Blockchains & Cryptocurrencies

Anonymity in Cryptocurrencies

Instructors: Matthew Green & Abhishek Jain
Johns Hopkins University - Spring 2019

Housekeeping

- Reminder: we have a midterm on 3/13!
  - This will cover all readings and lectures up through 3/11 (next Monday)
- Assignment 2 due 3/11 end of day
- Note: readings listed post-Spring Break are currently out of whack and will be updated soon

News?

News?

INSIGHTS CRYPTOCURRENCY EXCHANGE (ORGANIZED MARKET) BITCOIN

QuadrigaCX mystery deepens after cryptocurrency cold wallets found empty

Everything you need to know about Facebook's new cryptocurrency

Whatsapp is set to launch a coin, but what does this mean?

By Laurie Clarke | Mar 04, 2019

Share

Facebook is reportedly planning to launch its own cryptocurrency within Whatsapp, which would allow users to frictionlessly transact with one another through the service without incurring fees.

According to *Bloomberg*, the new cryptocurrency will initially focus on the remittance market in India, where there are hundreds of millions of Whatsapp users and most financial transfers today are made via mobile payments. It's worth noting however that this coin won't be a typical cryptocurrency, it will be a 'stablecoin'.

Review stuff (from last time)

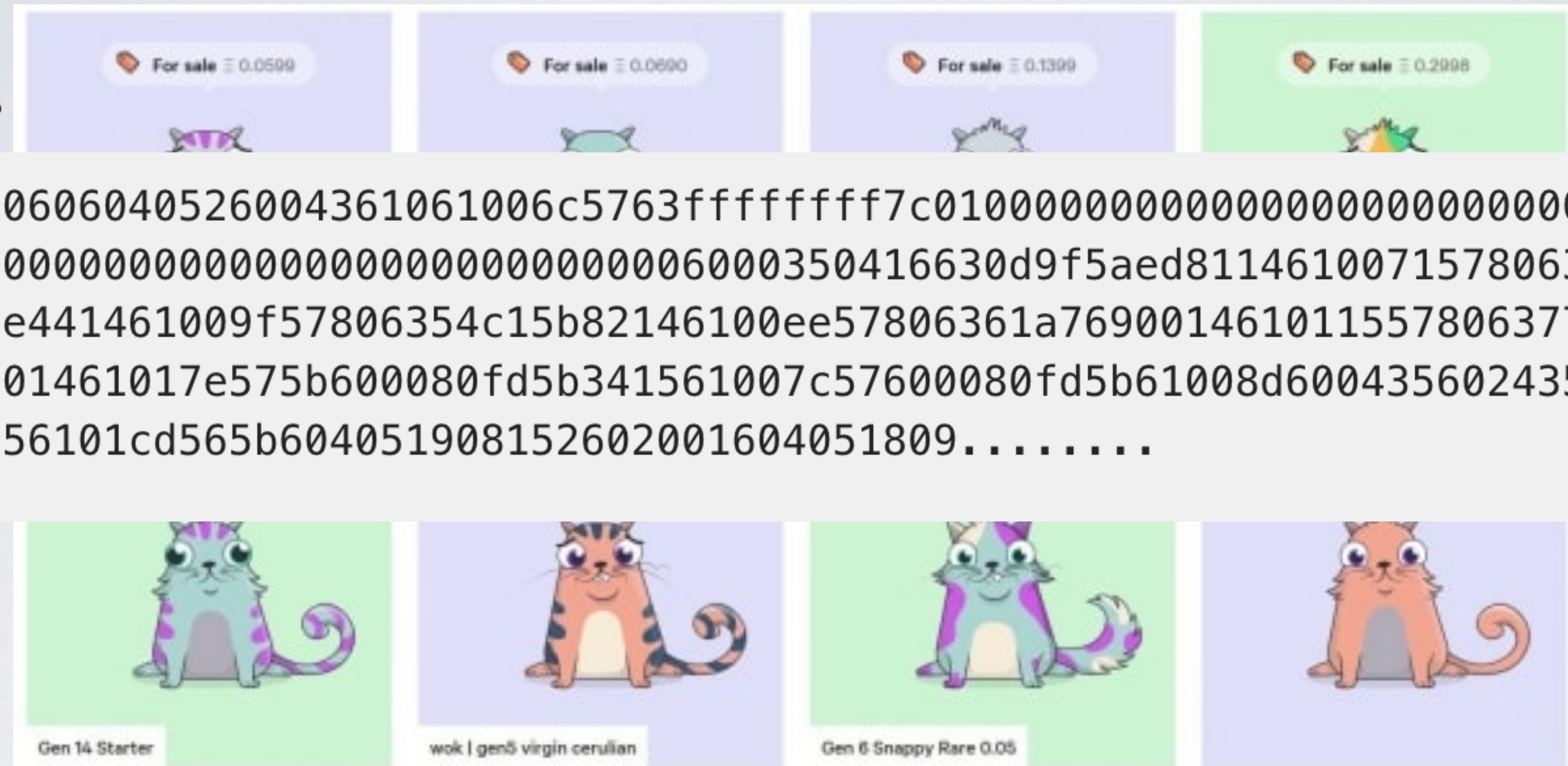
- Cryp

```
function giveBirth(uint256 _matronId)
        external
        whenNotPaused
        returns(uint256)
    {
        Kitty storage matron = kitties[_matronId];

// Check that the matron is a valid cat.
        require(matron.birthTime != 0);

// Check that the matron is pregnant, and that its time has come!
        require(_isReadyToGiveBirth(matron));

// Grab a reference to the sire in storage.
        uint256 sireId = matron.siringWithId;
        Kitty storage sire = kitties[sireId];

// Determine the higher generation number of the two parents
        uint16 parentGen = matron.generation;
        if (sire.generation > matron.generation) {
            parentGen = sire.generation;
        }

// Call the sooper-sekret gene mixing operation.
        uint256 childGenes = geneScience.mixGenes(matron.genes,
sire.genes, matron.cooldownEndBlock - 1);
```

