CS 194: Distributed Systems
Final Review

Scott Shenker and Ion Stoica
Computer Science Division
Department of Electrical Engineering and Computer Sciences
University of California, Berkeley
Berkeley, CA 94720-1776

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During this Class…

- Learn the basics of distributed systems
- Two parts:
- First part: traditional distributed system theory
  - Algorithms and protocols to implement basic services
- Second part: examples of distributed systems
  - Illustrate the context in which classic algorithms/protocols are used
  - Discuss the non-traditional distributed systems

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Traditional Distributed Systems Theory

- Deal with implementing services required to build such systems
  - Usually strong assumptions and semantics

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Clock Synchronization

- Real clocks:
  - Cristian's algorithm (UTC time-server based)
  - Berkeley algorithm (no UTC signal, but master)
- Logical clocks: capture the causality between events in a distributed system
  - E.g., Lamport timestamps

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Elections

- Need to select a special node, that all other nodes agree on
- Assume all nodes have unique ID
- Example methods for picking node with highest ID
  - Bully algorithm
  - Gossip method

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Exclusion

- Ensuring that a critical resource is accessed by no more than one process at the same time
- Methods:
  - Centralized coordinator: ask, get permission, release
  - Distributed coordinator: treat all nodes as coordinator
    - If two nodes are competing, timestamps resolve conflict
  - Interlocking permission sets: Every node I asks permission from set P[I], where P[I] and P[J] always have nonempty intersections

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Concurrency Control

- Want to allow several transactions to be in progress
- But the result must be the same as some sequential order of transactions
- Use locking policies:
  - Grab and hold
  - Grab and unlock when not needed
  - Lock when first needed, unlock when done
  - Two-phase locking
- Which policies can have deadlock?

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Agreement

- How do two or more processes reach agreement?
- **Two-Army Problem**
  - Assumptions
    - Processes are correct
    - Adversary can intercept messages
  - No solution
- **Byzantine agreement**
  - Assumptions:
    - Processes subject to arbitrary failures
    - Messages delivery is correct, and bounded
  - Solution: In a system with m faulty processes agreement can be achieved only if there are $2m+1$ functioning correctly

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Distributed Commit

- **Goal**: Either **all** members of a group decide to perform an operation, or **none** of them perform the operation
- Assumptions:
  - Crash failures that can be recovered
  - Communication failures detectable by timeouts
- Solution: two phase commit (2PC)
- Notes:
  - Commit requires a set of processes to agree…
  - …similar to the two-army problem…
  - … but solvable because simpler because stronger assumptions

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Group Communication

- **Reliable multicast**: all non-faulty processes which do not join/leave during communication receive the message
  - Example: SRM
- **Atomic multicast**: all messages are delivered in the same order to all processes
  - Birman et al. algorithm

Multicast	Basic Message Ordering	Total-ordered Delivery?
Reliable multicast	None	No
FIFO multicast	FIFO-ordered delivery	No
Causal multicast	Causal-ordered delivery	No
Atomic multicast	None	Yes
FIFO atomic multicast	FIFO-ordered delivery	Yes
Causal atomic multicast	Causal-ordered delivery	Yes

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Data Replication and Consistency

- Scalability requires replicated data
- Application correctness requires some form of consistency
  - Here we focus on individual operations, not transactions
- Consistency models:
  - Strict consistency (in your dreams…)
  - Linearizable (in your proofs….)
  - Sequential consistency: same order of operations
  - Causal consistency: all causal operations ordered
  - FIFO consistency: operations within process ordered
- Mechanisms
  - Local cache replicas: pull, push, lease (produce sequential consistency)
  - Replicated-write protocols: quorum techniques

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Security (Requirements)

- **Authentication**: ensures that sender and receiver are who they are claiming to be
- **Data integrity**: ensure that data is not changed from source to destination
- **Confidentiality**: ensures that data is red only by authorized users
- **Non-repudiation**: ensures that the sender has strong evidence that the receiver has received the message, and the receiver has strong evidence of the sender identity (not discussed in this class)

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Security (Solutions)

- Security foundation: cryptographic algorithms
  - Secret key cryptography, Data Encryption Standard (DES)
  - Public key cryptography, RSA algorithm
  - Message digest, MD5
- Confidentiality → data encryption
- Integrity → digital signature
- Authentication
  - Shared secrete key based authentication
  - Key Distribution Center (KDC) based authentication
    - E.g., Needham-Schroeder Protocol
  - Public key cryptography authentication
- Key management → Public Key Infrastructure (PKI), Kerberos

