Introduction to Information Security
14-741/18-631 Fall 2021
Unit 5, Lecture 4: Intro to Cryptocurrencies

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Part I: Overview

Most Common Types of Cryptocurrencies

- **Bitcoin**
  - Most famous and recognizable
- **Bitcoin cash**
  - Introduced in 2017; faster; block size is 8 MB
- **Litecoin**
  - Shorter transaction time; lower fees; faster processing
- **Ethereum**
  - Smart Contracts; Focuses on decentralized applications
- **Ripple** (Not blockchain based; meant for larger corporations)
- **Stellar** (money transfers; non-profit;)
- **NEO** (Ethereum competitor)

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
    - Verification needed for digital currencies, are duplication of coins simply means "copying bits"
      - Without verification double-spending is possible
      - Physical currencies avoid this by using physical security features
  - 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"**
  - Although Casascius provides neat physical artifacts
    - Those are technically one-time use wallets

- **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 essentially the public key of the wallet)

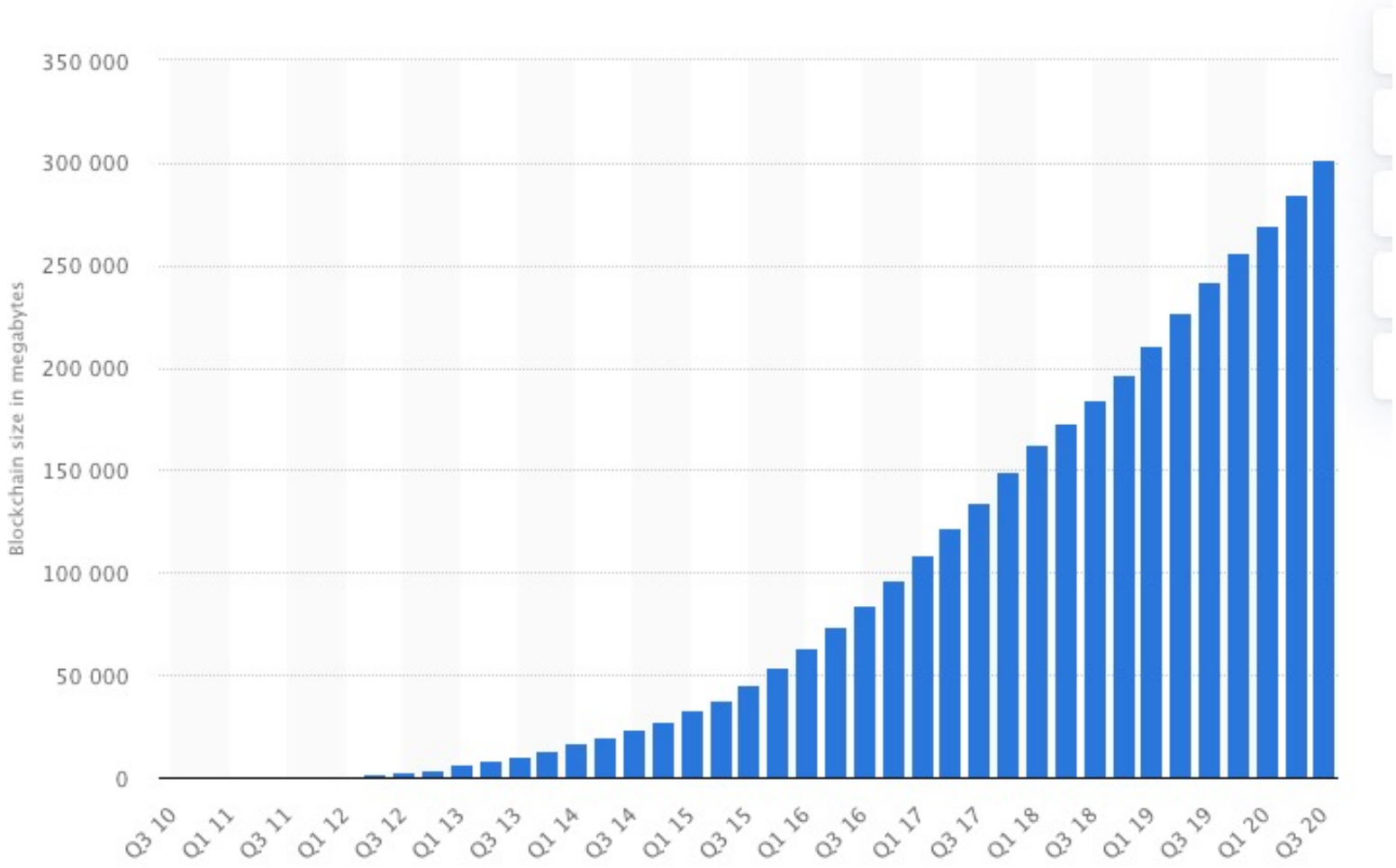
Bitcoin Transactions

- **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

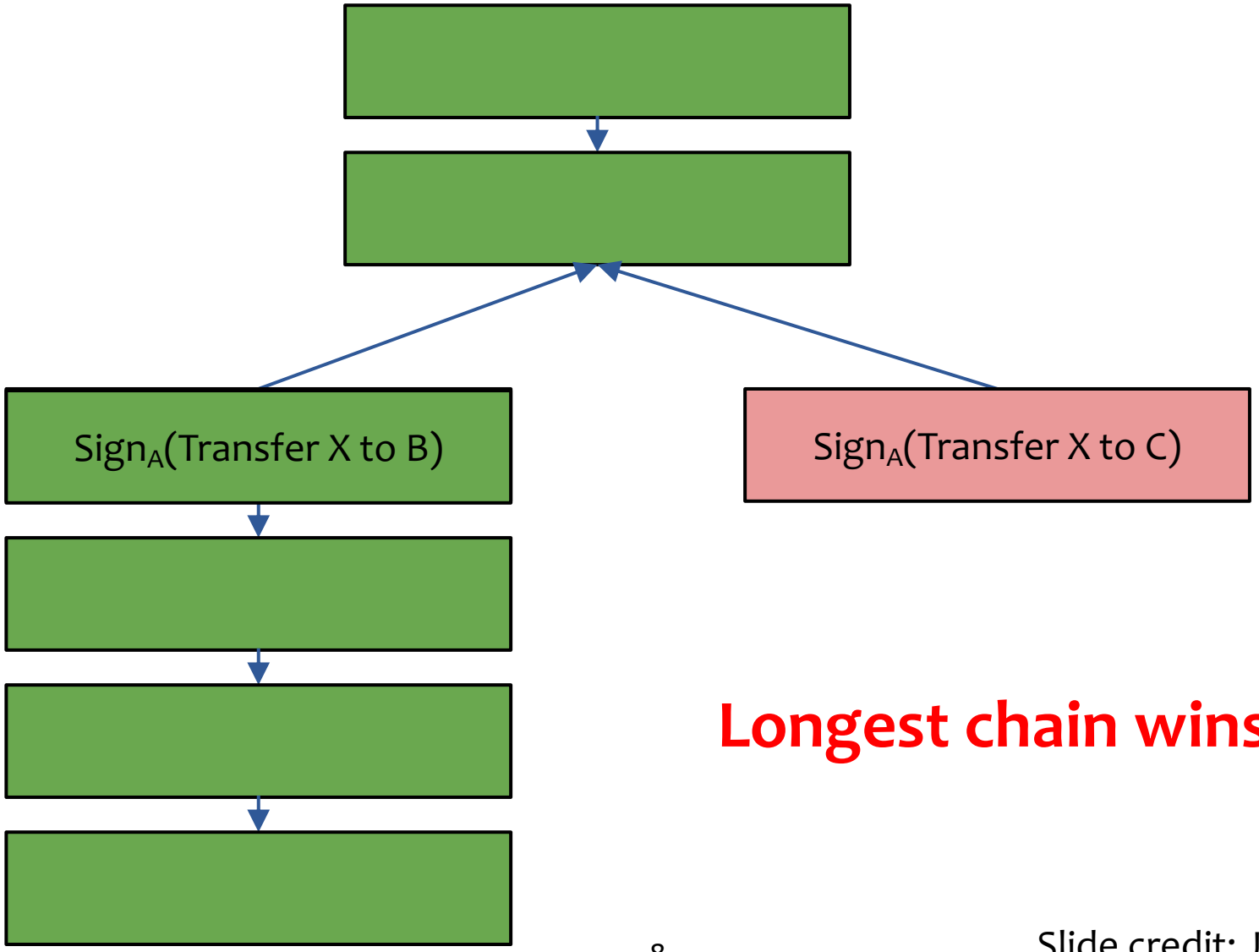
- **Bob now has 1 BTC**
  - He wants to send it to Charlie…
  - … while keeping it for himself at the same time
- **To prevent this Bob (and Alice before him) has to broadcast the transaction to everybody in the Bitcoin network**
- **Then other peers can verify that the transaction is not a double-spend**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

