CS162
Operating Systems and Systems Programming
Lecture 24

Coordination

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https://cs162.org/

Slides based on prior slide decks from David Culler, Ion Stoica, John Kubiatowicz, Alison Norman and Lorenzo Alvisi

Recall: End To End Principle

Think twice before implementing functionality in the network

If hosts can implement functionality correctly, implement it in a lower layer only as a performance enhancement

But do so only if it does not impose burden on applications that do not require that functionality

This is the interpretation we are using

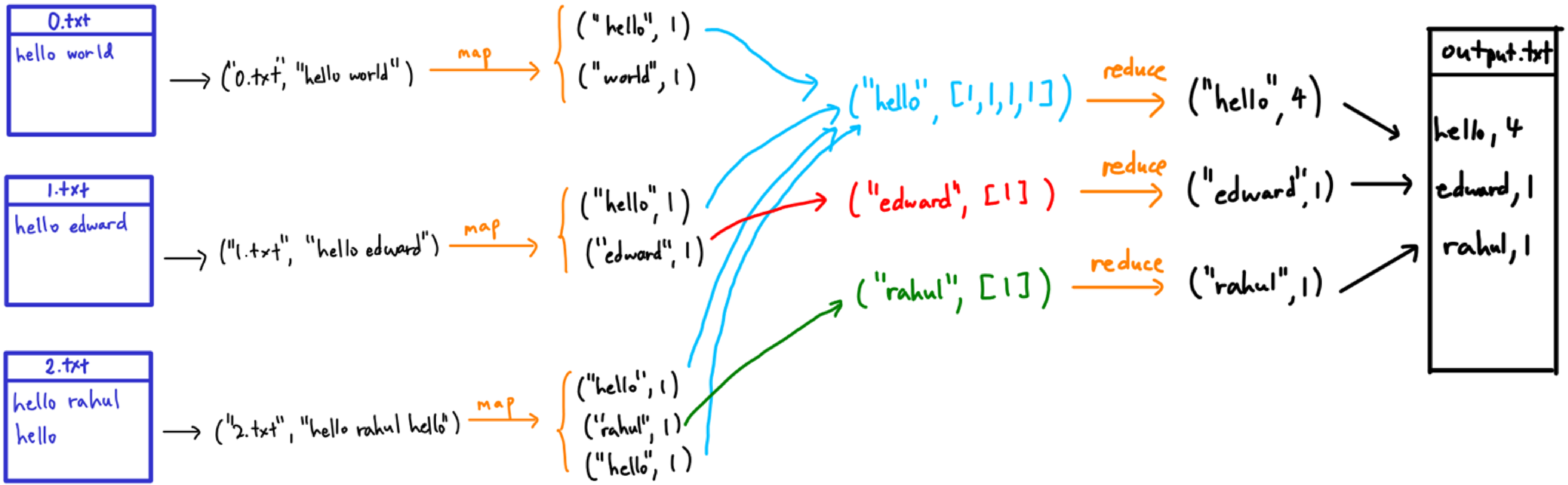
Recall: Map Reduce

How can we implement word count
using only map and reduce?

Three steps:

1) convert files into pairs of (key,value)
2) Define a map function. Apply to all files
3) Shuffle! All elements with same key go to same reduce
4) Define a reduce function. Apply to result of the map function.

Recall: Map Reduce



Recall: Idempotence is back!

When a worker fails, simply retry failed tasks!

Since failed tasks are retried, application map and reduce functions generally should be pure, deterministic functions of their arguments.

Should not depend on the current time, randomness, resources accessed over the network, etc.

Tasks that are not pure functions can be run on MapReduce, but the results may or may not be cohesive

Topic roadmap

Distributed File Systems

Peer-To-Peer System:
The Internet

Distributed Data Processing

Coordination
(Atomic Commit and Consensus)

Coordination: making distributed decisions

Functionality is spread across machines. Requires coordination to reach distributed decision

Distributed Protocols are hard!

