

MASARYK UNIVERSITY
FACULTY OF INFORMATICS



Darknet market analysis and user de-anonymization

MASTER'S THESIS

Tomáš Šíma

Brno, Spring 2018

MASARYK UNIVERSITY
FACULTY OF INFORMATICS



Darknet market analysis and user de-anonymization

MASTER'S THESIS

Tomáš Šíma

Brno, Spring 2018

This is where a copy of the official signed thesis assignment and a copy of the Statement of an Author is located in the printed version of the document.

Declaration

Hereby I declare that this paper is my original authorial work, which I have worked out on my own. All sources, references, and literature used or excerpted during elaboration of this work are properly cited and listed in complete reference to the due source.

Tomáš Šíma

Advisor: RNDr. Martin Stehlík

Acknowledgements

I would like to thank my supervisor RNDr. Martin Stehlík Ph.D. for guiding me and providing technical support for my work.

I would also like to thank Mgr. Jaroslav Šeděnka for his continuous stream of helpful comments and ideas.

Access to computing and storage facilities owned by parties and projects contributing to the National Grid Infrastructure MetaCentrum provided under the programme "Projects of Large Research, Development, and Innovations Infrastructures " (CESNET LM2015042), is greatly appreciated.

Abstract

This thesis has two goals. The first goal is to perform quantitative statistical analysis of Valhalla cryptomarket. We scraped Valhalla cryptomarket website for information about vendors, listings and buyers and brought up a lot of interesting statistics about them.

The second goal of this thesis is to create a tool to find, analyze and visualize publicly available data, which can be helpful to deanonymize users of drug markets available via Tor on dark web. The aim of this tool is to help investigators with collecting intelligence about entities related to these drug markets. Users and operators of these markets employ multiple means to prevent their deanonymization. Cryptomarkets are operated as Tor services, PGP encryption is often required to communicate between multiple parties and bitcoin is used as a way of paying for goods or services.

We scraped multiple publicly available social sites and websites related to bitcoin (Twitter, Bitcointalk, Reddit, blockchain.info...) and also drug markets themselves. We stored all the data in a neo4j database, which is a graph database based on PostgreSQL. We created a tool, which collect these data, import them to database, compute multiple heuristics and provides user and interface for visualizing data and metadata of addresses and identities related to cryptomarkets and blockchain. The tool can for given bitcoin address find the nearest addresses or transactions related to drug markets and also find the nearest addresses that are mentioned in scraped websites.

To test the efficiency of this tool, we created two profiles on Valhalla cryptomarket and performed multiple transactions to deposit and withdraw bitcoins. We imported into tool the bitcoin addresses of the first profile received bitcoins from and checked, if the tool is able to identify, that addresses owned by second profile had been sending/receiving bitcoin from Valhall market also.

Keywords

blockchain, bitcoin, darknet, drug market, Tor, cryptocurrency, anonymity, metadata, de-anonymization

Contents

1	Introduction	1
1.1	<i>Goals</i>	2
1.2	<i>Structure of the thesis</i>	2
2	Related terminology	4
2.1	<i>Cryptomarkets</i>	4
2.1.1	The process of ordering	5
2.1.2	Valhalla cryptomarket	5
2.1.3	Vendor's feedback	7
2.2	<i>Bitcoin and blockchain</i>	7
2.2.1	Addresses, bitcoins and transactions	8
2.2.2	Mining	9
2.2.3	Tumblers	10
2.3	<i>Tor - the onion routing</i>	11
2.4	<i>PGP</i>	12
3	Related work	14
3.1	<i>Blockchain analysis and linking bitcoin addresses</i>	14
3.2	<i>Behaviour of drug markets users and operators</i>	16
4	Methods and tools of data retrieval and analysis	18
4.1	<i>Valhalla cryptomarket webscraping</i>	18
4.2	<i>Valhalla cryptomarket metadata scraping and analysis</i>	20
4.3	<i>Publicly available data scraping</i>	21
4.4	<i>Retrieving, storing and analyzing blockchain data</i>	22
4.5	<i>Using own transactions to identify market wallets</i>	22
5	Application	25
6	Statistics of Valhalla cryptomarket	26
7	Testing and verification of the created tool	32
7.1	<i>Method of testing</i>	32
7.2	<i>results</i>	32
8	Conclusion and future work	33

Appendices	36
A Requirements and setup	37

List of Tables

- 2.1 Visited cryptomarkets 6
- 6.1 Countries that vendors shipp from 27
- 6.2 Estimated monthly revenue for selected drug categories a
by listing price 29

List of Figures

2.1	Tor routing schema	12
2.2	Tor packed encryption schem	13
4.1	Neo4j database ER diagram	23
6.1	Number of active listings for each seller	26
6.2	Prices of listings	28
6.3	Prices of listings in feedbacks	30
6.4	Vendors revenue by positive feedback ratio	31
6.5	Positive reviews of vendors	32
6.6	Positive/negative reviews of vendors	33
6.7	Number of reviews for vendors	34
6.8	Total revenue of vendors	35
6.9	Buyers spending and trades	35
A.1	Architecture of application	38

1 Introduction

The relative anonymity of the Internet offers an incentive for criminal parties to use the Internet as a tool for their activities. Internet facilitates some forms of existing crimes (selling drugs, guns and counterfeits, running Ponzi schemes) and also enables many new types of frauds like hacking, phishing and identity theft.

Publicly available statistics show that cybercriminals are much less likely to be discovered and persecuted than criminals operating offline. In the USA in 2010, there were 5628 robberies and the loot was recovered in more than 20% cases. [5] In the same year FBI recieved 303809 complaints related to cyber crime, resulting in just 6 convictions. [1] Criminals value their anonymity very highly and use various means to prevent being caught by police forces. [28] [31] [3]

A big problem for criminals was getting the money they got from criminal activity to their possession, since that required some form of physical presence or identification. Also, it was hard for two anonymous entities engaging in criminal activity to transfer value to each other, because it's hard to set up an anonymous bank account and neither party could be sure about the origin of the money they have received.

For bitcoin, there is no central authority requiring bitcoin address (bitcoin equivalent of bank account number) to be linked to person's identity and so criminals can just use their connection to the Internet to both receive and send bitcoins without disclosing their identity. However, all bitcoin transactions are publicly available and so each bitcoin can be tracked through the whole transaction history.

Cryptomarkets are online marketplaces, where vendors offer illicit goods and services. Cryptomarkets are accessible via Tor network as an .onion service, users of cryptomarkets use PGP to communicate with each other and use bitcoin as a way to transfer value. These mechanisms make it possible for cryptomarkets to publicly operate, yet be hard to reach by law enforcement. [8]

We scraped and examined data from Valhalla market, to our best knowledge one of the most popular and well established currently (February 2018) operating drug markets, in order to do a statistical analysis of the scale of its operations.

All the bitcoin transactions are stored in blockchain. Blockchain is publicly available, and so anyone can access data about bitcoin transactions. Bitcoin transactions transfer bitcoins between bitcoin addresses. It is common practice for users to generate new bitcoin address for each incoming transaction. When user pays via bitcoin, he might use bitcoins just from some small subset of his bitcoin addresses and so the recipient doesn't know about sender's addresses that were not used in the transaction. This mechanism helps sender not disclose how many bitcoins he owns in total and also protect receiver from finding all transactions that were done by sender in the past.

1.1 Goals

We created a toolchain for drug market users deanonymization by using publicly known data. The tool imports bitcoin blockchain into neo4j graph database in order to create a graph of transactions. It then runs multiple heuristics over this graph to cluster addresses that belong to the same user. The tool scrapes multiple public sources related to drug markets and bitcoin transactions in order to obtain some form of identification(username) linked to bitcoin address and adds this information to database. It provides GUI where user can insert address and the program finds addresses with linked identities that are few transactions away from the inserted address in the transaction graph. We also created multiple scripts for scraping information about trades from Valhalla market website and export them to .csv files and used these data for quantitative analysis of Valhalla market operations.

XXX - tool byl uspesny v detekovani tolika a tolika adres z pouzitych uctu, viz kapitola verifikace

1.2 Structure of the thesis

XXX - mozna se zmeni lehce jmena/poradi kapitol, jinak povidani stejne

Chapter Related works give an overview of works already done on similar topics.

Chapter Technology and terms starts with a quick introduction to bitcoin and blockchain, which is used for paying on crypto markets. It

also describes how cryptomarkets work and tools that are used by users and administrators of cryptomarkets.

The chapter Methods and tools describes the process of collecting and storing the data from bitcoin blockchain, drug markets and publicly available forums and social networks.

Deanonimization techniques chapter describes heuristics and methods that are used by the application to detect addresses used by drug markets and link the users of drug markets to publicly found identities.

Chapter Statistics of drug markets consists of various statistics about drug markets that were gathered during drug market website scraping. It contains two parts, the first is focused on statistics related to cash flows, the second part is giving insight about non-money related statistics.

The chapter called Application describes the functionality, implementation, usage and possible future development of the application for investigating bitcoin addresses, which was created as part of this thesis

Testing and verification chapter is about the testing of the created application. The last chapter is a discussion about achieved goals, problems of implementation and possible future improvements.

