/soap-envelope"
   xmlns:s="http://example.org/quotes">
   <env:Body>
     <s:GetStockQuoteResponse>
          <s:StockPrice>45.25</s:StockPrice>
     </s:GetStockQuoteResponse>
   </env:Body>
</env:Envelope>
```

Representative State Transfer

- RESTful Web Services
  - Simpler approach where clients use URLs and HTTP operations (GET, PUT, DELETE, POST) to manipulate resources represented in XML/JSON

```
GET /StockPrice/IBM HTTP/1.1
Host: www.stockquote.com
Accept: text/xml
Accept-Charset: utf-8
```

```
HTTP/1.1 200 OK
Content-Type: text/xml; charset=utf-8
Content-Length: nnn
<?xml version="1.0"?>
<s:Quote xmlns:s="http://example.org/quotes">
     <s:TickerSymbol>IBM</s:TickerSymbol>
     <s:StockPrice>45.25</s:StockPrice>
</s:Quote>
```

SOAP vs. REST WS

- Communication protocol
- Language, platform, and transport agnostic
- Usable in distributed computing environments
- Better support from other standards (WSDL, WS-*) and tooling from vendors
- Built-in error handling
- Extensible
- More "heavy-weight"
- Conceptually complex, harder to develop

- Architectural style
- Language and platform agnostic, but tied to the HTTP transport layer
- Only point-to-point communication: no intermediaries
- Lack of standards support
- Concise, simpler to develop, small learning curve
- Closer in design and philosophy to the Web

Web Services Description Language

- WSDL is a formal language for describing precisely the service provided by a WS
  a) Interfaces of operations, data types, message exchange patterns
  b) Binding: choice of protocols: e.g. SOAP/HTTP
  c) Endpoint of the service: e.g. URI
- Based on XML
- Can be automatically translated to client and server stubs
- Analogous to IDL in RPCs

Contents

Naming

- Documents referred by URIs
- Two forms of Uniform Resource Identifiers:

a) URN: Uniform Resource Name
   - Globally unique, location independent, and persistent reference to a document
   - e.g. urn:ietf:rfc:3187

b) URL: Uniform Resource Locator
   - Includes information on **how** and **where** to access the document (it is location dependent)
   - e.g. http://tools.ietf.org/html/rfc3187.html

Naming

- URL contents
  - Scheme: Application-level protocol for transferring the document (e.g. http, ftp)
  - DNS name/IP address of server
  - Pathname of the resource in server's file system
  - Input query to the resource
  - Fragment to identify a component of the resource

http:// servername [:port] [/pathname] [?query] [#fragment]

Naming

http://www.cs.vu.nl/home/steen/mbox

http://www.cs.vu.nl:80/home/steen/mbox

http://130.37.24.11:80/home/steen/mbox

http://www.cdk5.net

http://www.w3.org/standards/faq.html#intro

http://www.google.com/search?q=obama

scheme	server name	port	pathname	query	fragment
http	www.cs.vu.nl	(default)	/home/steen/mbox	(none)	(none)
http	www.cs.vu.nl	80	/home/steen/mbox	(none)	(none)
http	130.37.24.11	80	/home/steen/mbox	(none)	(none)
http	www.cdk5.net	(default)	(default)	(none)	(none)
http	www.w3.org	(default)	standards/faq.html	(none)	intro