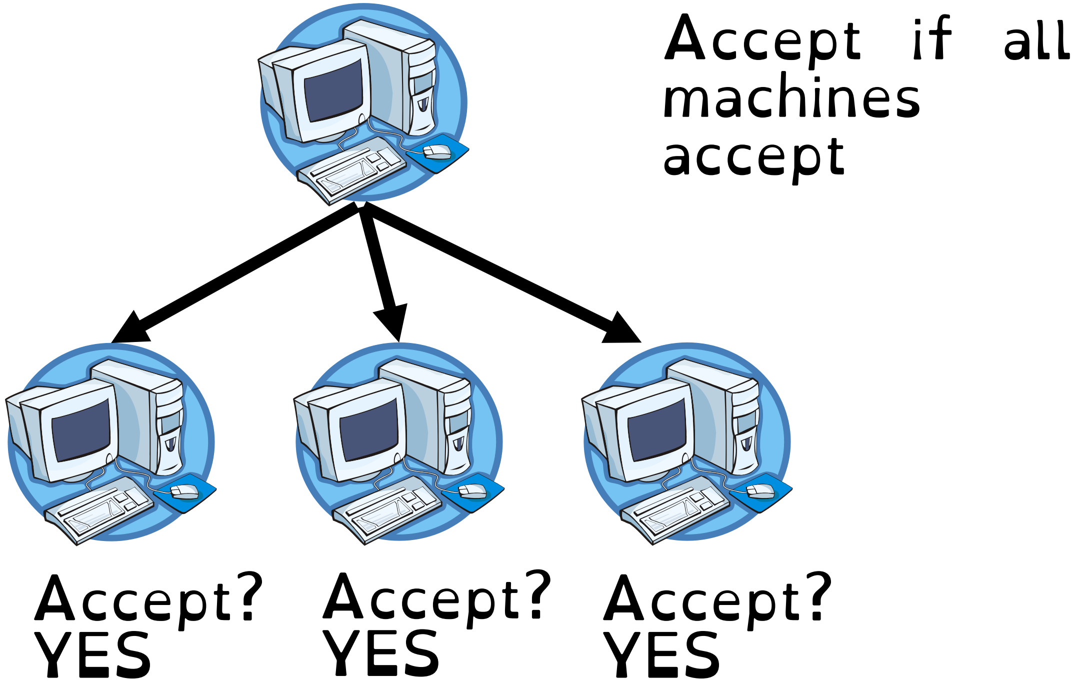
Coordination is hard!

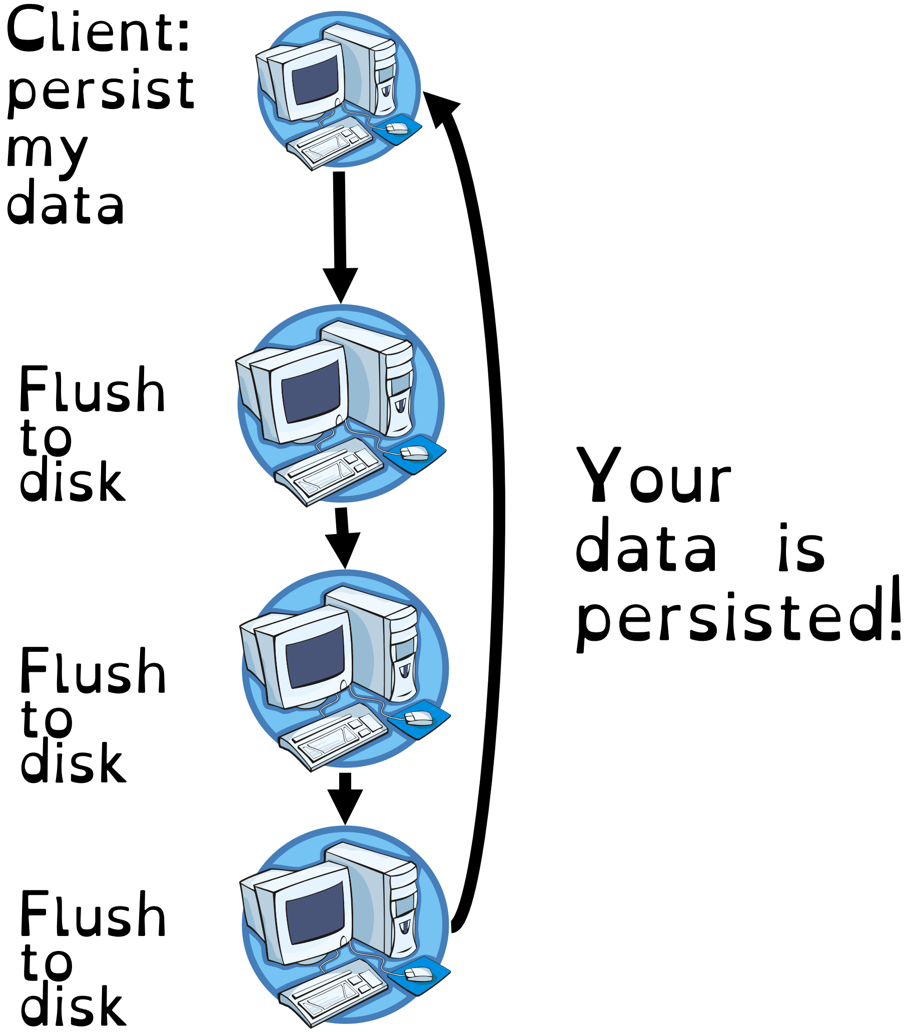
When machines can fail!

