IN BYZANTIUM

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The Byzantine Generals Problem

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Outline

- Introduction
- Impossibility results
- Algorithm: oral messages
- Algorithm: signed messages
- Discussion

- Extensions

Introduction

INTRODUCTION

- Generals coordinate via messengers
- Problem: traitors
- Attack will only succeed with enough troops
- Coordinate in the presence of traitors
- Note on system model:
  - Don’t really need a commander
  - Distributed Consensus $\leftrightarrow$ Byzantine Agreement
  - Just simplifies presentation

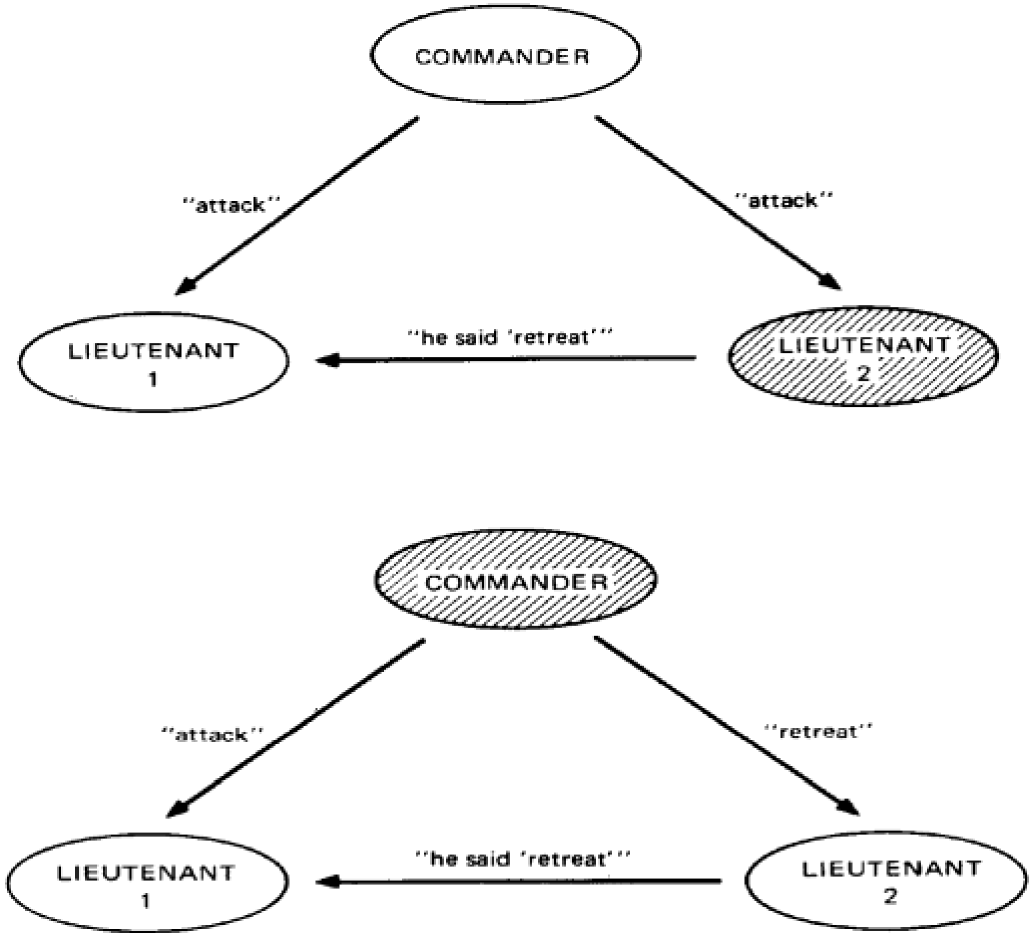
PROBLEM

- Commander, *N-1* lieutenants. *a* of the generals arbitrarily capricious
- Commander sends out Boolean order. Ensure:
  - All loyal lieutenants obey same order
  - If commander is loyal, his order must be the one obeyed
- Assumptions
  - Synchronous, reliable communication
  - Fully connected network
  - Sender identity cannot be forged

IMPOSSIBLITY RESULT

- Can’t be done with $N \le 3a$
- Specifically, for $N=3$, $a=1$:

IMPOSSIBLITY RESULT (N = 3, A = 1)



Does this construction generalize?

