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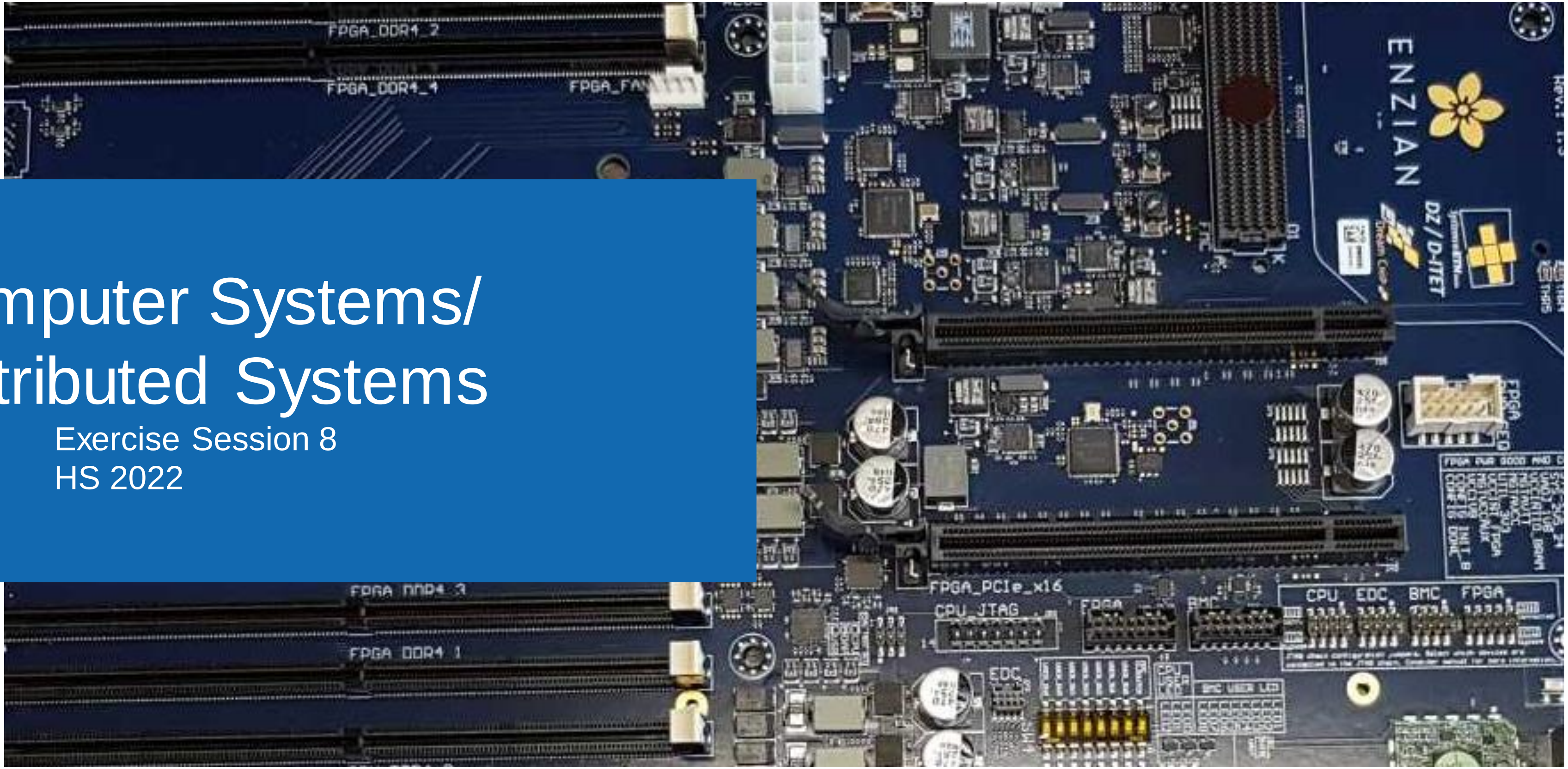
Distributed Computing

