Bitcoin system (in a nutshell)

Tim Roughgarden, Incentives in Computer Science
Lecture #9: Incentives in Bitcoin Mining,
http://timroughgarden.org/f16/l/l9.pdf

Transactions

A Bitcoin transaction:

1. One or more senders.
2. One or more recipients.
3. The amount of BTC (Bitcoins) transferred from each sender to each recipient.
4. A proof of ownership of the coins being transferred, in the form of a pointer back to most recent transactions involving the transferred coins.
5. A transaction fee, paid by the sender to the authorizer of the transaction.

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the ledger: the record of all the authorized transactions.

Transactions

Two important questions:

1. How do transactions get authorized and added to the ledger?
   (Traditionally, this would done by a centralized entity like a bank.)

2. How do Bitcoins get created in the first place?
   (Traditionally, money is printed by the government.)

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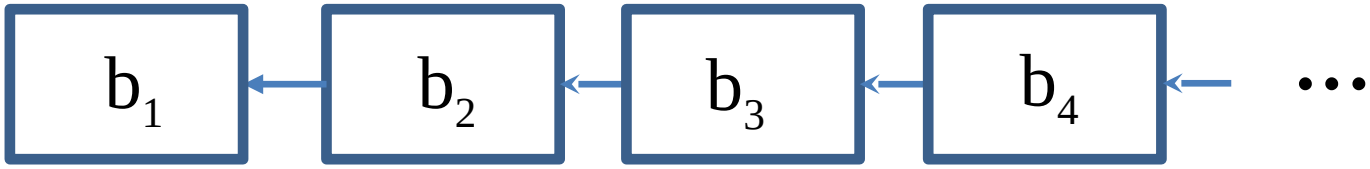

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Two key ingredients:

1. Any user can authorize a block. Bitcoin incentivizes users to do authorizations through explicit monetary rewards (in BTC, naturally).
2. Authorizing a new block of transactions involves a proof of work, meaning that the authorizer has to solve a computationally difficult puzzle.

Computational difficult puzzle

A block b is valid if $h(b)$ is sufficiently close to 0.

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parameter l chosen to keep the rate of valid block creation roughly every ten minutes

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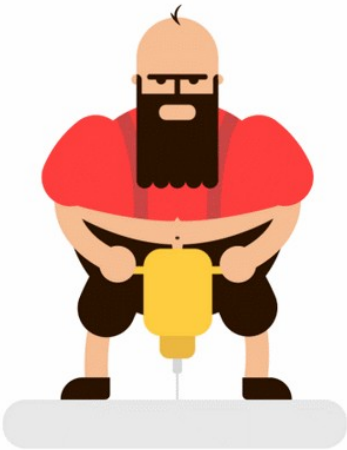
- chooses a subset of the transactions;
- inserts the hash of the current last block;
- arbitrarily set the bits in the nonce (and hope that the resulting block is valid).



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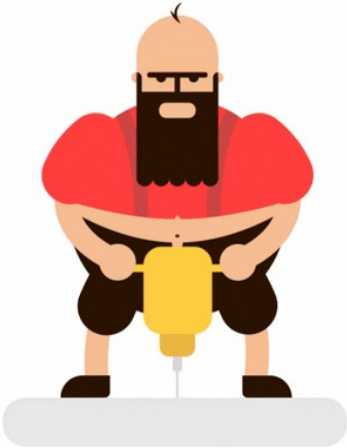
h is a cryptographic hash function

the accepted belief is that there is no algorithm for finding a valid block that is smarter or faster than random guessing or exhaustive search



Block Rewards and Bitcoin Mining

The reward that a miner gets for adding a new (valid) block to the blockchain has two ingredients:

1. A flat reward that does not depend on the contents of the block
   (When Bitcoin debuted this reward was 50 BTC, but the protocol dictates that this amount gets cut in half every four years. Currently, it is 6.25.)

2. The sum of the transaction fees of the transactions in the block
   (Currently, transaction fees are non-zero but typically constitute only a few percent of the overall reward.)

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the miner gets the new mined BTCs as special transaction inserted into the mined block

Forks

When a new valid block has been found:

-the miner is supposed to immediately broadcast it across the entire network, so that it gets appended to the blockchain;

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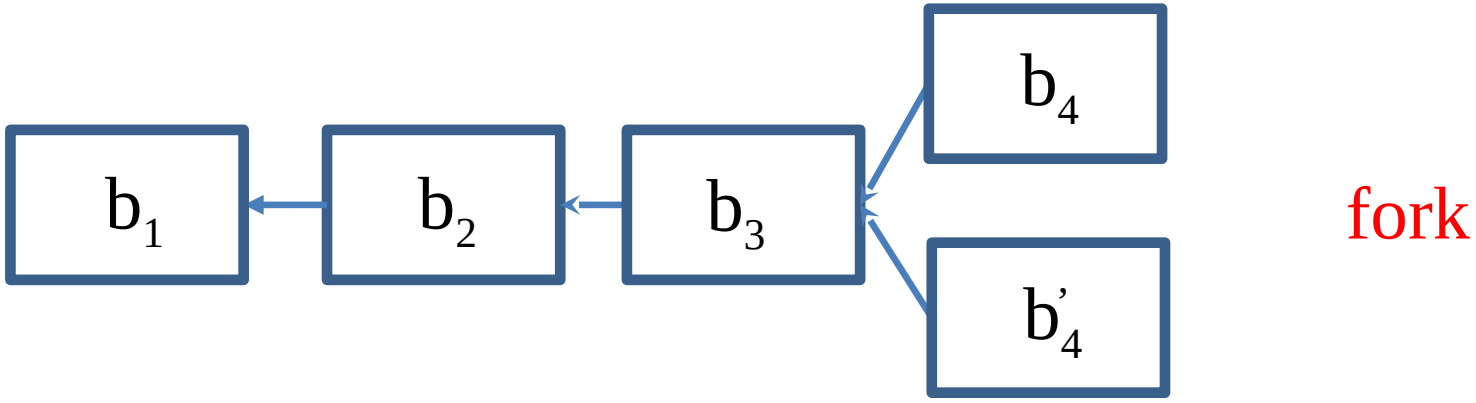
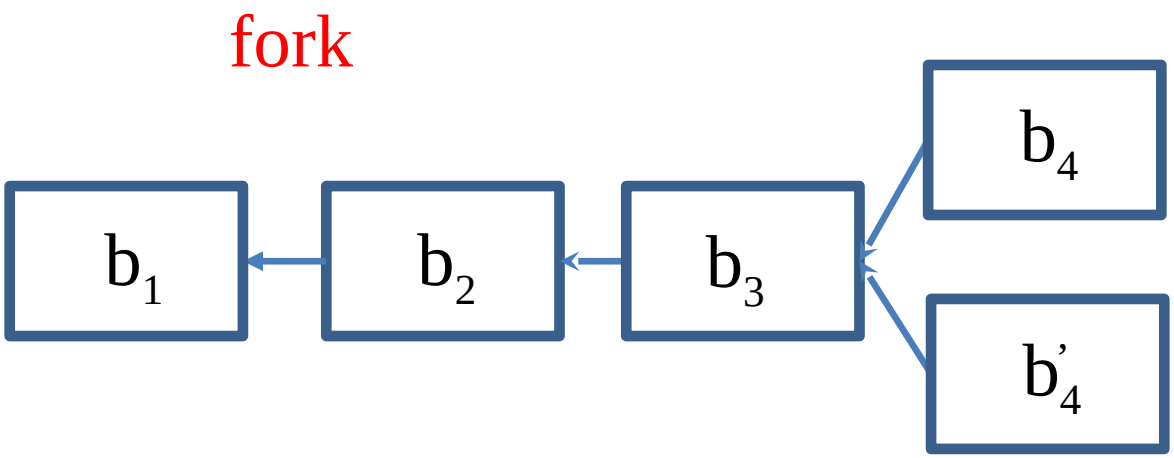
when two miners solve a block at roughly the same time:



Forks

Intended behavior when there is a fork:

- a user should regard the longest branch as the valid one;
- break ties according to the block that it heard about first.



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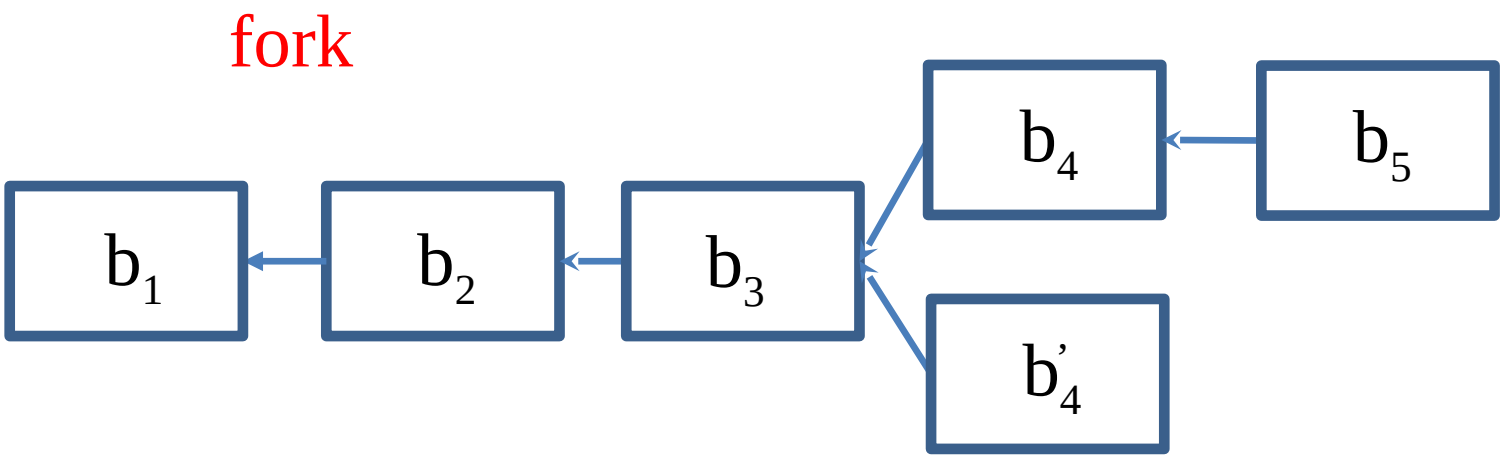

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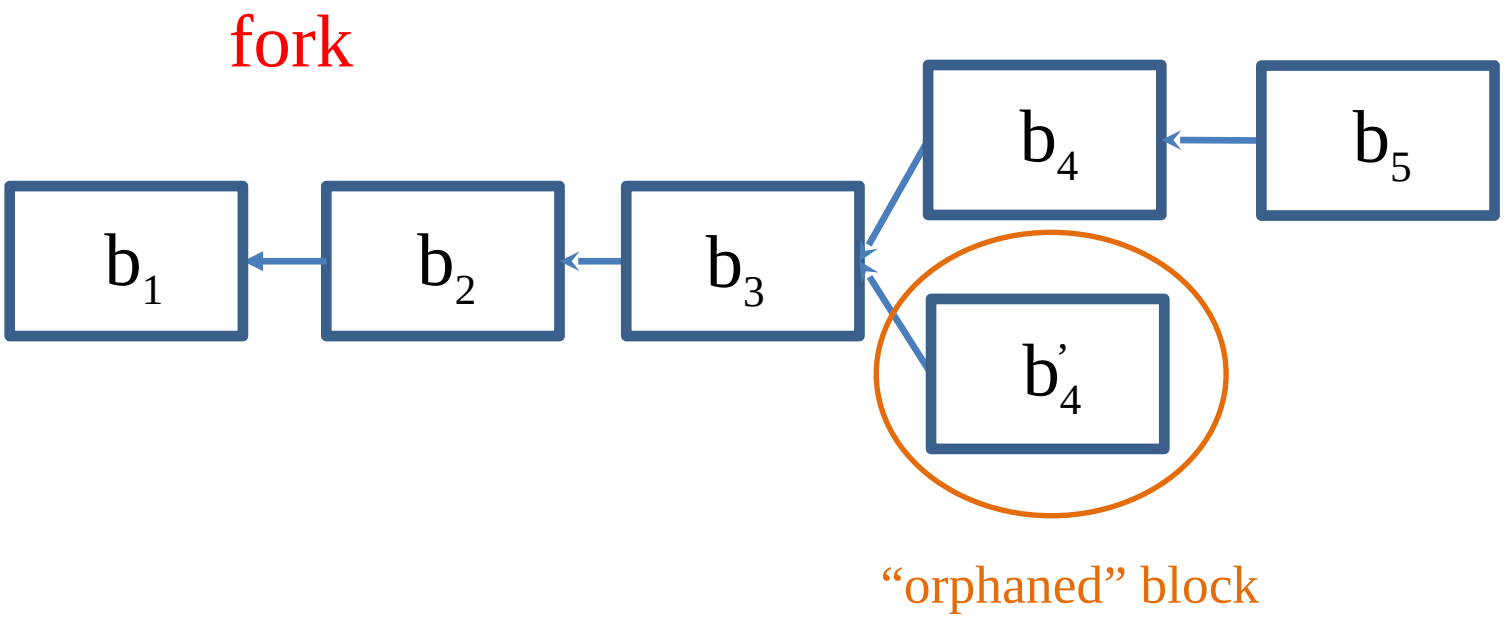

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Does a miner have convenience
to follow the protocol?

The Double-Spend Attack

Idea: miners deliberately create forks.

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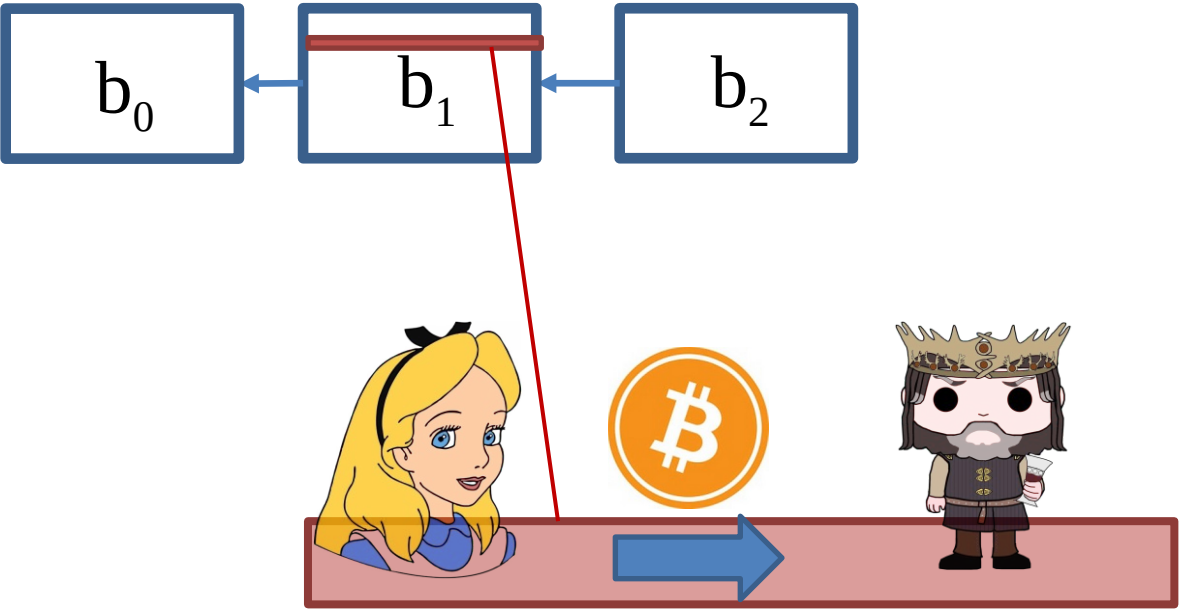
Assumption: Bob only ships the purchased goods to Alice once another block b_2 has been appended to b_1.



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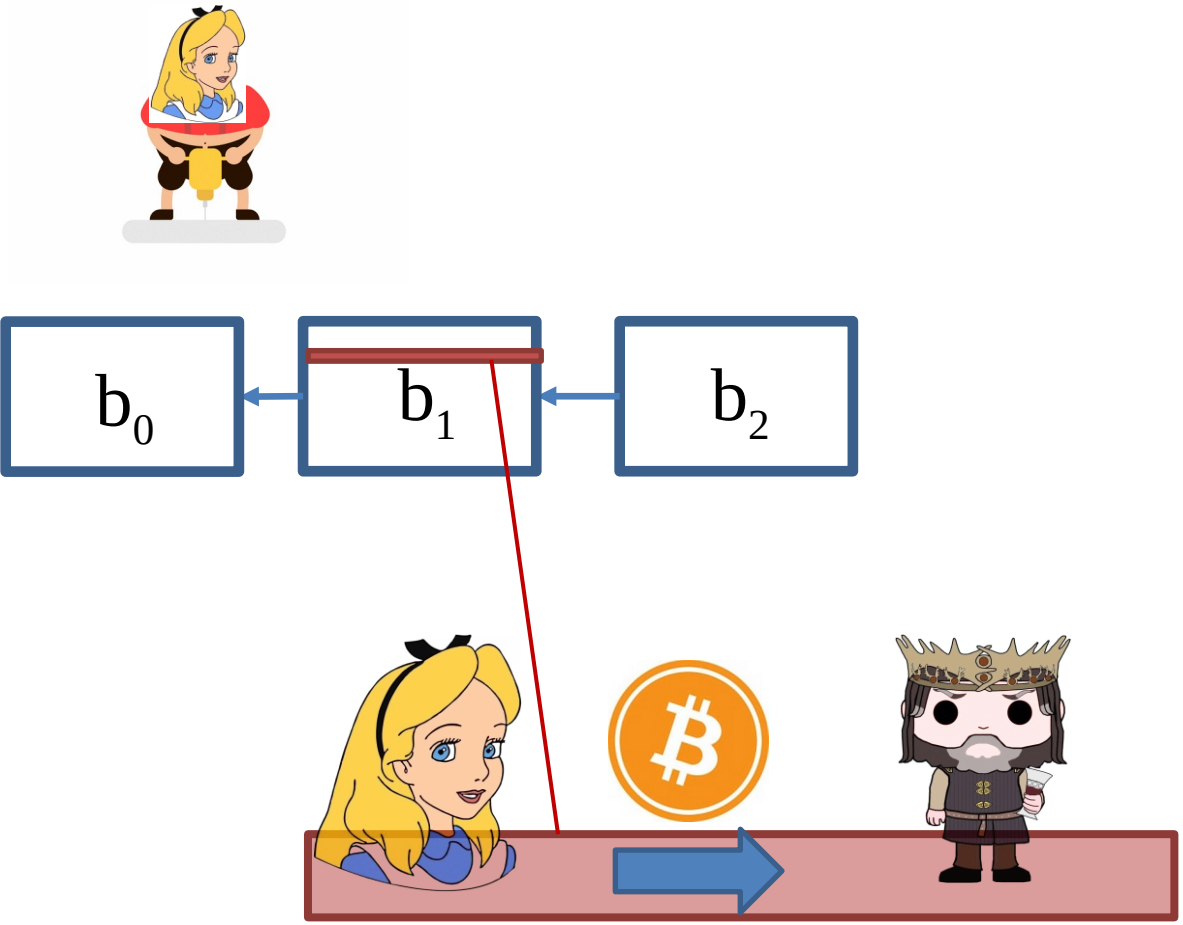

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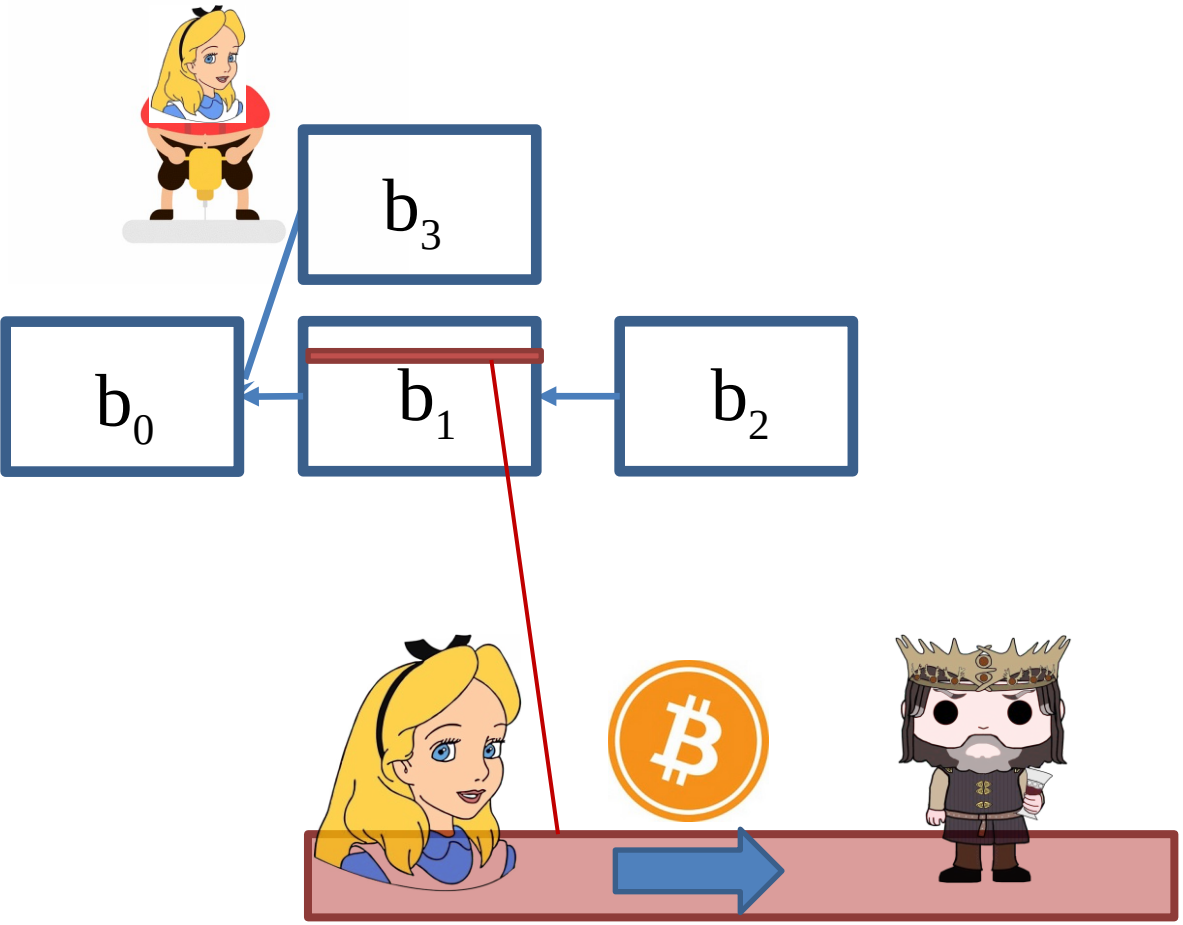

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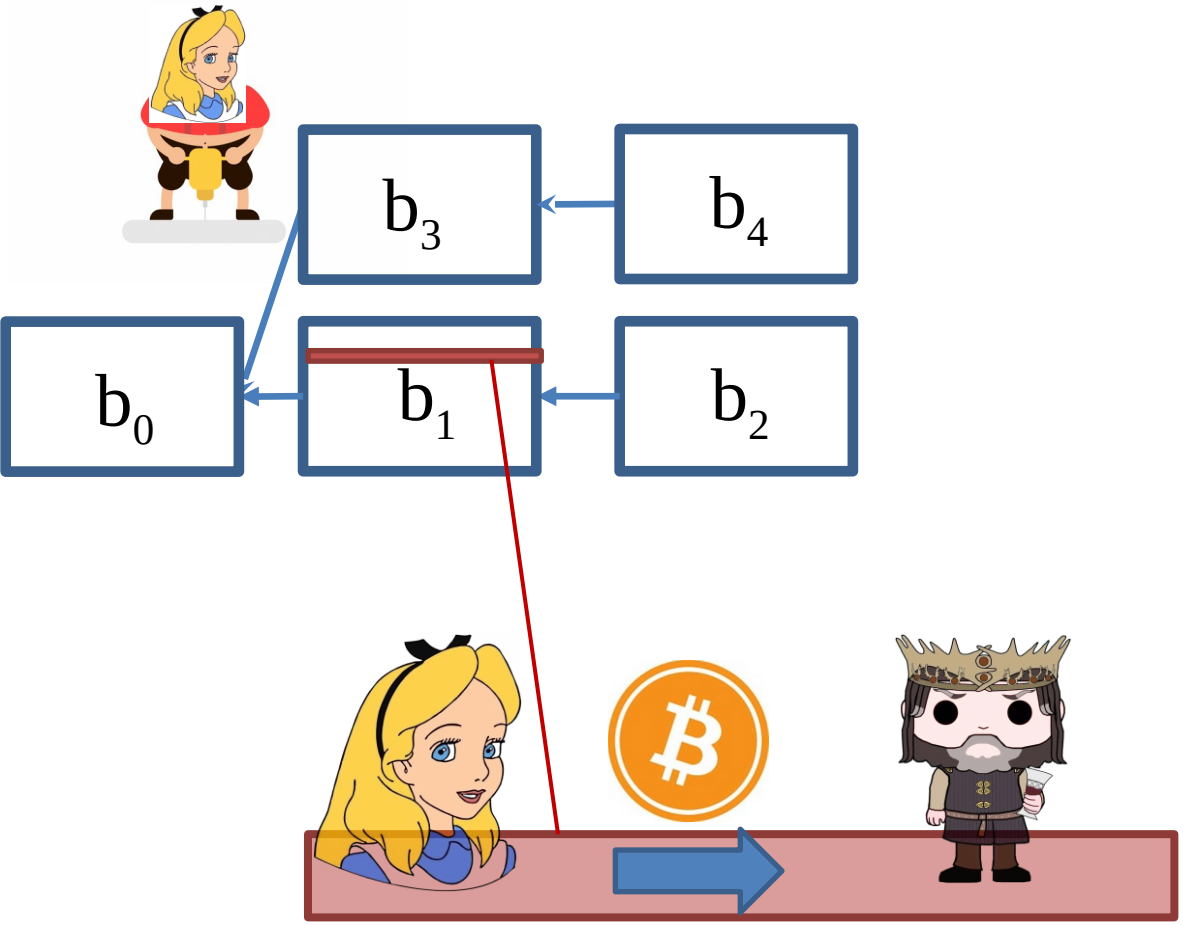

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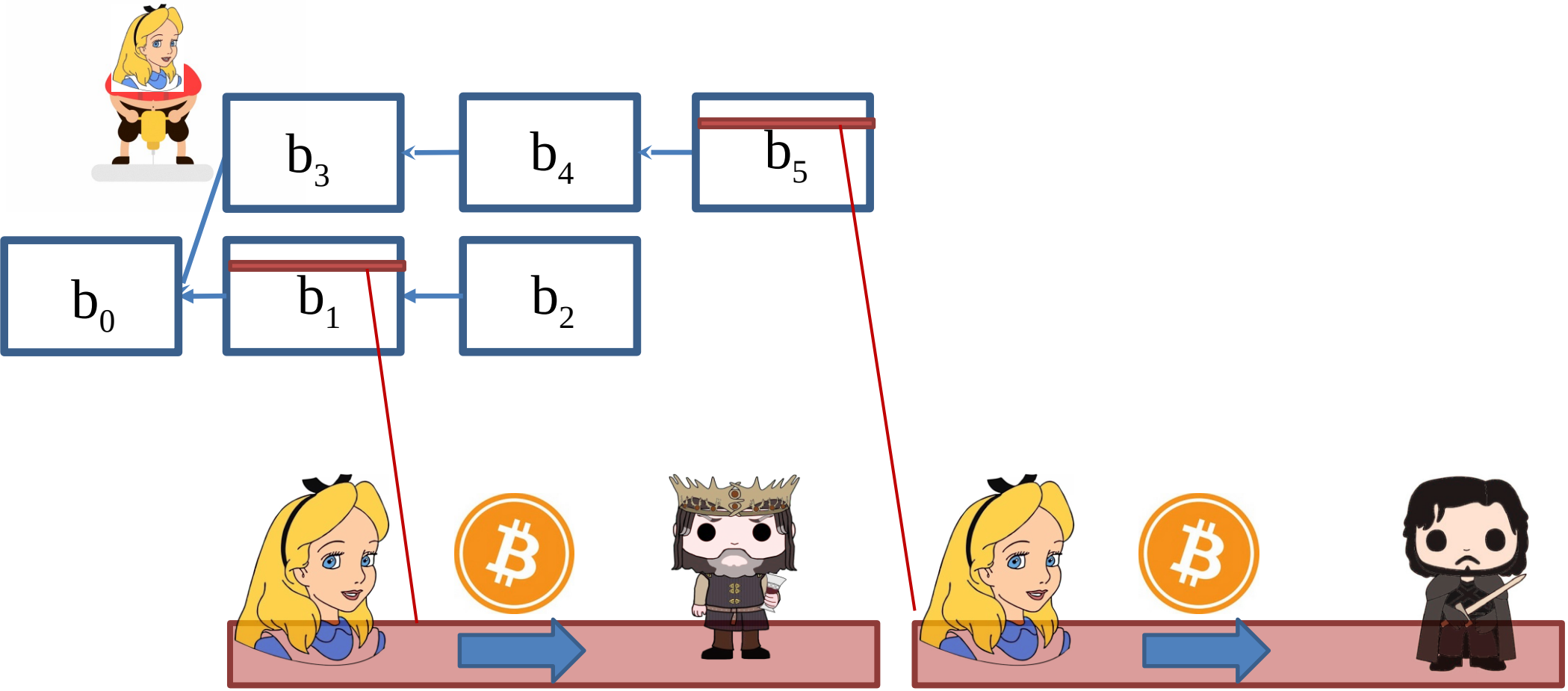

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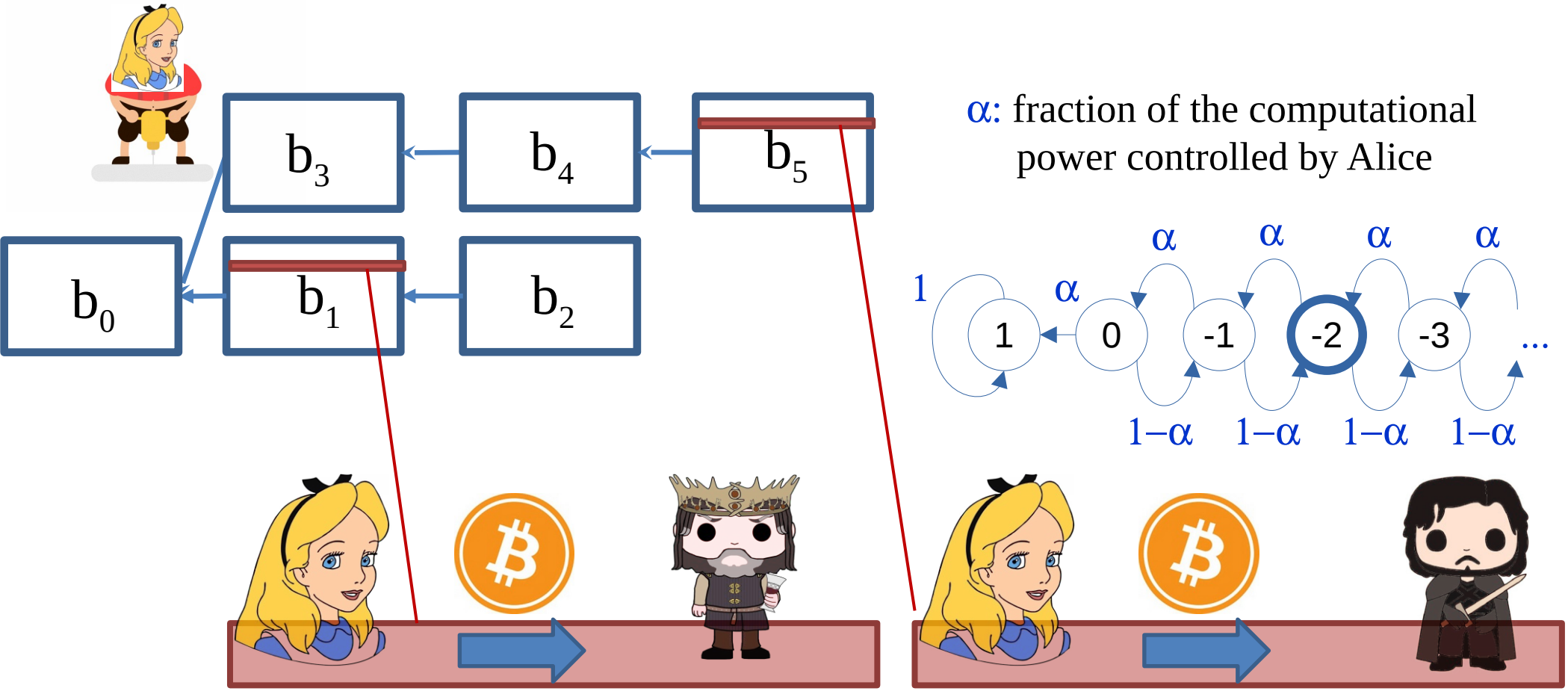

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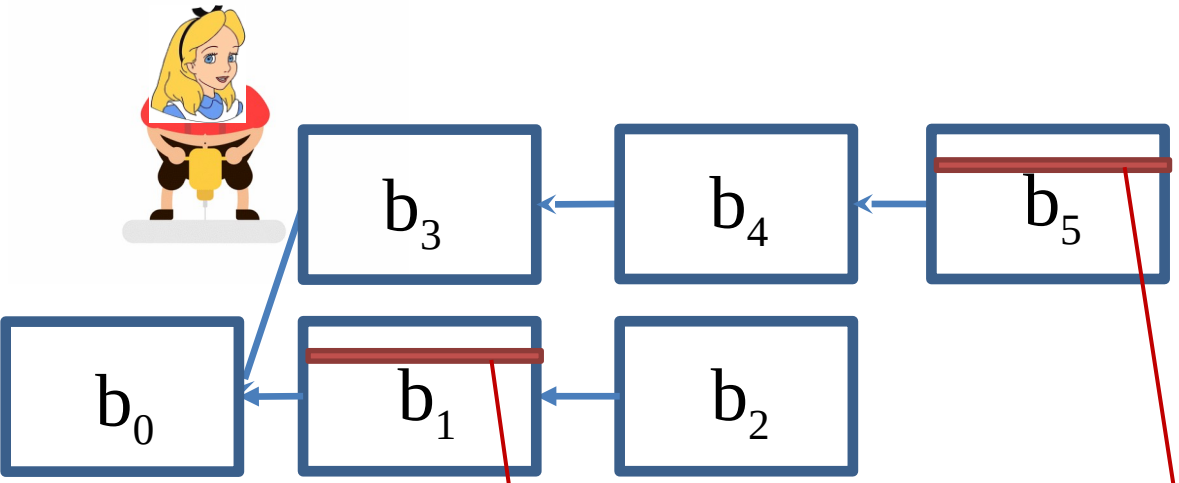
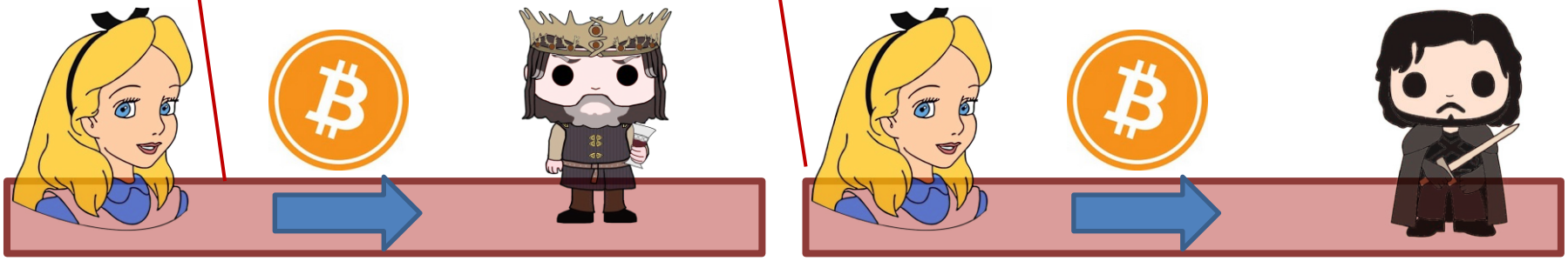


α: fraction of the computational power controlled by Alice

probability of success:
$(\alpha/(1-\alpha))^3$



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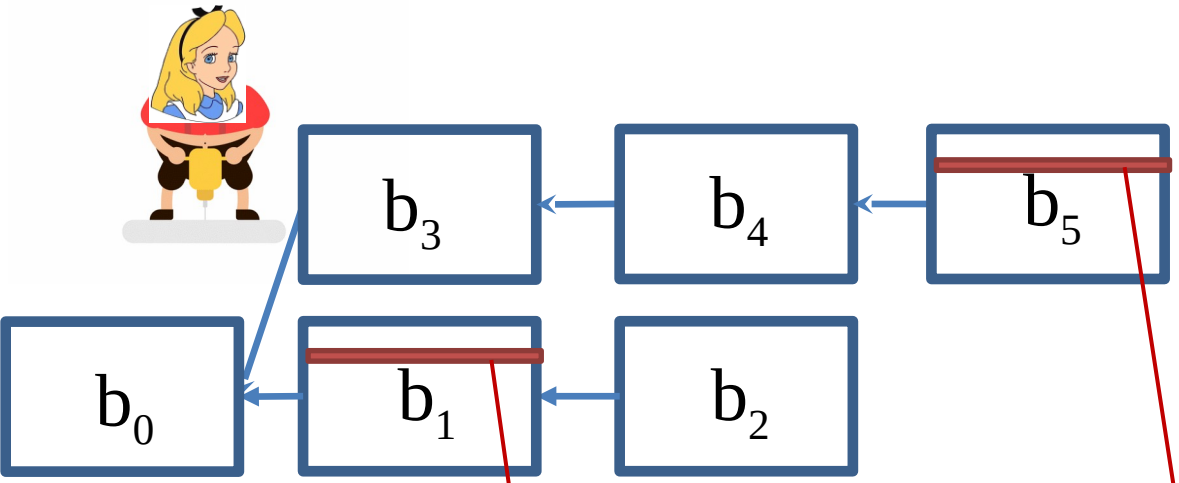
Assumption: Bob only ships the purchased goods to Alice once k other blocks have been appended to b_1.



