Session #9

Consensus in Bitcoin

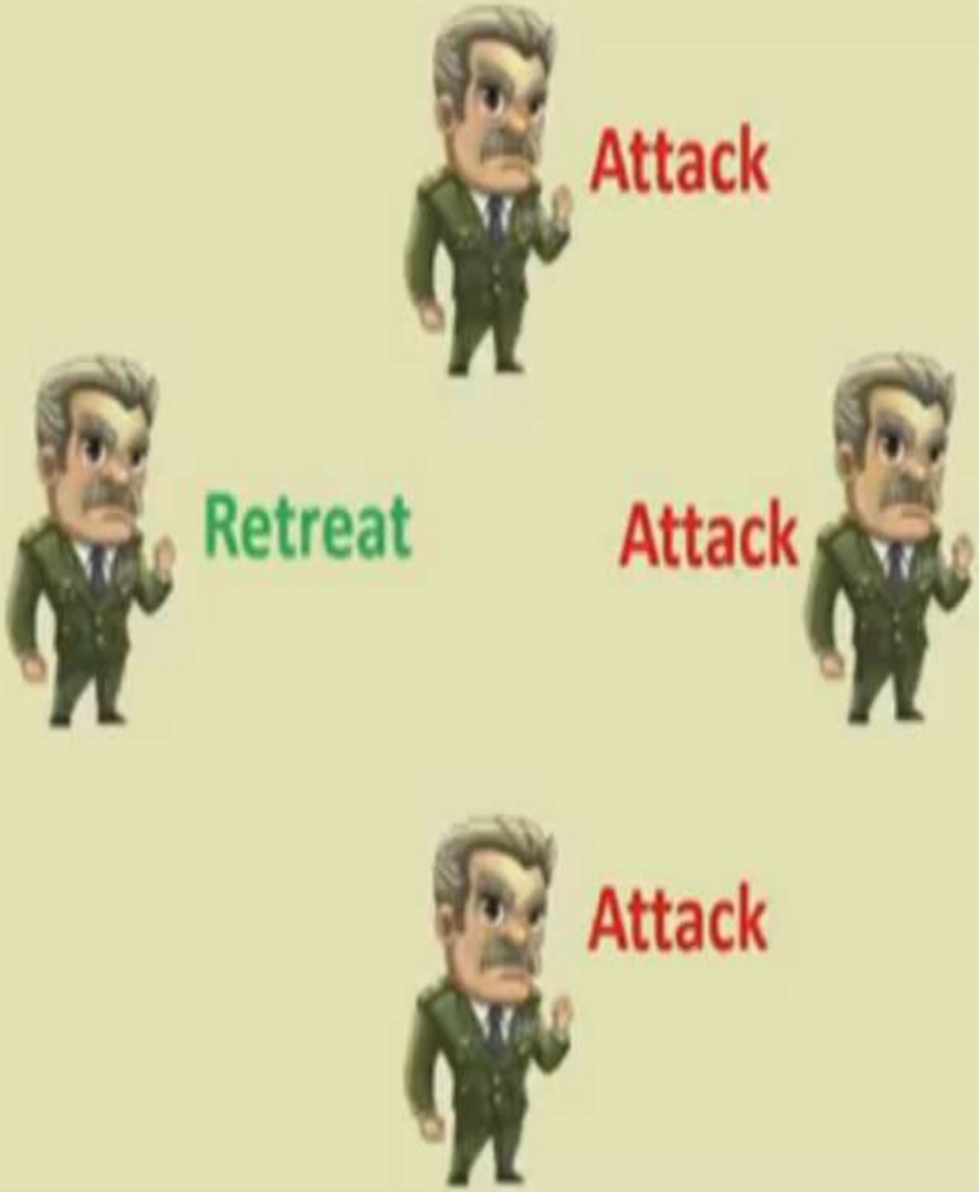
Agenda

- What is Consensus and Why Consensus is difficult?
- Distributed Consensus Properties
- Synchronous Message passing system and Asynchronous Message passing system
- Correctness of Distributed Consensus Protocol
- Consensus in Bitcoin Network

Consensus

- A procedure to reach in a common agreement in a distributed or decentralized multi-agent platform

- Important for a message passing system



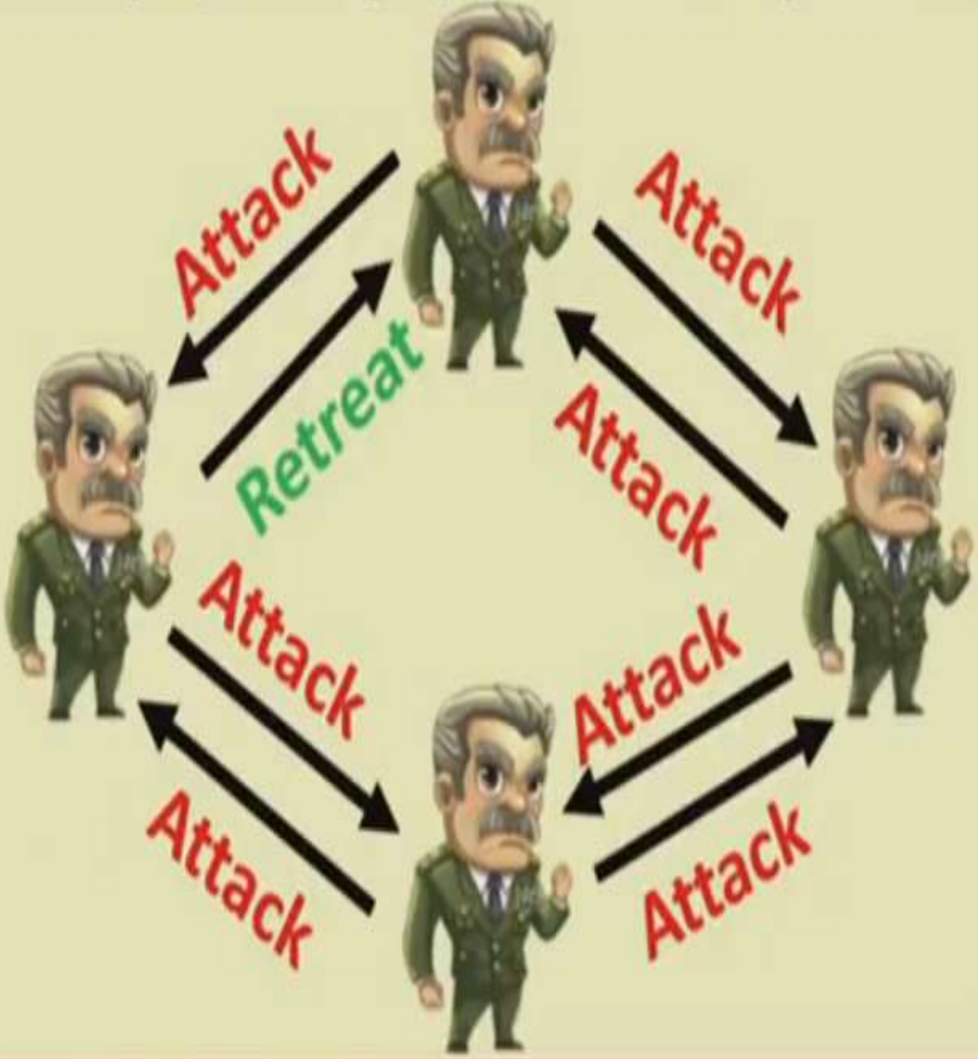
Why Consensus

- Reliability and fault tolerance in a distributed system
  - Ensure correct operations in the presence of faulty individuals

- Example:
  - Commit a transaction in a database
  - State machine replication
  - Clock synchronization

