Remote Invocation

To do ...

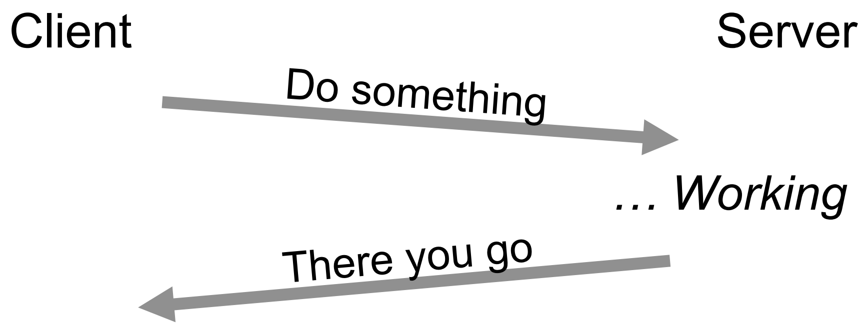
- Today
- Request-reply, RPC, RMI
- Next time: Indirect communication

Beyond message passing

- All IPC in distributed systems is based on low-level message passing
  - As we discussed in the last two lectures
- A bit too low level
  - Modern distributed systems can have 10^3-10^6 processes scattered around

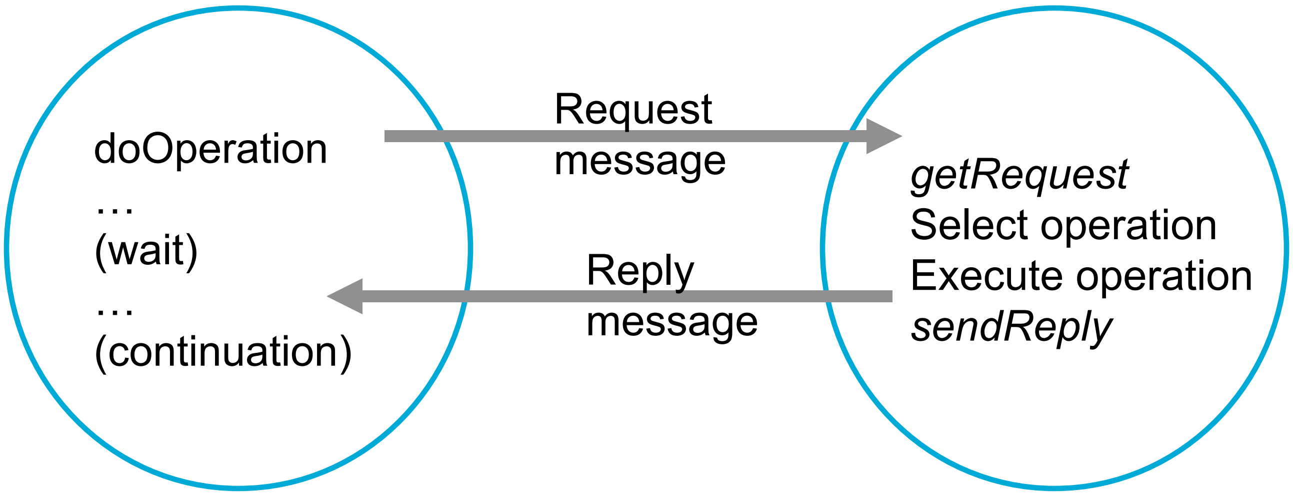
Beyond message passing

- Need a higher-level of abstraction – send/ receive exposes communication
- Are there programmer-friendlier models?
  - Today …
  - Request-reply – patterns in msg passing with little support for request/reply interactions
  - Remote procedure calls – extending procedure calls
  - Remote method invocation – … to remote objects



Request-reply protocols

- We can describe it based on three primitives
  - `doOperation` – used by client to invoke operation
    - Args specify remote server and arguments; result is a byte array
    - After sending it, client issues a receive to get the reply
  - `getRequest` – used by server to get request
  - `sendReply` – used by server to send reply
    - When received by client, original `doOperation` is unblocked



