Development of a payment channel over the Bitcoin network

Final degree project

David Lozano Jarque <bitcoin@davidlj95.com>

5th July 2017

Outline

Bitcoin's appearance

The creator

Satoshi Nakamoto @ Cryptography (`metzdowd.com`)
November 1st, 2008

Bitcoin P2P e-cash paper

Satoshi Nakamoto | Sat, 01 Nov 2008 16:16:33 -0700

I've been working on a new electronic cash system that's fully peer-to-peer, with no trusted third party.

The paper is available at:
http://www.bitcoin.org/bitcoin.pdf

The main properties:
Double-spending is prevented with a peer-to-peer network.
No mint or other trusted parties.
Participants can be anonymous.
New coins are made from Hashcash style proof-of-work.
The proof-of-work for new coin generation also powers the network to prevent double-spending.

Bitcoin: A Peer-to-Peer Electronic Cash System

Bitcoin: A Peer-to-Peer Electronic Cash System

Satoshi Nakamoto
satoshin@gmx.com
www.bitcoin.org

Abstract. A purely peer-to-peer version of electronic cash would allow online payments to be sent directly from one party to another without going through a financial institution. Digital signatures provide part of the solution, but the main benefits are lost if a trusted third party is still required to prevent double-spending. We propose a solution to the double-spending problem using a peer-to-peer network. The network timestamps transactions by hashing them into an ongoing chain of hash-based proof-of-work, forming a record that cannot be changed without redoing the proof-of-work. The longest chain not only serves as proof of the sequence of events witnessed, but proof that it came from the largest pool of CPU power. As long as a majority of CPU power is controlled by nodes that are not cooperating to attack the network, they'll generate the longest chain and outpace attackers. The network itself requires minimal structure. Messages are broadcast on a best effort basis, and nodes can leave and rejoin the network at will, accepting the longest proof-of-work chain as proof of what happened while they were gone.

Bitcoin's definition

Definition of Bitcoin

P2P network that allows payments between users without a trusted third party

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- Public ledger of transactions

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- Consensus via *proof-of-work* algorithm
- Cryptography-enforced (digital ECDSA signatures & hash functions)
- No trusted 3rd party (Pure P2P)

How do we move currency?

Transactions

What is a Bitcoin transaction?

Message specifying the transfer of currency units (called *bitcoins*)

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Basic Bitcoin transaction

`version`	`inputs`	`outputs`	`locktime`

`version`	***Alice***	***Bob***	`locktime`

Where do we store transactions?

Blocks

What is a Bitcoin block?

Collection of transactions

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Collection of transactions

Basic Bitcoin block

Magic number
Block size
Block header
Number of transactions
Transactions

version	inputs	outputs	locktime
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Blockchain

Bitcoin's *blockchain*

Distributed and replicated database containing a collection of blocks, each one linked to the previous one using **their hashes** forming **a chain**

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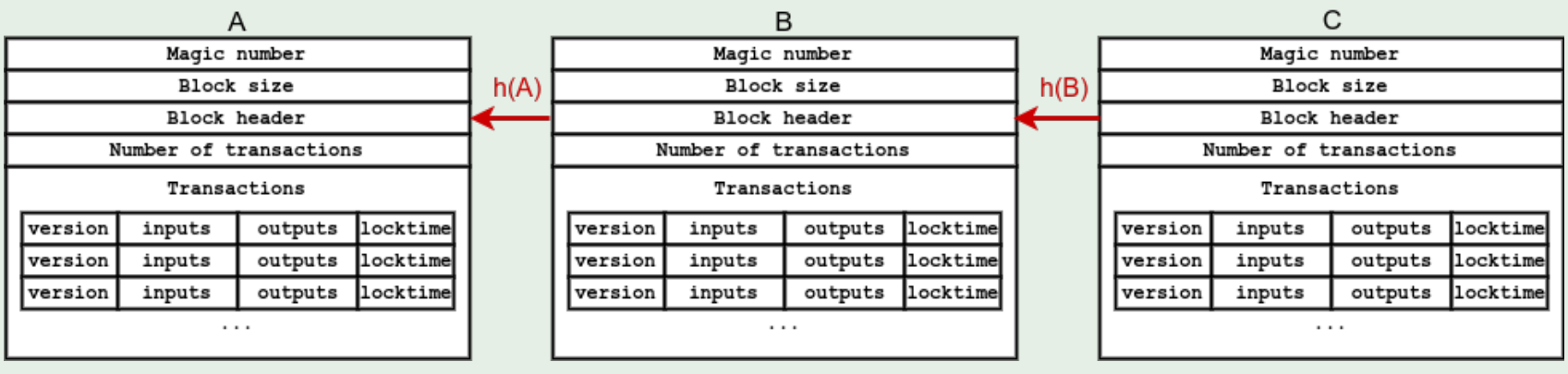

Blockchain

Rewards

Appending a new block to the chain is rewarded with **newly generated currency units** with a *no-input* transaction called a **generation transaction**

Who decides who can create next block?