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Final Exam Information

- Date, time: May 19, 12:30-3:30pm
- Final will include midterm material (1/3), but emphasize on second part (2/3)
  - This lecture reviews mainly the second part material
  - See midterm review for first part material!
- We'll post a practice exam by the end of this week
- Closed books; 8,5"x11" crib sheet (both sides)
- No calculators, PDAs, cell phones with cameras, etc
- Please use PENCIL and ERASER

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Outline

- Distributed File Systems
- Distributed Object-based Systems
- Coordination Systems
- Web

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Distributed File Systems

- Provide a client **transparent** access to files stored at a **remote** server
- Why would you want to store files remotely?
  - Sharing files
  - Reliability
  - Manageability

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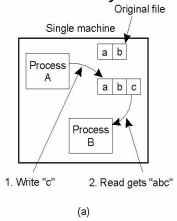
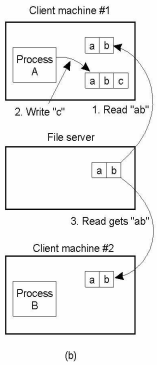
Semantics of File Sharing

a) On a single processor, when a *read* follows a *write*, the value returned by the *read* is the value just written

b) In a distributed system with caching, obsolete values may be returned





Semantics of File Sharing

Method	Comment
UNIX semantics	Every operation on a file is instantly visible to all processes
Session semantics	No changes are visible to other processes until the file is closed
Immutable files	No updates are possible; simplifies sharing and replication
Transaction	All changes occur atomically

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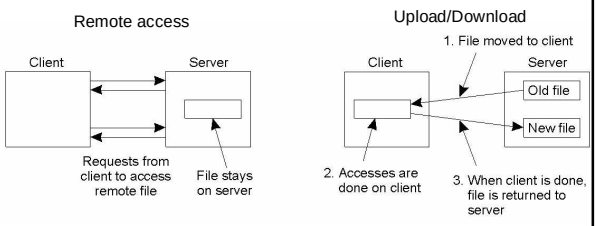
Access Model

- Two access models :
  - Remote access
  - Upload/Download



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Stateful vs. Stateless

- Stateless model: each call contains complete information to execute operation
- Stateful model: server maintain context (info) shared by consecutive operations
- Discussion: compare stateless and stateful design

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Network File System (NSF)

- A specification for a distributed file system (by Sun, 1984)
  - Implemented on various OS's
  - De facto standard in the UNIX community
  - Latest version is 4 (2000)
- NSF v1-v3
  - File sharing semantics: UNIX (if no caching)
  - Access model: remote access
  - Stateless design
- NSF v4:
  - File sharing semantics: session
  - Access model: upload/download
  - Stateful design

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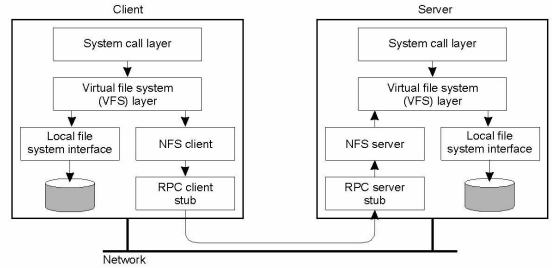
NFS Architecture

- Virtual File System (VFS) provide a uniform access to local and remote files



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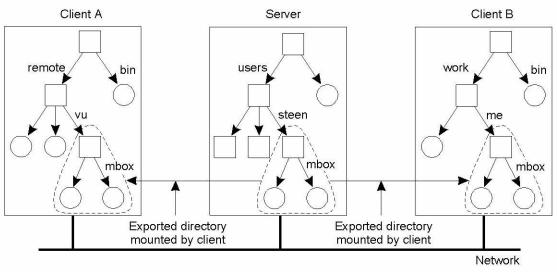
Naming

- Allow a client to mount a remote file system into its own local file system
- Pathnames are **not** globally unique; what's the implication?



