Lecture 3

Mechanics of Bitcoin

Recap: Bitcoin consensus

Bitcoin consensus gives us:

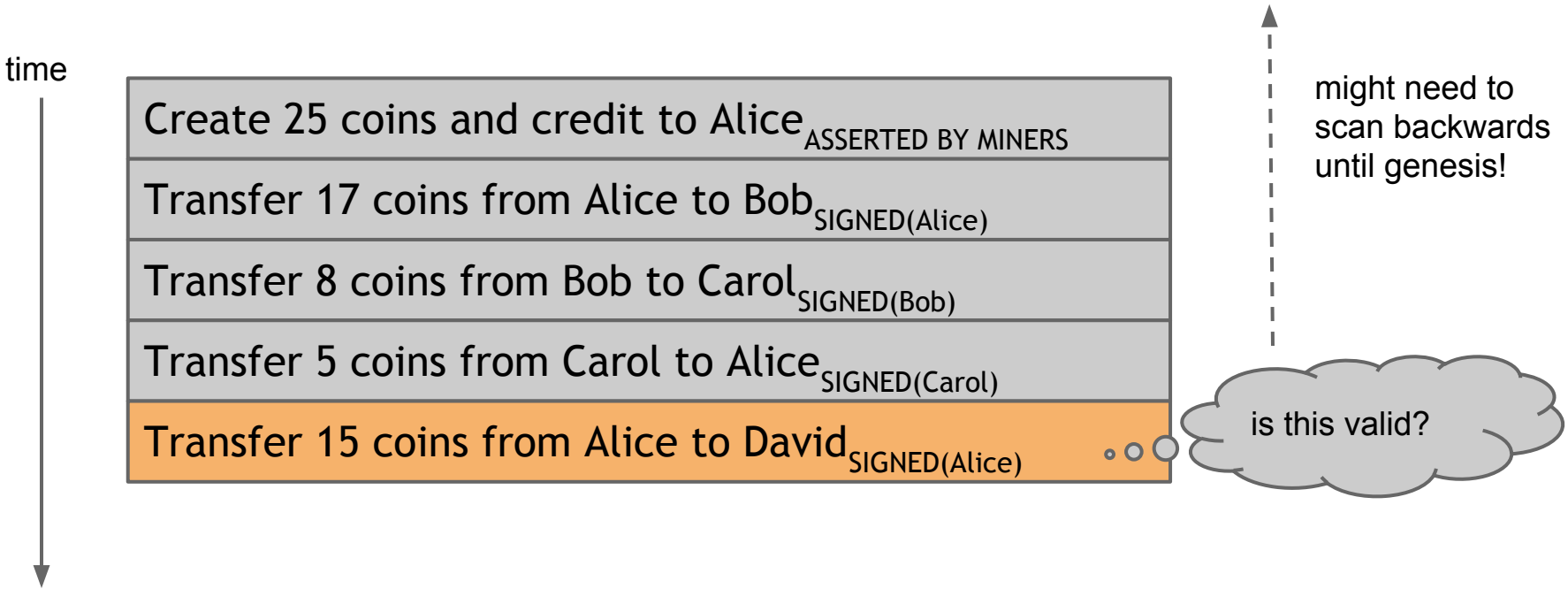
- Append-only ledger
- Decentralized consensus
- Miners to validate transactions

assuming a currency exists to motivate miners!

Lecture 3.1:

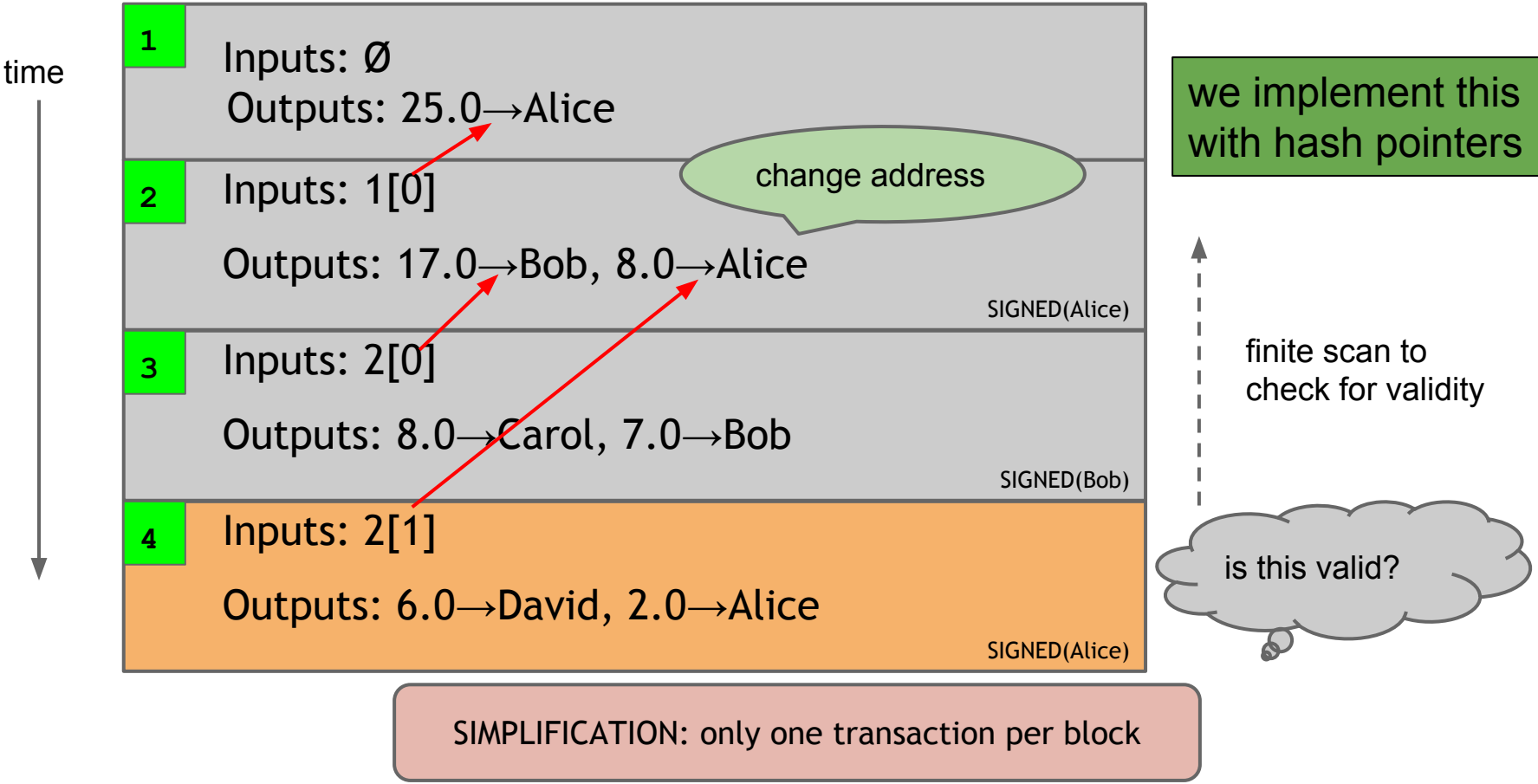
Bitcoin transactions

An account-based ledger (*not* Bitcoin)