When networks are slow and/or unreliable

When machines may receive conflicting proposals on what to do

Coordination: making distributed decisions



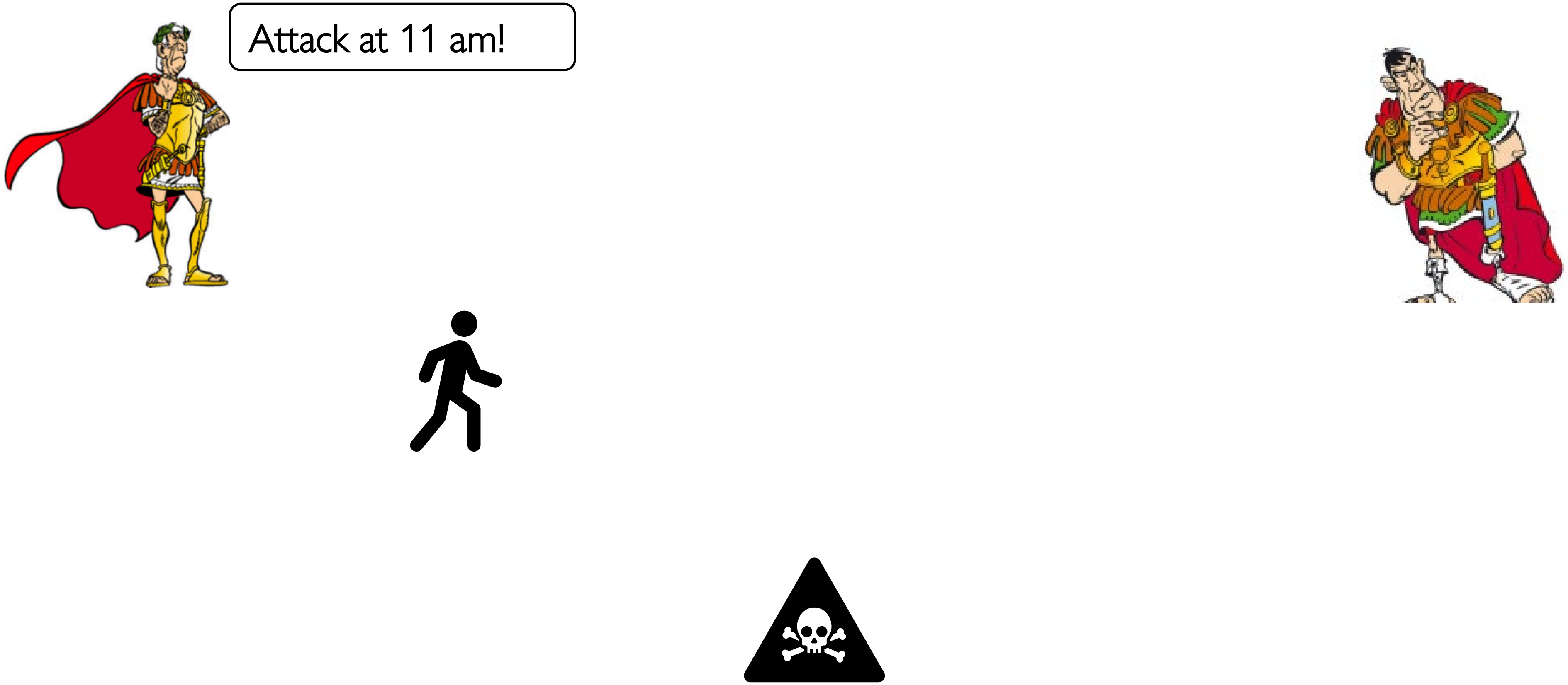


Agreeing simultaneously: General's Paradox

Two generals, on separate mountains
» Can only communicate via messengers
» Messengers can be captured

Problem: need to coordinate attack
» If they attack at different times, they all die
» If they attack at same time, they win

General's Paradox: Scenario 1



General's Paradox: Scenario 1

Attack at 11 am!

Yes! Attack at 11 am!

Is it safe for both of them to attack?

No! Caesar doesn't know that Brutus received the message!

General's Paradox: Scenario 1

Attack at 11 am!

Yes! Attack at 11 am!

Sends an ACK to Caesar!

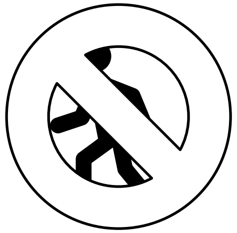
General's Paradox: Scenario 1

Attack at 11 am!

Yes! Attack at 11 am!

Now is it safe?