Request-reply protocols

- Normally, synchronous (client blocks) and reliable
  - Asynchronous is also possible
- Synchronous and asynchronous
  - Sender continues (asynchronous) or blocks (synchronous) until request has been accepted
  - Points of synchronization: (1) at request submission, (2) at request delivery or (3) after processing
- Reliability, two concerns
  - Integrity – msg arrives uncorrupted and without duplication
  - Reliability – msg arrives despite some packet drops

Request-reply protocols

- For reliability or request-reply communication
  - Messages need a requestId and a process identifier

- Failures partially depend on transport
  - TCP or UDP
  - Over UDP, omission and out-of-order issues
  - Process may also fail (crash failures)

- To handle omission failures – timers
  - For duplicate messages, msg id (keep a history) or idempotent operations

messageType: int (req/reply)
requestId: int
remoteReference
operationId: int
arguments: byte[]

Request-reply protocols

- Exchange styles – different behavior in front of failures
- *Request (R)* – When client doesn't need confirmation, asynchronous (typically over UDP)
- *Request-reply (RR)* – Useful for most client-server exchanges
  - No need special ack, server reply is an implicit ack
- *Request-reply-acknowledge Reply (RRA)* – Server can clean history

Name	Client	Server	Client
R	Request		
RR	Request	Reply	
RRA	Request	Reply	Ack reply

Using TCP or UDP to implement RR

- Client-server exchange can be built on UDP or TCP (or any other transport, of course)
- To avoid implementing multi-packet protocols, TCP
  - TCP reliability means no need for retransmissions, duplicate filtering or history
  - No problem with large transmissions, flow-control handles it
  - If multiple exchanges, connection overhead applies once
- If you can live without all this, maybe a more efficient protocol over UDP
  - Sun NSF transmits fixed-size blocks between client/server
  - All operations are idempotent, so no need for history

Data representation and marshalling

- Processes keep information in data structures
  - records, arrays, strings, trees …
- But IPC is in msgs, sequences of bytes
  - TCP/UDP gives the mechanisms to send sequences of bytes
  - Processes need a protocol to make the exchange meaningful
  - To serialise this data into a streamy of bytes to write it, and deserialise it to read it: marshalling and unmarshaling

Data representation and marshalling

- Marshalling/unmarshalling
  - Assembling/disassembling process' data for transmission
  - Client and server may have different data representations
  - Both need to properly interpret msg to transform it into machine-dependent representation
    - Agree on encoding
      - How are basic data values represented (integers, floats, …)
      - How are complex data values represented (arrays, unions)
    - Intermediate language or source's representation

- Multiple external representation alternatives
  - Sun's XDR, Corba, XML, ASN.1, Google's protocol buffer, JSON, Gob (Go specific)

An example with ASN.1*

Client code (missing error checking!)

```
package main

import (
        "bytes"
        "encoding/asn1"
        "net"
        "os" …
)

func main() {
   if len(os.Args) != 2 {
     fmt.Fprintf(os.Stderr, "Usage: %s host:port", os.Args[0])
      os.Exit(1)
   }
   service := os.Args[1]
   conn, err := net.Dial("tcp", service)

   result, err := readFully(conn)

   var newtime time.Time
   _, err1 := asn1.Unmarshal(result, &newtime)

   fmt.Println("After marshal/unmarshal: ", newtime.String())

   os.Exit(0)
}
```

*Complete example in https://jan.newmarch.name/go/serialisation/chapter-serialisation.html

HTTP as an example

- HyperText Transfer Protocol, on top of TCP
  - Specifies msgs exchanged, formats, methods, arguments and results, representation for marshaling …
  - Content negotiation – clients state format they can accept
  - Password-style authentication

- A fixed set of methods, some well-known ones
  - GET – Requests resource or run program pointed to by URL
  - HEAD – Same as GET but returns only metadata
  - POST – Provides data, depending on function supported by the program specified by the URL (e.g., posting a msg)
  - PUT – Requests to store data with the given URL as ID
  - Others: DELETE, OPTIONS, TRACE