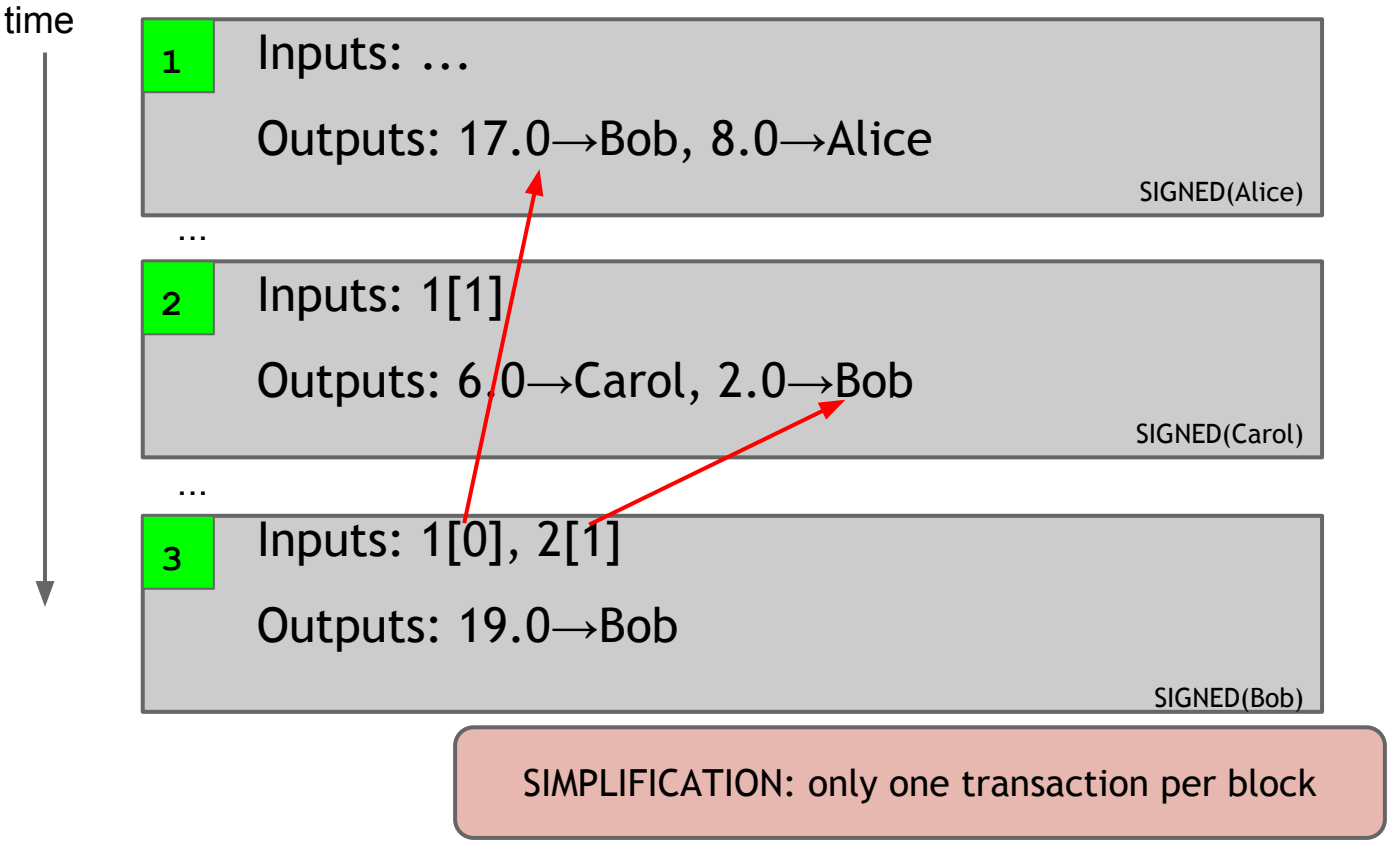


SIMPLIFICATION: only one transaction per block

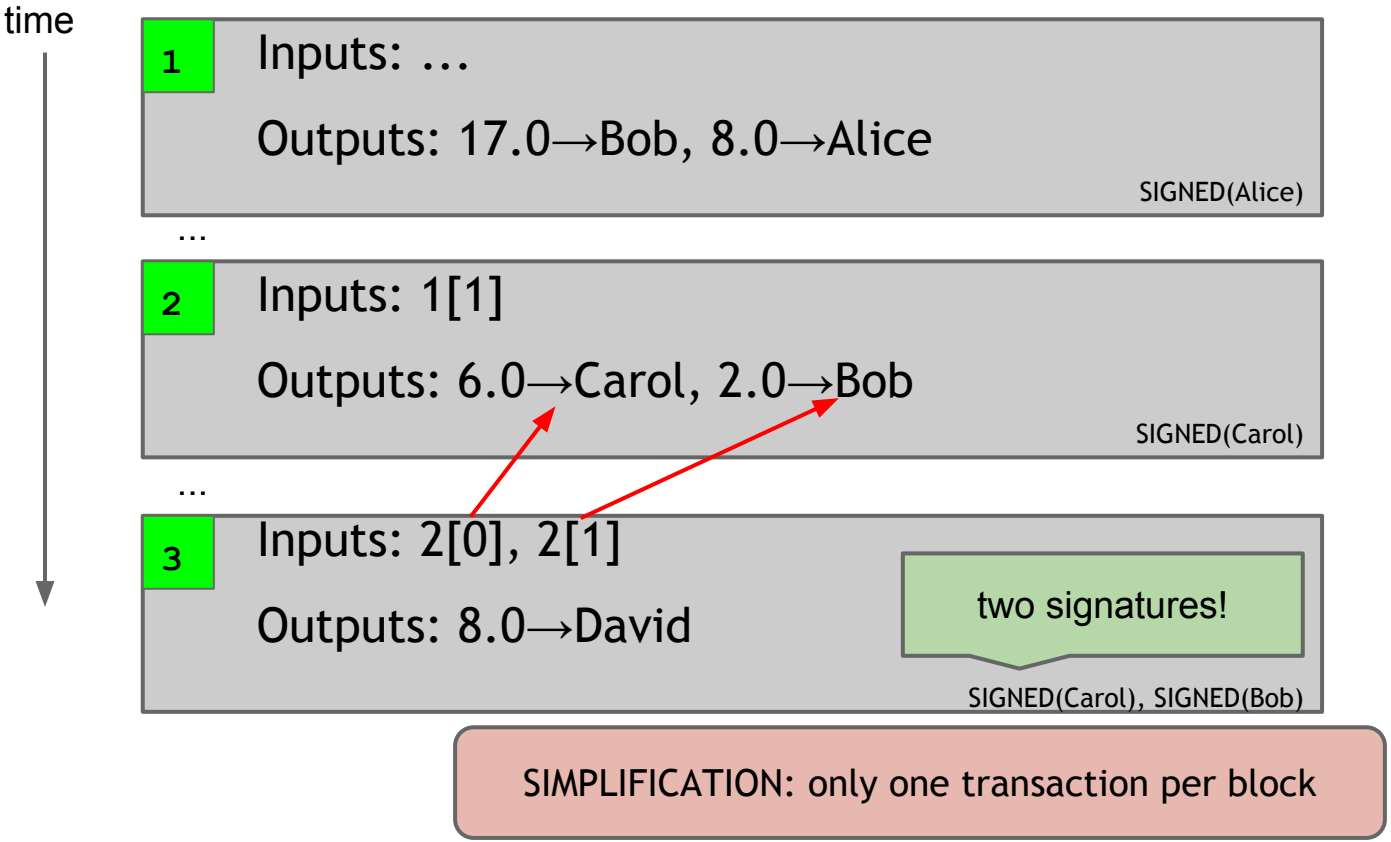
A transaction-based ledger (Bitcoin)



Merging value



Joint payments



The real deal: a Bitcoin transaction

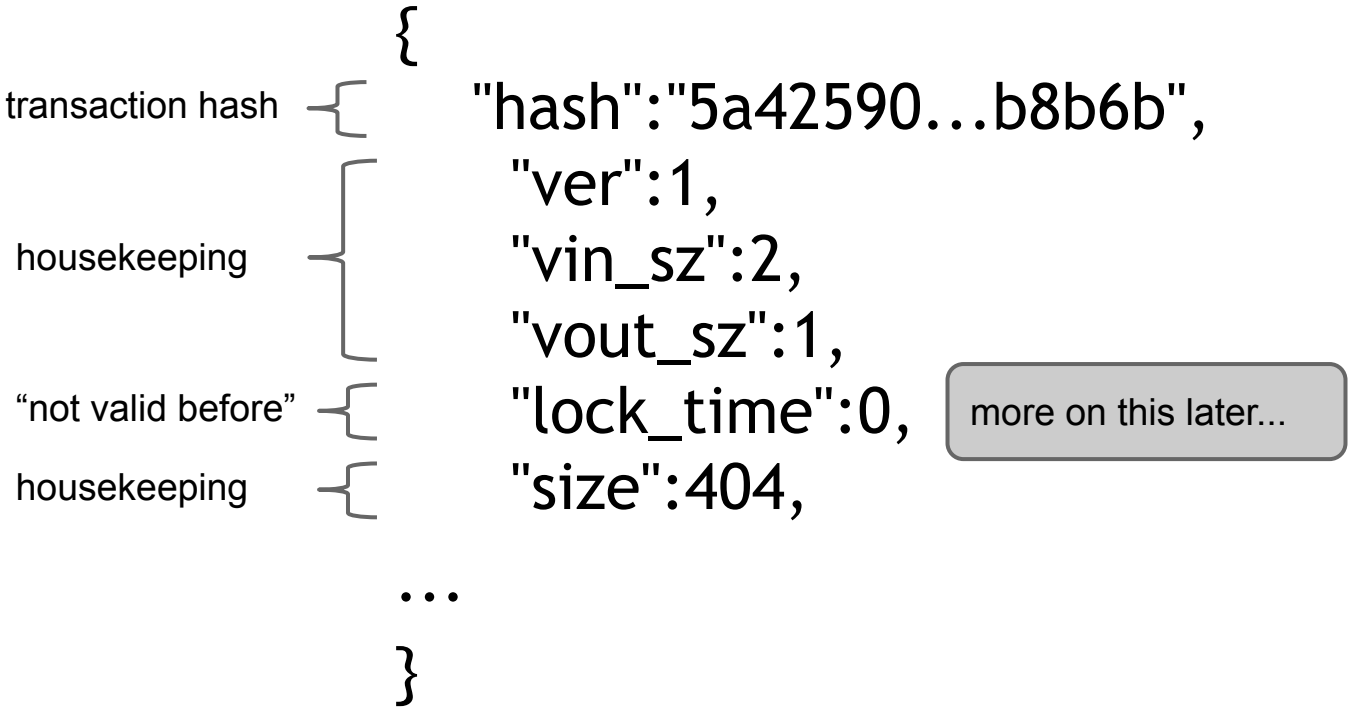
metadata

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

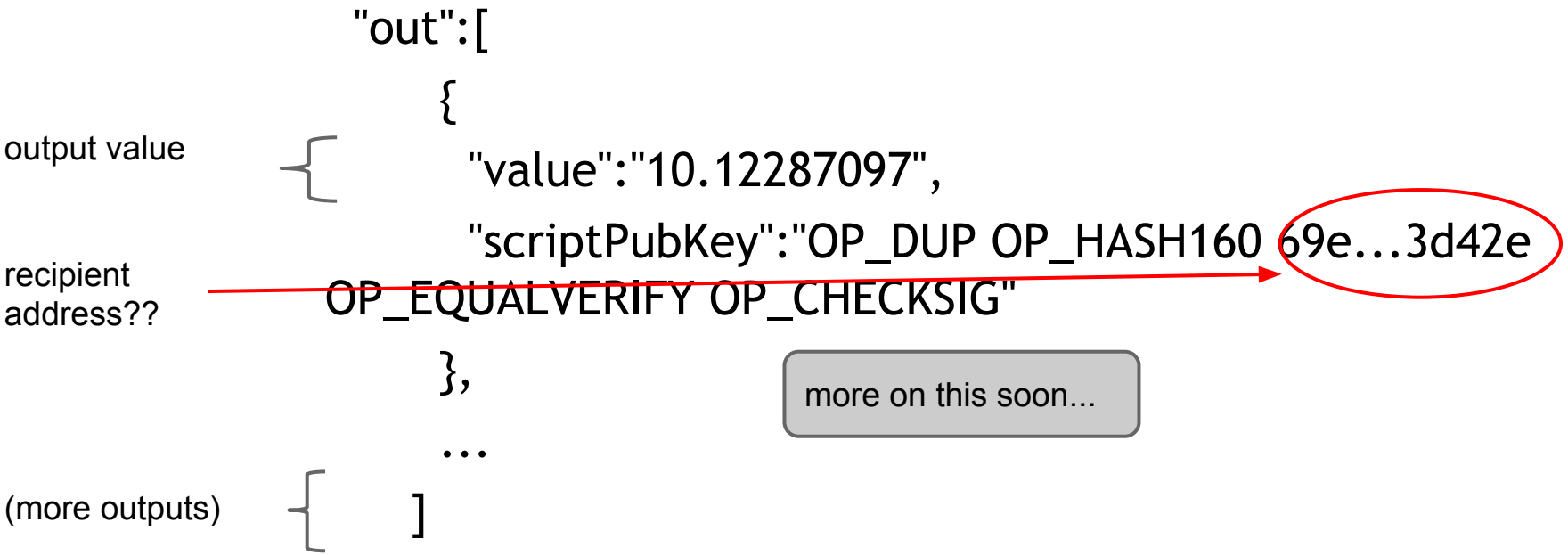
previous transaction

signature

(more inputs)