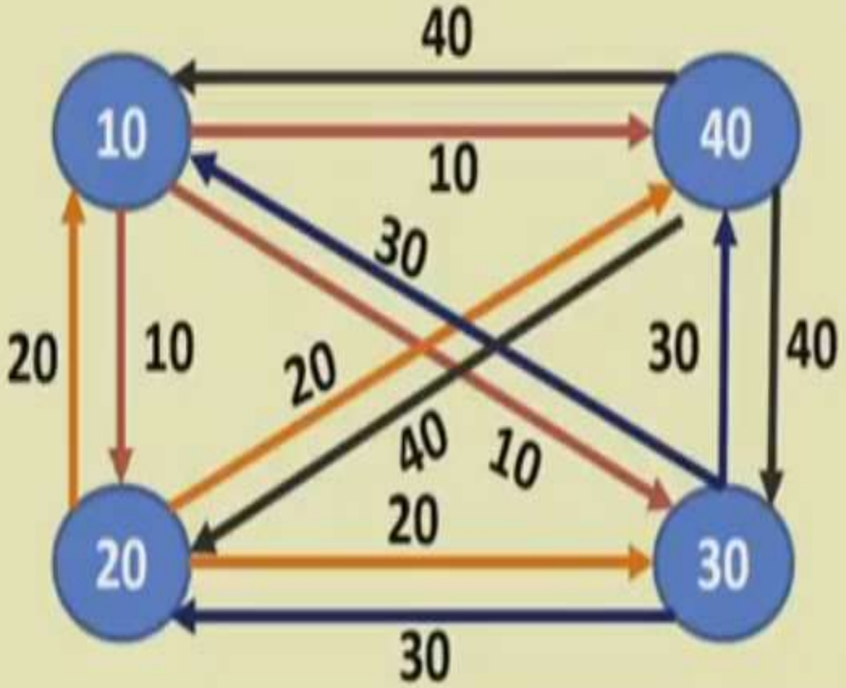
Why Consensus Can be Difficult in Certain Scenarios

- Consider a message passing system, and a general behaves maliciously



Distributed Consensus

- If there is **no failure**, it is easy and trivial to reach in a consensus
  - **Broadcast** the personal choice to all
  - Apply a **choice function**, say the maximum of all the values



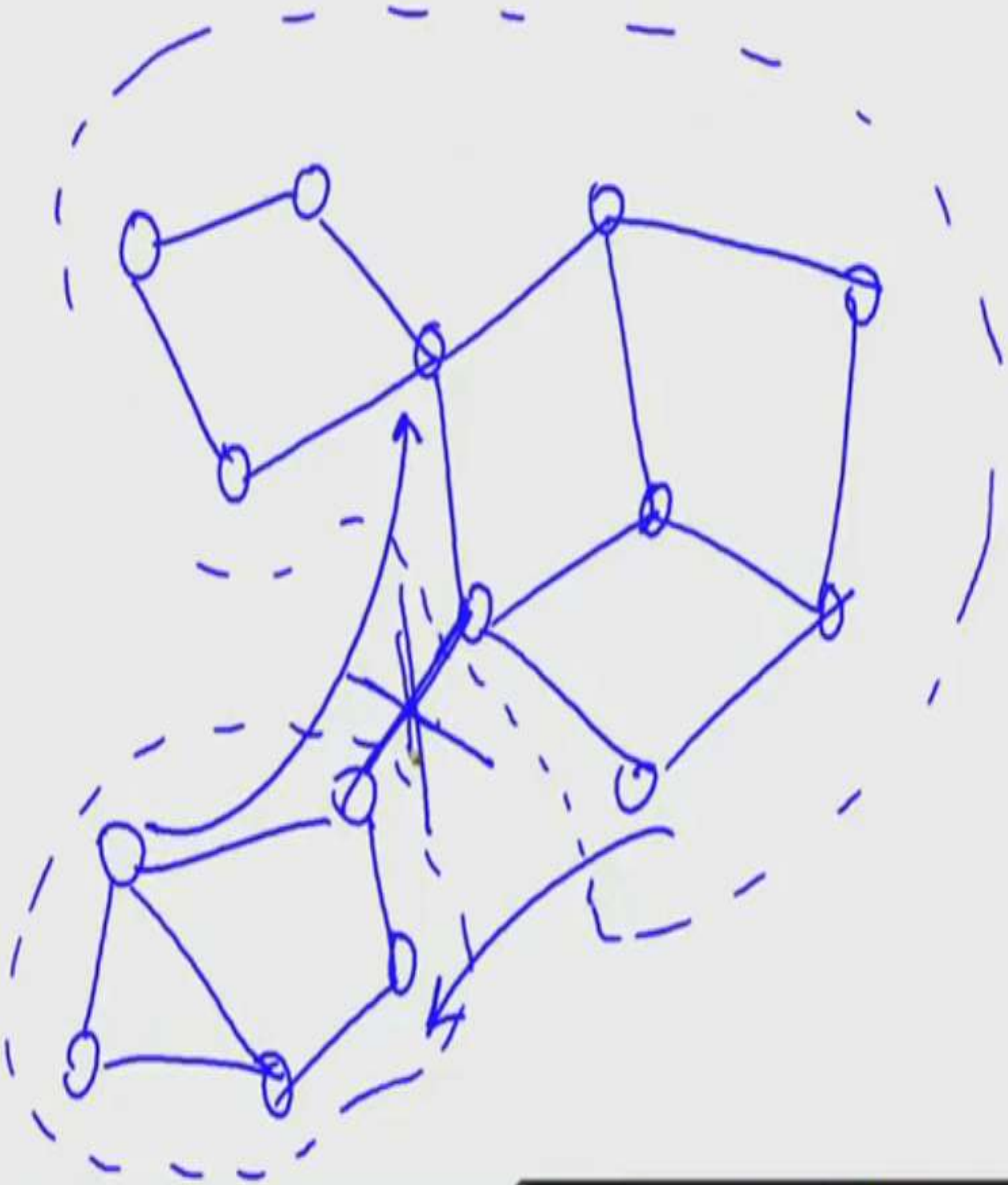
Distributed Consensus

- There can be various types of faults in a distributed system.

- **Crash Fault:** A node suddenly crashes or becomes unavailable in the middle of a communication

- **Network or Partitioned Faults:** A network fault occurs (say the link failure) and the network gets partitioned

- **Byzantine Faults:** A node starts behaving maliciously



Distributed Consensus - Properties

- **Termination**: Every correct individual decides some value at the end of the consensus protocol

- **Validity:** If all the individuals proposes the same value, then all correct individuals decide on that value

- **Integrity:** Every correct individual decides at most one value, and the decided value must be proposed by some individuals

- **Agreement:** Every correct individual must agree on the same value

Synchronous vs Asynchronous Systems

- **Synchronous Message Passing System:** The message must be received within a predefined time interval
  - Strong guarantee on message transmission delay

- **Asynchronous Message Passing System:** There is no upper bound on the message transmission delay or the message reception time
  - No timing constraint, message can be delayed for arbitrary period of times

Asynchronous Consensus

- **FLP85 (Impossibility Result):** In a **purely asynchronous distributed system**, the consensus problem is **impossible** (**with a deterministic solution**) to solve if in the presence of a **single crash failure**.
  - Results by Fischer, Lynch and Patterson (most influential paper awarded in ACM PODC 2001)
  - Randomized algorithms may exist

Synchronous Consensus

- Various consensus algorithms has been explored by the distributed system community
  - Paxos
  - Raft
  - Byzantine fault tolerance (BFT)

We'll look into these consensus algorithms, but later !!

Correctness of a Distributed Consensus Protocol

- **Safety:** Correct individuals must not agree on an incorrect value
  - Nothing bad happend

- **Liveliness** (or **Liveness**)**:** Every correct value must be accepted eventually
  - Something good eventually happens

Correctness of Distributed Consensus

- **Safety:** Correct individuals must not agree on incorrect value
  - Nothing bad happened
- **Liveliness (or Liveness):** Every correct value must be accepted eventually
  - Something good eventually happens