HTTP as an example

- Clients invoke methods to be applied to resources at the server (given by the URL)
- Msgs marshalled into ASCII text strings
- Connections
  - Client interaction in version 1.0
    - Client request a connection at default (or given) port
    - … sends request msg to server
    - Server sends reply
    - Connection is closed
  - Setting/closing a connection per request is costly
    - HTTP 1.1 uses persistent connections
    - Can be close by client, server or after being idle for a while

HTTP as an example

```
$ telnet www.golang.org 80
Trying 64.233.191.141...
Connected to golang.org.
Escape character is '^]'.
GET /index.htm HTTP/1.1
host: www.golang.org

HTTP/1.1 302 Found
Location: http://golang.org/index.htm
Date: Thu, 09 Apr 2015 14:21:32 GMT
Content-Type: text/html; charset=UTF-8
Server: Google Frontend
Content-Length: 224
Alternate-Protocol: 80:quic,p=0.5

<HTML><HEAD><meta http-equiv="content-type"
content="text/html;charset=u
<TITLE>302 Moved</TITLE></HE
<H1>302 Moved</H1>
The document has moved
<A HREF="http://golang.org/i
</BODY></HTML>
…
```

Using telnet

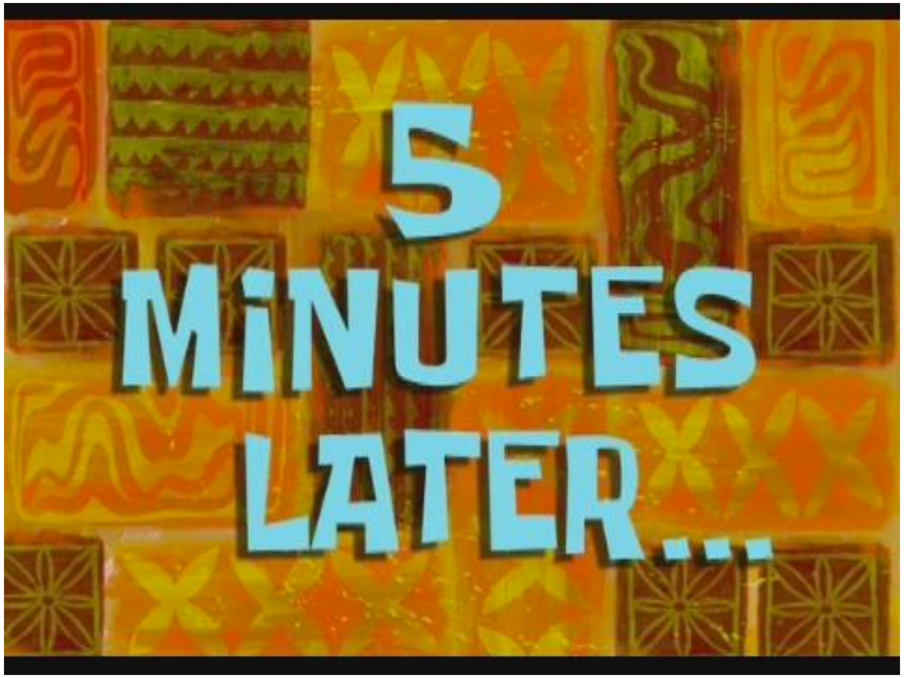
Using go

```
package main

import (
        "net/http" …
func main() {
        response, err := http.Get("http://golang.org")
        if err != nil { …
        defer response.Body.Close()
        contents, err := ioutil.ReadAll(response.Body)
        if err != nil { …
        fmt.Printf("%s\n", string(contents))
}
```