- Are the numbers $N=3$, $a=1$ special?
- No
- Suppose we have a solution for some (N, a), with $N \le 3a$
- Can simulate the three node case
  - Intuition: have each of the three nodes simulate roughly $N/3$
  - Warning: can be tricky to formalize

DOES THIS CONSTRUCTION GENERALIZE?

- Would using non-Boolean values help?
- No
- Suppose we had ints (e.g. timestamps), required only that the final values be within a certain range
- Reduction: can simulate Boolean case
  - E.g. final value bValue = (10 <= iValue <= 15)
- Note: reducibility isn't everything

ALGORITHM

- Suppose we have $N > 3a$. Can solve.
- Notation:
  - G = set of generals
  - N (= $|G|$) and a as earlier
  - BFT(G, a) – the problem we want to solve
  - Broadcast(G, a, t) – the algorithm
- Final result:
  - Broadcast(G, a, a) solves BFT(G, a)

ALGORITHM

Broadcast(G, a, 0):

T=now

Commander c sends value x_c to all lieutenants

Receive messages for T=now

x_p = (message received) ? x_c : default

Every lieutenant p agrees on $y_p = x_p$

ALGORITHM

Broadcast(G, a, t):

T=now

Commander c sends x_c to all lieutenants

Receive messages for T = now

Each lieutenant p does

x_p = (message received) ? x_c : default

Act as general in Broadcast(G\{p}, a-1, t-1)

