18734: Foundations of Privacy

Bitcoin

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Part I: Reconstructing Bitcoin

Goal

- A rational reconstruction of Bitcoin

1. Start with straw man design
2. Identify weaknesses
3. Augment design and iterate

Step 1: A signed letter of intent

- Alice: "I, Alice, am giving Bob one coin"
- Alice digitally signs message and announces bits to everyone.
- Properties
  - Establishment of Alice's intent
  - Limited protection from forgery
- Weakness
  - Coins are not unique; can be duplicated

Step 2: Unique serial nos. on coins

- Alice: "I, Alice, am giving Bob one coin, with serial number 8740348"
- Alice: "I, Alice, am giving Bob one coin, with serial number 8770431"
- Bank issues coins with unique serial numbers, keeps track of who owns coins, verifies transactions

- Properties
  - Establishment of Alice's intent
  - Better protection from forgery
- Weaknesses
  - Need trusted bank to issue coins, keep track of who owns coins, verify transactions
  - Bank can link transactions to identity

Possible design

- E-cash lecture on Nov 18
  - Retain bank
  - Ensure that bank cannot link transactions to identity
  - Agents cannot double spend their electronic coins
- Key novelty in Bitcoin design
  - No centralized bank

Step 3: Making *everyone* the bank

- Everyone maintains a copy of the public ledger (block chain) of transactions (keeps track of who owns coins)
- Alice: "I, Alice, am giving Bob one coin, with serial number 8740348"
- Bob uses his copy of the block chain to check that the coin is Alice's; he broadcasts both Alice's message and his acceptance of the transaction to the entire network, and everyone updates their copy of the block chain.

- Weaknesses
  - How to get serial numbers?
  - Double-spending: What if Alice gives the same coin to Bob and Charlie at the same time?

A Network Verification Design

- Bob does not verify Alice's coin by himself.
- Asks everyone on the network to verify
- When "enough" people confirm that the coin is indeed Alice's, Bob accepts and everyone updates their block chain

- Weakness:
  - Sybil attack: Alice creates many fake agents who lie for her; Alice spends the same coin many times

Step 4: Proof-of-work

- Computationally costly for network users to validate transactions
- Reward network users for validating transactions

- Properties
  - Sybil attack won't work unless dishonest agents put in significant computational resources
  - Verifiers rewarded with fixed number of bitcoins for a batch of transactions (details soon)
  - Additional ideas to ensure that ledger succinctly maintains history of all transactions (details soon)

Part II: Overview

Bitcoin primer (1/2)

- A peer-to-peer digital payment system
- Completely decentralized digital currency 
  - **No central mint** to produce currency
  - **No central bank** to verify transactions
  - Once confirmed, transactions are **irreversible**
  - Predictable, capped, currency supply
- Key innovation in Bitcoin: coin production and verification is done by **network consensus**

Bitcoin primer (2/2)

- **There is actually no notion of a "coin"**

- Bitcoins are exchanged from "wallet" to "wallet"
- **Transactions** are at the heart of the protocol
- Wallets are represented by **addresses** (e.g., *1VayNert*…)
  - (An address is the public key of the wallet)

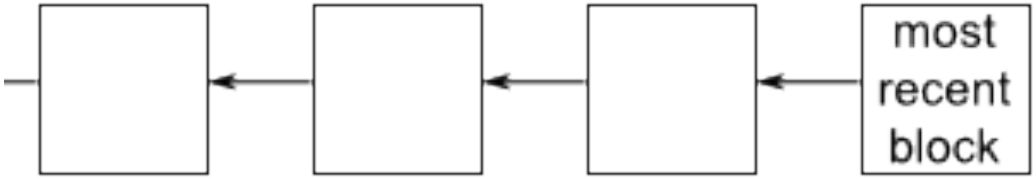
Bitcoin transactions

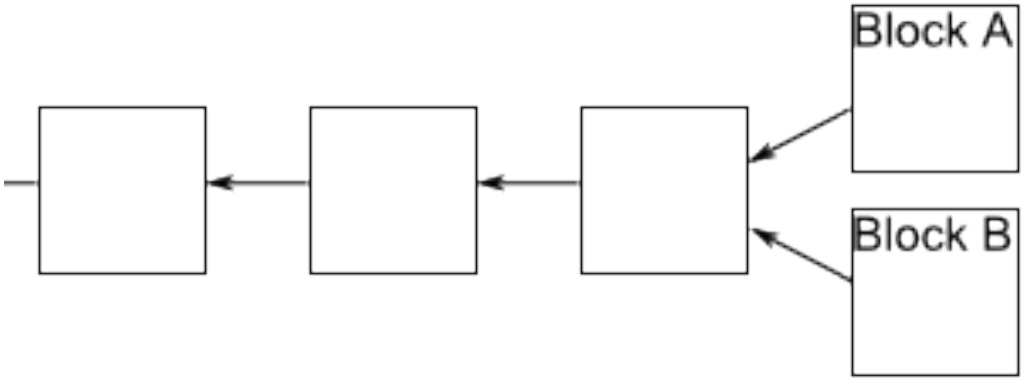
- Alice wants to send 1 BTC to Bob
  - She picks a transaction (or a group of transactions) that she has previously been the recipient of and that cumulatively contain at least 1 BTC
  - She then appends Bob's wallet address to the transaction and digitally signs it
- When Bob subsequently wants to spend the 1 BTC, all he has to do is to repeat the operation

Preventing double-spending

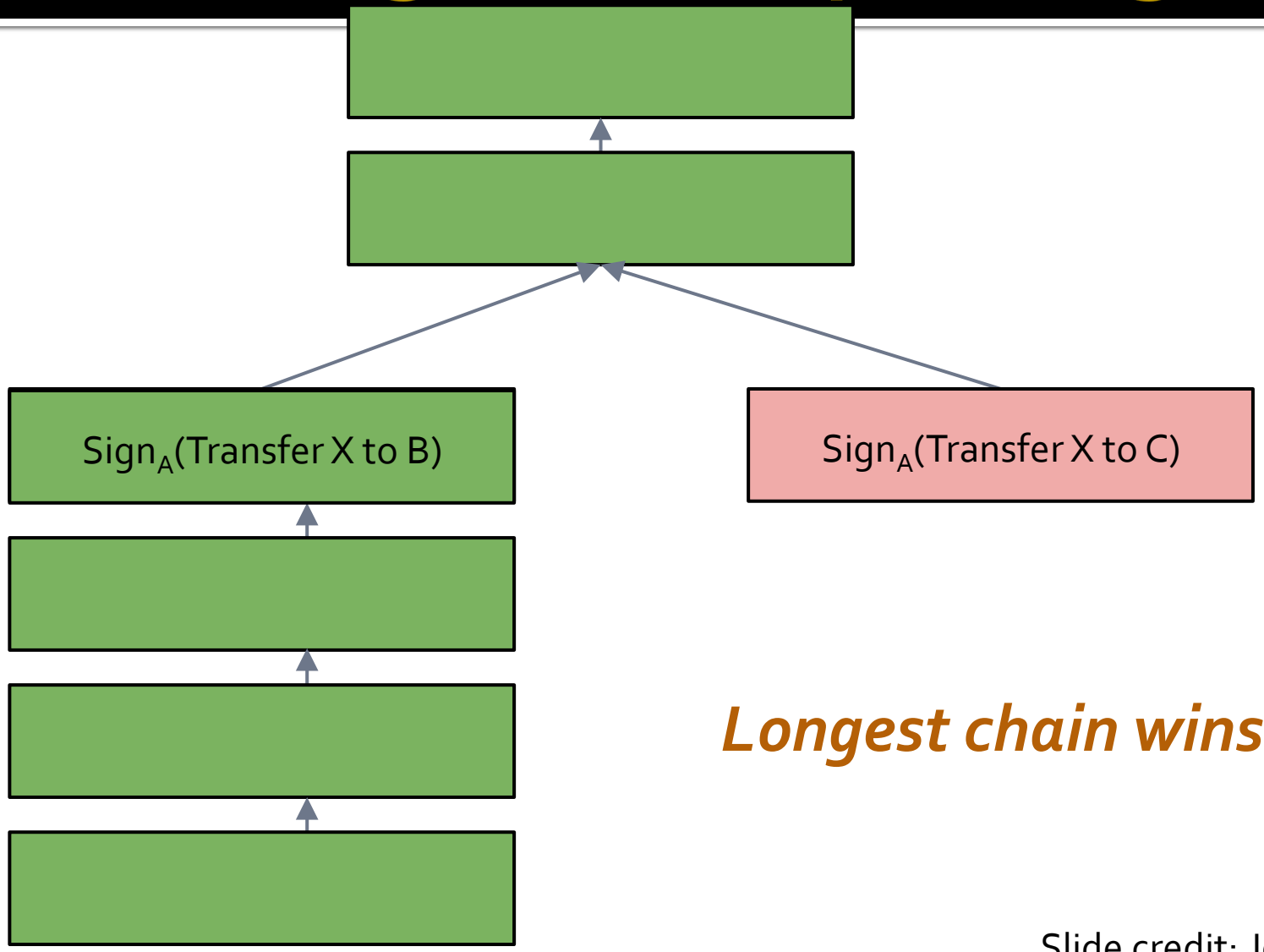
- Bob now has 1 BTC
  - He wants to send it to Charlie…
  - … while keeping it for himself at the same time
- To prevent this Bob (and Alice before him) **has to broadcast** the transaction to everybody in the Bitcoin network
- Then other peers can verify that the transaction is not a double-spend
- Once this is done, the transaction is **embedded forever in a public ledger**

The Block Chain of Transactions





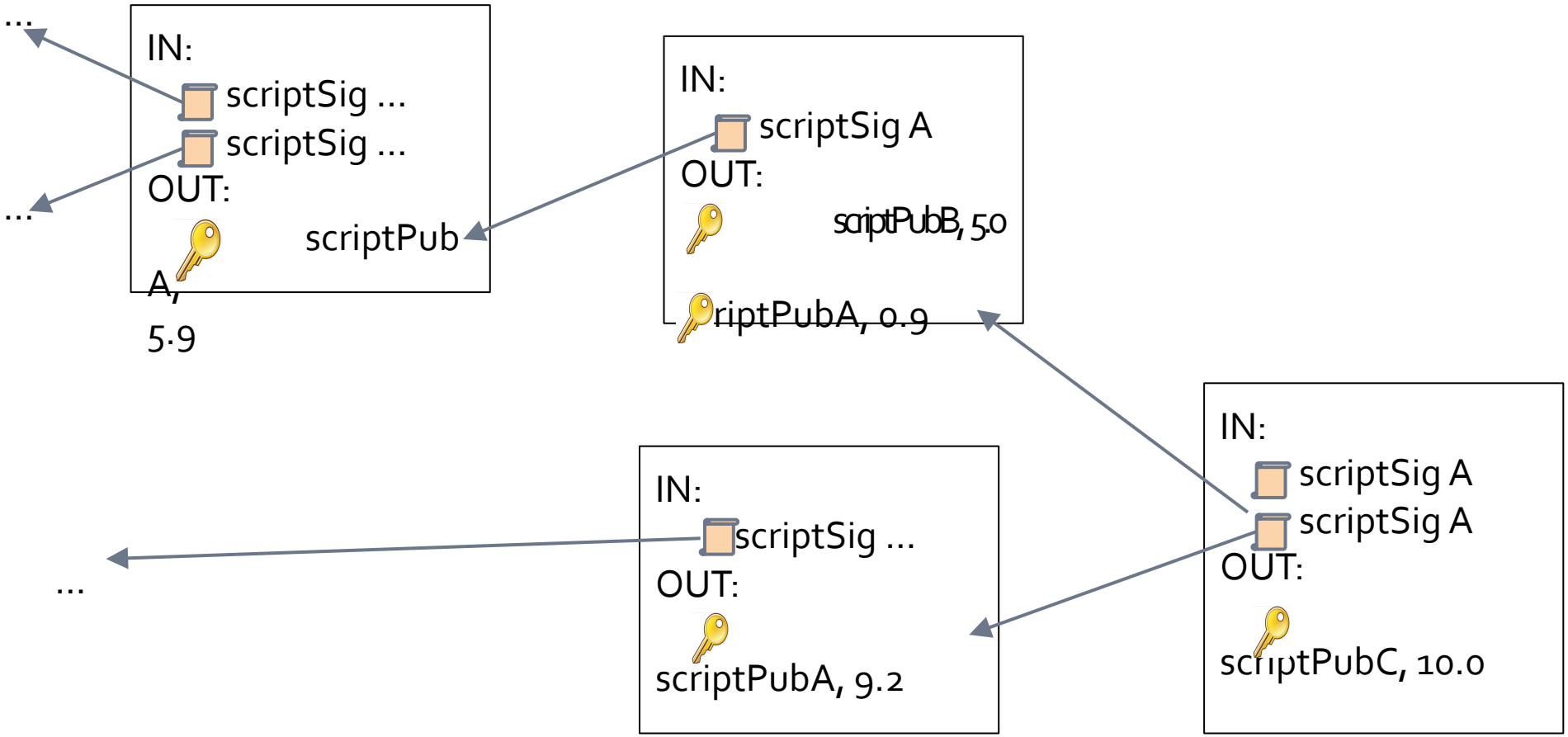
Preventing double spending



Longest chain wins

Slide credit: Joe Bonneau

Bitcoin is *transaction-based*



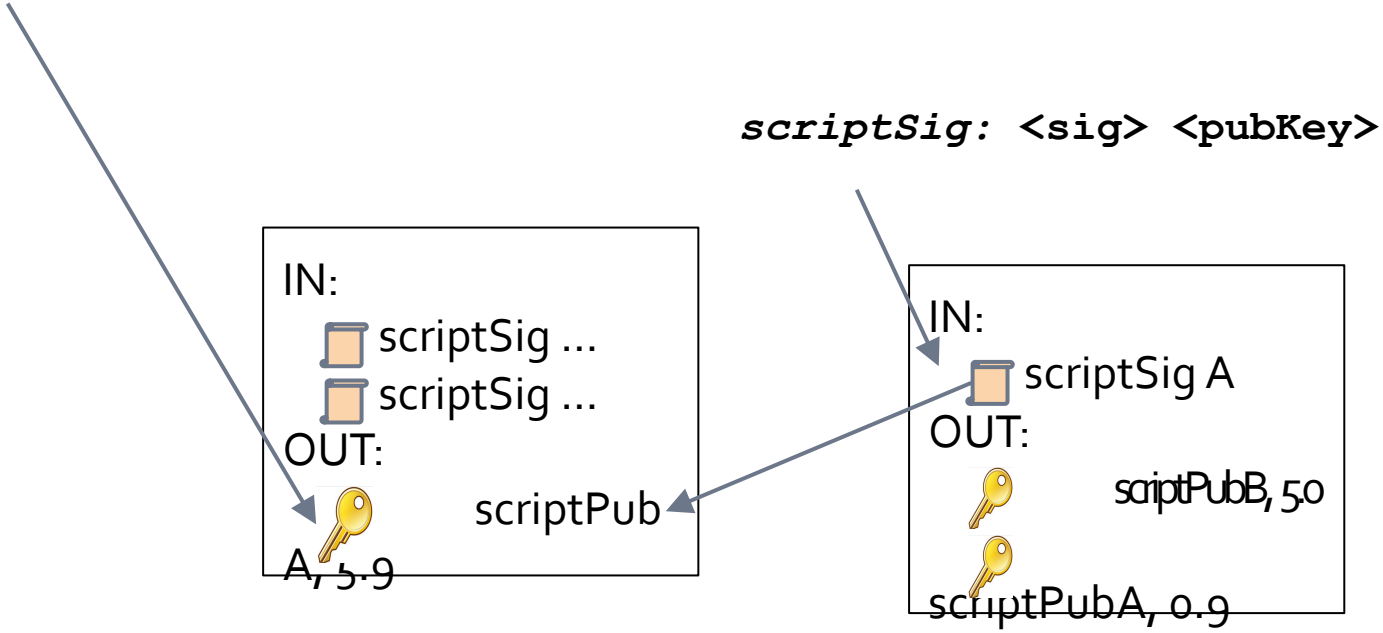
Slide credit: Joe Bonneau

A Bitcoin Transaction

```
1.  {"hash":"7c4025...",          //serial number: hash of transaction
2.  "ver":1,                      // protocol version
3.   "vin_sz":1,                  // no.of inputs
4.  "vout_sz":1,                  // no.of outputs
5.  "lock_time":0,                // transaction finalized after time
6.  "size":224,                   // no. of bytes in transaction
7.  "in":[                        // input of transaction 7-11
8.  {"prev_out":                  // input is an output of a previous transact.
9.  {"hash":"2007ae...",          // serial number of previous transact.
10. "n":0},                       // output number of previous transact.
11. "scriptSig":"304502... 042b2d..."}], // signature and pub key of sender
12. "out":[                       // output of transaction 12-14
13. {"value":"0.31900000",        // outputs 0.319 BTC
14. "scriptPubKey":"OP_DUP OP_HASH160 a7db6f OP_EQUALVERIFY
    OP_CHECKSIG"}]}               // script for verifying transaction
```

Bitcoin transactions specify *scripts*

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

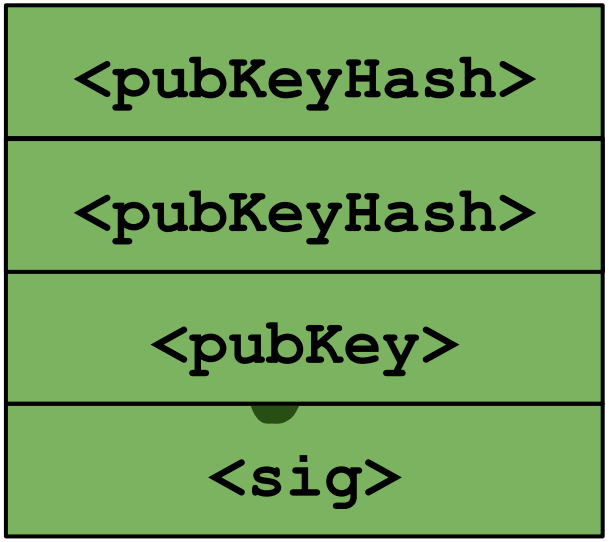


Redemption script:

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

Slide credit: Joe Bonneau

Bitcoin transactions specify *scripts*



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

Slide credit: Joe Bonneau

Bitcoin script features

https://en.bitcoin.it/wiki/Script

Part III: Mining Bitcoin

Coin production

- Coin production is embedded in the verification process
- Verifiers ("miners") verify batches of transactions at once
  - In exchange for which they are allowed to add a "creation" transaction to the batch and give themselves a fixed amount of money
    - 50 BTC originally, 25 BTC now, divided by two every so often
  - Verification is combined with a "proof-of-work" scheme to ensure
    - That transactions have proper timestamping
    - That currency production is rate-limited

More on mining incentives

- Miners solve a cryptographic puzzle:
  Find x s.t. H(x||l) < y where l is the batch of transactions.

- There is no good algorithm to solve this (H is a cryptographically secure hash function)
  - **Brute-force:** try $x=0$, $x=1$, $x=2$, $x=\ldots$
  - The lower y, the harder the puzzle

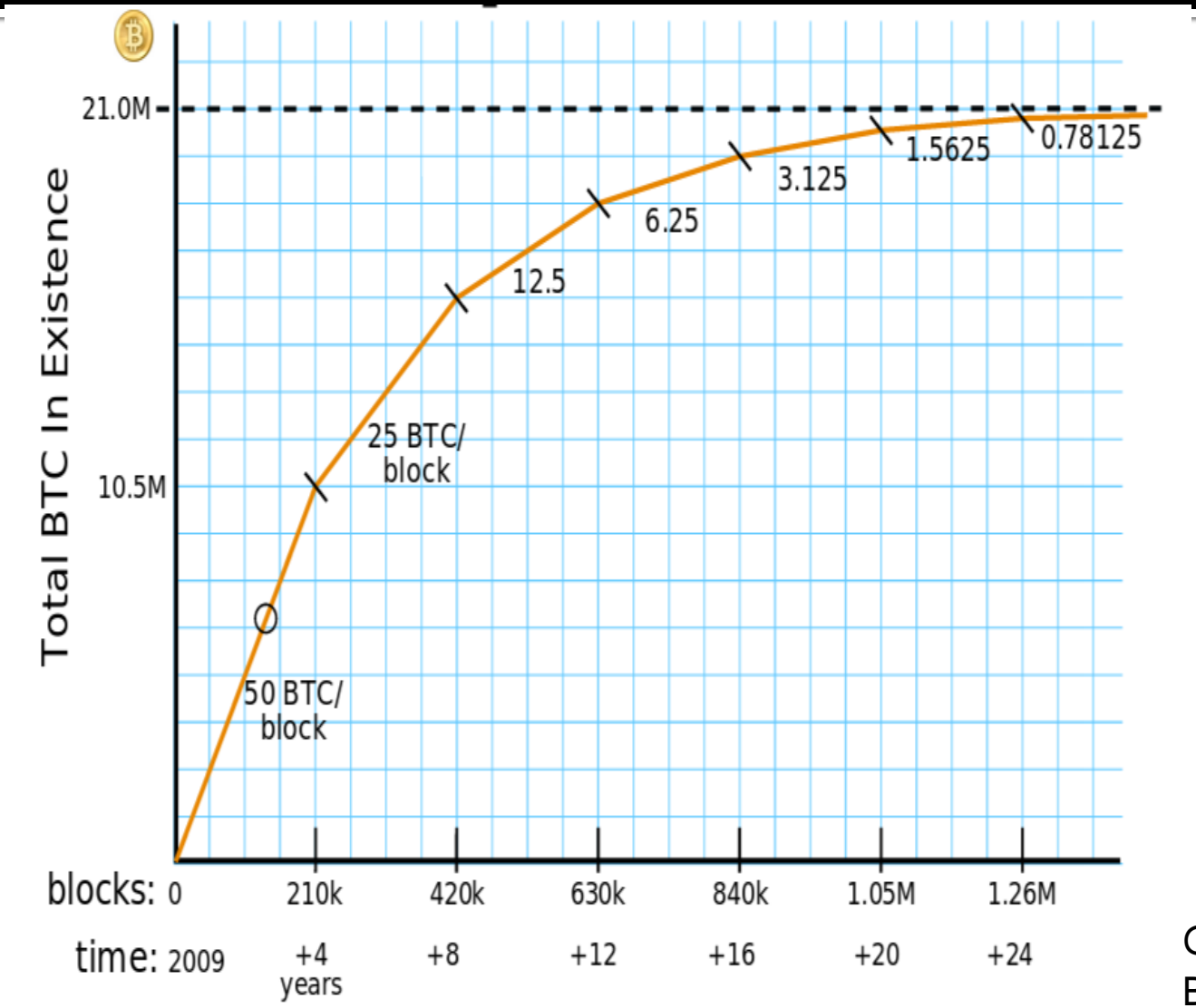
- Difficulty is tunable and is (by edict) designed to be inversely proportional to the total computational power of the network

- The goal is to have one block every ten minutes
  - Predictable supply of currency (independent of the difficulty)
  - **But this limits how quickly transactions can be verified**
    - At least 10 minutes, usually 60 minutes is recommended

Transaction fees

- In addition to the bonus they get for mining, miners get "transaction fees"
  - Leftover "change" voluntarily left in transactions
- Because the bonus is decreasing over time, the expectation is that transaction fees will increase over time to make up for lost mining revenue

Mining rewards



Courtesy:
Brian Warner

Total network capacity

- 2^{64} hashes per block (every 10 minutes!)
- 2^{75} hashes in 2013
  - In exchange for ~**US$250M**
- Consuming > **100 MW**

Slide credit: Joe Bonneau

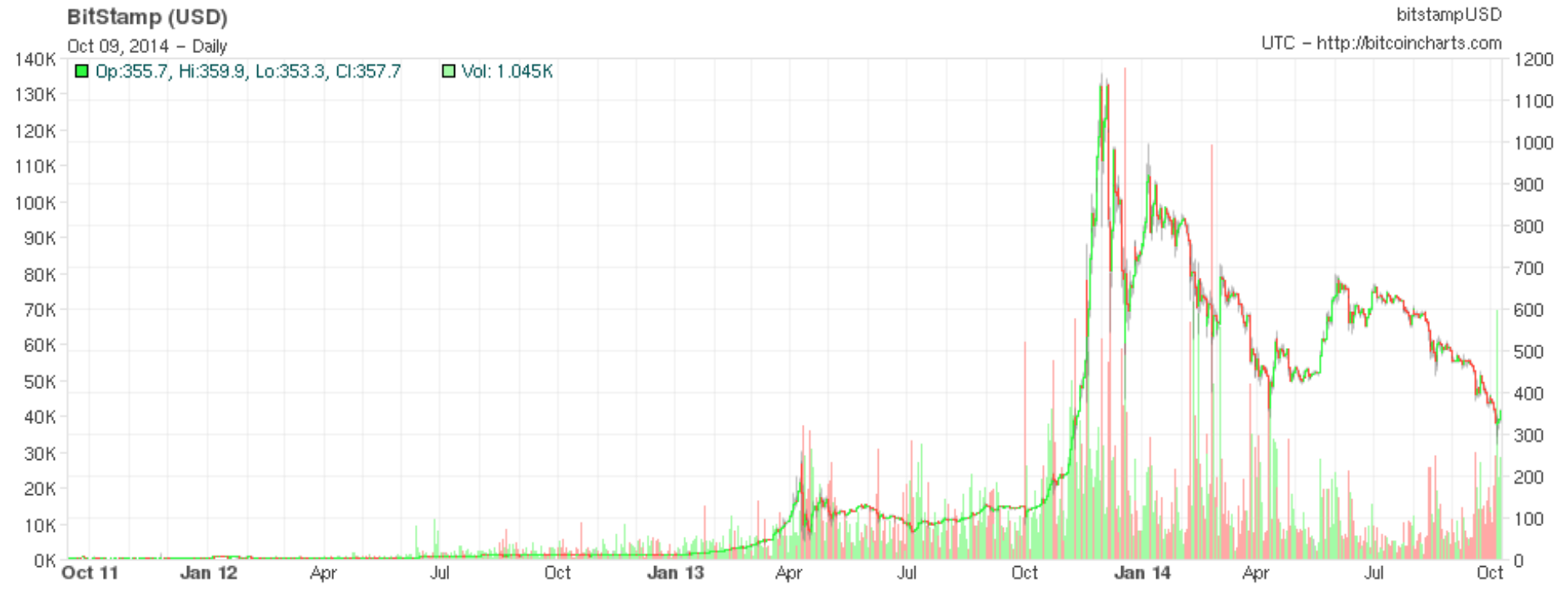
Part IV: Using Bitcoin

Getting Bitcoin

- Become a miner
  - Nowadays only profitable if dedicated (ASIC) hardware
- Buy at an exchange
  - CampBX, Bitstamp, BTC-e, Coinbase…
  - (Mt.Gox before they went bankrupt)
  - Very **high concentration** on exchanges through which money is exchanged
    - Exchanges fail pretty often…
  - Increasingly scrutinized by regulators
- Buy from individuals
  - Satoshi Square in NYC

Main Bitcoin uses

- As a speculative instrument
  - People invest in BTC, betting on its rising value
  - Dominant use thus far



Main Bitcoin uses

- As a currency
  - Only currency accepted on underground marketplaces (Silk Road, Evolution,…)
    - (Except for LiteCoin, which is a clone of Bitcoin)
    - Because of its "anonymity properties"
    - Still relatively modest
      - Entire Silk Road revenue represented in 1st half of 2012 about $15M/ annum
  - Gambling, poker sites
    - Large number of transactions, volume not very high
  - Other uses still in their infancy
    - Campaign contributions, online stores (e.g., Overstock), etc

Part V: Anonymity?

Pseudonymity vs anonymity

- Wallets are public/private key pairs
  - Can create as many as you want
  - Think of them as zero-cost pseudonyms
- There is no central authority issuing Bitcoins or vetting transactions
- This means Bitcoin is anonymous, right?

NO!

Bitcoin tracing

- Anonymity here implies **unlinkability** of transactions
- The **entire** ledger of **all transactions** is available, **forever**
  - Technically in a compressed form, but transaction chains can all be reconstructed
- Even if you add intermediary dummy steps wallets, linking the source and the destination of a transaction may be done by graph analysis…
  - Something that computer scientists know how to do!
    - Reid & Harrigan, 2011
    - Shamir & Ron, 2012
    - Meiklejohn et al., 2013
- Families of wallets can be pooled together as belonging to the same actual user…
- …and if somehow you can get the user's identity, the game is over

Anonymizing Bitcoin

- Mixers

- Did Alice give 10 BTC to Charles or Daisy?

Anonymizing Bitcoin

- Mixers in practice

- Need to also introduce arbitrary delays
- Introduction of change addresses, etc
- Mixer can be dishonest!

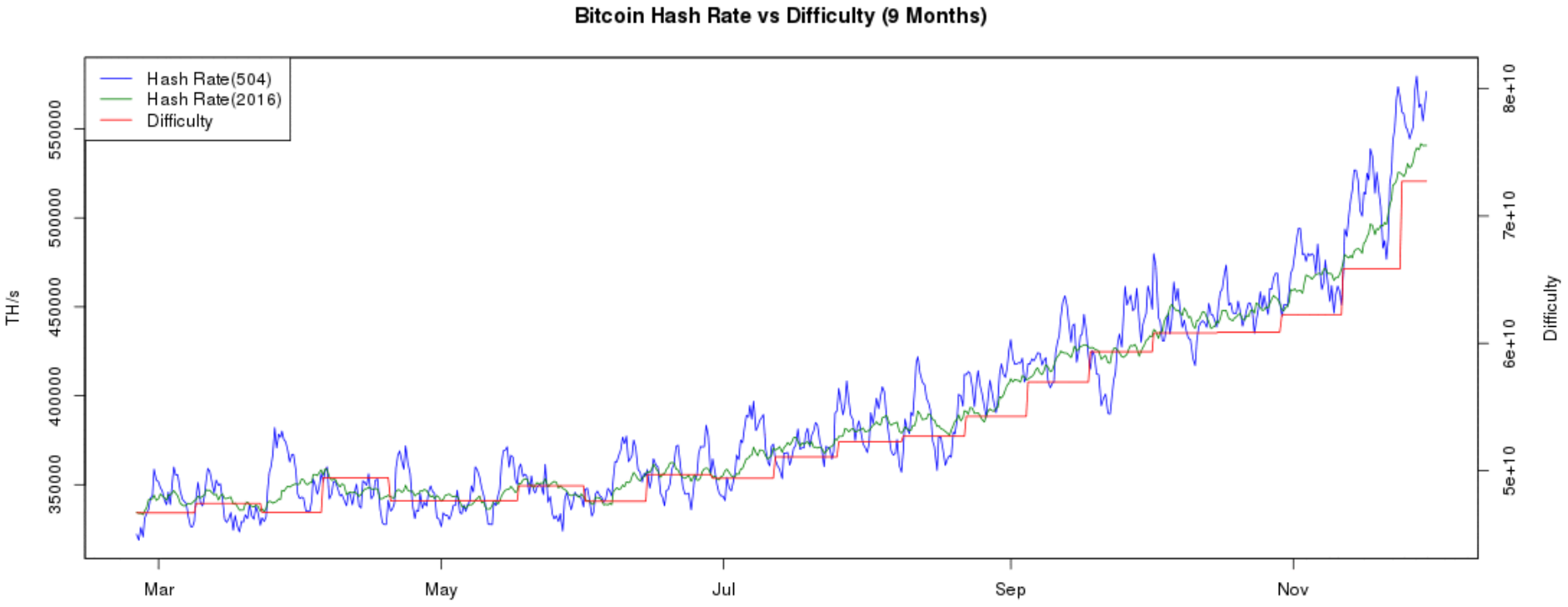
Anonymizing Bitcoin

- It's unclear how good existing Bitcoin mixers are
  - Key difference with message mixing (Tor, mixnets)
    - You can't implement arbitrary "padding" – money has to go somewhere eventually
  - Possible measure: taint
    - Amount of money that can be traced back to a given source
  - Recent research suggests existing mixers are not effective or downright dishonest

Acknowledgment

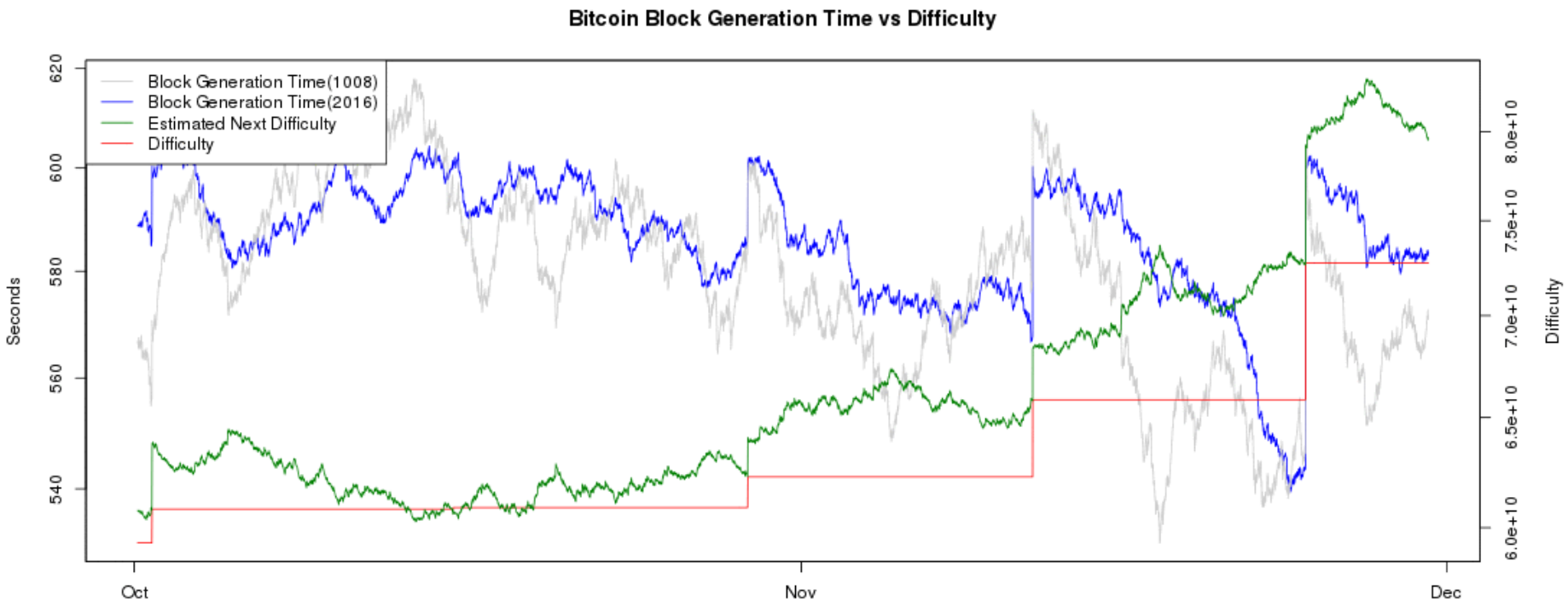
- Slides 2-10, 15, 18, 21 are mine
- Thanks to Nicolas Christin for all other slides

Mining difficulty



bitcoinwisdom.com

Difficulty adjustment



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Bitcoin mining hardware

TerraMiner™ IV – 2TH/s Networked ASIC Miner

$5,999

Shipping June 2014

300 GH Bitcoin Mining Card

The Monarch BPU 300 C

$1,497.00

Qty: 1 ADD TO CART

Pre-Order Terms: This is a pre-order. 28nm ASIC bitcoin mining hardware products are shipped according to placement in the order queue, and delivery may take 3 months or more after order. All sales are final.

THE LEOPARD

DETAILS :

- **2,5 TH/s**
- Dimensions: 15" x 13.3" x 13.7" (38cm x 34cm x 35cm)
- 28nm ASIC technology
- Silent Cooling
- In-built WiFi Connection (without Antenna)
- Less than 750 watt (0.3 per GH)
- 1 Year Guarantee

- $ 5.800

COMES WITH :

1. Power Supply
2. Free Remote Power Outlet & Smartphone App
3. Free User Guide
4. Free Personal Assistance for Setup

SHIPPING :

- Worldwide, Express
- Included in the price
- Available: 100 Units: Shipping April (Week 3)

Slide credit: Joe Bonneau

Should I mine bitcoins?

Chilkoot pass,
Klondike 1898

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