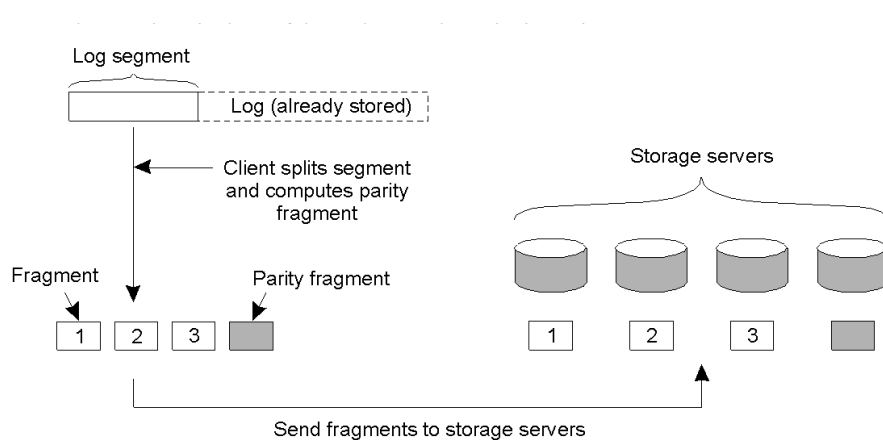# Today: World Wide Web
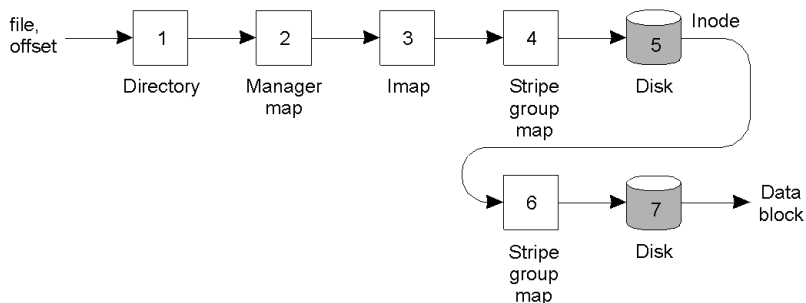
- WWW principles

- Case Study: web caching as an illustrative example
  - Invalidate versus updates
  - Push versus Pull
  - Cooperation between replicas

Processes in xFS

Reading a File Block

- Reading a block of data in xFS.

xFS Naming

- Main data structures used in xFS.

Data structure	Description
Manager map	Maps file ID to manager
Imap	Maps file ID to log address of file's inode
Inode	Maps block number (i.e., offset) to log address of block
File identifier	Reference used to index into manager map
File directory	Maps a file name to a file identifier
Log addresses	Triplet of stripe group, ID, segment ID, and segment offset
Stripe group map	Maps stripe group ID to list of storage servers

Traditional Web-Based Systems
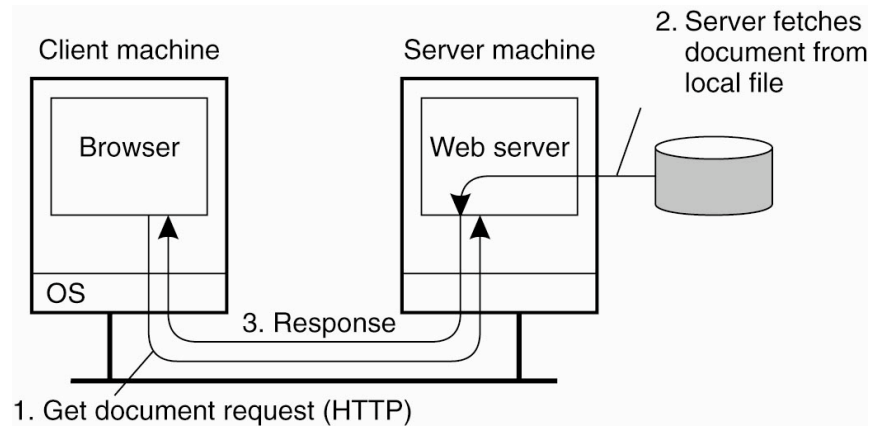
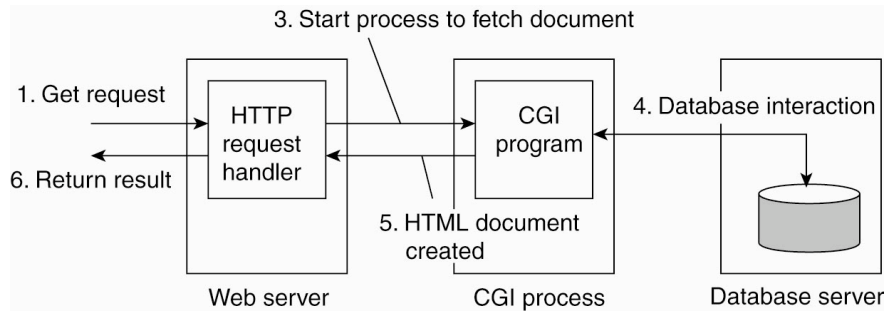- The overall organization of a traditional Web site.

