Network Analysis and Traceability on Monero Blockchain

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Abstract

Monero was introduced as a privacy-focused alternative to Bitcoin in 2014. Based on privacy enhancing features such as ring signatures, stealth addresses and RingCT, it is supposed to protect the privacy of users while still solving the issue of double spending, which is rare in crypto currency. However, Monero is not foolproof when it comes to privacy, as previous studies have shown that it is vulnerable to weakness such as the 0-mixin attack. In this study, we explore just how much of Monero transactions are traceable, using previously known exploits to de-anonymize Monero inputs. The end goal of this study is to show that Monero is not as untraceable as thought to be, and that for Monero to achieve its privacy goals, it has to enforce privacy-by-default measures, such as using a minimum number of mixins.

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1 Introduction

1.1 Objectives and Scope

The objective of this project would be to explore the extent to which the privacy features of Monero actually protects the privacy of its users. This will be done by first scraping the data of Monero transactions from publicly available block explorers, such as xmrchain.net. The data will then be imported into a graph-based database, and a tool will be built to help traverse, analyze and visualize the graph produced. One can then determine the extent to which the transactions on the Monero blockchain can be traced.

1.2 Motivation

Blockchain technology was introduced to the world when Satoshi Nakomoto wrote the Bitcoin white paper in 2009. A blockchain is an ever-growing ledger of data, which are stored in blocks, that are linked together cryptographically, ensuring the immutability of the data stored within. It has many applications, including cryptocurrency, which is favored by some due to its decentralized nature which renders it immune from government intervention, monetary policies, and censorship. Blockchain also has more commercial applications, such as inventory and supply chain management.

However, the openness of blockchain has a downside: a lack of privacy in certain use cases where privacy is important. For example, in cryptocurrency, the pseudonymous nature of wallets means that once a wallet is connected to a real-world entity, all the previous transactions made by that wallet can then be traced back to the real-world entity. The open nature of blockchain also results in a decrease in fungibility, since coins that were part of illicit transactions can be ‘blacklisted’. Another example would be a blockchain based voting system, where voting records should be kept secret.

To solve the issue of a lack of privacy, a few privacy-oriented blockchains have been created. More specifically, privacy-oriented cryptocurrency such as ZCash, which uses zero-knowledge proofs, and Monero, which has built-in, privacy-by-default features such as RingCT and stealth addresses, have emerged.

However, such features are not perfect. There has been previous research that has pointed out weaknesses in the design of Monero, such as the 0-mixin attack against older transactions when no minimum number of mixins were enforced on users, as well as temporal analysis, which is based on the theory that the mixin with the highest block number is the most likely to be the real input to a transaction.

2 Blockchain Technology

A blockchain is a growing list of records, individually known as blocks, that are linked together cryptographically. Every block typically contains a cryptographic hash digest of the pervious block it was built on, a timestamp of when the block is mined, as well as transaction data. [1] The transaction data in blocks are immutable by design. This is because once data is recorded in a specific block, it cannot be altered without changing all subsequent blocks. A change in data results in a change in hash digest of the block it is contained in, and since a subsequent block references previous block through its hash digest, a change in data results in a change in hash digest for all subsequent blocks. For a blockchain to be used as a distributed ledger, as is the case in cryptocurrencies such as Bitcoin, the blockchain is usually managed by a peer-to-peer network where all nodes adhere to a consensus protocol for validating new blocks. A blockchain can be considered to exemplify a distributed computing system with high Byzantine fault tolerance.

2.1 Blocks

Data in blocks include a list of valid transactions, that are hashed and encoded into a Merkle Tree, which is illustrated in the figure below.

