**Recap: RPC**

- RPC enables programmers to call functions in remote processes.
- IDL (Interface Definition Language) allows programmers to define remote procedure calls.
- Stubs are used to make it appear that the call is local.
- Semantics
  - Cannot provide exactly once
  - At least once
  - At most once
  - Depends on the application requirements

**Let’s Consider This…**

One Reason: Impossibility of Consensus

- Q: Should Steve give an A to everybody taking CSE 486/586?
- Input: everyone says either yes/no.
- Output: an agreement of yes or no.
- Bad news
  - Asynchronous systems cannot guarantee that they will reach consensus even with one faulty process.
- Many consensus problems
  - Reliable, totally-ordered multicast (what we saw already)
  - Mutual exclusion, leader election, etc. (what we will see)
  - Cannot reach consensus.

The Consensus Problem

- N processes
- Each process $p$ has
  - input variable $x_p$: initially either 0 or 1
  - output variable $y_p$: initially $b$ (unchanged) – can be changed only once
- Consensus problem: Design a protocol so that either
  - all non-faulty processes set their output variables to 0
  - Or all non-faulty processes set their output variables to 1
  - There is at least one initial state that leads to each outcomes 1 and 2 above

**Recap: RPC**

- Client Process
- Client Function
- Client Stub
- Marshalling/unmarshalling
- Socket API
- Server Process
- Server Function
- Server Stub
- Marshalling/unmarshalling
- Socket API
Assumptions (System Model)
- Processes fail only by crash-stopping
- Synchronous system: bounds on
  - Message delays
  - Max time for each process step
    - e.g., multiprocessor (common clock across processors)
- Asynchronous system: no such bounds
  - E.g., the Internet

Example: State Machine Replication
- Run multiple copies of a state machine
- For what?
  - Reliability
- All copies agree on the order of execution.
  - Many mission-critical systems operate like this.
    - Air traffic control systems, Warship control systems, etc.

First: Synchronous Systems
- Every process starts with an initial input value (0 or 1).
- Every process keeps the history of values received so far.
- The protocol proceeds in rounds.
- At each round, everyone multicasts the history of values.
- After all the rounds are done, pick the minimum.

Why Does It Work?
- Assume that two non-faulty processes differ in their final set of values → proof by contradiction
- Suppose \( p_i \) and \( p_j \) are these processes.
- Assume that \( p_j \) possesses a value \( v \) that \( p_i \) does not possess.
- Intuition: \( p_i \) must have consistently missed \( v \) in all rounds. Let’s backtrack this.
  - In the last round, some third process, \( p_k \), sent \( v \) to \( p_i \) and crashed before sending \( v \) to \( p_j \).
  - Any process sending \( v \) in the penultimate round must have crashed; otherwise, both \( p_i \) and \( p_j \) should have received \( v \).
  - Proceeding in this way, we infer at least one crash in each of the preceding rounds.
  - But we have assumed at most \( f \) crashes can occur and there are \( f+1 \) rounds → contradiction.

Second: Asynchronous Systems
- Messages have arbitrary delay, processes arbitrarily slow
- Impossible to achieve consensus
  - even a single failed is enough to avoid the system from reaching agreement
- A slow process indistinguishable from a crashed process
- Impossibility applies to any protocol that claims to solve consensus
- Proved in a now-famous result by Fischer, Lynch and Patterson, 1983 (FLP)
  - Stopped many distributed system designers dead in their tracks
  - A lot of claims of "reliability" vanished overnight
Are We Doomed?

- Asynchronous systems (i.e., systems with arbitrary delay) cannot guarantee that they will reach consensus even with one faulty process.
- Key word: “guarantee”
  - Does not mean that processes can never reach a consensus if one is faulty
  - Allows room for reaching agreement with some probability greater than zero
  - In practice many systems reach consensus.
- How to get around this?
  - Two key things in the result: one faulty process & arbitrary delay

Techniques to Overcome Impossibility

- Technique 1: masking faults (crash-stop)
  - For example, use persistent storage and keep local checkpoints
  - Then upon a failure, restart the process and recover from the last checkpoint.
  - This masks fault, but may introduce arbitrary delays.
- Technique 2: using failure detectors
  - For example, if a process is slow, mark it as a failed process.
  - Then actually kill it somehow, or discard all the messages from that point on (fail-silent)
  - This effectively turns an asynchronous system into a synchronous system
  - Failure detectors might not be 100% accurate and requires a long timeout value to be reasonably accurate.

CSE 486/586 Administrivia

- PA2 due in 1 week
- Midterm on Wednesday (3/12)

Recall

- Each process $p$ has a state
  - program counter, registers, stack, local variables
  - input register $xp$ : initially either 0 or 1
  - output register $yp$ : initially $b$ (undeclared)
- Consensus Problem: Design a protocol so that either
  - all non-faulty processes set their output variables to 0
  - Or non-faulty all processes set their output variables to 1
  - (No trivial solutions allowed)

Proof of Impossibility: Reminder

- State machine
  - Forget real time, everything is in steps & state transitions.
  - Equally applicable to a single process as well as distributed processes
- A state (S1) is reachable from another state (S0) if there is a sequence of events from S0 to S1.
- There an initial state with an initial set of input values.
**Different Definition of “State”**

- State of a process
- Configuration: = Global state. Collection of states, one per process; and state of the global buffer
- Each Event consists atomically of three sub-steps:
  - receipt of a message by a process (say p), and
  - processing of message, and
  - sending out of all necessary messages by p (into the global message buffer)
- Note: this event is different from the Lamport events
- Schedule: sequence of events

**Lemma 1**

Schedules are commutative

- Let config. $C$ have a set of decision values $V$ reachable from it
  - If $|V| = 2$, config. $C$ is bivalent
  - If $|V| = 1$, config. $C$ is said to be 0-valent or 1-valent, as is the case
- Bivalent means that the outcome is unpredictable (but still doesn’t mean that consensus is not guaranteed). Three possibilities:
  - Unanimous 0
  - Unanimous 1
  - 0’s and 1’s

**Guaranteeing Consensus**

- If we want to say that a protocol guarantees consensus (with one faulty process & arbitrary delays), we should be able to say the following:
  - Consider all possible input sets (i.e., all initial configurations).
  - For each input set (i.e., for each initial configuration), the protocol should produce either 0 or 1 even with one failure for all possible execution paths (runs).
    - i.e., no “0’s and 1’s”
  - The impossibility result: We can’t do that.
    - i.e., there is always a run that will produce “0’s and 1’s”.

**State Valencies**

- Let config. $C$ have a set of decision values $V$ reachable from it
  - If $|V| = 2$, config. $C$ is bivalent
  - If $|V| = 1$, config. $C$ is said to be 0-valent or 1-valent, as is the case
- Bivalent means that the outcome is unpredictable (but still doesn’t mean that consensus is not guaranteed). Three possibilities:
  - Unanimous 0
  - Unanimous 1
  - 0’s and 1’s

**The Theorem**

- Lemma 2: There exists an initial configuration that is bivalent
- Lemma 3: Starting from a bivalent config., there is always another bivalent config. that is reachable
- Insight: It is not possible to distinguish a faulty node from a slow node.
- Theorem (Impossibility of Consensus): There is always a run of events in an asynchronous distributed system (given any algorithm) such that the group of processes never reaches consensus (i.e., always stays bivalent)
Summary

- **Consensus**: reaching an agreement
- Possible in synchronous systems
- Asynchronous systems cannot guarantee.
  - Asynchronous systems cannot guarantee that they will reach consensus even with one faulty process.

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