Consistency

David E. Culler

CS162 – Operating Systems and Systems Programming

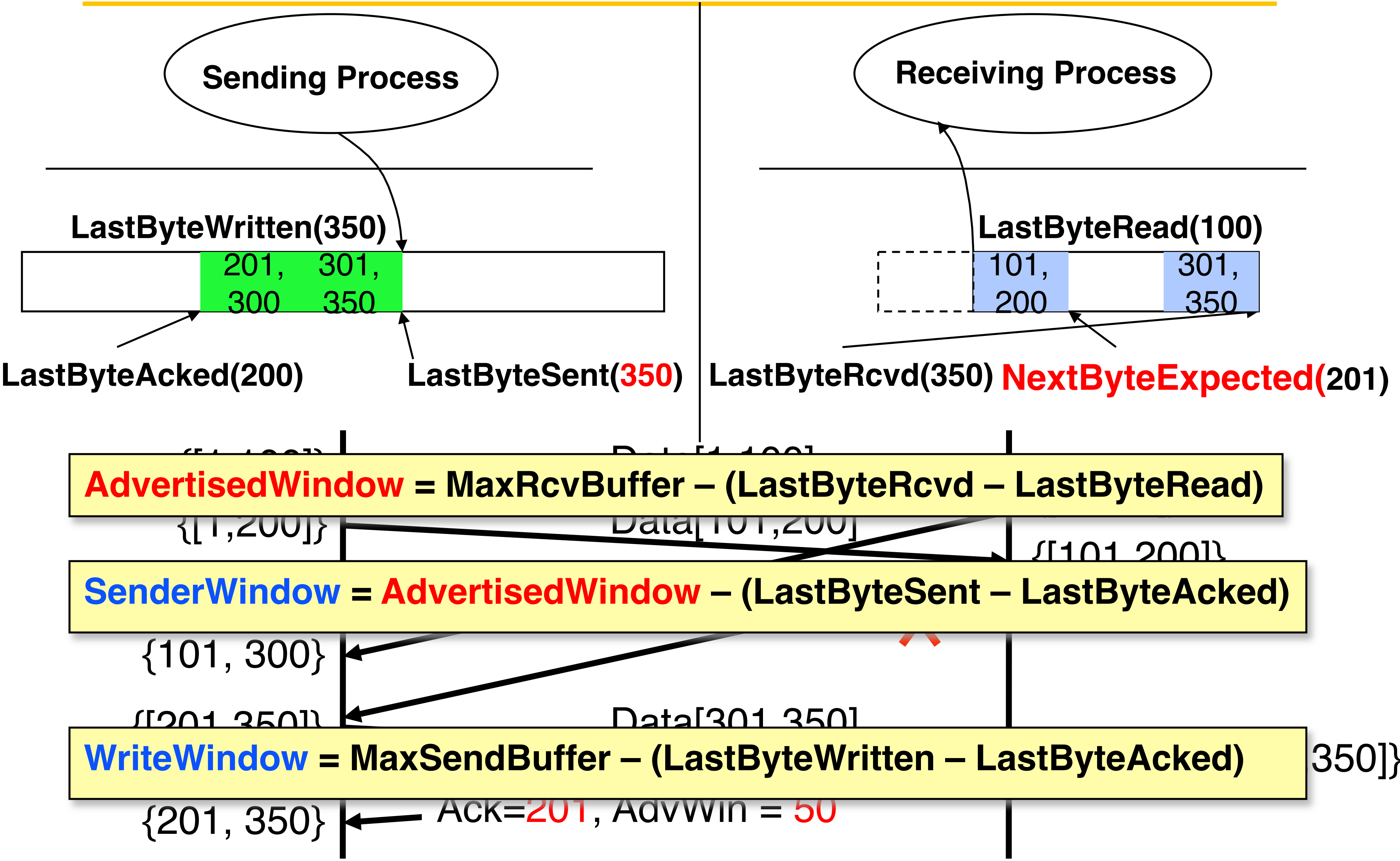
http://cs162.eecs.berkeley.edu/

Lecture 35

Nov 19, 2014

Read:

Recap: TCP Flow Control



AdvertisedWindow = MaxRcvBuffer – (LastByteRcvd – LastByteRead)

SenderWindow = AdvertisedWindow – (LastByteSent – LastByteAcked)

WriteWindow = MaxSendBuffer – (LastByteWritten – LastByteAcked)

Summary: Reliability & Flow Control

- **Flow control: three pairs of producer consumers**
  - **Sending process → sending TCP**
  - **Sending TCP → receiving TCP**
  - **Receiving TCP → receiving process**

- **AdvertisedWindow: tells sender how much new data the receiver can buffer**
- **SenderWindow: specifies how more the sender can transmit.**
  - **Depends on AdvertisedWindow and on data sent since sender received AdvertisedWindow**
- **WriteWindow: How much more the sending application can send to the sending OS**

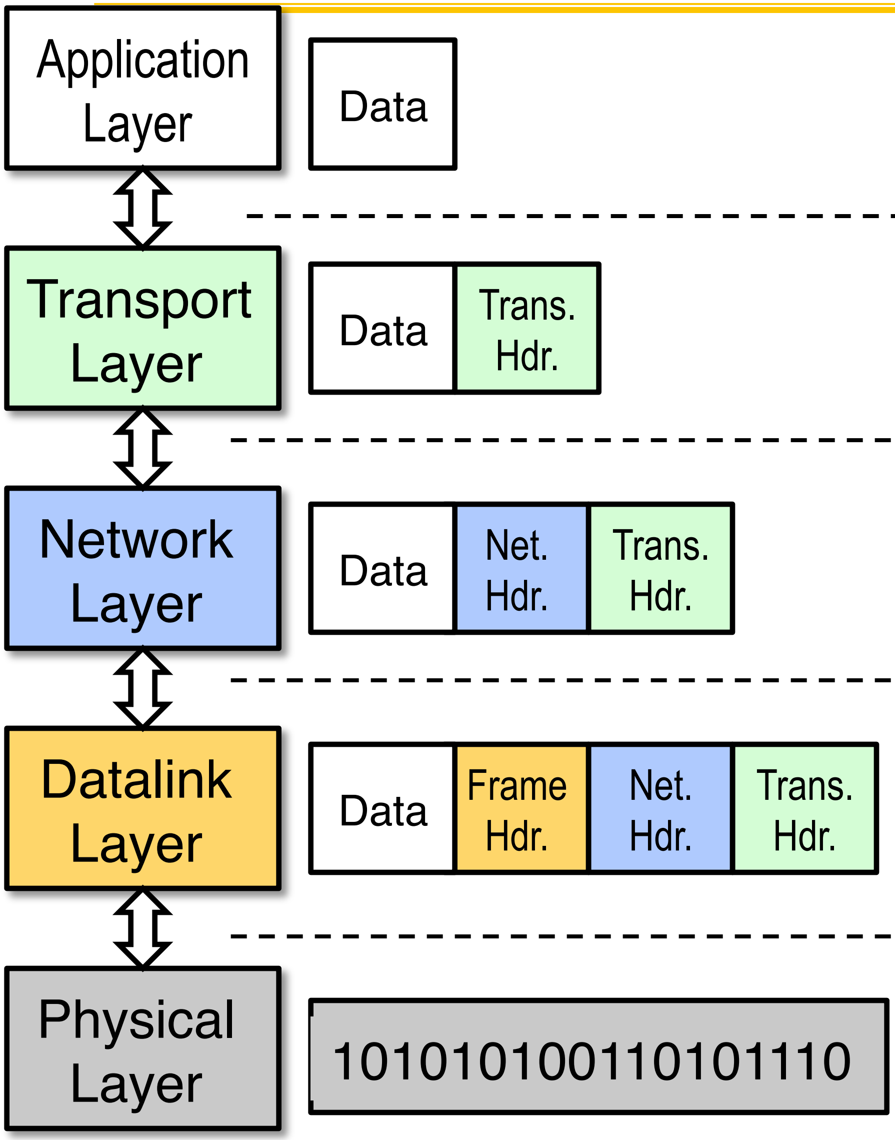
Discussion

- Why not have a huge buffer at the receiver (memory is cheap!)?

- Sending window (SndWnd) also depends on network congestion
  - Congestion control: ensure that a fast sender doesn't overwhelm a router in the network
  - discussed in detail in CS168

- In practice there is other sets of buffers in the protocol stack, at the link layer (i.e., Network Interface Card)

Internet Layering – engineering for intelligence and change



Any distributed protocol (e.g., HTTP, Skype, p2p, KV protocol in your project)

Send *segments* to another *process* running on same or different node

Send *packets* to another node possibly *located* in a different network

Send *frames* to other node directly connected to same physical network

Send *bits* to other node directly connected to same physical network

The Shared Storage Abstraction

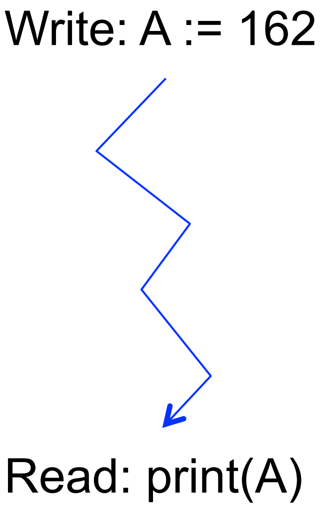
- Information (and therefore control) is communicated from one point of computation to another by
  - The former storing/writing/sending to a location in a shared address space
  - And the second later loading/reading/receiving the contents of that location

- Memory (address) space of a process
- File systems
- Dropbox, …
- Google Docs, …
- Facebook, …

What are you assuming?

