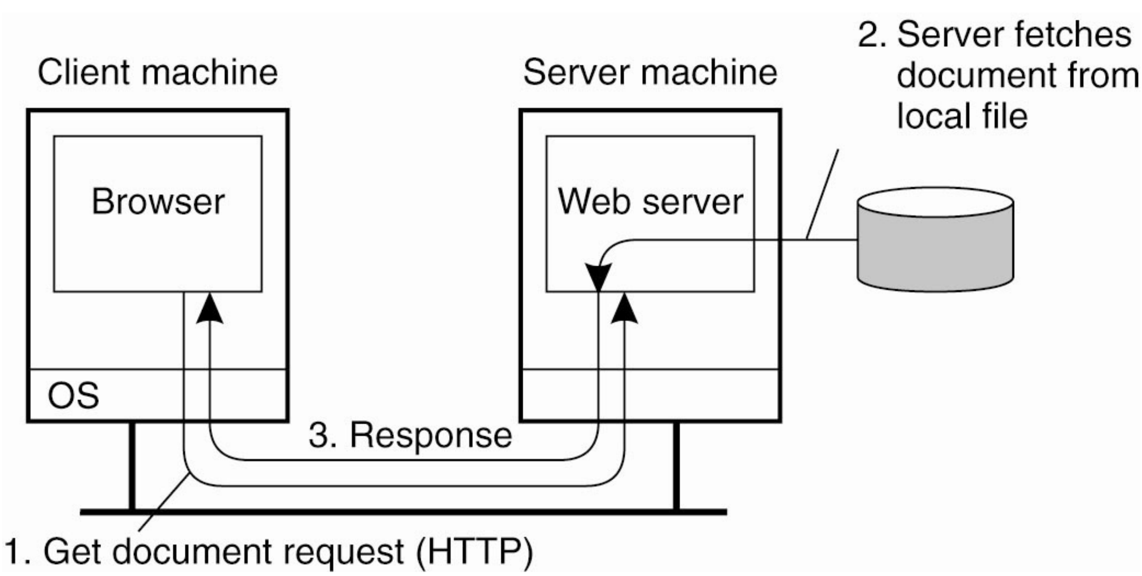
Distributed Web Applications

- WWW principles

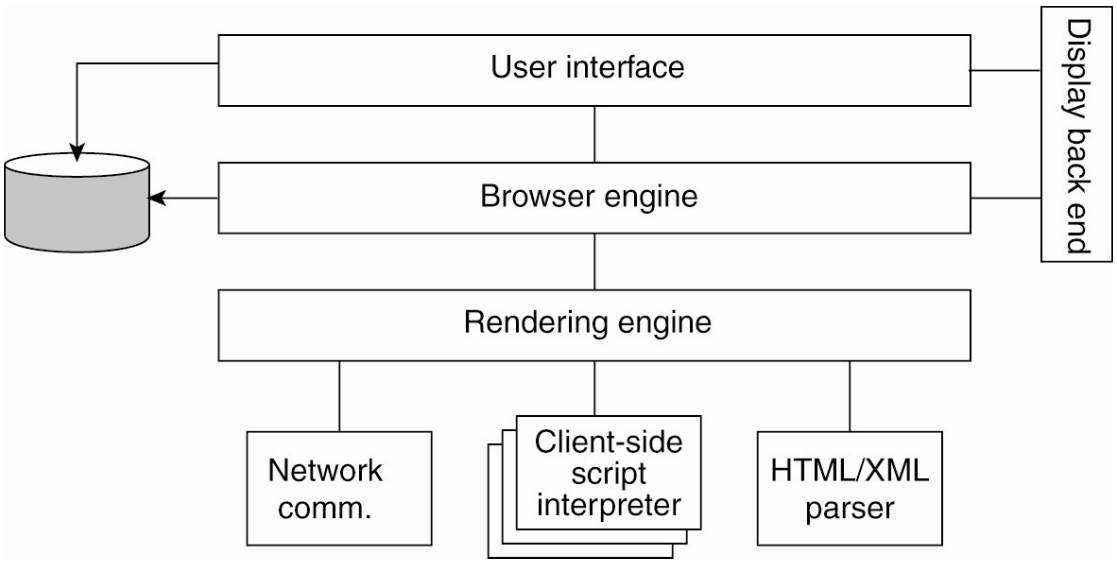
- Case Study: web caching as an illustrative example
  - Invalidate versus updates
  - Push versus Pull
  - Cooperation between replicas

