CS162
Operating Systems and Systems Programming
Lecture 23

Remote Procedure Call

November 27, 2013
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Goals for Today

- Remote Procedure Call
- Examples using RPC
  - Distributed File Systems
  - World-Wide Web

Note: Some slides and/or pictures in the following are adapted from slides ©2005 Silberschatz, Galvin, and Gagne, notes by Joseph and Kubiatowicz.

Distributed Systems – Message Passing

- Distributed systems use a variety of messaging frameworks to communicate:
  - e.g. the protocols for TCP: connecting, flow control, loss…
  - 2PC for transaction processing
  - HTTP GET and POST
  - UDP messages for MS SQL Server (last time)
- Disadvantages of message passing:
  - Complex, stateful protocols, versions, feature creep
  - Need error recovery, data protection, etc.
  - Ad-hoc checks for message integrity
  - Resources consumed on server between messages (DoS risk)
  - Need to program for different OSes, target languages,…
- Want a higher-level abstraction that addresses these issues, but whose effects are application-specific

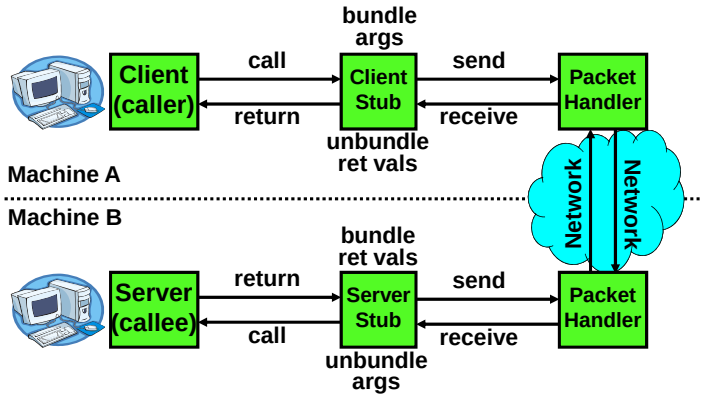
Remote Procedure Call

- Another option: Remote Procedure Call (RPC)
  - Looks like a local procedure call on client:
    ```
    file.read(1024);
    ```
  - Translated automatically into a procedure call on remote machine (server)
- Implementation:
  - Uses request/response message passing "under the covers"
  - Deals with many of the generic challenges of protocols that use message passing – may even be "transactional" - but usually not.
  - Allows the programmer to focus on the message **effects**: as though the procedure were executed on the server.

RPC Details

- Client and server use "stubs" to glue pieces together
  - Client 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



RPC Binding

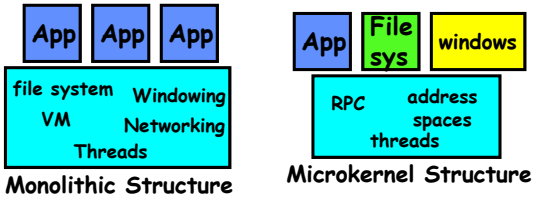
- How does client know which machine to send RPC?
  - Need to translate name of remote service into network endpoint (e.g., host:port)
  - Binding: the process of converting a user-visible name into a network endpoint
    - » This is another word for "naming" at network level
    - » Static: fixed at 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
- Object registry (if used)
  - Contains remote object names and client stub code
  - Allows dynamic loading of remote object stub

Cross-Domain Communication/Location Transparency

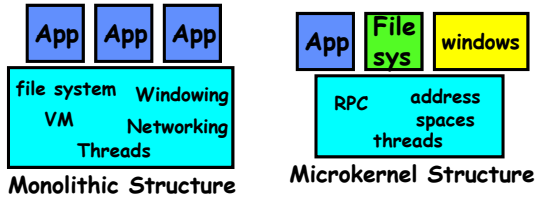
- How do address spaces communicate with one another?
  - Shared Memory with Semaphores, monitors, etc…
  - File System
  - Pipes (1-way communication)
  - "Remote" procedure call (2-way communication)
- RPC's can be used to communicate between address spaces on different machines or the same machine
  - Services can be run wherever it's most appropriate
  - Access to local and remote services looks the same
- Examples of modern RPC systems:
  - ONC/RPC (originally SUN RPC) in Linux, Windows,…
  - DCE/RPC (Distributed Computing Environment/RPC)
  - MSRPC: Microsoft version of DCE/RPC
  - RMI (Java Remote Method Invocation)