2 Related terminology

In this chapter, I explain the terms and technology related to online drug markets. Online drug markets use several technologies that are crucial to their anonymous operation. Bitcoin enables different parties to exchange value in an anonymous way. Tor allows users and administrators of a marketplace to hide from any third party doing packet sniffing on the network, that they are accessing drug marketplace. It also hides the location on drug marketplace web server from its users. PGP enables sellers and vendors to communicate between each other in an encrypted way, so that drug market administrators cannot eavesdrop on that communication.

2.1 Cryptomarkets

Illegal online markets have been around for more than 30 years [19]. On these markets, users can sell and buy drugs, weapons, hacking tools, stolen credit cards, counterfeit currency, forged documents and other illegal goods and services. Most markets forbid selling the most unambiguously harmful goods, such as child pornography or hitman services.

In 2011 there appeared a new type of illegal online marketplace called cryptomarket. A cryptomarket is an illegal online market accessible only via Tor network and using bitcoins as a means of making payments. These two technologies provided a safer environment than previous markets hosted on forums and chatrooms.

Physical products, like drugs, are sent to a buyer via ordinary mail to the address provided by the buyer. The package is disguised as packages containing common goods sent by big online retailers. [21]

Cryptomarkets are popular with vendors, because they offer them high influx of customers and secure and anonymous environment for conducting their business [29]. Cryptomarkets offer safer, more comfortable and more professional way of buying drugs, avoiding the need to meet face to face with dealers [6].

Nowadays, there exist multiple cryptomarkets competing against each other and the risk of a failure of a deal is still high [33]. In order to protect buyers, cryptomarkets use Escrow and vendors' feedback to

identify scammers and minimize losses. Silkroad cryptomarket used Tumbler services [24], which makes it harder to detect and analyze bitcoin transaction. Valhalla cryptomarket claims that they users can withdraw bitcoin from them using bitcoin tumbler too.

2.1.1 The process of ordering

Most of the cryptomarkets are publicly available and there is no fee for creating a user account. The act of buying drugs from them is considered user-friendly by buyers and is similar to the process of buying goods from popular lawfull e-shops like Amazon.

The whole process consists roughly of these steps:

1. User creates an account on cryptomarket if he doesn't have one already
2. He tops up his account by sending bitcoins to the bitcoin address, that was generated for his deposits.
3. He than finds an offer that he is interested in and buy it in a similar way as in any other e-shop.
4. Buyers' money is now locked by cryptomarket.
5. The buyer and vendor communicate out the way of delivery.
6. If the buyer receives goods or services, he confirms it and money is unlocked to the vendor.
7. Buyer gives feedback to the vendor.
8. Vendor withdraw bitcoins from the market to his bitcoin address.

Vendors value their feedback ratings very highly, so they encourage buyers to leave positive feedback when the transaction goes well.

2.1.2 Valhalla cryptomarket

We selected Valhalla cryptomarket based on three metrics. The first metric is its size.

Table 2.1: Visited cryptomarkets

Cryptomarket name	Number of listings
Dream Market	72830
Valhalla	25309
Wall street market	10566
Point market	9202

We checked list of active cryptomarkets on reddit community "r/-darknetmarkets" and website <https://www.deepdotweb.com>. <https://www.deepdotweb.com> has alexa ranking 23500, which roughly corresponds to thousands visitors a day. The reddit community is the first link for google query "darkmarkets list" and has more than 160 000 readers. So we consider these sites to be relevant enough to not miss the biggest cryptomarkets in their lists. Cryptomarkets taken into consideration are in table 2.1.

Valhalla market is well known operating cryptomarket. With more than 20 000 active listings and 600 vendors, it's the second biggest currently operating cryptomarket.

Among these cryptomarkets only Valhalla and Dream market has been operating since 2013. This is to advantage of our analysis, as we can analyze matured cryptomarket with vendors, who have been selling for a longer time and have more reviews.

Among cryptomarkets mentioned above, Valhalla cryptomarket provides the most information about vendors and buyers. Each feedback for given vendor consists of buyer's comment, date the feedbacks were given, the listing the user gave feedback to, the sum of money the buyer spent on market, the amount of trades the buyer did on the Valhalla market and first and last 2 digits of the buyer's nickname. (eq. for buyer with nickname "gopnik789" it shows "go***89")

The 2 first and last digits of buyer's username are really unique for Valhalla market, other markets offer first and last character of buyer's username at most. This will drastically help with recognizing the same buyer among multiple feedbacks. Valhalla is also the only market from the markets above, where customer feedback also contains the associated listing. This allows us to detect the most profitable and popular listings.

2.1.3 Vendor's feedback

Cryptomarkets usually employ reputation systems [23], where buyers can share their satisfaction with vendors. These systems are similar to systems used in popular e-commerce websites like Amazon or Ebay. Users can give feedback only to vendors they have traded with. On some cryptomarkets, it is only possible to upvote and downvote vendors, on some others, people can rate different parts of their interaction with the seller, like the easiness of communication, the speed of sending the goods and unsuspectingness of packaging.

Feedback is not mandatory, but vendors encourage buyers to give them positive feedback [3][26], because the positive feedback ratio gives the vendor a significant advantage over vendors with worse feedback.

2.2 Bitcoin and blockchain

Bitcoin [20] is the first decentralized peer to peer cryptocurrency, created by the anonymous author(s) known by pseudonym Satoshi Nakamoto in 2008. Bitcoin transactions are not verified by central authority, they are processed by distributed peer to peer network of bitcoin nodes instead. The source code of bitcoin nodes is an open source and can be downloaded and run locally. The entire history of transactions is stored in a distributed public ledger called blockchain. Bitcoin combines multiple cryptography algorithms to achieve consensus among nodes on the state of the blockchain. The state of blockchain is protected by the computing power of bitcoin miners using cryptography to validate and add new transactions. State of blockchain should only be modified by adding the new block of transactions to the end of the blockchain. Third party attacker could theoretically modify blockchain if he had 51% of the whole mining computing power. This has nearly happened once, mining pool Ghash.io accounted for more than 42% of mining power in 9.1.2014. In reaction to that event, some of miners mining under this mining pool leaved pool in order to prevent this from happening. Also, it sometimes happens, that two miners add different new block to the blockchain at the same time and for some time, there exist two versions of blockchain with different last block. These two versions exist until the next block is found for

one version. Miners then accept the longer chain of the two versions and the shorter one is discarded. It is therefore recommended to wait multiple blocks after the transaction is added into blockchain to be sure it does not disappear by this forking.

2.2.1 Addresses, bitcoins and transactions

In order to receive and send bitcoins, a user needs to have a bitcoin address. A bitcoin address is simply a BASE58 encoded public key with 4 bytes added for checksum. Each address has its associated private key. In order to send bitcoin from bitcoin address, a user needs to have a private key associated with the given bitcoin address. Storage and usage of bitcoin addresses and associated private keys is automatically managed by software called bitcoin wallet. There exist many third party software wallets.

All the transactions, bitcoins and addresses are stored in the blockchain, the balance of all addresses and all transactions is publicly available. In order to not see the whole history of transactions of the address owner, the bitcoin wallets generate a new bitcoin address for each of new incoming transaction. When spending bitcoins, it uses one or more of the addresses the wallet generated previously. Therefore, when pairing the address to identity, we can directly obtain just the history of transactions related to the given address, but can not get all transactions and balance of the user, as he is likely to own multiple bitcoin addresses.

Bitcoins in blockchain are represented as inputs and outputs of the transaction. Each transaction has some inputs and outputs. Input and output is the same data structure, it only differs in its relationship to the given transaction. Each input/output consists of its unique identifier, its value in bitcoins and bitcoin address that owns it. Every output can be used exactly once as an input of a new transaction, and therefore the owner of an output can not spend one output multiple times.

When the sender sends a bitcoin to the recipient, he generates a transaction. The new transaction comply with the following:

- He owns addresses of the inputs = He can spend only bitcoins he owns

- No input has been used as an input in any other transaction = He cannot spend one output multiple times
- The sum of bitcoins of transaction inputs is equal to the sum of bitcoins of transaction outputs + fees

The new transaction must have 1 or more outputs. There can be multiple outputs in a transaction with different associated addresses and bitcoin value, however, there happens to be a common pattern. When the sender sends bitcoins to one recipient, the transaction typically contains two outputs. One output contains the recipient's address and the volume of bitcoins he receives. One output is called "change output". Since the sender usually doesn't own outputs that sum to be equal to the number of bitcoins he wants to send, he adds a second output to the transaction. The second output has an address he owns and amount of bitcoins he will get back from the transaction. This is the only way to split bitcoins into smaller parts.

When sending bitcoins from wallet, wallet software creates transaction data and signs it with keys of addresses that are sending the bitcoins. Then it sends it to one or multiple bitcoin nodes. Nodes collect transactions from users and broadcast them to other nodes on best effort basis. The validity of the transaction is later checked by miners and if everything is ok, they add it to the next block.

