Blockchains & Cryptocurrencies

Mechanics of Bitcoin

Instructor: Matthew Green
Johns Hopkins University - Fall 2020

Many slides based on NBFMG

Housekeeping

- Pace of material?
- Office hours
- A1 is due 9/24 11:59pm Baltimore time
- **Project groups and proposal is due 10/8 end of day**
    - Project ideas up on main Github Wiki page

News?

Today

- Finish talking about Bitcoin at a high level
- Talk about the low-level mechanics of real Bitcoin

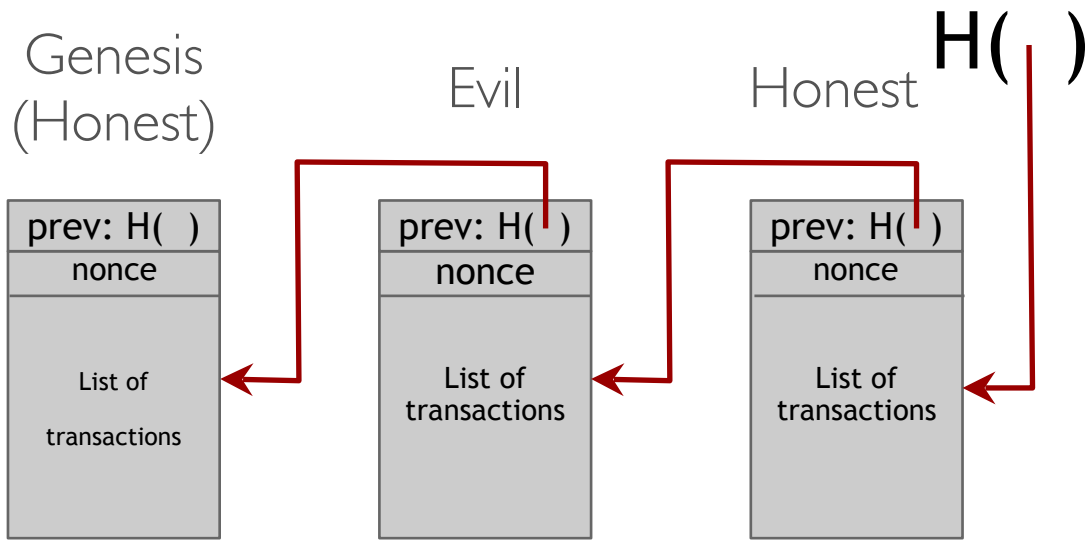
Bitcoin: A Peer-to-Peer Electronic Cash System

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.

1. Introduction

Review


Genesis
(Honest)
Evil
Honest
H( )
prev: H( )
nonce
List of
transactions
prev: H( )
nonce
List of
transactions
prev: H( )
nonce
List of
transactions

Selecting T (Bitcoin)

Every block contains a (packed) encoding of T (target) which corresponds to ***"difficulty" (d)***

d = ((2^{16} - 1) * 2^{8*26}) / T <- relationship between d, T

Goals:

- Bitcoin block time should average 10 minutes
- 2016 blocks * 10 minutes == 2 weeks
- Everyone in the network agrees on *T*
- *Hence must be a function of chain data*

This brings back a notion of time

What if there’s a collision?

Sometimes two separate nodes find a valid solution simultaneously

This can result in network partition

What if there’s a collision?

Image CC-BY-3 Theymos taken from the Bitcoin wiki

What if there’s a collision?

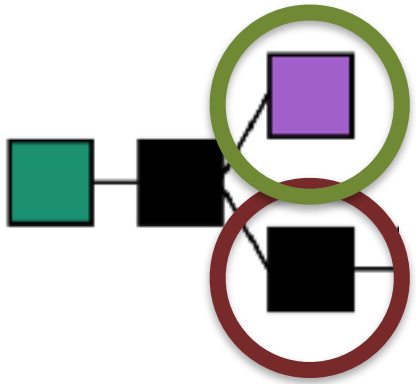
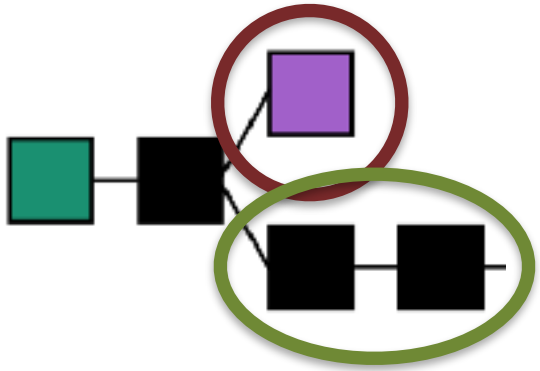


Image CC-BY-3 Theymos taken from the Bitcoin wiki

What if there’s a collision?



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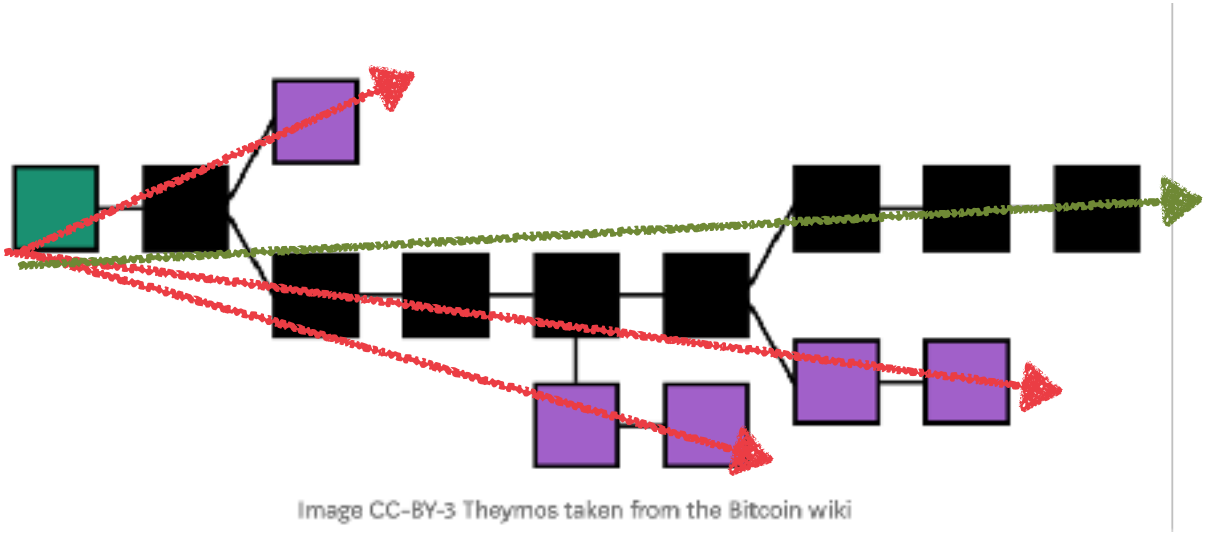
“Longest chain rule”



