



Computer Systems

Assignment 11

1 Eventual Consistency & Bitcoin

Quiz

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-established 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.

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

Basic

1.2 Double Spending

Figure ?? 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.

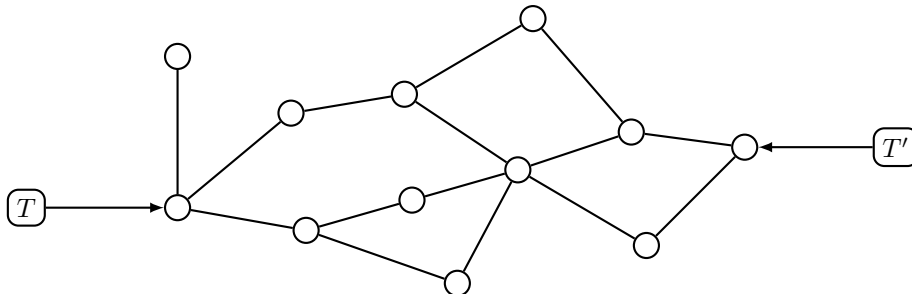


Figure 1: Random Bitcoin network

- 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?

1.3 The Transaction Graph

In Bitcoin existing money is stored as ‘outputs’. An output is essentially a tuple (address, value). A transaction has a list of inputs, which reference existing outputs to destroy and a list of new outputs to create.

Because of this construction inputs claim the entire value associated with an output, even if the intended transfer is for a much smaller value than what the input references. If the input claims a larger value than needed for the transfer the user simply adds a *change output*, which returns the excess bitcoins to an address owned by the sender.

- a) Draw the transaction graph created by the following transactions. Assume no fees are paid to the miners. Draw transactions as rectangles and outputs as circles. Arrows should point from outputs to the transactions spending them and from transactions to the outputs they are creating.
 - (a) Address A mines 50 BTC.
 - (b) Address B mines 50 BTC.
 - (c) A sends 20 BTC to C.
 - (d) B sends 30 BTC to C.
 - (e) C sends 40 BTC to A.
- b) Mark the still unspent transaction outputs (UTXO) in your graph.
- c) Why do inputs always spend the entire output value and not just the part that is needed for the transfer? Assume you can spend parts of an output and explain what would be needed to validate transactions and prevent the illegal generation of money.

Advanced

1.4 Bitcoin Script

Bitcoin implements a simple scripting language called “Bitcoin Script” to give additional conditions on transactions apart from correct signatures. The scripts are evaluated by the miners, which reject transactions and blocks containing such scripts if the script evaluates with an error.

With scripts, a timelocked transaction could be created that states something like:

A and B sign that they want to spend the existing outputs ref_1, ref_2, ref_3 and create $new_output_1, new_output_2$. This transaction is invalid in a block with a blockheight lower than 450,000.

Similarly it is possible to create outputs with more complex spending conditions. E.g., instead of requiring a valid signature to spend an output it is possible to require multiple signatures by different parties:

A and B sign that they want to spend the existing outputs ref_1, ref_2, ref_3 and create a new output that can be spent with two signatures corresponding to two of the three public keys pub_1, pub_2, pub_3 .

Using timelocks and “multisig outputs” it is possible to replace uncommitted transactions by creating a first transaction with a large timelock and spending the same coins in a replacement transaction with a smaller timelock. The smaller timelock ensures that the second transaction can be executed before the first one becomes valid.

Building on this idea, a “payment channel”¹ can be created where money can be exchanged with someone else securely without doing every transaction on the blockchain. This works by replacing the transaction and moving money between the outputs. The construction is shown in Figure ??.

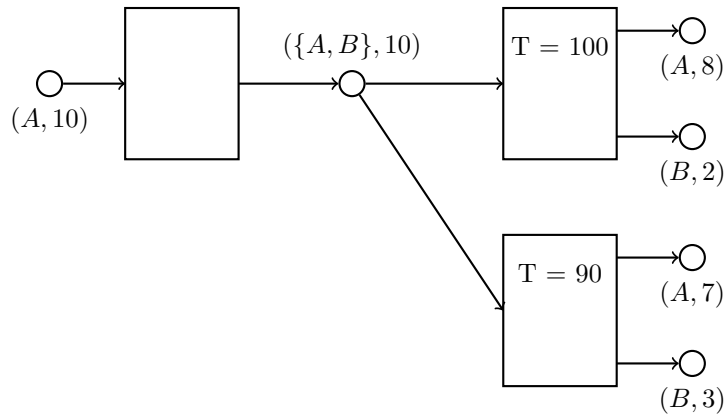


Figure 2: A “payment channel”. A and B both have to sign to spend the output in the middle. The upper transaction can only be committed starting from blockheight 100, the lower one starting from blockheight 90.