Microkernel Operating Systems

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



Microkernel Operating Systems

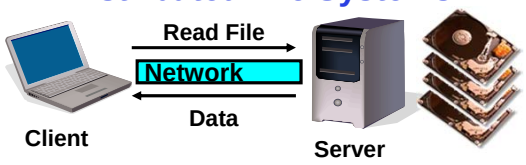


- Why split the OS into separate domains?
  - Fault isolation: bugs are more isolated (build a firewall)
  - Enforces modularity: allows incremental upgrades of pieces of software (client or server)
  - Location transparent: service can be local or remote
    - » For example in the X windowing system: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

Problems with RPC

- Handling failures
  - Different failure modes in distributed system than on a single machine
  - Without RPC a failure within a procedure call usually meant whole application would crash/die
  - With RPC a failure within a procedure call means remote machine crashed, but local one could continue working
  - Answer? Distributed transactions can help
- Performance
  - Cost of Procedure call « same-machine RPC « network RPC
  - Means programmers must be aware they are using RPC (so much for transparency!)
    - » Caching can help, but may make failure handling even more complex

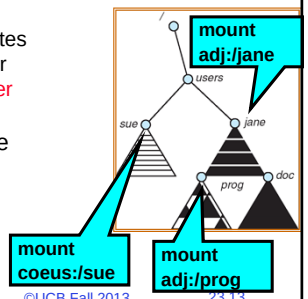
Distributed File Systems



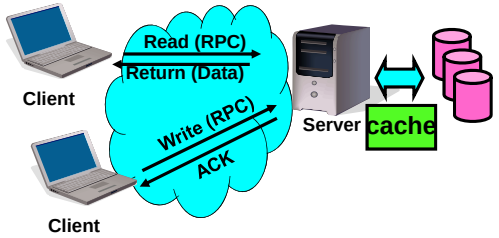
- Distributed File System:
  - **Transparent** access to files stored on a remote disk
  - **Transparent concurrency**: All clients have the same view of the state of the file system.
  - **Failure transparency** The client and client programs should operate correctly after a server failure.
  - **Replication transparency** To support scalability, we may wish to replicate files across multiple servers. Clients should be unaware of this.
  - **Migration transparency** Files should be able to move around without the client's knowledge.

Distributed File Systems

- Naming choices (always an issue):
  - *Hostname:*localname: Name files explicitly
    - » No location or migration transparency
  - *Mounting* of remote file systems
    - » System manager mounts remote file system by giving name and local mount point
    - » Transparent to user: all reads and writes look like local reads and writes to user e.g. /users/sue/foo→/sue/foo on server
  - *A single, global name space:* every file in the world has unique name
    - » Location Transparency: servers can change and files can move without involving user



Simple Distributed File System

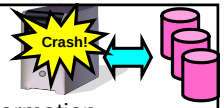


- EVERY read and write gets forwarded to server
- Advantage: Server provides completely consistent view of file system to multiple clients
- Problems? Performance!
  - Going over network is slower than going to local memory
  - Server can be a bottleneck

Failures

- What if server crashes? Can client wait until server comes back up and continue as before?
  - Any data in server memory but not on disk can be lost
  - Shared state across RPC: What if server crashes after seek? Then, when client does "read", it will fail
  - Message retries: suppose server crashes after it does UNIX "rm foo", but before acknowledgment?
    - » Message system will retry: send it again
    - » How does it know not to delete it again? (could solve with two-phase commit protocol, but NFS takes a more ad hoc approach)

