# *Network and Distributed File Systems*

**With content from**
Distributed Communication Systems
Christophe Bisciglia, Aaron Kimball, & Sierra Michels-Slettvet



## From Local to Network File System

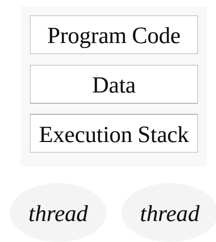
- So far, we have assumed that files are stored on local disk …
- How can we generalize the design to access files stored on a remote server?
- Need to invoke file creation and management methods on the remote server
- Basic mechanisms:
  - Message passing primitives
  - Remote Procedure Calls (RPC)

- A network file system is likely to be better than a local file system in what respects?
  - A. Read/write performance
  - B. Availability
  - C. Fault tolerance
  - D. Ease of management

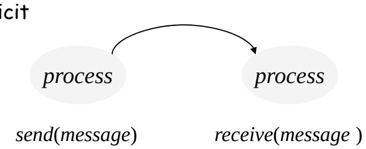


## Process Coordination
**Two fundamental approaches**

- Communication and synchronization based on...
  - Shared memory
    - Assume processes/threads can read & write a set of shared memory locations
    - Inter-process communication is implicit, synchronization is explicit




  - Message passing
    - Inter-process communication is explicit, synchronization is implicit



## Process Coordination
**Shared Memory *v.* Message Passing**

- Shared memory
  - Efficient, familiar
  - Difficult to provide across machine boundaries.

```
            global  int x = 0;

process foo              process bar
begin                    begin
  :                        :
 x := 1                    while(x==0) ;
  :                        :
end foo                  end bar
```

Message passing

Extensible to communication in distributed systems

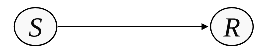
Canonical syntax:

```
   send(int id, String message);
receive(int id, String message);
```

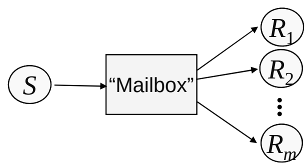


## Message Passing
**Naming communicants**

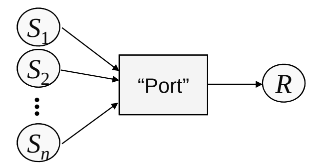
- How do processes refer to each other?
  - Does a sender explicitly name a receiver?




Can a message be sent to a group?




Can a receiver receive from a group? (a reduction operation)



## Web requests conform to what model?

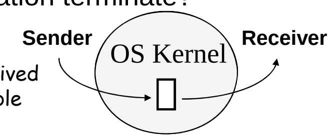
1. Many-to-one
2. One-to-one
3. One-to-many



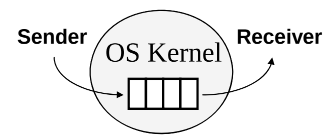
## Message Passing Issues
### Synchronization semantics

- When does a *send/receive* operation terminate?

Blocking:
Sender waits until its message is received
Receiver waits if no message is available




Non-blocking:
Send operation “immediately” returns
Receive operation returns if no message is available




Partially blocking/non-blocking:
send()/receive() with *timeout*

## Semantics of Message Passing

***send*(*receiver*, *message*)**

**Synchronization**

| Naming | **Blocking** | **Non-blocking** |
|---|---|---|
| **Explicit (single)** | Send message to *receiver* Wait until message is accepted. | Send message to *receiver* |
| **Implicit (group)** | Broadcast message to all receivers. Wait until message is accepted by all | Broadcast message to all receivers |



## Semantics of Message Passing

***receive*(*sender*, *message*)**

**Synchronization**

| Naming | **Blocking** | **Non-blocking** |
|---|---|---|
| **Explicit (single)** | Wait for a message from *sender* | If there is a message from *sender* then receive it, else continue |
| **Implicit (group)** | Wait for a message from any sender | If there is a message from any sender then receive it, else continue |