Here first the left transaction is executed, this is called “opening” the channel. Then the transaction on the top right is prepared, but not executed. It can then be replaced by using lower timelocks.

- What advantages does a payment channel have over regular Bitcoin transactions?
- Why is the opening transaction needed? What could A do if the output being spent by the timelocked transactions would not require B’s signature?
- The channel cannot be used longer than the timeouts of the locktimes are. As soon as the first lock times out, the transaction needs to be executed, otherwise older replaced versions might become active as well. If someone wants to create a channel that he only uses occasionally, he needs to set the initial timelock far into the future.

Bitcoin also allows to define timelocks relative to the time the spent outputs were created. Can you think of a system that uses these relative timelocks to create channels that can be held open forever?

2 Advanced Blockchain

Basic

2.1 Randomness from previous Block

Consider the following (simple) Proof of Stake model: Assume there is a known set of validators who have each put up some currency as stake. For every block, the protocol needs to select one

¹Be careful, there are different versions with different features. In the lecture script are unidirectional channels. Here we are discussing an extended version: “Duplex Micropayment Channels”. Duplex, because it is possible to move money in both directions.

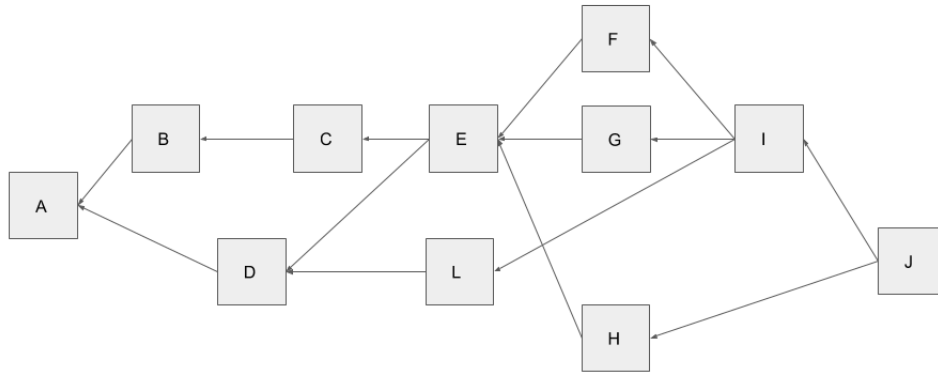
of these validators randomly. The probability of a particular validator being selected should be proportional to the amount of stake it has committed to the protocol.

Let's say the protocol selects the next validator as follows: We hash the previous block B and all its contents (transactions, metadata, timestamp, signatures, etc.) to get a hash value $h := h(B)$. Let's say the image of the hash function is $[0, H]$. We can partition this range into proportional sub-ranges based on the stake of each validator. Based on where h lands in this range, pick the validator whose sub-range overlaps with h to obtain the next validator.

How does this scheme devolve into proof-of-work?

2.2 DAG-Blockchain

Consider the following DAG-blockchain:



Arrows point from a child block to its parent blocks. Block A is the genesis block. Assume that the letters show the total order with respect to the blocks' hash values (this might be different from the DAG order).

- What is the total order of block J 's DAG-ancestors (the output of Algorithm on block J)?
- When creating the next block K , is there a way to assign its parents such that J 's total order changes in the previous question?

Advanced

2.3 Selfish mining

The analysis of selfish mining shows that the selfish miner receives block rewards disproportionate to his hashing power share. Argue why this could be profitable in practice.

Remark: This is intended as an open question that might not have a definite answer. It is intended to spark discussion and encourage deeper understanding of the selfish mining problem.

2.4 Smart Contracts

Solidity is a high level programming language that compiles down to the EVM (Ethereum Virtual Machine). Solidity's documentation² has an example cryptocurrency smart contract. Modify this smart contract so that the creator can add more minters and any of them can mint more coins. Deploy this modified smart contract on the Ropsten Ethereum test network. A test network for Ethereum resembles the main network, but the Ether that is used in this network has no value. The test network is used for development/testing purposes. Through the smart contract ABI (Application Binary Interface), invoke the call to add another minter, and a follow up call to let this new minter mint new coins for another unrelated address.

A few points:

²<https://solidity.readthedocs.io/en/latest/introduction-to-smart-contracts.html#subcurrency-example>

- You can either mine “fake” Ether on the Ropsten network, or request for Ether from a test faucet. Or request from some special websites.
- You can either run an Ethereum full node connected to the Ropsten network, or you can connect to a third party node that is run by others, like Infura or QuikNode.
- You can either compile/deploy the smart contract from scratch, or you can use a framework like Truffle.