Byzantine General Problems

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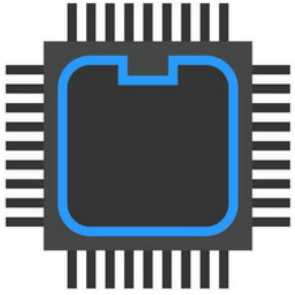
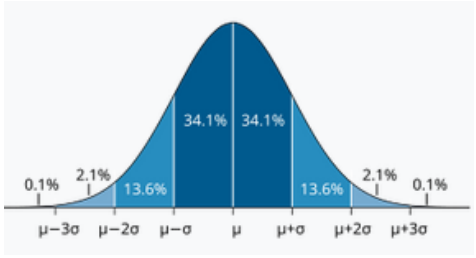
Introduction





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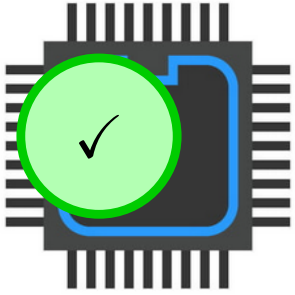

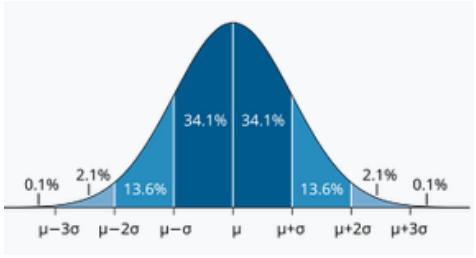

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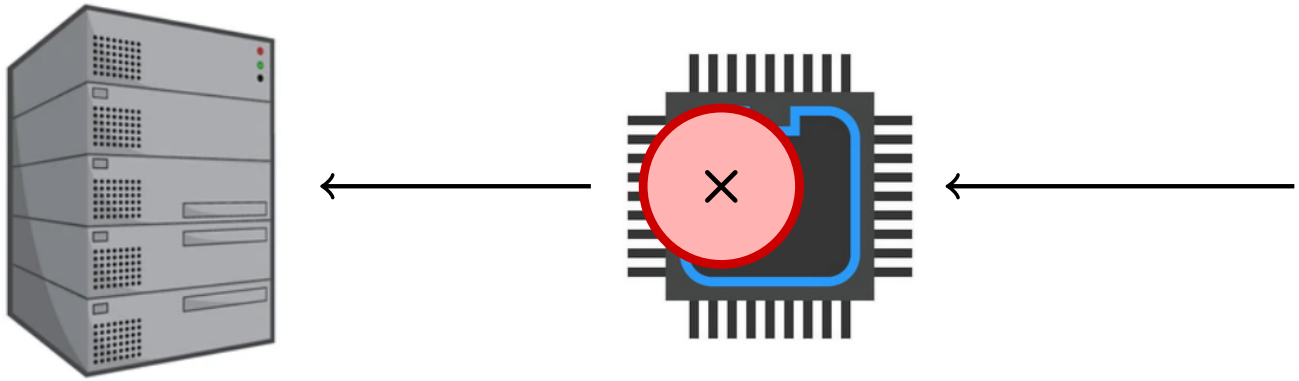


```
} catch (error) {
    console.error("কাজ হচ্ছে না ভাইয়া");
    res.status(500).send('Something went wrong on the server');
}
```

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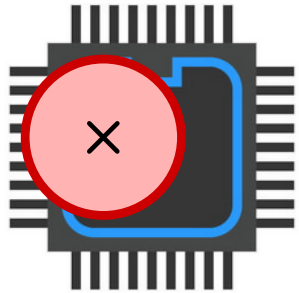

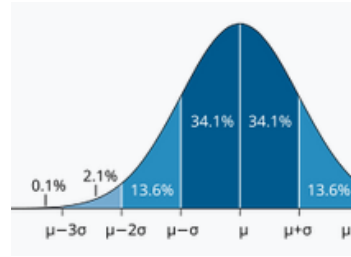

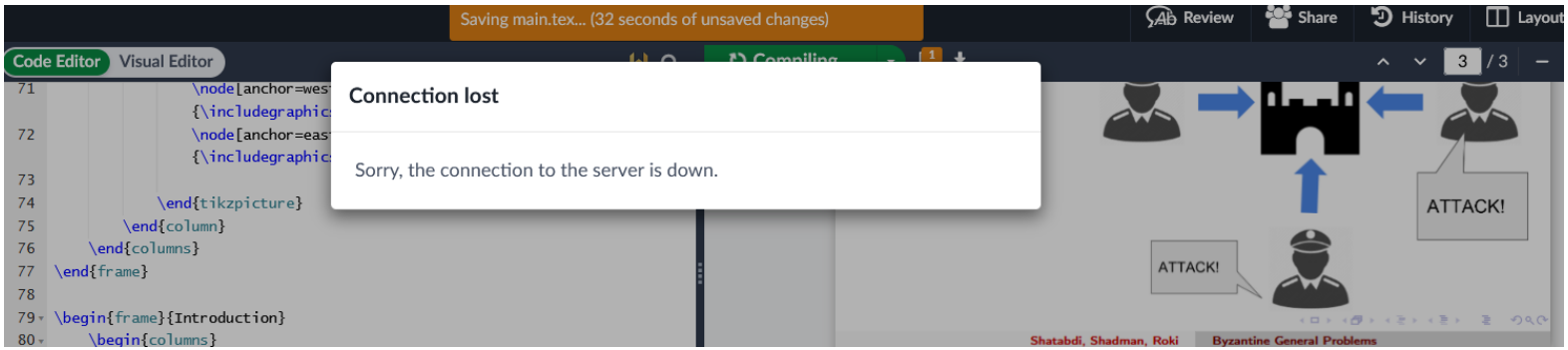

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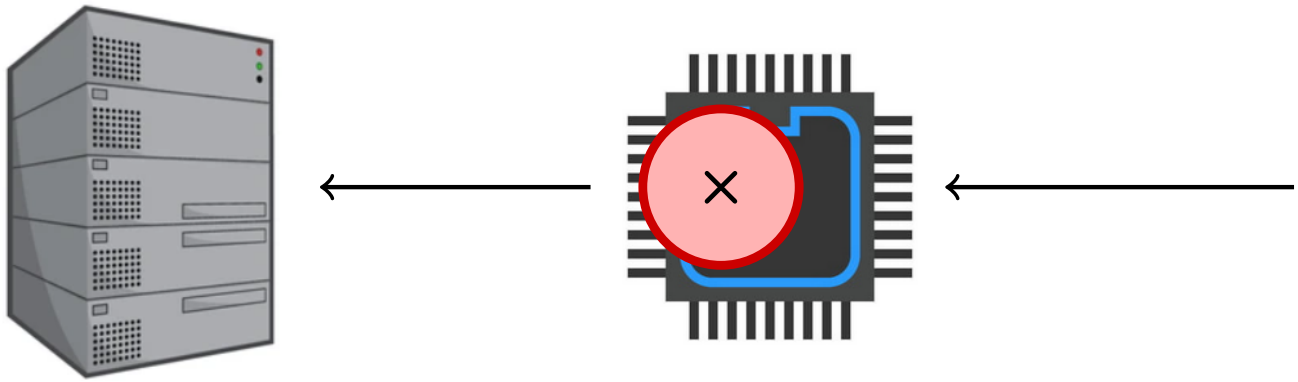

- The value of Facebook's share dropped by 5. 5% costing around 7 billion dollars.

"Wait a second, that's a lot of money, sloth!!!"

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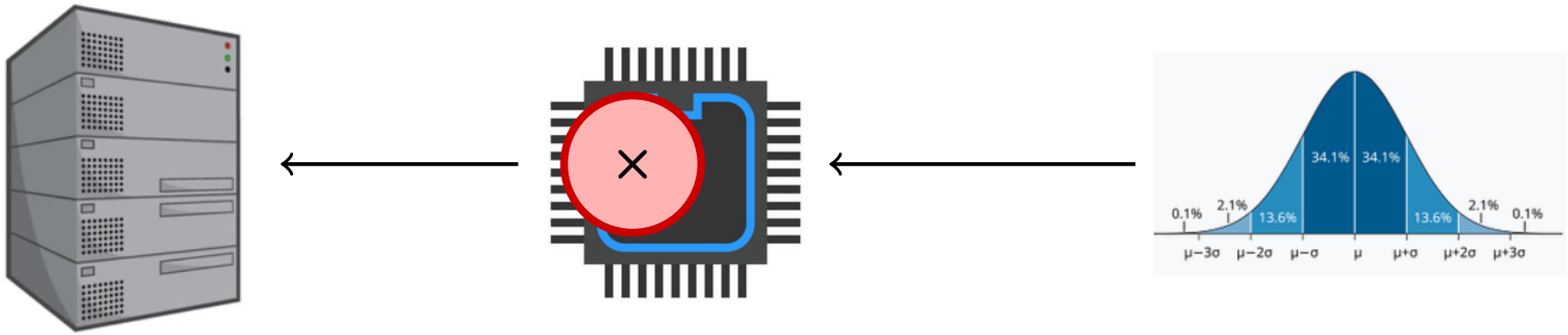
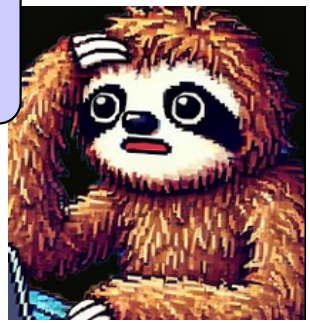
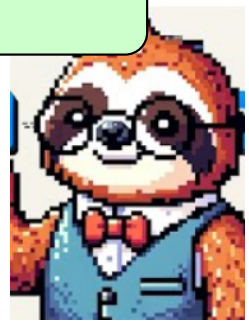


- The value of Facebook's share dropped by 5. 5% costing around 7 billion dollars.
- And also Amazon lost 528 million dollars

"Wait a second, that's a lot of money, sloth!!!"



"Yep, it is"



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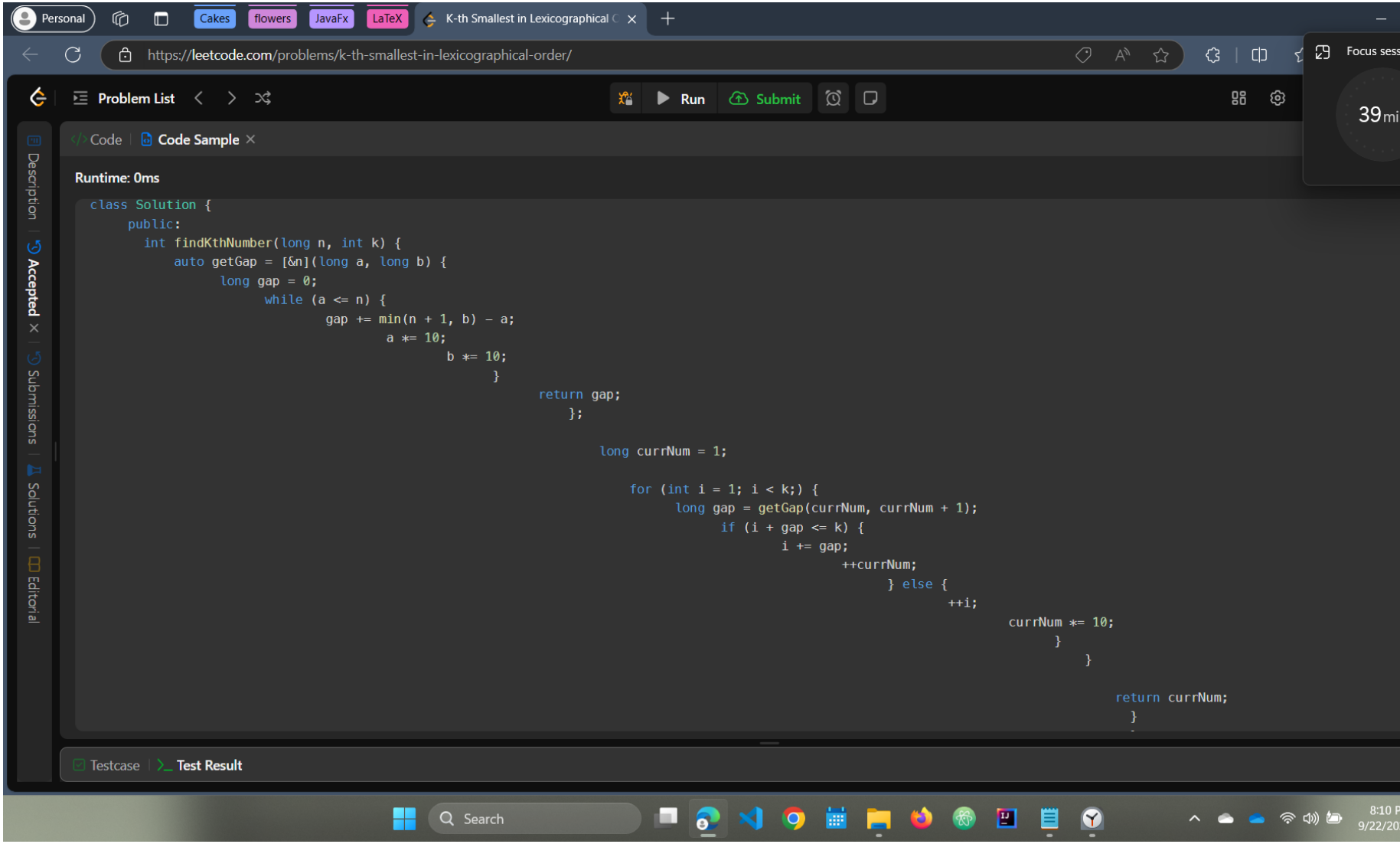


The Story Behind...

Hmmm , a white plane with lots of passengers , Seems suspicious!!

The Story Behind...

And ooh look the radar also says so

Hmmm , a white plane with lots of passengers , Seems suspicious!!

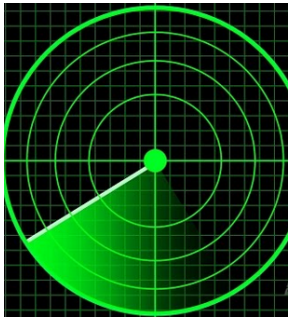
The Story Behind...

Okay boys , Let's nuke that plane , haha

Hmmm , a white plane with lots of passengers , Seems suspicious!!

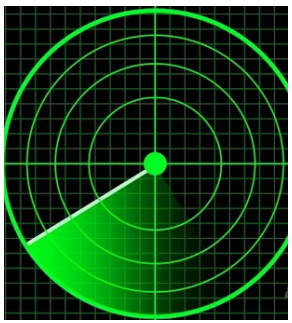
The Story Behind...

Hmm , an F-35 raptor ?
Looks good to me !!



The Story Behind...