Consensus

Proof-of-work

Piece of data difficult to generate but easy to verify it meets certain requirements

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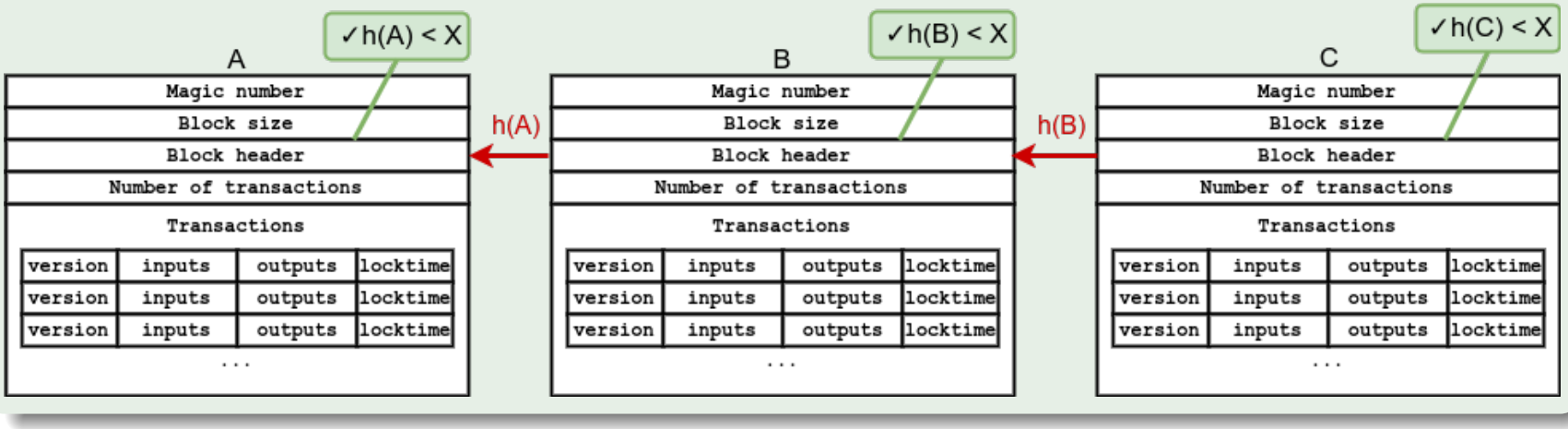
Bitcoin's *proof-of-work*

Field in block's header must contain a hash of the block itself whose value **is less than a dynamically adjusted value**

Proof-of-work

Basic Bitcoin's *blockchain* + *proof-of-work*



How to handle everything?

The Bitcoin client

A Bitcoin client

Software that allows to operate on the Bitcoin network, handling all data structures and network messages

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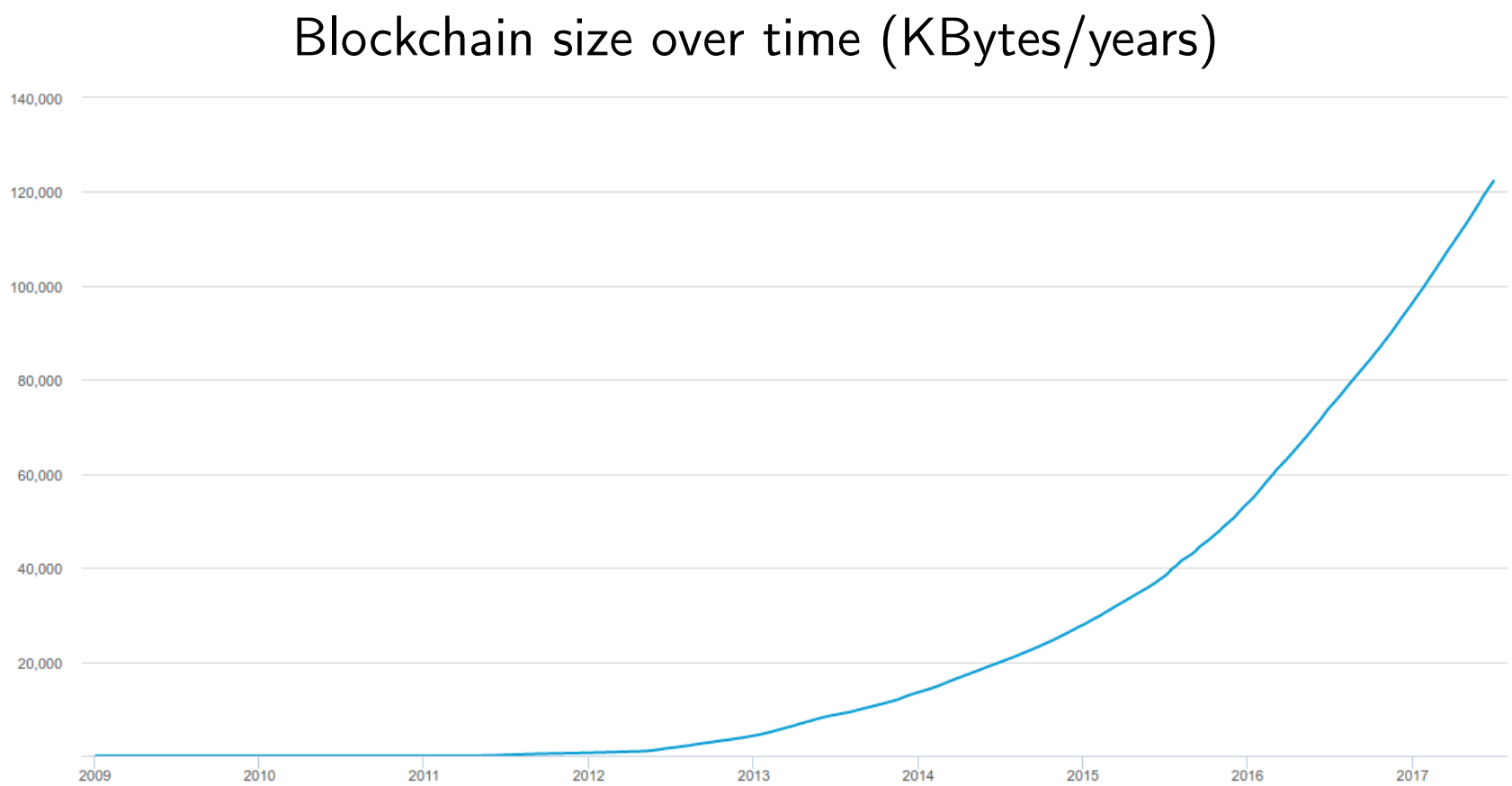
Most used client

Bitcoin Core (`bitcoin.org`) is the most used Bitcoin client (**85%** of nodes in the network)

What is the limit of the technology?