Bitcoin Ledger Size



Details: Worldwide; 2010 to 2020

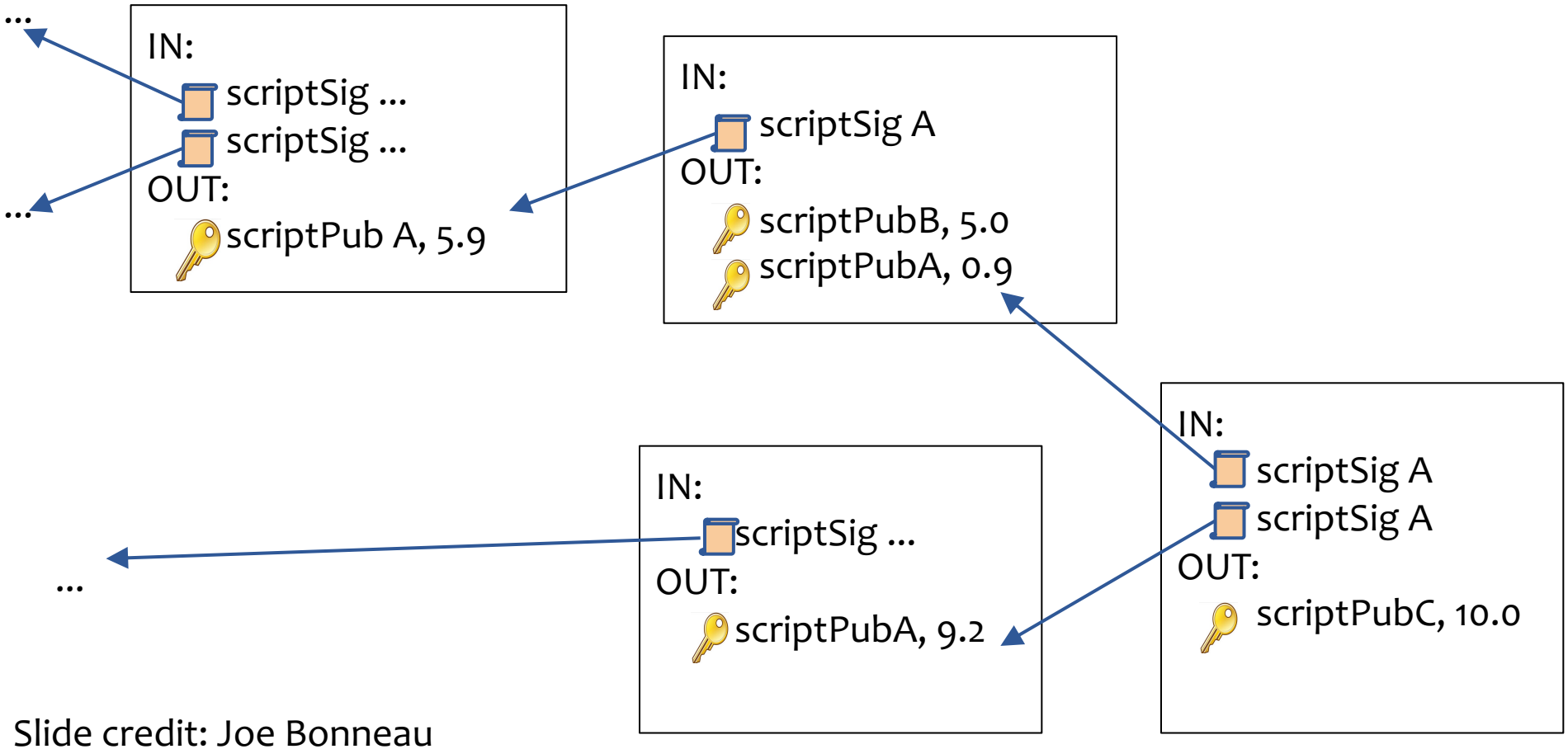
Preventing Double Spending



Longest chain wins

Slide credit: Joe Bonneau

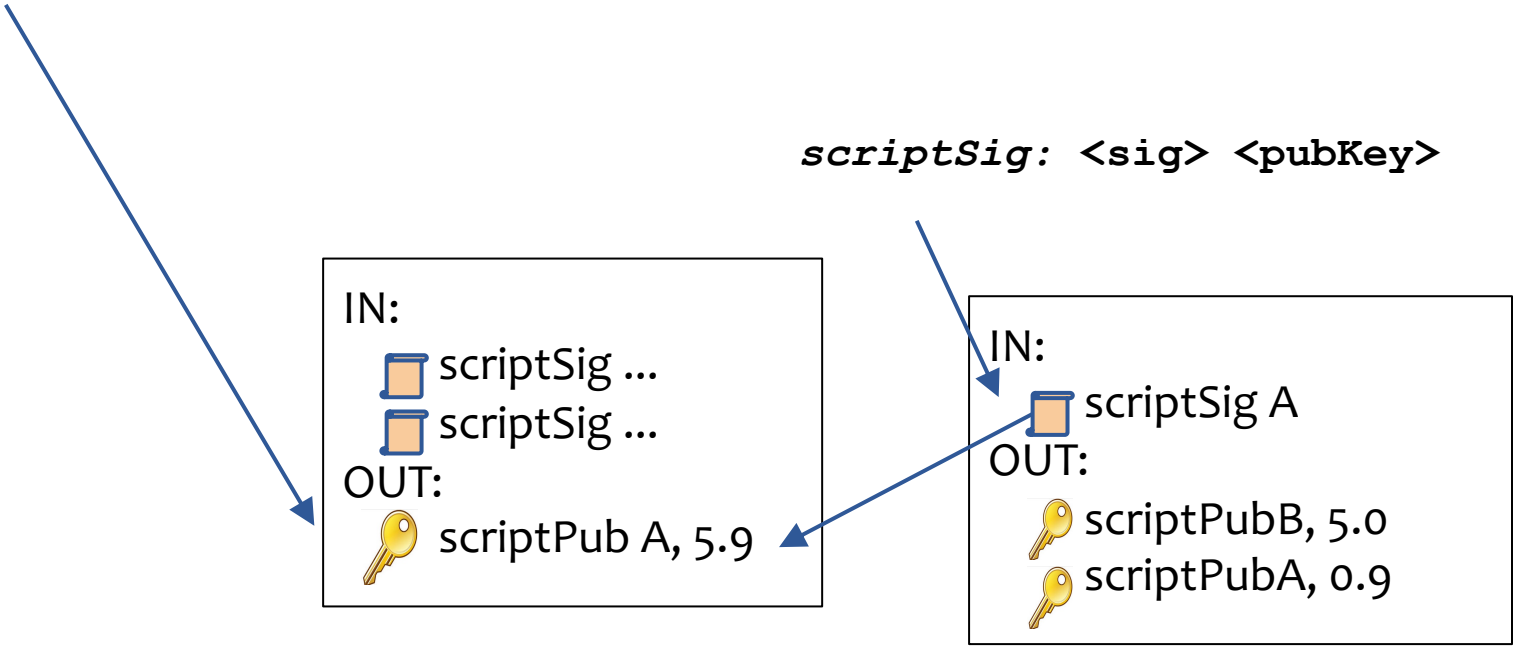
Bitcoin is Transaction-Based



Slide credit: Joe Bonneau

Bitcoin Transactions Specify Scripts

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

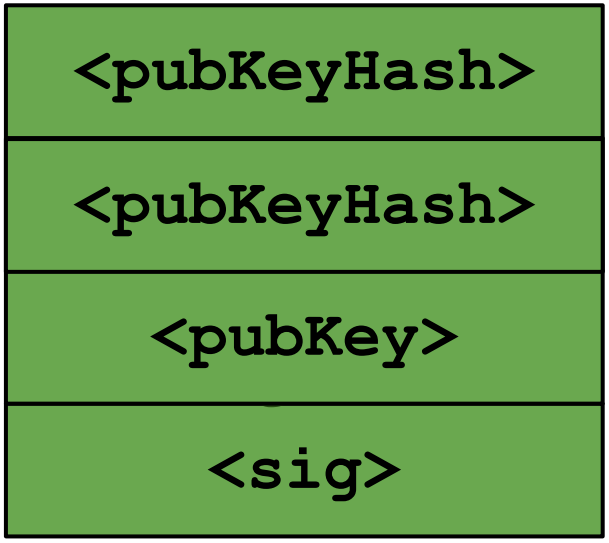


Redemption script:

```
<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, full details here

Bitcoin Script Features

- multiple signatures
- escrow
- time locking
- commitment opening
- ...

- smart contracts?

Slide credit: Joe Bonneau

Part II: 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, 12.5 BTC as of 7/9/2016, divided by two every so often, drop to 6.25 BTC estimated 5/22/2020
  - Verification is combined with a "proof-of-work" scheme to ensure
    - That transactions have proper timestamping
    - That currency production is rate-limited

Proof-of-Work /Mining Incentives

- **Miners essentially solve a cryptographic puzzle, essentially**

$$\text{find } x \text{ such that } H(x) < y$$

- **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

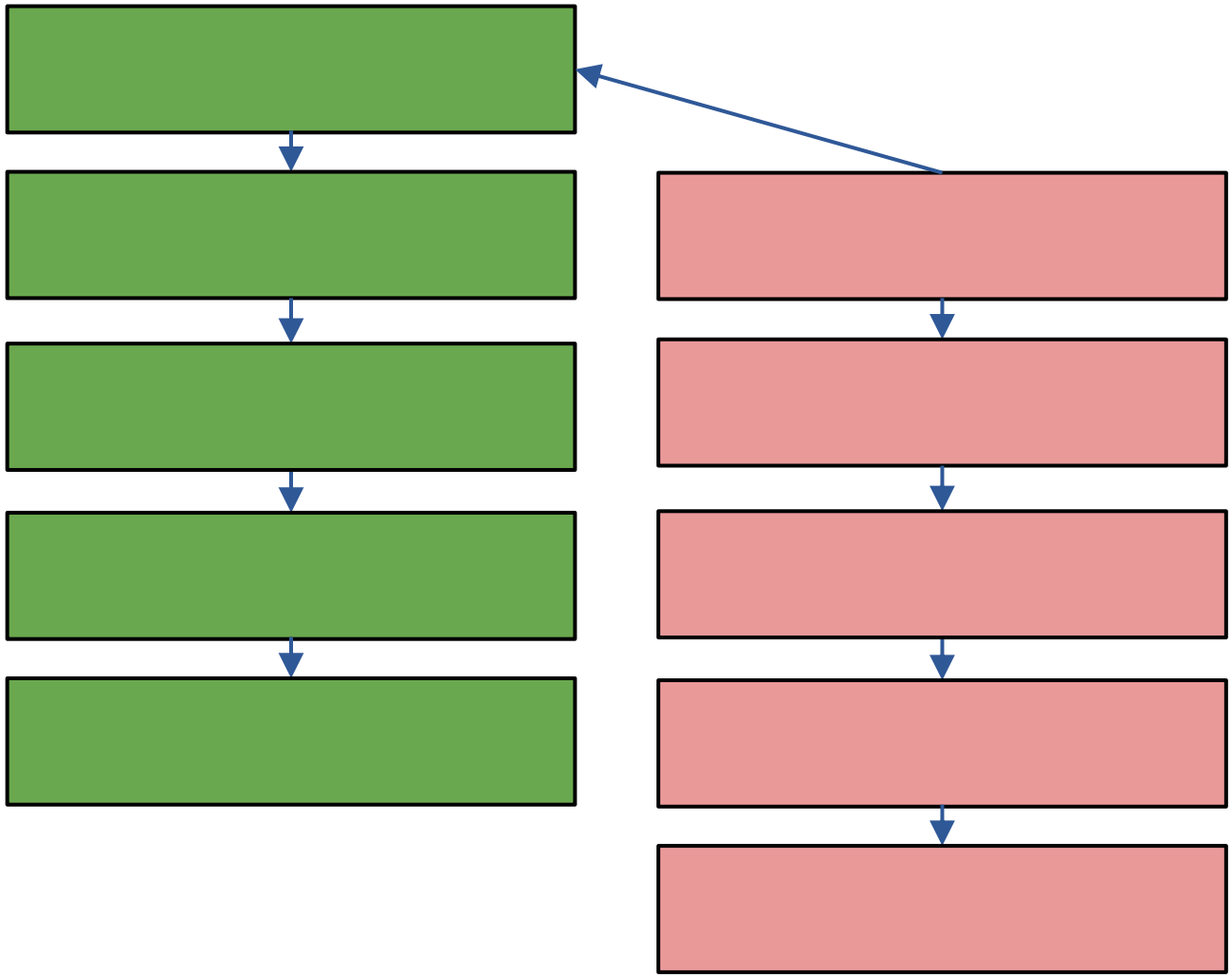
- **Difficulty is tunable and is (by edict) designed to be inversely proportional to the total computational power of the network**

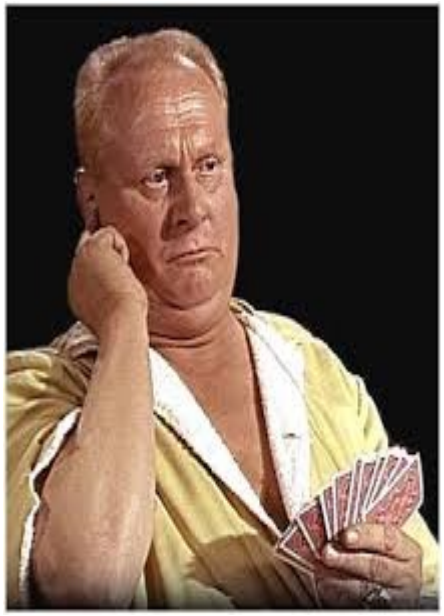
- **The goal is to have one block every ten minutes**
