

PROJECT PRESENTATION

PROJECT OBJECTIVE

- We have in a database all transactions between addresses and all transactions between actors from the beginning of bitcoin to the end of 2017 (and the rest is computing)
- Choose and obtain a small subset of this network that you consider interesting
 - Around a particular transaction (illegal activity ...)
 - About some actors
 - About a period
 - ...

PROJECT OBJECTIVE

- Apply tools you learned about during the class to better understand this network
- Write a report about what you learnt, and what you could learn with more time/data
 - If possible, a single Jupyter notebook with code and text
 - A separate report in PDF is also possible if relevant

PROJECT OBJECTIVE

- Recommendations:
- I recommend to limit yourself to a few thousand nodes, and less than 10.000 edges (filtering). Comparing a few graphs of this size can be relevant.
- The goal of the project is to interact!
 - Ask me if something is possible, how to do it... we are doing the project together.

DATA DESCRIPTION

SUMMARY OF THE PROCESS

1. Run a Bitcoin Node to download the full Blockchain
 - =>January 2021: **366 Go**
2. Use a tool (*bitcoin-etl*) to extract transactions as .json files
 - =>Until January 2018: **862G**
 - =>Total: **1.5 To**
3. Use co-spending heuristic to identify clusters
4. Use walletpal.com data to identify clusters of large actors
5. Create an Actor to Actor transaction records

ACTOR TO ACTOR TRANSACTION RECORDS

- Each transaction has a single actor in input
- It can have one or several actors in output.
 - Actors are identified by their names
 - Clusters are identified by a positive integer
 - Singleton addresses are identified by a negative integer
 - In the main file, we keep self-transactions, they can be removed
- Size:
 - December 2017: **768 Million** transactions, **28 G**
 - January 2021: TODO

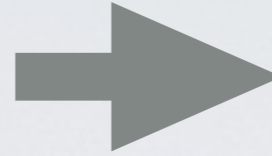
SOME IDEAS

BITCOIN BLOCKCHAIN ACTIVITY TRACKING EXAMPLE

1

Traditional Bank

Transfer (€)



→ deposited 75.00 € processed 2/10/2017

Operations

| Account | Name | Amount | Date |
|-----------|-----------|----------|---------------------|
| available | operation | +75.00 € | 2/10/2017 - 3:28 PM |

2

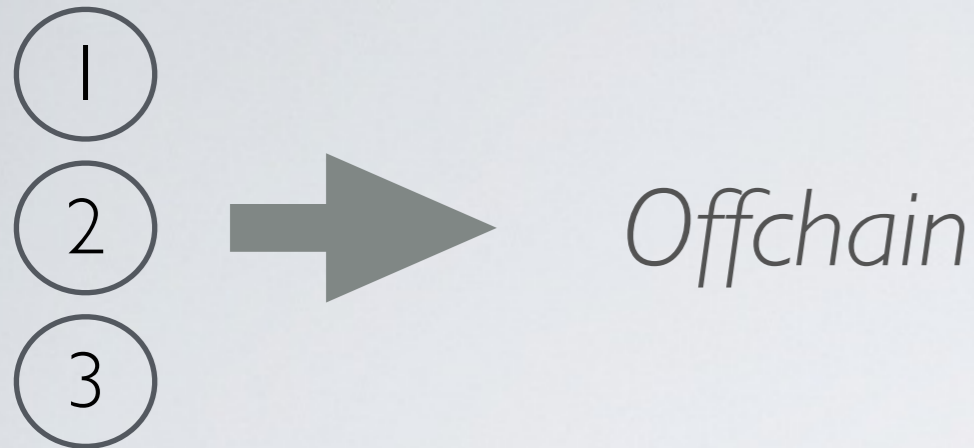
Initial Bitcoin purchase (trading)

↑ bought 0.05423052 btc for 921.99 € average filled 2/10/2017

3

“Trading”

| | | | | | |
|----------|----------------|----------------|---------|--------|-----------|
| ↓ sold | 0.07130000 btc | for 1,059.00 € | average | filled | 2/22/2017 |
| ↑ bought | 0.07136414 btc | for 1,008.91 € | average | filled | 2/18/2017 |
| ↓ sold | 0.07400000 btc | for 980.17 € | average | filled | 2/18/2017 |
| ↑ bought | 0.05076142 btc | for 985.00 € | average | filled | 2/17/2017 |
| ↓ sold | 0.02600000 btc | for 975.01 € | average | filled | 2/16/2017 |



- How it works (probably)

- ▶ The exchange company owns a stock of Bitcoin
- ▶ It maintains a list of customer accounts, and how much each customer owns at time t
- ▶ When customer $c1$ buys btc to a customer $c2$, change in the internal database of the company (scripture)
 - Goal: no transaction fees, easier to manage
- ▶ The company itself certainly buy and sell on the market to ensure liquidity
 - Success=more customers who want to buy=>need to provide fresh coins
 - Need of buying/selling on the blockchain
- ▶ The company need enough reserve since customers can order bitcoin transactions from their (*virtual*) account to a *real bitcoin wallet*

bought

0.05417748 btc for 1,974.99 € average

filled 5/28/2017

9:23GMT+1

| timestamp | sender | receiver | value | date | value_btc |
|-----------|--------------|-------------|-----------|---------------------|-----------|
| 619503540 | -192947146 | Paymium.com | 4276511 | 2017-05-28 00:01:10 | 0.042765 |
| 619622203 | 35172026 | Paymium.com | 21408870 | 2017-05-28 03:03:35 | 0.214089 |
| 619627952 | 36676998 | Paymium.com | 1278580 | 2017-05-28 03:03:35 | 0.012786 |
| 619641058 | 320110 | Paymium.com | 2889754 | 2017-05-28 03:11:24 | 0.028898 |
| 619678470 | 234 | Paymium.com | 50000000 | 2017-05-28 04:36:58 | 0.500000 |
| 619720731 | 21 | Paymium.com | 500000000 | 2017-05-28 06:35:57 | 5.000000 |
| 619724954 | Poloniex.com | Paymium.com | 90000000 | 2017-05-28 06:47:51 | 0.900000 |
| 619734802 | 15195288 | Paymium.com | 563100 | 2017-05-28 06:38:12 | 0.005631 |
| 619742071 | 32328334 | Paymium.com | 300000000 | 2017-05-28 07:26:43 | 3.000000 |
| 619749598 | Bitstamp.net | Paymium.com | 500000000 | 2017-05-28 07:32:40 | 5.000000 |
| 619773769 | Poloniex.com | Paymium.com | 5990000 | 2017-05-28 09:01:43 | 0.059900 |
| 619813537 | Poloniex.com | Paymium.com | 299990000 | 2017-05-28 10:54:40 | 2.999900 |
| 619814805 | -193097249 | Paymium.com | 5000000 | 2017-05-28 10:59:38 | 0.050000 |
| 619816324 | -193098289 | Paymium.com | 501097 | 2017-05-28 11:07:45 | 0.005011 |
| 619859643 | Ettrex.com | Paymium.com | 99900000 | 2017-05-28 12:01:10 | 0.999000 |
| 619870536 | -193116479 | Paymium.com | 4113900 | 2017-05-28 11:36:47 | 0.041139 |
| 619874781 | 5224442 | Paymium.com | 1373550 | 2017-05-28 11:54:15 | 0.013735 |
| 619877124 | -193121122 | Paymium.com | 365283 | 2017-05-28 12:16:50 | 0.003653 |
| 619880471 | -193122823 | Paymium.com | 59539 | 2017-05-28 11:54:15 | 0.000595 |
| 619880482 | -193122827 | Paymium.com | 58606 | 2017-05-28 11:54:15 | 0.000586 |
| 619882043 | Paymium.com | 16096 | 620000 | 2017-05-28 12:09:47 | 0.006200 |
| 619882044 | Paymium.com | 222 | 6800000 | 2017-05-28 12:09:47 | 0.068000 |

