Advanced Operating Systems: Three Easy Pieces

Distributed Operating Systems

Outline

- What is Distributed System
- Key characteristics of Distributed Systems
- Challenges with distributed System
- Build reliable messaging over unreliable layers
- What is an RPC
- Distributed File System:
  - NFS Architecture
  - Client caching

What is Distributed System

What is a Distributed System

A distributed system is one where a machine I've never heard of can cause my program to fail.

— ***Leslie Lamport***

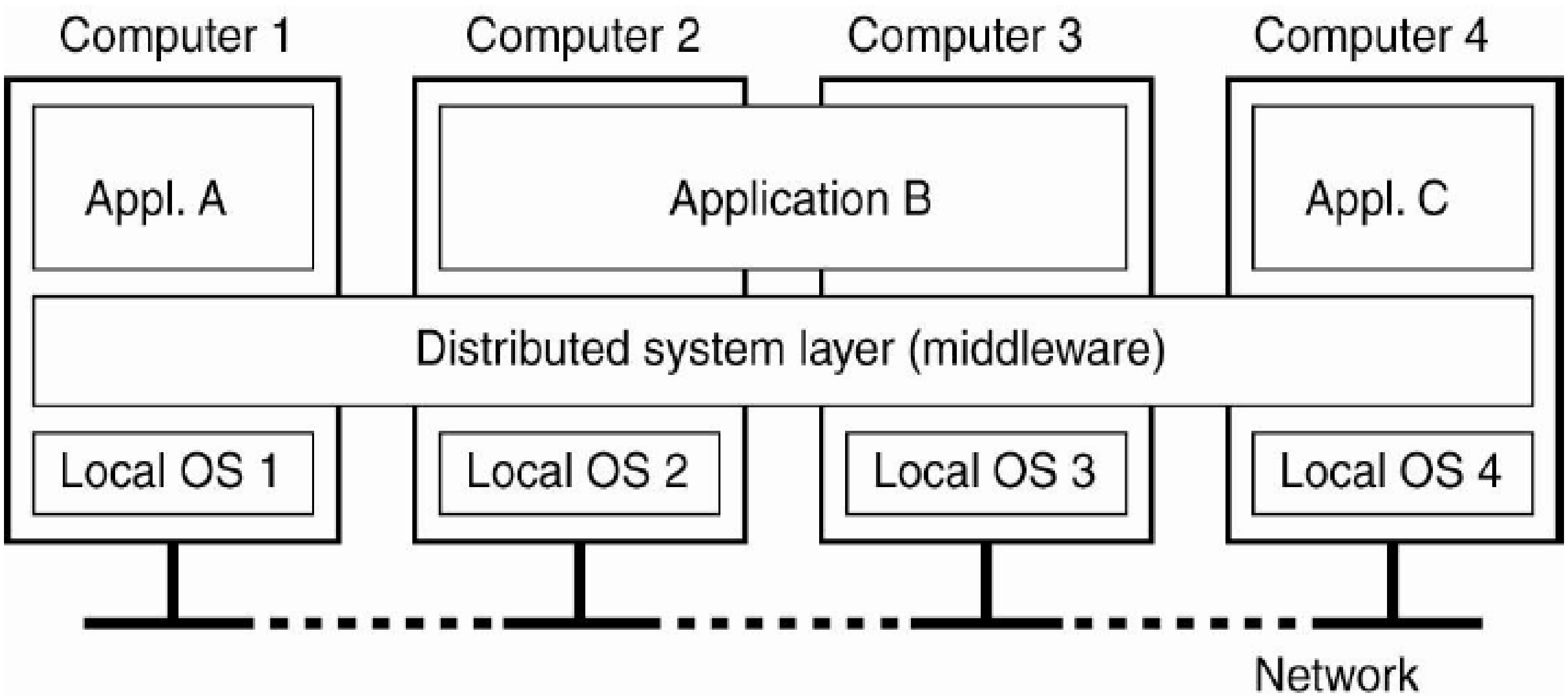
Definition:

More than 1 machine working together to solve a problem

Examples:

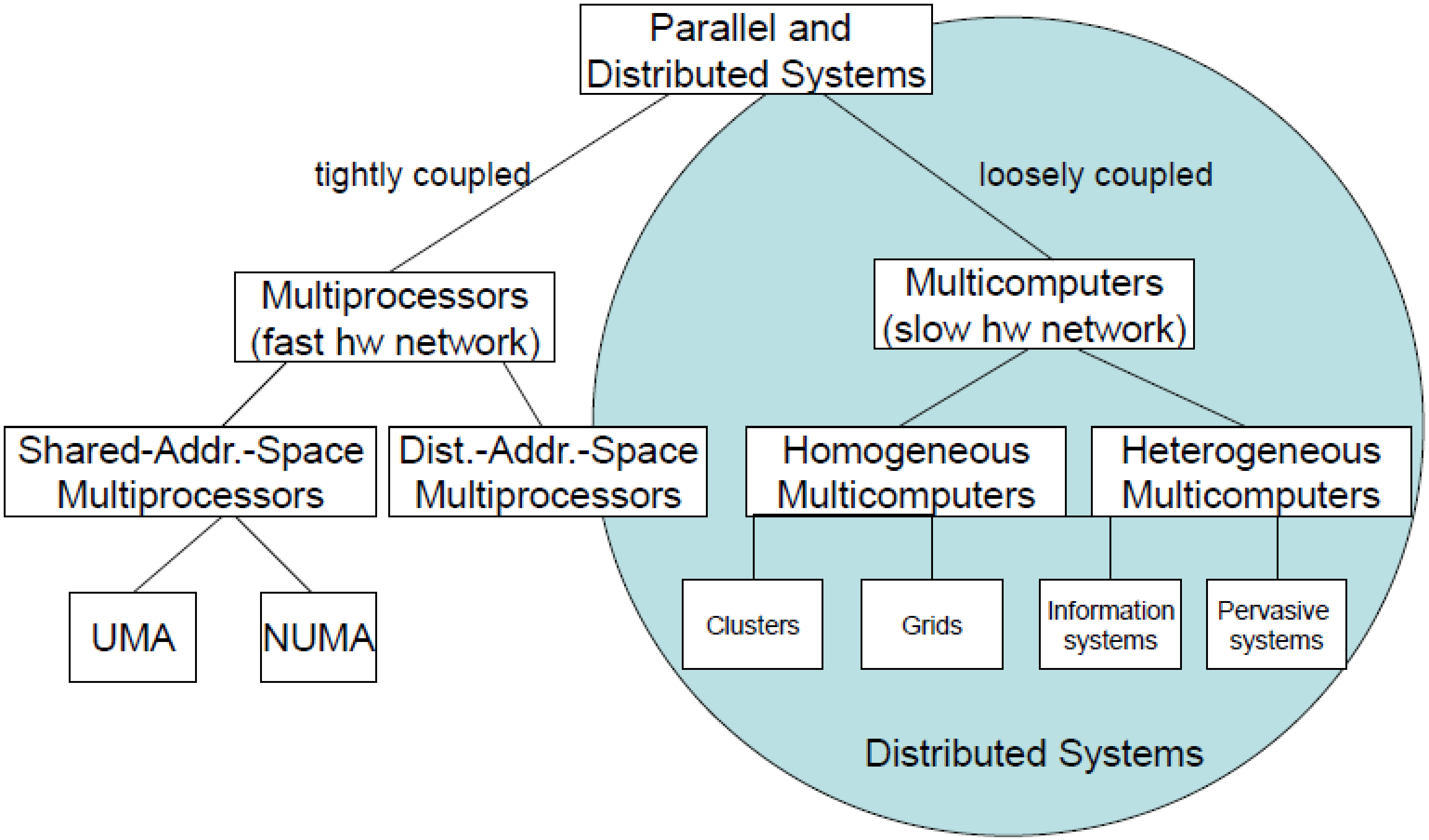
- **Client/server:** web server and web client
- **Cluster:** page rank computation
- **Peer-2-Peer:** Twitter, etc.

High-level Architecture (1)

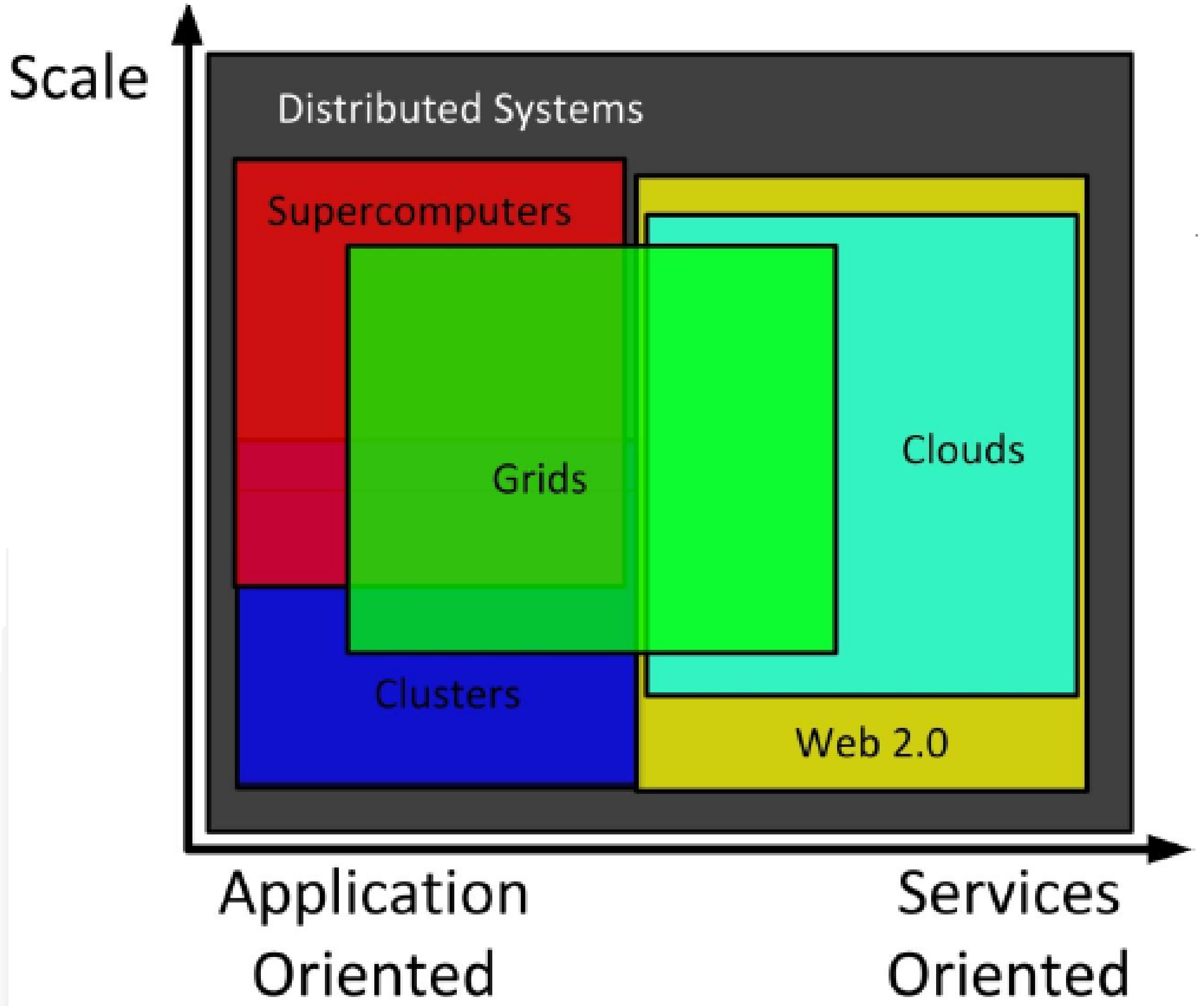


A distributed system organized as middleware. The middleware layer extends over multiple machines, and offers each application the same interface.

High-level Architecture (2)



Distributed Systems: Clusters, Grids, Clouds, and Supercomputers



Why go Distributed?