Stateless Protocol

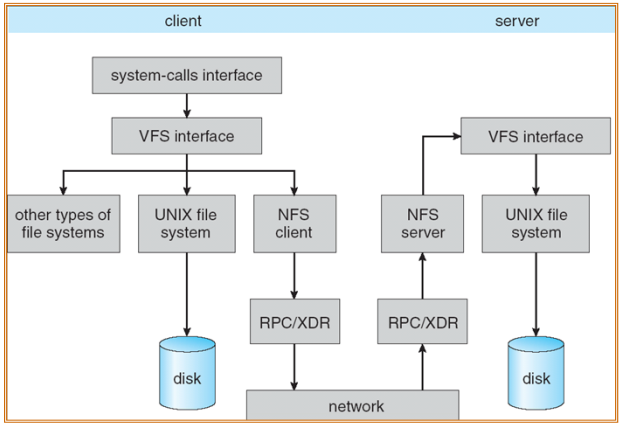


- Stateless protocol: A protocol in which all information required to process a request is passed with request
  - Server keeps no state about client, except as hints to help improve performance (e.g. a cache)
  - Thus, if server crashes and restarted, requests can continue where left off (in many cases)
- What if client crashes?
  - Might lose modified data in client cache
- Examples:
  - HTTP
  - REST (Representational State Transfer)
- Stateful
  - SOAP (Simple Object Access Protocol) - usually over HTTP!

Network File System (NFS)

- Three Layers for NFS system
  - UNIX file-system interface: open, read, write, close calls + file descriptors
  - VFS layer: distinguishes local from remote files
    - » Calls the NFS protocol procedures for remote requests
  - NFS service layer: bottom layer of the architecture
    - » Implements the NFS protocol

Schematic View of NFS Architecture



Network File System (NFS)

- NFS Protocol: RPC for file operations on server
  - Reading/searching a directory
  - Manipulating links and directories
  - Accessing file attributes/reading and writing files
- Write-through caching: Modified data committed to server's disk before results are returned to the client
  - Lose some of the advantages of caching
  - Time to perform write() can be long
  - Need some mechanism for readers to eventually notice changes! (more on this later)

NFS Continued

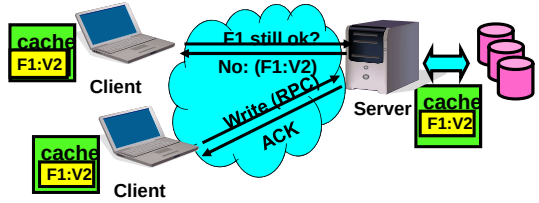
- NFS servers are stateless; each request provides all arguments require for execution
  - E.g. reads include information for entire operation, such as `ReadAt(inumber,position)`, not `Read(openfile)`
  - No need to perform network open() or close() on file – each operation stands on its own
- Idempotent: Performing requests multiple times has same effect as performing it exactly once
  - Example: Server crashes between disk I/O and message send, client resend read, server does operation again
  - Example: Read and write file blocks: just re-read or re-write file block – no side effects
  - Example: What about "remove"? NFS does operation twice and second time returns an advisory error

NFS Continued

- Failure Model: Transparent to client system
  - Is this a good idea? What if you are in the middle of reading a file and server crashes?
  - Options (NFS Provides both):
    - » Hang until server comes back up (next week?)
    - » Return an error. (Of course, most applications don't know they are talking over network)

NFS Cache consistency

- NFS protocol: weak consistency
  - Client polls server periodically to check for changes
    - » Polls server if data hasn't been checked in last 3-30 seconds (exact timeout it tunable parameter).
    - » Thus, when file is changed on one client, server is notified, but other clients use old version of file until timeout.



What if multiple clients write to same file?

- » In NFS, can get either version (or parts of both)
- » Completely arbitrary!