Annotated code from: https://medium.com/@montedong/towards-cracking-crypto-kitties-genetic-code-629fcd37b09b

• Cryptokitties

•




```
0x60606040526004361061006c5763ffffffff7c0100000000000000000000000000
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97ee441461009f57806354c15b82146100ee57806361a76900146101155780637 7a7
4a201461017e575b600080fd5b341561007c57600080fd5b61008d60043560243560
44356101cd565b6040519081526020016040518 09........
```

Annotated code from: https://medium.com/@montedong/towards-cracking-crypto-kitties-genetic-code-629fcd37b09b

- Reverse engineering Cryptokitties (see link below):
  - Kitty gets "pregnant", I.e., commit to DNA of sirer and matron
  - Then kitty "gives birth" sometime later, and this is when DNA is computed
- The DNA combination is randomized by the Ethereum block hash at birth time
- Are there attacks on this type of randomness?

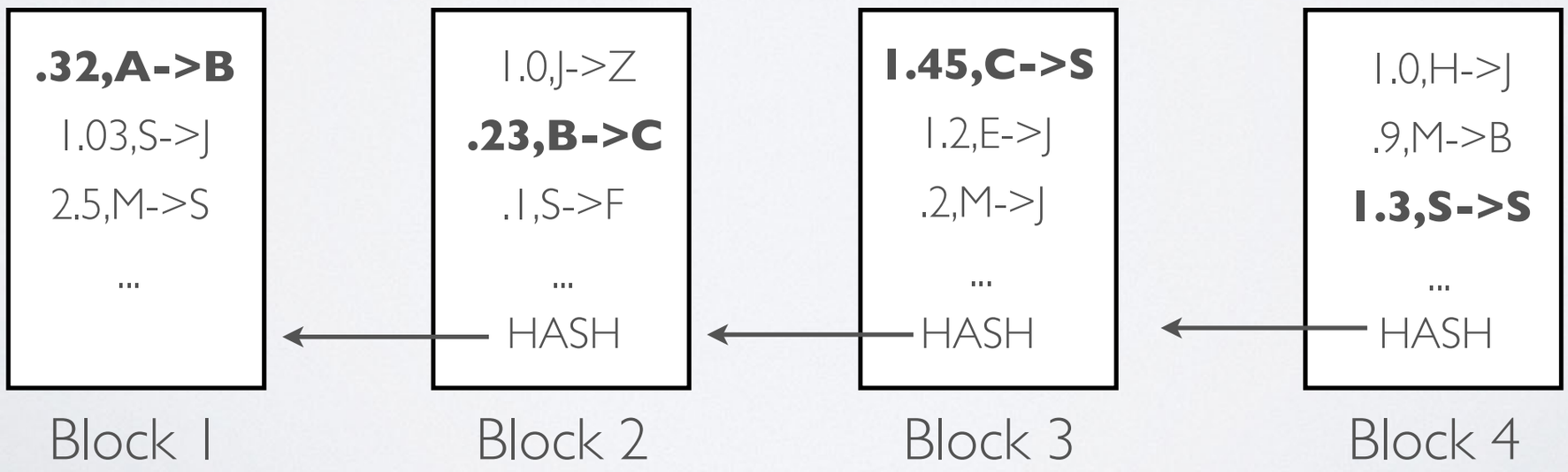
Annotated code from: https://medium.com/@montedong/towards-cracking-crypto-kitties-genetic-code-629fcd37b09b

- Decentralized exchanges
  - Allow you to trade Ethereum-native tokens (e.g., ERC20 tokens)
  - If you could perform a "swap" from another blockchain to an Ethereum token, then you could trade that currency too
- What problems come up here?

Anonymity

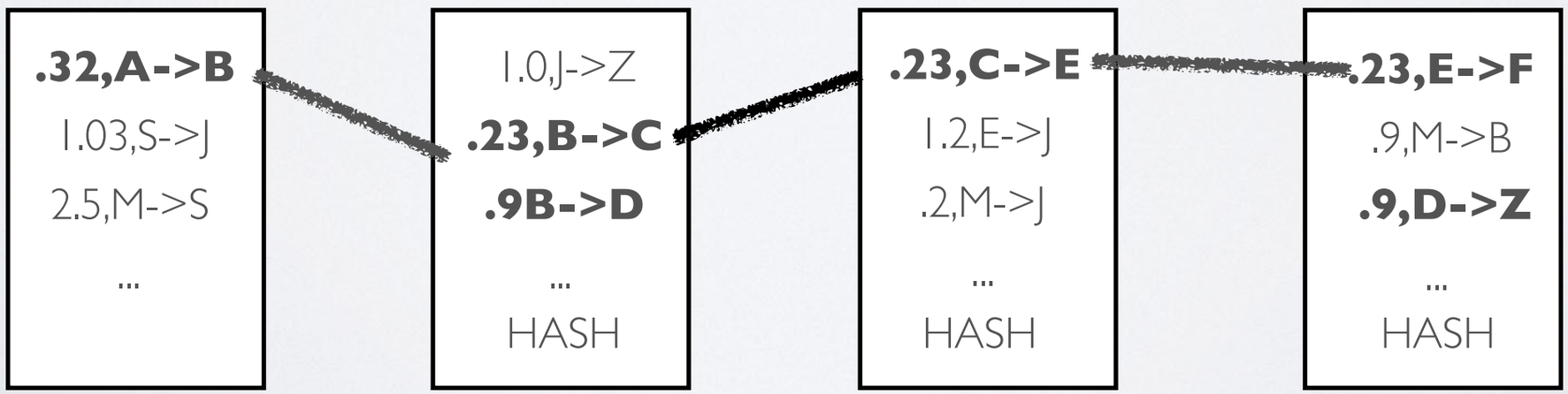
Bitcoin: review

- Bitcoin's core innovation is the blockchain
  - A decentralized append-only ledger (divided into 'blocks' of many transactions)
  - Massively replicated
- Everyone can download and see transactions