Traditional Web-Based Systems



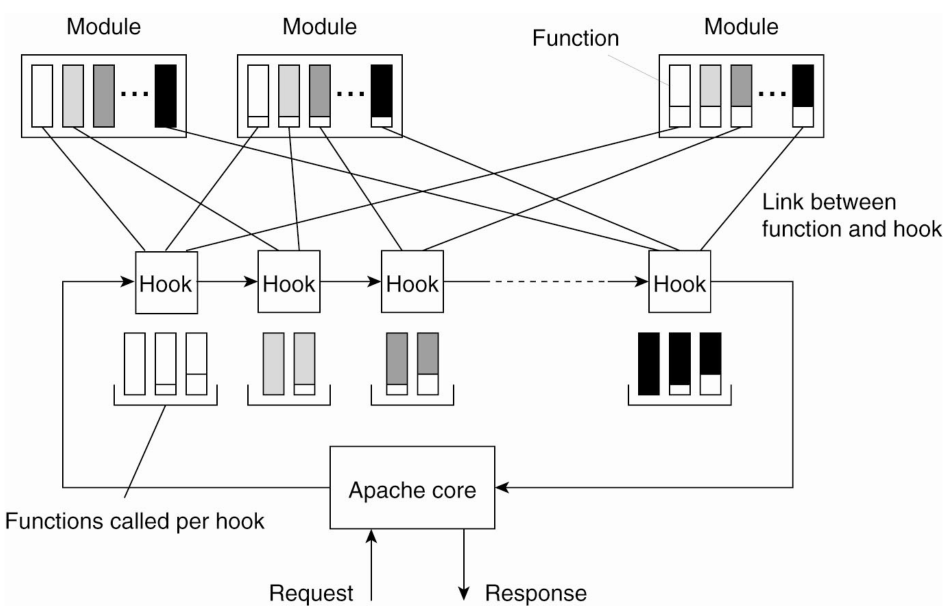
- Client-server web applications

Web Browser Clients



- The logical components of a Web browser.

The Apache Web Server

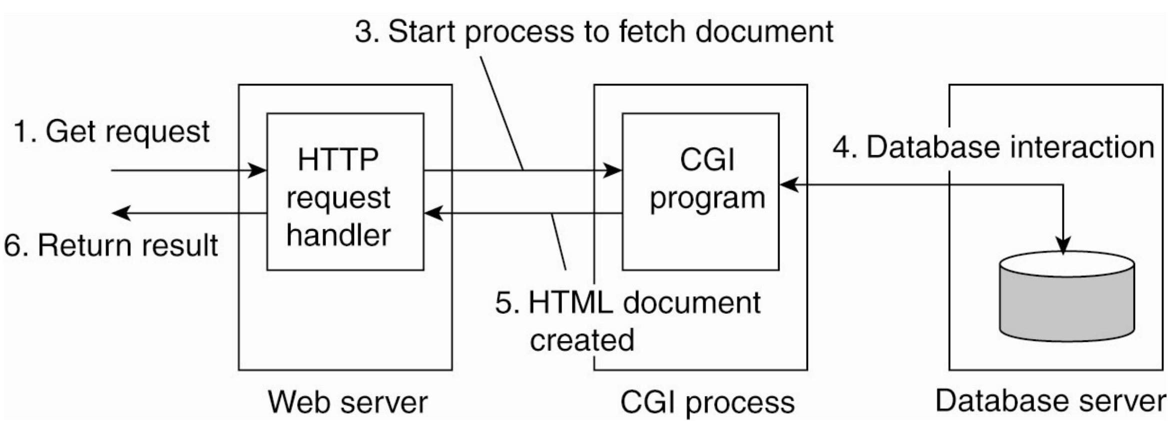


- The general organization of the Apache Web server.

Proxy Servers

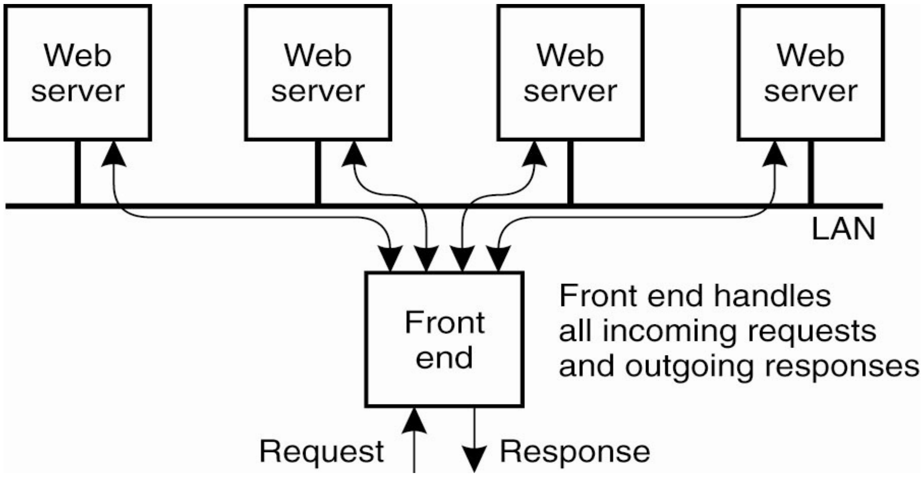
- Using a Web proxy when the browser does not speak FTP (or for caching and offloading)