CODA

- Developed at CMU
  - Based on Andrew File System (AFS), another distributed system developed at CMU
- Goals
  - **Scalability:** system should grow without major problems
  - **Fault-Tolerance:** system should remain usable in the presence of server failures, communication failures and voluntary disconnections
  - **Disconnected mode** for **portable computers**
- **Design philosophy: Scalability and Accessibility more important than consistency**

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CODA

- Sharing model: transaction
  - Session viewed as a transaction
- Access model: upload/download

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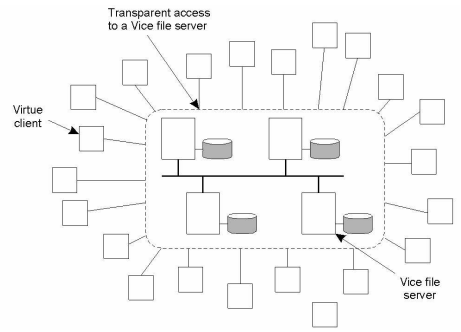
Overall Organization of AFS & Coda



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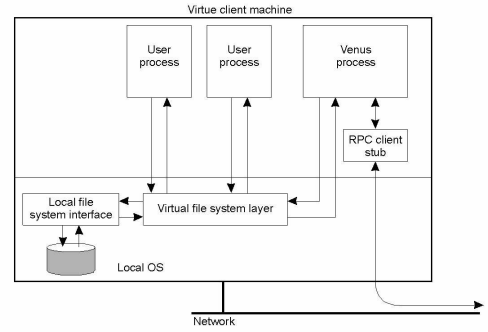
Internal Organization of Virtue



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Communication

- Based on RPC2: provides reliable transmission on top of UDP
- RPC2 supports side-effects, i.e., user defined protocols
- RPC2 provides support for multicast
  - Transparent for the client

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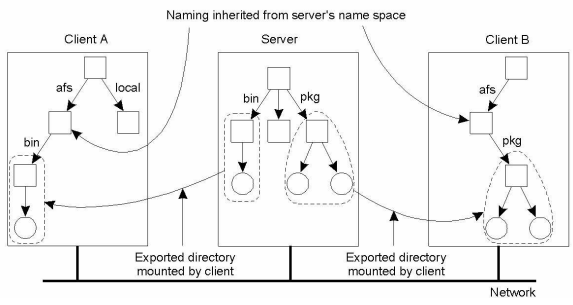
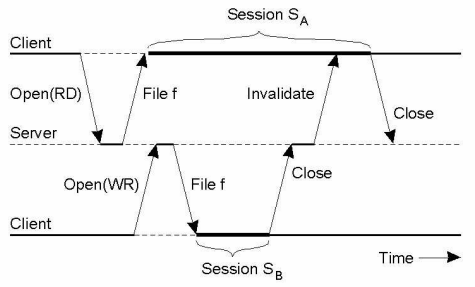
Naming

- Single shared naming space (vs. client-based in NFS)



Sharing Files in Coda

- Transaction semantics: session is treated like a transaction



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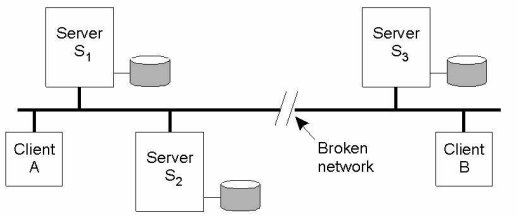
Handling Network Partition

- Versioning vector when partition happens: [1,1,1]
- Client A updates file → versioning vector in its partition: [2,2,1]
- Client B updates file → versioning vector in its partition: [1,1,2]
- Partition repaired → compare versioning vectors: **conflict**!



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Outline

- Distributed File Systems
- Distributed Object-based Systems
- Coordination Systems
- Web

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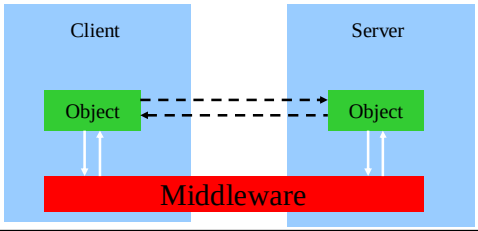
Distributed Object-based Systems

- Goal: **transparently** access remote objects in a distributed system
- Challenges:
  - Ensure semantics of invoking a **local** object
  - Accommodate heterogeneity, e.g., multiple languages, OSes, …



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Two Examples

- Common Object Request Broker Architecture (CORBA)
  - International standard: multiple languages, OSes, vendors
- Distributed Common Object Model (DCOM)
  - MS standard: only MS OSes

