Distributed Computing III

Murphy was an optimist

CSSE6400

Richard Thomas

May 8, 2023

Question

What communication faults may occur?

Question

What communication faults may occur?

Answer

- Message not delivered

Question

What communication faults may occur?

Answer

- Message not delivered
- Message delayed

Question

What communication faults may occur?

Answer

- Message not delivered
- Message delayed
- Receiver failed

Question

What communication faults may occur?

Answer

- Message not delivered
- Message delayed
- Receiver failed
- Receiver busy

Question

What communication faults may occur?

Answer

- Message not delivered
- Message delayed
- Receiver failed
- Receiver busy
- Reply not received

Question

What communication faults may occur?

Answer

- Message not delivered
- Message delayed
- Receiver failed
- Receiver busy
- Reply not received
- Reply delayed

- Lost in transit
- Network delay or receiver overloaded, but message will be processed later
- Receiver software has crashed or node has died
- Receiver temporarily not replying (e.g. garbage collection has frozen other processes)
- Request was processed but reply lost in transit
- Reply will be received later

Question

How do we detect faults?

Question

How do we detect faults?

Answer

- No listener on port – RST or FIN packet

Question

How do we detect faults?

Answer

- No listener on port – RST or FIN packet
- Process crashes – Monitor report failure

Question

How do we detect faults?

Answer

- No listener on port – RST or FIN packet
- Process crashes – Monitor report failure
- IP address not reachable – unreachable packet

Question

How do we detect faults?

Answer

- No listener on port – RST or FIN packet
- Process crashes – Monitor report failure
- IP address not reachable – unreachable packet
- Query switches

Question

How do we detect faults?

Answer

- No listener on port – RST or FIN packet
- Process crashes – Monitor report failure
- IP address not reachable – unreachable packet
- Query switches
- Timeout

- Assumes node is running & reachable. OS should close or refuse connection. Error packet may be lost in transit.
- Assumes node is running & reachable. Most reliable.
- Router has to determine address is not reachable, which is no easier than for your application.
- Need permissions to do this. Will only have this in your own data centre.
- UDP reduces network transmission time guarantee – does not perform retransmission

Question

What to do if fault is detected?

Question

What to do if fault is detected?

Answer

- Retry
- Restart

- How many retries? How often?
- Exponential backoff with jitter
- How long to wait to restart?
- Too long reduces responsiveness.
- Unacknowledged messages need to be sent to other nodes – reducing performance.
- Too short may prematurely declare nodes dead.
- May lead to contention – two nodes processing the same request.
- May lead to cascading failure – load is sent to other nodes, slowing them down so they are then declared dead ….

Definition 1. Idempotency

Repeating an operation does not change receiver's state.

- Idempotent consumer pattern
- Tag messages with an ID, so repeated messages can be ignored
- Or, redo messages that do not change state (e.g. queries)

Byzantine Generals Problem

- *n* generals need to agree on plan
- Can only communicate via messenger
- Messenger may be delayed or lost
- Some generals are traitors
  - Send dishonest messages
  - Pretend to have not received message

Link analogy to Byzantine faults

Definition 2. Byzantine Faults

Nodes in a distributed system may ‘lie’ – send faulty or corrupted messages or responses.

- A message that causes the receiver to fail.
- Incorrect responses (e.g. they have finished processing a message but haven’t).
- Can be due to faults or malicious hosts.
- Difficult to deal with all possible variations of these faults.

Question

Can we design a system to be Byzantine fault tolerant?

Question

Can we design a system to be Byzantine fault tolerant?

Answer

Yes, but, it is *challenging*.

- Most systems don't attempt to
- Some need to (e.g. safety critical systems, blockchain, …)
- Refer to CSSE3012 Safety Critical guest lecture.

Limited Fault Tolerance

- Validate format of received messages
  - Need strategy to handle & report errors

Limited Fault Tolerance

- Validate format of received messages
  - Need strategy to handle & report errors
- Santise inputs
  - Assume any input from external sources may be malicious

Limited Fault Tolerance

- Validate format of received messages
  - Need strategy to handle & report errors
- Santise inputs
  - Assume any input from external sources may be malicious
- Retrieve data from multiple sources
  - If possible
  - e.g. Multiple NTP servers

Assumption

If all nodes are part of our system, we may assume there are no Byzantine faults.