Paymium on-chain activity on 2017-05-28

Hard to say what it corresponds too...
But my exact transaction is not there

... (153 total)

4 Sending 0.005 btc from Paymium exchange to my personal wallet



← transferred 0.00500000 btc 👁 processed 2/10/2017

| Hash | 2017-02-10 19:48 |
|---|---------------------------------------|
| 1431198bef5645bcce667c11f988257292c... | |
| 1FNhjTqbogGenAtiVn... 0.03000000 BTC | 1FBov1eSTzbEWFhNP... 0.04811430 BTC |
| 1FNhjTqbogGenAtiVn... 0.29980000 BTC | 1FnJ7ifPVs6pVzPAHj... 0.15385554 BTC |
| 1ChT8jHwnu28S8Gse... 0.00552015 BTC | 1PLS2uFx9RCXj6y7o... 0.03240000 BTC |
| 134JTcD1rwYzf3mJh... 0.01066365 BTC | 1JPDfDbpYu7ZMN54... 0.11000000 BTC |
| 1F2DnSngMqhx3Bc5t... 0.00102304 BTC | 1Acekhv2vRYE8JUY... 0.10000000 BTC |
| 1PmJouprMuWvnuz1... 0.00060627 BTC | 125UVAGTHgRpUWu... 5.00000000 BTC |
| 1CNKsJdKEGAfk7A6... 0.02800000 BTC | 1LCy45fGKy5DDyLX7... 0.19080000 BTC |
| 1Jv324ZskcMwVaHo... 0.04971298 BTC | 1JQAJC1as3zqGvh3R... 0.10780000 BTC |
| 1Jv324ZskcMwVaHo... 0.02700664 BTC | 1uQWT55a31oXbG7y... 0.06000000 BTC |
| 1FyJw1oF7ojJVfb... 200.00000000 BTC | 1AtG2dZL2QT9Anob... 0.26000000 BTC |
| Load more inputs... (1 remaining) | 19P2i6fCFLyhsZWVd... 0.05476170 BTC |
| | 1NAr6doa9jzdAtjfcED... 0.00100000 BTC |
| | 1GZjj8XvbdVvMgiSm... 0.21500000 BTC |
| | 32SRuobXXWbxRYeLt... 0.11180000 BTC |
| | 1DtnwrYpuj2AviHBKL... 0.31386546 BTC |
| | 1mxx5bDua8844zAik... 0.03416878 BTC |
| | 1X9rcMVx8SvZ5uPz... 0.00500000 BTC |
| | 1Hxm69VGPXfGu7k... 0.01000000 BTC |
| | 1CEoEkc1xzb5mBhpa... 0.00547958 BTC |
| | 3ErsNJgohjZ9DeJcz... 0.56630000 BTC |
| | 13sSQcEjasD7S5PZn... 0.01185000 BTC |
| | 17McVX1jhiEMg5Mnt... 0.85516806 BTC |
| | 1LHY6mAeqHVYbpZ... 0.37096600 BTC |
| | 15Gw27cNPkqgUxqe... 0.26954988 BTC |
| | 15wgdri64ZuV8QY... 0.26955280 BTC |
| | 1KbB2KsEV2wUkAAx... 0.10780000 BTC |
| | 1Bjkr17q2TF37nvTdC... 1.00000000 BTC |
| | 16zFtGxAF7RWnPAy... 0.10712284 BTC |
| | 14qiXwDXJLUM5P7h... 0.04280000 BTC |
| | 1FyJw1oF7ojJVfbM... 193.37661929 BTC |
| Fee | +0.00500000 BTC |
| 0.00150000 BTC (55.310 sat/B - 13.827 sat/WU - 2712 bytes) | |

4

The screenshot shows a Bitcoin transaction interface. At the top, the hash '1431198bef5645bcce667c11f988257292c...' and the date '2017-02-10 19:48' are visible. The transaction consists of multiple inputs and outputs. A red circle highlights the first input: '1FNhjTqbogGenAtiVn... 0.03000000 BTC'. Another red circle highlights the output: '1FyJw1oF7ojJVfbM... 193.37661929 BTC'. A green arrow points from the first input to the highlighted output. At the bottom, the fee is '0.00150000 BTC (55.310 sat/B - 13.827 sat/WU - 2712 bytes)' and a green box shows '+0.00500000 BTC'.

| Hash | Amount | Unit |
|---|------------------|-----------------|
| 1431198bef5645bcce667c11f988257292c... | 2017-02-10 19:48 | |
| 1FNhjTqbogGenAtiVn... | 0.03000000 | BTC |
| 1FNhjTqbogGenAtiVn... | 0.29980000 | BTC |
| 1ChT8jHwnu28S8Gse... | 0.00552015 | BTC |
| 134JTcD1rwYzf3mJh... | 0.01066365 | BTC |
| 1F2DnSngMqhx3Bc5t... | 0.00102304 | BTC |
| 1PmJouprMuWvnuz1... | 0.00060627 | BTC |
| 1CNKsJdKEGafk7A6... | 0.02800000 | BTC |
| 1Jv324ZskcMwVaHo... | 0.04971298 | BTC |
| 1Jv324ZskcMwVaHo... | 0.02700664 | BTC |
| 1FyJw1oF7ojJVfb... | 200.00000000 | BTC |
| Load more inputs... (1 remaining) | | |
| 1FBov1eSTzbEWFhNP... | 0.04811430 | BTC |
| 1FnJ7ifPVs6pVzPAHj... | 0.15385554 | BTC |
| 1PLS2uFx9RCXj6y7o... | 0.03240000 | BTC |
| 1JPDFdbpYu7ZMN54... | 0.11000000 | BTC |
| 1Acehkhv2vRYE8JUJ... | 0.10000000 | BTC |
| 125UVAGTHgRpUWu... | 5.00000000 | BTC |
| 1LCy45fGKy5DDyLX7... | 0.19080000 | BTC |
| 1JQAJC1as3zqGvh3R... | 0.10780000 | BTC |
| 1uQWT55a31oXbG7y... | 0.06000000 | BTC |
| 1AtG2dZL2QT9Anob... | 0.26000000 | BTC |
| 19P2i6fCFLyhsZWVd... | 0.05476170 | BTC |
| 1NAr6doa9jzdAtjfcED... | 0.00100000 | BTC |
| 1GZjj8XvbdVvMgiSm... | 0.21500000 | BTC |
| 32SRuobXXWbxRYeLt... | 0.11180000 | BTC |
| 1DtnwrYpuj2AviHBKL... | 0.31386546 | BTC |
| 1MXx5bDua8844zAiK... | 0.03416878 | BTC |
| 1X9rcMVx8SvZ5uPz... | 0.00500000 | BTC |
| 1Hxm69vGPXrGu7kB... | 0.01000000 | BTC |
| 1CEoEkc1xzb5mBhpa... | 0.00547958 | BTC |
| 3ErsNJgohjZ9DeJcz... | 0.56630000 | BTC |
| 13sSQcEjasD7S5PZn... | 0.01185000 | BTC |
| 17McVX1jhiEMg5Mnt... | 0.85516806 | BTC |
| 1LHY6mAeqHVVYbpZ... | 0.37096600 | BTC |
| 15Gw27cNPkqgUxqe... | 0.26954988 | BTC |
| 15wgdri64ZuV8QY... | 0.26955280 | BTC |
| 1KbB2KsEV2wUkAAx... | 0.10780000 | BTC |
| 1Bjkr17q2TF37nvTdC... | 1.00000000 | BTC |
| 16zFtGxAF7RWNpZAY... | 0.10712284 | BTC |
| 14giYwDXJLUM3P7i... | 0.04280000 | BTC |
| 1FyJw1oF7ojJVfbM... | 193.37661929 | BTC |
| Fee | 0.00150000 | BTC |
| (55.310 sat/B - 13.827 sat/WU - 2712 bytes) | | |
| | | +0.00500000 BTC |

The exchange do not write on-chain transaction for each custom activity, but instead factorize them.