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

The real deal: transaction outputs



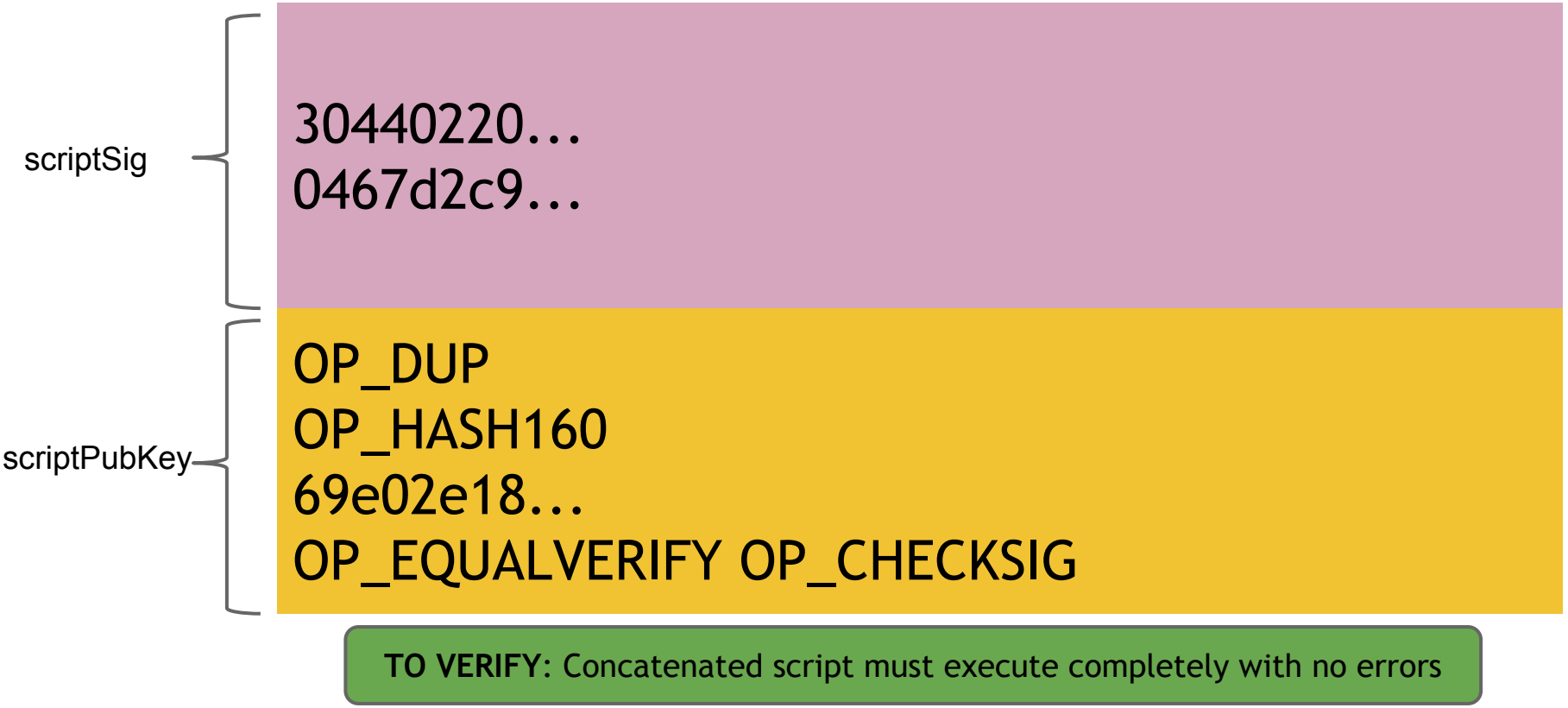
Lecture 3.2:

Bitcoin scripts

Output “addresses” are really *scripts*

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

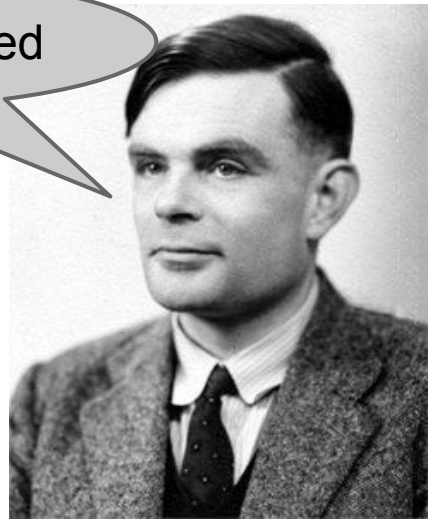
Input “addresses” are *also* scripts



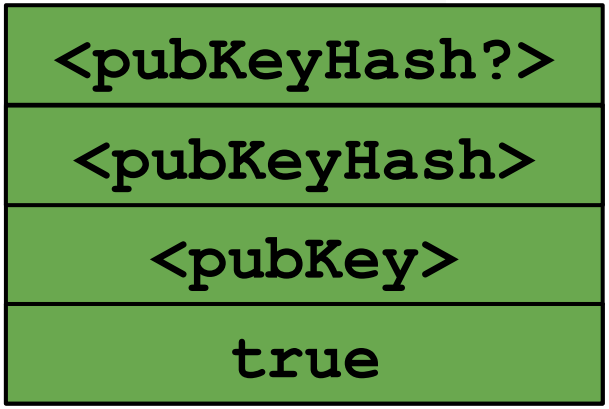
Bitcoin scripting language (“Script”)

Design goals

- Built for Bitcoin (inspired by Forth)
- Simple, compact
- Support for cryptography
- Stack-based
- Limits on time/memory
- No looping



Bitcoin script execution example



```
<sig> <pubKey> OP_DUP OP_HASH160 <pubKeyHash?> OP_EQUALVERIFY OP_CHECKSIG
```

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 (as of 2014)

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

More on this soon

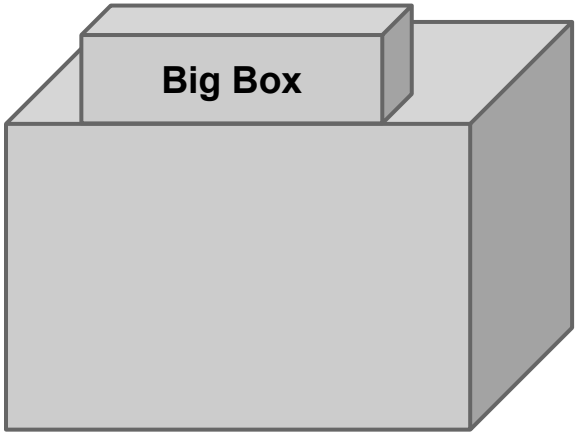
Proof-of-burn

nothing’s going to redeem that ☹️

OP_RETURN
<arbitrary data>

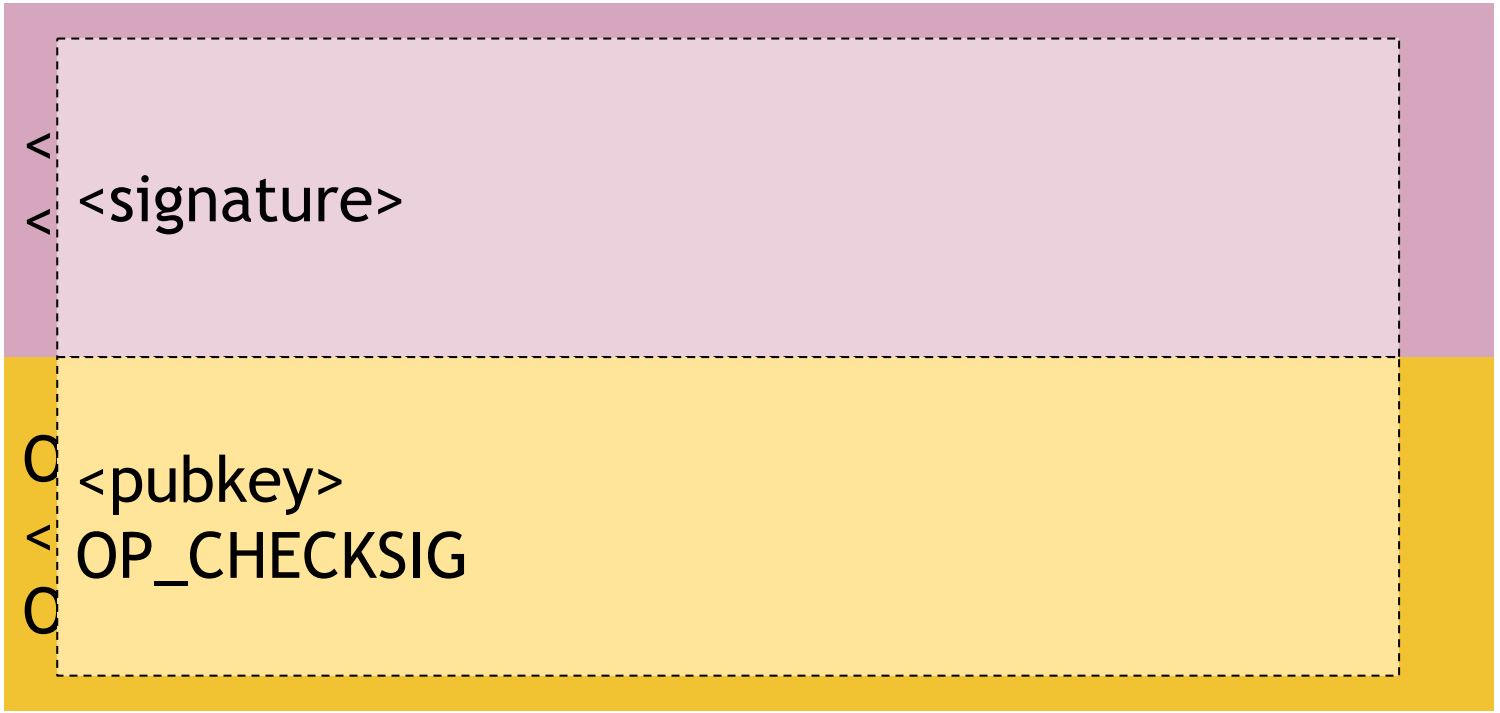
Should senders specify scripts?