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probability of success:

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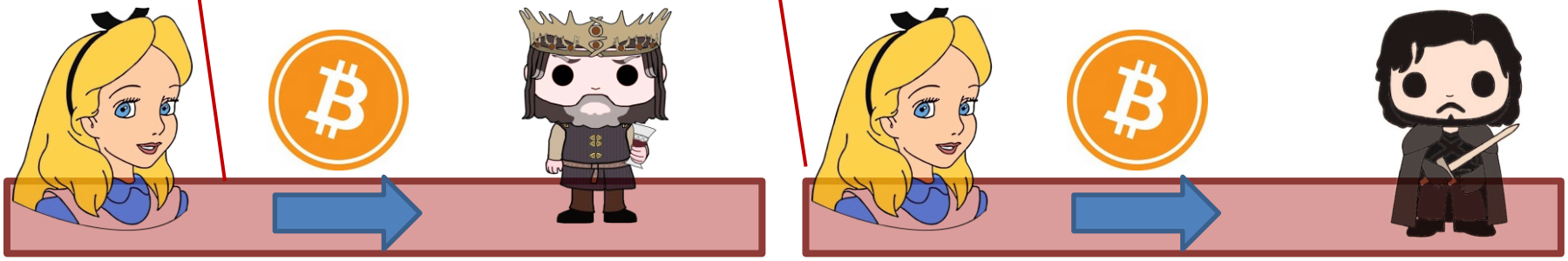
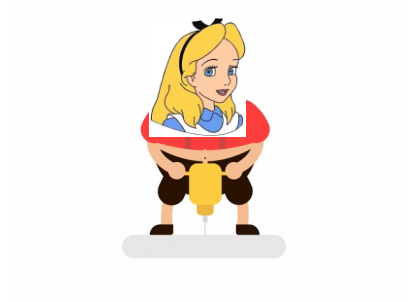
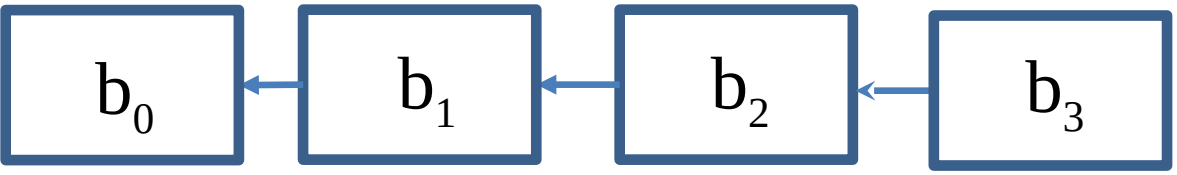


The 51% Attack

if Alice controls $\geq 50\%$ of the computational power





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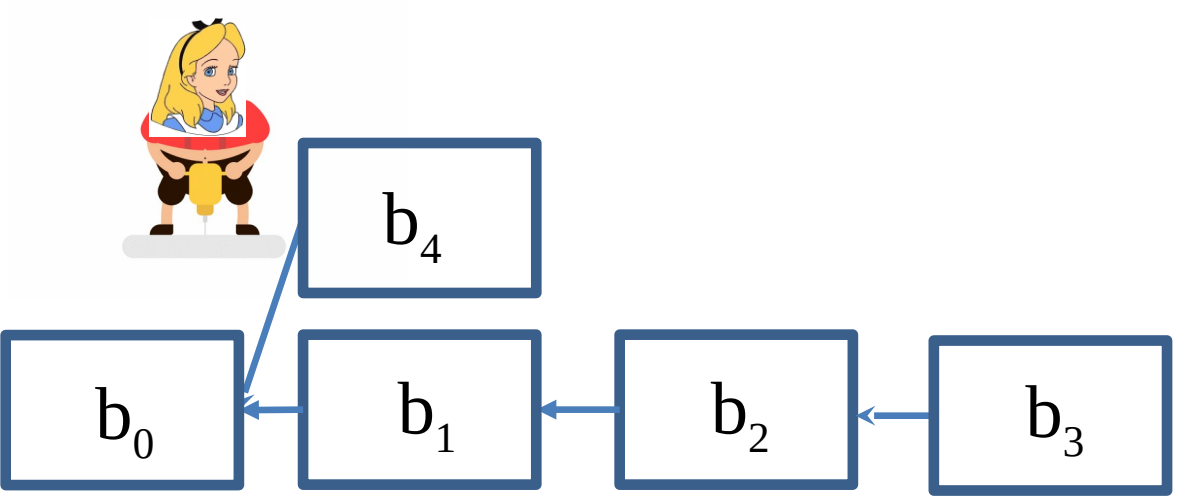

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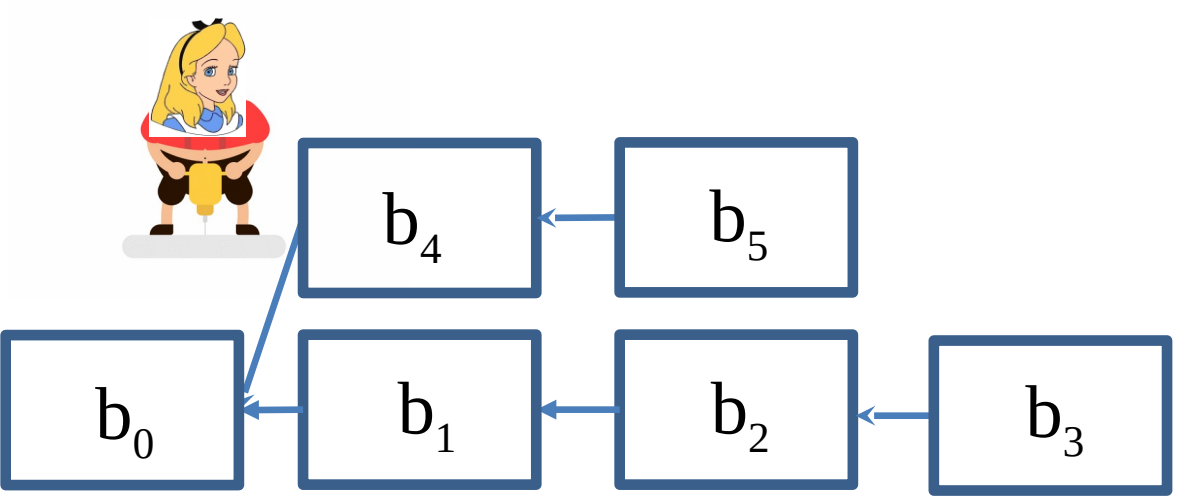

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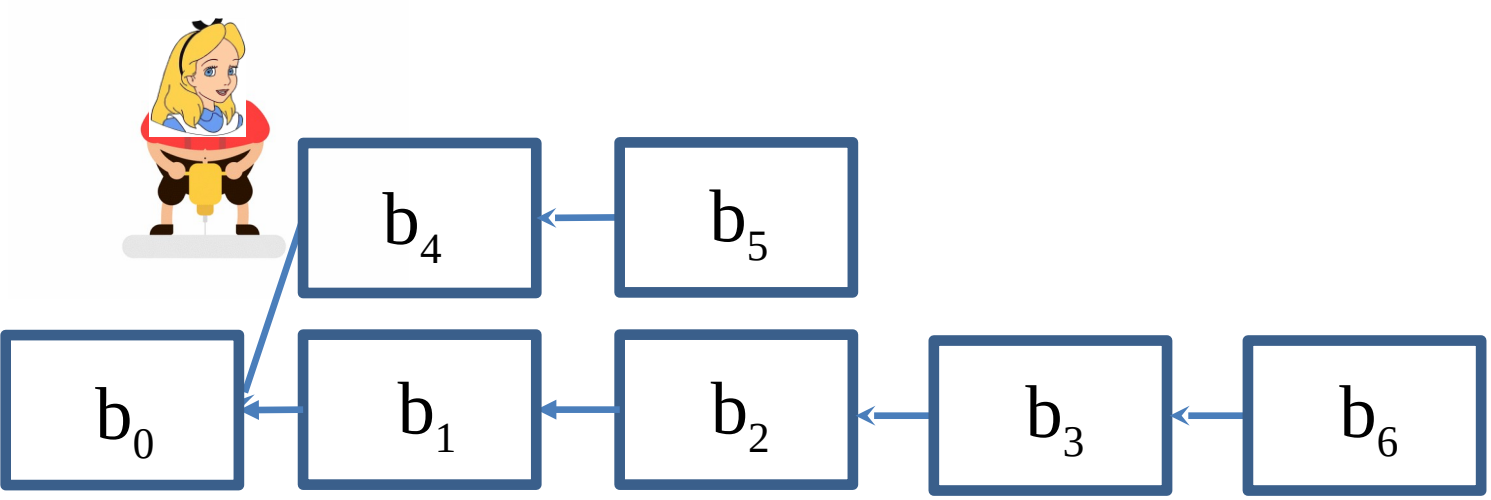

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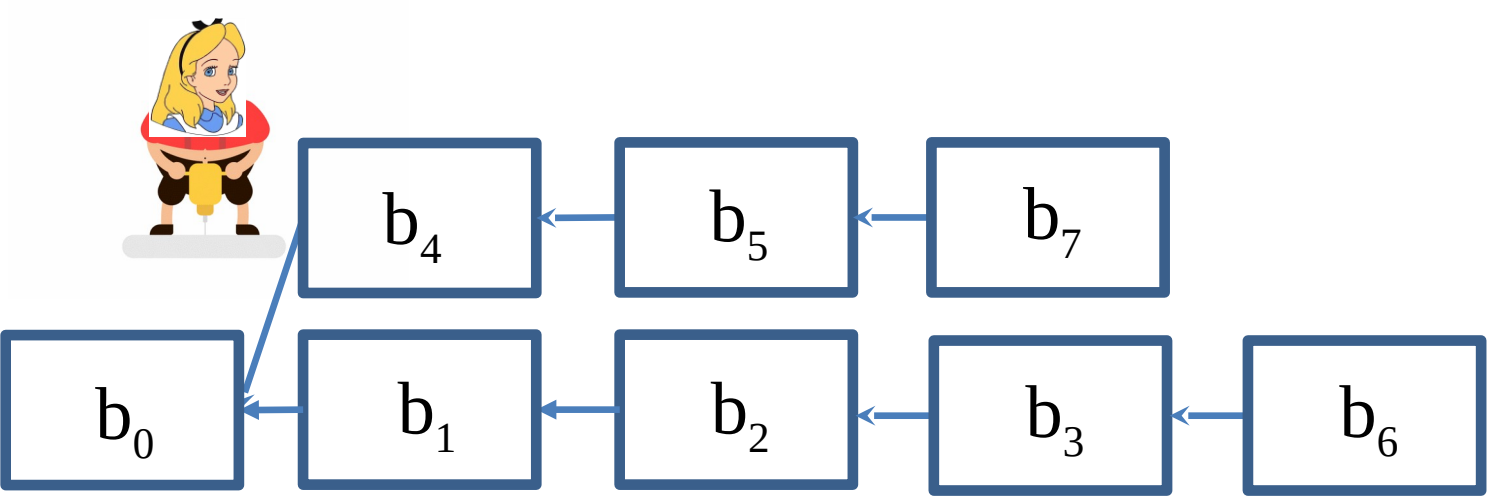

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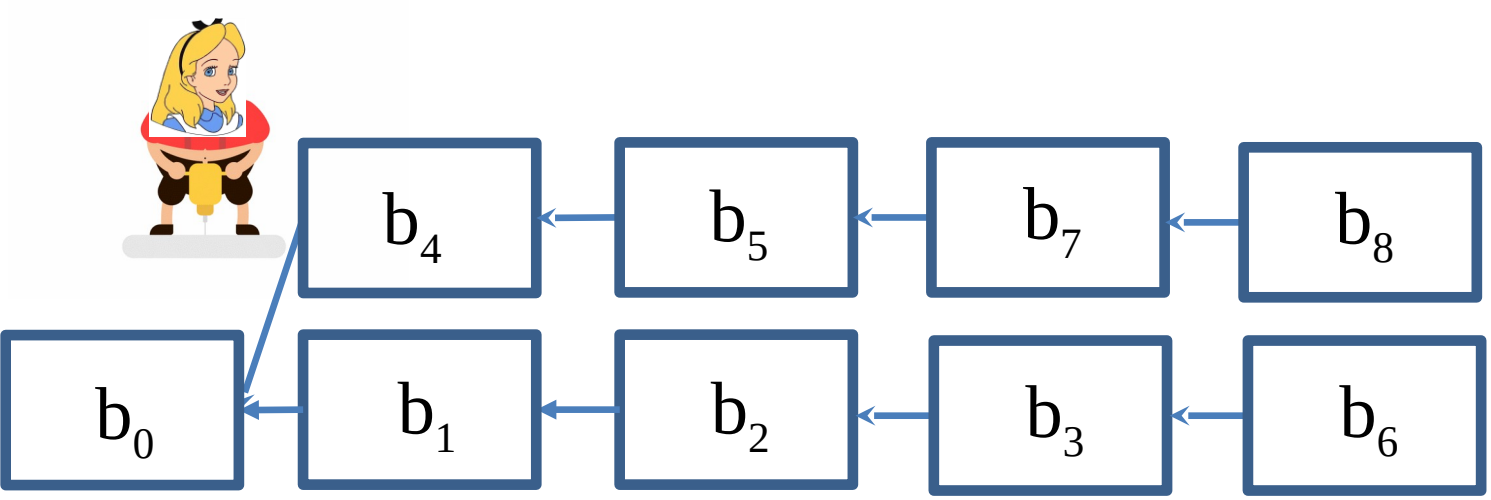

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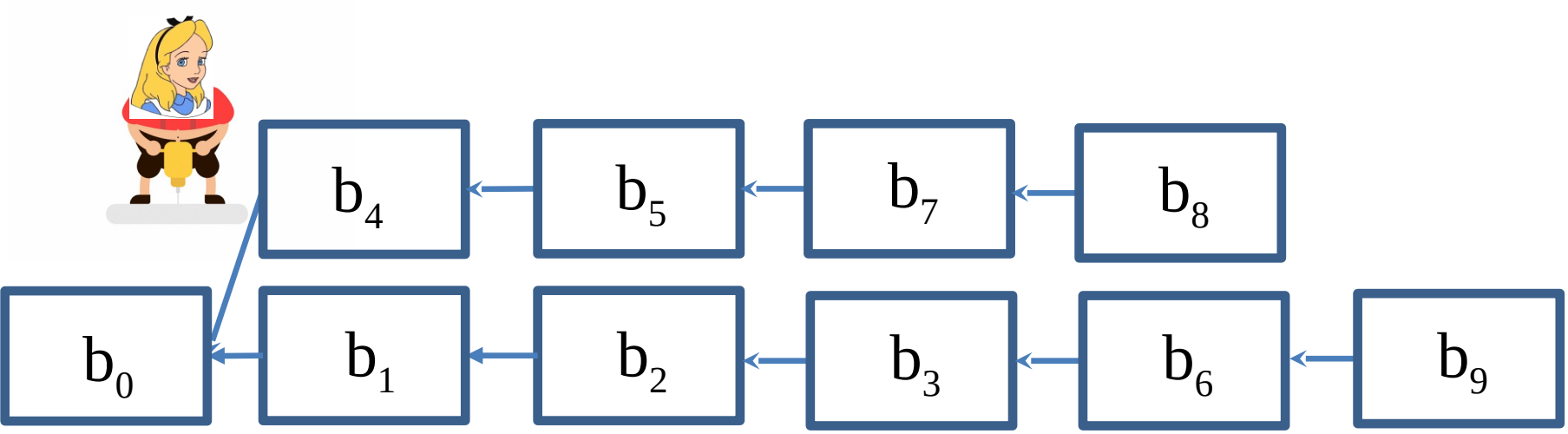

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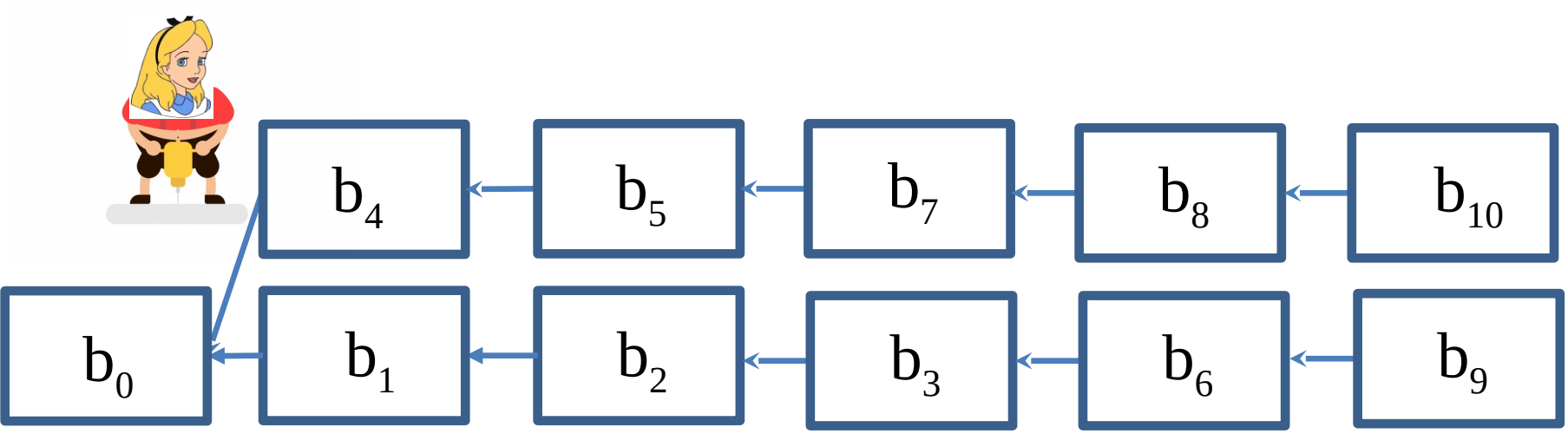

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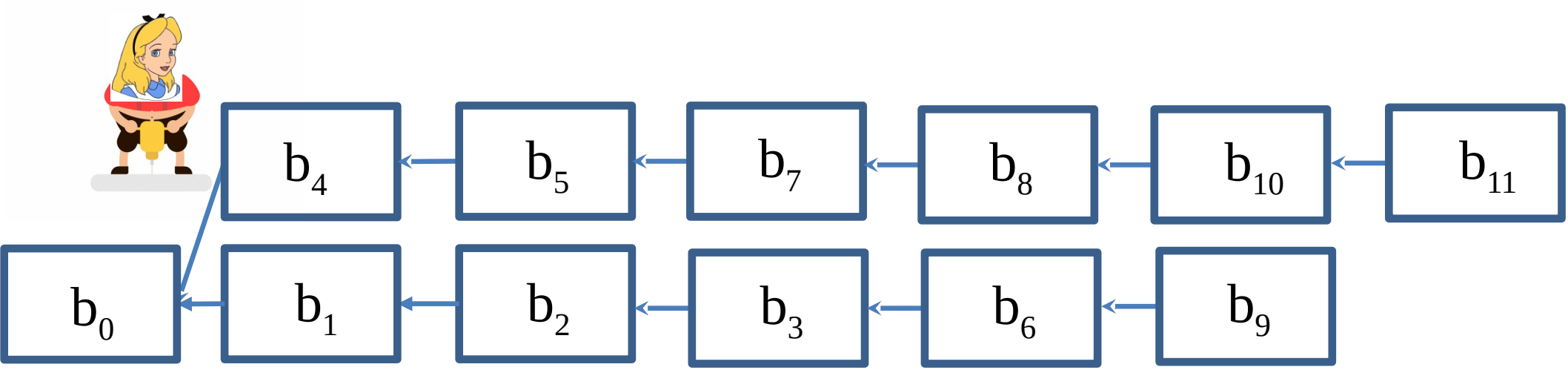

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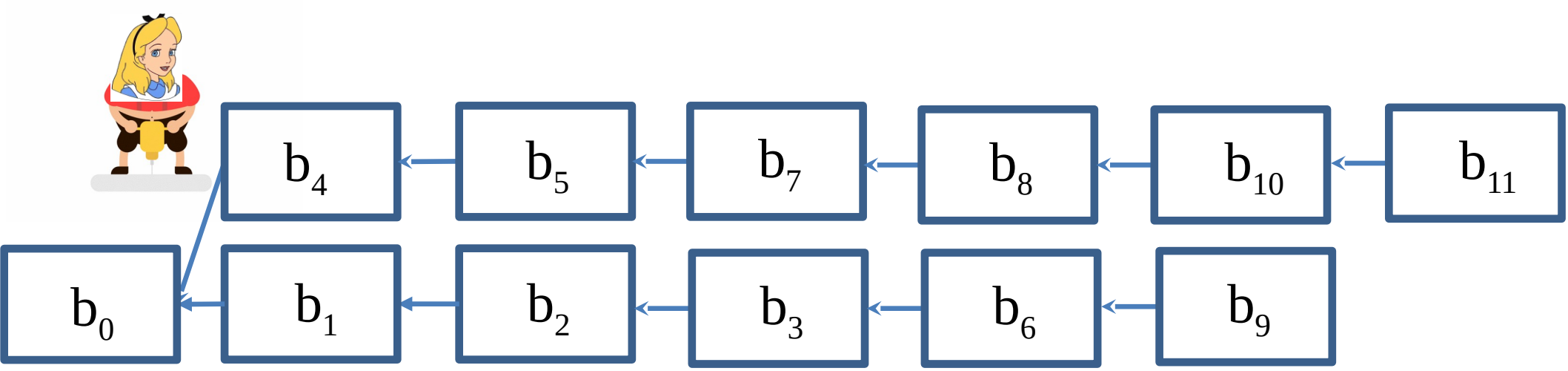

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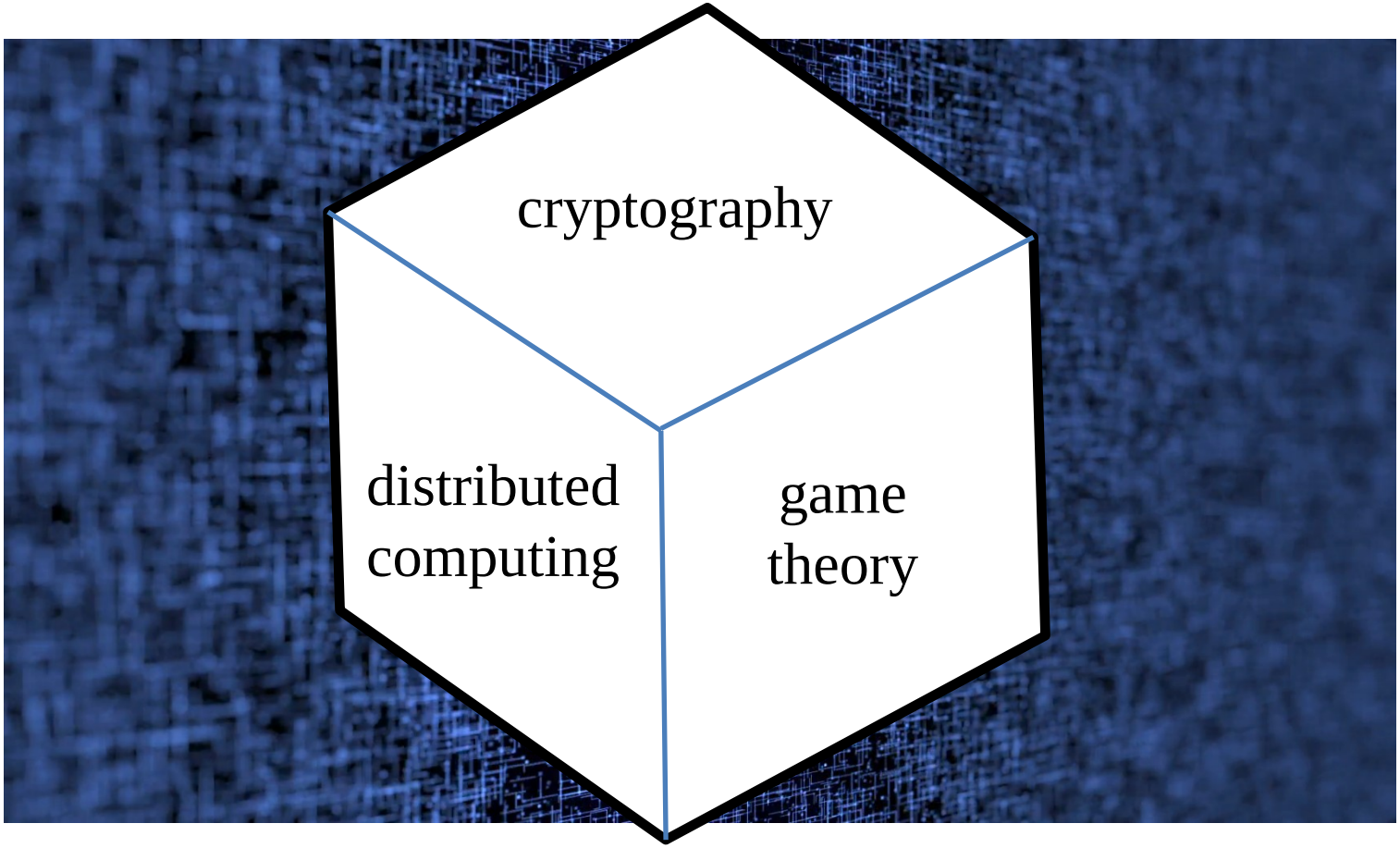
Alice will eventually build the longest chain (with probability 1)

Consensus & fault tolerance: distributed and strategic aspects of the Blockchain technology

Aspects of the Blockchain technology



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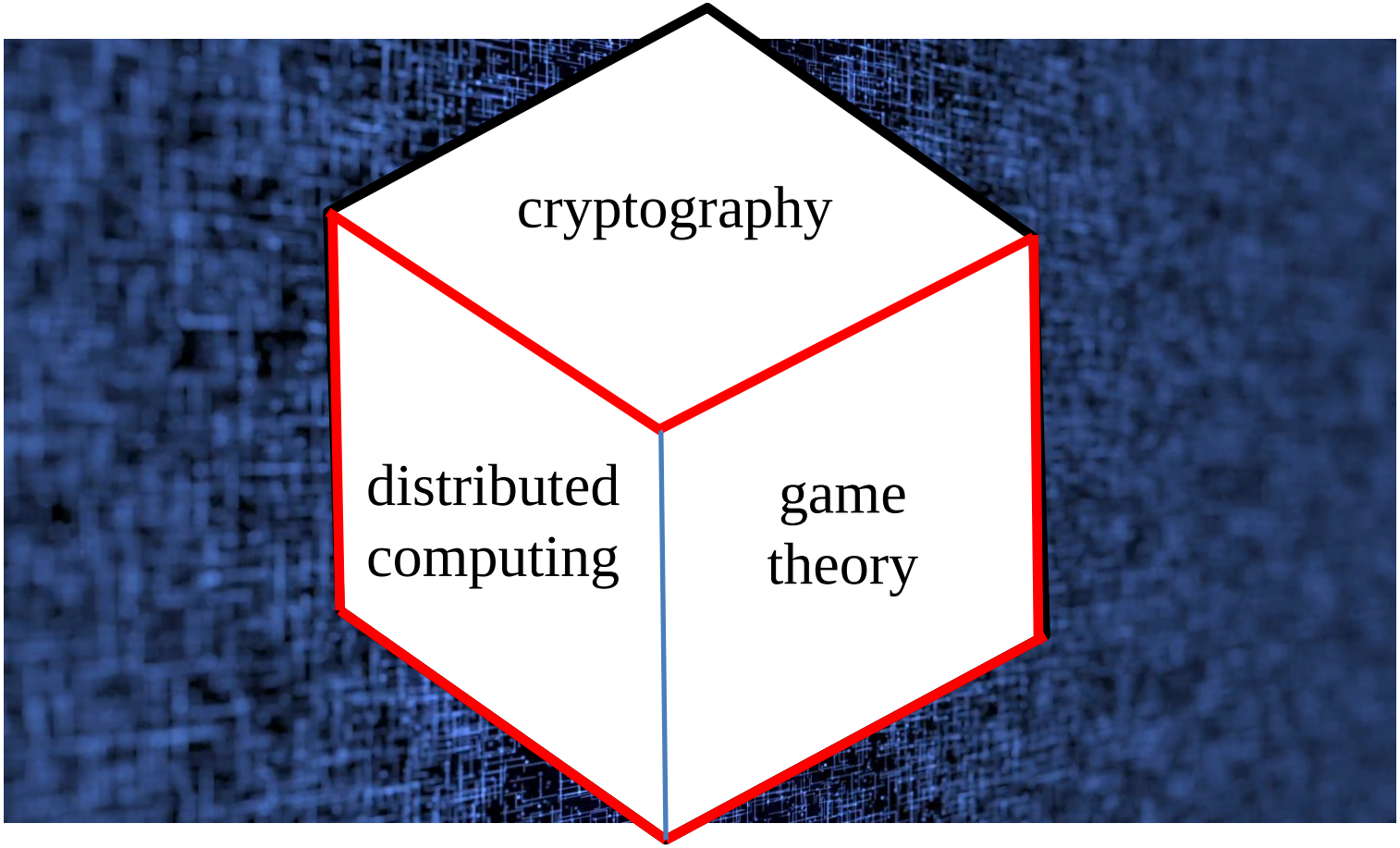

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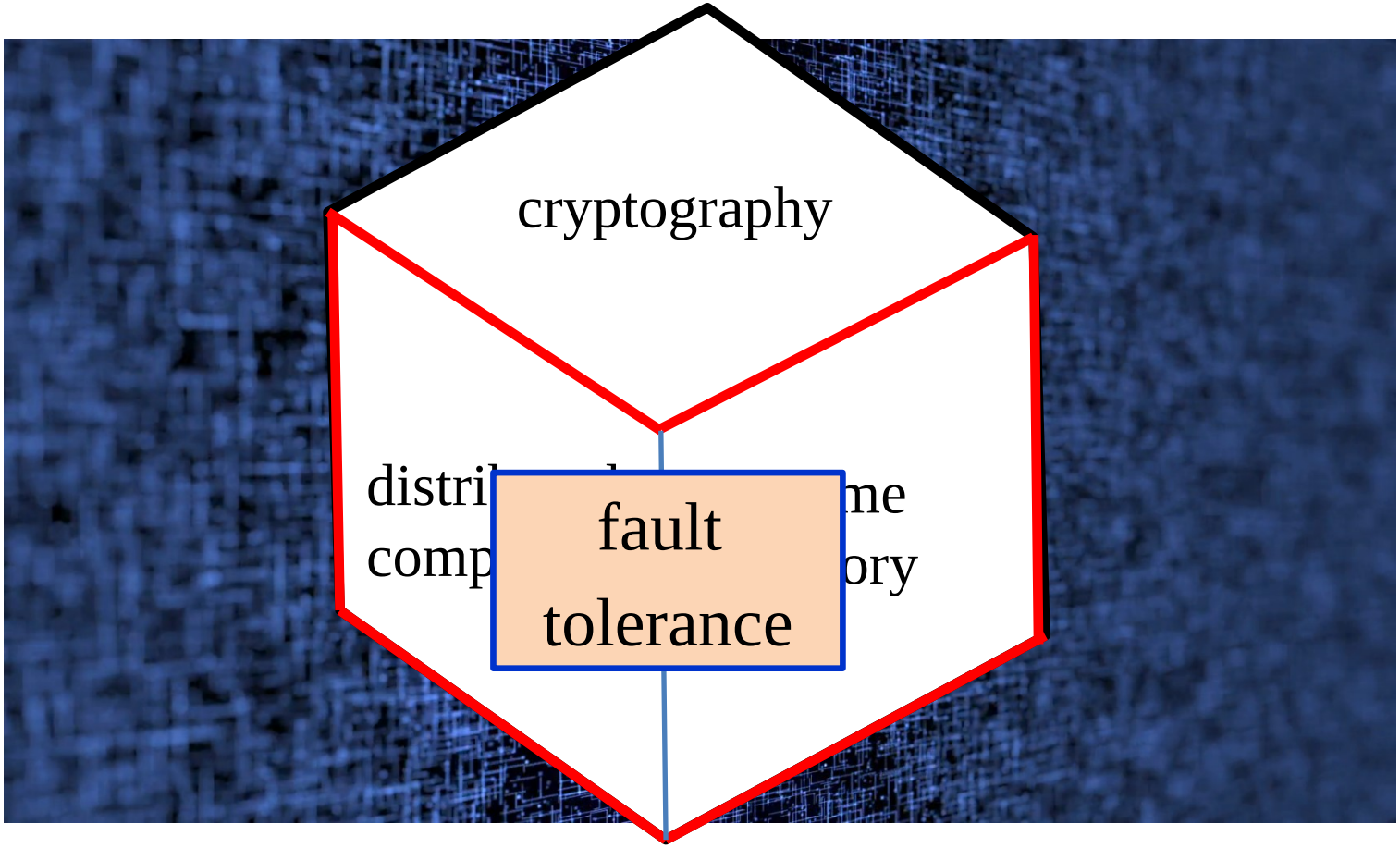
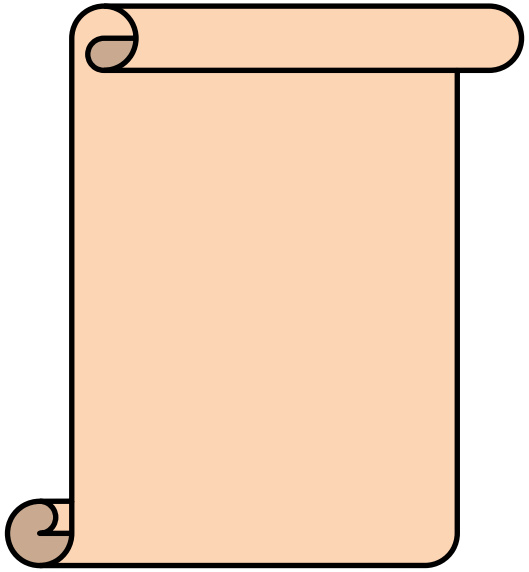


the distributed ledger problem

problem:

maintain a ledger containing a sequence of commands such that:

- all agents agree on the content of the ledger
- every agent can fairly write its commands



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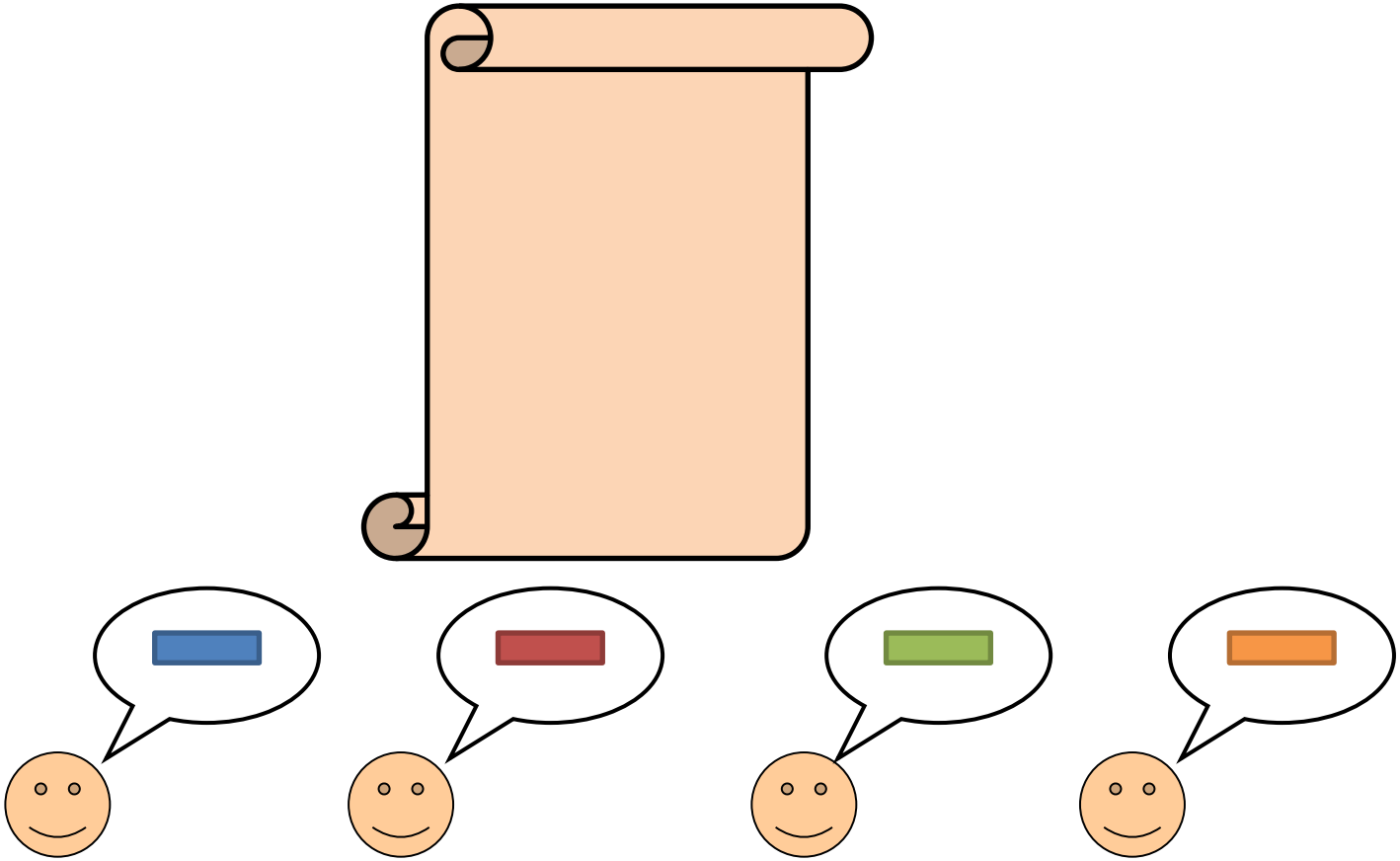

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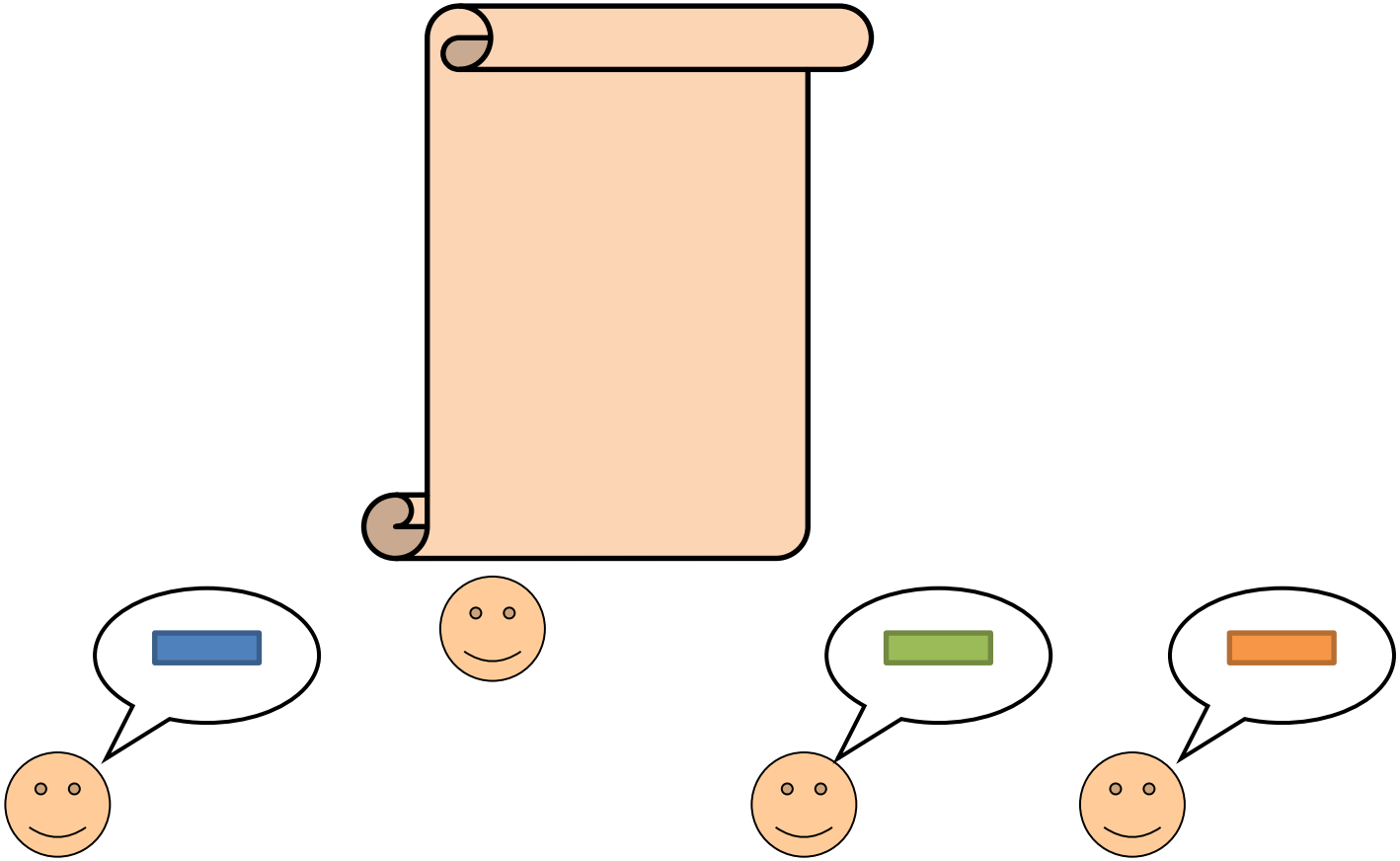

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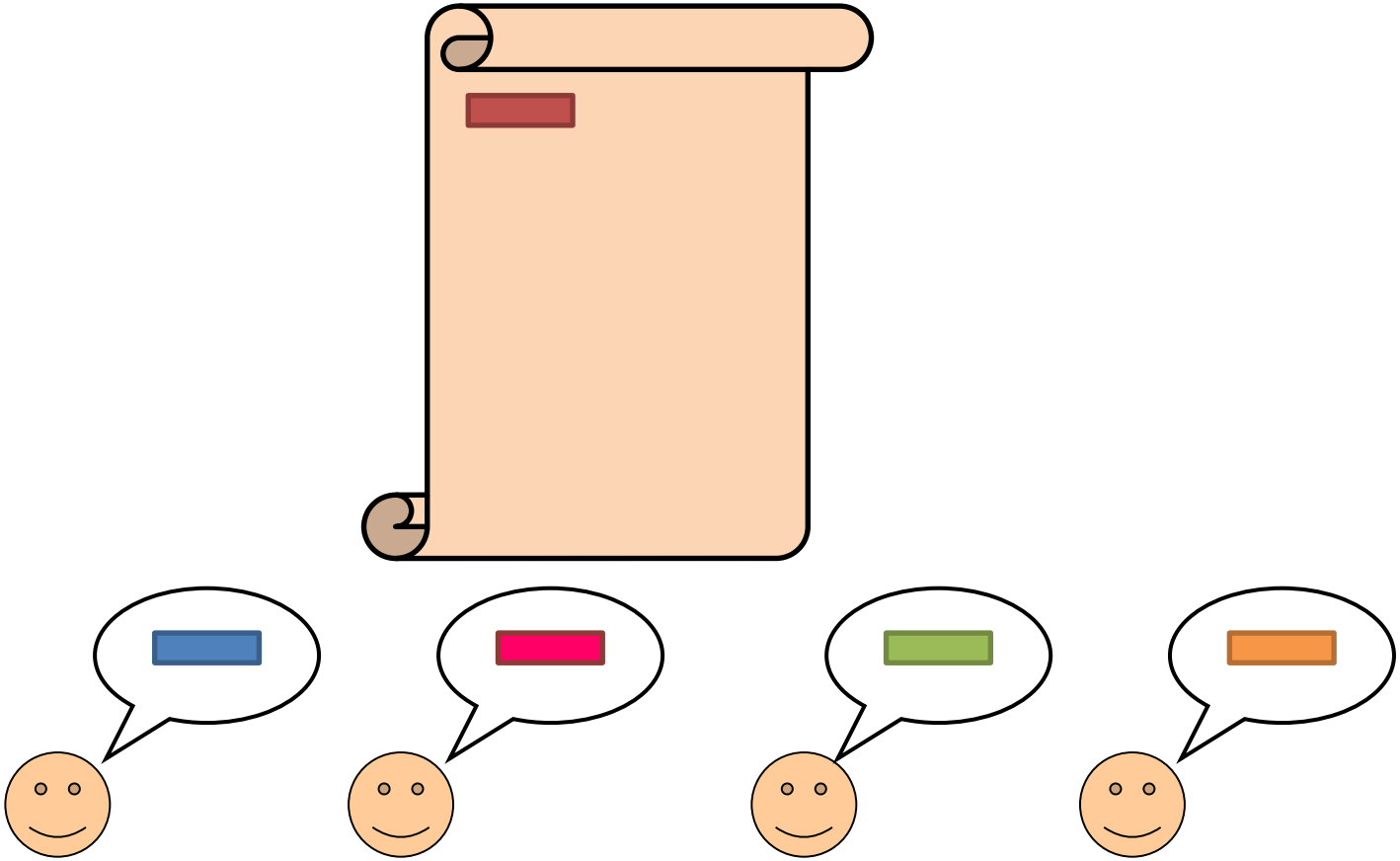

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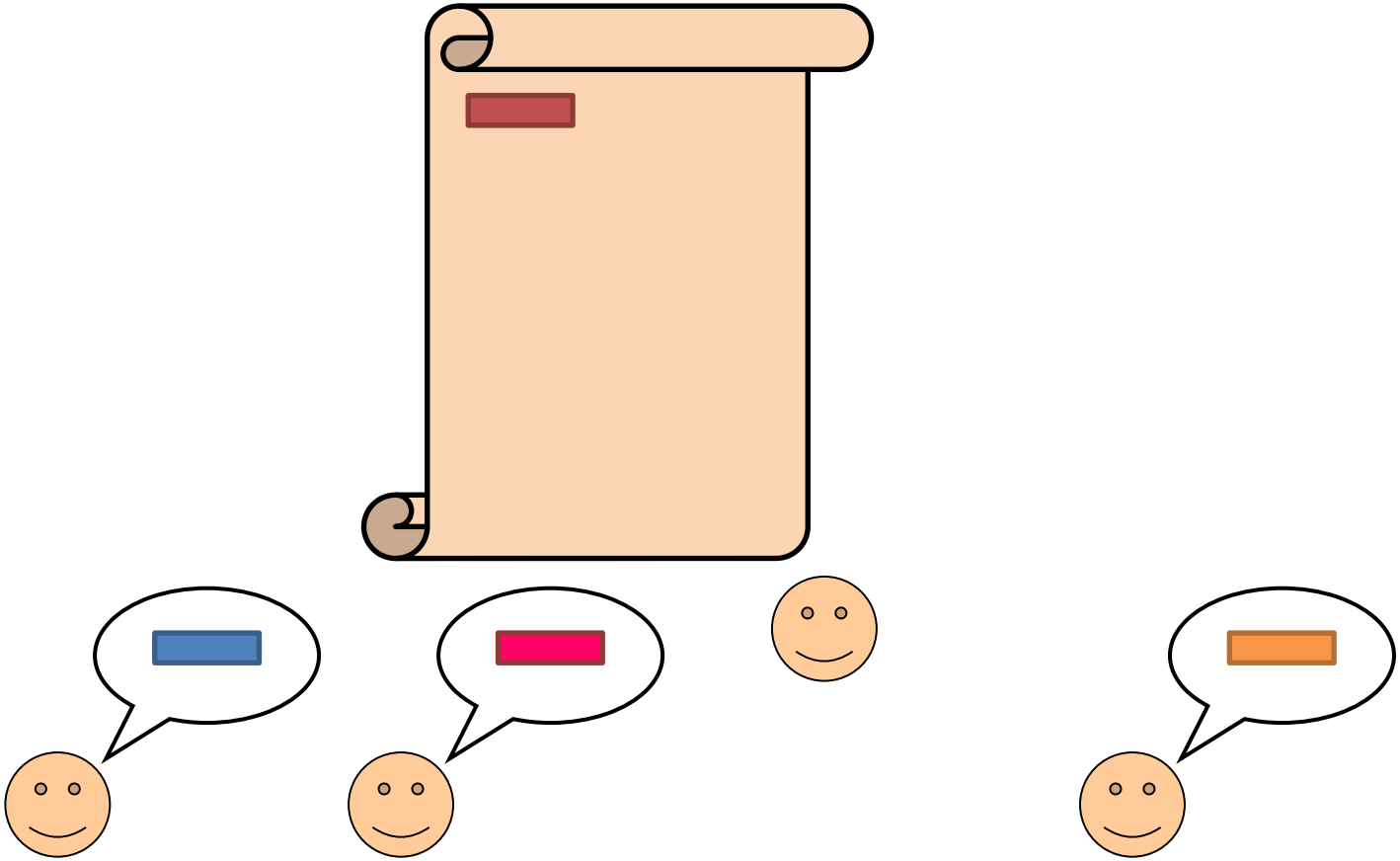

problem:

maintain a ledger containing a sequence of commands such that:

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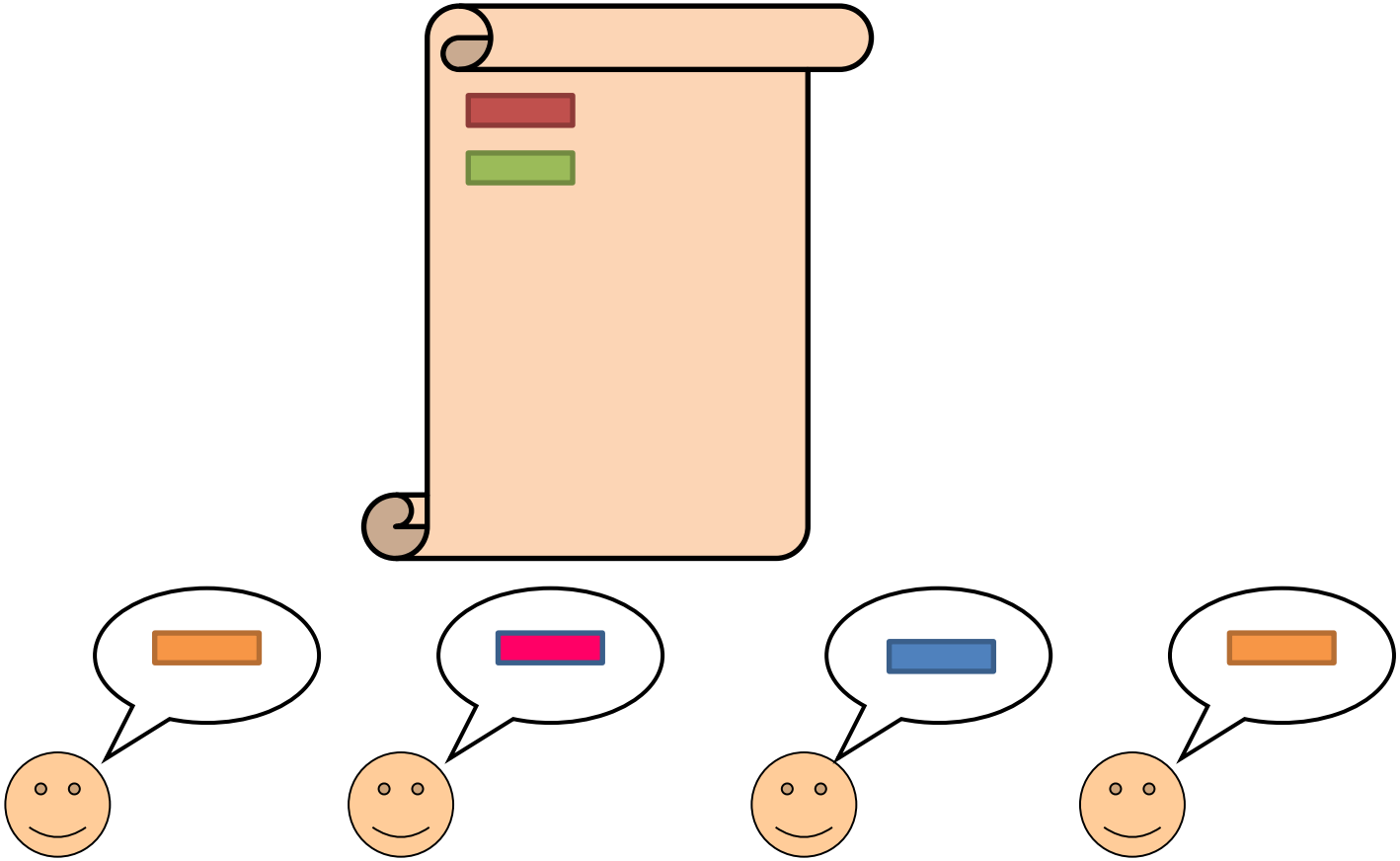

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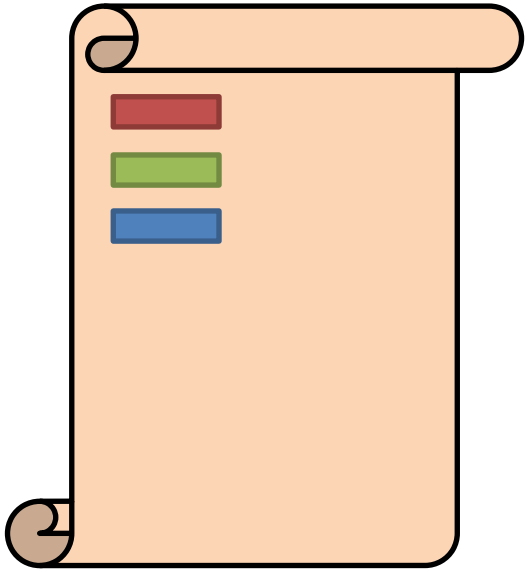

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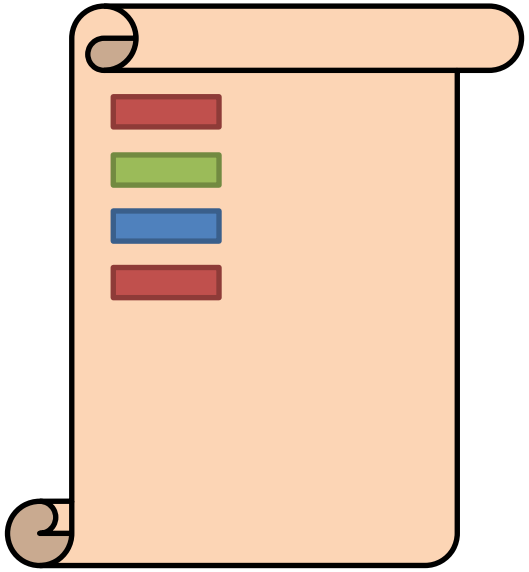

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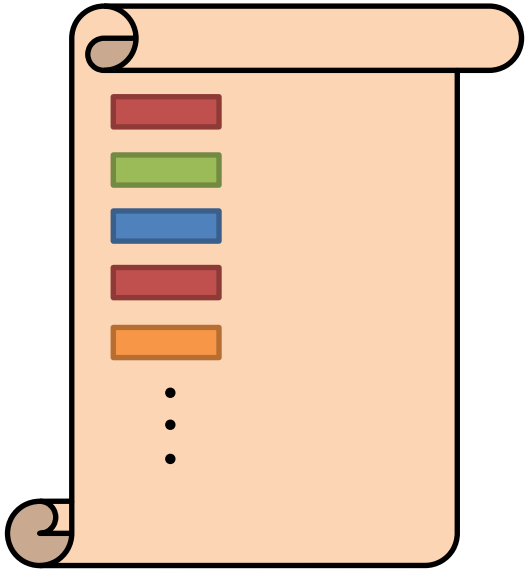

problem:

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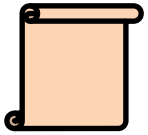
In Bitcoin System:

 = node of the network

 = blockchain

 = block (of transactions)

problem:

maintain a distributed ledger containing a seq. of commands such that:

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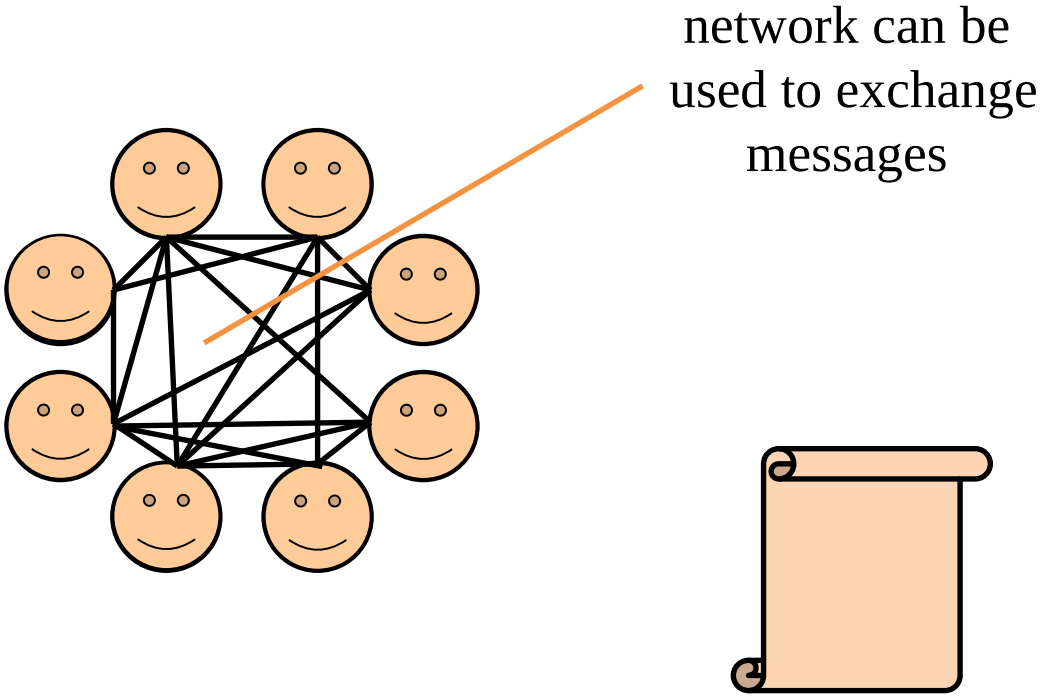

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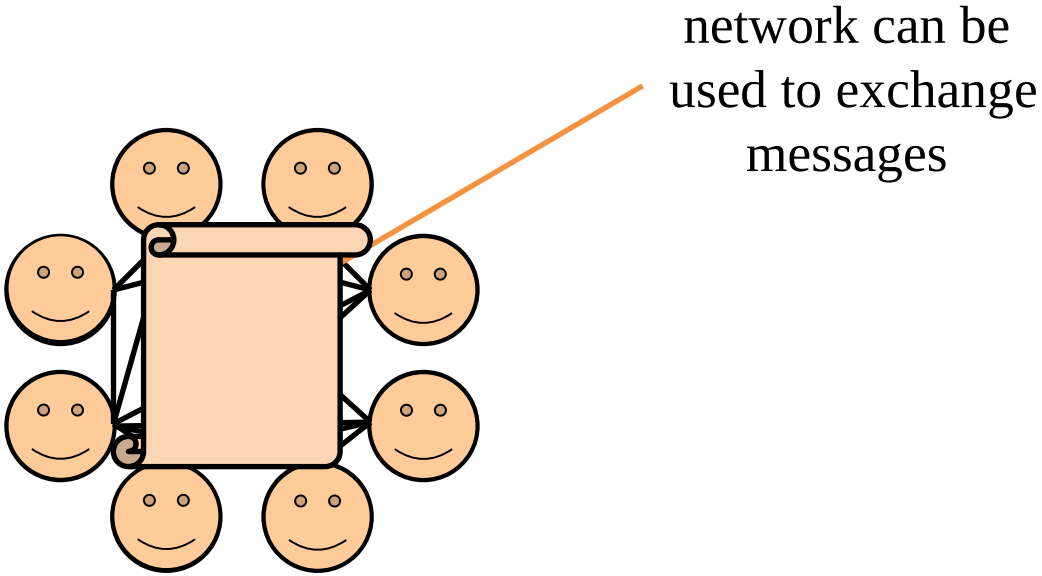
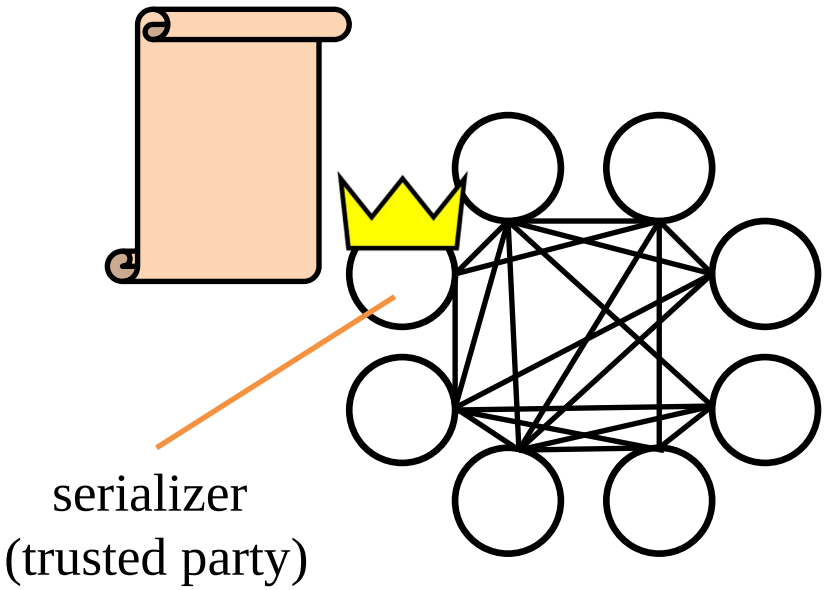


a simple solution



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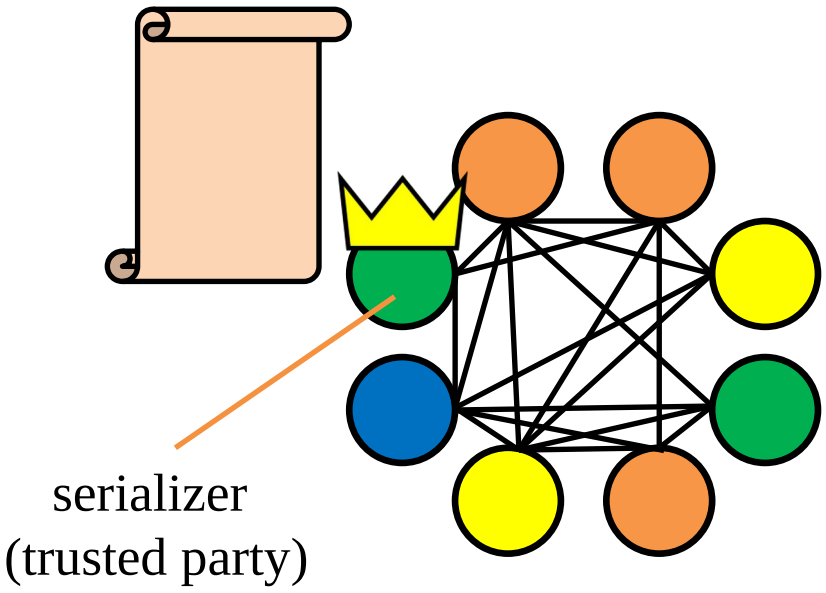

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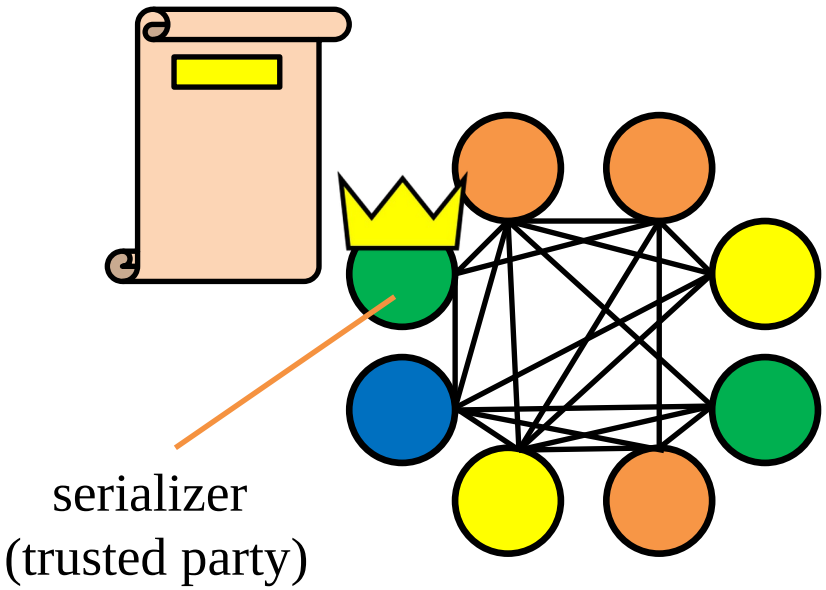

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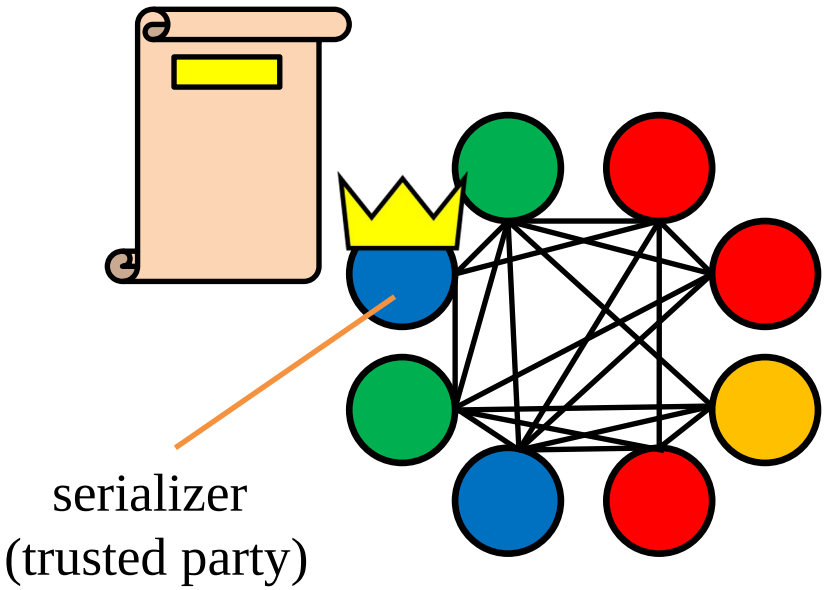

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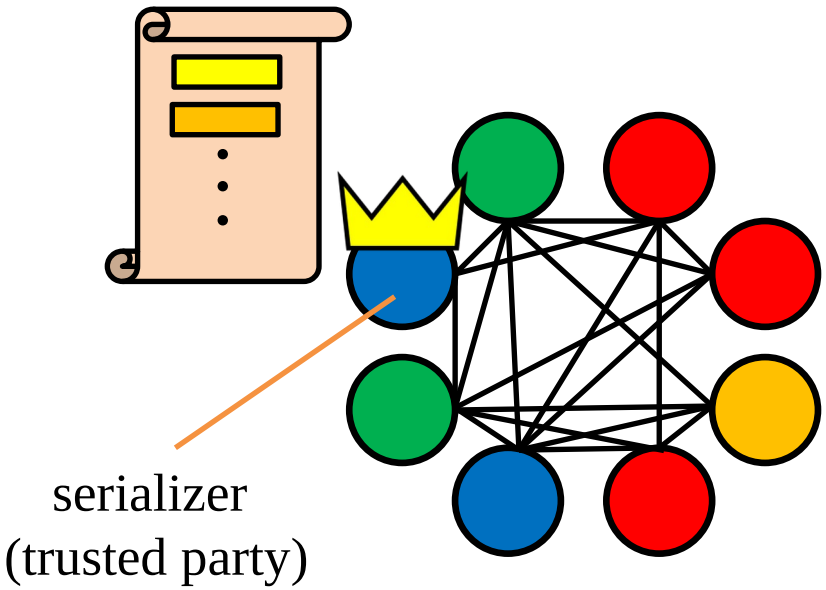

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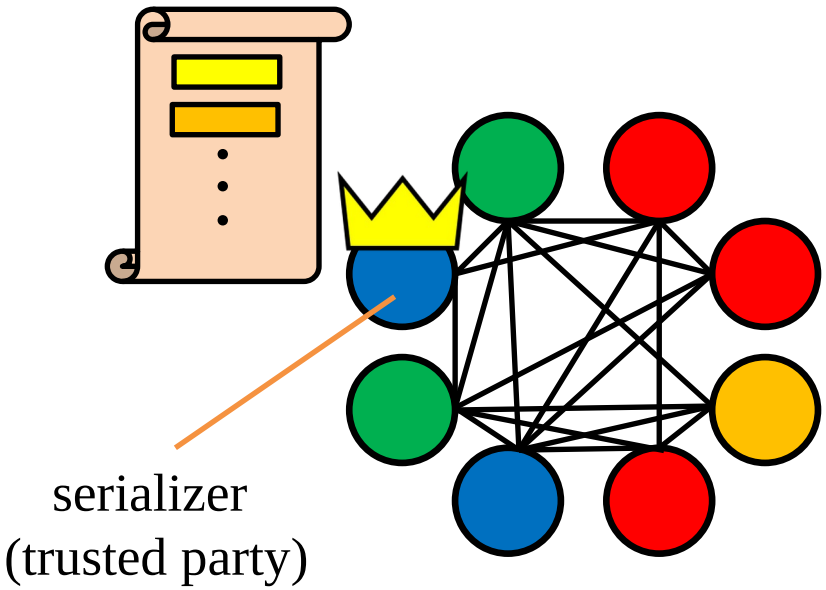
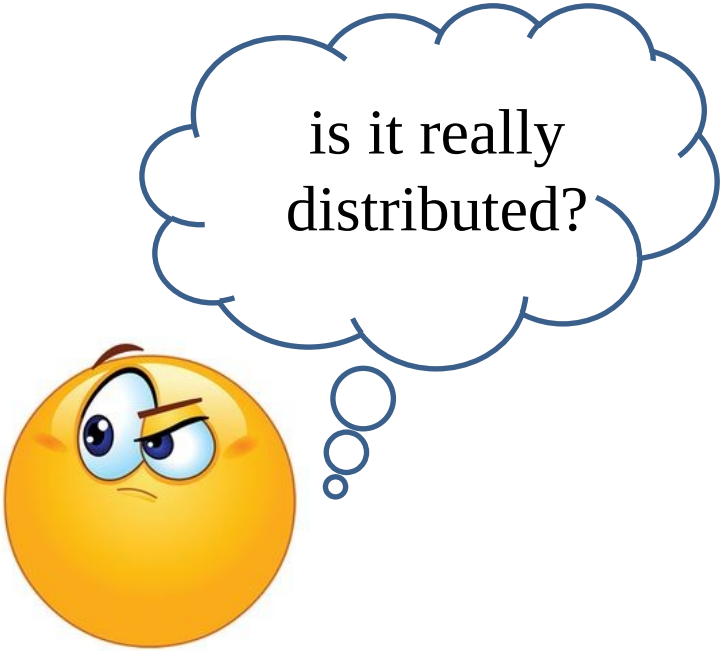
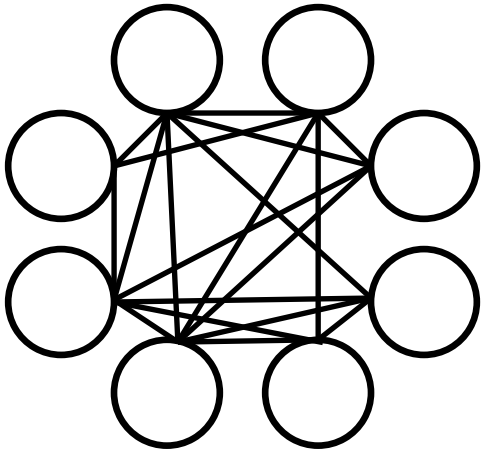




- what if the serializer fails?
- what if the serializer is not honest?

fault tolerance

a better solution



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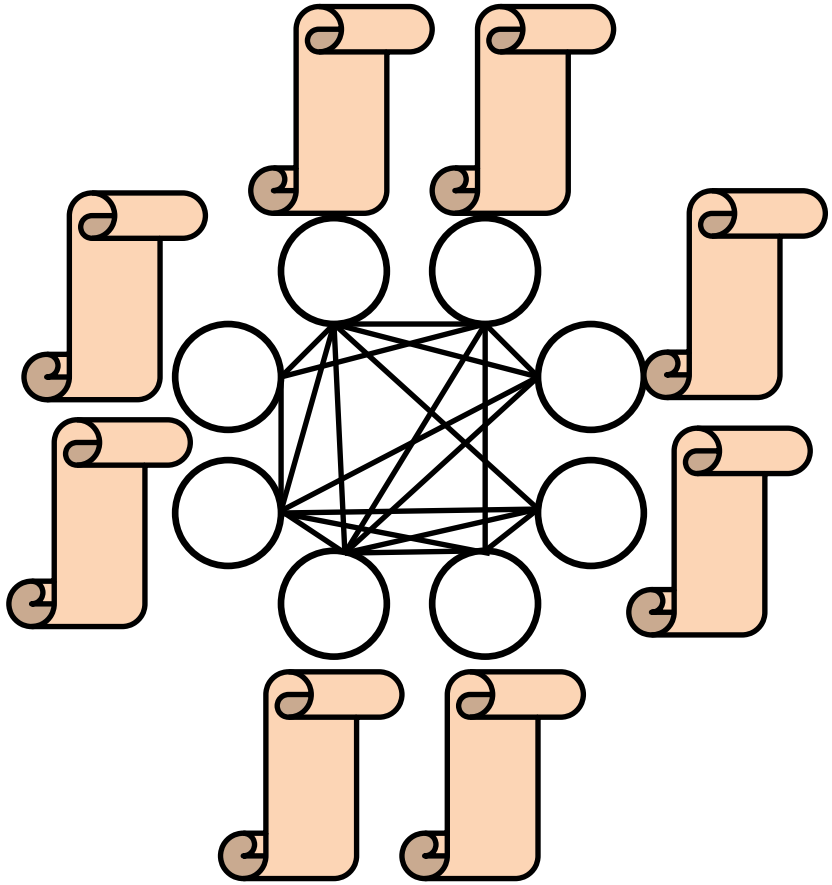

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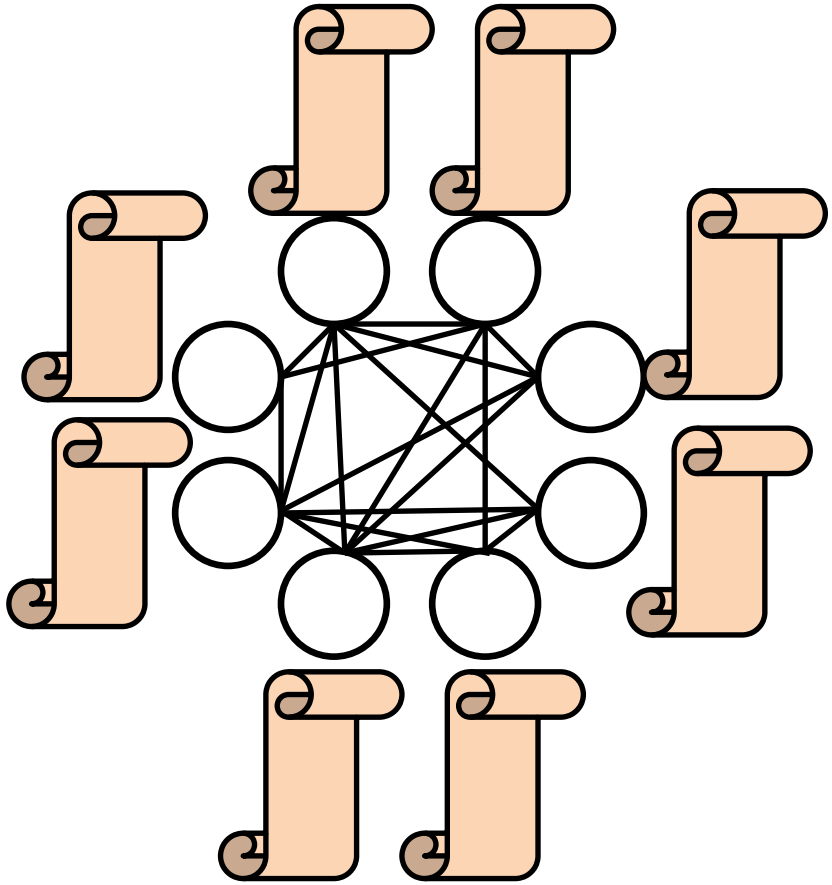

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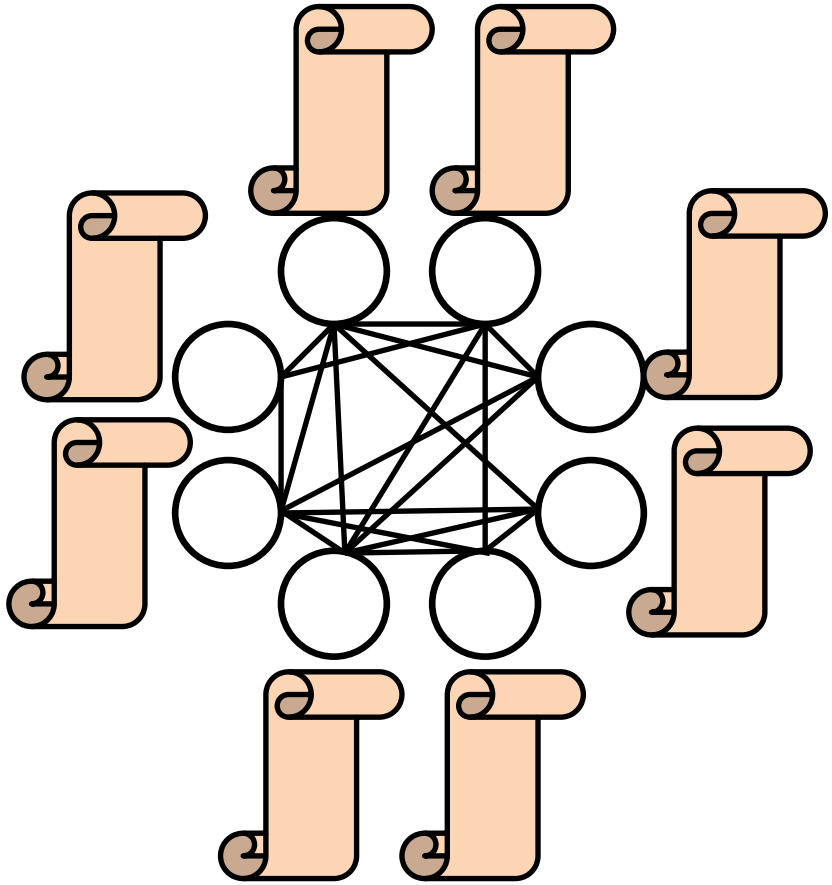
a better solution



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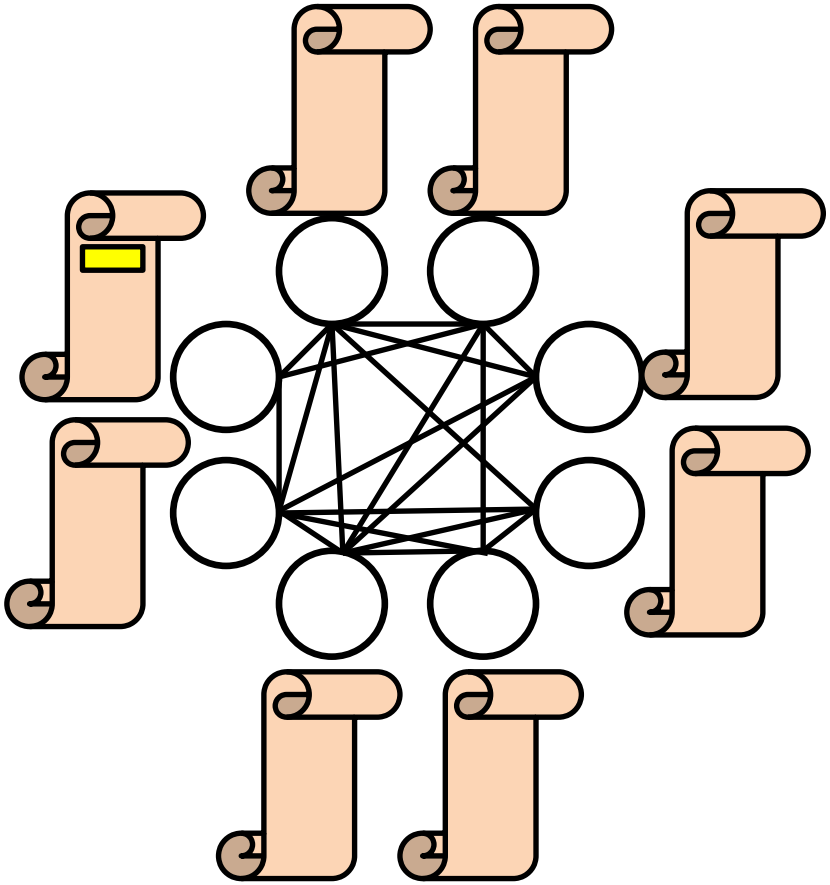

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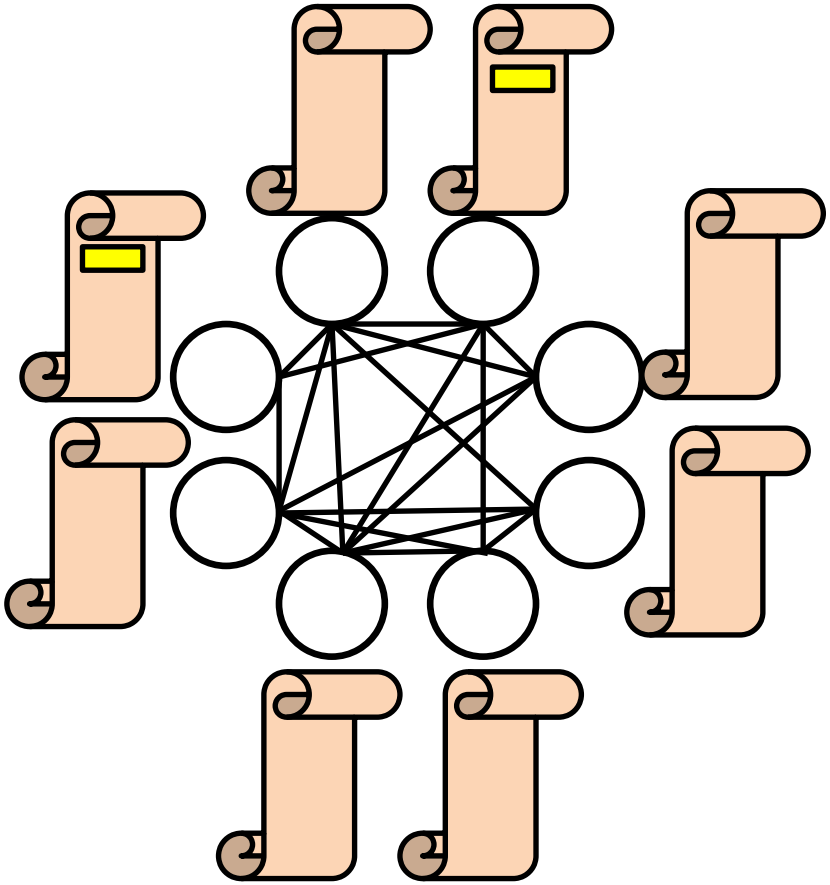

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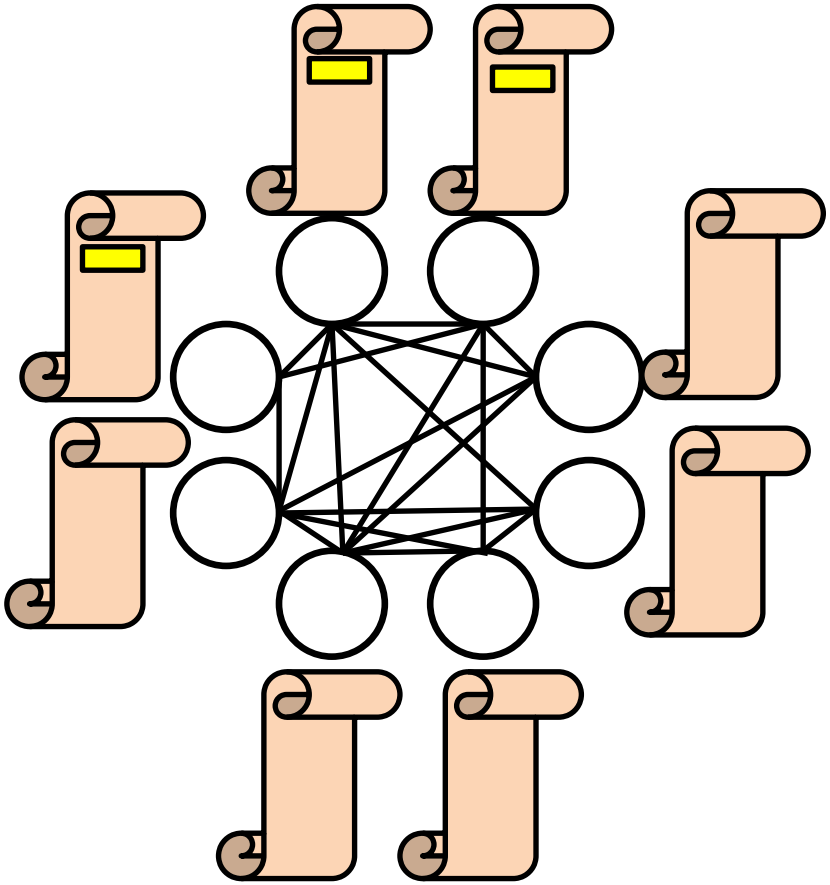

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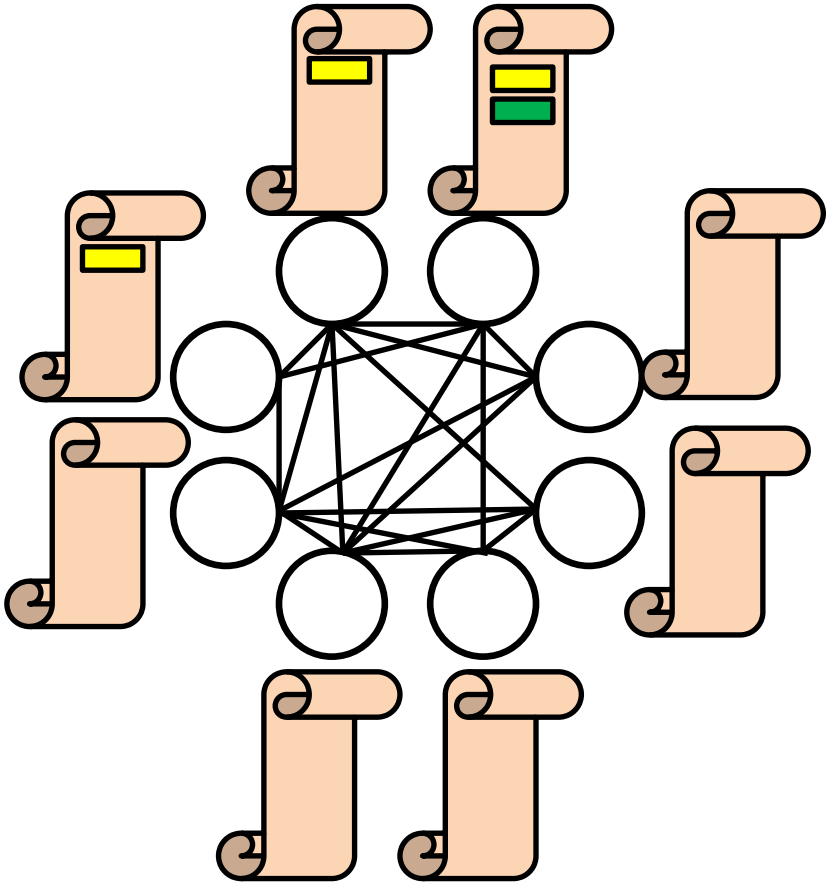

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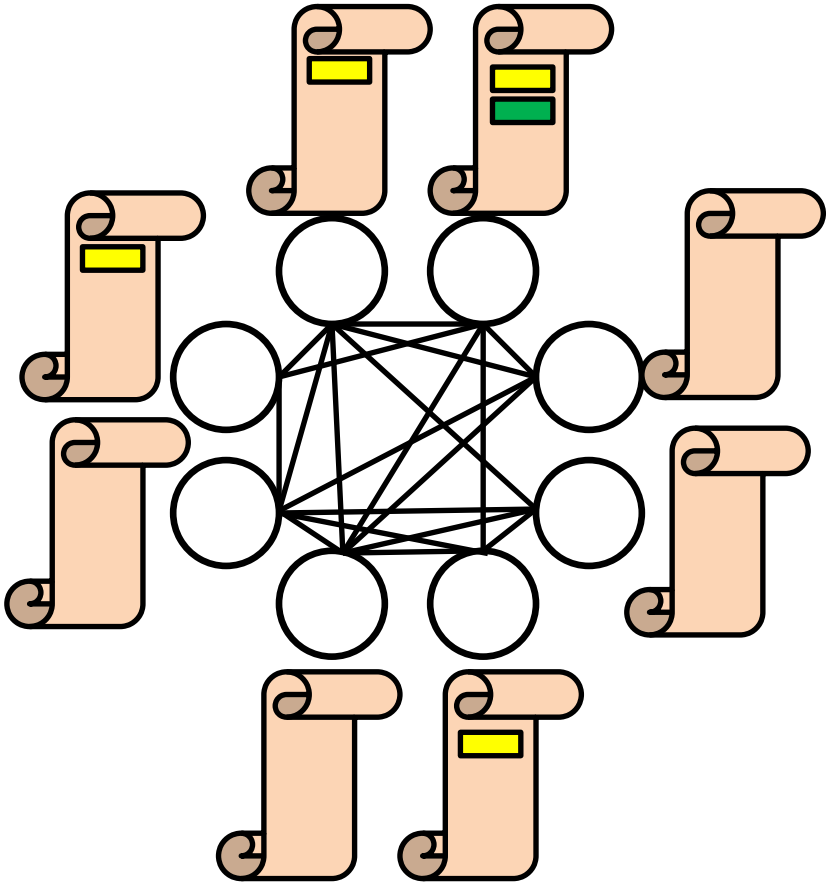

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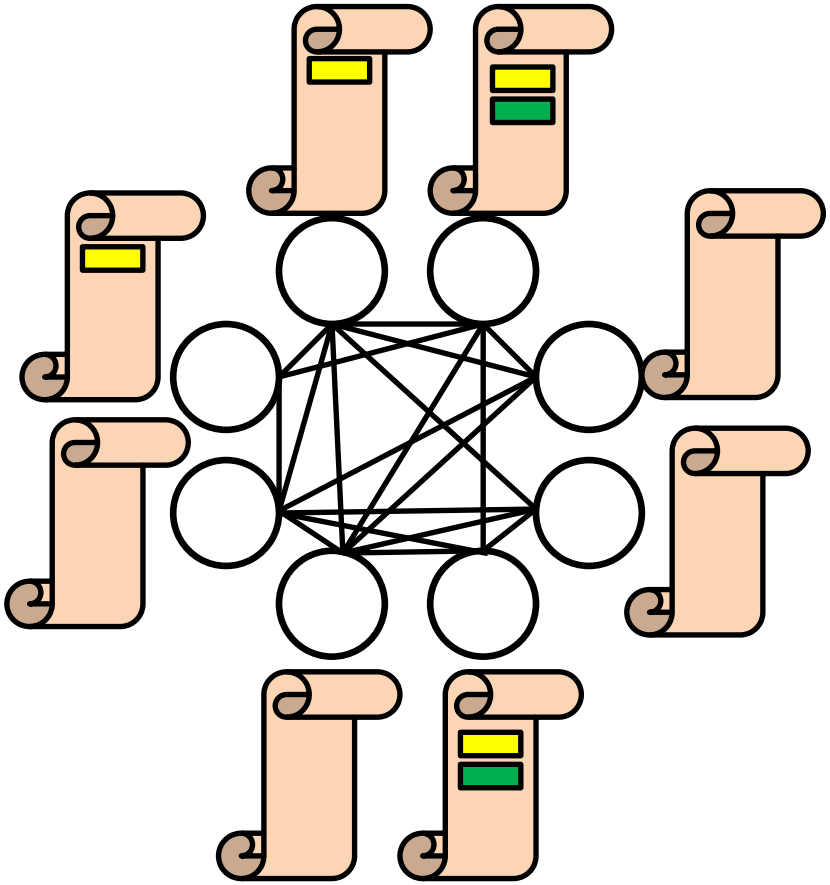