And Look there's nothing on the radar



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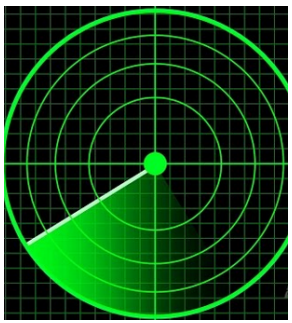

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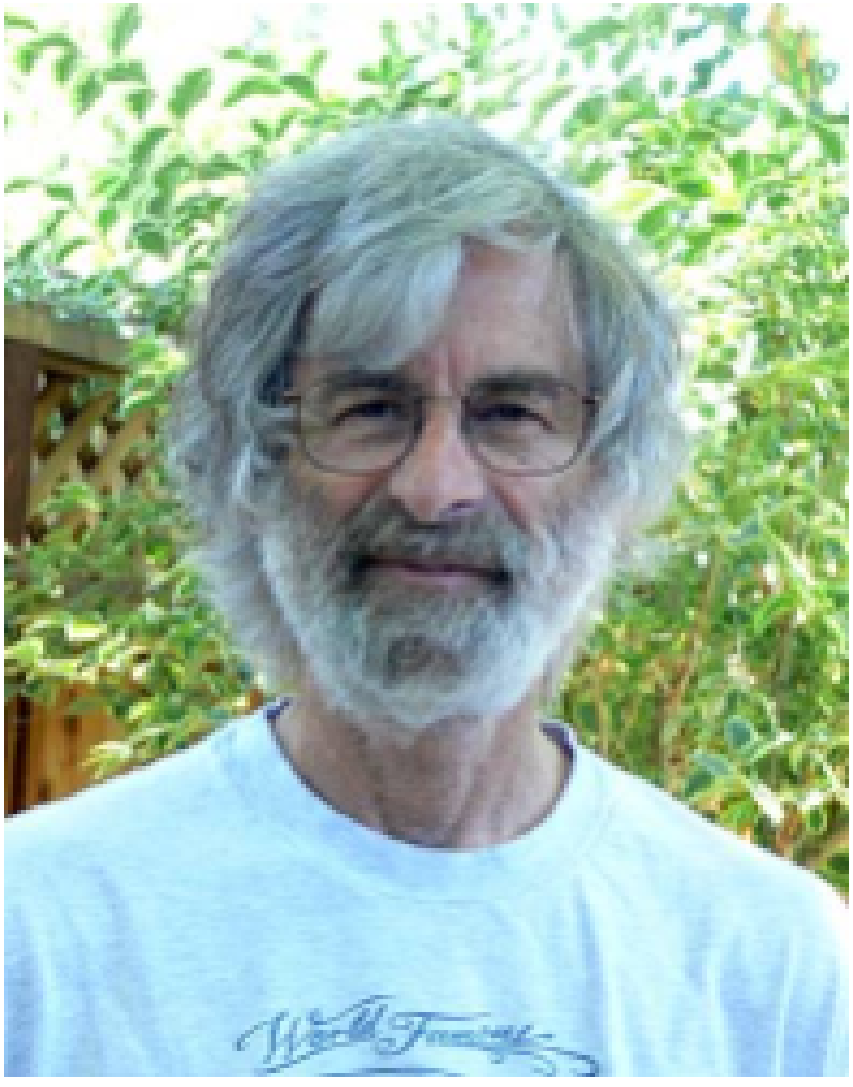
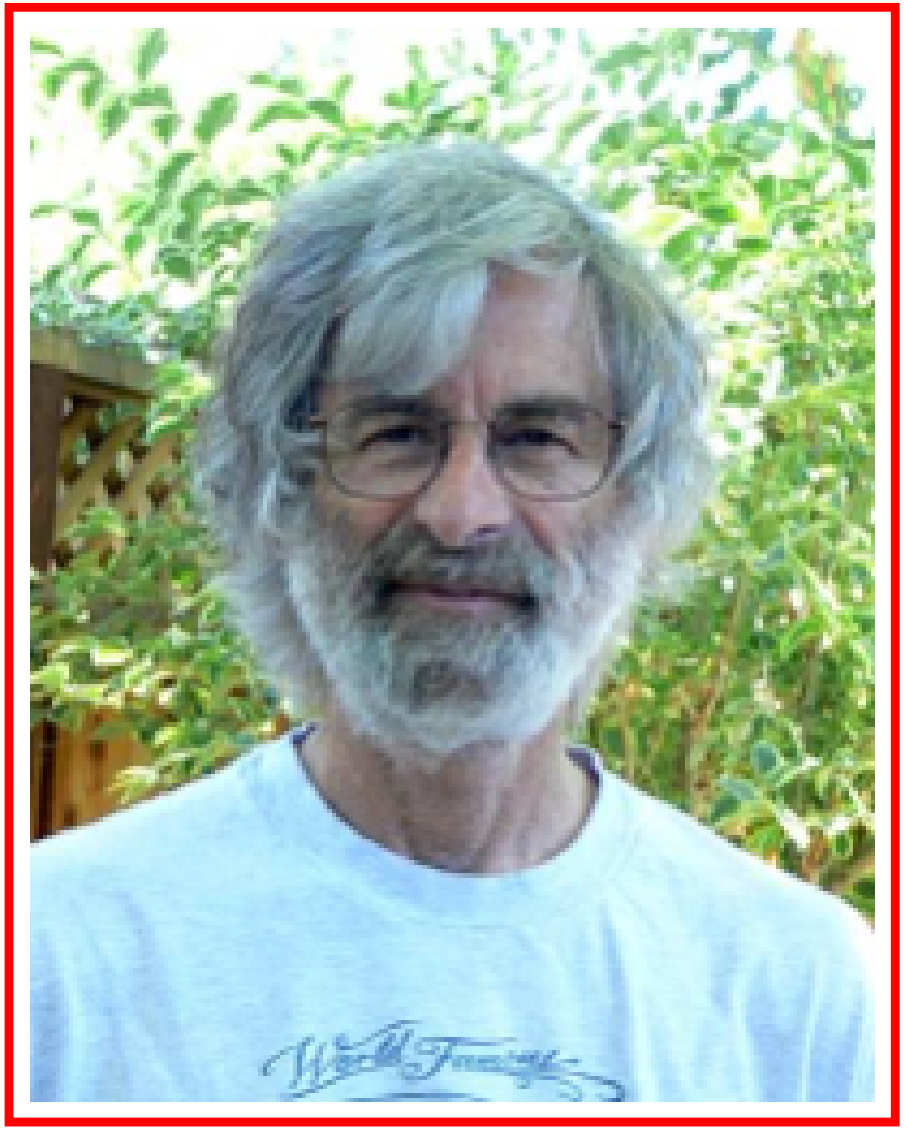
The Story Behind...

Figure: Robert Shoshtack



The Story Behind...