Multitiered Architectures



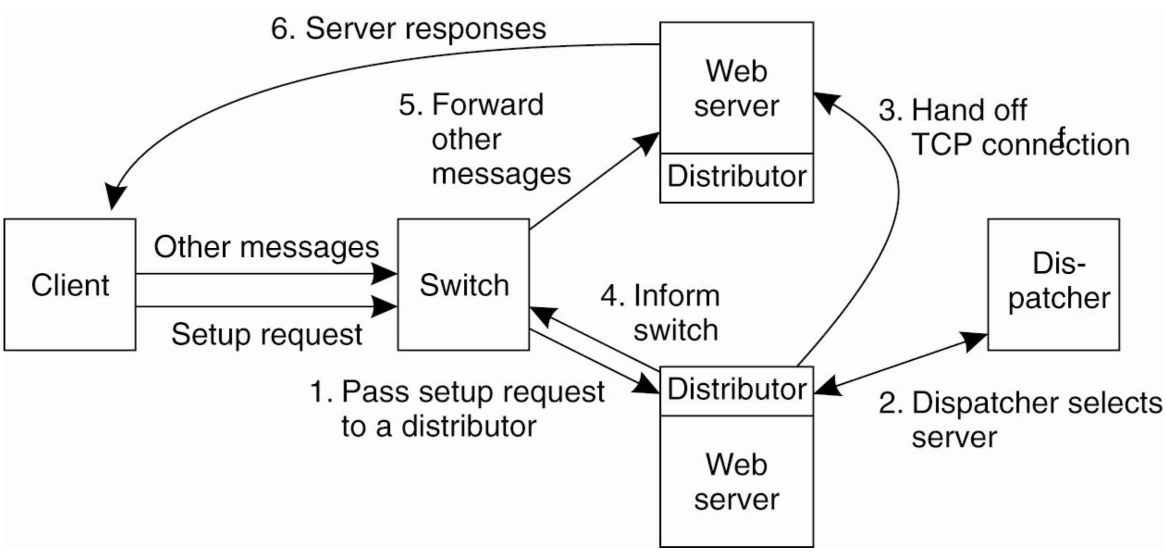
- Three tiers: HTTP, application, and database tier

Web Server Clusters



- Clients connect to front-end dispatcher, which forwards requests to a replica (recall discussion from Cluster scheduling)
- Each replica can be a tiered system
  – For consistency, database can be a common/non-replicated

Web Server Clusters (2)



- A scalable content-aware cluster of Web servers.

Web Clusters

- Request-based scheduling
  - Forward each request to a replica based on a policy
- Session-based scheduling
  - Forward each session to a replica based on a policy
- Scheduling policy: round-robin, least loaded
- HTTP redirect vs TCP splicing vs TCP handoff

Elastic Scaling

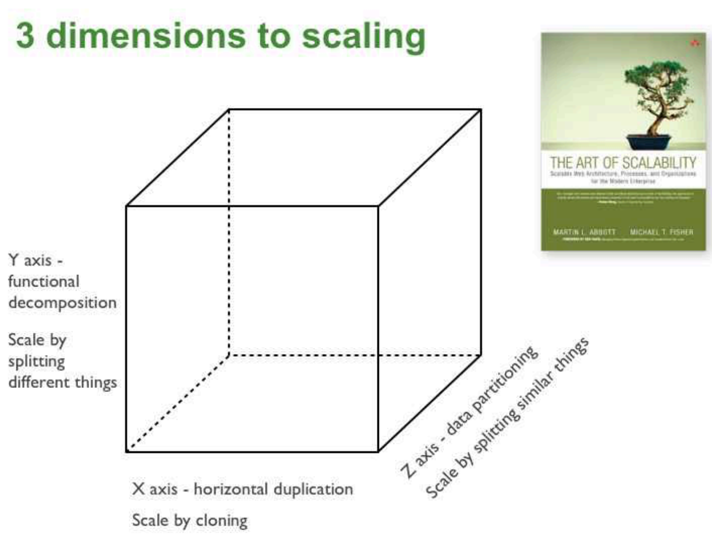
- Web workloads: temporal time of day, seasonal variations
  - Flash crowds: black friday, sports events, news events
- Overloads can occur even with clustering and replication
- Elastic scaling: dynamically vary application capacity based on workload (aka auto-scaling, dynamic provisioning)
- Two approaches:
  - Horizontal scaling: increase or decrease # of replicas based on load
  - Vertical scaling: increase or decrease size of replica (e.g., # of cores allocated to container or VM) based on load
- Proactive versus reactive scaling
  - Proactive: predict future load and scale in advance
  - Reactive: scale based on observed workload
- Common in large cloud-based web applications

