15-410

"...Mooooo!..."

IPC & RPC
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Synchronization

Scoreboard

- Oops! I reset group OS names by accident!
  - Please feel free to restore your requested name
- Congratulations groups who are on the board!
- That URL again
  - http://www.cs.cmu.edu/~410/scoreboard.html

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 1,000 times than `thr_fork` once
- Run tests as soon as you can
  - Scoreboard can be a source of inspiration!
- Carefully consider the P3extra overtime
  - In general, getting a really solid kernel is the best thing
    - » For your grade
    - » For your education!

Outline

A Pattern Language (for client-server messaging)

- Client view, server view, world view

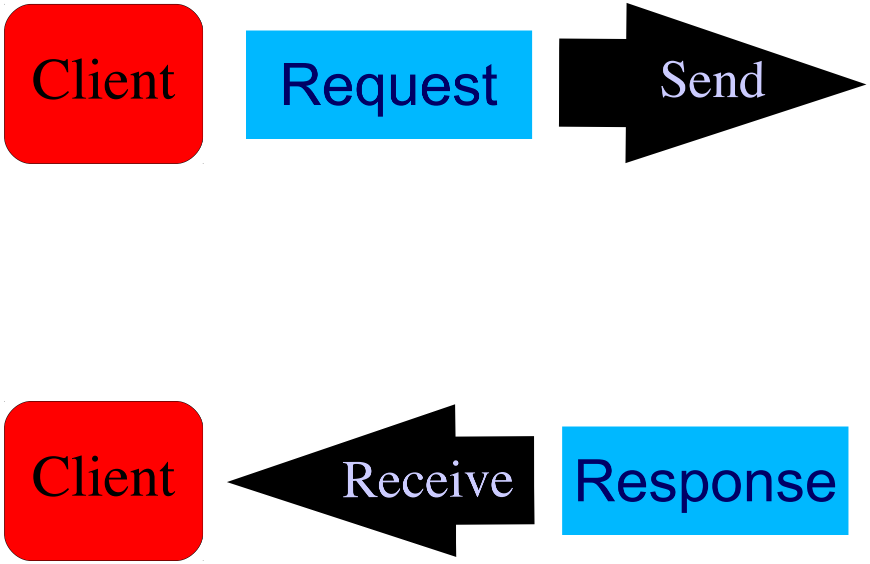
IPC – InterProcess Communication

RPC – Remote Procedure Call

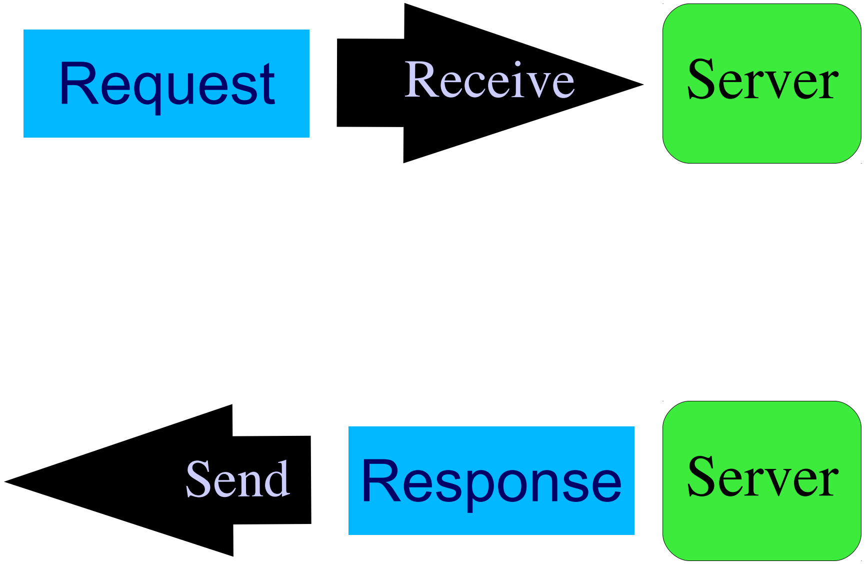
Textbook

- OSC - Sections 3.4-3.6
- OS:P+P - missing

Client View



Server View



Reality?

Those views are *correct with respect to each viewer*

The kernel's view is more complex

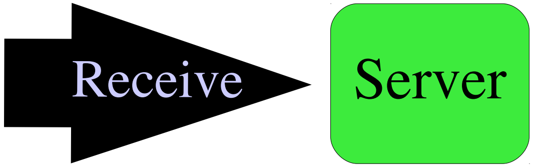
Reality?