http	www.google.com	(default)	search	q=obama	(none)

Naming

- Examples of URIs with various schemes

Name	Used for	Example
http	HTTP	http://www.cs.vu.nl:80/globe
mailto	E-mail	mailto:steen@cs.vu.nl
ftp	FTP	ftp://ftp.cs.vu.nl/pub/minix/README
file	Local file	file:/edu/book/work/chp/11/11
data	Inline data	data:text/plain;charset=iso-8859-7,%e1%e2%e3
telnet	Remote login	telnet://flits.cs.vu.nl
tel	Telephone	tel:+31201234567
modem	Modem	modem:+31201234567;type=v32

Universal Description Discovery Interface

- UDDI is the name & directory service for WS
- Stores service descriptions in the form of WSDL documents
- Clients can look up services <u>by name</u> (name service) or <u>by attribute</u> (directory service)
- Service descriptions can be <u>replicated</u> across several servers
- Any server may respond to queries without any interaction with rest
  - Unlike LDAP, which partitions data among servers

Universal Description Discovery Interface

- Changes to a service description must be performed at the owner server (i.e. primary)
  - When a client publishes a service at a server, this server becomes its owner
  - Ownership can be passed on to another server
- Changes are propagated periodically by organizing servers in a logical ring
  - Server S_1 advertises its changes to its successor S_2
  - S_2 requests (pulls) its missing changes from S_1
  - S_2 forwards its own advertisement along the ring

Contents

Synchronization

- Not an issue in traditional web-based systems
  - Nothing to synchronize since servers do not exchange information with other servers
  - WWW is a read-mostly system. Updates are done by a single entity
- But today distributed authoring of documents is emerging
  - Synchronization is needed
  - Let’s see how this is accomplished in collaborative editing of documents: Google Docs
    - Based on **Operational Transformation (OT)**

Google Docs collaboration

- A document is stored in the server as a list of chronological changes: <u>revision log</u>
  - 3 basic types of changes: inserting text, deleting text, and applying styles to a range of text
    - e.g. {InsertText 'SDX' @10}, {DeleteText @9-11}, {ApplyStyle bold @10-20}
  - Append each change to the end of the revision log
- Collaborative protocol to sync changes
  1. Each editor sends changes to the server and waits for acknowledgement
     - Changes during this period are keep in a pending list (never send more than one change at a time)

Google Docs collaboration

2. For each change, server updates revision log, acknowledges a new revision to the sender and sends change to the other editors
3. Each editor transforms incoming changes against its pending changes so that they make sense relative to the local version of the document
   - Operational Transformation to define the different ways that InsertText, DeleteText, and ApplyStyle changes can be paired and transformed against each other
     – https://drive.googleblog.com/2010/09/whats-different-about-new-google-docs_22.html