Blockchain size



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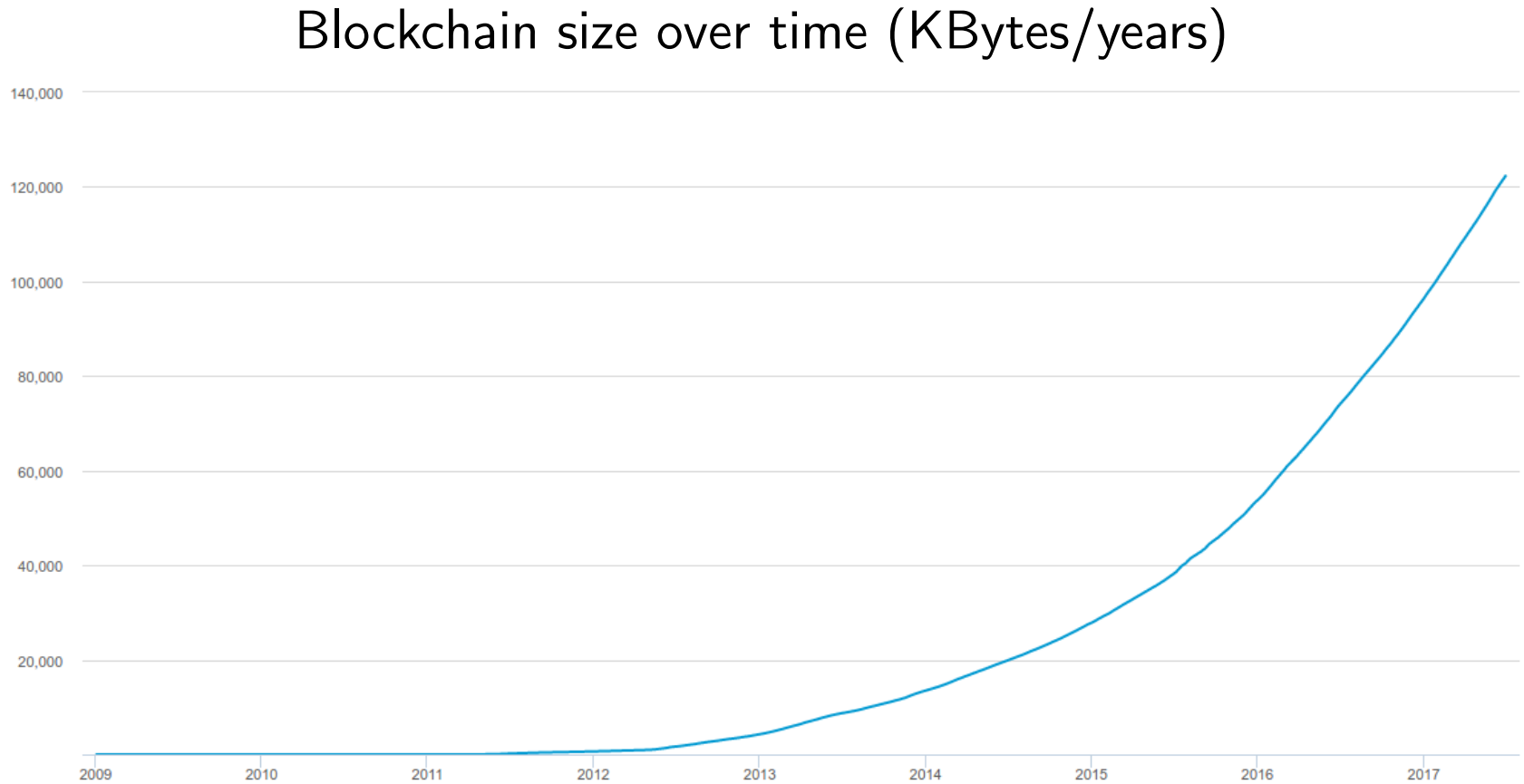

Current blockchain size is approximately **120GB**

Blockchain size

Increasing transaction demand

As Bitcoin becomes more popular, more users arrive therefore more transactions need to be processed

Transaction throughput

Throughput limits

Because of the protocol, blocks must

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1. **Appear every 10 minutes** (approximately) due to *proof-of-work* difficulty adjustment