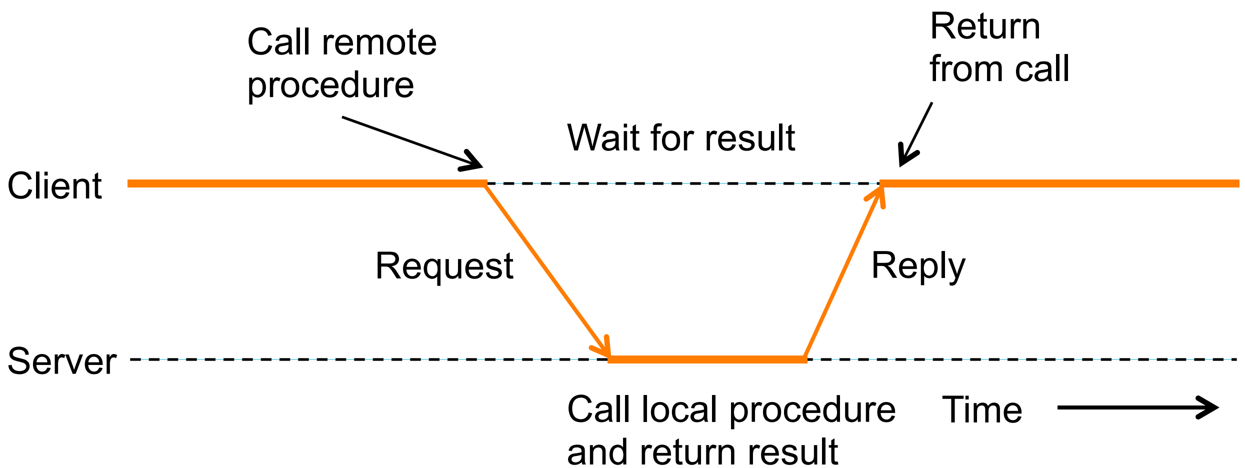
Back in 5’

- … RPC and RMI



Remote Procedure Call (RPC)

- Earliest and best known example of a more programmer friendly model [Birrell and Nelson ’84]
- Some observations
  - Developers are familiar with simple procedure model
  - Well engineered procedures operate in isolation
  - No fundamental reason not to execute procedures on a separate machine
- Can hide sender/receiver comm. using proc calls?



RPC details

- RPC promote programming with interfaces
  - Better abstractions & maintainability, language independence
  - Interface specification with lang independence – Interface Definition Languages (e.g., XDR, Corba IDL)

- RPC, local procedure calls and transparency
  - Parameter passing and global variables
    - Copy in/copy out semantics – while procedure is being executed, nothing can be assumed about parameter values
    - All data to be worked on is passed by parameters; no ref to globals
  - How about pointers?
    - Copy/restore, no call-by-reference
    - Remote reference for more complex structures
  - Failures and latency