It reduces individual transaction fees.

Same for inputs.

Note the change address with a large amount

5

Sending back **0.001** from Wallet to Paymium Exchange

Address I received payment to

Address provided by Paymium

| | | | | | |
|------|--|----------------|---|--|----------------------------------|
| Hash | 40a08e1ff76d8133c151705f816bec87c75a8d7dd0957b4bd1ecd... | | | 2017-02-11 07:56 | |
| | 1X9rcMVx8SvZ5uPzpjaaPn6psXkw5LZhB | 0.00500000 BTC | → | 1NdhZ1TBi1dE8uk1qzUqYR2x7dRi52j5wr 1ArvJf54cVwJ2Y6gH6nic63ofQeiN32jbf | 0.00100000 BTC 0.00380700 BTC |
| Fee | 0.00019300 BTC (85.778 sat/B - 21.444 sat/WU - 225 bytes) | | | | 0.00480700 BTC |

High fees:
20% of the amount sent

Change
(My address in my wallet)

What happens with coins sent at this address?

| | | |
|------|--|------------------|
| Hash | 40a08e1ff56d8133c151705f816bec87c75a8d7dd0957b4bd1ecd... | 2017-02-11 07:56 |
| | 1X9rcMVx8SvZ5uPzpjaaPn6psXkw5LZhB 0.00500000 BTC | 0.00100000 BTC |
| | | 0.00380700 BTC |
| Fee | 0.00019300 BTC (85.778 sat/B - 21.444 sat/WU - 225 bytes) | 0.00480700 BTC |

| | | |
|------|---|---|
| Hash | 59c821350e1291c55ae8e0286b05e3627... | 2017-02-11 14:09 |
| | 1HsSSUvaMuL3VUw... 0.72080588 BTC | 1544JSQRTLCKfhJ1E... 0.05040000 BTC |
| | 1NdhZ1Tbi1dE8uk1qz... 0.00100000 BTC | 1HzGDkZN7fe4rAmW... 0.04910000 BTC |
| | 1KM3b551HzSQ4MQ... 0.00951400 BTC | 128DsHfMjaeCDunze... 0.44900000 BTC |
| | 1HUxJ5kTqLNhuMzy... 0.45732080 BTC | 1NCe8eAhHzyZPneYh... 0.11000000 BTC |
| | 1BoBVfPfk3BxaN1M1... 0.03900991 BTC | 1CjcXagRZviJwWSH... 0.06900000 BTC |
| | 1MgQhKRk4QqMTgeY... 0.01447889 BTC | 1A4wdSpiToSc3rw1G... 2.30000000 BTC |
| | 1FyJw1oF7ojJVfbM... 193.18850960 BTC | 19DBZUM62sYv66up... 0.05344623 BTC |
| | | 1PKmMMR7S26Usrjkj... 0.34257068 BTC |
| | | 17puCgUUALRV222V... 2.09300000 BTC |
| | | 1HoEKSQfmCebgcKo... 0.04000000 BTC |
| | | Load more outputs... (19 remaining) |
| Fee | 0.00150000 BTC (72.886 sat/B - 18.222 sat/WU - 2058 bytes) | -0.00100000 BTC |

“My” coins have been spent the same day, and not by me!
=> 1Ndh... Is not “my” address, it’s paymium’s address.
It’s just that when coins are sent to this address, Paymium *credit* my customer account of the same amount.

6

Using my wallet coins to buy some real things (Amazon gift card)

Hash: 40a08e1ff56d8133c151705f816bec87c75a8d7dd0957b4bd1ecd... 2017-02-11 07:56

1X9rcMVx8SvZ5uPzpjaaPn6psXkw5LZhB 0.00500000 BTC → 1NdhZ1Tbi1dE8uk1qzUqYR2x7dRi52j5wr 0.00100000 BTC
1ArvJf54cVwJ2Y6gH6nic63ofQeiN32jbf 0.00380700 BTC

Fee: 0.00019300 BTC (85.778 sat/B - 21.444 sat/WU - 225 bytes) **0.00480700 BTC**

Hash: 1650dd5cd9233705193aa83e42d8460d... 2021-01-27 23:16

1ArvJf54cVwJ2Y6gH... 0.00380700 BTC → bc1qcp8uuxkx48ylrg... 0.00060200 BTC
3JnJU19y21FgySKoX... 0.00300300 BTC

Fee: 0.00020200 BTC (91.403 sat/B - 22.851 sat/WU - 221 bytes) **-0.00380700 BTC**

Company selling gift card

Hash: 7578596ecc510bb93d662d97d8bf6c8b7... 2021-01-28 05:08

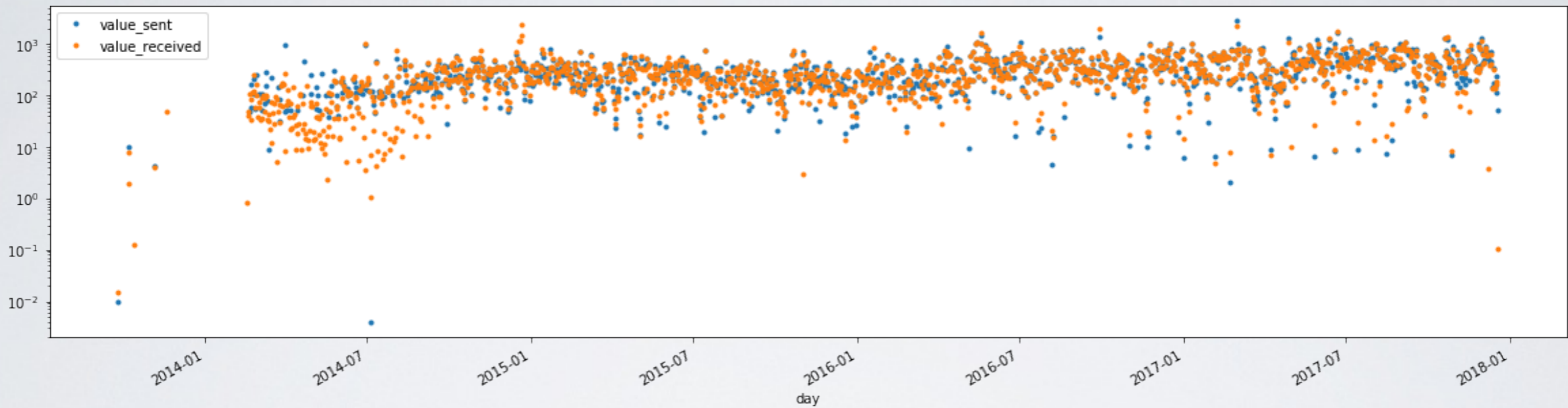
3PxxW8ghgJuC4J5y1... 0.00438600 BTC → bc1qj4zp28m9r3elw5... 7.00529441 BTC
3Q2xe5JyvuL5mvxn... 0.01404900 BTC
38LwzsRkxqXe3jfSD... 0.00806700 BTC
3C8i2YX1EWurpK9qt... 0.00318400 BTC
34Z85bRMu4jE5mRm... 0.00212500 BTC
35zcYgpERQo9SUUo... 0.01549100 BTC
3GZ2PMcvphAiYdA2... 0.00325000 BTC
349AFe7DdK4bfJZ7R... 0.00212600 BTC
3N3W124kvbjPQ89u... 0.02365300 BTC
32dkoFUb5bh9ECPG... 0.00314300 BTC

Load more inputs... (776 remaining)

