A Fistful of Bitcoins: Characterizing Payments Among Men with No Names

Sarah Meiklejohn (UC San Diego)
Marjori Pomarole (UC San Diego)
Grant Jordan (UC San Diego)
Kirill Levchenko (UC San Diego)
Damon McCoy (George Mason University)
Geoff Voelker (UC San Diego)
Stefan Savage (UC San Diego)

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CHART OF THE DAY: Bitcoin Is Going Totally Parabolic Again

MATTHEW BOESLER | OCT. 23, 2013, 4:09 PM | 2,347 | 2

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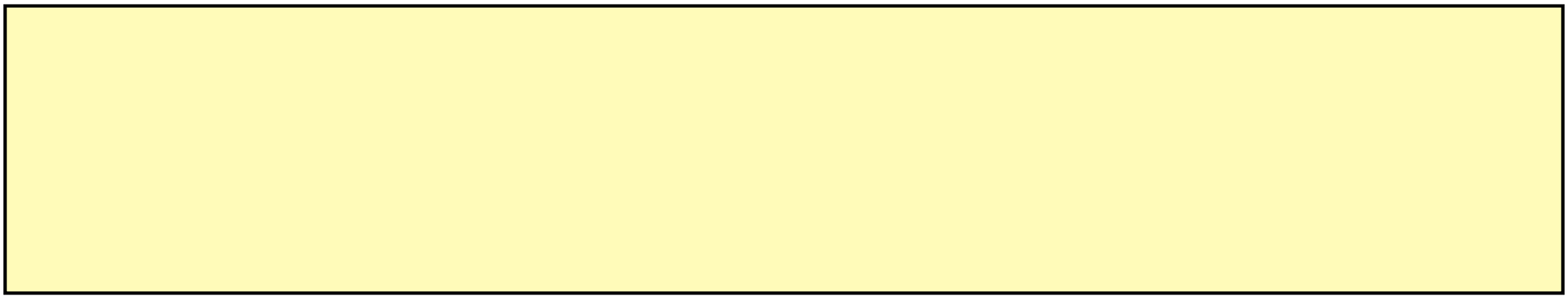

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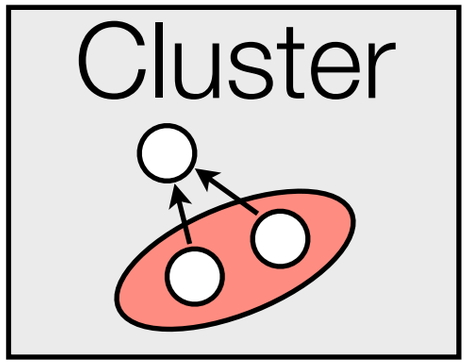

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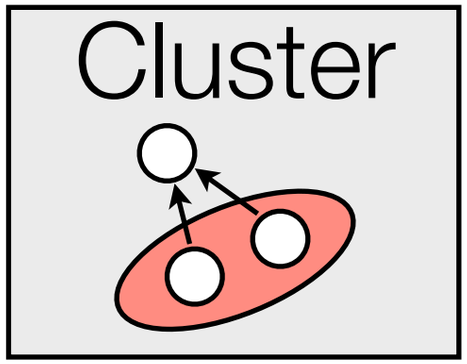

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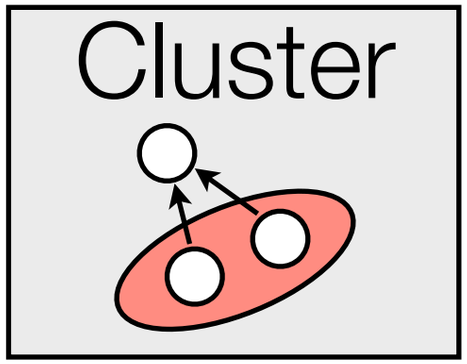

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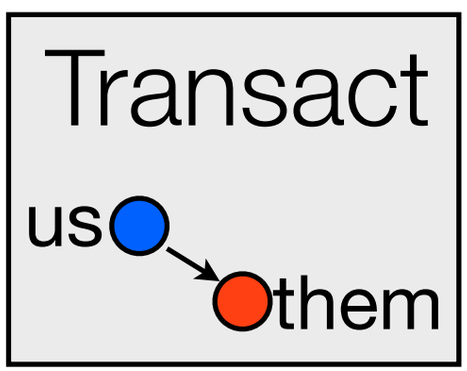

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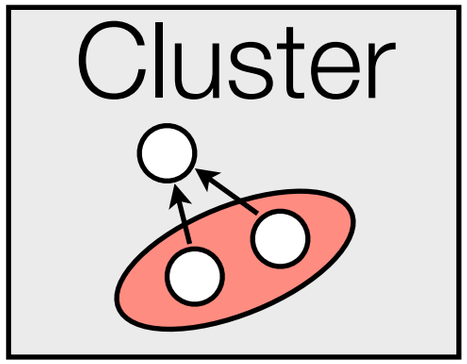

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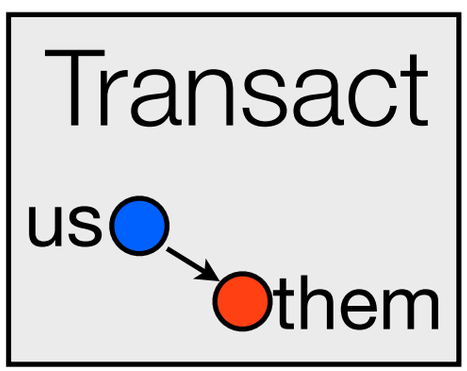

Combine these techniques to de-anonymize flows of bitcoins

Outline

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How does Bitcoin work?

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How does Bitcoin work?

Analysis

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How does Bitcoin work?

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Results

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How does Bitcoin work?
Public keys
Transactions
Blocks

Analysis

Results

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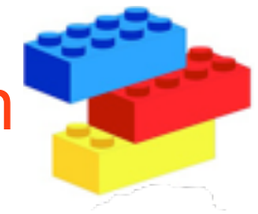
Components of Bitcoin

Components of Bitcoin

The global transaction ledger is called the block chain



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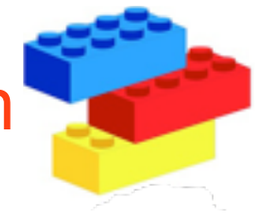
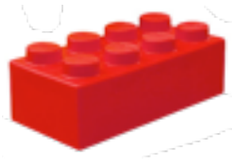
The global transaction ledger is called the block chain 

A block is a collection of transactions 

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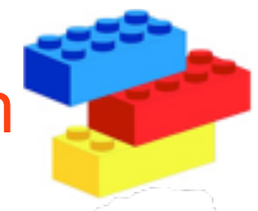
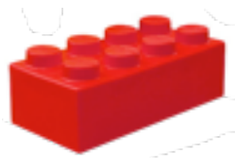
The global transaction ledger is called the block chain 

A block is a collection of transactions 

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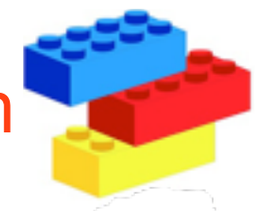
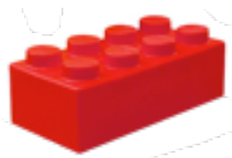
The global transaction ledger is called the block chain 

A block is a collection of transactions 

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A pseudonym is the hash of an ECDSA public key; owner possesses the corresponding secret key

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Transactions form a chain

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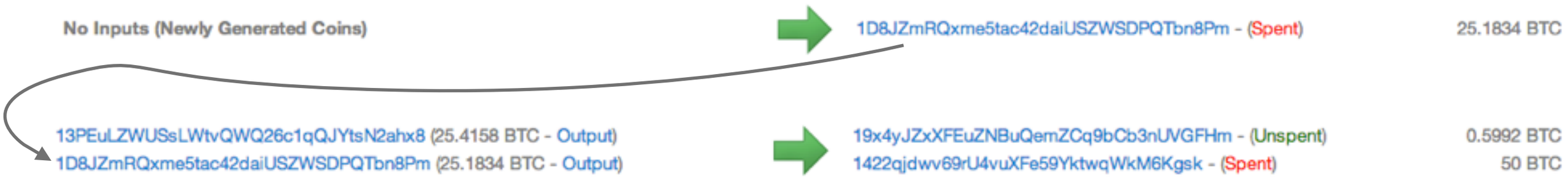

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Each transaction must reference a previous transaction, so all bitcoins received must be spent all at once

Outline

How does Bitcoin work?

Analysis
Clustering addresses
Naming clusters

Results

Conclusions

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Users can use arbitrarily many public keys (pseudonyms); as a result the Bitcoin graph is complicated and has 12 million public keys

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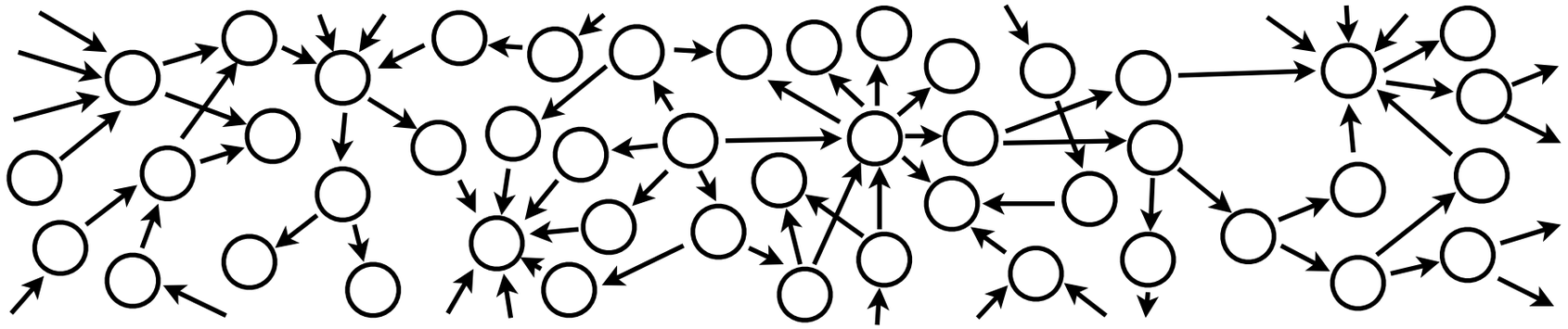

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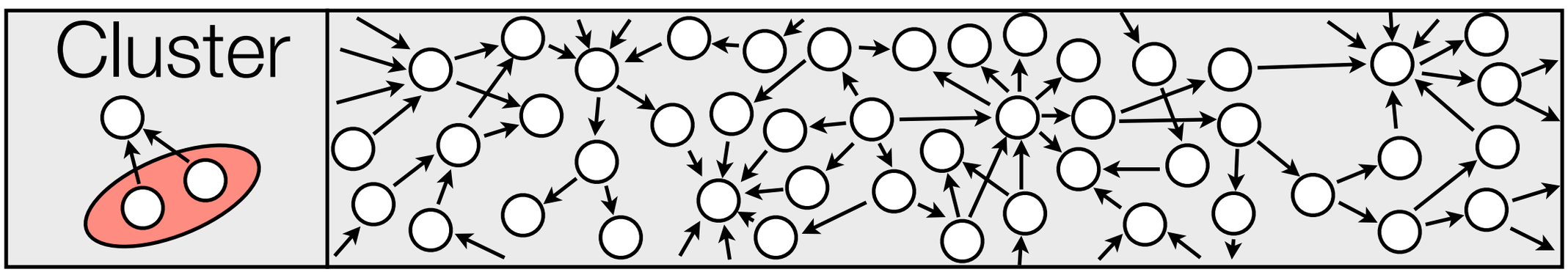

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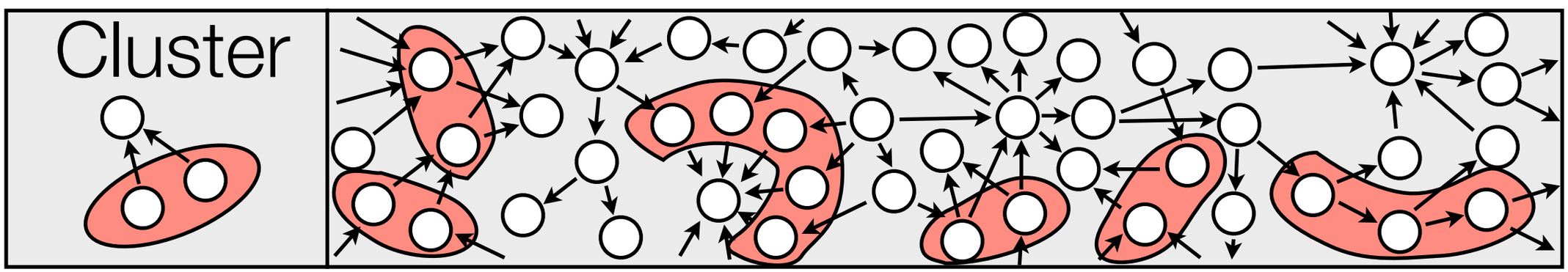

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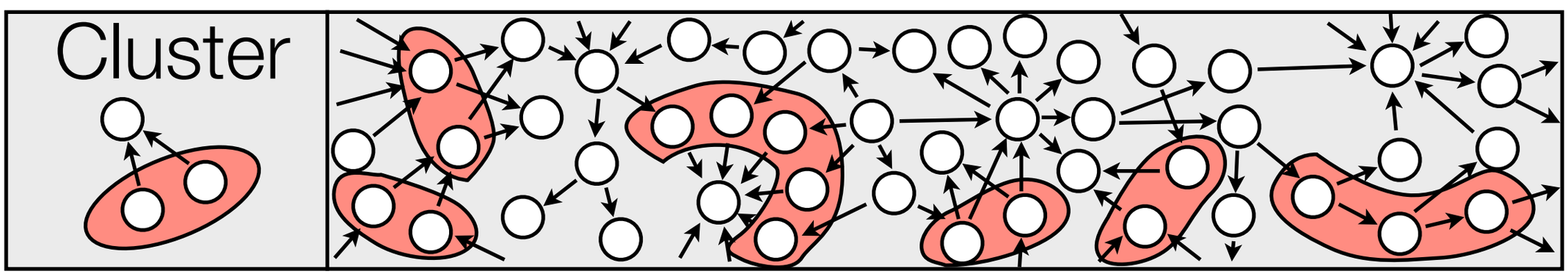

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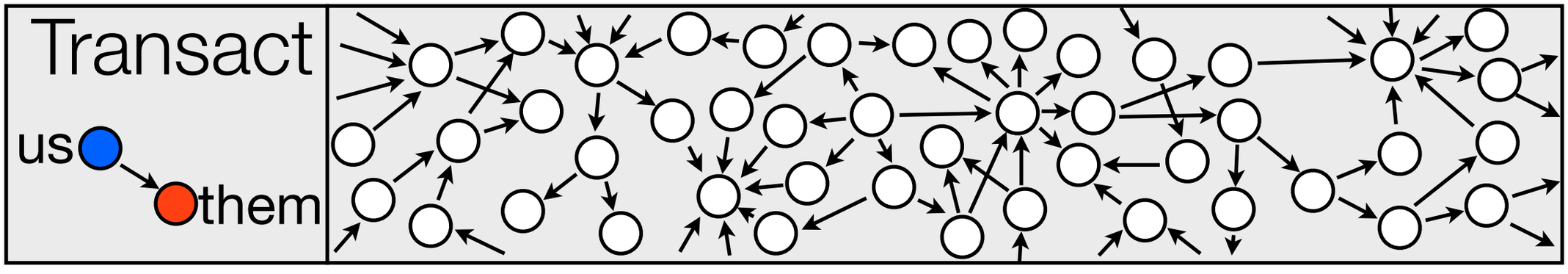

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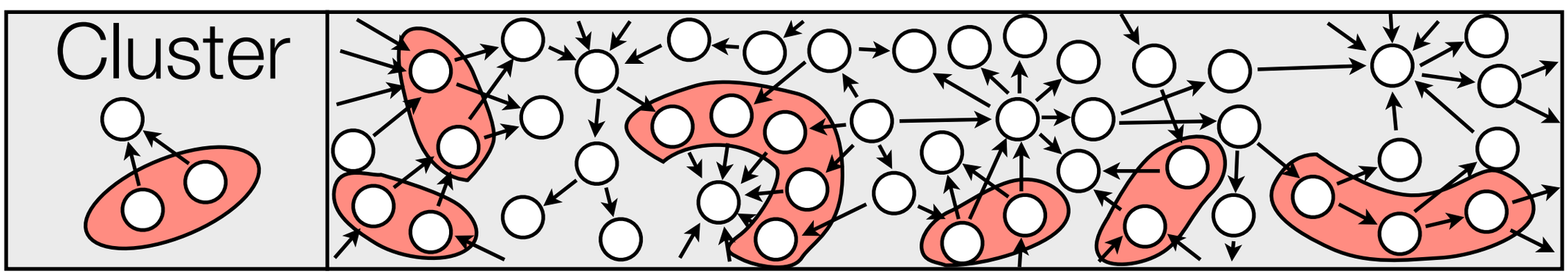