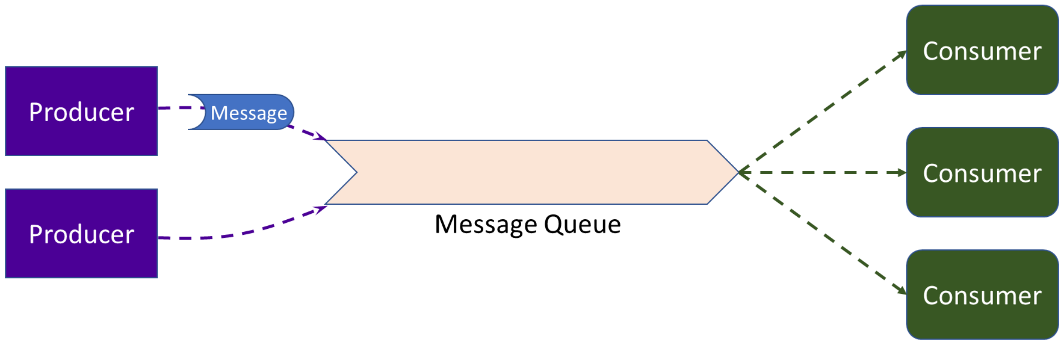
- Santise user input
- Byzantine faults may still arise
  - Logic defects
    - Same code is usually deployed to all replicated nodes, defeating easy fault tolerance solutions

Definition 3. Poison Message

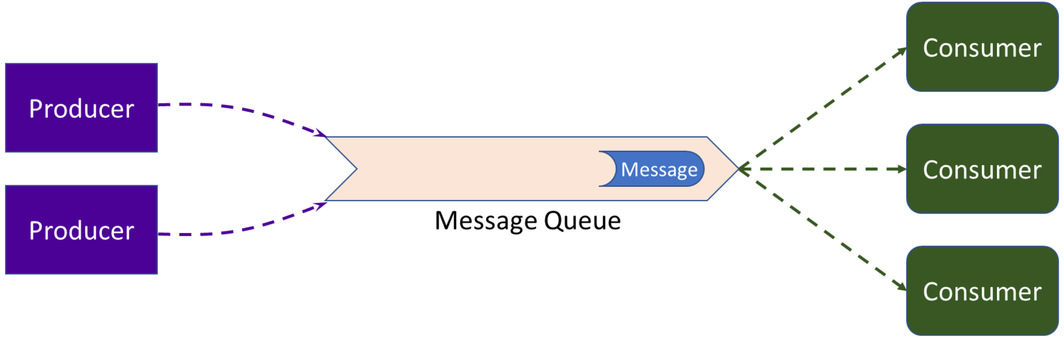
A message that causes the receiver to fail.

- Could literally cause the receiver to crash
- Often the receiver just cannot process the message and aborts processing

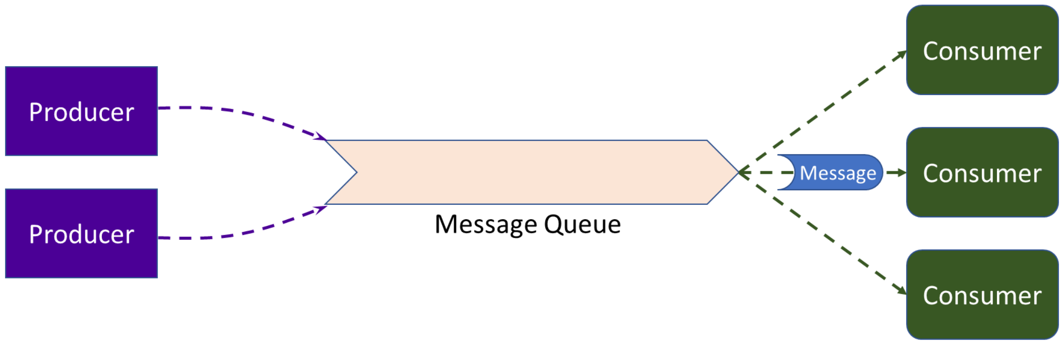
Normal Message Flow



- Sequence of slides with an animation of a poison message.
- First 3 slides are an example of a message being queued and processed.
- Slides 4-8 are an example of a poison message blocking the queue.
- Should comment that poison messages block processing regardless of how they're delivered.
- A message queue or service isn't the key blocking point.
- Async messages sent directly to a consumer requires it to queue them as they're processed, leading to the same blocking issue.



