CS162 Operating Systems and Systems Programming Lecture 22

Client-Server

November 14, 2011

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http://inst.eecs.berkeley.edu/~cs162

Distributed Systems are Everywhere!

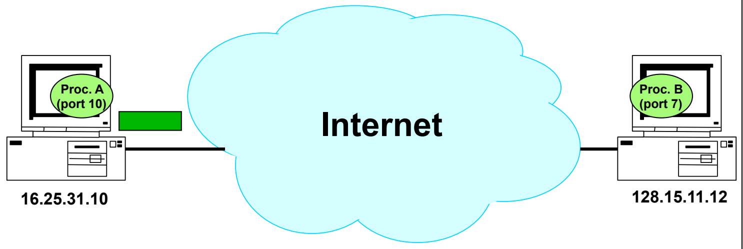
- We need (want?) to share physical devices (e.g., printers) and information (e.g., files)
- Many applications are distributed in nature (e.g., ATM machines, airline reservations)
- Many large problems can be solved by decomposing smaller problems that run in parallel (e.g., MapReduce, SETI@home)
- Next four capstone lectures cover four distributed system models
  - Client-server, Multimedia content delivery, Peer-to-peer, and Cloud (cluster) computing

Client-Server

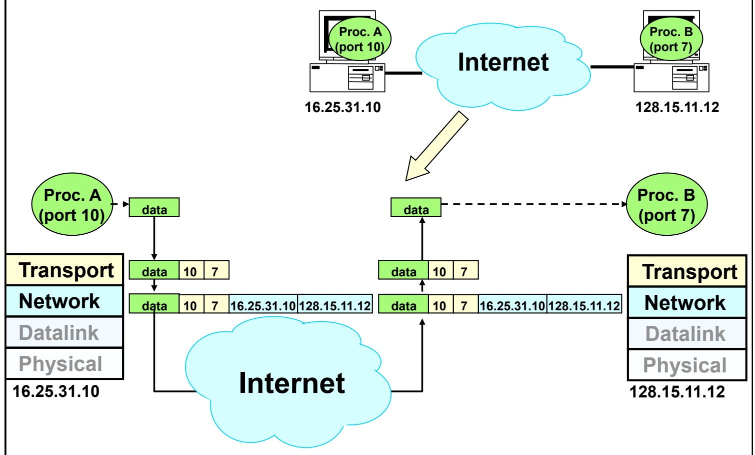
- One or more clients interacting with one or more servers providing a service, e.g.,
  - Web
  - E-mail, chat
  - Printer
  - Airline reservation
  - On-line shopping
  - Store/streaming video, audio, and/or photos
  - …
- In this lecture
  - End-to-end message communication
  - Remote Procedure Calls
  - World Wide Web

Message Passing

- Process A (e.g., client) sends a packet to process B (e.g., server)



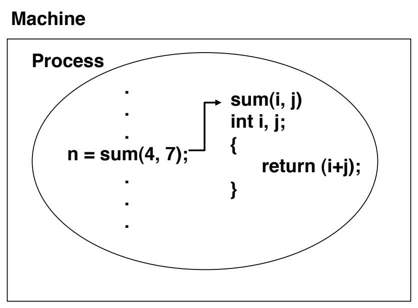
Message Passing Details



From Message Passing to Remote Procedure Call

- Raw messaging is a bit too low-level for programming
- Another option: Remote Procedure Call (RPC)
  - Looks like a local procedure call on client
  - Translated automatically into a procedure call on remote machine (server)
- RPC's can be used to communicate between address spaces on different machines *or the same machine*
  - Services can be run wherever it's most appropriate
  - Access to local and remote services looks the same
- Examples of modern RPC systems:
  - CORBA (Common Object Request Broker Architecture)
  - DCOM (Distributed COM)
  - RMI (Java Remote Method Invocation)
- Implementation:
  - Uses request/response message passing "under the covers"