NFS Pros and Cons

- NFS Pros:
  - Simple, Highly portable
- NFS Cons:
  - Sometimes inconsistent!
  - Doesn't scale to large # clients
    - » Must keep checking to see if caches out of date
    - » Server becomes bottleneck due to polling traffic

Andrew File System

- Andrew File System (AFS, late 80's) → DCE DFS (commercial product)
- Callbacks: Server records who has copy of file
  - On changes, server immediately tells all with old copy
  - No polling bandwidth (continuous checking) needed
- Write through on close
  - Changes not propagated to server until close()
  - Session semantics: updates visible to other clients only after the file is closed
    - » As a result, do not get partial writes: all or nothing!
    - » Although, for processes on local machine, updates visible immediately to other programs who have file open
- In AFS, everyone who has file open sees old version
  - Don't get newer versions until reopen file

Andrew File System (con't)

- Data cached on local disk of client as well as memory
  - On open with a cache miss (file not on local disk):
    - » Get file from server, set up callback with server
  - On write followed by close:
    - » Send copy to server; tells all clients with copies to fetch new version from server on next open (using callbacks)
- What if server crashes? Lose all callback state!
  - Reconstruct callback information from client: go ask everyone "who has which files cached?"

Andrew File System (con't)

- AFS Pro: Relative to NFS, less server load:
  - Disk as cache ⇒ more files can be cached locally
  - Callbacks ⇒ server not involved if file is read-only
- For both AFS and NFS: central server is bottleneck!
  - Performance: all writes→server, cache misses→server
  - Availability: Server is single point of failure
  - Cost: server machine's high cost relative to workstation

Administrivia

- MIDTERM II 5:30-7pm in 145 Dwinelle (A-L) and 2060 Valley LSB (M-Z)
  - **Review: 306 Soda 7-9pm, Sunday Dec 1**
  - Covers Lectures #14-24, projects, and readings
  - One sheet of notes, both sides
- **Project 4 Initial Design Due Monday**

5min Break

Quiz 23.1: RPC and NFS

- Q1: True _ False _ RPC requires special networking support and functionality
- Q2: True _ False _ The client and server for RPC must use the same hardware architecture (e.g., little endian)
- Q3: True _ False _ Local procedure call << same-machine RPC << remote machine RPC
- Q4: True _ False _ NFS provides weak client-server data consistency

Quiz 23.1: RPC and NFS

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- Q4: True X False _ NFS provides weak client-server data consistency

Distributed Object-Oriented Systems

Distributed systems, like any complex software benefit from careful software architecture, especially object-oriented programming.

Major efforts were devoted to OOP distributed systems architectures:

- CORBA (Common Object Request Broker Architecture)
- DCOM (Distributed Component Object Model) from MS, which drew heavily from the open system DCE/DFS

These systems use remote methods, and add object proxying and even garbage collection.

Internet-Scale Distributed Computing

- CORBA and DCOM were robust, powerful RPC-based distributed object systems. They were supposed to become the substrate for internet-scale distributed computing. What happened? (they didn't)
- From last time:
  - Morris worm
  - Code Red
  - Slammer …….. which led to…
- Ubiquitous firewalls, packet filters etc., across the internet.
- HTTP (port 80) was the only reliable route to a remote host

Internet-Scale Distributed Computing

- One approach is to tunnel other types of payload (other than HTTP) through port 80, and demultiplex at the server. Usually, but not always, this works.
- Instead many systems have used HTTP directly as a high-level transport for RPC. A cluster of technologies have developed around data messaging, RPC and distributed objects over HTTP:
  - SOAP/WSDL
  - REST
  - and enabled by XML and JSON (JavaScript Object Notation)

WWW- SOAP RPC

SOAP covers the following four main areas:

- **A message format** for one-way communication describing how a message can be packed into an XML document.
- A **description** of how a SOAP message should be transported using HTTP (for Web-based interaction) or SMTP (for e-mail-based interaction).
- A **set of rules** that must be followed when processing a SOAP message and a simple classification of the entities involved in processing a SOAP message.
- A **set of conventions** on how to turn an RPC call into a SOAP message and back.