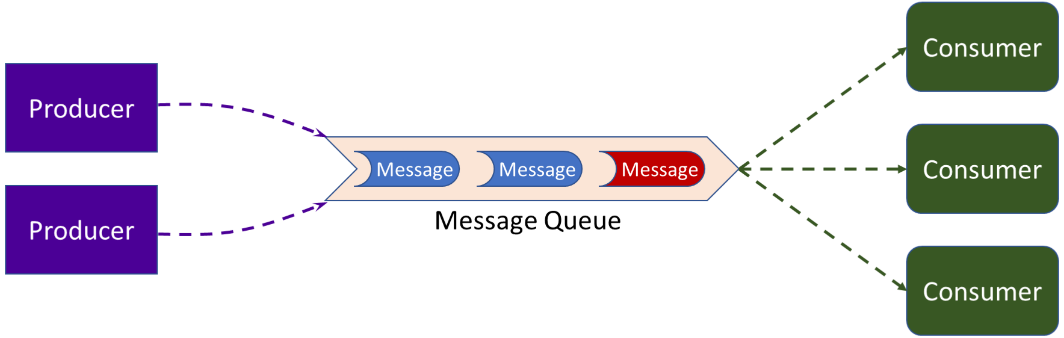
- Sequence of slides with an animation of a poison message.
- First 3 slides are an example of a message being queued and processed.
- Slides 4-8 are an example of a poison message blocking the queue.
- Should comment that poison messages block processing regardless of how they're delivered.
- A message queue or service isn't the key blocking point.
- Async messages sent directly to a consumer requires it to queue them as they're processed, leading to the same blocking issue.



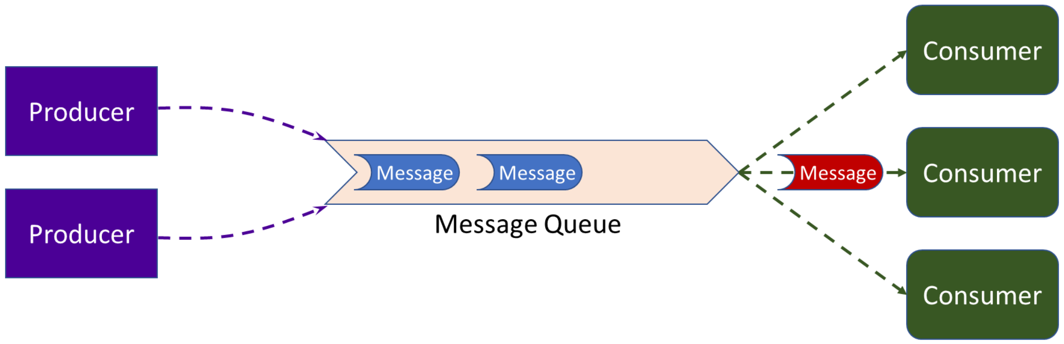
- Sequence of slides with an animation of a poison message.
- First 3 slides are an example of a message being queued and processed.
- Slides 4-8 are an example of a poison message blocking the queue.
- Should comment that poison messages block processing regardless of how they're delivered.
- A message queue or service isn't the key blocking point.
- Async messages sent directly to a consumer requires it to queue them as they're processed, leading to the same blocking issue.