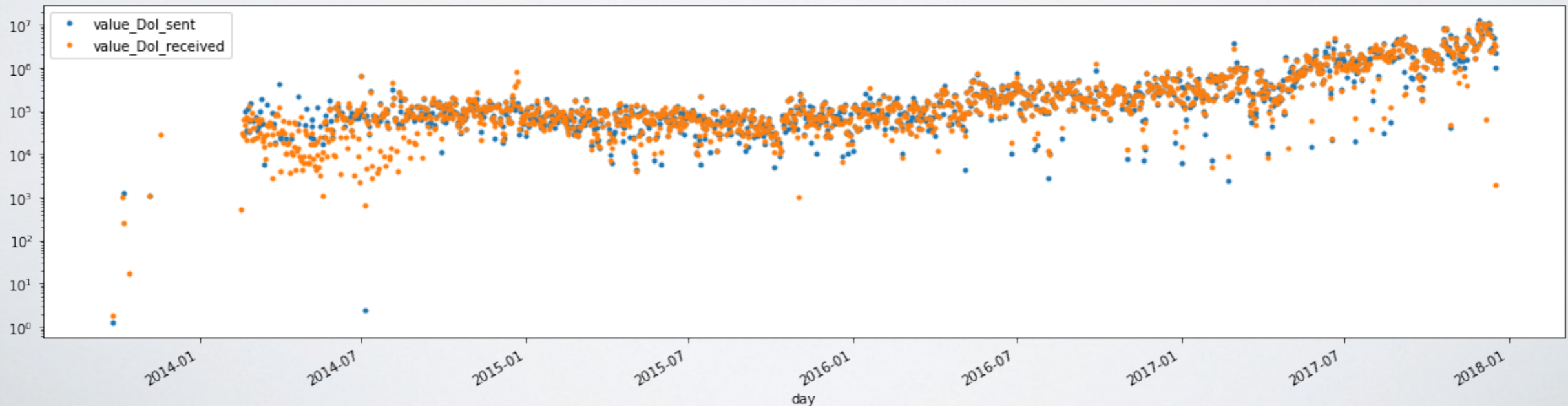
Fee: 0.00163316 BTC (1.211 sat/B - 0.571 sat/WU - 134825 bytes) **-0.00300300 BTC**

PAYMIUM ACTIVITY

Dayly sent/received amounts in btc



Dayly sent/received amounts in \$



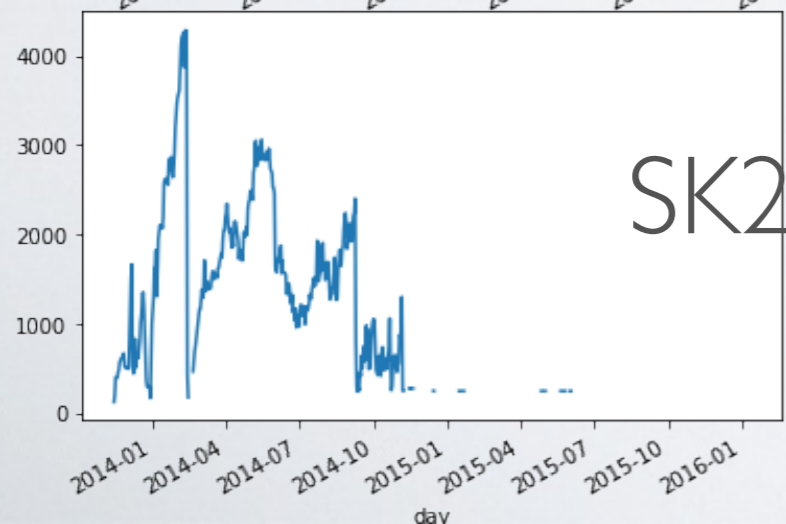
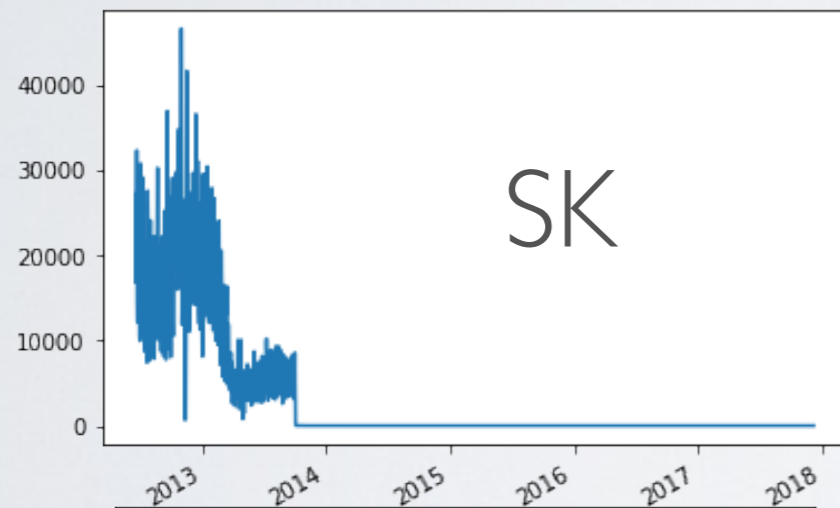
Cumulative of the difference between amounts
received and sent
(Btc owned)



SILK ROAD

Silk Road was a website infamous for illegal product selling (drugs, etc.)

Daily transactions
Amounts (btc)



Top 10 actors who
Sent/Received the most to/from Silk-Road

(Mostly
anonymous
eWallet and
Mixing services)

| | |
|-----------------------|--------------|
| SilkRoadMarketplace | 6.393444e+06 |
| ePay.info | 5.057304e+05 |
| Instawallet.org | 1.785853e+05 |
| Bitcoin.de-old | 6.506796e+04 |
| Bitstamp.net-old | 4.965712e+04 |
| 10666 | 4.130923e+04 |
| 89090 | 3.998100e+04 |
| 363 | 3.533352e+04 |
| BTC-e.com-old | 3.511806e+04 |
| LocalBitcoins.com-old | 3.451882e+04 |

| | |
|---------------------|--------------|
| SilkRoadMarketplace | 6.393601e+06 |
| BitcoinFog | 1.791251e+05 |
| Instawallet.org | 1.615579e+05 |
| ePay.info | 1.478182e+05 |
| Bitstamp.net-old | 1.451114e+05 |
| 2077410 | 1.445200e+05 |
| 89090 | 1.137133e+05 |
| 223978 | 7.453770e+04 |
| 28928788 | 5.878110e+04 |
| -6337253 | 5.000000e+04 |

SILK ROAD

Some of the last transactions made by SR2...
Same private Wallet, same amounts...

| | | | | | | |
|-----------|------------|-----------------|----------|-------------|---------------------|------------|
| 138077500 | 1415256435 | SilkRoad2Market | 35339862 | 10000000000 | 2014-11-06 06:47:15 | 2014-11-06 |
| 138081140 | 1415256435 | SilkRoad2Market | 35339862 | 10000000000 | 2014-11-06 06:47:15 | 2014-11-06 |
| 138081181 | 1415256435 | SilkRoad2Market | 35339862 | 10000000000 | 2014-11-06 06:47:15 | 2014-11-06 |
| 138081229 | 1415256435 | SilkRoad2Market | 35339862 | 10000000000 | 2014-11-06 06:47:15 | 2014-11-06 |
| 138081666 | 1415256435 | SilkRoad2Market | 35339862 | 10000000000 | 2014-11-06 06:47:15 | 2014-11-06 |
| 138081914 | 1415256435 | SilkRoad2Market | 35339862 | 10000000000 | 2014-11-06 06:47:15 | 2014-11-06 |
| 138081996 | 1415256435 | SilkRoad2Market | 35339862 | 10000000000 | 2014-11-06 06:47:15 | 2014-11-06 |
| 138082018 | 1415256435 | SilkRoad2Market | 35339862 | 10000000000 | 2014-11-06 06:47:15 | 2014-11-06 |
| 138082050 | 1415256435 | SilkRoad2Market | 35339862 | 10000000000 | 2014-11-06 06:47:15 | 2014-11-06 |
| 138082069 | 1415256435 | SilkRoad2Market | 35339862 | 2500000000 | 2014-11-06 06:47:15 | 2014-11-06 |
| 138082087 | 1415256435 | SilkRoad2Market | 35339862 | 2500000000 | 2014-11-06 06:47:15 | 2014-11-06 |
| 138082134 | 1415256435 | SilkRoad2Market | 35339862 | 10000000000 | 2014-11-06 06:47:15 | 2014-11-06 |
| 138082146 | 1415256435 | SilkRoad2Market | 35339862 | 10000000000 | 2014-11-06 06:47:15 | 2014-11-06 |
| 138082166 | 1415256435 | SilkRoad2Market | 35339862 | 5000000000 | 2014-11-06 06:47:15 | 2014-11-06 |
| 138082206 | 1415256435 | SilkRoad2Market | 35339862 | 5000000000 | 2014-11-06 06:47:15 | 2014-11-06 |
| 138082248 | 1415256435 | SilkRoad2Market | 35339862 | 10000000000 | 2014-11-06 06:47:15 | 2014-11-06 |