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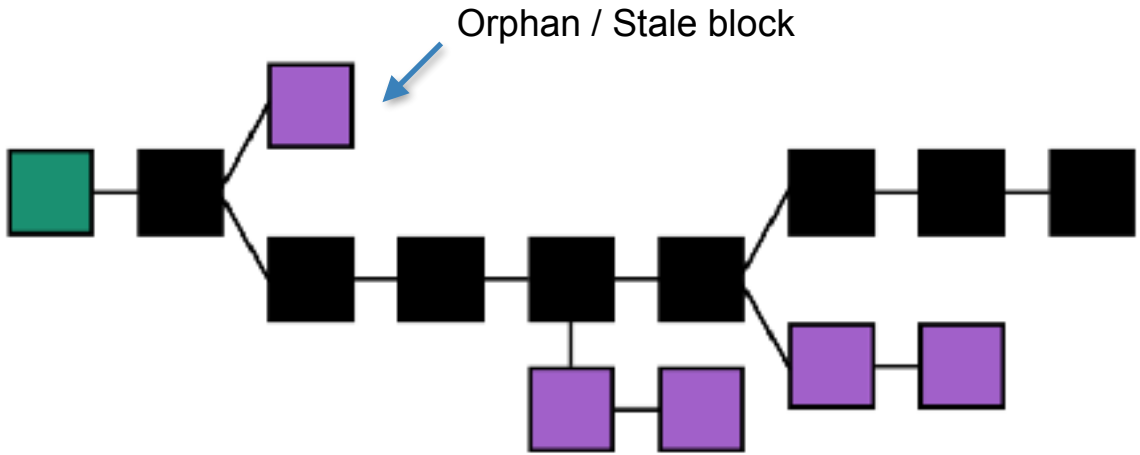

Image CC-BY-3 Theymos taken from the Bitcoin wiki

This is good and bad

Good: if we experience a “chain fork” and the network is connected (I.e., not totally partitioned), then eventually we will learn about both forks

Good: if the “hash power” behind the two chains is unequal, we will probably end up with one chain getting longer

Even if the hash power is equal, the inherent randomness of the puzzle (PoW) will likely cause one chain to advance

As one chain grows longer, other nodes will adopt it, and start adding to it

What’s the bad?

What’s the bad?

When a chain becomes longer than the “current chain” a node thinks is the longest chain, they must abandon that older chain

Finality

“Finality is the assurance or guarantee that cryptocurrency transactions cannot be altered, reversed, or canceled after they are completed.”

https://academy.binance.com/glossary/finality

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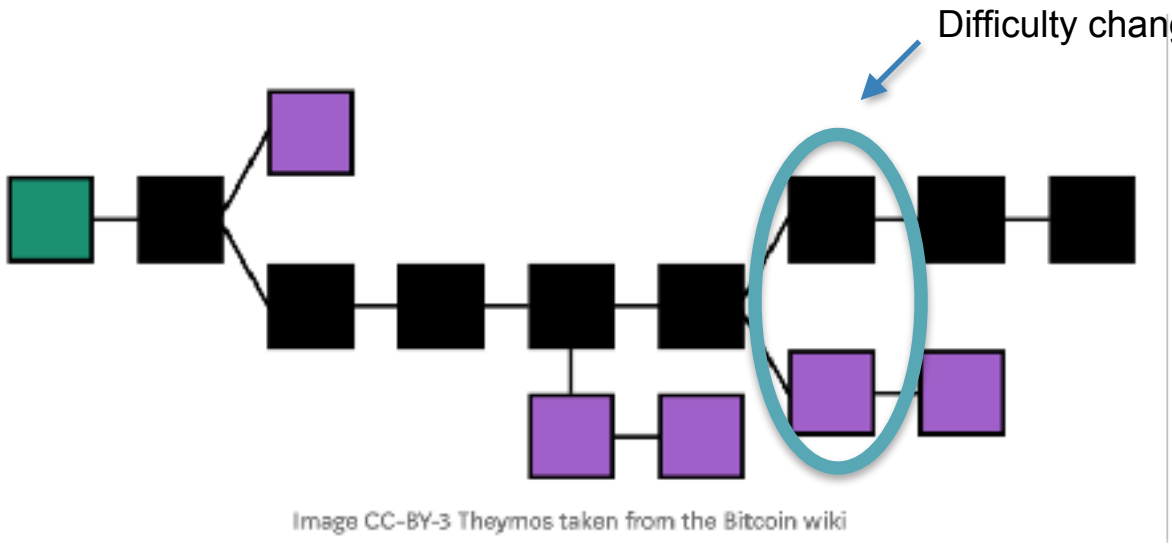
Bitcoin’s finality is probabilistic (and computational)

Reorganizations become less probable (and more expensive) over time, but they never become impossible*

Q: What if difficulty changes?



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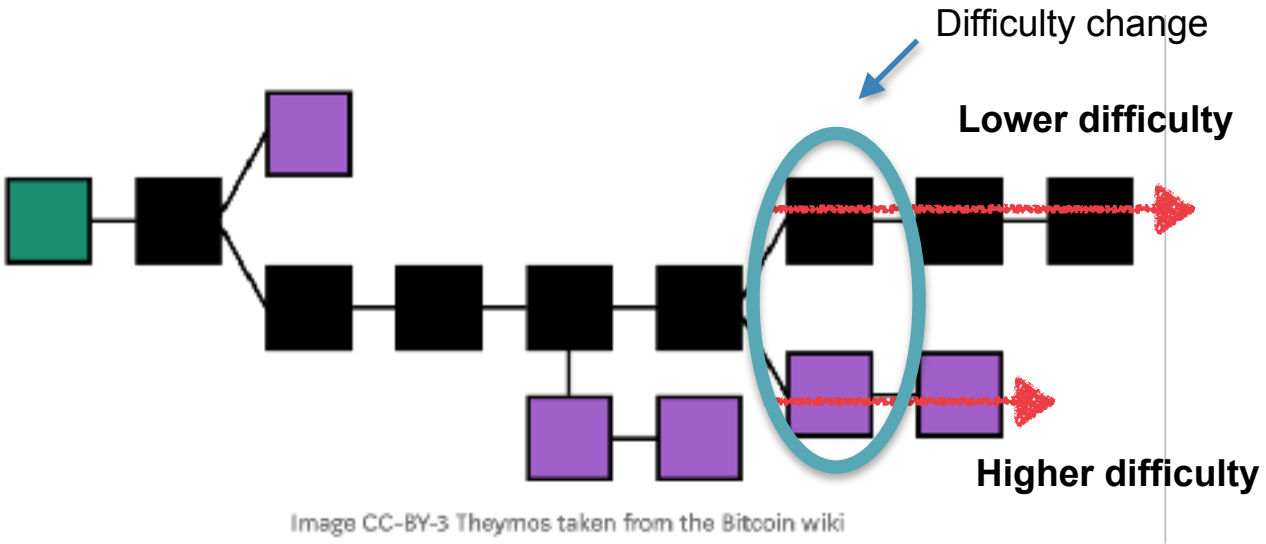