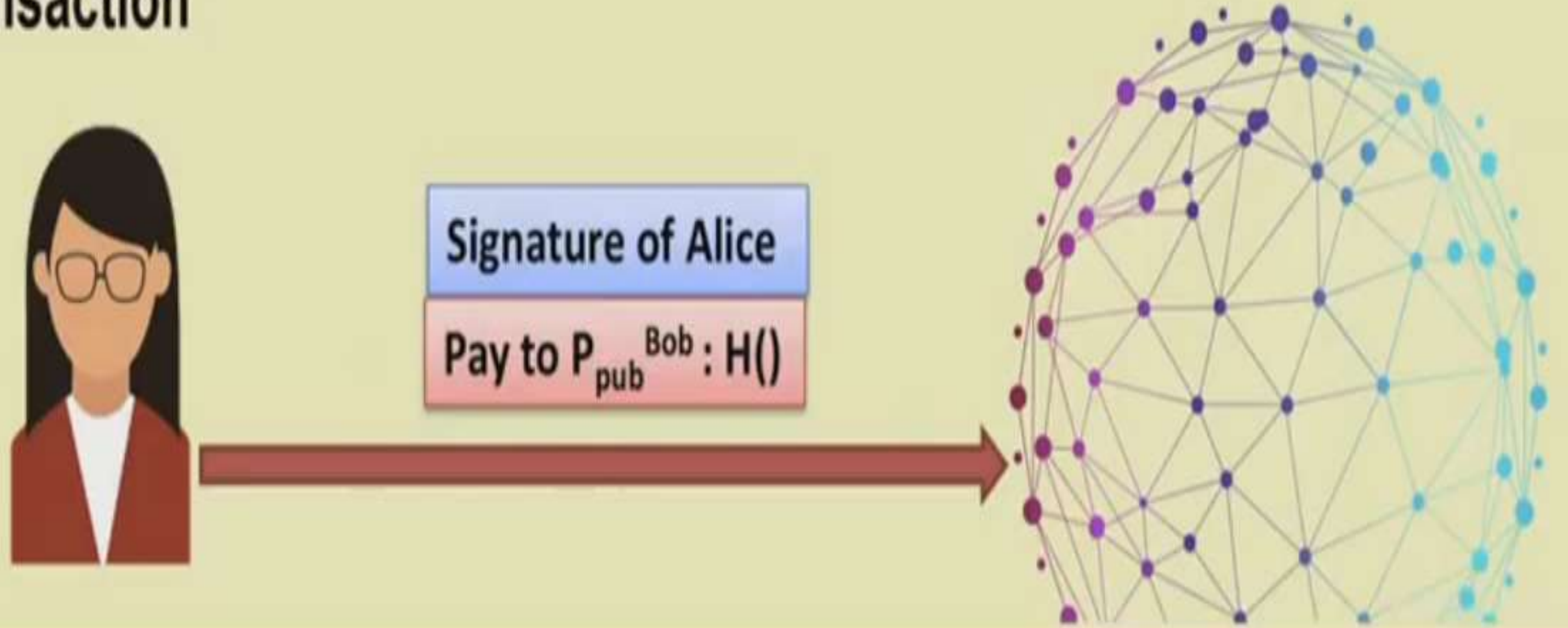
Consensus in an Open System

- The tradition distributed consensus protocols are based on
  - Message passing (when individuals are connected over the Internet)
  - Shared memory (when a common memory place is available to read and write the shared variables that everyone can access)

- Message passing requires a **closed** environment – everyone need to know the identity of others

Why Do We Require Consensus in Bitcoin Network

- Bitcoin is a peer-to-peer network
- Alice broadcast a transaction in this peer-to-peer network
- **All the nodes in this network need to agree on the correctness of this transaction**

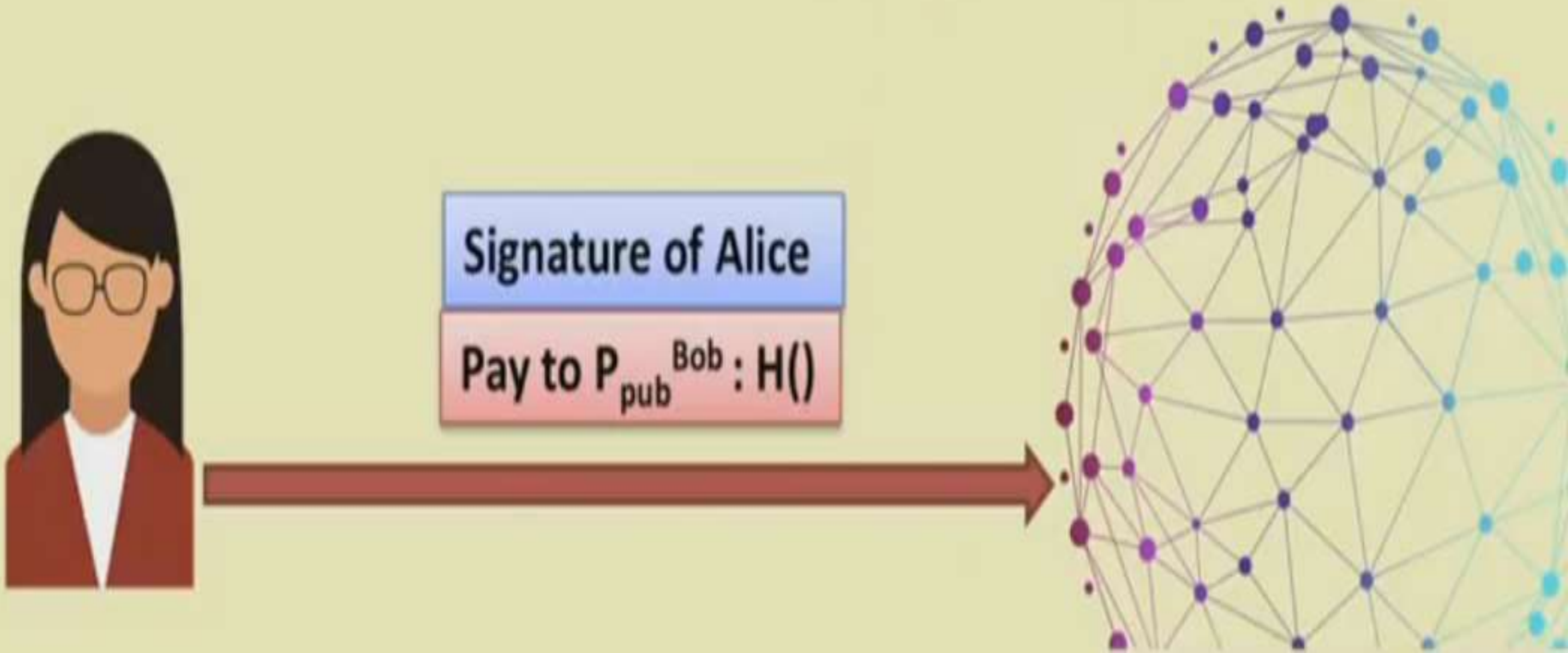


Signature of Alice

Pay to P_{pub}^{Bob} : H()

Why Do We Require Consensus in Bitcoin Network

- A node does not know all the peers in the network – this is an **open network**
- Some nodes can also initiate **malicious transactions**



Signature of Alice

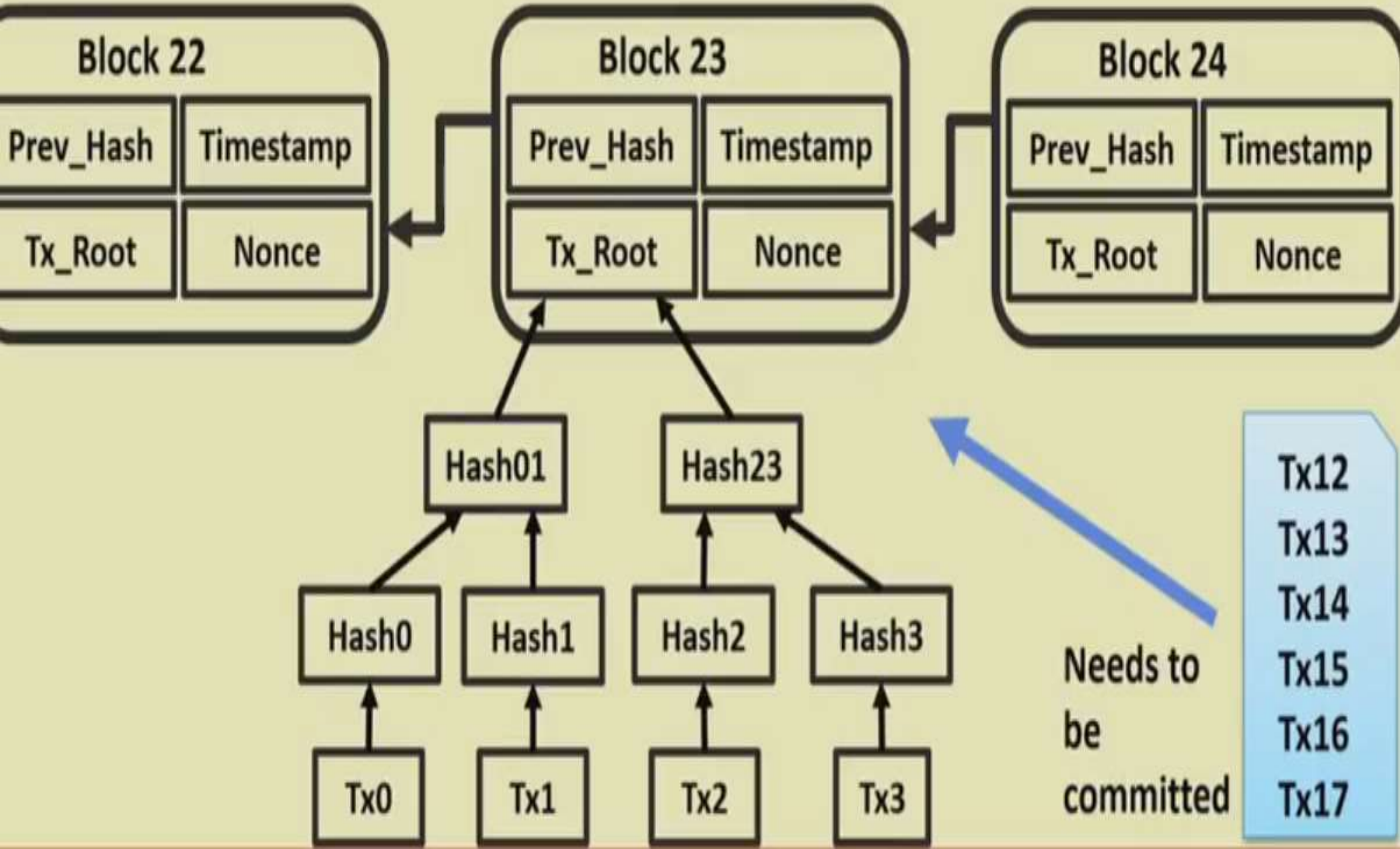
Pay to P_{pub}^{Bob} : H()