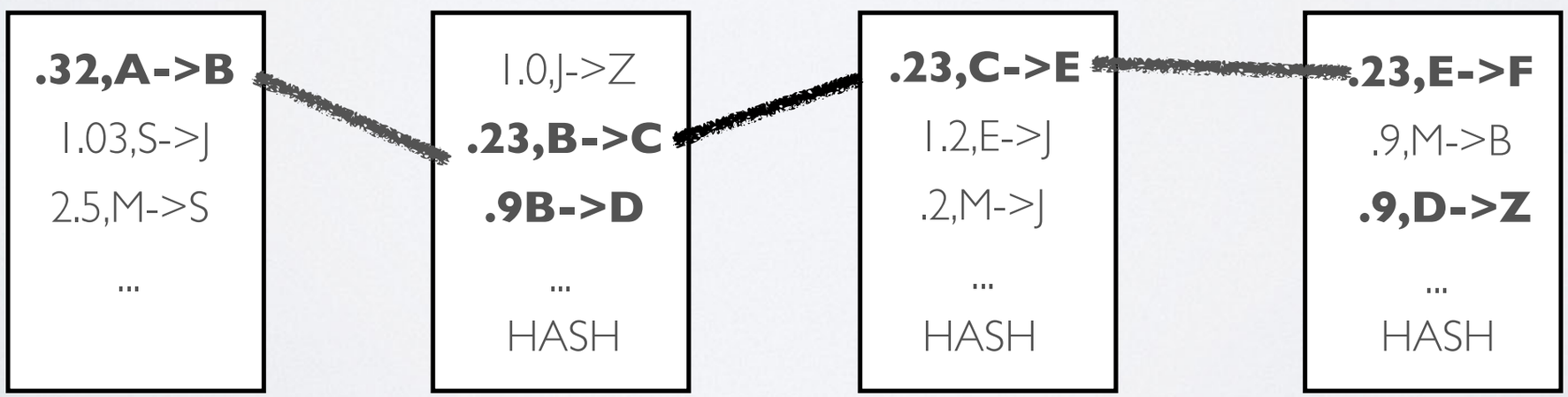
Bitcoin privacy

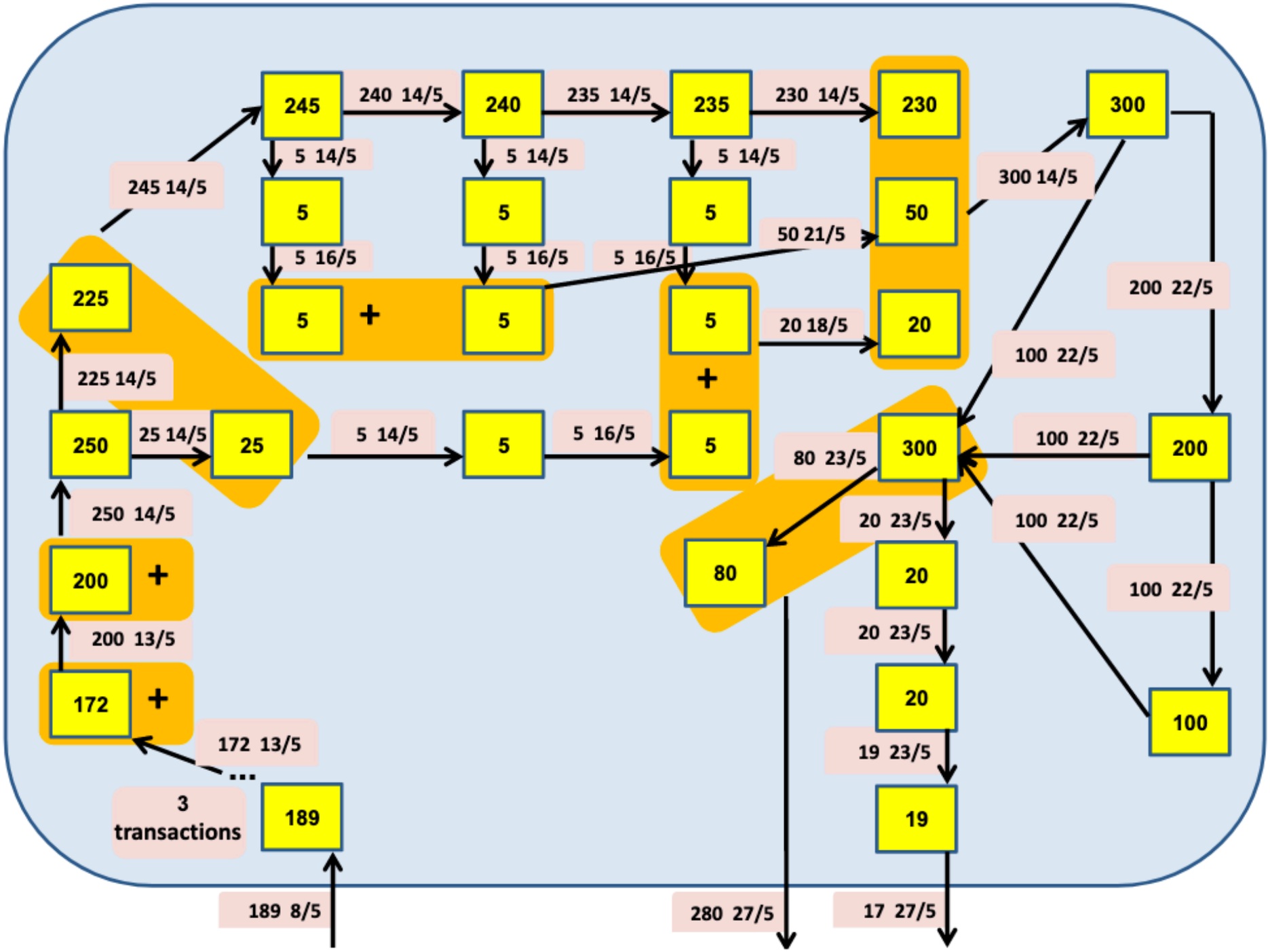
- **Disadvantage: Bitcoin is not very anonymous**
  - All these transactions are visible to the world, your neighbors, etc.
  - If people can link you to your address, you're screwed
  - How does one address this?