Image CC-BY-3 Theymos taken from the Bitcoin wiki

A: “Chain with most hashwork”

Bitcoin doesn’t exactly use the longest chain rule

Instead, it employs a calculation that takes block difficulty into account

Each block has a difficulty. Convert to expected # of hashes to find block. Total these values. Chain with largest total is “longest”.

Most of the time, this is equivalent to longest chain

How many blocks can the adversary make?

Consider an adversary that controls a r-fraction of the hash power

How many blocks in expectation can they build in a t-block window?

What is the probability that they dominate that t-block window?

We will see some attacks that leverage these simplified calculations later….

How do we incentivize mining?

How do we incentivize mining?

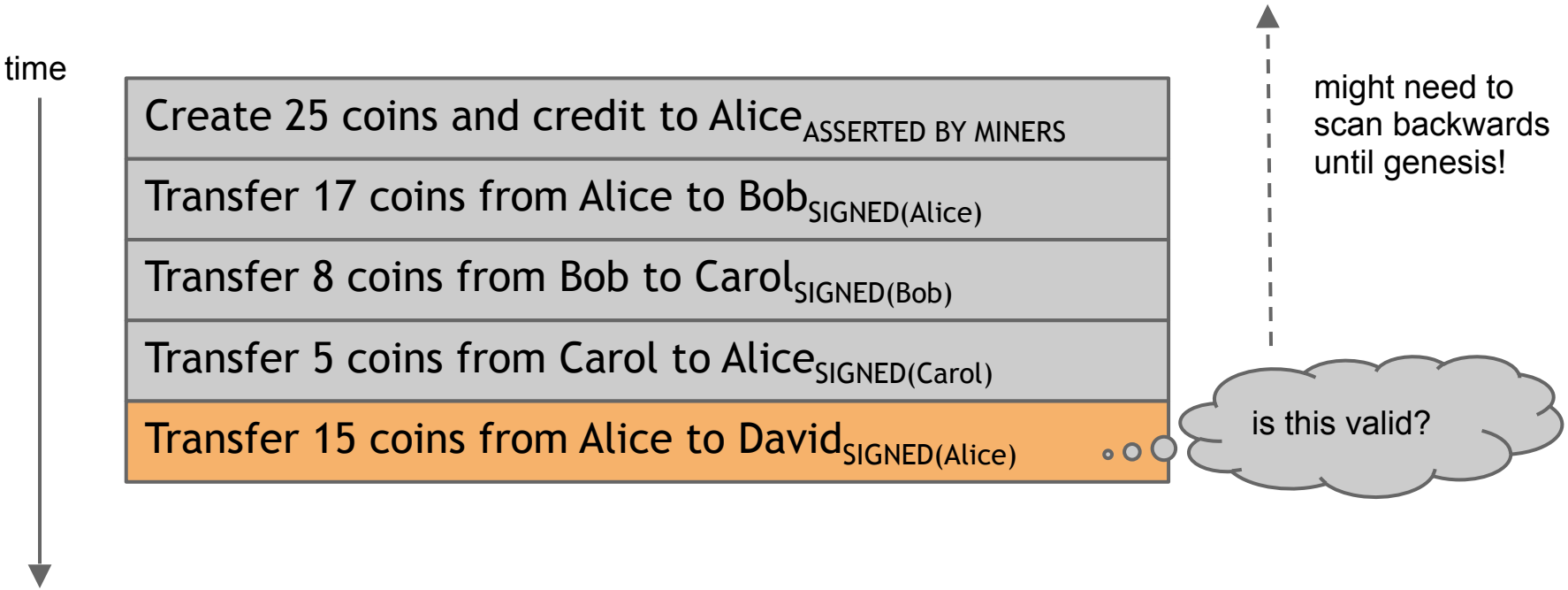
Two answers to this question in Bitcoin:

1. “Transaction fees” Each transaction has a “tip” that can be collected by the node who mines it into a block (incentivizes inclusion of transactions)

2. “Block reward” 50/25/12.5/… BTC made from scratch (in a special Coinbase transaction) and given to the miner