– Example: https://drive.googleblog.com/2010/09/whats-different-about-new-google-docs.html

Contents

- Architecture
- Communication
- Naming
- Synchronization
- **Consistency & replication**
- Fault tolerance

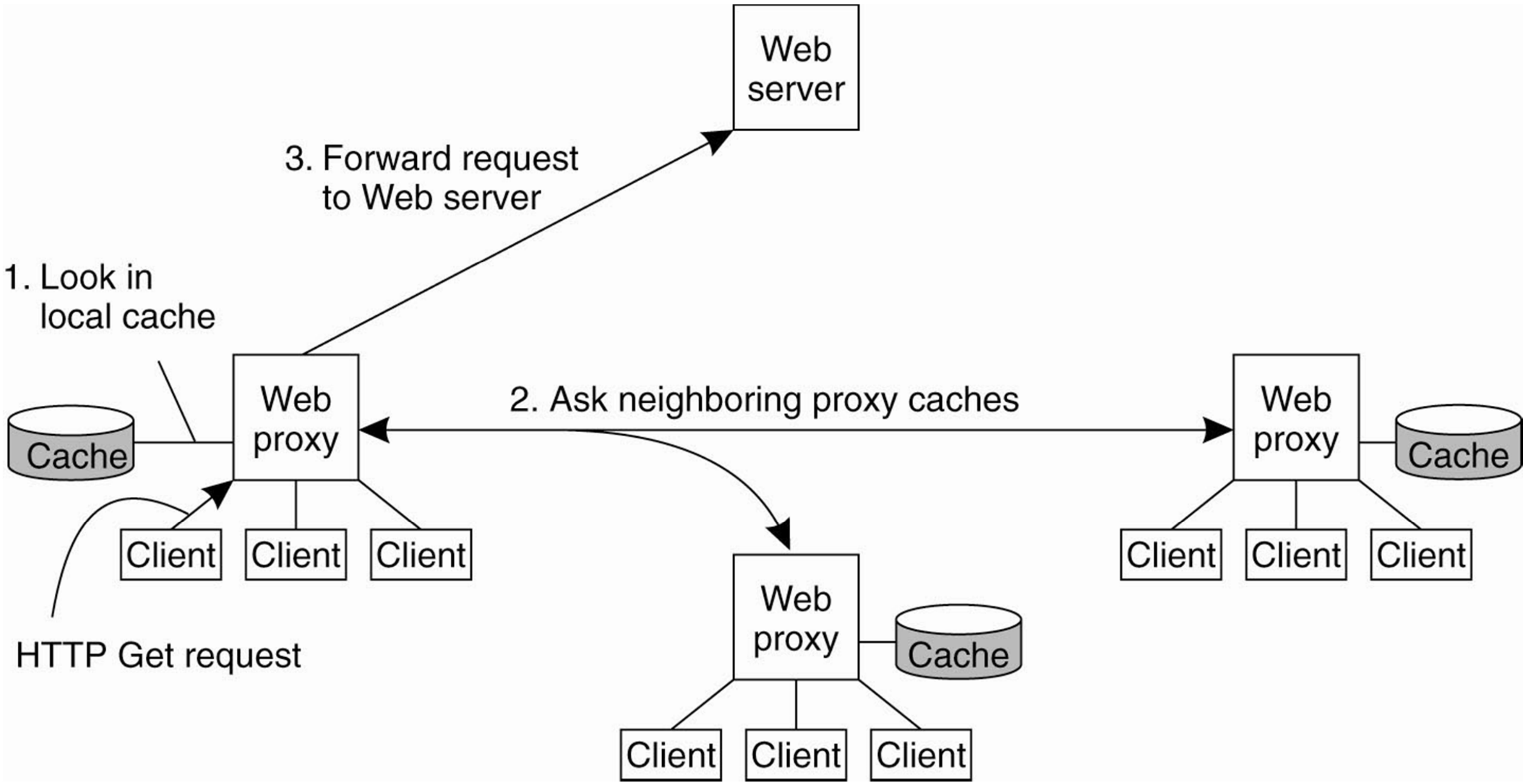
Client-side caching

1. Browser's cache
2. Web proxy caching
   – Site installs a separate **proxy server** that passes all requests from local clients to the Web servers
   – Proxy subsequently caches incoming documents

   a) Hierarchical caches
      • Place caches covering a region (even a country)
      • On cache miss, the request is moved upward

   b) Cooperative caching
      • On cache miss, the Web proxy checks the neighboring proxies

Cooperative caching



Cache-consistency protocols

1. Always verify validity by contacting server
   – Use `If-Modified-Since` HTTP request header to download the document only if it has changed
   – Strong consistency (↑) but server must be contacted for each request (↓)
2. Age-based consistency (e.g. Squid proxy)
   – Assign an expiration time to each document
      • Depends on the last modification time of a document and the time when it was cached
      • Document is considered valid until this time
   – Better performance (↑) but weak consistency (↓)

Contents

- Architecture
- Communication
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- Synchronization
- **Consistency & replication**
  - **Content Distribution Networks (CDN)**
- Fault tolerance

Content Distribution Networks

- Goal: Improve content delivery performance & reliability without tremendous infrastructure investments by the content providers
- Idea: <u>distributed Web server</u>
  - CDN **replicates** contents across the Web and delivers them to users on behalf of origin sites

↑ Reduces the load on origin servers
  - Can handle better flash crowds

↑ Reduces client perceived response time
  - Bring content closer to end-users

Content Distribution Networks

- What content to replicate?
  - Full-site: the entire origin site is replicated into the CDN servers
  - Partial-site: only embedded objects are replicated into the CDN servers
  - Caching results of previous queries is also possible
- How to choose the best CDN server to serve the client request?
  - See 'Request dispatching policies' (slides 14-16)
  - Typical metrics considered in CDNs: distance to client, client perceived latency, load of servers

Content Distribution Networks

- How to enforce consistency between servers?
  - Primary-based approach: updates are carried out at the origin server
  - Typically, CDN servers use a ‘pull’ approach to retrieve updated content from the origin server
    - Origin server can instruct CDN servers about how long the content is to be considered fresh
  - A ‘push’ approach could be used for specific contents if the expense of bandwidth is worth
  - Origin server has also the option to invalidate some content in the CDN servers

Content Distribution Networks

- How to route client requests to CDN servers?