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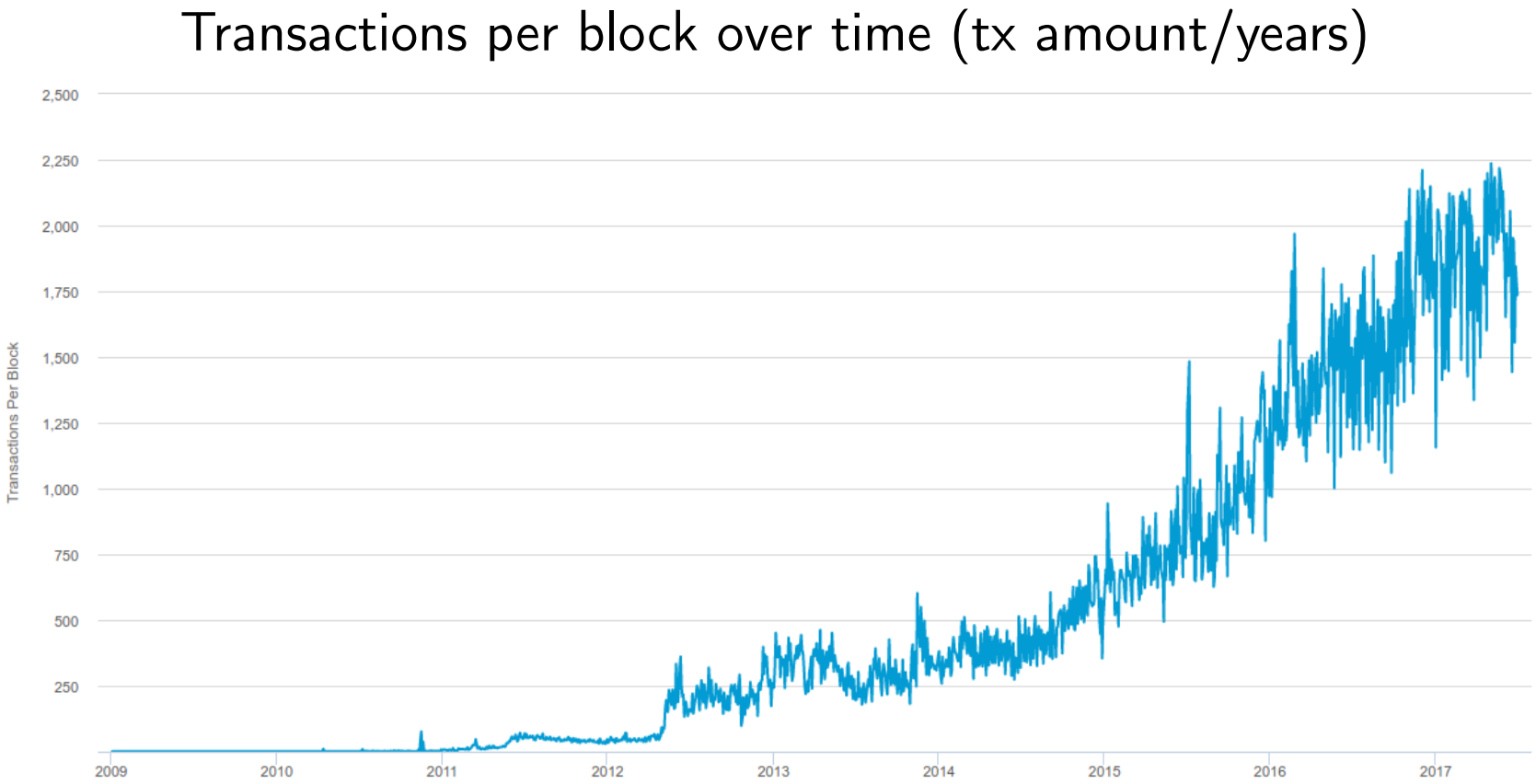
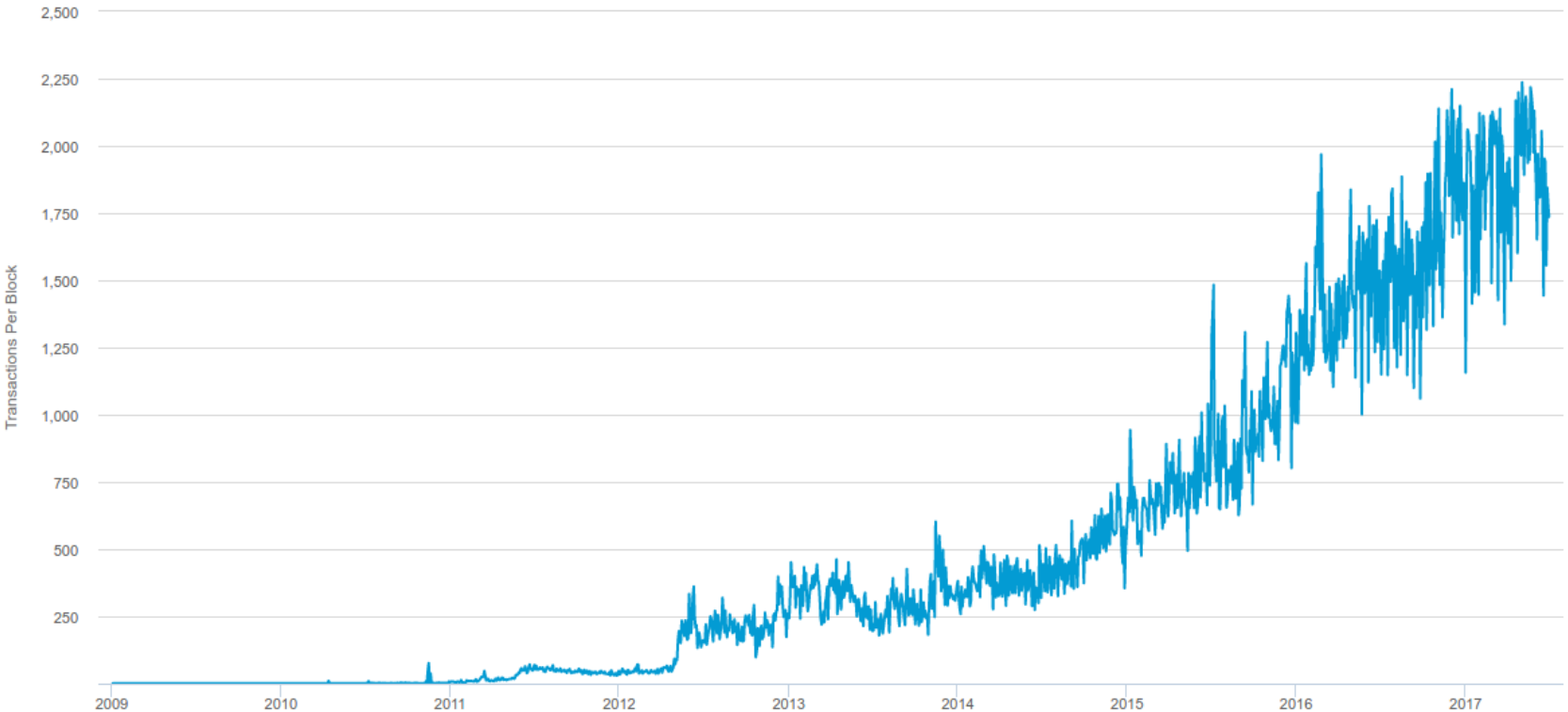
1. **Appear every 10 minutes** (approximately) due to *proof-of-work* difficulty adjustment
2. **1MB maximum block size** to control the *blockchain* growth rate