- More computing power
- More storage capacity
- Fault tolerance
- Data sharing
- Why Cloud

Key Characteristics of Distributed Systems

Key Characteristics

- Support for resource sharing
- Openness
- Concurrency
- Scalability
- Fault tolerance (reliability)
- Transparency (distribution transparency)

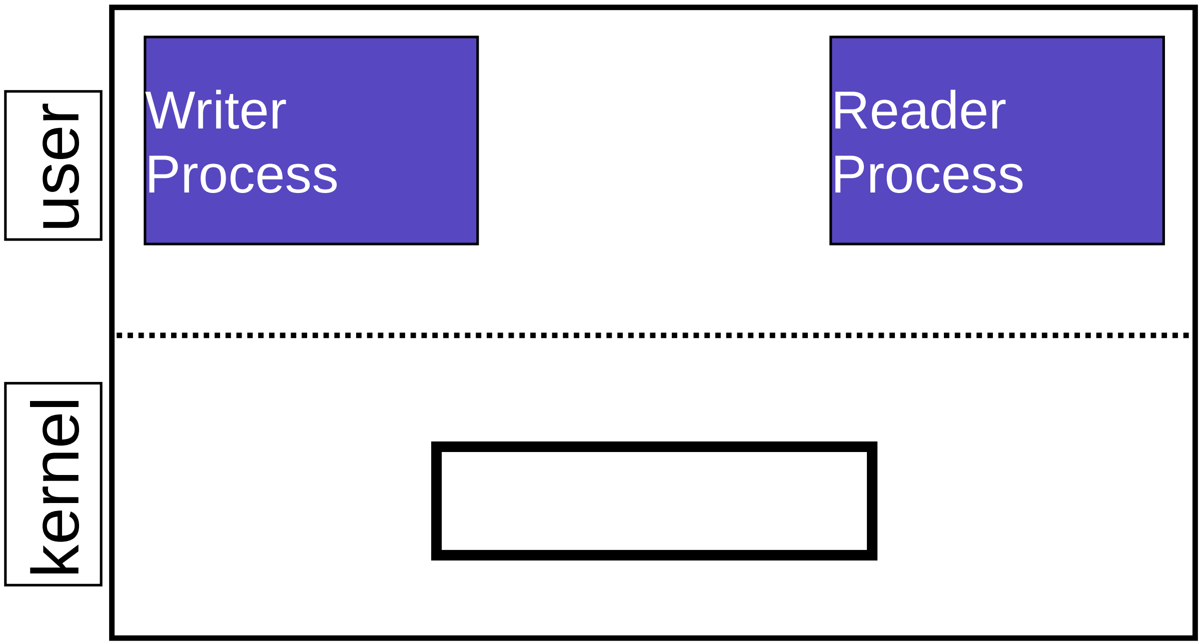
Challenges with Distributed System

Challenges with Distributed Systems?

- **Global consistent system state**; network delays
- **System failure**: need to worry about partial failure
- **Communication failure**: links are unreliable
  - bit errors
  - packet loss
  - node/link failure
- **Motivation example:**

  Why are network sockets less reliable than Unix pipes (no network)?

Pipe



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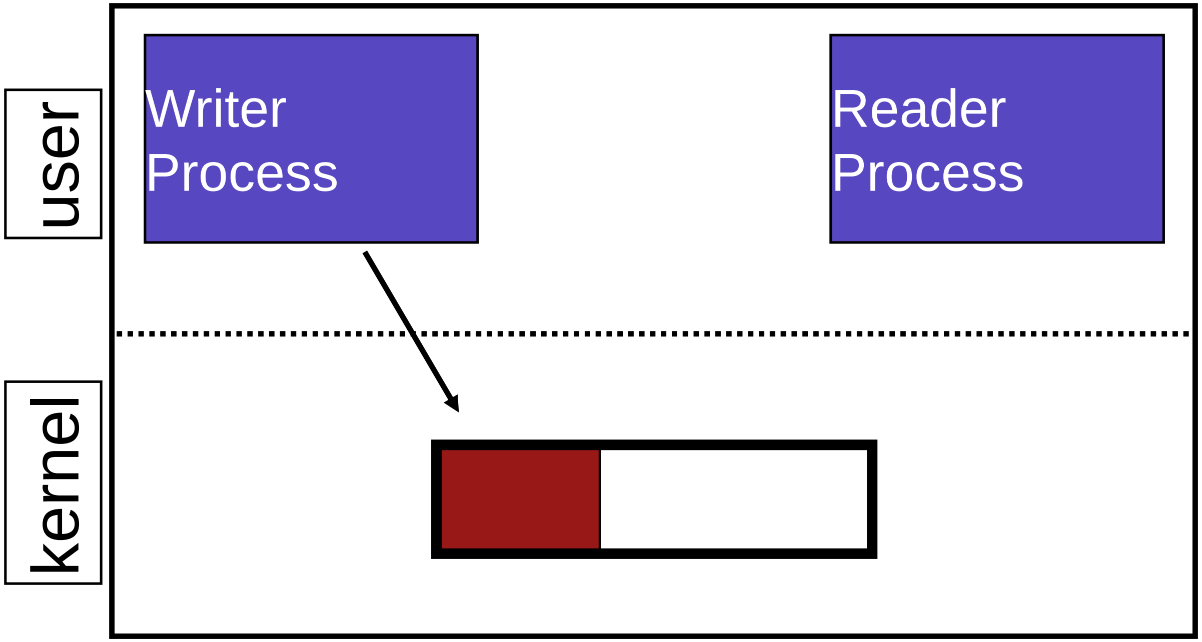

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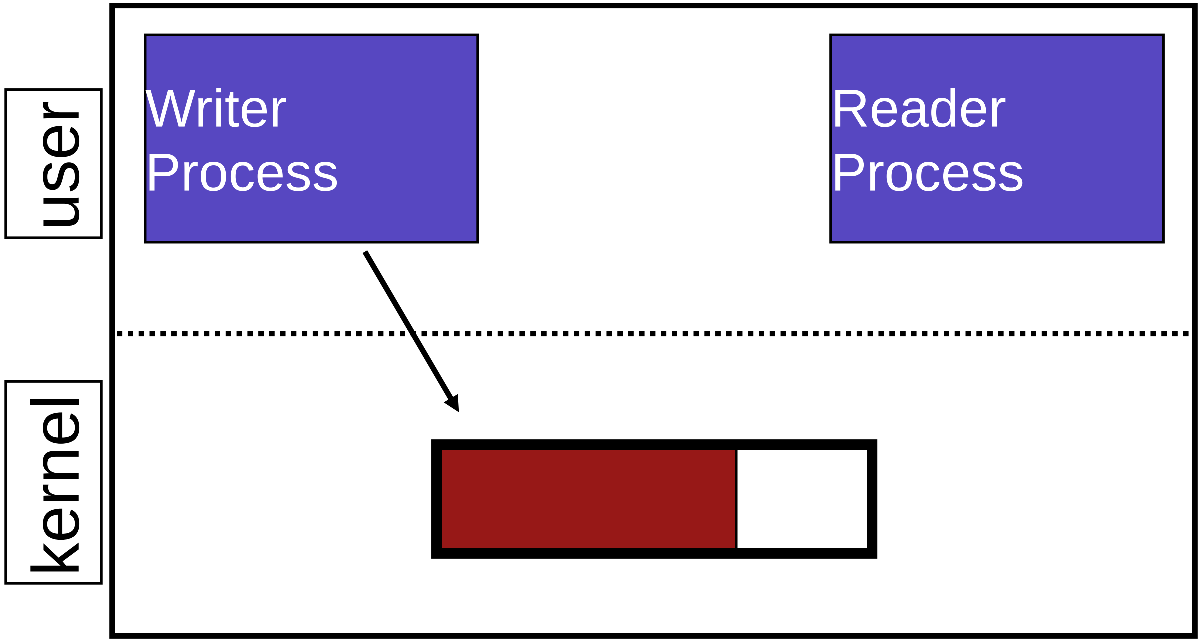

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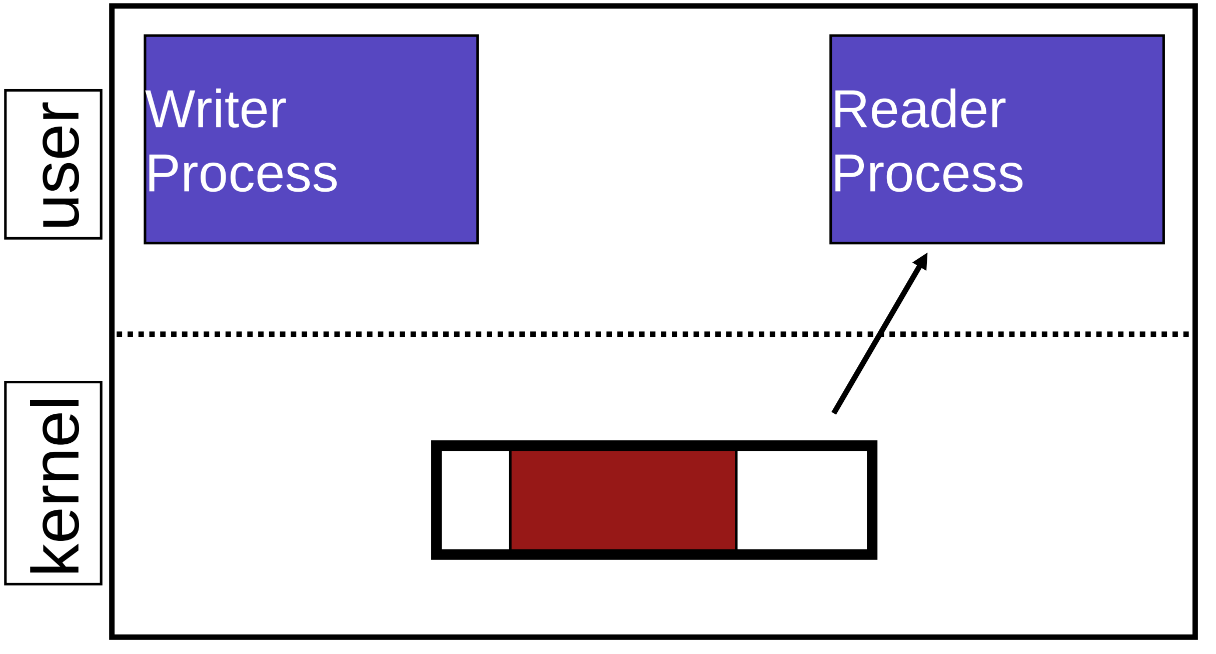

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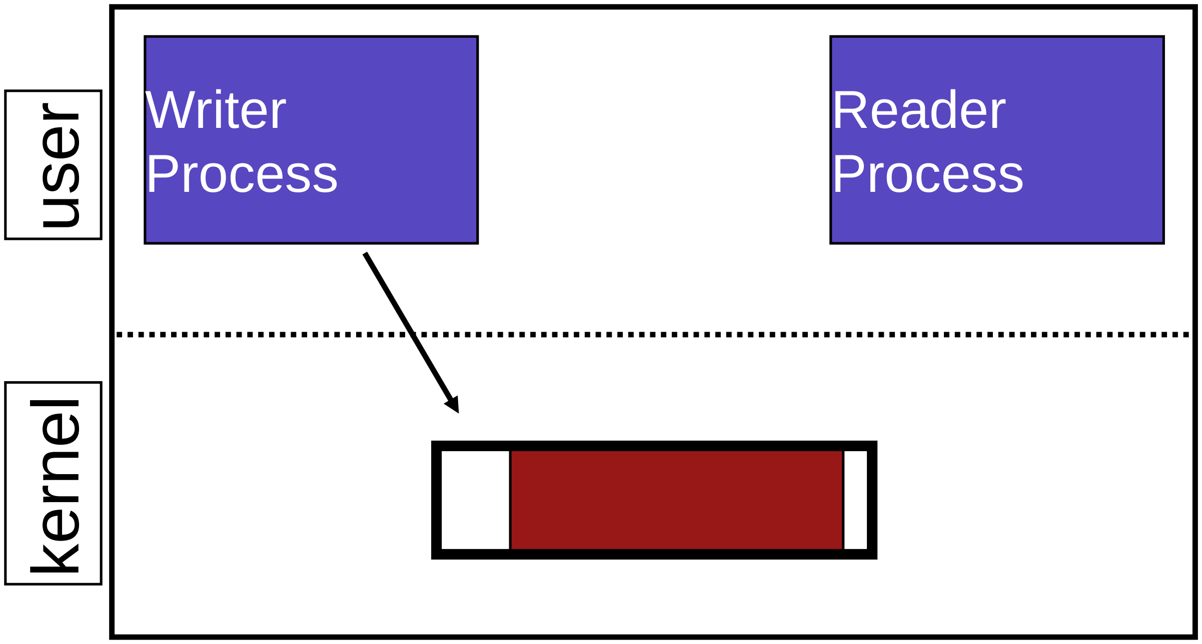