Web Documents

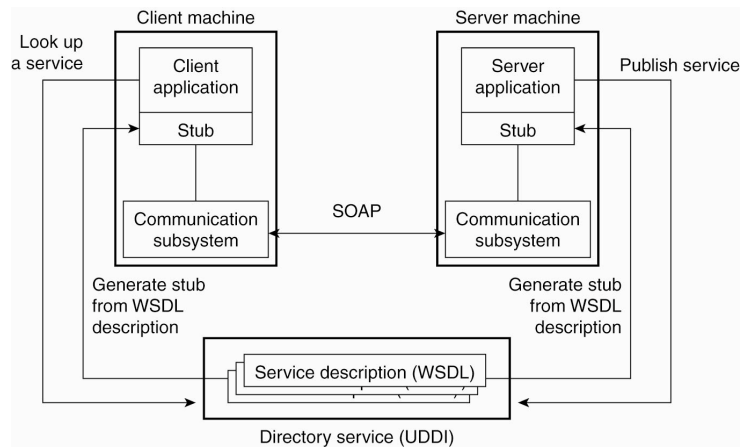| Type	Subtype	Description
Text	Plain	Unformatted text
	HTML	Text including HTML markup commands
	XML	Text including XML markup commands
Image	GIF	Still image in GIF format
	JPEG	Still image in JPEG format
Audio	Basic	Audio, 8-bit PCM sampled at 8000 Hz
	Tone	A specific audible tone
Video	MPEG	Movie in MPEG format
	Pointer	Representation of a pointer device for presentations
Application	Octet-stream	An uninterpreted byte sequence
	Postscript	A printable document in Postscript
	PDF	A printable document in PDF
Multipart	Mixed	Independent parts in the specified order
	Parallel	Parts must be viewed simultaneously

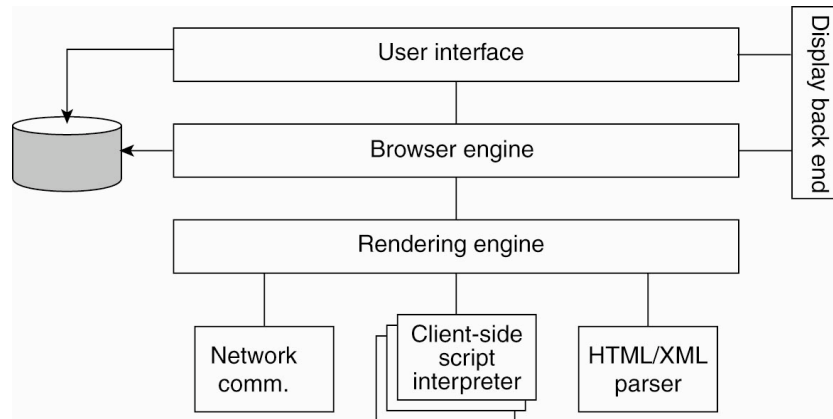- Six top-level MIME types and some common subtypes.

Multitiered Architectures

3. Start process to fetch document

1. Get request

HTTP request handler

CGI program

4. Database interaction

6. Return result

5. HTML document created

Web server CGI process Database server

- The principle of using server-side CGI programs.

Web Services Fundamentals

Client machine Server machine

Look up a service

Client application

Stub

Server application

Stub

Publish service

Communication subsystem

SOAP

Communication subsystem

Generate stub from WSDL description

Generate stub from WSDL description

Service description (WSDL)

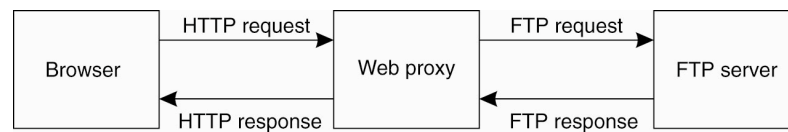Directory service (UDDI)

- The principle of a Web service.