Figure: Robert Shoshtack



Byzantine Generals Problem

Problem Formulation

- Communication through messages.
- Generals must decide upon a plan
- Concensus

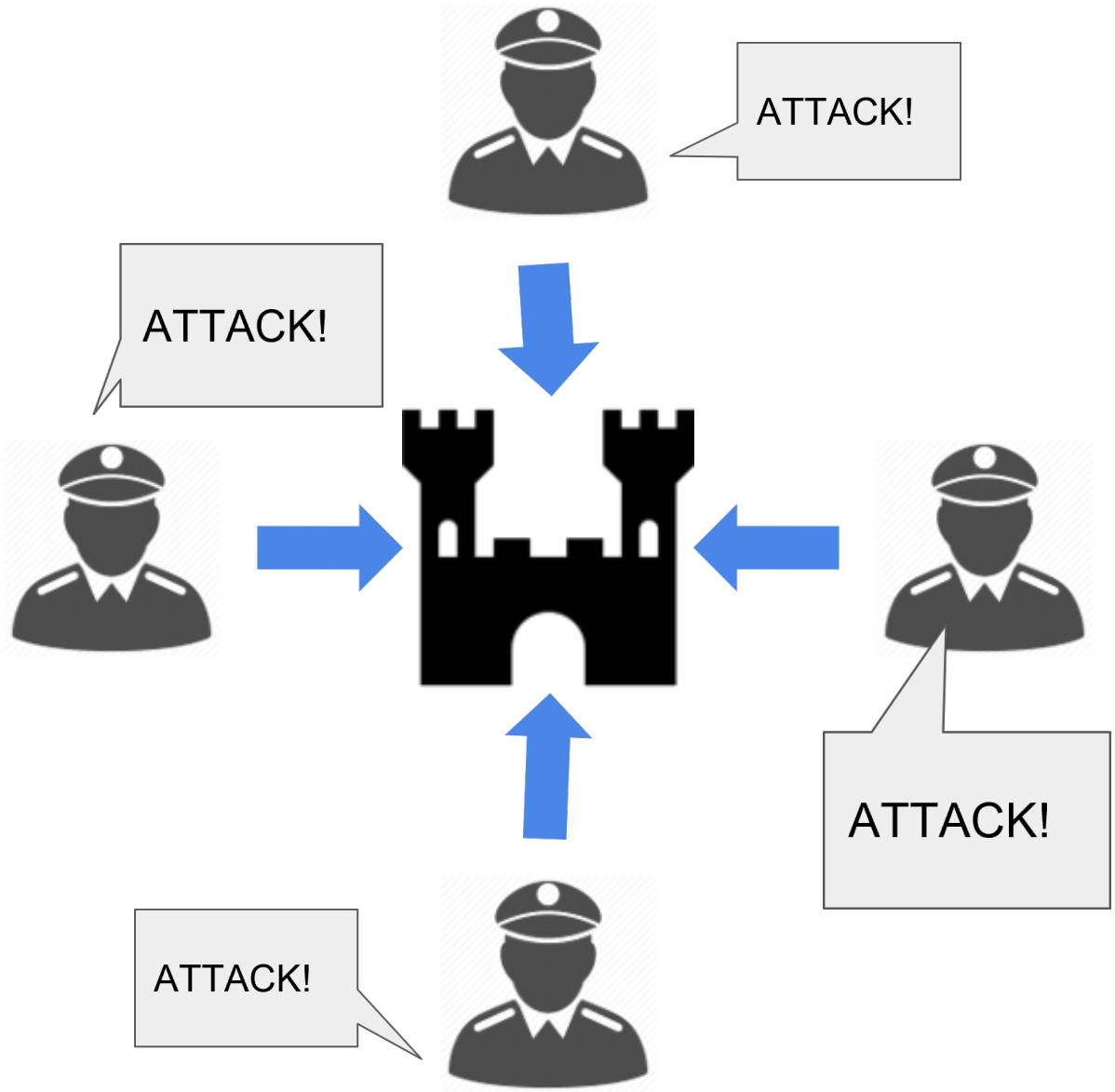




Byzantine Generals Problem

Consensus to Attack

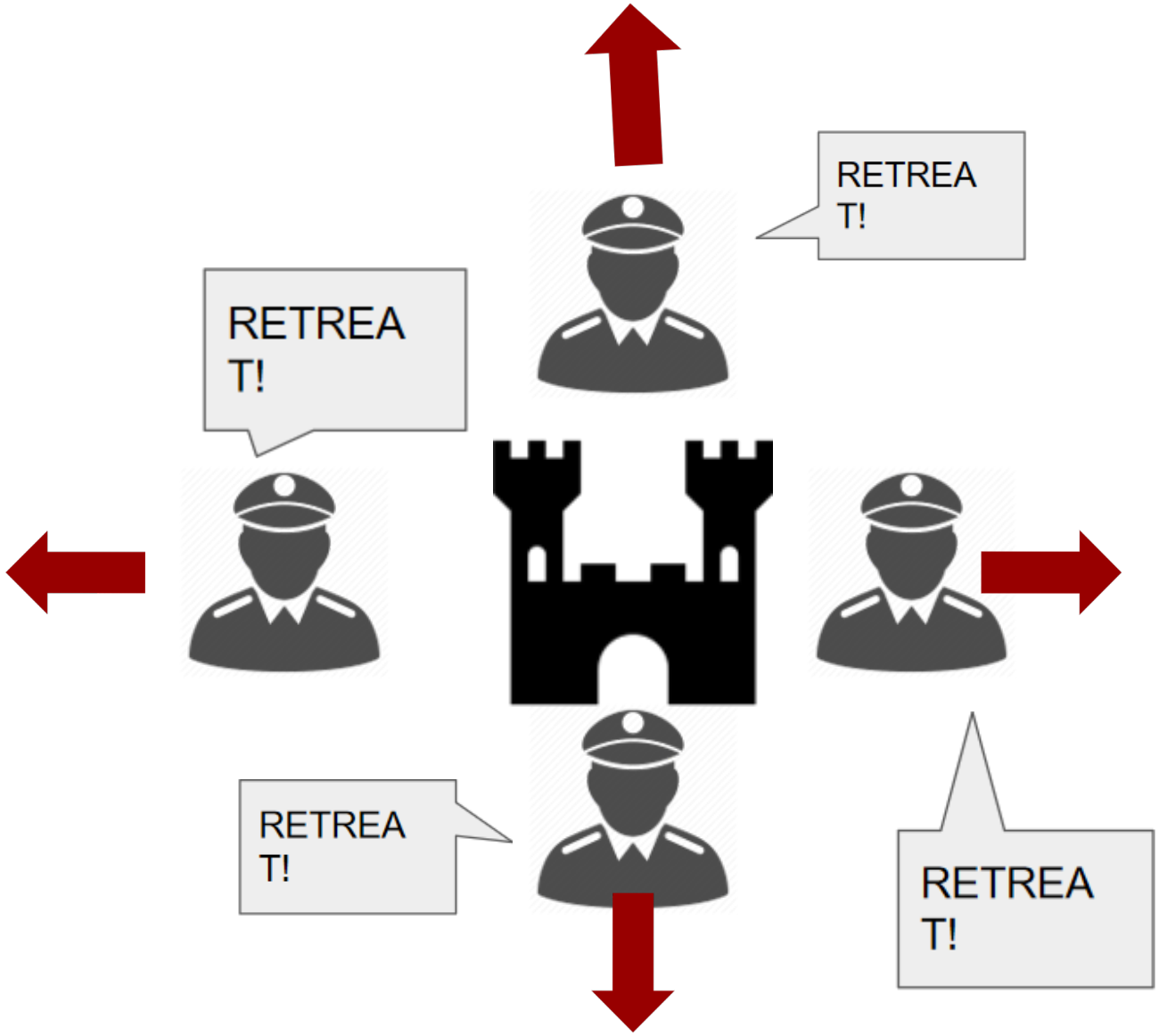
- ***Attack***



Byzantine Generals Problem

Consensus to Retreat

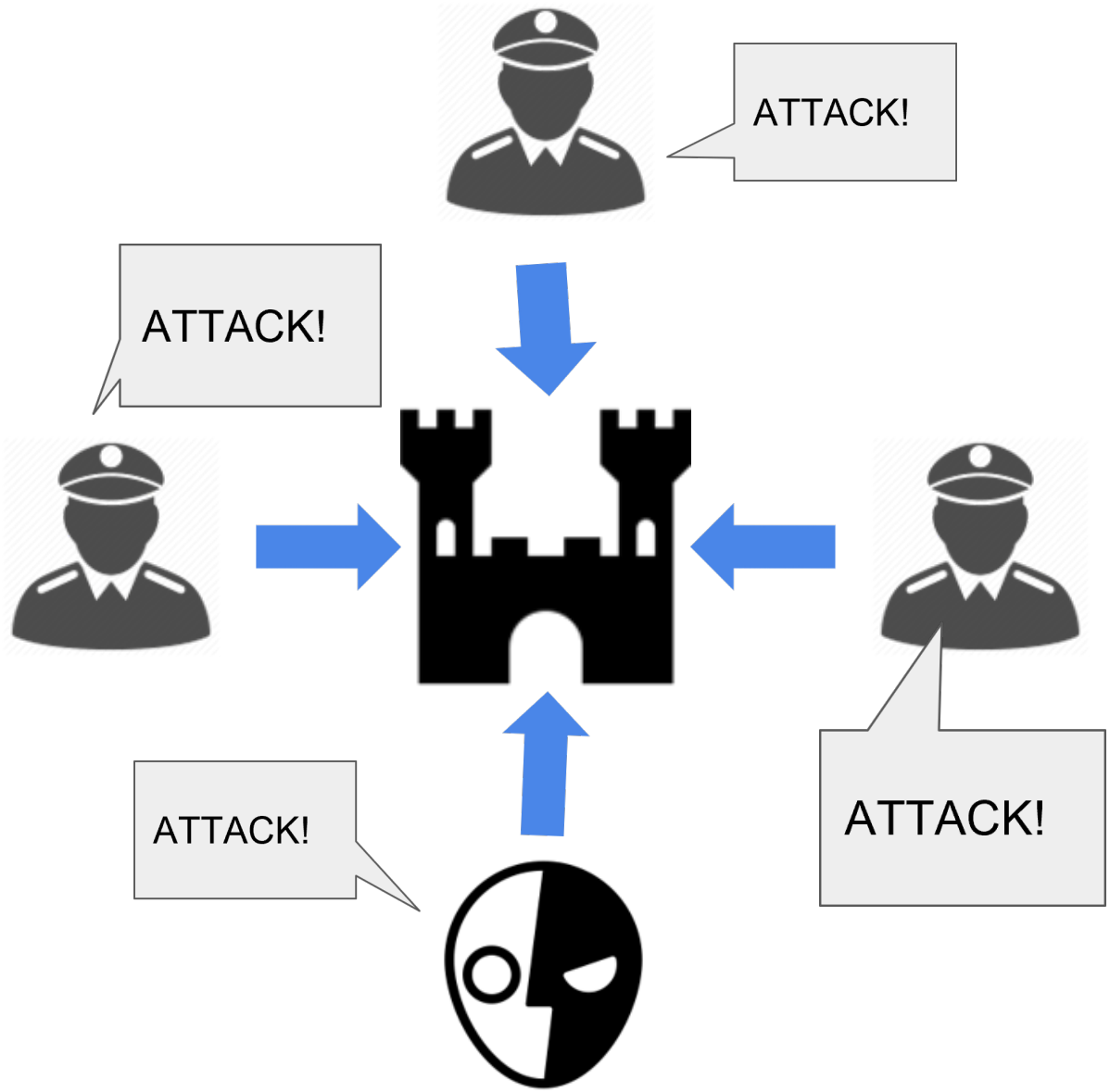
- *Retreat*



Byzantine Generals Problem

Consensus to Attack with Traitor Included

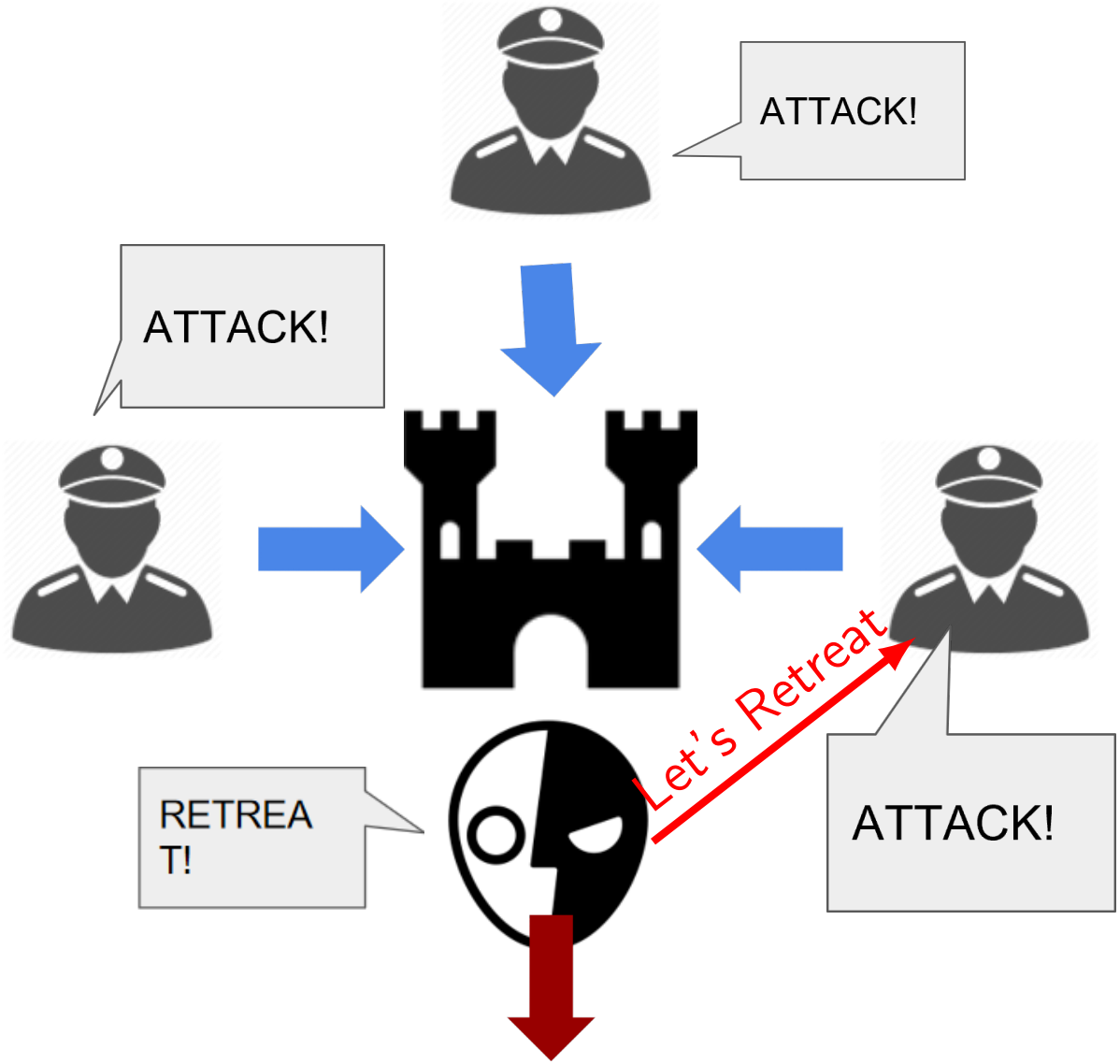
- Traitors
- The *loyal Generals* must reach a *consensus* .



Byzantine Generals Problem

Traitor Interfering

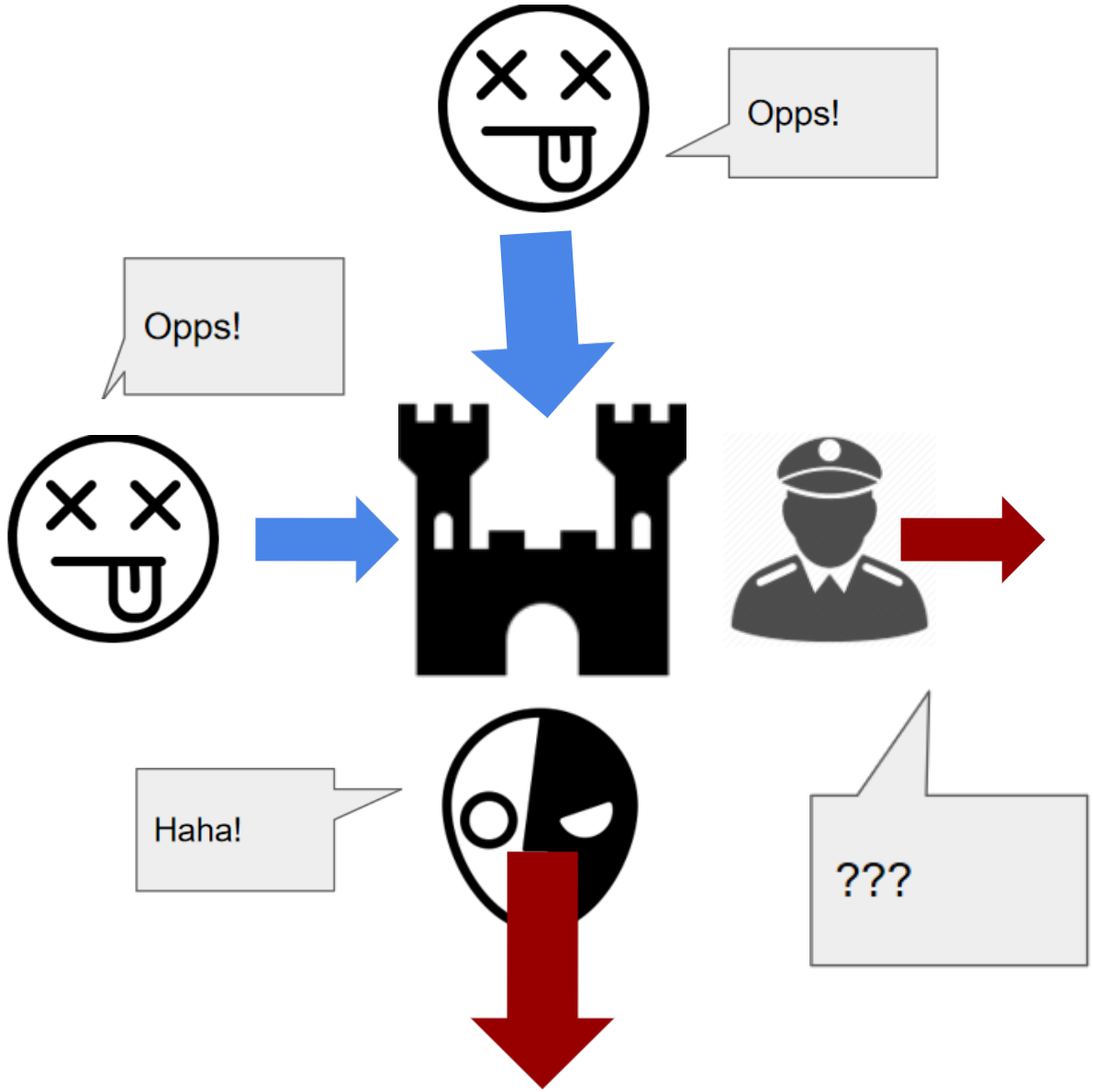
- Traitors can act arbitrarily .



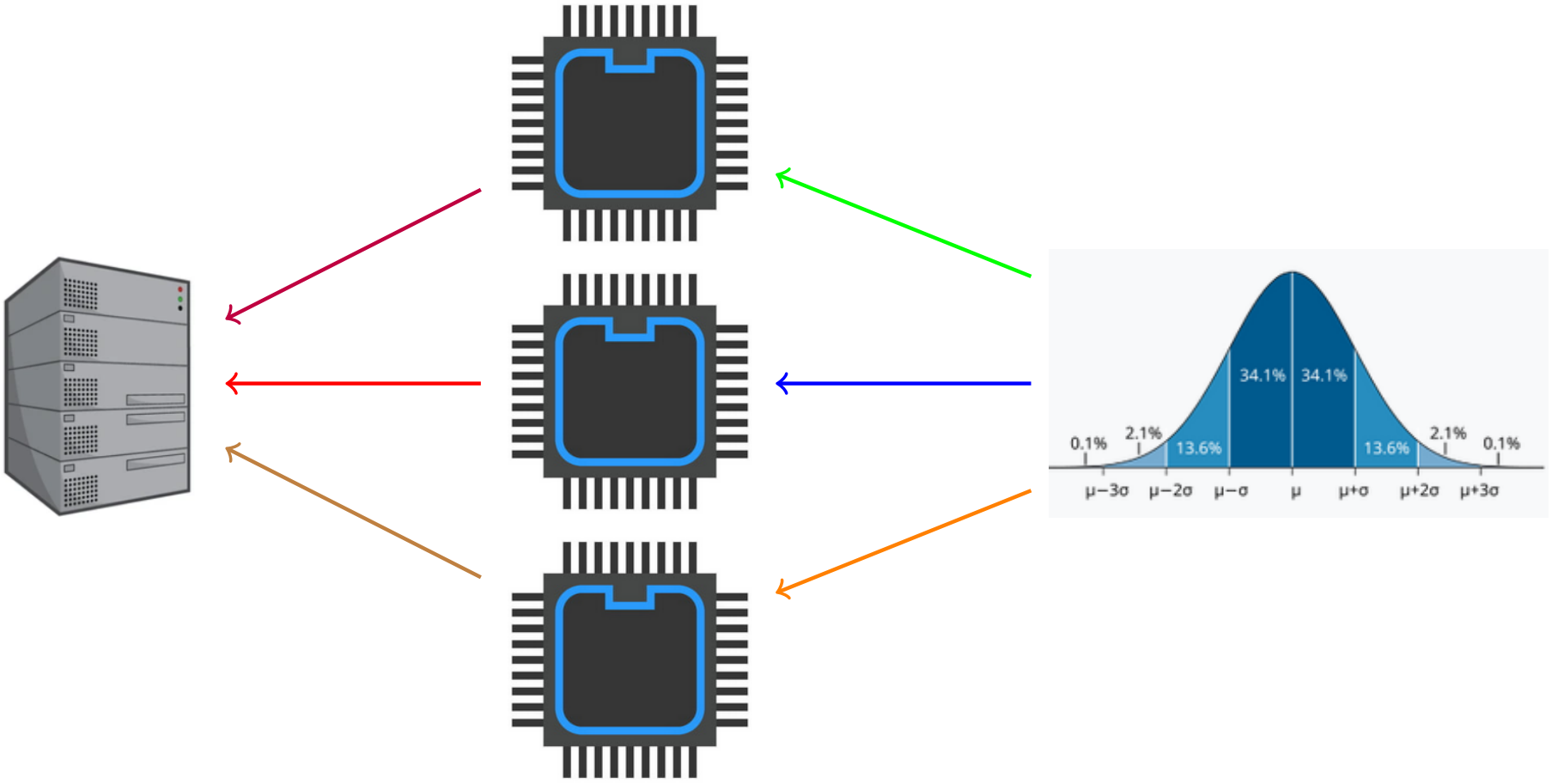
Byzantine Generals Problem

Traitor is Successful

- A traitor can easily foil any effective strategy if he is not dealt with.



Relevance of Byzantine Generals Problem to Computer Science..



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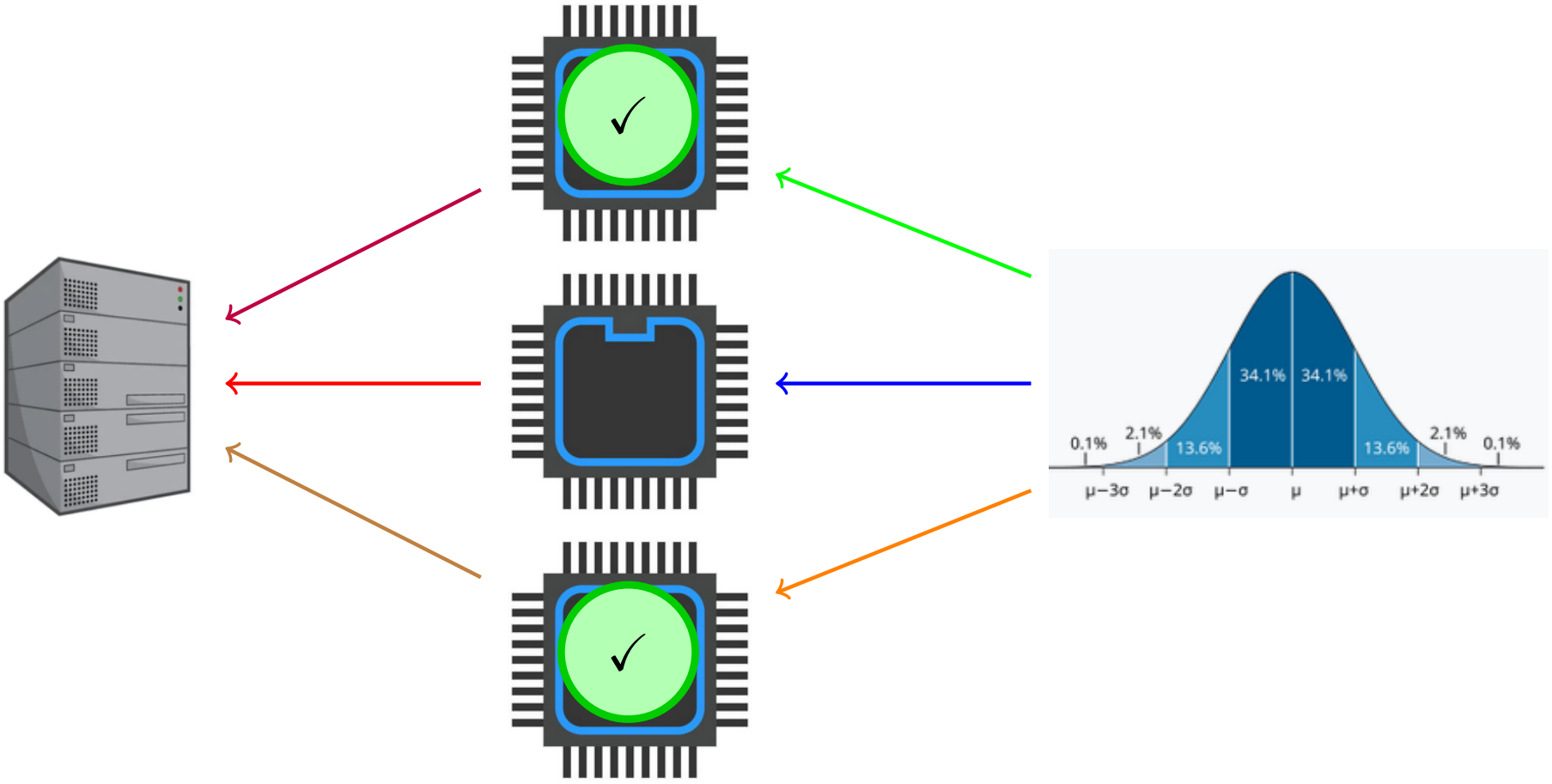