  - Predictable supply of currency (independent of the difficulty)
  - **But this limits how quickly transactions can be verified**
    - At least 10 minutes, usually 60 minutes is recommended

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**

51% Attacks

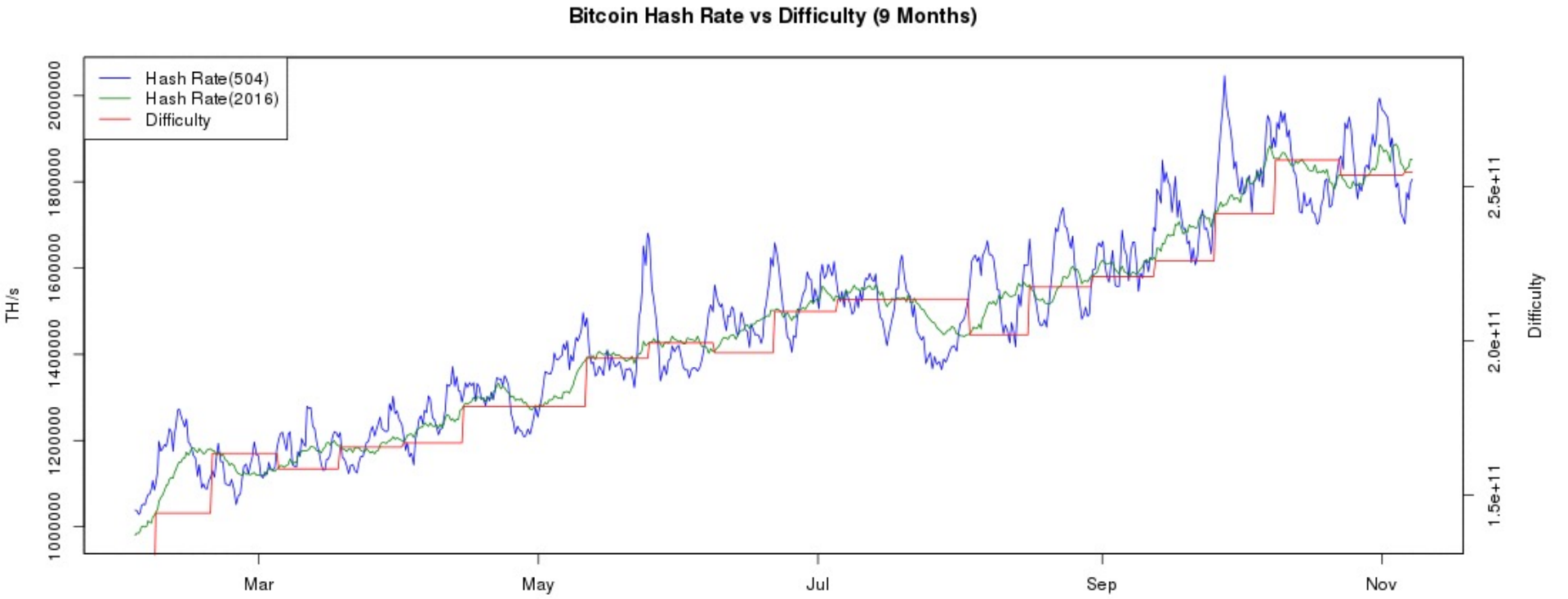




Goldfinger Attack?

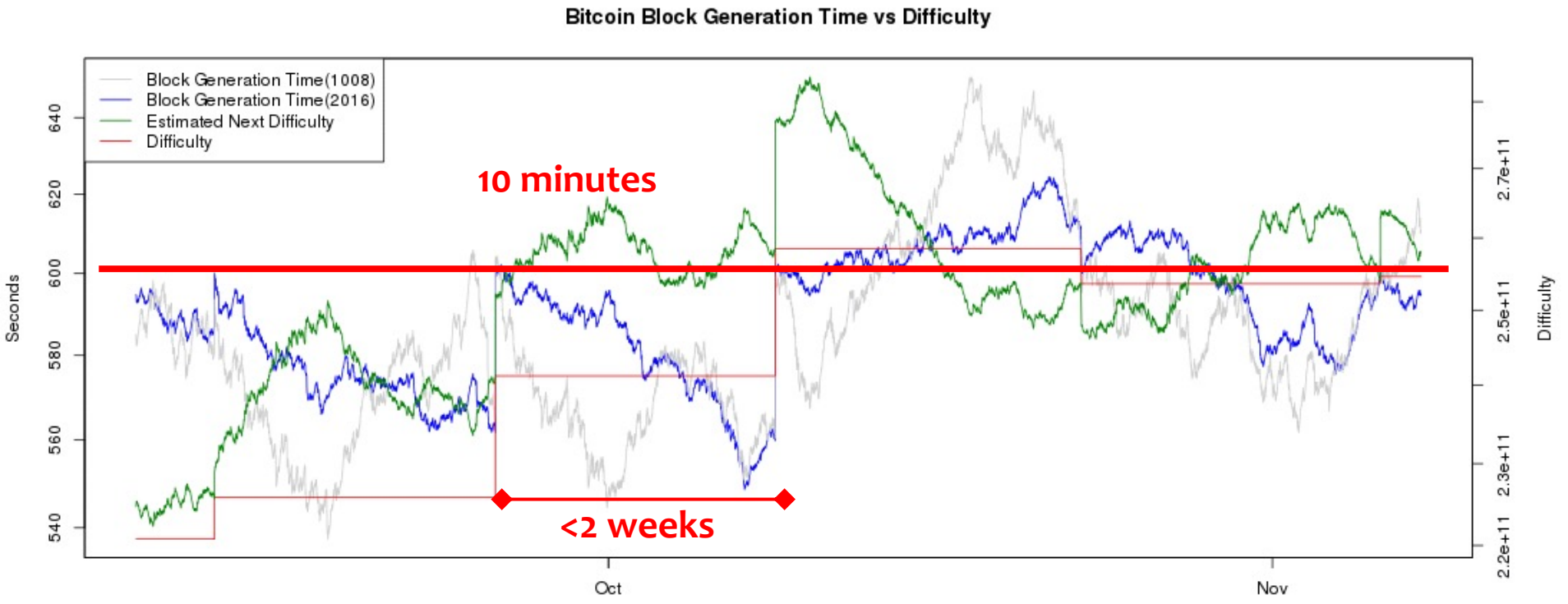
Slide credit: Joe Bonneau

Mining Difficulty



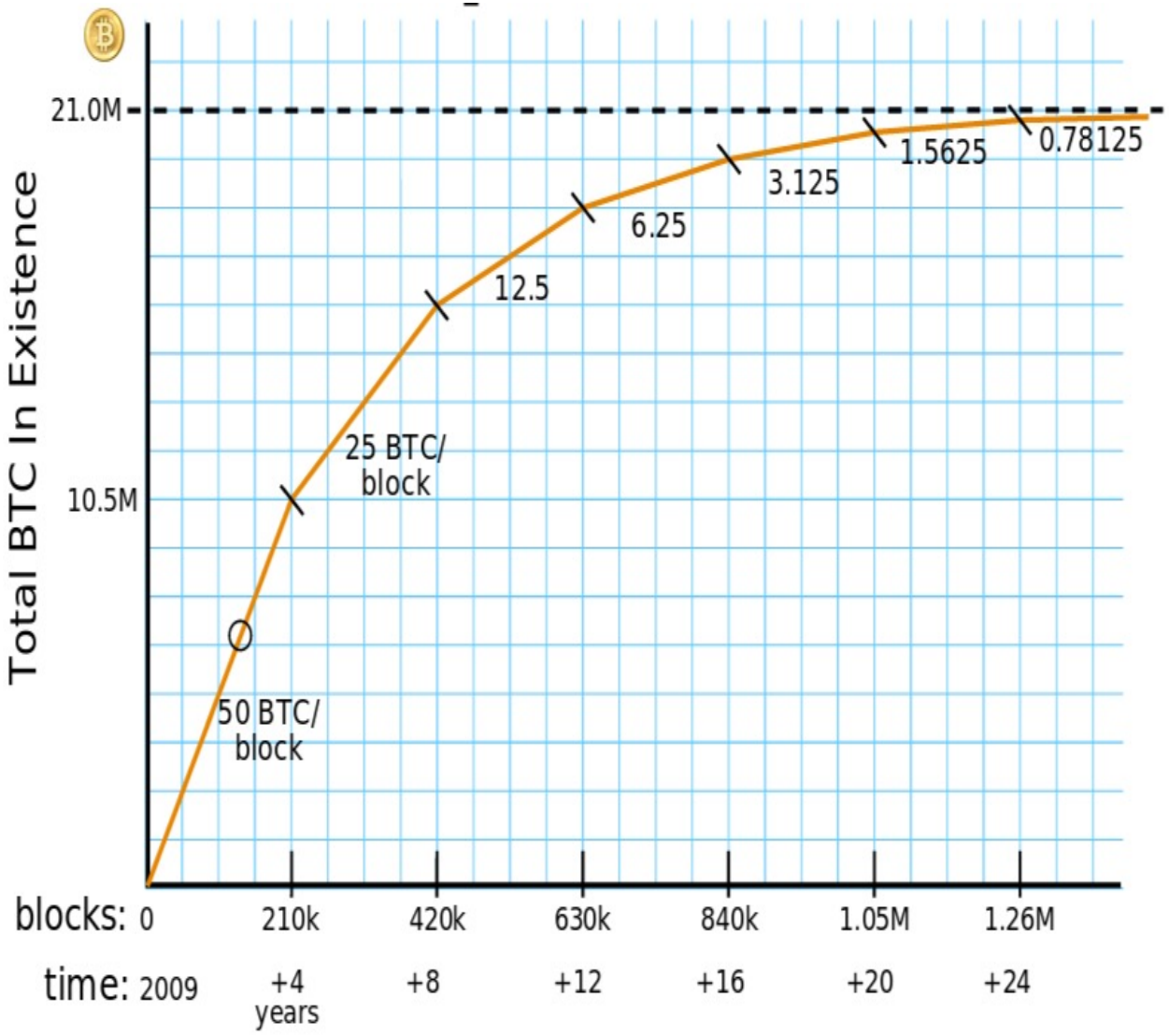
bitcoinwisdom.com

Difficulty Adjustment



bitcoinwisdom.com

Mining Rewards



Courtesy:
Brian Warner

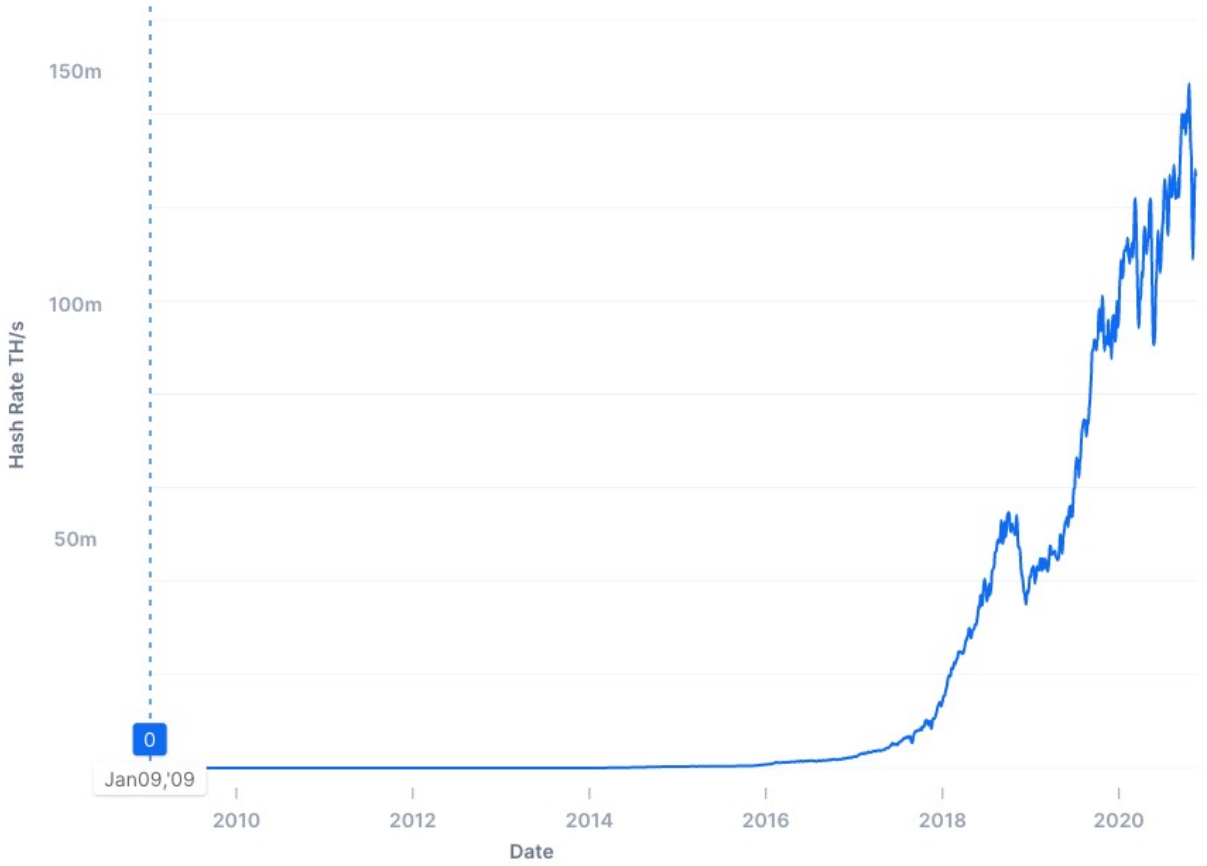
Total Network Capacity

- **Feb 2019: $2^{74.4}$ hashes per block (every 10 minutes!)**
- **Consuming >> 4.2GW continuously **
  - *Assuming ~10,000 MegaH/J (AntMiner S9)
- **2^{75} hashes in 2015… in one hour!**
- **Computation of power is very hard to do nowadays – see https://digiconomist.net/bitcoin-energy-consumption**
- **Recent historical perspective:**

Year	2017	2018
Total # of hashes	$2^{87.37}$	$2^{89.89}$
~power*	**> 0.6 GW (5.4 TWh/yr)**	**> 3.6 GW (31 TWh/yr)**
Profit	> US $1.6B	**> US $4.7 B**

Slide credit: Nicolas Christin

Bitcoin Hash Rate



Source: https://www.blockchain.com/charts/hash-rate

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

Slide credit: Joe Bonneau

Mining Pools

Mint(25, K_{POOL})

0x0000000000000003f89...

0x000000000000a877902e...

0x000000000001e8709ce...

0x00000000000490c6b00...