Micro-services Architecture

- Micro-services: application is a collection of smaller services
  - Example of service-oriented architecture
  - Modular approach to overcome "monolith hell"
- Each microservice is small and can be maintained independently of others
- Each is independently deployable
- Clustering and auto-scaling can be performed independently

Scaling Web applications

- Three approaches for scaling



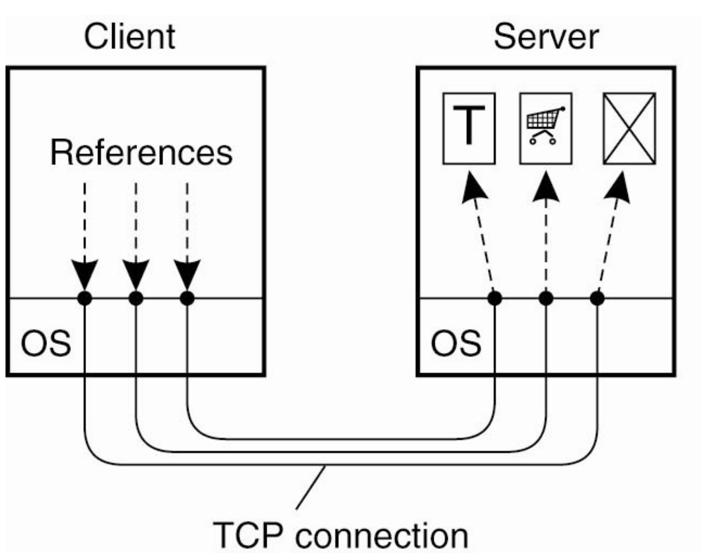
https://microservices.io/articles/scalecube.html

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.

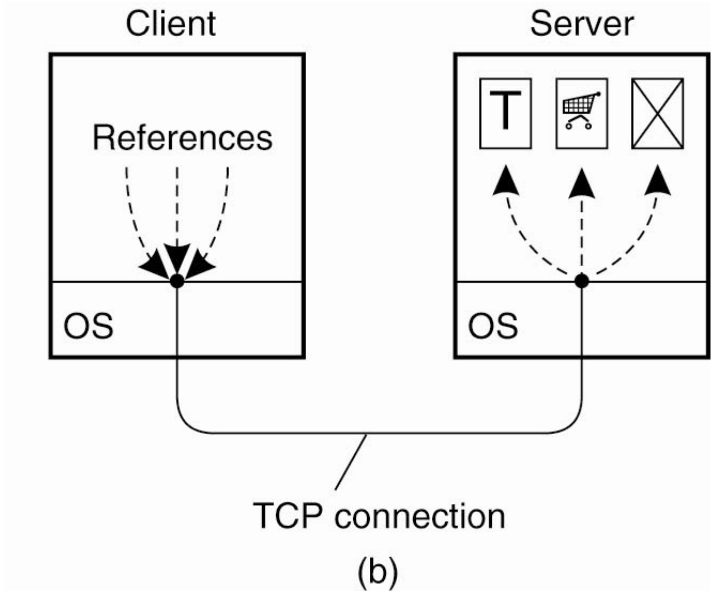
HTTP Connections



(a)

- Using nonpersistent connections.

HTTP 1.1 Connections



- (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

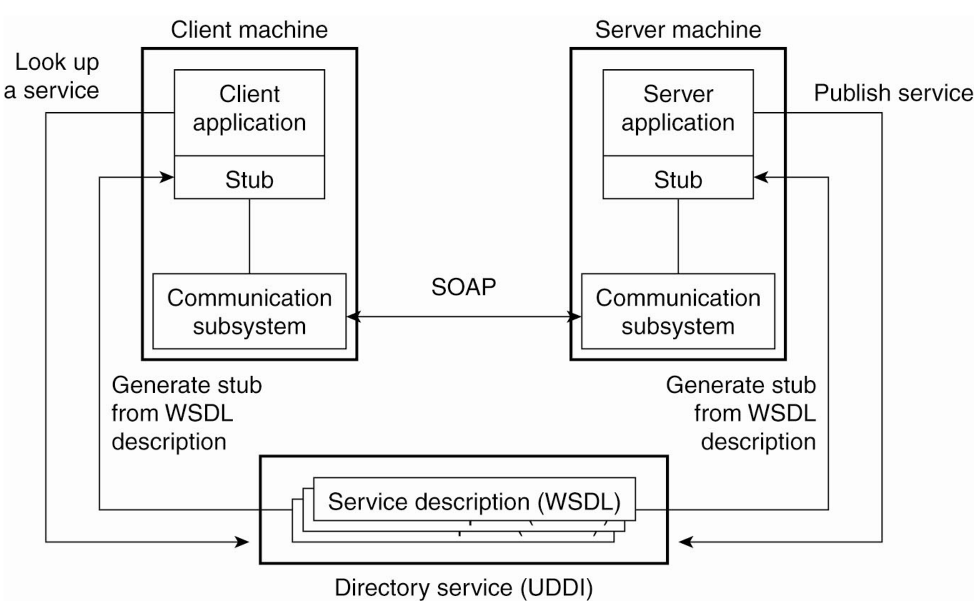
- Operations supported by HTTP.