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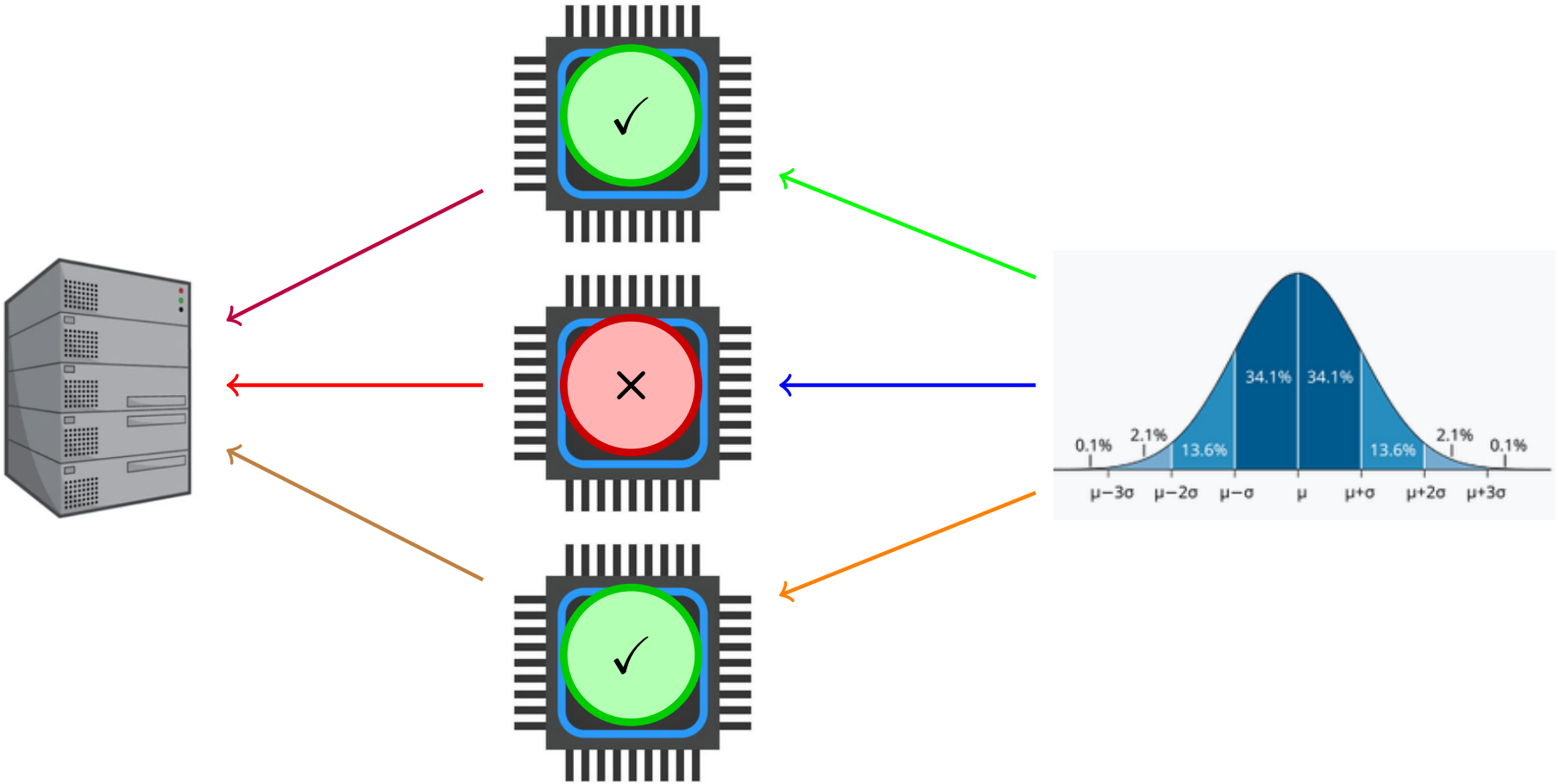
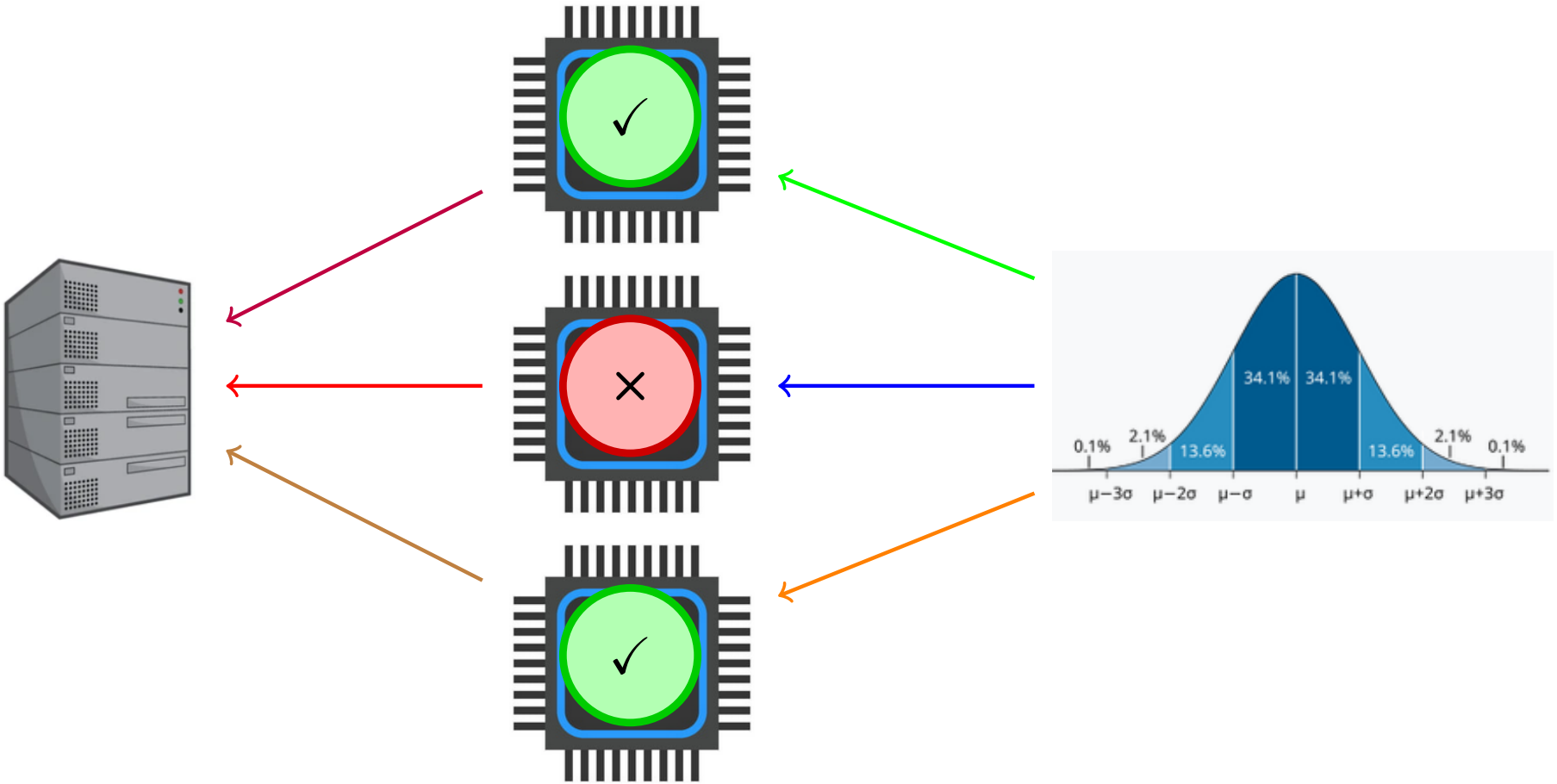


Relevance of Byzantine Generals Problem to Computer Science..



Same goes for radars and sensitive identification technology.

The Problem Revisited...

The Byzantine Generals Problem

The **Byzantine Generals Problem** is a way to understand how computer systems can agree on a decision, even when some parts might not work correctly or try to deceive others.

- We can relate it with the situation where how a group of generals, represented as computer nodes or processes, must agree on a decision (e.g., whether to attack or retreat), despite the presence of traitors among them.

A Simplified Version

There are a total of n officers on the battlefield.

Figure: Battlefield Scenario with Generals

A Simplified Version...

There are a total of n officers on the battlefield.

- One officer is the **commanding general**, who will send order to the remaining n-1 are **lieutenant generals** such that
  - **Condition 1:** All loyal lieutenants must obey the same order.
  - **Condition 2:** If the commanding general is loyal, all loyal lieutenants must follow the order he sends.

Figure: Battlefield Scenario with Generals

On the way of solution...

What is Byzantine generals problem

- All loyal lieutenants obey the same order.
- If the commanding general is loyal, then every loyal lieutenant obeys the order he sends.

On the way of solution...

What is Byzantine generals problem

- Consistency/Agreement
- If the commanding general is loyal, then every loyal lieutenant obeys the order he sends.

On the way of solution...

What is Byzantine generals problem

- Consistency/Agreement
- **If the commanding general is loyal**, then every loyal lieutenant obeys the order he sends.

On the way of solution...

What is Byzantine generals problem

- Consistency/Agreement
- Validity

On the way of solution...

What is Byzantine generals problem

- Consistency/Agreement
- Validity
- Termination

Impossibility Result

Impossibility Result

Now we will go through two main strategies.

- Oral messages
- Signed messages

Impossibility Result: Oral Messages

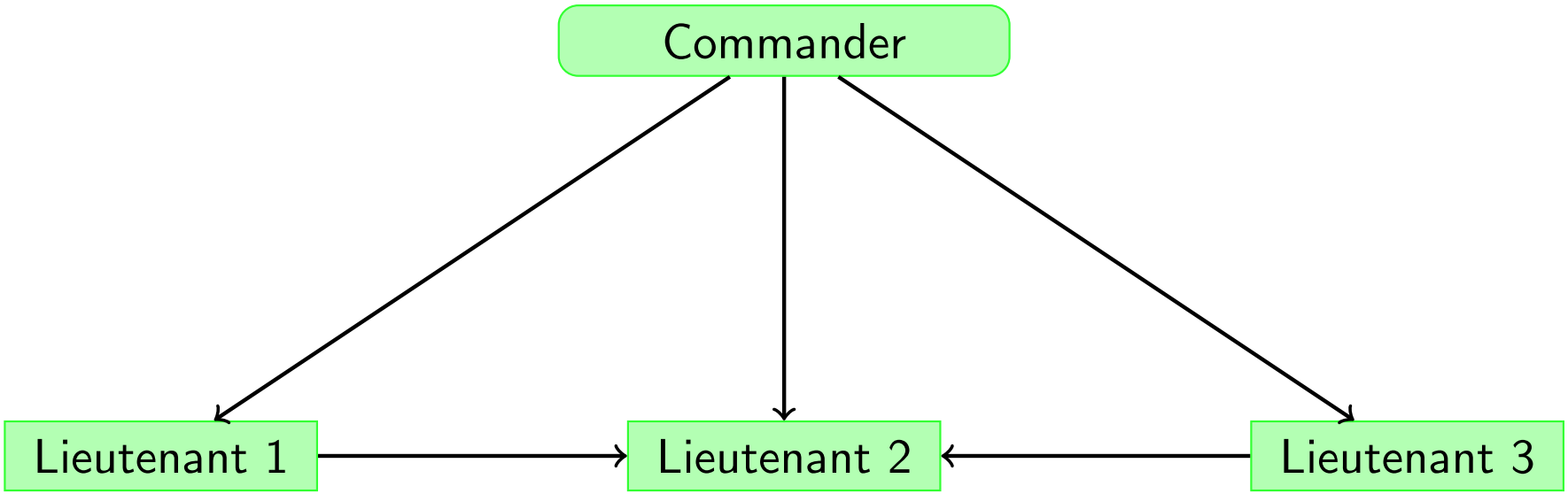
"if the generals can send only oral messages, then no solution will work unless more than $\frac{2}{3}$ of the generals are loyal."

Oral Messages

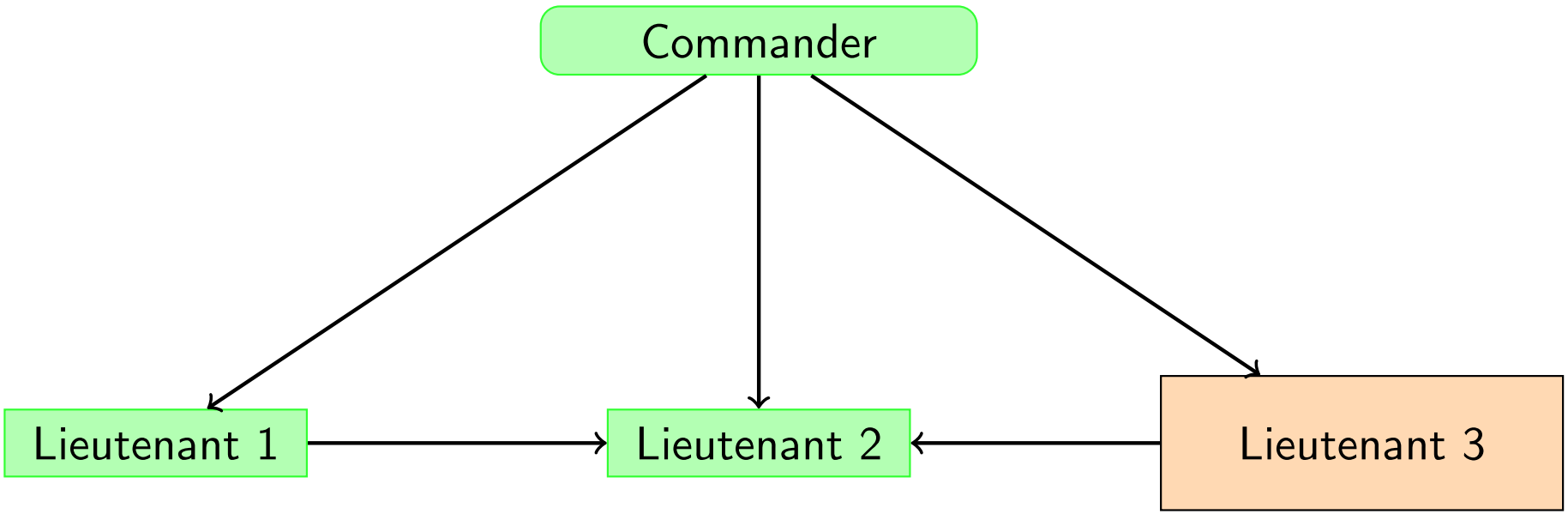
What are ORAL MESSAGES ???