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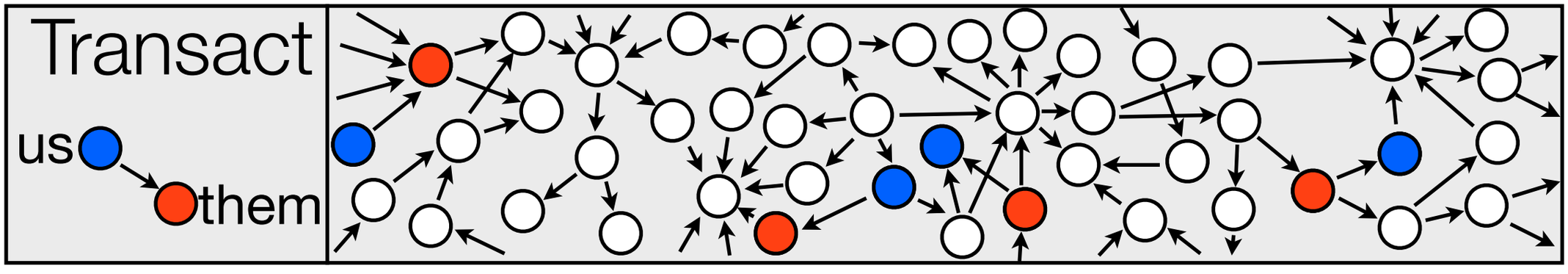
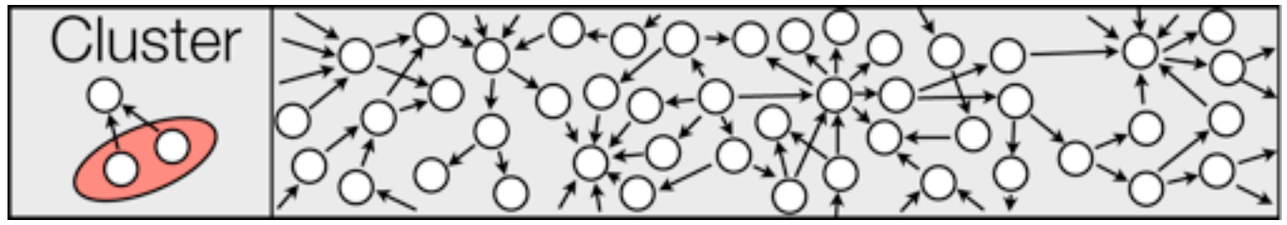


Collect ground truth data by participating in transactions

Clustering by inputs



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16H9oN1JFXSHEv16X8PLeS77MMF3EKqEiH (30.28851 BTC - Output)
17RHwSeN5Ky8gGwTHCH8j4mZH3eqQNbrav (30.58936 BTC - Output)
13b78oU4oCid4gQw87bvUMUZ1XpnZqwNQ1 (12.9148 BTC - Output)
16BzfEpwF9P6ULmmMcbdag3m2ZaETGgwYN (29.55 BTC - Output)
1CusinkMvW53WtupuspCMDyi8gZ2sb13zv (30.28851 BTC - Output)
1PXA5YNC2MWYtssfsBTBPMWXW8cDkPuMTB (30.28851 BTC - Output)
1Gg2D33ySPndnSELBnmze1QsmycSdeGVkX (30.28851 BTC - Output)
1FdPwjg7XJfrEqdQnduusg2K51UuJDACCi (30.28851 BTC - Output)
178AKou6Q2741uPqt9FQfB26ZUK16f3yDt (29.36578 BTC - Output)
1LZe2eSEKr8ik6ja8k8YNSh1amR2czmwwe (30 BTC - Output)
16ah8vzFqtnyCPtp57Y55bkXwSot7Bd3ic (29.84 BTC - Output)
1Dn92DXHrPNVH7EMrD5oawDedWdk43Jjkk (29.83951 BTC - Output)
1NvC4vQVbwJUjXWHBHKiGKAmKRMkRKe7gv (30.13 BTC - Output)
14kSwoX2cPkwRtKW5KTwBFGtraYpXrYckW (99.45 BTC - Output)
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1KRMiP4uLyy2hm86MRRQv4ghkQthVK6BH6 (29.6 BTC - Output)

1Z9ADFwVMZvgjN3HoNf91XoT2Lpth559F - (Spent) 0.01001 BTC
17iCsx5w55KcNdCRRp9xXFDcMU7btNhqpm - (Unspent) 675 BTC

6 Confirmations | 675.01001 BTC

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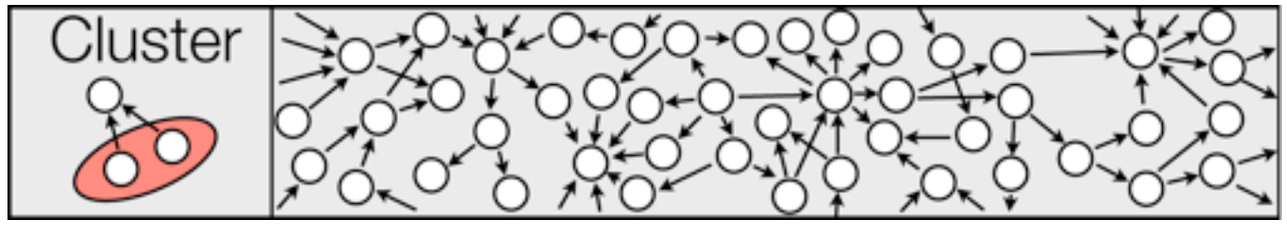

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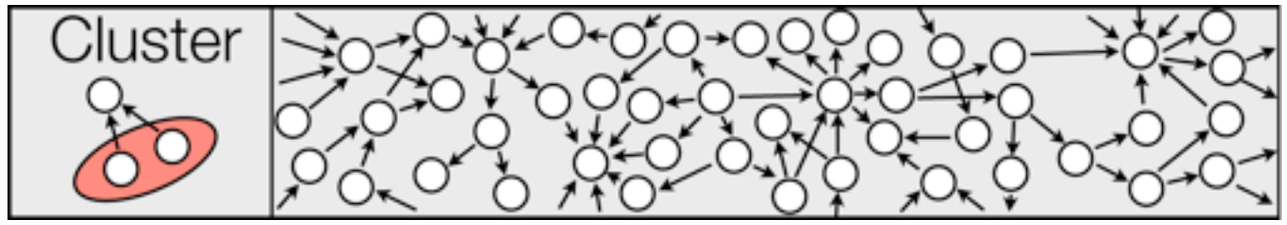

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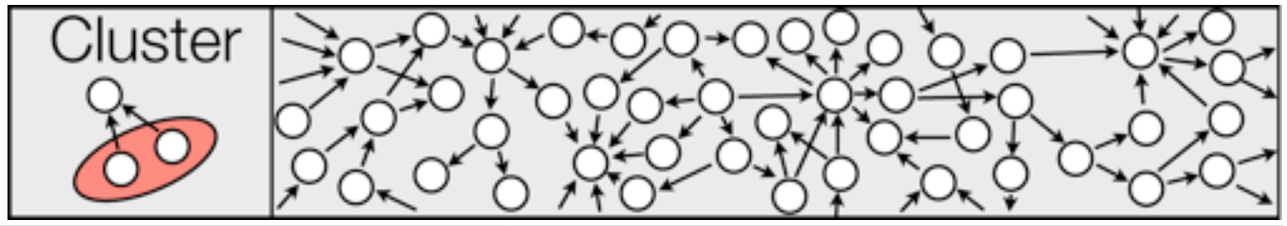
Heuristic #1: the same user controls these addresses

Heuristic 1: enough?



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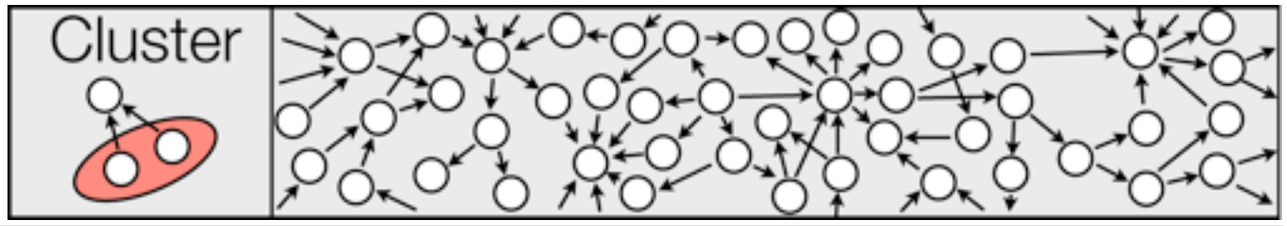

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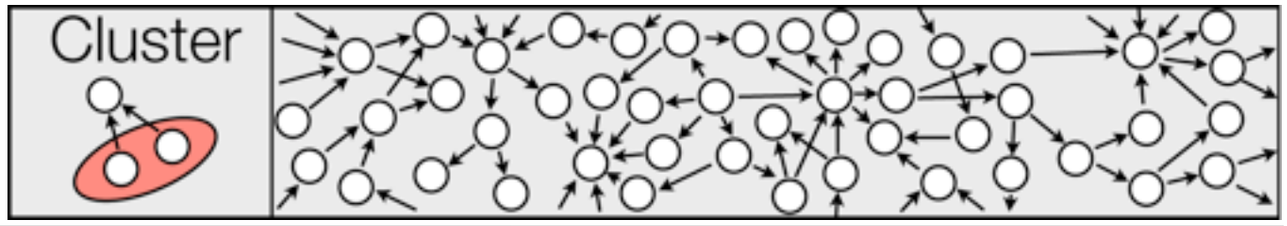

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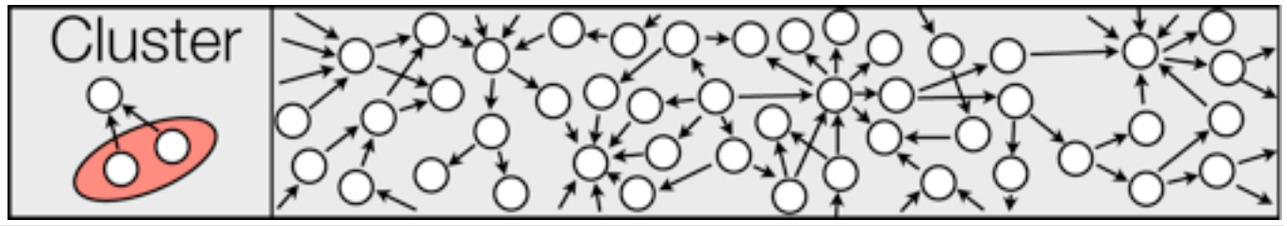

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Already yields a fairly robust graph: 5.5 million distinct clusters

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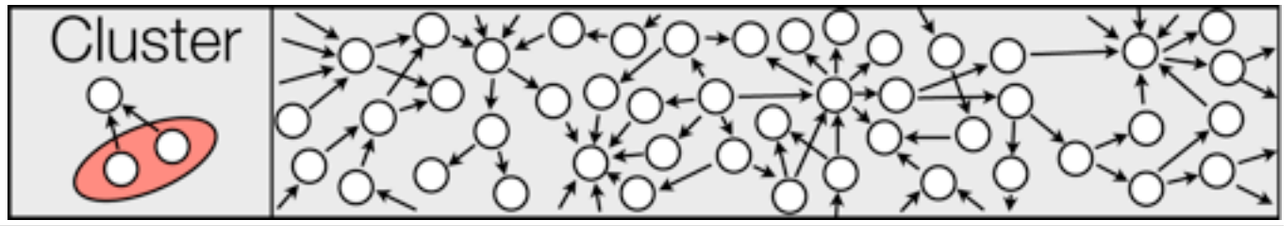

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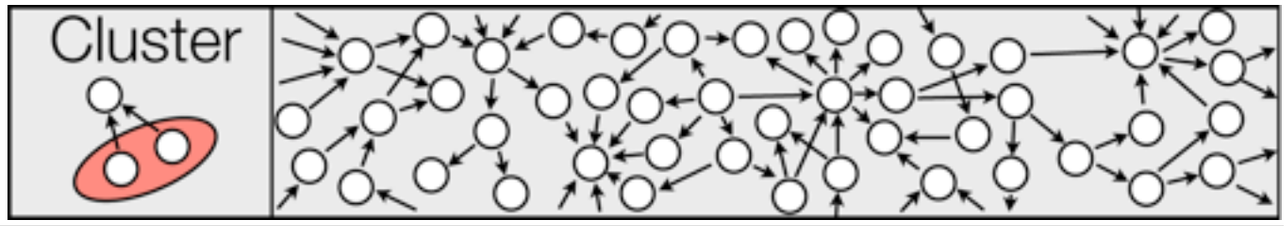
Already yields a fairly robust graph: 5.5 million distinct clusters

Our goal is to track flows of bitcoins

Heuristic 1: enough?



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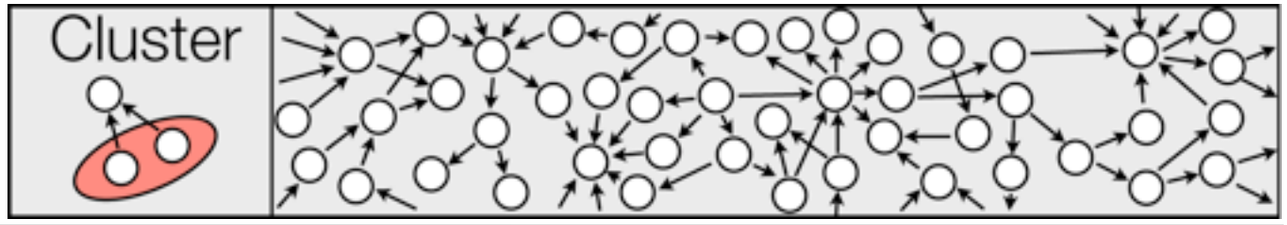
This is established: has been used before [RH13,RS13,A+13] and even acknowledged by Satoshi himself

Already yields a fairly robust graph: 5.5 million distinct clusters

Our goal is to track flows of bitcoins

Lots of flow remains in these clusters because of change addresses

Change addresses

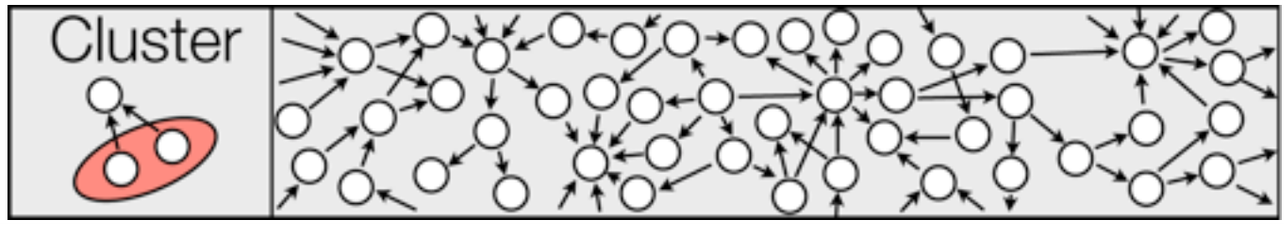


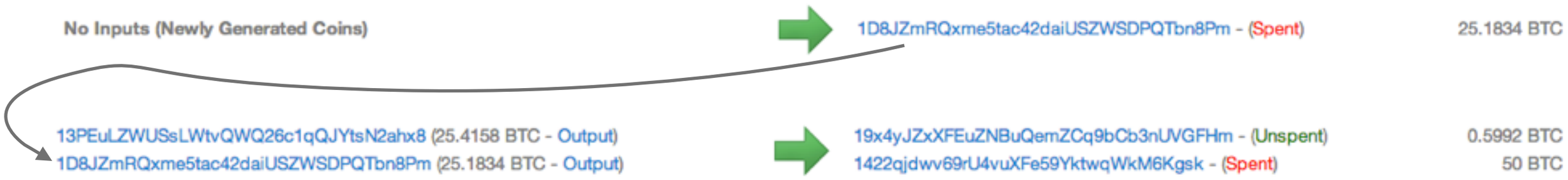
No Inputs (Newly Generated Coins) → 1D8JZmRQxme5tac42daiUSZWSDPQTbn8Pm - (Spent) 25.1834 BTC

13PEuLZWUSsLWtvQWQ26c1qQJYtsN2ahx8 (25.4158 BTC - Output) → 19x4yJZxXFEuZNBuQemZCq9bCb3nUVGFHm - (Unspent) 0.5992 BTC

1D8JZmRQxme5tac42daiUSZWSDPQTbn8Pm (25.1834 BTC - Output) → 1422qjdwv69rU4vuXFe59YktwqWkM6Kgsk - (Spent) 50 BTC

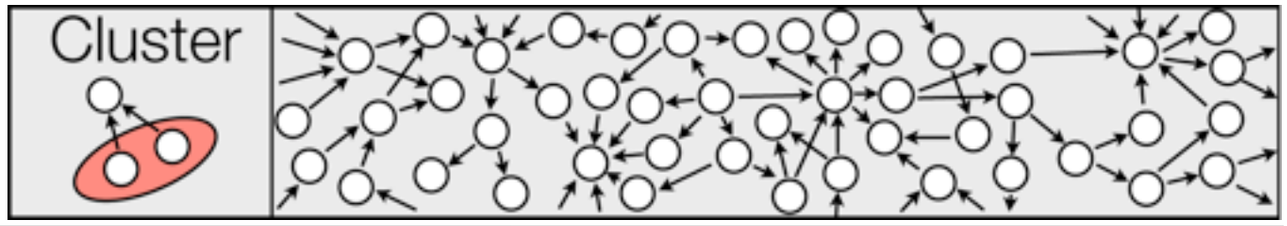
Change addresses

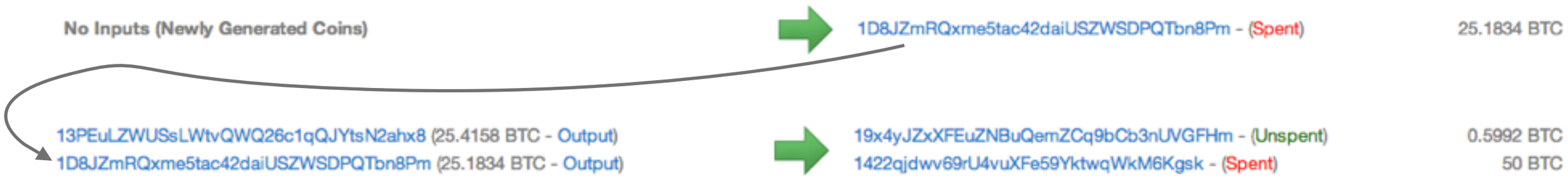




Each transaction must reference a previous transaction, so all bitcoins received must be spent all at once