Consensus in a Bitcoin Network

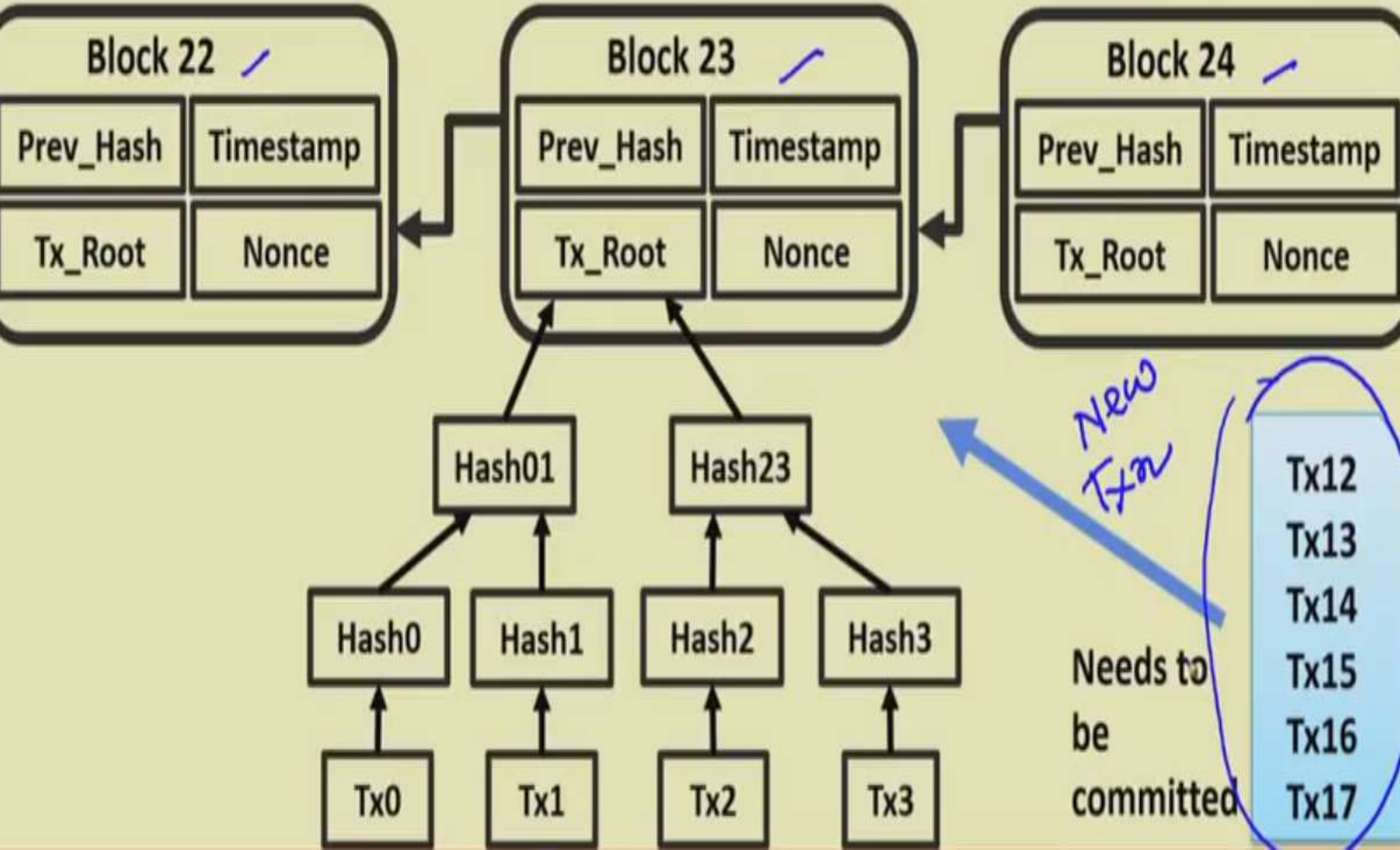
- Every node has **block of transactions** that has already reached into the consensus (**block of committed transactions**)

- The nodes also has a list of outstanding transactions that need to be validated against the block of committed transactions