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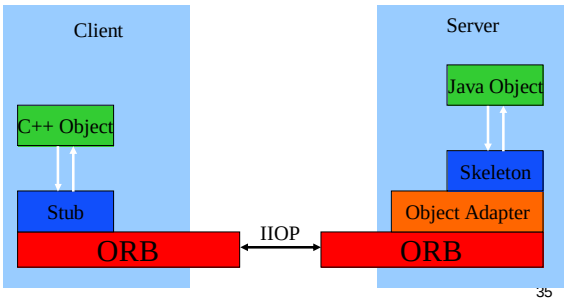
CORBA Architecture

- Remote-object: object implementation resides in server's address space



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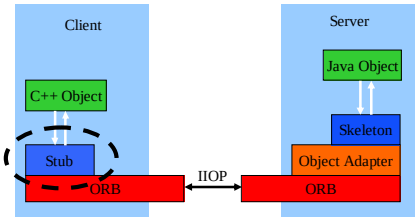
Stub

- Provides interface between client object and ORB
- Marshalling: client invocation
- Unmarshalling: server response



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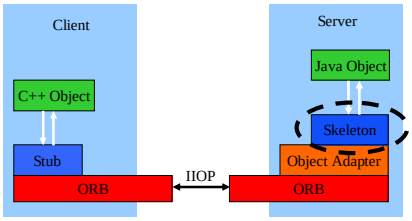
Skeleton

- Provides iterface between server object and ORB
- Unmarshaling: client invocation
- Marshaling: server response



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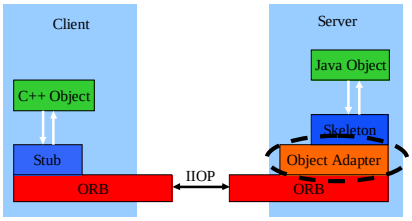
(Portable) Object Adapter (POA)

- Register class implementations
- Creates and destroys objects
- Handles method invokation
- Handles client authentication and access control



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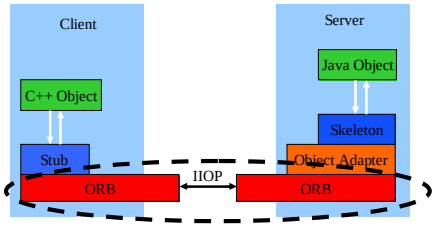
Object Request Broker (ORB)

- Communication infrastructure sending messages between objects
- Communication type:
  - GIOP (General Inter-ORB Protocol)
  - IIOP (Internet Inter-ORB Protocol) (GIOP on TCP/IP)



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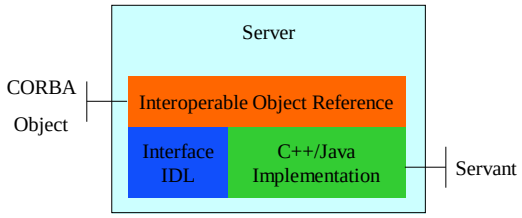
CORBA Object



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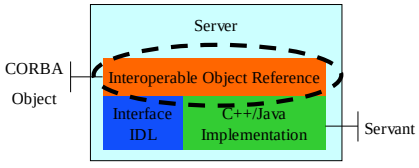
Interoperable Object Reference (IOR)

- Uniquely identifies an object (see object references)



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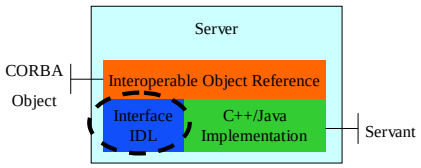
Interface Definition Language (IDL)

- Describes interface
- Language independent
- Client and server platform independent



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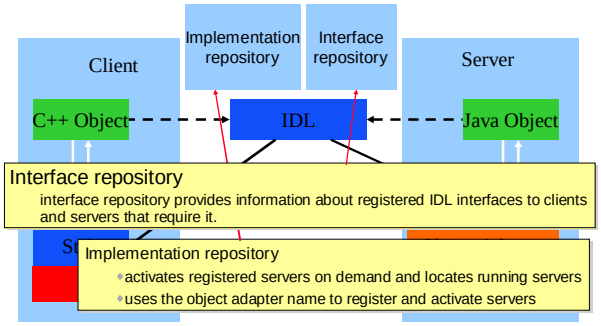
Overall CORBA Architecture



Example of CORBA Services

- Naming: Keeps track of association between object names and their reference. Allows ORB to locate referenced objects
- Life Cycle: Handles the creation, copying, moving, and deletion objects
- Trader: A "yellow pages" for objects. Lets you find them by the services they provide
- Event: Facilitates asynchronous communications through events
- Concurrency: Manages locks so objects can share resources
- Query: Locates objects by specified search criteria
- …