  ⇒ <u>redirection schemes</u>

A. HTTP redirection

- – The `Location` HTTP header in the response tells the client to resubmit its request to a CDN server
- ↑ Medium-grain granularity: individual Web pages
- ↑ Allows content-aware dispatching
- ↓ Lack of transparency
- ↓ Overhead: adds an address resolution and an extra message round-trip time for every request

Content Distribution Networks

B. URL rewriting

– Rewrite links for the embedded objects within the returned page to redirect client to CDN servers

– e.g. http://www.foo.com/images/logo.gif ⇒ http://a9.g.akamai.net/7/9/21/aaa7a80f016a2c/www.foo.com/images/logo.gif

↑ Fine-grain granularity: embedded objects

↑ Allows content-aware dispatching

↓ Additional load on the origin server to dynamically generate every Web page

↓ DNS overhead: an additional address resolution is needed for each embedded object

Content Distribution Networks

C. DNS redirection

– CDN takes control of the origin site DNS zone

– Modify DNS resolution so that each request is redirected to a different CDN server

↑ Transparent: seamless integration with DNS

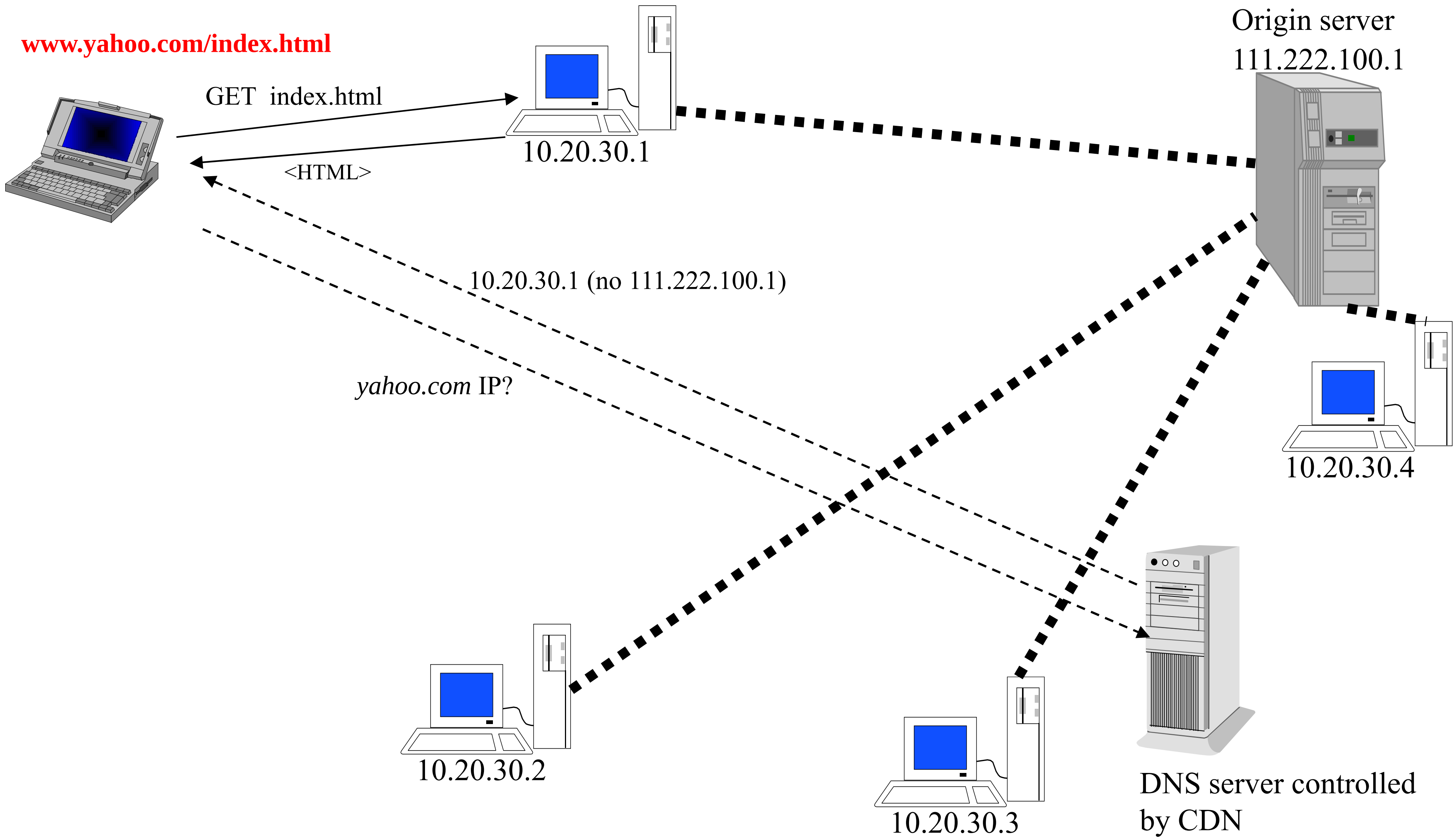
↑ No redirection overhead

↓ Only content-blind dispatching

↓ Caching at the browser and intermediate servers prevents many requests to contact the origin site

↓ Coarse-grain granularity: all client requests in a session will reach the same server

DNS redirection example



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- Consistency & replication
- **Fault tolerance**

Fault tolerance

- Mainly achieved through client-side caching and server replication

Summary

- WWW as a distributed system
  - From traditional client-server architectures for fetching hyperlinked documents to Web Services
  - Use of standardized protocols
    - Communication: HTTP, SOAP
    - Naming: URI, UDDI
  - Caching and replication for improving performance and fault tolerance (e.g. web proxy caching, CDN)
- Further details:
  - [Tanenbaum]: chapter 12
  - [Coulouris]: chapters 1.6 and 9