HTTP 2.0

- Http 1.1 allows pipelining over same connection
  – Most browsers do not use this feature
- HTTP v2: Designed to reduce message latency
  – No new message or response types
- Key features
  – Binary headers (over text headers of http 1.1)
  – Uses compression of headers and messages
  – Multiplex concurrent connection over same TCP connection
    - each connection has multiple "streams", each carrying a request and response
      – No blocking caused by pipelining in http 1.1

See https://developers.google.com/web/fundamentals/performance/http2/

Web Services Fundamentals



- The principle of a Web service.

Simple Object Access Protocol

```xml
<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.

RESTful Web Services

- SOAP heavy-weight protocol for web-based distributed computing
  - RESTful web service: lightweight , point-to-point XML comm
- REST=representative state transfer
  - HTTP GET => read
  - HTTP POST => create, update, delete
  - HTTP PUT => create, update
  - HTTP DELETE => delete
- Simpler than RPC-sytle SOAP
  - closer to the web

RESTful Example

```
GET /StockPrice/IBM HTTP/1.1
Host: example.org
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/stock-service">
     <s:TickerSymbol>IBM</s:TickerSymbol>
     <s:StockPrice>45.25</s:StockPrice>
</s:Quote>
```


Corresponding SOAP Call

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

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

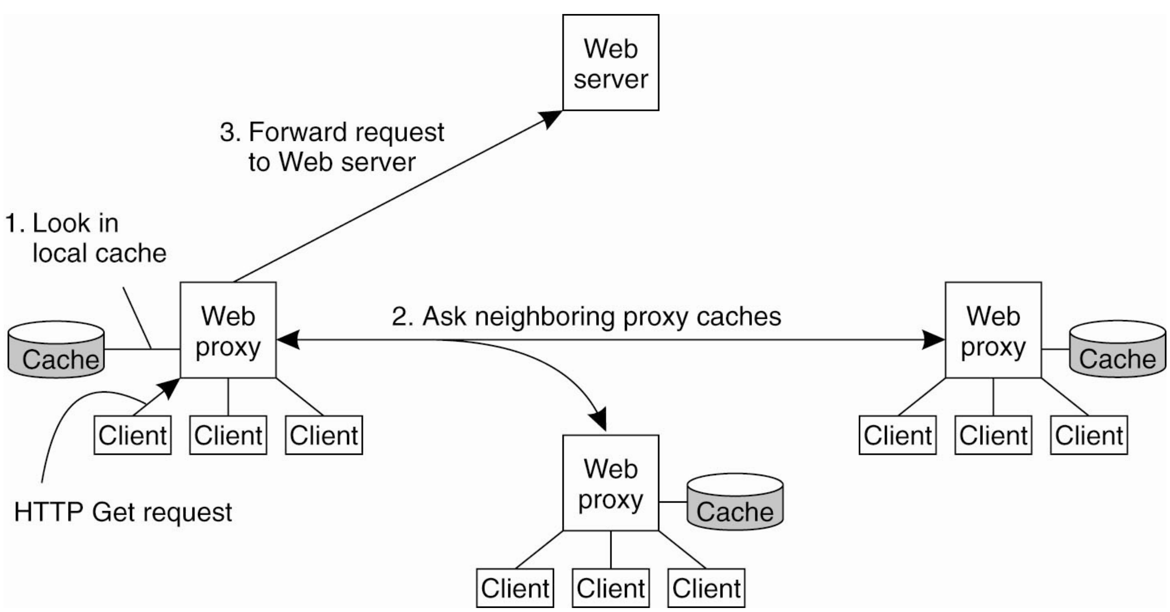
```
HTTP/1.1 200 OK
Content-Type: application/soap+xml; charset=utf-8
Content-Length: nnn

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

SOAP vs RESTful WS

- Language, platform and transport agnostic
- Supports general distributed computing
- Standards based (WSDL, UDDI dir. service...)
- Builtin error handling
- Extensible
- More heavy-weight
- Harder to develop

- Language and platform agnostic
- Point-to-point only; no intermediaries
- Lack of standards support for security, reliability (“roll you own”
- Simpler, less learning curve, less reliance on tools
- Tied to HTTP transport layer
- More concise