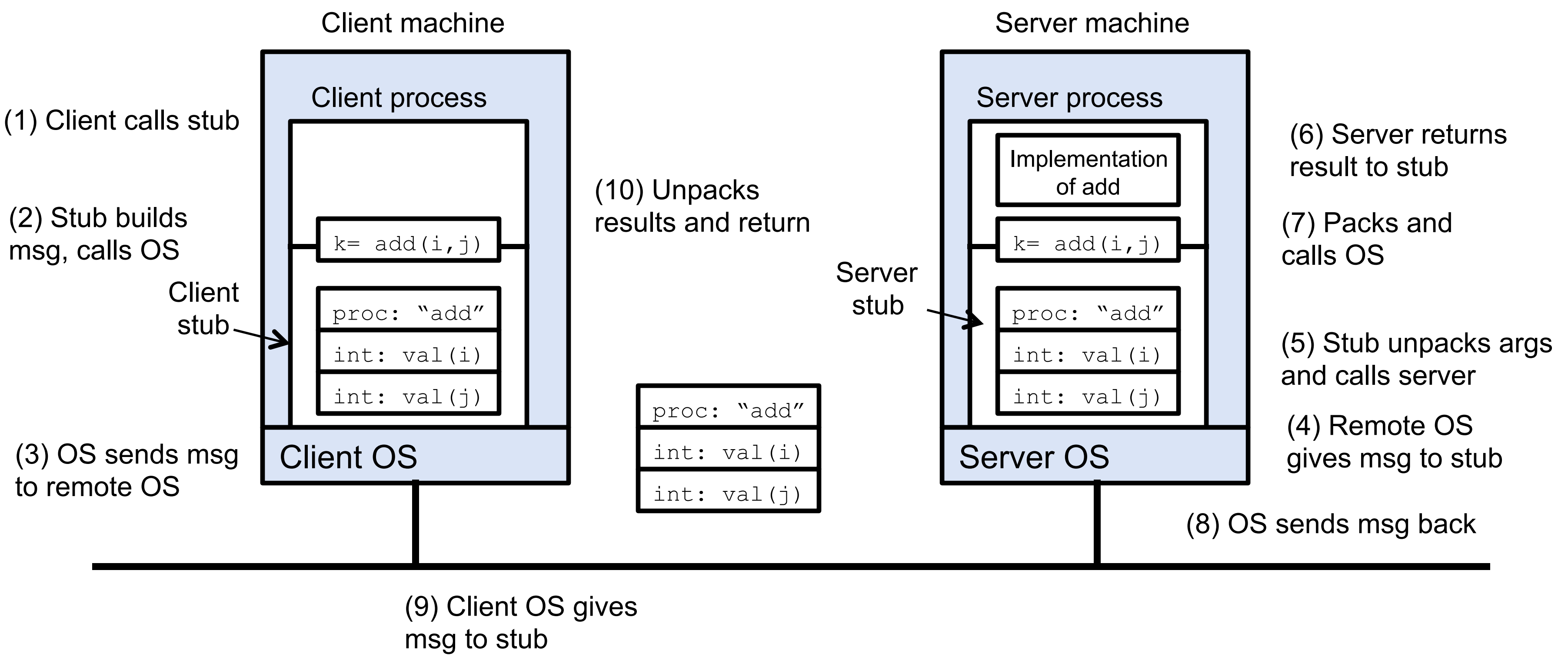
RPC details

- RPC call semantics
  - Depending on fault tolerance measures:
    - Retransmit request until getting a reply or decide server failed
    - Duplicate filtering at the server
    - Re-execute procedure or retransmit reply, keeping history of results at the server

Call semantics	Fault tolerance measures		
	Retransmit request	Duplicate filtering	Re-execute/retransmit
Maybe	No	NA	NA
At-least-once	Yes	No	Re-exec
At-most-once	Yes	Yes	Retransmit reply