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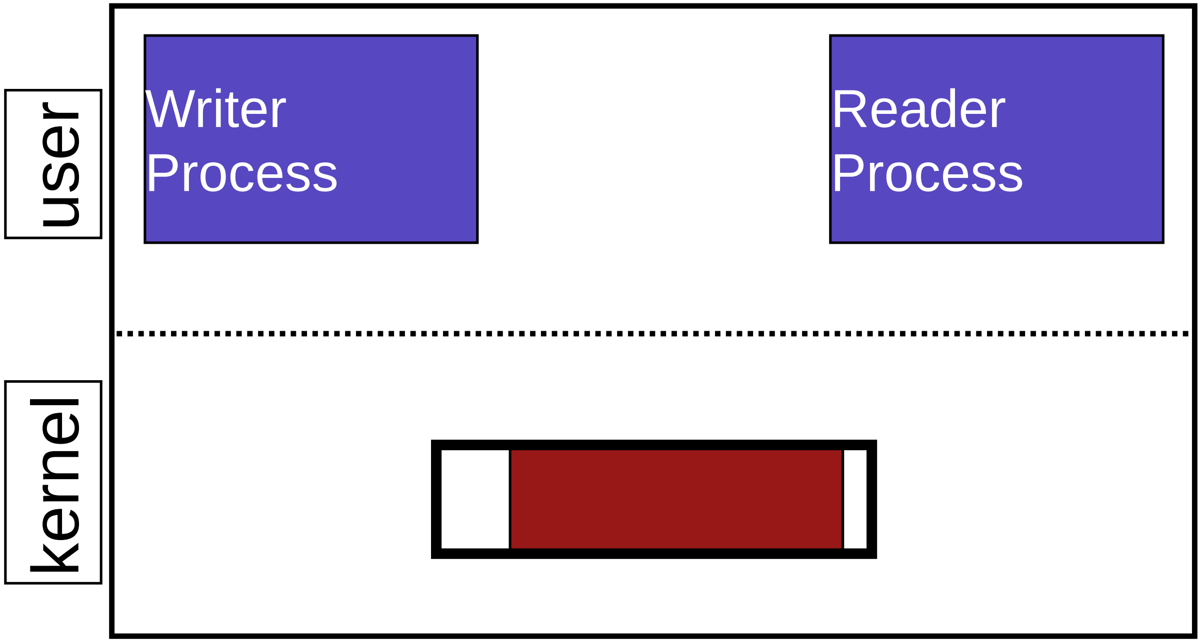

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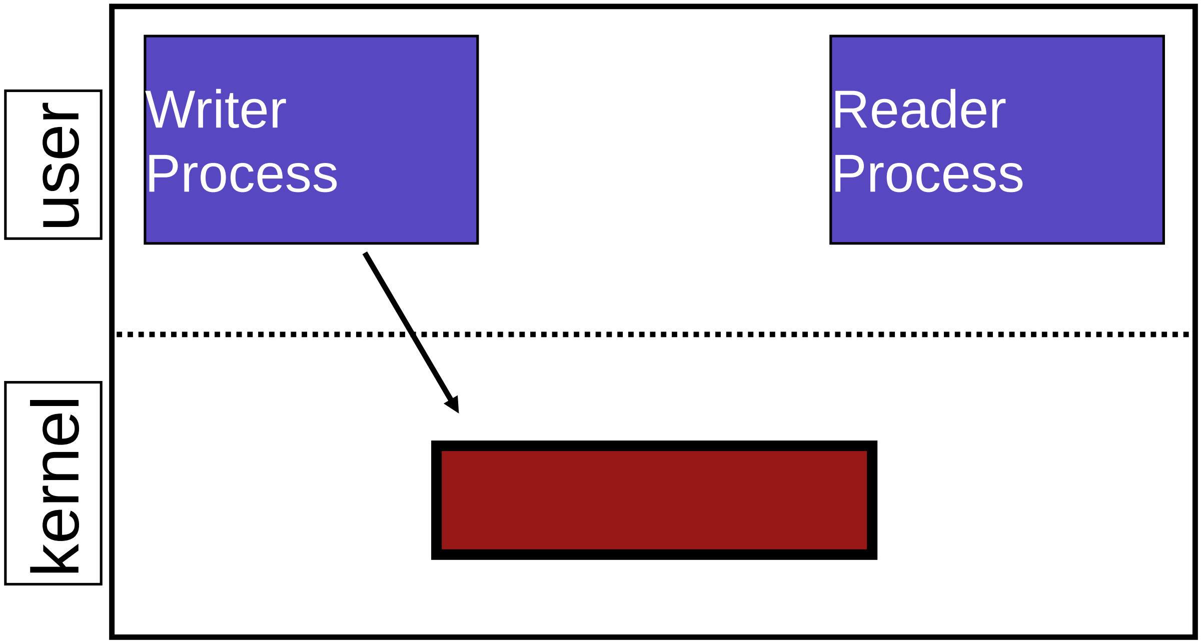

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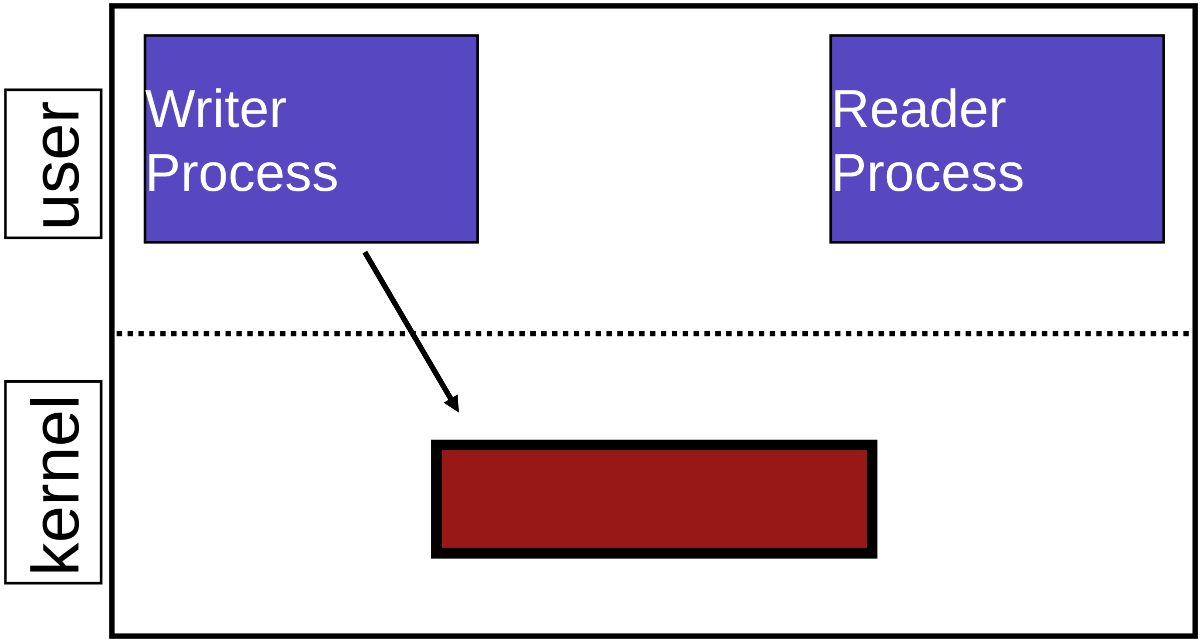
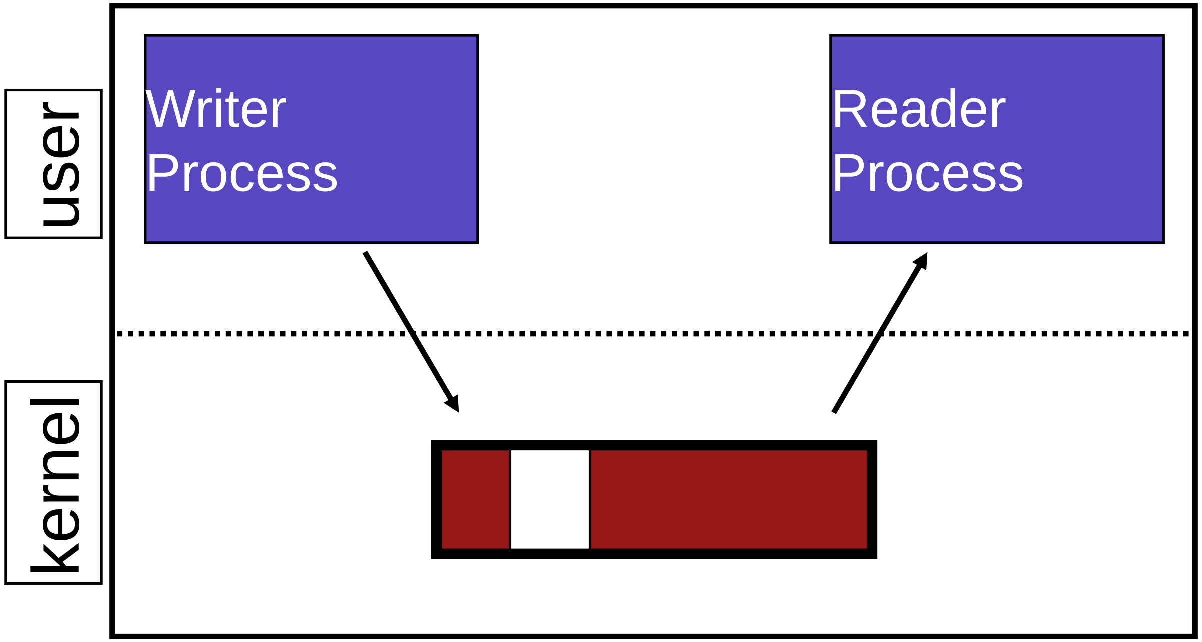