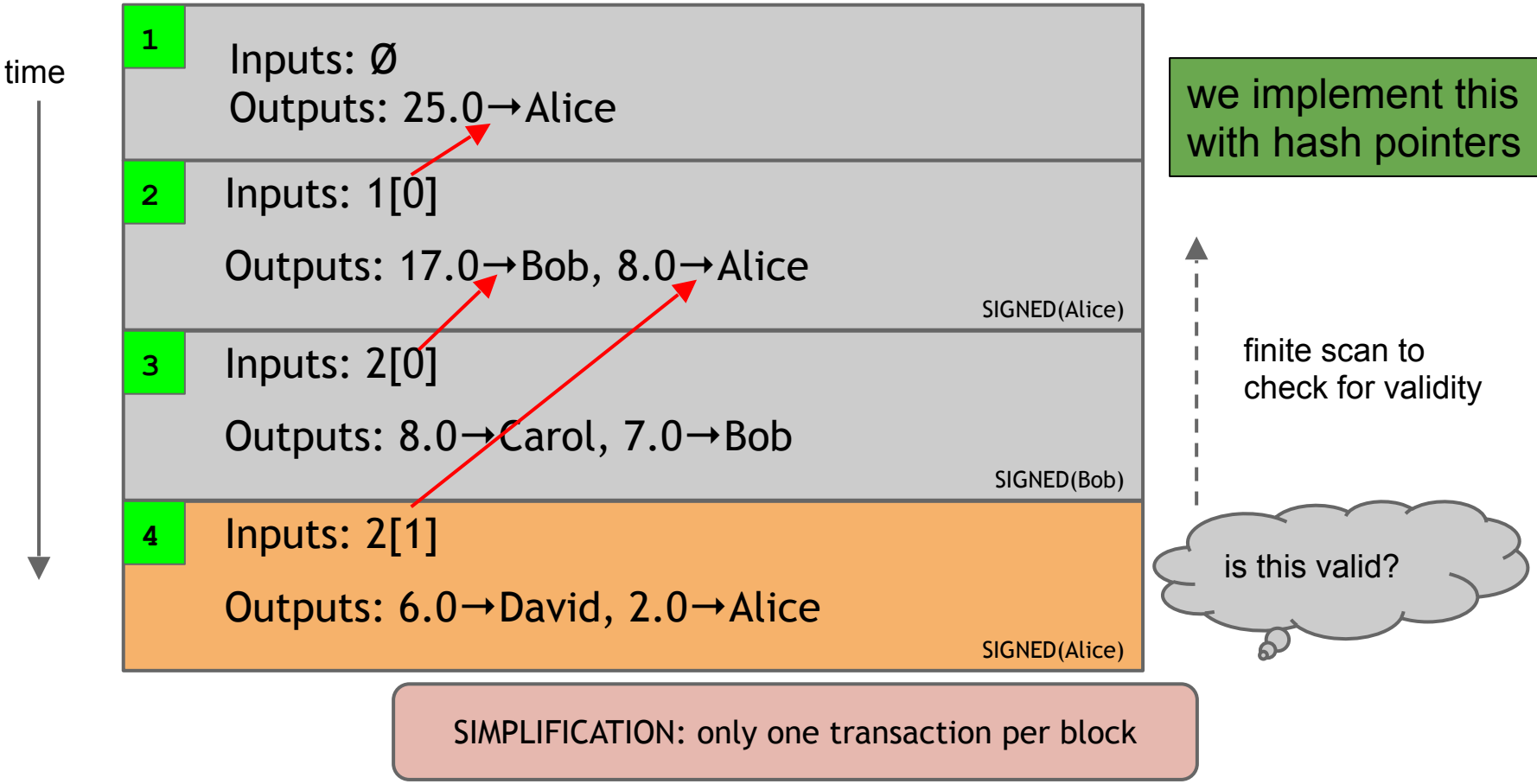
Bitcoin transactions

An account-based ledger (*not* Bitcoin)



SIMPLIFICATION: only one transaction per block

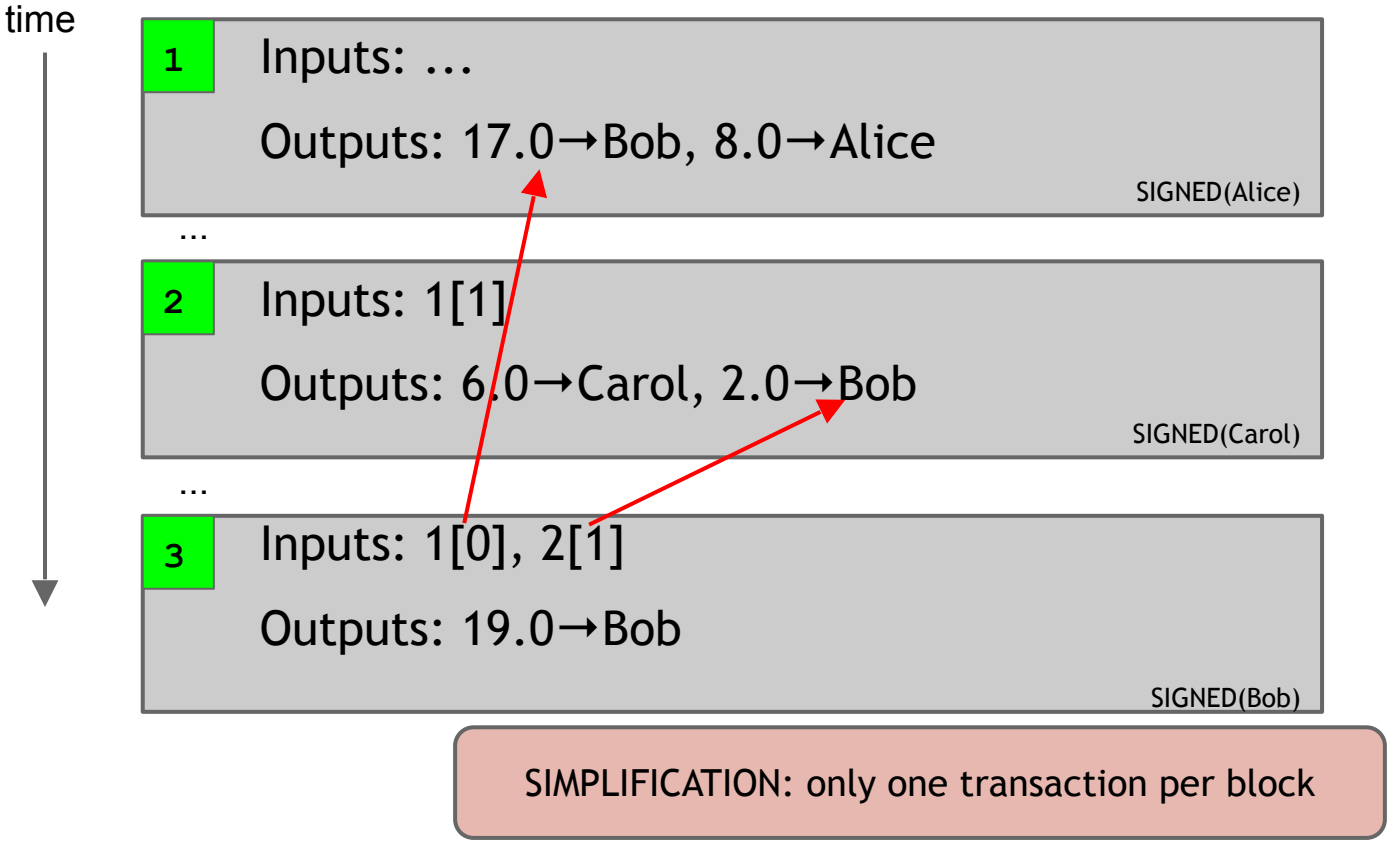
A transaction-based ledger (Bitcoin)