0x0000000000007313f89...

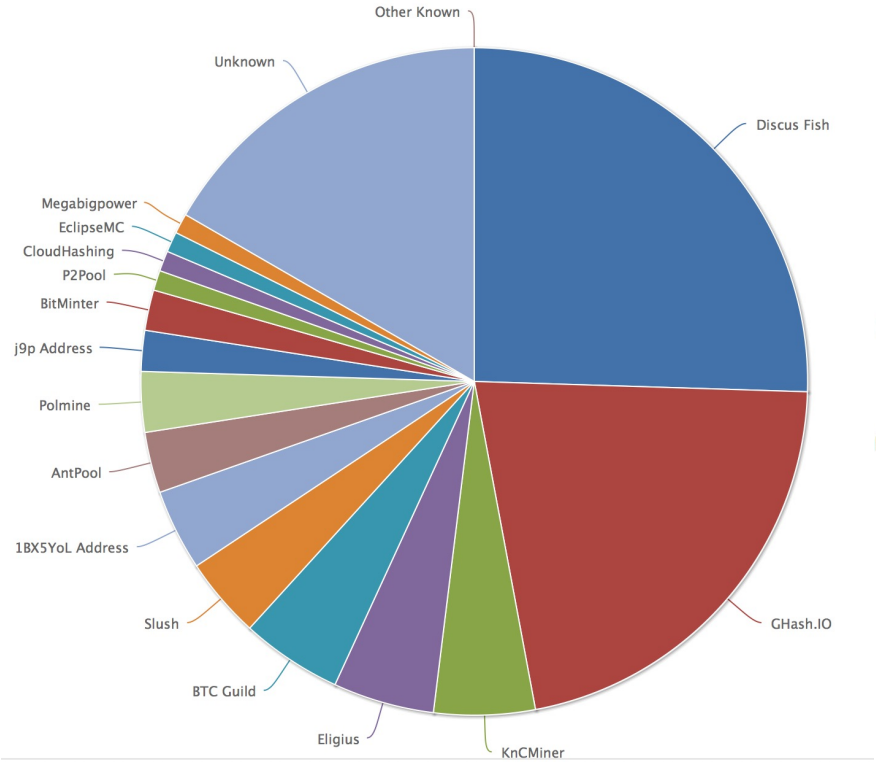
0x0000000000000003f89...

0x00000000000045a1611f...

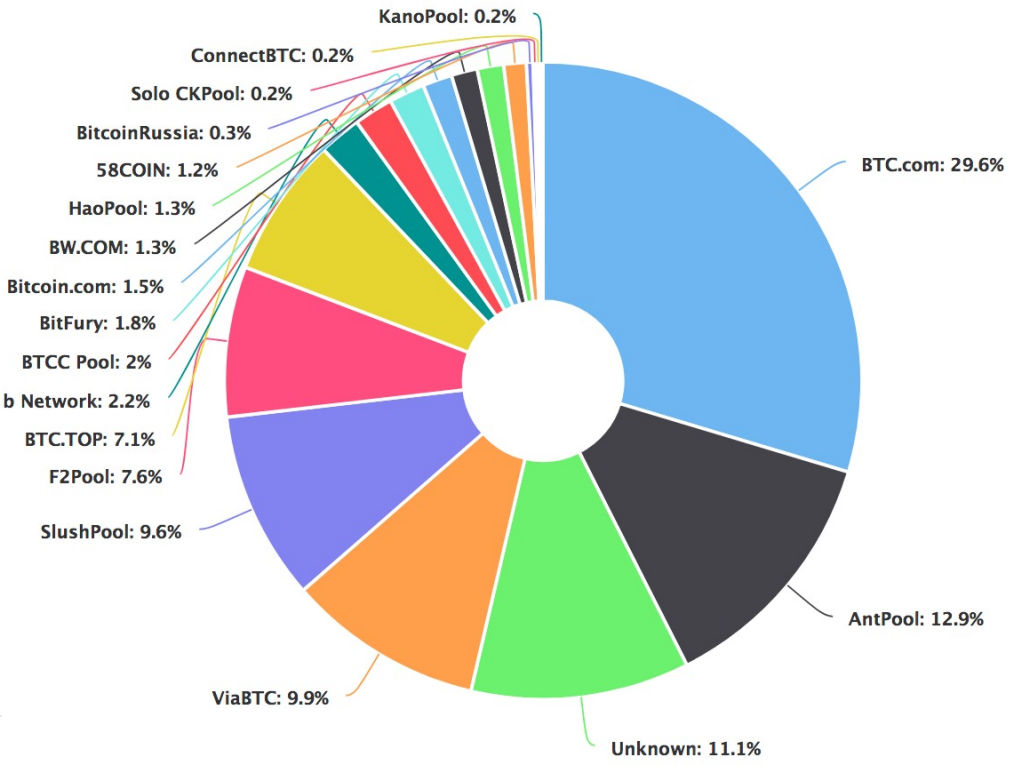
Slide credit: Joe Bonneau

Mining Pools

2013



2018



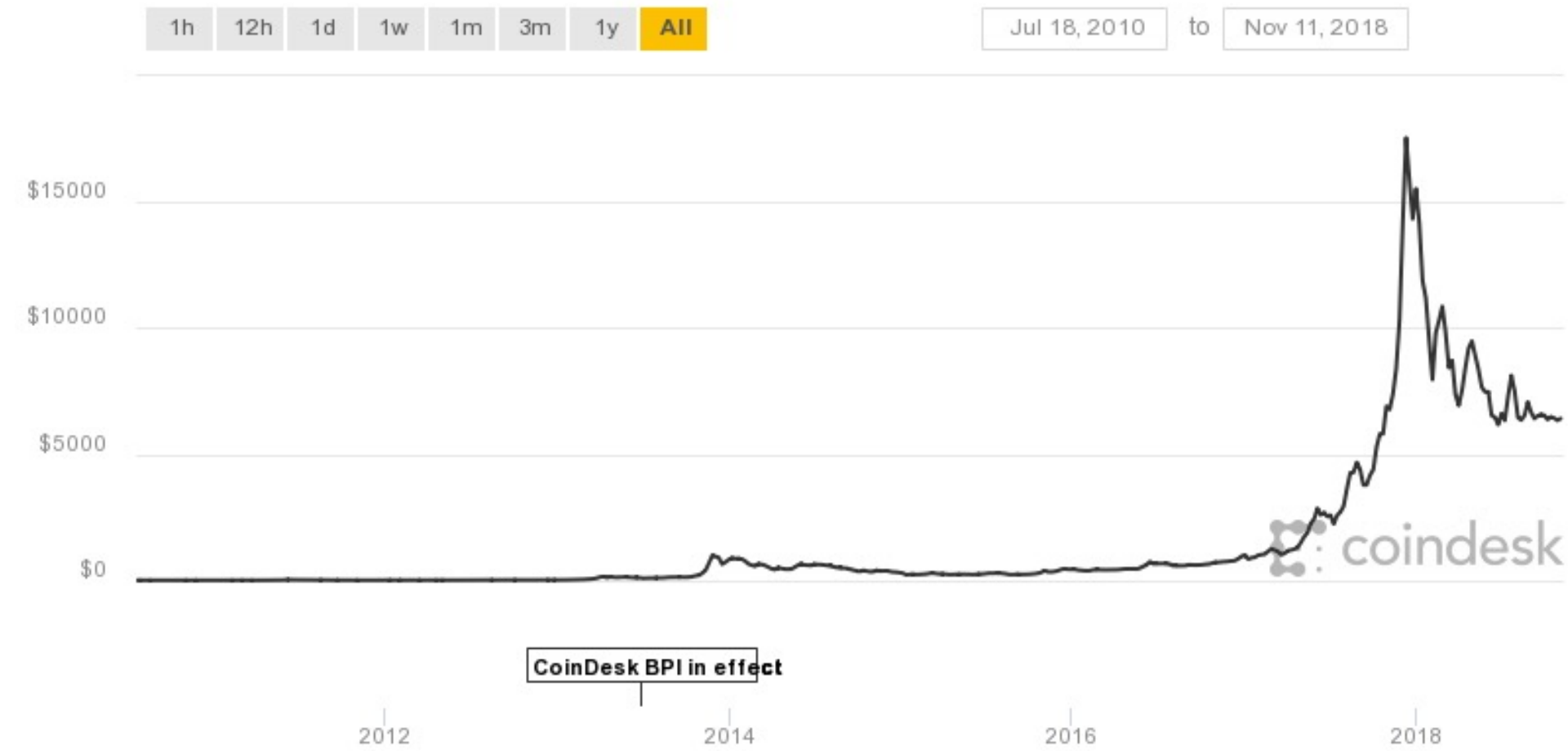
Part III: Using Bitcoin

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 regulator
- **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.

silkroadvb5piz3r.onion/silkroad

Startpage

Silk Road

anonymous market

messages 0 | orders 0 | account ฿0.00

Search Go

Shop by Category

- Drugs *11,247*
  - Cannabis *2,664*
  - Dissociatives *269*
  - Ecstasy *1,262*
  - Opioids *667*
  - Other *551*
  - Precursors *102*
  - Prescription *2,447*
  - Psychedelics *1,213*
  - Stimulants *1,551*
- Apparel *341*
- Art *3*
- Biotic materials *2*
- Books *912*
- Collectibles *14*
- Computer equipment *74*
- Custom Orders *89*
- Digital goods *630*
- Drug paraphernalia *330*
- Electronics *103*
- Erotica *626*
- Fireworks *15*
- Food *9*
- Forgeries *158*
- Hardware *27*
- Herbs & Supplements *11*
- Home & Garden *11*
- Jewelry *90*
- Lab Supplies *53*
- Lotteries & games *53*

Royal Customers 10G

฿1.66

Decanoate250, (1 x 10ml = 2.500mg)

฿0.39

XTC Pills MDMA 175mg x500

฿19.28

100g Dimethoxbenzaldehyde

฿1.45

LECKERMANN WEEKLY SKUNK IS BACK STRONG

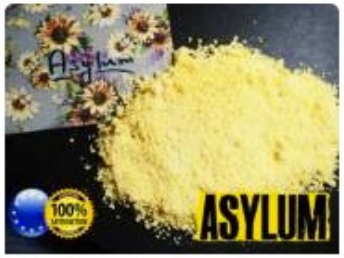
฿0.52

Good Quality Soap Bar | 126g(4.5oz) | UK Vendor

฿2.78

Modafinil 200mg - 300 Pills