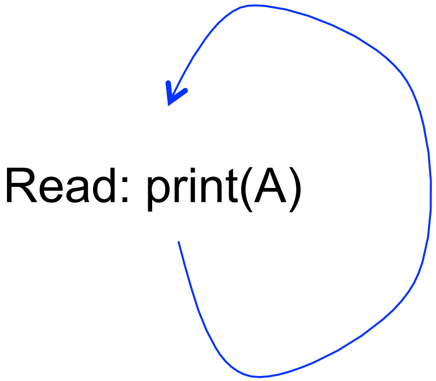
- Writes happen
  - Eventually a write will become visible to readers
  - Until another write happens to that location
- Within a sequential thread, a read following a write returns the value written by that write
  - Dependences are respected
  - Here a control dependence
  - Each read returns the most recent value written to the location

For example



Write: A := 162

Read: print(A)



Read: print(A)

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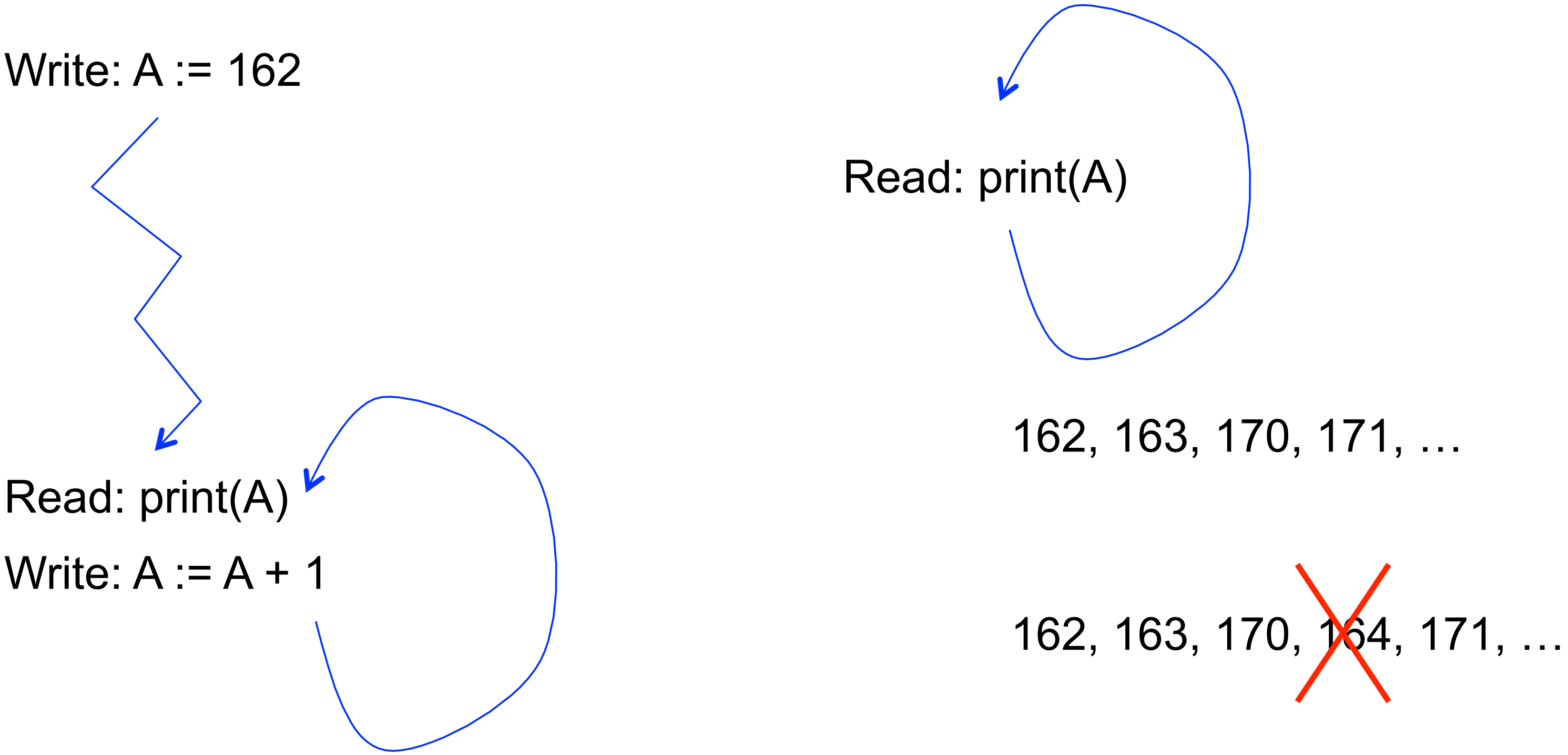
  - Each read returns the most recent value written to the location
- A sequence of writes will be visible in order
  - Control dependences
  - Data dependences

For example



Write: A := 162

Read: print(A)

Write: A := A + 1

Read: print(A)

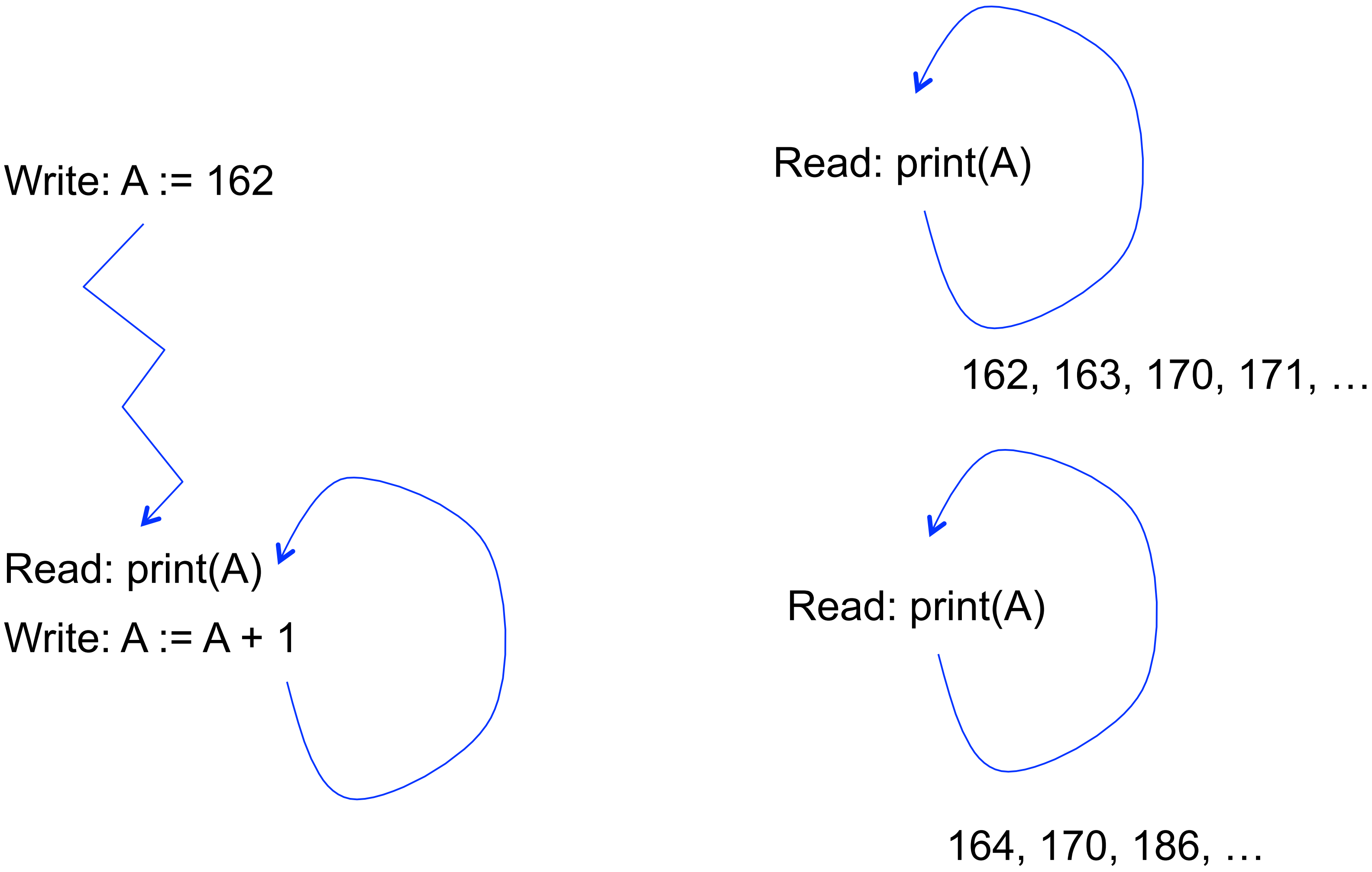
162, 163, 170, 171, …

162, 163, 170, ~~164~~, 171, …

What are you assuming?

- Writes happen
  - Eventually a write will become visible to readers
  - Until another write happens to that location
- Within a sequential thread, a read following a write returns the value written by that write
  - Dependences are respected
  - Here a control dependence
  - Each read returns the most recent value written to the location
- A sequence of writes will be visible in order
  - Control dependences
  - Data dependences
  - May not see every write, but the ones seen are consistent with order written
- A readers see a consistent order
  - It is as if the total order was visible to all and they took samples

For example



Write: A := 162

Read: print(A)

Write: A := A + 1

Read: print(A)

162, 163, 170, 171, …

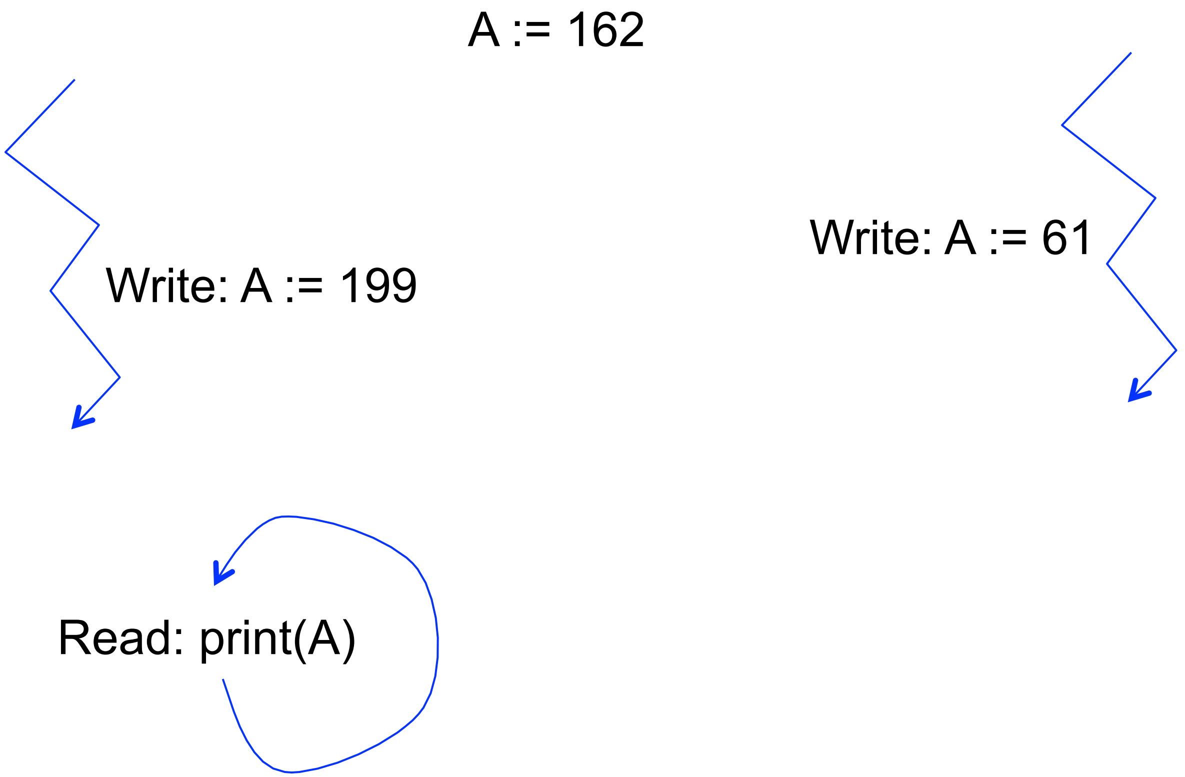
Read: print(A)