write waits for space

Pipe



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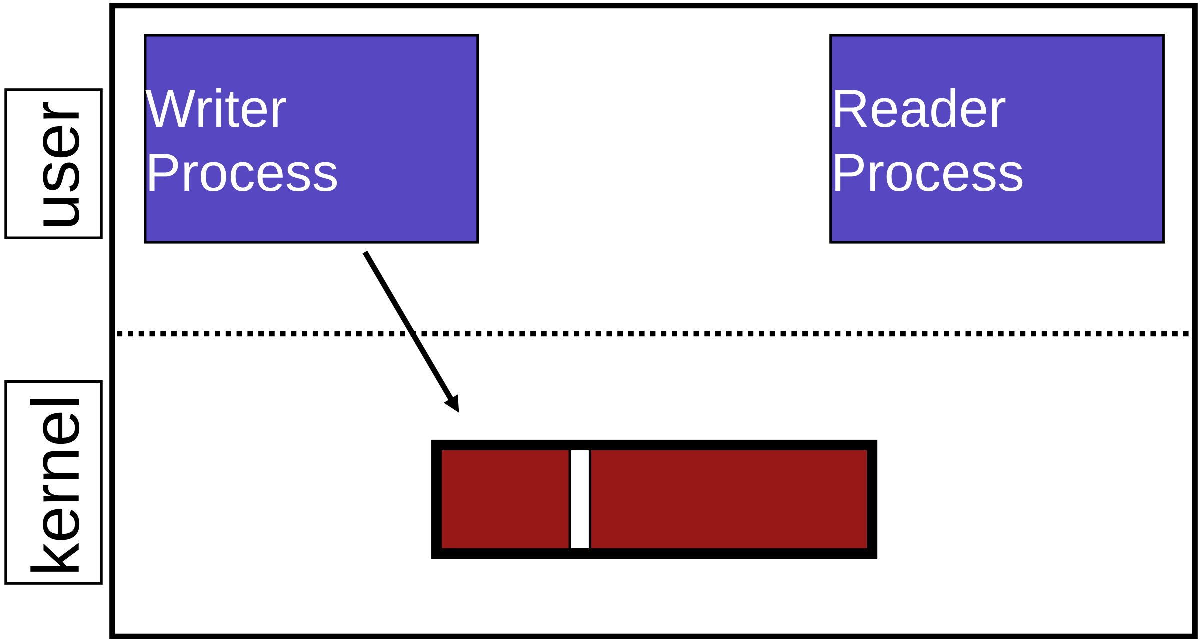
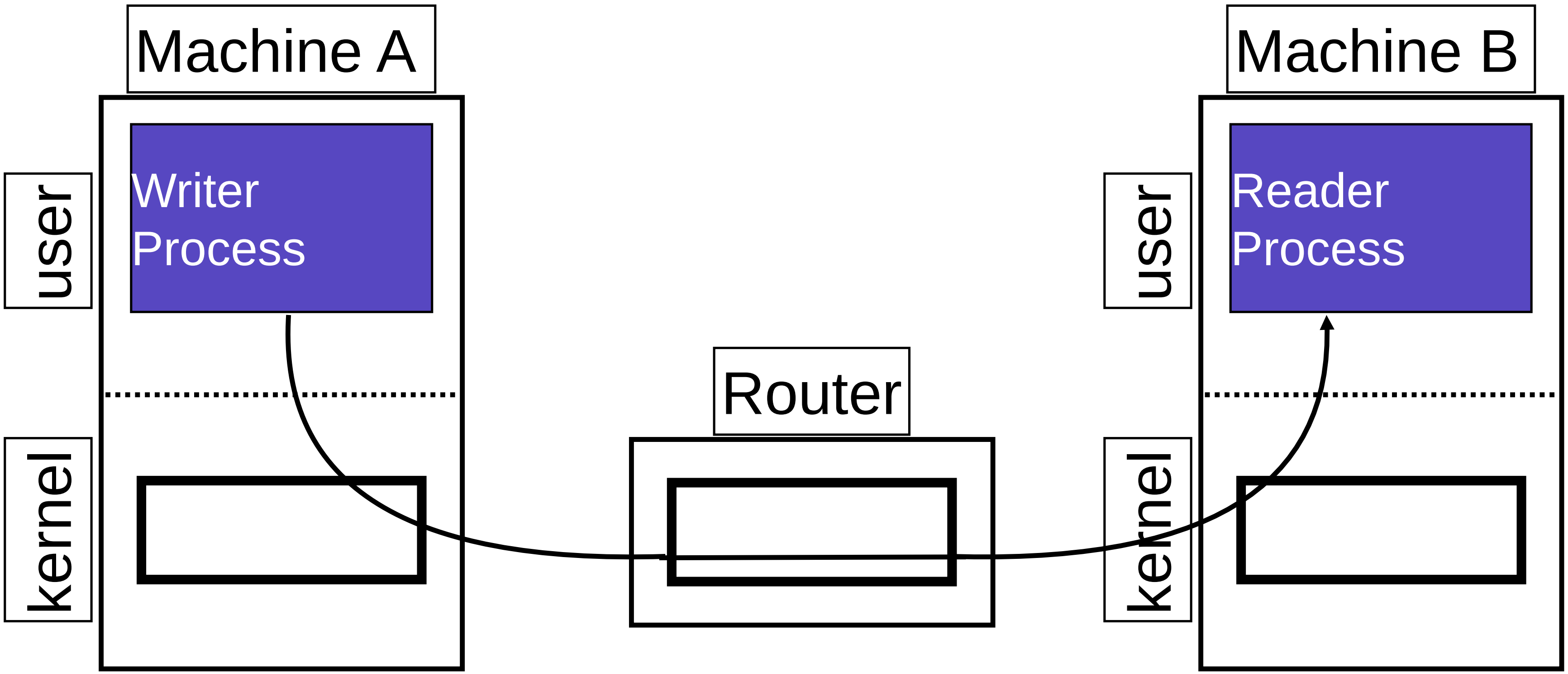
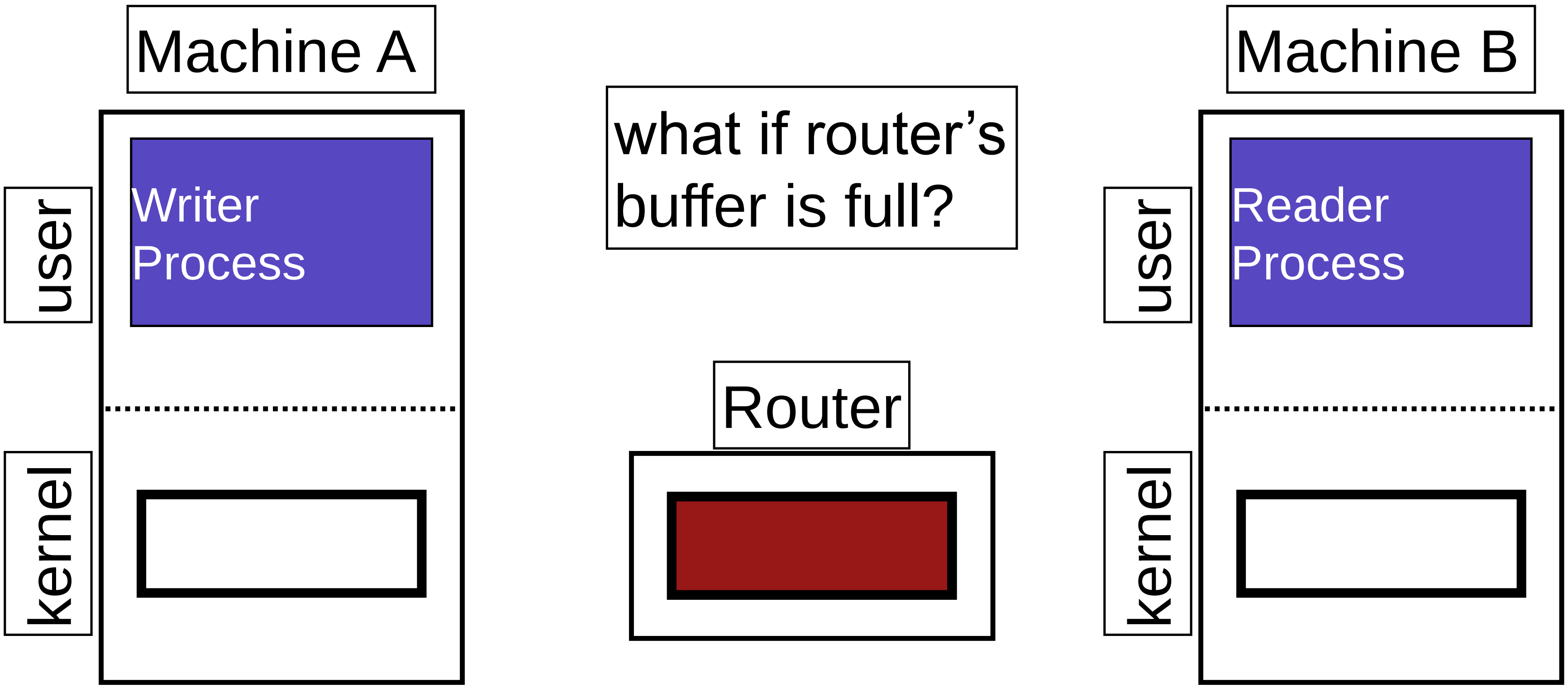


Network Socket



Network Socket



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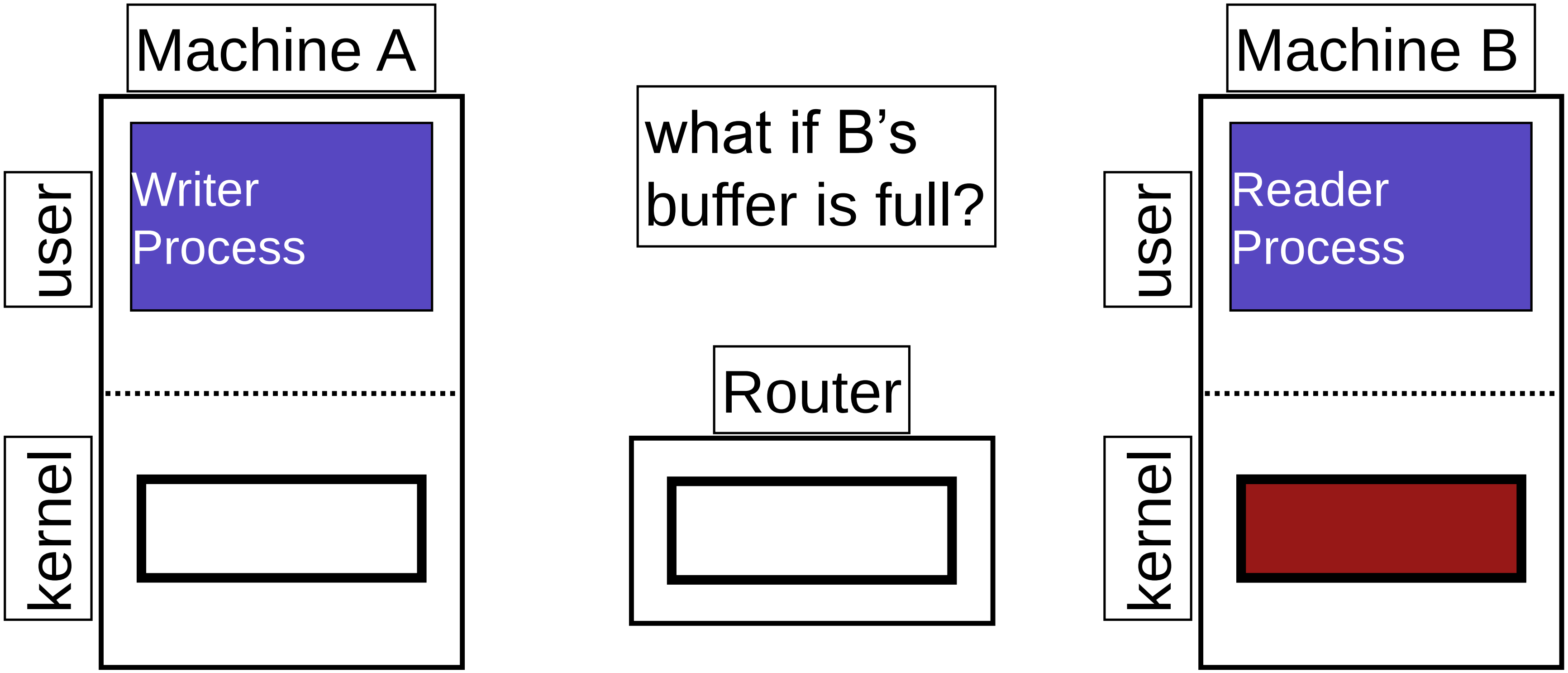