What does it matter?

- Threats range from privacy loss to extortion
- Other concrete threats:
    - allows front-running on trades
    - transaction censorship by miners

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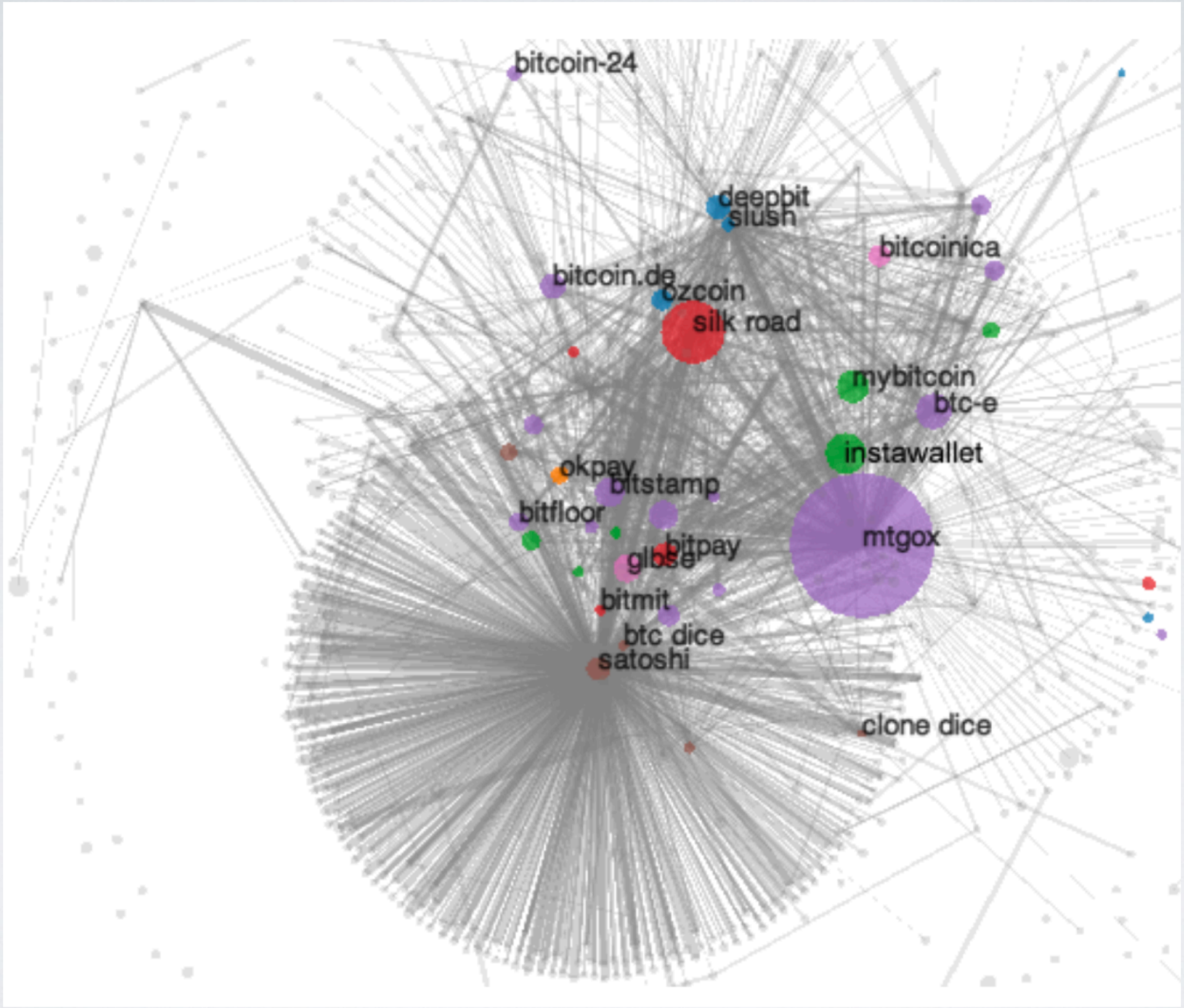
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deepbit
slush
bitcoinica
bitcoin.de
ozcoin
silk road
mybitcoin
btc-e
instawallet
okpay
bitstamp
bitfloor
mtgox
bitpay
globe
bitmit
btc dice
satoshi
clone dice

