

# Distributed Computing III

*Murphy was an optimist.*

— *O'Toole's Commentary*

*CSSE6400*

Richard Thomas

April 27, 2026

*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



*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

*Question*

What to do if fault is detected?

*Question*

What to do if fault is detected?

*Answer*

- Retry
- Restart



*Definition 0.* Idempotency

Repeating an operation does not change receiver's state.

# 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
  - Send messages pretending to be another general

### *Definition 0.* Byzantine Faults

Nodes in a distributed system may ‘lie’.

— Send faulty or corrupted messages or responses.

*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*.

## 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*

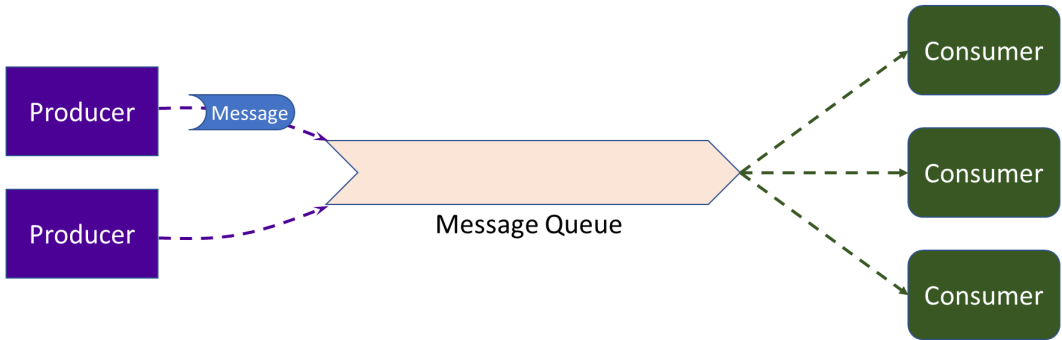
If all nodes are part of our system, we may assume there are no Byzantine faults.

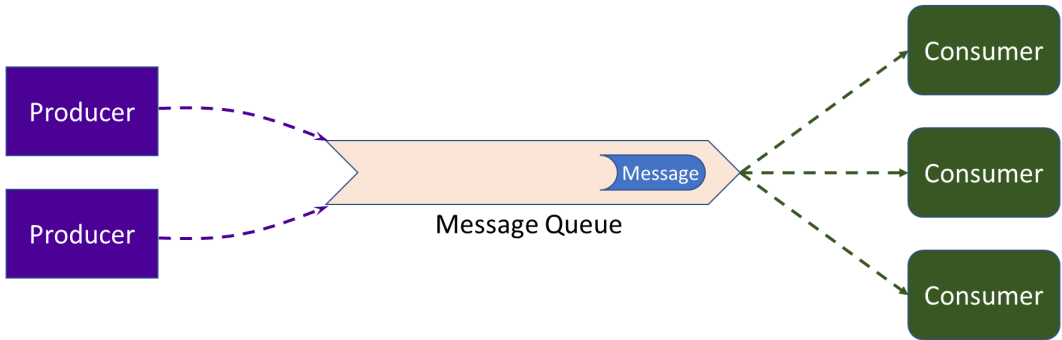
- Santise user input
- Byzantine faults may still arise
  - Logic defects
    - Same code is usually deployed to all replicated nodes, defeating easy fault tolerance solutions

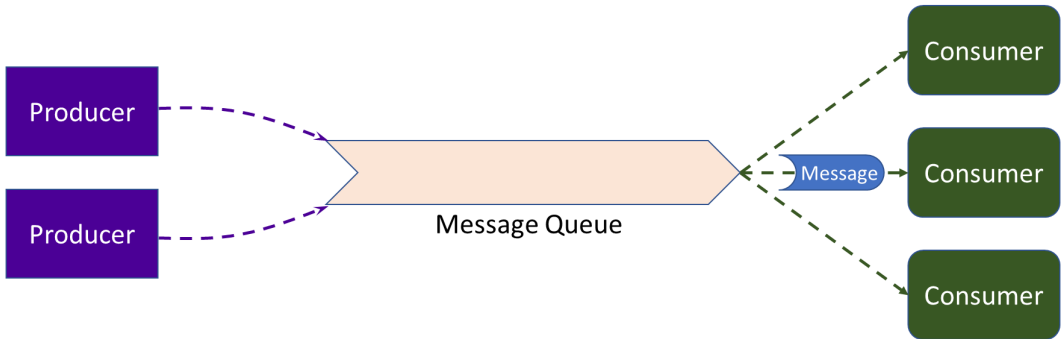
*Definition 0.* Poison Message

A message that causes the receiver to fail.