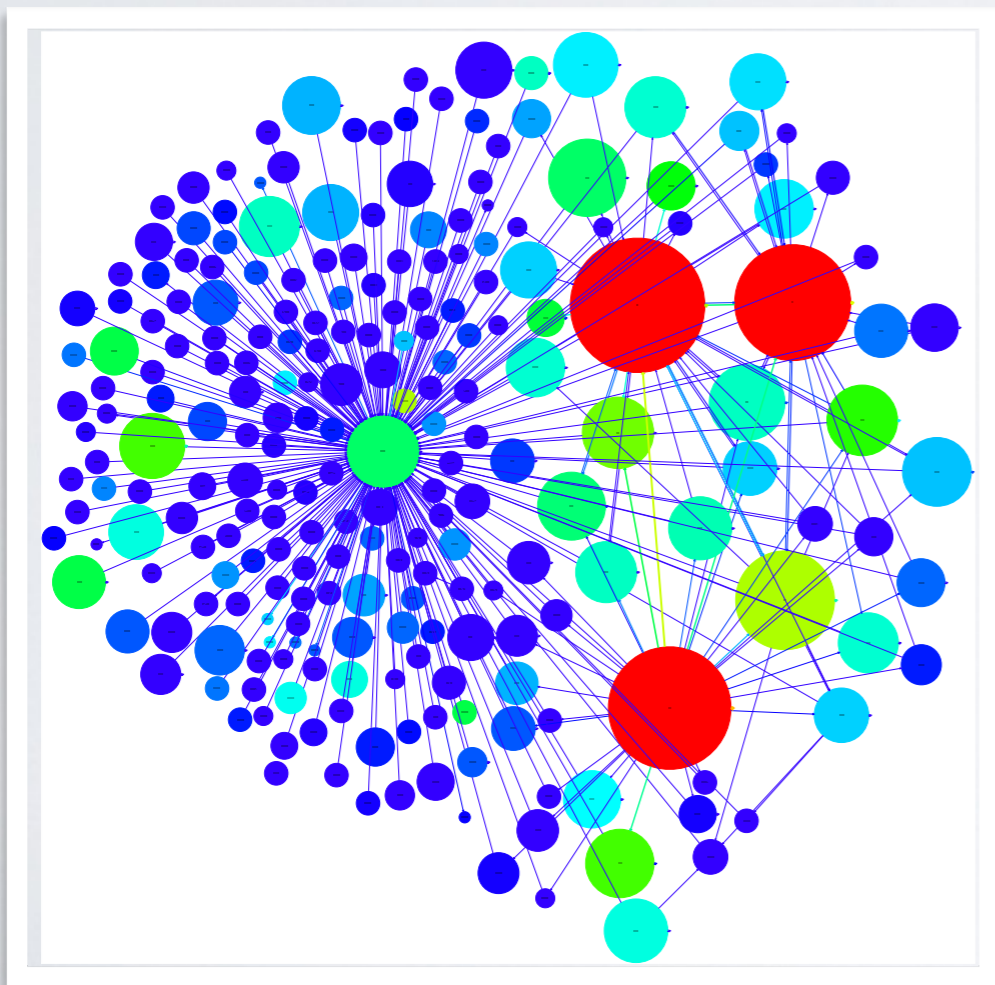
And then...

| | timestamp | sender | receiver | value | date | day | PriceUSD |
|-----------|------------|----------|------------|--------------|---------------------|------------|-------------|
| 588090783 | 1492427923 | 35339862 | -177532360 | 146799545224 | 2017-04-17 11:18:43 | 2017-04-17 | 1191.901201 |