฿2.65



0.2g DMT Freebase

฿0.48

1g cocaine high premium quality FLEX - high grade

฿1.32

How Was Anon Market Able to Survive?

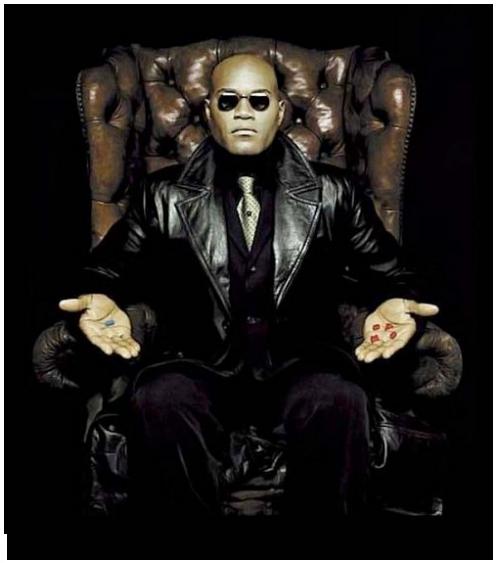
- **Tor "hidden service"**
  - Tor = peer-to-peer network that conceals IP addresses of traffic sources by bouncing traffic around peers
  - Website uses Tor to connect to the Internet
  - **Only** accessible through Tor
    - .onion address as opposed to .com, .org, .net
  - Server is very hard to locate for an attacker

- **Bitcoin for payments**
  - Peer-to-peer, decentralized currency
  - Some anonymity (no identity bound to wallets)
    - However the entire chain of transactions is public

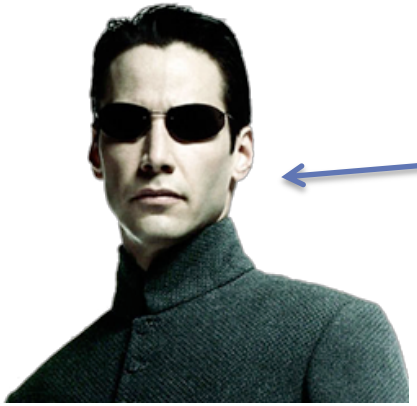
- Marketplace provides escrow mechanism to guarantee transaction completion
  - For buyers: Registration free, open to anyone
  - For sellers: Relatively modest account fee (refunded after a number of successful transactions)

Escrow Transactions

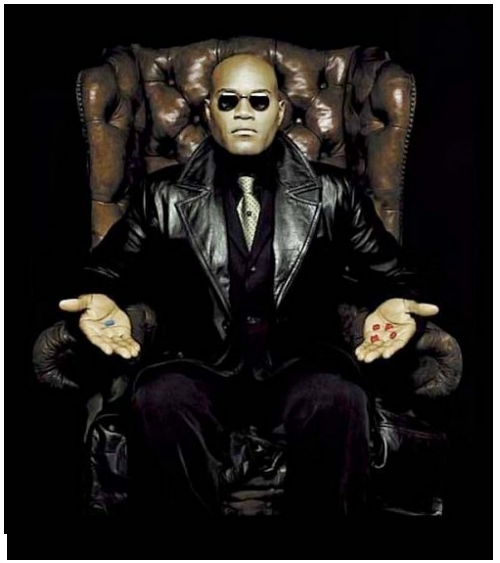
"I'll take the red pill"



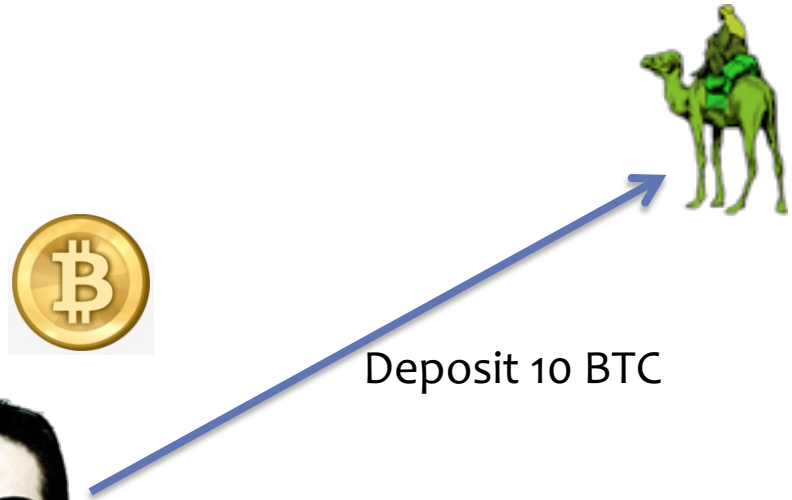
Escrow Transactions

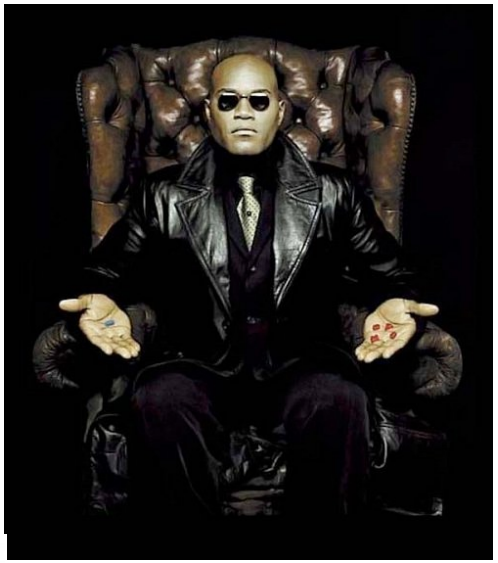


"The red pill is 10 BTC"



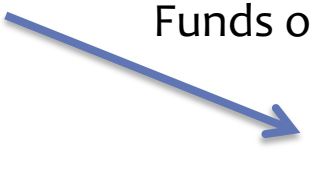
Escrow Transactions

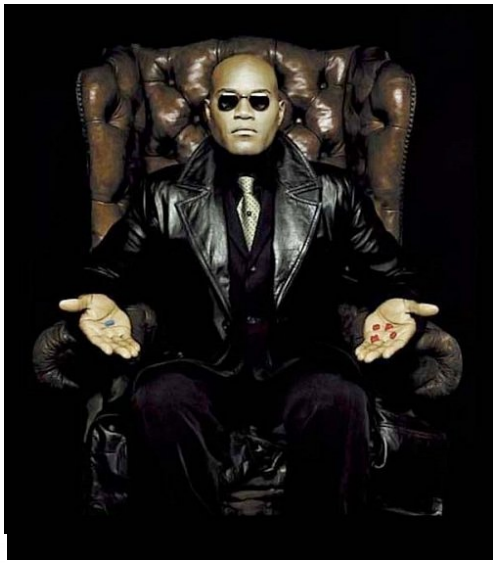




Escrow Transactions

Funds ok





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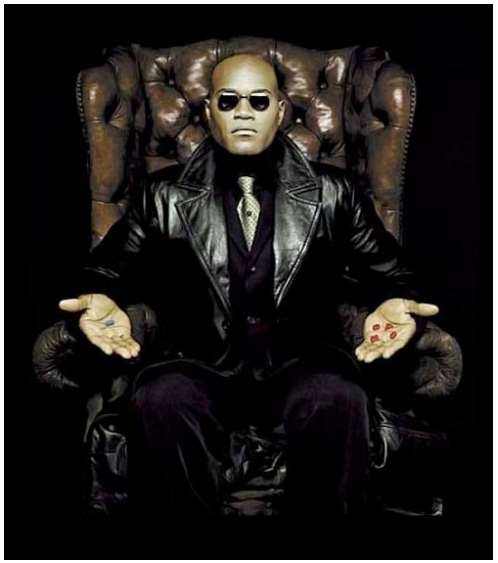
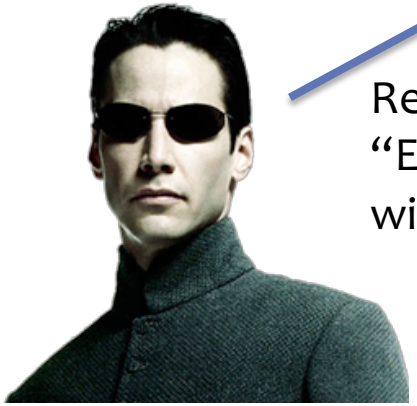
