

15-410
“...Mooooo!...”

IPC & RPC
Nov. 14, 2005

Dave Eckhardt
Bruce Maggs

Synchronization

Project 3 status poll

- Who is running tests?
- Who is confident of passing the hurdle by Friday?
Monday?
- Who is passing “mostly everything” (excepting, e.g., cho)

Synchronization

Project 3 tactical considerations

- Getting the shell running is important
 - We won't build a hand-load kernel for each test!
 - Test harness relies on shell to launch programs
- Getting a body of code *solid* is important
 - Better for `exec()` to work 1000 times than `thr_fork` once
- Run tests as soon as you can
- Carefully consider the P3extra overtime
 - In general, getting a really solid kernel is the best thing
 - » For your grade
 - » For your education!

Outline

IPC – InterProcess Communication

RPC – Remote Procedure Call

Textbook

- **Sections 3.4-3.6**

Scope of “IPC”

Communicating processes on one machine

Multiple machines?

- Virtualize single-machine IPC
- Switch to a “network” model
 - Failures happen
 - Administrative domain switch
 - ...
 - (RPC)

IPC parts

Naming

Synchronization/buffering

Message body issues

- Copy vs. reference
- Size

Naming

Message sent to *process* or to *mailbox*?

Process model

- `send(P, msg)`
- `receive(Q, &msg)` or `receive(&id, &msg)`

No need to set up “communication link”

- But you need to know process id's
- You get only one “link” per process pair

Naming

Mailbox model

- `send(box1, msg)`
- `receive(box1, &msg)` or `receive(&box, &msg)`

Where do mailbox id's come from?

- “name server” approach

```
box = createmailbox();  
register(box1, "Terry's process");  
boxT = lookup("Terry's process");
```

File system approach – *great* (if you have one)

```
box = createmailbox("/tmp/Terry");
```

Multiple Senders

Problem

- Receiver needs to know who sent request

First-cut solution

- Sender includes identifier in message body
- Problem?

Multiple Senders

Problem

- Receiver needs to know who sent request

Typical solution

- “Message” not just a byte array
- OS imposes structure
 - sender id (maybe process id and mailbox id)
 - maybe: type, priority, ...

Multiple Receivers

Problem

- Service may be “multi-threaded”
- Multiple receivers waiting for one mailbox

Typical solution

- OS “arbitrarily” chooses receiver per message
 - (Can you guess how?)

Synchronization

Issue

- Does communication imply synchronization?

Blocking send()?

- Ok for request/response pattern
- Provides assurance of message delivery
- *Bad* for producer/consumer pattern

Non-blocking send()?

- Raises buffering issue (below)

Synchronization

Blocking receive()?

- Ok/good for “server thread”
 - Remember, de-scheduling is a kernel *service*
- Ok/good for request/response pattern
- Awkward for some servers
 - Abort connection when client is “too idle”

Pure-non-blocking receive?

- Ok for polling
- Polling is costly

Synchronization

Receive-with-timeout

- Wait for message
- Abort if timeout expires
- Can be good for real-time systems
- What timeout value is appropriate?

Synchronization

Meta-receive

- Specify a group of mailboxes
- Wake up on first message

Receive-scan

- Specify list of mailboxes, timeout
- OS indicates which mailbox(es) are “ready” for what
- Unix: `select()`, `poll()`

Buffering

Issue

- How much space does OS provide “for free”?
- “Kernel memory” limited!

Options

- No buffering
 - implies blocking send
- Fixed size, undefined size
 - Send blocks *unpredictably*

A Buffering Problem

P1

```
send(P2, p1-my-status)  
receive(P2, &p1-peer-status)
```

P2

```
send(P1, p2-my-status)  
receive(P1, &p2-peer-status)
```

What's the problem?

- Can you draw a picture of it?

Message Size Issue

Ok to copy *small* messages sender $\Rightarrow$ receiver

Bad to copy *1-megabyte* messages

- (Why?)