164, 170, 186, …

Demo

- https://docs.google.com/a/berkeley.edu/spreadsheets/d/1INjjYqUnFurPLKnnWrexx09Ww5LS5BhNxKt3BoJY6Eg/edit

For example



A := 162

Write: A := 199

Write: A := 61

Read: print(A)

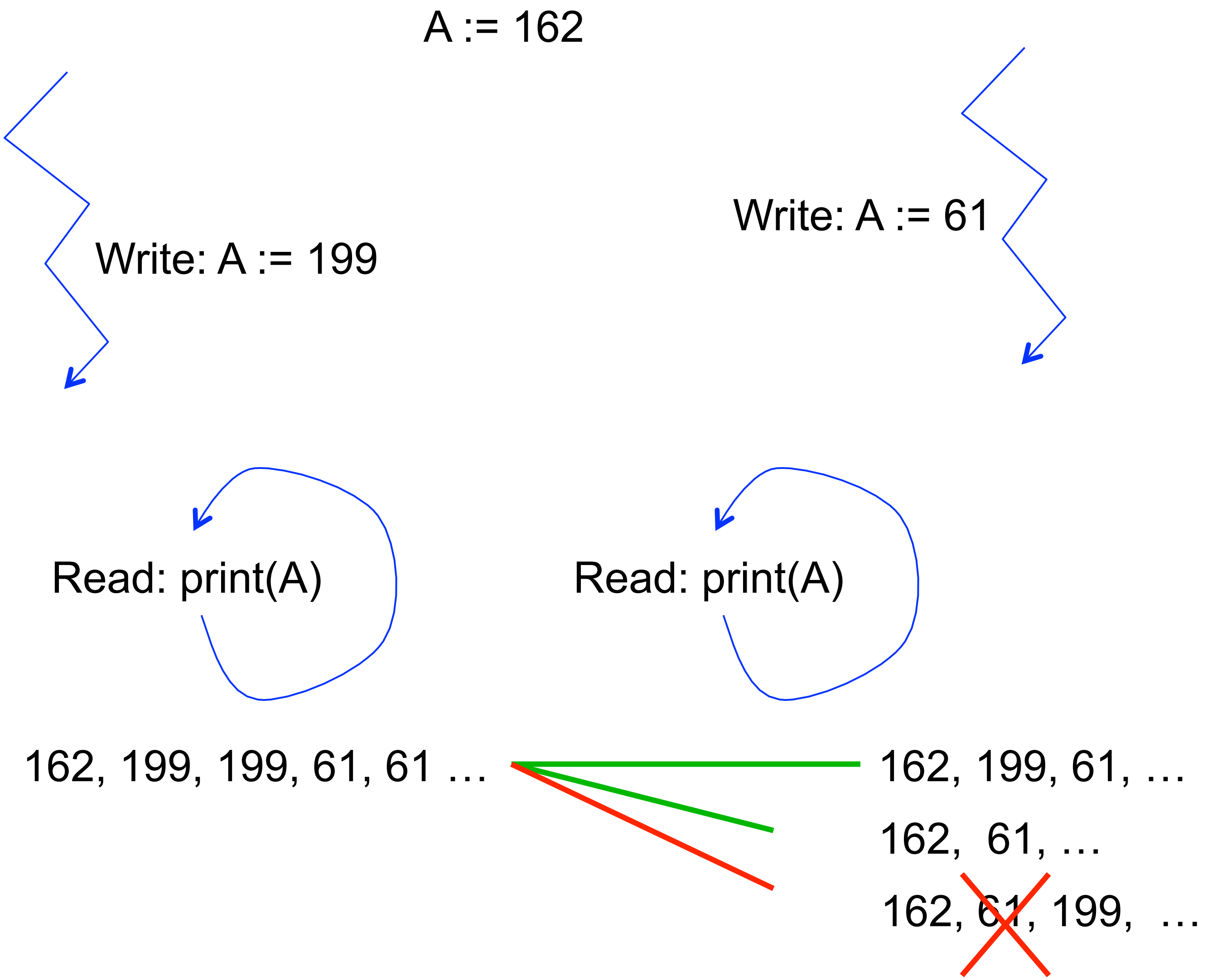
162, 199, 199, 61, 61 …

162, 61, 199, …

61, 199, …

~~162, 199, 61, 199 …~~

For example



A := 162

Write: A := 199

Write: A := 61

Read: print(A)

Read: print(A)

162, 199, 199, 61, 61 …

162, 199, 61, …

162, 61, …

162, ~~61~~, 199, …

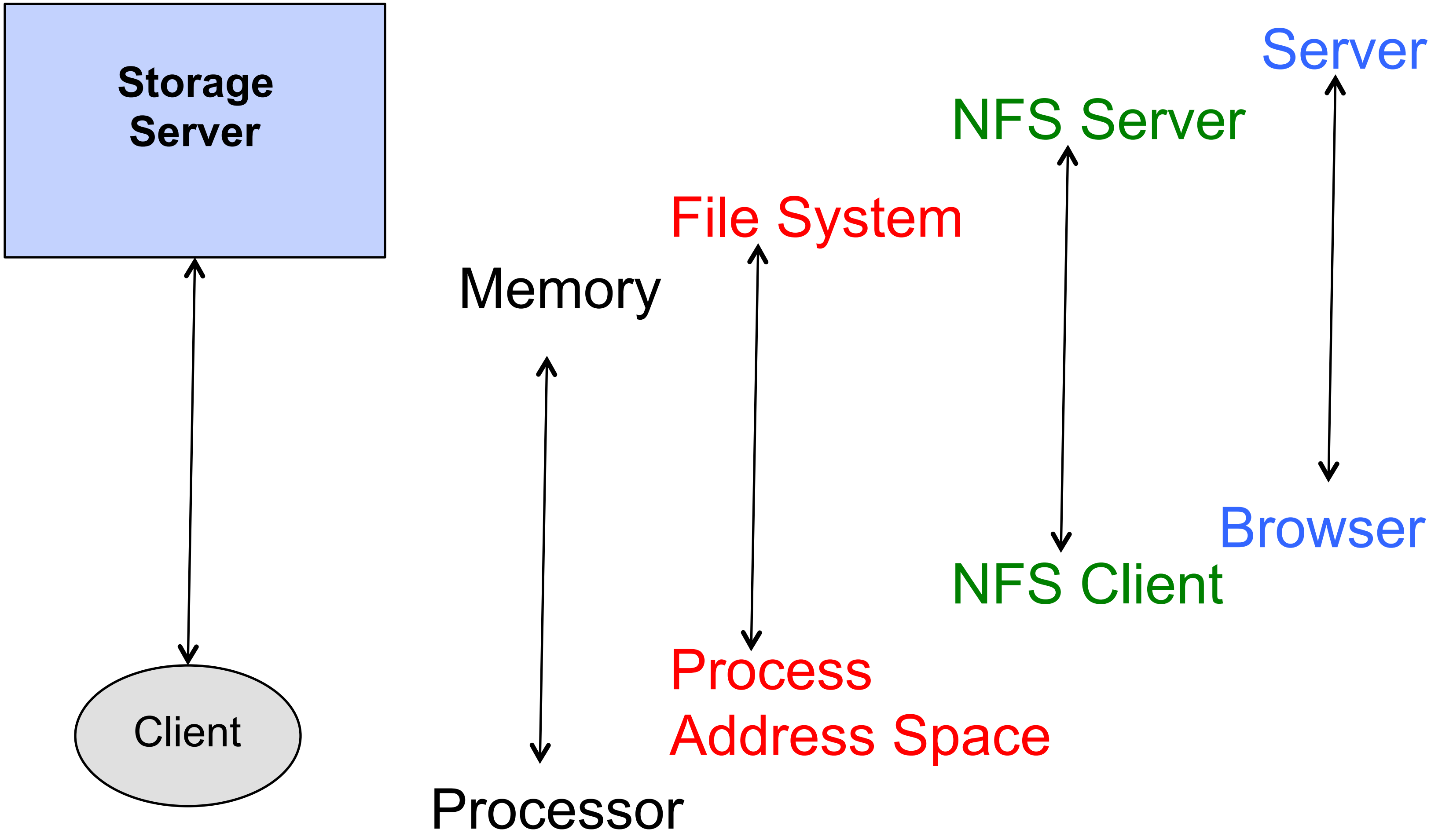
What is the key to performance AND reliability

- Replication

What is the source of inconsistency?