2.2.2 Mining

Miners are verifying transactions. Miners are running bitcoin nodes and mining software, which enables them to create a new block of transactions, add it to blockchain and broadcast a new, longer version, of blockchain to other nodes. Finding a new block of transactions is a hard problem from computational perspective. Miners look for a solution to the problem by brute-force and when they find a solution, they are able to generate a new block of transactions. The difficulty of the problem is adjusted every 2016 block, so that new block is generated on average every 10 minutes.

Some of the variables for the problem are dependent on the last block in the blockchain, so it is impossible to precompute the problem for blocks that will come in the future. Miner and anyone else knows

the definition of the problem just for the block that will immediately follow.

When miner generates a new block, he can claim all of the fees of transactions included in that block, also he is able to create a special transaction called coinbase transaction that sends bitcoins from nowhere to his address. By these coinbase transactions, new bitcoins are emitted into the network. He also broadcasts his new block, so other miners can update their blockchains.

2.2.3 Tumblers

Anyone can download blockchain and therefore obtain information about all bitcoin transactions that ever happened. It might seem that bitcoin transactions are anonymous, but when the user sends bitcoins to someone(exchange) who knows their identity, the recipient can pair the bitcoin address the bitcoins came from to the identity of the sender. Although bitcoin users usually use multiple bitcoin addresses, their transactions and addresses are still susceptible to blockchain cashflow analysis, which might identify other addresses of the owner of an address we already know.

Bitcoin Tumblers exist in order to prevent such analysis. A user sends bitcoins to the tumbler service and the service mixes his bitcoins with bitcoins of other users by performing multiple transactions between its bitcoin addresses. [18]

The structure of these transactions differs for different tumbler services. The user sends their bitcoins to an address owned by the tumbler, then he generates a new, never used bitcoin address with no tie to his previous addresses. He then receives bitcoins from tumbler service to his new bitcoin address.

There also exist peer-to-peer tumblers(CoinJoin, SharedCoin, Coin-swap), that enable multiple users to directly create transactions to mix bitcoins among themselves. These transactions can be performed multiple times with different actors.

2.3 Tor - the onion routing

Tor [10] is a free open source software that provides access to Tor network. Tor network is a network of Tor nodes. The goal of Tor project is to provide its users encrypted access to the Internet in order to prevent third parties from eavesdropping and analysis of the transmitted data. The communication of the user's computer with the network is encrypted and rerouted through multiple Tor nodes using onion routing technology. The usage of Tor can be detected by the third party, but the third party can not decrypt user's data that are transmitted via Tor. Some websites restrict access from Tor, due to many risks involved.

Communication between browser and web server is usually done via HTTPS protocol. This protocol uses asymmetric cryptography. The web server and browser exchange their public keys at the start of communication and encrypt the data using these keys. Decrypting the data is possible only by corresponding private keys, which the browser and web server keep locally. This protocol is susceptible to man in the middle attacks. If the attacker has control over the transmission from the start of communication, he can place himself in the middle of communication and act as a web server for the user and as a user for the web server. To prevent these types of attack, a certification authority is needed. The certification authority is an institution that signs public keys, belonging to the web server. When the browser receives the public key, it automatically checks, if it is signed by any authority from its list of authorities and if not, it displays a warning or error message.

The HTTPS protocol encrypts data, but doesn't hide the identity of the user from the web server, and also the Internet provider can see, where is the user connecting. In the Tor, the user's identity is hidden from the web server, and Internet provider can only see that user is connecting to TOR, but can not see where is the destination of the data that are transmitted via Tor. Tor uses Onion routing technology. When a user visits a website, there Tor software picks randomly a few Tor nodes from the network and establishes a circuit, as we can see on 2.1. The packet of data is encrypted with each public key of the node in the circuit, starting from the last node as on 2.2. No Tor node knows the whole path of the packet, only his neighbour nodes on the path. The Tor node knows the previous node he received the packet from.

It gets also the address of the next node by decrypting the packet and reading the added metadata.

How does Tor work? (Onion Routing)

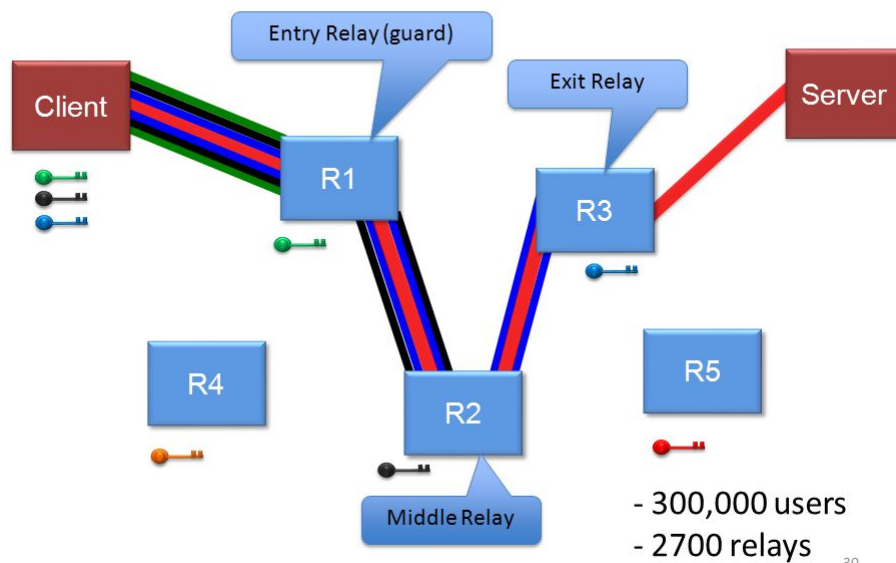


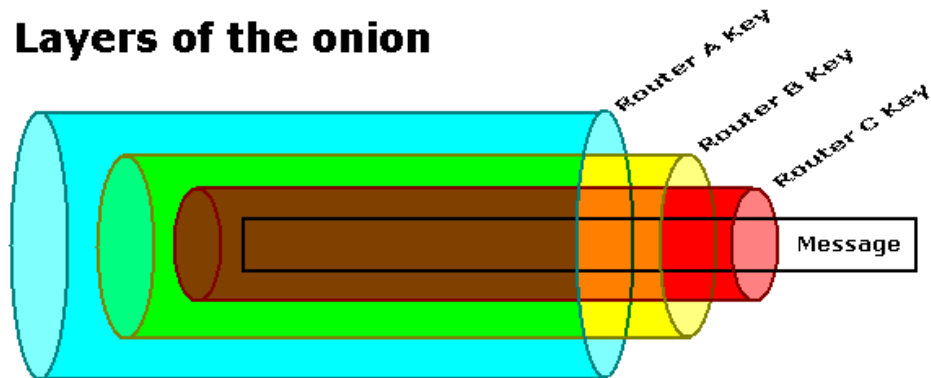
Figure 2.1: Tor routing schema

2.4 PGP

PGP [34] is a program for encrypting data and communication between two parties using public key cryptography. PGP is used for signing, encrypting and decrypting messages, mostly e-mails. PGP was developed in 1991 as an open source, with the intention to provide an open, widely used standard for encrypted communication. Nowadays, PGP program is not an open source anymore, but the standard is used by open source GPG software.

PGP uses public key cryptography. Unlike symmetric cryptography, public key cryptography uses two different keys for encrypting and decrypting. A user generates a pair of keys, a public key for encrypting emails sent to him and a private key, which the user keeps

Layers of the onion



Routing path



Figure 2.2: Tor packed encryption schem

for himself and uses for decrypting messages encrypted with the associated public key. The user also publishes his public key, so other users can send him encrypted messages.

PGP is used in the context of online drug markets as a means of secure communication between vendors and customers. Both vendor and customer have their public keys published on their profile page and use the public key of the other party to encrypt messages to them. This enables vendors and sellers to keep their communication private also from the administrators of the marketplace.

3 Related work

3.1 Blockchain analysis and linking bitcoin addresses

Multiple papers and tools were published regarding the analysis of blockchain. Blockchain contains all bitcoin transactions and anyone can simply check, the source and destination addresses of every transaction in the system. It is heavily encouraged for users of blockchain to use multiple bitcoin addresses and every major bitcoin wallet (software, for receiving and sending bitcoins) do so. It is a big challenge to cluster addresses belonging to the same user.

The authors of first research article [22] parsed blockchain files to create a graph of bitcoin transactions, with vertices as transactions and edges between them represented bitcoins flowing from one transaction to another. They created so-called user graph by clustering addresses belonging to the same user. They used simple heuristics that the owner of all input addresses used in a transaction must be the same. The first version of this article was published in 2011 and dealt with a much smaller number of people using bitcoin and smaller transaction graph. Their analysis also focuses on deanonymization through multiple aspects of bitcoin protocol, while this thesis focuses on deanonymization from transaction graph and public data.

Androulaky [4] performed clustering using two heuristics. The first one is the same as [22] did that all inputs of transaction belong to the same user. The second heuristics is clustering some outputs of the transaction with its inputs. Most transactions have two outputs, one is owned by the transaction recipient, the other one is called change. The change is an output of transaction that is owned by the sender. The change output is needed, because that is the only way to split bitcoin value of output. If the user owns 3BTC in one output and needs to transfer 1 BTC, it generates a transaction with two outputs, one worth of 1 BTC with the recipient address and second output worth 2 BTC with the address belonging to the sender. This way, the sender can split his bitcoins into smaller parts. They also employed multiple clustering techniques based on the behaviour of users. They tested the success of their clustering techniques in their simulated bitcoin environment.