T=now + t

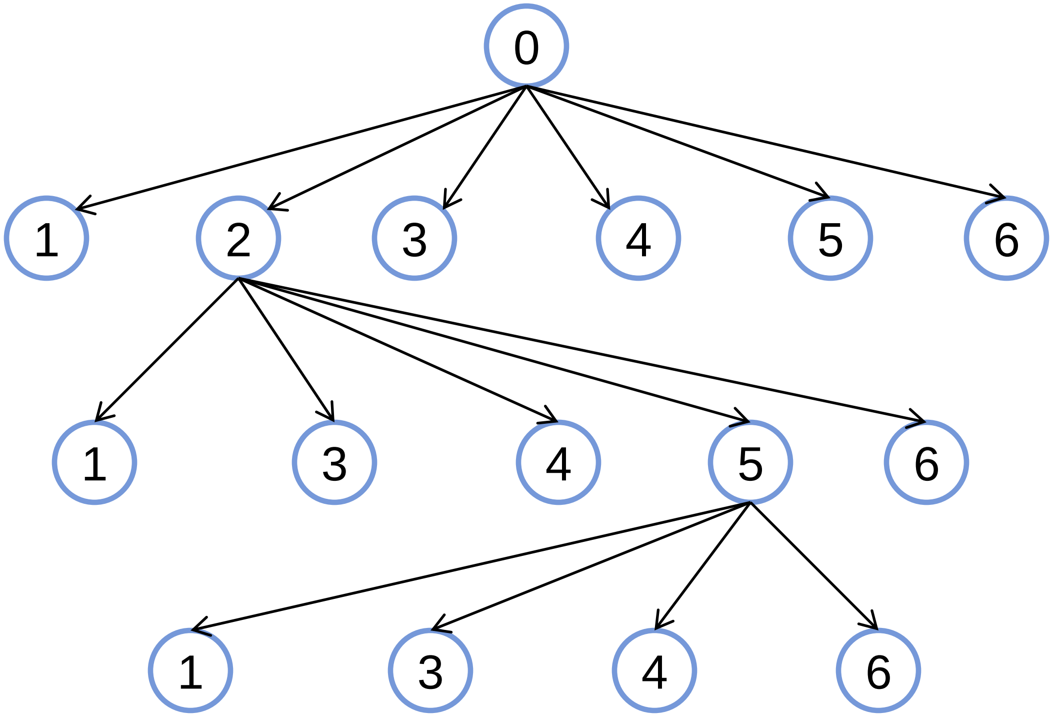
Receive messages for T = now + t

c decides on x_c

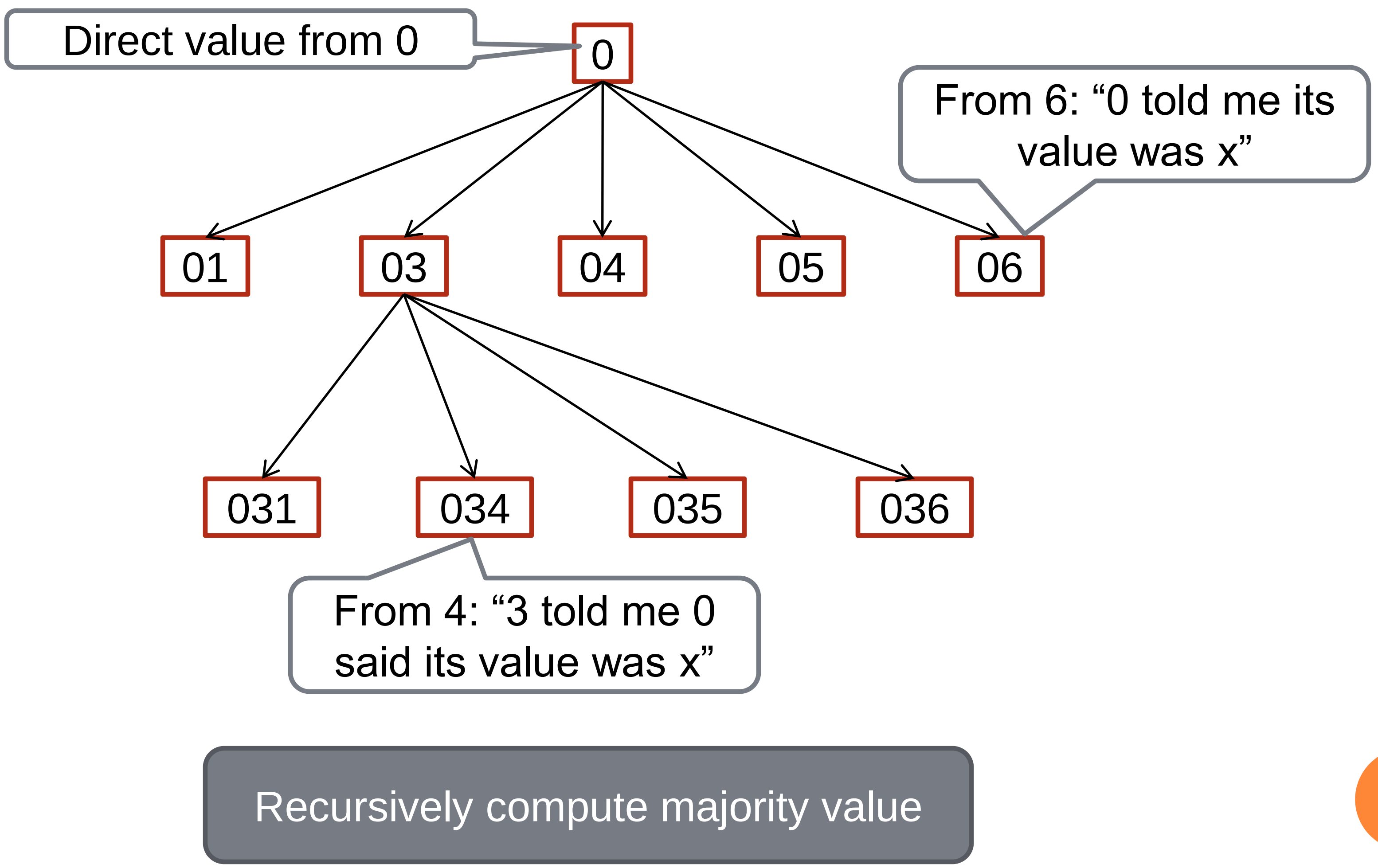
p decided on a value for each p' in G\{p}

y_p = majority(value_set)