A Possible Scenerio

Flowchart possibility Result



Flowchart Possibility Result



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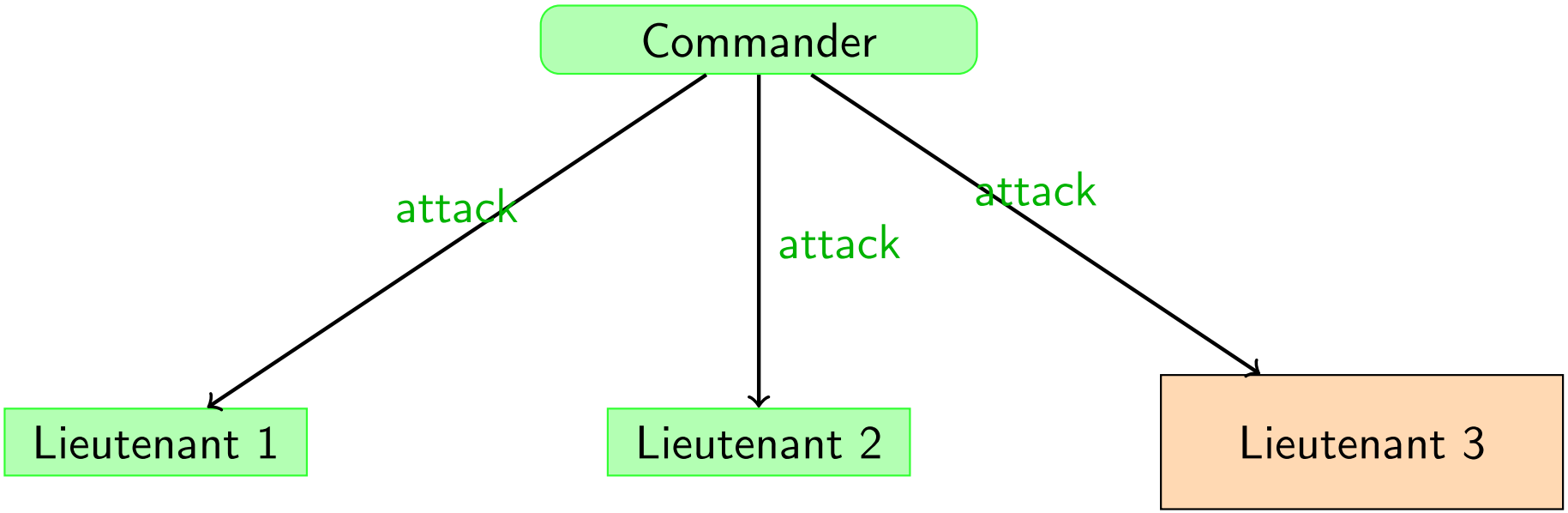

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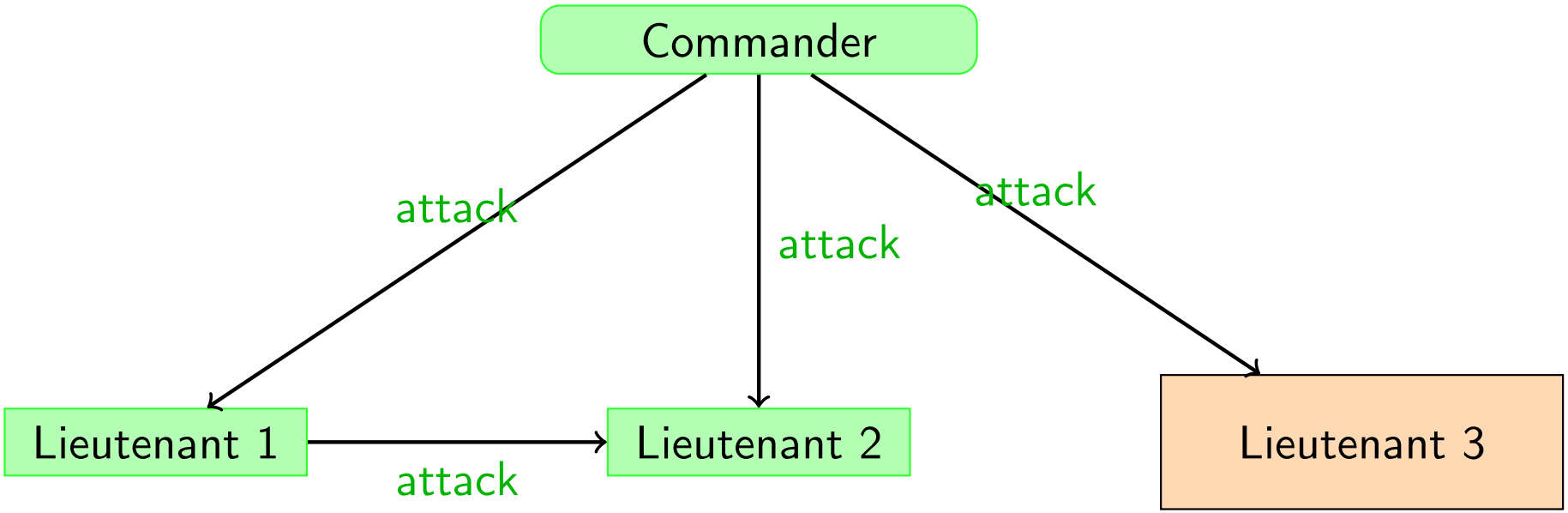

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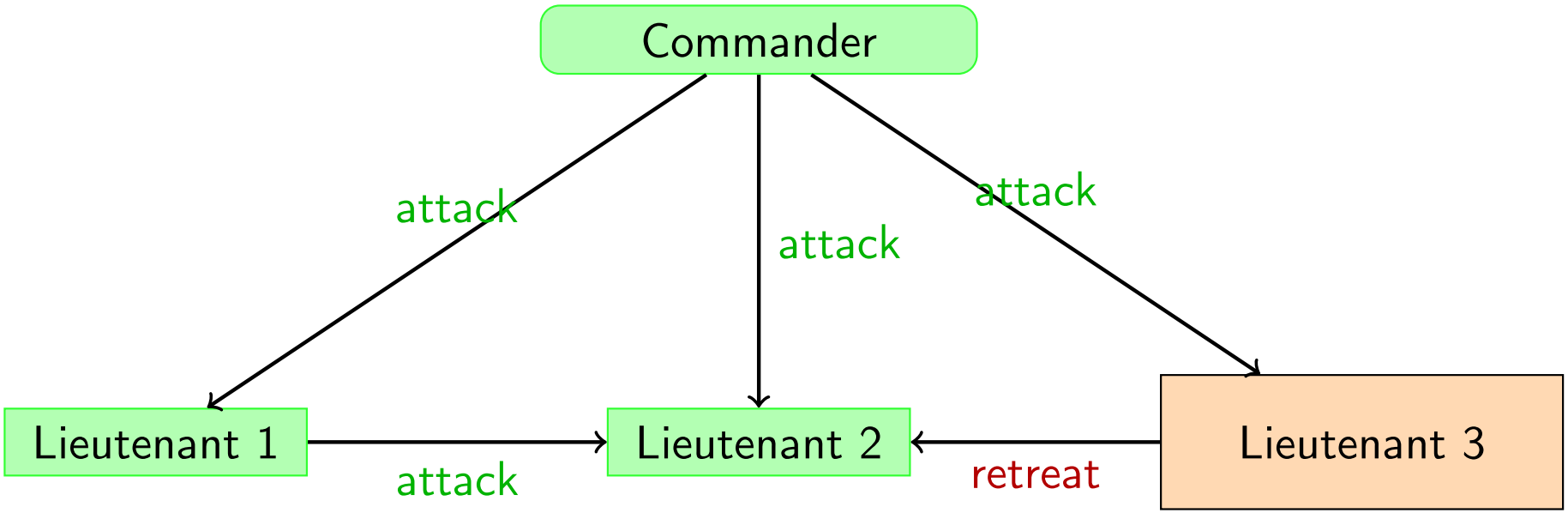
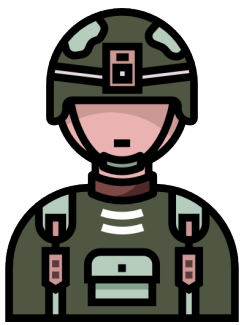
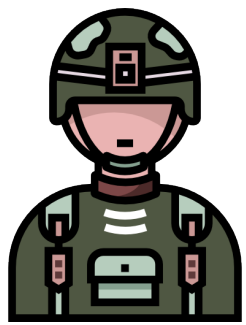


Impossiblity Proof

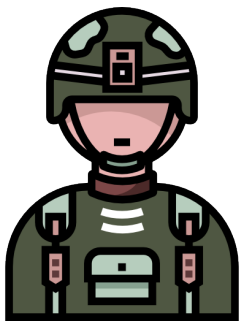
When only one of the generals or the commander is traitor.So the traitor is only one memeber. So the member , m=1

Impossibility Result Proof[m=1]

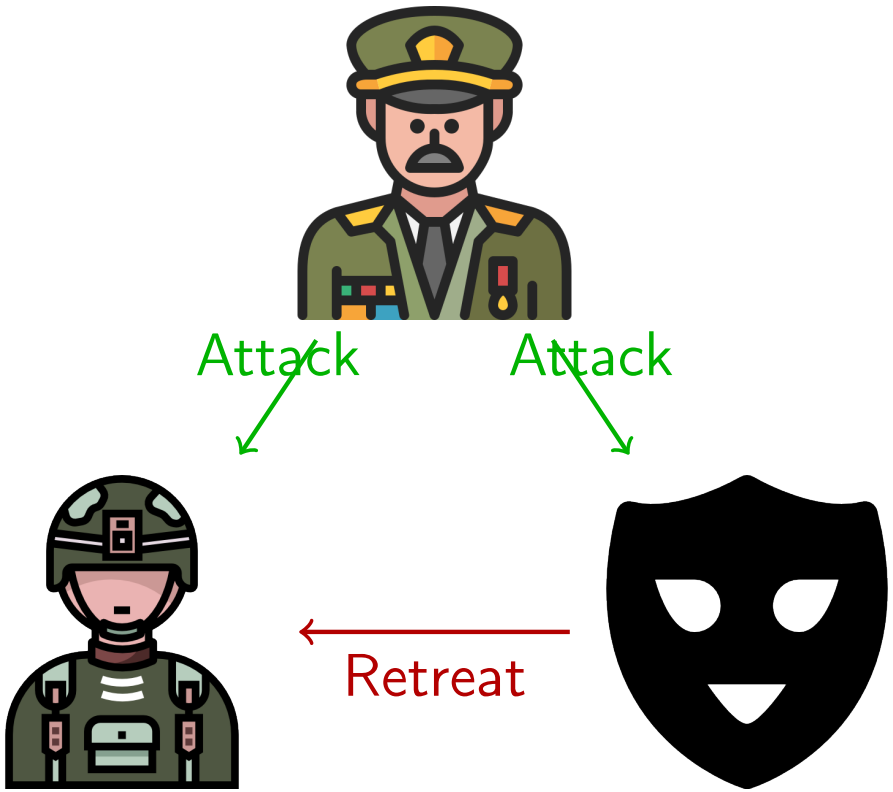




Impossibility Result Proof[m=1]



Impossibility Result Proof[m=1]



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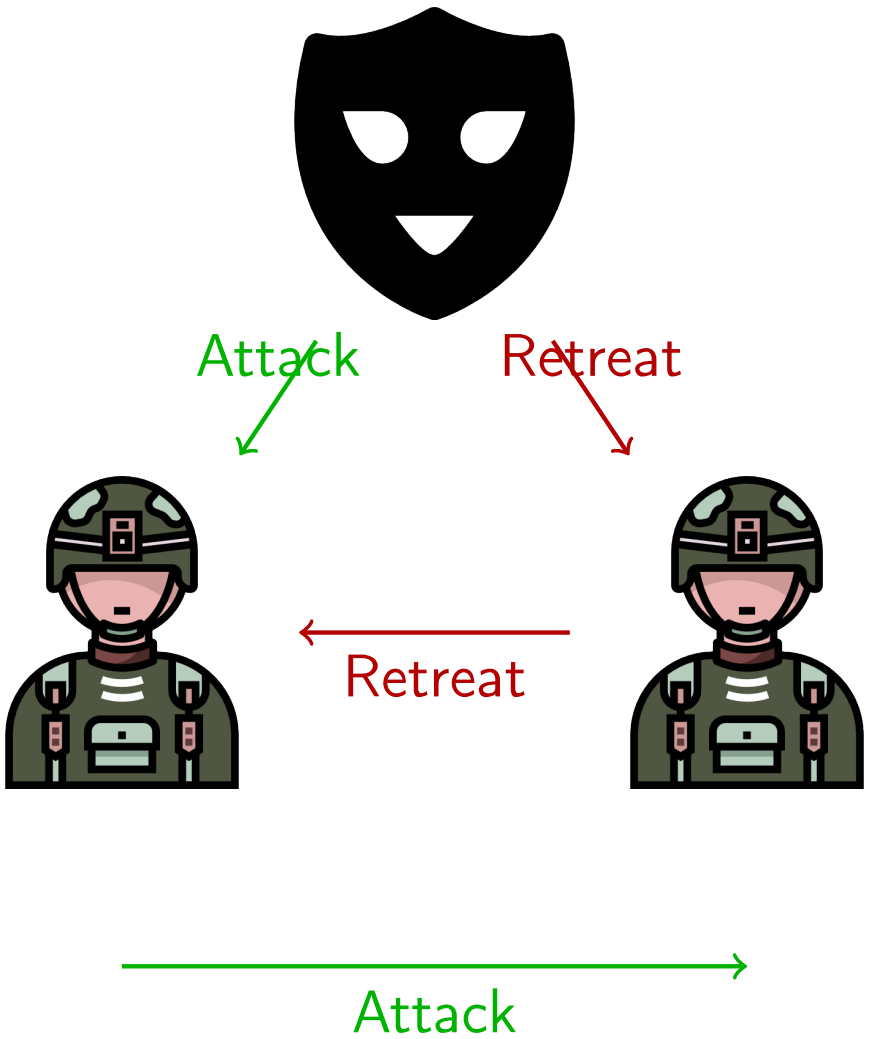
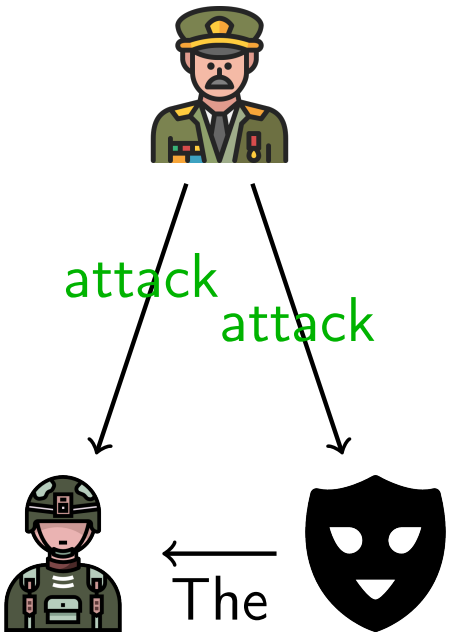
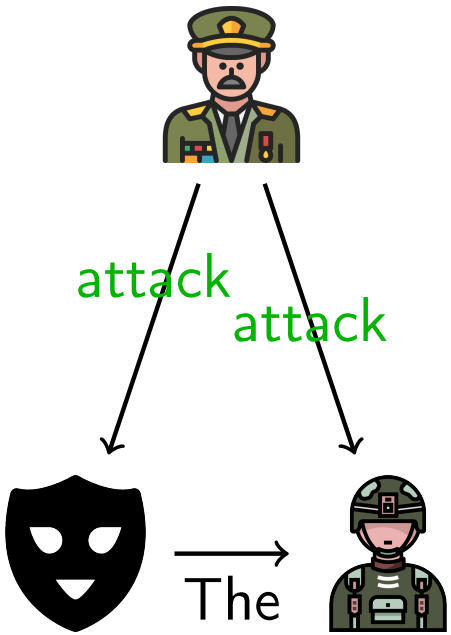
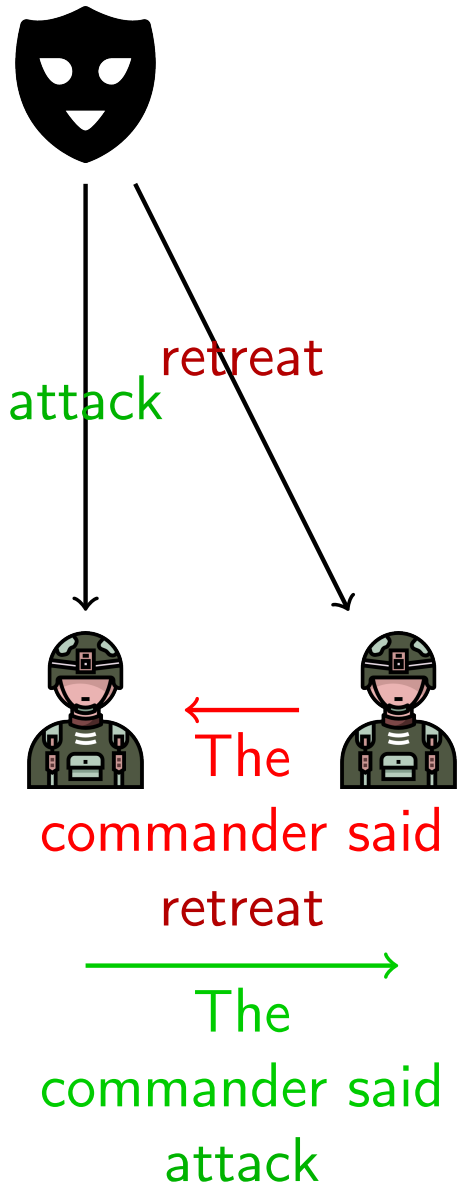