Coinbase, one of the first "Bitcoin Unicorns," faced major industry backlash after acquiring blockchain analysis firm Neutrino. | Source: Shutterstock

Coinbase Sought Neutrino After Losing Control Over Customer Data Being Sold

IN THE SUPREME COURT OF NOVA SCOTIA

IN THE MATTER OF:	Application by Quadriga Fintech Solutions Corp., Whiteside Capital Corporation and 0984750 B.C. Ltd. dba Quadriga CX and Quadriga Coin Exchange (collectively referred to as the "Applicants"), for relief under the Companies' Creditors Arrangement Act

43. The Applicants identified to the Monitor six (6) cold wallet addresses which Quadriga used in the past to secure bitcoin (the "**Identified Bitcoin Cold Wallets**"), the primary cryptocurrency traded on the Quadriga platform. The addresses of the Identified Bitcoin Cold Wallets identified by the Applicants are as follows:

(a) 1MhgmGaHwLAvvKVyFvy6zy9pRQFXaxwE9M;

(b) 1JPtxSGoekZfLQeYAWkbhBhkr2VEDADHZB;

(c) 1ECUQLuioJbFZAQchcZq9pggd4EwcpuANe;

(d) 1J9Fqc3TicNoy1Y7tgmhQznWrP5AVLXj9R;

(e) 1HyYMMCdCcHnfjwMW2jE4cv9qVkVDFUzVa; and

Bitcoin Address Addresses are identifiers which you use to send

Summary		Transactions		
Address	1MhgmGaHwLAvvKVyFvy6zy9pRQFXaxwE9M	No. Transactions	2111	
Hash 160	e31458ca4d933e612c97d9444a824fab6c7711c9	Total Received	14,073.11987636 BTC	
		Final Balance	19.54328527 BTC	

in the past to secure bitcoin (the "**Identified Bitcoin Cold Wallets**"), the primary

Summary		Transactions		
Address	1JPtxSGoekZfLQeYAWkbhBhkr2VEDADHZB	No. Transactions	1741	
Hash 160	becea8f53732df6354c6bf8cc8bdee6e77390f94	Total Received	12,436.02100587 BTC	
		Final Balance	33.19556316 BTC	

(c) 1ECUQLuioJbFZAQchcZq9pggd4EwcpuANe;

(d) 1J9Fqc3TicNoy1Y7tgmhQznWrP5AVLXj9R;

(e) 1HyYMMCdCcHnfjwMW2jE4cv9qVkVDFUzVa; and

Bitcoin Address Addresses are identifiers which you use to send

Summary	Transactions

4dd314417356d8f1f908724b7f77518c2bb45dad06ea70c7c8137325ea9de463 — **2019-02-06 17:24:07**

32GK5iiR47WSmB88FVYoNYgYj8JRdSzuBZ 3GHRJxQjKTV25bQhs8HSCdmRA19PZNBvtG 3KKxgqeK9XJkA2DGBvy2bux69cirPju2nv 3JZ7Lp3csarRZbSRVWtcGmHWJwwjh6QVZA 3NfVNUiY3Ykxas3ws2zJmCJikYMpv3aEvt 3JjqxJStfsNAbcV1cQmYiQTT6K1i9Mbgzv 35LHRCs3JLM8skEzusKkTPMACFPuKHYvhV 3B4jcfjuaUAZk3khbBcvFt1VMVB8WxDohM 3L8UtV59MrUmyoHozNDFuqz6SjQKTv1zis 38ACZBZPWprtEN8ZGbW1XxvJcFtGH1Hj3E	→	1JPtxSGoekZfLQeYAWkbhBhkr2VEDADHZB	0.60857038 BTC

0.60857038 BTC

4d0a8f0663b902c397198bcc06b44d24993056a47f6a4ddaa645843af7a5376f — **2019-02-06 17:21:18**

3K3pxgb2fFM6BAG2XvTnZNzptmXPSJjLAm 3DR9PddmHk1vE59RCRLvBBV2ZZKhKCQE6a 3Jrwdqr2qHcmcQQcSPTe9jQDEEhTHQWytD 31wySWG3iB7FN5L39RUnJzUk29MwBB1mbk 3LHWCTZ8hvLWMSASCpseDQa7Hk1g1k9Fmp 35gDrq7xK43Y5PUukPpJU3vWT8scGBU5bN 39m3QkS49vYjRMwMmAHSL6dNjB51WY5uaS 3Fj6QWJfdvfDvYzEggGvxcmfxsCAKD2WYE 39kQ5nqSPrgKgxvCzmQAUEmJDmzeEmkJwh 35EvkfcF2oRzYAhqmxbCCc1ECVhZyiasYK 35bohu2URxJWLNmWDQAmdaCoF5QZ6oq5cX 3BWbVZPX8xeAVD2j6dbY2ozYZw6r7xCWQK 32JeSgdHrUGZmmjsoTf5qouJXRtUvgyvgb 3QtBeESnsNqLCatzUtYfkQ5Fbrfe2kgv39	→	1JPtxSGoekZfLQeYAWkbhBhkr2VEDADHZB	2.80083949 BTC

(e) 1HyYMMCdCcHnfjwMW2jE4cv9qVkVDFUzVa; and

Electronic Cash (e-cash)

- Dates to Chaum [Chaum82] (many subsequent works)
  - Untraceable electronic cash
  - Withdraw 'coins' from a **central bank** (using blind signatures)
  - Even the bank can't track the coins

Blind signatures

- Allows a server ("signer") with a secret key to produce a signature for a user who has a message
  - Server does not learn the message being signed (blind)
  - User gets only one signature

Blind sign "Message"

signature(s)