Change addresses

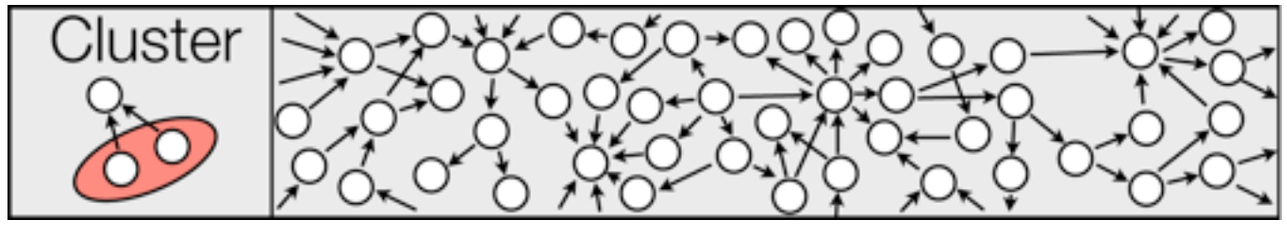


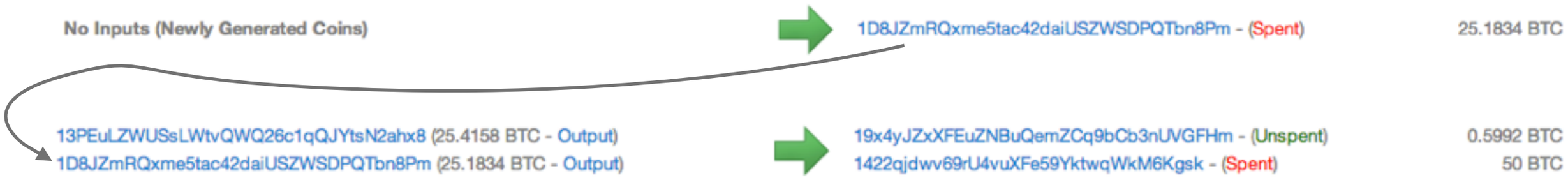


Each transaction must reference a previous transaction, so all bitcoins received must be spent all at once

Change address: used to collect excess bitcoins

Change addresses



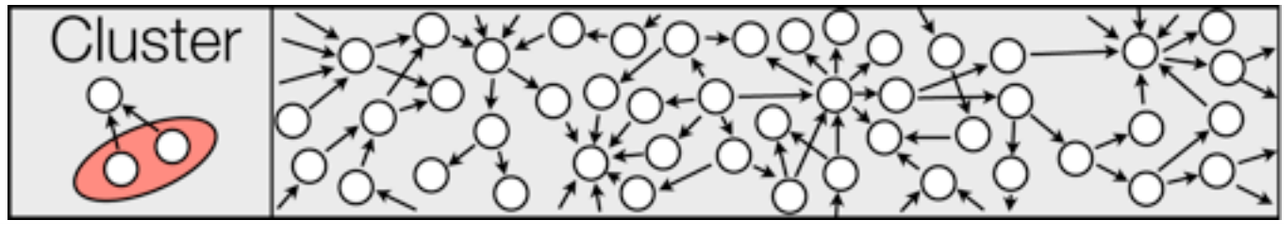


Each transaction must reference a previous transaction, so all bitcoins received must be spent all at once

Change address: used to collect excess bitcoins

In the standard client, change addresses are used at most twice: to receive and to spend

Clustering by change



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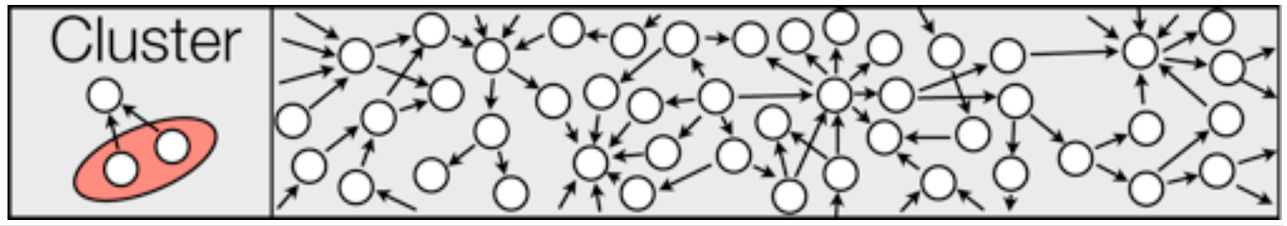
142Z7VauMVdSV5DADb62DsJ7wvW9ccq18t (30.28851 BTC - Output)
16H9oN1JFXSHEv16X8PLeS77MMF3EKqEiH (30.28851 BTC - Output)
17RHwSeN5Ky8gGwTHCH8j4mZH3eqQNbrav (30.58936 BTC - Output)
13b78oU4oCid4gQw87bvUMUZ1XpnZqwNQ1 (12.9148 BTC - Output)
16BzfEpwF9P6ULmmMcbdag3m2ZaETGgwYN (29.55 BTC - Output)
1CusinkMvW53WtupuspCMDyi8gZ2sb13zv (30.28851 BTC - Output)
1PXA5YNC2MWYtssfsBTBPMWXW8cDkPuMTB (30.28851 BTC - Output)
1Gg2D33ySPndnSELBnmze1QsmycSdeGVkX (30.28851 BTC - Output)
1FdPwjg7XJfrEqdQnduusg2K51UuJDACCi (30.28851 BTC - Output)
178AKou6Q2741uPqt9FQfB26ZUK16f3yDt (29.36578 BTC - Output)
1LZe2eSEKr8ik6ja8k8YNSh1amR2czmwwe (30 BTC - Output)
16ah8vzFqtnyCPtp57Y55bkXwSot7Bd3ic (29.84 BTC - Output)
1Dn92DXHrPNVH7EMrD5oawDedWdk43Jjkk (29.83951 BTC - Output)
1NvC4vQVbwJUjXWHBHKiGKAmKRMkRKe7gv (30.13 BTC - Output)
14kSwoX2cPkwRtKW5KTwBFGtraYpXrYckW (99.45 BTC - Output)
1AkMojTEiUXUa3f9SNjLZcvLtxY54wyC6n (141.9995 BTC - Output)
1KRMiP4uLyy2hm86MRRQv4ghkQthVK6BH6 (29.6 BTC - Output)

1Z9ADFwVMZvgjN3HoNf91XoT2Lpth559F - (Spent) 0.01001 BTC
17iCsx5w55KcNdCRRp9xXFDcMU7btNhqpm - (Unspent) 675 BTC

6 Confirmations | 675.01001 BTC

Clustering by change



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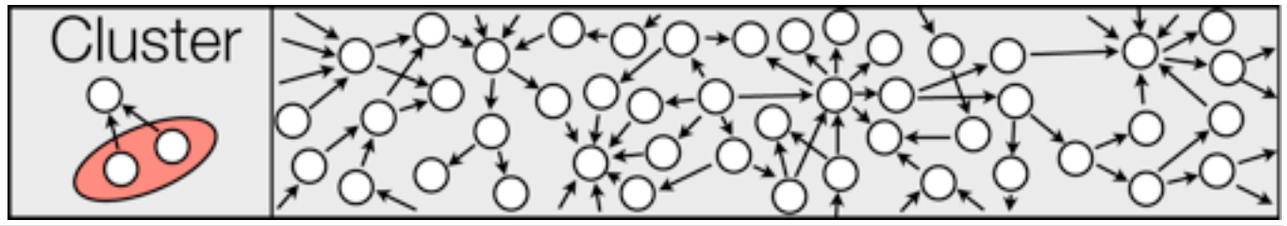

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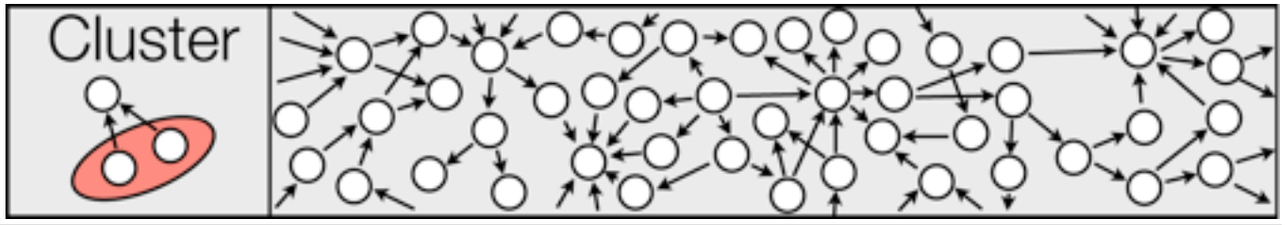
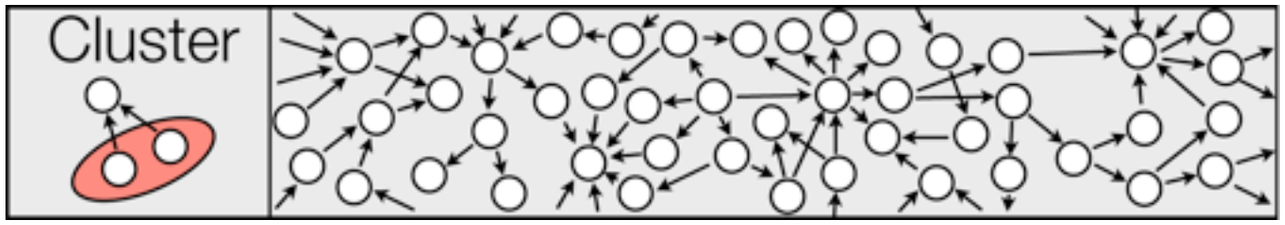
6 Confirmations | 675.01001 BTC

Heuristic #2: the same user also controls this address

Heuristic 2

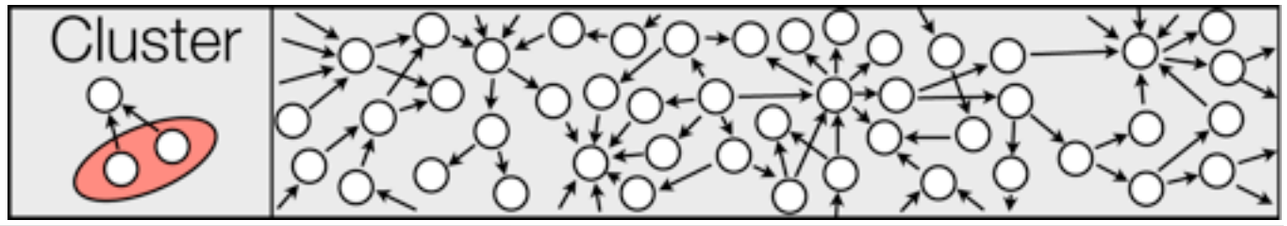


Heuristic 2



To identify change addresses, look for “one-time” output address

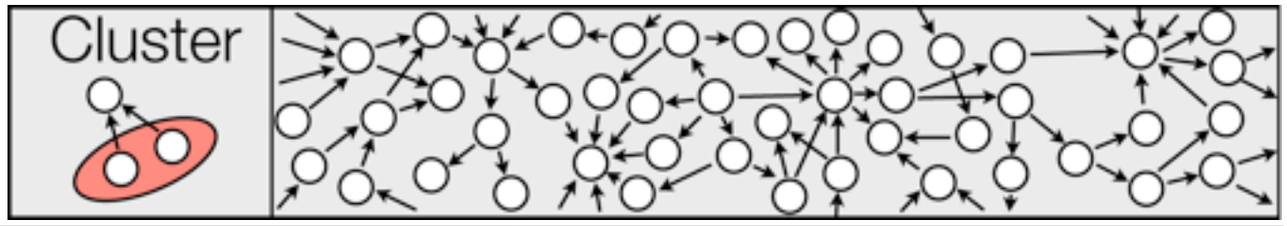
Heuristic 2



To identify change addresses, look for “one-time” output address

If there is exactly one such address, label it the change address

Heuristic 2

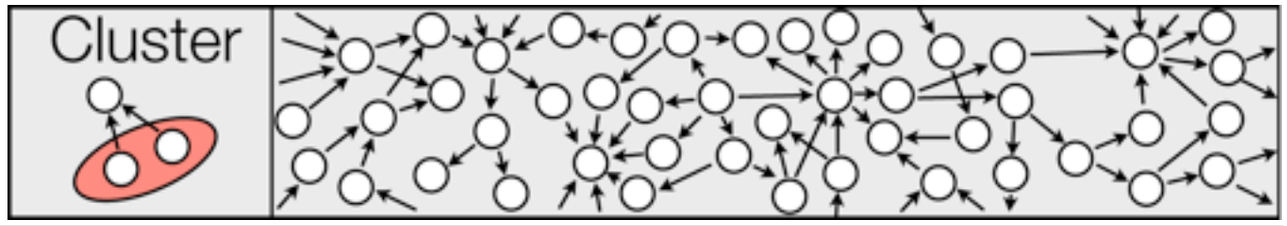


To identify change addresses, look for “one-time” output address

If there is exactly one such address, label it the change address

This isn’t conservative enough!

Heuristic 2



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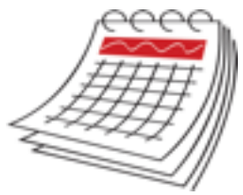
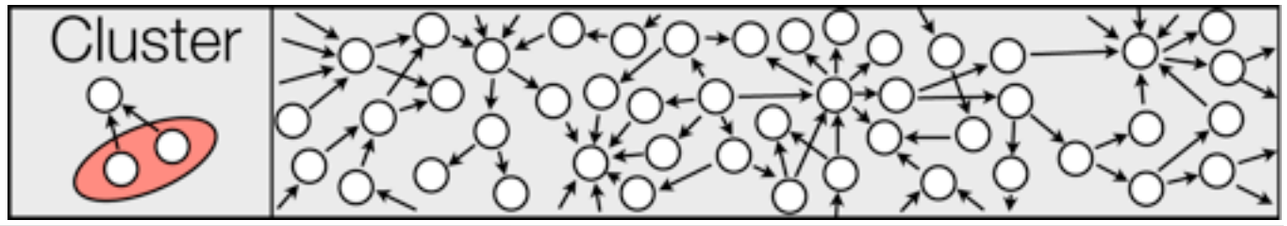
If there is exactly one such address, label it the change address

This isn’t conservative enough!

- Wait a week before identifying address 

Heuristic 2



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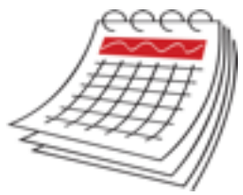
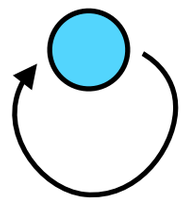
- Wait a week before identifying address 
- Ignore “self-change” addresses 

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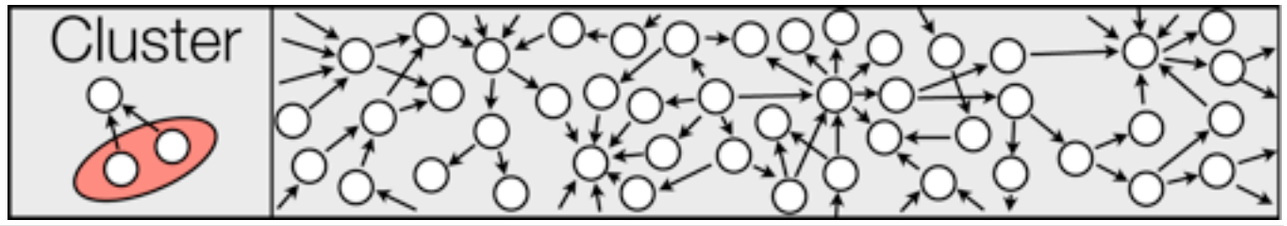

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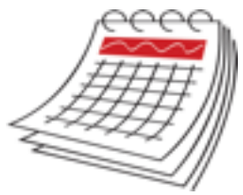
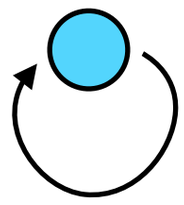
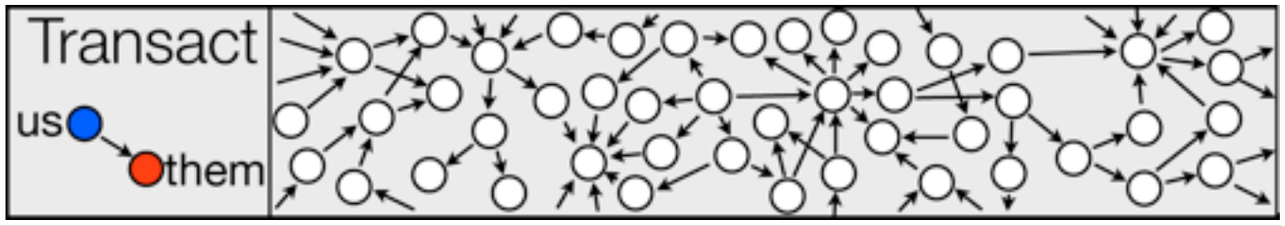
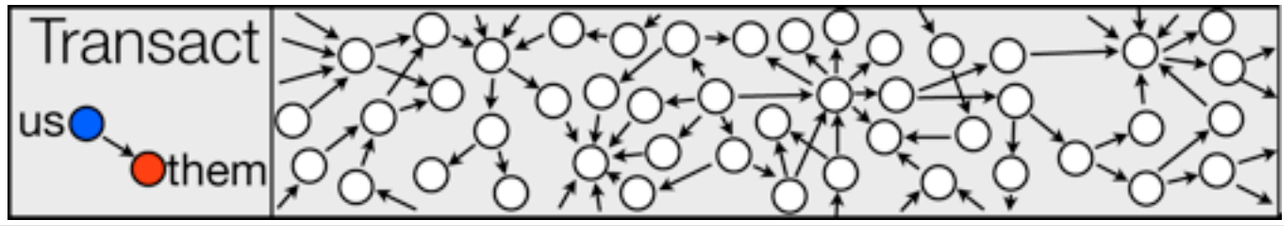
- Wait a week before identifying address 
- Ignore “self-change” addresses 
- Manually inspect some remaining addresses 