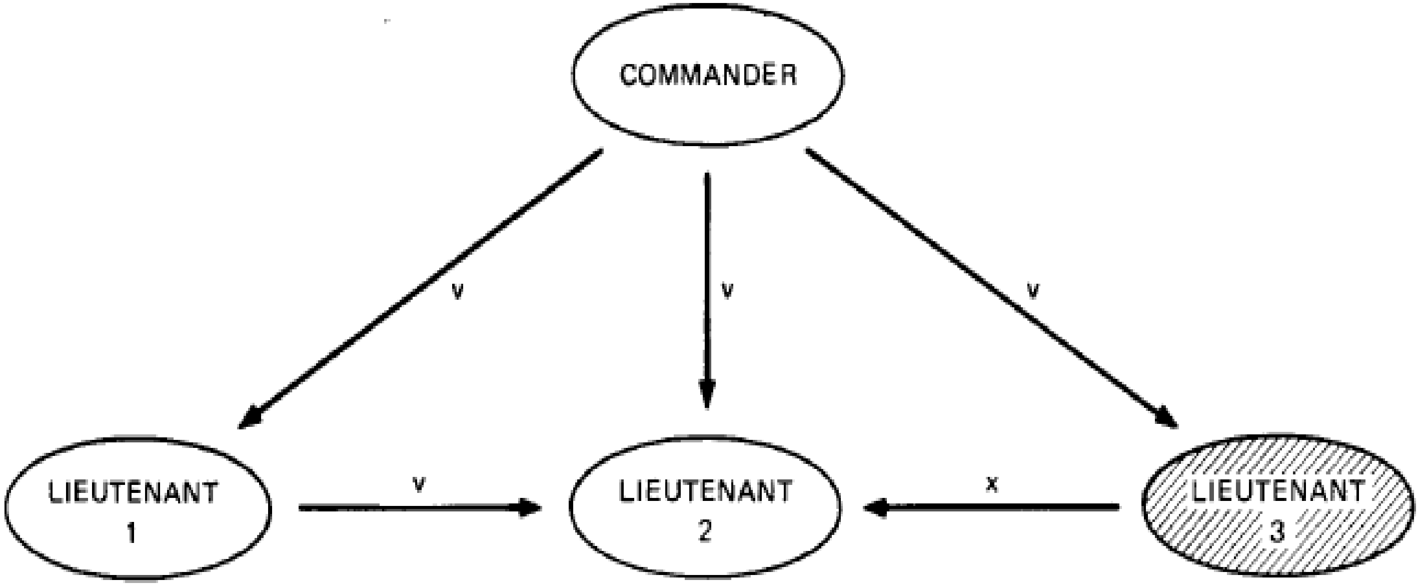
PHASE I: MESSAGE TREE (N=7, A=2)