Slides last updated: 01.12.2022



Computer Systems/ Distributed Systems

Exercise Session 8

HS 2022

Consistency, Availability, and Partition Tolerance

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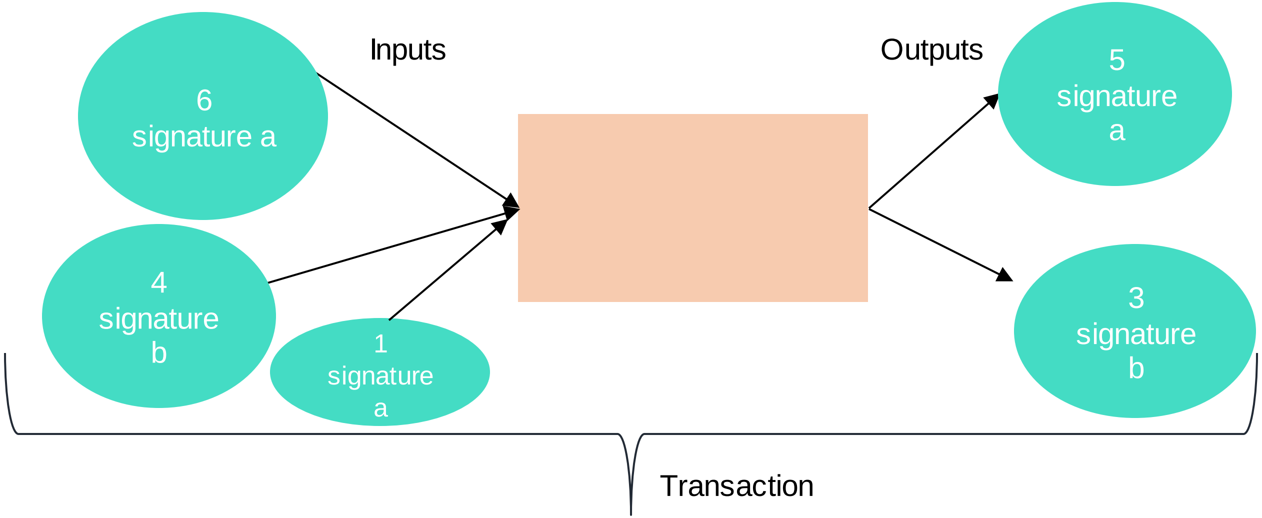
Distributed Computing

- Consistency:
  - All nodes agree on the current state of the system
- Availability:
  - The system is operational and instantly processing incoming requests
- Partition tolerance:
  - Still works correctly if a network partition happens
- Good news:
  - achieving any two is very easy
- Bad news:
  - achieving three is impossible (CAP theorem)
- => Eventual Consistency:
  - Guarantees that the state is eventually agreed upon, but the nodes may disagree temporarily

Bitcoin

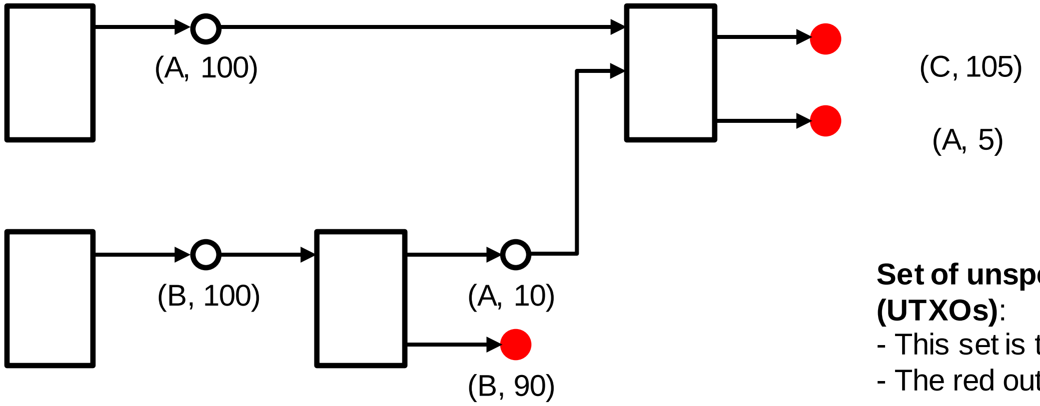
- Decentralized network consisting of nodes
- Users generate private/public key pair
  - Address is generated from public key
  - It is difficult to get users “real” identity from public key