Transaction throughput



Transaction throughput

Transactions per block over time (tx amount/years)



Approximately **2.000** transactions per block

Transaction throughput

Bitcoin's transaction throughput

Using previous information:

Transaction throughput

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$$\frac{2.000\ tx}{1\ block} \times$$

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According to an IBM's studio performed in August of 2010:

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What can we do?

Scalability solutions

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1. **Increase block size**: Bitcoin Unlimited (1 to 8 MB)
2. **Reduce transaction size**: `SegWit.co` (do not store transaction signatures, also fixes malleability issues)
3. **Decrease the demand of transactions**: Payment channels

Outline

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Transaction fields

Fields of a transaction are:

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Basic Bitcoin transaction

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`version`	*Alice*	*Bob*	`locktime`

Transactions

Extra "fields"

All transactions have an id (also called *txId*), that is the double SHA-256 hash of the transaction bytes

How are inputs and outputs specified?

Inputs specification

Input fields

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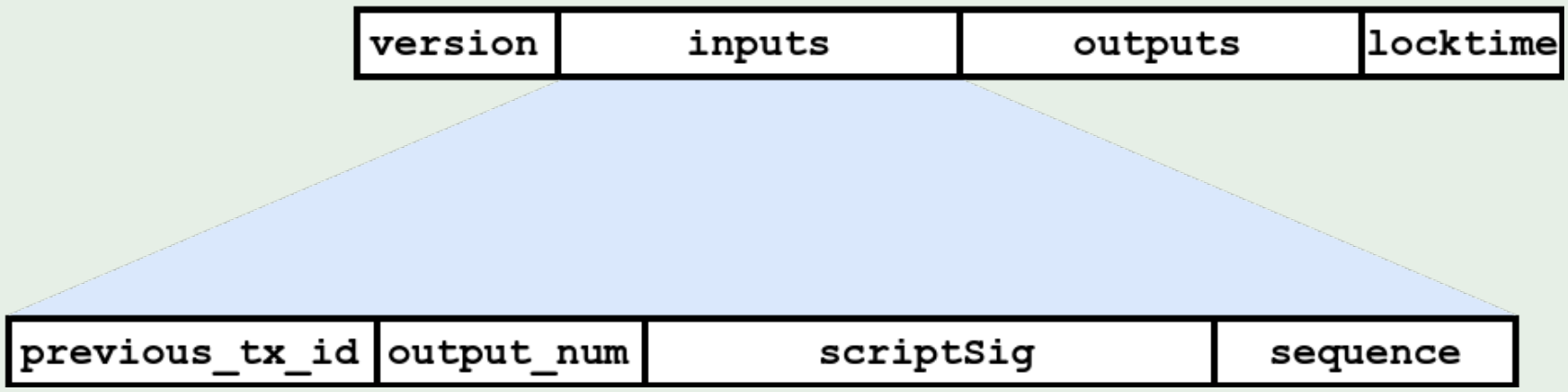
* output must not be spent by any other transaction (also called UTXO)