- Replication

Any Storage Abstraction



Storage Server

Client

Memory

Processor

File System

Process Address Space

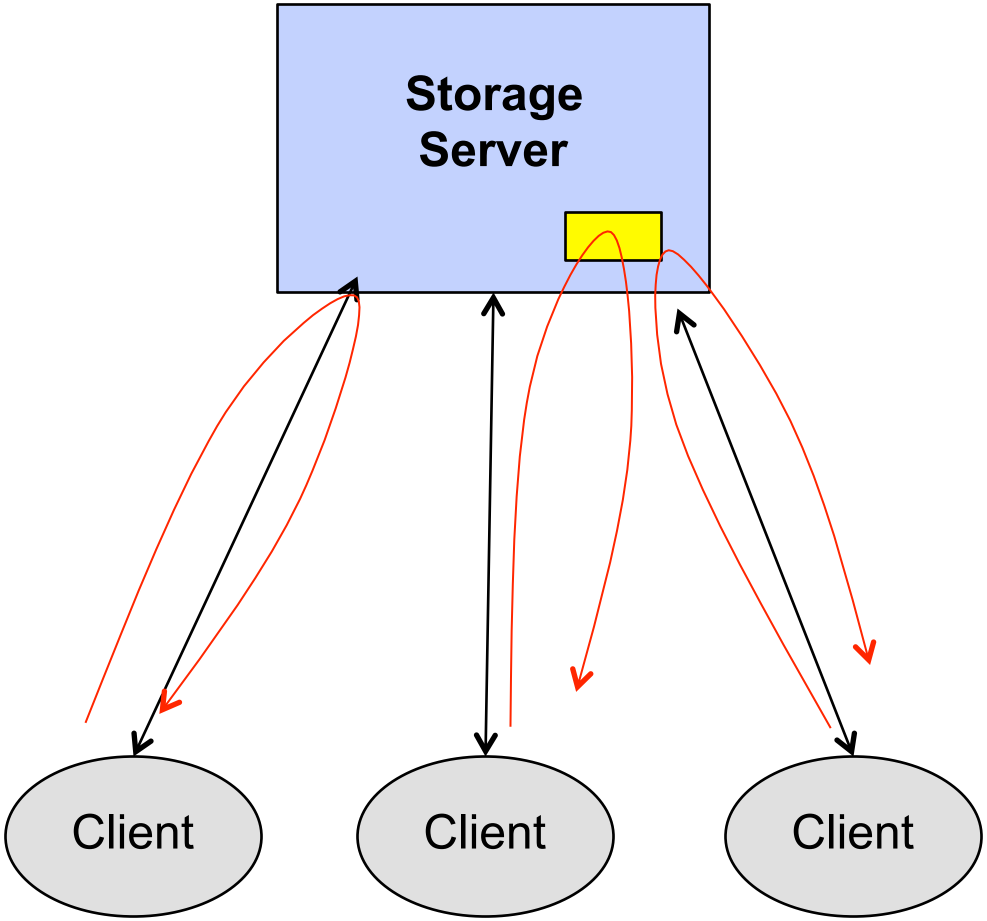
NFS Server

NFS Client

Server

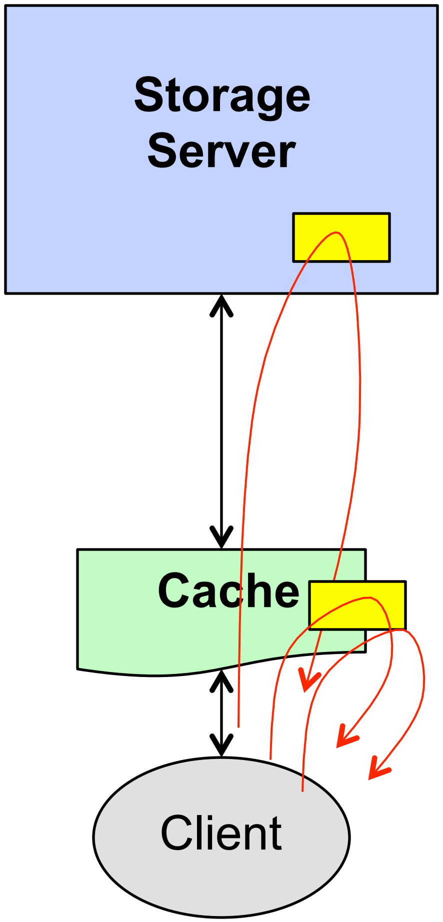
Browser

Multiple Clients access server: OK



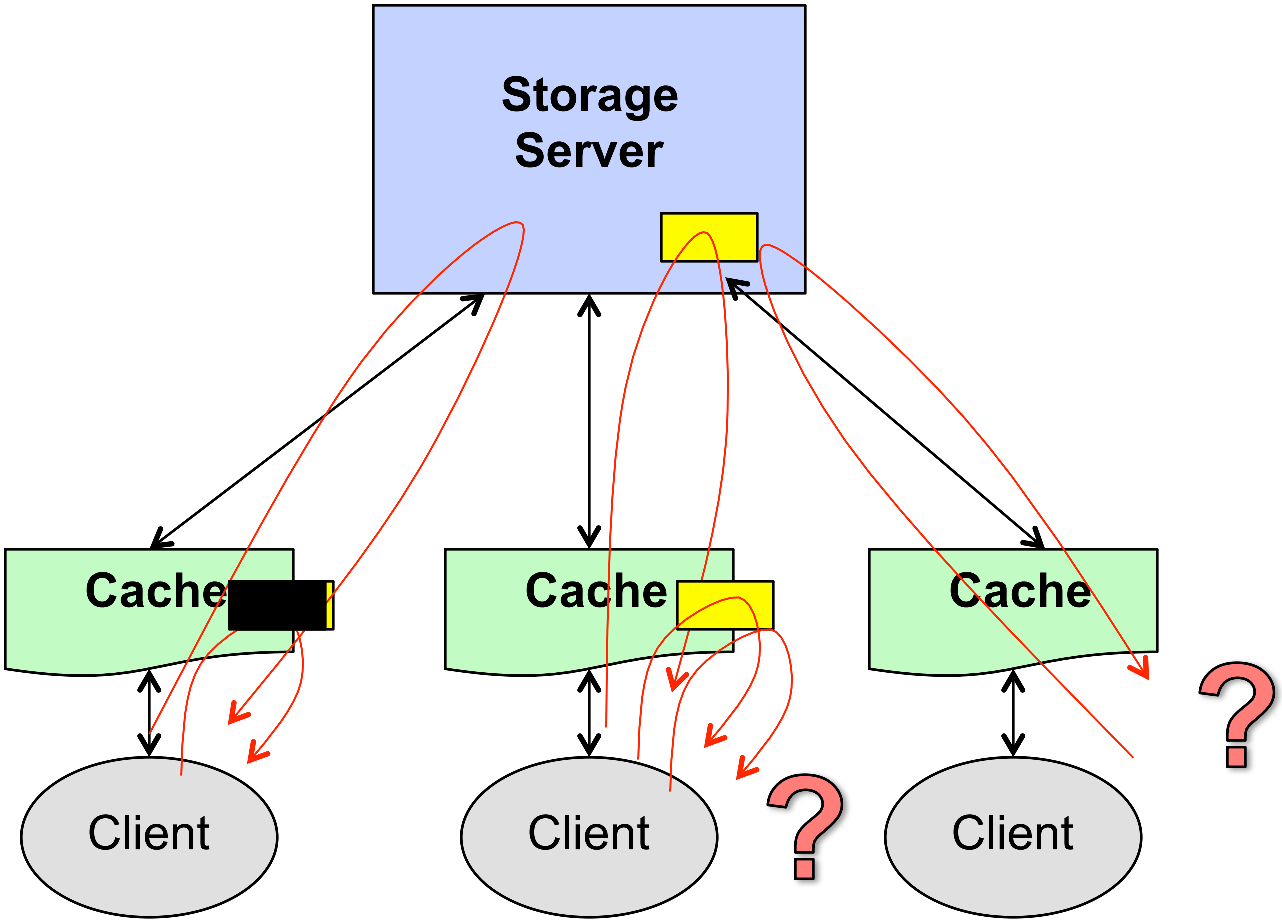
- **But slow**

Multi-level Storage Hierarchy: OK



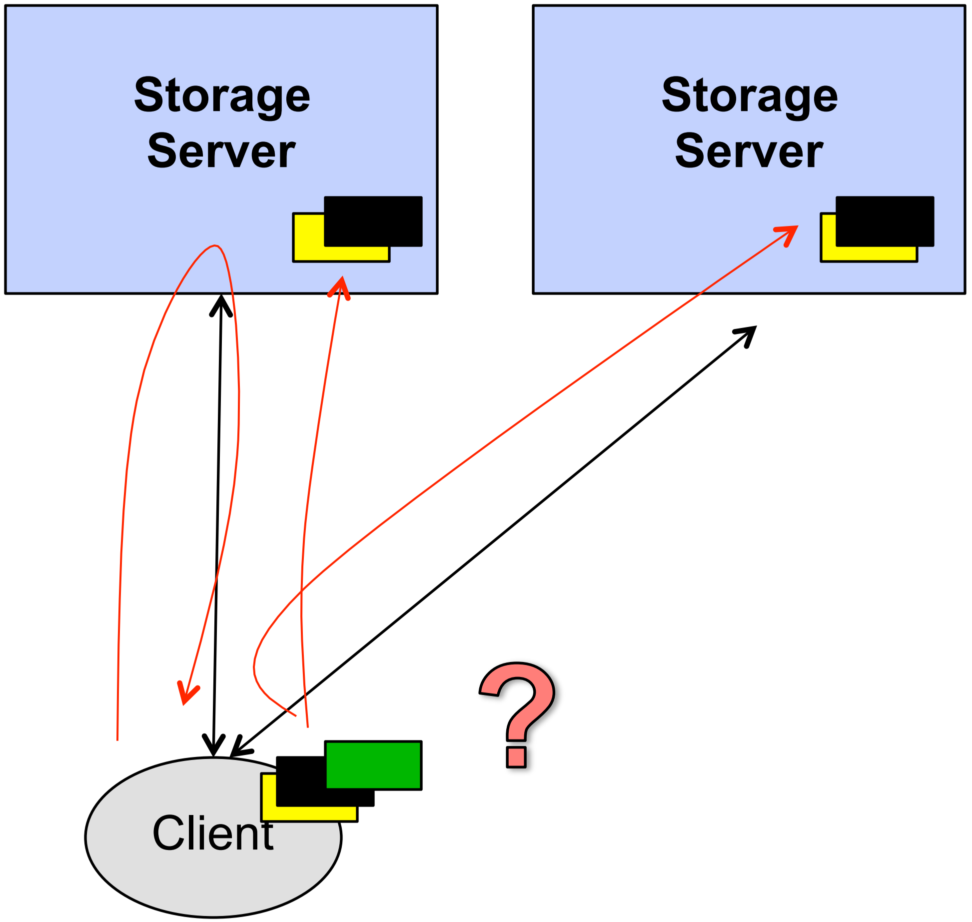
- **Replication within storage hierarchy to make it fast**