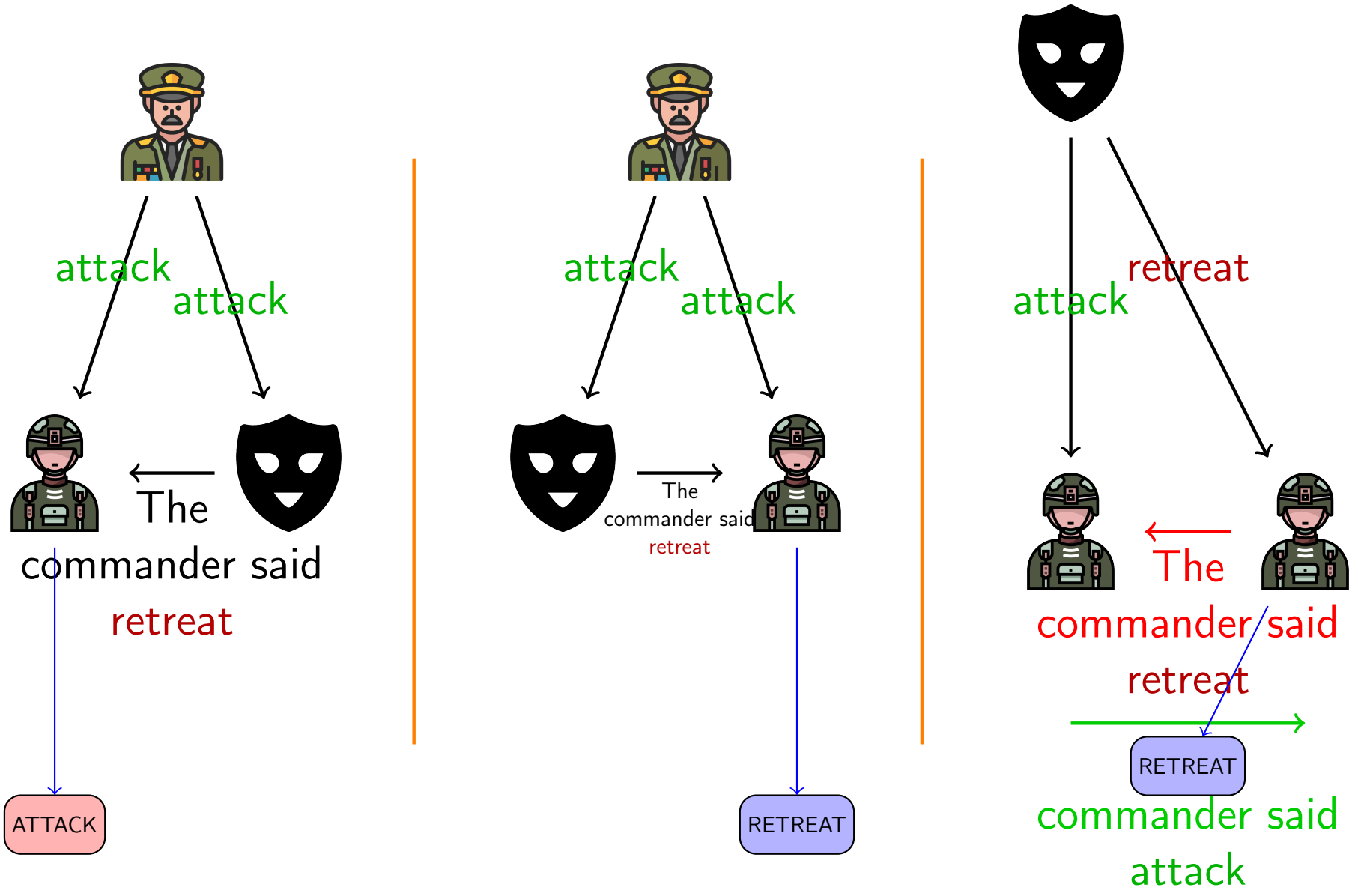
Three Scenarios [m=1]







Three Scenarios



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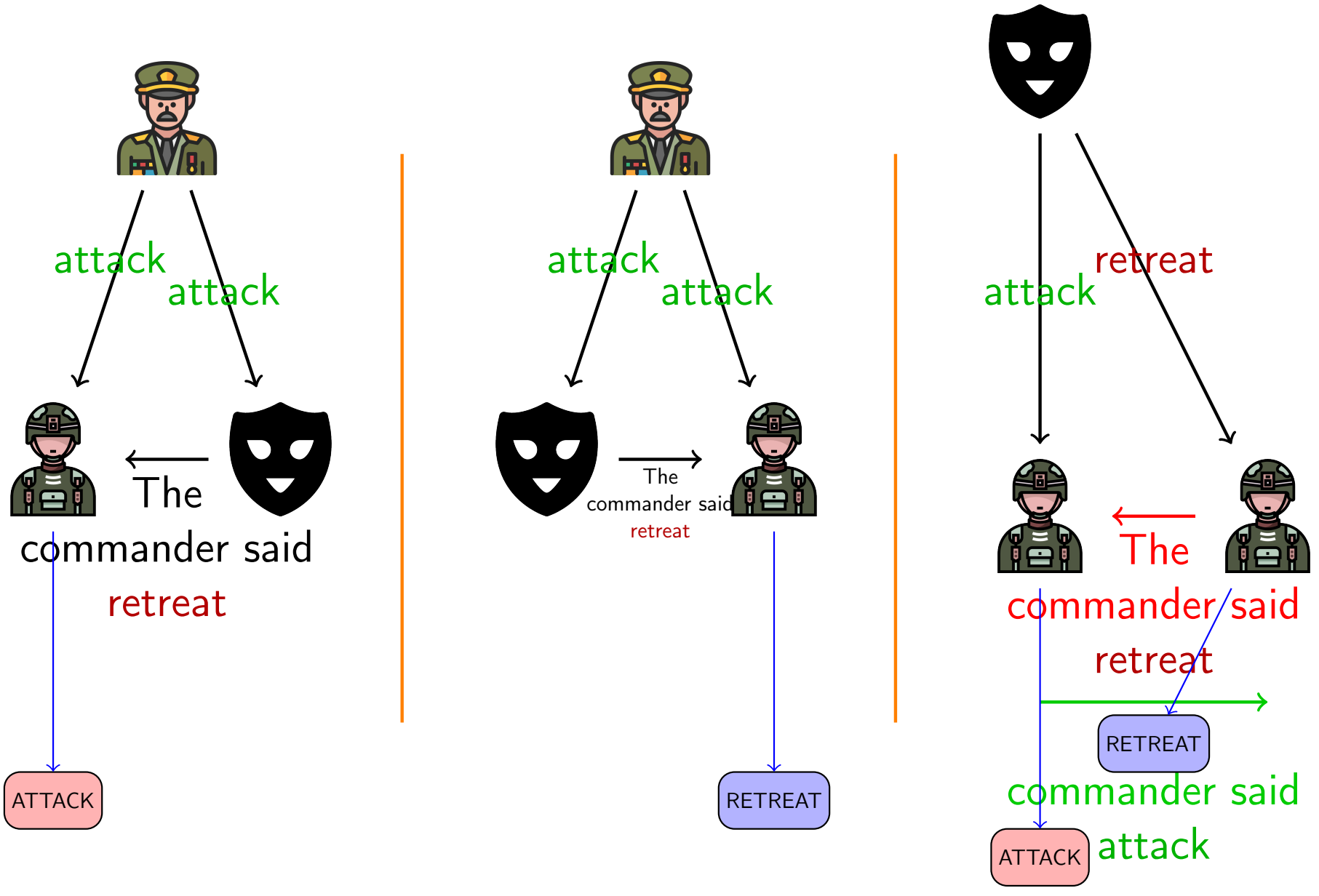

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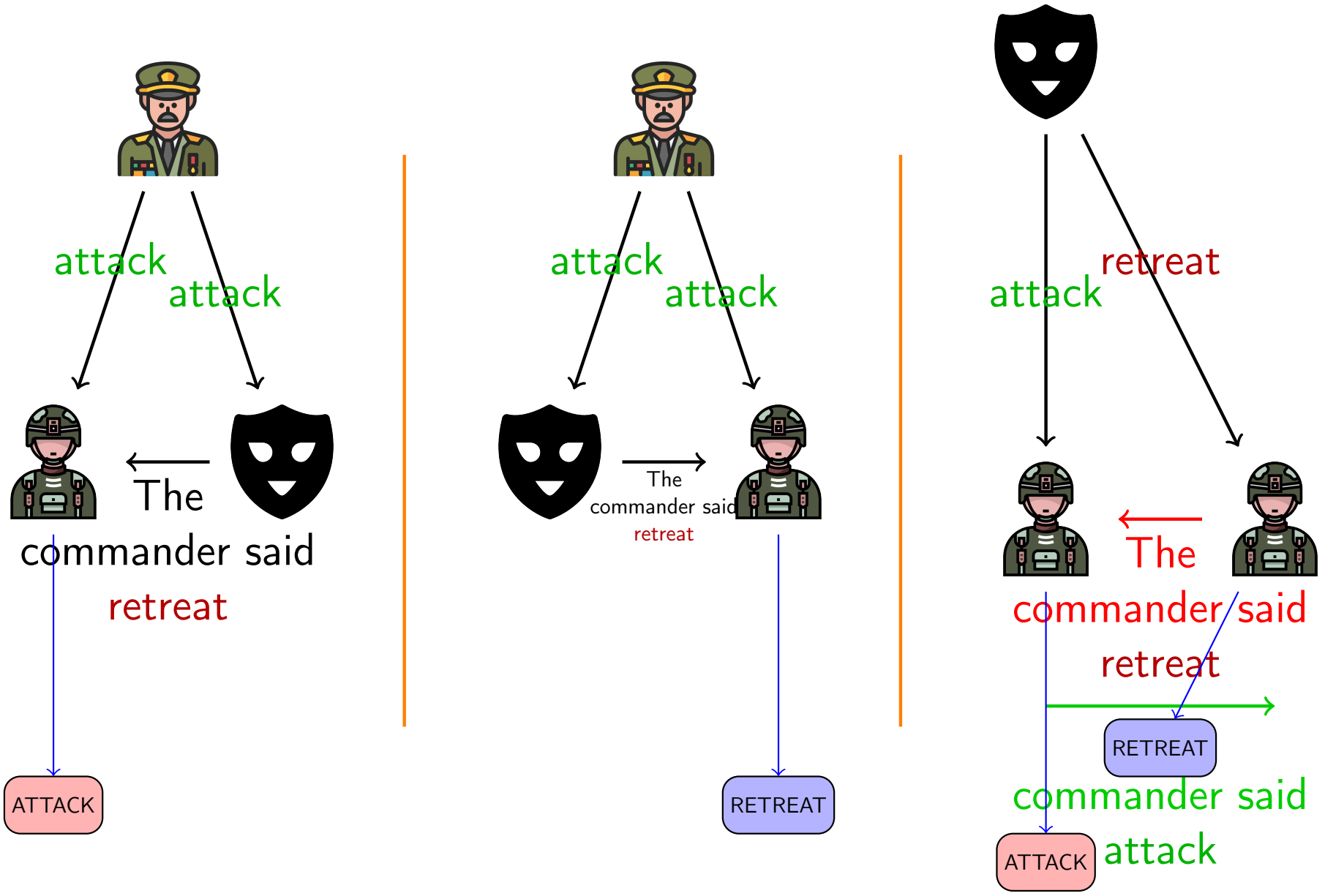

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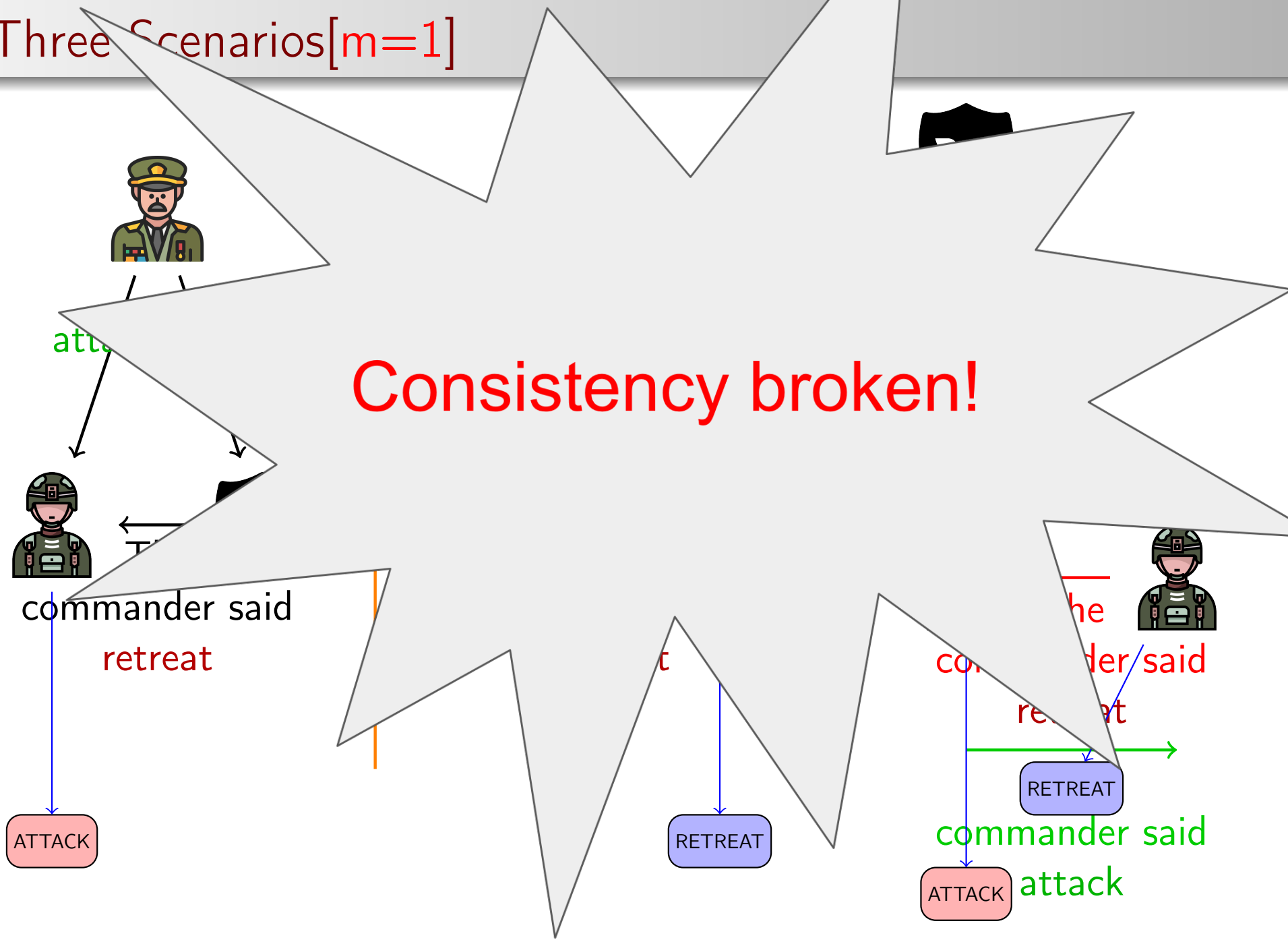
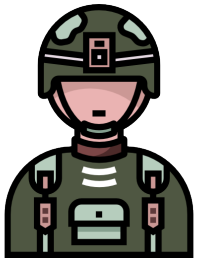
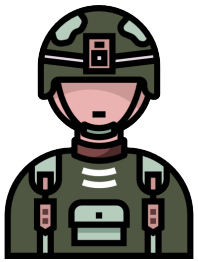