No! Messenger could have been attacked



General's Paradox: Scenario 1

Caesar needs to know that
Brutus knows that
Caesar knows that
Brutus knows that
They are attacking at **11** am

Impossible to achieve simultaneous actions with unreliable channels because never know whether messenger or ACK got lost

Agreeing simultaneously: General's Paradox

If the network is unreliable, it is impossible to guarantee two entities do something simultaneously

If nodes behave maliciously, impossible to get eventual agreement if there are less than 3f+1 parties present (of which f can misbehave)

Entire textbook on impossibility results in distributed computing …

Eventual Agreement: Two-Phase Commit

Two or more machines agree to do something, or not do it, atomically

No constraints on time, just that it will eventually happen!

Used in most modern distributed systems!
Representative of other coordination protocols

Eventual Agreement: Two-Phase Commit

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

Many important Database breakthroughs also from Jim Gray

Jim Gray

Eventual Agreement: Two-Phase Commit

Goal: determine whether should commit or abort a transaction

All processes that reach a decision reach the same one (*Agreement*)

A process cannot reverse its decision after it has reached one (*Finality*)

If there are no failures and every process votes yes, the decision will be commit (*Consistency*)

If all failures are repaired and there are no more failures, then all processes will eventually decide commit/abort (*Termination*)

2PC Terminology

Setup:

- One *coordinator*
- A set of *participants*

Each process has access to a *persistent log*:

Processes can crash and recover.

Recorded information on the log will persist after crashes

2PC Terminology

Coordinator asks all processes to vote

Each participant (including coordinator) can vote either YES or NO

- If all vote YES, coordinator must vote COMMIT
- If one of them votes NO, coordinator must vote ABORT

2PC: The easy case (No failures)

Coordinator Algorithm | **Worker Algorithm**

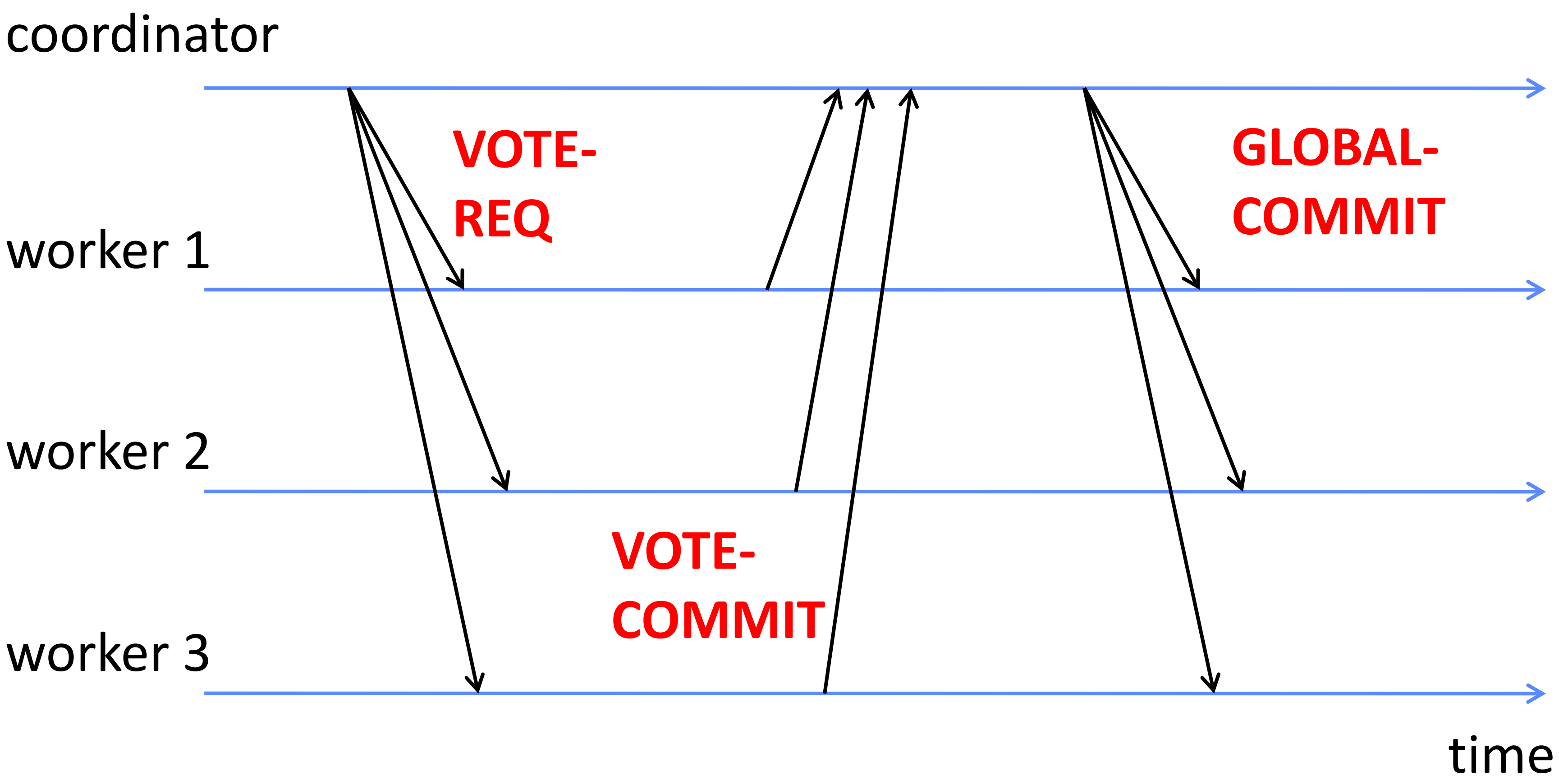
1. Coordinator sends **VOTE-REQ** to all workers