## Which do you think would be easier to program?

A. A message passing program that blocks.
B. A message passing program that does not block.



## RPC is not message passing

- Regular client-server protocols involve sending data back and forth according to shared state

```
Client:                        Server:
HTTP/1.0 index.html GET
                               200 OK
                               Length: 2400
                               (file data)
HTTP/1.0 hello.gif GET
                               200 OK
                               Length: 81494
                               …
```

## Remote Procedure Call

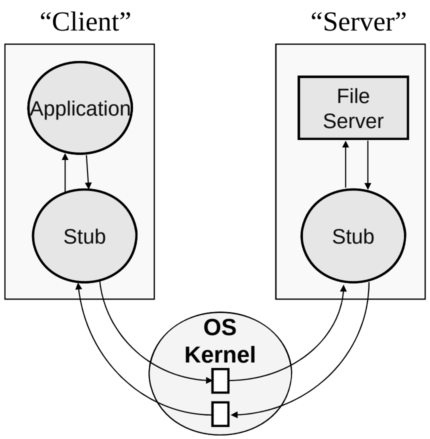
- RPC servers will call arbitrary functions in dll, exe, with arguments passed over the network, and return values back over network

| Client: | Server: |
| --- | --- |
| `foo.dll,bar(4, 10, “hello”)` | |
| | `“returned_string”` |
| `foo.dll,baz(42)` | |
| | `err: no such function` |
| … | |

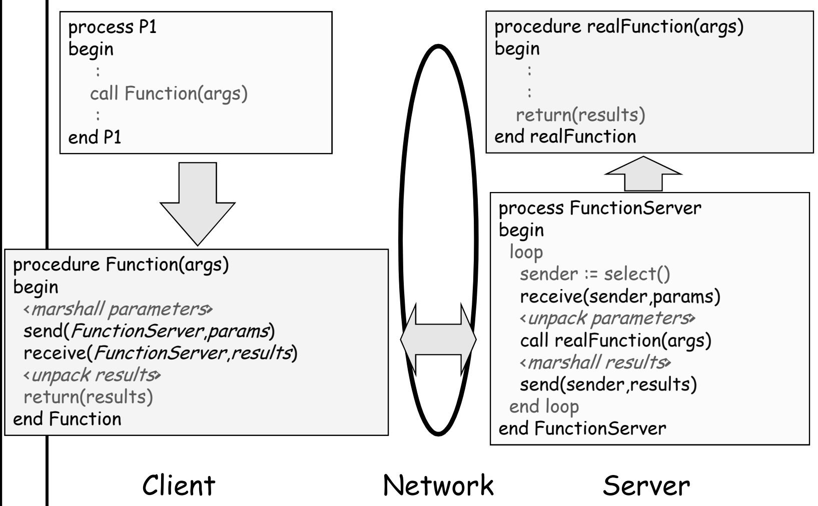


## RPC: Message Passing Evolves

- Remote procedure calls abstract out the *send/await-reply* paradigm into a “procedure call”
- Remote procedure calls can be made to look like “local” procedure calls by using a stub that hides the details of remote communication



## Remote Procedure Call






## RPC (Cont'd.)

- Similarities between procedure call and RPC
  - Parameters ↔ request message
  - Result ↔ reply message
  - Name of procedure ↔ passed in request message
  - Return address ↔ mailbox of the client
- Implementation issues:
  - Stub generation
    - Can be automated
    - Requires the signature of the procedure
  - How does a client locate a server? … Binding
    - Static – fixed at compile-time
    - Dynamic – determined at run-time with the help of a name service
  - Why run-time binding?
    - Automatic fail-over

## Problems with RPC

- Failure handling
  - A program may hang because of
    - Failure of a remote machine; or
    - Failure of the server application on the remote machine
  - An inherent problem with distributed systems, not just RPC
    - Lamport: “A distributed system is one where you can’t do work because some machine that you have never heard of has crashed”
- Performance
  - Cost of procedure call << same machine RPC << network RPC



**Java RMI (remote method invocation) is an example of an RPC system.**

A. Yes
B. No

**Why use RPC?**

A. Programmer convenience
B. Improve performance
C. Simplify implementation
D. Simplify API

## Network and Distributed File Systems

- Provide transparent access to files stored on remote disks
- Issues:
  - Naming: How do we locate a file?
  - Performance: How well does a distributed file system perform as compared to a local file system?
  - Failure handling: How do applications deal with remote server failures?
  - Consistency: How do we allow multiple remote clients to access the same files?