Bitcoin Transactions

- Conditions:
  - Sum of inputs must always be at least the sum of outputs
    - Unused part is used as transaction fee, gets paid to miner of block
  - An input must always be some whole output, no splitting allowed!
  - Money that a user “has” is defined as sum of unspent outputs

Bitcoin Transactions



Set of unspent transaction outputs (UTXOs):
- This set is the shared state of Bitcoin
- The red outputs

Transaction Broadcast

1. Issue transaction
2. Add transaction to local history

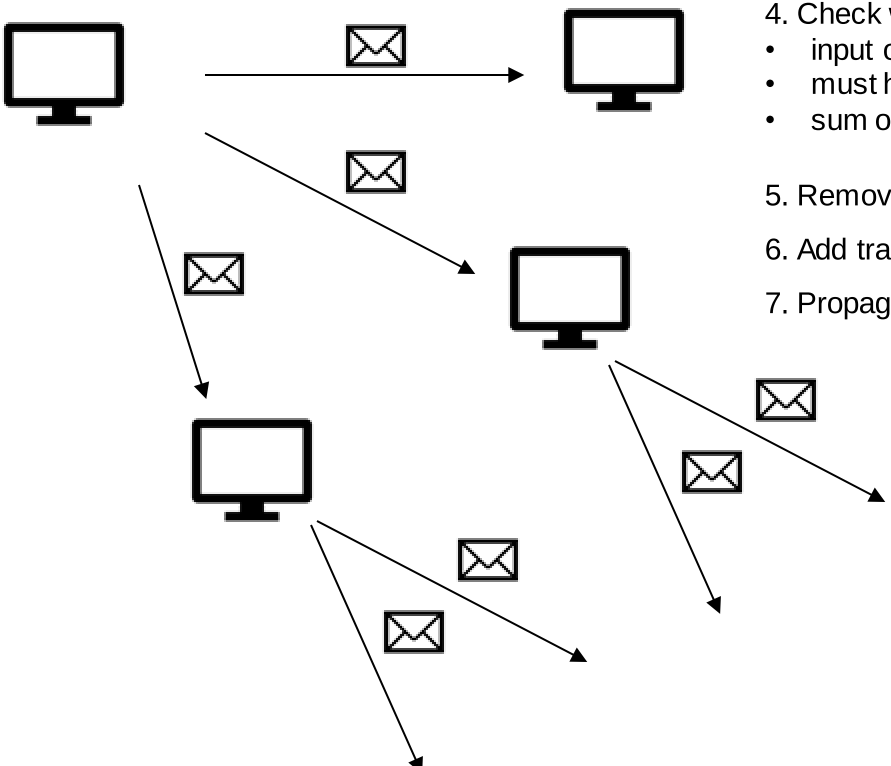
3. Send transaction to other nodes in network

4. Check whether transaction is valid
- input of transaction must be in local UTXO
- must have valid signature
- sum of inputs >= sum of outputs

5. Remove any input of transaction from local UTXO

6. Add transaction to local history

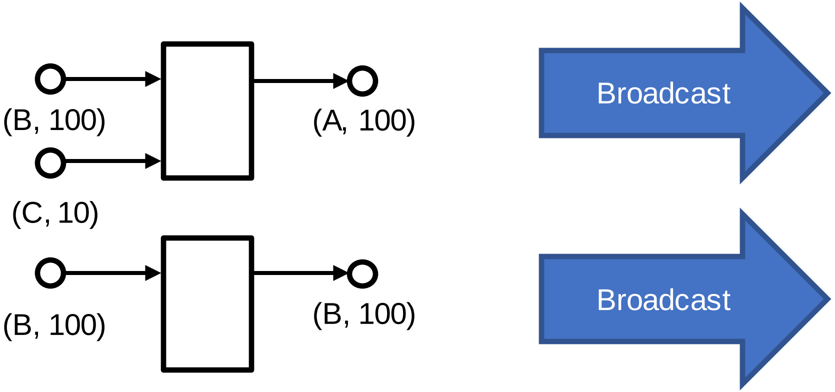
7. Propagate transaction further



Doublespend Attack

- Multiple transactions attempt to spend the same output

- Ex: In a transaction, an attacker pretends to transfer an output to a victim, only to doublespend the same amount in another transaction back to itself.