Advanced and similar work was done by [27]. They downloaded the blockchain, transformed to the database and performed clustering to get a graph of transactions between users. Then they developed a tool, which scraped data from multiple locations (Bitcointalk and bitcoin-OTC forum) to link off-chain data and identities to bitcoin addresses. They tested the tool on few popular transactions related to the seizure of Silkroad marketplace.

Similar work to this thesis was done by [13]. This paper uses data from Bitcointalk, the most popular bitcoin forum. They apply a simple algorithm to group multiple bitcoin addresses belonging to one user together. Then they use the scraped data to show that some of the Bitcointalk users were using Silkroad marketplace or other popular services accepting bitcoin.

Ron and Shamir [25] focus on bringing interesting statistics about bitcoin transaction graph and provided a detailed analysis of really big bitcoin movements (more than 5000 BTC) through transactions in the network. In their other study [24], they analyzed transactions performed by Ross Ulbricht, who was the administrator of Silkroad marketplace. The FBI published their bitcoin address, which they used to collect all seized bitcoins from Ross Ulbricht. They took the size and frequency of transactions related to the seized bitcoins prior to the seizure and compared it to the estimated income of Silkroad. They found discrepancies between the relatively stable income of Silkroad marketplace and unstable balances in bitcoin addresses that were seized by FBI. They conclude that FBI seized around 22% of Ross Ulbricht's bitcoins and found addresses that possess some of these bitcoins, which has not been used since Ross' arrest.

In contrast to previously mentioned papers, Meiklejohn [17] doesn't only passively scan blockchain, they actively send bitcoins to addresses of well-known services to track their bitcoins in the following transactions executed by the service. They also used the same two heuristics for clustering addresses as Androulaki. [4] They concluded that the network does not offer enough anonymity and large transactions can be traced.

All of the previously mentioned works had to deal with much smaller transaction graph, as the usage of bitcoin grew exponentially over the last year. To the best of my knowledge, no previous work

utilizes so many resources of data as this work. Also, the aim of this tool is to be able

to identify even just regular users of drug markets, not just big and important transactions.

3.2 Behaviour of drug markets users and operators

Emerging cryptomarkets brought the attention of the scientific community and lots of articles have been published related to the phenomena of drug trafficking via the Internet. Most of these papers were investigating the topic from the social and criminology perspective and performing qualitative analysis. [3] [6] [14] [12] [30] [32] [16]

There are only a few articles focusing on statistically describing fully operating drug market and it's vendors by collecting and analyzing data from a cryptomarket webpage. Short description of works like that follows. Aldridge [2] scraped Silkroad in September 2013, the most popular cryptomarket of that time . He focuses on how the vendors and buyers perceive a risk of arrest and attempt to limit them. He concludes that users of cryptomarket are aware of the risks both related to their physical and online activity and actively reduce their risk.

Decary [9] focus on answering the question, how loyal are buyers on cryptomarkets to vendors. It seems, those popular vendors successfully build their loyal customer base. These findings make sense, given the natural health risks related to using drugs, customers prefer vendors with high reputation and trust.

Broseus [7] restricted his research to vendors shipping from Canada and track their activity through multiple markets. His findings include that same vendors use same usernames and sometimes PGP keys on multiple marketplaces because reputation is highly valued in these cryptomarkets and so vendors try to keep it when moving to the new marketplace. Also by his findings, some vendors are highly specialized in selling on the category of drugs, while others offer a wide range of drugs.

Article by Doliver [11] is most similar to this work. They scraped and analyzed two popular cryptomarkets, Agora and Evolution and quantitatively assess the characteristics of vendors from both mar-

kets, focusing on the difference between different markets' vendor populations.

All previously mentioned works were analyzing cryptomarkets that are not operational nowadays, while this work focus on describing the vendors from currently operating drug market Valhalla and examine, if the behaviour of vendors or the nature of cryptomarkets has changed significantly. We also not only passively scraped cryptomarket's webpage, but also created a user account on the marketplace and sent/received bitcoins from the marketplace in order to get data about the cryptomarket's flow of money.

4 Methods and tools of data retrieval and analysis

4.1 Valhalla cryptomarket webscraping

We scraped data from Valhalla¹ cryptomarket during january and february 2018. We used official Tor daemon and software called privoxy, to create a local proxy that will redirect all incoming traffic through Tor network. The privoxy was needed because Tor daemon creates SOCKS proxy, which can not be used by wget. So we created an HTTP proxy by privoxy, which redirected the traffic through Tor SOCKS proxy.

For web scraping Valhalla market, we did not have to implement any login and captcha solving functionality. We at first logged in manually and provided HTTP cookie with assigned session ID to the wget, so that wget could use that session ID to browse Valhalla logged in.

Addresses of all market listings are in pattern `http://Valhallaxmn3fydu.onion/products/xxx` where `xxx` is a number incrementing with each new listing. The last listing had number 103770 and only 25309 numbers lead to the valid listing page. Rest of the numbers lead to 404 error. We believe, that these numbers refer to listings that were delisted by the vendor or administrator.

Vendor profile pages were in format `http://Valhallaxmn3fydu.onion/xxx` and their reviews in the format `http://Valhallaxmn3fydu.onion/xxx/palautteet` where `xxx` is a vendor nickname.

We wrote a small script in bash to iterate through all of the listings and download them using wget command line tool. After downloading all the listing pages, we parsed the downloaded files using python and common Linux command line tools(cat, grep, cut, sed). We have not used python HTML parsing libraries(like BeautifulSoup) for parsing downloaded webpages because HTML elements of Valhalla web pages don't have any unique identifiers and so these libraries bring us no advantage.

1. Available at <http://Valhallaxmn3fydu.onion>

By scraping the listings pages, we got unique vendor nicknames, which we used for downloading and scraping vendor's profile and feedback pages. The shortcoming of this method is that we were able to download and analyze only sellers, that have at least one active listing at the time of data collection.

From each listing, we parsed:

- Vendor's nickname = string
- Subcategory = 3 string tags
- Title of listing = string
- Price = float

From each vendor, we parsed:

- Vendor's nickname = string
- number of positive and negative feedback = 2 integers
- revenue = integer $0 \leq x \leq 10000$ USD, for vendors with higher revenue it shows 10000+
- PGP key = string, is not mandatory for all vendors
- Country = string, country from which vendor ships if available

From feedback page, we parsed the following variables for each feedback:

- vendor nickname = string
- rating = 1-5
- date = Timestamp, days resolution
- first and last 2 characters of buyers nickname = string of length 4
- money the author of review spent on Valhalla market = int
- trades the author of review done = int

4.2 Valhalla cryptomarket metadata scraping and analysis

We tested these keys, if they are vulnerable to ROCA attack, via python module roca-detect. None of these keys were vulnerable. All these PGP keys were searched for User-Id in metadata of PGP key and these user-Ids were searched by google. None of the searches for user-Ids(both nicknames and mail addresses) returned any results.

We thought that metadata from the photos of drugs, which vendors upload to show in their listing, might contain some information leading to identity disclosure. We downloaded 20 images from valhalla market and examined EXIF metadata using identify command line tool.

Only metadata directly depending on image content, like the amount of red, green and blue colours, were different for different images. Metadata that could potentially help disclosing user identity, like date of creation and modification, signature and name of software version were the same for all images. The software version contained exactly this string: "ImageMagick 6.8.99 Q16 x86_64 20170731 <http://www.imagemagick.org>". ImageMagick is popular software library used for manipulating images, so it seems that market automatically rewrite EXIF metadata in uploaded images in order to protect privacy of users. To test this hypothesis, we created vendor account and uploaded an image with custom-made EXIF metadata. We then downloaded the uploaded image from webpage and saw that EXIF metadata were indeed overwritten.

We tested if every transaction that is happening on drug market has its counter transaction in bitcoin blockchain. We deposited some BTC to cryptomarket and bought a permissible virtually deliverable product(Guide on weightlifting) and checked if anything happened to the deposited bitcoins. There was no follow up transaction happening for weeks after the deposit transaction was done. This means that markets don't transfer bitcoins when service or goods are bought. All of bitcoin transactions that these drug markets do are accepting bitcoins deposits, sending bitcoins to withdrawing users and bitcoin tumbler transactions for obstructing analysis of their bitcoin cashflows. We made multiple deposits and withdrawals from Valhalla in order to

track, where were the deposited bitcoins later transferred and where have the withdrawn bitcoins been transferred from. These deposits and withdrawals have been used for our application for detecting bitcoin addresses owned by Valhalla cryptomarket.

We tried to scan ports of drug markets servers and fingerprint their web server, in order to find any vectors for further information gathering. We scanned Valhalla server using netcat and found that the only opened port is number 443(HTTPS), which is used by web server. The webserver was popular software called nginx, as we detected both from HTTP headers and from webserver fingerprinting tool httprecon. The results of port scan and web server fingerprinting doesn't indicate any new vectors for gathering data about cryptomarket.