Consensus in a Bitcoin Network



Consensus in a Bitcoin Network



Needs to be committed

Consensus in Bitcoin

- Per transaction consensus
  - Inefficient

- Block based consensus

New Block of Transactions

Tx12

Tx13

Tx14

Tx15

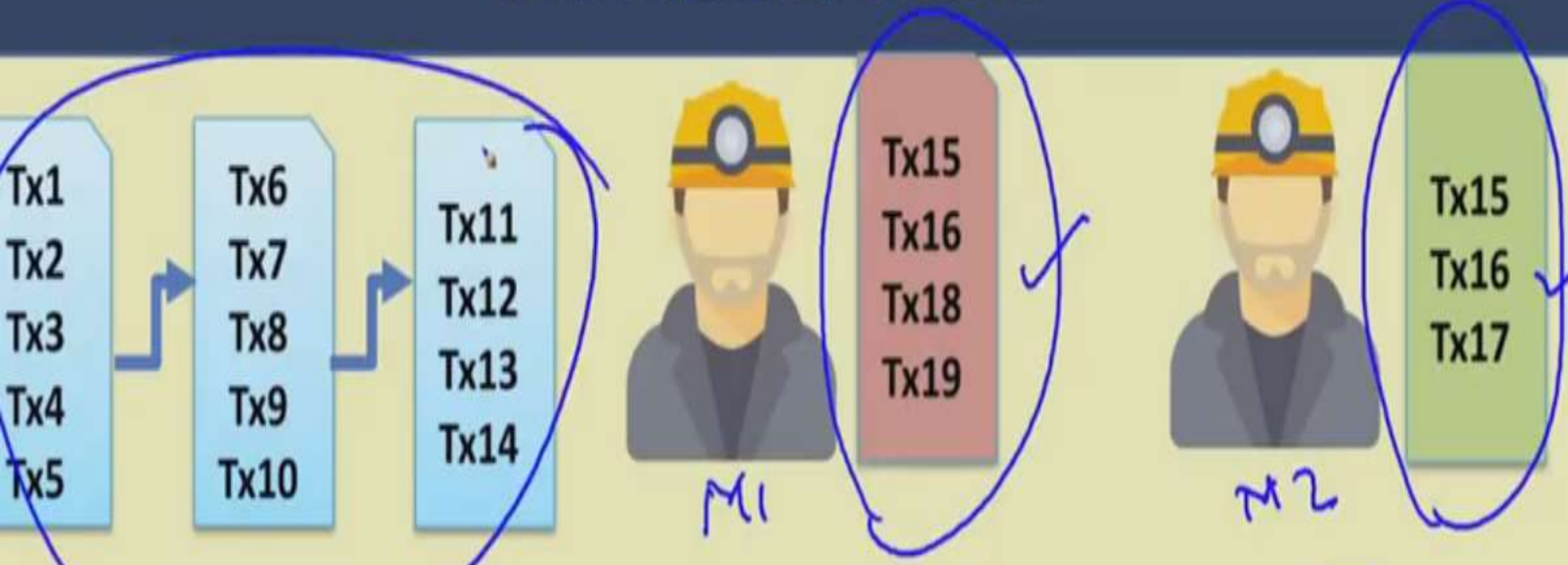
Tx16

Tx17

Apply consensus over the entire block of transactions

- Here comes the Blockchain

Consensus in Bitcoin



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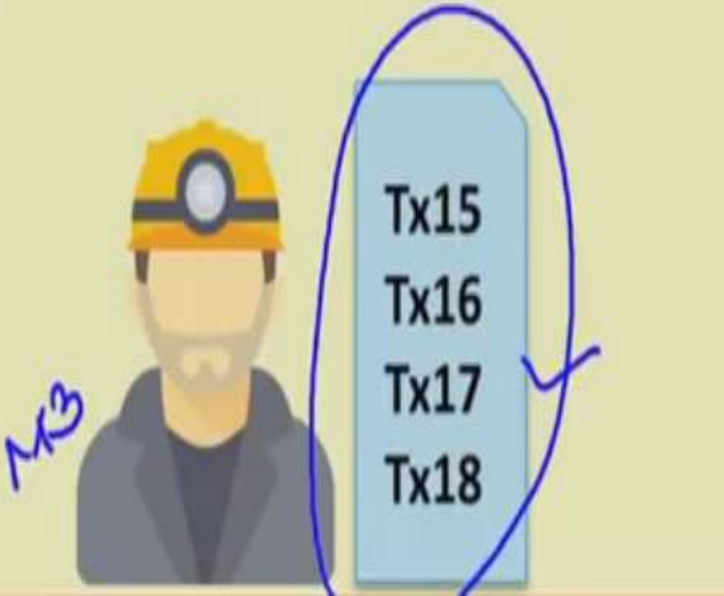

Tx15
Tx16
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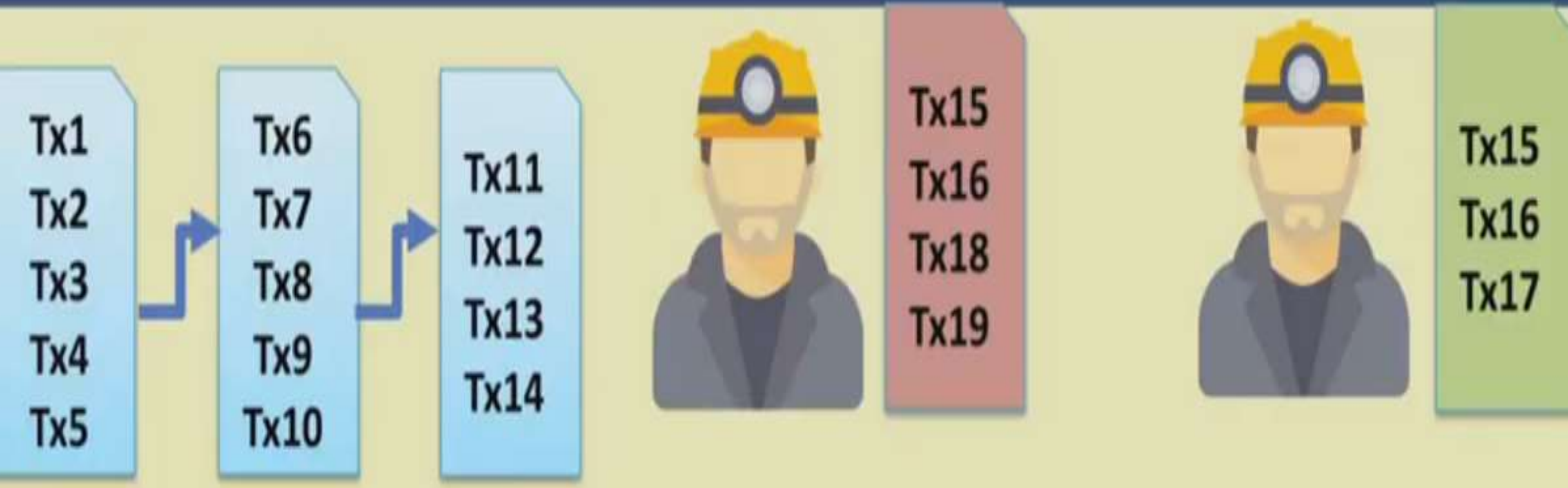
Bitcoin Consensus Objective:

Which block do we add next?

Consensus in Bitcoin

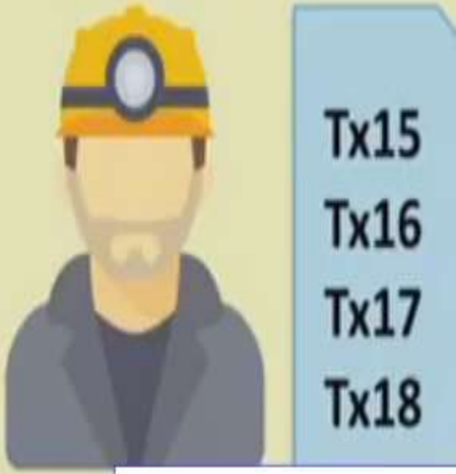


Bitcoin Consensus Objective:

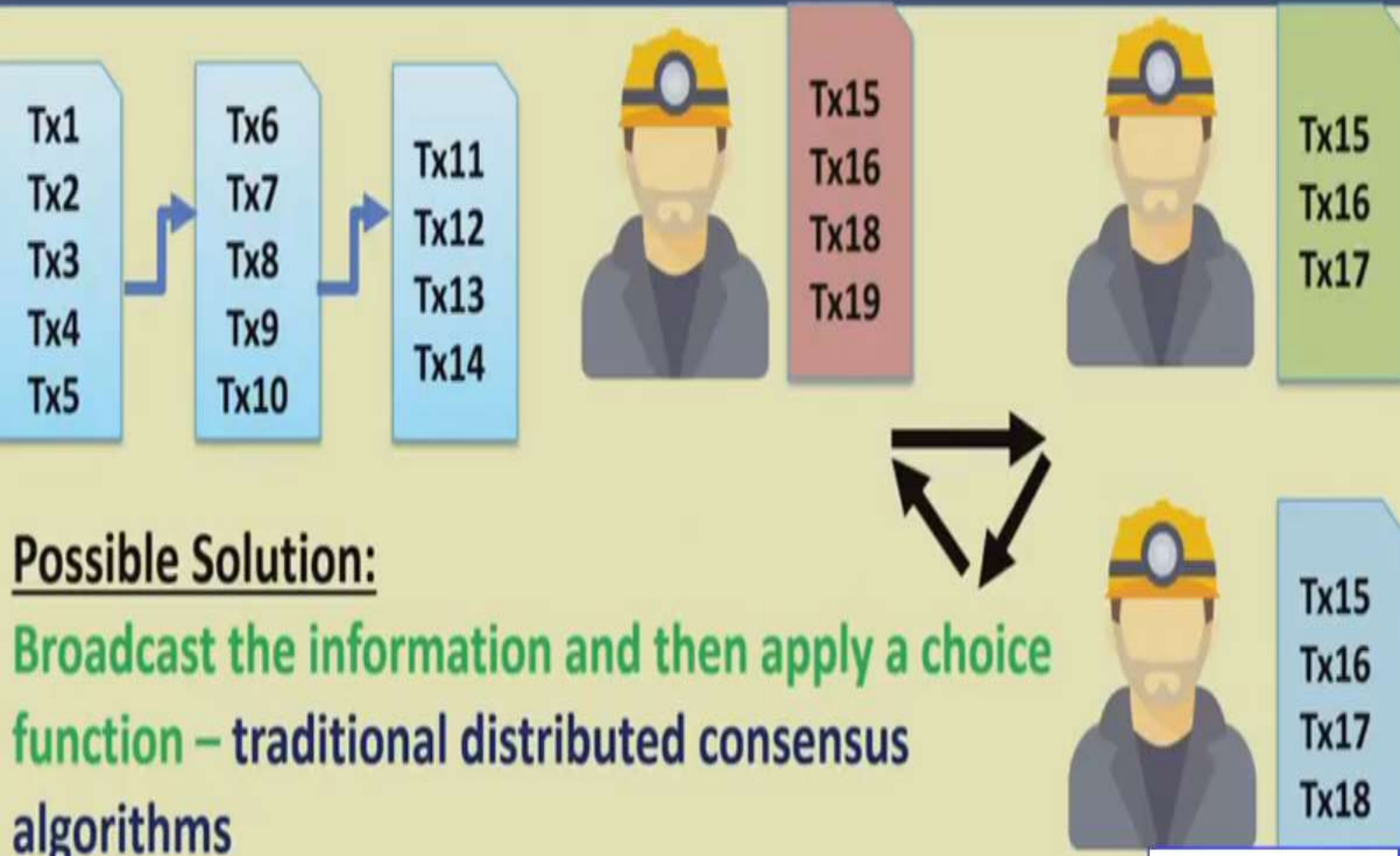
Which block do we add next?