Data collection

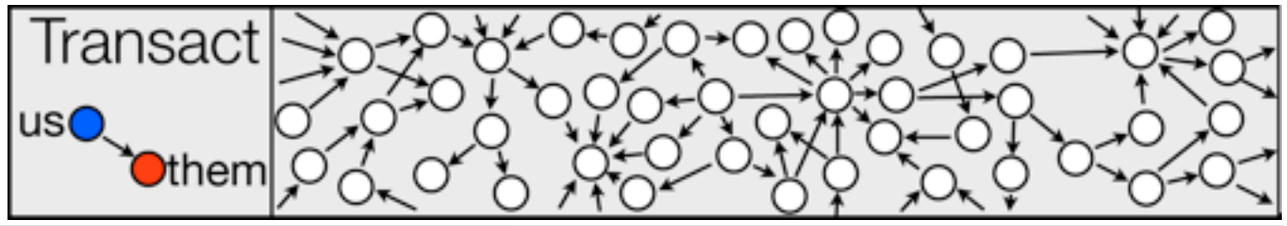


Data collection



Engaged in transactions with:

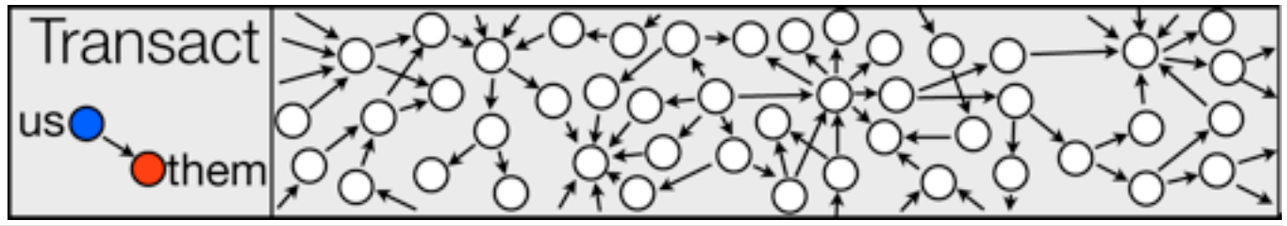
Data collection



Engaged in transactions with:

- Exchanges

Data collection

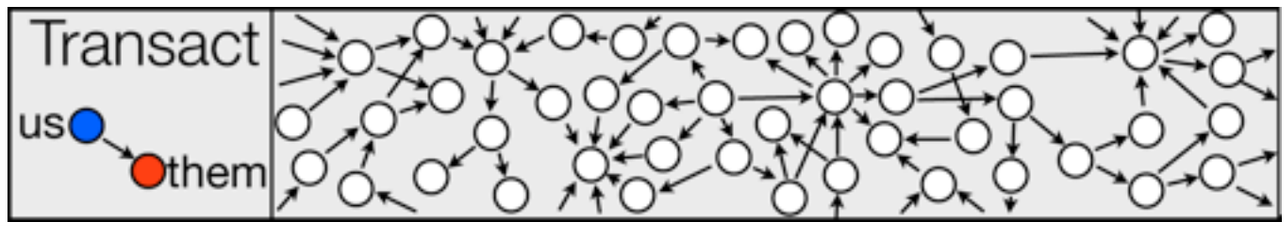


Engaged in transactions with:

- Exchanges

- Vendors

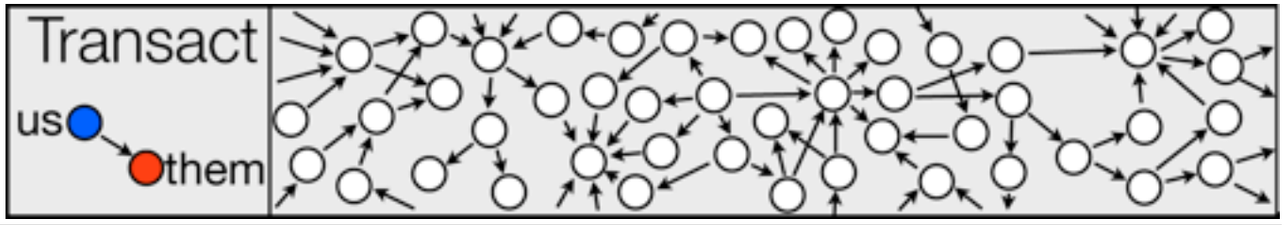
Data collection



Engaged in transactions with:

- Exchanges
- Vendors
- Mining pools

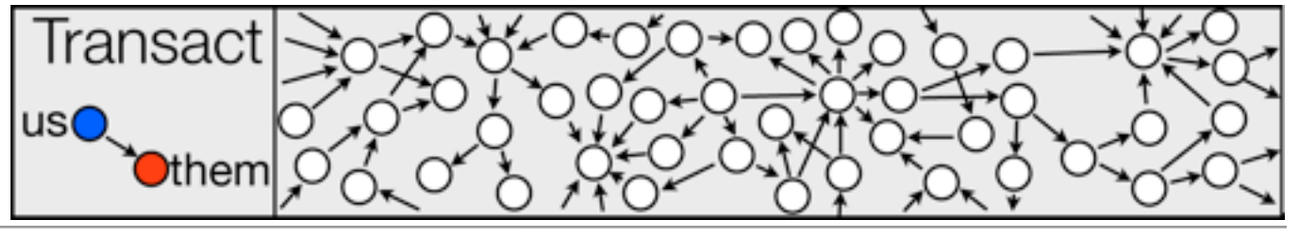
Data collection



Engaged in transactions with:

- Exchanges
- Vendors
- Mining pools
- Gambling sites

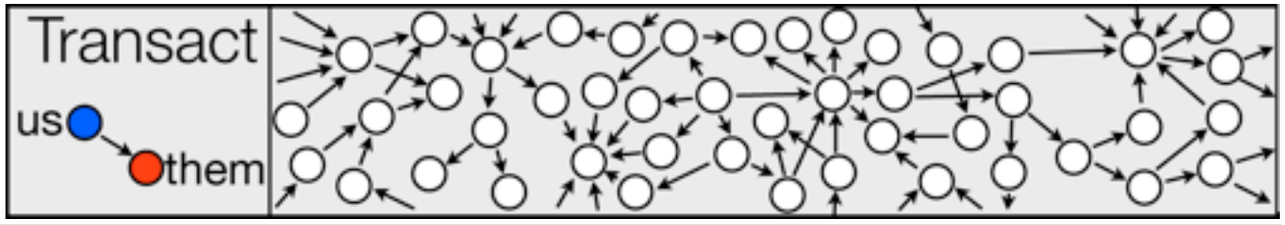
Data collection



Engaged in transactions with:

- Exchanges
- Vendors
- Mining pools
- Gambling sites
- Wallet services

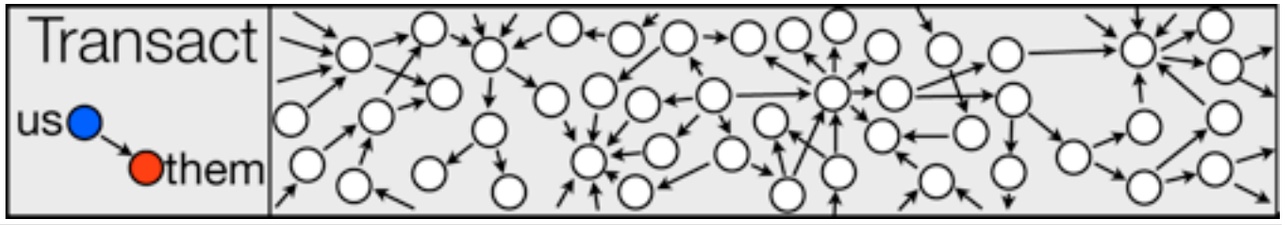
Data collection



Engaged in transactions with:

- Exchanges
- Vendors
- Mining pools
- Gambling sites
- Wallet services
- Mix services

Data collection

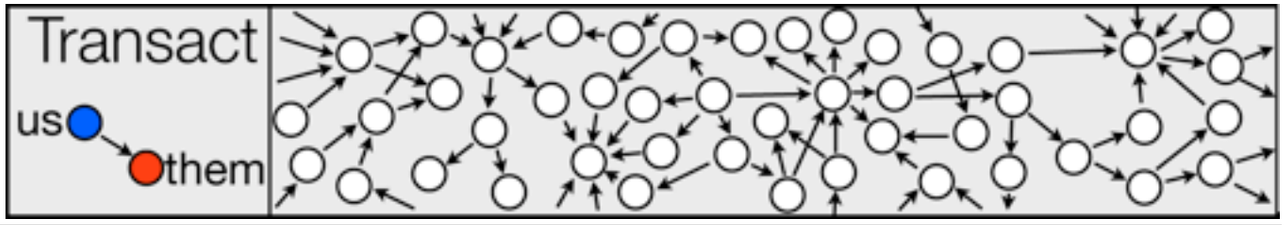


Engaged in transactions with:

- Exchanges
- Vendors
- Mining pools
- Gambling sites
- Wallet services
- Mix services

Scraped published tags

Data collection



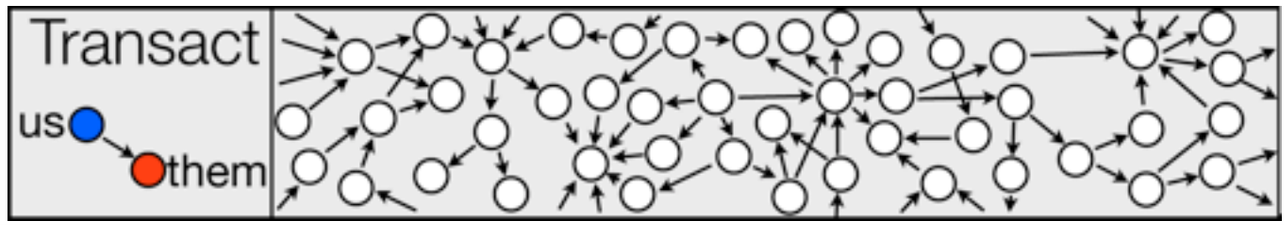
Engaged in transactions with:

- Exchanges
- Vendors
- Mining pools
- Gambling sites
- Wallet services
- Mix services

Scraped published tags

Found addresses discussed on forums

Exchanges



Bitcoin-24

BTC e

aurum exchange

Bitcoin-Central

CAMP BX
BITCOIN TRADING PLATFORM

BitInstant

bitcoin.de
Bitcoin-Marketplace - Made in Germany!

VirtEx
Canadian Virtual Exchange

BITCOIN NORDIC
Bitcoins easy. Bitcoins fast.

Bitcurex
The new age of currency.

ICBIT
Bitcoin Exchange

btcQuick

bitfloor

mercadobitcoin

FastCash4Bitcoins

BitMarket.eu
YOUR PLACE TO EXCHANGE BITCOINS

MT.GOX

LILION TRANSFER
Login | Registration

BITME

TRADING LTD.
THEROCK

NANAIMO GOLD
DIGITAL CURRENCY EXCHANGE

BITSTAMP

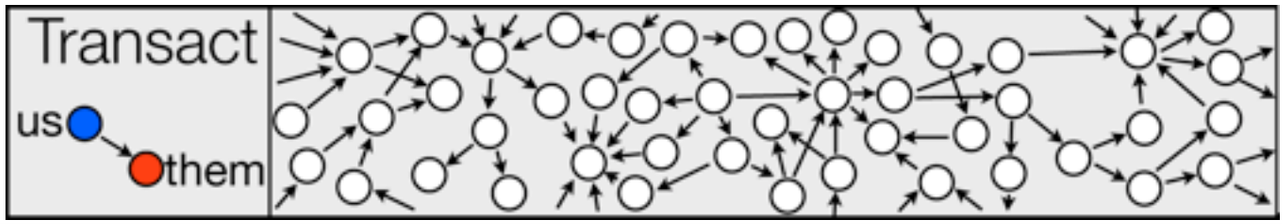
Vircurex

OKPAY payments made easy

Bitcoin China

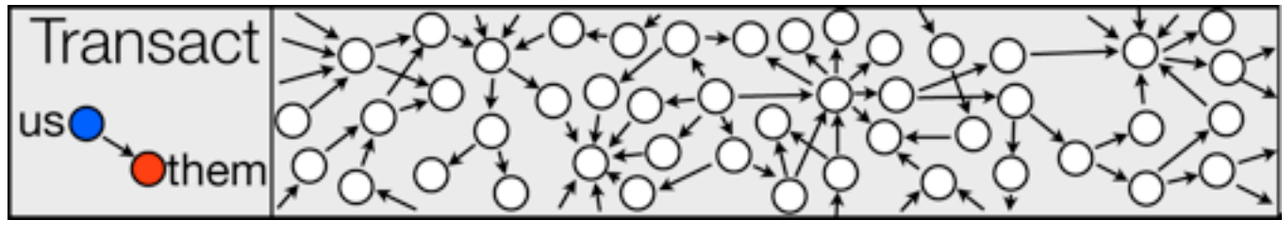
VirWoX
virtual world exchange

Vendors


Transact
us
them

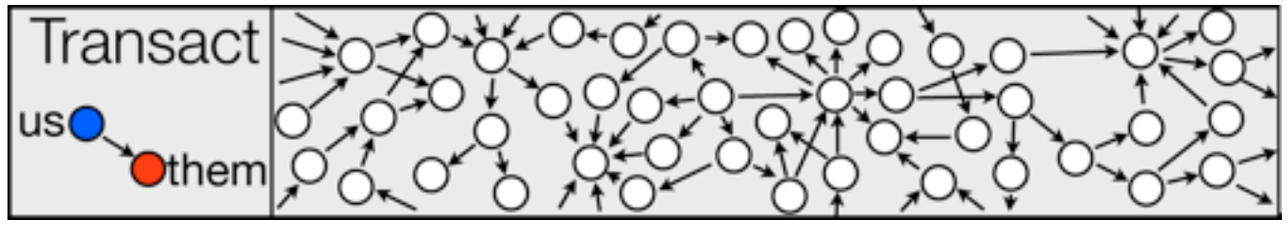

House
SUPER MARIO 3
ubuntu
CASIO
Bitcoin
organic colombian la rochela
Baklava
bitcoin.org
ZYROSTARS
THE LITTLE BOOK OF ANSWERS

Published tags



1LDCRDhNBiTaurUmJKqRef3cGpWLWfEpFk	BitAurum.eu	https://www.bitaurum.eu
1NmduGNyC5XejoysbuioodCN3jR3yf64xM	Electrum	http://electrum.ecdsa.org/community.html
1BTC24yVKQdQNAa4vX71xLUC5A8Za7Rr71	Bitcoin-24.com	https://bitcoin-24.com
14FHqYSgAi39CEJksUJJsK8JzJzyqFpLVk	xkcd	http://xkcd.com/bitcoin/
16xTfttqg6DbvkAGpPvWWpEhEC4e1fCG7G	Genesis2church.org	http://genesis2church.org/donate-with-bitcoin.html
13RcqwggWi9VwcPCZ5BeScxZLWPtt3NVzf	Skeptinerd	http://www.skeptinerd.com/donate-with-bitcoin/
1Kj7V3CYk4TzmE5cgYR7UVbejgFVRbqSwu	WeUseCoins	http://www.weusecoins.com/about.php
1HCMw4nJMT9C6aXaE4EFUb4UbYLg9qpGqw	A Lightning War for Liberty	http://libertyblitzkrieg.com/donate-via-bitcoin-2/

Trolling Bitcoin forums



Re: betco.in's a ghost town now?
April 13, 2012, 12:19:17 AM

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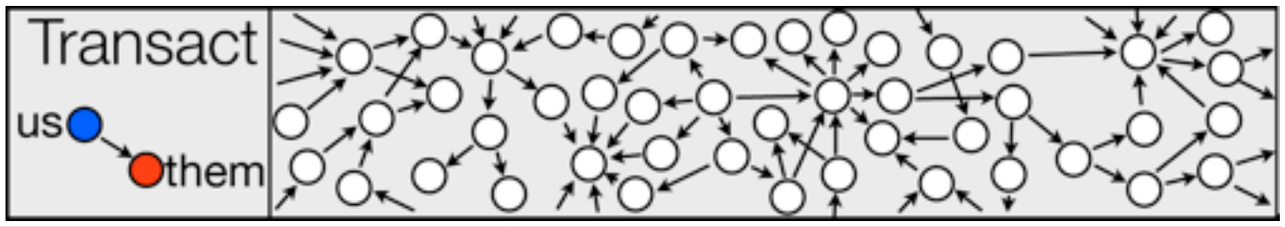

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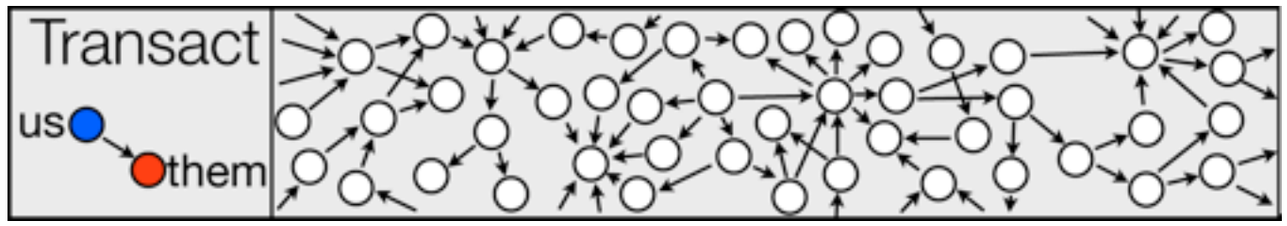

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bf70ac1d2b702dbe0e14fbefb3a0cb2ff5ee5aa425cfe4249f16d6ede7b3ff14 **(Fee: 0 BTC - Size: 798 bytes) 2012-04-11 11:14:03**