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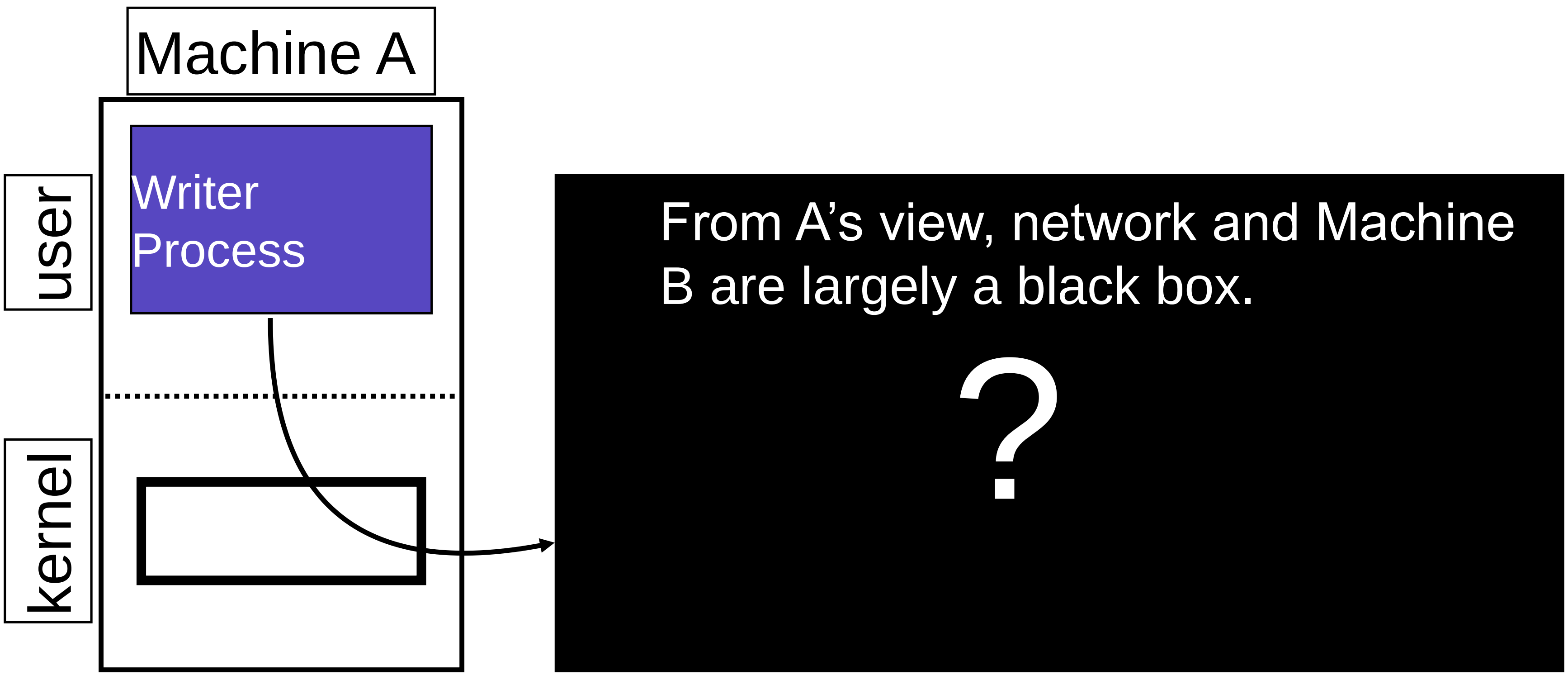


Communication Overview

- **Raw messages:** UDP
- **Reliable messages:** TCP
- **Remote procedure call:** RPC

Raw Message: UDP

UDP: User Datagram Protocol

API:

- reads and writes over socket file descriptors
- messages sent from/to ports to a target process on a machine

Provide minimal reliability features:

- messages may be lost
- messages may be **reordered**
- messages may be duplicated
- **only protection:** data integrity - checksums to ensure data not corrupted

Raw Message: UDP

Advantages:

- Lightweight
- Some applications make better reliability decisions themselves (e.g., video conferencing programs)

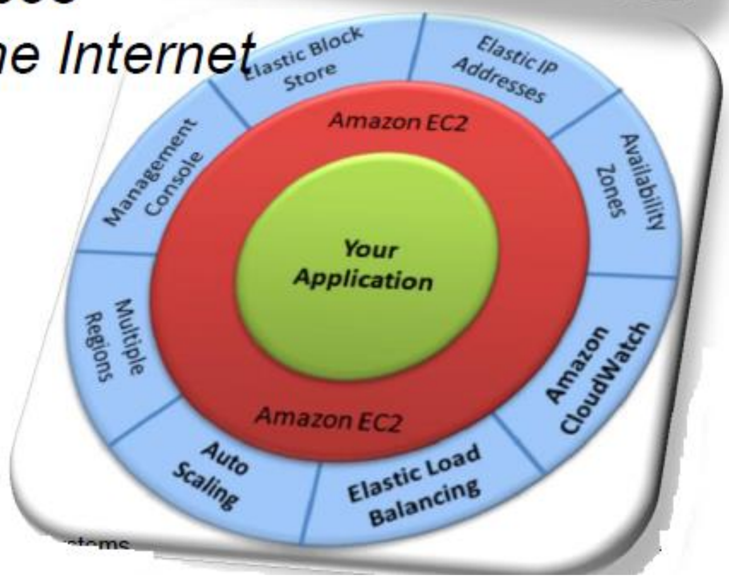
Disadvantages:

- Shift the reliability burden to the application. More difficult to write applications correctly

Why Cloud

- *A large-scale distributed computing paradigm driven by:*
  1. *economies of scale*
  2. *virtualization*
  3. *dynamically-scalable resources*
  4. *delivered on demand over the Internet*

Clouds ~ hosting

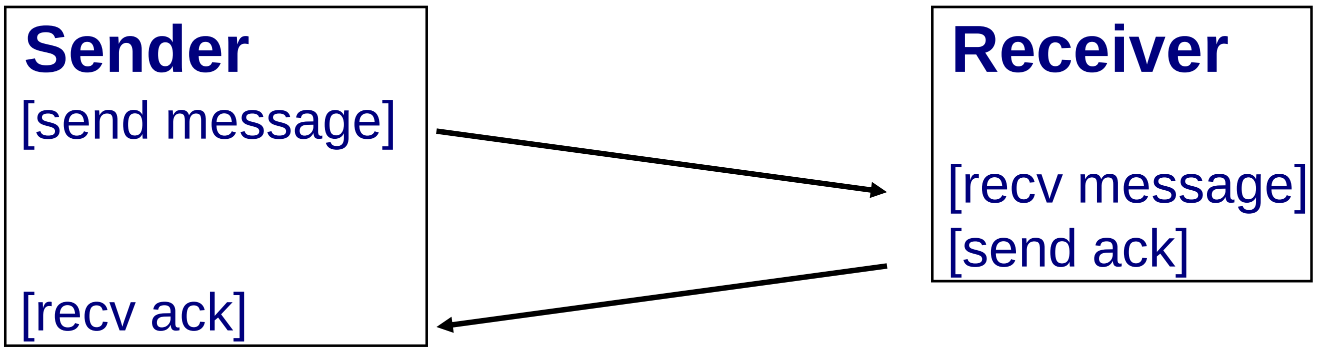


Build Reliable Messaging over Unreliable Layers

Reliable Messages: Layering Strategy

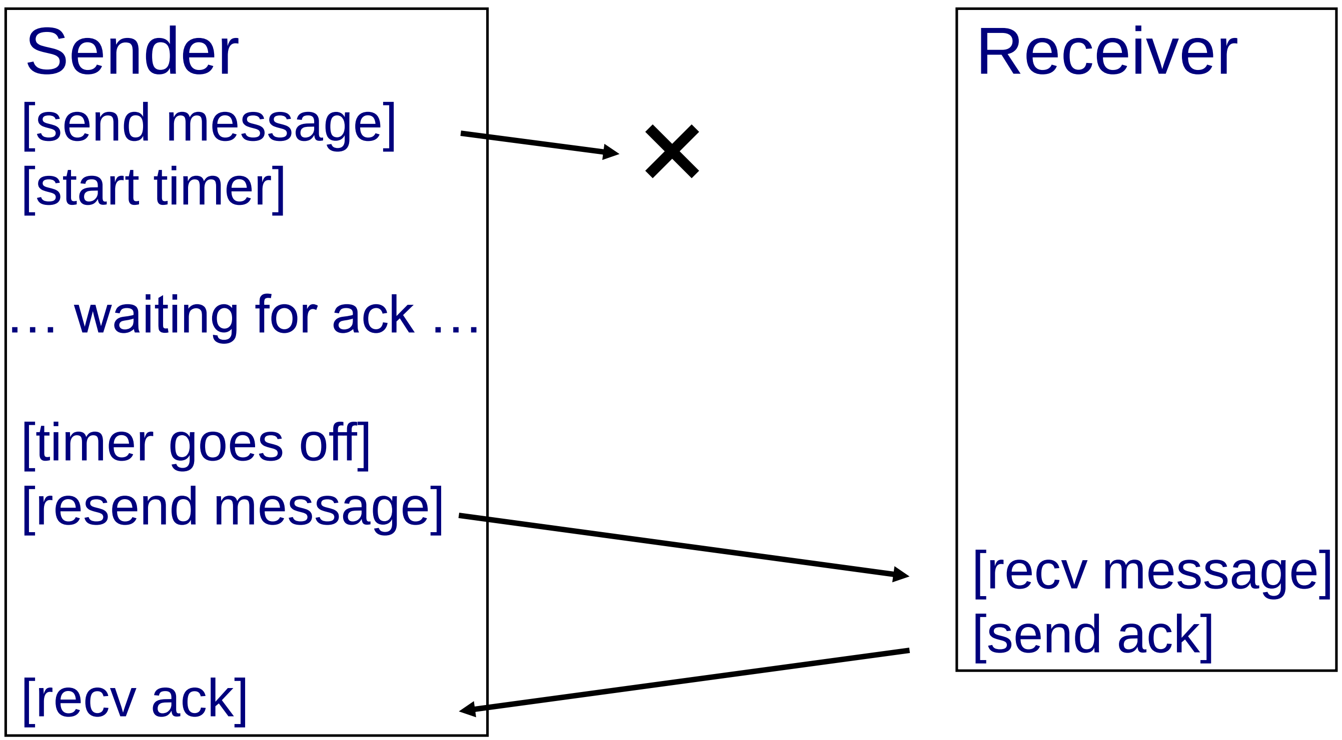
- **TCP:** Transmission Control Protocol
- **Using software**, build reliable, logical connections over unreliable hardware connections
- **Techniques:**
  - **Acknowledgment** (ACK)
  - **Timeout**
  - **Remember sent Messages**: having msg-id as part of the message header

Technique #1: ACK



Sender knows (ACK) message was received

Technique #2: TIMEOUT



Technique #2: TIMEOUT

- **How long to wait?** Timeout goes off, resend the message

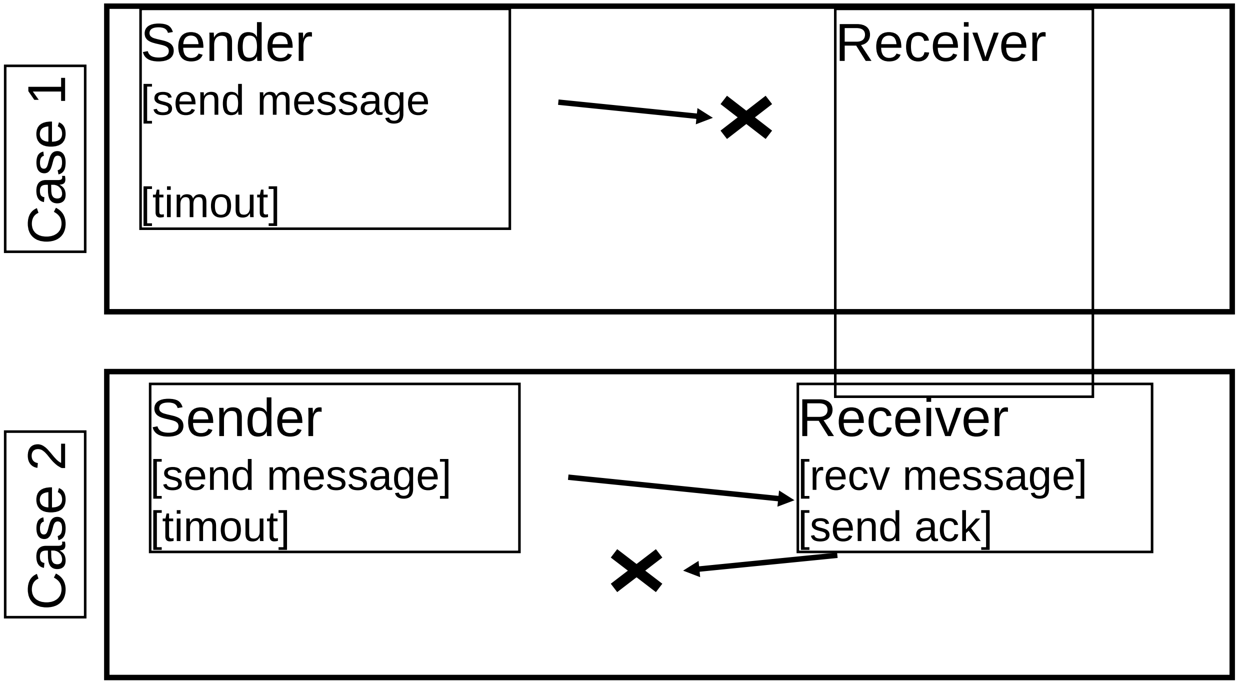
- **How long to wait: Too long?**
  - System feels unresponsive – poor r.p.t

- **How long to wait: Too short?**
  - Messages needlessly re-sent
  - Messages may have been dropped due to overloaded server. Resending makes overload worse!