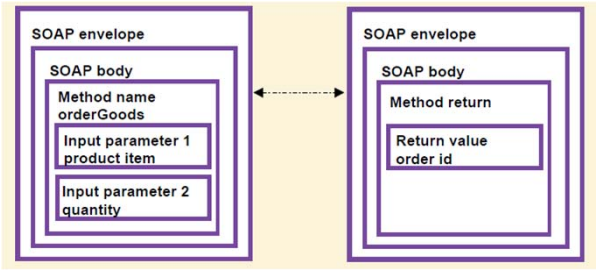
Soap Message

Typically an XML element containing header and body elements

```
<SOAP:Envelope xmlns:SOAP=
      "http://schemas.xmlsoap.org/soap/envelope/">
   <SOAP:Header>
      <!– content of header goes here –>
   </SOAP:Header>
   <SOAP:Body>
      <!– content of body goes here –>
   </SOAP:Body>
</SOAP:Envelope>
```


SOAP RPC

SOAP RPC messages typically encode arguments that are presented to the calling program as parameters and return values:



Soap RPC

```
POST /travelservice
SOAPAction: "http://www.acme-travel.com/flightinfo"
Content-Type: text/xml; charset="utf-8"
Content-Length: nnnn

<SOAP:Envelope xmlns:SOAP=
    "http://schemas.xmlsoap.org/soap/envelope/">
  <SOAP:Body>
    <m:GetFlightInfo
      xmlns:m="http://www.acme-travel.com/flightinfo"
      SOAP:encodingStyle=
        "http://schemas.xmlsoap.org/soap/encoding/"
      xmlns:xsd="http://www.w3.org/2001/XMLSchema"
      xmlns:xsi=
        "http://www.w3.org/2001/XMLSchema-instance">
      <airlineName xsi:type="xsd:string">UL
      </airlineName>
        <flightNumber xsi:type="xsd:int">506
        </flightNumber>
    </m:GetFlightInfo>
  </SOAP:Body>
</SOAP:Envelope>
```


Soap Response

```
HTTP/1.1 200 OK
Content-Type: text/xml; charset="utf-8"
Content-Length: nnnn

<SOAP:Envelope xmlns:SOAP=
    "http://schemas.xmlsoap.org/soap/envelope/">
  <SOAP:Body>
    <m:GetFlightInfoResponse
        xmlns:m="http://www.acme-travel.com/flightinfo"
        SOAP:encodingStyle=
          "http://schemas.xmlsoap.org/soap/encoding/"
        xmlns:xsd="http://www.w3.org/2001/XMLSchema"
        xmlns:xsi=
          "http://www.w3.org/2001/XMLSchema-instance">
      <flightInfo>
        <gate xsi:type="xsd:int">10</gate>
        <status xsi:type="xsd:string">ON TIME</status>
      </flightInfo>
    </m:GetFlightInfoResponse>
  </SOAP:Body>
</SOAP:Envelope>
```


WSDL

Is "Web Services Description Language" an XML format for specifying metadata about a SOAP protocol.

WSDL is used to describe precisely

- ***what*** a service does, i.e., the operations the service provides,
- ***where*** it resides, i.e., details of the protocol specific address, e.g., a URL, and
- ***how*** to invoke it, i.e., details of the data formats and protocols