Processes – Clients

- The logical components of a Web browser.

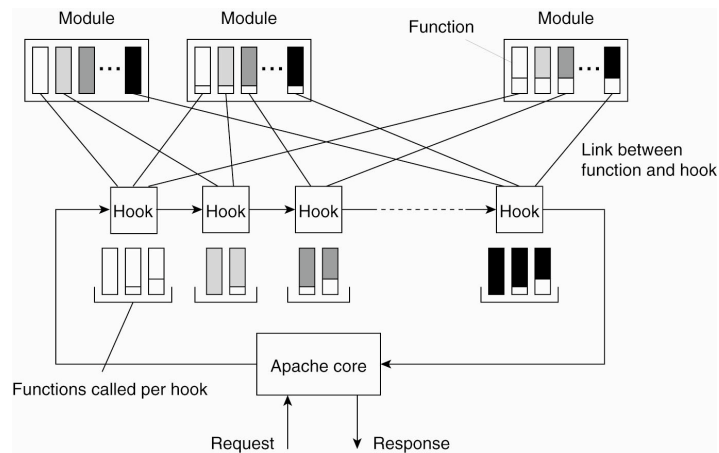# Processes – Clients

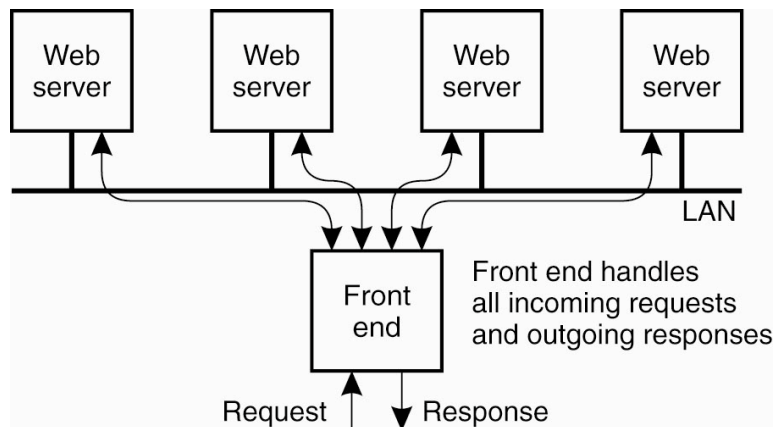- Using a Web proxy when the browser does not speak FTP (or for caching)

The Apache Web Server
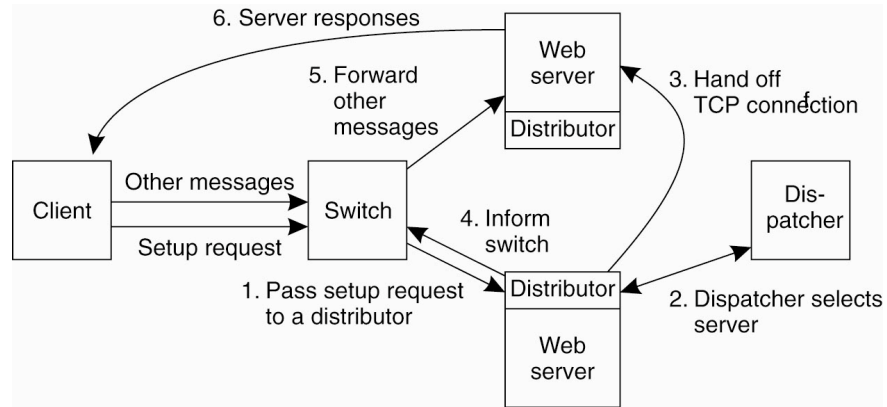

- The general organization of the Apache Web server.

Web Server Clusters

- The principle of using a server cluster in combination with a front end to implement a Web service.

Web Server Clusters (2)

- A scalable content-aware cluster of Web servers.