EXAMPLES FROM THE SCIENTIFIC LITERATURE

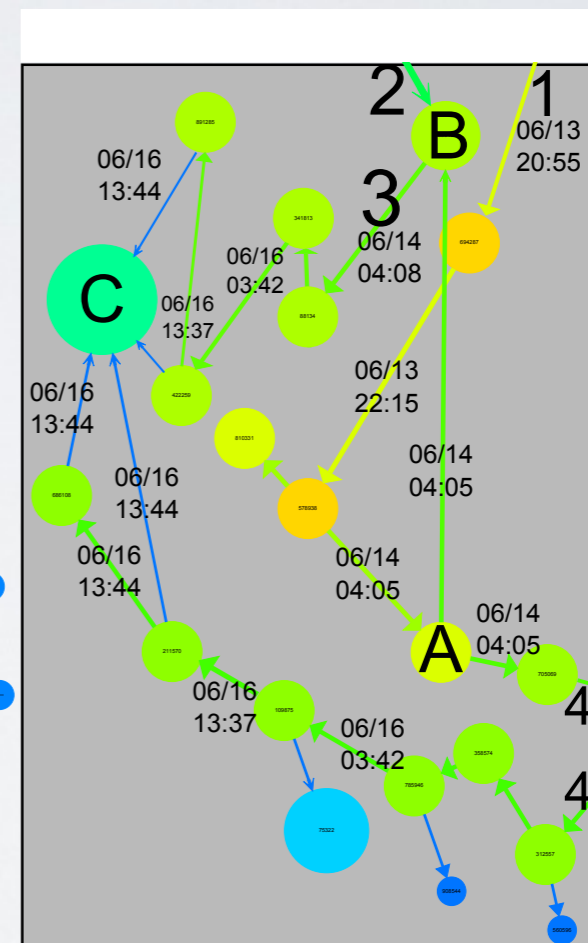
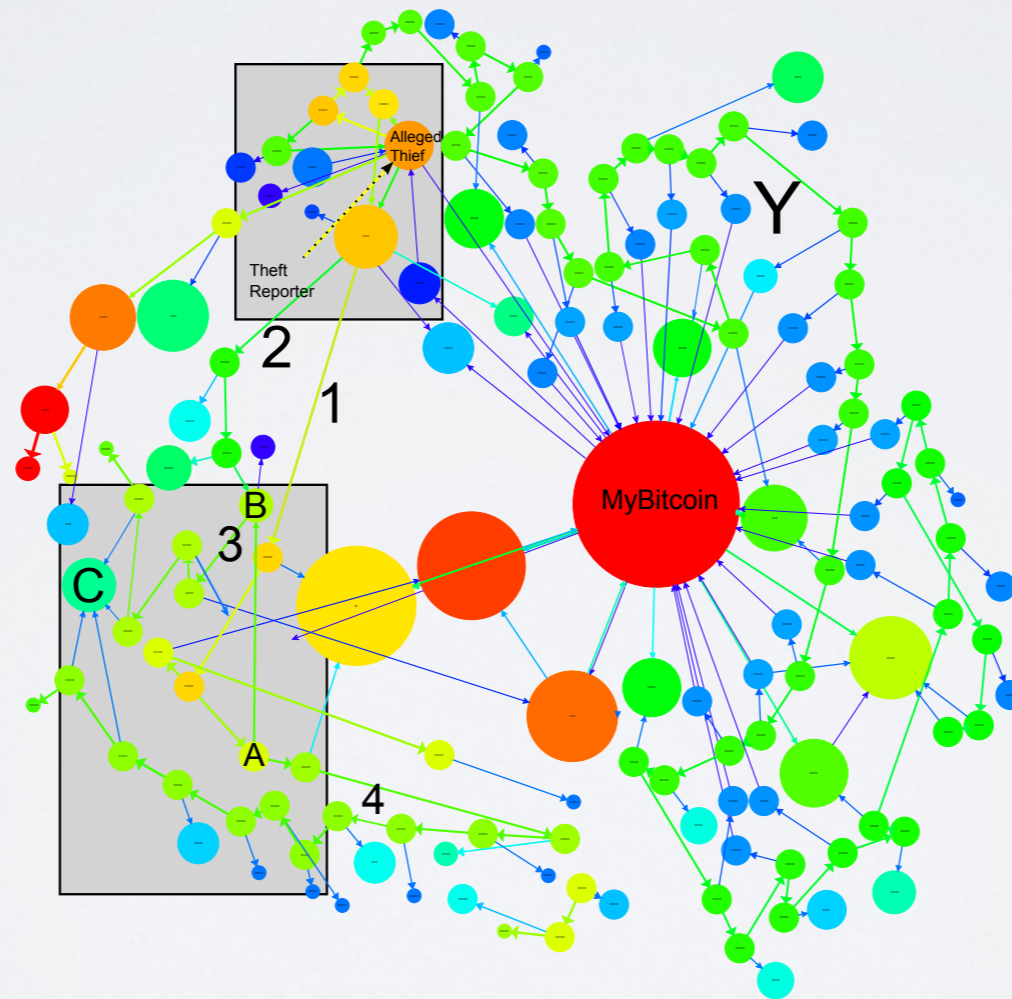
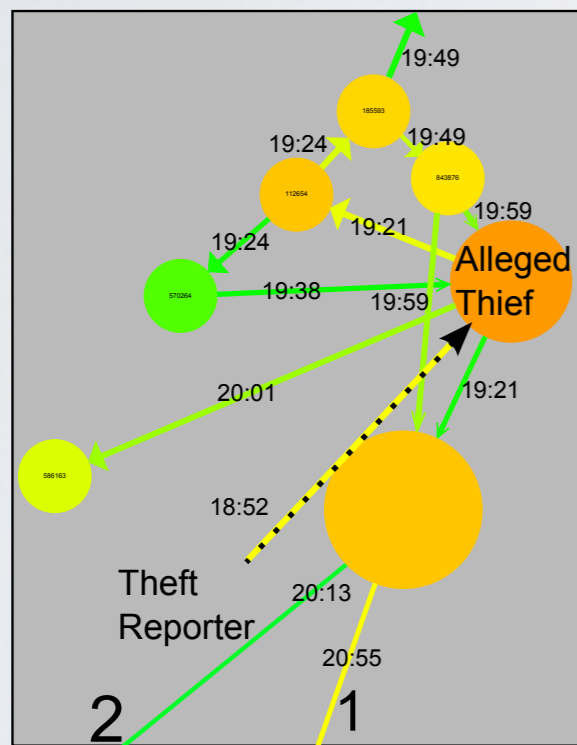
EGO-CENTERED NETWORK