Technique #2: TIMEOUT

- **One strategy:** be adaptive
- **Adjust timeout** based on how long acks usually take
- **For each missing ack**, wait longer between retries
- **What does a lost ack really mean**?

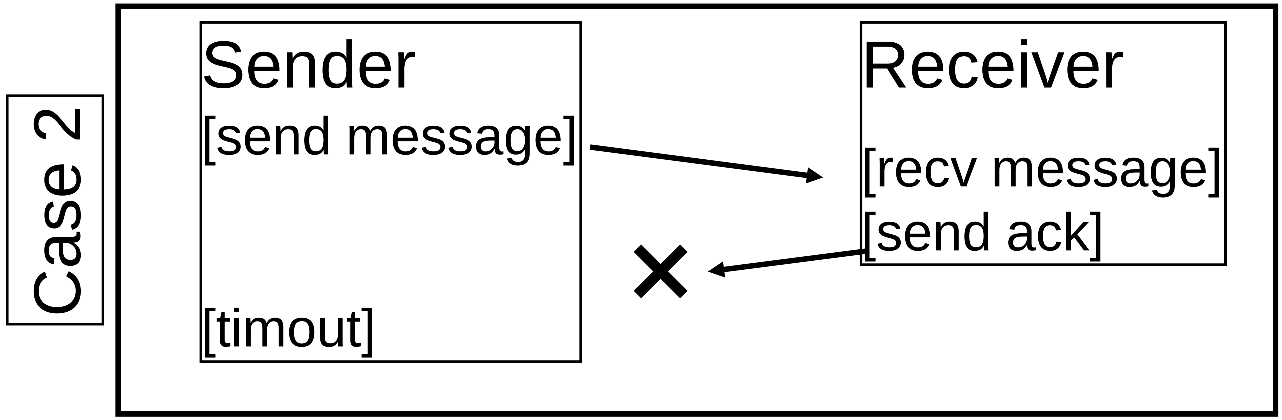
How do you Handle lost ACK



Lost ACK:
How can sender tell between these two cases?

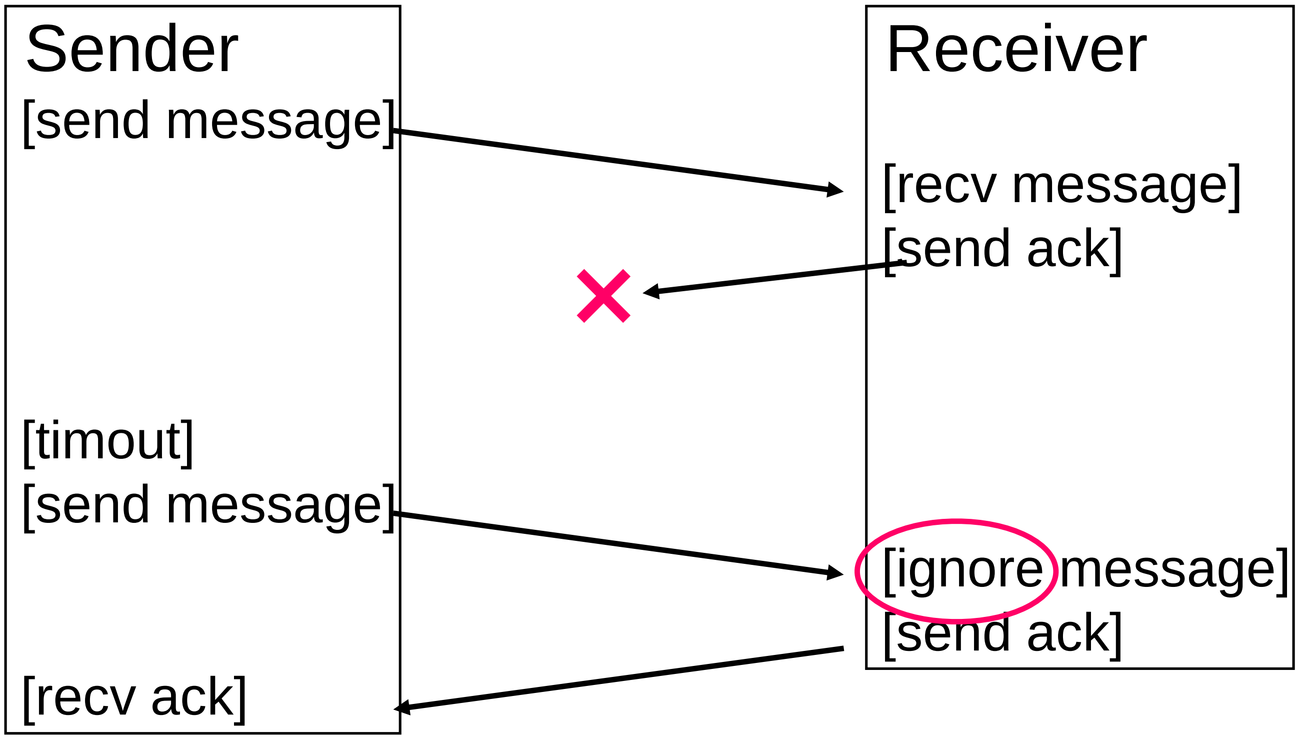
- **ACK**: message received exactly once
- **No ACK:** message may or may not have been received
- **What if message is a command to increment counter? non-idempotent…**

PROPOSED SOLUTION



- **Proposal:**
  Sender could send an **AckAck** msg to receiver so receiver knows whether to retry sending an Ack
- Sound good? No

Technique #3: REMEMBERS MESSAGES



Q) How does receiver know when to ignore a request?
Ans) Sequence number

Transmission Control Protocol: TCP

- Most popular protocol is based on seq-nums
- Receiver (server) Buffers (cache) response messages in the kernel to deliver to receiver/user in order
- Timeouts are adaptive

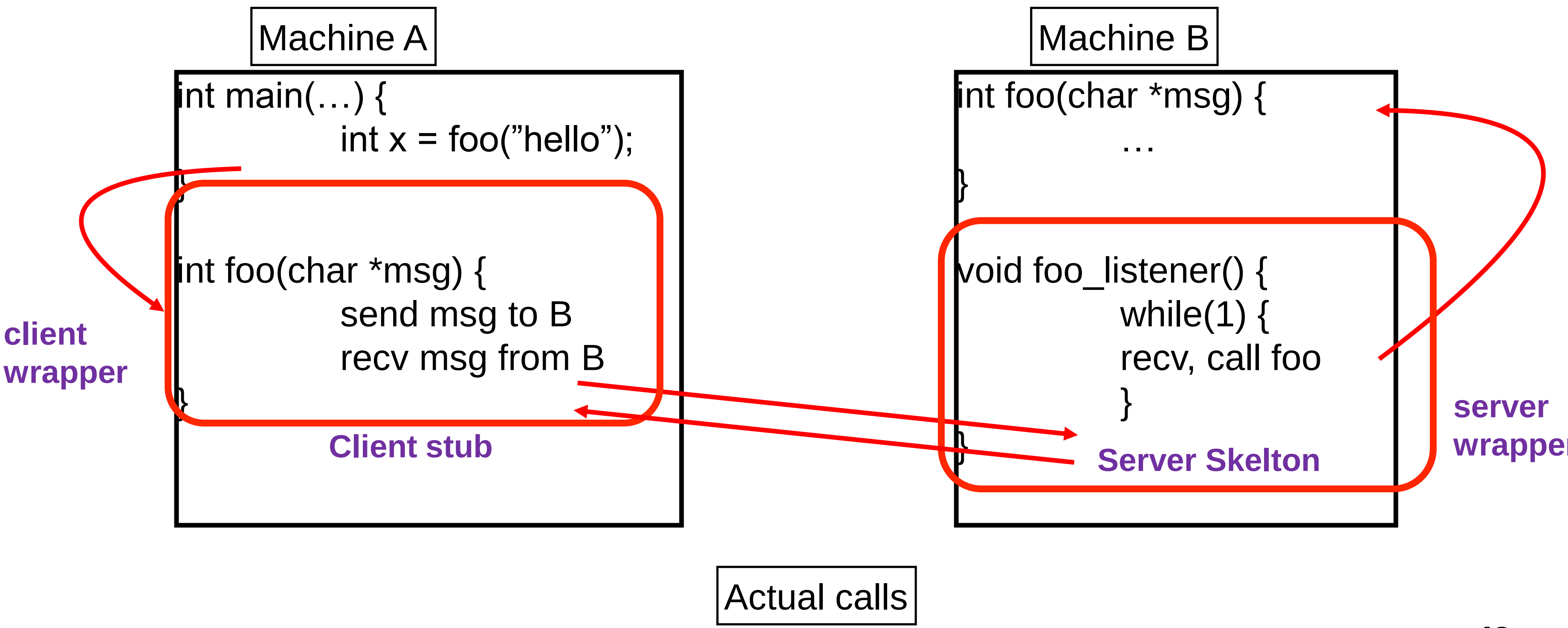
Communications Overview

- Raw messages: UDP
- Reliable messages: TCP
- Remote procedure call: RPC

What is an RPC

Remote Procedure Call: RPC

- **What could be easier** than calling a function?
- **Strategy**: create wrappers so calling a function on another machine feels just like calling a local function
- Very common abstraction



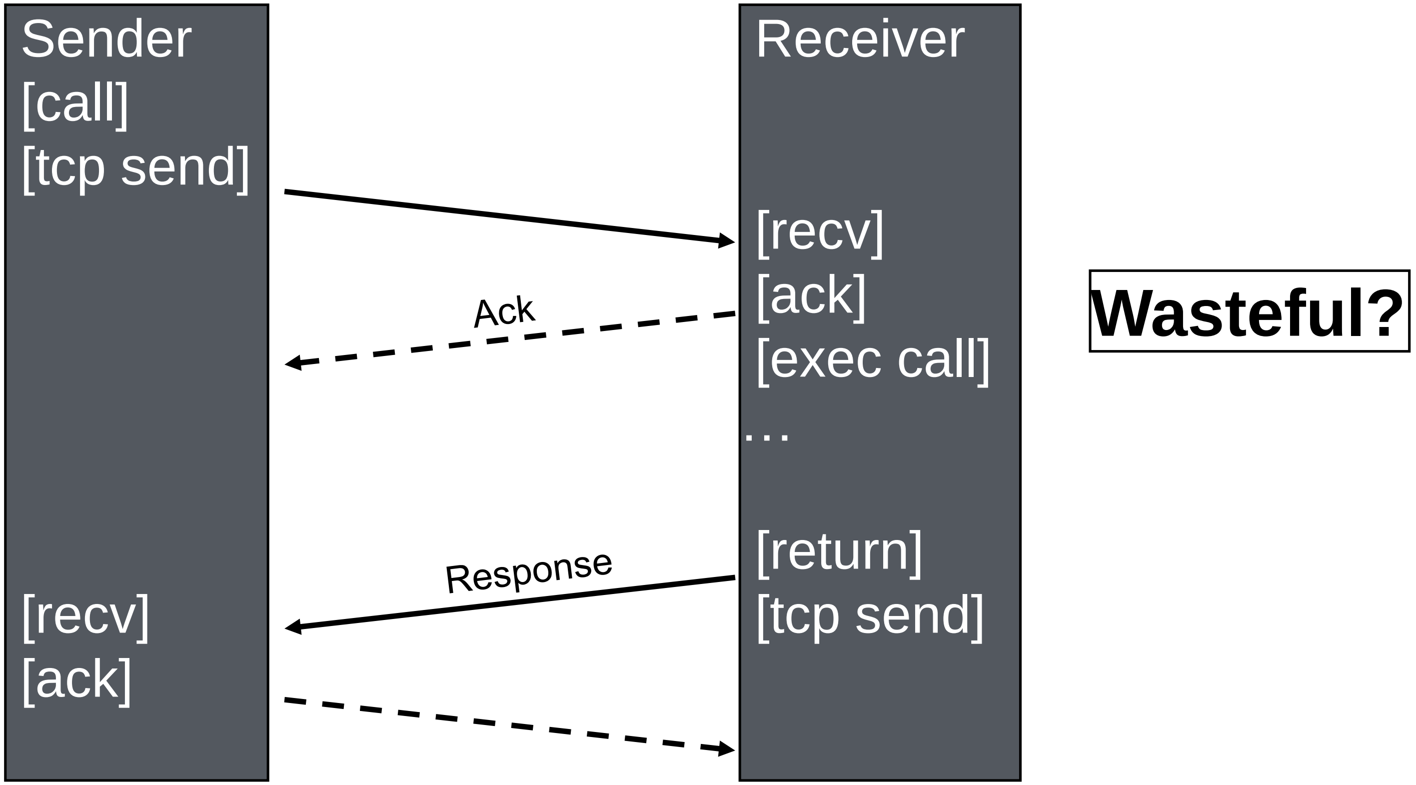
RPC Tools

- RPC packages help with two components:
  1. **Runtime library**
     - Thread pool
     - Socket listeners call functions on server (worker threads)

  2. **Stub generation / compiler**
     - Create wrappers automatically
     - Many tools available (rpcgen, thrift, protobufs)*

* rpcgen: https://en.wikipedia.org/wiki/RPCGEN
Thrift (Apache RPC): https://thrift.apache.org/
Protobufs (lang independent for serializing data structures):
https://en.wikipedia.org/wiki/Protocol_Buffers
https://developers.google.com/protocol-buffers/

RPC Over TCP



- Use UDP and piggybacking the ACK to be part of the returned server message back to the client; unless serving the sender request takes long time.
- If the server function takes log time then send separate ACK.