HTTP Connections
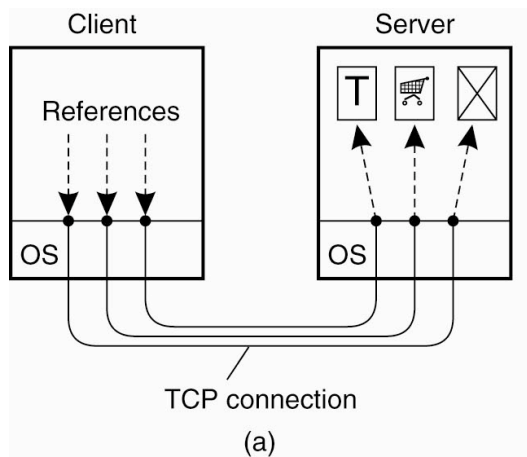
- Using nonpersistent connections.

HTTP Connections

Client   Server

References

OS   OS

TCP connection

(b)
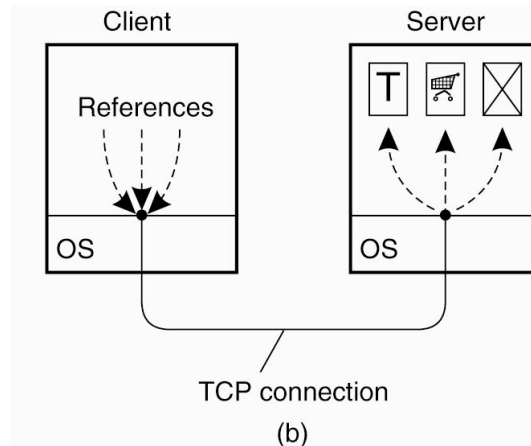
- (b) Using persistent connections.

HTTP Methods

Operation	Description
Head	Request to return the header of a document
Get	Request to return a document to the client
Put	Request to store a document
Post	Provide data that are to be added to a document (collection)
Delete	Request to delete a document

- Operations supported by HTTP.

Simple Object Access Protocol

```
<env:Envelope xmlns:env="http://www.w3.org/2003/05/soap-envelope">
    <env:Header>
        <n:alertcontrol xmlns:n="http://example.org/alertcontrol">
            <n:priority>1</n:priority>
            <n:expires>2001-06-22T14:00:00-05:00</n:expires>
        </n:alertcontrol>
    </env:Header>
    <env:Body>
        <m:alert xmlns:m="http://example.org/alert">
            <m:msg>Pick up Mary at school at 2pm</m:msg>
        </m:alert>
    </env:Body>
</env:Envelope>
```
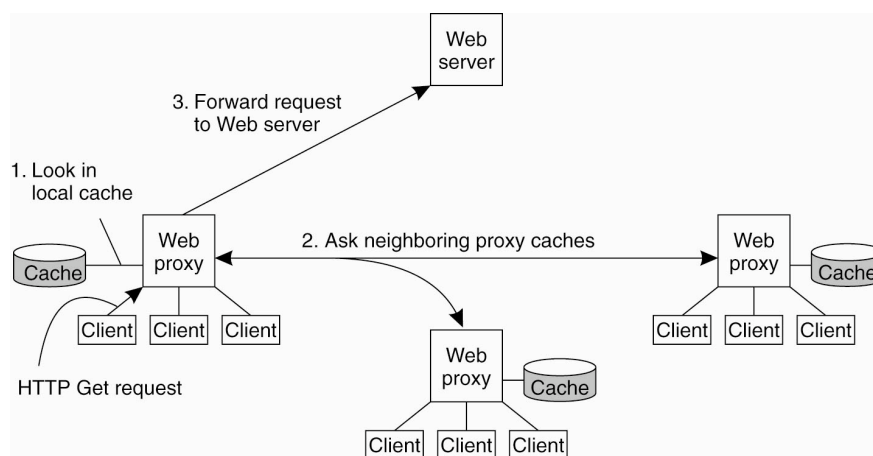
- An example of an XML-based SOAP message.

Computer Science   CS677: Distributed OS   Lecture 22, page 17

Web Proxy Caching

- The principle of cooperative caching.