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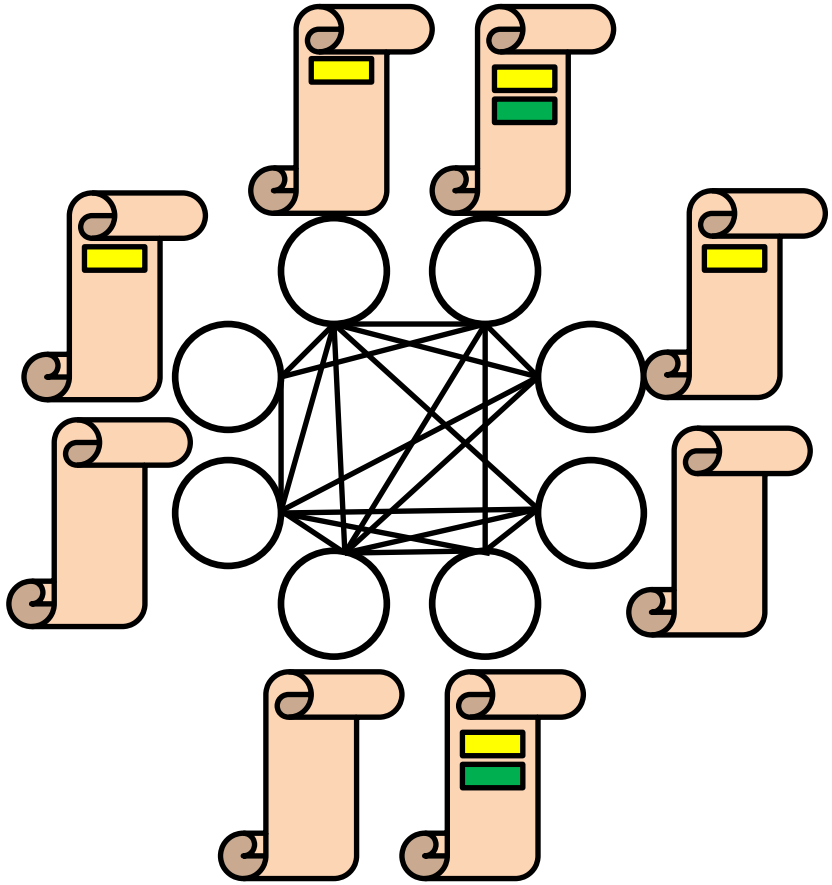

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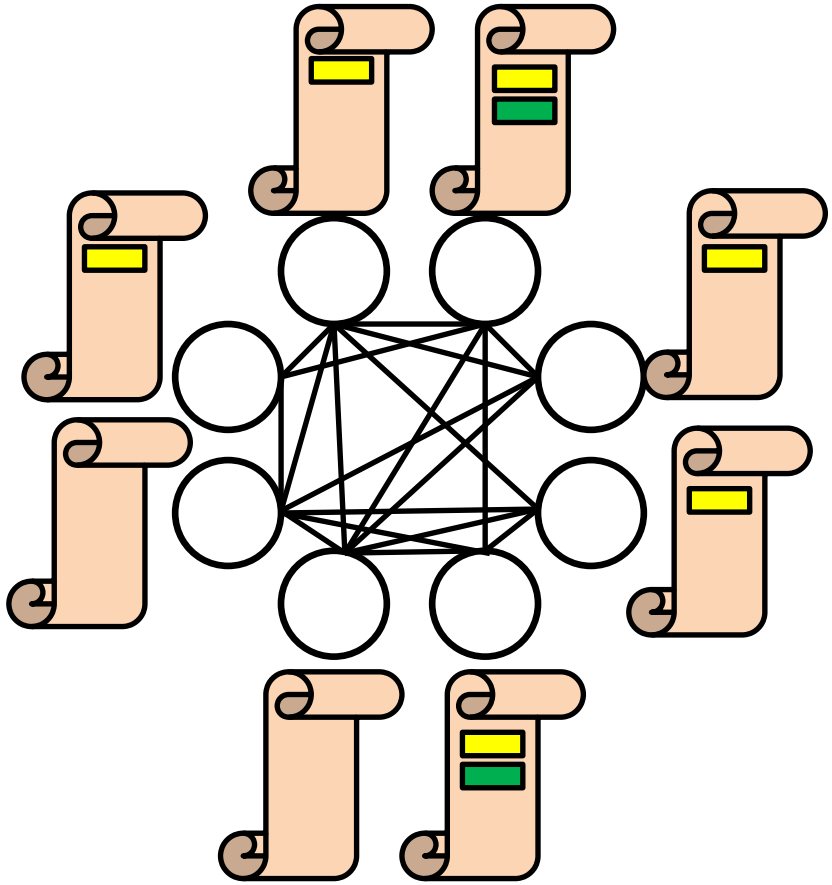

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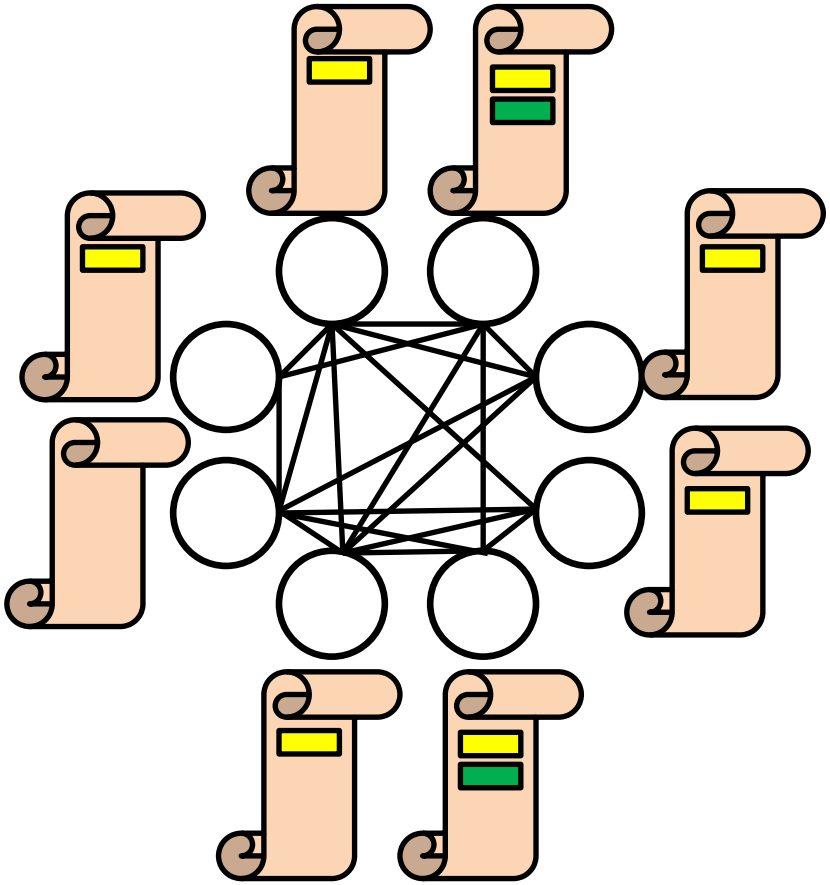

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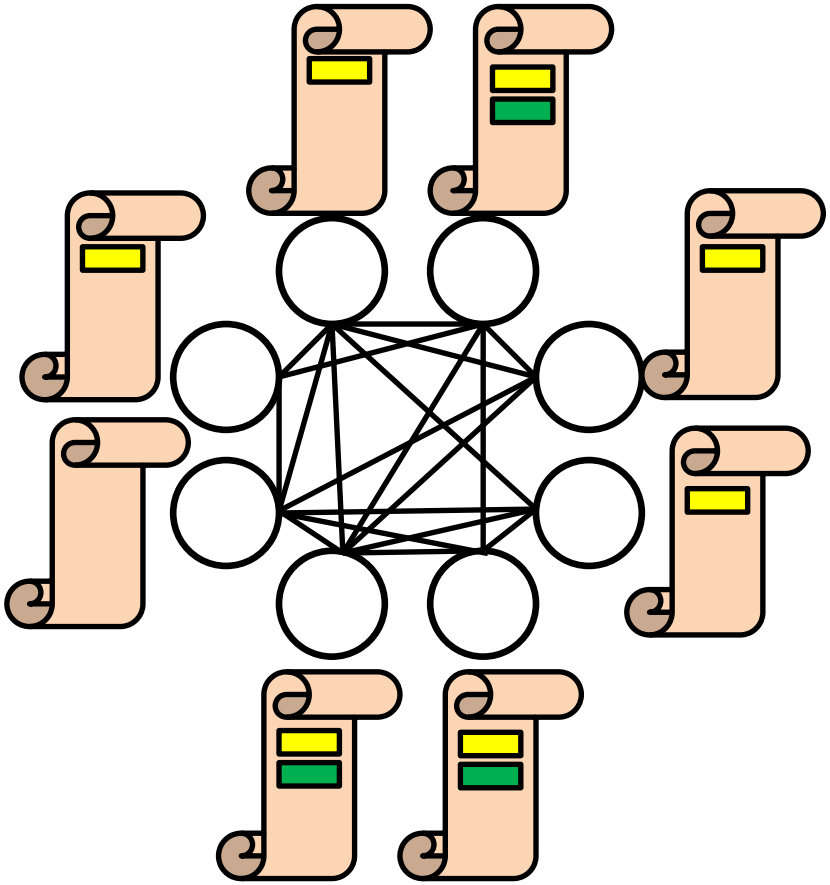

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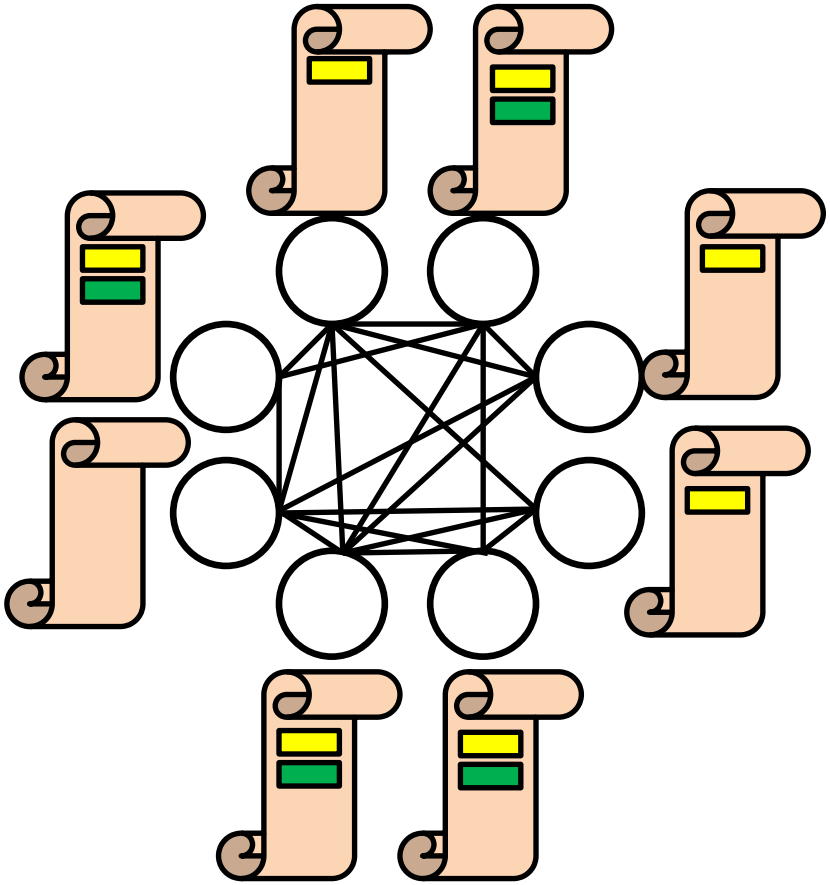

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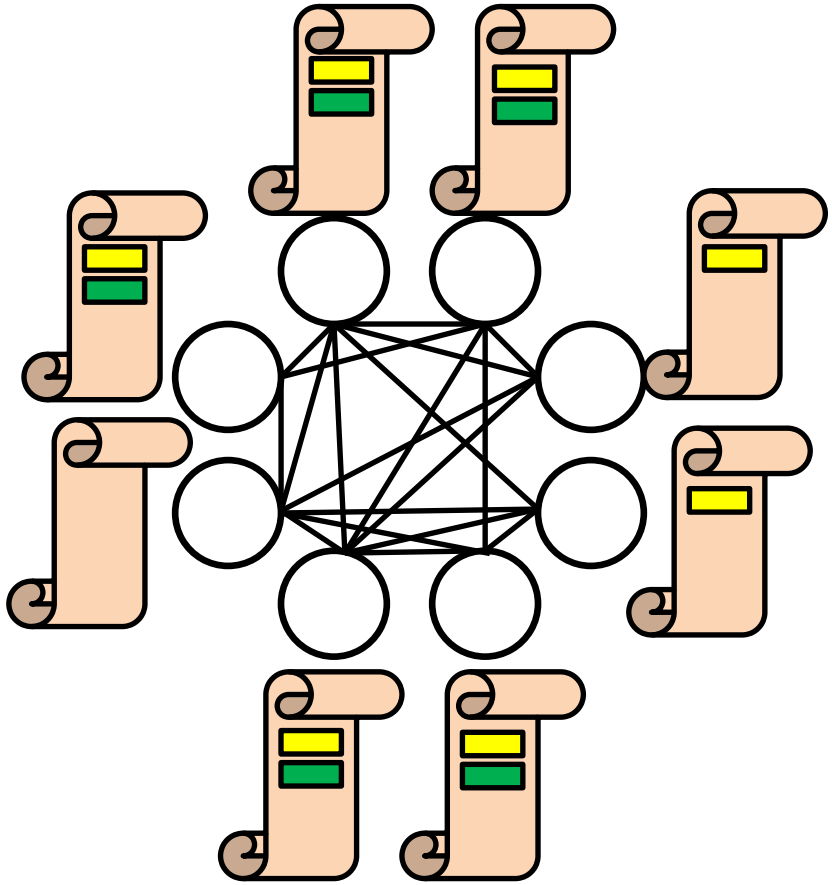

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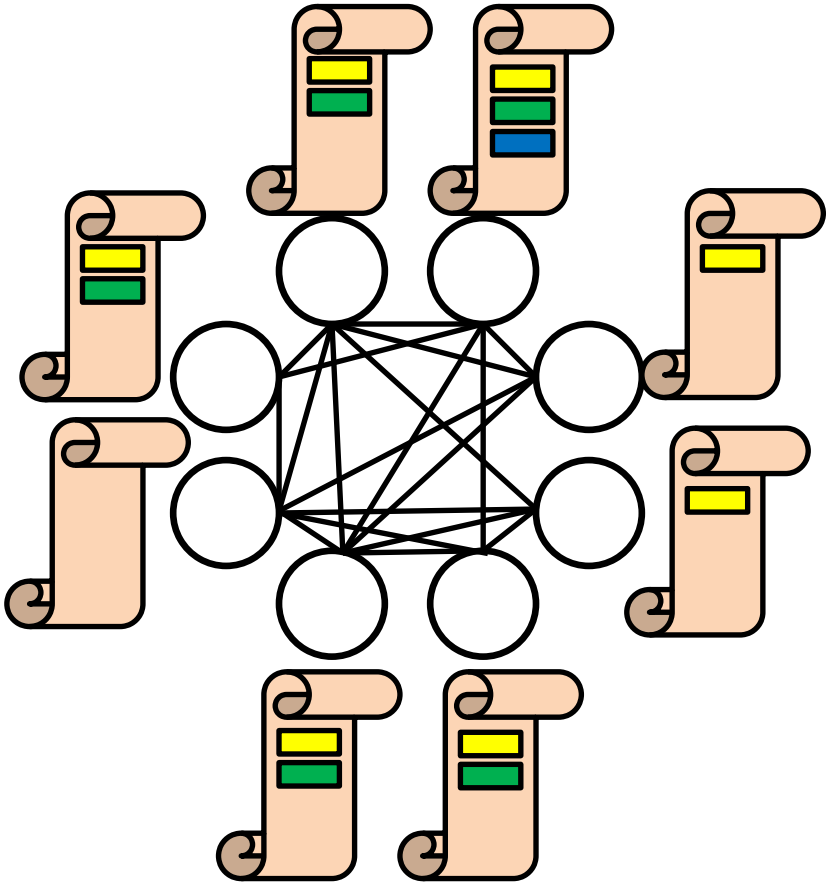

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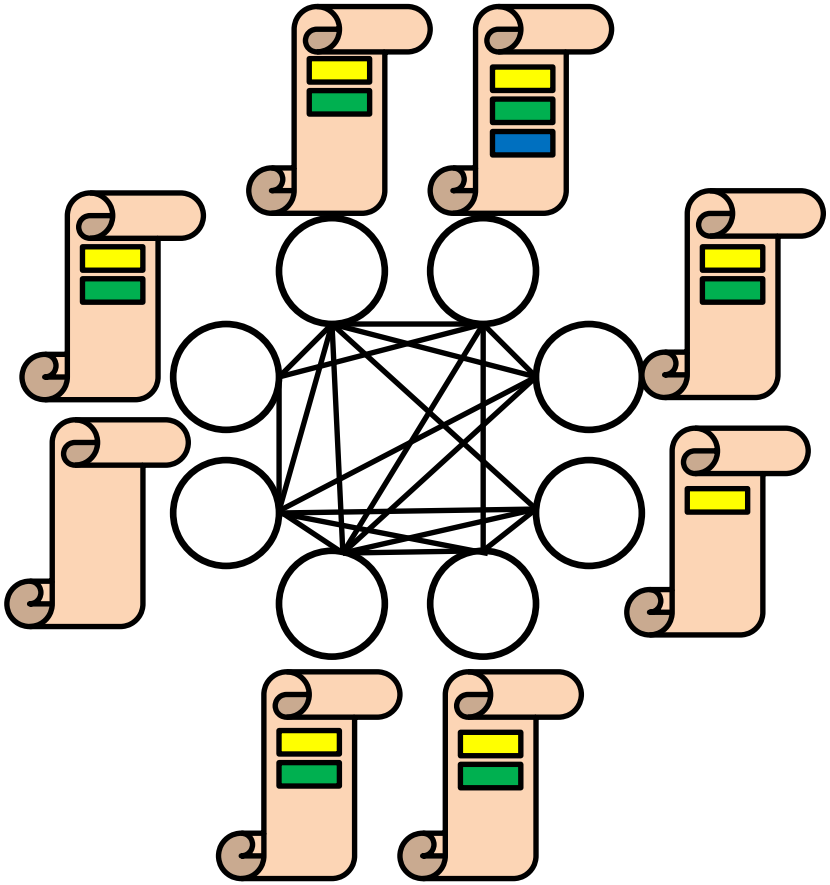

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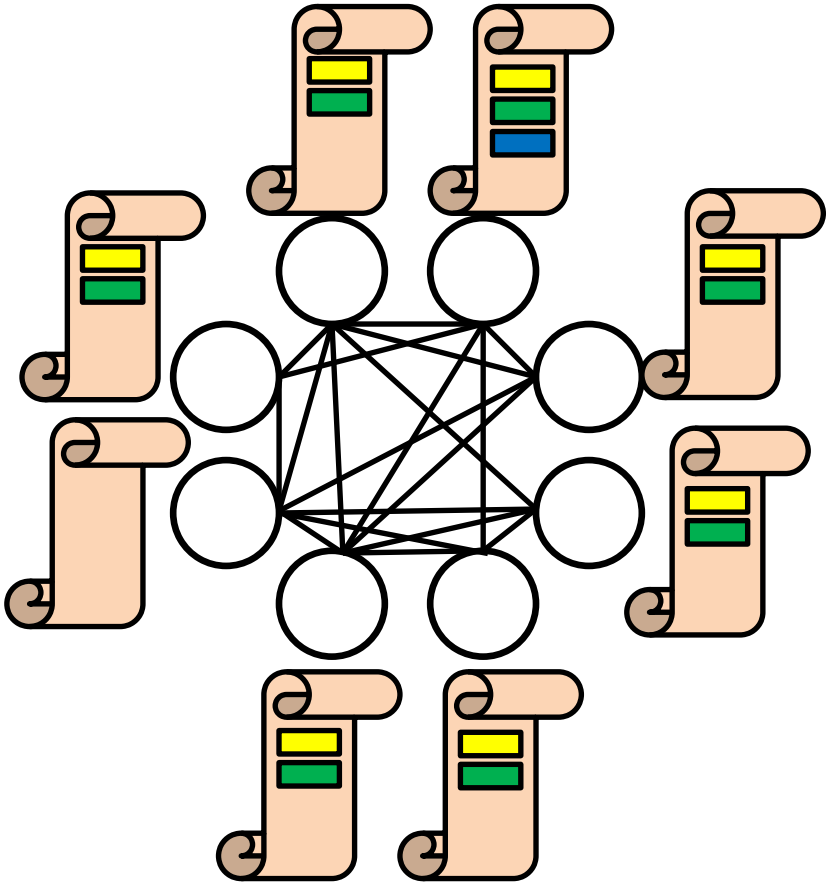

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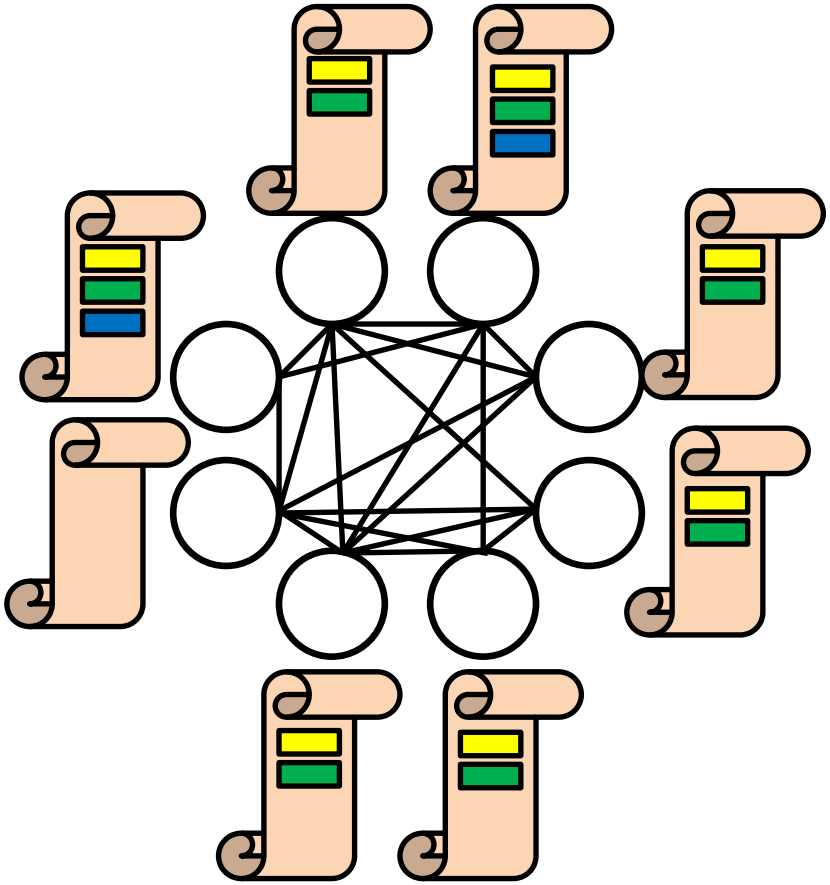

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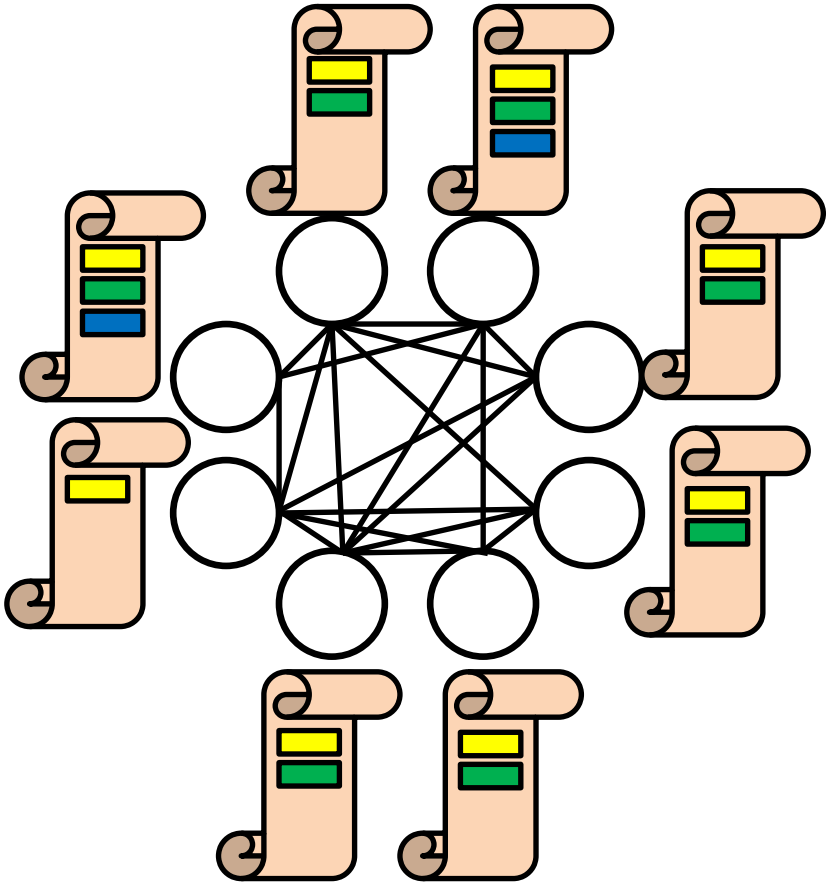

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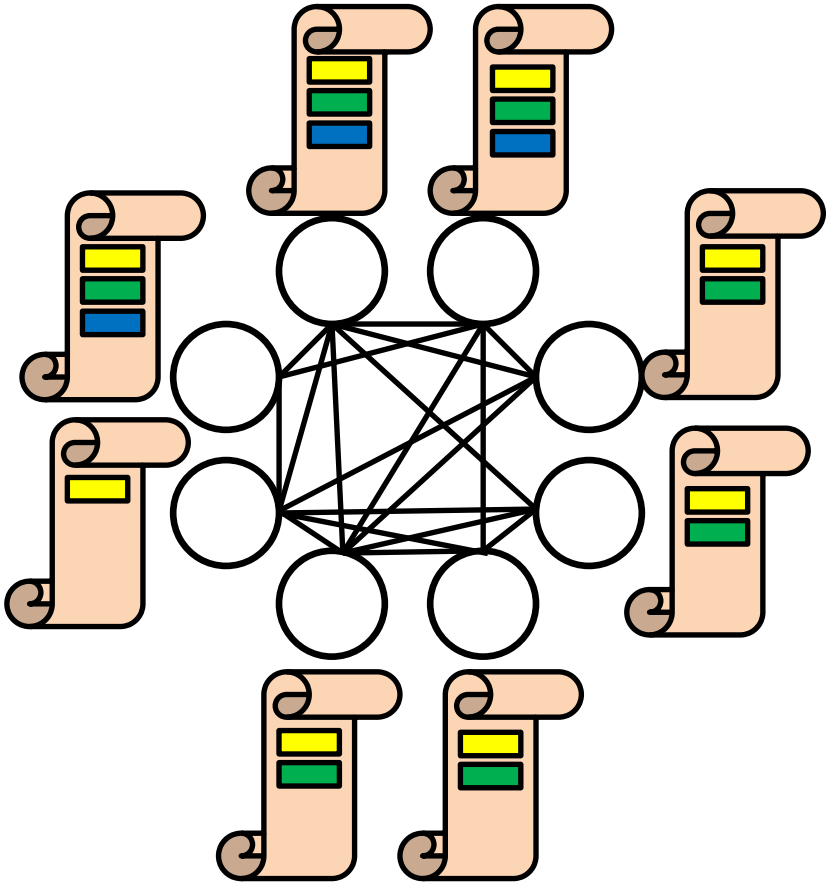

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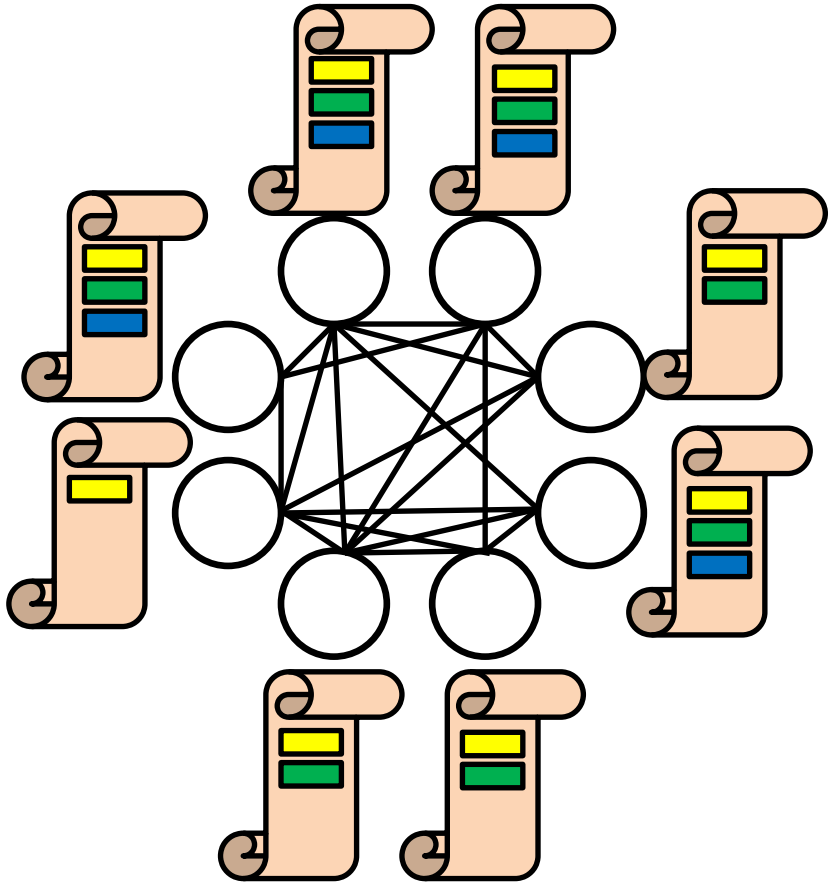

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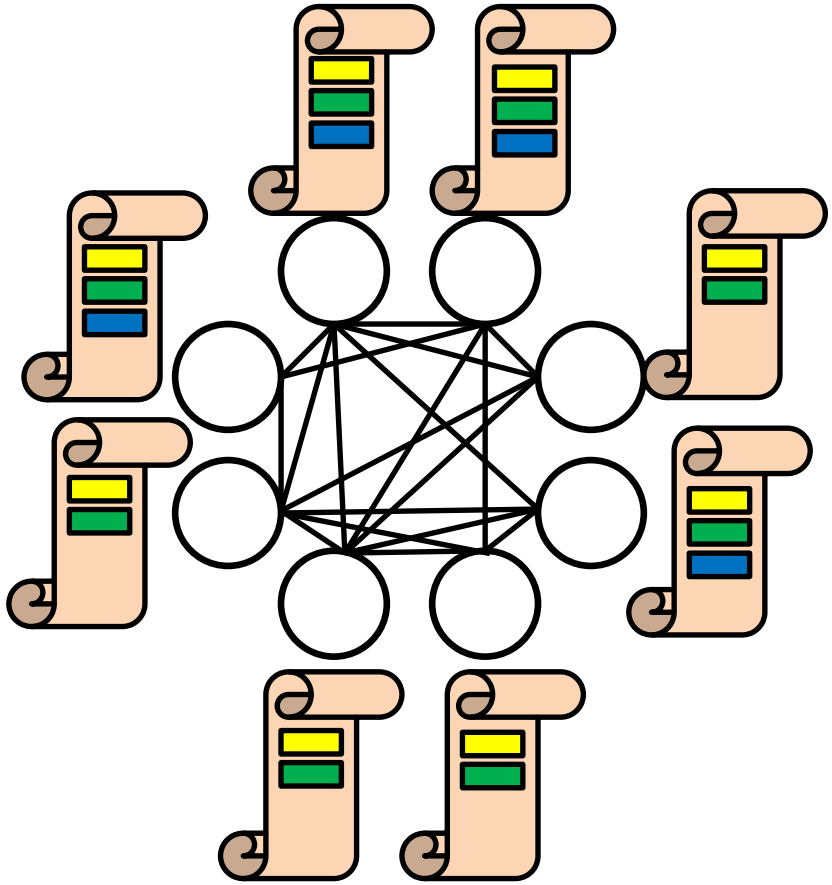

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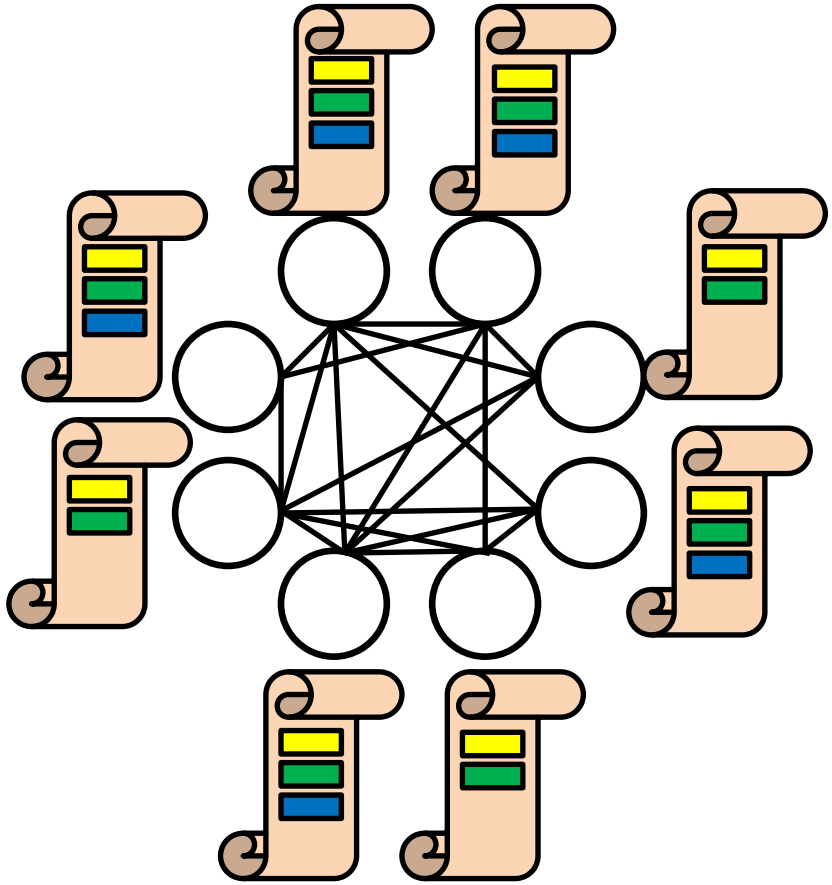

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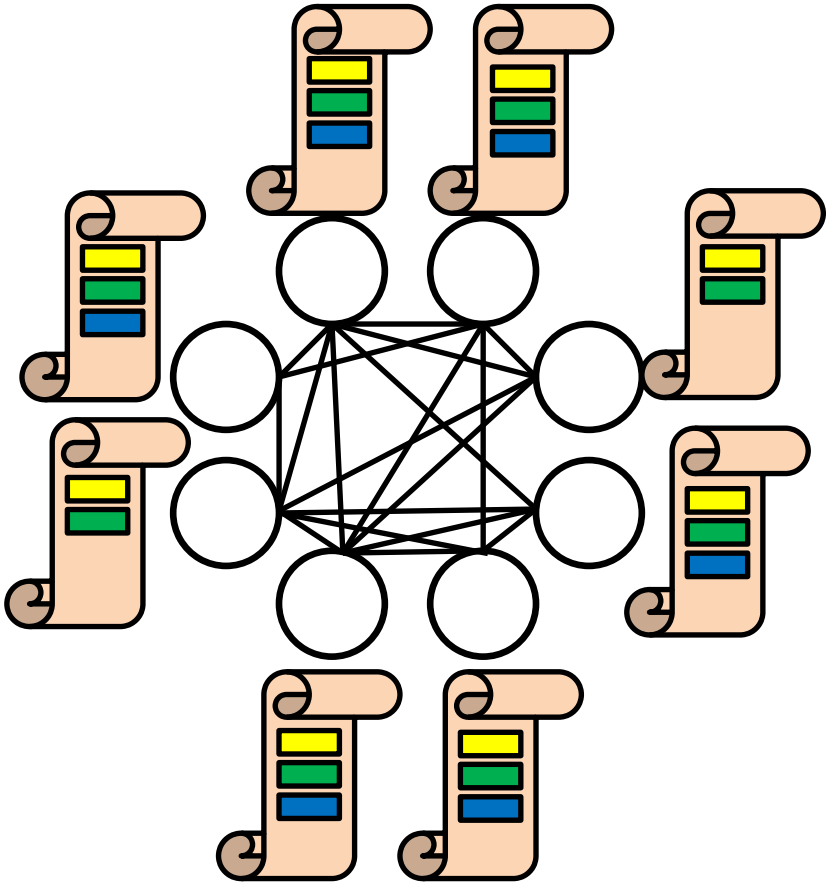

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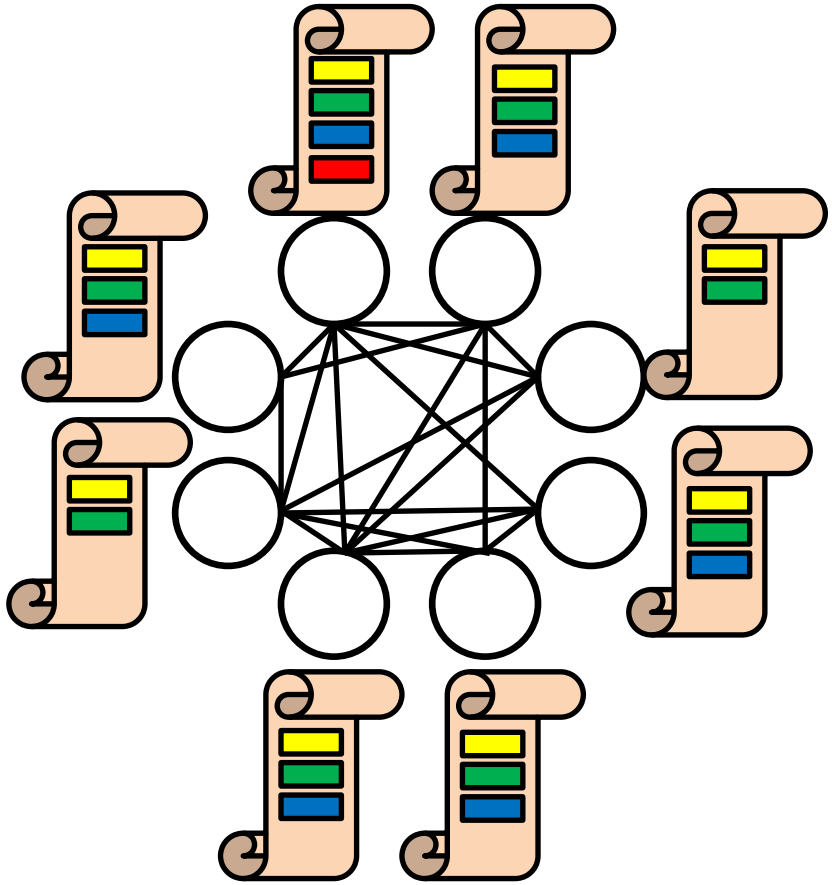

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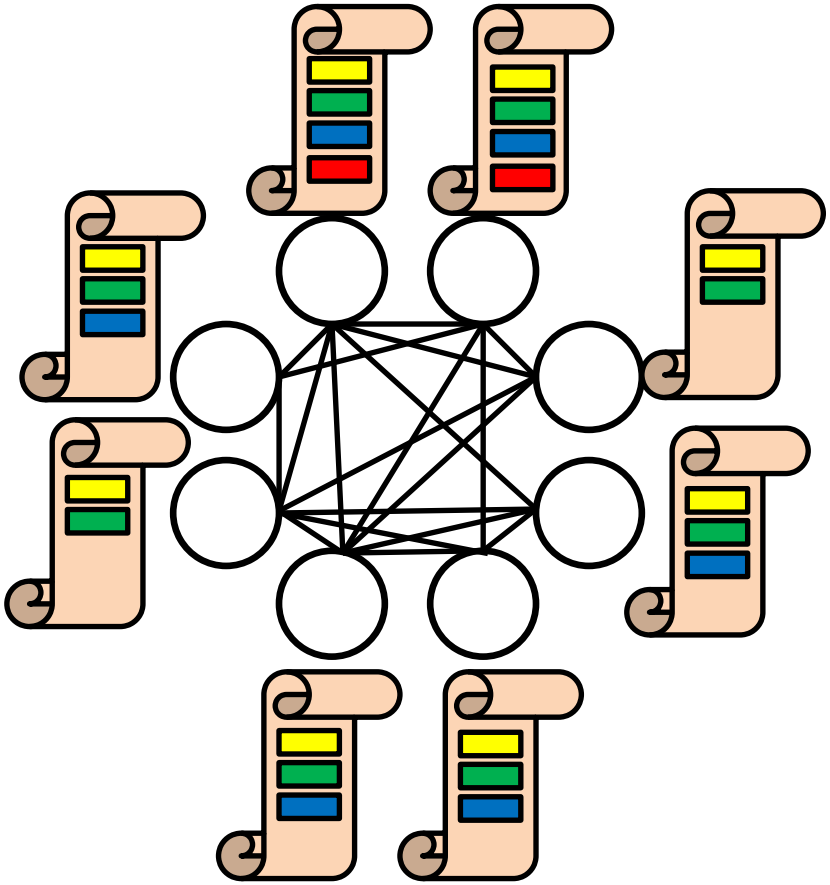