2.
- Send **VOTE-COMMIT** or **VOTE-ABORT** to coordinator
- If sent **VOTE-ABORT** immediately abort

3. Collect votes
- If receive **VOTE-COMMIT** from all N workers, send **GLOBAL-COMMIT** to all workers
- If don't receive **VOTE-COMMIT** from all N workers, send **GLOBAL-ABORT** to all workers

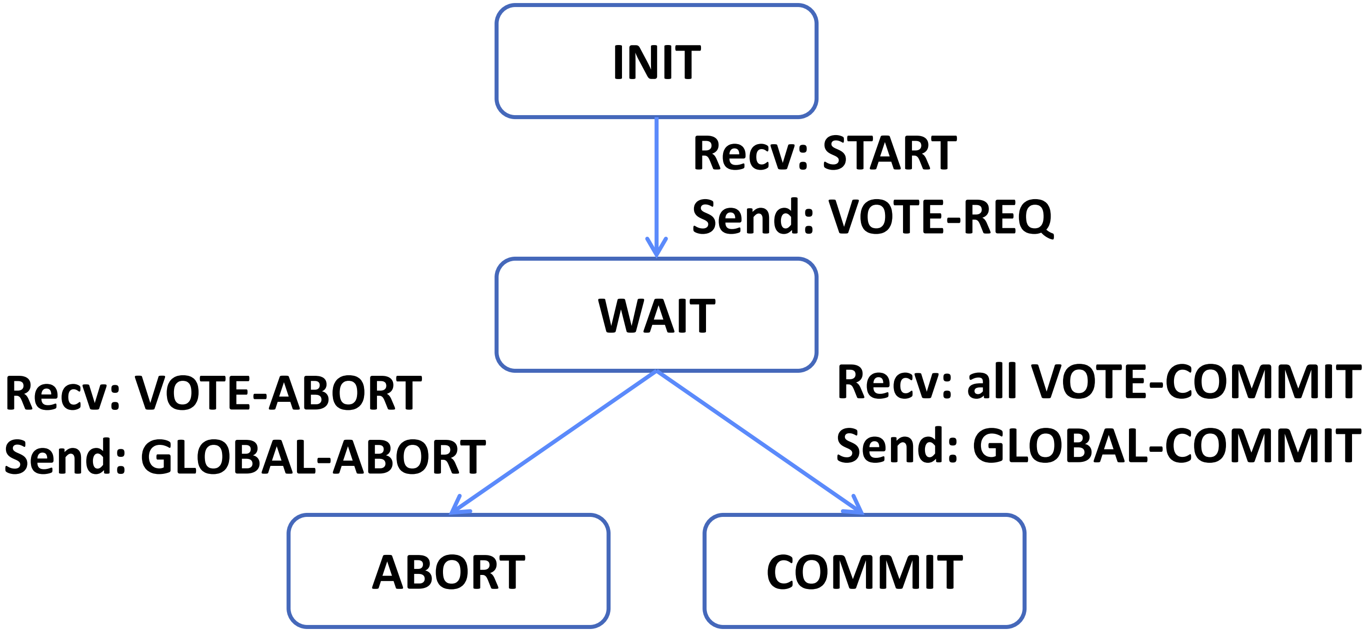
4.
- If receive **GLOBAL-COMMIT** then commit
- If receive **GLOBAL-ABORT** then abort

Failure Free Example Execution



State Machine of Coordinator

Coordinator implements simple state machine



What about failures?