Bad suggestion: “Chop up large messages”

- Evades the issue

“Out-of-line” Data

Message can *refer to* memory regions

- (page-aligned, multiple-page)
- Either “copy” or *transfer ownership* to receiver
- Can share the physical memory
 - Mooooo!

“Rendezvous”

Concept

- Blocking send
- Blocking receive

Great for OS

- No buffering required!

Theoretically interesting

Popular in a variety of languages

- (most of them called “Ada”)

Example: Mach IPC

Why study Mach?

- “Pure” “clean” capability/message-passing system
- Low abstraction count
- This *is* CMU...

Why not?

- Failed to reach market
- Performance problems with multi-server approach?

Verdict: hmm... (GNU Hurd? Godot??)

Mach IPC – ports

Port: Mach “mailbox” object

- One receiver
 - (one “backup” receiver)
- Potentially many senders

Ports identify system objects

- Each task identified/controlled by a port
- Each *thread* identified/controlled by a port
- Kernel exceptions delivered to “exception port”
 - “External Pager Interface” - page faults in user space!

Mach IPC – Port Rights

Receive rights

- “Receive end” of a port
- Held by one task
- Capability typically unpublished
 - receive rights imply ownership

Send rights

- “Send end” - ability to transmit message to mailbox
- Frequently published via “name server” task
- Confer no rights (beyond “denial of service”)

Mach IPC – Message Contents

Memory regions

- In-line for “small” messages (copied)
- Out-of-line for “large” messages
 - Sender may de-allocate on send
 - Otherwise, copy-on-write

“Port rights”

- Sender specifies task-local port #
- OS translates to internal port-id while queued
- Receiver observes task-local port #

Mach IPC – Operations

send

- block, block(n milliseconds), don't-block
- “send just one”
 - when destination full, queue 1 message in *sender thread*
 - sender notified when transfer completes

receive

- receive from port
- receive from *port set*
- block, block(n milliseconds), don't-block

Mach IPC – “RPC”

Common pattern: “Remote” Procedure Call

- Really: “cross-task” procedure call

Client synchronization/message flow

- Blocking send, blocking receive

Client must allow server to respond

- Transfer “send rights” in message
 - “Send-once rights” speed hack

Server message flow (N threads)

- Blocking receive, non-blocking send

Mach IPC – Naming

Port send rights are OS-managed capabilities

- unguessable, unforgeable

How to contact a server?

- Ask the name server task
 - *Trusted* – source of all capabilities

How to contact the name server?

- Task creator specifies name server for new task
 - Can create custom environment for task tree
 - » By convention, send rights to name server are located at a particular client port number (like stdin/stdout/stderr)
- System boot task launches nameserver, gives out rights

IPC Summary

Naming

- Name server?
- File system?

Queueing/blocking

Copy/share/transfer

A Unix surprise

- `sendmsg()/recvmsg()` pass file descriptors!

RPC Overview

RPC = Remote *Procedure Call*

Concept: extend IPC across machines

- Maybe across “administrative domains”

Marshalling

Server location

Call semantics

Request flow

RPC Model

Approach

```
d = computeNthDigit(CONST_PI, 3000);
```

- Abstract away from “who computes it”
- Should “work the same” when remote Cray does the job

Issues

- Must specify server *somehow*
- What “digit value” is “server down”?
 - Exceptions useful in “modern” languages

Marshalling

Values must cross the network

Machine formats differ

- Integer byte order
 - www.scieng.com/ByteOrder.PDF
- Floating point format
 - IEEE 754 or not
- Memory packing/alignment issues

Marshalling

Define a “network format”

- ASN.1 - “self-describing” via in-line tags
- XDR – not

“Serialize” language-level object to byte stream

- Rules typically recursive
 - Serialize a struct by serializing its fields in order
- Implementation probably should *not* be recursive
 - (Why not?)