Multiple Clients and Multi-Level



- **Fast, but not OK**

Multiple Servers

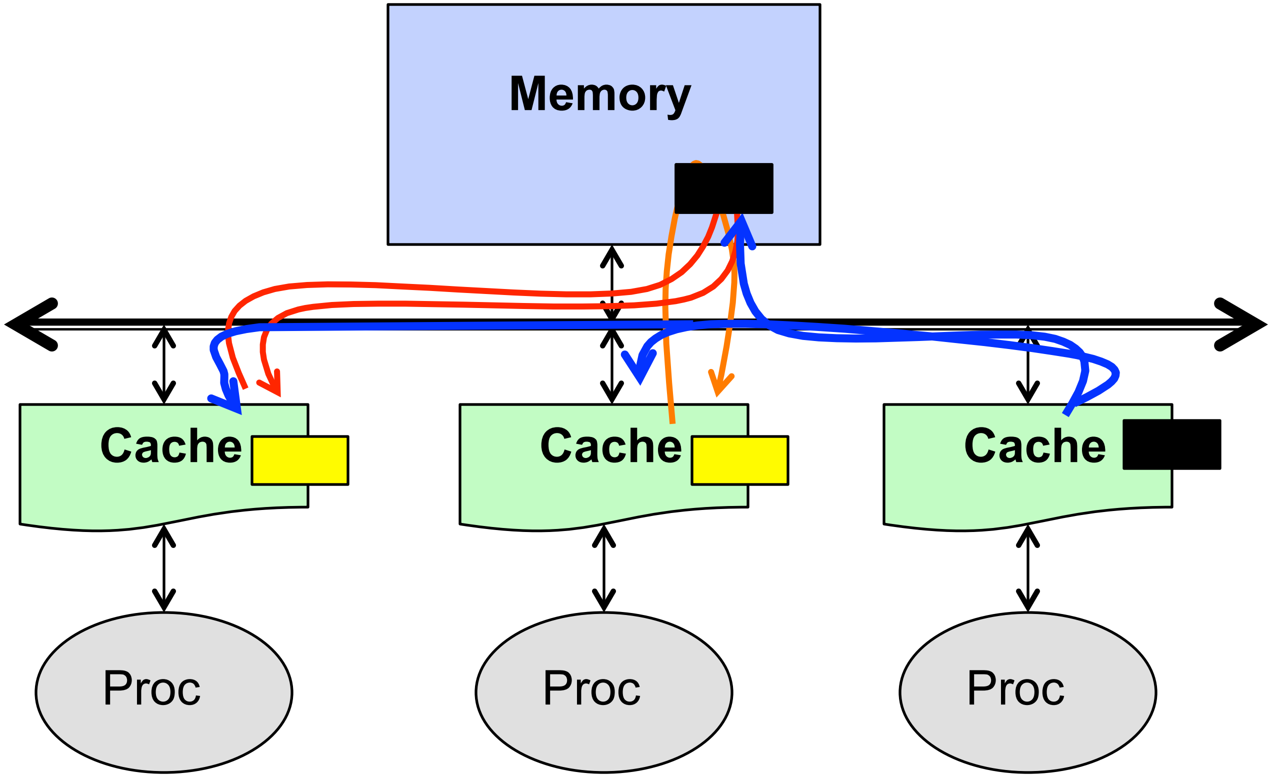


- What happens if cannot update all the replicas?
- Availability => Inconsistency

Basic solution to multiple client replicas

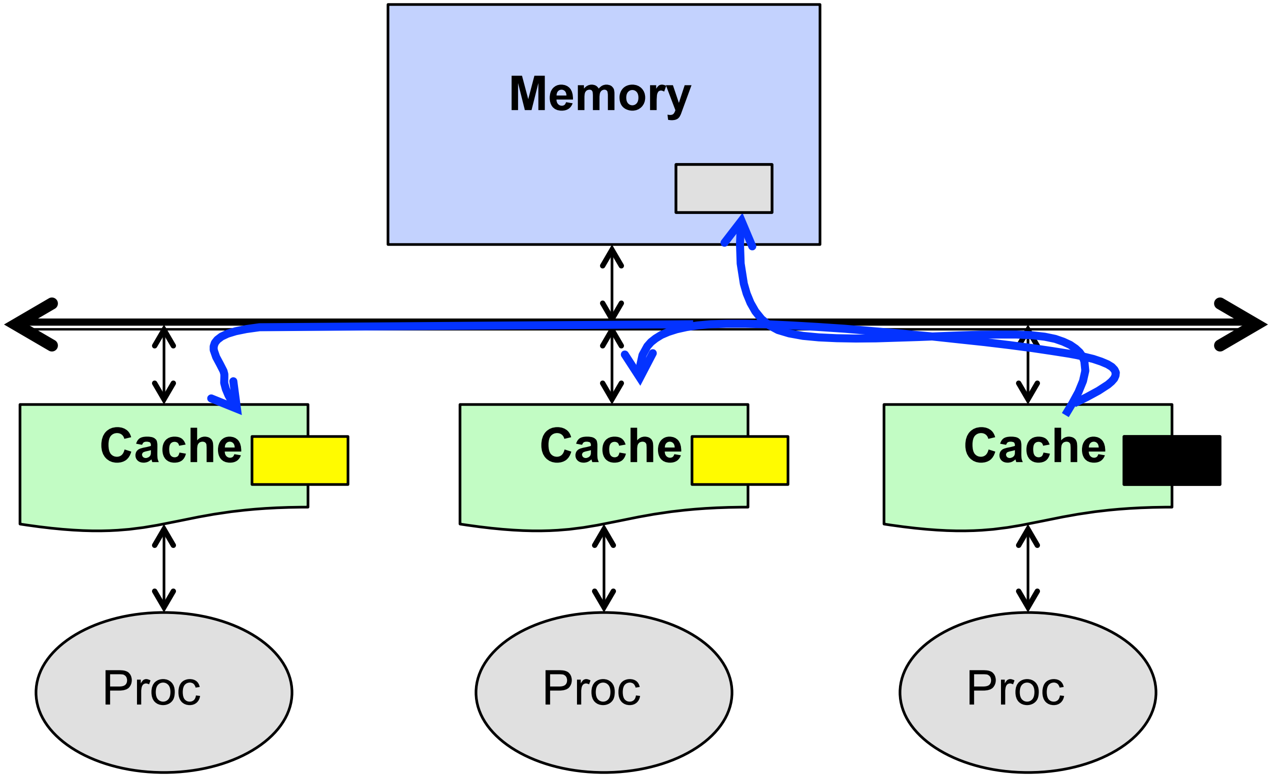
- Enforce single-writer multiple reader discipline
- Allow readers to cache copies
- Before an update is performed, writer must gain exclusive access
- Simple Approach: invalidate all the copies then update
- Who keeps track of what?

The Multi-processor/Core case



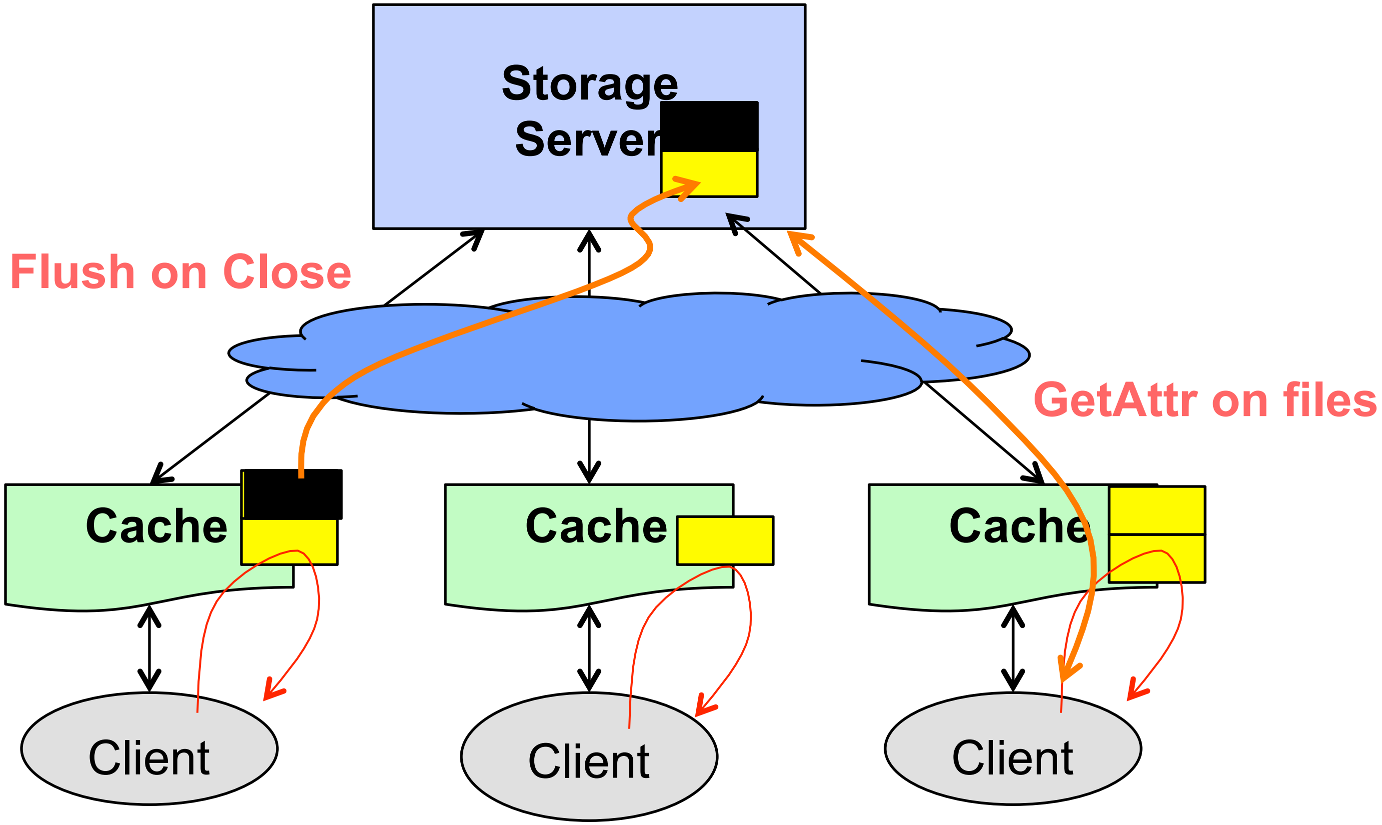
- **Interconnect is a broadcast medium**
- **All clients can observe all writes and invalidate local replicas (write-thru invalidate protocol)**