Coordinator Algorithm

1. Coordinator sends **VOTE-REQ** to all workers

Worker Algorithm

2.
– Send **VOTE-COMMIT** or **VOTE-ABORT** to coordinator
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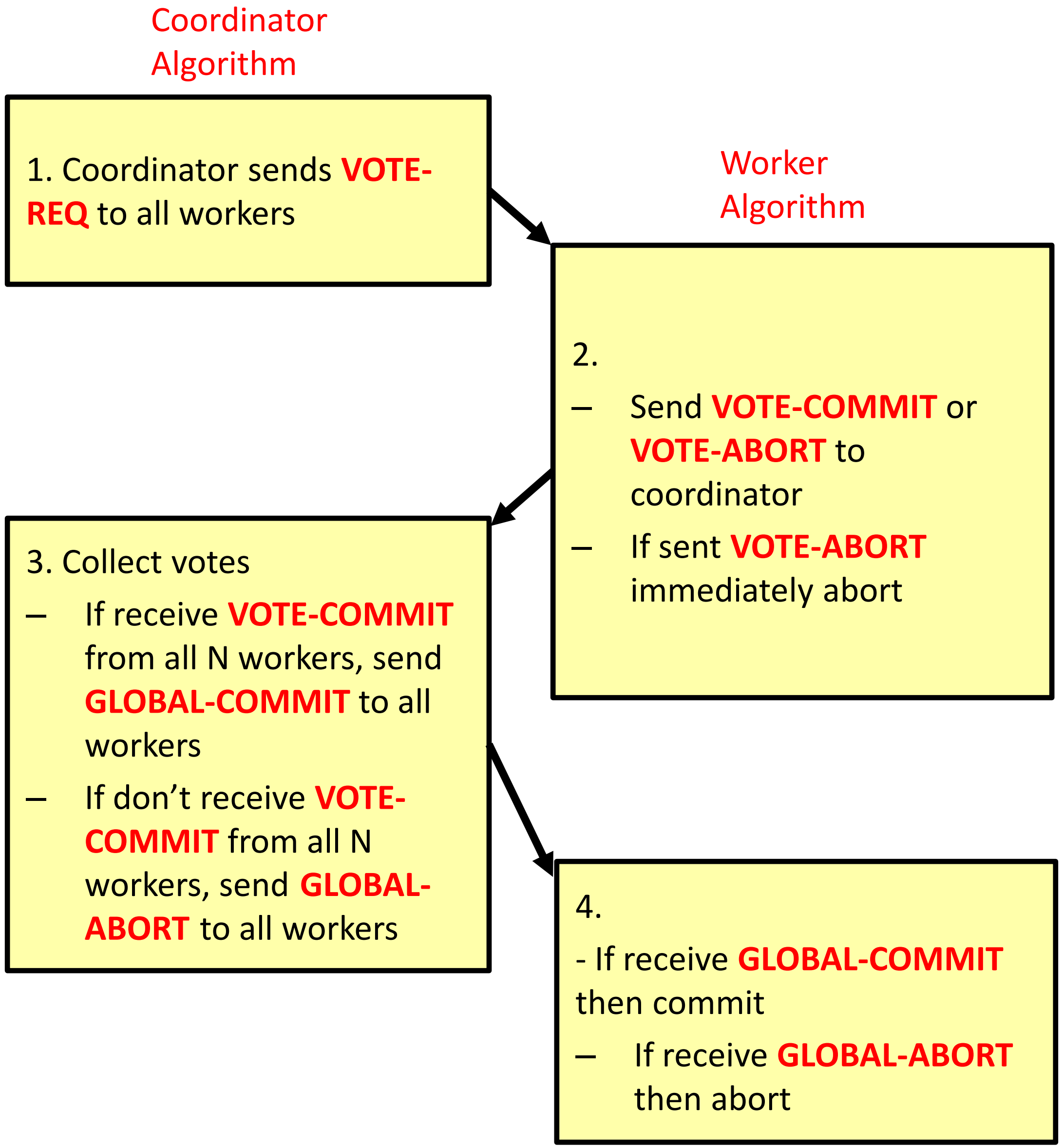
- If receive **GLOBAL-COMMIT** then commit
– If receive **GLOBAL-ABORT** then abort

1) What happens when waiting for a message that never comes?

2) What happens during when participant recovers from a failure?

What happens when a message never comes?



- Step 2: worker waiting from VOTE-REQ from coordinator
- Step 3: Coordinator is waiting for vote from participants
- Step 4: Worker who voted YES is waiting for decision

What happens when a message never comes?

Coordinator Algorithm

1. Coordinator sends **VOTE-REQ** to all workers

Worker Algorithm

2.
- Send **VOTE-COMMIT** or **VOTE-ABORT** to coordinator
- If sent **VOTE-ABORT** immediately abort

3. Collect votes
- If receive **VOTE-COMMIT** from all N workers, send **GLOBAL-COMMIT** to all workers
- If don't receive **VOTE-COMMIT** from all N workers, send **GLOBAL-ABORT** to all workers

4.
- If receive **GLOBAL-COMMIT** then commit
- If receive **GLOBAL-ABORT** then abort

- Step 2: worker waiting from VOTE-REQ from coordinator

  Since it has not cast its vote yet, worker can decide abort and halt

- Step 3: Coordinator is waiting for vote from participants

  Coordinator can always vote abort herself, so votes abort and sends GLOBAL-ABORT to all participants

- Step 4: Worker who voted COMMIT is waiting for decision

  Worker cannot decide: it must run a termination protocol

Termination Protocol

- Option 1: Simply wait for coordinator to recover.