WSDL

Service Implementation section →

Service Interface section ↓

```
<message name="GetFlightInfoInput">
  <part name="airlineName" type="xsd:string"/>
  <part name="flightNumber" type="xsd:int"/>
</message>

<message name="GetFlightInfoOutput">
  <part name="flightInfo" type="fixsd:FlightInfoType"/>
</message>

<message name="CheckInInput">
  <part name="body" element="eticketxsd:Ticket"/>
</message>

<portType name="AirportServicePortType">
  <operation name="GetFlightInfo">
    <input message="tns:GetFlightInfoInput"/>
    <output message="tns:GetFlightInfoOutput"/>
  </operation>
  <operation name="CheckIn">
    <input message="tns:CheckInInput"/>
</operation>
</portType>
```

```
<binding name="AirportServiceSoapBinding"
         type="tns:AirportServicePortType">
  <soap:binding transport=
         "http://schemas.xmlsoap.org/soap/http"/>
  <operation name="GetFlightInfo">
    <soap:operation style="rpc"
         soapAction="http://acme-travel/flightinfo"/>
    <input>
      <soap:body use="encoded"
         namespace="http://acme-travel.com/flightinfo"
         encodingStyle=
         "http://schemas.xmlsoap.org/soap/encoding/"/>
    </input>
    <output>
      <soap:body use="encoded"
         namespace="http://acme-travel.com/flightinfo"
         encodingStyle=
         "http://schemas.xmlsoap.org/soap/encoding/"/>
    </output>
  </operation>
  <operation name="CheckIn">
    <soap:operation style="document"
         soapAction="http://acme-travel.com/checkin"/>
    <input>
      <soap:body use="literal"/>
    </input>
  </operation>
</binding>

<service name="travelservice">
  <port name="travelservicePort"
         binding="tns:AirportServiceSoapBinding">
    <soap:address location=
         "http://acmetravel.com/travelservice"/>
  </port>
</service>
```

REST – "post RPC"

REpresentation State Transfer

Stateless Client/Server Protocol: Principles

1. Each message in the protocol contains all the information needed by the receiver to understand and/or process it. This constraint attempts to "keep things simple" and avoid needless complexity

2. Set of Uniquely Addressable Resources
   – "Everything is a Resource" in a RESTful system
   – Requires universal syntax for resource identification (e.g. URI)

REST

3. Set of Well-Defined Operations that can be applied to all resources
   – In context of HTTP, the primary methods are
   – POST, GET, PUT, DELETE
   – these are similar (but not exactly) to the database notion of
   – CRUD (Create, Read, Update, Delete)

4. The use of Hypermedia both for Application Information and State Transitions
   – Resources are typically stored in a structured data format that supports hypermedia links, such as XHTML or XML

REST

Idempotency: repeated application of the operation does not change the state of the target

Method	Meaning	Idempotent?
GET	Retrieve a COPY of a Resource	YES
DELETE	Remove a Resource	YES
POST	Update a Resource	NO
PUT	Create a Resource	YES

REST example

```
<user>
   <name>Jane</name>
   <gender>female</gender>
   <location href="http://www.example.org/us/ny/new_york">
      New York City, NY, USA</location>
</user>
```

This documentation is a representation used for the User resource

It might live at http://www.example.org/users/jane/

- If a user needs information about Jane, they GET this resource
- If they need to modify it, they GET it, modify it, and PUT it back
- The href to the Location resource allows savvy clients to gain access to its information with another simple GET request

Implication: Clients cannot be "thin"; need to understand resource formats

REST vs. RPC

In RPC systems, the design emphasis is on **verbs**

- What operations can I invoke on a system?
- getUser(), addUser(), removeUser(), updateUser(), getLocation(), updateLocation(), listUsers(), listLocations(), etc.

In REST systems, the design emphasis is on **nouns**

- User, Location
- In REST, you would define XML representations for these resources and then apply the standard methods to them

Conclusion

- Remote Procedure Call (RPC): Call procedure on remote machine
  - Provides same interface as procedure
  - Automatic packing and unpacking of arguments without user programming (in stub)
- Distributed File System:
  - Transparent access to files stored on a remote disk
    - » NFS uses caching for performance
- SOAP and WSDL:
  - An RPC protocol and an RPC description format
- REST:
  - Simplicity of RPC without any state and without “verbs”