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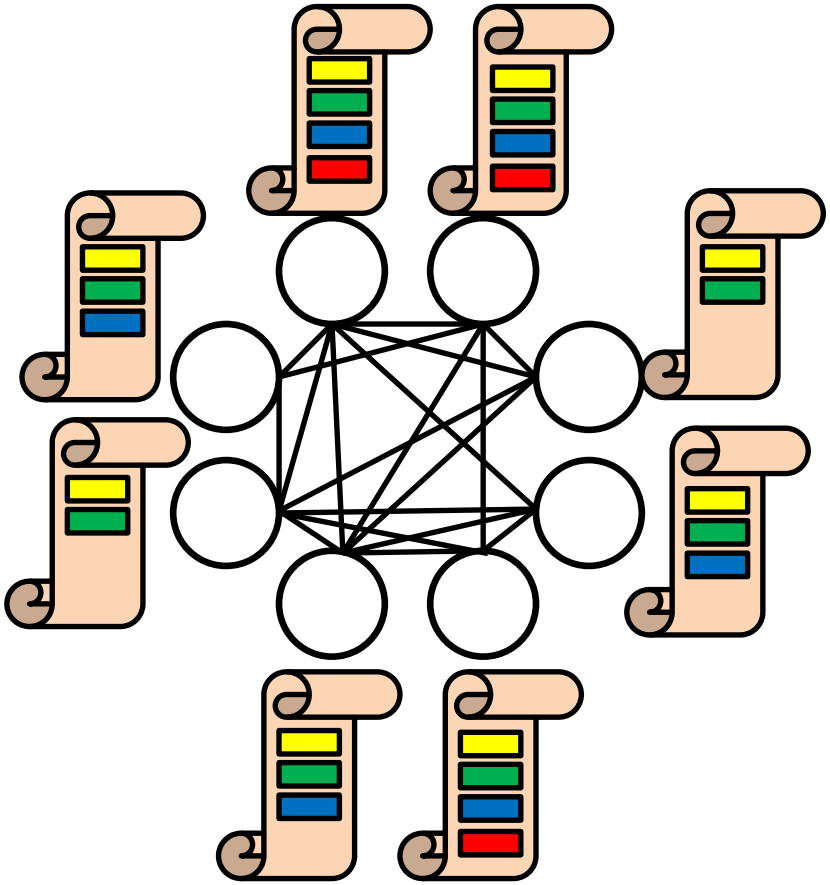

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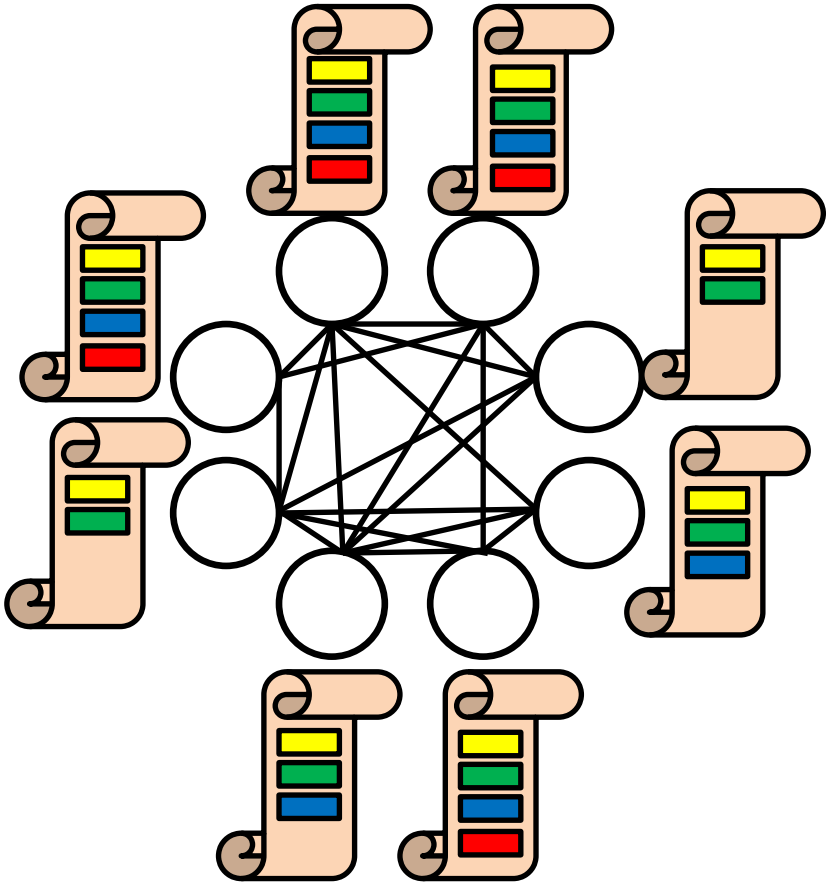

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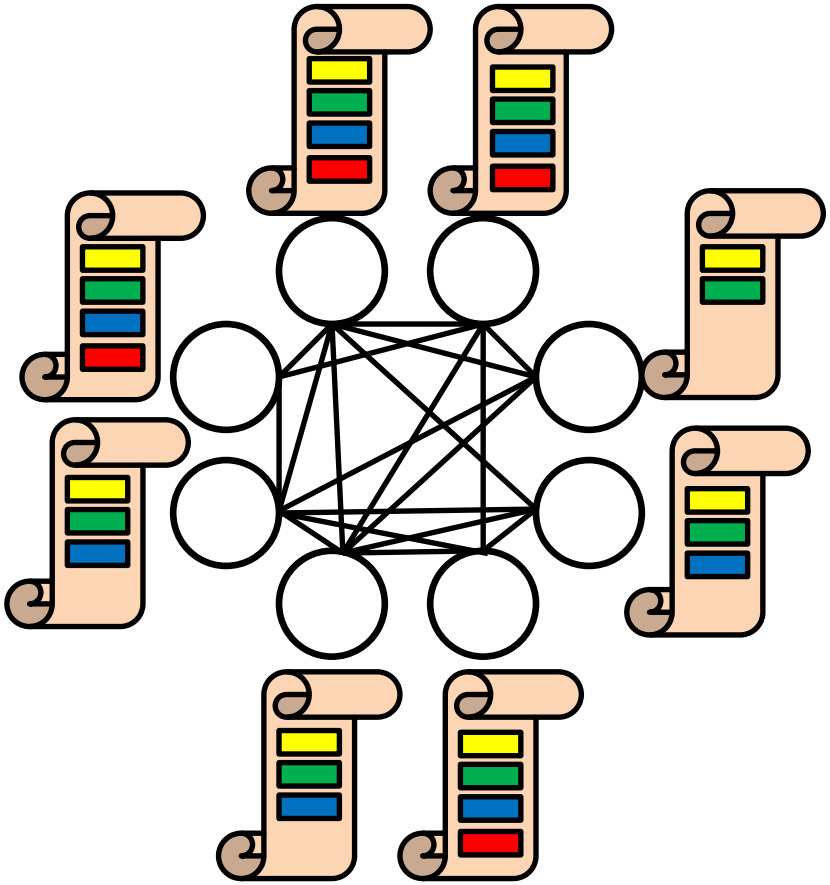

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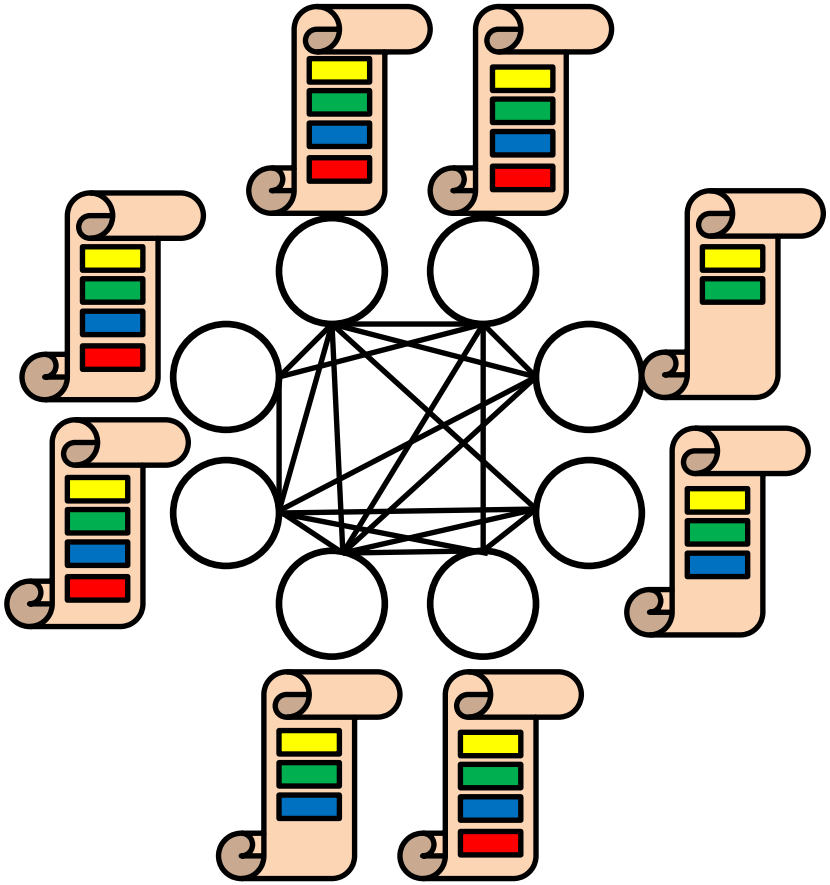

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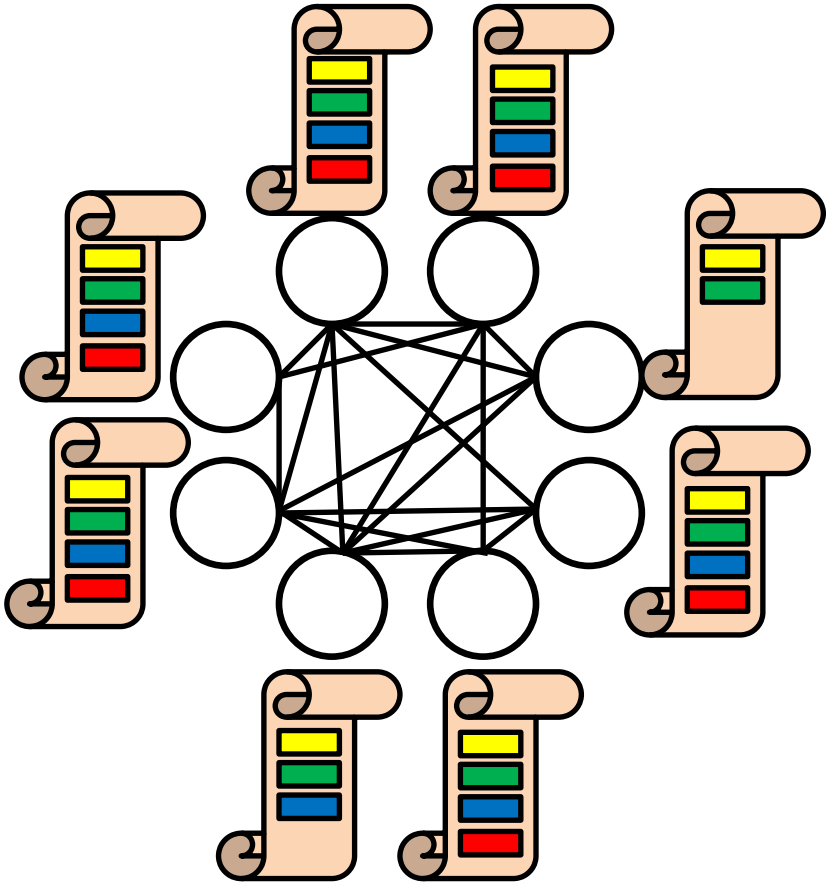

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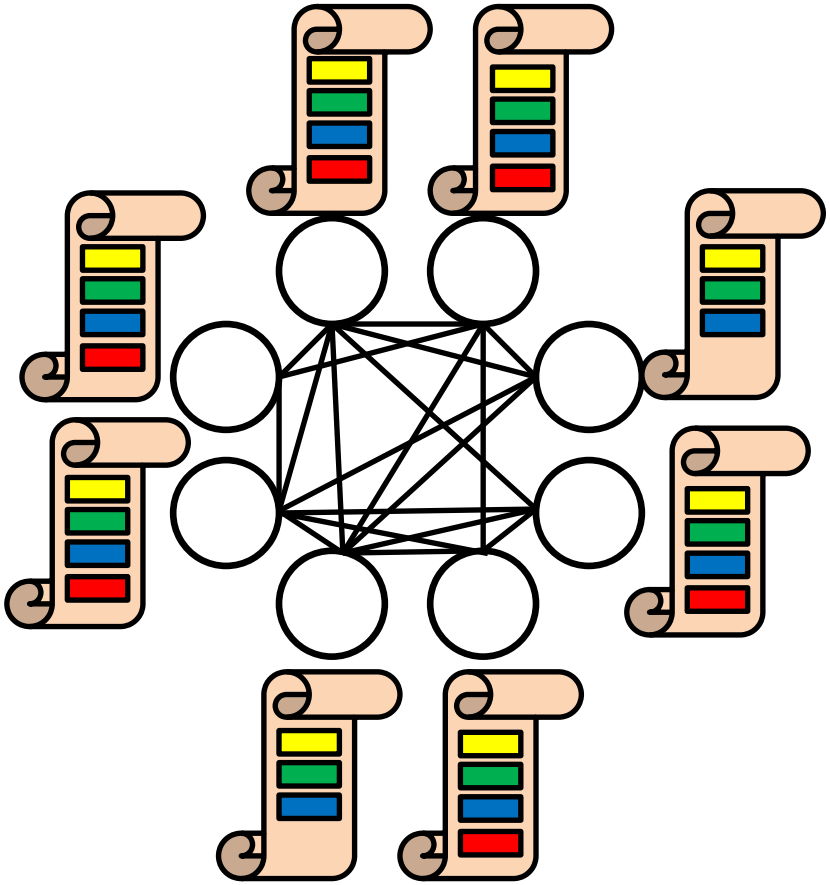
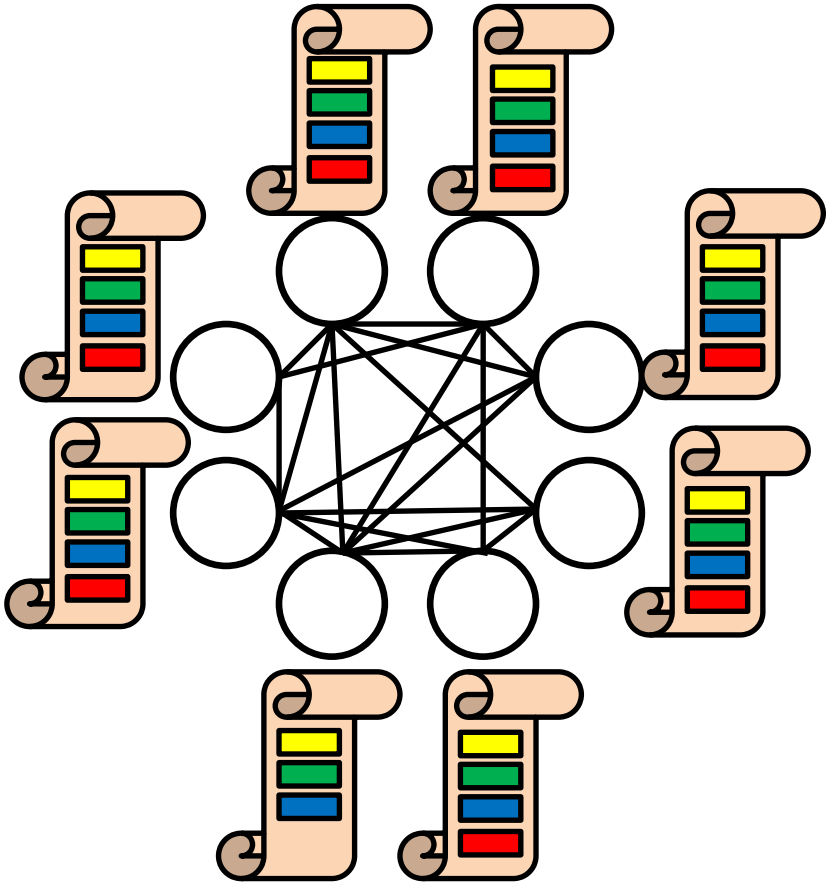


Consistency:
all nodes always agree on the current state of the ledger

Eventual consistency:
all nodes eventually agree on the current state of the ledger (if no new updates are issued)

a better solution



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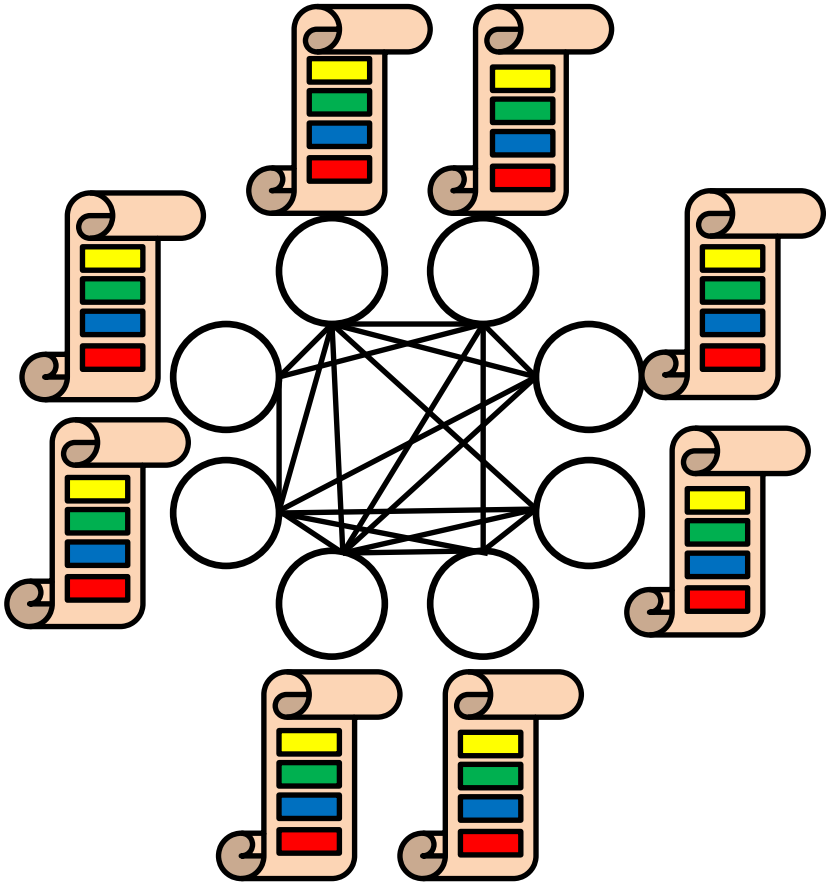
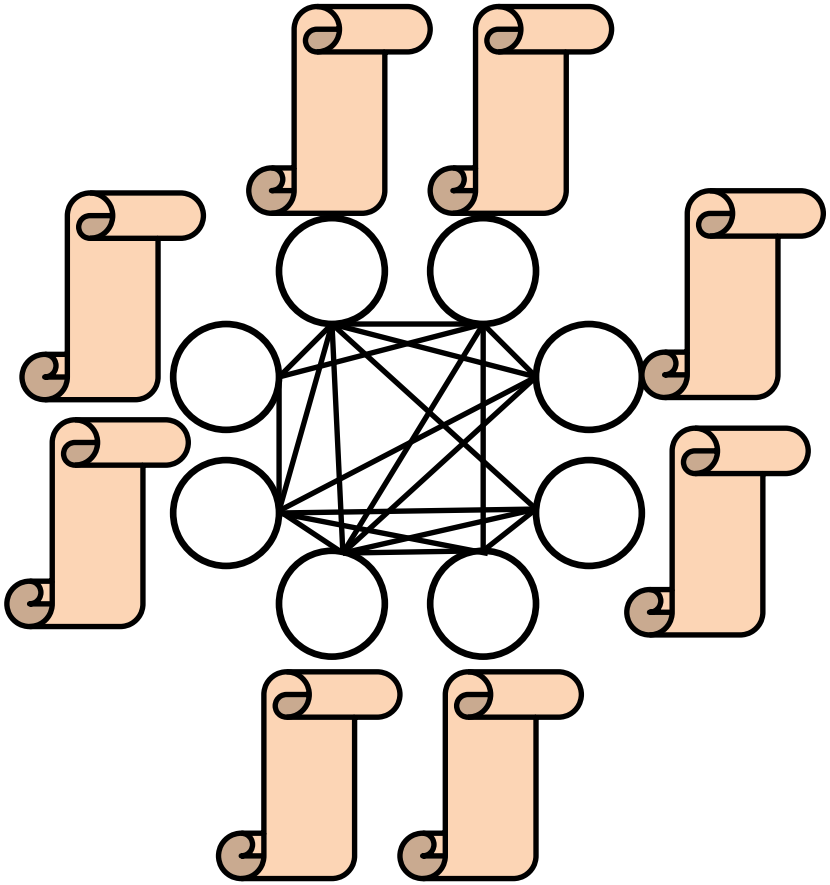


Consistency:
all nodes always agree on the current state of the ledger

Eventual consistency:
all nodes eventually agree on the current state of the ledger (if no new updates are issued)

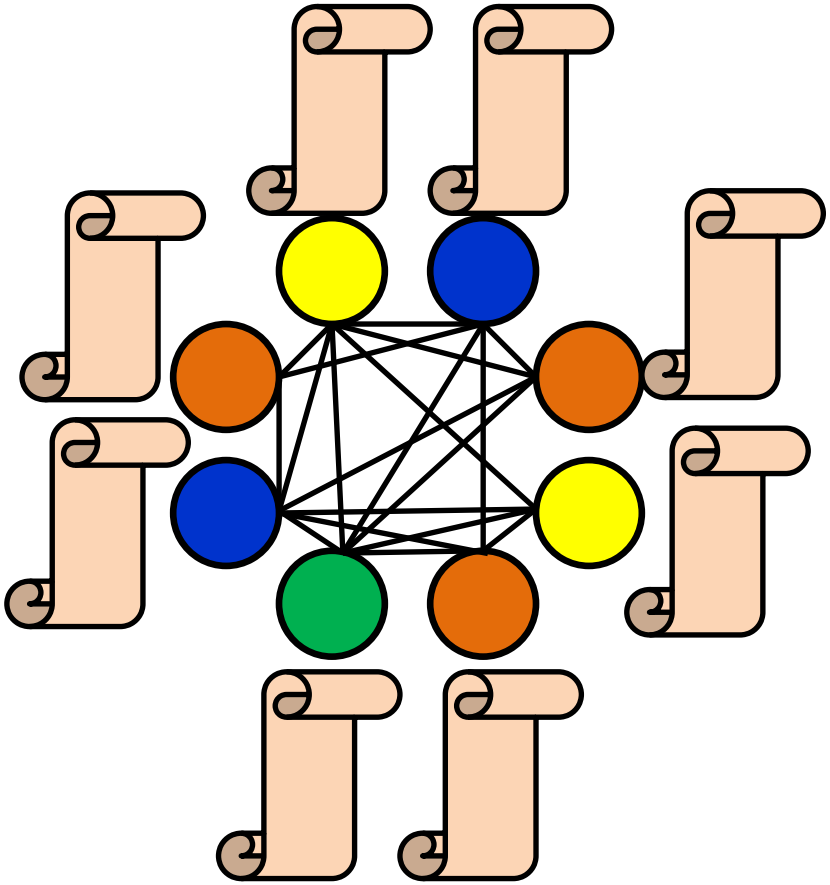
How to solve the distributed ledger problem

distributed ledger via repeated consensus



repeat:

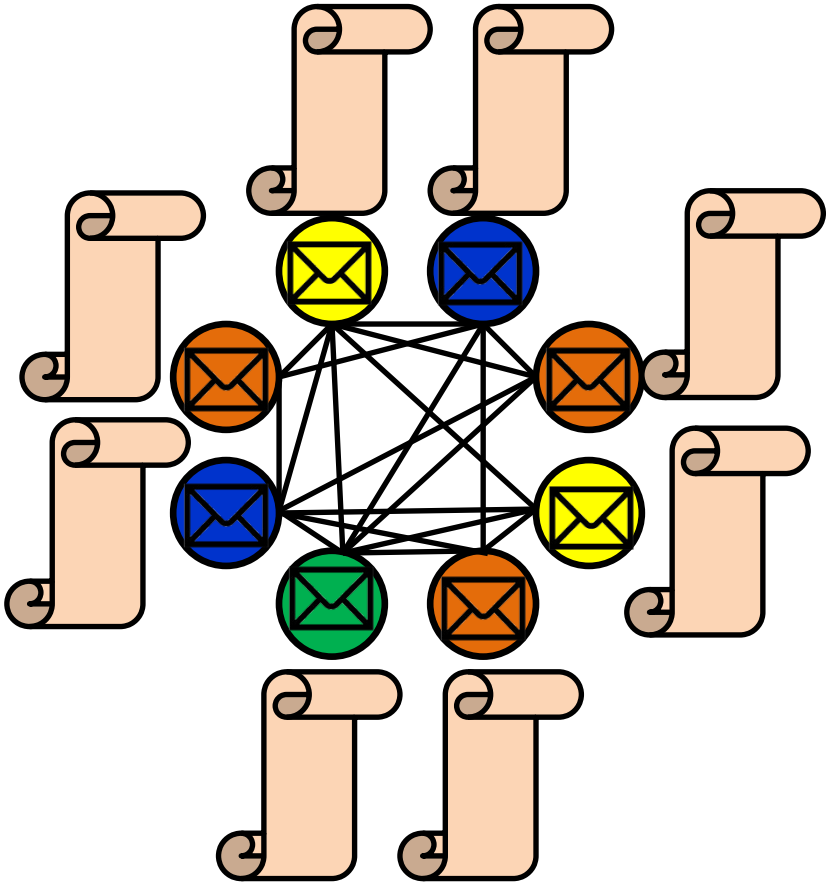
distributed ledger via repeated consensus



repeat:

- each node supports its command

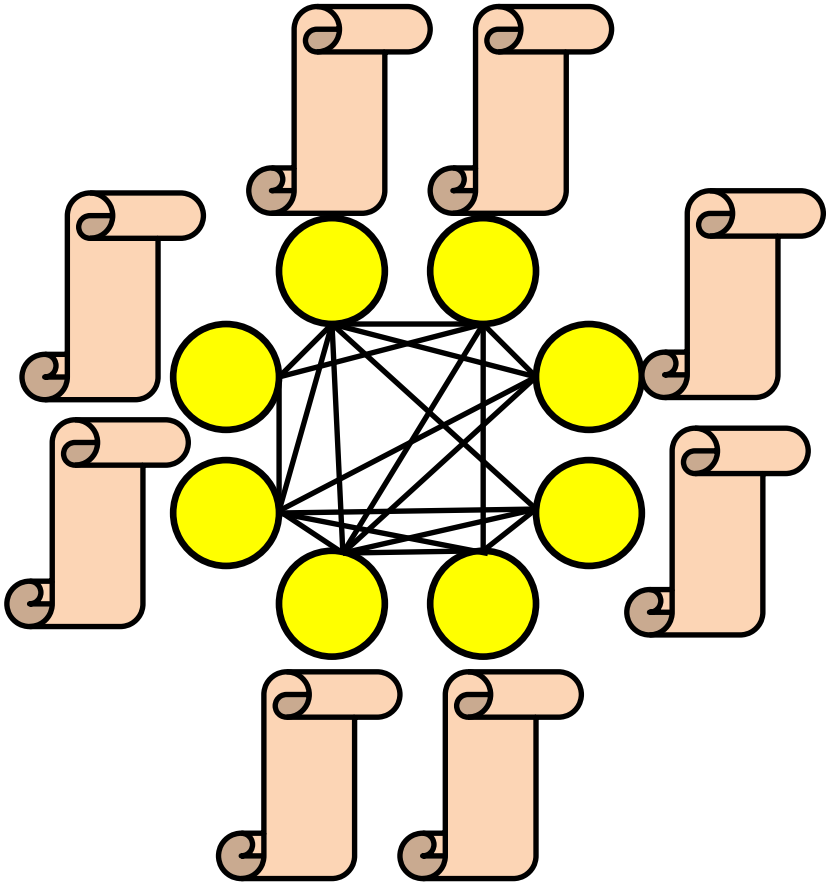
distributed ledger via repeated consensus



repeat:

- each node supports its command
- exchange messages to get an agreement on the winning command

distributed ledger via repeated consensus



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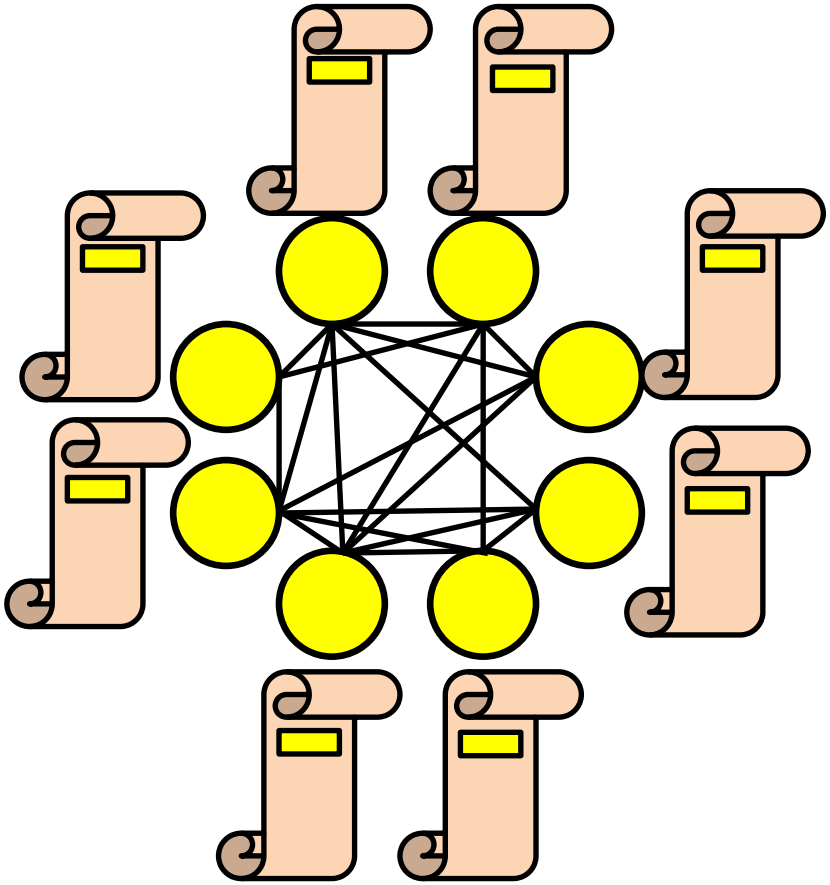

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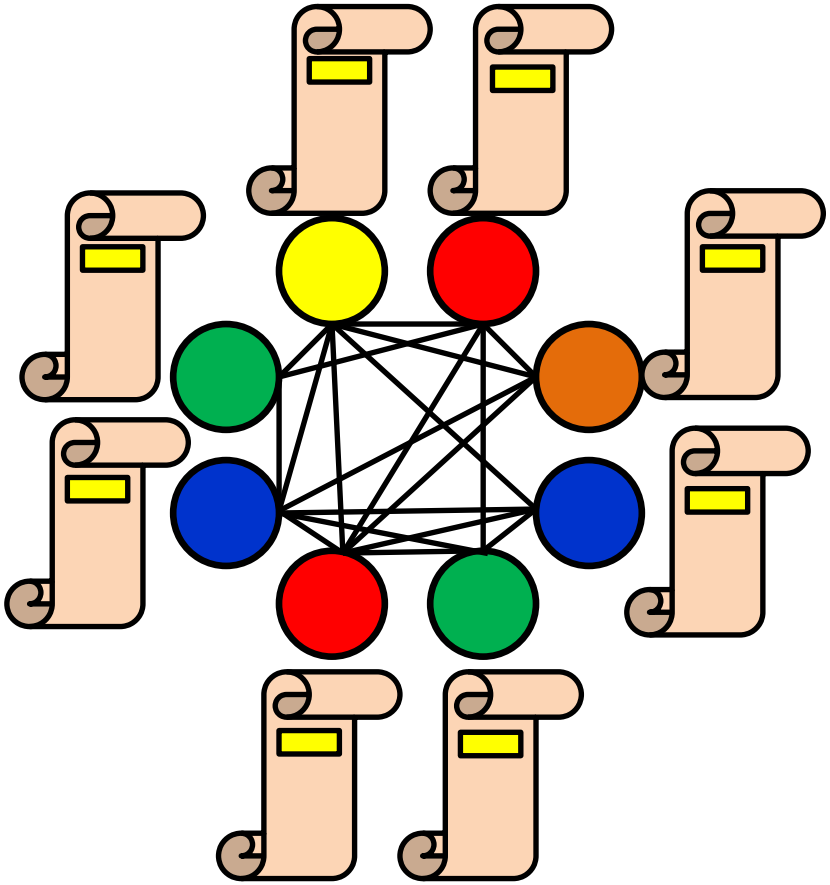

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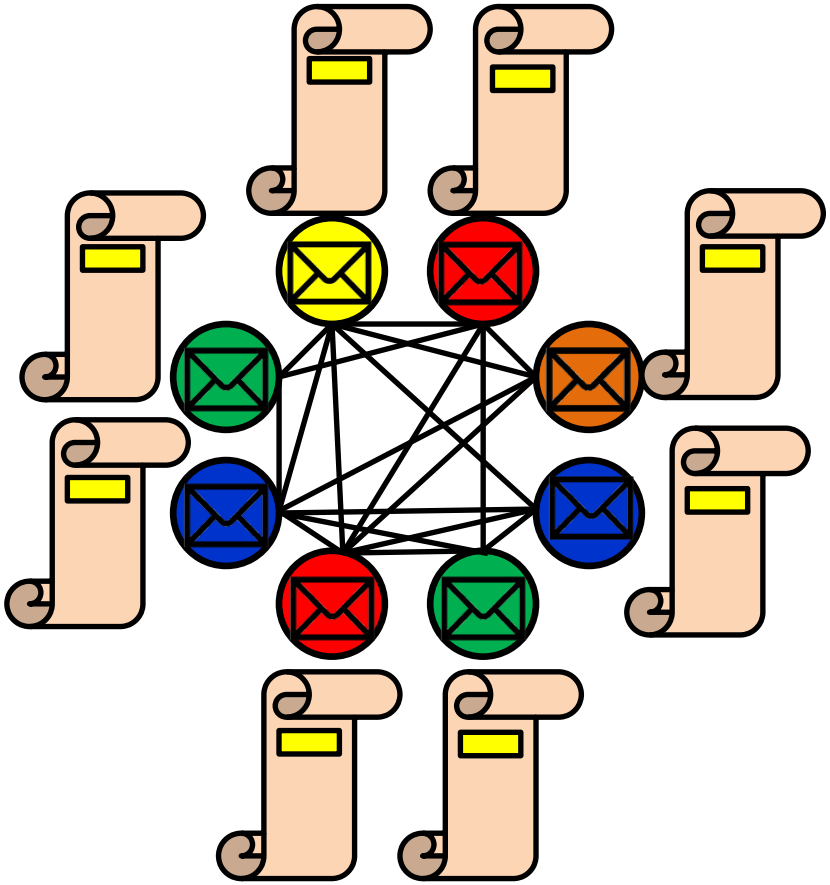

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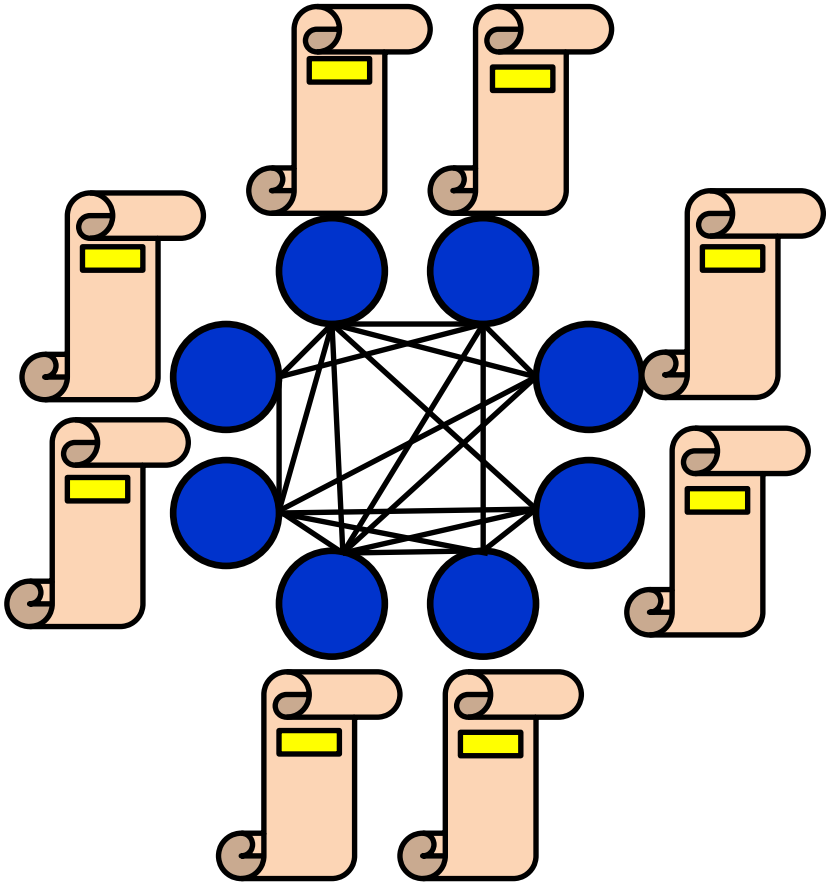

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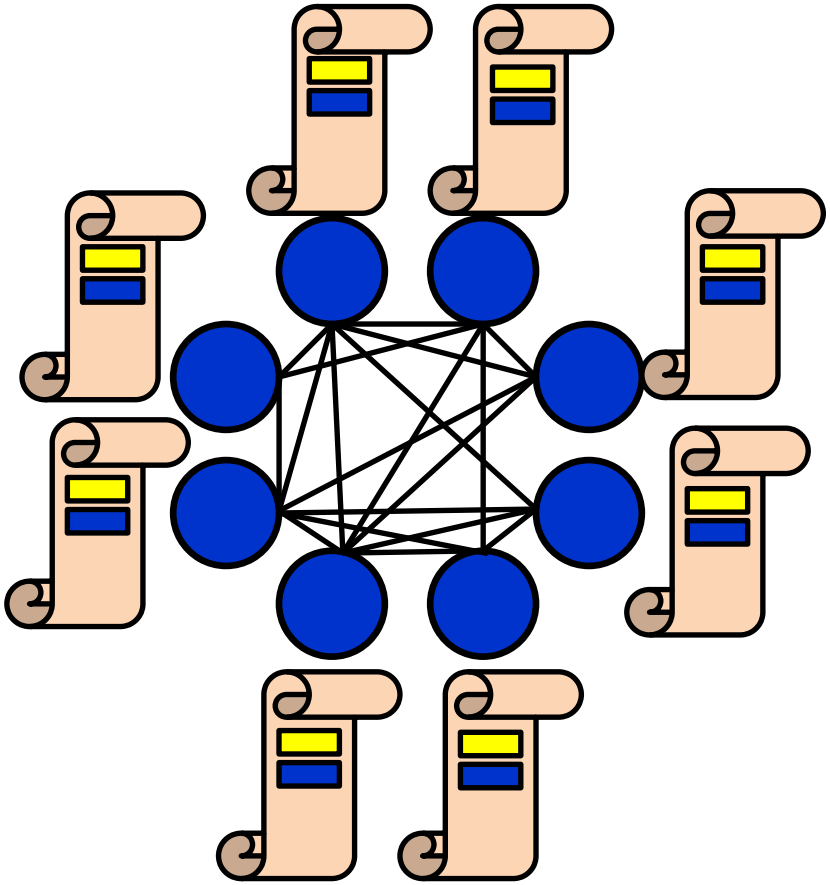

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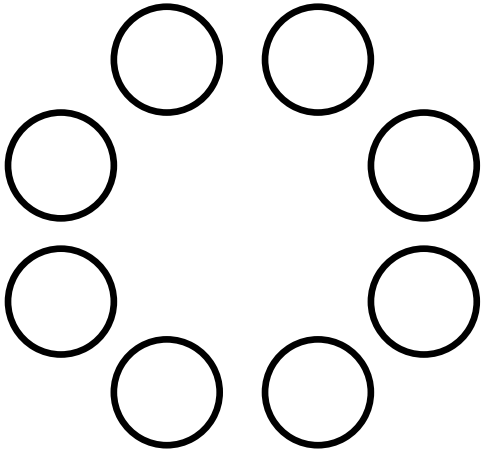
the consensus problem

Consensus Problem

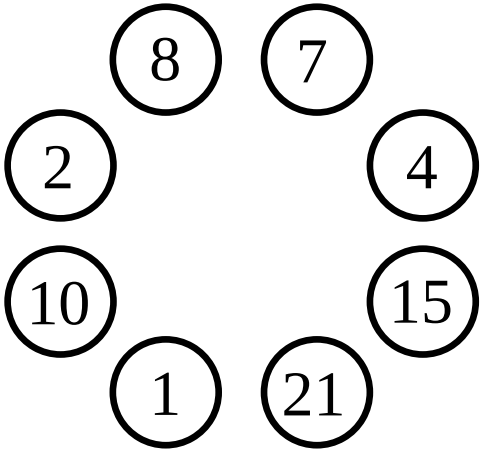
a set of n nodes



Consensus Problem

a set of *n* nodes

each node has:
  unique ID



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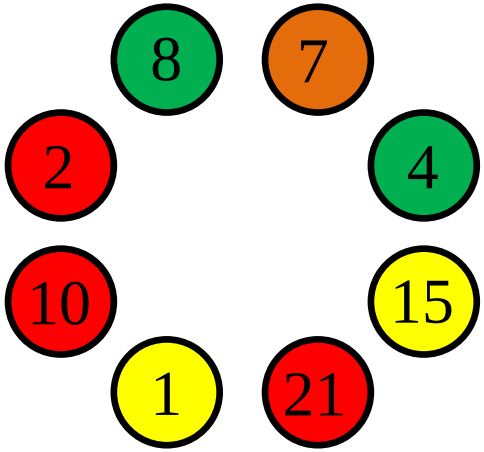

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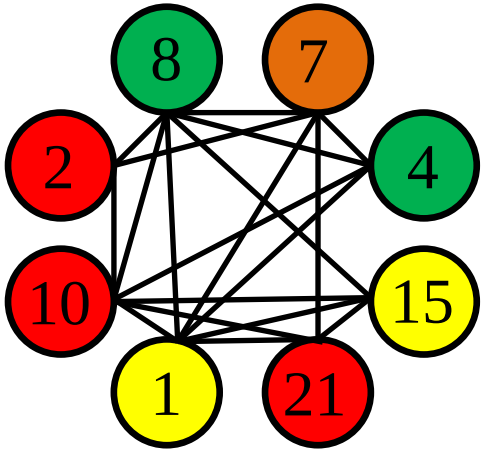
an underlying communication graph G



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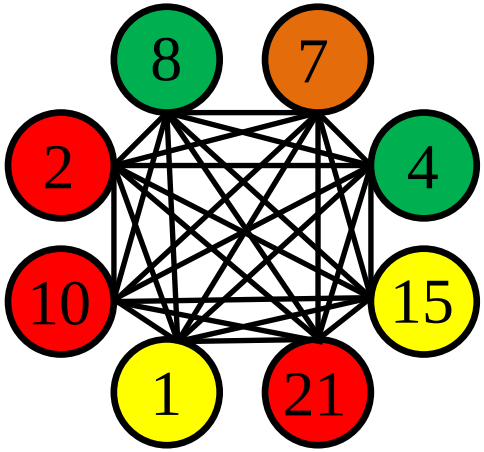
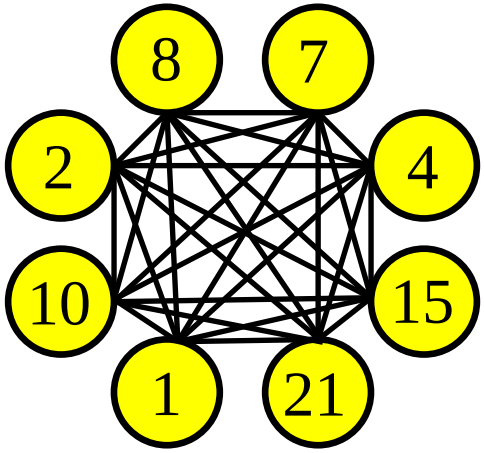


Goal: a *distributed protocol* guaranteeing

Termination (protocol eventually ends)



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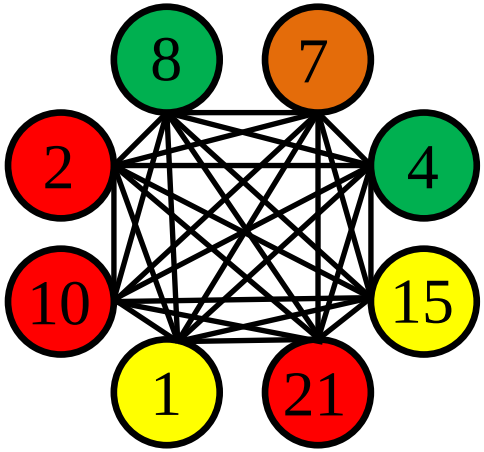

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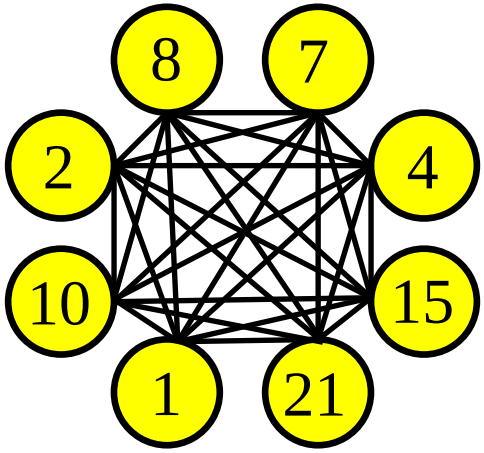
Agreement (monochromatic final configuration)



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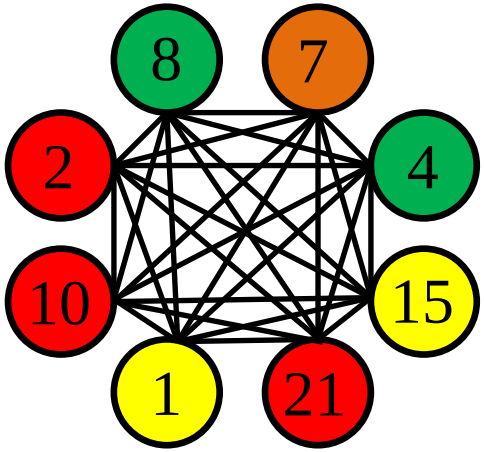

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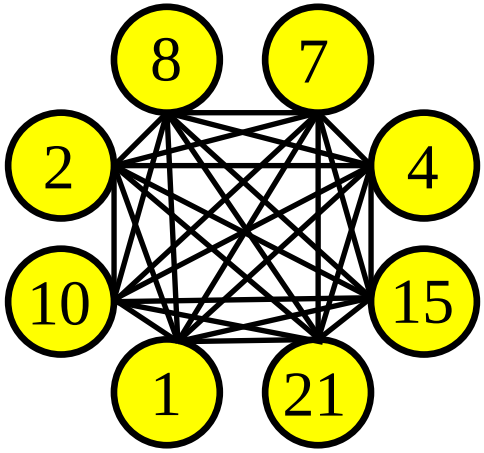
Validity

the *winning color* is initially supported by some node



Models of computation

- shared clock
- computation proceeds in *rounds*
- messages sent in a round arrive in the next round
- in a round, a node receives mgs & computes & sends msgs

- no shared clock
- no rounds
- messages arrive in the finite but unbounded time

Models of computation

Quality measures:

- # of messages
- size of the messages
- # of rounds (sync. model)

- shared clock
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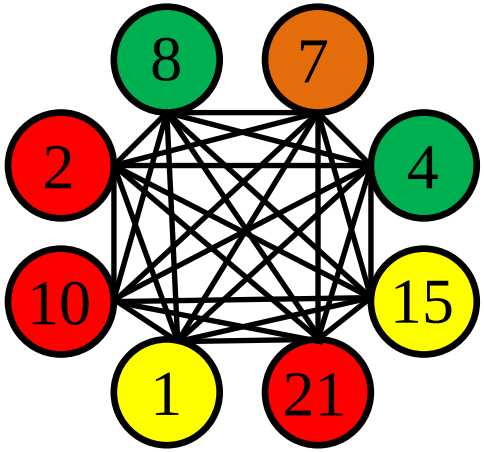

Goal: a *distributed protocol* guaranteeing ...