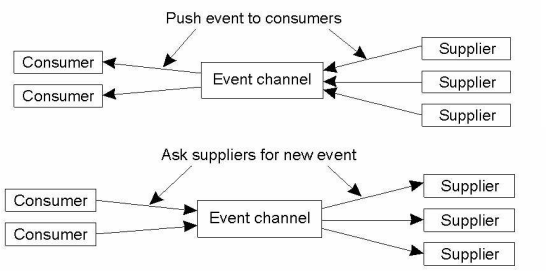
Object Invocation Models

- Invocation models supported in CORBA

Request type	Failure semantics	Description
Synchronous	At-most-once	Caller blocks until a response is returned or an exception is raised
One-way	Best effort delivery	Caller continues immediately without waiting for any response from the server
Deferred synchronous	At-most-once	Caller continues immediately and can later block until response is delivered

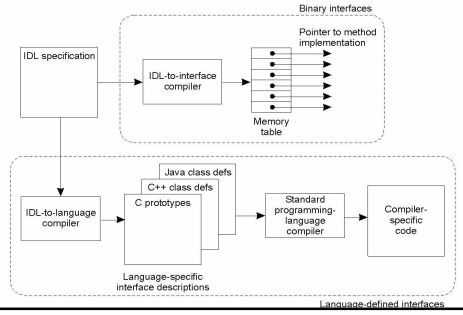
Event and Notification Services

- Models:
  - Push: consumers need to register to a channel
  - Pull: consumers explicitly ask for events

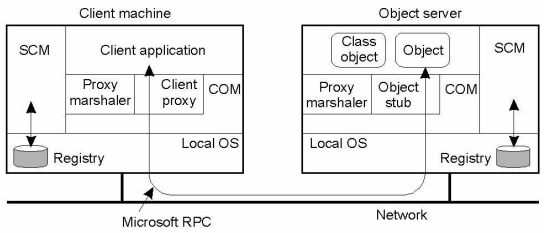


CORBA vs DCOM

- CORBA: language-defined interface
- DCOM: binary interface



DCOM Architecture



- SCM: Service Control Manager

Creating objects

- Classes of objects have globally unique identifiers (GUIDs)
  - 128 bit numbers
  - Also called class ids (CLSID)
- DCOM provides functions to create objects given a server name and a class id
  - The SCM on the client connects to the SCM of the server and requests creation of the object

Outline

- Distributed File Systems
- Distributed Object-based Systems
- Coordination Systems
- Web

Coordination Systems

- Handle all communication and cooperation between processes/objects in a distributed system
  - Emphasize **not** on transparency
  - Object distribution is **explicit**
- Can be classified along two dimensions:
  - **Temporal**: do sender and receiver need to be active simultaneously?
  - **Referential**: do sender need to know the identifier of the receiver?

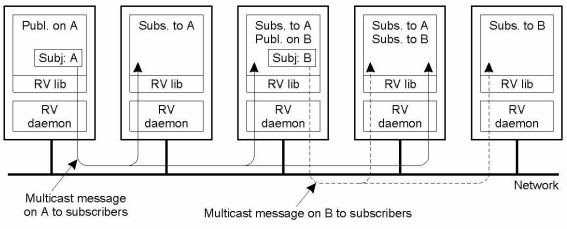
Taxonomy of Coordination Models

Referential \ Temporal	Coupled	Uncoupled
Coupled	Direct	Mailbox
Uncoupled	Meeting oriented	Generative communication

TIB/Rendezvous System

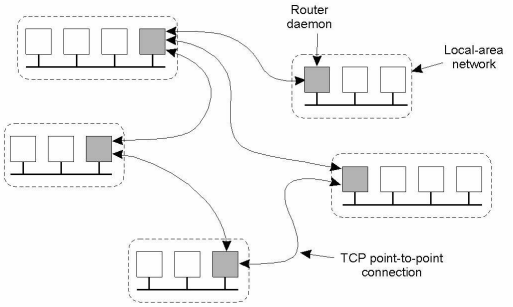
- Meeting oriented model (a.k.a. publish/subscriber)
- Build around concept of **information bus**
- Messages are **subject-based** addressed
  - A message doesn't specify destination, but a **subject name**
- A message is delivered to all objects interested in message's subject