Challenge:

The miners do not know each other



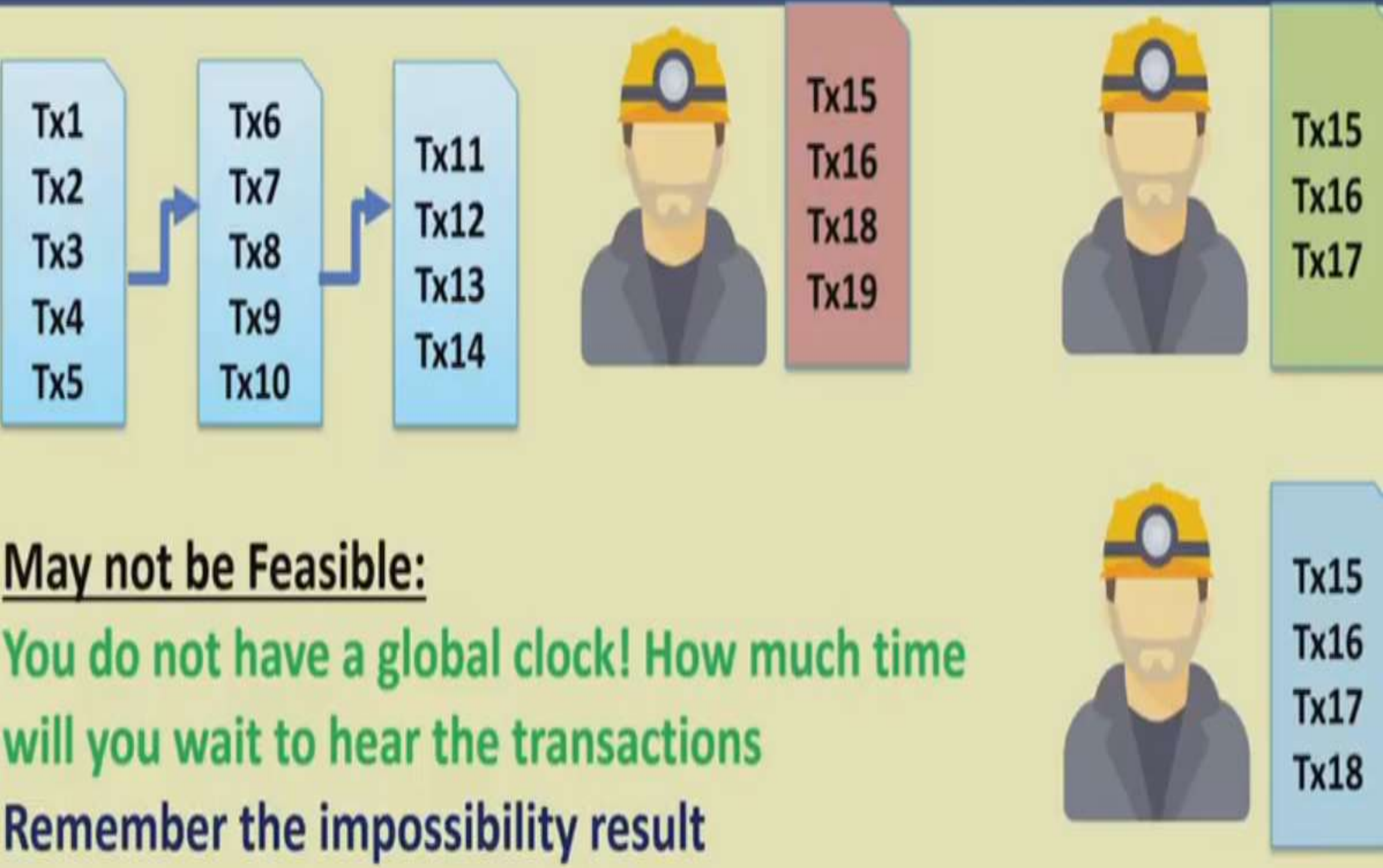
Consensus in Bitcoin



Possible Solution:

Broadcast the information and then apply a choice function – traditional distributed consensus algorithms

Consensus in Bitcoin



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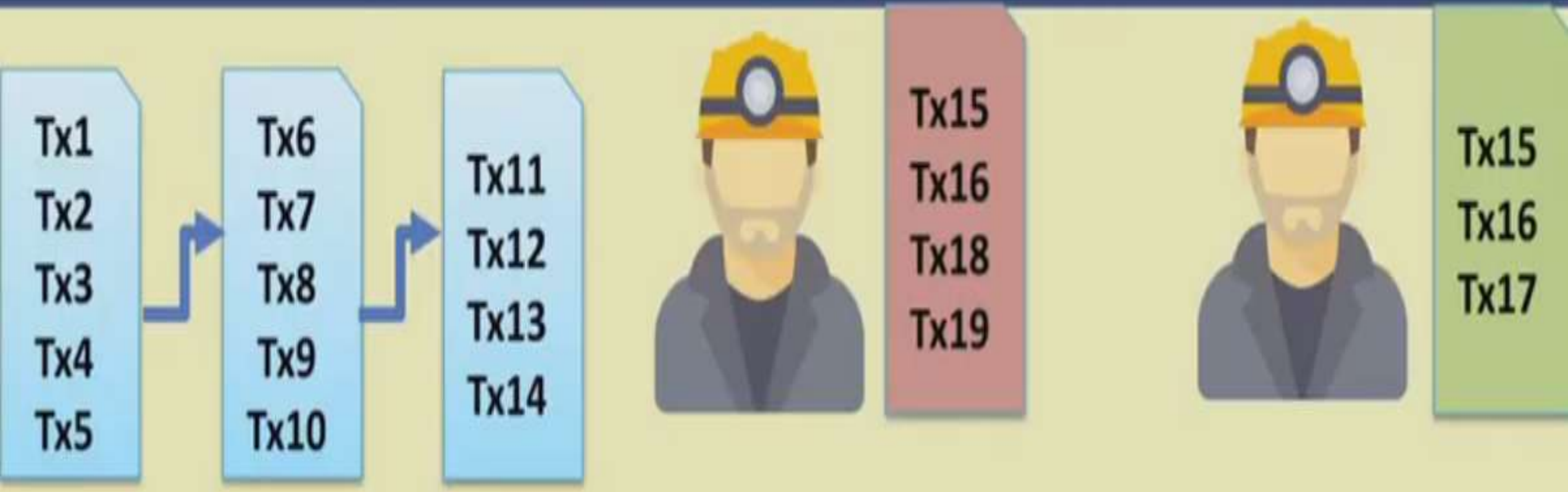
May not be Feasible:

You do not have a global clock! How much time will you wait to hear the transactions

Remember the impossibility result

Consensus in Bitcoin



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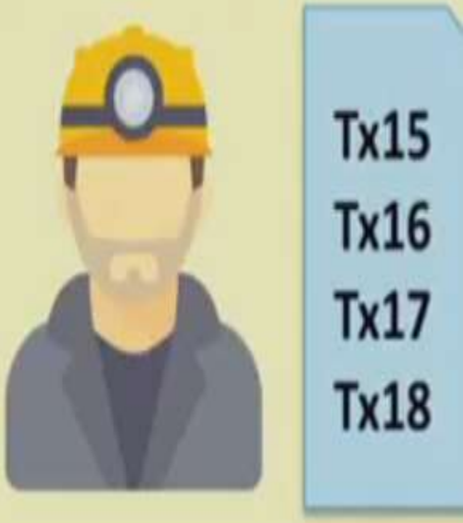