Simple solution:

Leader Election & convergence to leader's color

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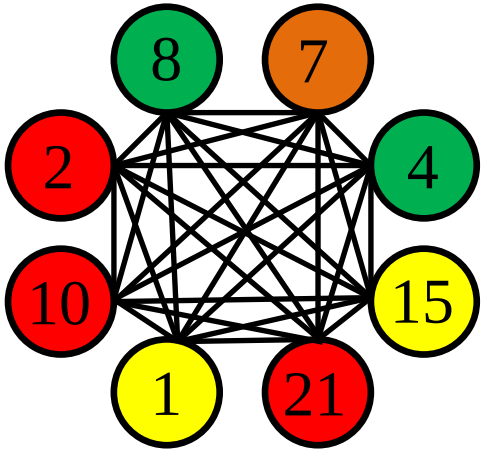

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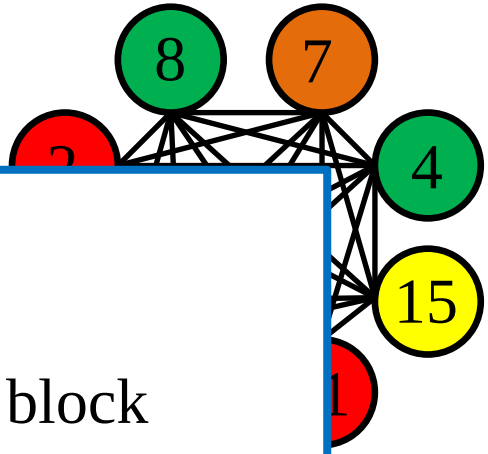
Find-min protocol

Consensus Problem

a set of *n* nodes

each node has:



In the Bitcoin System:

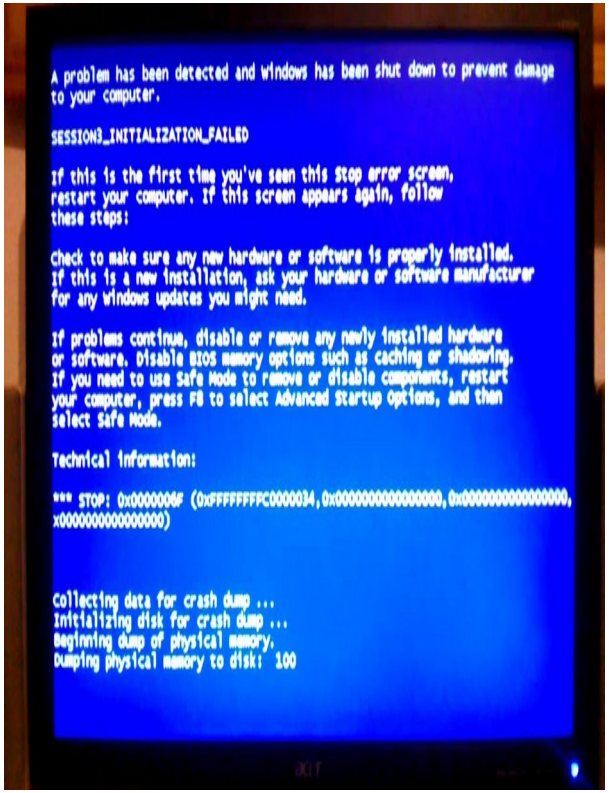
the leader is the node that solves the next block

Leader Election & convergence to leader's color

Find-min protocol

Fault Tolerance

Type of failures

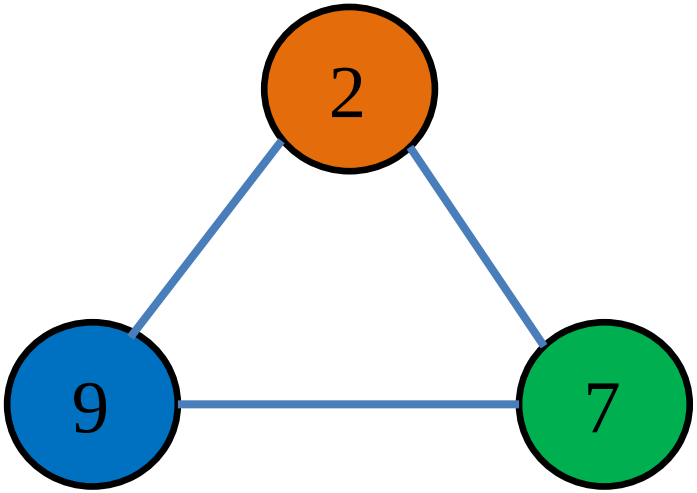


Crash failures

Simple solution:

Leader Election & convergence to leader's color

Find-min protocol



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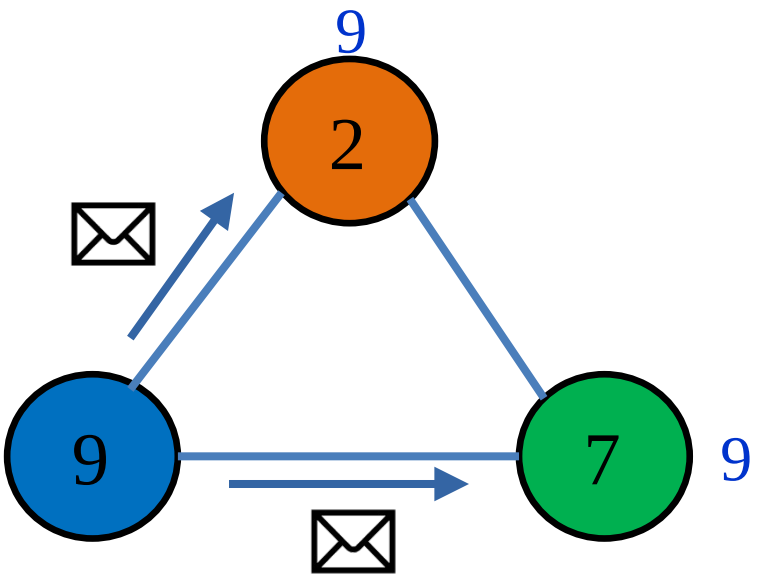

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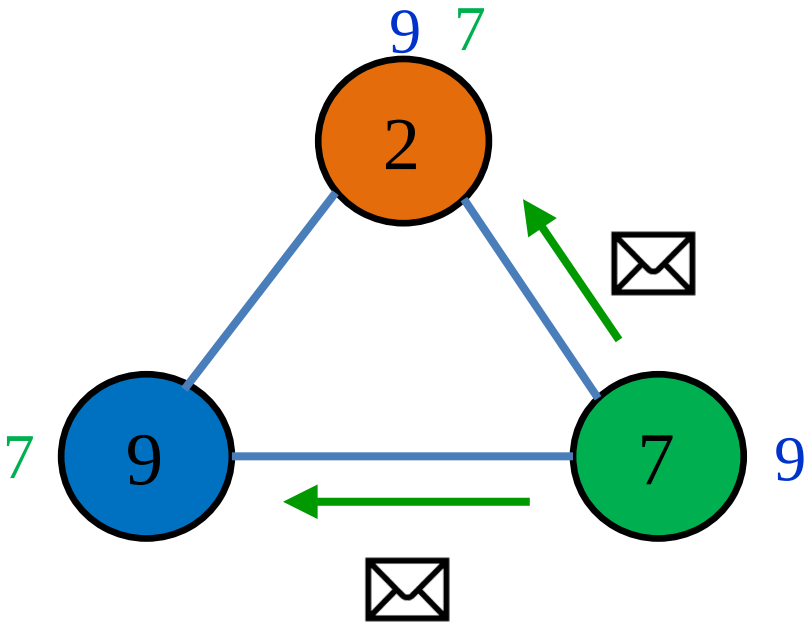

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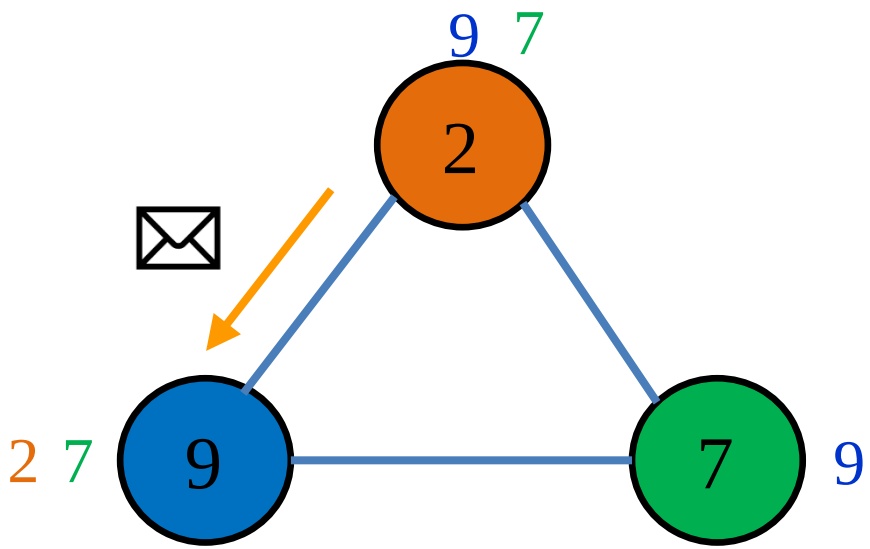

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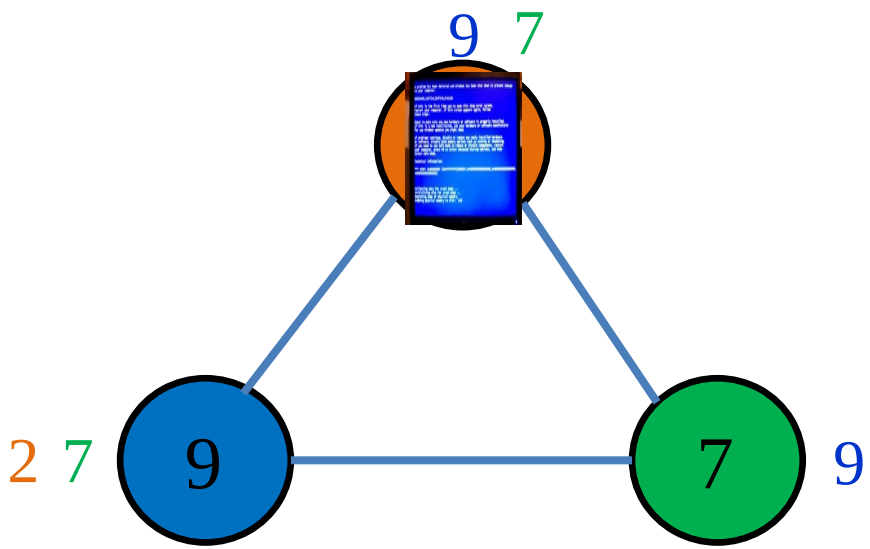

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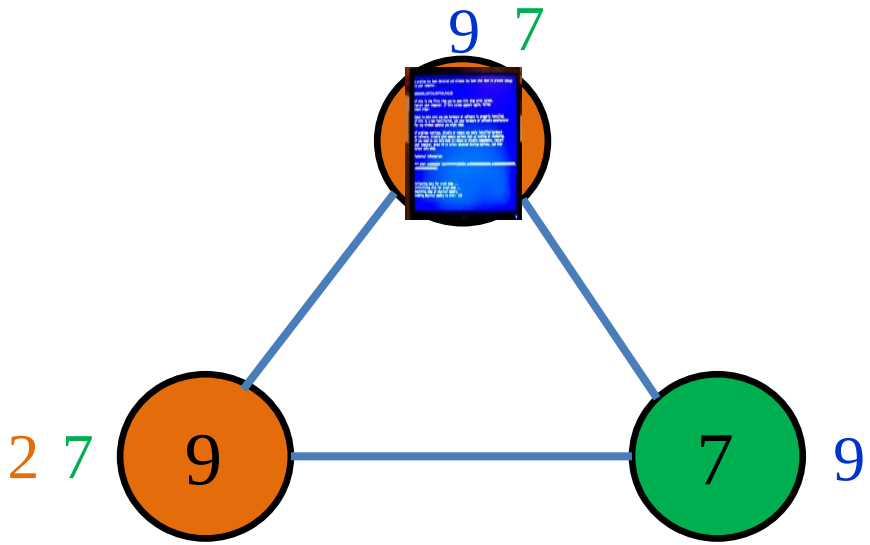
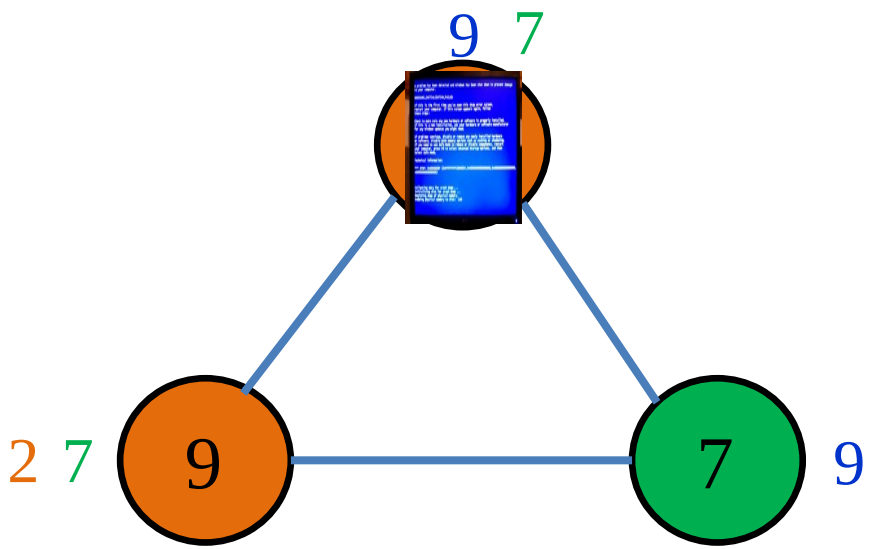


Simple solution:

Leader Election & convergence to leader's color

Find-min protocol

no agreement!



Theorem (1985)

There is no deterministic algorithm which always achieve consensus in the asynchronous model, with $f > 0$ crash failures.

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There is a randomized algorithm achieving consensus in the asynchronous model if up to $f < n/2$ nodes crash. No consensus algorithm can tolerate $f \geq n/2$ many crash failures.

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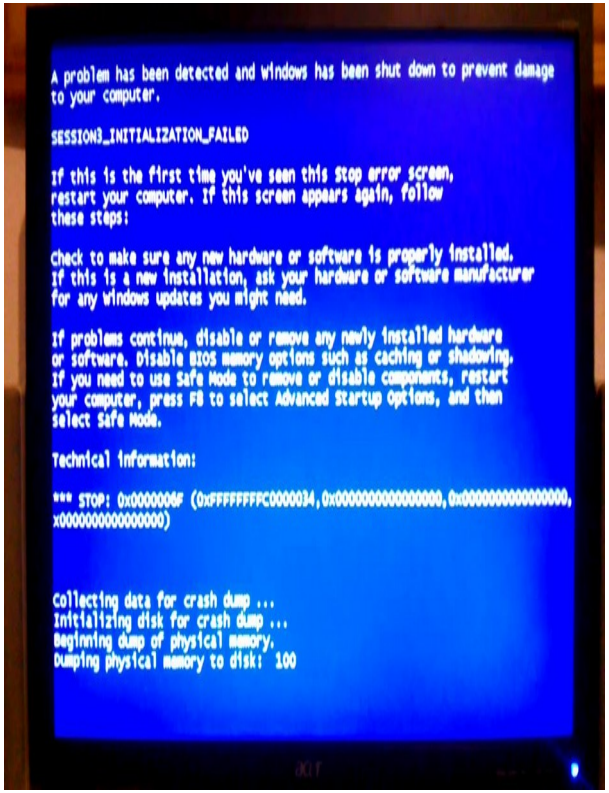
Theorem (1983)

There is a consensus algorithm for the synchronous model that tolerates any $f < n$ crash failures.

Type of failures



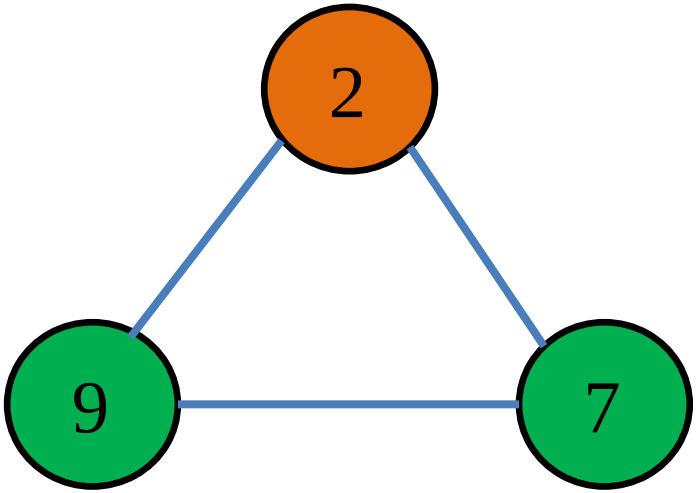
Crash failures

Byzantine failures

Simple solution:

Leader Election & convergence to leader's color

Find-min protocol



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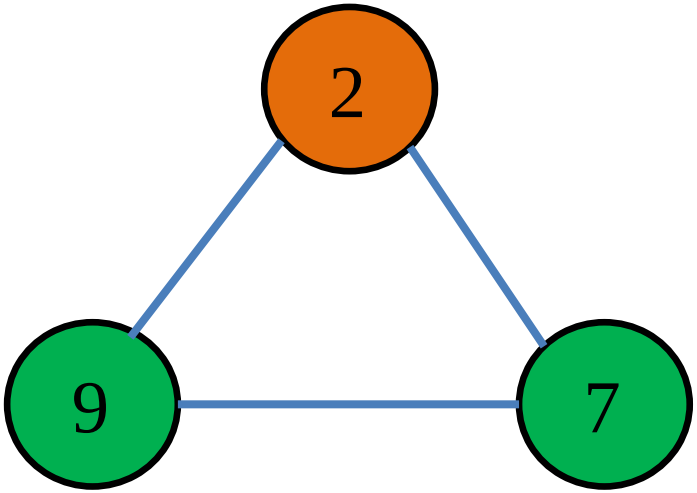

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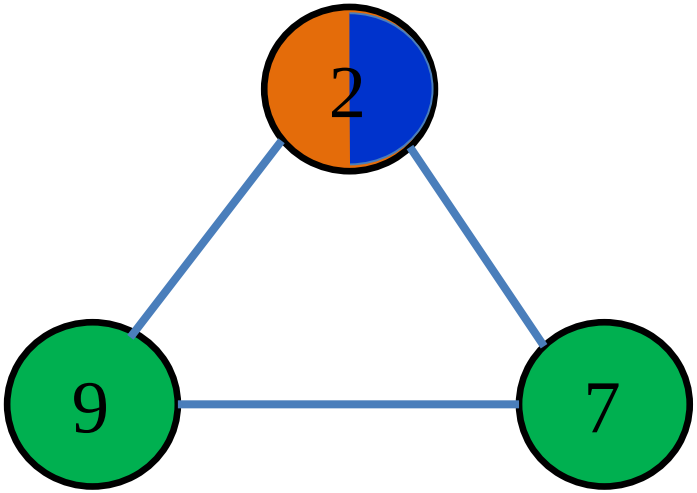

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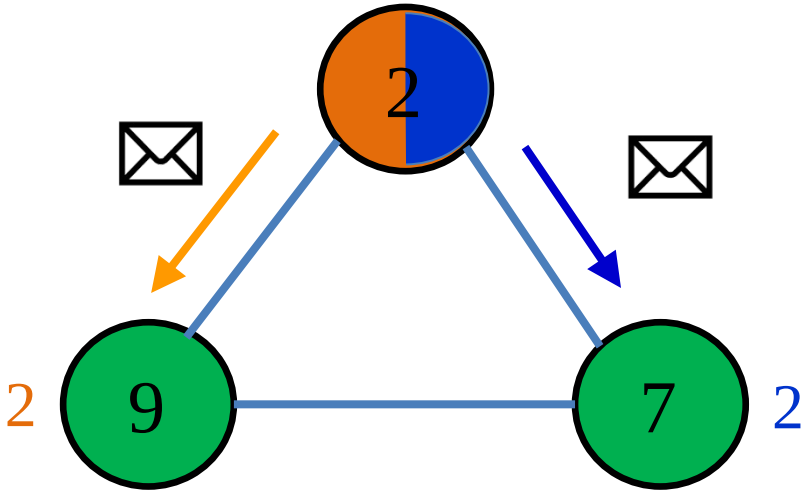

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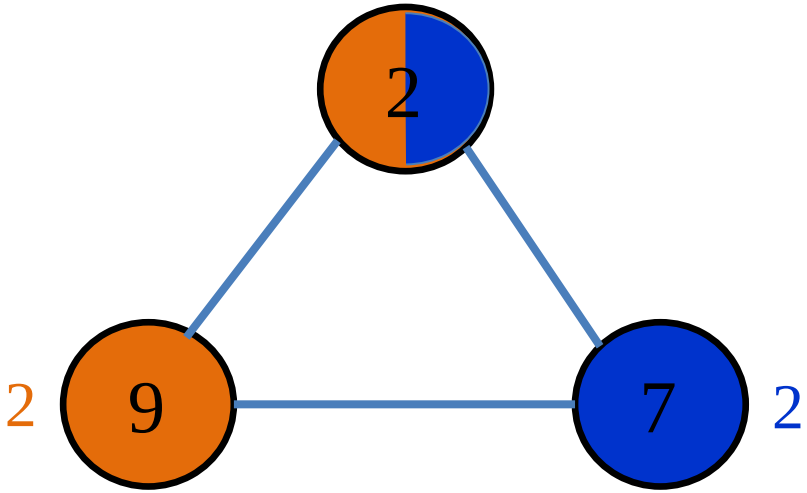

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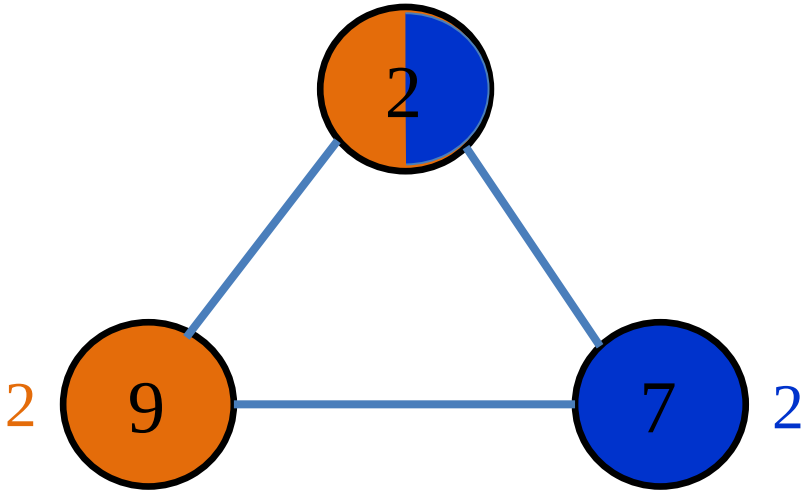

no agreement!

Theorem (1985)

There exists a randomized algorithm achieving consensus in the asynchronous model if up to $f<n/3$ nodes are byzantine.

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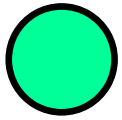
Theorem (1980)

No consensus algorithm can work for $f \geq n/3$ byzantine nodes, even in the synchronous model.

implicit assumption:

 = 1

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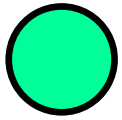
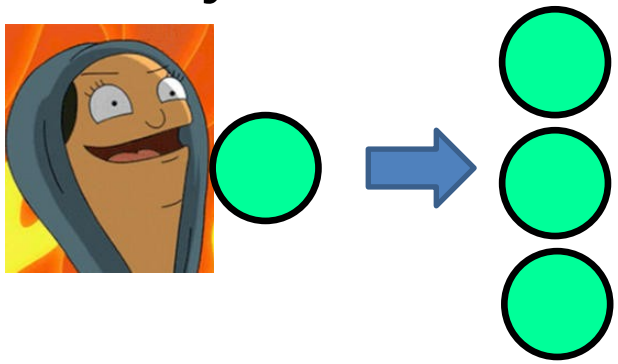
 = 1

Sybil attack:



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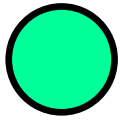 = 1

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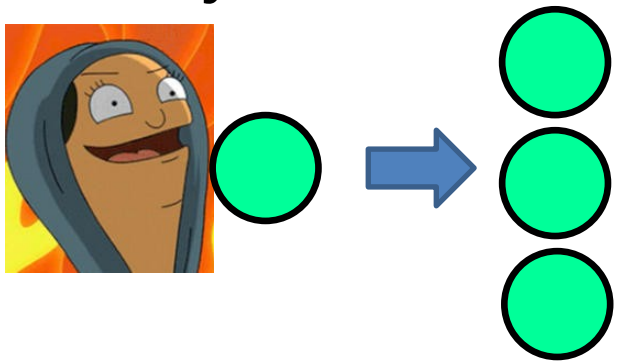


Proof of Work idea:

 = 1

Fair Consensus Problem

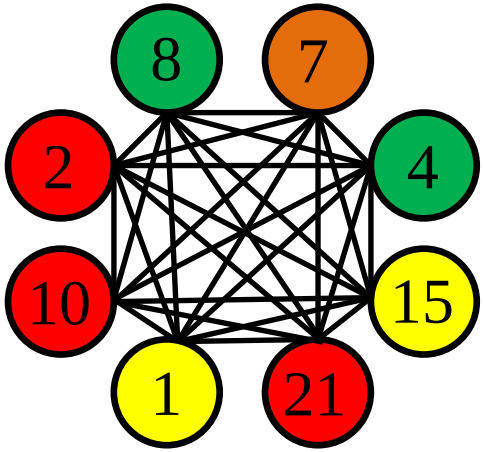
a set of n nodes

each node has:

unique ID

a color in {●●● …● }

an underlying communication graph G



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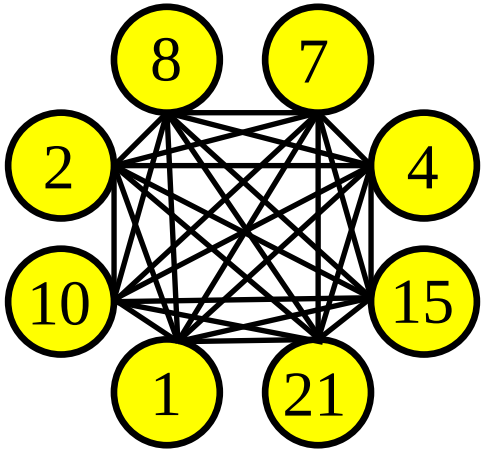

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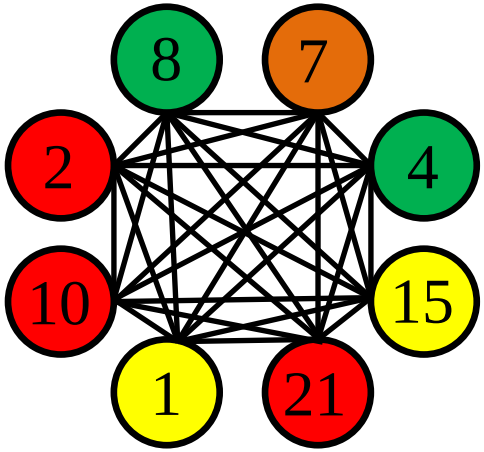
an underlying communication graph G



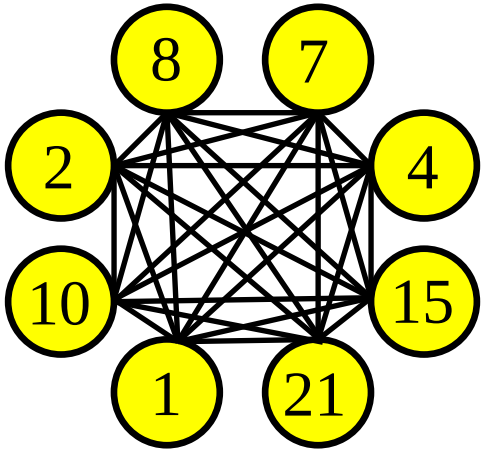
Goal: a *distributed protocol* guaranteeing

Termination (protocol eventually ends)

Agreement (monochromatic final configuration)

~~Validity~~ → Fairness

the probability that a color becomes the *winning color* is equal to the fraction of nodes initially supporting it



Fair Consensus Problem

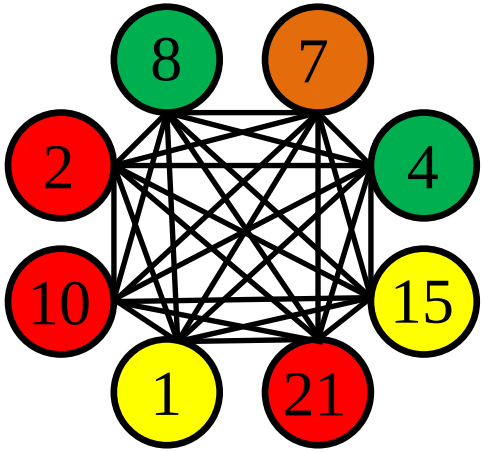
a set of n nodes

each node has:

unique ID

a color in {● ● ● …● }

an underlying communication graph G



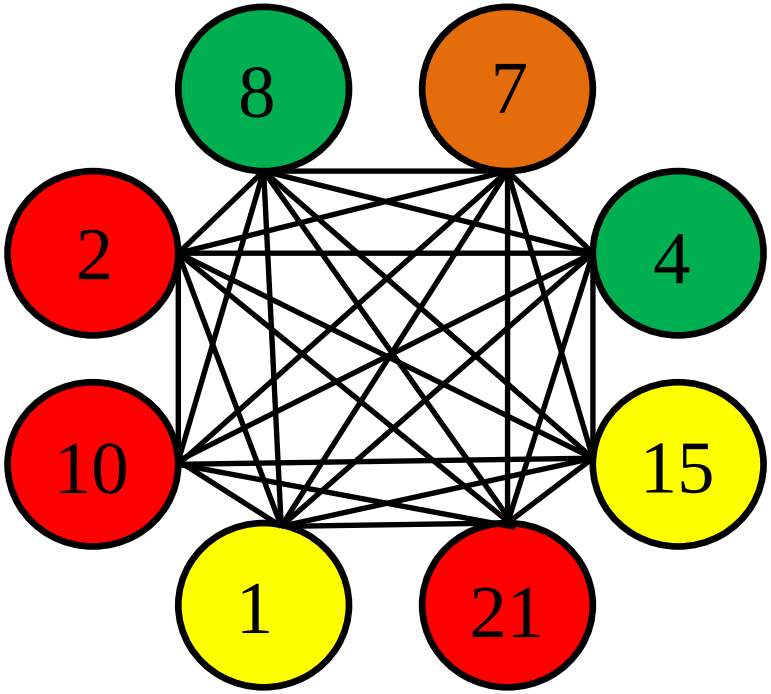
Goal: a *distributed protocol* guaranteeing

Simple solution:

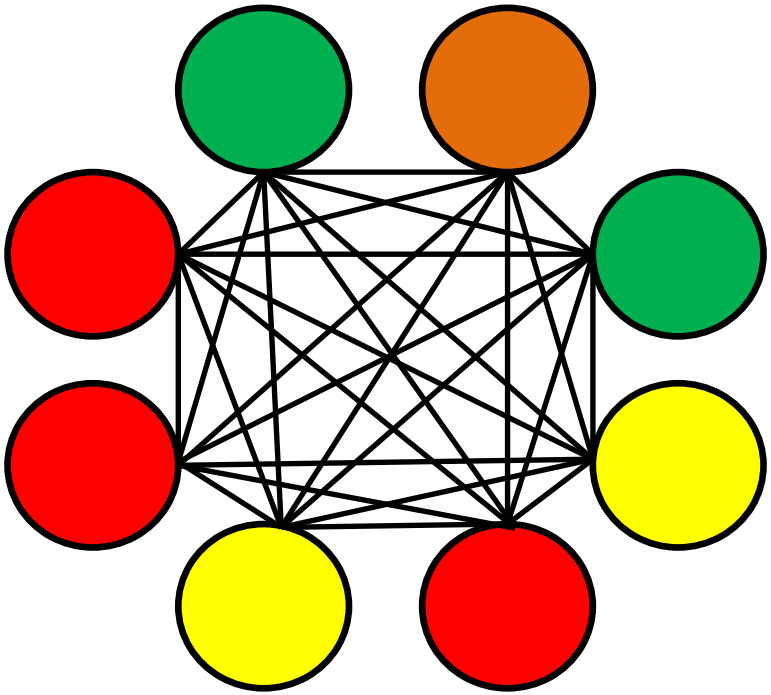
Choose a leader **uniformly at random** & convergence to leader's color

Randomized Leader Election

Initial configuration:

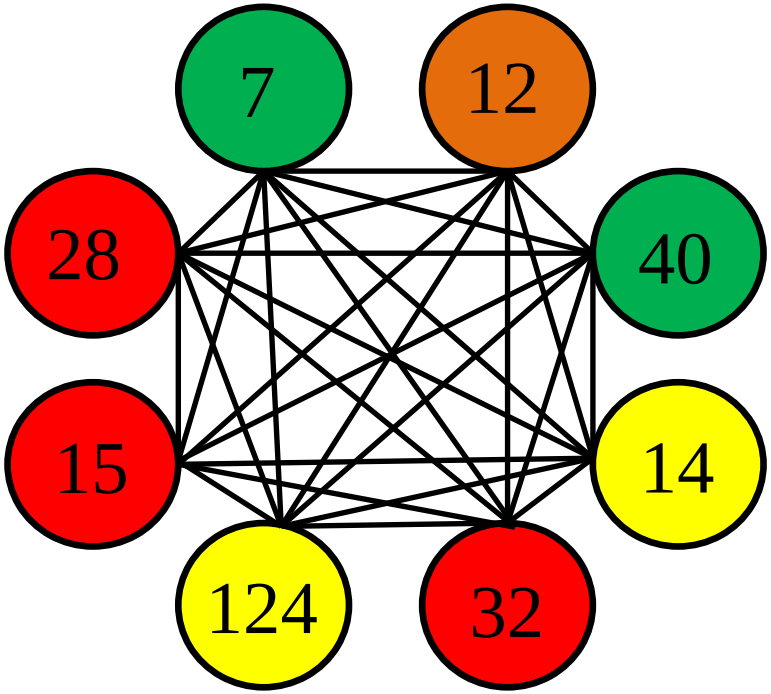


Randomized Leader Election



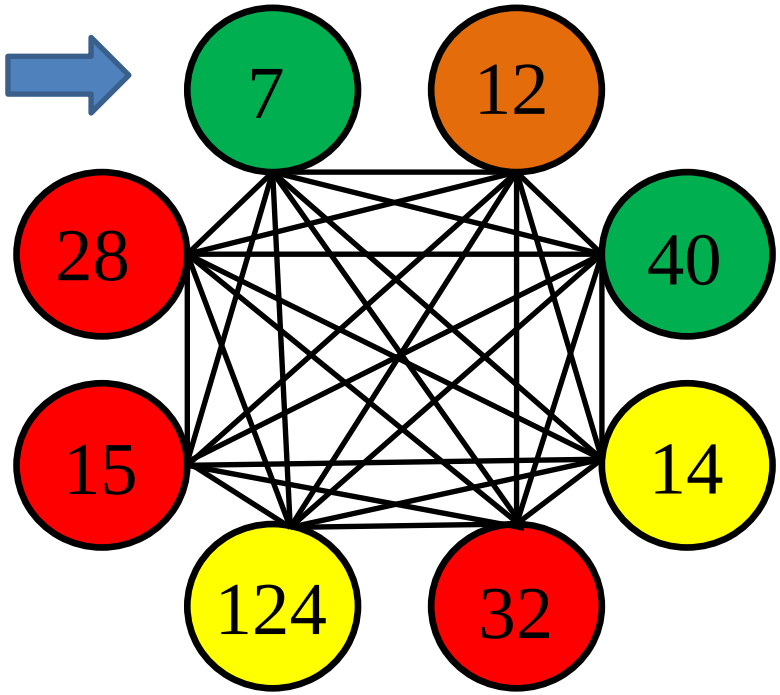
nodes do not use their unique IDs

Randomized Leader Election



each node u chooses a value k_u in $[0,n^3]$ u.a.r.

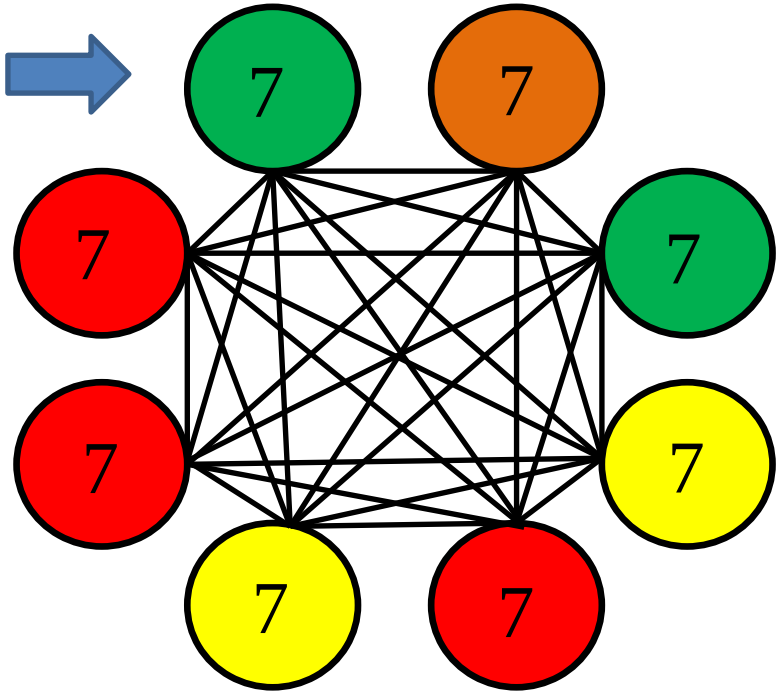
Randomized Leader Election



each node u chooses a value k_u in $[0,n^3]$ u.a.r.

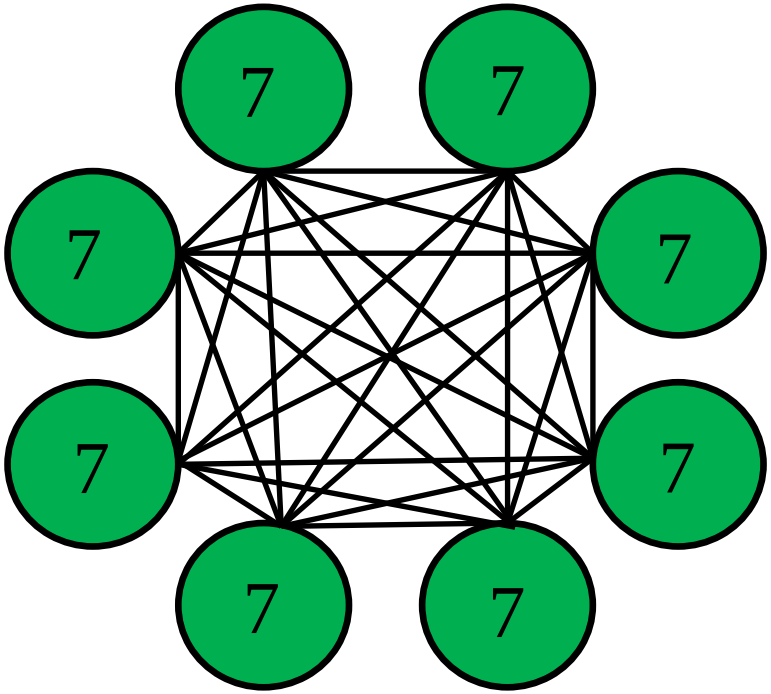
the minimum k value
is unique w.h.p.