1FE71fnpTXYbVxZnRXZKxpPvsKBv5ZCJst (10 BTC - Output)		
1FE71fnpTXYbVxZnRXZKxpPvsKBv5ZCJst (4.42577016 BTC - Output)	1HVi6re6zDr5c5v9Sk2mmL9u7svEHfiBt4	0.22895016 BTC
1FE71fnpTXYbVxZnRXZKxpPvsKBv5ZCJst (2 BTC - Output)	1L4kz6BA8mzi8KLV9VQ2pYcW8QQFVihWLg	17 BTC
1Mu4tcypjQ6hypaqQ9x4h8CCs4bg9pH9Zz (0.80318 BTC - Output)		

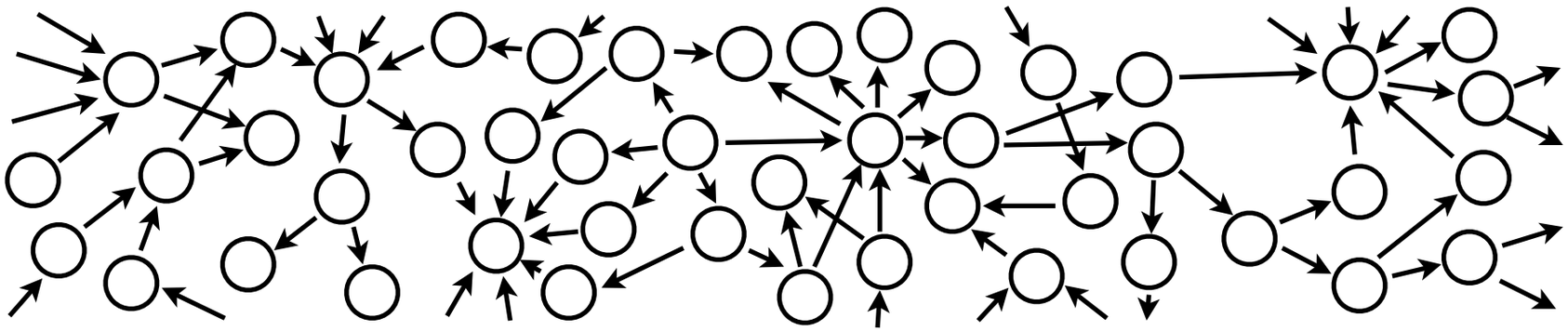
17 BTC

40fc8f6b2f222fb2871a38a245132ed1eada9ff6aec8d46ebe74b29c64fd82a7 **(Fee: 0 BTC - Size: 437 bytes) 2012-04-11 10:51:01**

1CcRiHgr3HWK5bHJ38jBwgLVmBUWRzqEu6 (121.258 BTC - Output)	1KPGDc6oHpvWoUSyssxqmRgwtUqsyyey2y	0.038 BTC
1Lgnzb1p9YE3uKwGpspMQZ1NcAD1EMxzSh (43.78 BTC - Output)	1L4kz6BA8mzi8KLV9VQ2pYcW8QQFVihWLg	165 BTC

165 BTC

Putting it all together



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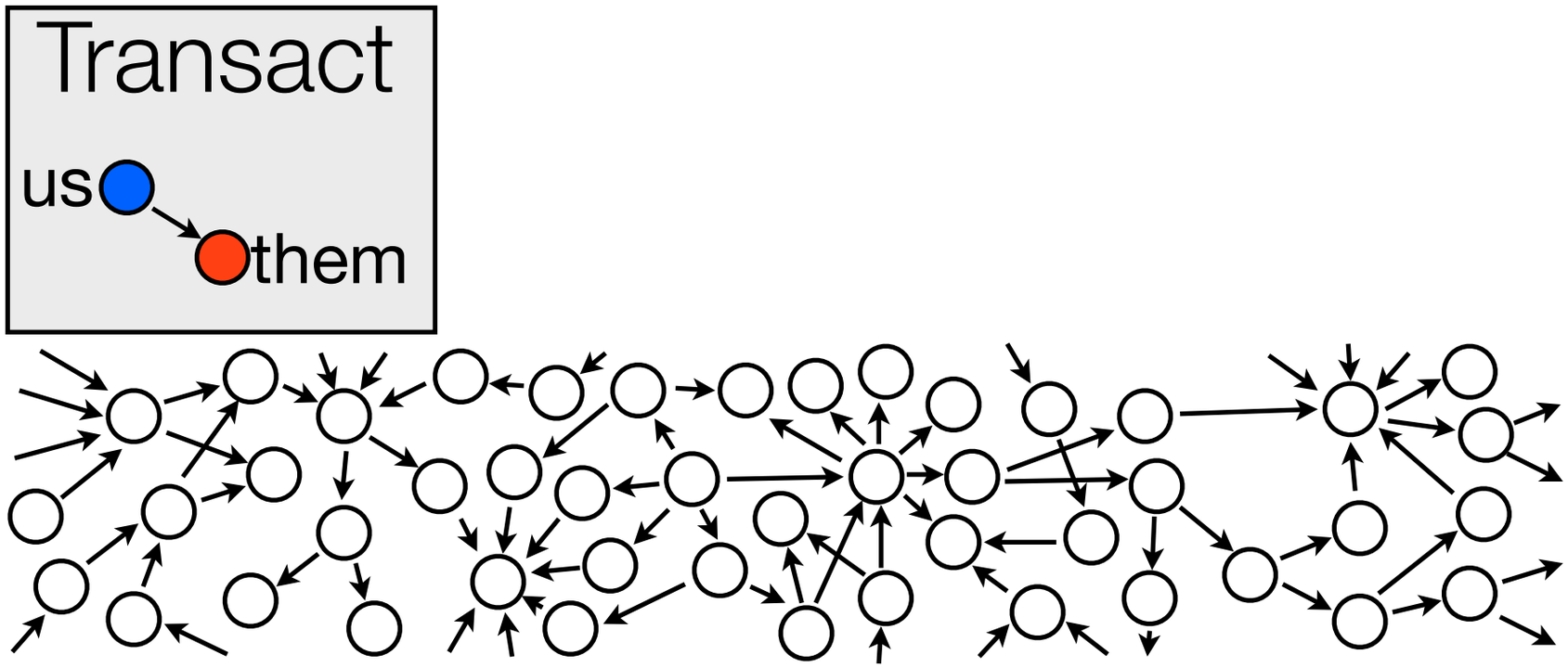

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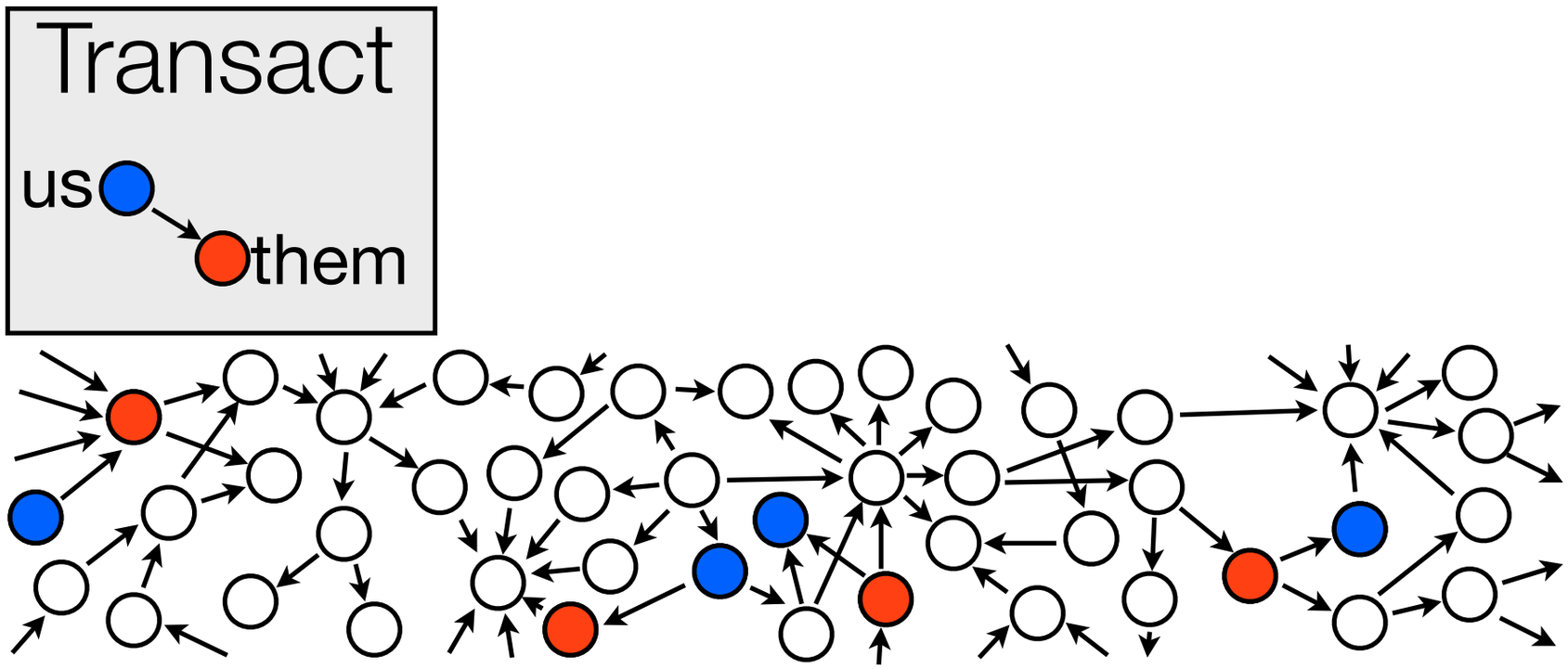

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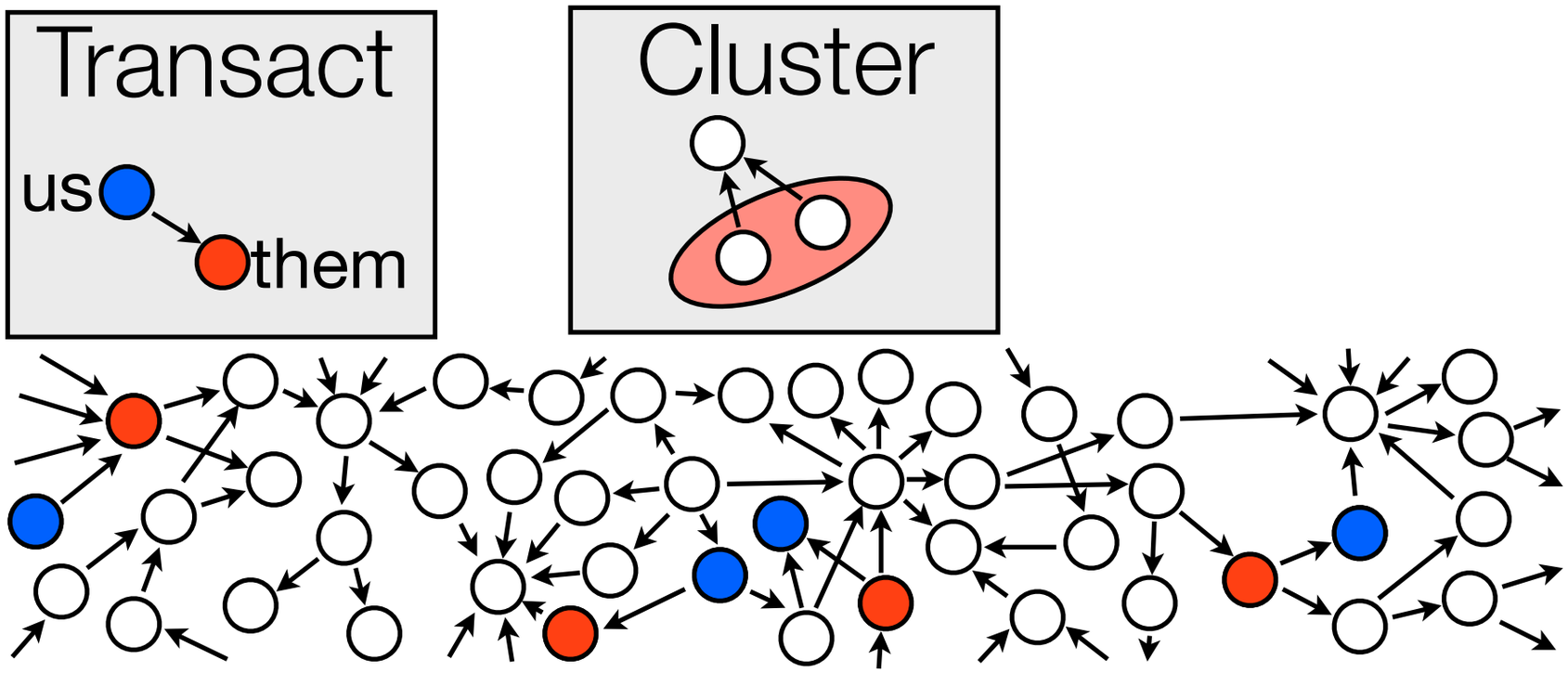

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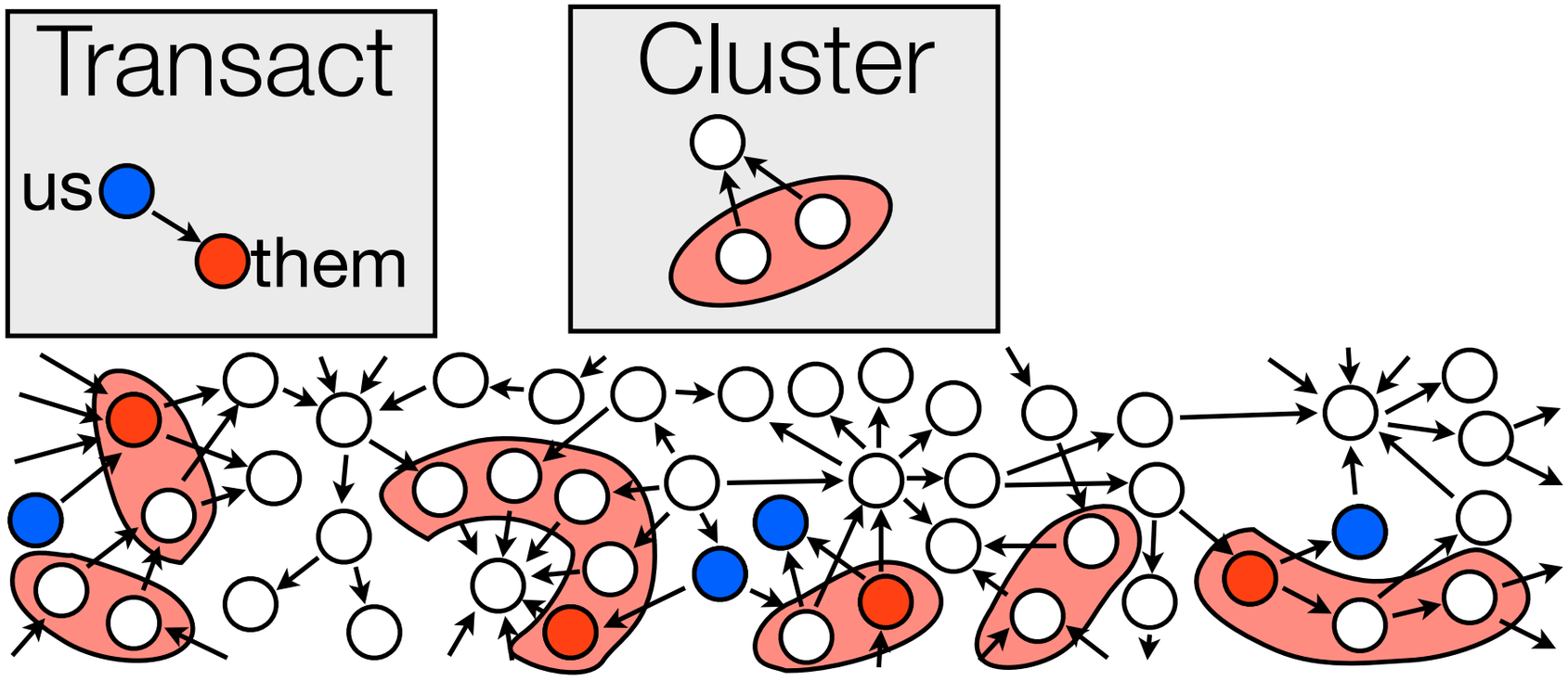

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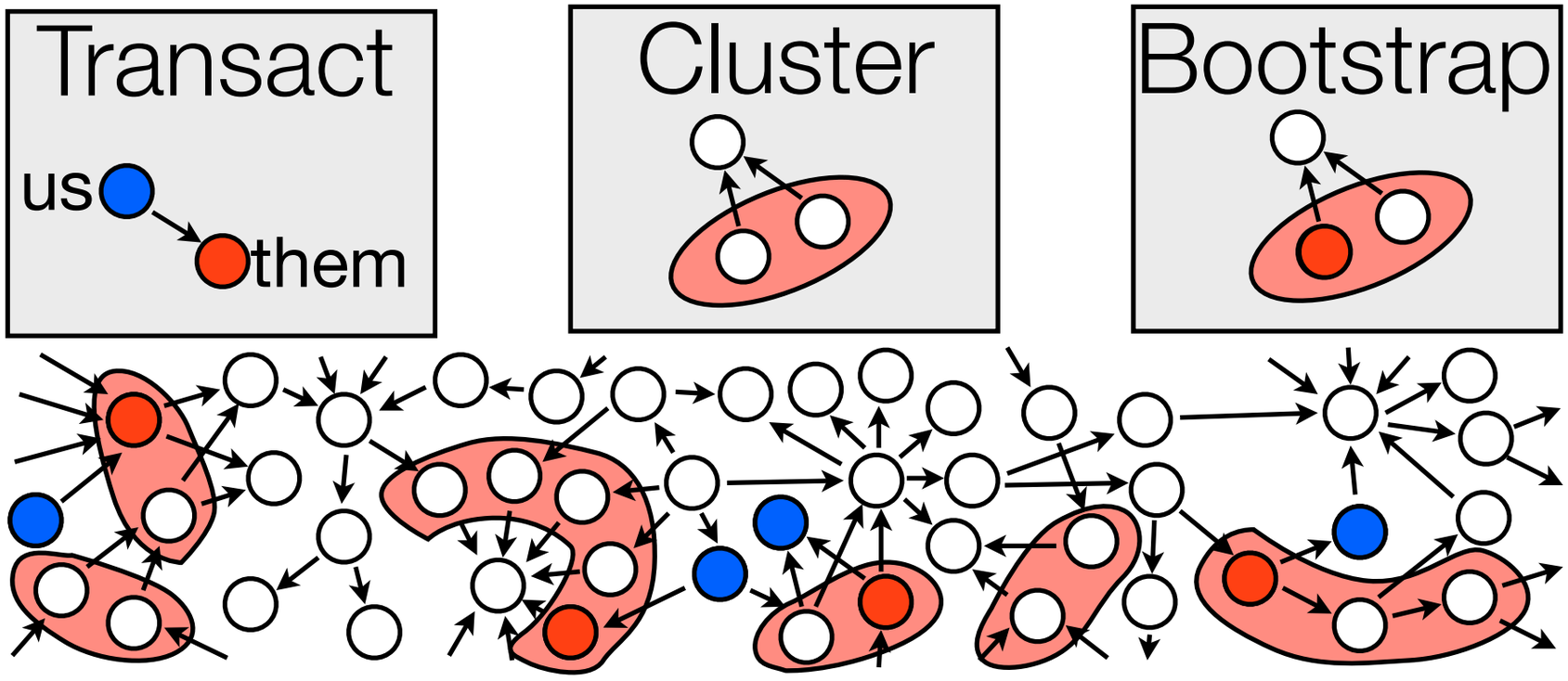

