Agreement Protocols

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

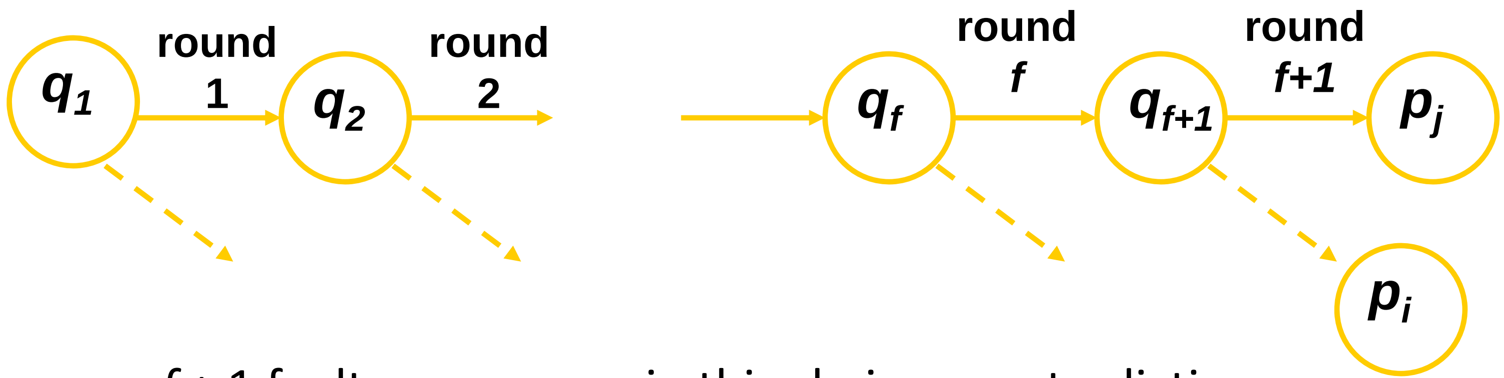
Correctness of Crash Consensus Algo

- 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

<u>Agreement</u>:

- 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
- $n^2 \bullet |V|$ 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*
    - <u>Agreement Condition:</u> All non-faulty processes must agree on a common value.
    - <u>Validity Condition:</u> 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

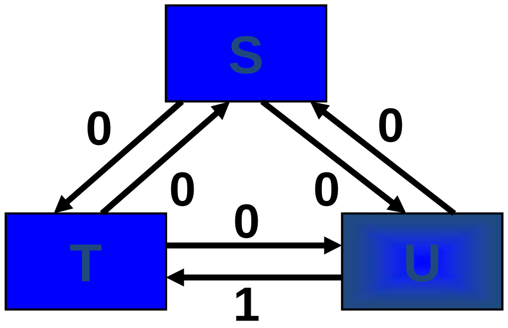
- No solution possible if:
  - asynchronous system, or
  - $n < (3m + 1)$

- Lower Bound:
  - Needs at least $(m+1)$ rounds of message exchanges

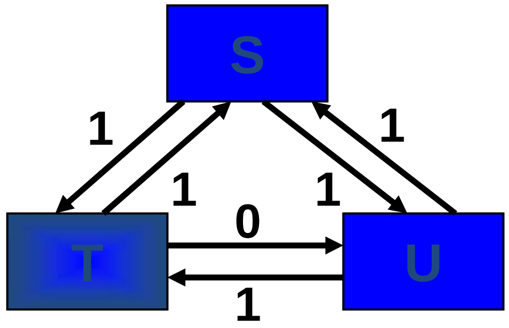
- "*Oral*" messages – messages can be forged / changed in any manner, but the receiver always knows the sender

Proof

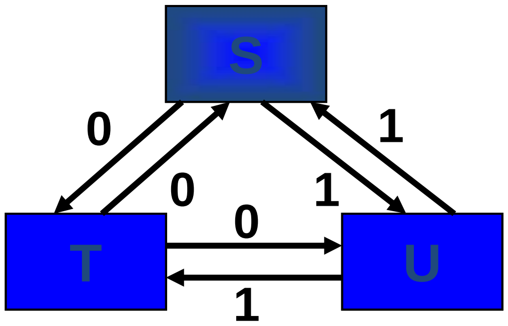
Theorem: ***There is no t-Byzantine-robust broadcast protocol for t ≥ N/3***



Scenario-0: T must decide 0



Scenario-1: U must decide 1



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 $\langle$value, $x_g\rangle$ 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 $\langle$value, $x\rangle$ 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 $\langle$value, $x_g\rangle$ to all processes, the lieutenants do not send.

Receive messages of pulse 1.

Lieutenant p acts as follows:

if a message $\langle$value, $x\rangle$ 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 $Broadcast_q(N - 1, t - 1)$

$y_p = major\ (W_p)$

Features

- Termination: If *Broadcast*(N, t) is started in pulse 1, every process decides in pulse $t + 1$
- Dependence: 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
- Agreement: 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)