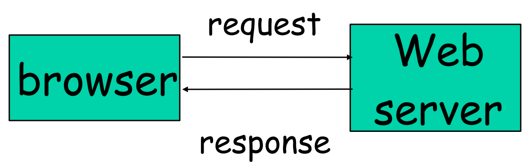
Web Proxy Caching

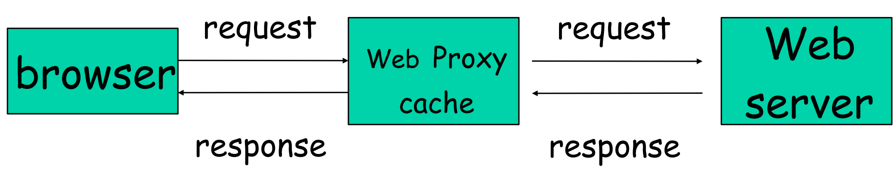


- The principle of cooperative caching.

Web Caching

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



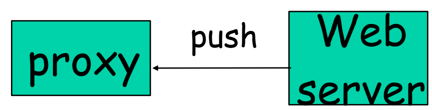


Consistency Issues

- 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

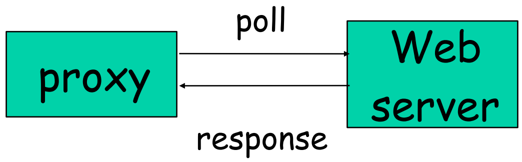
- Server tracks all proxies that have requested objects
- If a web page is modified, notify each proxy
- Notification types
  - Indicate object has changed [invalidate]
  - Send new version of object [update]
- How to decide between invalidate and updates?
  - Pros and cons?
  - One approach: send updates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



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

Pull-based Approaches



- 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

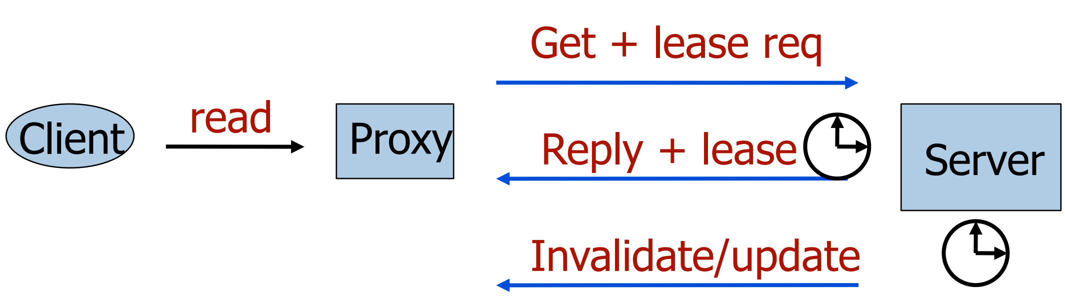
- Proxy can dynamically determine the refresh interval
  - Compute based on past observations
    - Start with a conservative refresh interval
    - Increase interval if object has not changed between two successive polls
    - Decrease interval if object is updated between two polls
    - Adaptive: 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