The Multi-processor/Core case



- **Write-Back via read-exclusive**
- **Atomic Read-modify-write**

NFS “Eventual” Consistency



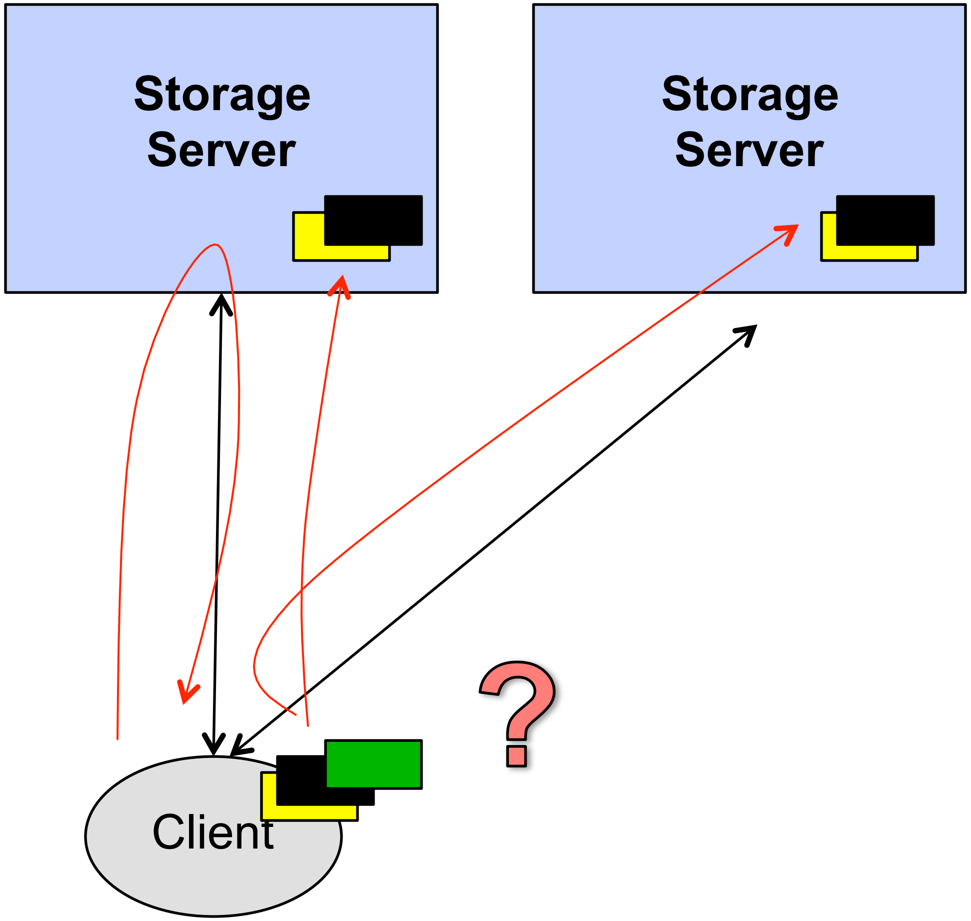
- Stateless server allows multiple cached copies
  - Files written locally (at own risk)
- Update Visibility by “flush on close”
- GetAttributes on file ops to check modify since cache

Other Options

- Server can keep a “directory” of cached copies
- On update, sends invalidate to clients holding copies
- Or can send updates to clients
- Pros and Cons ???

- OS Consistency = Architecture Coherence requires invalidate copies prior to write
- Write buffer has be to be treated as primary copy
  - like transaction log

Multiple Servers



- **What happens if cannot update all the replicas?**
- **Availability => Inconsistency**

Durability and Atomicity

- How do you make sure transaction results persist in the face of failures (e.g., server node failures)?

- Replicate store / database
  - Commit transaction to each replica

- What happens if you have failures during a transaction commit?
  - Need to ensure atomicity: either transaction is committed on all replicas or none at all

Two Phase (2PC) Commit

- **2PC is a distributed protocol**

- **High-level problem statement**
  - **If no node fails and all nodes are ready to commit, then all nodes COMMIT**
  - **Otherwise ABORT at all nodes**

- **Developed by Turing award winner Jim Gray (first Berkeley CS PhD, 1969)**

2PC Algorithm

- One coordinator
- N workers (replicas)

- High level algorithm description
  - Coordinator asks all workers if they can commit
  - If all workers reply "VOTE-COMMIT", then coordinator broadcasts "GLOBAL-COMMIT",

    Otherwise coordinator broadcasts "GLOBAL-ABORT"
  - Workers obey the GLOBAL messages

Detailed Algorithm

Coordinator Algorithm

Coordinator sends VOTE-REQ to all workers

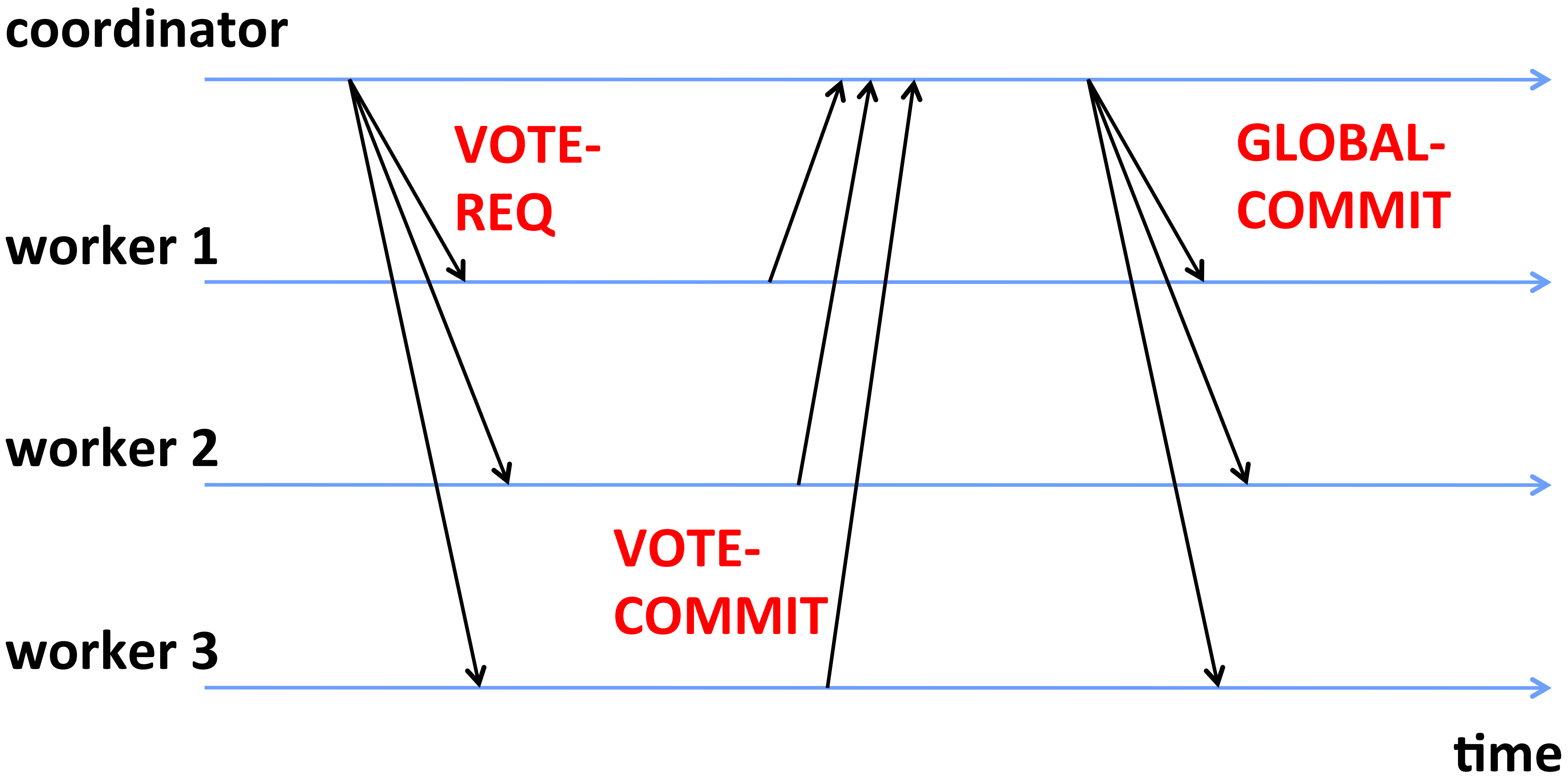
- If receive VOTE-COMMIT from all N workers, send GLOBAL-COMMIT to all workers
- If doesn't receive VOTE-COMMIT from all N workers, send GLOBAL-ABORT to all workers

Worker Algorithm

- Wait for VOTE-REQ from coordinator
- If ready, send VOTE-COMMIT to coordinator
- If not ready, send VOTE-ABORT to coordinator
  - And immediately abort

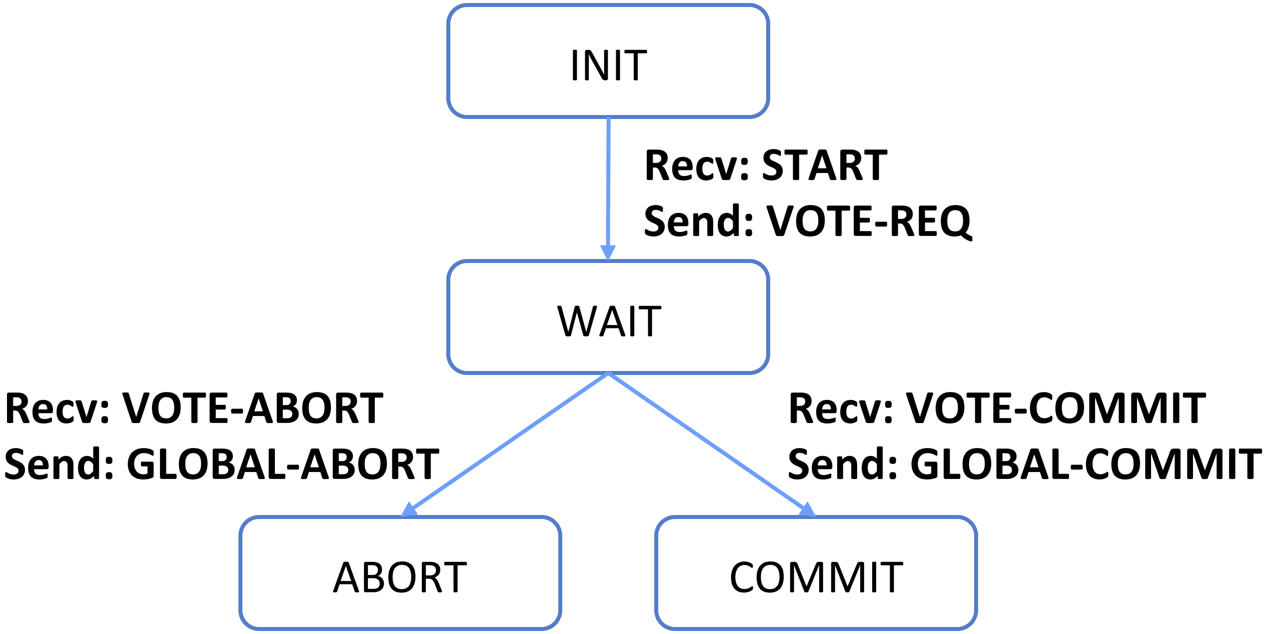
- If receive GLOBAL-COMMIT then commit
- If receive GLOBAL-ABORT then abort