Poison Message

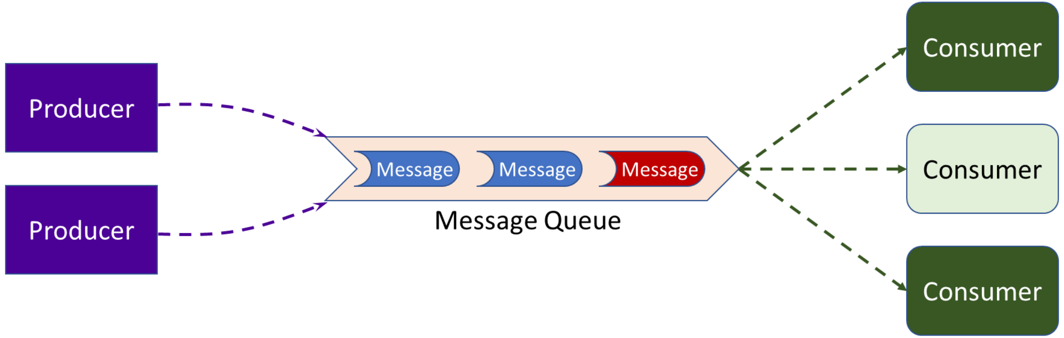
- Receiver can’t process message.
- Always fails – Not due to transient failure.
- Failed messages are retried.
- Returned to front of queue – Preserve message order.
- Next receiver fails to process message – Infinite loop.
- Blocks sending of following messages.



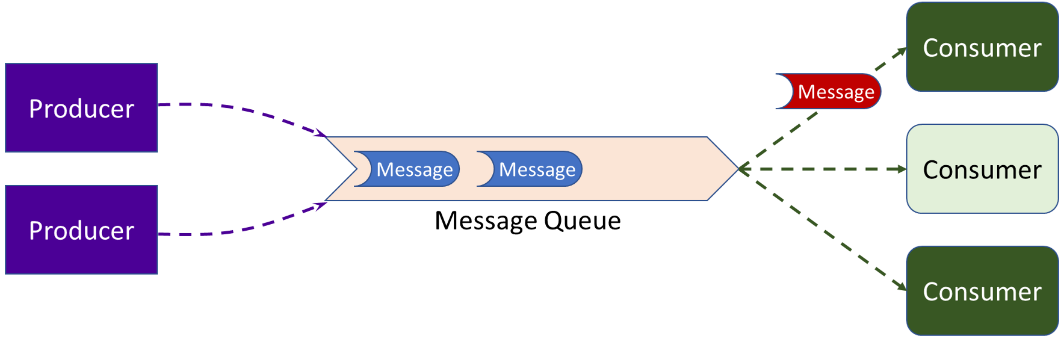
- Sequence of slides with an animation of a poison message.
- First 3 slides are an example of a message being queued and processed.
- Slides 4-8 are an example of a poison message blocking the queue.
- Should comment that poison messages block processing regardless of how they're delivered.
- A message queue or service isn't the key blocking point.
- Async messages sent directly to a consumer requires it to queue them as they're processed, leading to the same blocking issue.



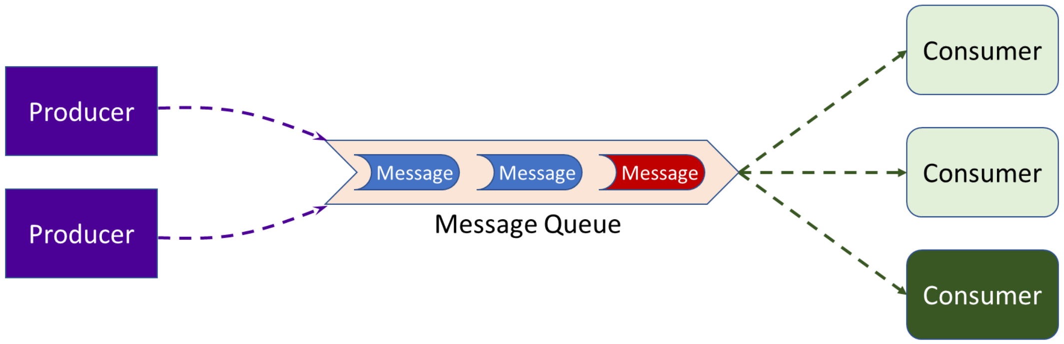
- Sequence of slides with an animation of a poison message.
- First 3 slides are an example of a message being queued and processed.
- Slides 4-8 are an example of a poison message blocking the queue.
- Should comment that poison messages block processing regardless of how they're delivered.
- A message queue or service isn't the key blocking point.
- Async messages sent directly to a consumer requires it to queue them as they're processed, leading to the same blocking issue.