Example: Local Procedure Call



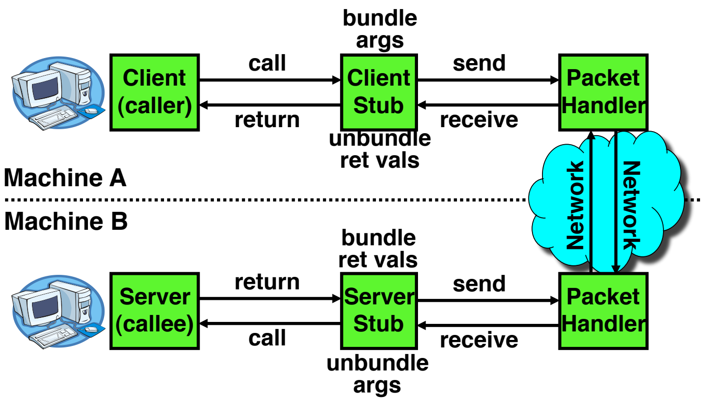
Remote Procedure Call

- **Transparently** invoke a procedure (services) implemented in a different address space either on the same machine or a **different** machine
  - Services can be run wherever it's most appropriate
  - Access to local and remote services looks the same
- Challenges:
  - Argument (parameter) passing, potentially across different architectures
  - Discover where the service is located
  - Handle failures **transparently**

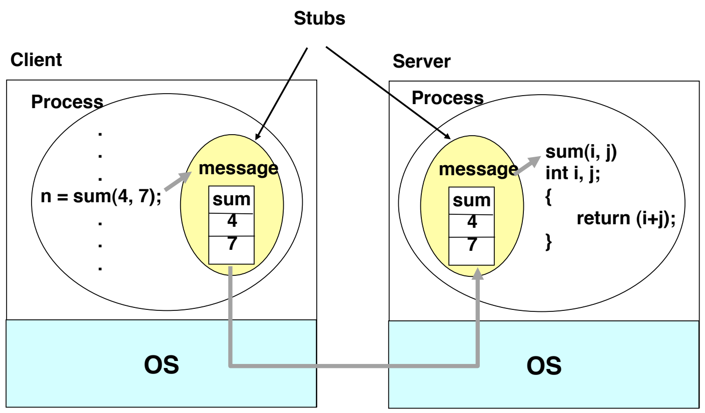
RPC: Argument Passing

- Client and server use “stubs” to glue pieces together
  - Client-side stub is responsible for “marshalling” arguments and “unmarshalling” the return values
  - Server-side stub is responsible for “unmarshalling” arguments and “marshalling” the return values
- Marshalling involves (depending on system) converting values to a canonical form, serializing objects, copying arguments passed by reference, etc.
  - Needs to account for cross-language and cross-platform issues
- Technique: compiler generated stubs
  - Input: interface definition language (IDL)
    - » Contains, among other things, types of arguments/return
  - Output: stub code in the appropriate source language

RPC Information Flow

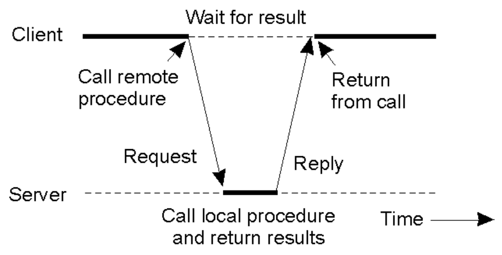


Example: Remote Procedure Call



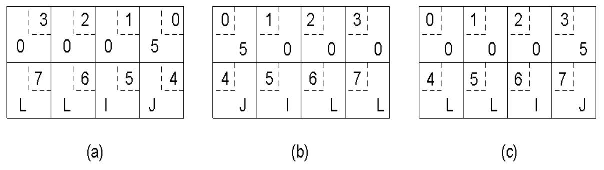
Client and Server Stubs

- Principle of RPC between a client and server program.