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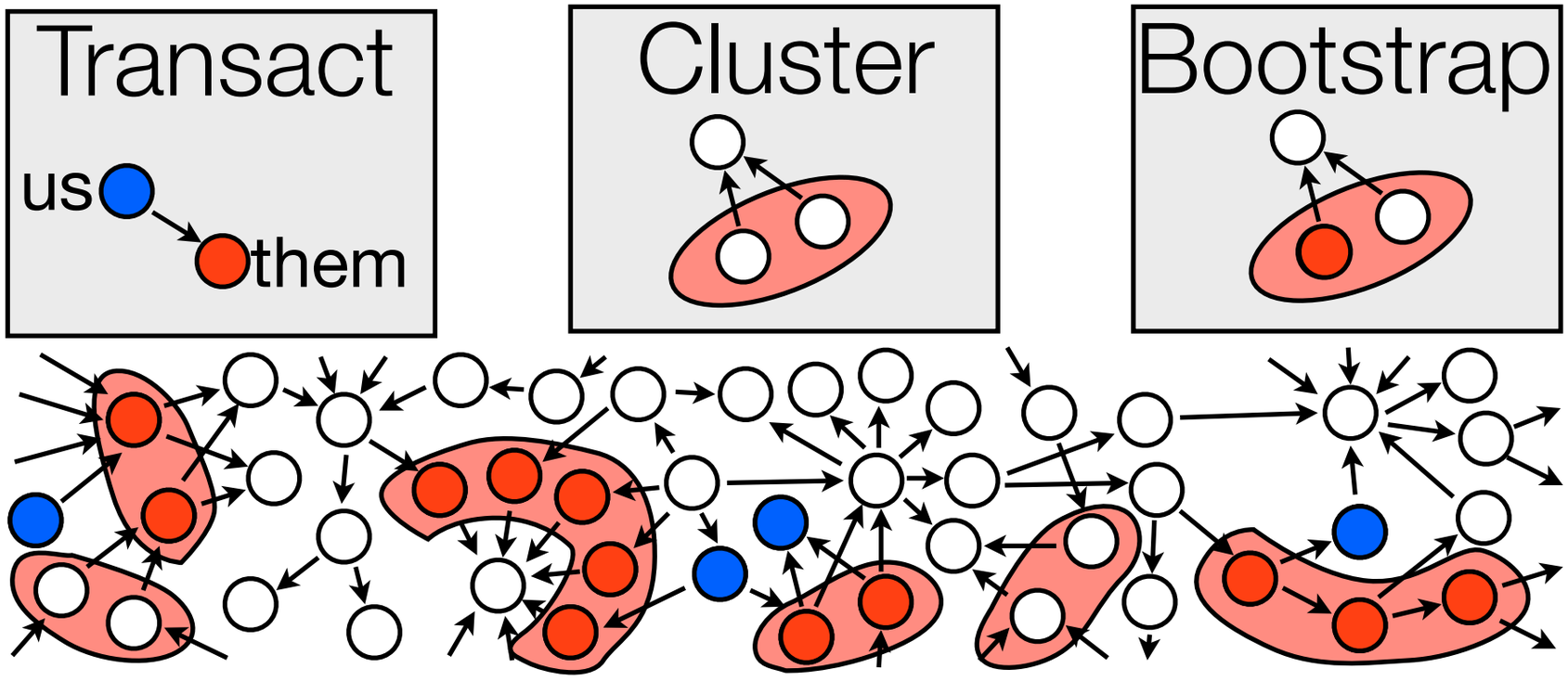

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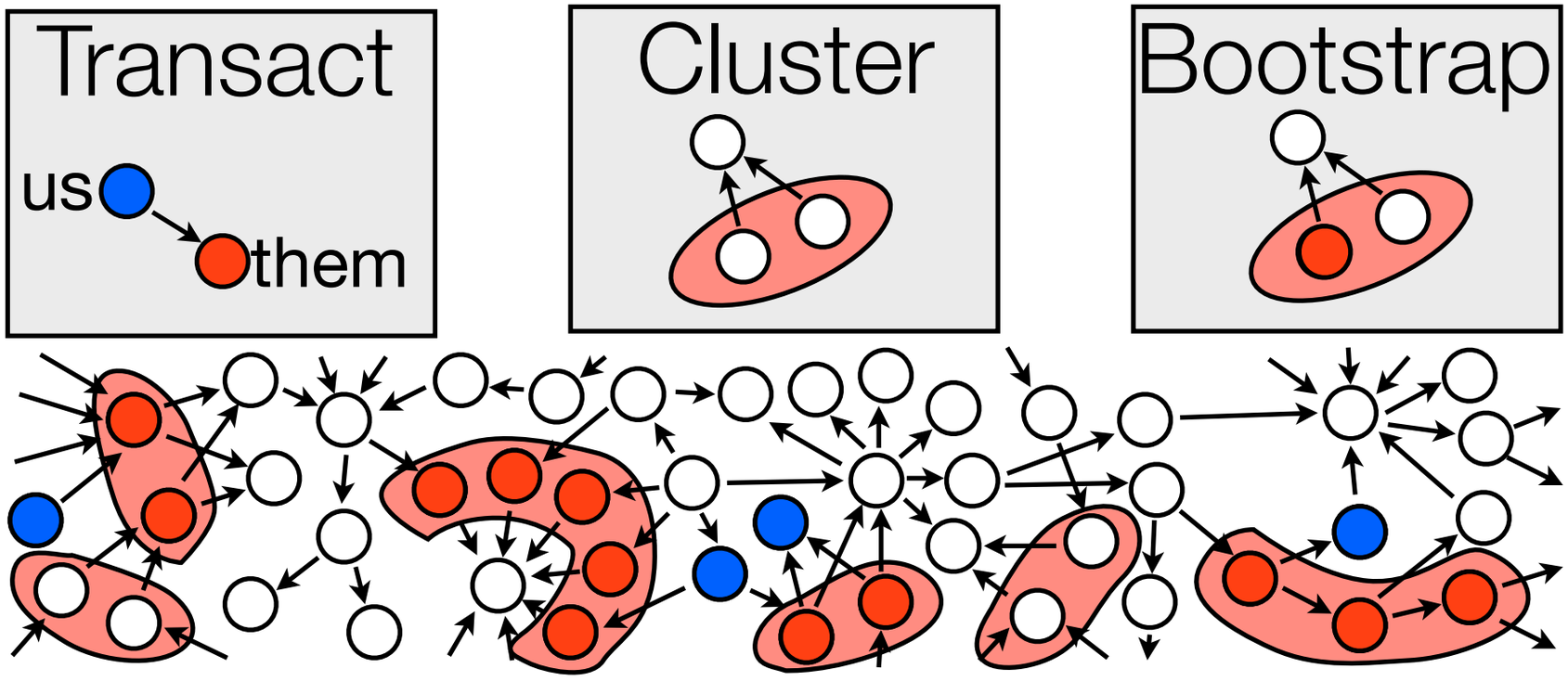


Interacted with 31 MtGox addresses, tagged 518,723!

Participated in 344 transactions and tagged 1.3M public keys

Outline

How does Bitcoin work?

Analysis

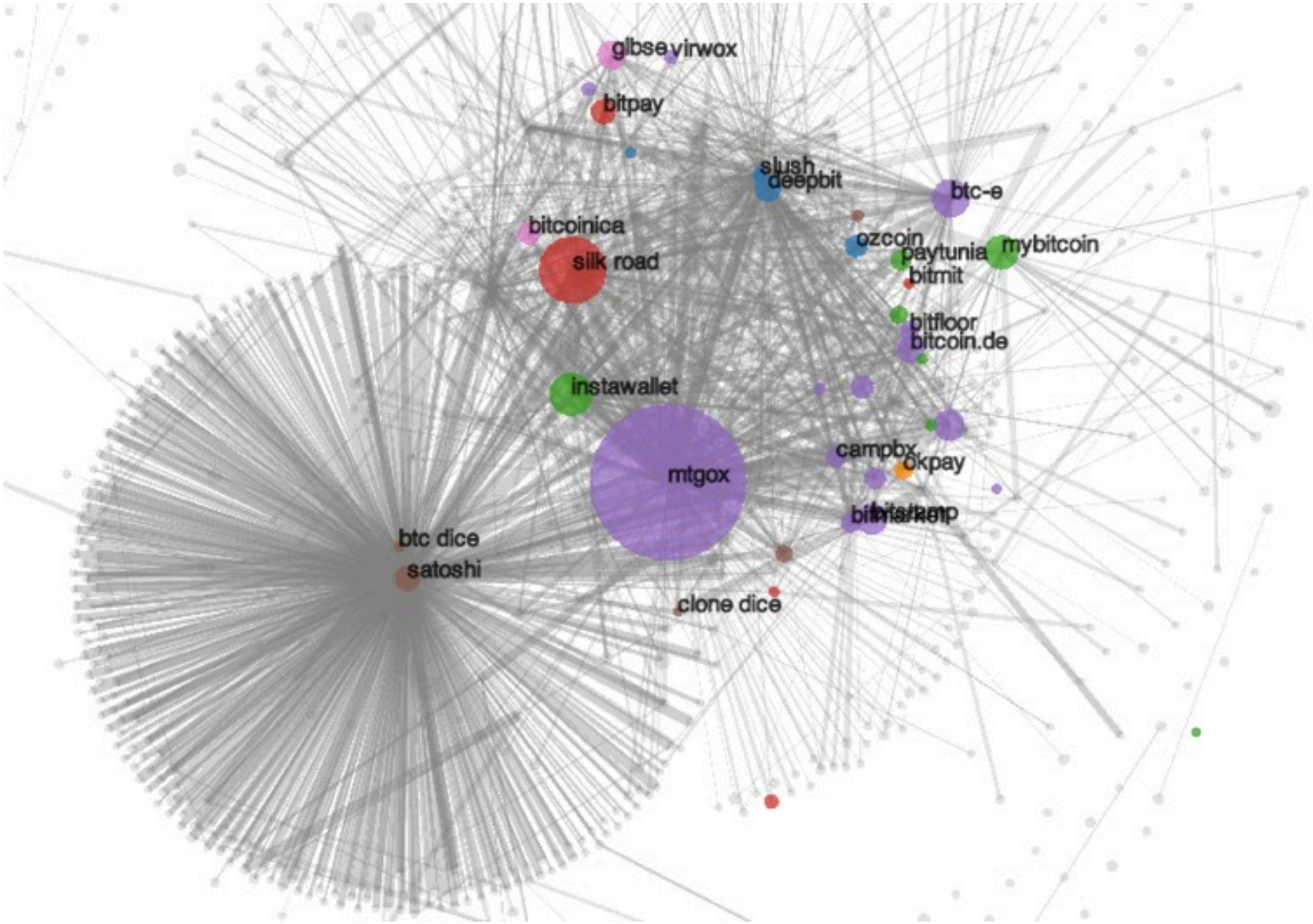
Results

Overall statistics

Tracking cluster activity

Conclusions

Clustering using our heuristics



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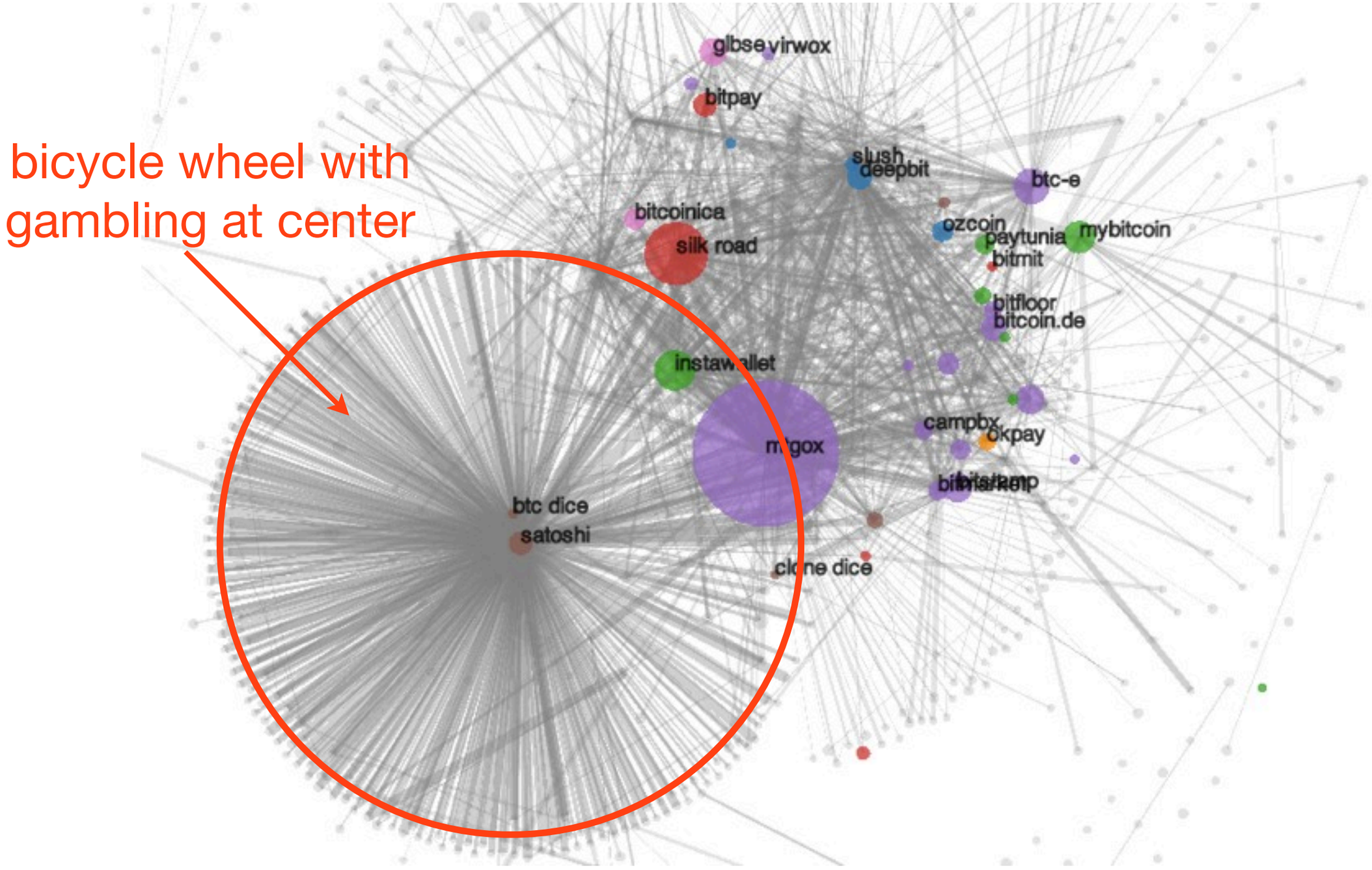