Computer Science   CS677: Distributed OS   Lecture 22, page 18

Web Caching

- Example of the web to illustrate caching and replication issues
  - Simpler model: clients are read-only, only server updates data

request
browser ← Web server
response

request   request
browser ← Web Proxy cache ← Web server
response   response
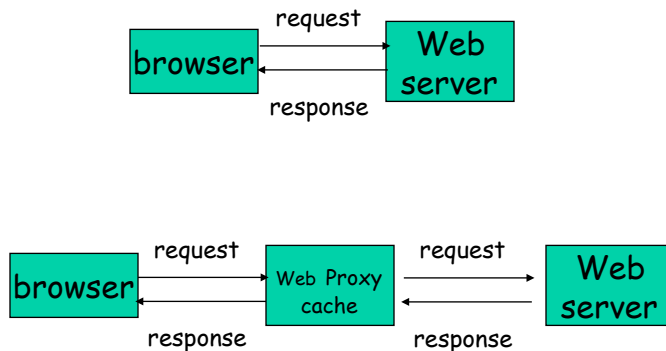
Consistency Issues

- Web pages tend to be updated over time
  - Some objects are static, others are dynamic
  - Different update frequencies (few minutes to few weeks)
- How can a proxy cache maintain consistency of cached data?
  - Send invalidate or update
  - Push versus pull

Push-based Approach

- Server tracks all proxies that have requested objects
- If a web page is modified, notify each proxy
- Notification types
  - Indicate object has changed [invalidate]
  - Send new version of object [update]
- How to decide between invalidate and updates?
  - Pros and cons?
  - One approach: send updates for more frequent objects, invalidate for rest

proxy ← push ← Web server

Computer Science   CS677: Distributed OS   Lecture 22, page 21
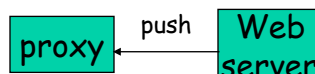
Push-based Approaches
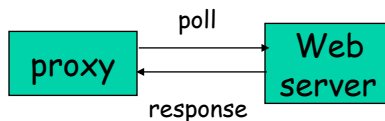
- Advantages
  - Provide tight consistency [minimal stale data]
  - Proxies can be passive
- Disadvantages
  - Need to maintain state at the server
    - Recall that HTTP is stateless
    - Need mechanisms beyond HTTP
  - State may need to be maintained indefinitely
    - Not resilient to server crashes

Computer Science   CS677: Distributed OS   Lecture 22, page 22

Pull-based Approaches

poll

proxy → Web server

response

- Proxy is entirely responsible for maintaining consistency
- Proxy periodically polls the server to see if object has changed
  - Use if-modified-since HTTP messages
- Key question: when should a proxy poll?
  - Server-assigned *Time-to-Live (TTL)* values
    - No guarantee if the object will change in the interim


Pull-based Approach: Intelligent Polling

- Proxy can dynamically determine the refresh interval
  - Compute based on past observations
    - Start with a conservative refresh interval
    - Increase interval if object has not changed between two successive polls
    - Decrease interval if object is updated between two polls
    - Adaptive: No prior knowledge of object characteristics needed

Pull-based Approach

- Advantages
  - Implementation using HTTP (If-modified-Since)
  - Server remains stateless
  - Resilient to both server and proxy failures
- Disadvantages
  - Weaker consistency guarantees (objects can change between two polls and proxy will contain stale data until next poll)
    - Strong consistency only if poll before every HTTP response
  - More sophisticated proxies required
  - High message overhead

Computer Science   CS677: Distributed OS   Lecture 22, page 25

A Hybrid Approach: Leases

- Lease: duration of time for which server agrees to notify proxy of modification
- Issue lease on first request, send notification until expiry
  - Need to renew lease upon expiry
- Smooth tradeoff between state and messages exchanged
  - Zero duration => polling, Infinite leases => server-push
- Efficiency depends on the *lease duration*

Computer Science   CS677: Distributed OS   Lecture 22, page 26
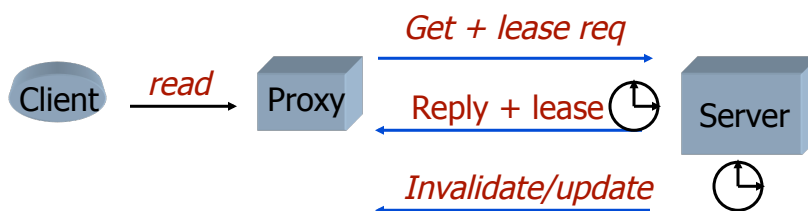
Policies for Leases Duration