4.3 Publicly available data scraping

In order to have some bitcoin addresses and bitcoins linked to identities, we searched Internet for pages, where are bitcoin addresses tied to real or virtual identities. The sites that we have decided to scrape were Bitcointalk forum, bitcoin-OTC, Reddit, Twitter and bitcoin.info. The Bitcointalk and bitcoin-OTC are the most popular Internet forums related to cryptocurrencies. URL address of profile page on Bitcointalk and bitcoin-OTC contains the profile number, which starts at 1 and is incremented by 1 for each new profile. It is therefore easy to iterate over all forum's profiles, including the ones with no posts, and check if they have associated bitcoin address. The scripts bitcointalk-scraper.py and bitcoinotc-scraper.py visit profile pages of all profiles on the forum and scrape usernames and bitcoin addresses. The Reddit and Twitter were scraped by twitter-scraper.py and reddit-scraper.py. The script contain several hardcoded phrases like "Don ate bitcoin" and "bitcoind address" and scrapes result of searches for such phrases. Bitcoin.info is a webpage that serves primarily as bitcoin blockchain explorer. Secondary, it gathers multiple statistics about bitcoin blockchain and also offers third parties having their bitcoin address and identity listed on their webpage. Some of these identities are verified by signing custom made message generated by blockchain.info with the bitcoin address associated private key. It means that the person posting bit-

coin address and identity to blockchain.info is owner of the address. The identities are stored as rows in csv files that have 3 columns:

1. bitcoin address
2. URL where was the address scraped
3. nickname of the associated identity

4.4 Retrieving, storing and analyzing blockchain data

XXX - dodelat In order to create a tool that will effectively search and visualize blockchain data, we need to store the blockchain locally in that way, so that common graph algorithms can be effectively executed. We ran the official bitcoin daemon (further referenced as bitcoind), to obtain a copy of bitcoin blockchain. Bitcoind store blockchain in multiple *.blk files. These files have structure, which is unfit for searching, processing and analysis of blockchain, so I used rusty-parser to parse these files and create csv files of transactions, outputs and addresses.

Then we imported these files into neo4j graph database, to have whole transaction graph in one place and be able to compute statistics and heuristics. All entities in the 4.1 are represented as graph nodes, the relationships between them are edges. XXX - dodelat

4.5 Using own transactions to identify market wallets

Valhalla cryptomarket generates unique deposit address for each new user. When user wants to buy something, he needs to deposit bitcoins to deposit address, that will top up his account balance and he used this account balance to buy stuff. Vendor or user can request withdrawing their bitcoins from cryptomarket and so the cryptomarket decrease their account balance and sends bitcoin to user's address.

For identifying bitcoin addresses that are owned by Valhalla cryptomarket, we deposited 0.05 Bitcoins to our user account on Valhalla cryptomarket and immediately performed multiple withdrawals by smaller amount to receive bitcoins back. When we requested bitcoin withdrawals, we received bitcoins from different address than the

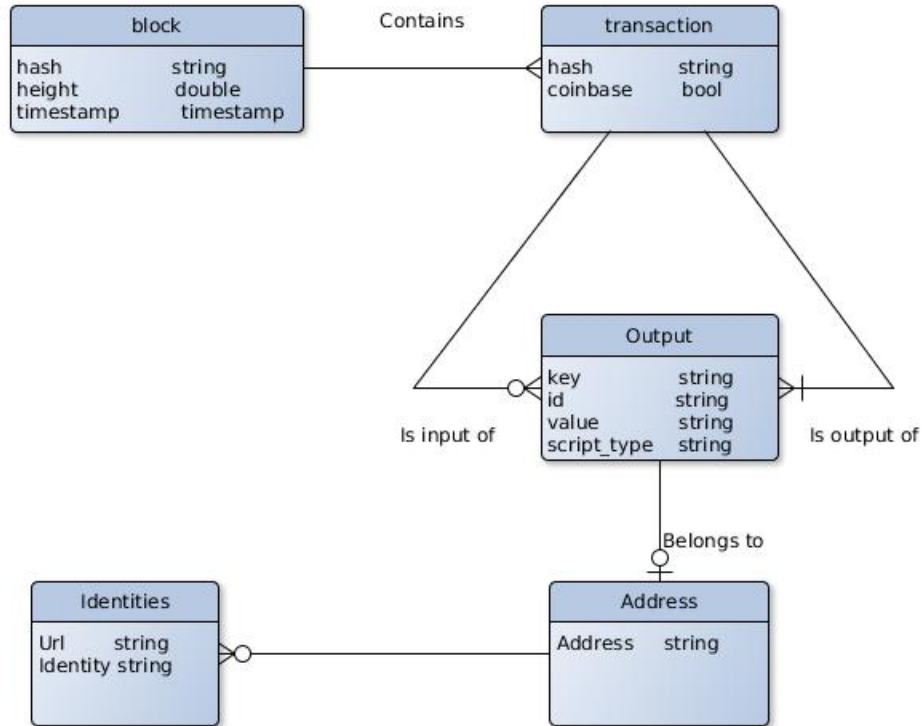


Figure 4.1: Neo4j database ER diagram

deposit one. We consider the deposit address and all addresses we received bitcoins from during withdrawals owned by cryptomarket.

Detecting just these addresses would not help us detect if someone sent or received bitcoins from Valhalla cryptomarket. Cryptomarkets use thousands of bitcoin addresses and bitcoin tumblers in order to obstruct analysis of blockchain data that aims to identify cryptomarket's users and administrators. In order to address this issue, we used two heuristics that were widely used in previous works [4][22] for clustering bitcoin addresses belonging to same user.

The first heuristic simply states that all inputs of one transaction belong to same user. This is logical, since users generally don't share their private keys and collaborate on creating one transaction. Inputs of one transaction have different bitcoin addresses, so we can check all inputs of any transaction owned by these addresses and find new

The second heuristics focus on detecting change address, as it was described in chapter XXX. If transaction has two outputs with two different addresses, when one address was used and one not, than we can safely assume that the not used address is a change address belonging to the same user [4].

We labeled each address in our blockchain transaction graph with unique user number and alternately run first and second heuristics until there were no changes in the user number property of addresses. Both of these heuristics are pretty strict and have just a negligible chance of falsely merging addresses not belonging to the same user[4]. There exist few proposals for anonymization methods that could make these heuristics misleading(like CoinJoin and dark wallet), but these are just concepts or in experimental alpha versions, not easily used by even advanced users.

5 Application

This chapter describes the application for searching in gathered data. The application consists of four parts.

- The scraping scripts that parse bitcoin blockchain and also scrapes data from publicly available sites mentioned in section 4.3.
- The computational module, which imports data to the database, create indexes and compute heuristics mentioned in chapter 4.5.
- Webserver that handles GUI requests and retrieves data from database.
- The web GUI written in HTML/JS/CSS for sending requests to webserver and visualisation of retrieved data.

6 Statistics of Valhalla cryptomarket

We managed to scrape 25309 vector listings from 981 vendors and 6381 feedbacks. There were 17314(68%) listings related to selling drug substances. Vendors had from 1(90 vendors) to 1083(1 vendor) active listings, with average of 25.69 (SD = 58.06) and median = 11.00 listings per vendor. The distribution can be seen in figure 6.1

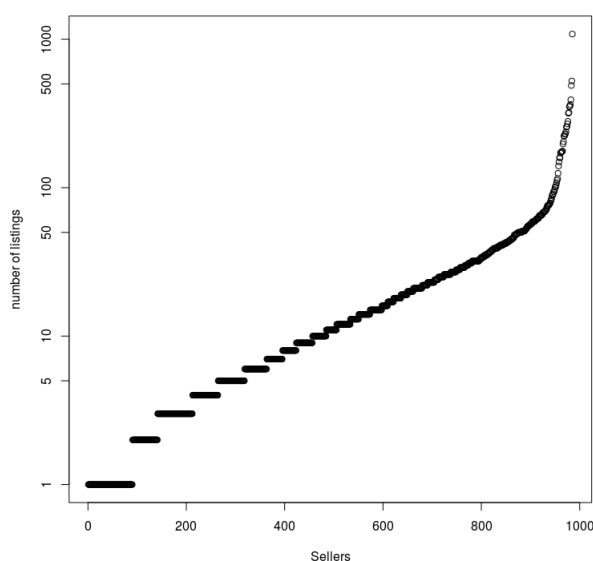


Figure 6.1: Number of active listings for each seller

Valhalla was originally established as a local Finnish market. That seems to be the reason for surprisingly many vendors shipping from Finland. Vendors were shipping drugs from 39 distinct countries, the frequency of countries the vendors were shipping from is in table 6.1.