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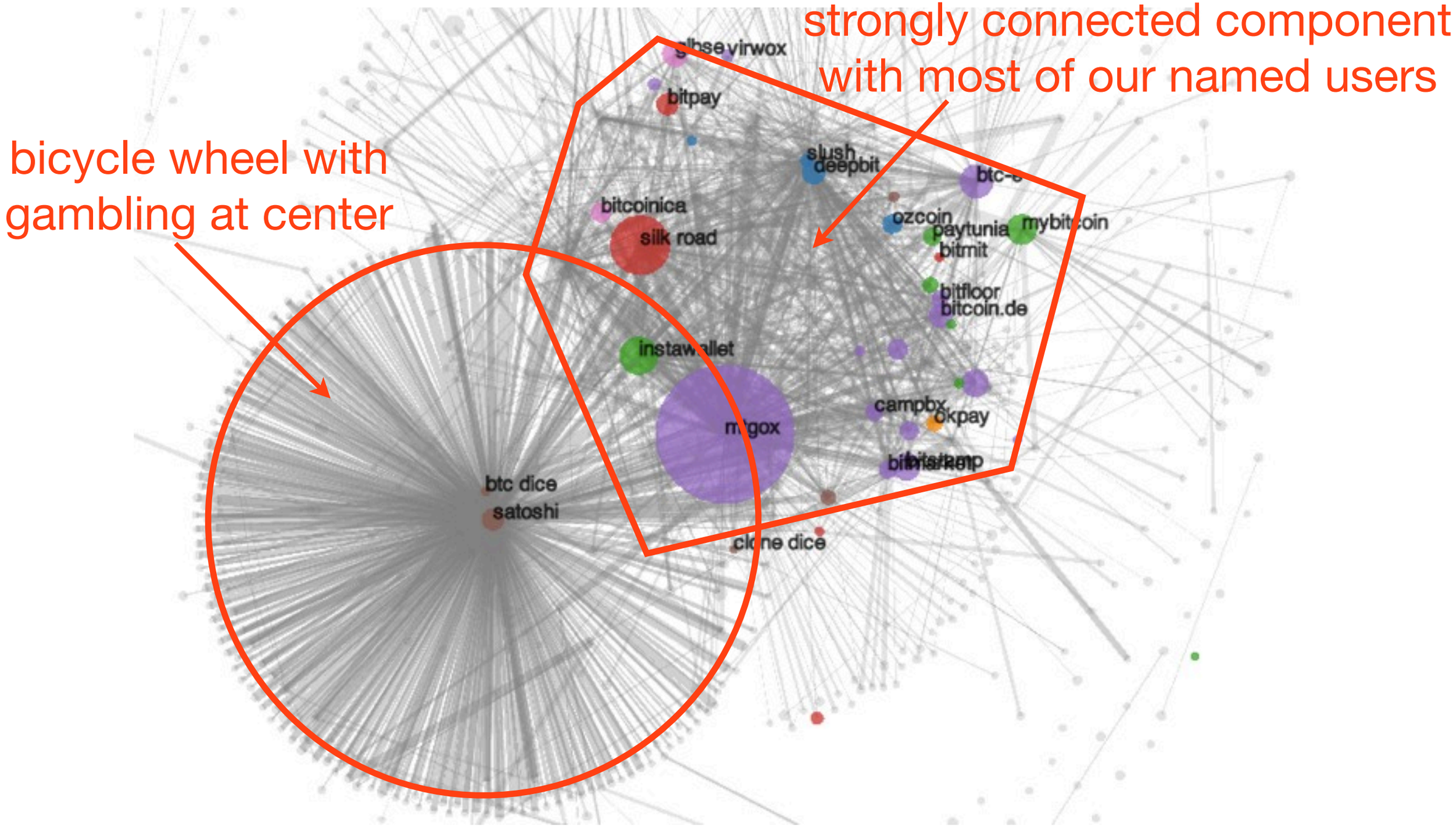

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Can see when bitcoins meaningfully cross cluster boundaries

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Allows us to systematically follow “peeling chains”

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1422qjdwv69rU4vuXFe59YktwqWkM6Kgsk (50 BTC - Output)

1GYnR2dWZFsibB8AkjjGKtMNsFCVH6KS21 - (Spent)	48.8325 BTC
1AF2149tLJXQ3JGDpe8gjfrUmmqA9kLNFC - (Unspent)	1.167 BTC

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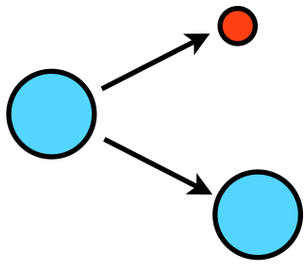

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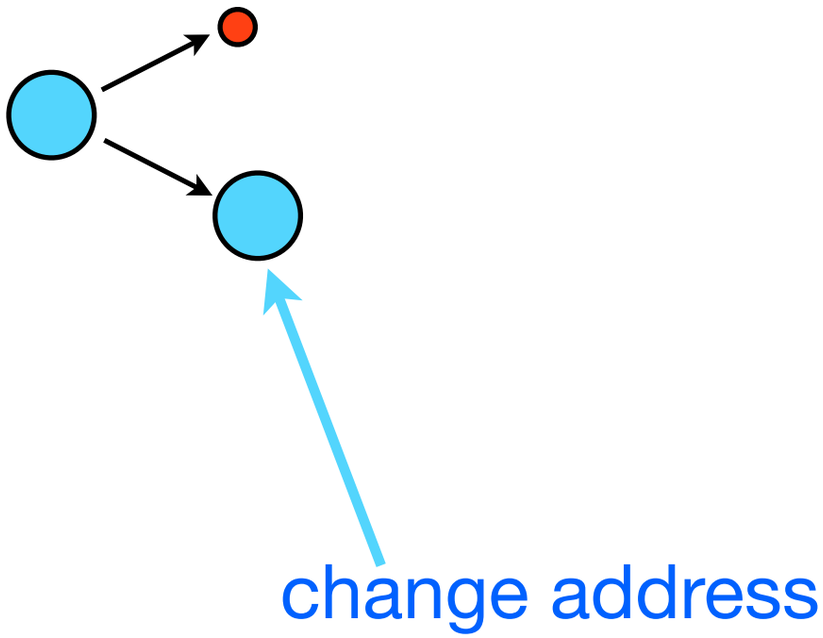

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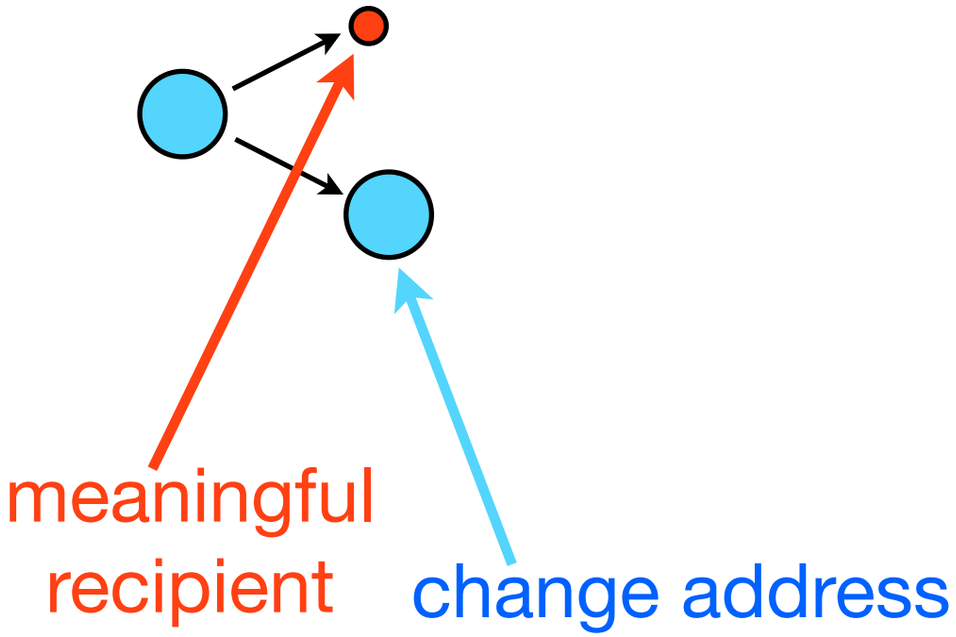

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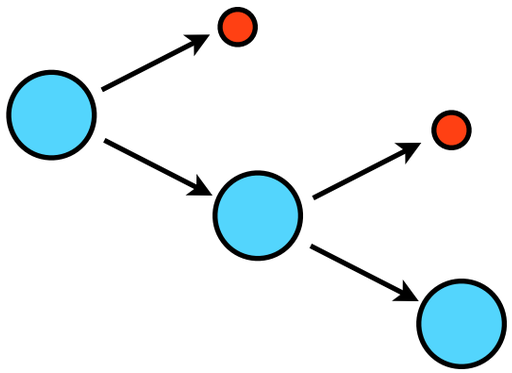

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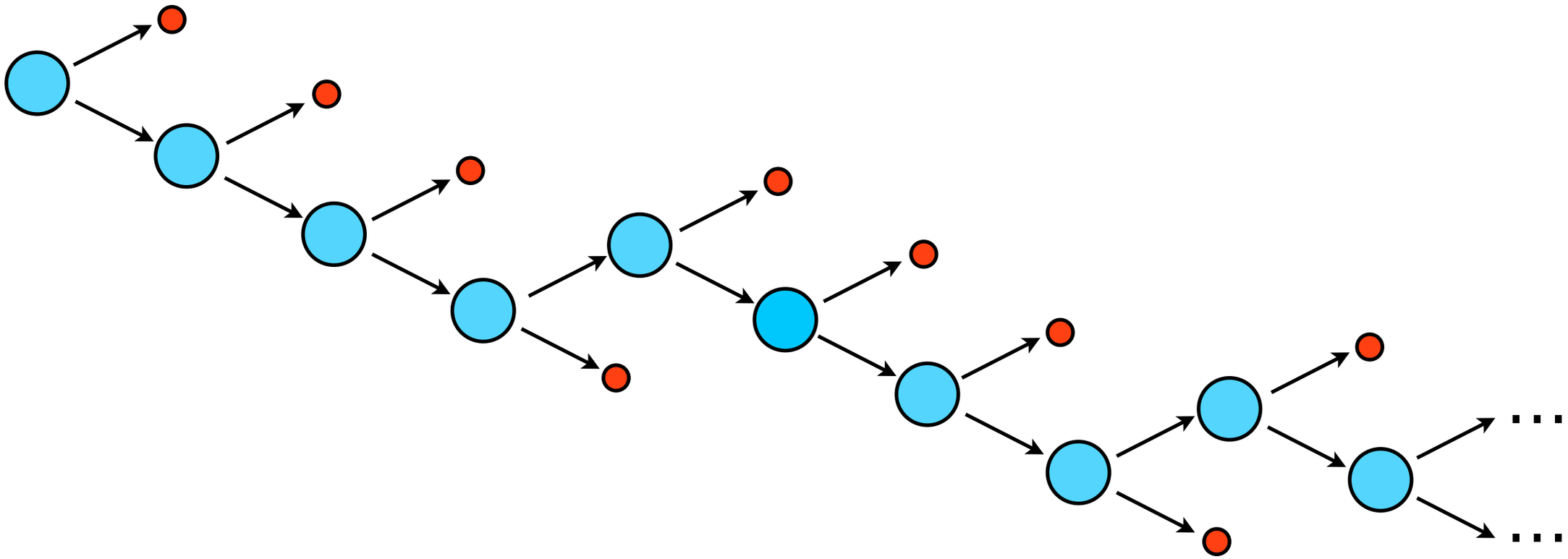

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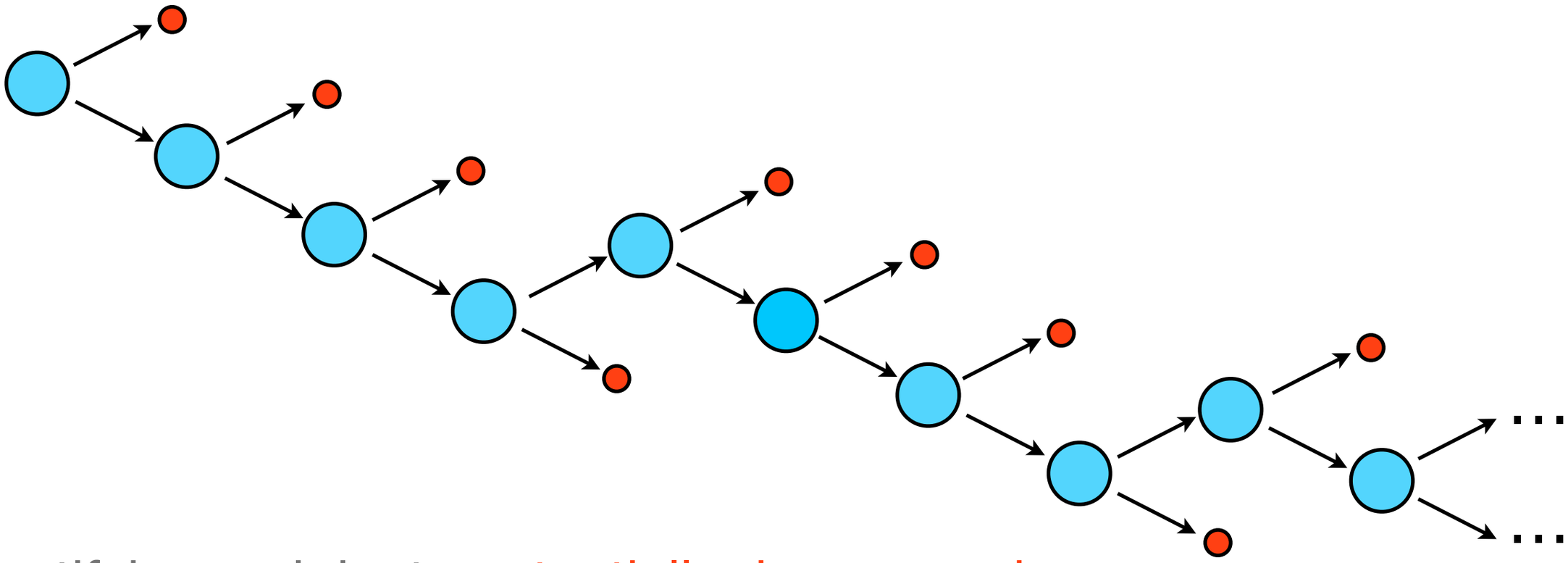

Identifying recipients potentially de-anonymizes user

Tracking illicitly-obtained bitcoins

By following peeling chains, we tracked money from known thefts and from one infamous address associated with Silk Road

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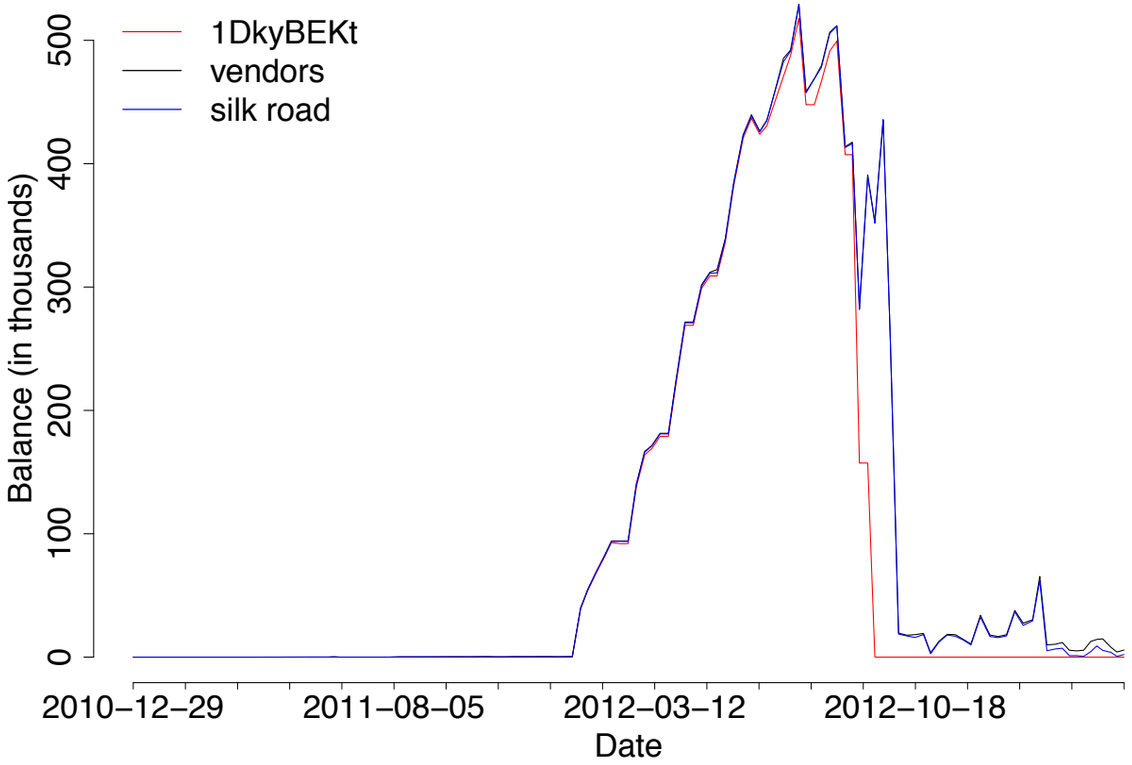

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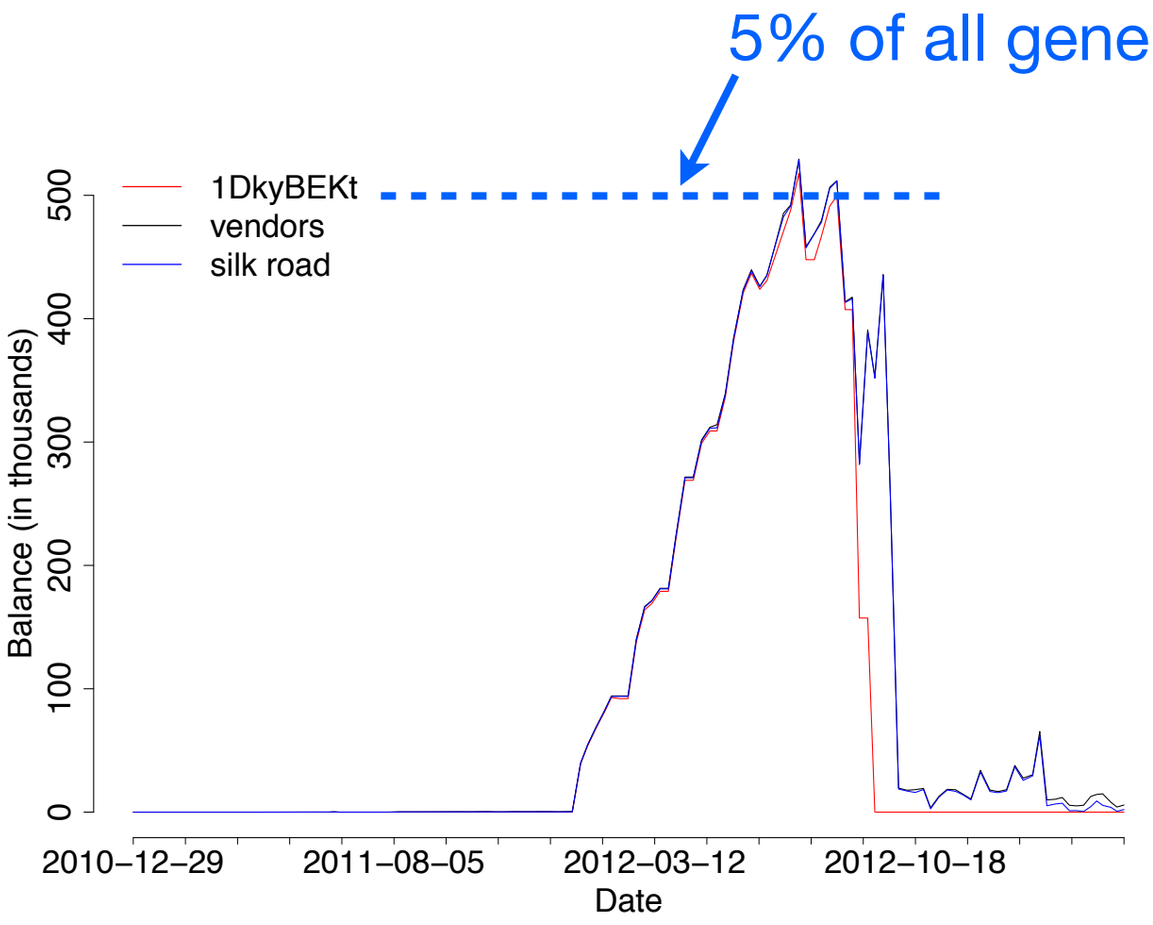