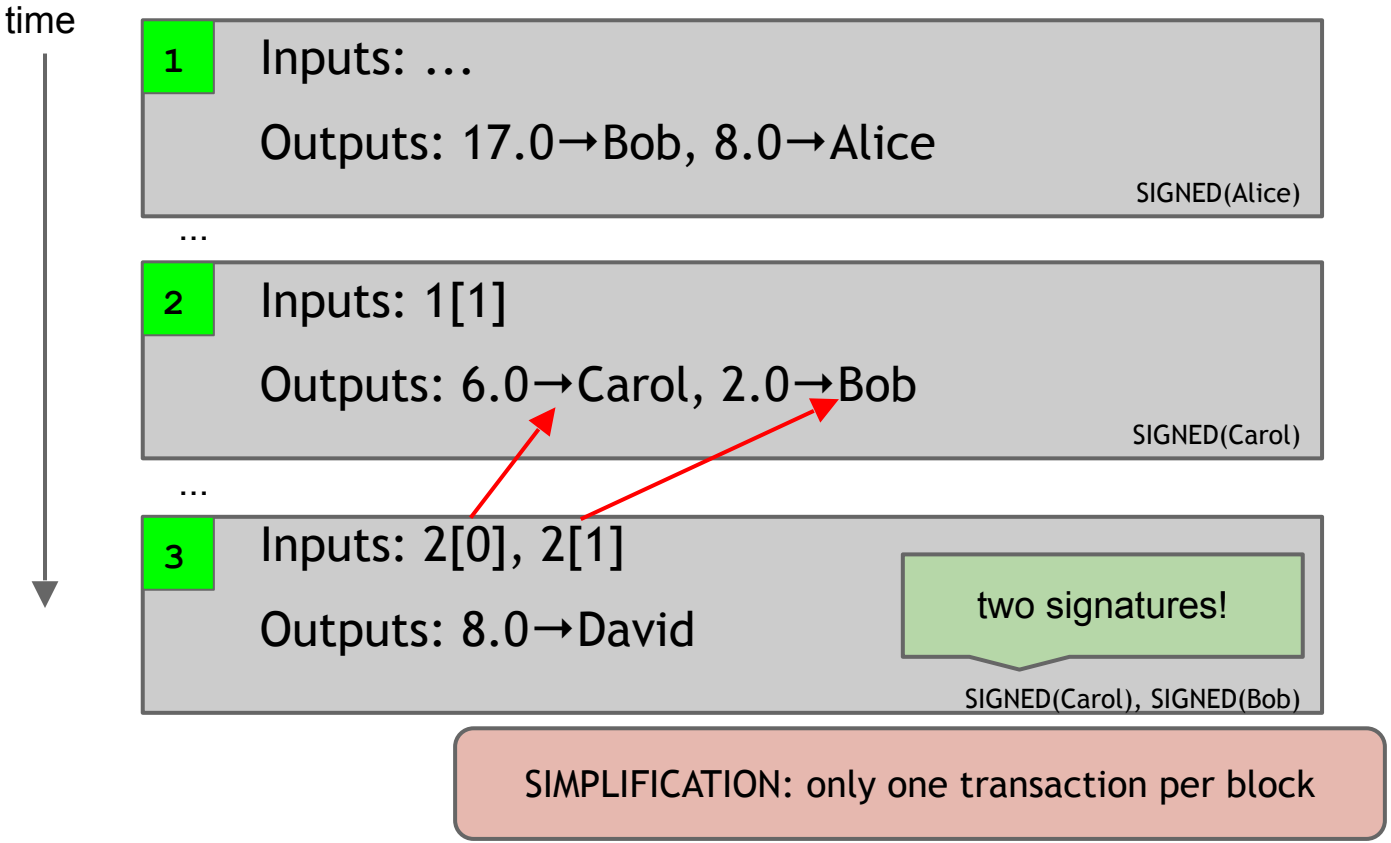
Referencing Transactions

- Hash pointers for transactions
- Within a transaction, refer to a particular output via serial numbers

Merging value



Joint payments



The real deal: a classical Bitcoin transaction

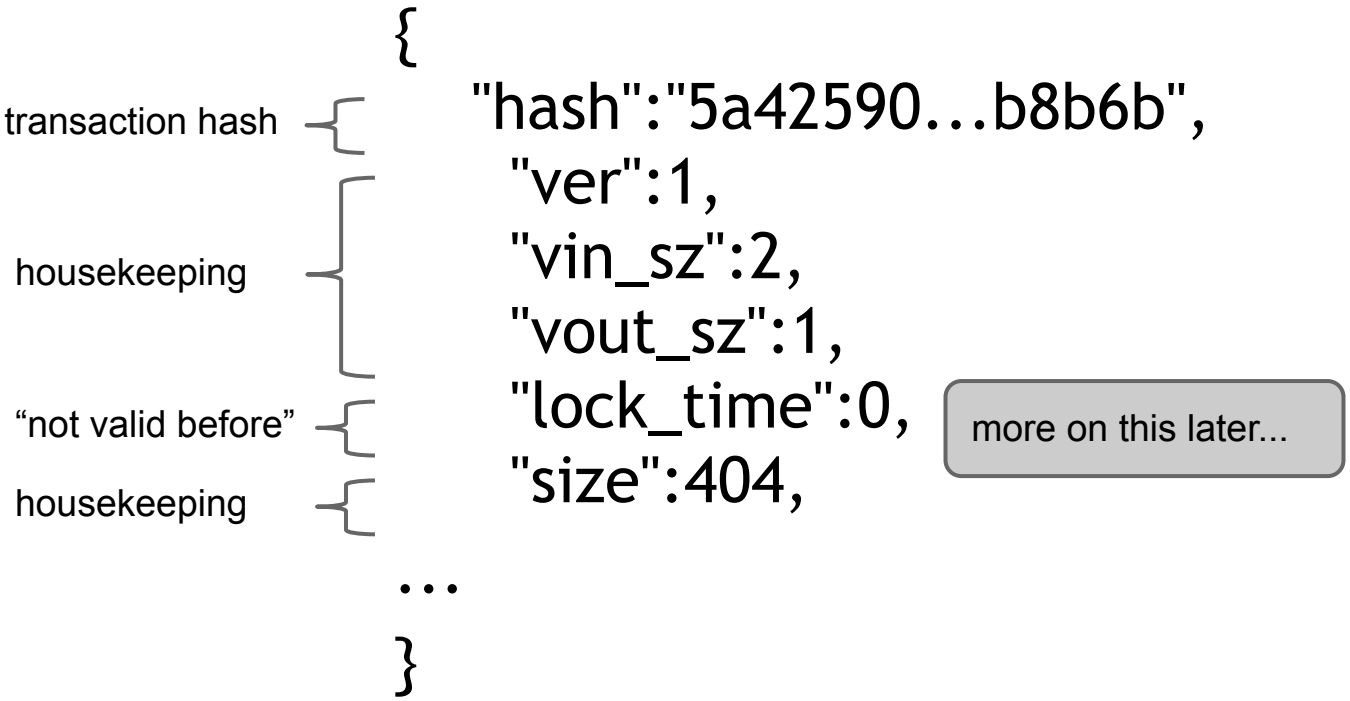
metadata

input(s)