Those views are *correct with respect to each viewer*

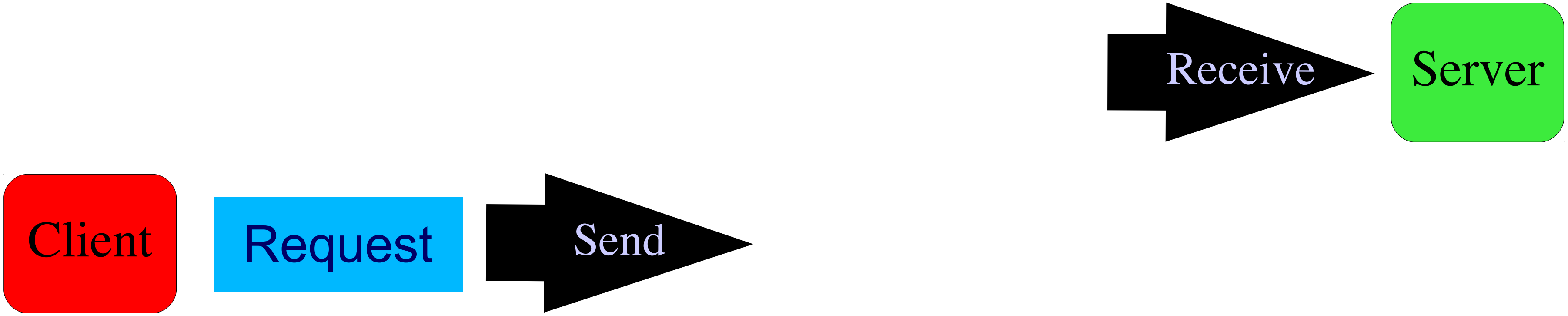
The kernel's view is more complex

- Data transfer, obviously
- Buffering (maybe)
- Blocking
- Matching a live request against a blocked request, or else blocking