TIB/Rendezvous Architecture



Wide-area Architecture

- Use IP multicast on LANs
- Overlay multicast in wide-area



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Communication Primitives

- **send()**: send message; non-blocking operation
- **sendreply()**: send a reply upon receiving a message; non-blocking operation
- **sendrequest()**: send message; blocks until a reply is received
- No receive operation; received messages are handled via events

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Events

- To subscribe to a subject, create a **listener event** object
- **Listener event** contains reference to a callback function
- When a message arrives, create an **event object** and enque it in an **event queue**
- Each **event queue** is associated a **dispatcher thread**
- **Dispatcher thread** removes object at the head of the queue and invokes callback function

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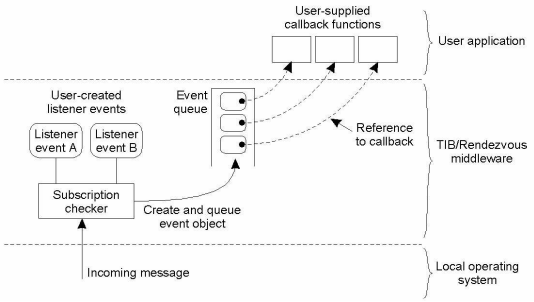
Handling Events



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Jini

- Generative communication model
- Built around the concept of tuple space
  - First proposed by Linda
- Tuple space
  - Distributed associative memory
  - Instantiated as a JavaSpace in Jini
- In addition, Jini
  - Provide distributed event and notification system
  - Allow clients discover services when become available

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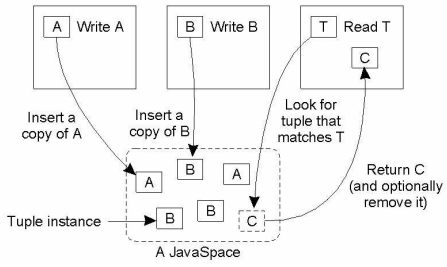
JavaSpace

- **write()**: create an object copy and store it in JavaSpace
- **read()**: return tuples from JavaSpace that match a template
- **take()**: like read, but removes tuple from JavaSpace



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Events

- A client can register with an object that has events of interest
- A client can tell object to pass event to another process
- Notification implemented by remote call

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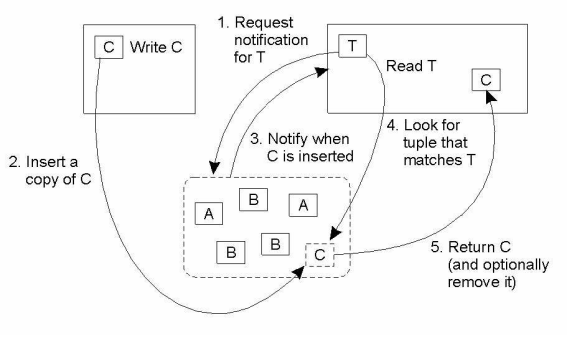
Using Events with JavaSpaces



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The Web

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

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Web Architecture

- 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

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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/~istoica/cs194/05/lecture.ppt
- 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

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Hyper Text Transfer Protocol (HTTP)

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

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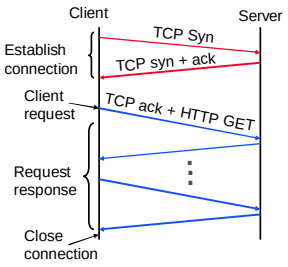
Big Picture



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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)

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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
     ```

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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>
```

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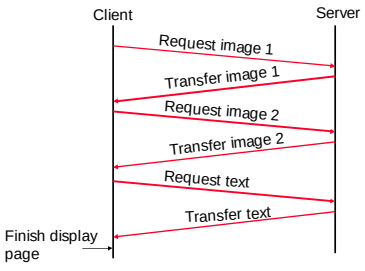
HTTP/1.0 Example



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HHTP/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
  - May never exit slow-start phase
- Connections may be set up in parallel (5 is default in most browsers)

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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

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Final Exam Information

- Date, time: May 19, 12:30-3:30pm
- Final will include midterm material (1/3), but emphasize on second part (2/3)
  - This lecture reviews mainly the second part material
  - See midterm review for first part material!
- We'll post a practice exam by the end of this week
- Closed books; 8,5"x11" crib sheet (both sides)
- No calculators, PDAs, cell phones with cameras, etc
- Please use PENCIL and ERASER

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