Proof-of-Work

- Right now we have infinitely growing memory pool and we can’t be sure that other nodes have the same pool
- Solution: Propagate memory pool through network and make sure everybody else will have same state
- Problem: How to avoid that everybody wants to propagate its own memory pool?
- Solution: Proof-of-Work
    - Proof that you put a certain amount of work into propagating your memory pool

Proof-of-Work

- Mining Blocks requires to proof that a certain amount of computational resources has been utilized

$$F_d(c, x) \rightarrow \{true, false\}$$

  - d: difficulty (is adapted all 24h)
  - c: challenge (the transactions and the hash of the previous block)
  - x: nonce (has to be found)

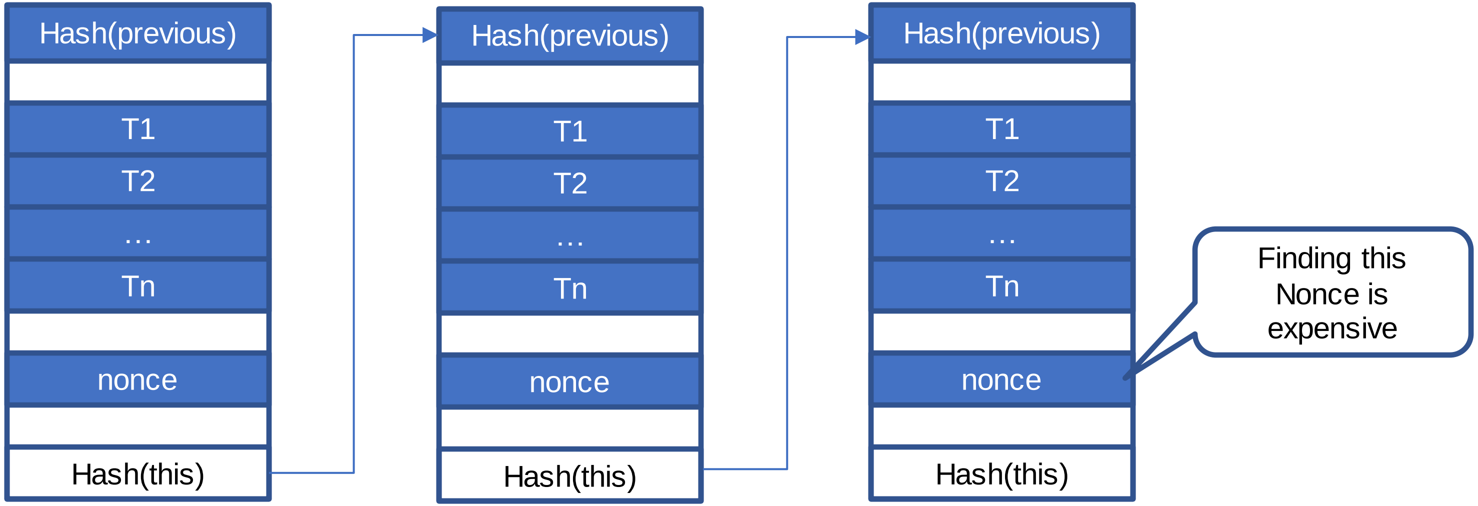
  - For fixed parameters d and c, finding x such that the function

$$\mathcal{F}_d(c, x) \rightarrow \text{SHA256}(\text{SHA256}(c|x)) < \frac{2^{224}}{d}.$$

Bitcoin chooses the difficulty such that a block is created all ~10 min

Block

- Data structure holding transactions reference to previous blocks and a nonce.
  - Header also contains more fields, such as a timestamp, the difficulty, network version, etc.
- Miner creates blocks with transactions from its memory pool



Mining

- Why should someone mine blocks?
  - You get a reward for each block you mine
  - You get the fee in the transactions

Bitcoin:

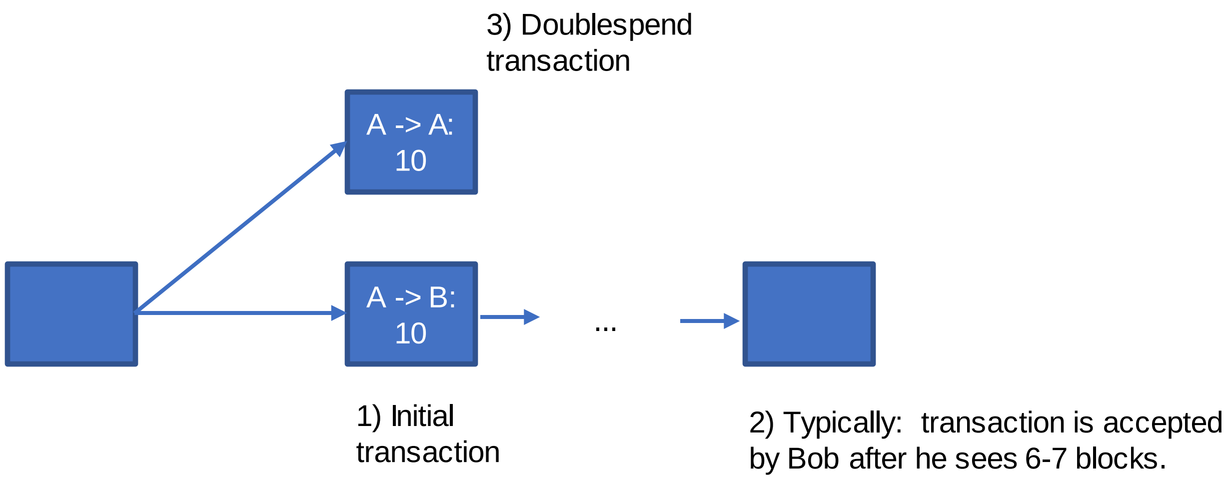
- Reward started at 50B and it is being halved every 210,000 blocks or 4 years in expectation
- This bounds the total number of Bitcoins to 21 million
- What will happen after that?

- Fee is the positive difference of input-output
- Miner include transactions which have a high fee.

- Problem: More miners -> more blocks are mined -> higher difficulty -> more Power needed

How does this prevent double spending?

- An intruder needs to have more than 50% of computation power to be faster in mining than all other together

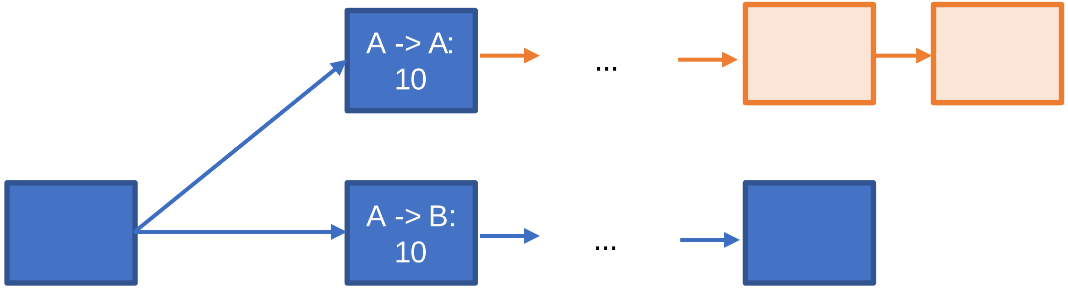


How does this prevent double spending?

- An intruder needs to have more than 50% of computation power to be faster in mining than all other together

4) The goal of Alice is now to make the branch where she spends the money to herself growing faster.