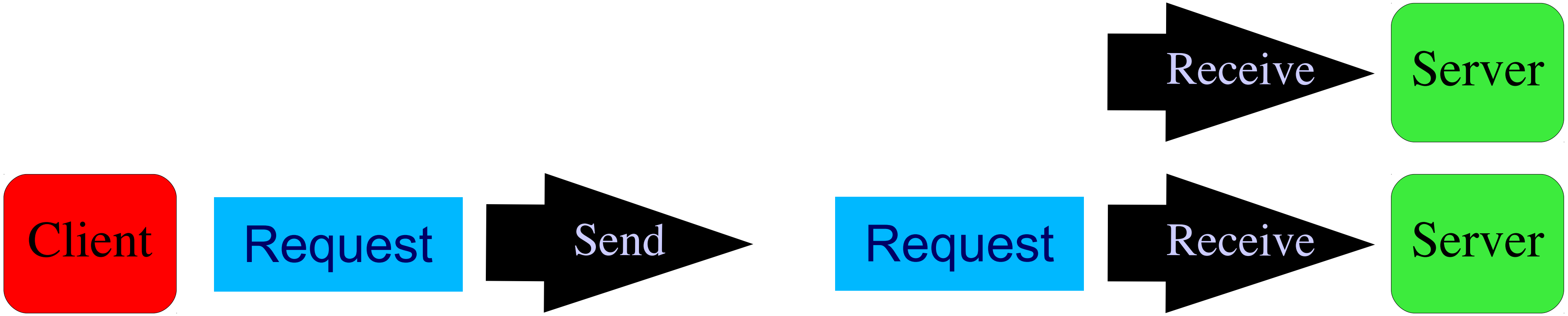
Receiver Prepares



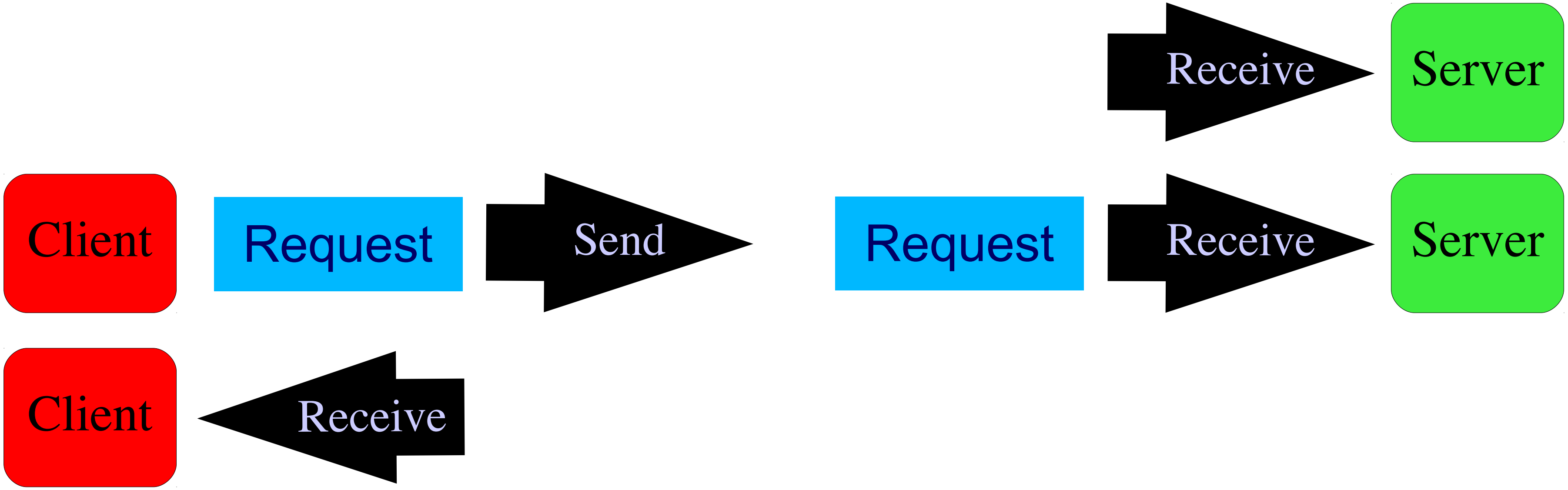
Client Sends Request



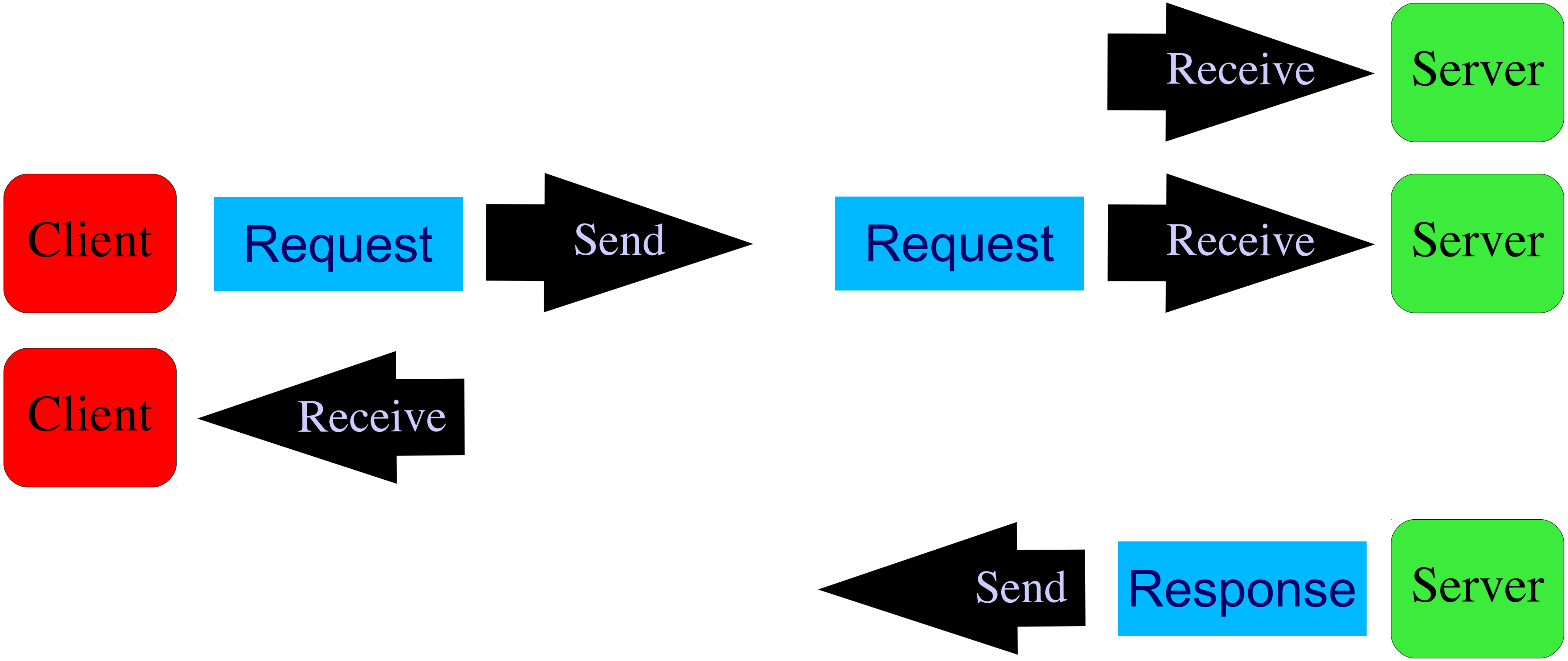
Send Matches Receive



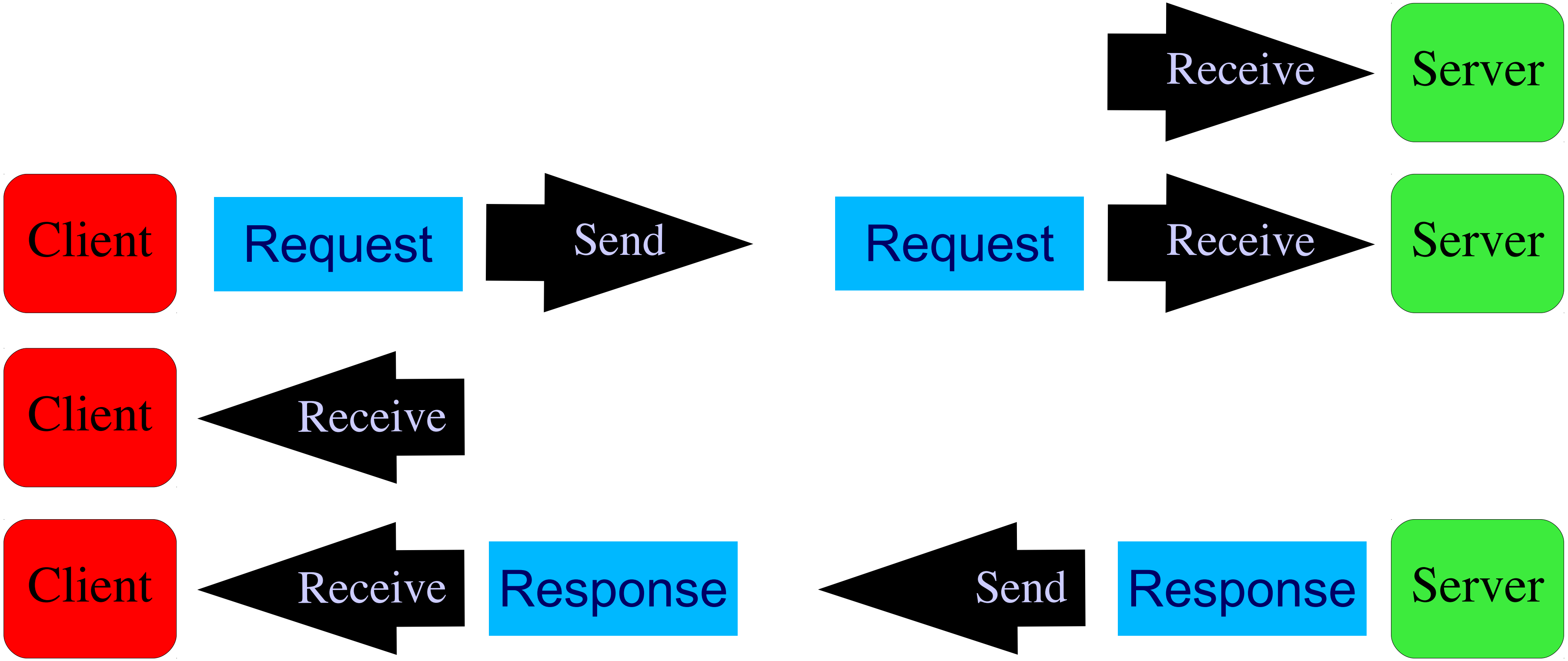
Client Posts Receive



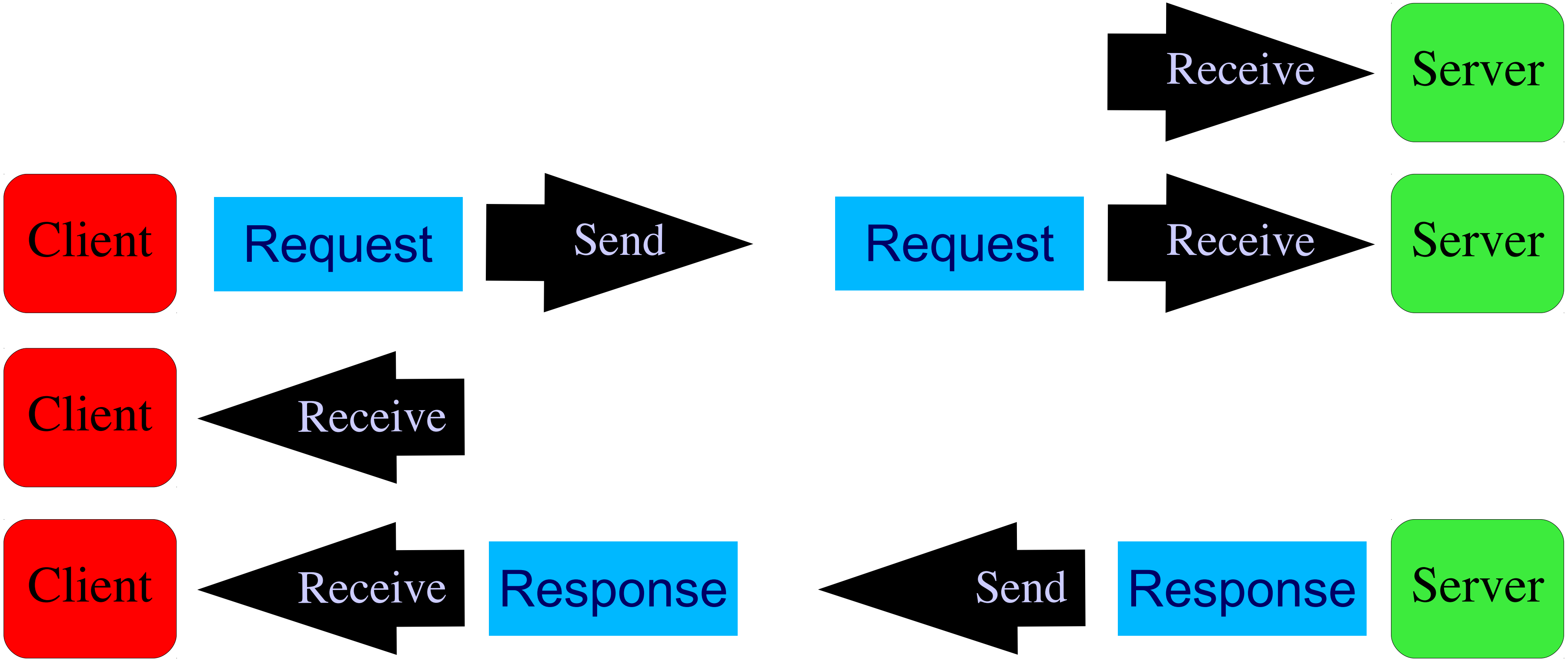
Server Posts Reply



Reply Matches Receive



Reply Matches Receive



Other event sequences are possible!

Scope of “IPC”

Communicating processes on one machine

What about 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

Typical solution

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

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 highly-reliable or real-time systems
- What timeout value is appropriate?
  - Depends on each specific and complete system
  - Timeout values are error prone

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)
```

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 ⇒ receiver

Bad to copy *1-megabyte* messages

- (Why?)

Bad suggestion: “Chop up large messages”

- Why?

Message Size Issue

Ok to copy *small* messages sender ⇒ 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”)

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, not published
    - 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/pdf/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 ≅ 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, 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

*R*emote *M*ethod *I*nvocation

Serialization: programmer/language cooperation

- *Dangerously* subtle!
  - Bloch, Effective Java

RMI > RPC

- Remote methods ≅ 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