Inputs specification

Basic transaction's input's fields



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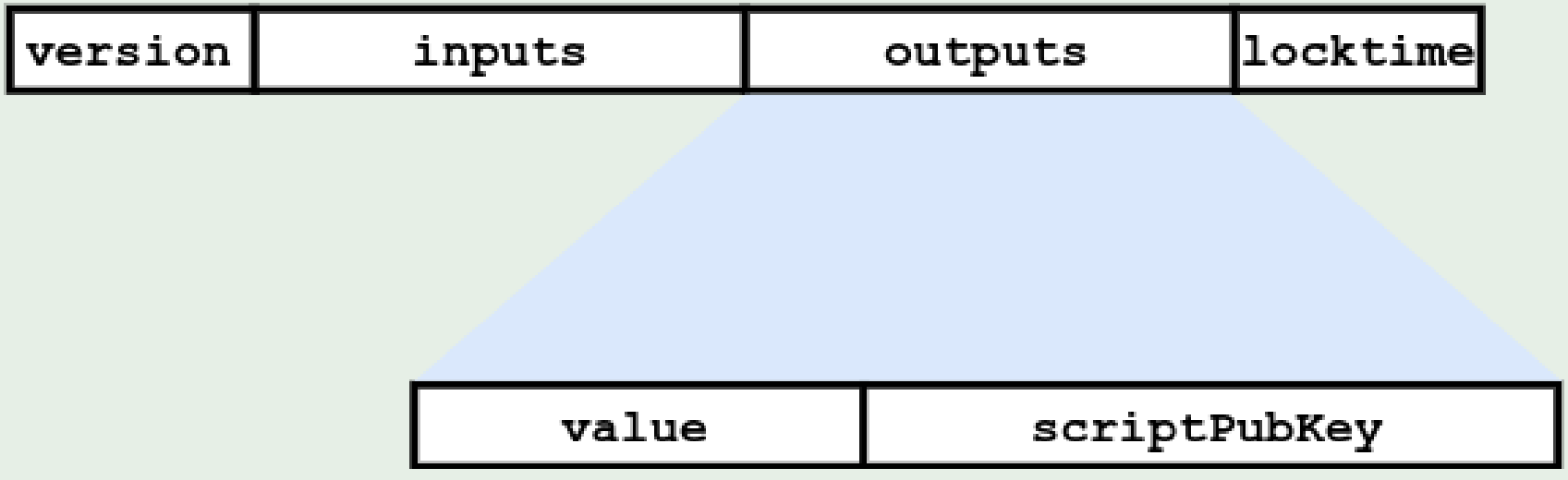

How do the scripts work?

Bitcoin's scripting

Bitcoin scripting language

Specificic scripting language for Bitcoin protocol (in transactions)

- Simple

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Technically

Sequentially read 1-byte opcodes that can perform arithmetical operations, store data into the stack, cryptographic operations and some logic and flow control operations

Transactions and scripts

Transactions validity

In order for a transaction to be valid it must:

1. **Valid inputs**: Inputs must refer to existing and non-spent outputs (UTXO)

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3. **Valid scripts**: The input script followed by the output script referred by the input must execute succesfully and leave a non-empty stack

Standard scripts: P2PKH

P2PKH: *pay-to-public-key-hash*

The output script (*scriptPubKey*) requires the input script (*scriptSig*) to specify a public key whose hash matches the specified and sign the spending transaction with that public key

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P2PKH sample

- **scriptPubKey**: `OP_DUP OP_HASH160 <pubKeyHash> OP_EQUALVERIFY OP_CHECKSIG`

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***redeemScripts* are Bitcoin's smart contracts**

What can we do with Smart Contracts?

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Payment channels

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Set of techniques designed to allow users to make multiple Bitcoin transactions without commiting all of them to the Bitcoin block chain

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Off-chain transactions

Bitcoin transactions that are not commited to the Bitcoin blockchain but would be valid if they were commited

Payment Channel basic scheme

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Which transactions are *off-chain*?

All **payment transactions are *off-chain***

Outline

What does a unidirectional payment channel allows us to do?

Unidirectional payment channel

What allows to do?

Incrementally pay amounts of funds from one party to another

Unidirectional payment channel

What allows to do?

Incrementally pay amounts of funds from one party to another

For instance...

We will create a channel to allow **Alice** pay **Bob** incremental amounts of funds

Locking funds

What do we need to do?

Lock funds into the channel so:

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How to refund

Lock the funds for an amount of time, so after that time (called the *channel expiry time*) the funds are given back to the funder

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2. Create a ***smart* funding transaction** with the time-lock integrated in the *smart contract*

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2. **Bob** stores the partially signed transaction that pays some amount of money to him
3. If **Alice** wants to pay more, repeats the first step with more funds (spending the same funding transaction)

Replace by economical incentive

Bob will **keep the latest payment transaction** and discard previous ones, as **the last will be the one that pays more to him**

Closure

What do we need to do?

Two situations can appear when closing the channel:

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Locking the funds

Ways to lock funds

In order to accomplish both properties to lock funds, we can:

1. Create a **funding transaction** and a time-locked **refund transaction**
2. Create a ***smart* funding transaction** with the time-lock integrated in the *smart contract*