In the graph 6.2 is shown distribution of prices of all listings in the market. The graph 6.3 show distribution of prices gathered from vendor feedbacks. The 6.3 might count one listing multiple times, as one listings might be bought several times and therefore appear multiple times in feedback. We expect that distribution of prices in these feedbacks reflects more accurately the prices of the goods or services that are actually bought at market. The average price of listing

Table 6.1: Countries that vendors shipp from

Countries vendors are shipping from	Count of vendors
Australia	3
Poland	3
Spain	4
Canada	4
France	5
Norway	5
Netherlands	12
Germany	13
United States	16
United Kingdom	23
Finland	28
Others	31
Unknown	834

is 336.2 Eur(1368.2 SD!) with median of 71.Eur, while for feedbacks, it is 82.7Eur(150.7 SD) with median of 55 Eur. There were only 22(0.3%) feedbacks with price > 1000EUR with only 5(0.01%) feedbacks with price > 2000 Eur. For listings, there were 1533(6.05%) active listings with price greater than 1000 EUR 673(2.7%) of them with price greater than 3550, while The titles of high prices listings don't indicate that these listings are somehow special expect it's price. These findings indicate that buyers tend to buy cheaper listings. The average price of the bought goods (82.7 EUR) is way below the emount someone who resale drugs would buy at one deal. There were 115 listings with zero price on the market, but no one of them was mantioned in feedbacks. The listings with 0 price had titles like "CARDING SERVICE *FREE*", "Custom order", "Free Carding Tutorial 2017" and "FREE SAMPLE 84% MDMA CRYSTAL ROCKS"

We calculated the total revenue for each category by multiplying the price of each listings by the number of associated feedbacks and summing over all listings in given category. This is a minimal revenue,

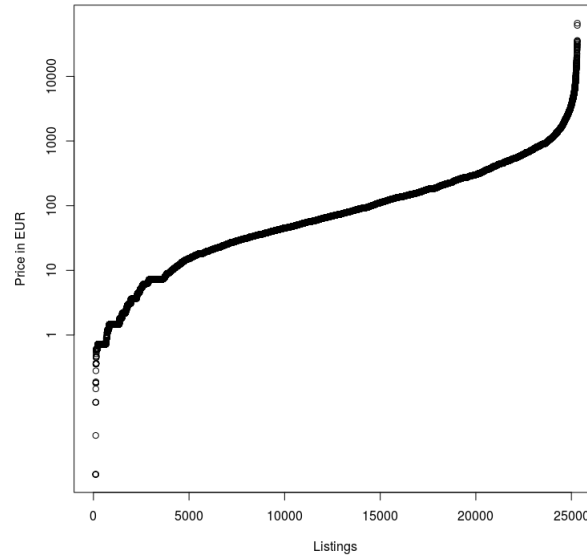


Figure 6.2: Prices of listings

as feedbacks can be given only if the trade happened on cryptomarket. Market share is a revenue of category divided by total revenue from all categories. The market shares of most popular categories is similar to market shares mentioned in previous works.?? Average price of occurred trades varied from between 60\$ and 150\$ for each category with two outliers. Opiates, which has the biggest price/dose ratio and self-defence, which had only 4 trades, 2 of them were custom listings and 2 of them were guns. Custom listings contains no description of any goods/services, just state "custom listing for user: xxx". We found totally 300 listings with word "custom" in their title. XXX - nejakej stat o custom listings

Most vendors maintained really high percentage of positive reviews. The percentage of positive reviews for all vendors: Min. 1st Qu. Median Mean 3rd Qu. Max. 0.0000 0.8710 0.9779 0.8145 0.9979 1.0000 When counting only vendors with more than 10 reviews,(304 sellers out of 981) we get: Min. 1st Qu. Median Mean 3rd Qu. Max. 0.0000 0.9523 0.9834 0.9373 0.9982 1.0000

Table 6.2: Estimated monthly revenue for selected drug categories a
by listing price

Category	listings	feedbacks	revenue	market share
Cannabis	5139	188	135693	27.6%
Stimulants	3493	1043	108157	22%
Opiates	1662	489	83135	16.9%
Pharmacy	2294	1104	62054	12.6%
Body building	679	402	31466	6.4%
Empathogens	2988	394	20344	4.1%
Other drugs	774	173	14350	2.9%
Psychedelics	1377	198	11796	2.4%
Other products	782	89	9106	1.8%
Self-defence	513	4	4635	0.9%
Services	1662	35	4061	0.8%
Dissociatives	290	38	2317	0.5%
Classifieds	649	18	2182	0.4%
Mushroom growing	26	2	178	0%
Digital items	2497	9	141	0%
Depressants	71	2	59	0%
Cannabis growing	56	2	44	0%
Paraphernalia	36	0	0	0%
Production / distribution	17	0	0	0%

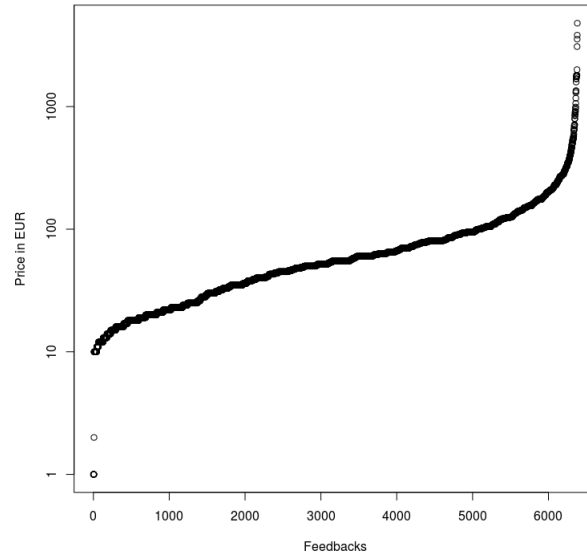


Figure 6.3: Prices of listings in feedbacks

Each circle in 6.6 represents one vendor and axes represent the number of positive and negative feedbacks that vendor received. We can see that vast majority only 2 vendors out of 666 have received more negative feedback than positive. Only 19 vendors out of 666 managed to get more than 50 negative feedbacks,; while all of these 19 vendors had more than 400 positive reviews. Only 40 vendors got more negative feedbacks than positive feedbacks. If we look at statistics of reviews from popular e-shop amazon(<http://minimaxir.com/2017/01/amazon-spark>) and consider one and two star reviews as negative, we can see that amazon sellers on average get between 5-25% negative reviews, depending on category of the goods. On the Valhalla market, vast majority of sellers have >95% of positive reviews, as is shown on ??.

Also, only 40 vendors have less than 80% positive reviews and out of that 36 have less 50 reviews in total. These numbers indicate that the customers of Valhalla market are much more picky about the vendor they choose than regular e-shop customers. If 6.8

asfd

6. STATISTICS OF VALHALLA CRYPTOMARKET

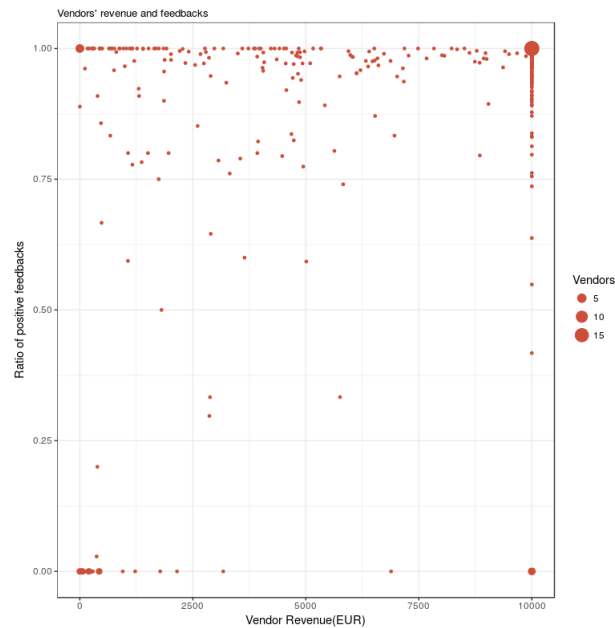


Figure 6.4: Vendors revenue by positive feedback ratio

We were interested, if repeat buyers are loyal customers. XXX -
jsou loajalni jak moc a jsou vendori kteri maji loajalnejsi zakazniky?cd

We can identify one customer buying multiple products from data from listings feedback page. Every feedback contains first two and last two characters of buyers username, and the total number and price of trades performed by buyer. The four letters gives at least $26 * 4$ distinct possible values, way higher number of than we can find in our 6000 feedbacks. Combined with the information about buyers trades, we can safely assume that we are able identify all the feedbacks given by one buyer. From our 6000 feedbacks, we gathered 2357 unique four letter combinations. When accounting for buyers total number and price of trades, we got 2365 unique combinations.

The 6.9 shows how many trades have buyers done and how much money have they spent. The cryptomarket's webpage does not show exactly the number of trades, it rounds the trades to 1,3,5,10,25,50,100,500,1000 and total spent to 10,25,50,100,500,1000,10000. 90% of buyers spent between 50\$ and 1000\$ on the market and 9% spent around 10000\$ or more.