- *What are the semantics of local procedure calls?*

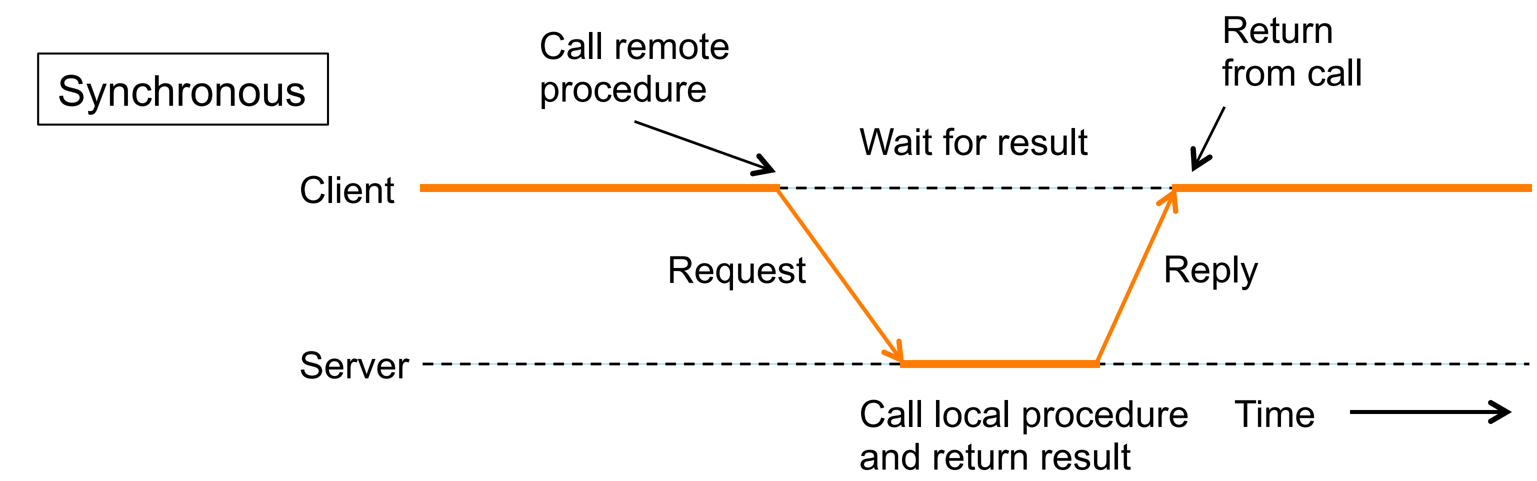
Basic RPC implementation and operation



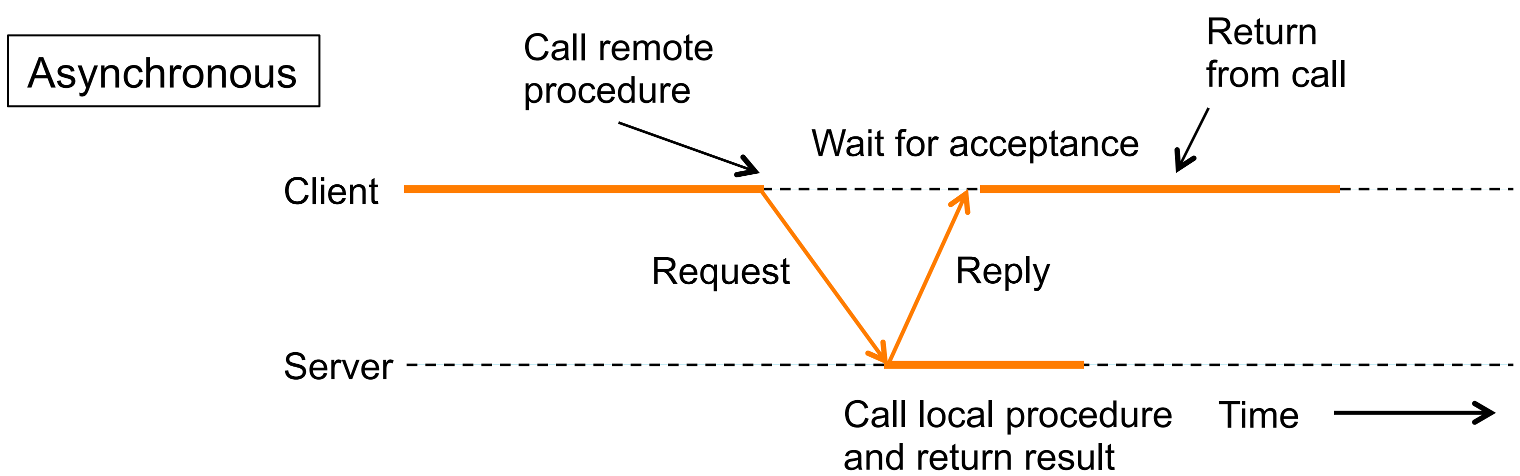
RPC details

- Runtime is given
  - RPCRuntime was part of Cedar in the original RPC system
- Programmers writes client and server
- Client and server-stub are user generated
  - Based on the interface specification
  - By *Lupine* in the original
- A binder for clients to find where to connect
  - Binder runs on a well-known-port
  - Manage table of references/ports for each service