- Age-based lease
  - Based on bi-modal nature of object lifetimes
  - Larger the expected lifetime longer the lease
- Renewal-frequency based
  - Based on skewed popularity
  - Proxy at which objects is popular gets longer lease
- Server load based
  - Based on adaptively controlling the state space
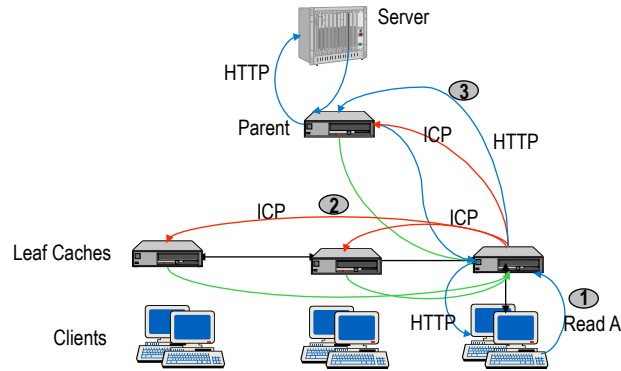 - Shorter leases during heavy load

Cooperative Caching

- Caching infrastructure can have multiple web proxies
  - Proxies can be arranged in a hierarchy or other structures
    - Overlay network of proxies: content distribution network
  - Proxies can cooperate with one another
    - Answer client requests
    - Propagate server notifications

Hierarchical Proxy Caching

Server

HTTP

Parent

ICP   HTTP

③

ICP   ②   ICP

Leaf Caches

HTTP   Read A

①

Clients

Examples: Squid, Harvest

Locating and Accessing Data

Server for B

Get A

Node Y   Node X

Get B

Node Z

Read A

(A,X)   Caches

Read B

Clients

Minimize cache hops on hit   Do not slow down misses
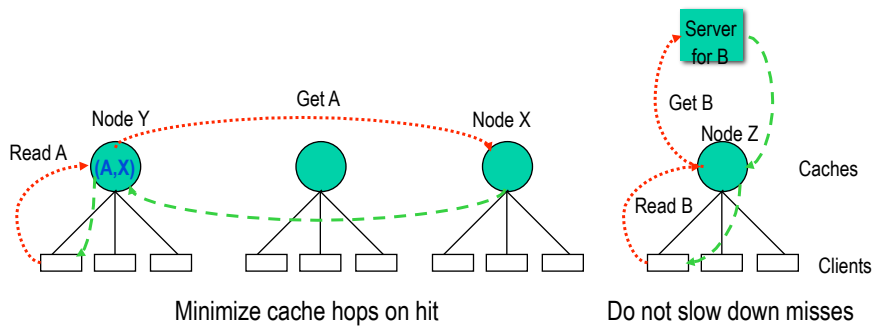
Properties

- Lookup is local
- Hit at most 2 hops
- Miss at most 2 hops (1 extra on wrong hint)

CDN Issues

- Which proxy answers a client request?
  - Ideally the "closest" proxy
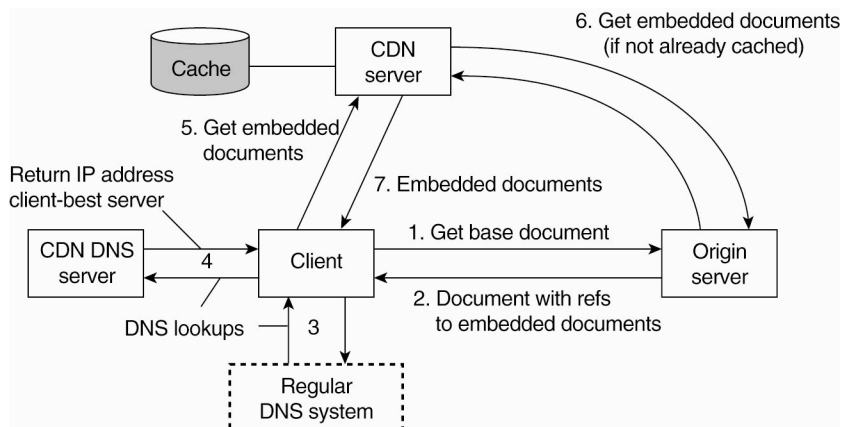 - Akamai uses a DNS-based approach

- Propagating notifications
  - Can use multicast or application level multicast to reduce overheads (in push-based approaches)

- Active area of research
  - Numerous research papers available

Computer Science   CS677: Distributed OS   Lecture 22, page 31

Adjustment Measures

- The principal working of the Akamai CDN.

Computer Science   CS677: Distributed OS   Lecture 22, page 32

Replication of Web Applications

Edge-server side | Origin-server side

Client — Server

query
response

Content-blind cache
Database copy
Content-aware cache
Schema

full/partial data replication

full schema replication/ query templates

Server

Authoritative database

Schema

Computer Science   CS677: Distributed OS   Lecture 22, page 33