I'm ready to pay for my purchases!

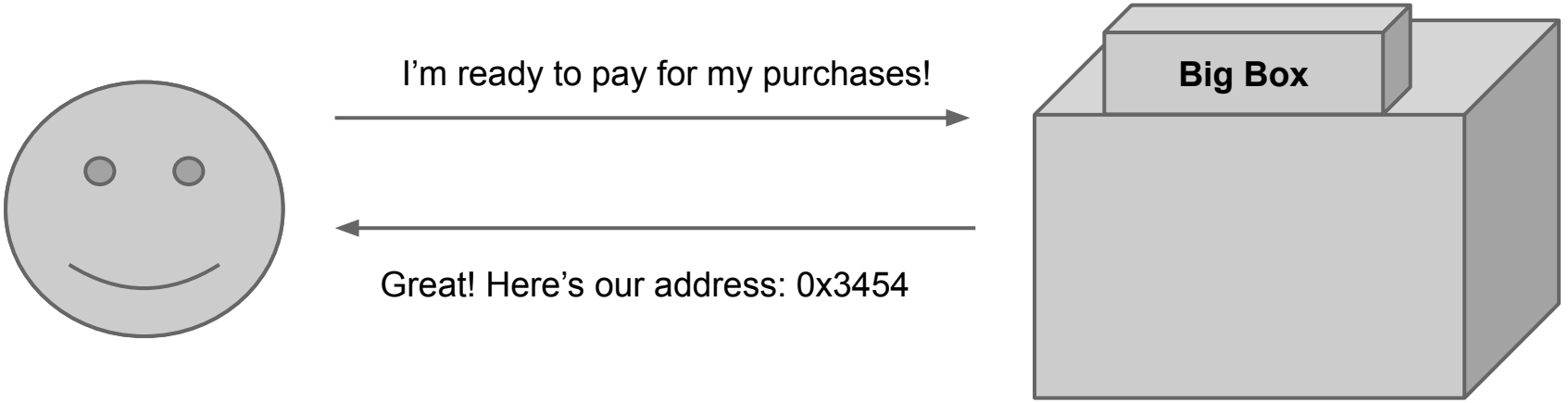


Cool! Well we're using MULTISIG now, so include a script requiring 2 of our 3 account managers to approve. Don't get any of those details wrong. Thanks for shopping at Big Box!

Idea: use the hash of redemption script



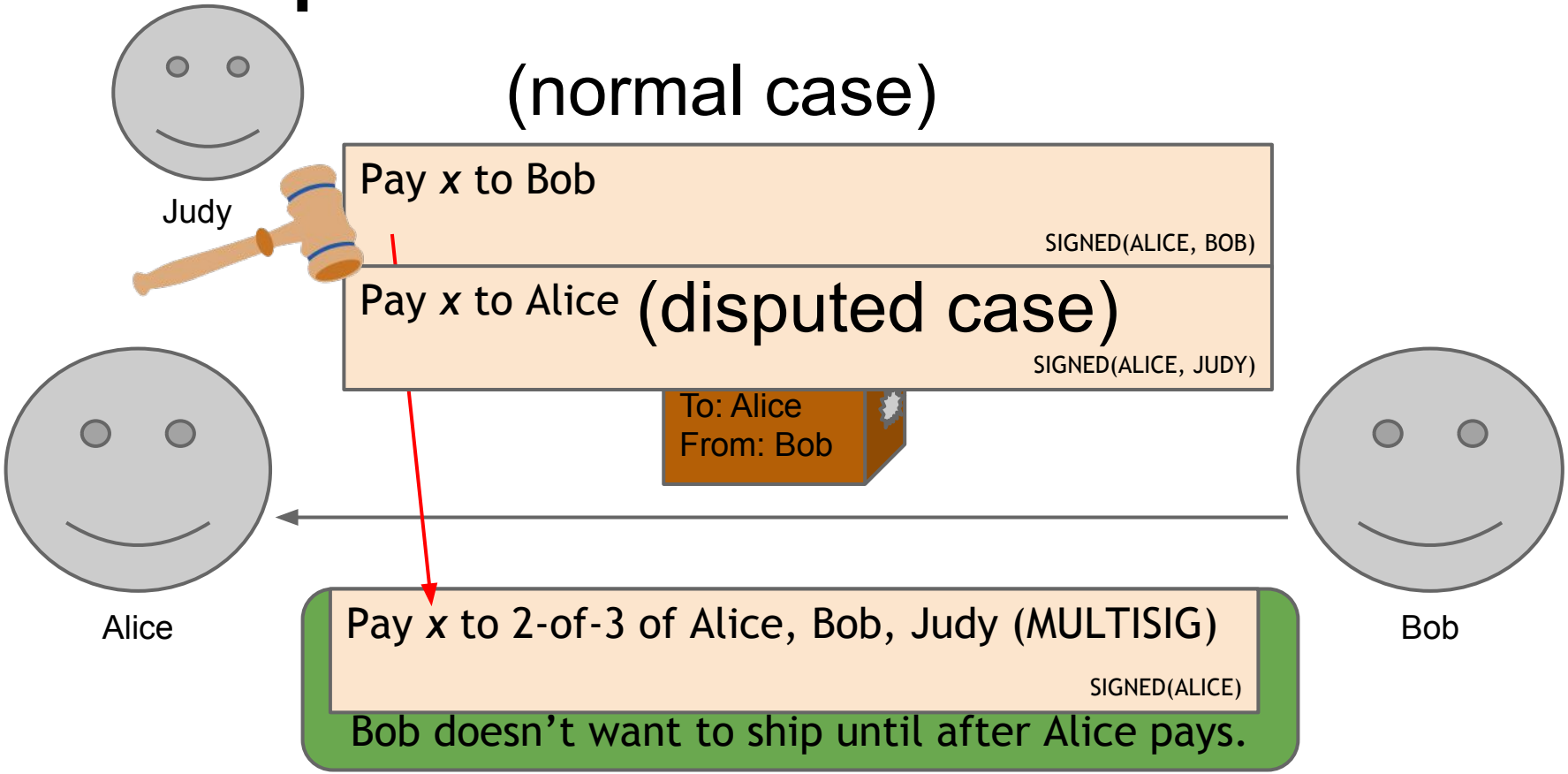
Pay to script hash



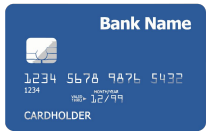
Lecture 3.3:

Applications of Bitcoin scripts

Example 1: Escrow transactions



Example 2: Green addresses

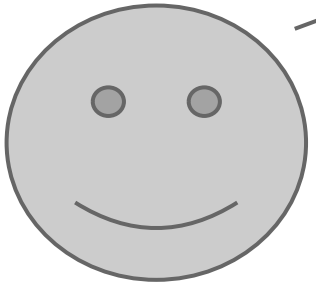


It's me, Alice! Could you make out a green payment to Bob?

Bank

004 days since last double spend!

Faraday cage



Alice

Pay x to Bob, y to Bank

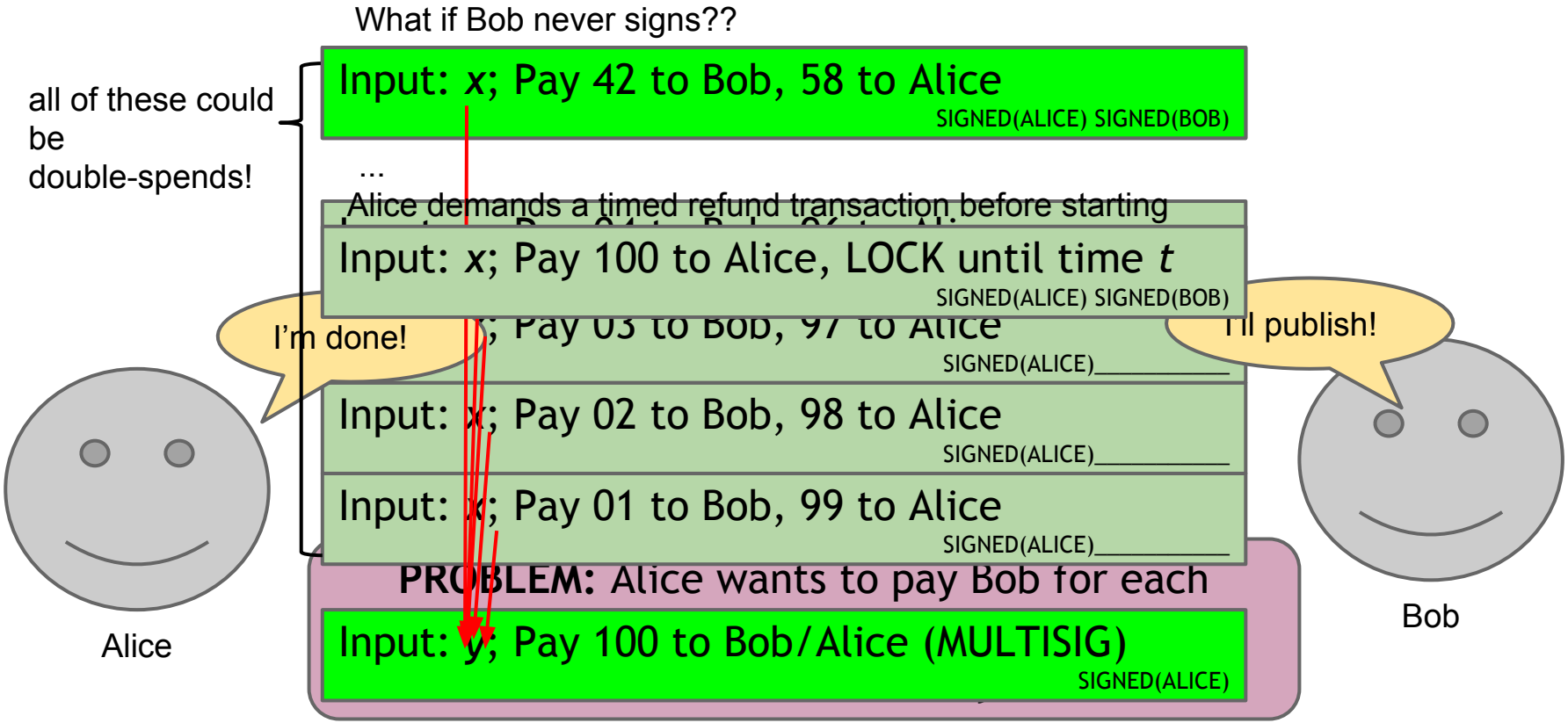
No double spend

SIGNED(BANK)

Bob

PROBLEM: Alice wants to pay Bob.
Bob can't wait 6 verifications to guard against double-spends, or is offline completely.