Chaum (CRYPTO '83)

Payer

$\mathbf{SN}_\sigma$

(Blind) signature

sk

Bank

pk

Merchant

Redeem/
verify not previously
spent

"Textbook" RSA signature

- RSA signature:
  - Compute a public modulus N = pq,
    secret exponent "d", private exponent "e"
    Output $pk = (N, e), sk = d$
  - Signature: encode message as $m \in \{1, \ldots, N-1\}$
    compute signature $\sigma = m^d \ mod \ N$
  - Verify a message and signature using pk, as: $m = \sigma^e \ mod \ N$

Textbook RSA blind signature

- RSA blind signature:
  - Key generation is unchanged
  - User computes a random element *r*
    calculates $S = m \cdot r^e \mod N$
    sends *S* to server
  - Server computes: $S' = S^d \ mod \ N$
    sends *S'* back to user
  - User computes $\sigma = S' \cdot r^{-1}$

    Note: much more secure if m = Hash(message)!

Why doesn't e-Cash work (well) on a blockchain?

Why doesn't e-Cash work (well) on a blockchain?

- Lack of centralized issuer
  - Technology fundamentally relies on a bank that holds a secret key
    - Who is going to take on this role in a decentralized system?
      - Volunteer nodes come and go, and aren't trustworthy
      - Anyone with this key can make unlimited tokens
- Seems fundamentally problematic

Bitcoin privacy solutions (early)

- **Generate a new address for each transaction**
  - Hierarchical wallet (BIP32) makes this easy, "pluralizes" one secret "key" into many addresses
- Sounds good, except for "change":
  - Leftover funds from a spend have to go somewhere
  - If they go to a new address, this links the old/new addresses

Bitcoin privacy solutions (early)

- **Mixes/Laundry services**
  - Create a centralized server, many people send coins
  - Mixer shuffles those together, sends the right amount back to each user (less a fee), thus unlinking the sources of transactions
    - Risk 1: Mixer can "exit" and steal your cash
    - Risk 2: Mixer keeps track of the sources/destinations
    - Risk 3: Low volume of mixing can make tracing easy

Bitcoin privacy solutions (early)

- **CoinJoin**
  - Proposed by Maxwell; variants even earlier by "killerstorm" on BitcoinTalk*
    - Solves the "scamming mixer" problem
- Idea: each transaction has multiple inputs and outputs
  - Have a mixer author one single transaction that consumes N equal-value inputs, produces N outputs
  - All N parties then sign it

Bitcoin privacy solutions (early)

- **CoinJoin** (cont'd)
  - Idea is that if you trust the mixer to formulate the TX (keep your data private), the mixer can't steal your funds
  - Since this is a single (atomic) transaction, it either goes through completely or all funds remain untouched
  - Parties keep custody of their funds
  - Could combine with Chaumian e-cash to get privacy (e.g., TumbleBit)
    * https://bitcointalk.org/index.php?topic=150681.0

Mixes/Coinjoin weaknesses

- Philosophical questions…?
- Still requires some centralized server
- Anonymity set:
  - "Anonymity set" for a transaction refers to the number of transactions that could plausibly represent the previous link in a transaction graph
  - Mixes/Coinjoin: size *N* for *N* users in a given time period (assumes all users are honest. If they aren't: 😱)
  - Longer time periods mean larger *N*, but less convenient

Mixes/Coinjoin weaknesses

- Improving anonymity set size?
  - Can we combine multiple, sequential mixings/CoinJoins to increase the anonymity set size?
    - E.g., 2x N-size CoinJoins gives N^2 anonymity set
- Any weaknesses?

Decentralizing E-Cash

- The challenge:
  - Without a central bank we have no more **secret keys** which rules out digital signatures
- We need a fundamentally different ingredient.

Zerocoin (MGGR14)

- Proposed as an extension to Bitcoin in 2014
  - Requires changes to the Bitcoin consensus protocol!
- I can take Bitcoin from my wallet
- Turn them into ‘Zerocoins’
- Where they get ‘mixed up’ with many other users’ coins
- I can redeem them to a new fresh Wallet

Minting Zerocoin

- Zerocoins are just numbers
  - Each is a digital commitment to a random serial number
  - Anyone can make one!

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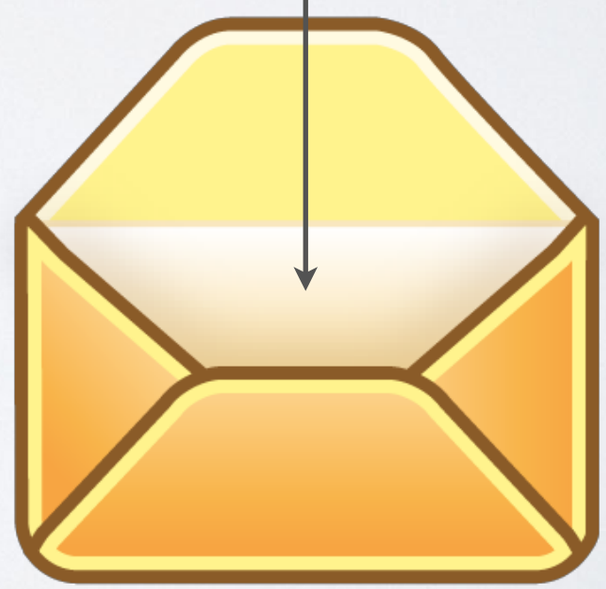

Minting Zerocoin

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  - Each is a digital commitment to a random serial number *SN*
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$$C = Commit(SN; r)$$