Encoding

- Server and client may encode arguments differently, e.g.,
  - Big-endian: store from most-to-least significant byte
  - Little-endian: store from least-to-most significant byte



a) Original message on x86 (e.g., little endian)

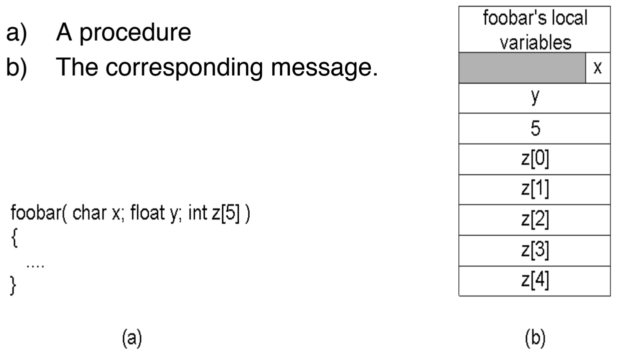
b) The message after receipt on the SPARC (e.g., big endian)

c) The message after being inverted. (The little numbers in boxes indicate the address of each byte)

Parameter Specification and Stub Generation

a) A procedure

b) The corresponding message.

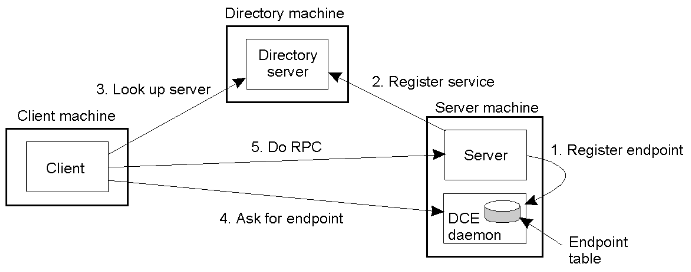


Service Discovery: RPC Binding

- How does client know which machine to send RPC?
  - Need to translate name of remote service into network endpoint (e.g., host:port)
  - Binding: the process of converting a user-visible name into a network endpoint
    - » Static: fixed at compile time
    - » Dynamic: performed at runtime
- Dynamic Binding
  - Most RPC systems use dynamic binding via name service
  - Why dynamic binding?
    - » Access control: check who is permitted to access service
    - » Fail-over: If server fails, use a different one

Example of RPC Binding

- Distributed Computing Environment (DCE) framework
- DCE daemon:
  - Allow local services to record their services locally
  - Resolve service name to local end-point (i.e., port)
- Directory machine: resolve service name to DCE daemon (host:port') on machine running the service



Page 4

RPC Semantics in the Presence of Failures

- The client is unable to locate the server
- The request message from the client to server is lost
- The reply message from the server is lost
- The server crashes after receiving a request
- The client crashes after sending a request

Client is Unable to Locate Server

- Causes: server down, different version of server binary, …
- Fixes
  - Return (-1) to indicate failure (in Unix use *errno* to indicate failure type)
    - » What if (-1) is a legal return value?
  - Use exceptions
    - » Transparency is lost

Lost Request Message

- Easiest to deal with
- Just retransmit the message!
- If multiple message are lost then
  - "client is unable to locate server" error

Lost Reply Message

- Far more difficult to deal with: client doesn't know what happened at server
  - Did server execute the procedure or not?
- Possible fixes
  - Retransmit the request
    - » Only works if operation is **idempotent**: it's fine to execute it twice
  - What if operation not idempotent?
    - » Assign unique sequence numbers to every request

Server Crashes

- Three cases
  - Crash after execution
  - Crash before execution
  - Crash during the execution
- Three possible semantics
  - At least once semantics
    - » Client keeps trying until it gets a reply
  - At most once semantics
    - » Client gives up on failure
  - Exactly once semantics
    - » Can this be correctly implemented?