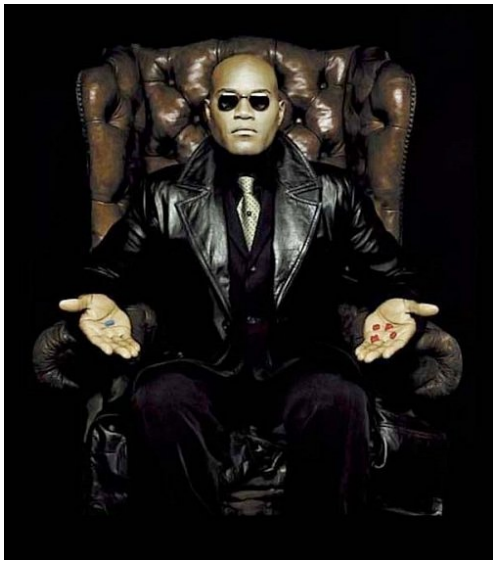


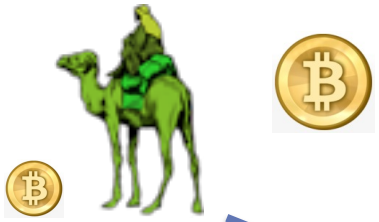
Escrow Transactions



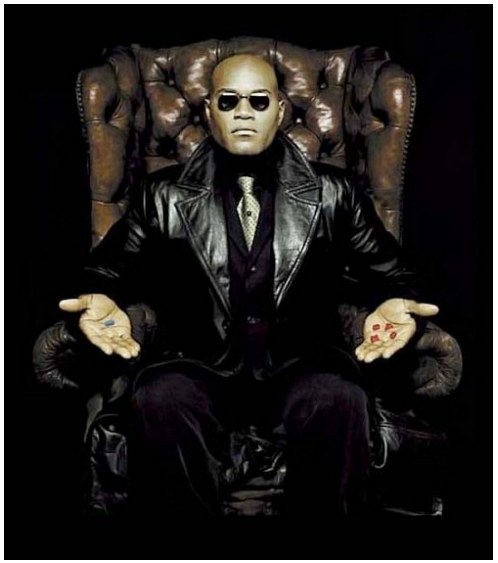
Received
"Excellent seller, would do business with again"



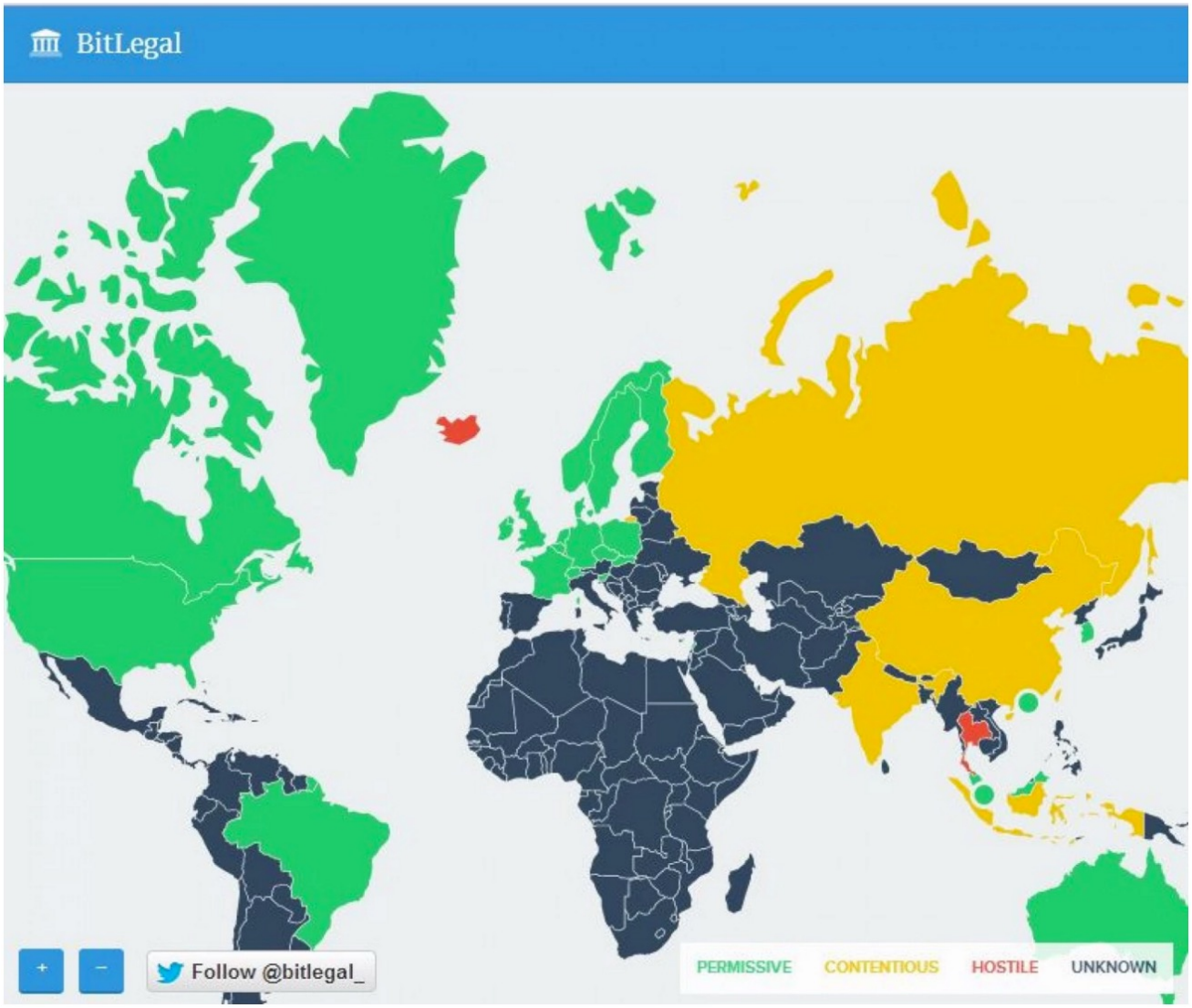
Escrow Transactions



Deposit 9 BTC



Bitcoin Regulation



Bitcoin Regulation

- **Is Bitcoin a currency, a commodity, or a security? Is Bitcoin a payments network, a protocol, or a digital bank of sorts**
- **Against**
  - No protections for consumers (Mt. Gox lost 850,000 bitcoins).
  - Used by criminals in dark markets
- **For**
  - Freedom
  - Transformative technology
- **New York becomes the first state to regulate bitcoin**
  - BitLicense Regulatory Framework

Part IV: 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?**

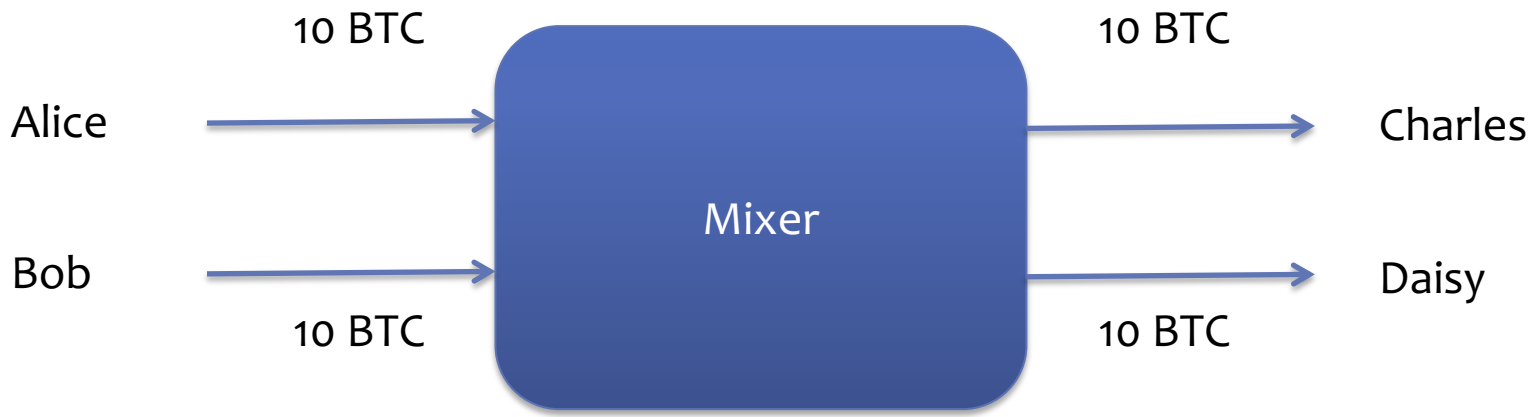
NO!

Bitcoin Tracing

- **Anonymity here implies un-linkability 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 (Meiklejohn et al.) suggests existing mixers are not effective or downright dishonest
- **Open problem: is it possible to design a (distributed) mixing algorithm that provides strong unlinkability guarantees?**

Ethereum Smart Contracts

Ethereum

- **2014: Whitepaper released, crowdsale**
- **Crypto-currency and more**
- **Similar to bitcoin**
  - Use public blockchain as ledger
  - Each block contains several transactions
  - Proof of work
- **Different from bitcoin**