Normal Message Flow

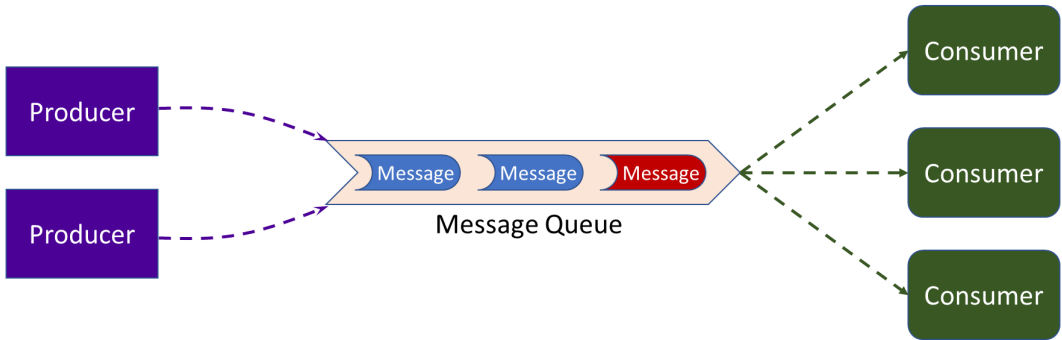




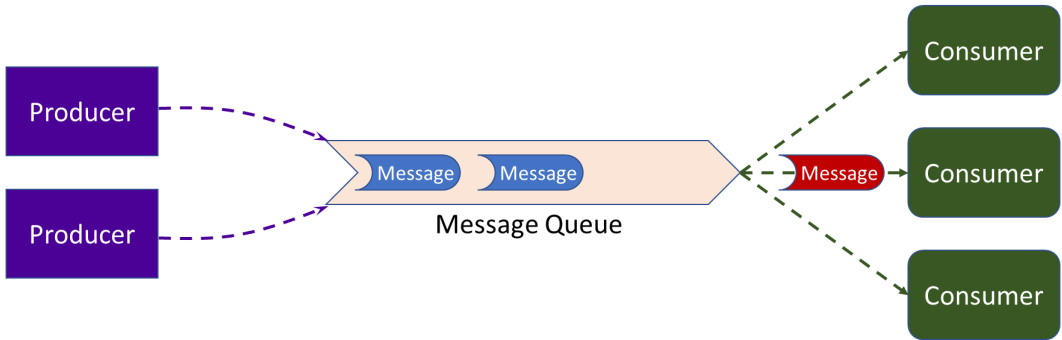


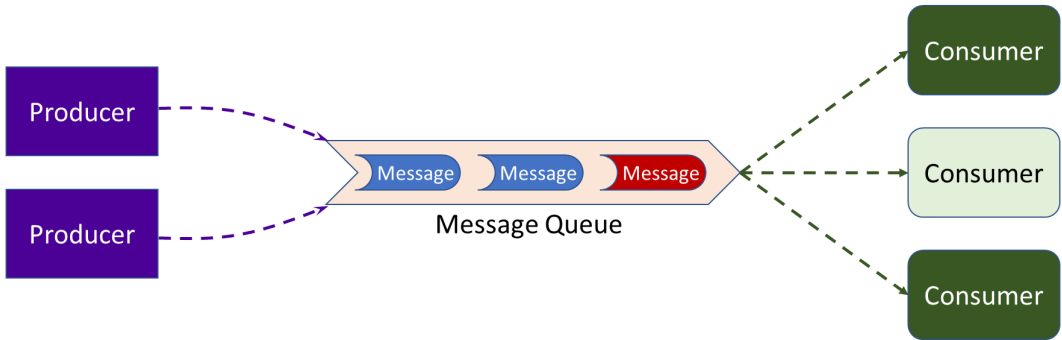
# Poison Message

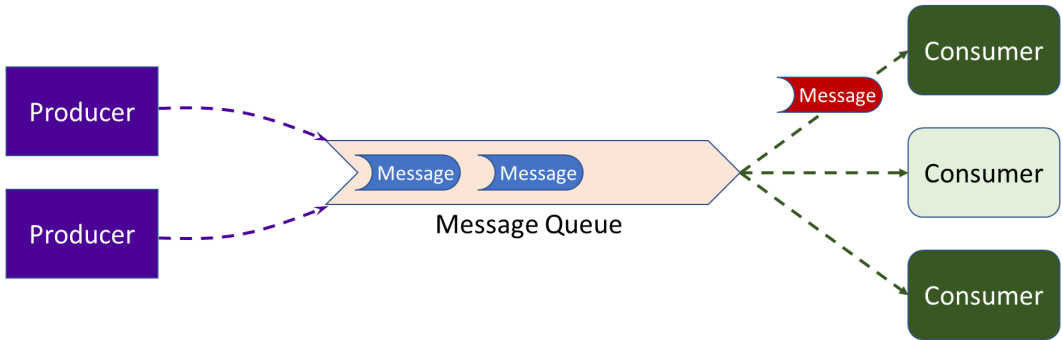


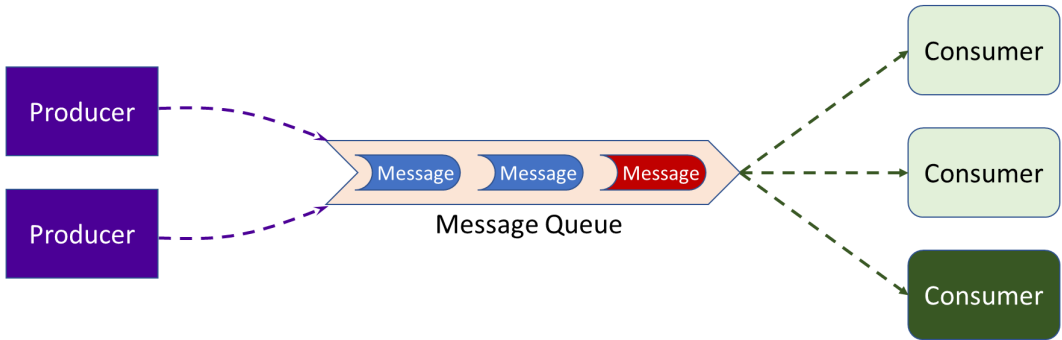












*Question*

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

# 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

## Handling Poison Messages

### 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

# Handling Poison Messages

## 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

# Handling Poison Messages

## 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 0.* Poison Pill Message

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

*Question*

Why use a poison pill message?



*Question*

Why use a poison pill message?

*Answer*

Graceful shutdown of system.

*Question*

How to order asynchronous messages?

*Question*

How to order asynchronous messages?

*Answer*

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

## *§ 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<sup>1</sup>

---

<sup>1</sup>See Distributed II slides 45 - 50.

## *Linearisability*

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

## *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



## *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

## 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

## *Causal Order*

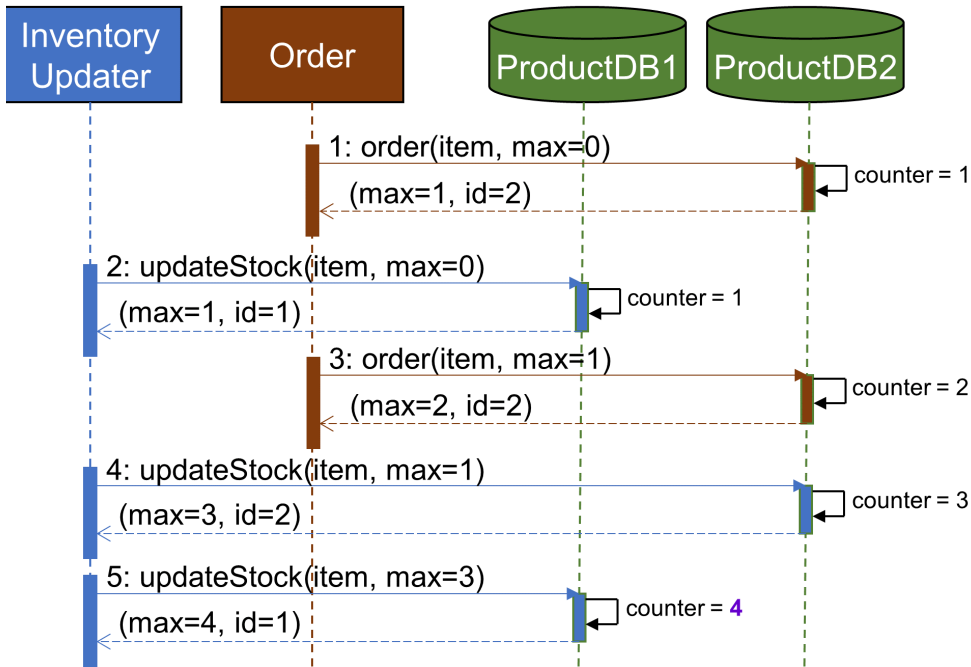
- Order is based on causality
  - What event needs to happen before another
  - Allows concurrent events

## *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



*Definition 0.* Consensus

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



*Definition 0.* Atomic Commit

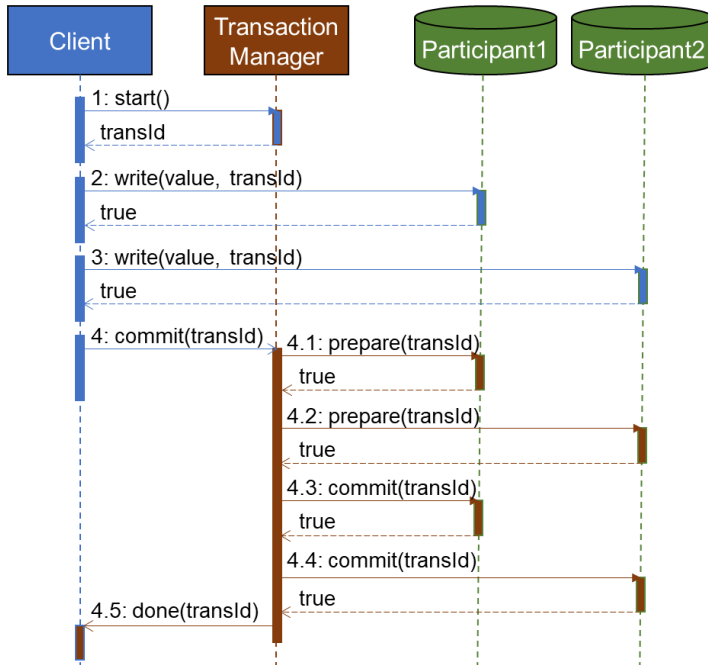
All nodes participating in a distributed transaction need to form consensus to complete the transaction.

## *Two-Phase Commit*

**Prepare** Confirm nodes can commit transaction

**Commit** Finalise commit once consensus is reached

- Abort if consensus can't be reached



## Distributed Systems Timing Assumptions

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

## Distributed Systems Timing Assumptions

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

## Distributed Systems Timing Assumptions

- Synchronous System
  - Not realistic due to faults above
  - Minimal performance benefit
- Partially Synchronous System
  - Assumes important message order is preserved
  - Assumes most faults are rare & transient
  - Error handling to catch faults
- Asynchronous 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 for recovery 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 for recovery close to prior state
- Arbitrary Failure
  - Nodes may perform spurious or malicious actions
    - Byzantine faults

- Distributed systems are hard to build
- Large systems have to be distributed
  - Monoliths can't scale to millions of users
- Use environments, tools & libraries
  - Leverage others' experience
- CSSE7610 Concurrency: Theory & Practice
  - Prove correctness of concurrent & distributed systems