Distributed File System

NFS Architecture

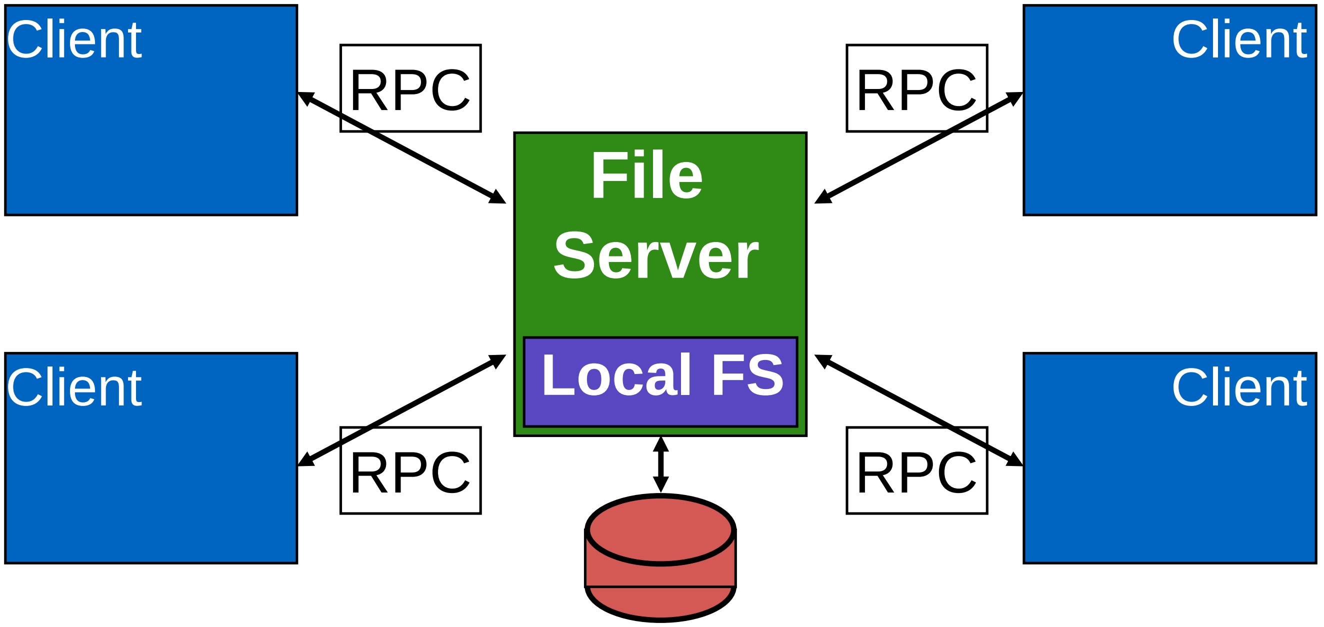
Distributed File Systems

- **File systems** are great use case for distributed systems
- **Local FS**:
  processes on same machine access shared files
- **Network FS**:
  processes on different machines access shared files in the same way
- **Network File System Goals:**
  - **Fast and simple** crash recovery
  - **Transparent access;** normal UNIX semantics
  - **Reasonable performance**

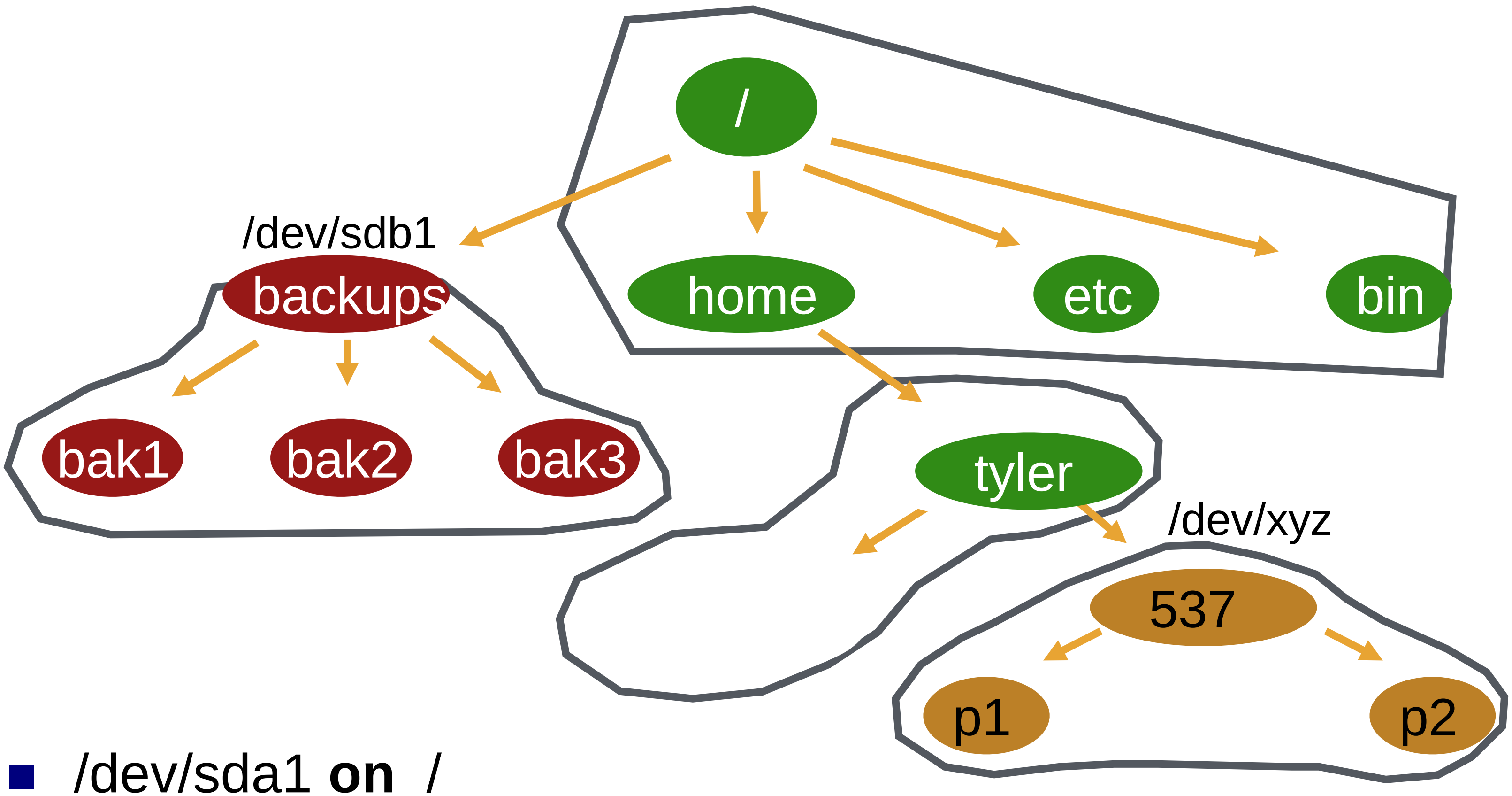
Overview

- **NFS Architecture**
- **Network API:** use RPC
- **Write Buffering** (delayed write to disk)
- **Cache**