If all failures are repaired and there are no more failures, then all processes will eventually decide commit/abort (Termination)

=> No need to recover until coordinator has recovered

- (Better) Option 2: Ask a friendly participant p

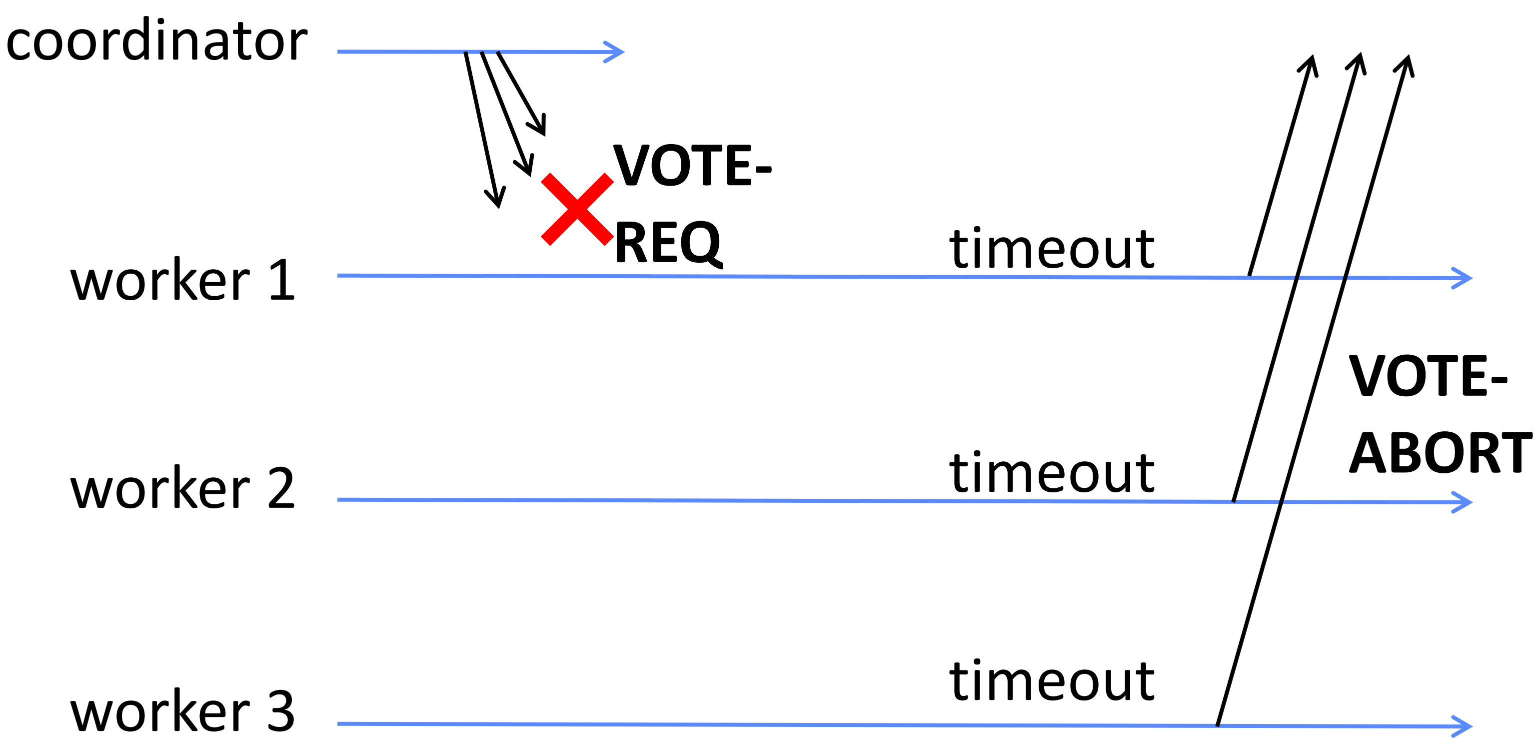
Case 1: If p has decided COMMIT/ABORT, forwards decision to initiator

Case 2: If P has not decided, votes ABORT, sends abort to initiator. Initiator knows decision will be ABORT. So can decide