Client Crashes

- Let's the server computation **orphan**
- Orphans can
  - Waste CPU cycles
  - Lock files
  - Client reboots and it gets the old reply immediately

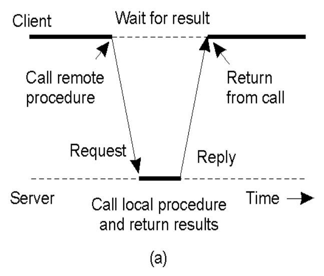
Client Crashes: Possible Solutions

- Extermination:
  - Client keeps a log, reads it when reboots, and kills the orphan
  - Disadvantage: high overhead to maintain the log
- Reincarnation:
  - Divide times in epochs
  - Client broadcasts epoch when reboots
  - Upon hearing a new epoch servers kills the orphans
  - Disadvantage: doesn't solve problem when network partitioned
- Expiration:
  - Each RPC is given a lease T to finish computation
  - If it does not, it needs to ask for another lease
  - If client reboots after T sec all orphans are gone
  - Problem: what is a good value of T?

RPC Semantics: Discussion

- The original goal: provide the same semantics as a local call
- Impossible to achieve in a distributed system
  - Dealing with remote failures fundamentally affects transparency
- Ideal interface: balance the easy of use with making visible the errors to users

Asynchronous RPC (1)

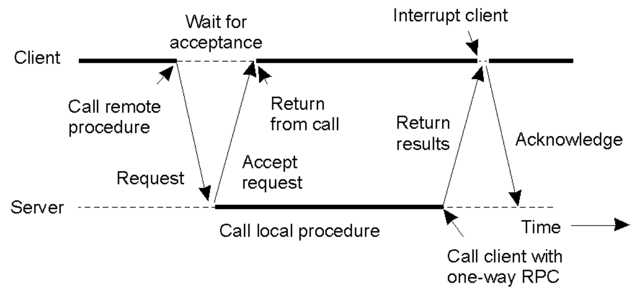


a) The interconnection between client and server in a traditional RPC

b) The interaction using asynchronous RPC

Asynchronous RPC (2)

- A client and server interacting through two asynchronous RPCs



Administrivia

- Prof. Joseph's office hours this week
  - Monday 2:30-3:30pm
  - Tuesday 1-2pm
- Prof. Joseph will not have office hours next week
- Final exam – Thu Dec 15 8-11am 155 Dwinelle
  - Comprehensive
  - Closed book, one double-sided handwritten notes sheet
  - Let us know any conflicts ASAP

How about trying undergraduate research?

- Work at cutting edge of EECS
- Meet profs, grad students outside class
- See if you'd enjoy graduate school
- Make résumé more competitive

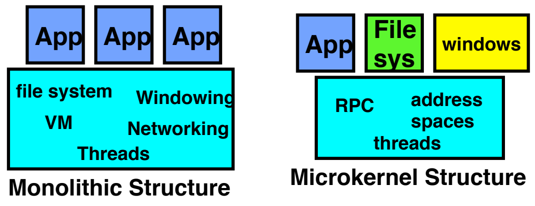
Prof. Armando Fox will give an informal presentation on "getting started in undergrad research" on Tuesday, Nov. 15, 5:30pm in the Woz

(he's the one on the left)

5min Break

Microkernel operating systems

- Example: split kernel into application-level servers.
  - File system looks remote, even though on same machine



- Why split the OS into separate domains?
  - Fault isolation: bugs are more isolated (build a firewall)
  - Enforces modularity: allows incremental upgrades of pieces of software (client or server)
  - Location transparent: service can be local or remote
    - » For example in the X windowing system: Each X client can be on a separate machine from X server; Neither has to run on the machine with the frame buffer.