3) Doublespend transaction

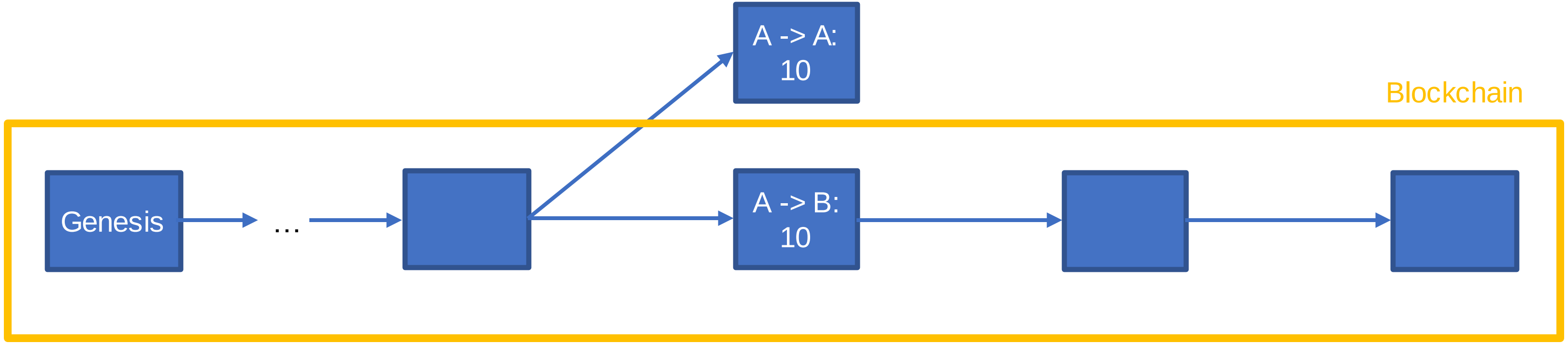


1) Initial transaction

2) Typically: The transaction is accepted by Bob after he sees 6-7 blocks.

Blockchain

- Starts with the genesis block and is the longest path from this genesis block to a leaf.
- Consistent transaction history on which all nodes eventually agree



Note: To ensure that you'll get the money you should wait 5-10 further blocks

Smart Contracts

- Contract between two or more parties, encoded in such a way that correct execution is guaranteed by blockchain
  - Timelock transaction: Tx will only get added to memory pool after some time has expired
  - Micropayment channel:
    - Idea: Two parties want to do multiple small transactions, but want to avoid fees. So they only submit first and last transaction to blockchain and privately do everything in between

Micropayment Channel Setup Transaction

Algorithm 16.26 Parties A and B create a 2-of-2 multisig output o

B sends a list I_B of inputs with c_B coins to A
A selects its own inputs I_A with c_A coins
A creates transaction $t_s\{[I_A, I_B], [o = c_A + c_B \rightarrow (A, B)]\}$
A creates timelocked transaction $t_r\{[o], [c_A \rightarrow A, c_B \rightarrow B]\}$ and signs it
A sends t_s and t_r to B
B signs both t_s and t_r and sends them to A
A signs t_s and broadcasts it to the Bitcoin network

A | B

A can't do anything with this, since no transaction has all required signatures

1) Creates shared "account", does not sign it
2) Creates timelocked transaction that unrolls shared account, signs it
3) Sends them to B

4) Signs both transactions

B can't do anything with this, since unroll transaction is not valid without create transaction

5) Signs create transaction
6) Broadcasts them to network

Micropayment Channel

Algorithm 16.27 Simple Micropayment Channel from S to R with capacity c

$c_S = c$, $c_R = 0$
S and R use Algorithm 16.26 to set up output o with value c from S
Create settlement transaction $t_f\{[o], [c_S \to S, c_R \to R]\}$
while channel open **and** $c_R < c$ **do**
  In exchange for good with value δ
  $c_R = c_R + \delta$
  $c_S = c_S - \delta$
  Update t_f with outputs $[c_R \to R, c_S \to S]$
  S signs and sends t_f to R
end while
R signs last t_f and broadcasts it

Set up shared account and unrolling

Create settlement transaction

While buyer still has money and timelock not expired

Exchange goods and adapt money

Update settlement transactions with new values

S signs transaction and sends it to R

R signs last transaction and broadcasts it before timelock expires

Why does s sign it?

- Like this, R always holds all fully signed transactions and can choose the last one (where he gets the most money)
- S cannot submit any transaction, so S cannot get the goods and later submit a transaction where S did not pay the money for it

Quiz

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1.1 Delayed Bitcoin

In the lecture we have seen that Bitcoin only has eventual consistency guarantees. The state of nodes may temporarily diverge as they accept different transactions and consistency will be re-estalished eventually by blocks confirming transactions. If, however, we consider a delayed state, i.e., the state as it was a given number Δ of blocks ago, then we can say that all nodes are consistent with high probability.

a) Can we say that the Δ-delayed state is strongly consistent for sufficiently large Δ?

b) Reward transactions make use of the increased consistency by allowing reward outputs to be spent after *maturing* for 100 blocks. What are the advantages of this maturation period?

1.1 Delayed Bitcoin

a) It is true that naturally occurring forks of length l decrease exponentially with l, however this covers naturally occuring blockchain forks only. As there is no information how much calculation power exists in total, it is always possible a large blockchain fork exists. This may be the result of a network partition or an attacker secretly running a large mining operation.