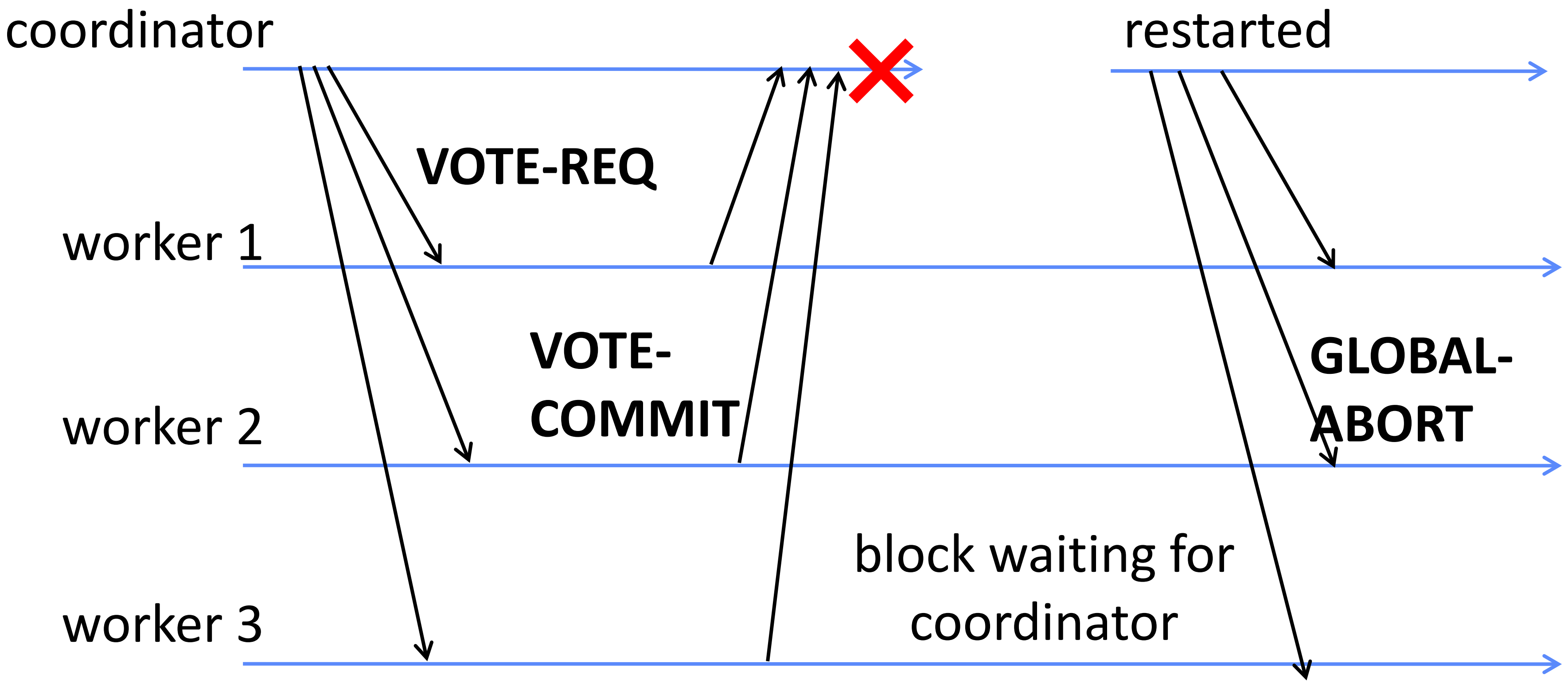
Case 3: If P has voted COMMIT, P is also stuck and can't help initiator

If every participant voted COMMIT and coordinator crashes before sending decision, must wait for coordinator to recover to decide!

Example of Coordinator Failure #1



Example of Coordinator Failure #2



Machine recovery

All nodes use stable storage to store current state (e.g. backed by disk/SSD)
Upon recovery, nodes can restore state and resume

When coordinator sends VOTE-REQ, writes START-2PC to log

=> Coordinator reads log, if sees VOTE-REQ but no decision, decides ABORT unilaterally

Before voting, participant writes VOTE-* to stable log, then sends vote

=> Participant reads log, if doesn't see record, sends VOTE-ABORT. If VOTE-COMMIT, contacts friend

Before sending decision, coordinator writes GLOBAL-* to stable log, then sends decision

=> Coordinator reads log, if sees GLOBAL-, resends decision*

After receiving GLOBAL-*, participant writes commit/abort to stable log

=> Participants read log, 2PC instance has already been terminated

2PC Summary

Why is 2PC not subject to the General's paradox?

- Because 2PC is about *all nodes eventually coming to the same decision – not necessarily at the same time!*
- Allowing us to reboot and continue allows time for collecting and collating decisions

Biggest downside of 2PC: blocking

- A failed node can prevent the system from making progress
- Still one of the most popular coordination algorithms today

Alternatives to 2PC

Three-Phase Commit: One more phase, allows nodes to fail or block and still make progress.

PAXOS: An alternative used by Google and others that does not have 2PC blocking problem
- Develop by Leslie Lamport (Turing Award Winner)
- No fixed leader, can choose new leader on fly, deal with failure

What happens if one or more of the nodes is malicious?
- Malicious: attempting to compromise the decision making
- Use a more hardened decision-making process: Byzantine Agreement and Blockchains