Asynchronous RPCs

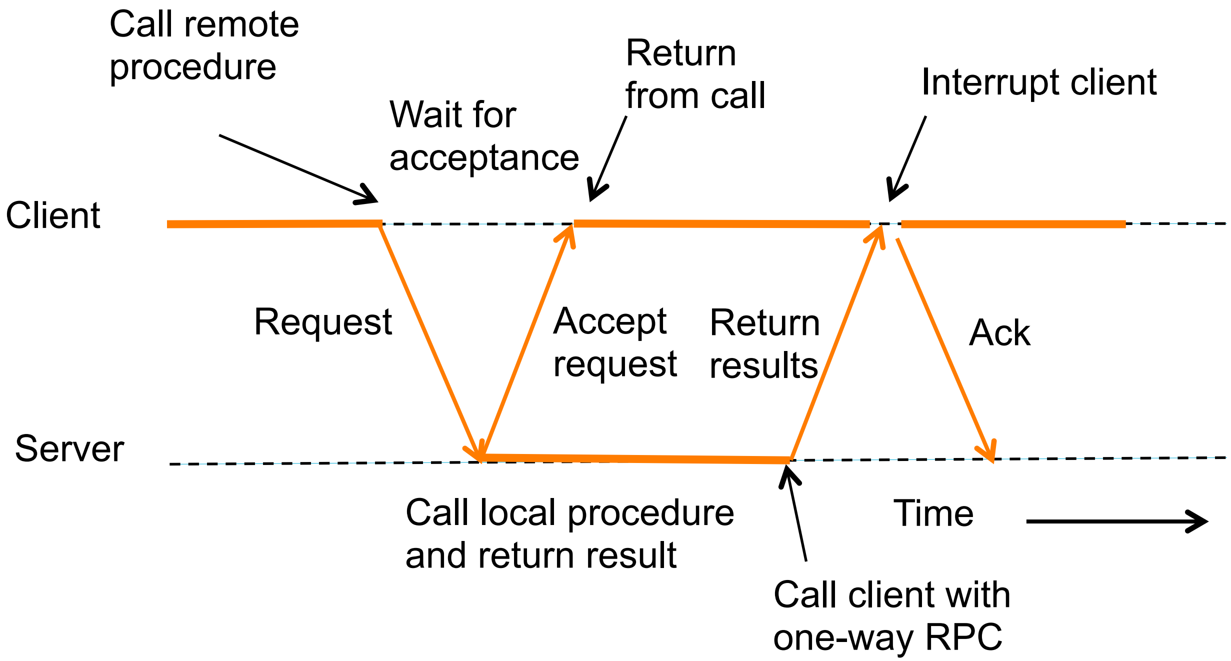


- Get rid of the strict request-reply behavior, but let the client continue w/o waiting for server's answer



Deferred synchronous RPCs

- Combining two asynchronous RPC is sometimes also referred to as deferred synchronous RPC



- A variation – Client can also do a (non)blocking poll at the server to see whether results are available

Sun RPC

- Defined in RFC 1831
- Designed for client-server communication in the Sun Network File System (NFS)
- Run over UDP or TCP, using at-least-once semantics
- Sun XDR as external data representation and IDL
- Interfaces are identified by program and version number
- Binder (port mapper) for clients to find where to connect
- Authentication through fields in the request/reply msgs

Remote Method Invocation

- RMI extends RPC into the world of distributed objects
  - As RPC, programming with interfaces
  - … also built on top of request-reply, offers similar call semantics
  - … and similar level of transparency

- But
  - Programmer can use OO programming features (objects, classes, inheritance …)
  - All objects have an object reference; refs can be passed on as parameters (first class values)
    - Not just parameter passing by value, good for complex parameters
  - For distributed objects, remote object refs and remote interfaces

Remote Method Invocation

- With OO, state partition among processes as objects
- If using a client-server model,
  - Objects managed by servers, invoked by clients through RMI
  - Objects could also be replicated and/or migrated for reliability, availability or performance

- Implementing RMI
  - Similar to RPC, a proxy object, two communication modules and a dispatcher & skeleton

- With distributed objects, distributed garbage collection

Distributed garbage collection

- One way to implement it – cooperating local collectors
  - Server keeps list of processes holding remote refs to its objects
  - When a client first receive a remote ref. to a remote object, adds itself as holder at server (*extra invocation*) and creates a proxy
    - Server adds clients to holders
  - When client garbage collects proxies for remote object, removes itself from holders at server (*extra invocation*) then deletes proxy
    - Server removes client from holders
  - Java's approach

- Keeping resources at servers and leases
  - What to do if clients go away? Set up leases granting the use of resources for a fixed period of time

Summary

- Powerful primitives can makes (distributed) programming them a lot easier
- Procedure calls
  - Simple way to pass control and data
  - Elegant and transparent way to distribute applications
  - Not the only way
- Hard to provide true transparency
  - Failures, performance, memory access, …
- How to deal with hard problems – let the programmer do it – “worse is better” (Richard Gabriel’s)