Marshalling

Issues

- Some types don't translate well
 - Ada has ranged integers, e.g., 44..59
 - Not everybody really likes 64-bit ints
 - Floating point formats are religious issues
- Performance!
 - Memory speed $\cong$ network speed
- The dreaded “pointer problem”

Marshalling

```
struct node {  
    int value;  
    struct node *neighbors[4];  
} nodes[1024];  
  
nnodes = sizeof(nodes) / sizeof(nodes[0]);  
  
n = occupancy(nodes, nnodes);  
bn = best_neighbor(node);  
i = value(node);
```

Implications?

Marshalling

```
n = occupancy(nodes, nnodes) ;
```

- Marshall array – ok

```
bn = best_neighbor(node) ;
```

- Marshall graph structure – not so ok

```
i = value(node) ;
```

- *Avoiding* marshalling graph – not obvious
 - “Node fault”??

Server Location

Which machine?

- Multiple AFS cells on the planet
- Each has multiple file servers

Approaches

- Special hostnames: www.cmu.edu
- Machine lists
 - AFS CellSrvDB /usr/vice/etc/CellServDB
- DNS SRV records (RFC 2782)

Server Location

Which port?

- **Must distinguish services on one machine**
 - Single machine can be AFS volume, vldb, pt server
- **Fixed port assignment**
 - AFS: fileserver UDP 7000, volume location 7003
 - /etc/services or www.iana.org/assignments/port-numbers
 - RFC 2468 www.rfc-editor.org/rfc/rfc2468.txt
- **Dynamic port assignment**
 - Contact “courier” / “matchmaker” service via RPC
 - ...on a fixed port assignment!

Call Semantics

Typically, caller blocks

- Matches procedure call semantics

Blocking can be expensive

- By a factor of *a million(!!)* over real procedure call

“Asynchronous RPC”

- Transmit request, do other work, check for reply
- Not really “PC” any more
- More like programming language “futures”

Fun Call Semantics

Batch RPC

- Send *list* of procedure calls
- Later calls can use results of earlier calls

Issues

- Abort batch if one call fails?
 - Yet another programming language?
- Typically wrecks “procedure call” abstraction
 - Your code must make N calls before 1st answer

Fun Call Semantics

Batch RPC Examples

- NFS v4 (eventually), RFC 3010
- Bloch, A Practical Approach to Replication of Abstract Data Objects

Sad Call semantics

Network failure

- Retransmit request
 - How long?

Server reboot

- Does client deal with RPC session restart?
- Did the call “happen” or not?
 - Retransmitting “remove foo.c” all day long may not be safe!

Client Flow

Client code calls *stub* routine

- “Regular code” which encapsulates the magic

Stub routine

- Locates communication channel
 - If not established: costly location/set-up/authentication
- Marshals information
 - Procedure #, parameters
- Sends message, awaits reply
- Unmarshals reply, returns to user code

Server Flow

Thread pool runs *skeleton* code

Skeleton code

- **Waits for request from a client**
- **Locates client state**
 - **Authentication/encryption context**
- **Unmarshals parameters**
- **Calls “real code”**
- **Marshals reply**
- **Sends reply**

RPC Deployment

Define interface

- Get it right, you'll live with it for a while!
- AFS & NFS RPC layers ~15 years old

“Stub generator”

- Special-purpose compiler
- Turns “interface spec” into stubs & skeleton

Link stub code with client & server

Run a server!

Java RMI

Remote Method Invocation

Serialization: programmer/language cooperation

- *Dangerously* subtle!
 - Bloch, Effective Java

RMI > RPC

- Remote methods $\cong$ remote procedures
- *Parameters* can be (differently) remote
 - Client on A can call method of class implemented on B passing object located on C
 - » (slowly)

RPC Summary

RPC is lots of fun

So much fun that lots of things don't do it

- SMTP
- HTTP

RPC = IPC

- + server location, marshalling, network failure, delays
- - special copy tricks, speed

Remote Objects? Effective Java, Bitter Java