The Web – History (I)

Vannevar Bush (1890-1974)

- 1945: Vannevar Bush, Memex:
- *"a device in which an individual stores all his books, records, and communications, and which is mechanized so that it may be consulted with exceeding speed and flexibility"*

(See http://www.iath.virginia.edu/elab/hfl0051.html)

The Web – History (II)

Ted Nelson

- 1967, Ted Nelson, 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 documents
- Coined the term "Hypertext"

The Web – History (III)

Tim Berners-Lee

- World Wide Web (WWW): a distributed database of "pages" linked through Hypertext Transport Protocol (HTTP)
  - First HTTP 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

The Web

- Core components:
  - Servers: store files and execute remote commands
  - Browsers: retrieve and display "pages"
  - Uniform Resource Locators (URLs): way to refer to pages
- A protocol to transfer information between clients and servers
  - HTTP

Uniform Record Locator (URL)

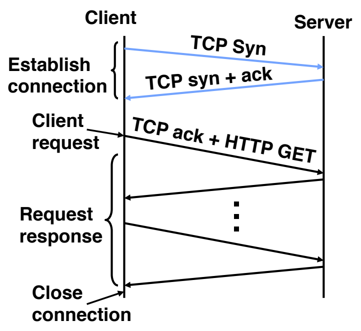
```
protocol://host-name:port/directory-path/resource
```

- Extend the idea of hierarchical namespaces to include anything in a file system
  - ftp://www.cs.berkeley.edu/~adj/publications.html
- Extend to program executions as well…
  - http://us.f413.mail.yahoo.com/ym/ShowLetter?box=%40B%40Bulk&MsgId=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

Hyper Text Transfer Protocol (HTTP)

- Client-server architecture
- Synchronous request/reply protocol
  - Runs over TCP, Port 80
- Stateless

Big Picture



Hyper Text Transfer Protocol Commands

- GET – transfer resource from given URL
- HEAD – GET resource metadata (headers) only
- PUT – store/modify resource under given URL
- DELETE – remove resource
- POST – provide input for a process identified by the given URL (usually used to post CGI parameters)

Response Codes

- 1x informational
- 2x success
- 3x redirection
- 4x client error in request
- 5x server error; can’t satisfy the request

Client Request

- Steps to get the resource:

  http://www.eecs.berkeley.edu/index.html

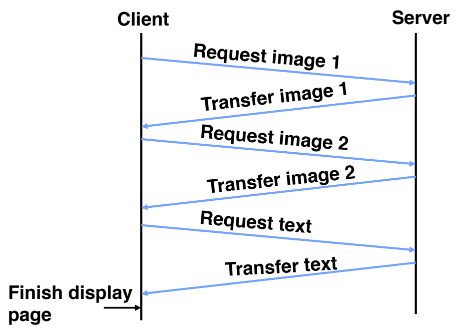
  1. Use DNS to obtain the IP address of www.eecs.berkeley.edu
  2. Send to an HTTP request:

```
GET /index.html HTTP/1.0
```

Server Response

```
HTTP/1.0 200 OK
Content-Type: text/html
Content-Length: 1234
Last-Modified: Mon, 19 Nov
2001 15:31:20 GMT
<HTML>
<HEAD>
<TITLE>EECS Home Page</TITLE>
</HEAD>
…
</BODY>
</HTML>
```

HTTP/1.0 Example



HTTP/1.0 Performance

- Create a new TCP connection for each resource
  - Large number of embedded objects in a web page
  - Many short lived connections
- TCP transfer
  - Too slow for small object
  - It takes time to ramp-up (i.e., exit slow-start phase)
- Connections may be set up in parallel (5 is default in most browsers)

HTTP/1.0 Caching Support

- A modifier to the GET request:
  - If-modified-since – return a "not modified" response if resource was not modified since specified time
- A response header:
  - Expires – specify to the client for how long it is safe to cache the resource
- A request directive:
  - No-cache – ignore all caches and get resource directly from server
- These features can be best taken advantage of with HTTP proxies
  - Locality of reference increases if many clients share a proxy

HTTP/1.1 (1996)

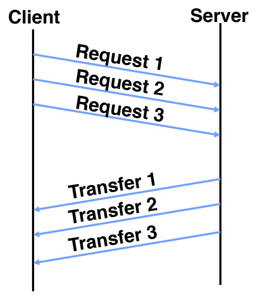
- Performance:
  - Persistent connections
  - Pipelined requests/responses
  - …
- Efficient caching support
  - Network Cache assumed more explicitly in the design
  - Gives more control to the server on how it wants data cached
- Support for virtual hosting
  - Allows to run multiple web servers on the same machine