Example 3: Efficient micro-payments



lock_time


```
{
    "hash":"5a42590...b8b6b",
      "ver":1,
      "vin_sz":2,
      "vout_sz":1,
      "lock_time":315415,
      "size":404,
...
}
```


Block index or real-world timestamp before which this transaction can't be published

More advanced scripts

- Multiplayer lotteries
- Hash pre-image challenges
- Coin-swapping protocols
    - Don’t miss the lecture on anonymity!

“Smart contracts”

Lecture 3.4:

Bitcoin blocks

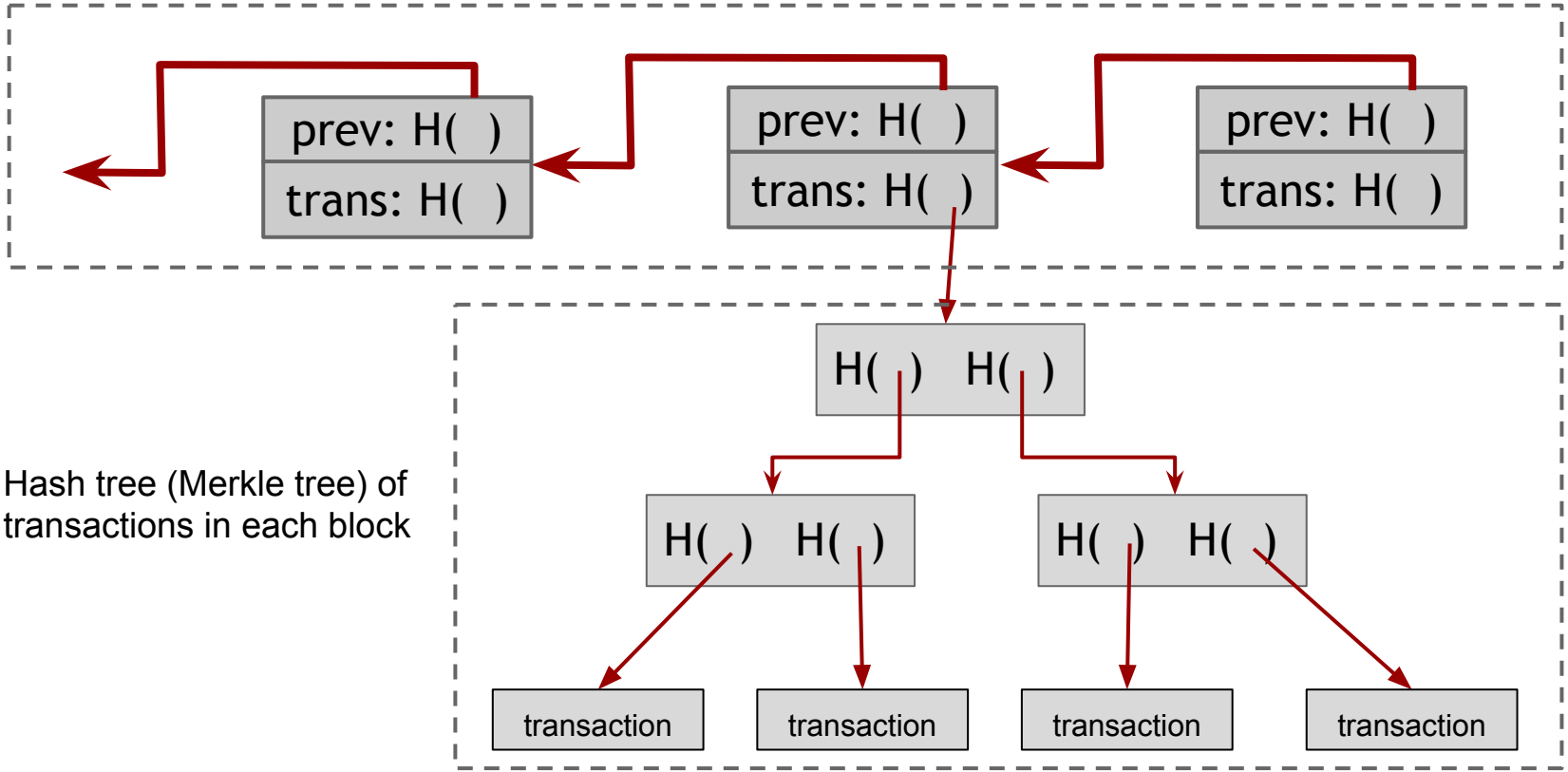
Bitcoin blocks

Why bundle transactions together?

- Single unit of work for miners
- Limit length of hash-chain of blocks
    - Faster to verify history