- Sequence of slides with an animation of a poison message.
- First 3 slides are an example of a message being queued and processed.
- Slides 4-8 are an example of a poison message blocking the queue.
- Should comment that poison messages block processing regardless of how they're delivered.
- A message queue or service isn't the key blocking point.
- Async messages sent directly to a consumer requires it to queue them as they're processed, leading to the same blocking issue.



- Sequence of slides with an animation of a poison message.
- First 3 slides are an example of a message being queued and processed.
- Slides 4-8 are an example of a poison message blocking the queue.
- Should comment that poison messages block processing regardless of how they're delivered.
- A message queue or service isn't the key blocking point.
- Async messages sent directly to a consumer requires it to queue them as they're processed, leading to the same blocking issue.



- Sequence of slides with an animation of a poison message.
- First 3 slides are an example of a message being queued and processed.
- Slides 4-8 are an example of a poison message blocking the queue.
- Should comment that poison messages block processing regardless of how they're delivered.
- A message queue or service isn't the key blocking point.
- Async messages sent directly to a consumer requires it to queue them as they're processed, leading to the same blocking issue.

Question

What causes a message to be poisonous?

Question

What causes a message to be poisonous?

Answer

- Content is invalid
  - e.g. Invalid product id sent to purchasing service
  - Error handling doesn’t cater for error case

Question

What causes a message to be poisonous?

Answer

- Content is invalid
  - e.g. Invalid product id sent to purchasing service
  - Error handling doesn't cater for error case
- System state is invalid
  - e.g. Add item to shopping cart that has been deleted
  - Logic doesn't handle out of order messages
    - Insidious asynchronous faults

- Invalid content may be
- corrupted data,
- old version of data structure,
- incorrect data, or
- malicious data.
- Invalid state may be
- events out of order (e.g. delete then update),
- logic error making state invalid, or
- external corruption of persistent state.

Detecting Poison Messages

Retry counter – with limit

- Where is counter stored?
  - Memory – What if server restarts?
  - DB – Slow
  - Must ensure counter is reset, regardless of how message is handled
    - e.g. Message is manually deleted

Detecting Poison Messages

Retry counter – with limit

- Where is counter stored?
  - Memory – What if server restarts?
  - DB – Slow
  - Must ensure counter is reset, regardless of how message is handled
    - e.g. Message is manually deleted

Message service may have a timeout property

- Message removed from queue
  - Pending messages get older while waiting for poison message
  - Transient network faults may exceed timeout

Detecting Poison Messages

Monitoring service

- Trigger action if message stays at top of queue for too long
- Can check for queue errors
  - No messages are being processed
  - Restart message service

Discard message

- System must not require guarantee of message delivery
- Suitable when message processing speed is most important

Handling Poison Messages

Discard message

- System must not require guarantee of message delivery
- Suitable when message processing speed is most important

Always retry

- Requires mechanism to fix message
  - Often requires manual intervention
- Suitable when message delivery is most important
- Very long delays in processing

Dead-letter queue

- Long transient failures result in adding many messages
  - e.g. Network failure
- Requires manual monitoring and intervention
- System must not require strict ordering of messages
- Suitable when message processing speed is important

Retry queue

- Transient failures also added
- Use a previous strategy to deal with poison messages
- System must not require strict ordering of messages
- Suitable when message processing speed is very important
  - Main queue is never blocked
  - Receivers need to process from two message queues

Definition 4. Poison Pill Message

Special message used to notify receiver it should no longer wait for messages.

Emphasise that this is different to a poison message

Question

Why use a poison pill message?

Question

Why use a poison pill message?

Answer

Graceful shutdown of system.

- Implementation is challenging with multiple producers and/or consumers
- It must be the last message received by all consumers

Question

How to order asynchronous messages?

Question

How to order asynchronous messages?

Answer

- Timestamps?
  - Can’t keep clocks in sync
  - Limited clock precision

- Trying to sync with NTP is unreliable
- Network delays during sync
- Clock drift between syncs
- Finite precision – two events may end up with the same timestamp, if they occur in quick succession

Data Issues

Consistency

Eventual Consistency weak guarantee

Linearisability strong guarantee

Causal Ordering strong guarantee

Eventual Consistency

- Allows stale reads
- May be appropriate for some systems
  - e.g. Social media updates[1]

[1] See Distributed II slides 40 - 44.