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*



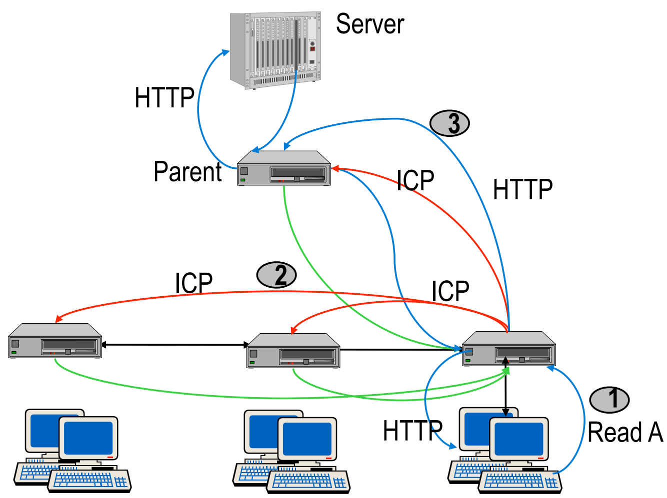
Policies for Leases Duration

- 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

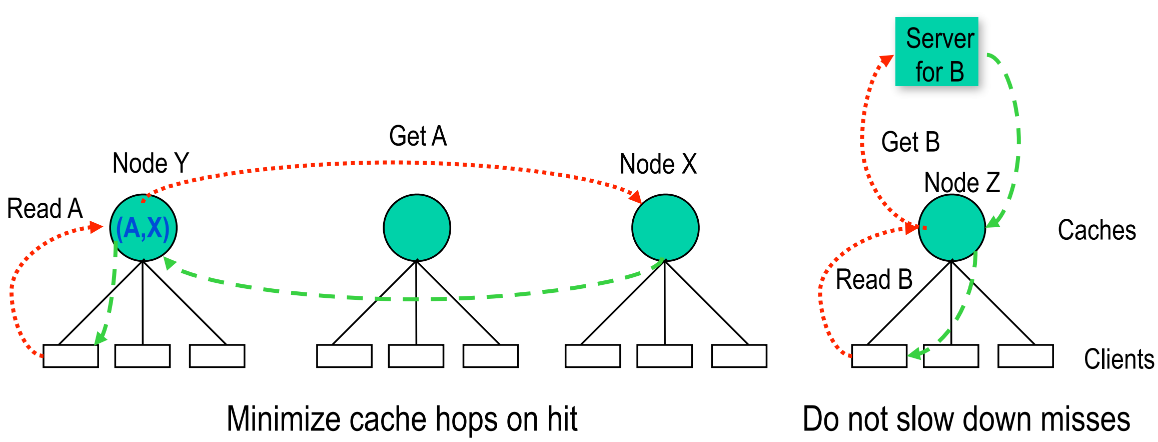
- Caching infrastructure can have multiple web proxies
  - Proxies can be arranged in a hierarchy or other structures
    - Overlay network of proxies: content distribution network
  - Proxies can cooperate with one another
    - Answer client requests
    - Propagate server notifications

Hierarchical Proxy Caching



Examples: Squid, Harvest

Locating and Accessing Data



Properties

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

Edge Computing

- Web caches effective when deployed close to clients
  - At the "Edge" of the network
- Edge Computing: paradigm where applications run on servers located at the edge of the network
- Benefits
  - Significantly lower latency than "remote" cloud servers
  - Higher bandwidth
  - Can tolerate network or cloud failures
- Complements cloud computing
  - Cloud providers offer edge servers as well as cloud servers

Edge Computing Origins

- Origins come from mobile computing and web caching
- Content delivery networks
  - Network of edge caches deployed as commercial service
  - Cache web content (especially rich content: images, video)
  - Deliver from closest edge proxy server
- Mobile computing
  - devices has limited resources, limited battery power
  - computational offload: offload work to more capable edge server
  - low latency offload important for interactive mobile applications
  - edge server sends results to the mobile

Content Delivery Networks

- Global network of edge proxies to deliver web content
  - edge clusters of varying sizes deployed in all parts of the world
  - Akamai CDN: 120K servers in 1100 networks, 80 countries
- Content providers are customers of CDN service
  - Examples: news sites, image-rich online stores, streaming sites
  - Decide what content to cache/offload to CDN
  - Embed links to cdn content: http://cdn.com/company/foo.mp4
  - Consistency responsibility of content providers
- Users access website normally
  - Some content fetched by browser from CDN cache

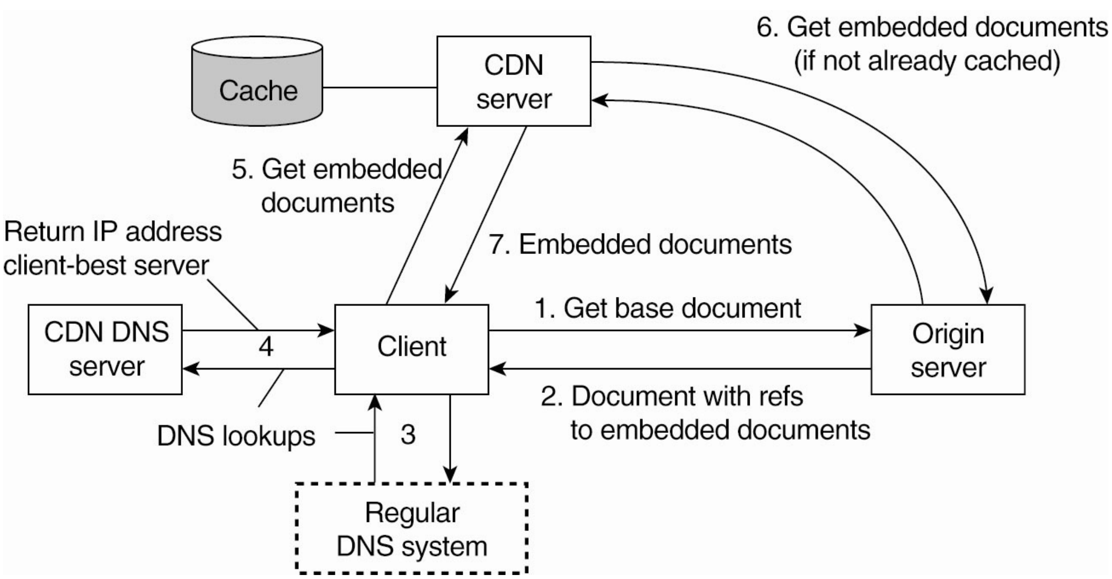
CDN Request Routing

- Web request need to be directed to nearby CDN server
- Two level load balancing
  - Global: decide which cluster to use to serve request
  - Local: decide which server in the cluster to use
- DNS-based approach is common
  - Special DNS server: resolve www.cnn.com/newsvideo.mp4
  - DNS checks location of client and resolves to IP address of nearby CDN server
  - Different users will get resolved to different edge locations