Persistent Connections

- Allow multiple transfers over one connection
- Avoid multiple TCP connection setups
- Avoid multiple TCP slow starts (i.e., TCP ramp ups)

Pipelined Requests/Responses

- Buffer requests and responses to reduce the number of packets
- Multiple requests can be contained in one TCP segment
- Note: order of responses has to be maintained



Caching and Replication

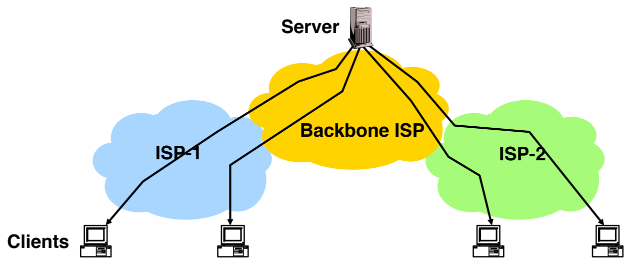
- Problem: You are a web content provider
  - How do you handle millions of web clients?
  - How do you ensure that all clients experience good performance?
  - How do you maintain availability in the presence of server and network failures?
- Solutions:
  - Add more servers at different locations → If you are CNN this might work!
  - Client-side and/or server-side Caching
  - Content Distribution Networks (Replication)

WWW Caching

- Use client-side caching to reduce number of interactions between clients and servers and/or reduce the size of the interactions:
  - Time-to-Live (TTL) fields – HTTP “Expires” header from server
  - Client polling – HTTP “If-Modified-Since” request headers from clients
  - Server refresh – HTML “META Refresh tag” causes periodic client poll
- What is the polling frequency for clients and servers?
  - Could be adaptive based upon a page’s age and its rate of change
- Server load is still significant!

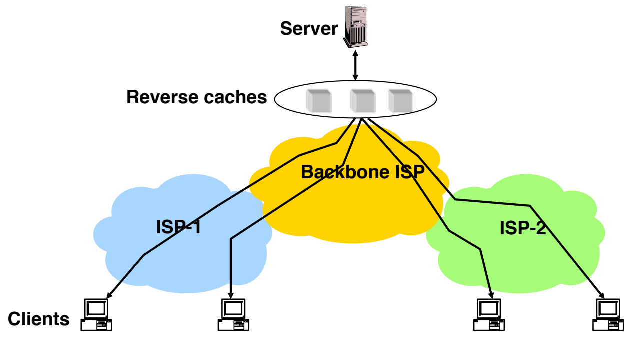
“Base-line”

- Many clients transfer same information
  - Generate unnecessary server and network load
  - Clients experience unnecessary latency



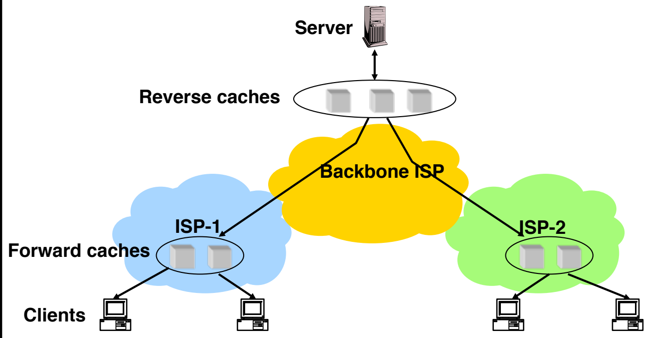
Reverse Caches

- Cache documents close to server → decrease server load
- Typically done by content providers
- Offloads busy server machines



Forward Proxies

- Cache documents close to clients → reduce network traffic and decrease latency
- Typically done by ISPs or corporate LANs