Failure Free Example Execution



State Machine of Coordinator

- **Coordinator implements simple state machine**



INIT

Recv: START
Send: VOTE-REQ

WAIT

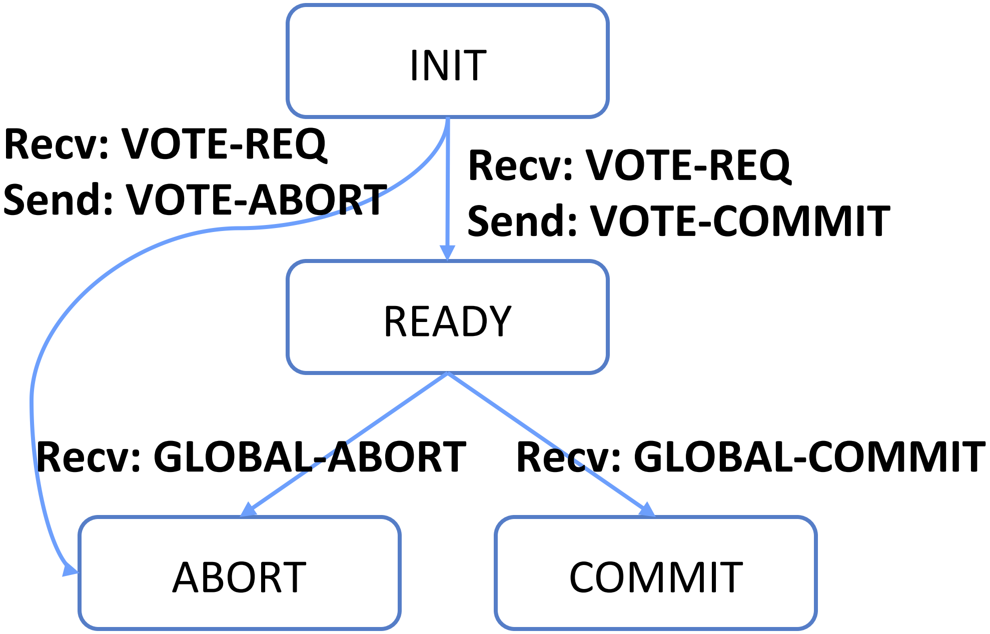
Recv: VOTE-ABORT
Send: GLOBAL-ABORT

Recv: VOTE-COMMIT
Send: GLOBAL-COMMIT

ABORT

COMMIT

State Machine of Workers



INIT

Recv: VOTE-REQ
Send: VOTE-ABORT

Recv: VOTE-REQ
Send: VOTE-COMMIT

READY

Recv: GLOBAL-ABORT

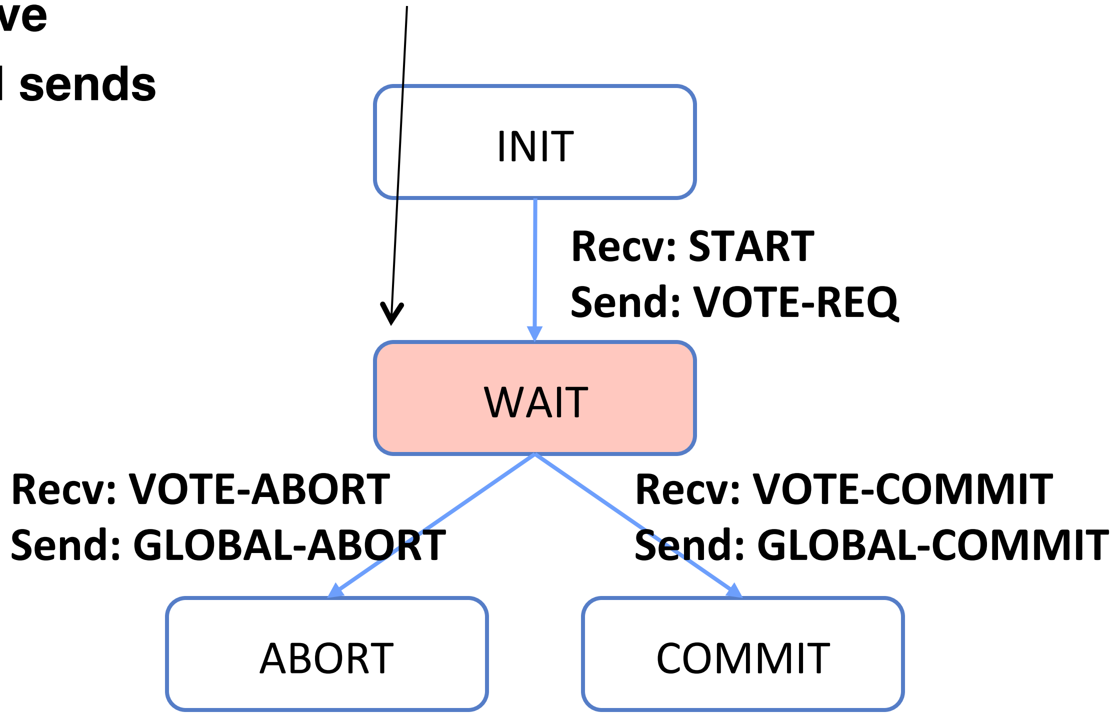
Recv: GLOBAL-COMMIT

ABORT

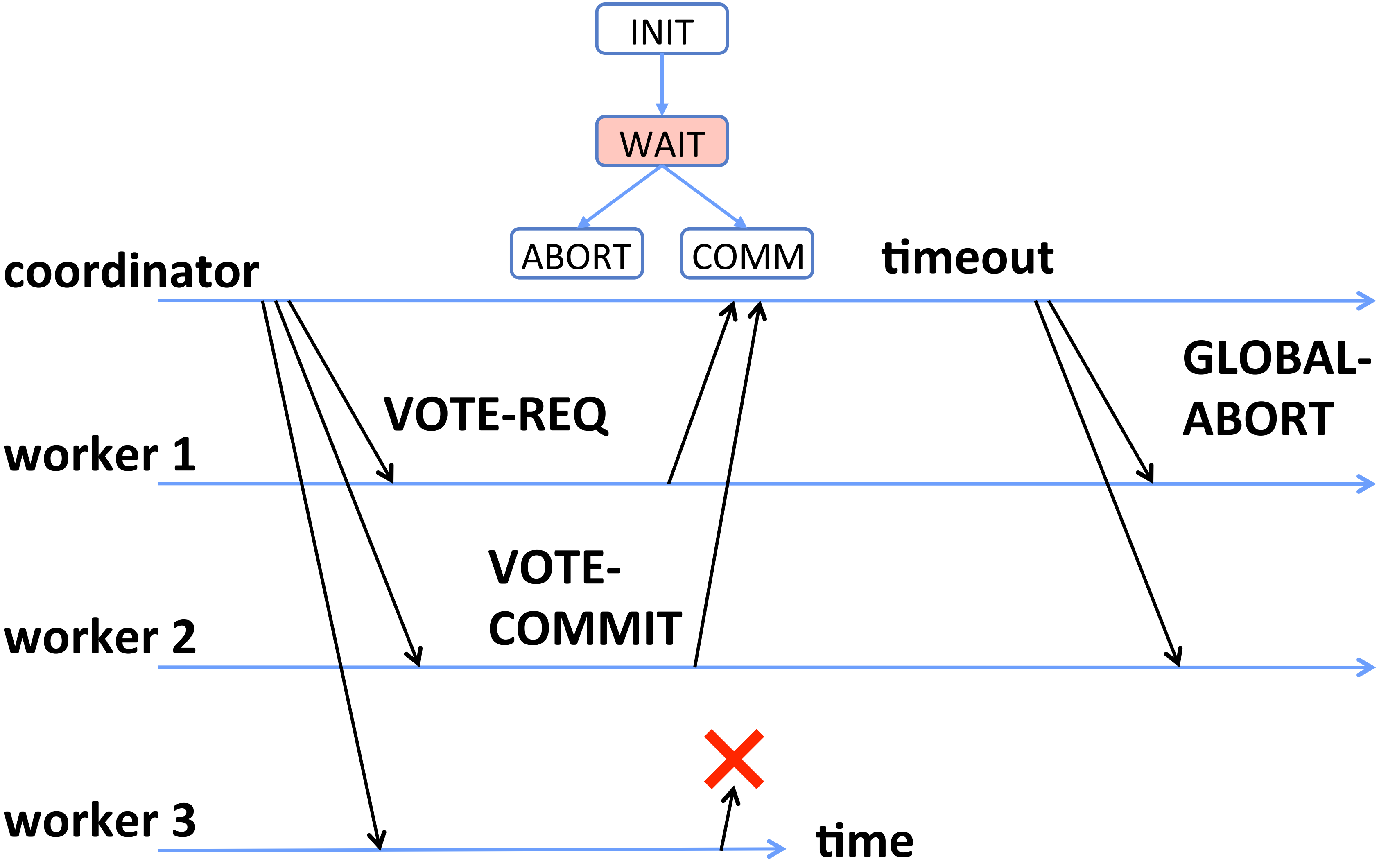
COMMIT

Dealing with Worker Failures

- How to deal with worker failures?
  - Failure only affects states in which the node is waiting for messages
  - Coordinator only waits for votes in "WAIT" state
  - In WAIT, if doesn't receive N votes, it times out and sends GLOBAL-ABORT