output(s)


```
{
    "hash":"5a42590fbe0a90ee8e8747244d6c84f0db1a3a24e8f1b95b10c9e050990b8b6b",
    "ver":1,
    "vin_sz":2,
    "vout_sz":1,
    "lock_time":0,
    "size":404,
    "in":[
      {
        "prev_out":{
          "hash":"3be4ac9728a0823cf5e2deb2e86fc0bd2aa503a91d307b42ba76117d79280260",
          "n":0
        },
          "scriptSig":"30440..."
      },
      {
        "prev_out":{
          "hash":"7508e6ab259b4df0fd5147bab0c949d81473db4518f81afc5c3f52f91ff6b34e",
          "n":0
        },
        "scriptSig":"3f3a4ce81...."
      }
    ],
    "out":[
      {
        "value":"10.12287097",
        "scriptPubKey":"OP_DUP OP_HASH160 69e02e18b5705a05dd6b28ed517716c894b3d42e OP_EQUALVERIFY OP_CHECKSIG"
      }
    ]
}
```

The real deal: transaction metadata



The real deal: transaction inputs

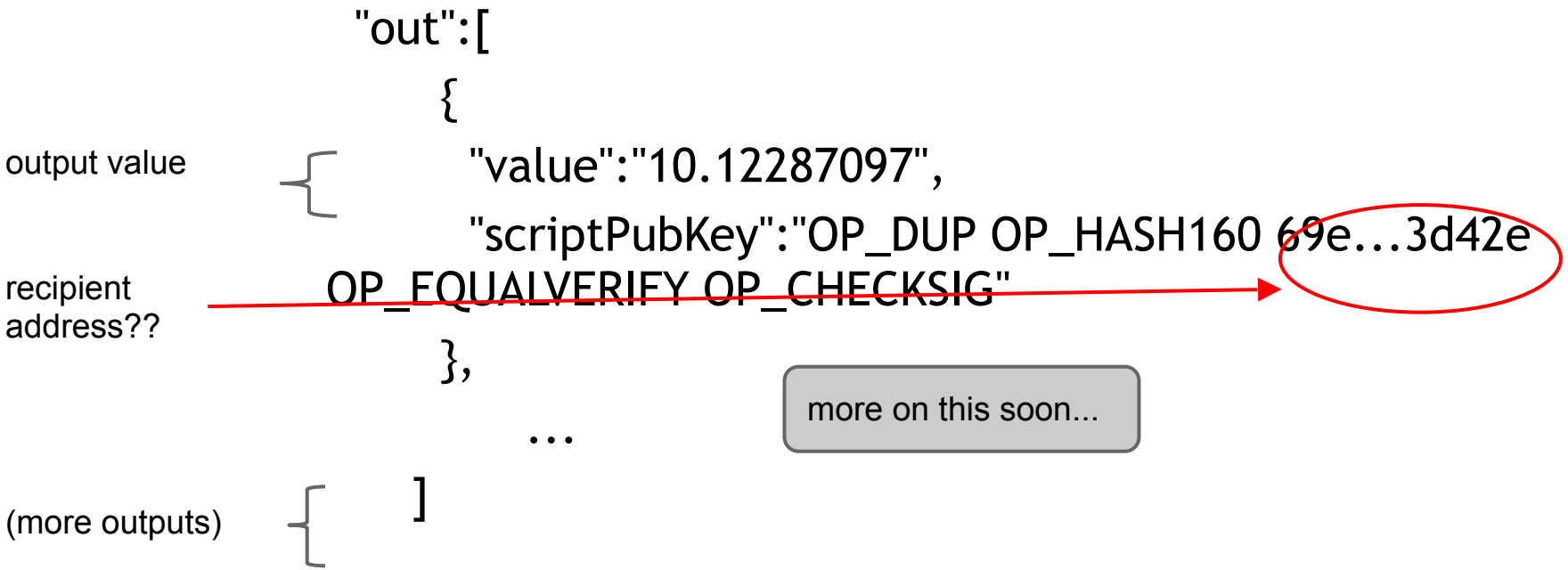
previous transaction

signature

(more inputs)

```
"in":[
  {
    "prev_out":{
      "hash":"3be4...80260",
      "n":0
    },
"scriptSig":"30440....3f3a4ce81"
  },
...
],
```