Randomized Leader Election



Find-min Protocol

Randomized Leader Election

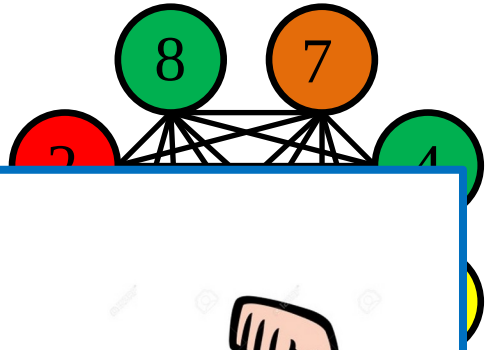


Convergence to leader’s color

Fair Consensus Problem

a set of *n* nodes

each node has:



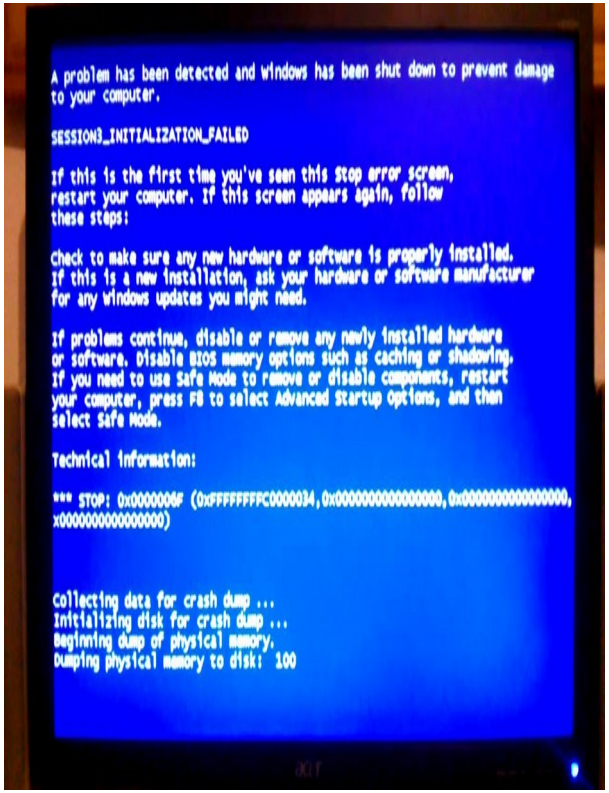
Goa

Choose a leader u.a.r. & convergence to leader's color

In the Bitcoin System:

the probability that a node becomes the leader is proportional to its computational power

Type of failures



Crash failures

Byzantine failures

rational selfish failures

A game-theoretic perspective

Each node is a selfish rational player

for each player/node u:

u's strategy: local algorithm used by u

A game-theoretic perspective

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for each player/node *u*:

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A game-theoretic perspective

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if the protocol fails

A game-theoretic perspective

Each node is a selfish rational player

for each player/node *u*:

u's strategy: local algorithm used by *u*

u's payoff:

if the winning color = u's color

if the winning color ≠ u's color

if the protocol fails

u's goal: to maximize its expected payoff

Rational Fair Consensus Problem

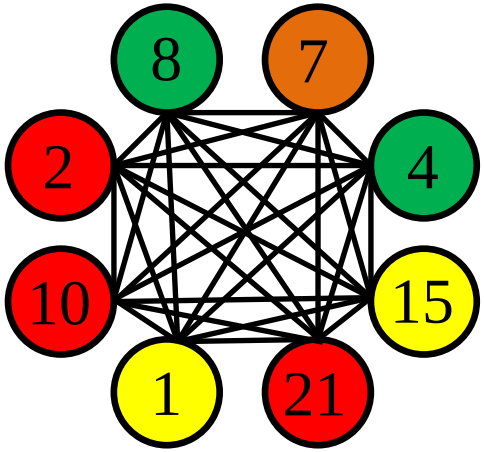
a set of n nodes

each node has:

unique ID

a color in {●●● …● }

an underlying communication graph G



a protocol solves the Rational Fair Consensus if

it solves the Fair Consensus problem

&

it is resilient to agent deviations

Resiliency to agent deviations

Def. 1. A protocol *P* is a **Nash Equilibrium** if, for any possible deviation of any agent *u*, *u*'s expected payoff in the new protocol *P'* does not increase.

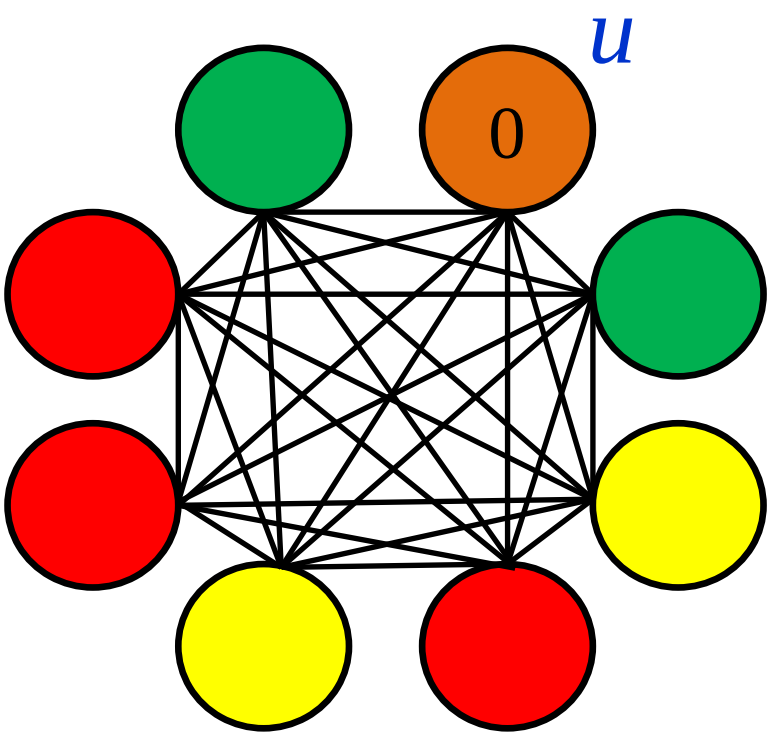
Resiliency to agent deviations

Def. 1. A protocol P is a **Nash Equilibrium** if, for any possible deviation of any agent u, u's expected payoff in the new protocol P' does not increase.

Def. 2. A protocol P is a **t-strong Equilibrium** if, for any possible deviation of any coalition C of players of size at most t, there is a player in C whose expected payoff in the new protocol P' does not increase.

Rational Fair Consensus Problem

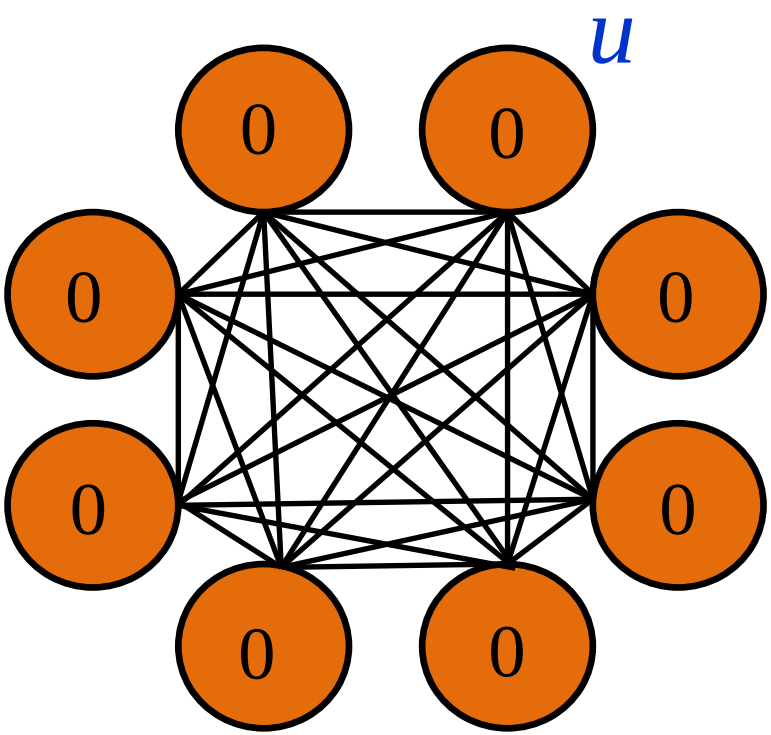
(the simple solution fails)



node u chooses a “random” value k_u =0

Rational Fair Consensus Problem

(the simple solution fails)



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Rational Fair Consensus Problem

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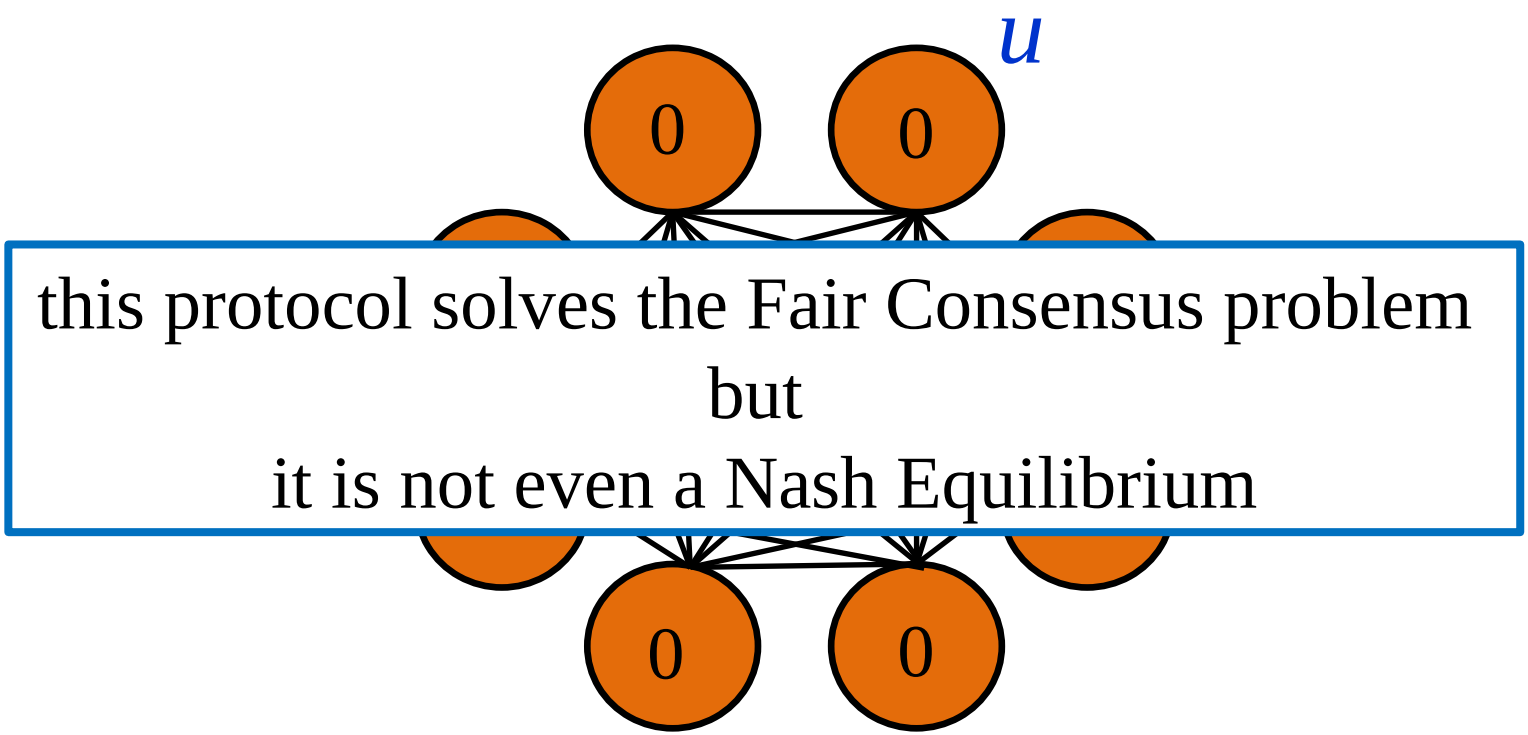


this protocol solves the Fair Consensus problem
but
it is not even a Nash Equilibrium

node u chooses a “random” value k_u =0

Bitcoin Mining Protocol:

- work on the next block to be added to the longest chain
- announce the solved block as soon as you get it

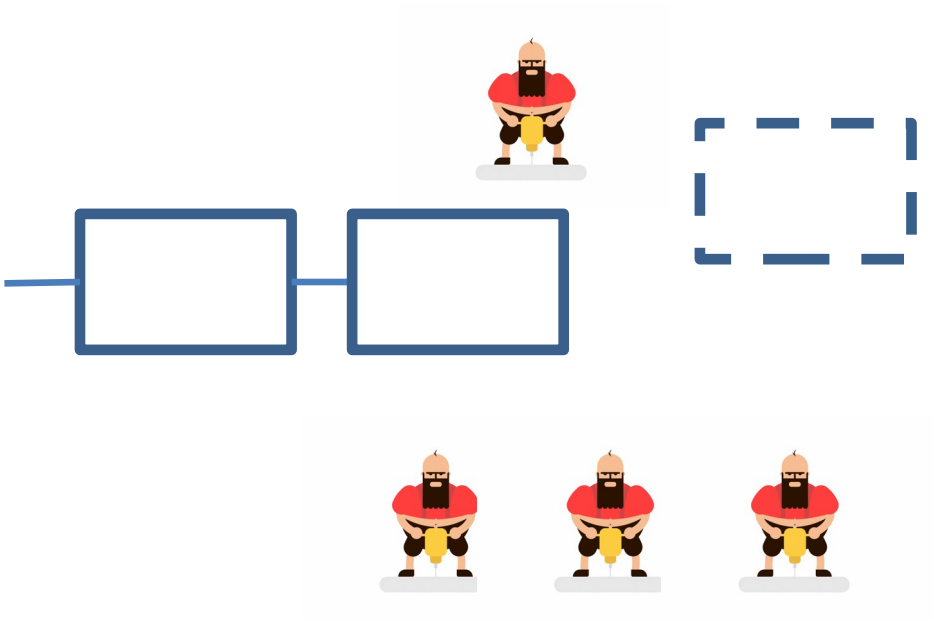
Bitcoin Mining Protocol:

- work on the next block to be added to the longest chain
- announce the solved block as soon as you get it

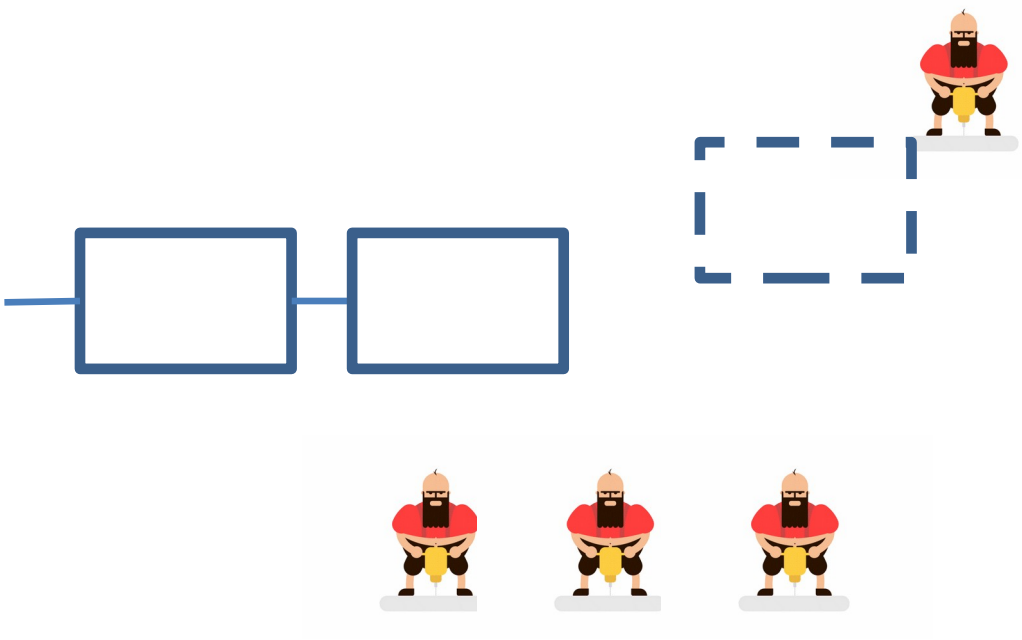
is it an equilibrium?

selfish mining

I. Eyal and E. Gun Sirer, Majority is not enough: Bitcoin mining is vulnerable, Financial Cryptography 2014



idea: selfishly decide when to announce solved blocks



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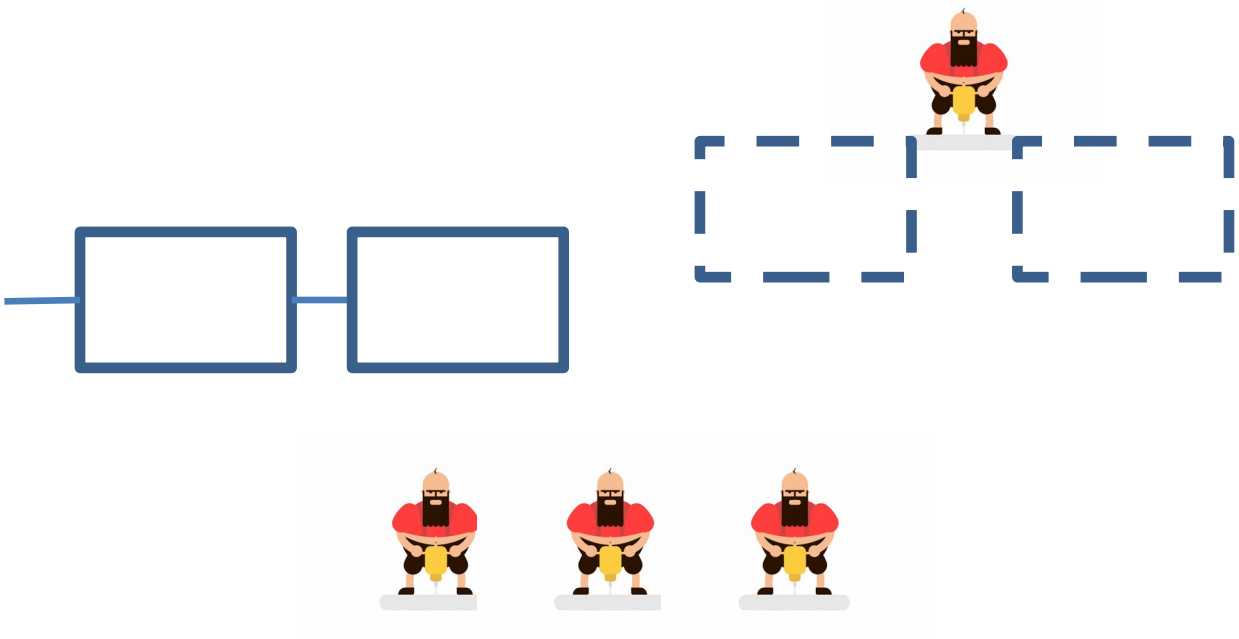

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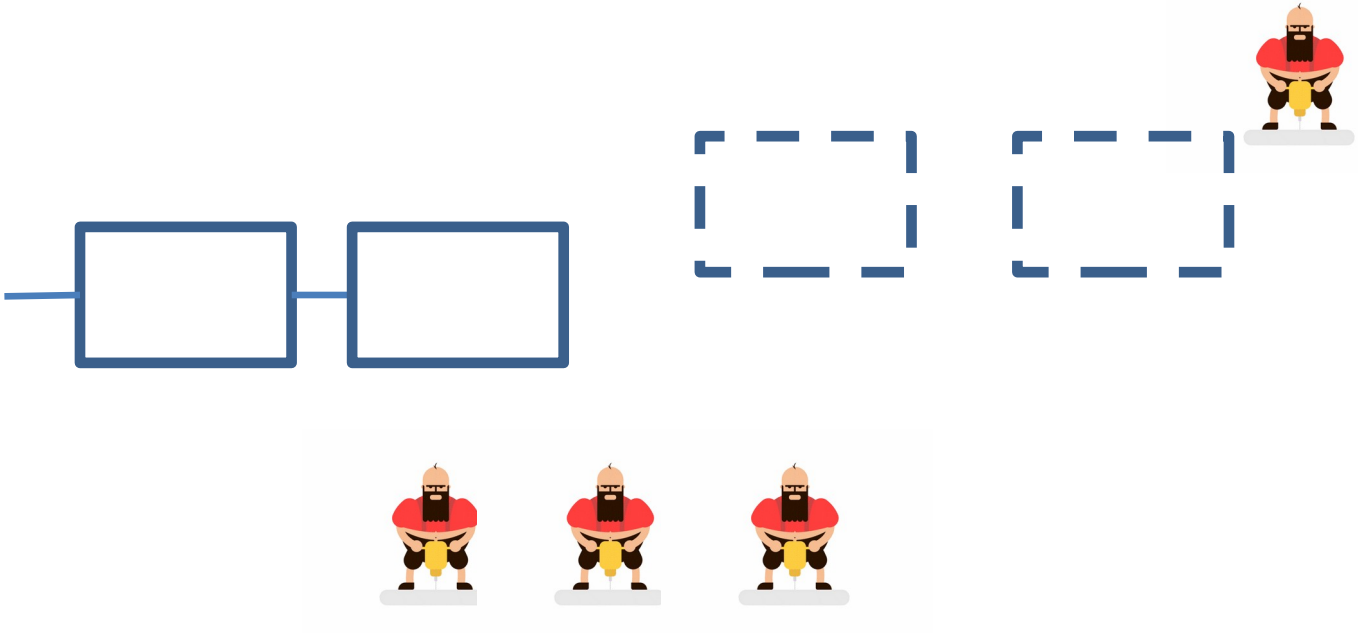

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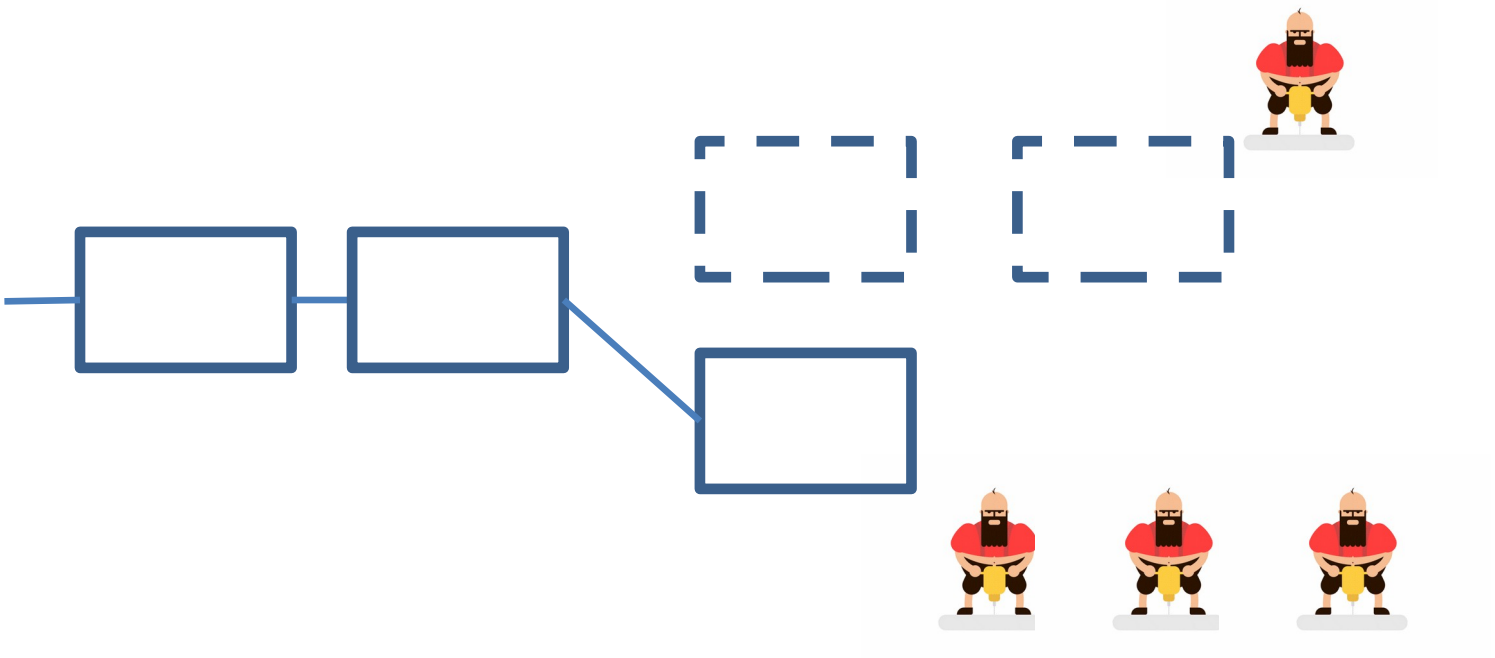

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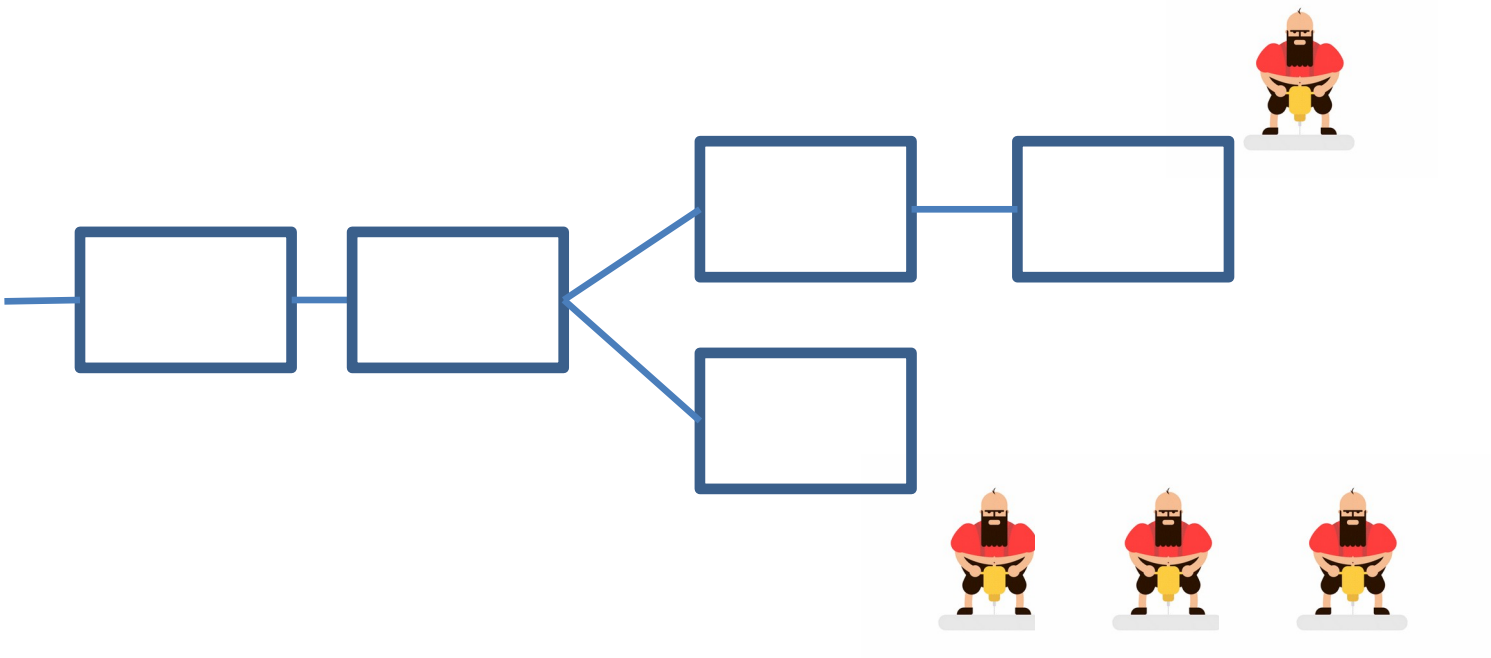

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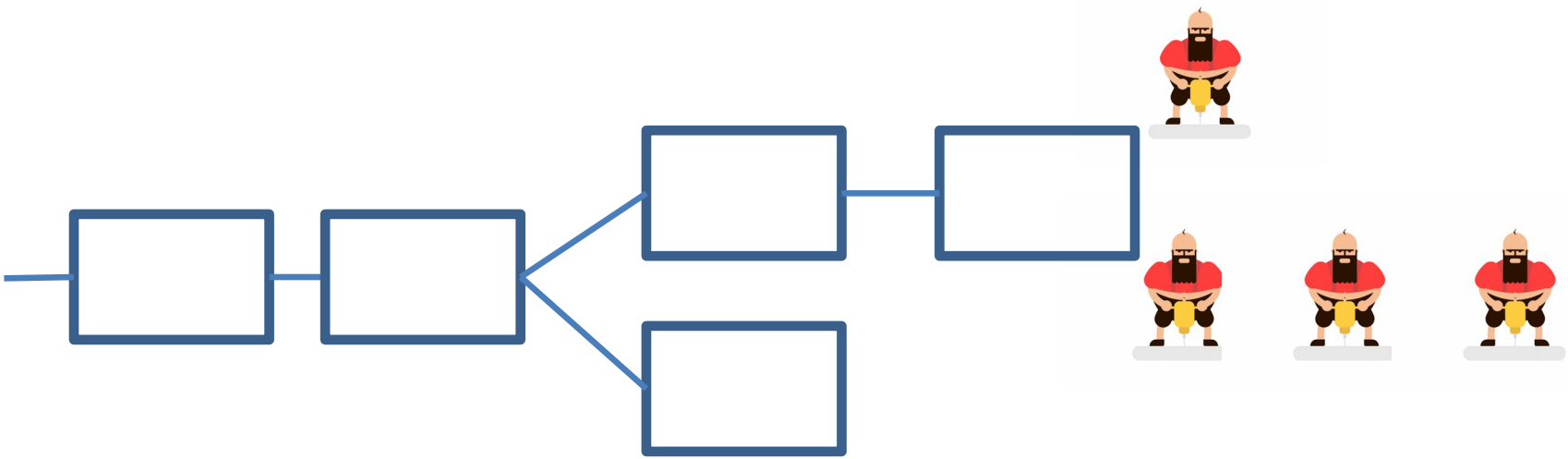

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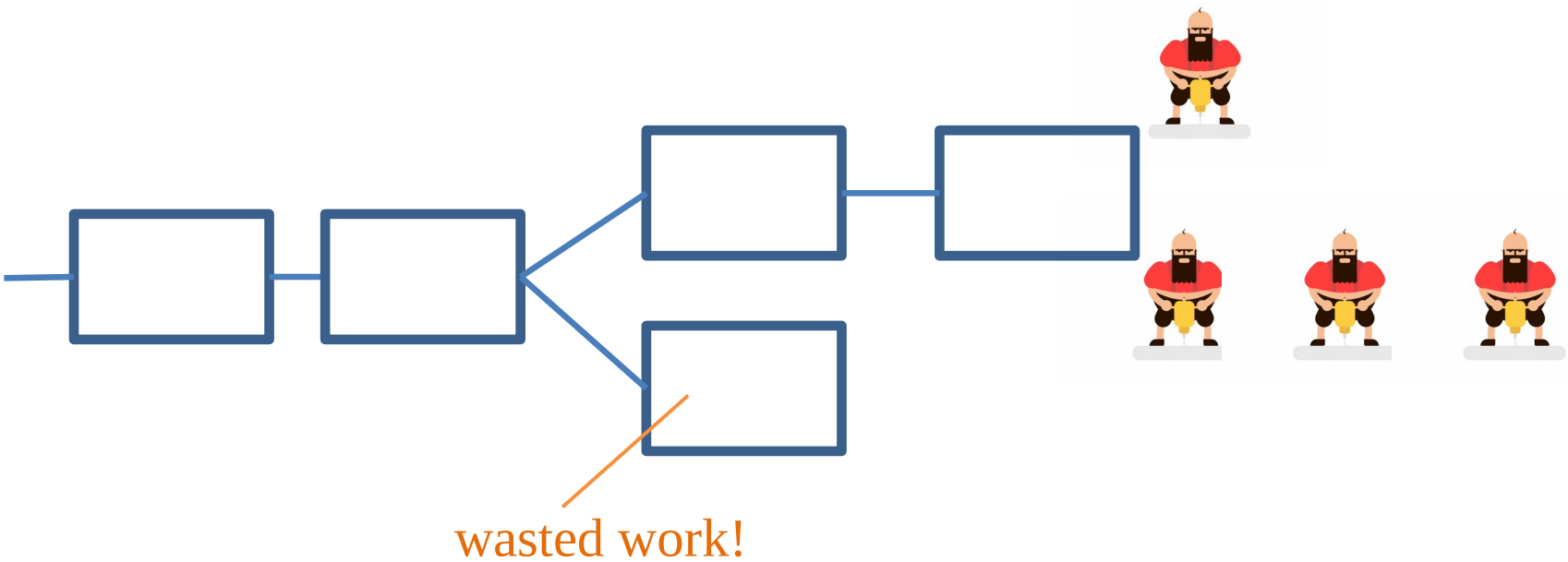

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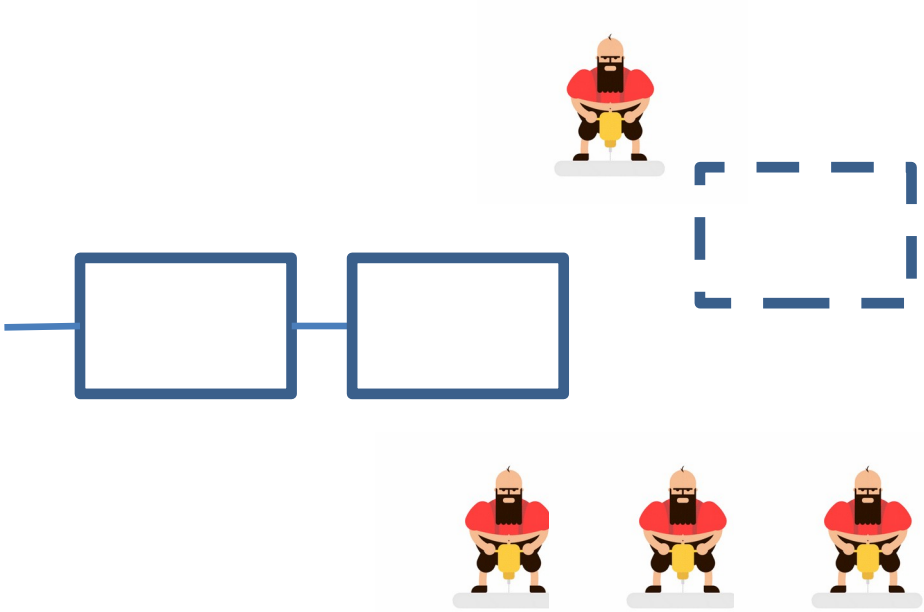

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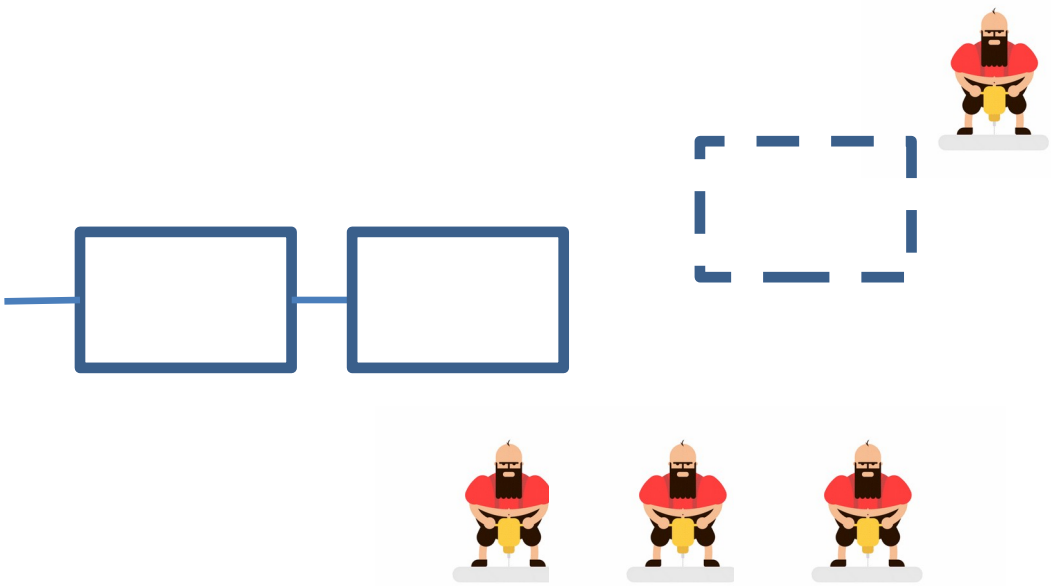

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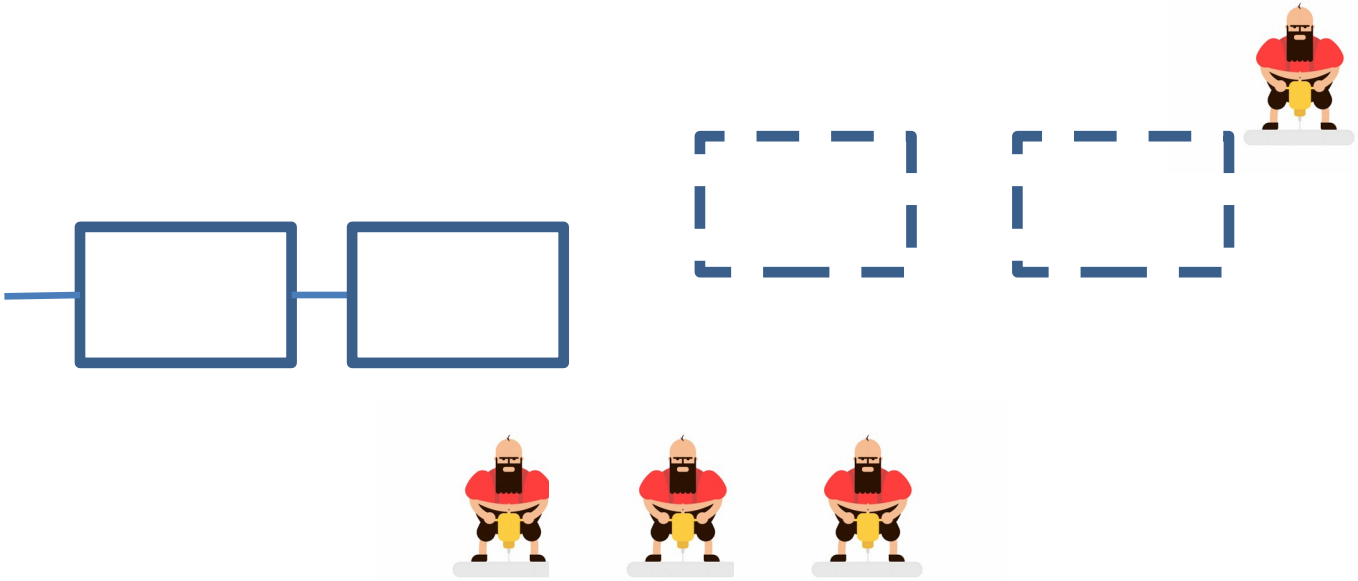

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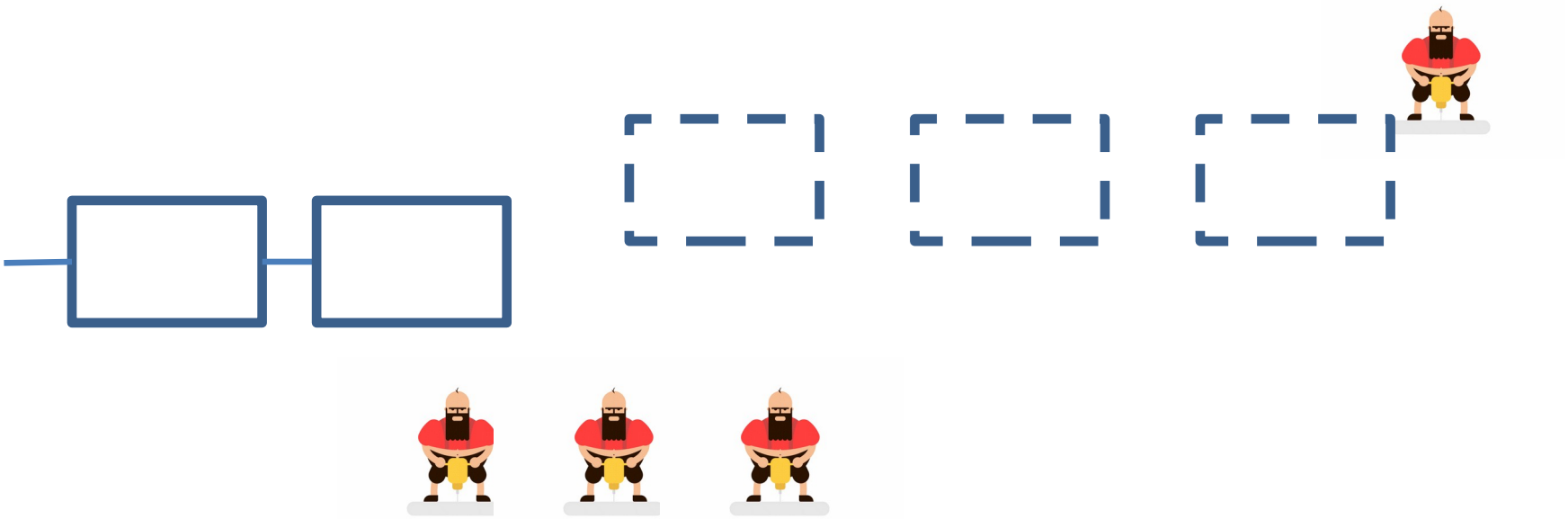