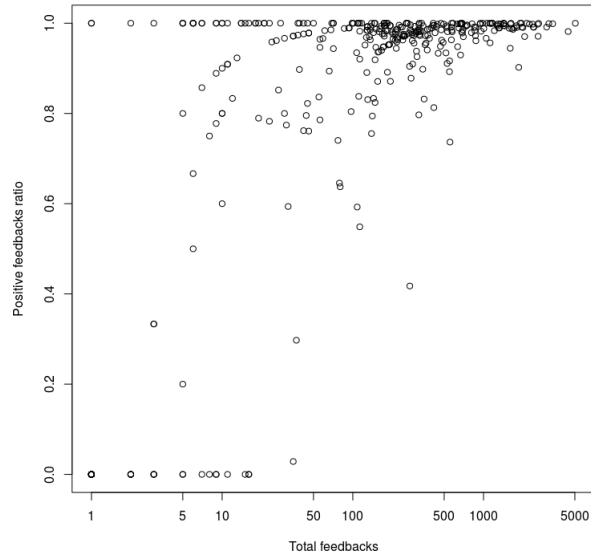


Figure 6.5: Positive reviews of vendors

7 Testing and verification of the created tool

This chapter describes the way, the POC application was tested.

The testing were performed by sending bitcoins to drug markets and withdrawing them. Than marking the addresses from where the bitcoins were received as 'a

7.1 Method of testing

7.2 results

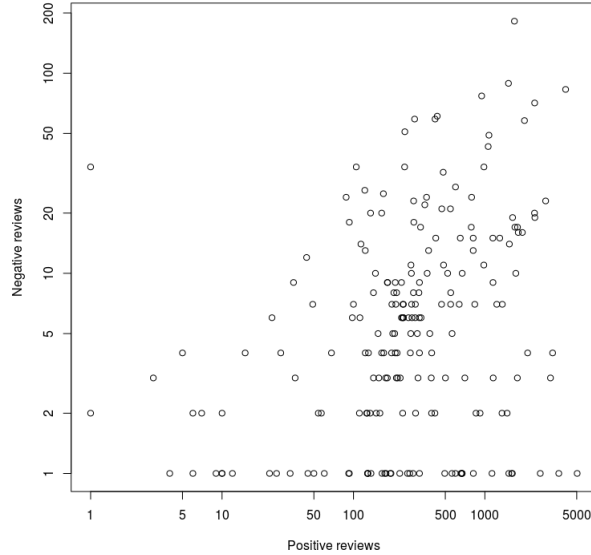


Figure 6.6: Positive/negative reviews of vendors

8 Conclusion and future work

We were succesfull with scraping Valhalla cryptomarket and bringing up meaningful statistics about it's operations. Our statistical findings and description are similar to what has been stated about cryptomarkets in previous works. We scraped Valhalla market just once, but the data about the feedbacks were related to the time frame of one month. If we monitored Valhalla market for longer time period, we could measure differences in the statistics over time and also get better granularity on the data over given timeframe.

The application is finding the nearest addresses with associated identities when the user inserts the address. It is searching these addresses by performing BFS over transactions up to the length of 5 transactions. BFS performance is pretty bad and the application could use more paralelism and also precompute data once, so that instalation would took more time because of precomputation, but using application would be much faster. Since we have started working on this application, new application frameworks for blockchain analysis

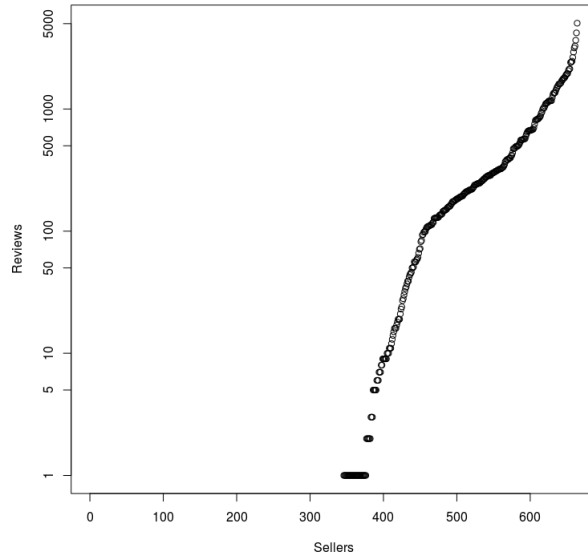


Figure 6.7: Number of reviews for vendors

have appeared [15] that claims much better performance than neo4j database. Faster performance would allow us to search for addresses that are farther from investigated address.

Also, more heuristics for clustering addresses have been described in [4]. These heuristics are not based just on transaction graph, but also on expected behaviour of users. These heuristics are less accurate, but offer more options to cluster addresses of same owner. The application could let user decide, which heuristics he wants to use and/or show, which identities were found by which combination of heuristics.

The GUI and code would definitely use some more polishing, a lot of possible configuration options are not parametrized, but hardcoded for default values.

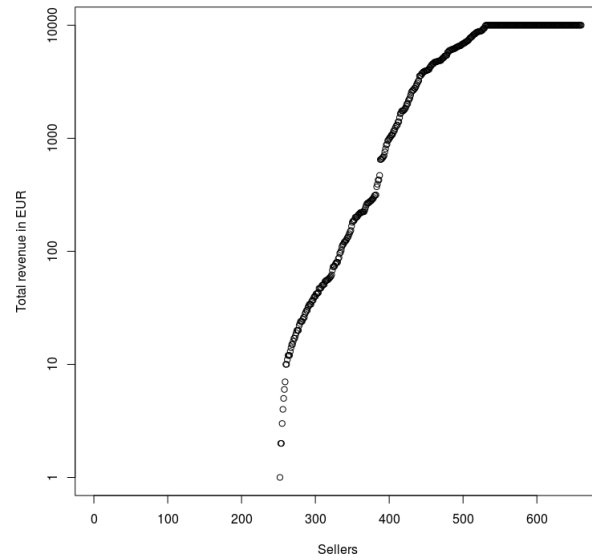


Figure 6.8: Total revenue of vendors

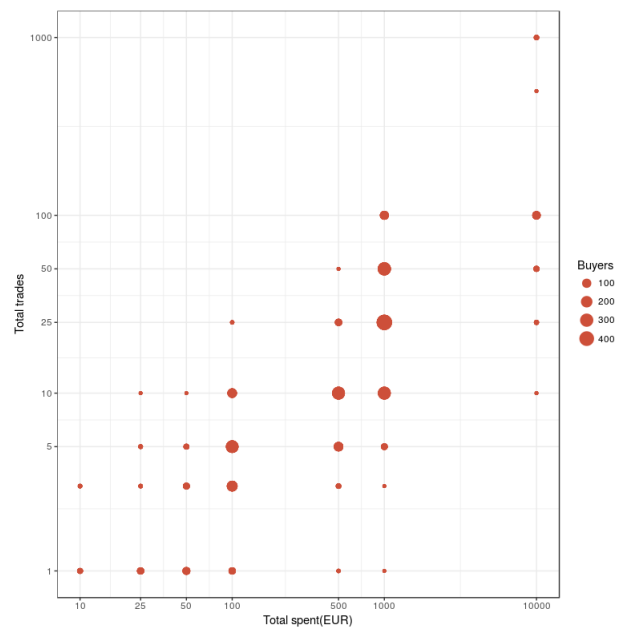


Figure 6.9: Buyers spending and trades

Appendices

A Requirements and setup

The user need to install Bitcoin Core(at least version 11.0), because the application uses bitcoin core API in order to import blockchain to database. After installing bitcoin core, user needs to run: "bitcoind -daemon -txindex -rest" and wait until the blockchain is downloaded and indexed. This might take several hours or even days. User can check the progress of blockchain synchronization by running "bitcoin-cli -getblockchaininfo" Bitcoin core stores data in .blk files defaultly in home directory.

Script `blockchain_to_csv.py` iterate through blockchain and generate several csv files with the data from blockchain that are needed by application. The script generates

- `addresses.csv`: sorted list of Bitcoin addressed
- `transactions.csv`: list of transactions (hash)
- `outputs.csv`: list of transaction outputs (output key, id, value)
- `rel_input.csv`: relationship between transactions and transaction outputs (tx_hash, output key)
- `rel_tx_output.csv`: relationship between transactions and transaction outputs (tx_hash, output key)
- `rel_output_address.csv`: relationship between outputs and addresses (output key, address)

The importing script (`csv_to_neo4j.py`) is responsible for parsing bitcoin blockchain files and importing the data into neo4j database. The importing script takes two parameters, the directory of .csv files created in previous step and directory for creating neo4j graph database. Having csv files as interminiary step is useful for debugging application and also provides easy way to using application with different blockchain or customly generated data.

The next script is `scrape_identities.sh`. It runs multiple python scrapers, each scraping one website. It than merges outputs of these scripts into single csv file, `identities.csv`.

File `identities.csv` contains 3 collumns.

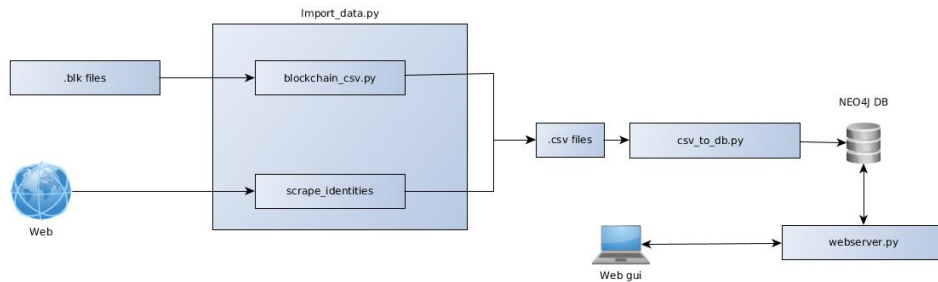


Figure A.1: Architecture of application

- Address - bitcoin address the identity is associated with
- Identity - String representing identity, usually username
- URL - Url where the Identity and Address were scraped

identities.csv can be imported into database by running identities_to_neo4j.py. The user can supply his own file with identities tied to bitcoin addresses in the same format as identities.csv and run identities_to_neo4j.py multiple times to add new identities to database.