  - Transactions can include Turing-complete programs that run when blocks are processed (Solidity language)
  - Helps developers build de-centralized applications

Transaction & Contracts: Accounts

- **Externally owned accounts (similar to wallet in Bitcoin)**
- **Contract accounts (controlled by smart contract programs)**
- **Send *ether* to contracts, send money from contracts to externally owned accounts**
  - examples in the homework

For more readings: https://ethereum.org/en/developers/docs/smart-contracts/

A Smart Contract

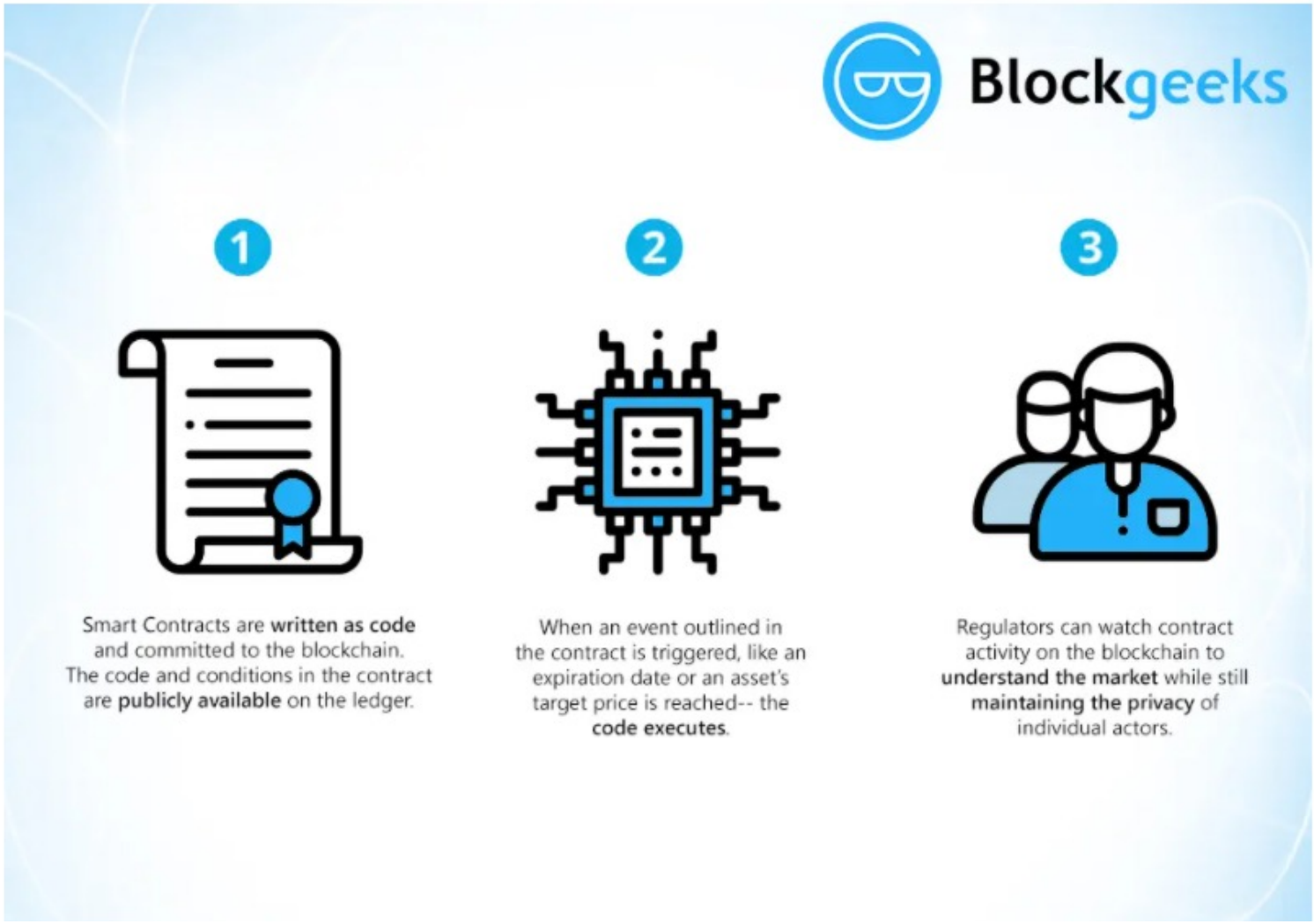
- **A program that runs on the blockchain**
- **Collection of code (its functions) and data (state)**
- **They have a balance and can send transactions**
- **Not controlled by the user**
  - Instead, deployed to the network
  - Run as programmed
- **User accounts interact with a smart contract**
  - Submitting transactions that execute a function defined on the smart contract
- **Can define rules and enforce rules via code**

For more readings: https://ethereum.org/en/developers/docs/smart-contracts/

Transaction & Contracts: Gas

- **What if someone writes a contract that never terminates?**
- **Gas: fuel for executing transactions and contracts**
  - Submitting transactions and contracts to the blockchain has an associated "gas" cost paid in Ether based on the complexity of the operations.

Why Smart Contracts?



Source: https://blockgeeks.com/guides/smart-contracts/

Solidity: Basics (v0.5.12)