Bitcoin block structure

Hash chain of blocks



Hash tree (Merkle tree) of transactions in each block

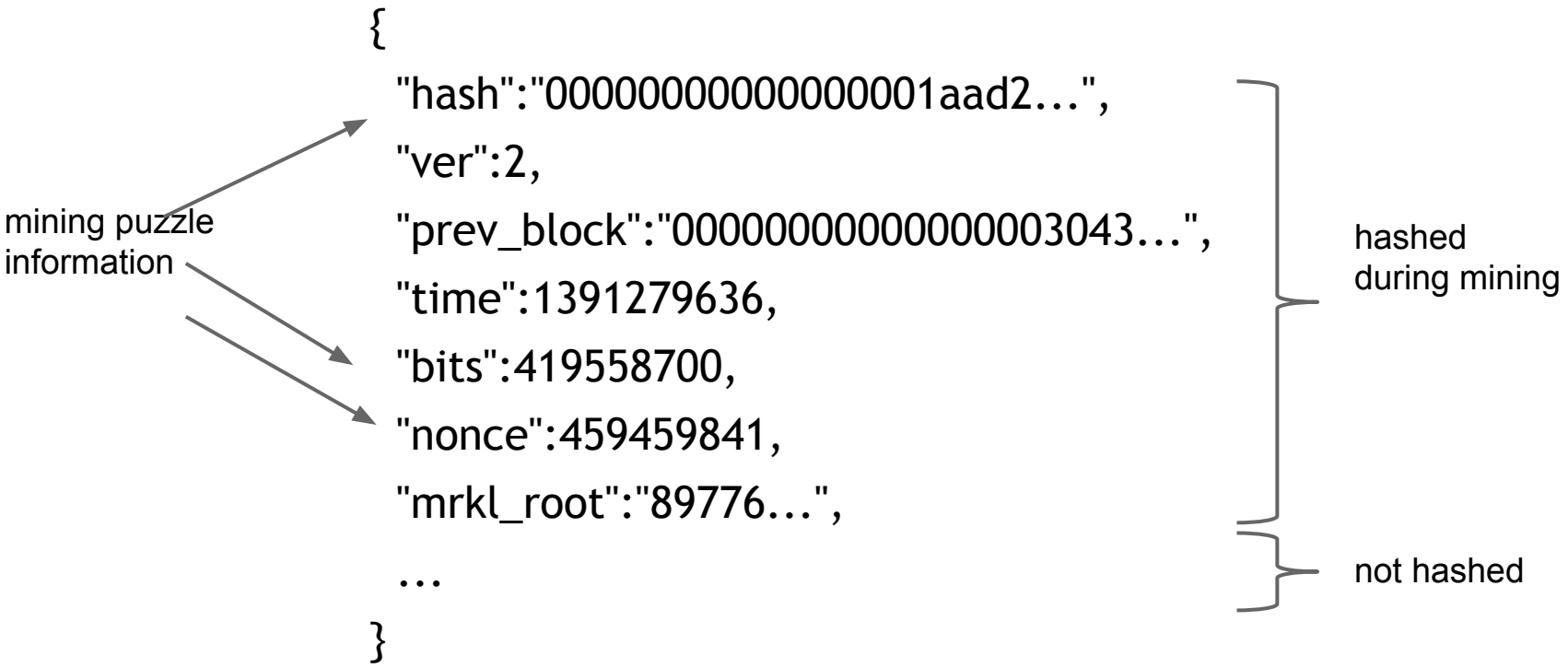
The real deal: a Bitcoin block

block header

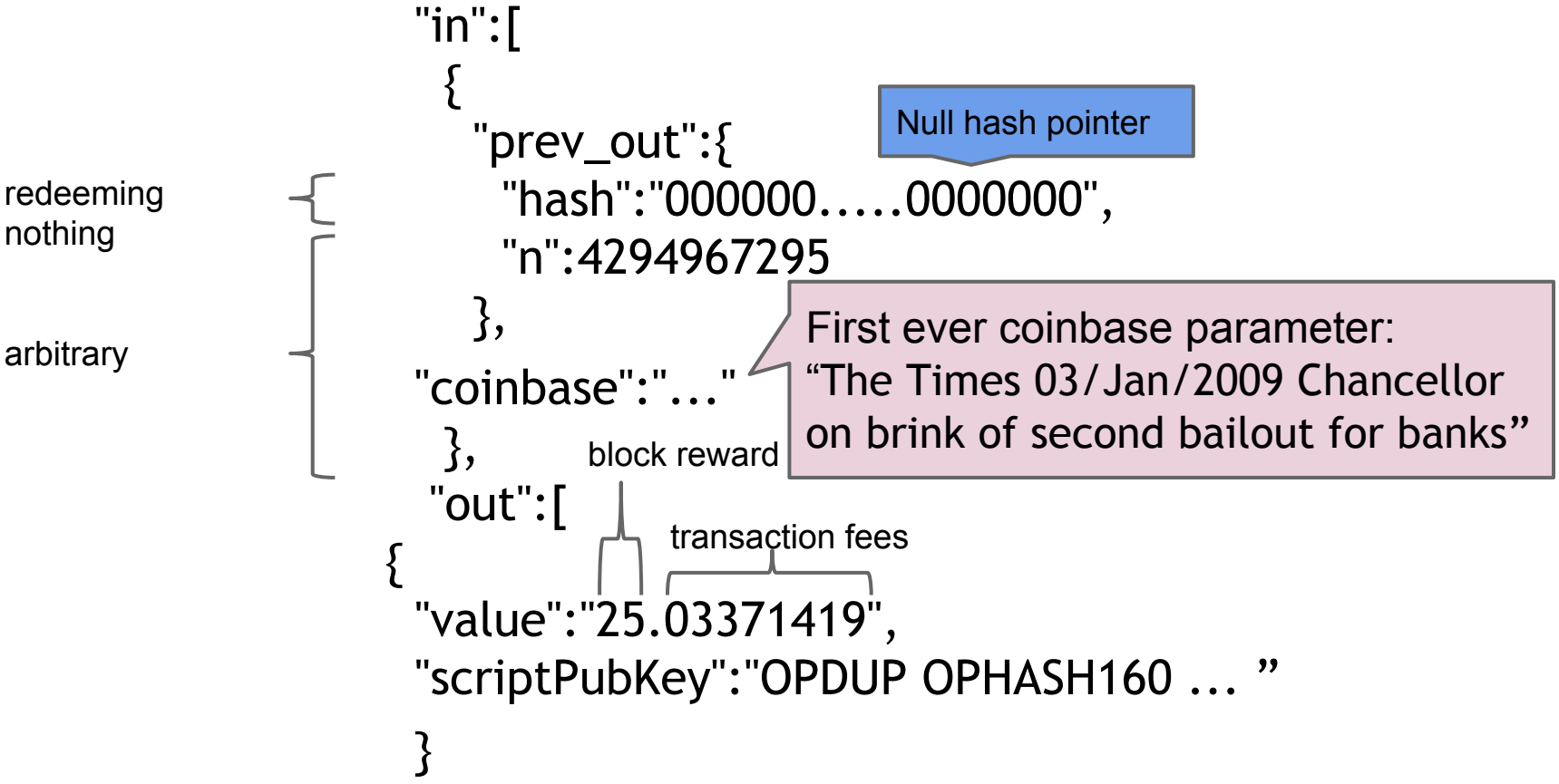
transaction data


```
{
  "hash":"0000000000000001aad2...",
  "ver":2,
  "prev_block":"0000000000000003043...",
  "time":1391279636,
  "bits":419558700,
  "nonce":459459841,
  "mrkl_root":"89776...",
  "n_tx":354,
  "size":181520,
  "tx":[
    ...
  ],
  "mrkl_tree":[
    "6bd5eb25...",
    ...
    "89776cdb..."
  ]
}
```

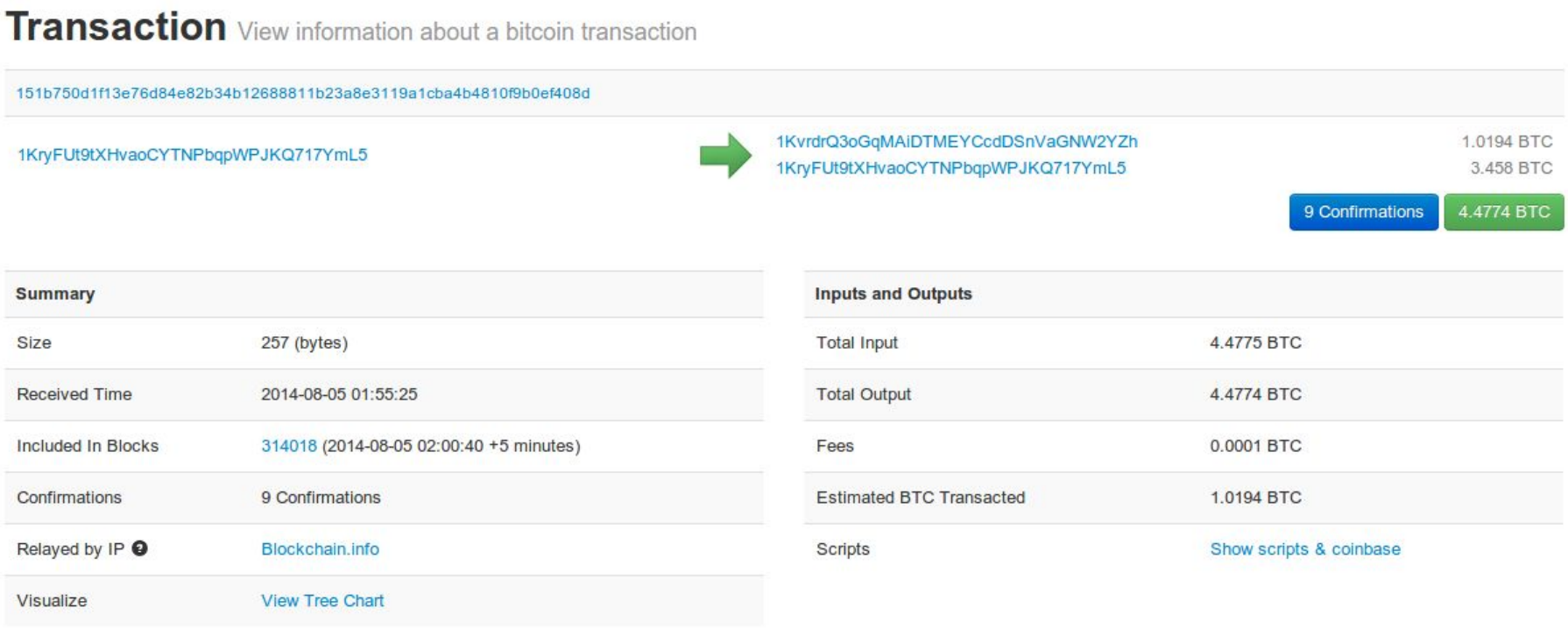
The real deal: a Bitcoin block header



The real deal: coinbase transaction



See for yourself!



Transaction View information about a bitcoin transaction

151b750d1f13e76d84e82b34b12688811b23a8e3119a1cba4b4810f9b0ef408d

1KryFUt9tXHvaoCYTNPbqpWPJKQ717YmL5

1KvrdrQ3oGqMAiDTMEYCcdDSnVaGNW2YZh 1.0194 BTC
1KryFUt9tXHvaoCYTNPbqpWPJKQ717YmL5 3.458 BTC

9 Confirmations 4.4774 BTC

Summary	
Size	257 (bytes)
Received Time	2014-08-05 01:55:25
Included In Blocks	314018 (2014-08-05 02:00:40 +5 minutes)
Confirmations	9 Confirmations
Relayed by IP	Blockchain.info
Visualize	View Tree Chart

Inputs and Outputs	
Total Input	4.4775 BTC
Total Output	4.4774 BTC
Fees	0.0001 BTC
Estimated BTC Transacted	1.0194 BTC
Scripts	Show scripts & coinbase

blockchain.info (and many other sites)

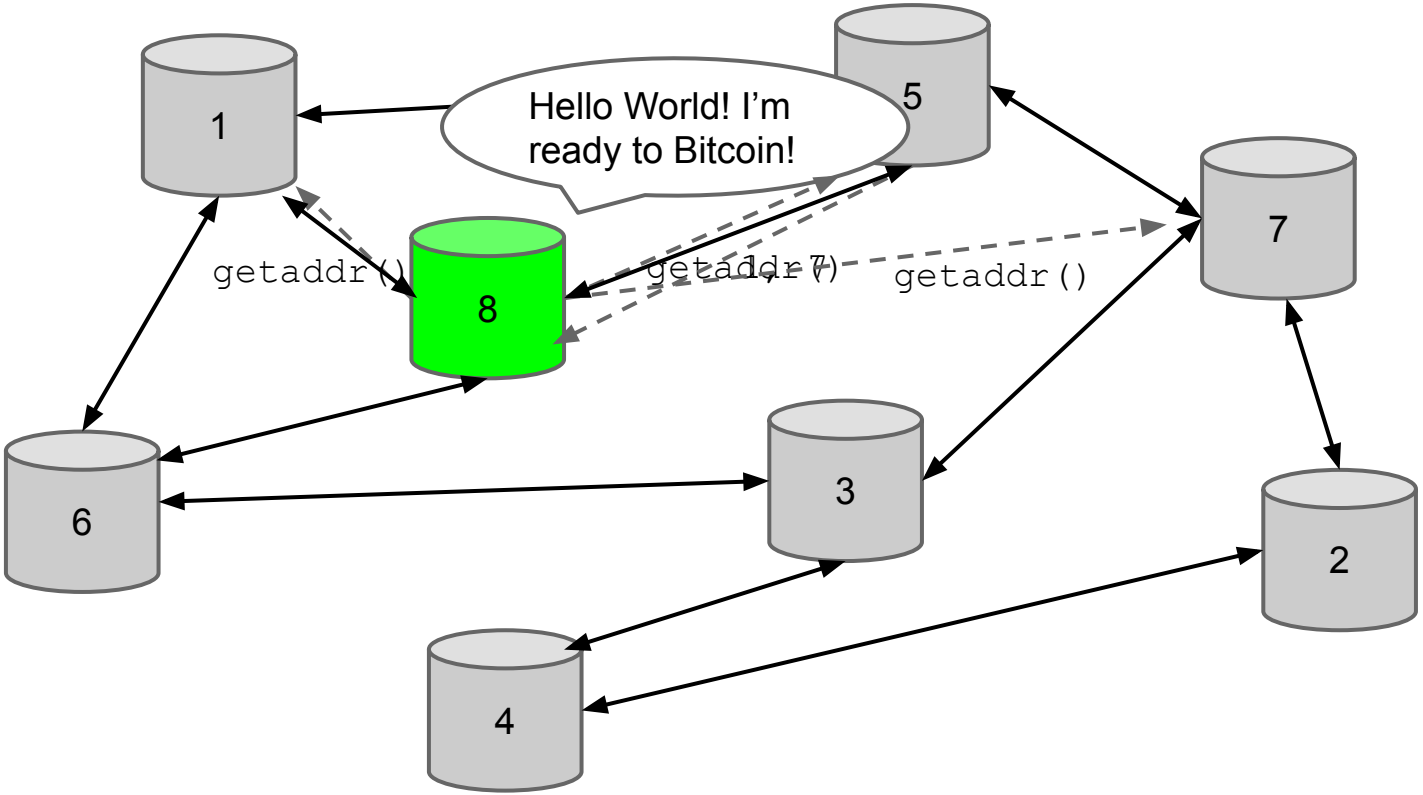
Lecture 3.5:

The Bitcoin network

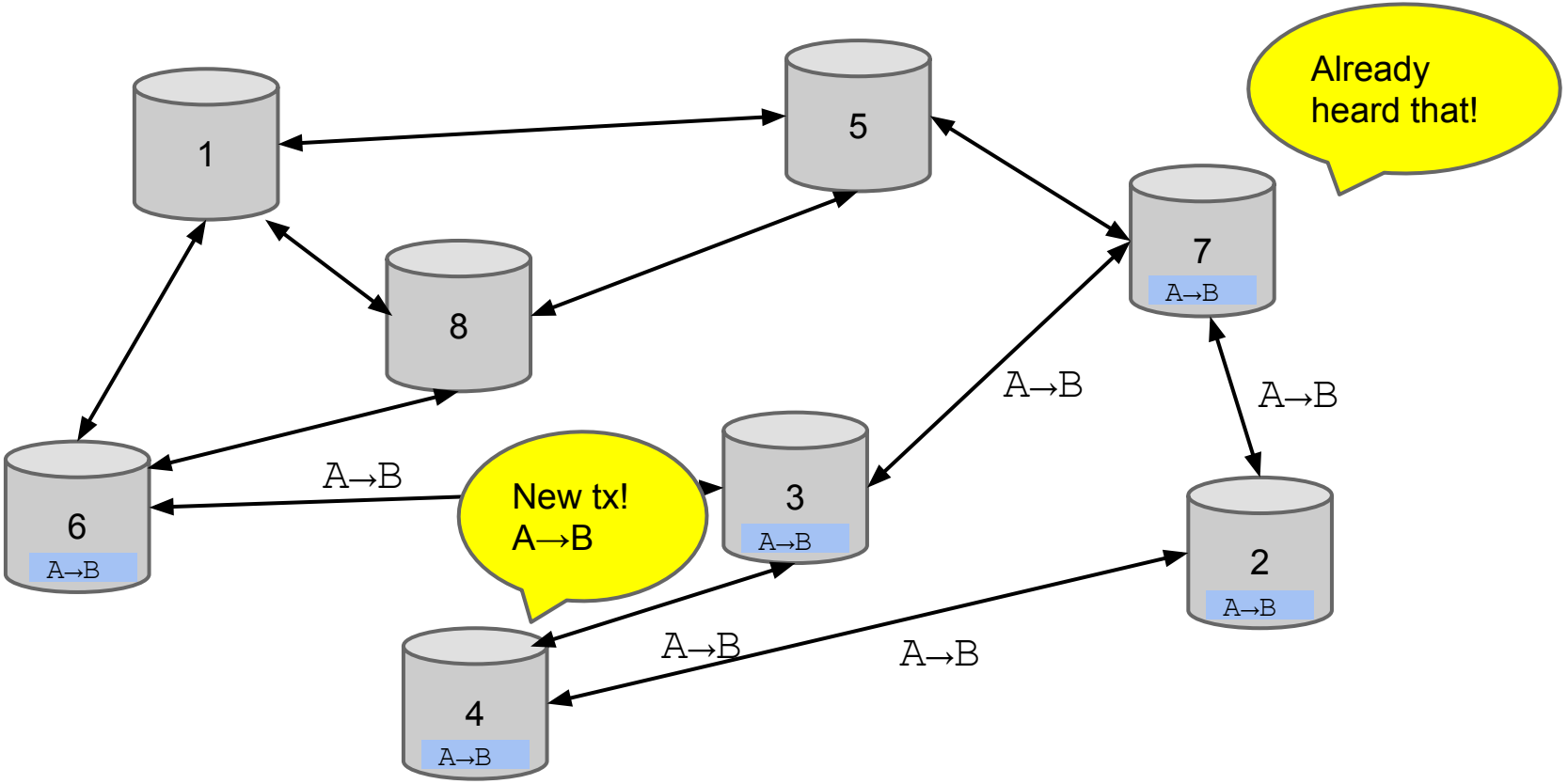
Bitcoin P2P network

- Ad-hoc protocol (runs on TCP port 8333)
- Ad-hoc network with random topology
- All nodes are equal
- New nodes can join at any time
- Forget non-responding nodes after 3 hr

Joining the Bitcoin P2P network

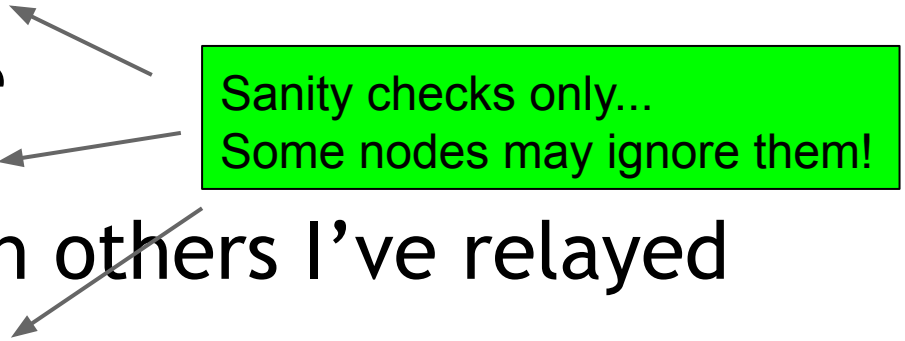


Transaction propagation (flooding)

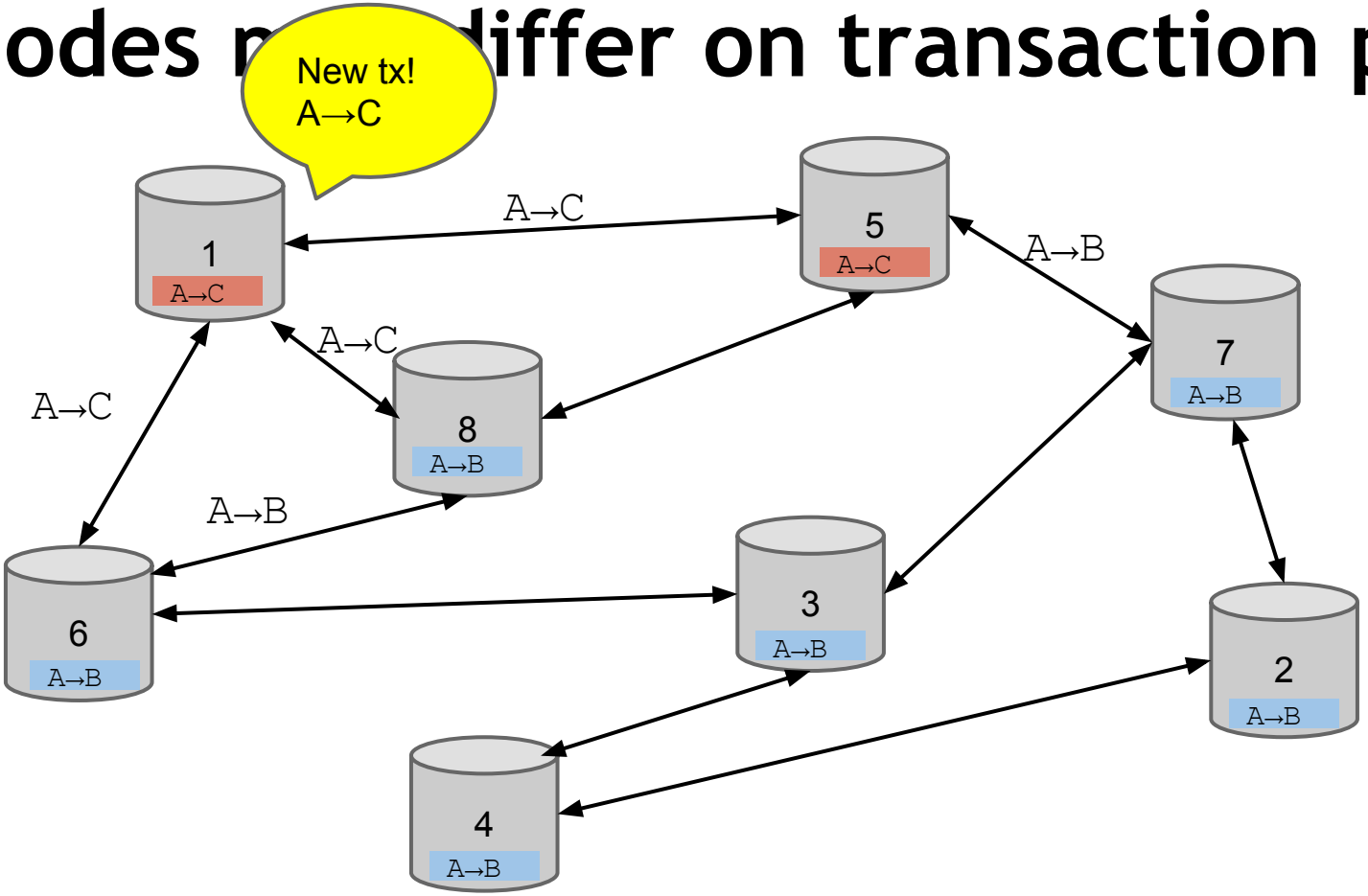


Should I relay a proposed transaction?

- Transaction valid with current block chain
- (default) script matches a whitelist
  - Avoid unusual scripts
- Haven’t seen before
  - Avoid infinite loops
- Doesn’t conflict with others I’ve relayed
  - Avoid double-spends



Nodes may differ on transaction pool



Race conditions

Transactions or blocks may *conflict*

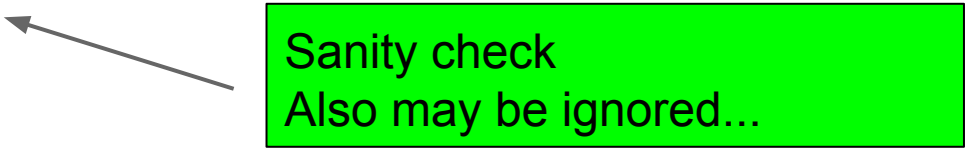
- Default behavior: accept what you hear first
- Network position matters
- Miners may implement other logic!