Tx15
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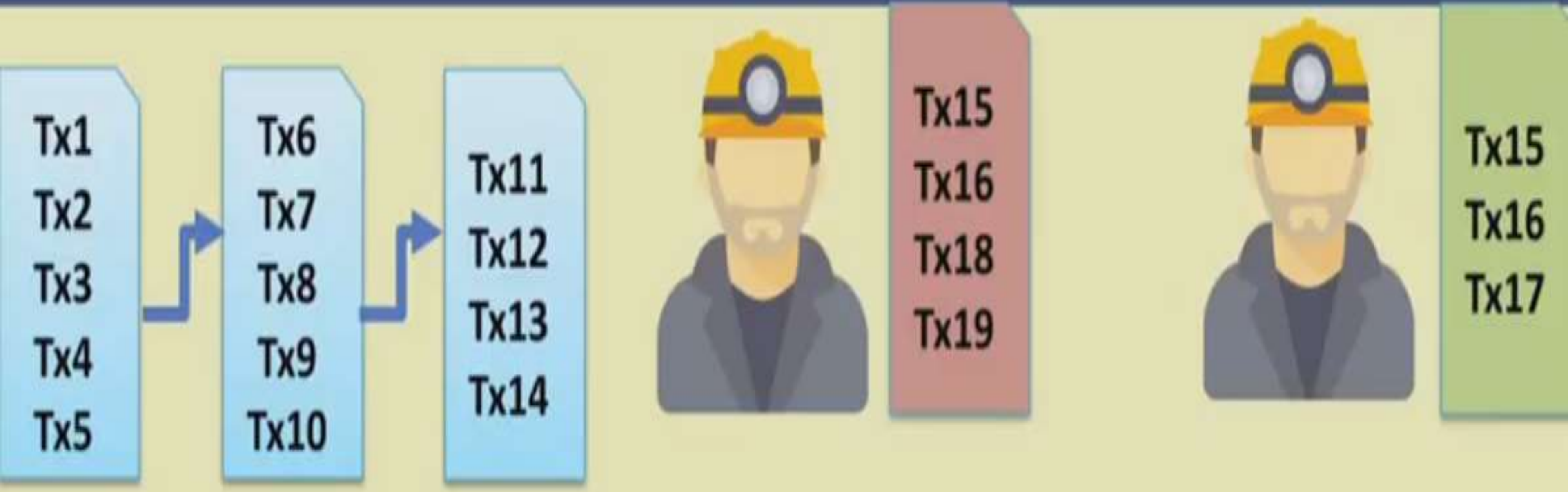
Observation - 1:

- Any valid block (a block with all valid transactions) can be accepted, even if it is proposed by only one miner

Consensus in Bitcoin



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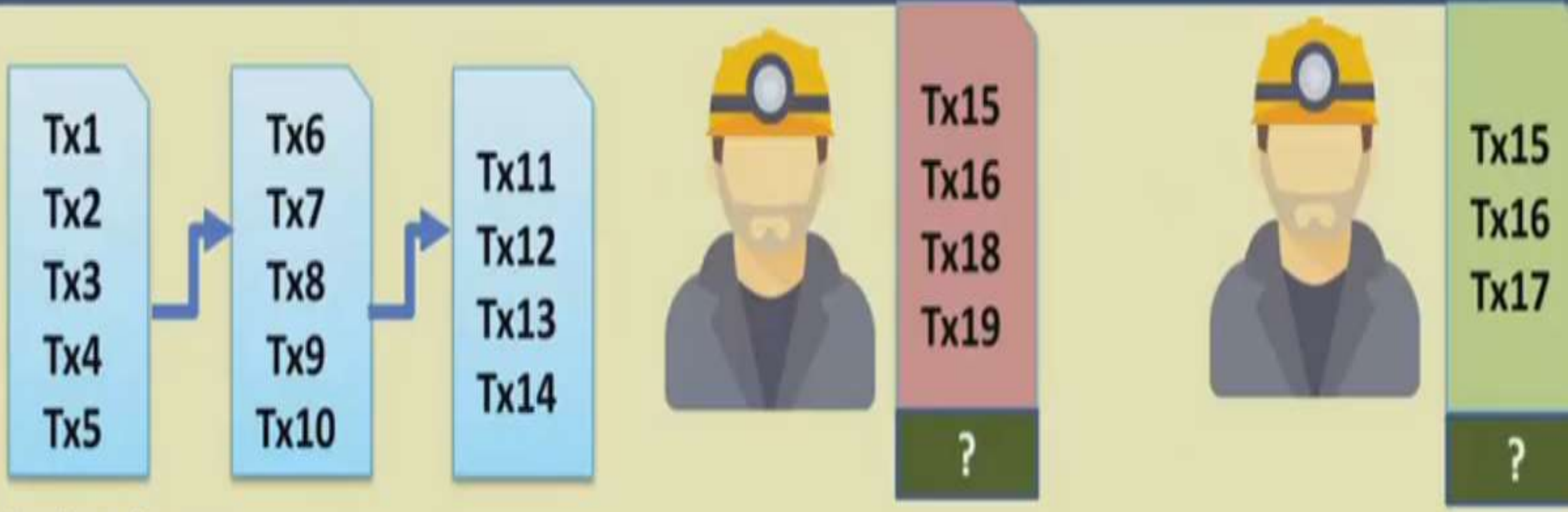
Observation - 2:

- The protocol can work in rounds
  - Broadcast the accepted block to the peers
  - Collect the next set of transactions

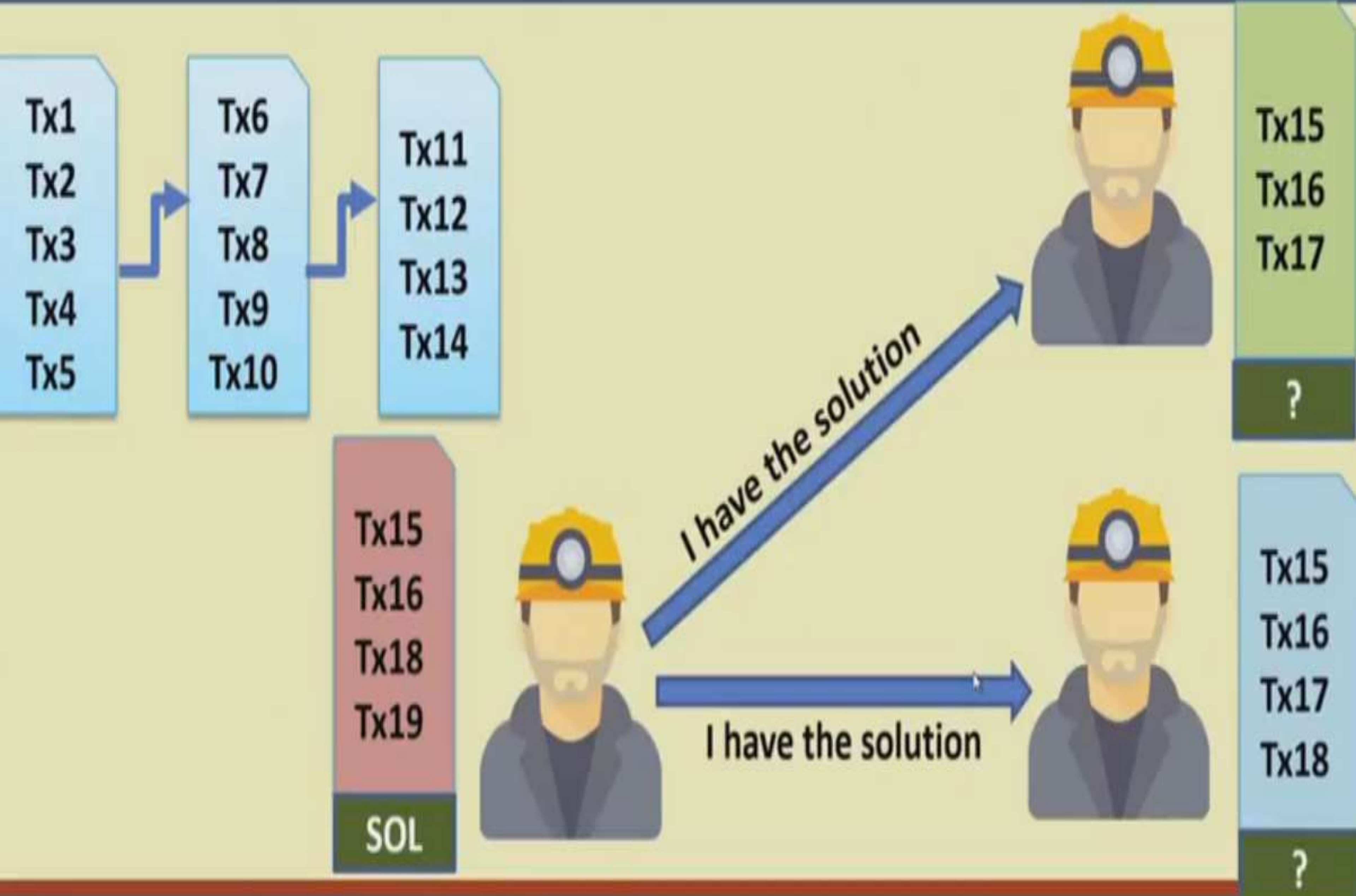
Consensus in Bitcoin



Solution:

- Every miner independently tries to solve a challenge
- The block is accepted for the miner who can prove first that the challenge has been solved

Consensus in Bitcoin



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SOL

I have the solution

I have the solution

Tx15
Tx16
Tx17

?

