Byzantine Fault Tolerance in a Distributed System

- **Byzantine Faults**
- **Byzantine General's Problem**

The object of Byzantine fault tolerance is to be able to defend against failures, in which components of a system fail in arbitrary ways, i.e., not just by stopping or crashing but by processing requests incorrectly, corrupting their local state, and/or producing incorrect or inconsistent outputs. The Byzantine failure models real-world environments in which computers and networks may behave in unexpected ways due to hardware failures, network congestion and disconnection, as well as malicious attacks. Byzantine failure-tolerant algorithms must cope with such failures and still satisfy the specifications of the problems they are designed to solve.

Byzantine General’s Problem

(Lamport had to pick a group that would not offend anybody today)

- A Byzantine Fault is an incorrect operation (algorithm) that occurs in a distributed system that can be classified as:

  Omission Failure – a failure of not being present such as failing to respond to a request or not receiving a request.

  Execution Failure or Lying – a failure due to sending incorrect or inconsistent data, corrupting the local state or responding to a request incorrectly.

  - Examples

    Round off errors passed from one function to another and then another, etc.

    Corrupted system databases where the error is not detected

    Compiler errors

    An undetected bit flip producing a bad message

- This is a worse case model since the Byzantine Fault can generate misleading information causing a maximum of confusion.

- The Byzantine General’s Problem is an illustrative example of Byzantine Faults

- A number of different armies want to besiege an enemy city. Success requires agreement on a common plan amongst the disbursed army; communication is only by messengers.

  Complication: There may be traitors who send out conflicting messages to sow confusion.

  Challenge: Find an algorithm that ensures the armies come to an agreement and attack at the same time.

- Real World Relationships

  Generals → processors

  Traitors → faulty processors or faulty system components (including software)

  Messengers → processor communications/system data bus

Byzantine General’s Problem Scenario

Several armies, each under the command of a general, are camped outside a city which they plan to attack.

One of the generals will issue the order *attack* or *retreat*.

One or several of the generals may be traitors. To win the battle all loyal generals must attack at the same time.

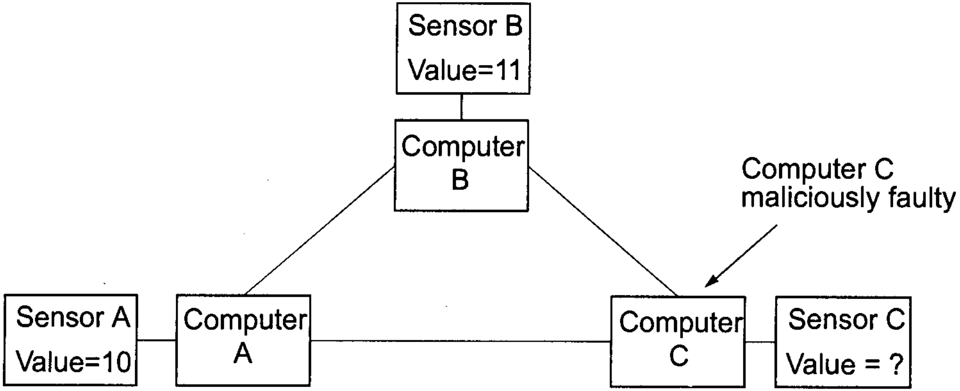
The traitors will attempt to fool the loyal generals so that not all of them attack at the same time.

To stop the traitor’s malicious plan, all generals exchange messages directly with each other.

- **Problem**

  How do replicated units reach agreement on a non-replicated value in the presence of malicious faults? Simple voting algorithms cannot handle the ‘malicious’ faults.

Impossibility to reach agreement on sensor values



Voting algorithm: Use median value.

Computer *C* sends value = 9 to Computer *A* and *value = 12* to Computer *B*

A uses *median*{9,10,11} = 10, *B* uses *median*{10, 11, 12} = 11

C's malicious behaviour causes A and B to work with inconsistent values.

Solution*

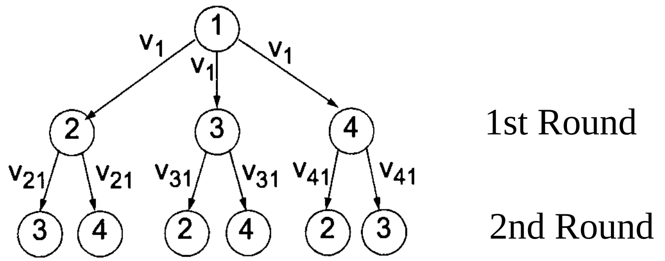
To reach agreement between the loyal generals in the presence of **m faults**

- There must be at least **3m + 1** processors to deal with m faults (traitors)
- Each processor must be connected to each other through at least **2m + 1** communication paths
- **m + 1** rounds of messages must be exchanged
- The processors must be synchronized within a known skew of each other

Such a system is called **Byzantine Resilient** which is a fully fault tolerant system.

* for Unprotected or Oral messages versus Signed messages

Tolerating One Byzantine Fault

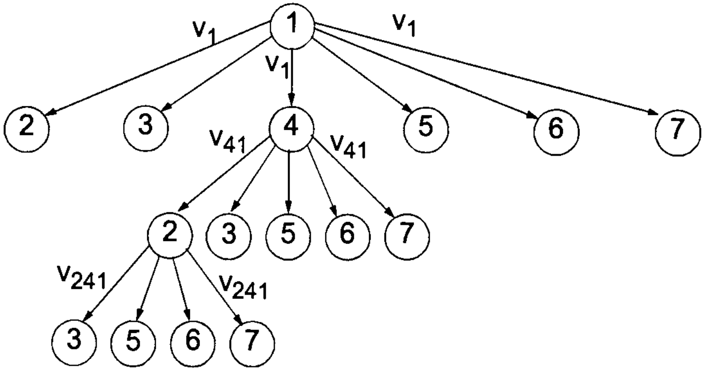


Unit 2 uses $v'_1 = \mathit{majority}\{v_1, v_{31}, v_{41}\}$

Number of messages for agreement on one value is: $3 + 2 \cdot 3 = 9$ messages

A majority decision involving 4 units (e.g. 4 sensor values) requires: $9 \cdot 4 = 36$ messages

Tolerating Two Byzantine Faults



Unit 2 uses $v'_1 = \textit{majority}\{v_1, v'_{31}, v'_{41}, v'_{51}, v'_{61}, v'_{71}\}$

$$v'_{41} = \textit{majority}\{v_{41}, v_{341}, v_{541}, v_{641}, v_{741}\}$$

Number of messages for agreement on one value is $6 + 6(5 + 5 \cdot 4) = 156$ messages