NFS Architecture

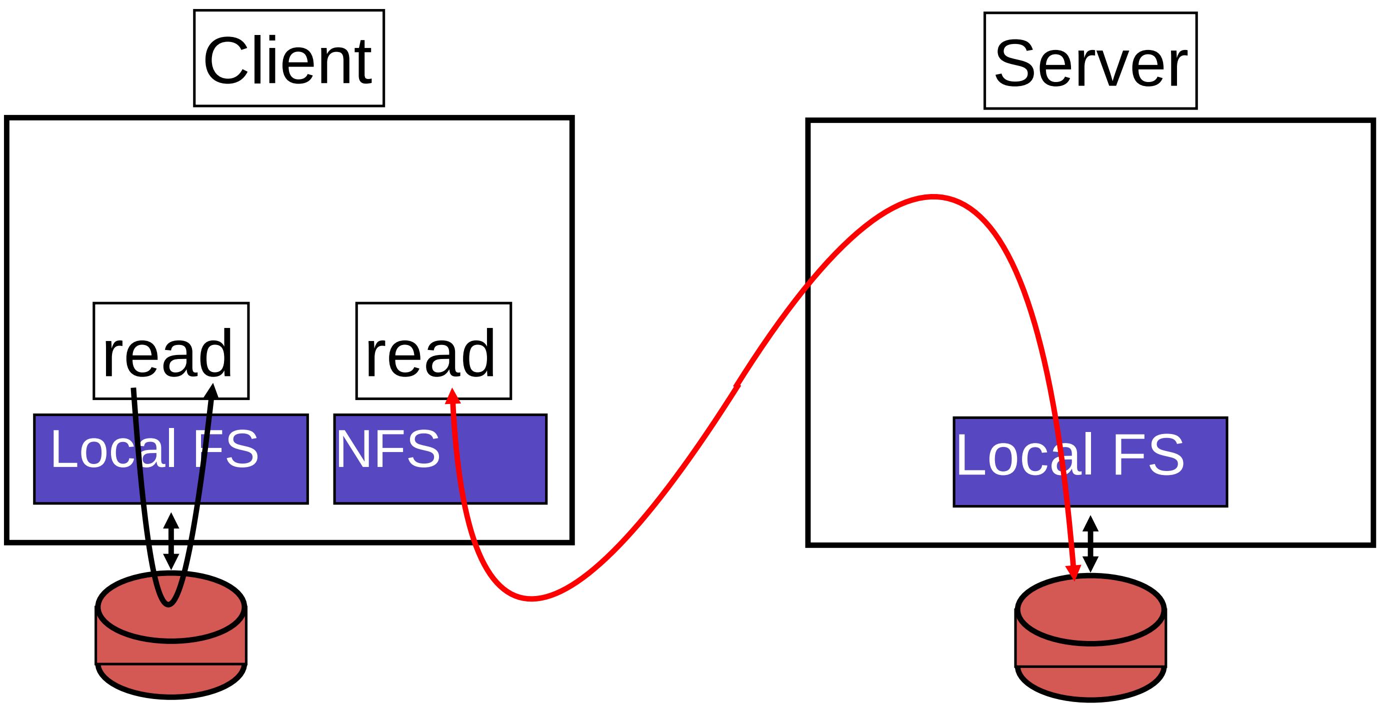


Mount

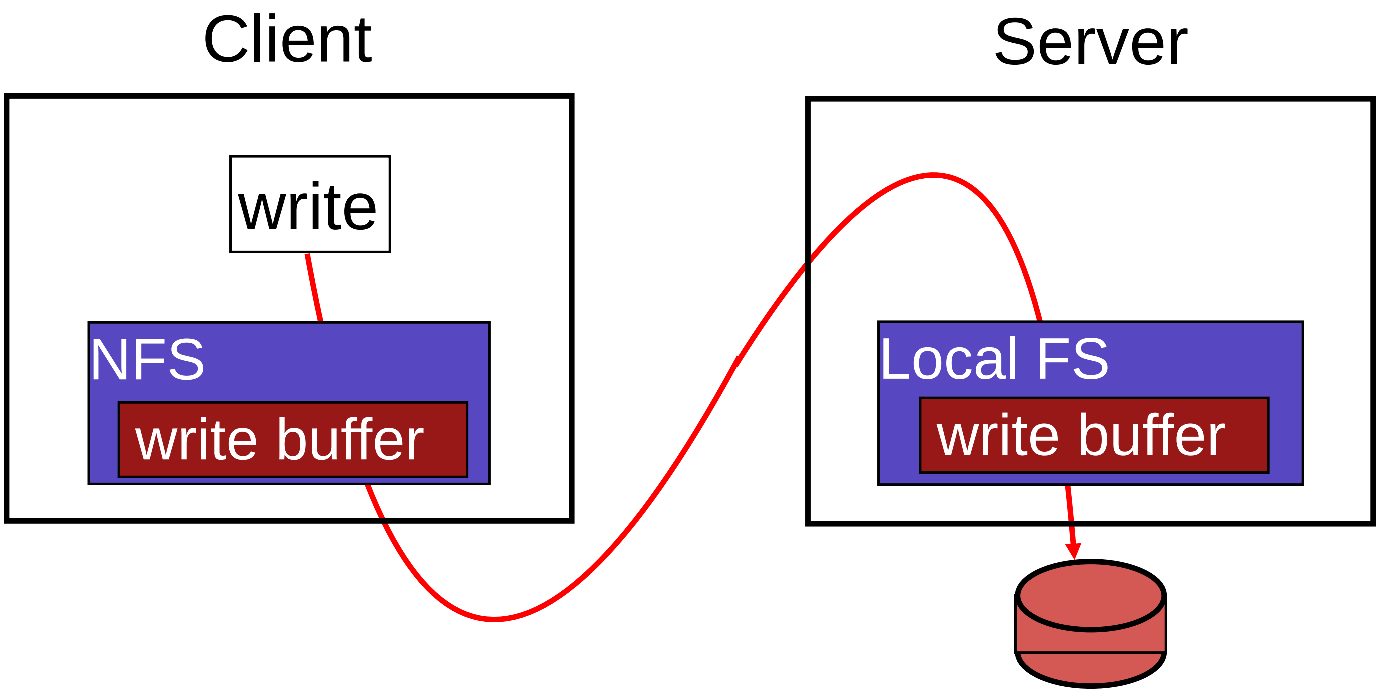


- /dev/sda1 **on** /
- /dev/sdb1 **on** /backups
- /dev/xyz **on** /home/tyler

General Strategy: Export FS

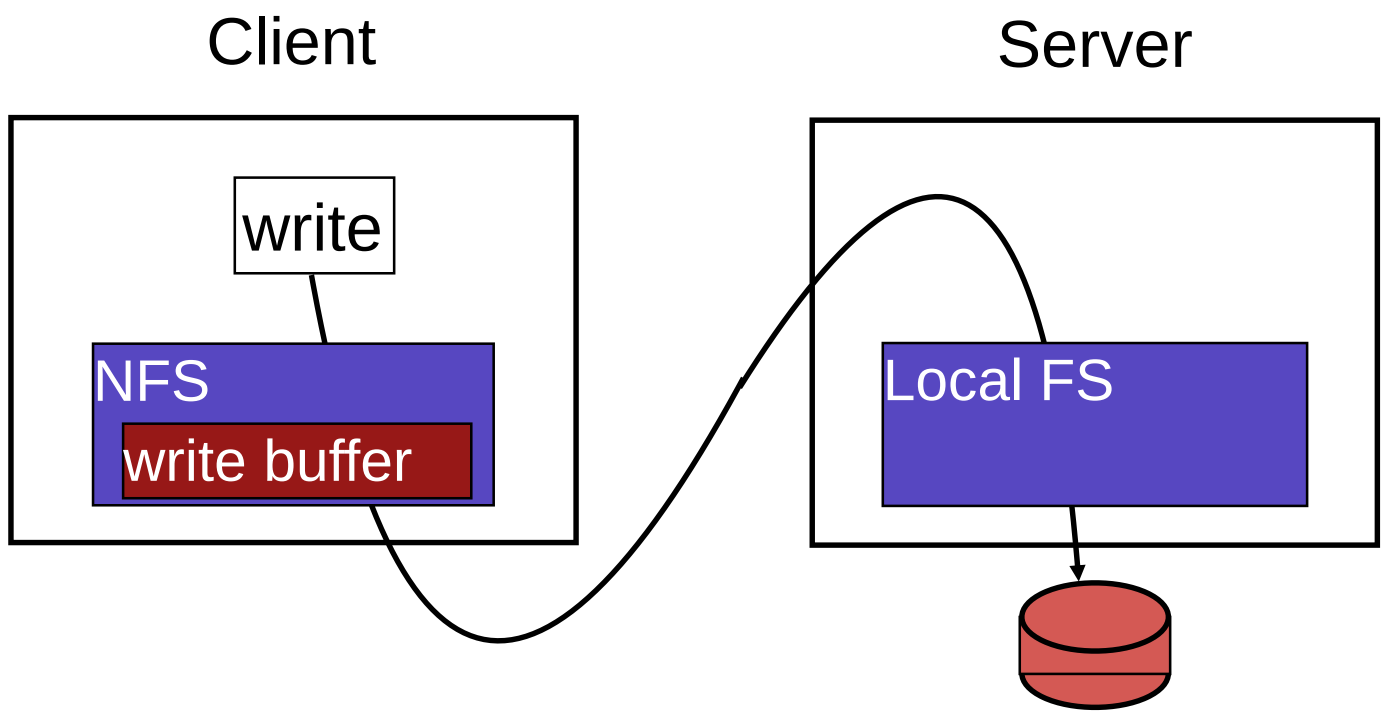


Write Buffers (delayed write)



- Server acknowledges write once data in the server cache but before the write is pushed to disk
- What happens if server crashes before writing to disk?

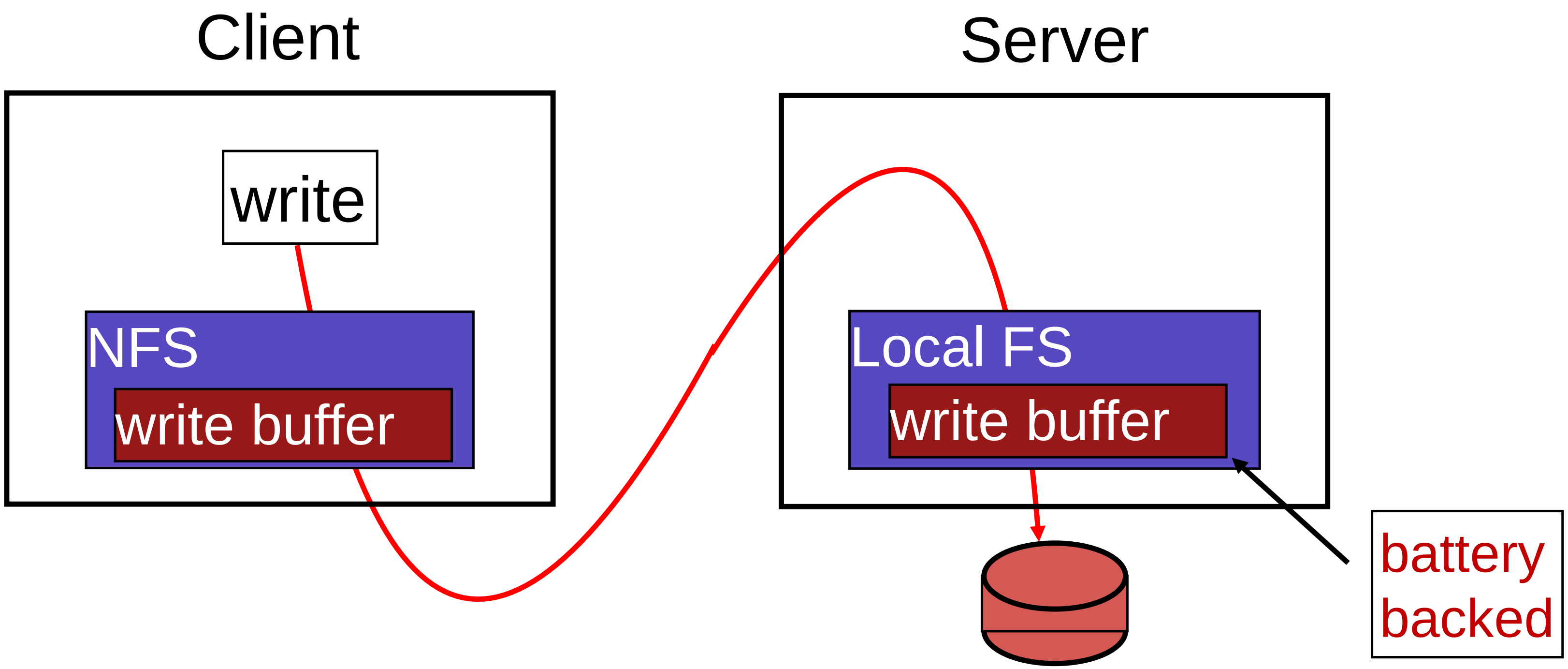
Write Buffers



1. Don’t use server write buffer
   (persist data to disk before acknowledging write)

Problem: Slow!

Write Buffers



2. use persistent write buffer (more $$ expensive)

Client Caching

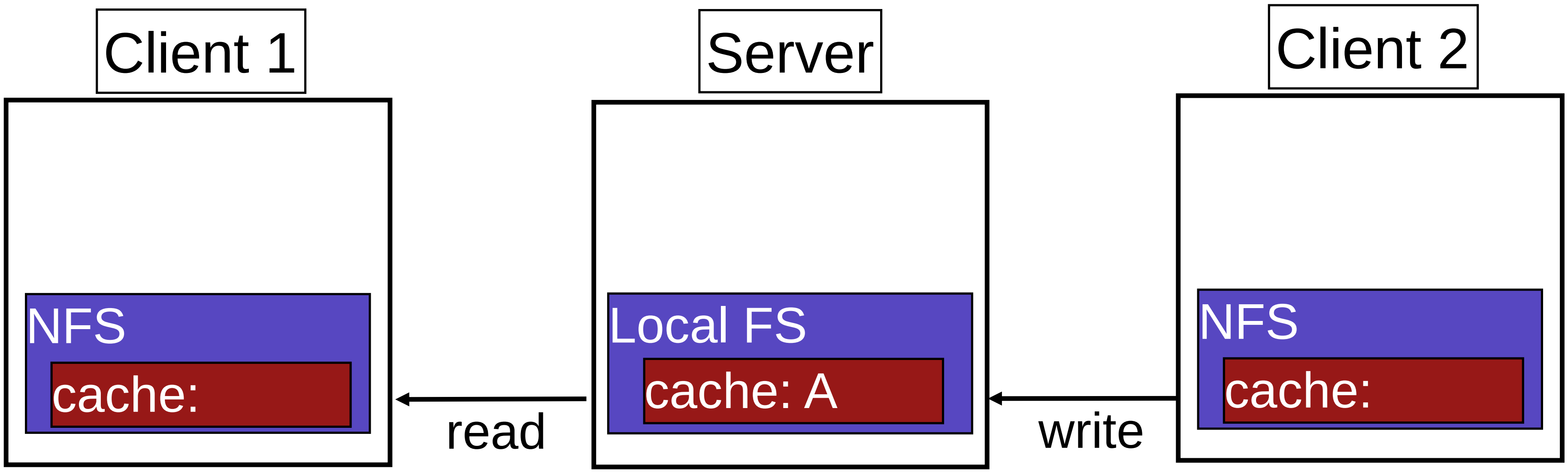
Cache Consistency

NFS can cache data in three places:

- Server memory
- Client memory
- Client disk

How to make sure all versions are in sync?

Distributed Cache



Cache consistency is expensive

One possible solution is to invalidate cache entries after a given time; it means that you minimize the chances for reading out-of-date data!

END