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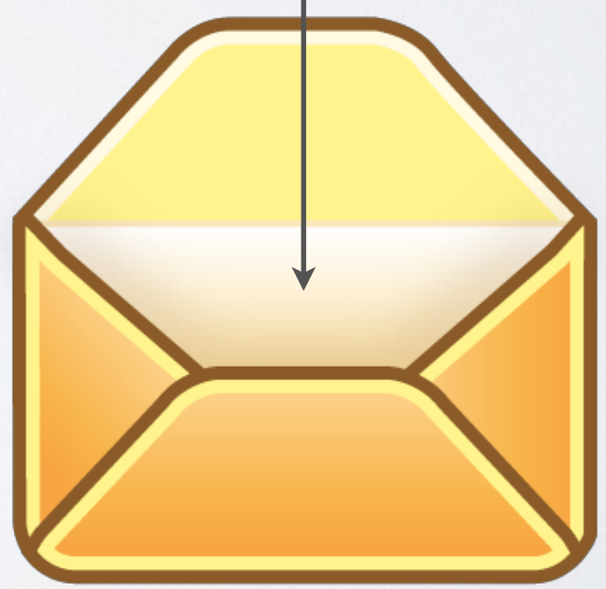
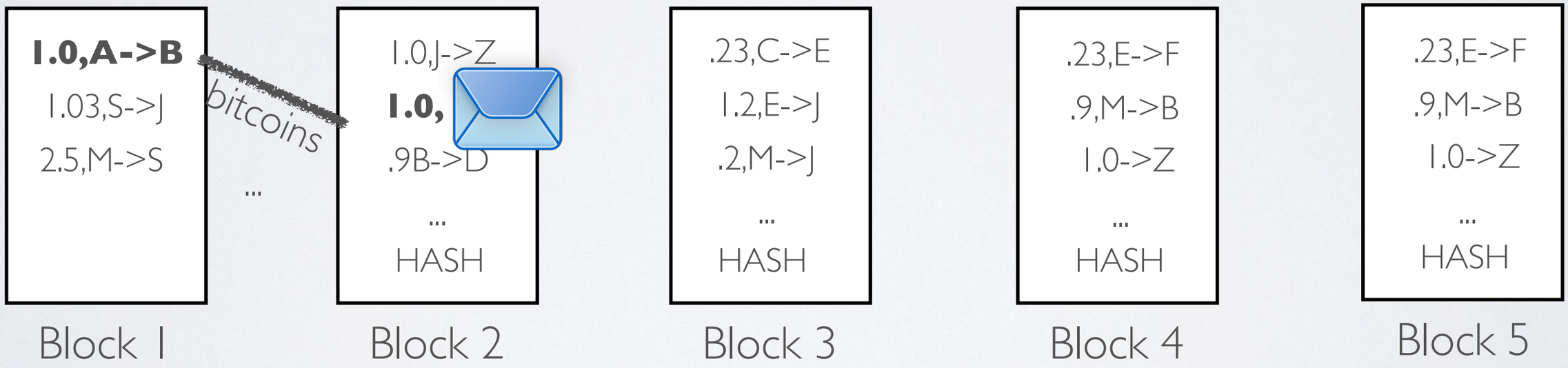


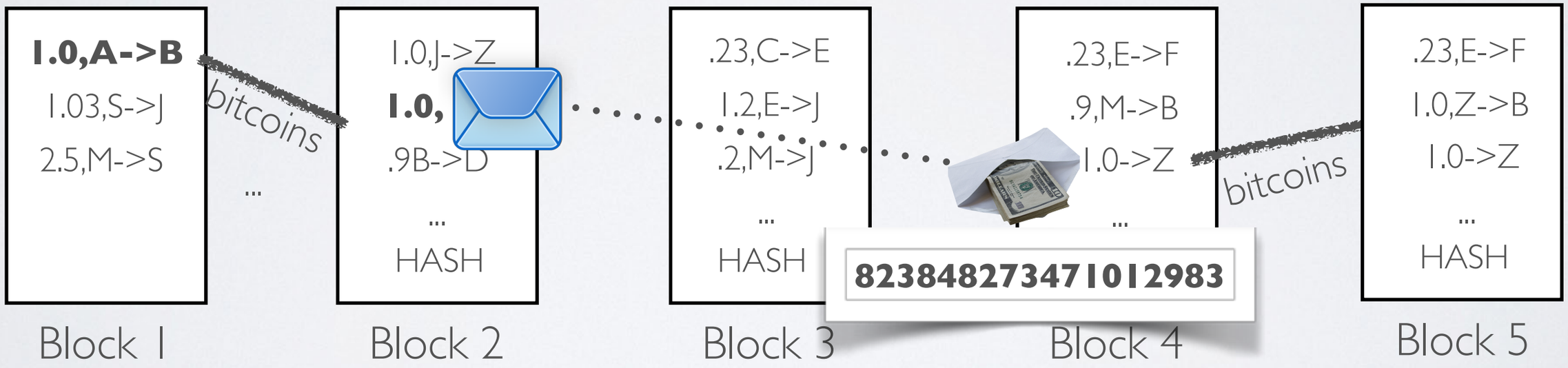
Minting Zerocoin

- Zerocoins are just numbers
  - They have value once you write them into a valid transaction on the blockchain
  - Valid: has inputs totaling some value e.g., 1 bitcoin