This is a general problem with all "open-membership" consensus systems, where the number of existing consensus nodes is unknown and new nodes may join at any time. As it is always possible a much larger unknown part of the network exists, it is impossible to have strong consistency.

In the Bitcoin world an attack where an attacker is secretly mining a second blockchain to later revert many blocks is called a 51% attack, because it was thought necessary to have a majority of the mining power to do so. However later research showed that by using other weaknesses in Bitcoin it is possible to do such attacks already with about a third of the mining power.

b) The delay in this case prevents coins from completely vanishing in the case of a fork. Newly mined coins only exist in the fork containing the block that created them. In case of a blockchain fork the coins would disappear and transactions spending them would become invalid as well. It would therefore be possible to taint any number of transactions that are valid in one fork and not valid in another. Waiting for maturation ensures that it is very improbable that the coins will later disappear accidentially.

Note that this is however only a protection against someone accidentially sending you money that disappears with a discontinued fork. The same thing can still happen, if someone with evil intent double spends the same coins on the other side of the fork. You will not be able to replay a transaction of a discontinued fork on the new active chain if the old owner spent them in a different transaction in the meantime. To prevent theft by such an attacker you need to wait enough time to regard the chance of forks continuing to exist to be small enough. A common value used is about one hour after a transaction entered a block (∼6 blocks).

Quiz

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2.2 Double Spending

Figure 1 represents the topology of a small Bitcoin network. Further assume that the two transactions T and T' of a doublespend are released simultaneously at the two nodes in the network and that forwarding is synchronous, i.e., after t rounds a transaction was forwarded t hops.

a) Once the transactions have fully propagated, which nodes know about which transactions?

b) Assuming that all nodes have the same computational power, i.e., same chances of finding a block, what is the probability that T will be confirmed?

c) Assuming the rightmost node, which sees T' first, has 20% of the computational power and all nodes have equal parts of the remaining 80%, what is the probability that T' will be confirmed?

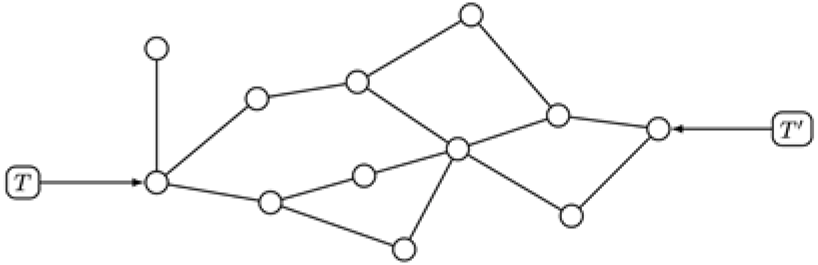

Figure 1: Random Bitcoin network

Quiz

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2.2 Double Spending

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a) Once the transactions have fully propagated, which nodes know about which transactions?

b) Assuming that all nodes have the same computational power, i.e., same chances of finding a block, what is the probability that T will be confirmed?

$$\frac{7}{12}$$

c) Assuming the rightmost node, which sees T' first, has 20% of the computational power and all nodes have equal parts of the remaining 80%, what is the probability that T' will be confirmed?