- Once value is written, all reads see same value
  - Regardless of replica read from

- Once value is written, all reads see same value
  - Regardless of replica read from
- Single-leader replication
  - Read from leader
  - Read from synchronous follower

- Once value is written, all reads see same value
  - Regardless of replica read from
- Single-leader replication
  - Read from leader
  - Read from synchronous follower
- Multi-leader replication can’t be linearised

Linearisability

- Once value is written, all reads see same value
  - Regardless of replica read from
- Single-leader replication
  - Read from leader
  - Read from synchronous follower
- Multi-leader replication can't be linearised
- Leaderless replication
  - Lock value on quorum before writing

- Abstraction over replicated database
- Used when uniqueness needs to be guaranteed
- e.g. Multiple withdrawals from an account
- SLR – defeats most performance benefits
- Leaderless – similar performance cost to SLR

Causal Order

- Order is based on causality
  - What event needs to happen before another
  - Allows concurrent events

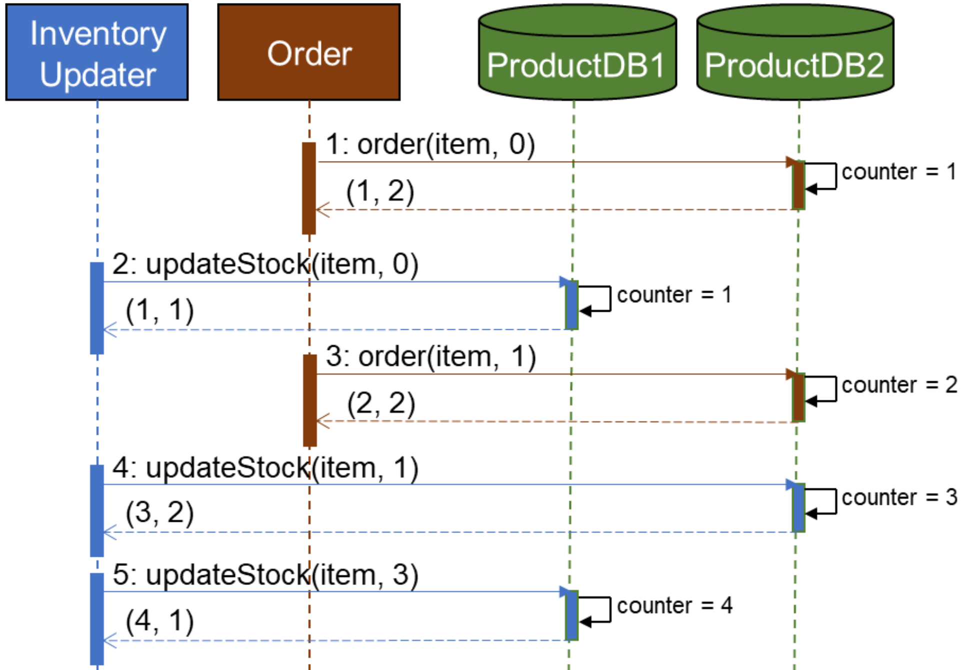
Causal Order

- Order is based on causality
  - What event needs to happen before another
  - Allows concurrent events
- Single-leader replication
  - Record sequence number of writes in log
  - Followers read log to execute writes

Causal Order

- Order is based on causality
  - What event needs to happen before another
  - Allows concurrent events
- Single-leader replication
  - Record sequence number of writes in log
  - Followers read log to execute writes
- Lamport timestamps

- Linearisation defines a total order
- Causal ordering defines a partial order
- e.g. Git repo history with branching as causal order
- Not as strict as linearisability, so less performance cost



Inventory Updater
Order
ProductDB1
ProductDB2
1: order(item, 0)
counter = 1
(1, 2)
2: updateStock(item, 0)
counter = 1
(1, 1)
3: order(item, 1)
counter = 2
(2, 2)
4: updateStock(item, 1)
counter = 3
(3, 2)
5: updateStock(item, 3)
counter = 4
(4, 1)

Definition 5. Consensus

A set of nodes in the system agree on some aspect of the system's state.

Abstraction to make it easier to reason about system state.