- Wikileaks



Green in the center : wikileaks

A BITCOIN THEFT



MONEY LAUNDERING

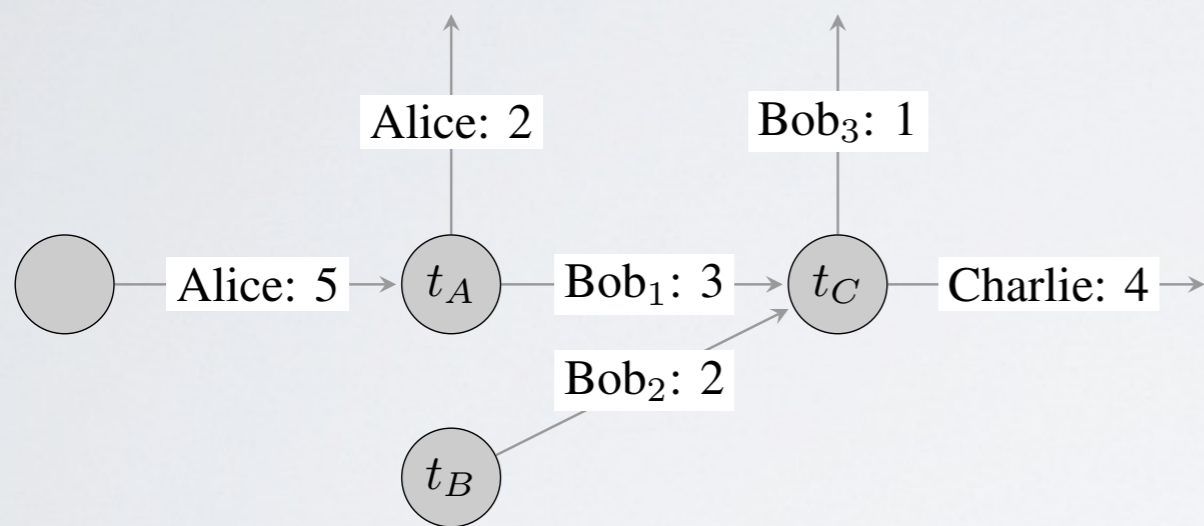


Figure 1. Example of a partial transaction graph

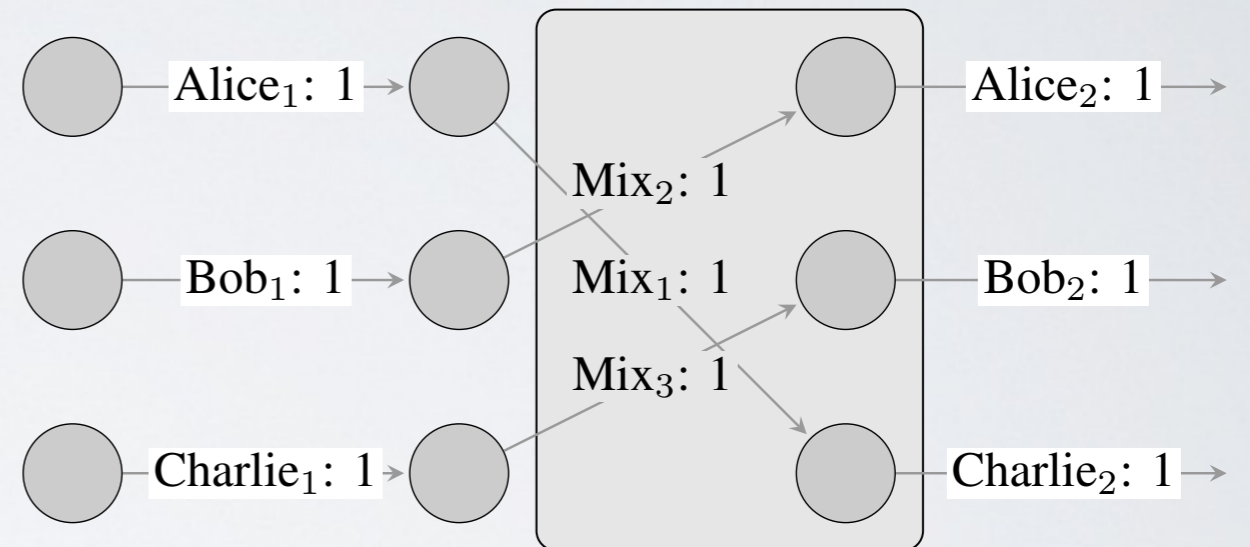
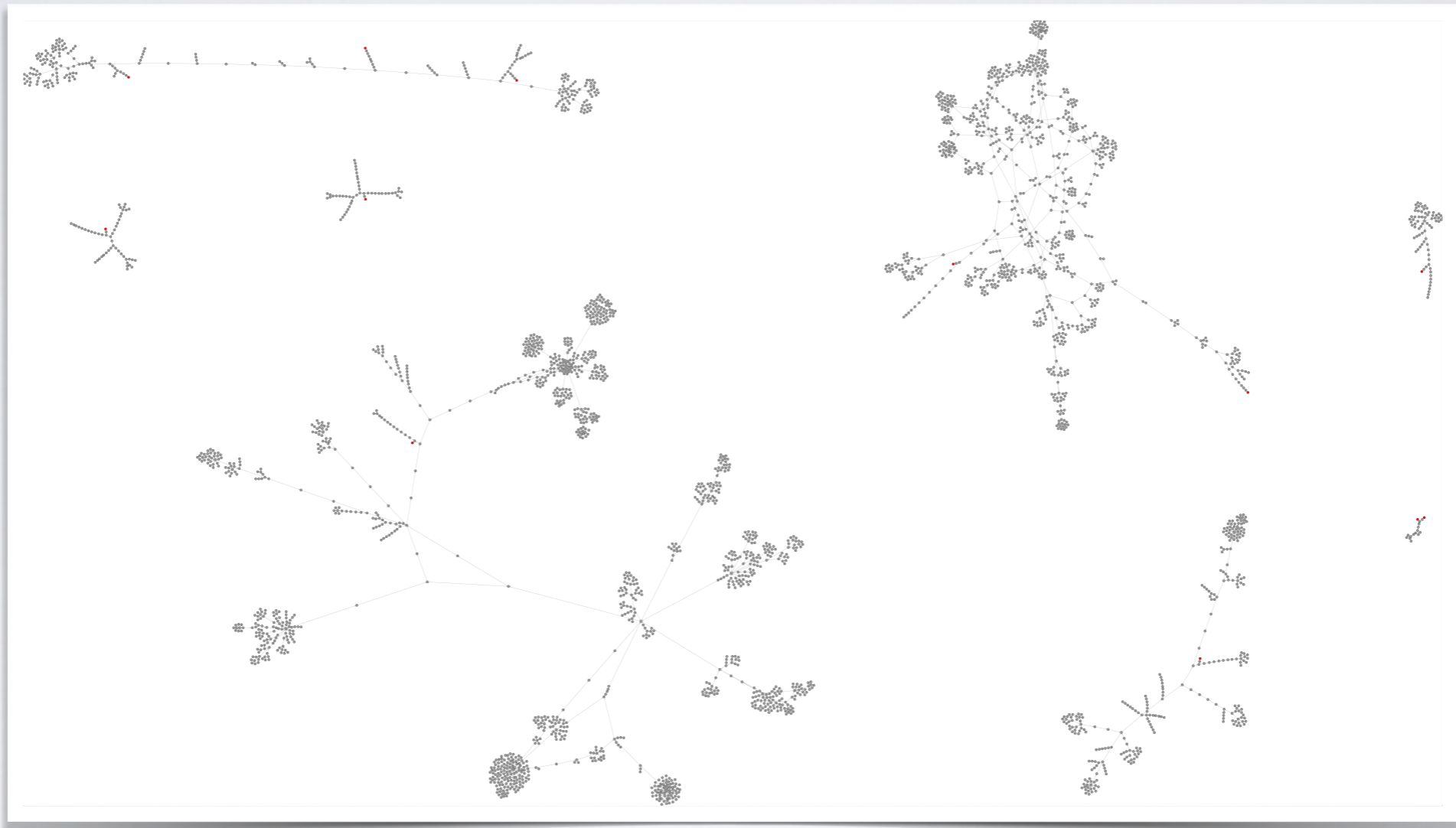


Figure 2. Block diagram of a hypothetical Bitcoin mixing service

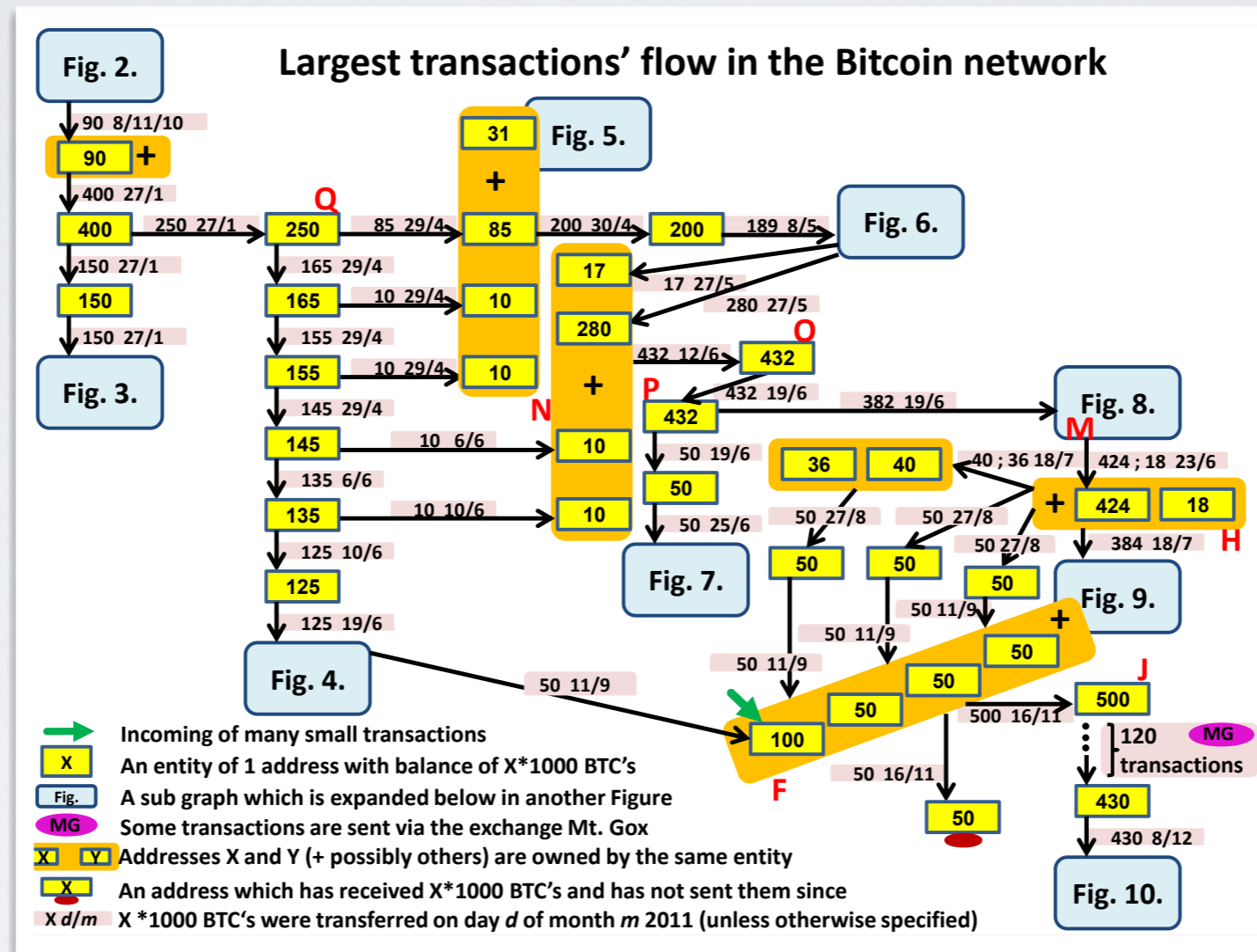
[Möser & Böhme]