Script cluster_identities.py connects to database and runs queries that will cluster bitcoin addresses into clusters belonging to the same user. Computing these heuristics is very disk read/write heavy. For 3 months of blockchain data (December 2017 - February 2018) it ran multiple hours.

At this phase, all data needed for using the application are in the database. We can now run application/webserver.py to start a web server that will serve webpage with GUI on address: "127.0.0.1:5000".

The GUI has one input form, where user should write the bitcoin address he is interested in. The GUI then shows multiple information about the inserted address, nearby addresses and identities. It consists of 5 parts, these are highlighted in the screenshot ??.

The first part is simple HTML form where user submits bitcoin address he is interested in. After submission, the rest of the parts show information about given address.

The table in part 2 shows list of nearby addresses with known identity. The distance is number of transactions between inserted address and address in table. It also shows where the URL the identity

was found and amount of bitcoins that went through that address over the history of blockchain. In section 3, there are two pie charts. The first pie-chart shows bitcoins that were received by the address and what percentage of received bitcoins was the application able to link to some identity. The second pie chart shows the same information for outgoing bitcoins, the percentage of bitcoins that were sent from this address and ended up in address that we were able to find associated identity.

The transaction graph in part 4 shows searched address in the middle and its associated transactions. Incoming transactions on left and outgoing transactions on right. Each transaction also shows a pie chart showing same data as pie charts in section 3. This way, user can identify outgoing transaction with the most bitcoins that were lately identified.

The last section is a graph that shows the path of transactions between searched address and identified addresses. The x axis shows distance of transactions from the searched address, positive for transactions that transferred bitcoins from searched address to some address we identify, negative is for transactions that transferred bitcoins from identified address to our searched address.

XXX - dat screenshot nejakeho searche a presny priklad, co konkretno znamena

Bibliography

- [1] *2010 Internet Crime Report*. https://pdf.ic3.gov/2010_IC3Report.pdf: Internet Crime Complaint Center, 2011.
- [2] Judith Aldridge and Rebecca Askew. "Delivery dilemmas: How drug cryptomarket users identify and seek to reduce their risk of detection by law enforcement". In: *International Journal of Drug Policy* 41 (2017), pp. 101–109.
- [3] Judith Aldridge and David Décary-Hétu. "Not an'Ebay for Drugs': the Cryptomarket'Silk Road'as a paradigm shifting criminal innovation". In: (2014).
- [4] Elli Androulaki et al. "Evaluating user privacy in bitcoin". In: *International Conference on Financial Cryptography and Data Security*. Springer. 2013, pp. 34–51.
- [5] *Bank Crime Statistics (BCS). Federal Insured Financial Institutions, January 1, 2010 – December 31, 2010*. XXX: Federal bureau of investigation, 2011.
- [6] Monica J Barratt, Jason A Ferris, and Adam R Winstock. "Use of Silk Road, the online drug marketplace, in the United Kingdom, Australia and the United States". In: *Addiction* 109.5 (2014), pp. 774–783.
- [7] Julian Broséus et al. "Studying illicit drug trafficking on Darknet markets: structure and organisation from a Canadian perspective". In: *Forensic science international* 264 (2016), pp. 7–14.
- [8] Joseph Cox. "Staying in the shadows: The use of bitcoin and encryption in cryptomarkets". In: *Internet and drug markets, EMCDDA insights* (2016), pp. 41–47.
- [9] David Décary-Hétu and Olivier Quessy-Doré. "Are repeat buyers in cryptomarkets loyal customers? Repeat business between dyads of cryptomarket vendors and users". In: *American Behavioral Scientist* 61.11 (2017), pp. 1341–1357.
- [10] Roger Dingledine, Nick Mathewson, and Paul Syverson. *Tor: The second-generation onion router*. Tech. rep. Naval Research Lab Washington DC, 2004.
- [11] Diana S Dolliver and Jennifer L Kenney. "Characteristics of drug vendors on the Tor network: a cryptomarket comparison". In: *Victims & Offenders* 11.4 (2016), pp. 600–620.

- [12] Diana S Dolliver and Katherine L Love. "Criminogenic Asymmetries in Cyberspace: A Comparative Analysis of Two Tor Marketplaces". In: *Journal of Globalization Studies* 6.2 (2015), pp. 75–96.
- [13] Michael Fleder, Michael S Kester, and Sudeep Pillai. "Bitcoin transaction graph analysis". In: *arXiv preprint arXiv:1502.01657* (2015).
- [14] Nicolas Christin. "Traveling the Silk Road: A measurement analysis of a large anonymous online marketplace". In: *Proceedings of the 22nd international conference on World Wide Web*. ACM. 2013, pp. 213–224.
- [15] Harry Kalodner et al. "BlockSci: Design and applications of a blockchain analysis platform". In: *arXiv preprint arXiv:1709.02489* (2017).
- [16] James Martin. "Lost on the Silk Road: Online drug distribution and the 'cryptomarket'". In: *Criminology & Criminal Justice* 14.3 (2014), pp. 351–367.
- [17] Sarah Meiklejohn et al. "A fistful of bitcoins: characterizing payments among men with no names". In: *Proceedings of the 2013 conference on Internet measurement conference*. ACM. 2013, pp. 127–140.
- [18] Malte Moser, Rainer Bohme, and Dominic Breuker. "An inquiry into money laundering tools in the Bitcoin ecosystem". In: *eCrime Researchers Summit (eCRS), 2013*. IEEE. 2013, pp. 1–14.
- [19] Marti Motoyama et al. "An analysis of underground forums". In: *Proceedings of the 2011 ACM SIGCOMM conference on Internet measurement conference*. ACM. 2011, pp. 71–80.
- [20] Satoshi Nakamoto. *Bitcoin: A peer-to-peer electronic cash system*. 2008.
- [21] Masarah-Cynthia Paquet-Clouston. "Are Cryptomarkets the Future of Drug Dealing? Assessing the Structure of the Drug Market Hosted on Cryptomarkets". In: (2017).
- [22] Fergal Reid and Martin Harrigan. "An analysis of anonymity in the bitcoin system". In: *Security and privacy in social networks*. Springer, 2013, pp. 197–223.
- [23] Paul Resnick et al. "Reputation systems". In: *Communications of the ACM* 43.12 (2000), pp. 45–48.

- [24] Dorit Ron and Adi Shamir. "How did dread pirate roberts acquire and protect his bitcoin wealth?" In: *International Conference on Financial Cryptography and Data Security*. Springer. 2014, pp. 3–15.
- [25] Dorit Ron and Adi Shamir. "Quantitative analysis of the full bitcoin transaction graph". In: *International Conference on Financial Cryptography and Data Security*. Springer. 2013, pp. 6–24.
- [26] Kyle Soska and Nicolas Christin. "Measuring the Longitudinal Evolution of the Online Anonymous Marketplace Ecosystem." In: *USENIX Security Symposium*. 2015, pp. 33–48.
- [27] Michele Spagnuolo, Federico Maggi, and Stefano Zanero. "Bitiodine: Extracting intelligence from the bitcoin network". In: *International Conference on Financial Cryptography and Data Security*. Springer. 2014, pp. 457–468.
- [28] Meropi Tzanetakis et al. "The transparency paradox. Building trust, resolving disputes and optimising logistics on conventional and online drugs markets". In: *International Journal of Drug Policy* 35 (2016), pp. 58–68.
- [29] Marie Claire Van Hout and Tim Bingham. "Responsible vendors, intelligent consumers: Silk Road, the online revolution in drug trading". In: *International Journal of Drug Policy* 25.2 (2014), pp. 183–189.
- [30] Marie Claire Van Hout and Tim Bingham. "'Silk Road', the virtual drug marketplace: A single case study of user experiences". In: *International Journal of Drug Policy* 24.5 (2013), pp. 385–391.
- [31] Marie Claire Van Hout and Tim Bingham. "'Surfing the Silk Road': A study of users' experiences". In: *International Journal of Drug Policy* 24.6 (2013), pp. 524–529.
- [32] Charlotte Walsh. "Drugs, the Internet and change". In: *Journal of psychoactive drugs* 43.1 (2011), pp. 55–63.
- [33] Frank Wehinger. "The Dark Net: Self-regulation dynamics of illegal online markets for identities and related services". In: *Intelligence and Security Informatics Conference (EISIC), 2011 European*. IEEE. 2011, pp. 209–213.
- [34] Philip R. Zimmermann. *The Official PGP User's Guide*. Cambridge, MA, USA: MIT Press, 1995. ISBN: 0-262-74017-6.