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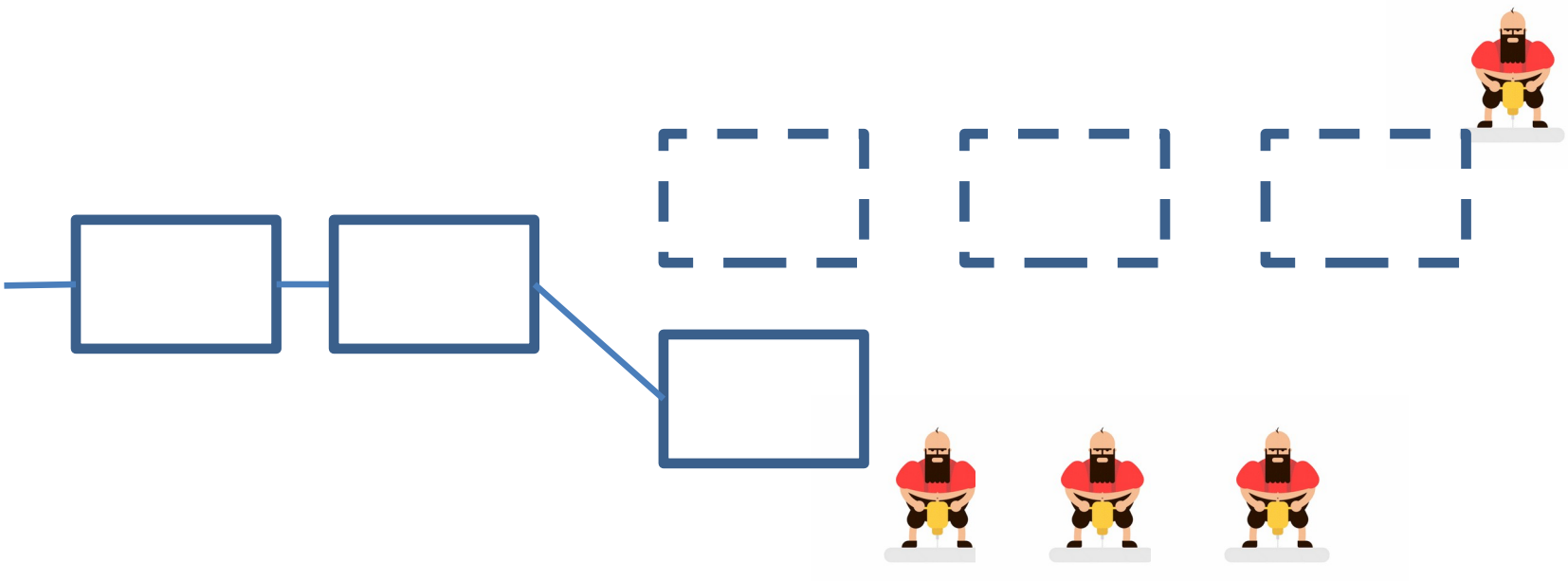

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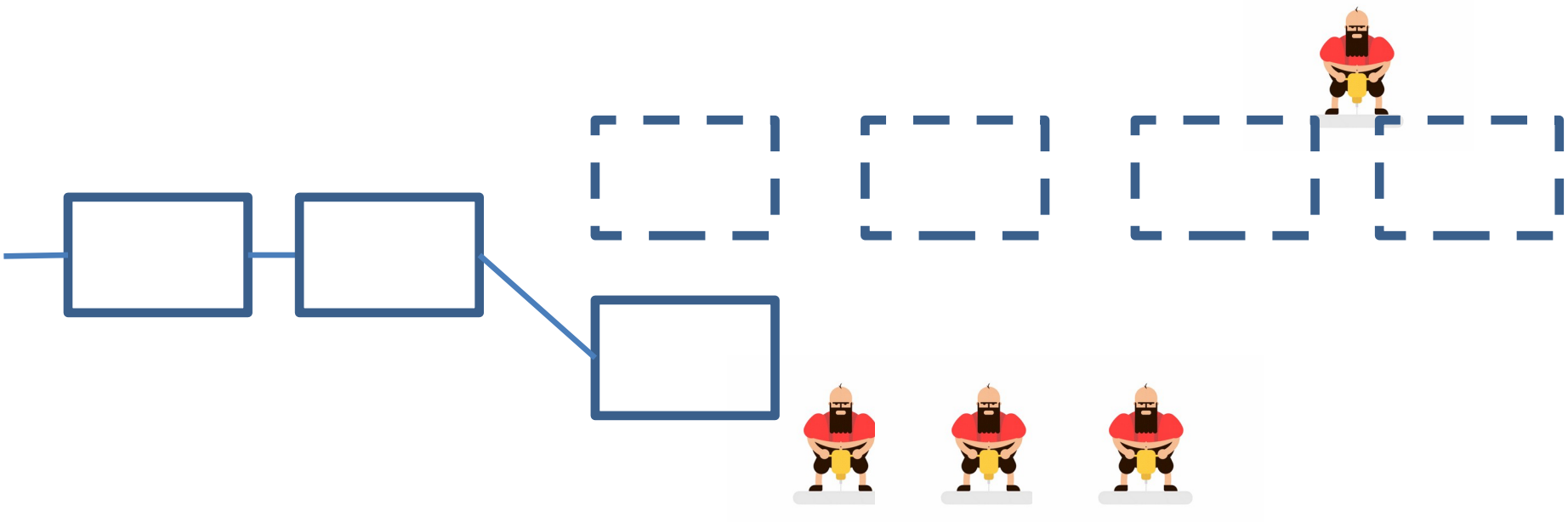

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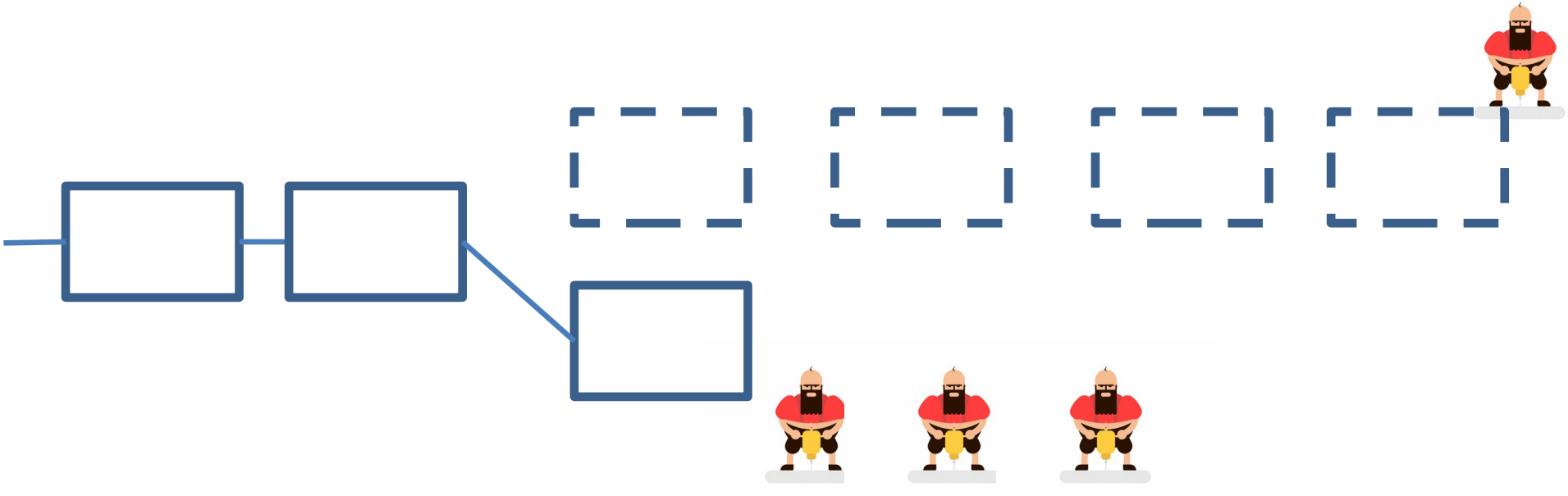

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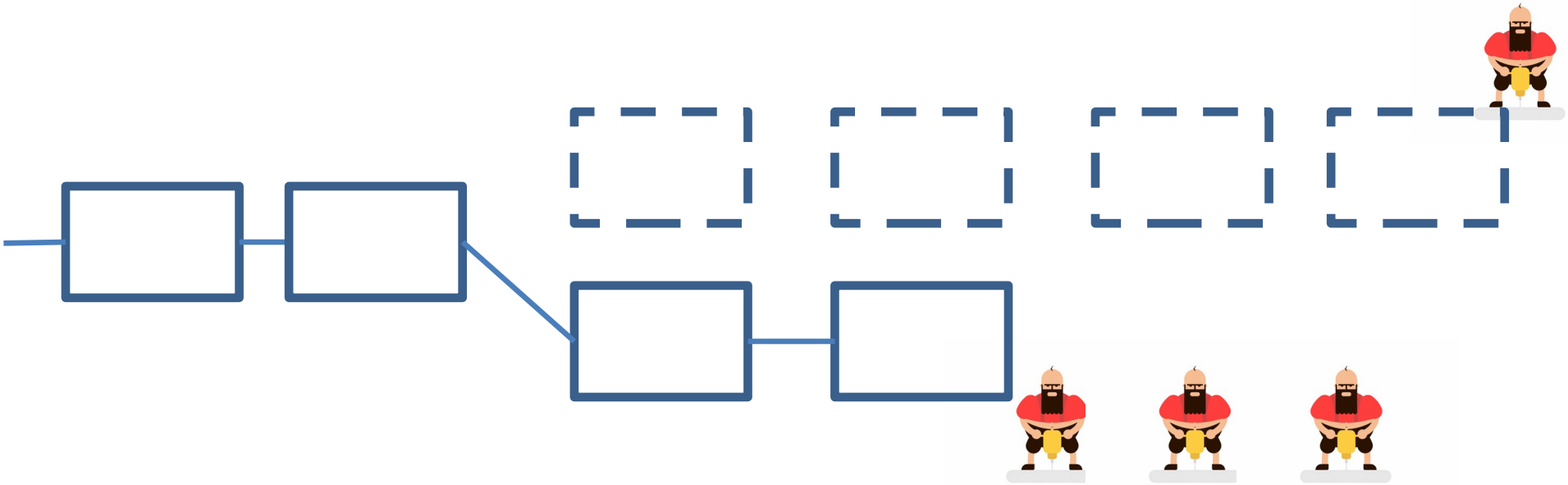

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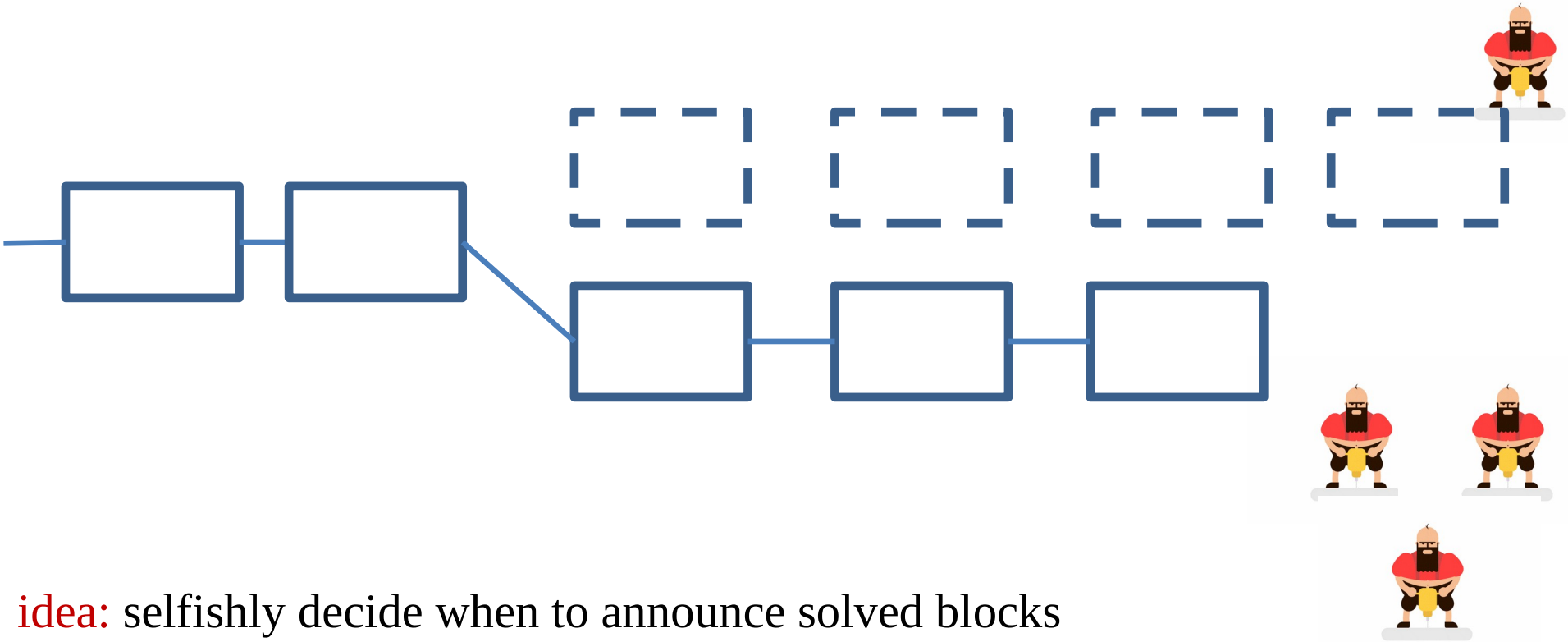

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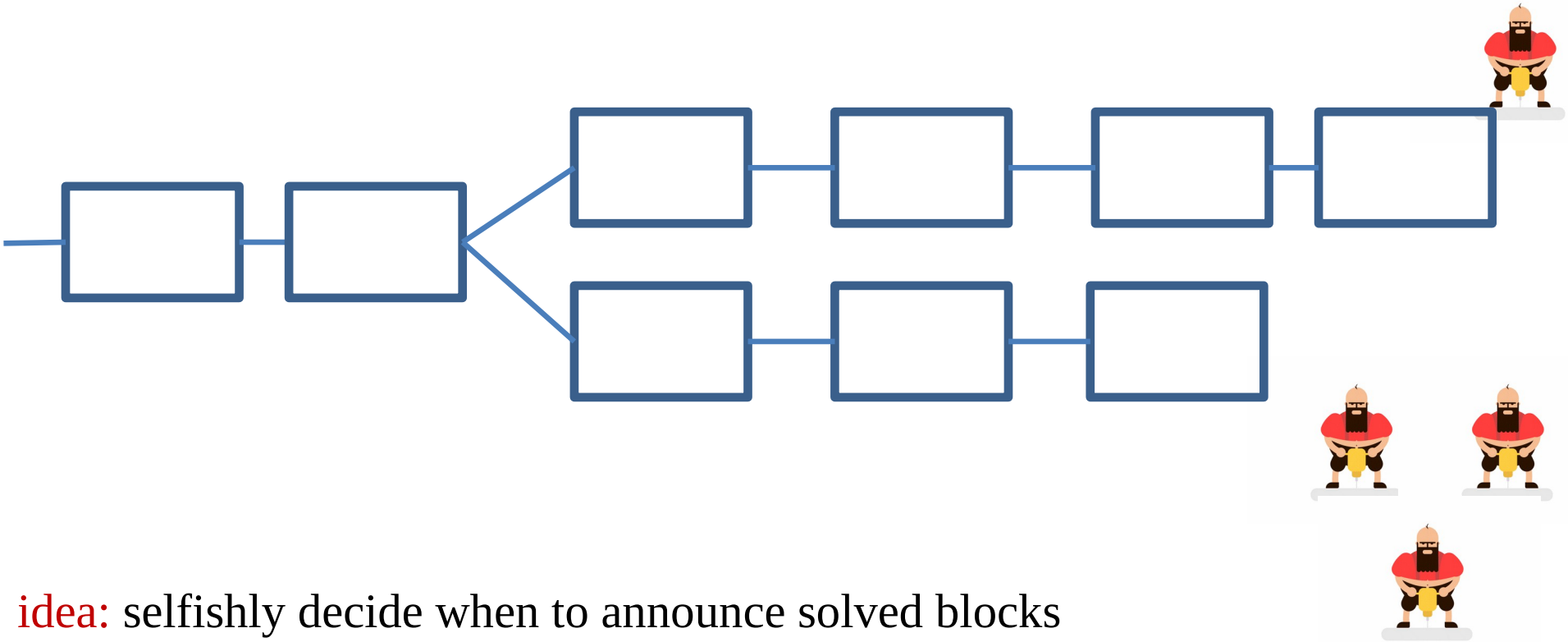

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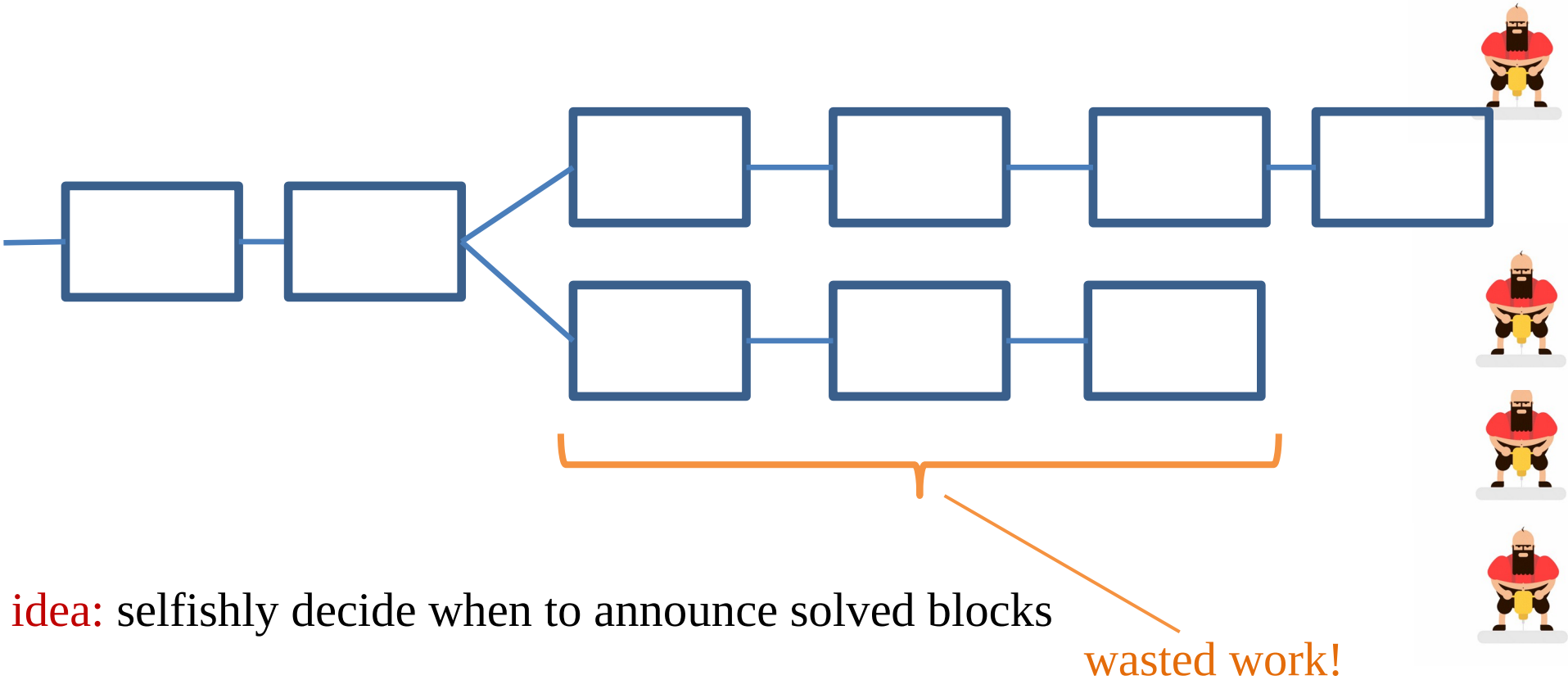

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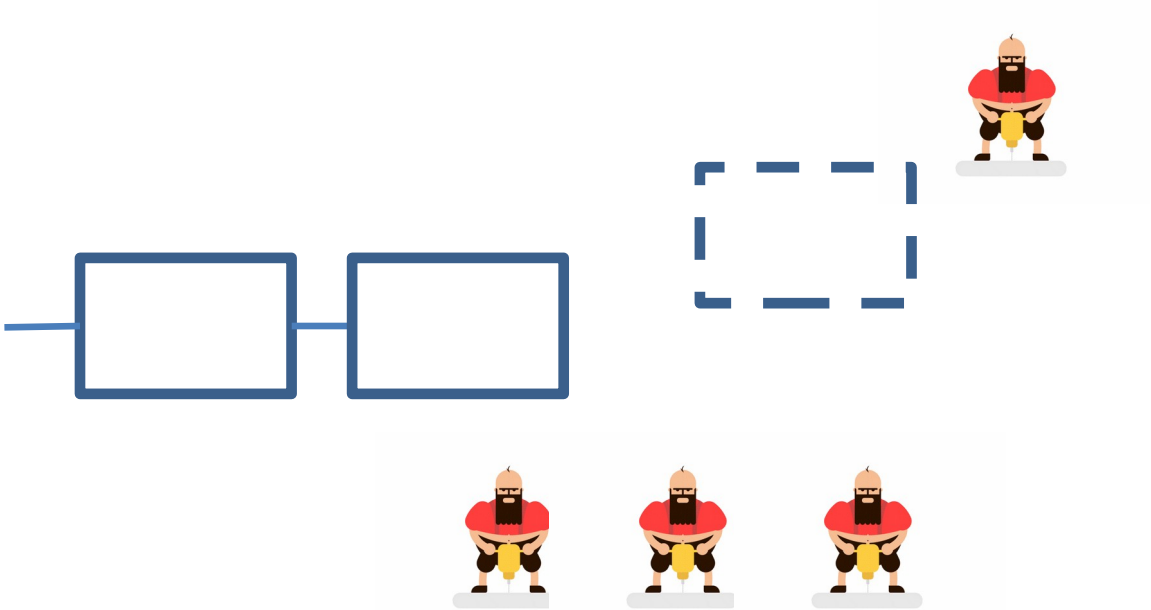

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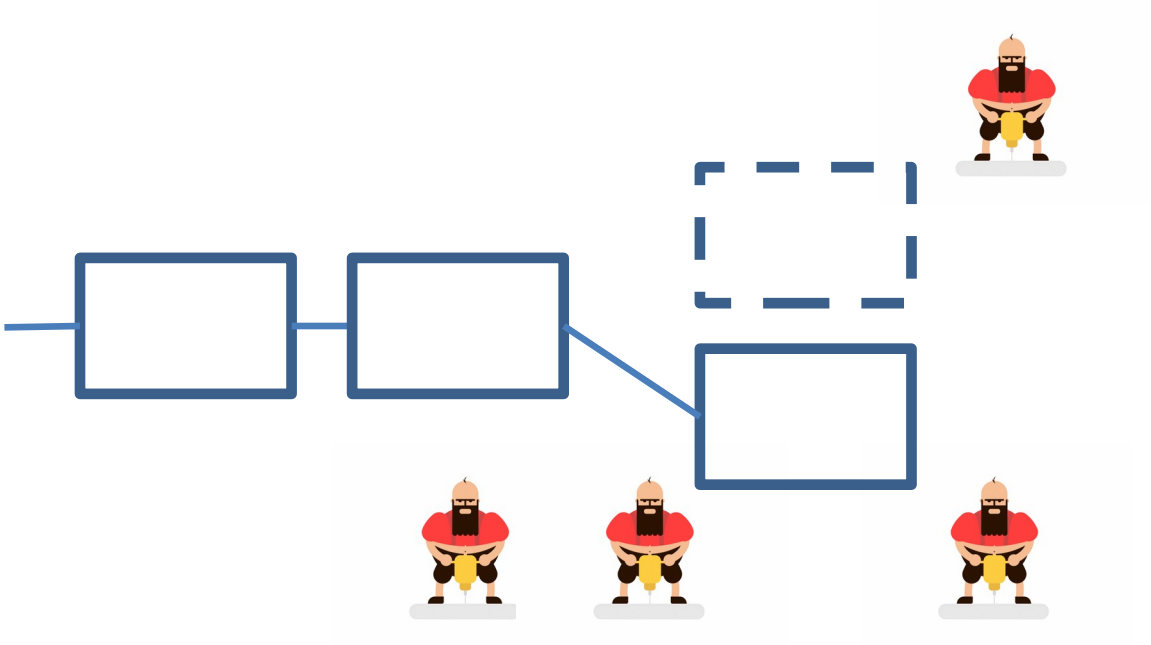

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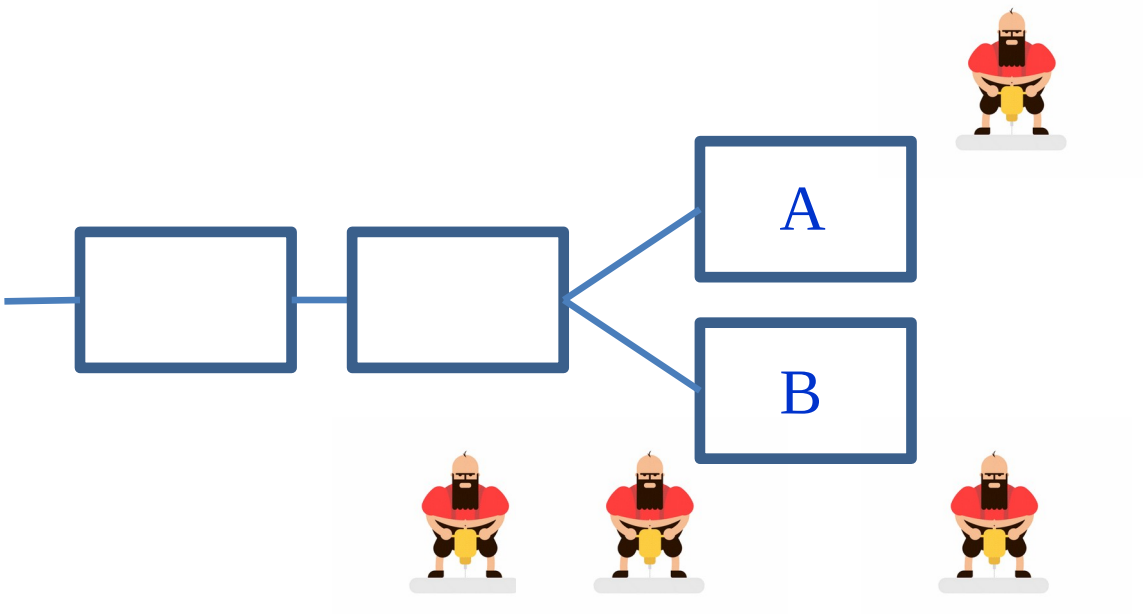

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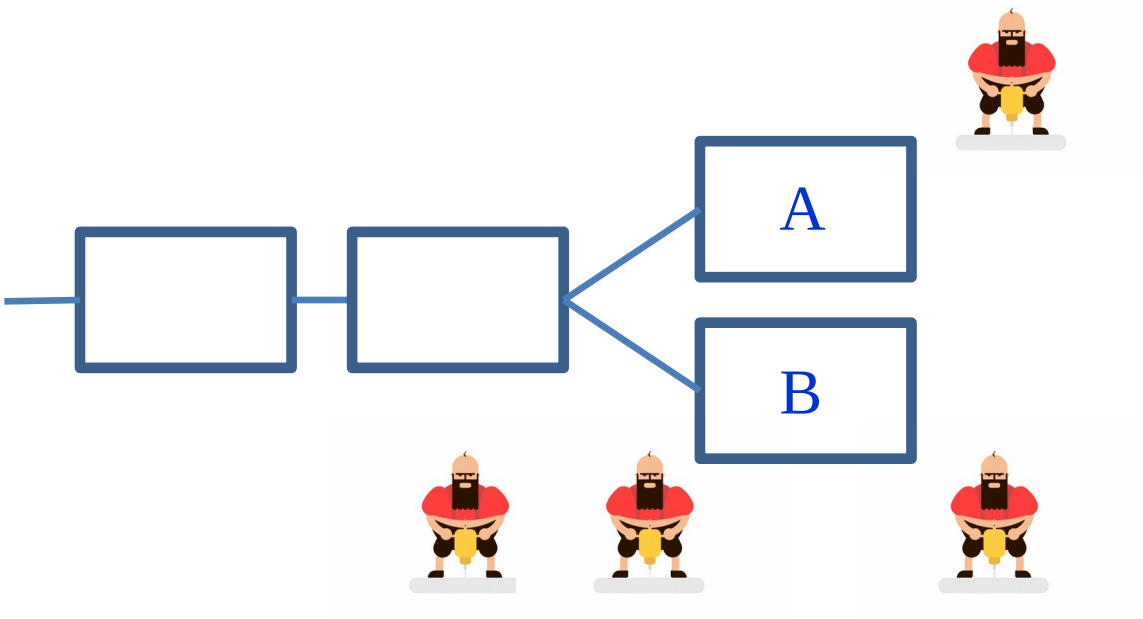

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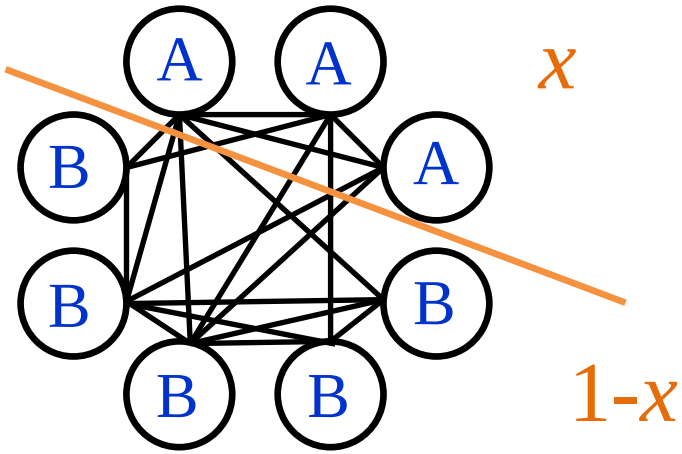

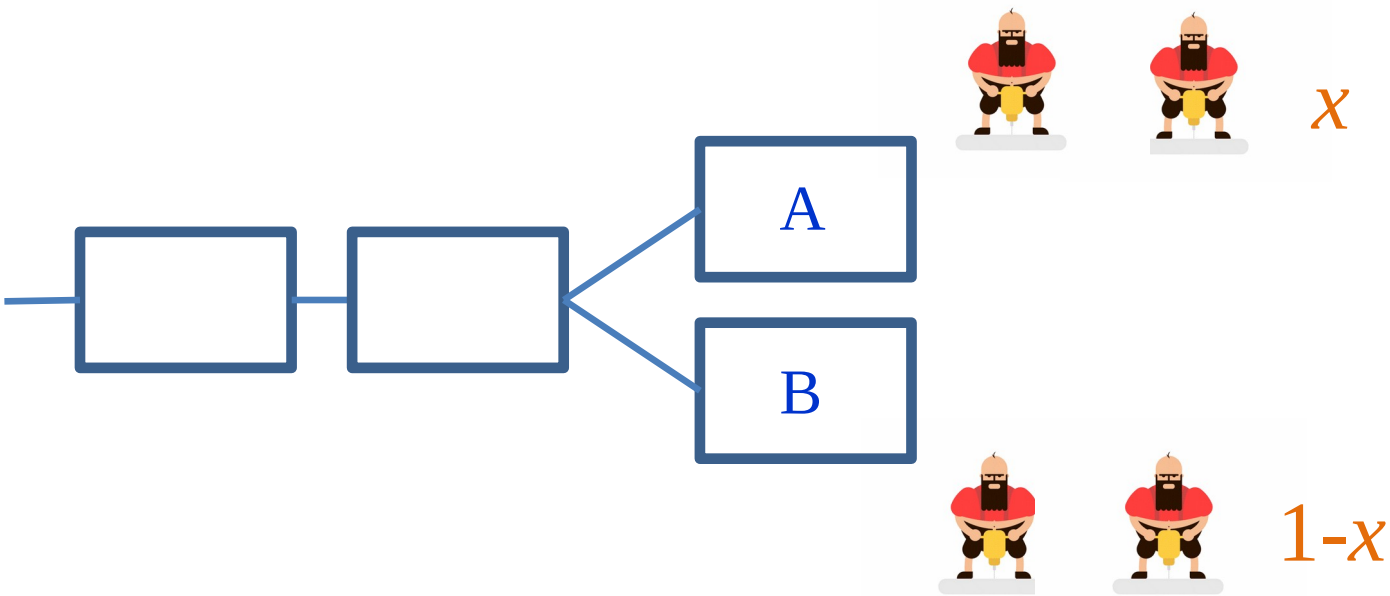

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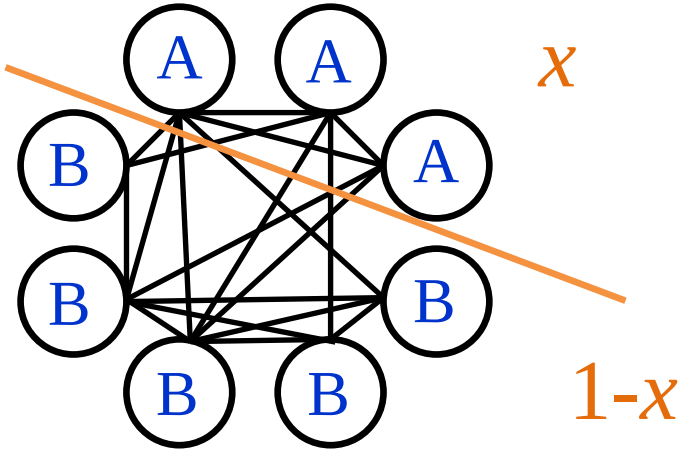

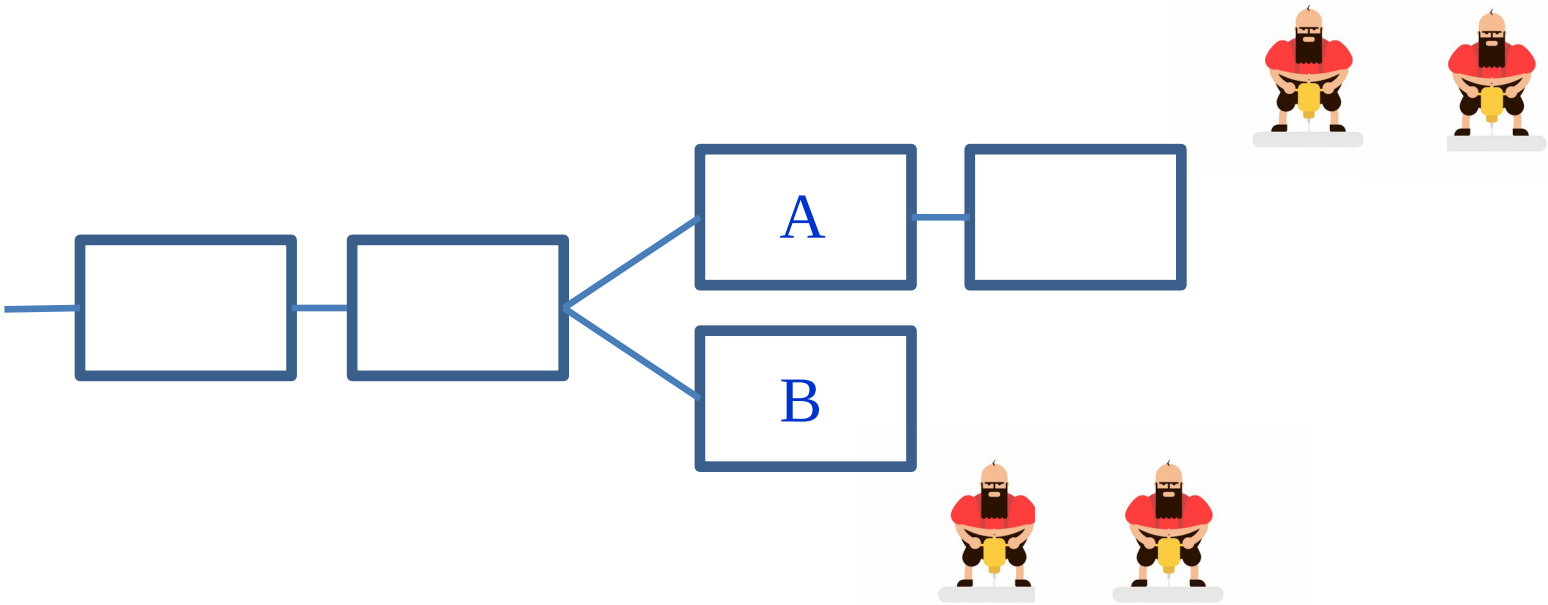

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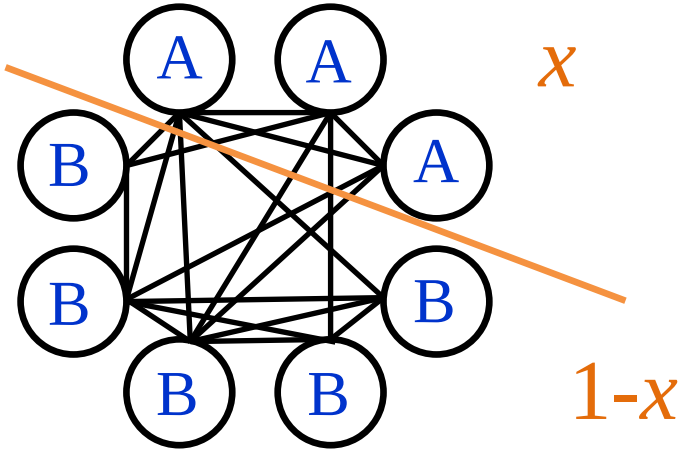

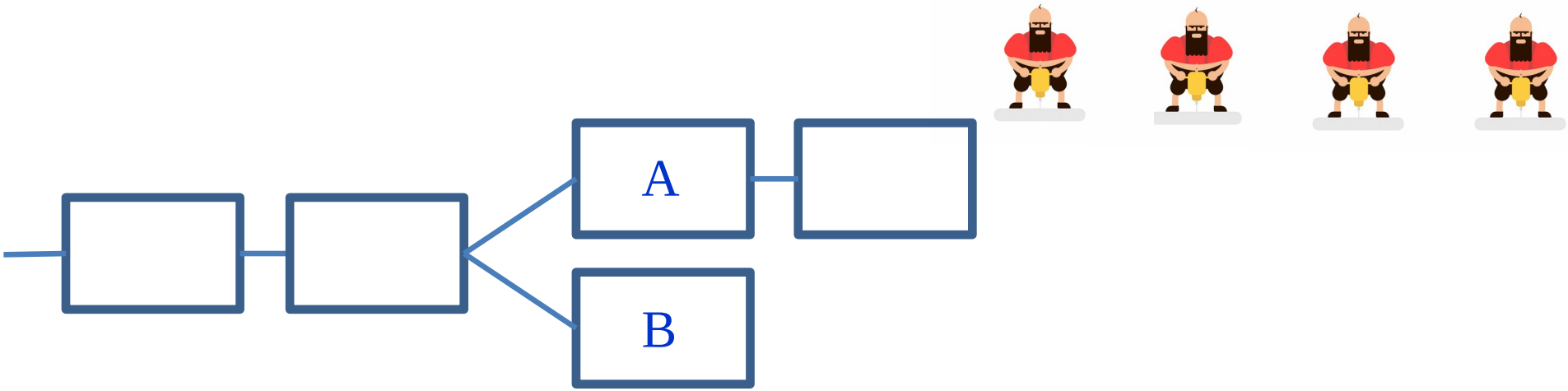

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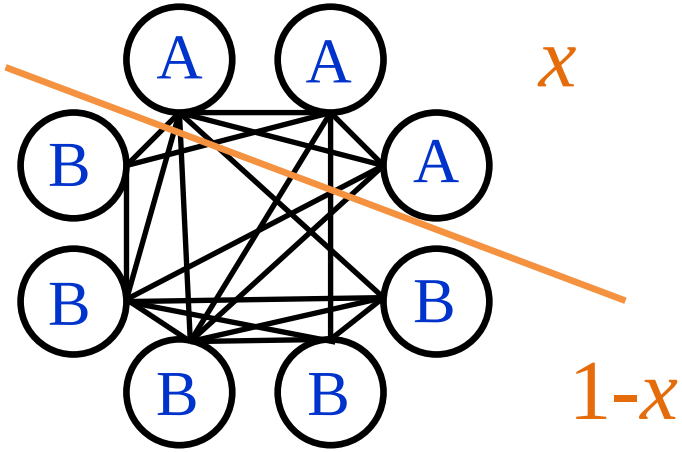

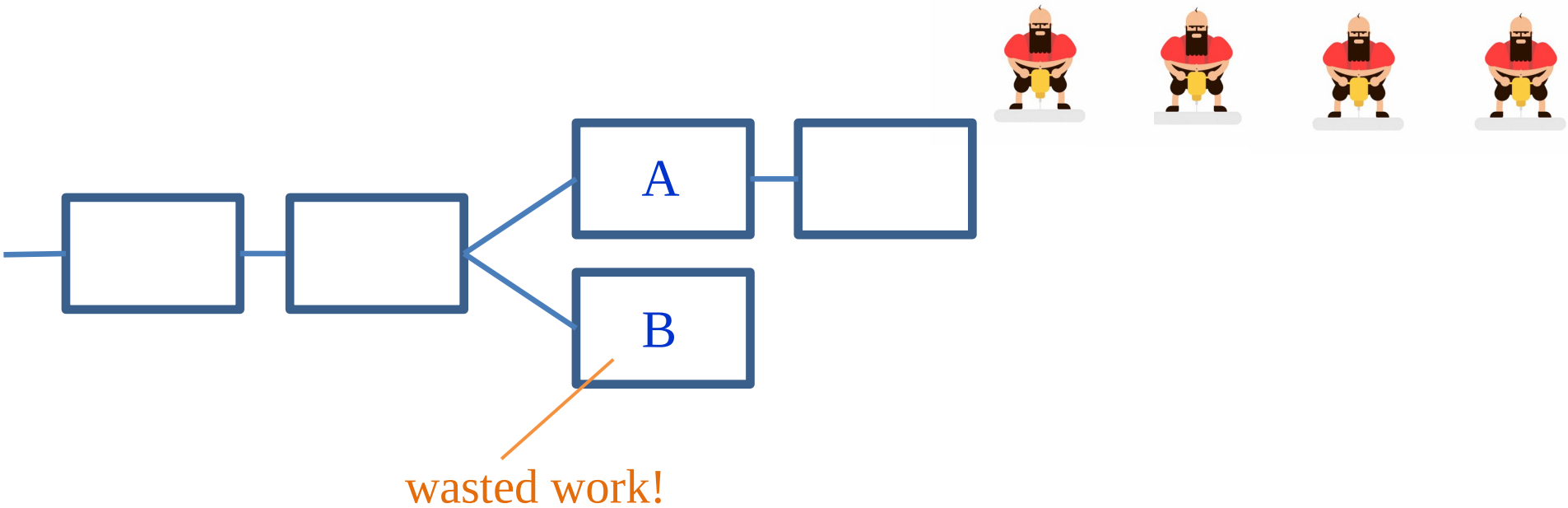

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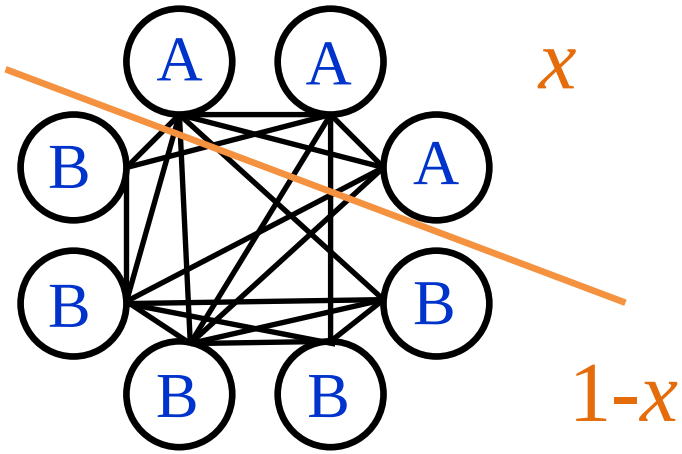

Convenient if:

- > 1/3 of the total computational power of the network

OR

- > 1/4 of the total computational power of the network & x ≥ 1/2

idea: