Models of Distributed Systems

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Distributed Systems
ECE419

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Lecture notes on Concurrent and Distributed Systems

Overview

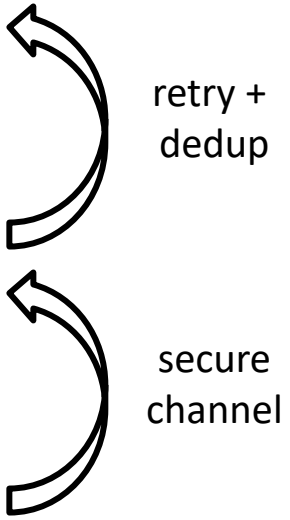
- System models
- Failures and failure detectors

System models

- A machine (computer, phone, car, etc.) is called a node
- A model of a distributed system specifies assumptions about faults that may occur
  - Network behavior (e.g. message loss)
  - Node behavior (e.g. crashes)
  - Timing behavior (e.g. delays)

System model: network behavior

- Assume bidirectional, point-to-point communication between two nodes, with one of:
  - Reliable links
    - A message is received if and only if it is sent
    - Messages may be reordered
  - Best-effort links
    - Messages may be lost, duplicated, or reordered
    - If you keep retrying, a message eventually gets through
  - Insecure links
    - A malicious adversary may interfere with messages, e.g., eavesdrop, modify, drop, spoof, replay



- Network partition: some links drop/delay all messages for extended periods of time

System model: node behavior

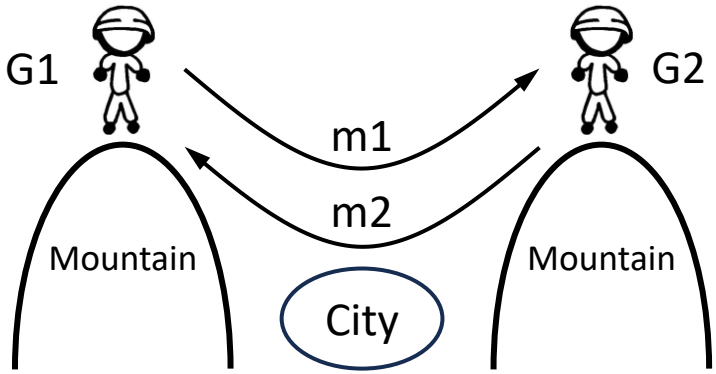
- When executing an algorithm, assume node may have:
  - Crash-stop (fail-stop) failure
    - A node may crash at any time, e.g., due to power failure
    - After crashing, it stops executing forever
  - Crash-recovery (fail-recovery) failure
    - A node may crash at any time, losing its in-memory state
    - It may resume executing sometime later
    - Data on non-volatile storage (e.g., disk, SSD) survives crash
  - Byzantine (fail-arbitrary) failure
    - A node is faulty if it deviates from the algorithm
    - Faulty nodes may execute incorrectly, including being malicious
- A node that is not faulty is called correct

System model: timing behavior

- Assume one of the following for network and nodes:
  - Synchronous
    - Message latency no greater than a known upper bound
    - Nodes execute algorithm at a known speed
    - Algorithms easier to design, but unrealistic assumptions
  - Asynchronous
    - Messages can be delayed arbitrarily
    - Nodes can pause execution arbitrarily
    - No timing guarantees at all
    - Algorithms more robust, but hard to design, sometimes impossible …

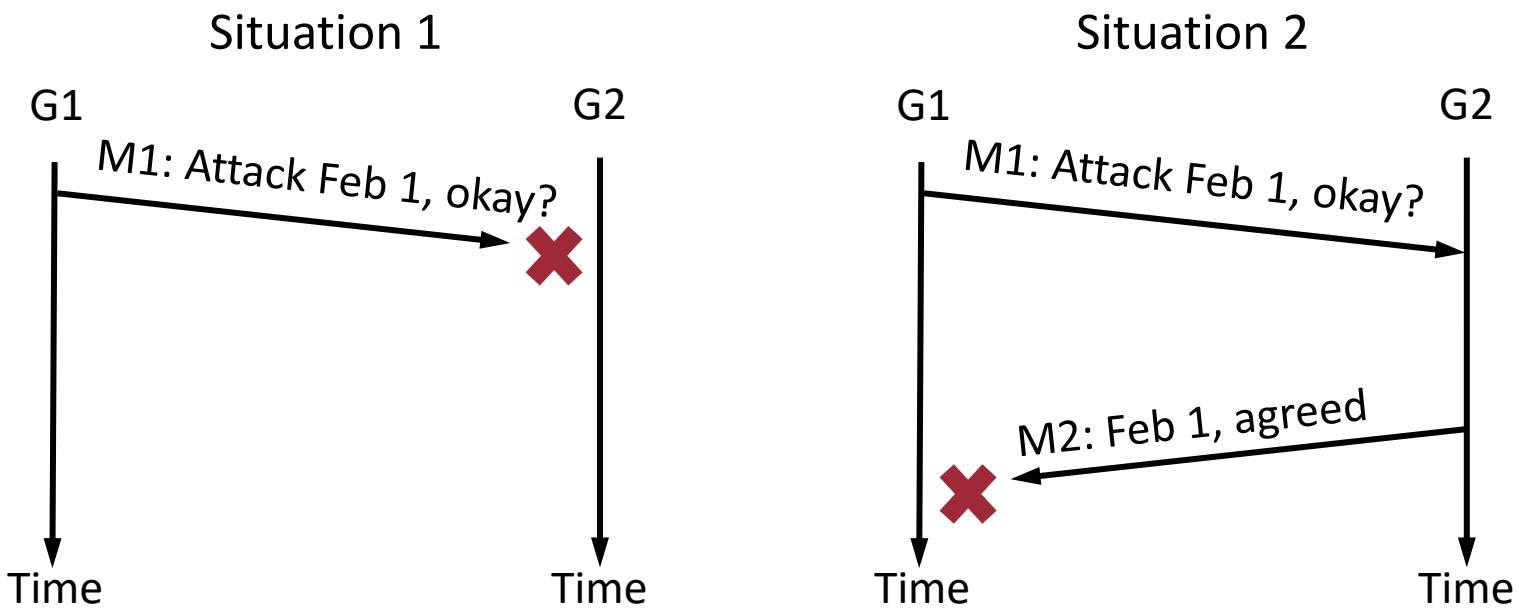
Two Generals problem

- A thought experiment that shows the challenge with coordinating actions over asynchronous links
  - Used to motivate the atomic commit problem (discussed later)
- Problem:
  - Two generals need to agree to attack to win (or else they lose)
  - Only communicate by sending messages (that may not arrive)



Two Generals dilemma

- For G1, Situations 1 and 2 are indistinguishable
- Should generals attack before or after receiving reply?
  - If before, then general may lose
  - If after, then generals wait forever … why?



System model: timing behavior

- Let's look at a third timing model:
  - Synchronous
    - Message latency no greater than a known upper bound
    - Nodes execute algorithm at a known speed
    - Algorithms easier to design, but unrealistic assumptions
  - Asynchronous
    - Messages can be delayed arbitrarily
    - Nodes can pause execution arbitrarily
    - No timing guarantees at all
    - Algorithms more robust, but hard to design/make guarantees
  - Partially synchronous
    - The system is asynchronous for some finite (but unknown) periods of time, synchronous otherwise
    - Practical algorithms designed for realistic environments

Why partially synchronous?

- Networks usually have predictable latency,
  but latency may increase due to:
  - Message loss requiring retry
  - Congestion/contention causing queueing
  - Network/route reconfiguration
- Nodes usually execute code at a predictable speed,
  but occasional slowdown may occur due to:
  - IO accesses
  - Operating system scheduling
  - Stop-the-world garbage collection pauses
  - Page faults, swapping, thrashing

Summary of system models

- For each of the three, pick one:
  - Network: reliable, best-effort, or insecure
  - Nodes: crash-stop, crash-recovery, or byzantine
  - Timing: synchronous, asynchronous, or partially synchronous
- These models are the basis for any distributed system!
  - If your fault assumptions are wrong, all bets are off!

Failures and Failure Detectors

Availability

- Online store wants to sell stuff 24/7!
  - Service unavailability = downtime = financial loss
- Availability: fraction of time service functions correctly
  - Two nines = 99% up = down 3.7 days/year
  - Three nines = 99.9% up = down 8.8 hours/year
  - Four nines = 99.99% up = down 53 minutes/year
  - Five nines = 99.999% up = down 5.3 minutes/year
- Service-Level Objective (SLO): availability expectation
  - e.g., 99.9% of requests in a day get a response in 200 ms
- Service-Level Agreement (SLA): contract specifying an SLO, with penalties for violation

Achieving high availability

- Failure: system stops working, causes unavailability
- Fault: part of system fails, may also cause unavailability
  - Node fault: crashes, malicious behavior
  - Network fault: packet drops, delays, network partitions
- Improve availability by
  - Reducing frequency of faults
    - E.g., use higher quality and redundant hardware
  - Software fault tolerance
    - Ensure that system continues working, despite some faults
      - E.g., avoid single point of failure, a single node/link fault leads to failure
    - As a first step, requires detecting failures

Failure (Fault) detectors

- Failure detector: algorithm that detects whether another node is faulty (typically, crashed)
- Perfect failure detector: labels a node as faulty if and only if it has crashed
- Typical implementation for crash-stop/crash-recovery
  - Send message, await response,
    label node as crashed if no reply within some timeout
- Problem: cannot reliably tell the difference between crashed/delayed node, lost/delayed message

Failure detection in partially synchronous systems

- Perfect timeout-based failure detector only possible in synchronous crash-stop system with reliable links
  - But real systems are partially synchronous or asynchronous!
- Eventually perfect failure detector possible in partially synchronous systems
  - May temporarily mislabel a correct node as crashed
  - May temporarily mislabel a crashed node as correct
  - But eventually, labels a node as crashed iff it has crashed
- Reflects the reality that detection is not instantaneous, so spurious timeouts may occur

Conclusions

- The system model specifies assumptions about 1) faults in networks, 2) faults in nodes, and 3) timing behavior
- Correct design of distributed algorithms and systems depends on these assumptions
- Distributed systems strive to provide high availability
  - With large systems, h/w failures become more common
  - Need to detect and tolerate faults in software
  - Cannot assume accurate failure detection in real systems