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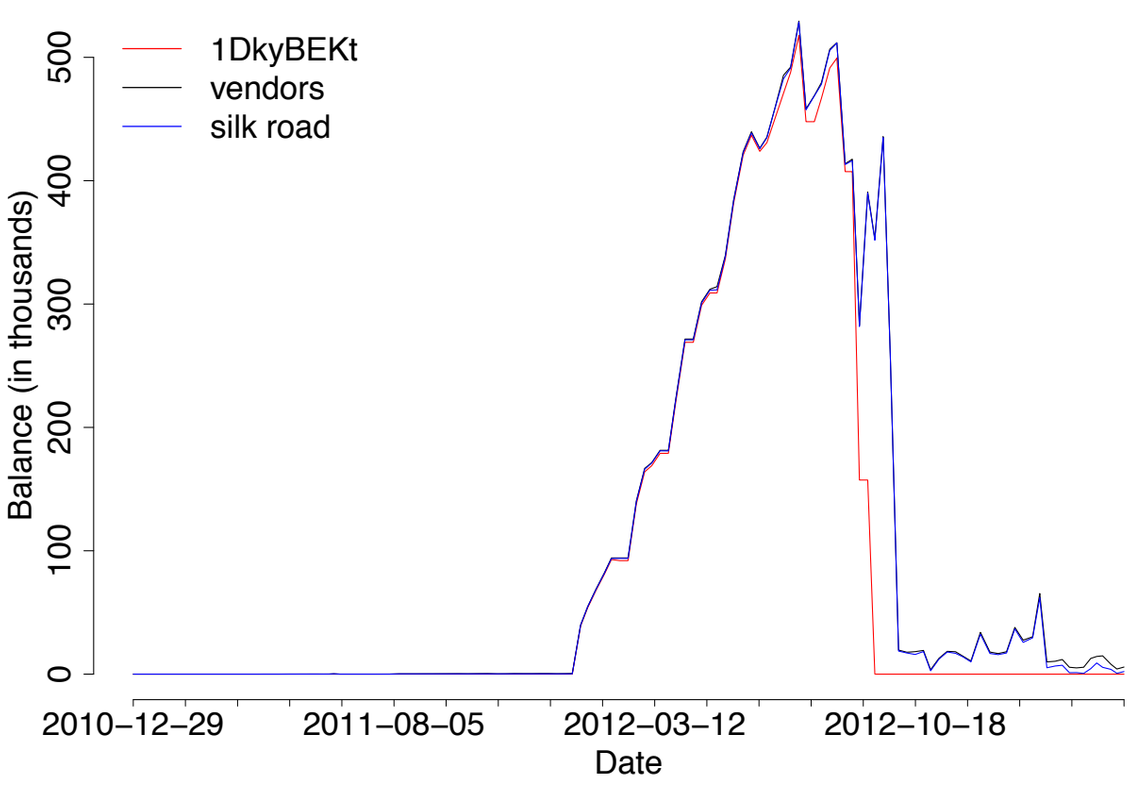

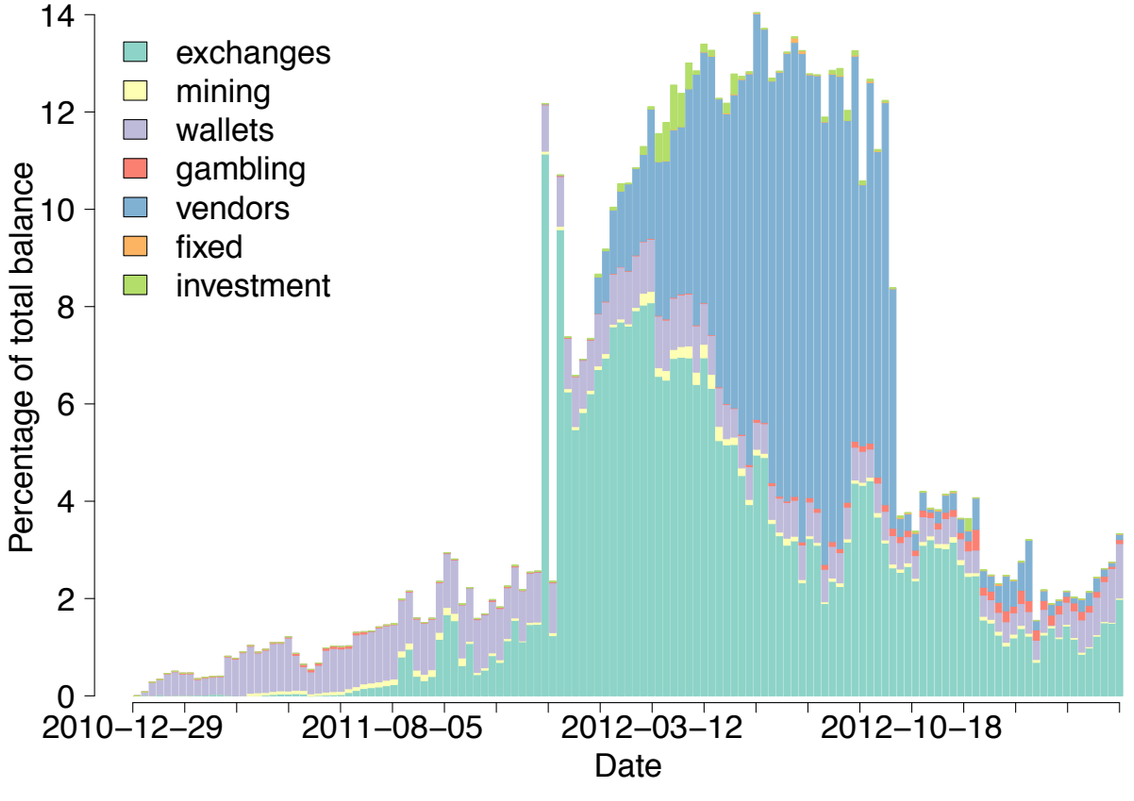

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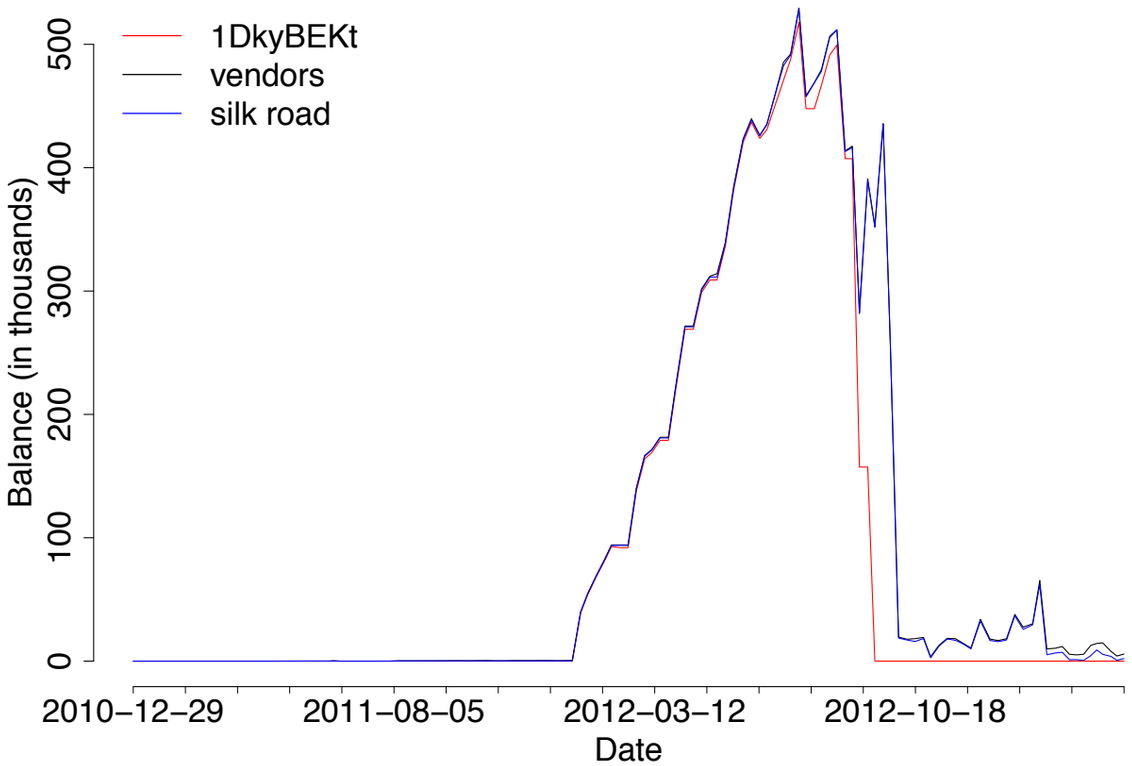
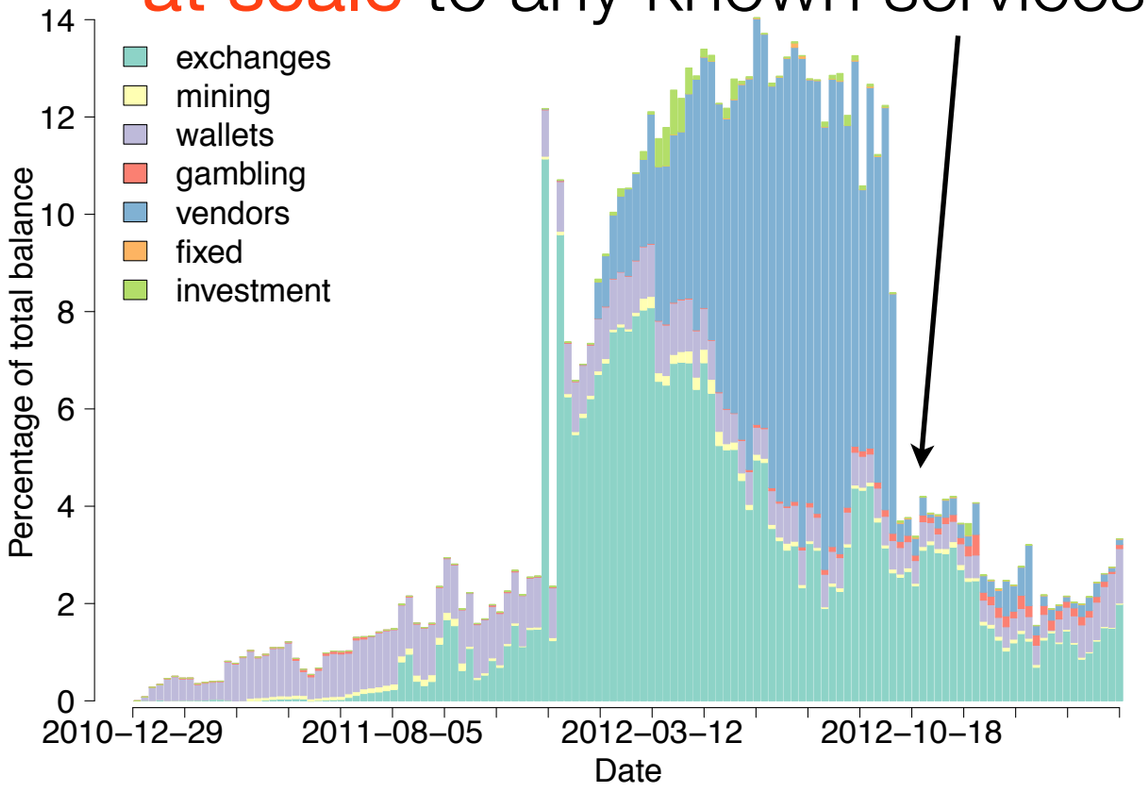


Dissipated bitcoins did not flow at scale to any known services



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But we saw peels to known exchanges

	First		Second		Third	
Service	Peels	BTC	Peels	BTC	Peels	BTC
Bitcoin-24			1	2	3	124
Bitcoin Central					2	2
Bitcoin.de					1	4
Bitmarket					1	1
Bitstamp			5	97	1	1
BTC-e					1	250
CA VirtEx	1	3	1	10	3	22
Mercado Bitcoin					1	9
Mt. Gox	11	492	14	70	5	35
OKPay	2	151			1	125

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Again, saw many peels to known exchanges

Theft	BTC	Date	Movement	Exchanges?
MyBitcoin	4019	Jun 2011	A/P/S	Yes
Linode	46,648	Mar 2012	A/P/F	Yes
Betcoin	3171	Mar 2012	F/A/P	Yes
Bitcoinica	18,547	May 2012	P/A	Yes
Bitcoinica	40,000	Jul 2012	P/A/S	Yes
Bitfloor	24,078	Sep 2012	P/A/P	Yes
Trojan	3257	Oct 2012	F/A	No

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Hypothesis: if you subpoena the exchange, you can identify the thief

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Contacted by Andy Greenberg of Forbes to test hypothesis

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SECURITY | 9/05/2013 @ 10:36AM | 131,694 views

Follow The Bitcoins: How We Got Busted Buying Drugs On Silk Road's Black Market

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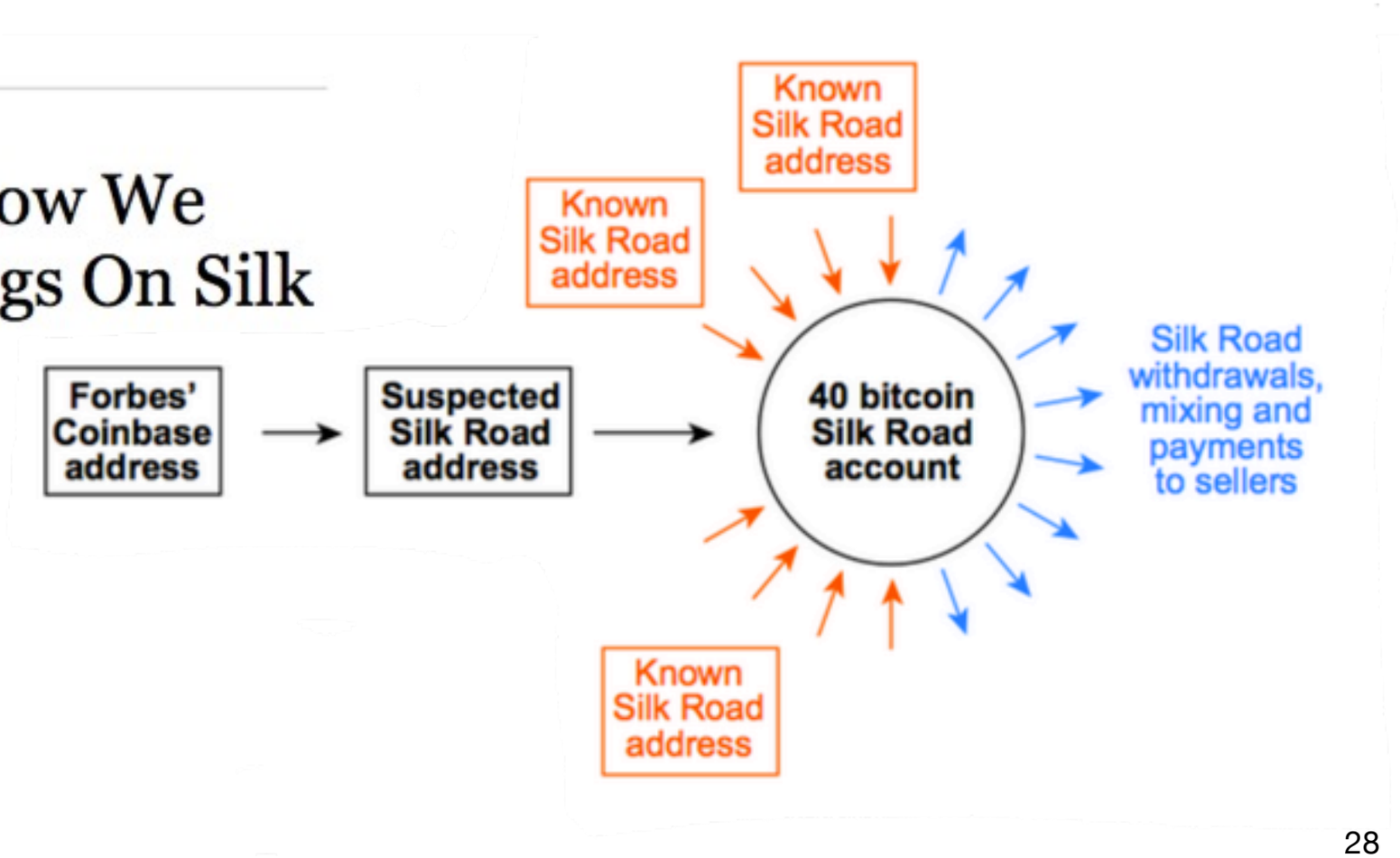

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Our analysis provides a real-world way to track flows of bitcoins

Seems hard to launder significant quantities of money

Thanks! Any questions?