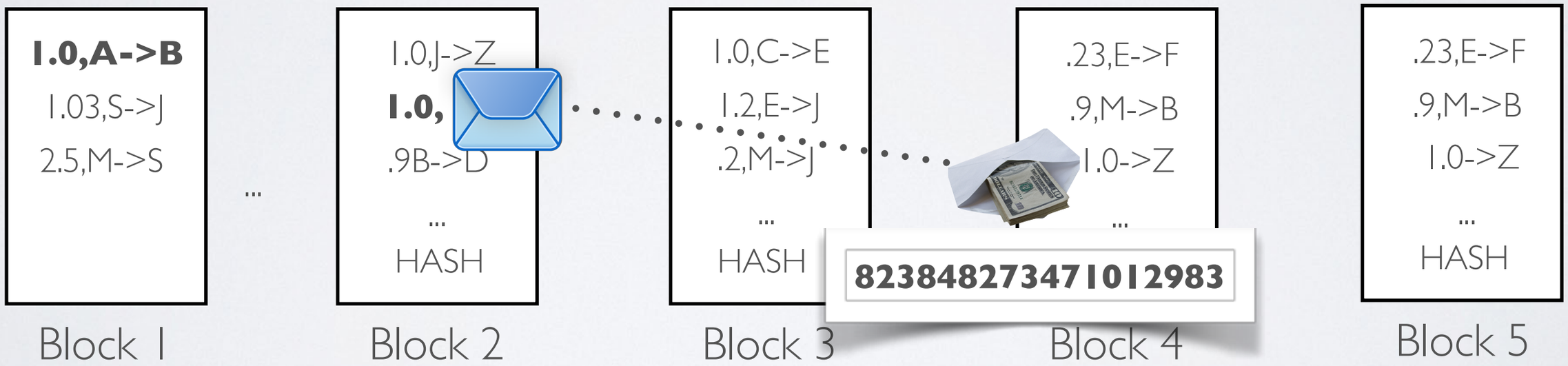
Redeeming Zerocoin

- You can redeem zerocoins back into bitcoins
  - Reveal the serial number &
    Prove that it corresponds to some Zerocoin on the chain
  - In exchange you get one bitcoin (if SN is not already used)



Spending Zerocoin

- Why is spending anonymous?
  - It's all in the way we 'prove' we have a Zerocoin
  - This is done using a zero knowledge proof



Spending Zerocoin

- Zero knowledge [Goldwasser, Micali 1980s, and beyond]
  - Prove a statement without revealing any other information
  - Here we prove that:
    (a) there exists a Zerocoin in the block chain
    (b) we just revealed the actual serial number inside of it
- Revealing the serial number prevents double spending
- The trick is doing this efficiently!

Spending Zerocoin

- Zero knowledge [Goldwasser, Micali 1980s, and beyond]
  - Prove a statement without revealing any other information (other than that a statement is true)

Spending Zerocoin

- Zero knowledge [Goldwasser, Micali 1980s, and beyond]
  - Prove a statement without revealing any other information
  - Here we prove that:
    (a) there exists a Zerocoin (commitment) in the block chain
    (b) the thing we revealed is the opening to that commitment
  - Revealing the serial number prevents double spending
  - The trick is doing this efficiently!

Spending Zerocoin

- Possible proof statement (not efficient, see CryptoNote):
  - Public values: list of Zerocoin commitments $C_1, C_2, \ldots, C_N$
    Revealed serial number *SN*
    - Prove you know a coin *C* and randomness *r* such that:

$$C = C_1 \ \vee \ C = C_2 \ \vee \ \ldots \ \vee \ C = C_N$$
$$\wedge \ C = Commit(SN; r)$$

- Problem: using standard techniques, this ZK proof has cost/size O(*N*)

Spending Zerocoin

- Zerocoin (actual protocol)
  - Use an efficient RSA one-way accumulator
  - Accumulate $C_1, C_2, \ldots, C_N$ to produce a short value A
  - Then prove knowledge of a short witness s.t. $C \in inputs(A)$
  - And prove knowledge that C opens to the serial number

Requires a DDL proof (**~25kb**)
for each spend. In the block chain.

Spending Zerocoin

- Zerocoin (actual protocol)
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CryptoNote & RingCT

- 2012: CryptoNote
  - Originally launched as part of the ByteCoin currency, predates Zerocoin
  - Anonymous creators, did a pre-mine
  - Was forked multiple times into many different currencies, including bitmonero -> Monero
  - Protocol ideas later improved into RingCT, which hid amounts as well as inputs (used in Monero today)

CryptoNote idea

- Each transaction lists a set of N inputs (all same value).
- One is the real input, and N-1 are "cover traffic", AKA "mixins"
  - A ZKP proves that that the transaction creator has a key to one of the input transaction, but not *which one*
    - *This requires a proof ("ring signature") of size O(N)*
- Post proof plus a "key image" (function of the secret key) to prevent that transaction being spent twice

RingCT idea

- Extends this idea to support variable-value transactions
- Add to the commitment a transaction value *V*

$$C = Commit(SN \| V; r)$$

- Encrypt the commitment and randomness under a recipient's public key, store the ciphertext on the chain

$$Ciph = \mathsf{Encrypt}(pk, SN \| r \| V)$$

- Must also prove that the output value of the next commitment is less than or equal to input transaction(s)

Anonymity set comparison

- Anonymity set in CoinJoin:
  - **M**: where **M** is number of inputs in the transaction (bounded by TX size)
- Anonymity set in ByteCoin/RingCT:
  - **N**: where **N** is the number of inputs allowed in a transaction (bounded by TX size, 7-11 historically)
- Anonymity set in Zerocoin:
  - **P**: where **P** is number of total Zerocoins minted on the blockchain thus far* (independent of TX size)

Next time

- So far we've given a very high level view of Zerocoin, CryptoNote/RingCT
  - Next time we'll talk about Zerocash (Zcash) and MimbleWimble
- As well as other online techniques like Tumblebit