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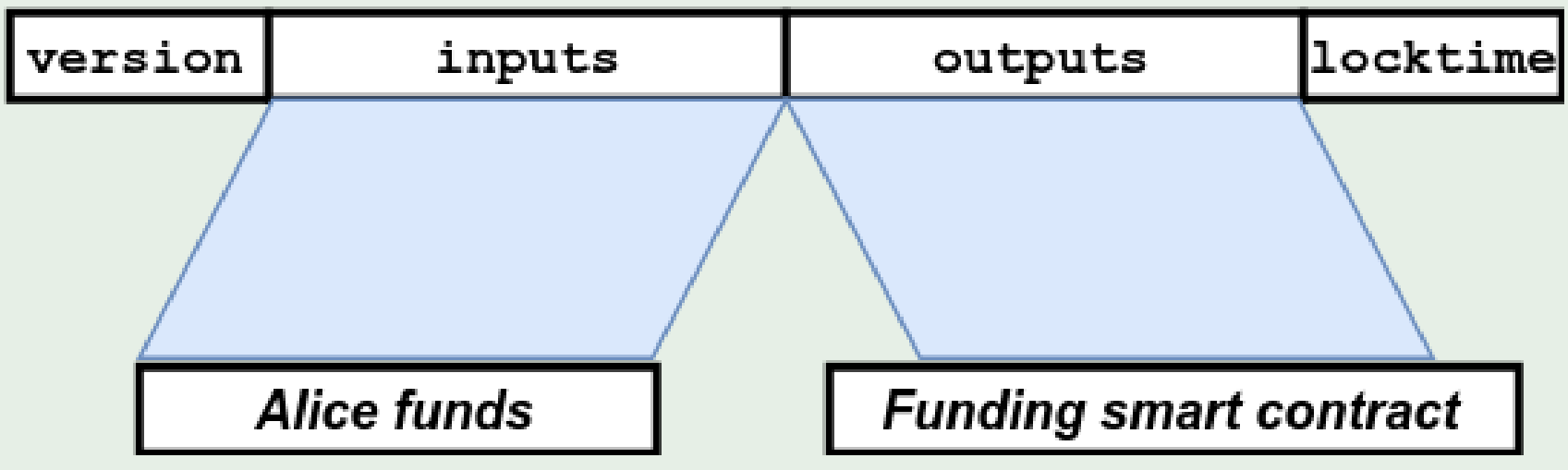
The implementation

With the **BIP-65**, an opcode appeared to create time-locked smart contracts, so we can create a ***smart* funding transaction** with the time lock integrated

Funding transaction

Funding transaction



Funding transaction

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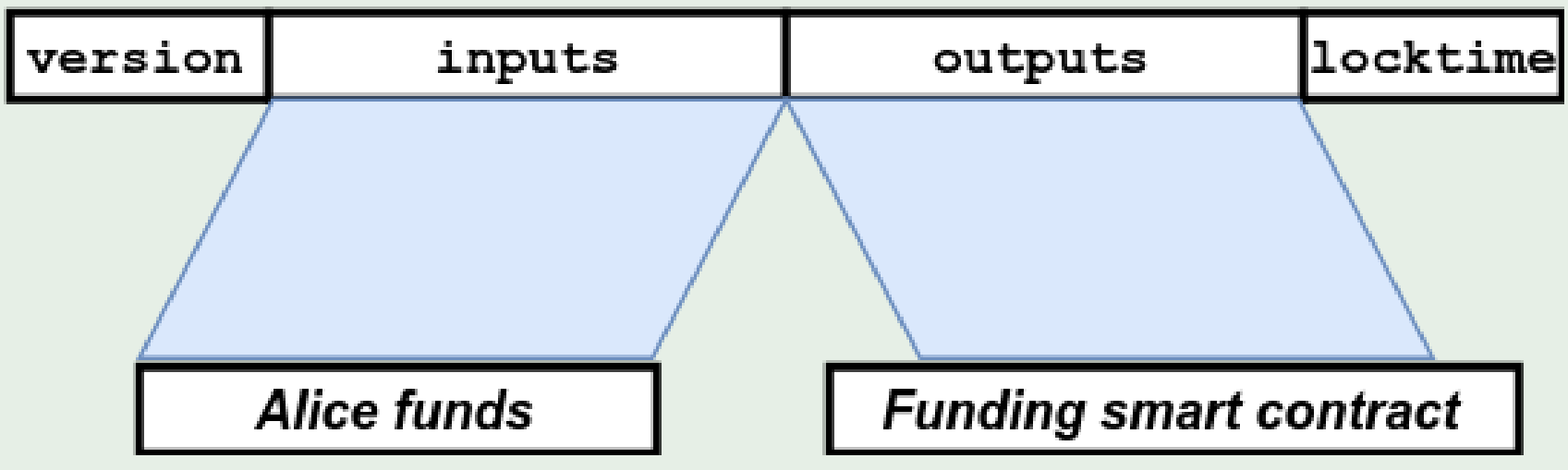

Funding transaction

Funding smart contract

As we said, we need to design a *redeemScript* in order to create a Bitcoin smart contract:

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```
OP_IF <time>
OP_CHECKLOCKTIMEVERIFY OP_DROP <PubKeyAlice_1>
OP_CHECKSIG
OP_ELSE
OP_2 <PubKeyAlice_2> <PubKeyBob> OP_2 OP_CHECKMULTISIG
OP_ENDIF
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Technically...

As we are creating a P2SH, then the output script must be:
`OP_HASH160 <redeemScript_hash> OP_EQUAL`