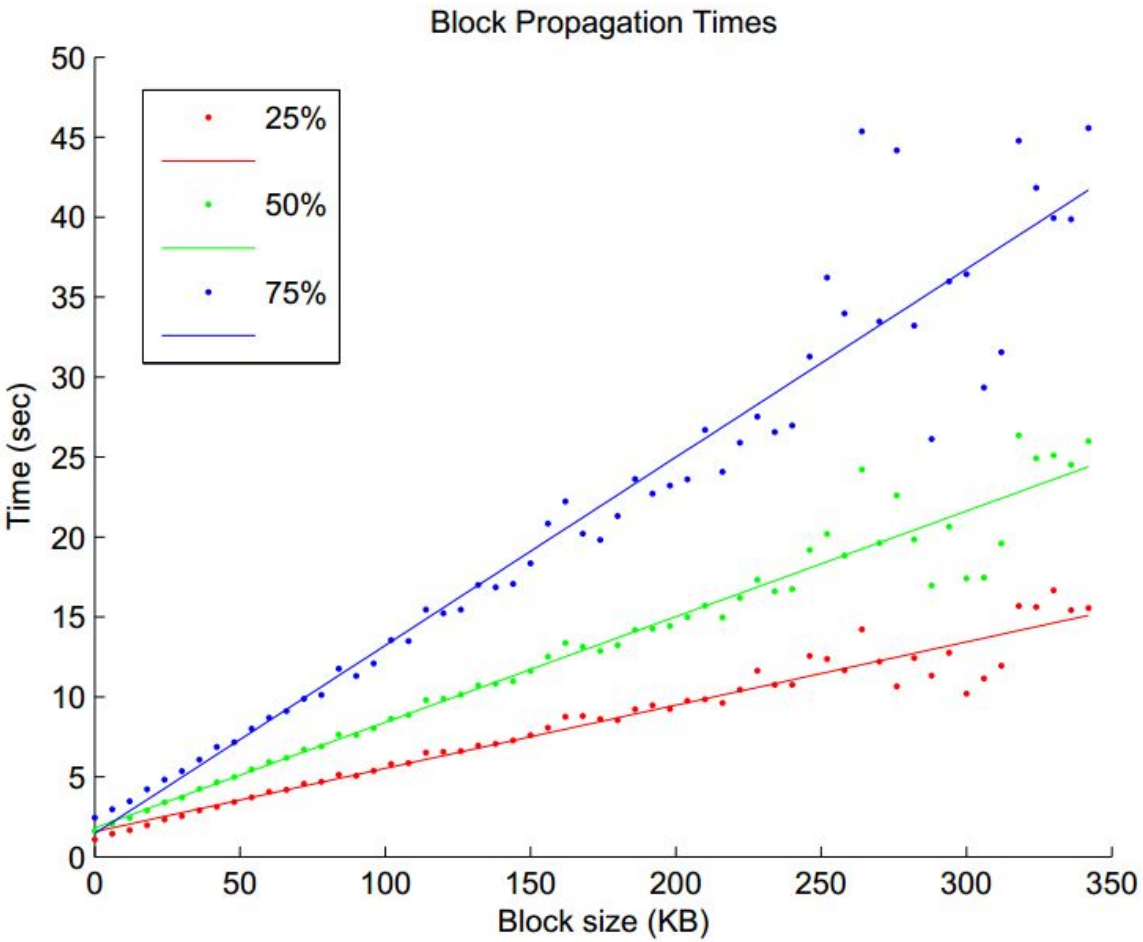
Stay tune for our lecture on mining!

Block propagation nearly identical

Relay a new block when you hear it if:

- Block meets the hash target
- Block has all valid transactions
  - Run *all* scripts, even if you wouldn't relay
- Block builds on current longest chain
  - Avoid forks





Source: Yonatan Sompolinsky and Aviv Zohar: “Accelerating Bitcoin’s Transaction Processing” 2014

How big is the network?

- Impossible to measure exactly
- Estimates-up to 1M IP addresses/month
- Only about 5-10k “full nodes”
    - Permanently connected
    - Fully-validate
- This number may be dropping!

Fully-validating nodes

- Permanently connected
- Store entire block chain
- Hear and forward every node/transaction

Storage costs

Tracking the UTXO set

- **U**nspent **T**ransaction **O**utput
  - Everything else can be stored on disk
- Currently ~12 M UTXOs
  - Out of 44 M transactions
- Can easily fit into RAM

Thin/SPV clients (not fully-validating)

Idea: don’t store everything

- Store block headers only
- Request transactions as needed
  - To verify incoming payment
- Trust fully-validating nodes

1000x cost savings! (20 GB-23MB)

Software diversity

- About 90% of nodes run “Core Bitcoin” (C++)
  - Some are out of date versions
- Other implementations running successfully
  - BitcoinJ (Java)
  - Libbitcoin (C++)
  - btcd (Go)
- “Original Satoshi client”

Lecture 3.6:

Limitations & improvements

Hard-coded limits in Bitcoin

- 10 min. average creation time per block
- 1 M bytes in a block
- 20,000 signature operations per block
- 100 M *satoshis* per bitcoin
- 23M total bitcoins maximum
- 50,25,12.5... bitcoin mining reward

These affect economic balance of power too much to change now

Throughput limits in Bitcoin

- 1 M bytes/block (10 min)
- >250 bytes/transaction
- 7 transactions/sec ☹️

Compare to:

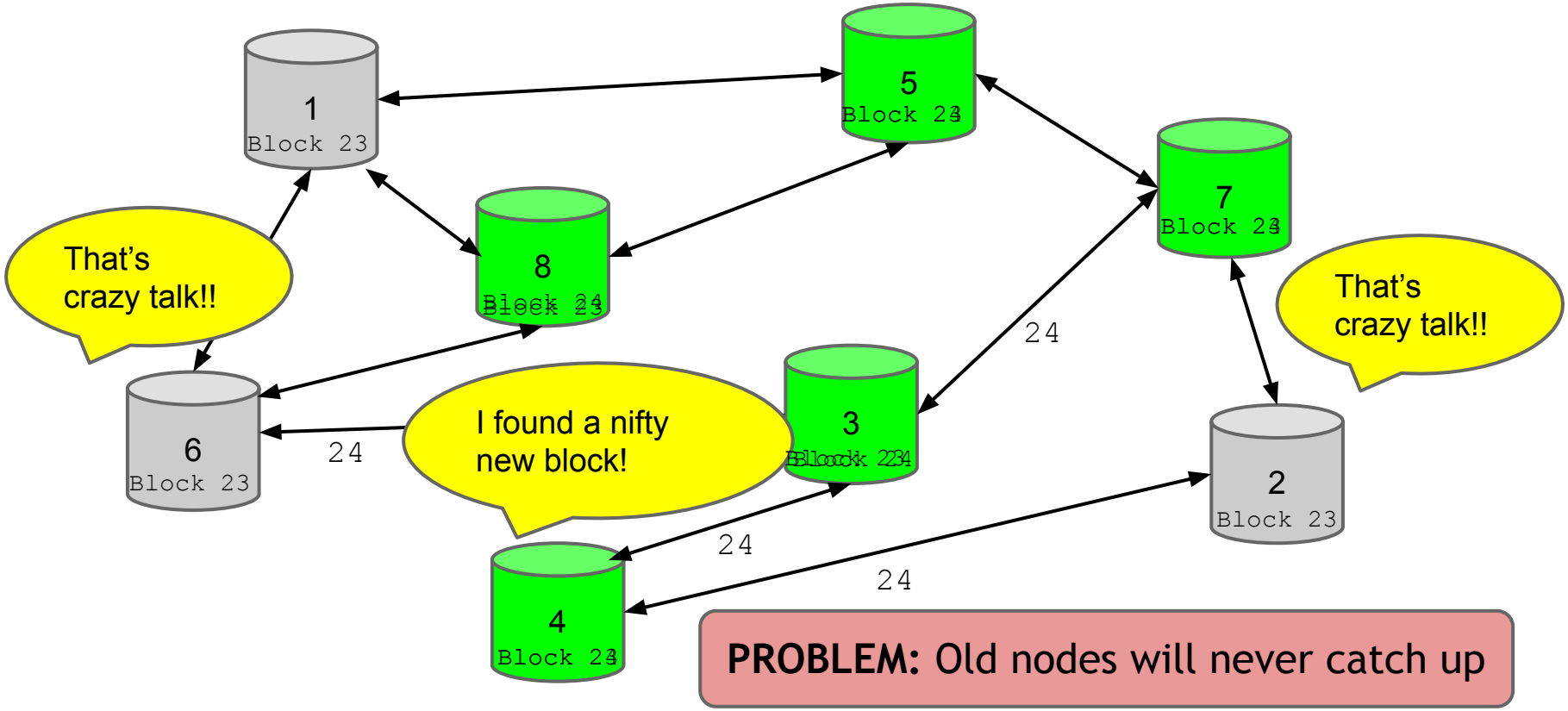
- VISA: 2,000-10,000 transactions/sec
- PayPal: 50-100 transaction/sec

Cryptographic limits in Bitcoin

- Only 1 signature algorithm (ECDSA/P256)
- Hard-coded hash functions

Crypto primitives might break by 2040...

“Hard-forking” changes to Bitcoin



Soft forks

Observation: we can add new features which only *limit* the set of valid transactions

Need majority of nodes to enforce new rules

Old nodes will approve

RISK: Old nodes might mine now-invalid blocks

Soft fork example: pay to script hash

<signature>
<<pubkey> OP_CHECKSIG>

OP_HASH160
<hash of redemption script>
OP_EQUAL

Old nodes will just approve the hash, not run the embedded script

Soft fork possibilities

- New signature schemes
- Extra per-block metadata
  - Shove in the coinbase parameter
  - Commit to UTXO tree in each block

Hard forks

- New op codes
- Changes to size limits
- Changes to mining rate
- Many small bug fixes

Currently seem very unlikely to happen

Stay tuned for our lecture on altcoins!

In the next lecture...

Human beings aren’t Bitcoin nodes

- How do people interact with the network?
- How do people exchange bitcoins for cash?
- How do people securely store bitcoins?

Currency needs to work for people, not nodes