Consensus Properties

Uniform Agreement All nodes must agree on the decision

Integrity Nodes can only vote once

Validity Result must have been proposed by a node

Termination Every node that doesn't crash must decide

- Uniform agreement and integrity are key
- Validity avoids nonsensical solutions (e.g. always agreeing to a null decision)
- Termination enforces fault tolerance, it requires that progress is made towards a solution

Definition 6. Atomic Commit

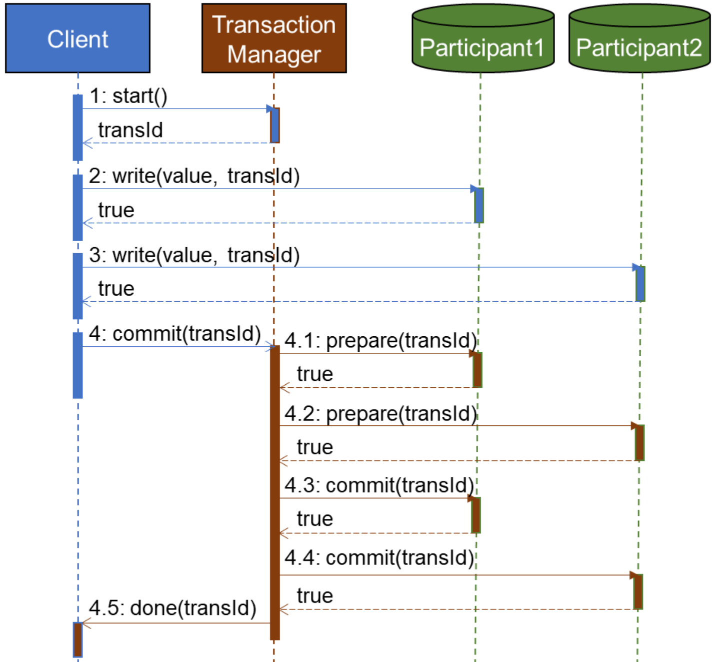
All nodes participating in a distributed transaction need to form consensus to complete the transaction.

Based on transaction atomicity from ACID.

Prepare Confirm nodes can commit transaction

Commit Finalise commit once consensus is reached

- Abort if consensus can't be reached



- Transaction ID used to track writes
- Prepare does all steps of a commit, aside from confirming it – It cannot be revoked by participant
- Commit intent is recorded in log before sending to participants
- Even if a particiant fails, commit can proceed when it recovers
- Comment on performance costs

Distributed Systems Timing Assumptions

- Synchonous System
  - Not realistic due to faults above
  - Minimal performance benefit

Distributed Systems Timing Assumptions

- Synchonous System
  - Not realistic due to faults above
  - Minimal performance benefit
- Partially Synchonous System
  - Assumes important message order is preserved
  - Assumes most faults are rare & transient
  - Error handling to catch faults

Distributed Systems Timing Assumptions

- Synchonous System
  - Not realistic due to faults above
  - Minimal performance benefit
- Partially Synchonous System
  - Assumes important message order is preserved
  - Assumes most faults are rare & transient
  - Error handling to catch faults
- Asynchonous System
  - No timing assumptions
  - Important message order managed by application
  - Difficult & limited design

Distributed Systems Node Failure Assumptions

- Crash Stop
  - Node fails and never restarts

Distributed Systems Node Failure Assumptions

- Crash Stop
  - Node fails and never restarts
- Crash Recovery
  - Node fails and restarts
    - Requires persistent memory to recover to close to prior state

Distributed Systems Node Failure Assumptions

- Crash Stop
  - Node fails and never restarts
- Crash Recovery
  - Node fails and restarts
    - Requires persistent memory to recover to close to prior state
- Arbitrary Failure
  - Nodes may perform spurious or malicious actions
    - Byzantine faults

- Crash Stop – Cloud-based system that kills crashed nodes.
- Crash Recovery – Any system that allows nodes to be restarted.
- Crash Recovery – May lose some steps in memory for non-critical tasks.
- Arbitrary Failure – Nodes may send faulty or malicious messages.

- Distributed systems are hard to build
- Large systems have to be distributed
  - Monoliths can’t scale to millions of users
- Use environments, tools & libraries
  - Leaverage others’ experience