MONEY LAUNDERING



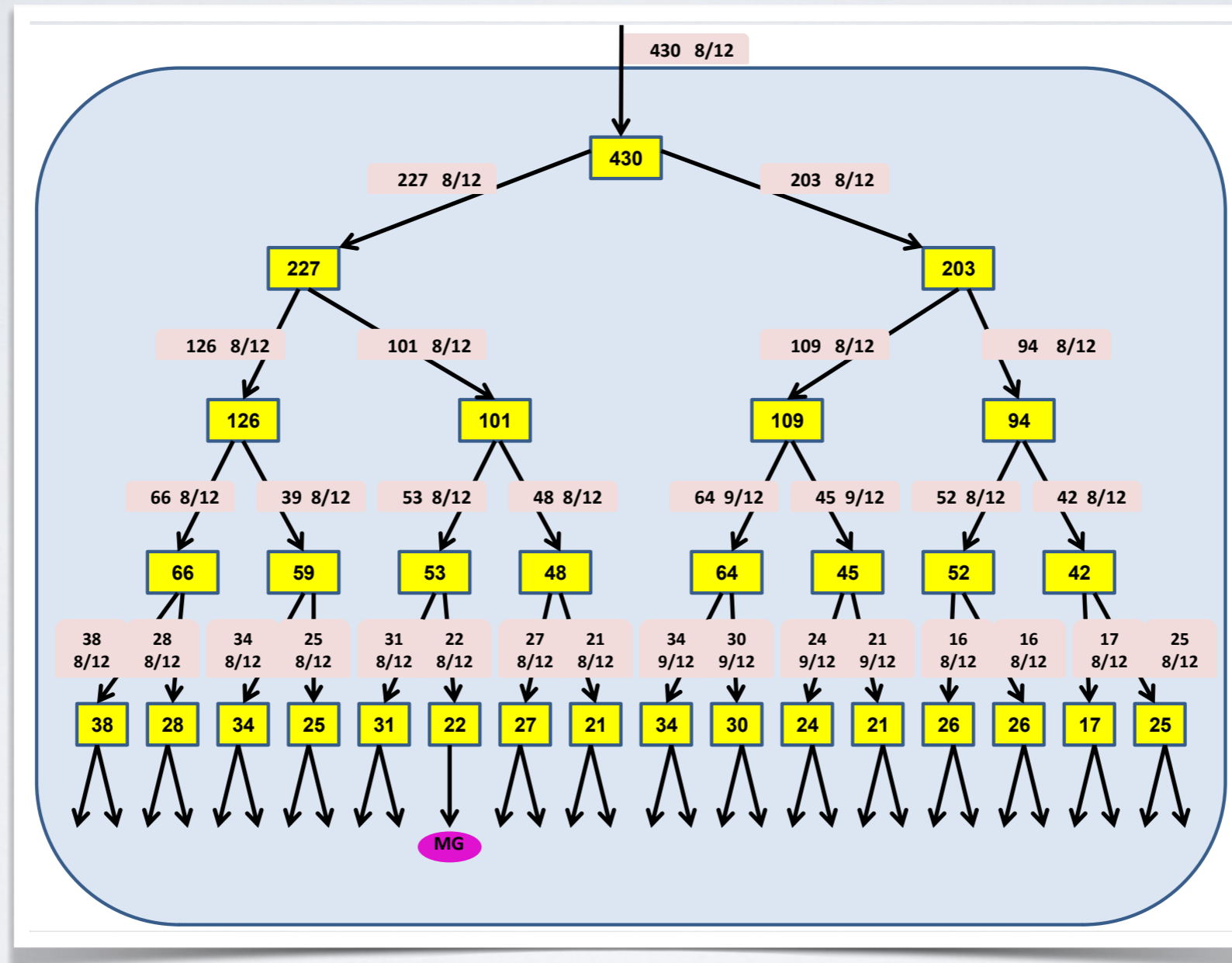
[Möser & Böhme]

EXCEPTIONAL TRANSACTIONS ANALYSIS



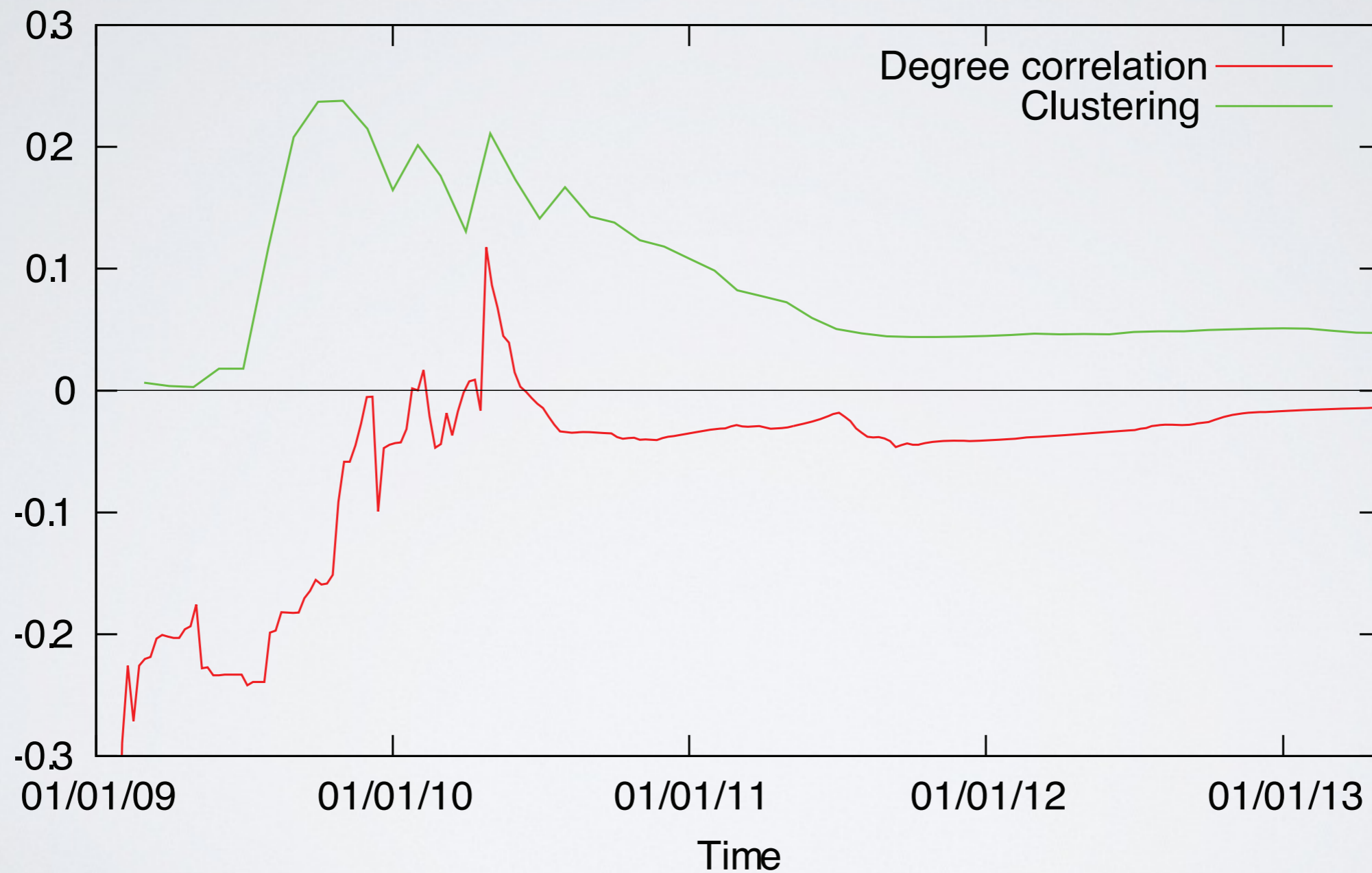
[Ron & Shamir]

EXCEPTIONAL TRANSACTIONS ANALYSIS



[Ron & Shamir]

ANALYSIS OF NETWORK PROPERTIES



[Kondor et al]