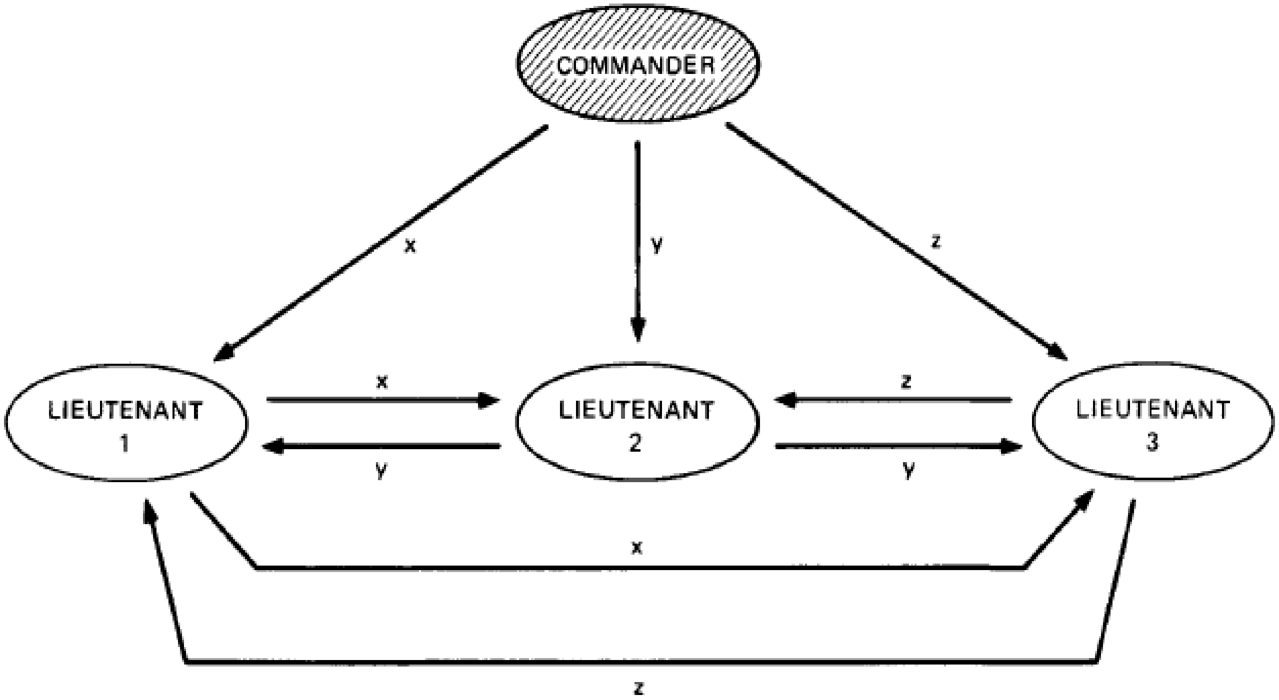
PHASE II: DECISION TREE (AT NODE 2)



EXAMPLE (N = 4, A = 1): I



EXAMPLE (N = 4, A = 1): II



WHY DOES THIS WORK?

- Primary result:
  - If $N > 2a + t$, Broadcast(G, a, t) solves BFT(G, a) if commander is loyal
- That is: enough to ensure *some* node in every path is loyal
- This is why we executed for *a+1* rounds
- See paper for details

Signed Messages

- What if we had signed messages?
- Remember: we needed multiple rounds to exchange messages like “A told me B told him C said his value was D”
- We only had one-hop unforgeability guarantees
- If we had end-to-end signatures: could solve for any *N*, any *a*
- Algorithm in paper is reactive (asynchronous)
- Details omitted: see paper

Discussion

- Time complexity O(a)
- But message complexity $O(N^a)$
- Better algorithms exist (see any distsys text)

- Can only overcome faults – cannot identify source

Extension: Other Topologies

- Lamport et al. show that same algo works for 3-regular graphs
- Other special cases:
  - Rings
  - Random graphs
  - Hierarchical clusters
- General topology?

Extension: No Synchrony

- BFT impossible in asynchronous networks (Fischer et al, 1985)
- However, good approximation algorithms exist
- Dolev et al's MSR – in each round, do:
  - Label value with round number. Broadcast to everyone else
  - Receive at least *N-a* values, collect into multiset
  - Drop largest and smallest a values
  - Replace own value with mean
- Problem: *what* do you converge to?

Extension: Better Fault Models

- E.g. work by Azadmanesh, Kieckhafer
- a = arbitrarily capricious faults
- s = symmetric faults
- b = benign/detectable faults (e.g. crashes)
- Requirement is $N > 3a + 2s + b + 1$
- They also have a five-mode model
  - Incorporates two modes of network failure