## Naming Issues

- Two Approaches To File Naming
  - Explicit naming: <file server: file name >
    - E.g., windows file shares
    - //witchel-laptop/Users/witchel/Desktop
  - Implicit naming
    - Location transparency: file name does not include name of the server where the file is stored
- Server must be identified.
- Most common solution (e.g., NFS)
  - Static, location-transparent mapping
  - Example: NFS Mount protocol
    - Mount/attach remote directories as local directories
    - Maintain a mount table with directory → server mapping, e.g., mount zathras:/vol/vol0/users/witchel /home/witchel

## Performance Issues: Simple Case

- Simple case: straightforward use of RPC
  - Use RPC to forward every file system request (e.g., open, seek, read, write, close, etc.) to the remote server
  - Remote server executes each operation as a local request
  - Remote server responds back with the result
- Advantage:
  - Server provides a consistent view of the file system to distributed clients. What does consistent mean?
- Disadvantage:
  - Poor performance

Solution: Caching



**Why does turning every file system operation into an RPC to a server perform poorly?**

1. Disk latency is larger than network latency
2. Network latency is larger than disk latency
3. No server-side cache
4. No client-side cache

## Sun's Network File System (NFS)

- Cache data blocks, file headers, etc. both at client and server
  - Generally, caches are maintained in memory; client-side disk can also be used for caching
  - Cache update policy: write-back or write-through
- Advantage:
  - Read, Write, Stat etc. can be performed locally
    - Reduce network load and
    - Improve client performance
- Problem: How to deal with failures and cache consistency?
  - What if server crashes? Can client wait for the server to come back up and continue as before?
    - Data in server memory can be lost
    - Client state maintained at the server is lost (e.g., seek + read)
    - Messages may be retried
  - What if clients crash?
    - Loose modified data in client cache



## NFS Protocol: Statelessness

- Stateful vs. stateless server architectures
- NFS uses a stateless protocol
  - Server maintains no state about clients or open files (except as hints to improve performance)
  - Each file request must provide complete information
    - Example: ReadAt(inode, position) rather than Read(inode)
  - When server crashes and restarts, it processes requests as if nothing has happened !
- Idempotent operations
  - All requests can be repeated without any adverse effects
- Result:
  - Server failures are (almost) transparent to clients
  - When server fails, clients hang until the server recovers or crash after a timeout

## NFS Protocol: Consistency

- What if multiple clients share the same file?
  - Easy if both are reading files …
  - But what if one or more clients start modifying files?
- Client-initiated weak consistency protocol
  - Clients poll the server periodically to check if the file has changed
  - When a file changes at a client, server is notified
    - Generally, using a delayed write-back policy
  - Clients on detecting a new version of file at the server obtain a new version
- Consistency semantics determined by the cache update policy and the file-status polling frequency
- Other possibility: server-initiated consistency protocol



## NFS: Summary

- Key features:
  - Location-transparent naming
  - Client-side and server-side caching for performance
  - Stateless, client-driven architecture
  - Weak consistency semantics
- Advantages:
  - Simple
  - Highly portable
- Disadvantages:
  - Inconsistency problems

## Andrew File System (AFS): A Case Study

- Originally developed at CMU → later adapted to DFS by IBM
- Key features:
  - Callbacks: server maintains a list of who has which files
  - Write-through on file close
    - On receiving a new copy, server notifies all clients with a file copy
  - Consistency semantics:
    - Updates are visible only on file close
  - Caching:
    - Use local disk of clients as caches
    - Can store larger amount in cache → smaller server load
  - Handling server failures:
    - Loose all callback state → need a recovery protocol to rebuild state
- Pros and cons:
  - Use of local disk as a cache reduces server load
  - Callbacks → server is not involved in read-only files at all
  - Central server is still the bottleneck (for writes, failures, …)