CDN Issues

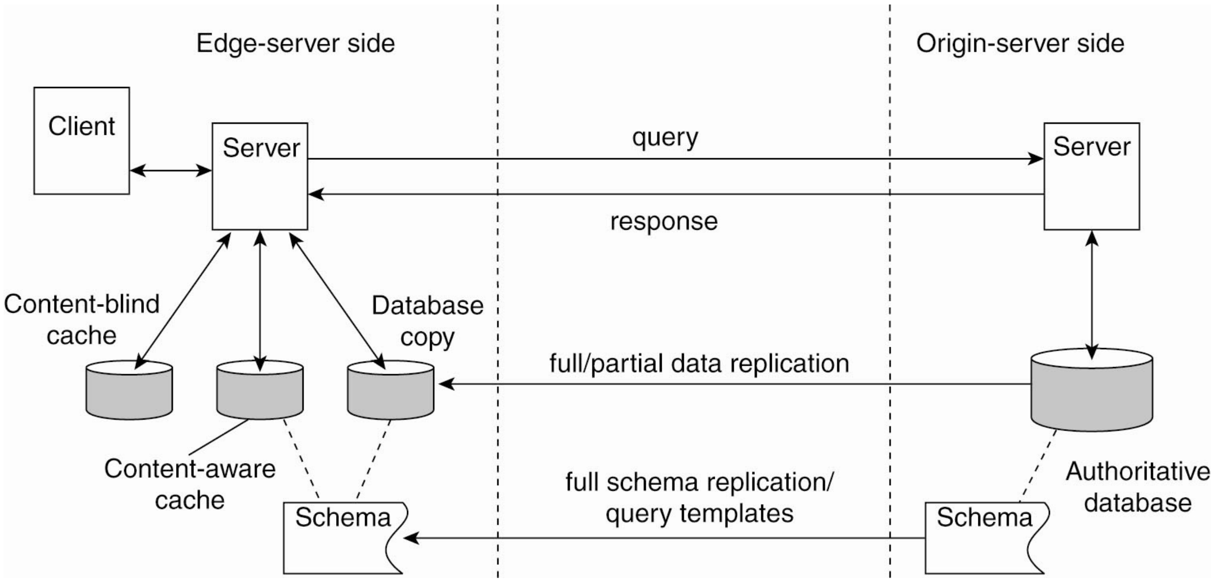
- Which proxy answers a client request?
  - Ideally the "closest" proxy
  - Akamai uses a DNS-based approach
- Propagating notifications
  - Can use multicast or application level multicast to reduce overheads (in push-based approaches)
- Active area of research
  - Numerous research papers available

CDN Request Processing



- The principal working of the Akamai CDN.

CDN Hosting of Web Applications



Mobile Edge Computing

- Use case: Mobile offload of compute-intensive tasks
- Example: augmented reality, virtual reality (mobile AR/VR)
  - mobile phone or headset has limited resources, limited battery
  - Low latency / response times for interactive use experience
  - mobile devices may lack a GPU or mobile GPU may be limited
- Today's smartphones are highly capable (multiple cores, mobile GPU, neural processor)
  - mobile offload more suitable for less capable devices (e.g., AR headset)
- 5G cellular providers: deploy edge servers near cell towers
  - industrial automation, autonomous vehicles

Edge Computing Today

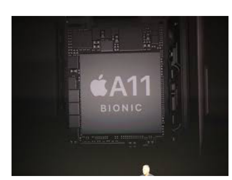
- Emerging approach for latency-sensitive applications
- Edge AI: run AI (deep learning) inference at edge
  - home security camera sends feed, run object detection
- Low latency offload: autonomous vehicles, smart city sensors, smart home etc.
- Edge computing as an extension to cloud
  - Cloud regions augmented by local regions
    - Local regions are edge clusters that offer normal cloud service (but at lower latency) E.g., AWS Boston region
  - Internet of Things (IoT) data processing sevices

Specialized Edge Computing

- Edge accelerators: special hardware to accelerate edge tasks on resource constrained edge servers
  - Nvidia Jetson GPU, Google edge Tensor processing Unit (TUP), Intel   Vision Processing Unit (VPU)
- Example: IoT ML inference on edge accelerators
  - Efficient inference on resource-constrained edge servers

Google Edge TPU

Nvidia Jetson Nano GPU



Apple Neural Engine

Cloud and Edge Architectures

- Offload to cloud, edge, specialized edge,