$$20+4 * \frac{80}{11} = 49\%$$

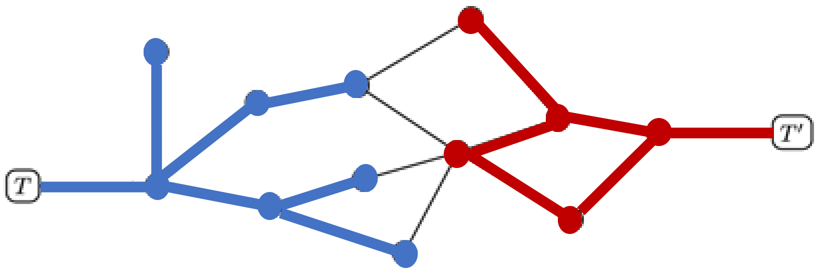


Figure 1: Random Bitcoin network

Selfish Mining

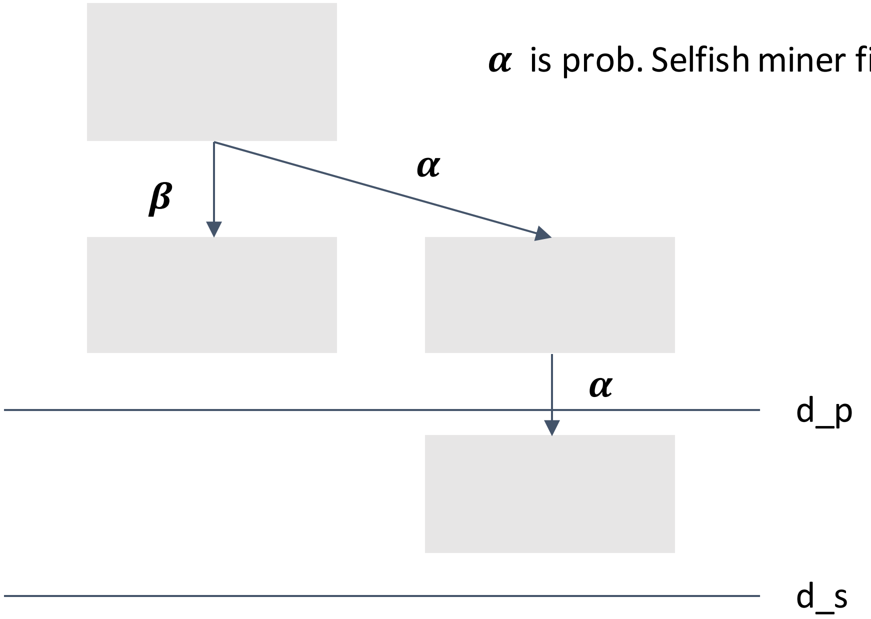
Algorithm 24.2 Selfish Mining

Idea: Mine secretly, without immediately publishing newly found blocks
Let d_p be the depth of the public blockchain
Let d_s be the depth of the secretly mined blockchain
if a new block b_p is published, i.e., d_p has increased by 1 **then**
    if $d_p > d_s$ **then**
        Start mining on that newly published block b_p
    else if $d_p = d_s$ **then**
        Publish secretly mined block b_s
        Mine on b_s and publish newly found block immediately
    else if $d_p = d_s - 1$ **then**
        Publish all secretly mined blocks
    end if
end if

Selfish Mining

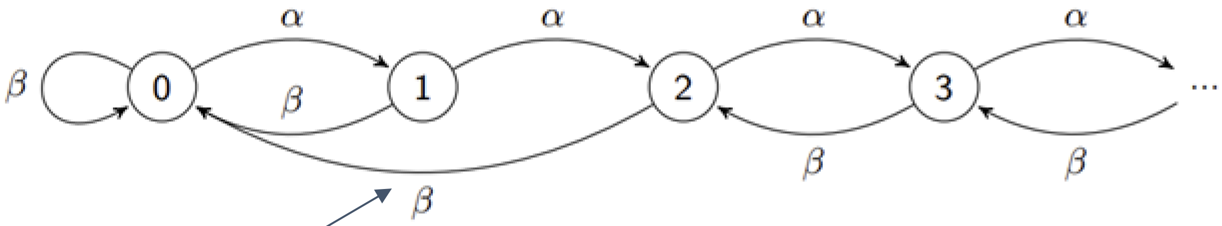
β is prob. others find block

α is prob. Selfish miner finds block



- Selfish miner does not release its block immediately, but keeps secret and works on "grandchildren" (secret)
- **Advantage**: selfish miner can work on next-next block, while others still work on next block.
- **Disadvantage** : Work on blocks (and rewards) potentially rendered useless when public chain gets longer.

Selfish Mining



Selfish minor is two block ahead and new public block -> release all secret blocks

$$\frac{\alpha(1-\alpha)^2(4\alpha+\gamma(1-2\alpha))-\alpha^3}{1-\alpha(1+(2-\alpha)\alpha)}.$$

Ratio of mining power

Share of reachable nodes if selfish miner publishes

Ethereum smart contracts

- Smart contract creation: A transaction with recipient with address 0 deploys a new smart contract
- Smart Contract Execution Transaction: A transaction with a smart contract address in its recipient field and code to execute a function of that contract in its data field
- Gas: The unit of an atomic computation, i.e ADDing two numbers costs 3 Gas