```
contract Coin {
        // The keyword "public" makes those variables easily readable from outside.
        address public minter;
        mapping (address => uint) public balances;

        // Events allow light clients to react to changes efficiently.
        event Sent(address from, address to, uint amount);

        // This is the constructor whose code is  run only when the contract is created.
        constructor() public { minter = msg.sender; }

    // Sends an amount of newly created coins to an address; can only be called by the contract creator.
        function mint(address receiver, uint amount) public {
            require(msg.sender == minter);
            require(amount < 1e60);
            balances[receiver] += amount;  }
        // Sends an amount of existing coins from any caller to an address.
        function send(address receiver, uint amount) public {
            require(amount <= balances[msg.sender], "Insufficient balance.");
            balances[msg.sender] -= amount;
            balances[receiver] += amount;
            emit Sent(msg.sender, receiver, amount); }
}
```

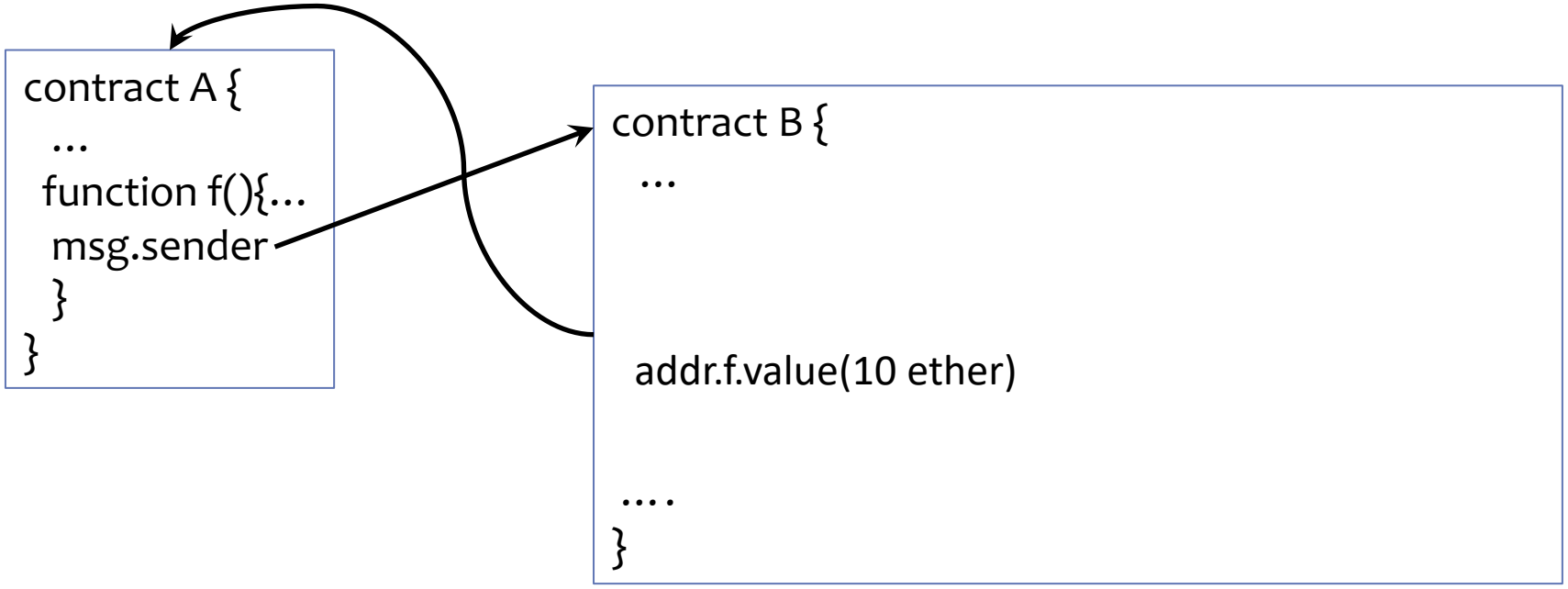
160-bit value, no arithmetic operations

permanently stores address of the contract creator

Only creator can call mint

Only maximum amount of tokens

Transactions & Contracts: distributed applications

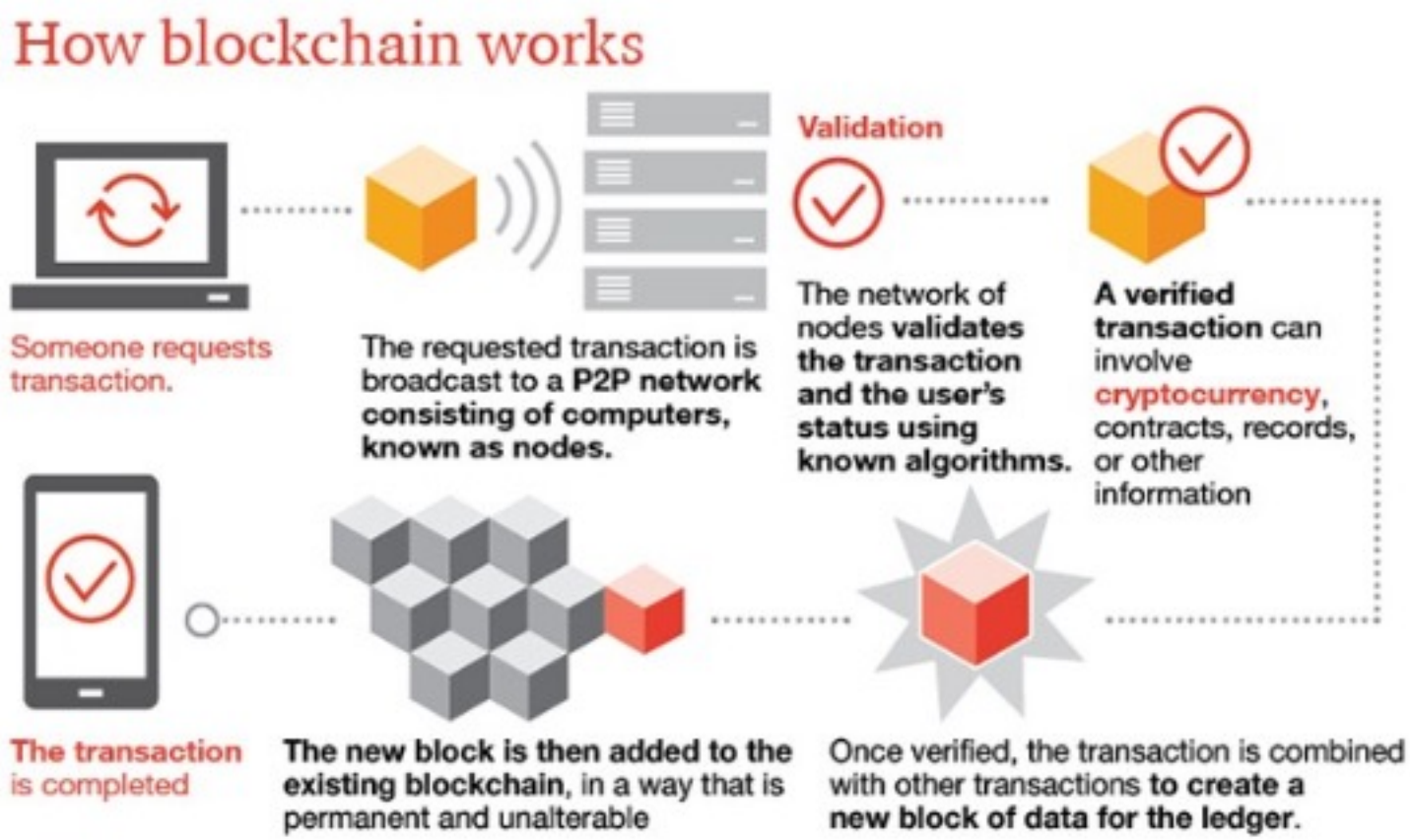


Solidity: Fallback Functions

- **A contract can have exactly one unnamed function, which is called fallback function**
  - function(){….}
- **It is called when**
  - a function f is called but f does not match any function name in the contract
  - Or no function name is supplied
- addr.call.value(x)()
  - Invoke the fallback function at addr and send x ether to it

The Blockchain Technology

Blockchain Overview



Source: pwc, United States

New Application for Blockchain

- **Research in interest into good applications of Blockchain and smart contracts**
  - Autonomous cars
  - Financial services (reduce transaction costs)
  - Voting (cast votes electronically, immediate verifiable results)
  - Healthcare
    - Share patient information with multiple providers
    - Preserve privacy

Memory-Based Proof of work

- **Goal: performance is less sensitive to hardware specs**
- **Computation speed is bound by main memory accesses**
- **Example Algorithms**
  - CryptoNight
    - Released in 2013 as part of CryptoNote blockchain
    - Memory hard-loop; sequence of random reads and writes in a scratchpad (small memory area)
    - Fits on CPU cache
  - Ethash
    - Used by Ethereum.
    - Memory hard-loop randomly reads DAG area (memory slices larger than scratchpad)
  - Cuckoo Cycle
    - Solves a PoW puzzle that finds cycles or other structures in large random graphs

Proof-of-Stake

- **Current common consensus algorithm is proof of work(PoW)**
  - Energy consumption
  - No penalty for fraud
  - Miners increase processing power to improve their chances
- **Proof-of-Stake**
  - More energy efficient
  - Removes the high-powered computing from the consensus algorithm
  - More complicated
    - security?
  - “Validators” set aside a certain amount as collateral

How PoS Works

- **“Validator” instead of “miner”**
- **The validator has an economic state**
  - The “stake” their funds on the blocks that they believe are valid
- **Validators take turns to propose and vote**
  - Votes are weighed by size of collateral amount
- **Anyone can become a validator**
  - If and only if they hold some ether as collateral amount
- **An algorithm determines the validators to be chosen for a block**
- **Validators no longer increase processing power**
  - Increase “stake” to improve chances
- **Verifying bad (fraudulent) blocks can result in loss of stake**

Takeaway Slide

- **Bitcoins, Ethereum and other cryptocurrencies are applications of crypto**
  - Decentralized Peer-to-peer digital payment systems
- **Eventually, the blockchain technology is now attractive to other applications**
- **Security challenges**
  - Attacks (e.g. 51%)
  - Anonymity
  - Others?
- **Other challenges include**
  - Computation recourses
  - Environmental impact
- **Proof-of-work and proof-of-stake**
  - An ongoing area of research and development