Agreement Protocols

CS60002: Distributed Systems

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Classification of Faults

- **Based on components that failed**
  - Program / process
  - Processor / machine
  - Link
  - Storage
  - Clock

- **Based on behavior of faulty component**
  - Crash – just halts
  - Failstop – crash with additional conditions
  - Omission – fails to perform some steps
  - Byzantine – behaves arbitrarily
  - Timing – violates timing constraints

Classification of Tolerance

- Types of tolerance:
  - Masking – system always behaves as per specifications even in presence of faults
  - Non-masking – system may violate specifications in presence of faults. Should at least behave in a well-defined manner

- Fault tolerant system should specify:
  - Class of faults tolerated
  - What tolerance is given from each class

Core problems

- Agreement (multiple processes agree on some value)
- Clock synchronization
- Stable storage (data accessible after crash)
- Reliable communication (point-to-point, broadcast, multicast)
- Atomic actions

Overview of Consensus Results

- Let f be the maximum number of faulty processors.
- Tight bounds for message passing:

	Crash failures	Byzantine failures
Number of rounds	$f + 1$	$f + 1$
Total number of processors	$f + 1$	$3f + 1$
Message size	polynomial	polynomial

Overview of Consensus Results

- *Impossible* in asynchronous case.
  - Even if we only want to tolerate a single crash failure.
  - True both for message passing and shared read-write memory.

Consensus Algorithm for Crash Failures

Code for each processor:

v := my input

at each round 1 through *f+1:*

  if I have not yet sent *v* then send *v* to all

  wait to receive messages for this round

  v := minimum among all received values and current value of *v*

  if this is round *f+1* then decide on *v*

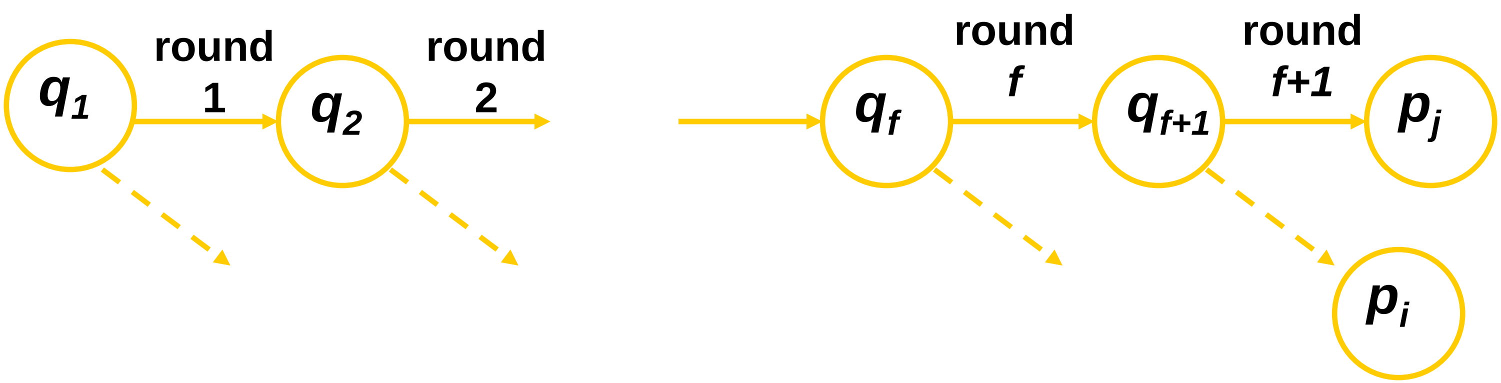
Correctness of Crash Consensus Algo

- **Termination:** By the code, finish in round $f + 1$.
- **Validity:** Holds since processors do not introduce spurious messages
  - if all inputs are the same, then that is the only value ever in circulation.

Correctness of Crash Consensus Algo

Agreement:

- Suppose in contradiction p_j decides on a smaller value, *x*, than does p_i.
- Then *x* was hidden from p_i by a chain of faulty processors:



- There are *f* + 1 faulty processors in this chain, a contradiction.

Performance of Crash Consensus Algo

- Number of processors $n > f$
- $f + 1$ rounds
- $n^2 \cdot |V|$ messages, each of size $\log|V|$ bits, where V is the input set.

Lower Bound on Rounds

Assumptions:

- $n > f + 1$
- every processor is supposed to send a message to every other processor in every round
- Input set is {0,1}

Byzantine Agreement Problems

Model :

- Total of *n* processes, at most *m* of which can be faulty
- Reliable communication medium
- Fully connected
- Receiver always knows the identity of the sender of a message
- Byzantine faults
- Synchronous system
  - In each round, a process receives messages, performs computation, and sends messages.

Byzantine Agreement

- Also known as Byzantine Generals problem
  - One process *x* broadcasts a value *v*
    - **Agreement Condition:** All non-faulty processes must agree on a common value.
    - **Validity Condition:** The agreed upon value must be *v* if *x* is non-faulty.