Tx15
Tx16
Tx17
Tx18

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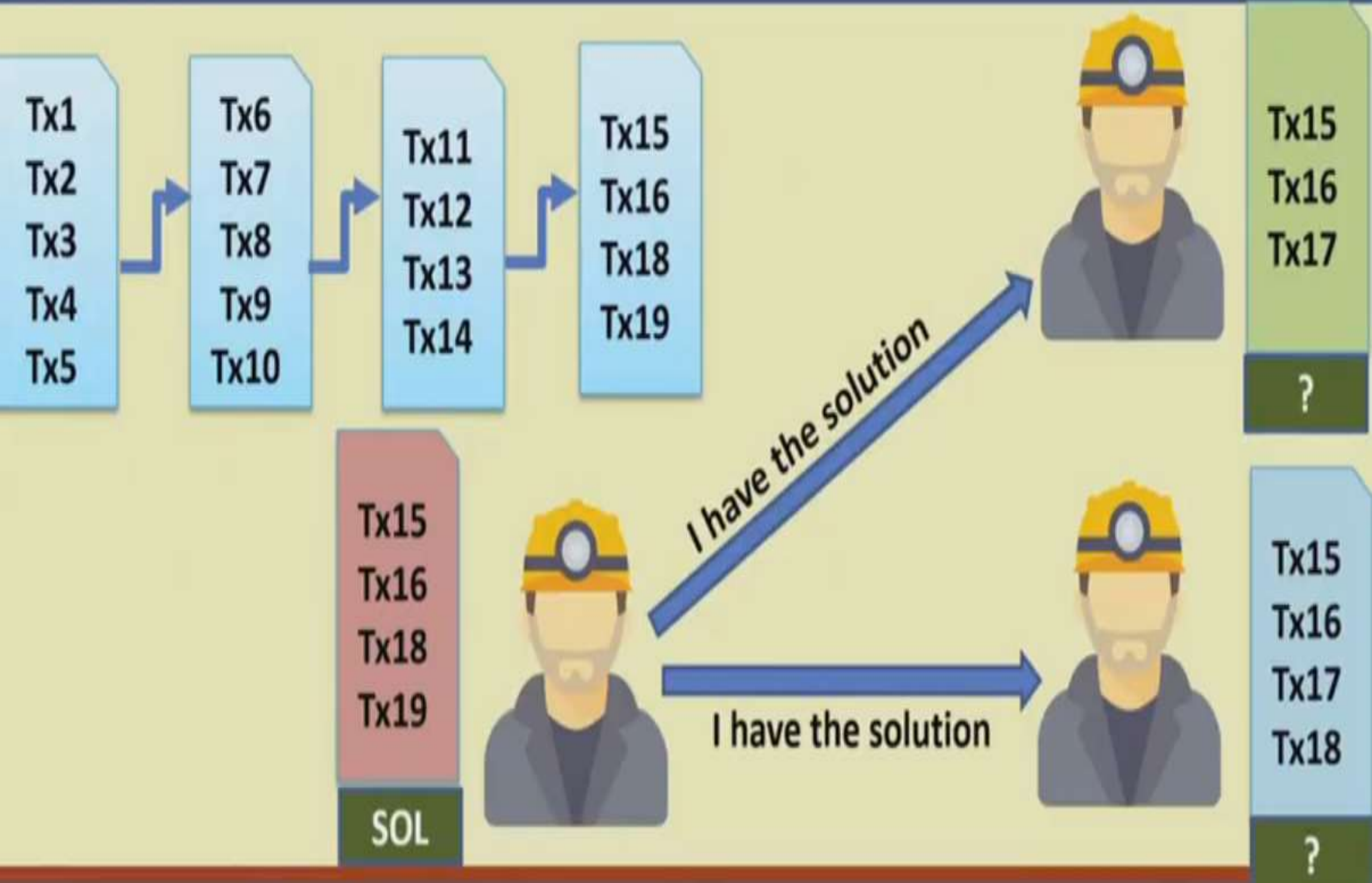
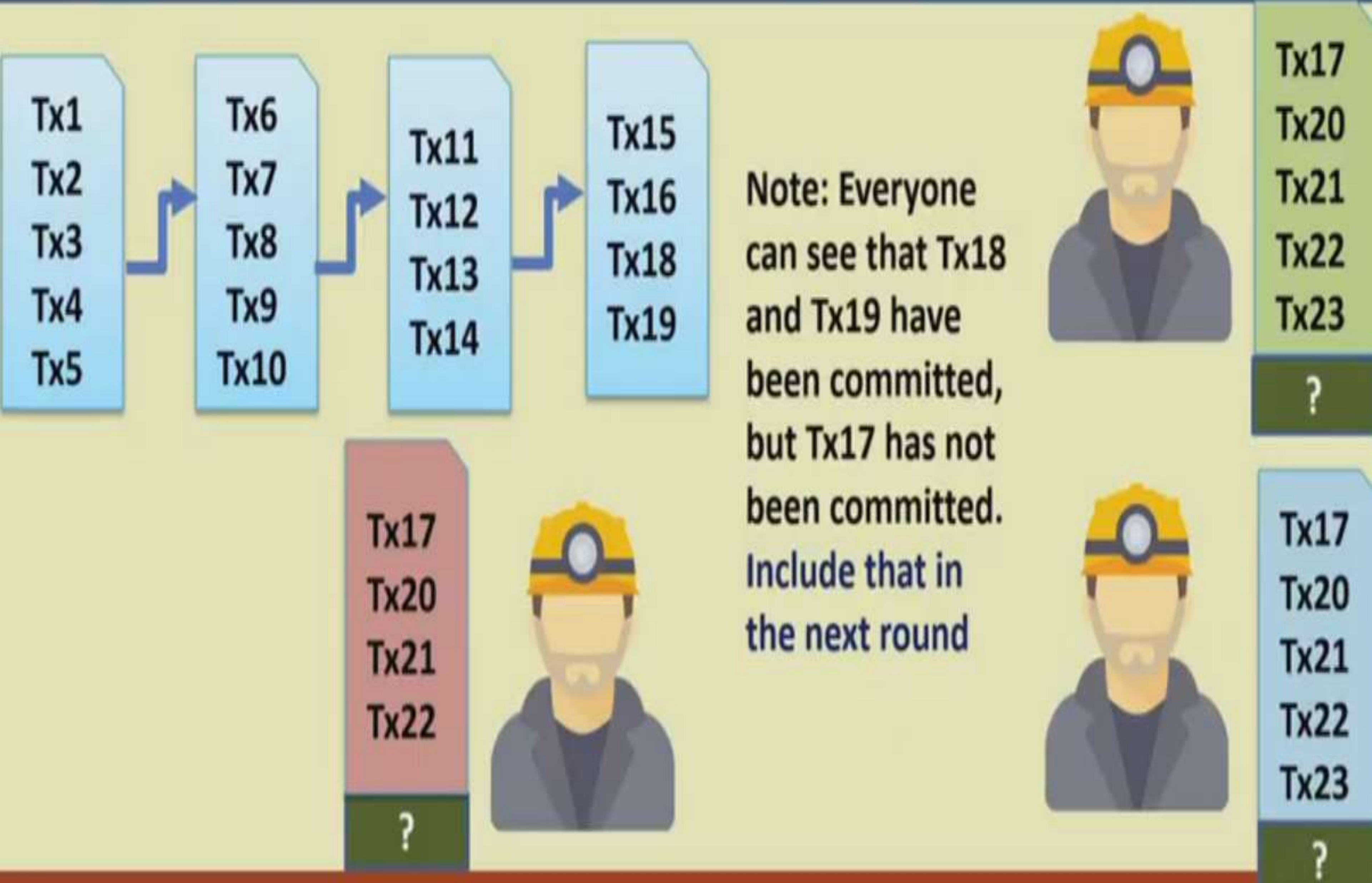
Consensus in Bitcoin



Consensus in Bitcoin



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Tx6 Tx7 Tx8 Tx9 Tx10

Tx11 Tx12 Tx13 Tx14

Tx15 Tx16 Tx18 Tx19

Tx17 Tx20 Tx21 Tx22

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Tx17 Tx20 Tx21 Tx22 Tx23

?

Tx17 Tx20 Tx21 Tx22 Tx23

?

Note: Everyone can see that Tx18 and Tx19 have been committed, but Tx17 has not been committed. Include that in the next round

THANK YOU