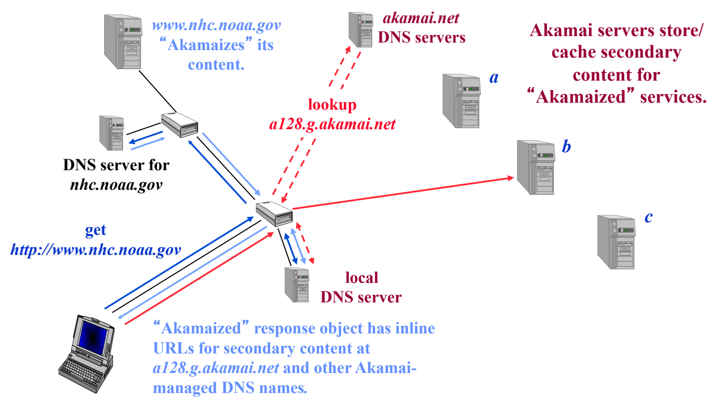
Content Distribution Networks (CDNs)

- Integrate forward and reverse caching functionalities into one overlay network (usually) administrated by one entity
  - Example: Akamai
- Documents are cached both
  - As a result of clients' requests (pull)
  - Pushed in the expectation of a high access rate
- Beside caching do processing, e.g.,
  - Handle dynamic web pages
  - Transcoding

Example: Akamai

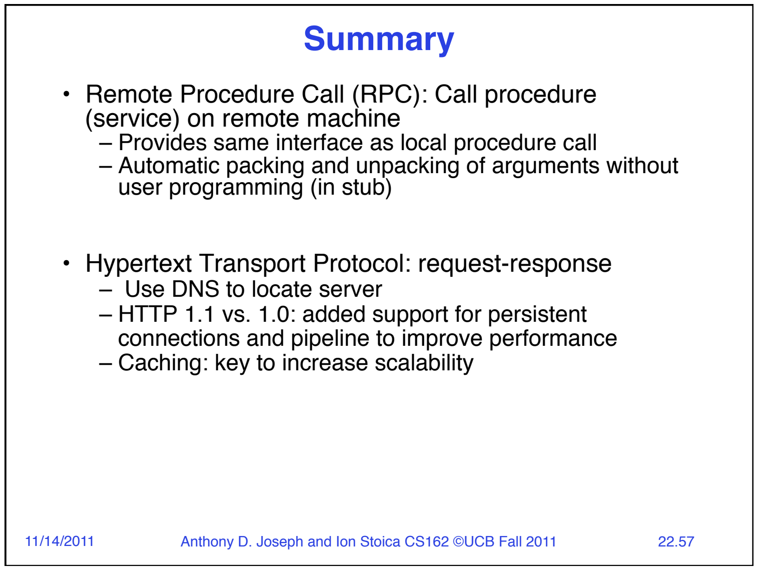
- Akamai creates new domain names for each client content provider.
  - e.g., *a128.g.akamai.net*
- The CDN's DNS servers are authoritative for the new domains
- The client content provider modifies its content so that embedded URLs reference the new domains.
  - "Akamaize" content, e.g.: *http://www.cnn.com/image-of-the-day.gif* becomes *http://a128.g.akamai.net/image-of-the-day.gif*.

Example: Akamai



Caching Challenges

- Caching static traffic easy, but only ~40% of traffic
- Dynamic and multimedia is harder
  - Multimedia is a big win: Megabytes versus Kilobytes
- Same cache consistency problems as before
- Caching is changing the Internet architecture
  - Places functionality at higher levels of comm. protocols



Summary

- Remote Procedure Call (RPC): Call procedure (service) on remote machine
  - Provides same interface as local procedure call
  - Automatic packing and unpacking of arguments without user programming (in stub)
- Hypertext Transport Protocol: request-response
  - Use DNS to locate server
  - HTTP 1.1 vs. 1.0: added support for persistent connections and pipeline to improve performance
  - Caching: key to increase scalability