Impossibility Result m>1

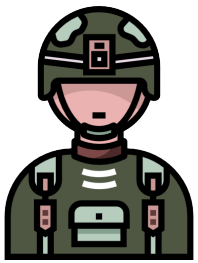
Proof by cointradiction:



x



y

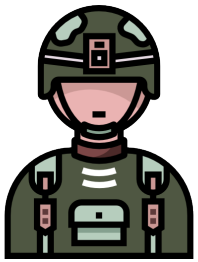


z

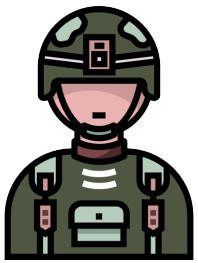
Impossibility Result m>1

According to protocol f

x



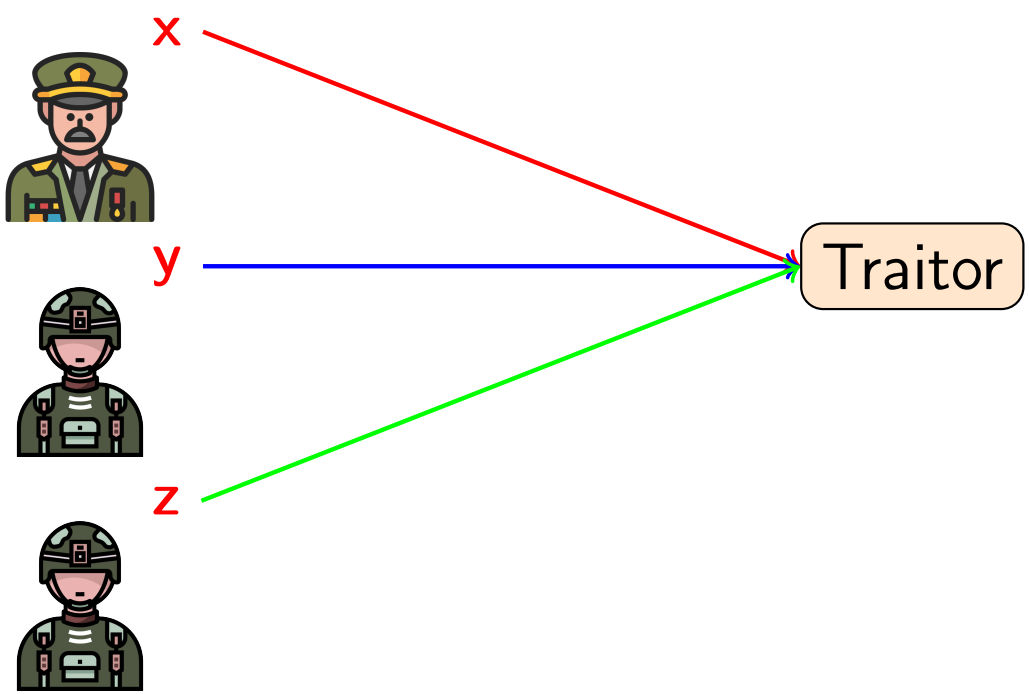
y



z

Impossibility Result[m>1]

According to protocol f



To be continued...

At most m simulated traitors

Protocol $\mathbf{f}$ can solve it...

Impossibility Result m>1

Assumption: $m > 1$ by contradiction

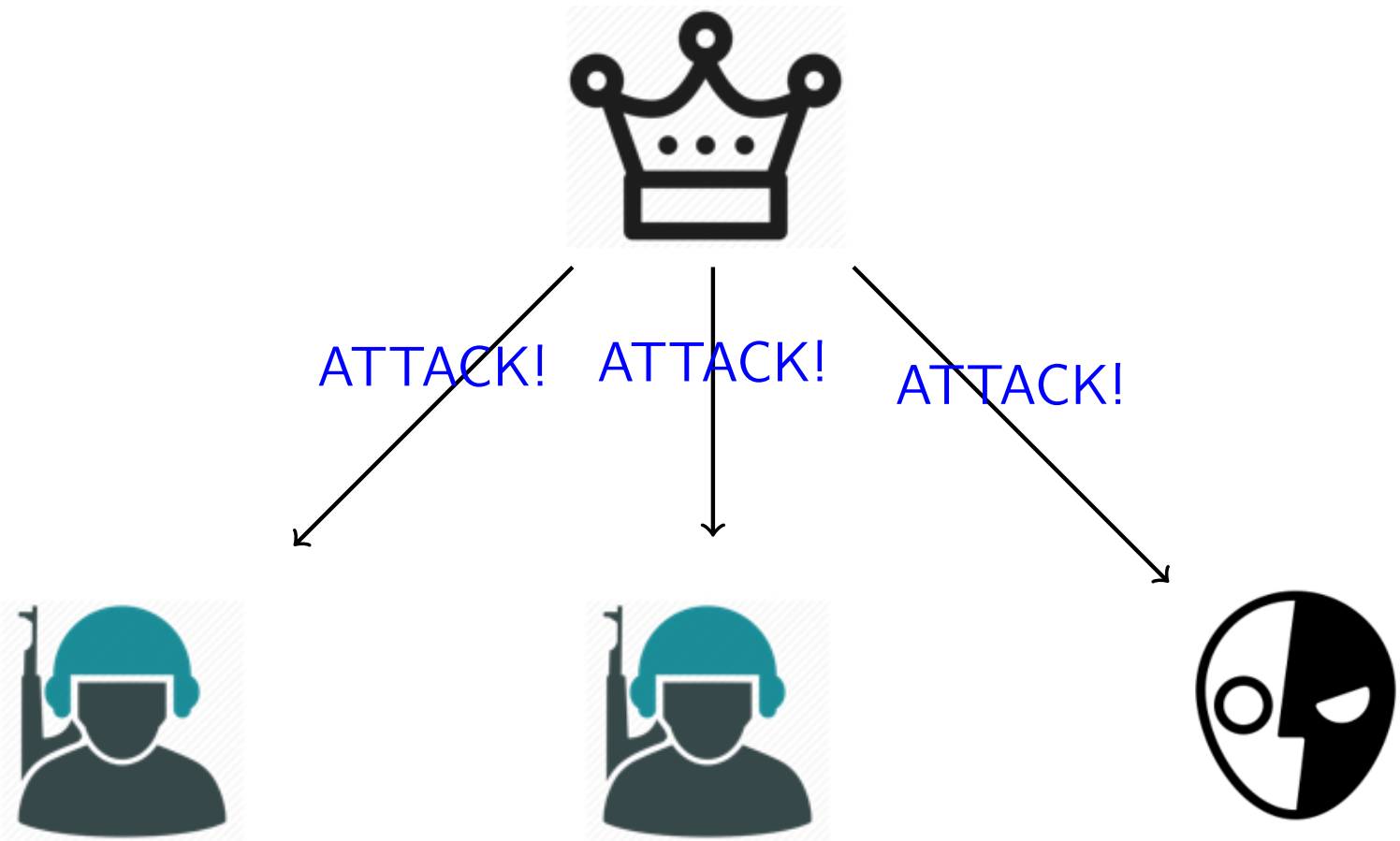
- If $m > 1$, then $m = 1$
- $m = 1$ can't be solved.
- (contradiction).

Oral Messages Fault!!!

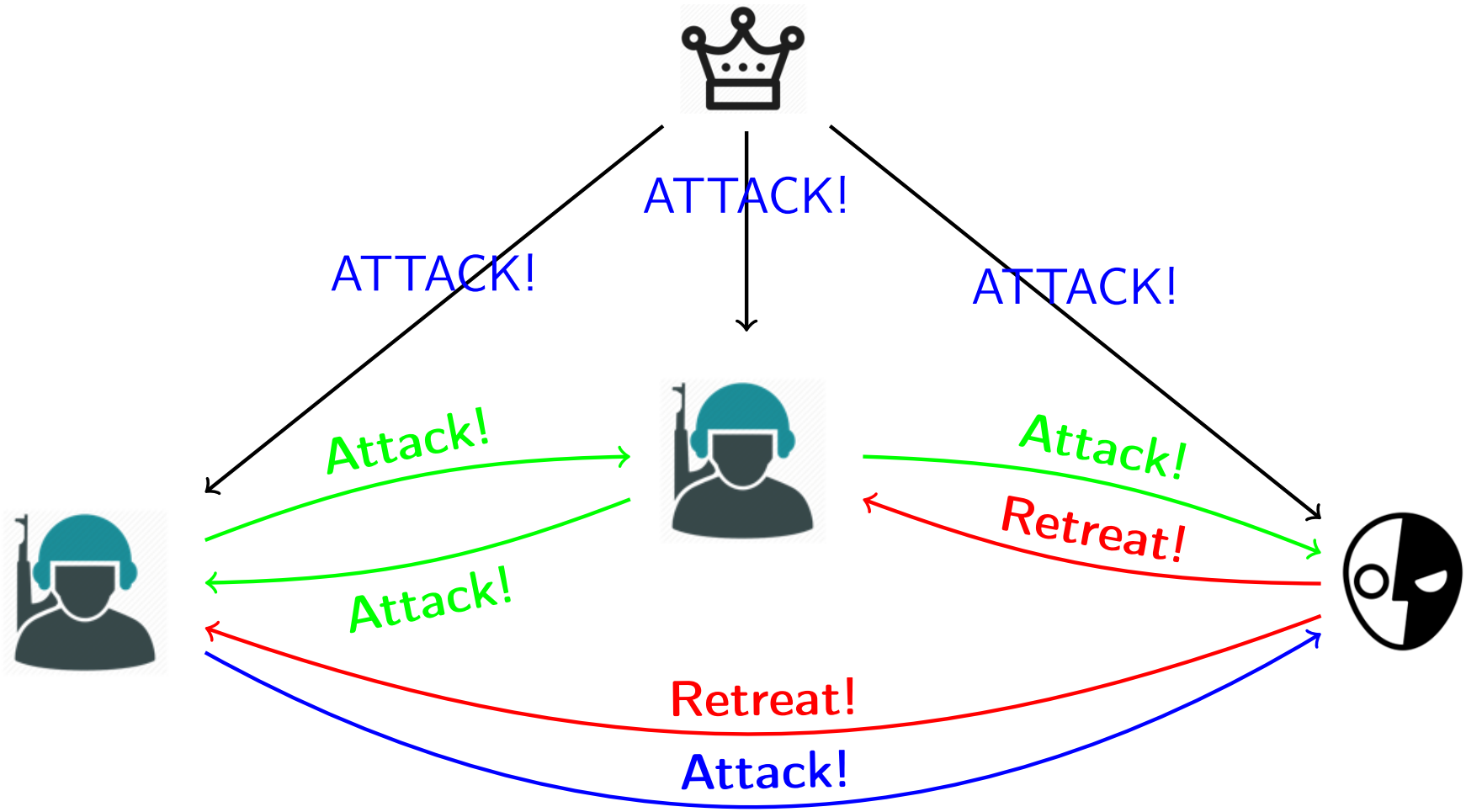
Solutions

So.. The Solution???

Solutions 1:Oral Messages->OM(1)



OM(1)-3*OM(0)


ATTACK!
ATTACK!
ATTACK!
Attack!
Attack!
Attack!
Retreat!
Retreat!
Attack!

Oral Messages

- Intuition: For every message M received, we solve a smaller BGP containing all but the current commander to tell others M has been received.
- OM(m) solvable for m traitors when 3m<n

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- **OM(m)** solvable for m traitors when 3m<n

Oral Messages

Formally...

- OM(k)
  - k==0
    - Commander sends value to everyone and everyone sends back the value they received
  - k>0
    - Commander sends value to everyone
    - Everyone starts a smaller BGP OM(K-1) where current Lieutenant becomes the new Commander
    - Everyone participated n-1 OM(k-1) and get n-1 values, return the majority

Complexity:(n-1)*MC(OM(k-1)) + n-1 = $O(n^m)$

Oral Messages

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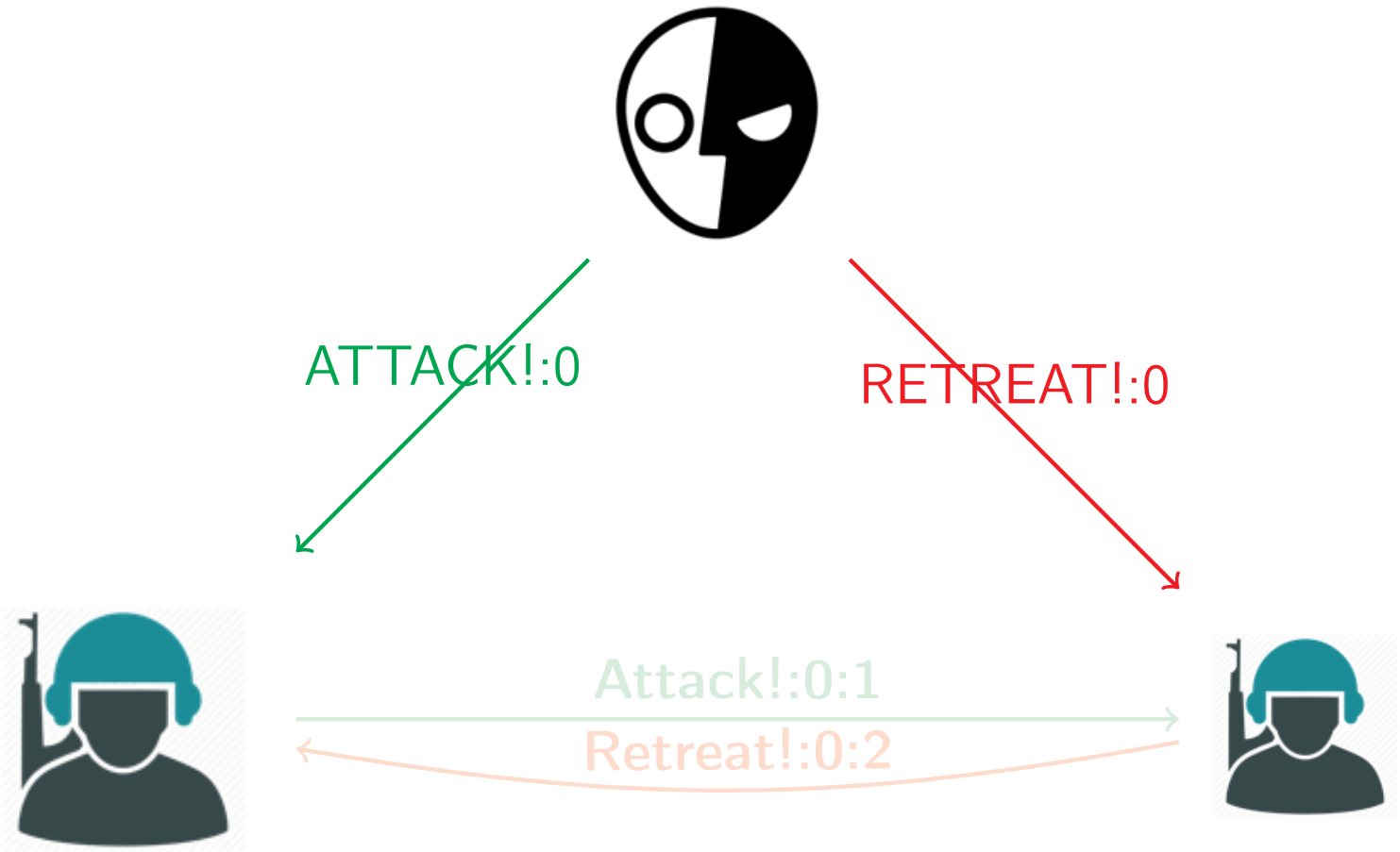
Oral Messages

Finally...