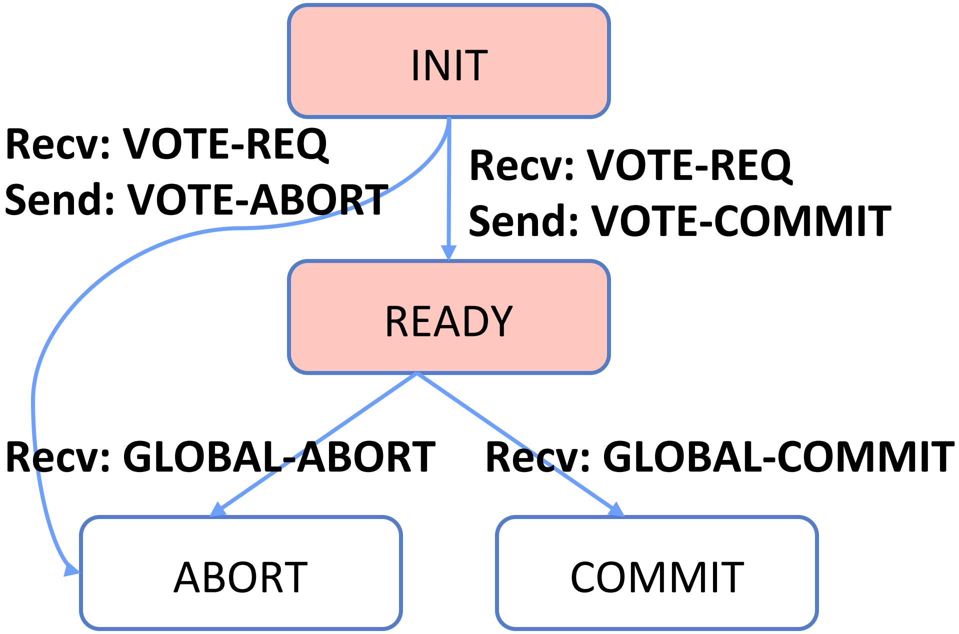


Example of Worker Failure

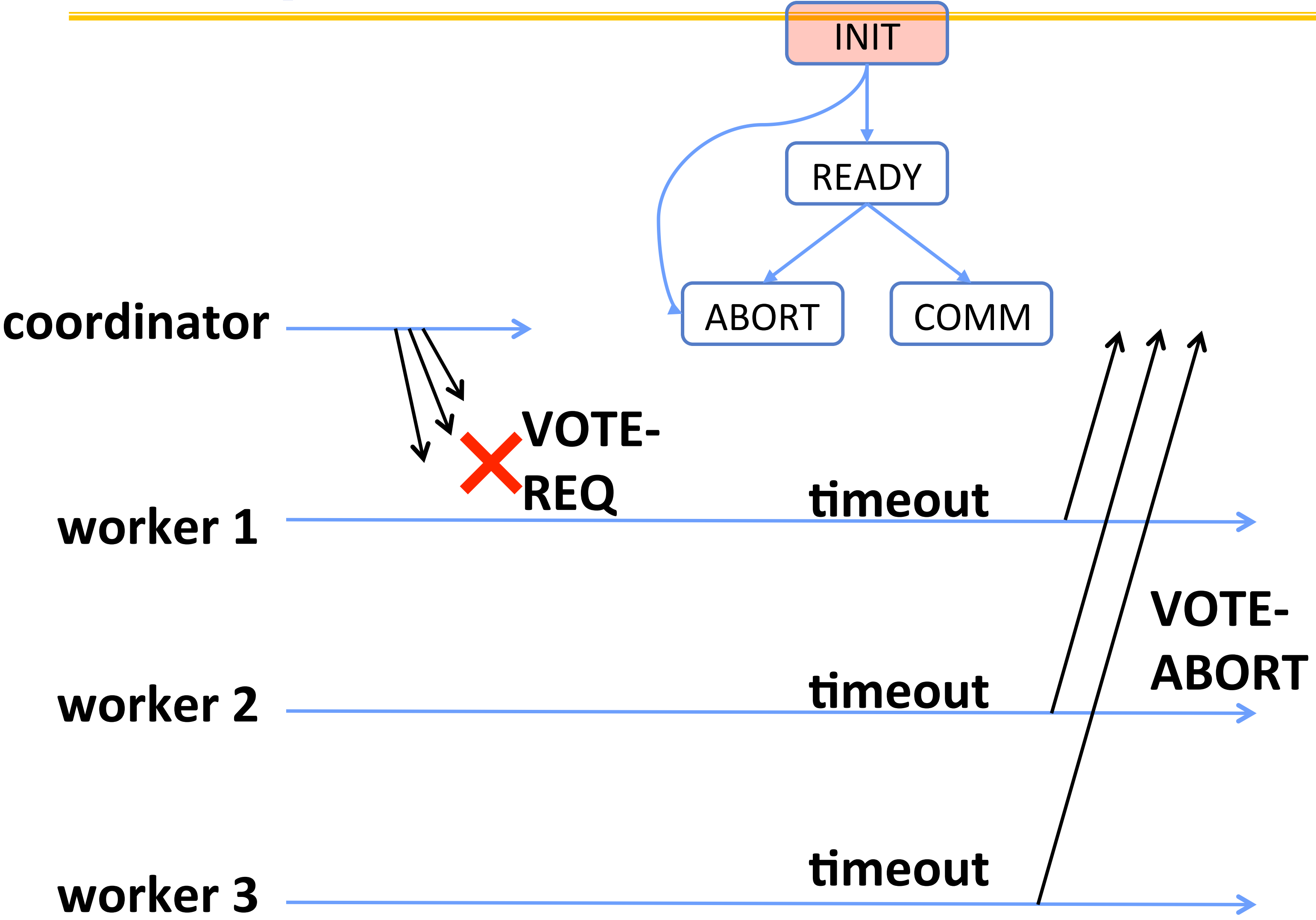


Dealing with Coordinator Failure

- **How to deal with coordinator failures?**
  - **worker waits for VOTE-REQ in INIT**
    - **Worker can time out and abort (coordinator handles it)**
  - **worker waits for GLOBAL-* message in READY**
    - **If coordinator fails, workers must BLOCK waiting for coordinator to recover and send GLOBAL_* message**



Example of Coordinator Failure #1



INIT

READY

ABORT

COMM

coordinator

VOTE-REQ

worker 1

timeout

VOTE-ABORT

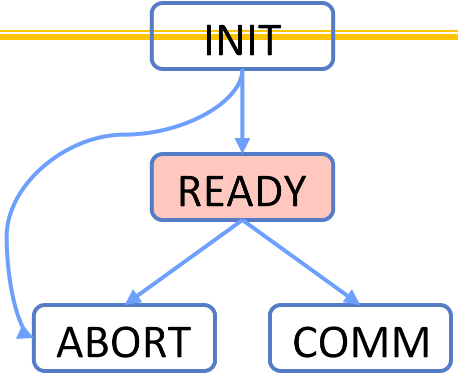
worker 2

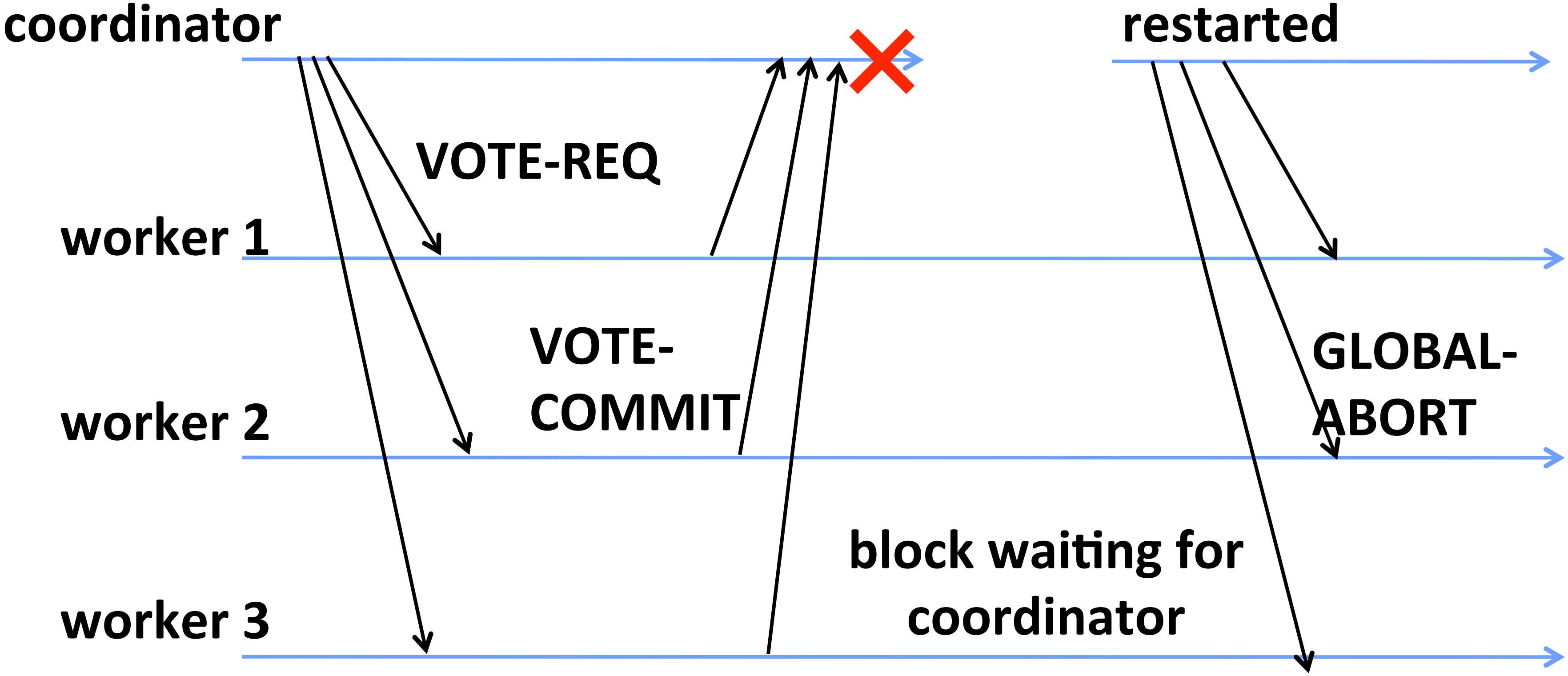
timeout

worker 3

timeout

Example of Coordinator Failure #2





Durability

- All nodes use stable storage* to store which state they are in

- Upon recovery, it can restore state and resume:
  - Coordinator aborts in INIT, WAIT, or ABORT
  - Coordinator commits in COMMIT
  - Worker aborts in INIT, ABORT
  - Worker commits in COMMIT
  - Worker asks Coordinator in READY

* - stable storage is non-volatile storage (e.g. backed by disk) that guarantees atomic writes.

Blocking for Coordinator to Recover

- **A worker waiting for global decision can ask fellow workers about their state**
  - **If another worker is in ABORT or COMMIT state then coordinator must have sent GLOBAL-***
  - **Thus, worker can safely abort or commit, respectively**
  - **If another worker is still in INIT state then both workers can decide to abort**
  - **If all workers are in ready, need to BLOCK (don't know if coordinator wanted to abort or commit)**