Variants

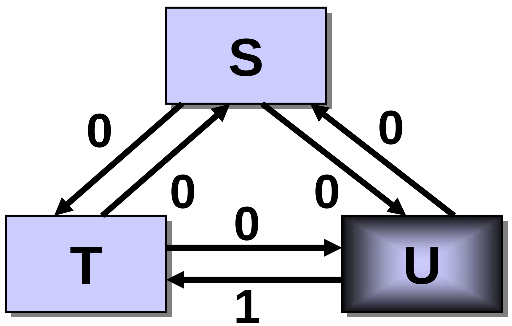
- **Consensus**
  - **Each process broadcasts its initial value**
    - **Satisfy agreement condition**
    - **If initial value of all non-faulty processes is *v*, then the agreed upon value must be *v***
- **Interactive Consistency**
  - **Each process *k* broadcasts its own value v_k**
    - **All non-faulty processes agree on a common vector ($v_1,v_2,\ldots,v_n$)**
    - **If the k^{th} process is non-faulty, then the k^{th} value in the vector agreed upon by non-faulty processes must be v_k**
- ***Solution to Byzantine agreement problem implies solution to other two***

Byzantine Agreement Problem

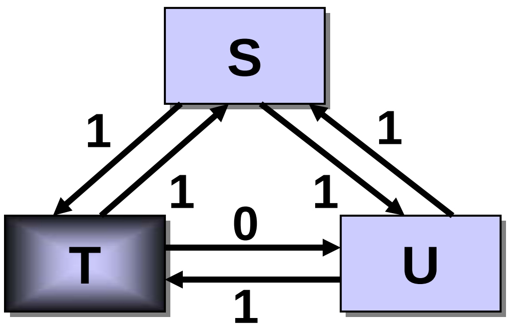
- **No solution possible if**:
  - asynchronous system, or
  - $n < (3m + 1)$
- **Lower Bound**:
  - Needs at least $(m+1)$ rounds of message exchanges
- "*Oral*" messages – messages can be forged / changed in any manner, but the receiver always knows the sender

Proof

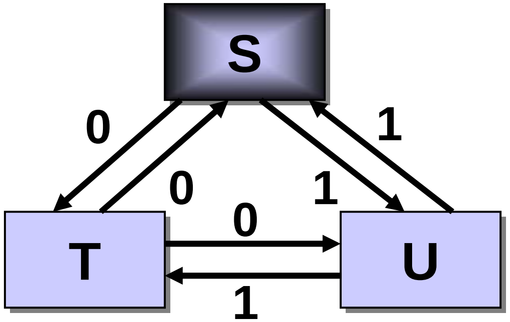
Theorem: ***There is no t-Byzantine-robust broadcast protocol for $t \geq N/3$***



Scenario-0: **T must decide 0**



Scenario-1: **U must decide 0**



Scenario-2:

- **-- similar to Scenario-0 for T**
- **-- similar to Scenario-1 for U**
- **-- T decides 0 and U decides 1**

Lamport-Shostak-Pease Algorithm

- Algorithm *Broadcast*(*N*, *t*) where *t* is the resilience

For t = 0, *Broadcast*(*N*, 0):

Pulse

1 The general sends ⟨value, x_g⟩ to all processes,
the lieutenants do not send.
Receive messages of pulse 1.
The general decides on x_g.
Lieutenants decide as follows:
if a message ⟨value, x⟩ was received from g in pulse-1
then decide on x
else decide on *udef*

Lamport-Shostak-Pease Algorithm contd..

For $t > 0$, *Broadcast*(N, t):

Pulse	
1	The general sends ⟨value, x_g⟩ to all processes, the lieutenants do not send. Receive messages of pulse 1. Lieutenant p acts as follows: if a message ⟨value, x⟩ was received from g in pulse-1 then $x_p = x$ else $x_p = udef$; Announce x_p to the other lieutenants by acting as a general in $Broadcast_p(N - 1, t - 1)$ in the next pulse

Pulse	
$t + 1$	Receive messages of pulse $t + 1$. The general decides on x_g. For lieutenant p: A decision occurs in $Broadcast_q(N - 1, t - 1)$ for each lieutenant q $W_p[q]$ = decision in $Broadcast_q(N - 1, t - 1)$ $y_p = max\,(W_p)$

Features

- **<u>Termination</u>: If *Broadcast*(*N, t*) is started in pulse 1, every process decides in pulse $t + 1$**
- **<u>Dependence</u>: If the general is correct, if there are *f* faulty processes, and if $N > 2f + t$, then all correct processes decide on the input of the general**
- **<u>Agreement</u>: All correct processes decide on the same value**

The Broadcast(N, t) protocol is a t-Byzantine-robust broadcast protocol for $t < N/3$

Time complexity: O($t + 1$)   Message complexity: O(N^t)