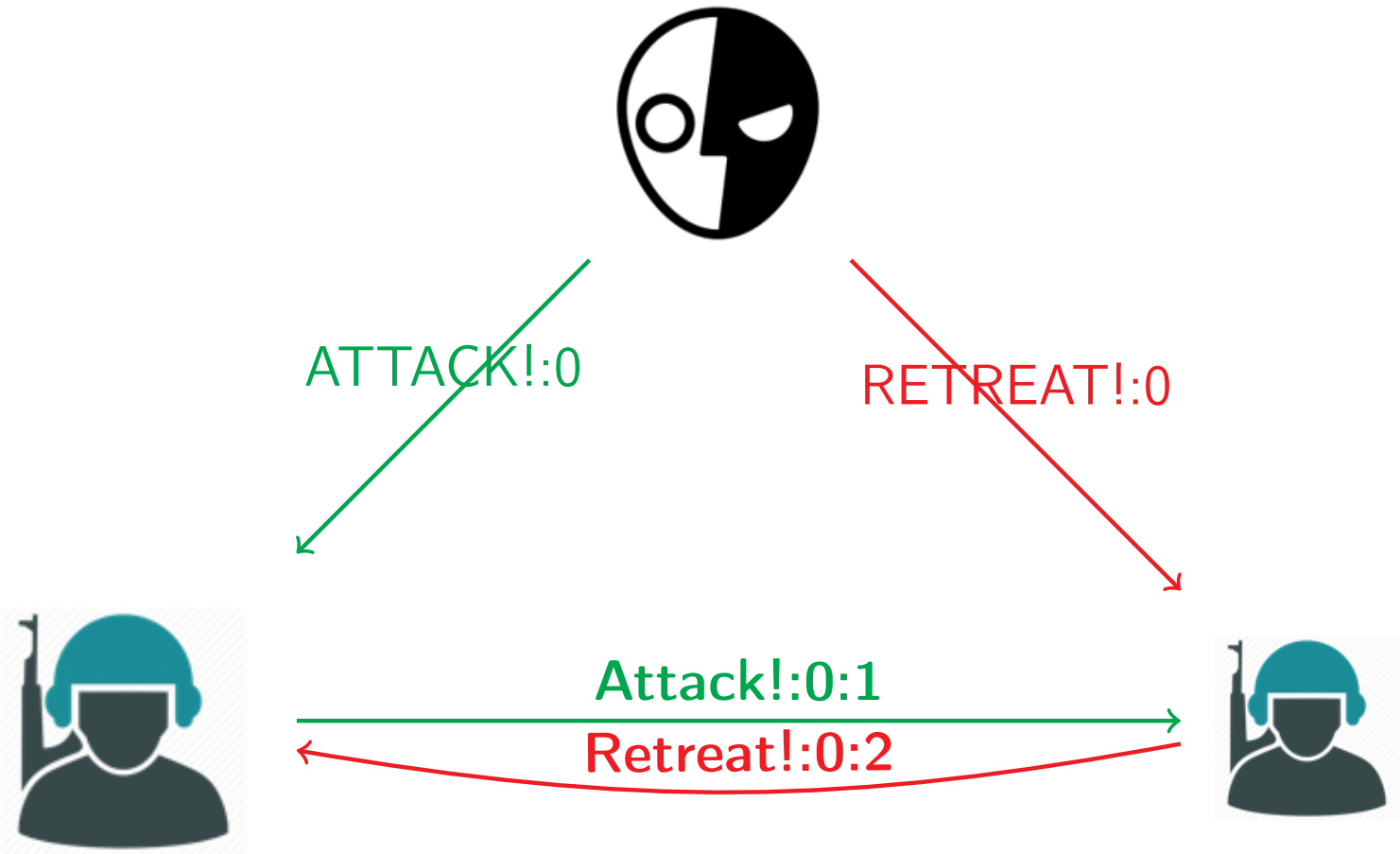
- OM(k)
  - k==0
    - Commander sends value to everyone and everyone sends back the value they received
  - k>0
    - Commander sends value to everyone
    - Everyone starts a smaller BGP OM(K-1) where current Lieutenant becomes the new Commander
    - Everyone participated n-1 OM(k-1) and get n-1 values, return the majority

Complexity: (n-1)*MC(OM(k-1)) + n-1 = $O(n^m)$

Solutions 2: Signed Messages

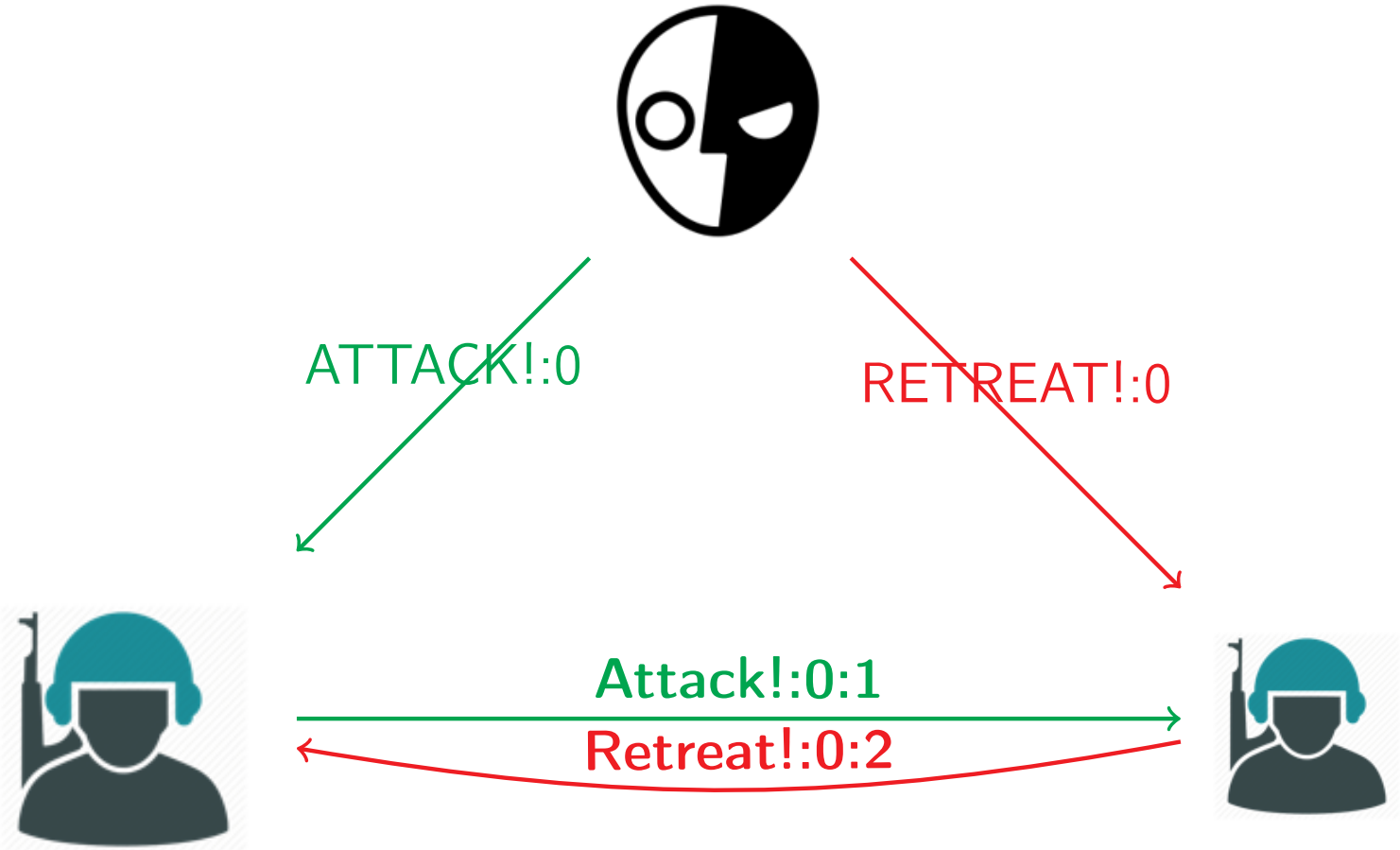


Solutions 2: Signed Messages



$V(1) == V(2)$

Solutions 2: Signed Messages



Choice(V(1))==Choice(V(2))

Minimum Number

Minimum number required for which an *f*-resilient consensus protocol exists

	synchrony	asynchrony	partial synchrony
fail-stop	f+1	inf	2f+1
crash	f+1	inf	2f+1 (Paxos)
byzantine with digital signature	f+1 (SM(f+1))	inf	
byzantine with authenticated channel	3f+1 (OM(f))	inf	

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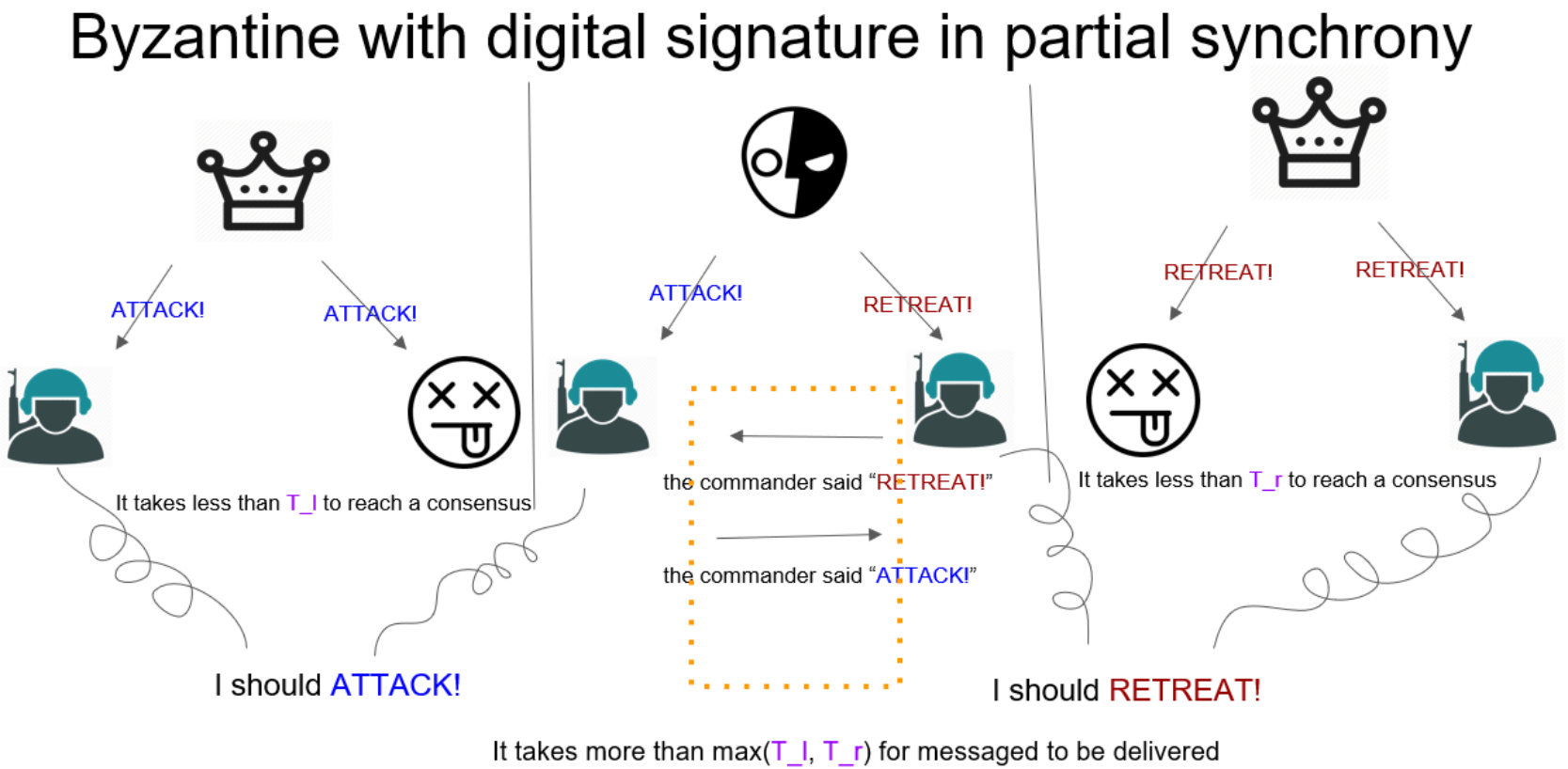
Byzantine with digital signature in partial synchrony

1. synchronous 1/3 faults.
2. Sound familiar?
3. Assume there exist a protocol that can solve it.

Partial Synchrony



Practical Byzantine Fault Tolerance

- Commander sends the value to every lieutenant
- Every lieutenant
  - If it receives a new value v, broadcast `(prepare, v)`
  - If it receives $2f+1$ `(prepare, v)`, broadcast `(commit, v)`
  - If it receives $2f+1$ `(commit, v)`, broadcast `(committed, v)`
  - If it receives $f+1$ `(committed, v)`, broadcast `(committed, v)`
- Ensure agreement
- Ensure liveness under a loyal commander
- What if the commander is faulty?
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byzantine with digital signature	f+1 (SM(f+1))	inf	3f+1(PBFT)
byzantine with authenticated channel	3f+1 (OM(f))	inf	

Application

Blockchain and Cryptocurrencies

- **Problem Context:** In decentralized systems like Bitcoin, there are no central authorities to ensure all nodes agree on the state of the ledger.
- **Solution:** Byzantine Fault Tolerance (BFT) algorithms ensure consensus despite malicious or faulty nodes.

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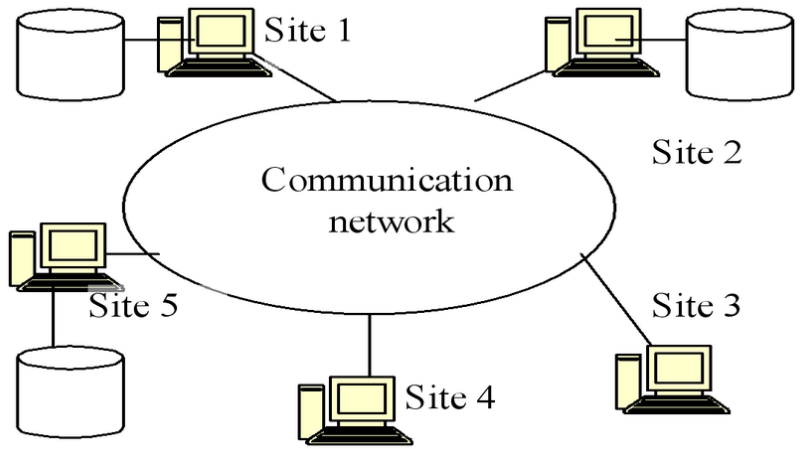
Distributed Databases

- Challenge is to ensure that all nodes have consistent data.
- Byzantine fault tolerance can help maintain data consistency.



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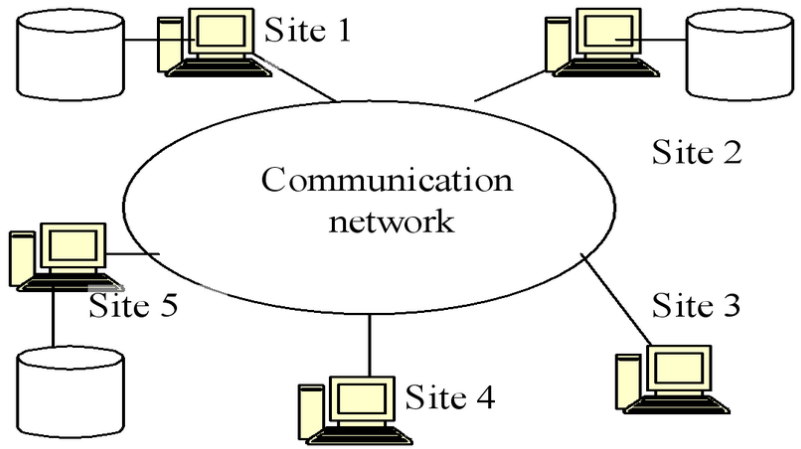

Conclusion

Key Takeaway

Byzantine Fault Tolerance (BFT) is the cornerstone of reliability in distributed systems. It enables:

- **Consensus:** Agreement among nodes, even with faulty or malicious participants.
- **Scalability:** Essential for decentralized systems like blockchain.
- **Resilience:** Smooth functioning in unpredictable environments.

"By leveraging BFT protocols, we build systems that stand strong amidst failures."

The End