The real deal: transaction outputs

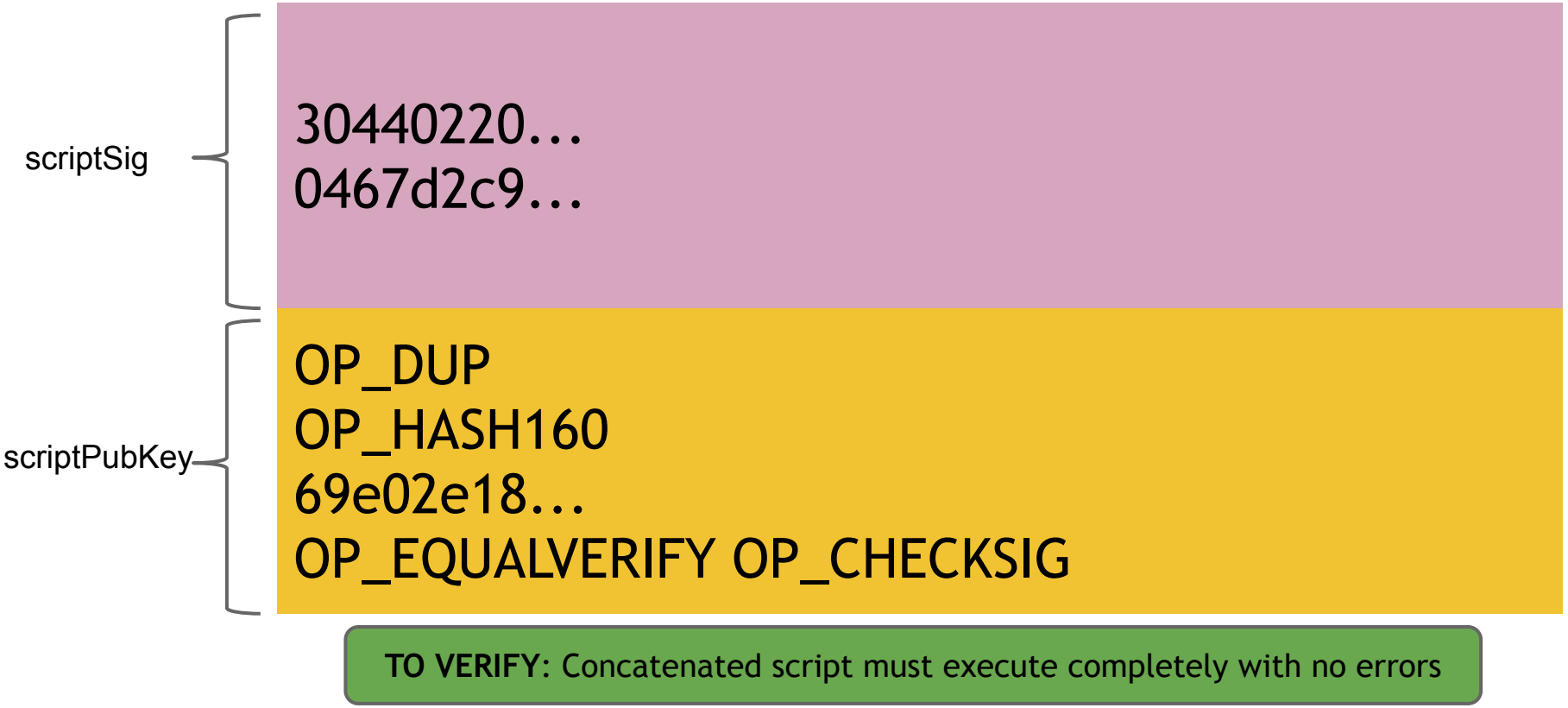


Bitcoin scripts

Output “addresses” are really *scripts*

```
OP_DUP
OP_HASH160
69e02e18...
OP_EQUALVERIFY OP_CHECKSIG
```

Input “addresses” are *also* scripts



Bitcoin scripting language (“Script”)

Design goals

- Built for Bitcoin
- Simple, compact
- Support for cryptography
- Stack-based
- Limits on time/memory
- No looping

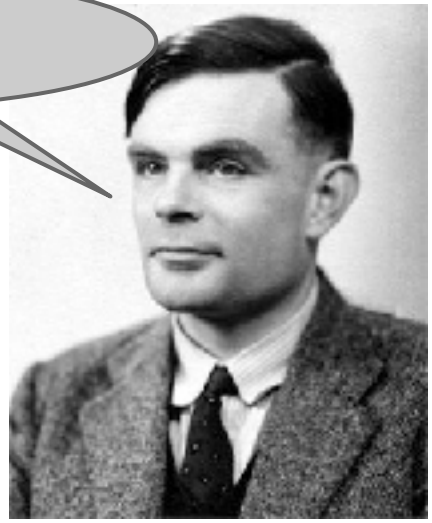
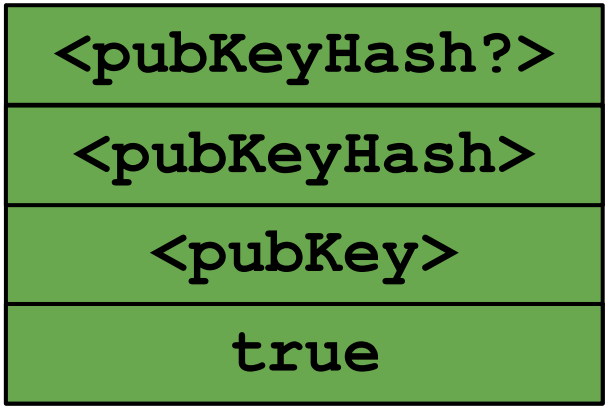
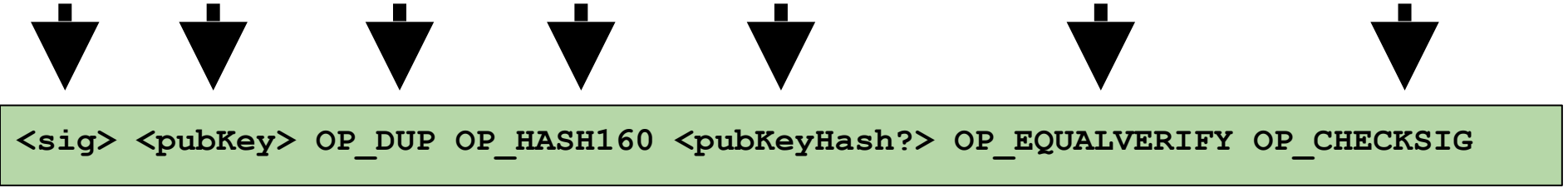


image via Jessie St. Amand

Bitcoin script execution example





Bitcoin script instructions

256 opcodes total (15 disabled, 75 reserved)

- Arithmetic
- If/then
- Logic/data handling
- Crypto!
  - Hashes
  - Signature verification
  - Multi-signature verification

OP_CHECKMULTISIG

- Built-in support for joint signatures
- Specify *n* public keys
- Specify *t*
- Verification requires *t* signatures

BUG ALERT: Extra data value popped from the stack and ignored

Bitcoin scripts in practice (“original”)

- Most nodes whitelist known scripts
- 99.9% are simple signature checks
- ~0.01% are MULTISIG
- ~0.01% are Pay-to-Script-Ha
- Remainder are errors, proof-of-burn

More on this soon

* numbers from NBFMG and slightly out of date

Proof-of-burn

nothing’s going to redeem that ☹️

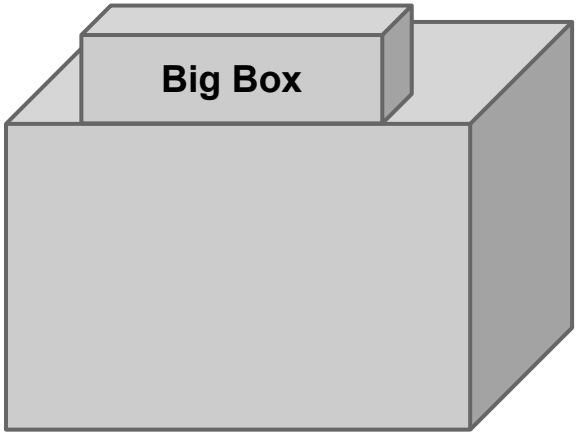
OP_RETURN
<arbitrary data>

Proof-of-burn: Applications

- Can be used to publish arbitrary data on the blockchain (e.g., timestamping a document)
- Bootstrap Altcoins by requiring people to destroy bitcoins in order to get new altcoins