Paying funds

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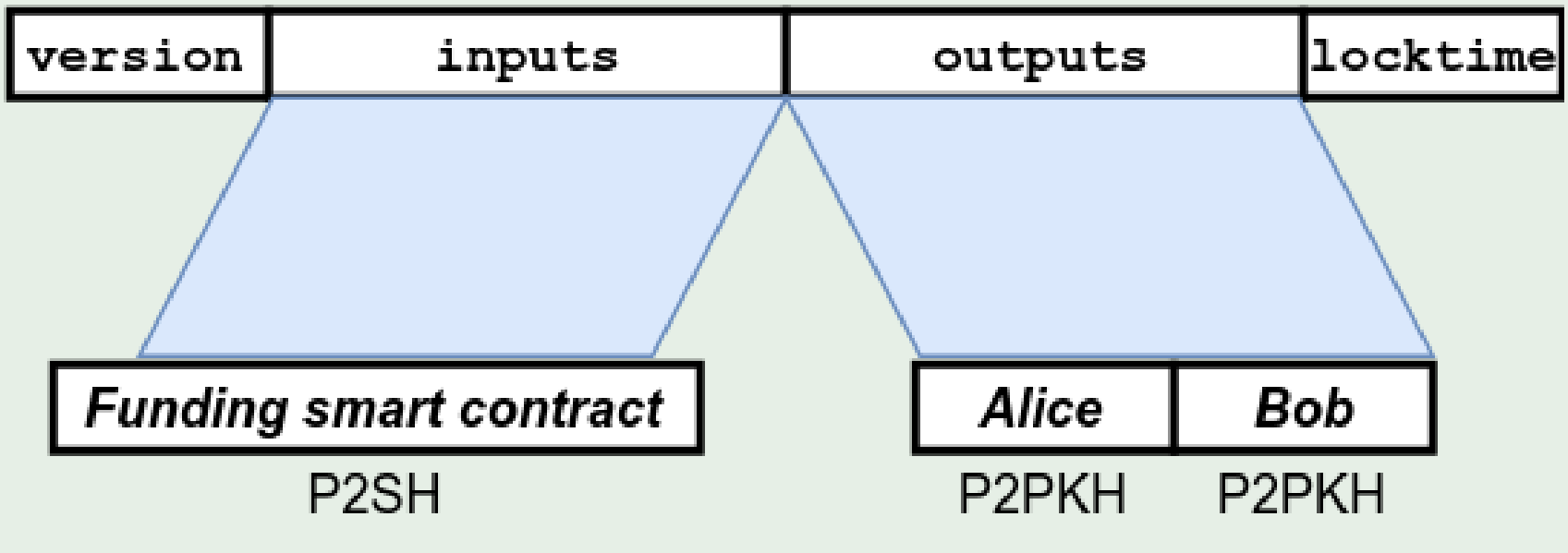
The implementation

Alice creates a transaction that spends the funding transaction, with two outputs: one with some amount for Bob and the rest for herself

Payment transaction

Payment transaction



Payment transaction

Spending funding smart contract

We now need to spend the *redeemScript*

Payment transaction

Spending funding smart contract

We now need to spend the *redeemScript*

```
<sig_Alice> <sig_Bob> OP_0
```

Technically...

As we are spending a P2SH, then the input script must be:
`<sig_Alice> <sig_Bob> OP_0 <redeemScript>`

Closure transaction

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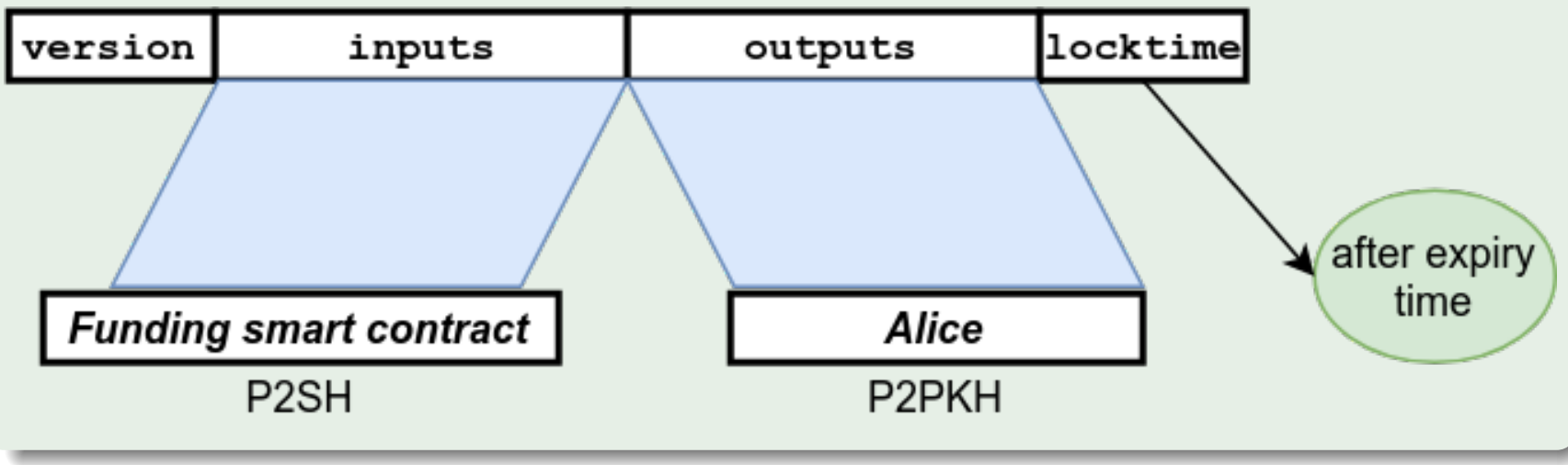
Graceful closure

Bob simply broadcasts the latest payment transaction once signed and before channel expiry time

Closure transaction

Closure transaction (refund)



Closure transaction

Spending funding smart contract (refund)

We now need to spend the *redeemScript*

Closure transaction

Spending funding smart contract (refund)

We now need to spend the *redeemScript*

```
<sig_Alice> OP_1
```

Closure transaction

Spending funding smart contract (refund)

We now need to spend the *redeemScript*

```
<sig_Alice> OP_1
```

Technically...

As we are spending a P2SH, then the input script must be:
`<sig_Alice> OP_1 <redeemScript>`

What if we want Bob to pay Alice too?

Outline