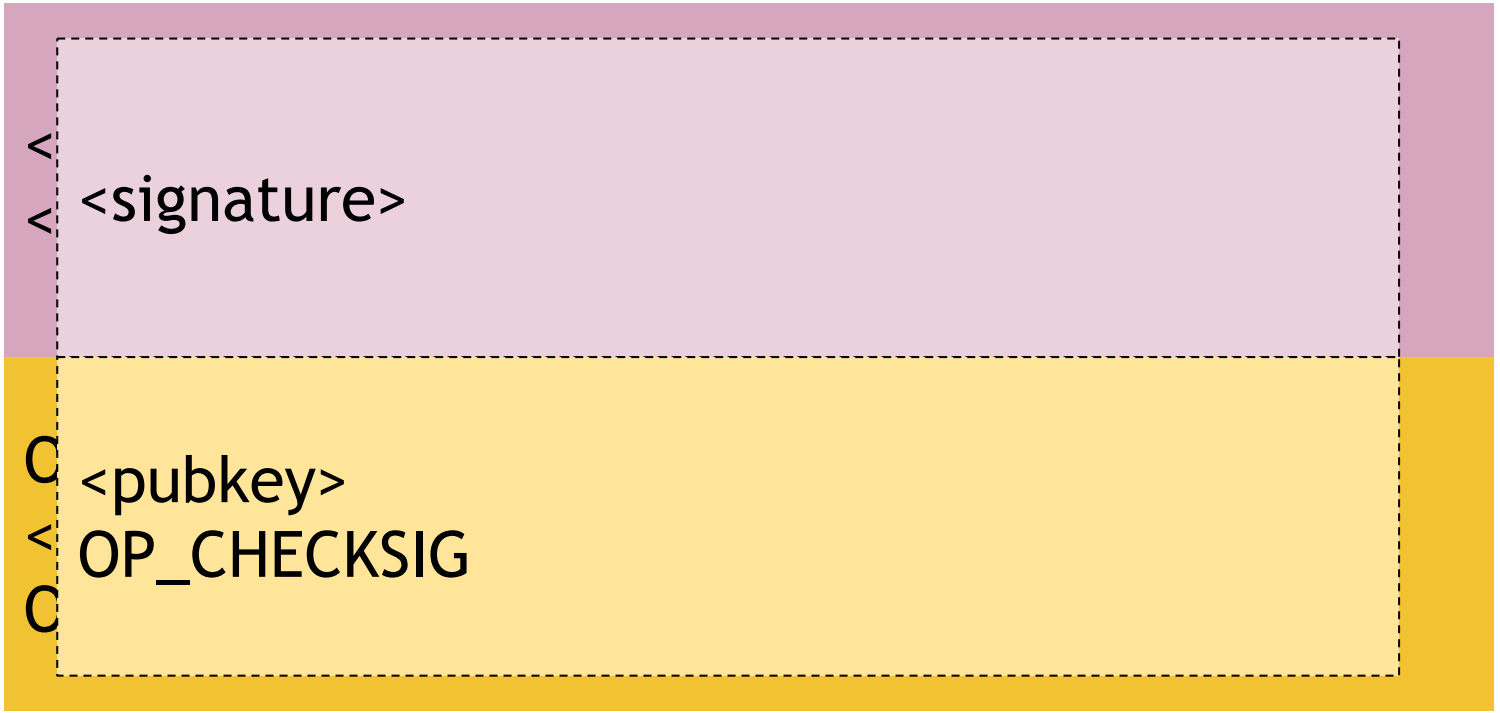
Should senders specify scripts?

I’m ready to pay for my purchases!

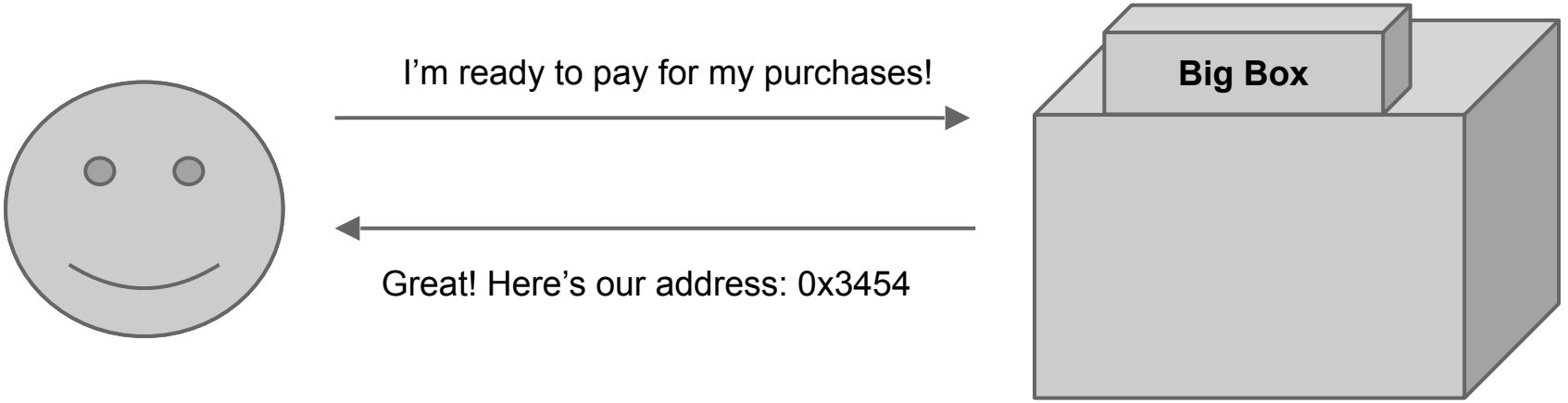


Cool! Well we’re using MULTISIG now, so include a script requiring 2 of our 3 account managers to approve. Don’t get any of those details wrong. Thanks for shopping at Big Box!

Idea: use the hash of redemption script



Pay to script hash



Block size limits and Segwit