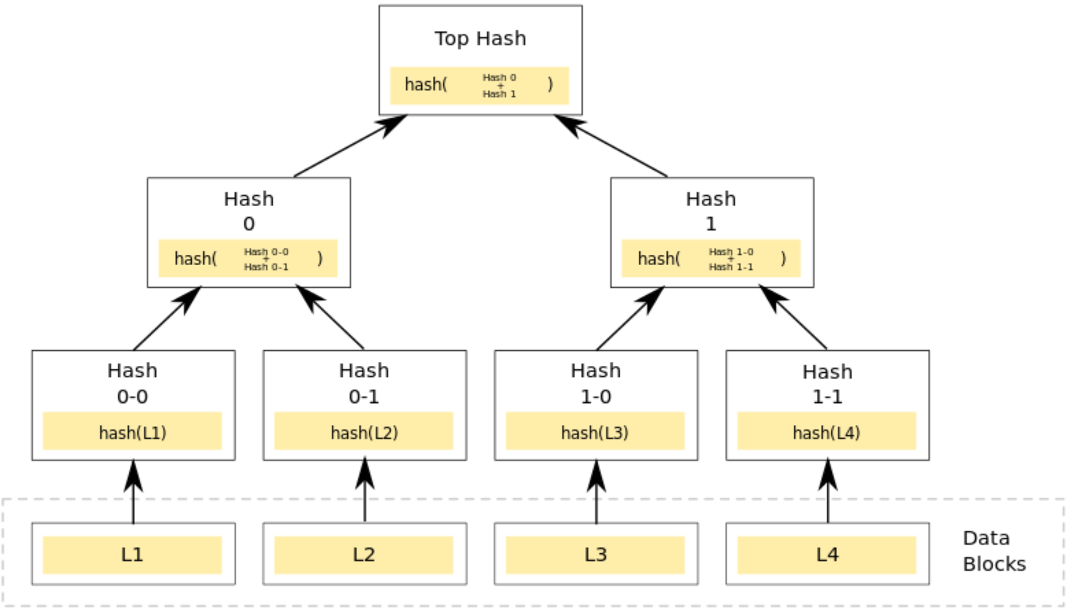


Figure 1: An example of a Merkle Tree

A Merkle tree is a data structure in which every leaf node is labelled with the cryptographic hash of a data block (in this case, blocks L1-L4), and every non-leaf node is labelled with the cryptographic hash of the labels of its child nodes. Merkle trees allow for efficient and secure verification of the contents of large data structures. [2]

Each block also contains the cryptographic hash of the previous block, which links the 2 blocks. This process of referencing the previous block is what maintains the immutability and integrity of data in a blockchain.

2.2 Block Time

The block time is the average time it takes for the network to generate one extra block in the blockchain, and it differs for every blockchain. Block time is usually determined by the consensus protocol, but it can also be affected by factors such as total hash power in the network, as well as the mining difficulty at the current block. The mining difficulty of a blockchain is periodically adjusted based on the total hash power in the network to keep the block time near a target time. For cryptocurrencies, block time is significant as shorter block times results in faster transactions on average. The block time for Ethereum is set to between 14 and 15 seconds, while for Bitcoin it is on average 10 minutes. [3]

2.3 Consensus Mechanisms

A network of blockchain nodes, like any other distributed computing systems, need a way of achieving and maintaining consensus. There are 2 popular consensus mechanisms in blockchain, namely Proof-of-Work (PoW) and Proof-of-Stake (PoS).

2.3.1 Proof-of-Work (PoW)

Proof of work (PoW) is a form of cryptographic proof in which one party (the prover) proves to others (the verifiers) that a certain amount of computational effort has been expended for some purpose. Usually, it involves producing some data (often a cryptographic hash) that is difficult, in terms of computational power and time, to produce, but is easy to verify. The piece of data produced must meet some pre-determined requirement. Bitcoin uses the Hashcash PoW system, along with the SHA-256 hashing algorithm, to secure the Bitcoin blockchain.

In Bitcoin, in order for a block to be accepted by the network, the miner of the block needs to produce a valid PoW – the SHA-256 hash of the block data concatenated with a nonce needs to be less than or equal to the target value, which is a 256-bit integer. The nonce is incremented after every failed attempt to generate a valid PoW. The lower the target value, the higher the mining difficulty of the block is. The mining difficulty needs to be high enough such that the probability of an individual node finding a valid PoW is low.

Since in Bitcoin, each block references the previous block by its hash, in order for a malicious actor to alter data in a block that has already been mined, the malicious actor also needs to alter all subsequent blocks. In the case of competing chains, the Bitcoin network recognises the chain with the largest cumulative PoW as the legitimate chain.

3 Monero

Monero is a privacy-focused cryptocurrency released on 18 April, 2014. Monero is based on CryptoNote, and uses a obfuscated public ledger, meaning that any node in the network can send or broadcast transactions, but no outside observer can tell the source, amount, or destination. Monero uses a PoW mechanism to issue new coins and incentivize miners to secure the network and validate transactions. [4] As of 2019, Monero has switched to the RandomX PoW algorithm to further increase ASIC-resistance of Monero mining. [5]

3.1 Privacy Features

Monero uses different privacy-enhancing technologies (PETs) to achieve anonymity and fungibility. Such technologies include stealth addresses, ring signatures, as well as RingCT, which will be discussed below. While some features, like stealth addresses and ring signatures are included from the first block and are part of Monero's core features, others, like RingCT and the standardization of ring sizes, were introduced as measures to improve privacy in response to research pointing out flaws in Monero's existing PETs.

3.1.1 Stealth Addresses

Stealth addresses are an important part of Monero's inherent privacy. They allow and require the sender to create random one-time addresses for every transaction on behalf of the recipient. One-time stealth addresses are generated using the Dual-Key Stealth Address Protocol (DKSAP) [6], based on 2 pieces of information: the first is a shared secret produced by the elliptic-curve Diffie–Hellman (ECDH) key agreement, and the second is the public key of the recipient. The recipient then actively scans the blockchain, detects if a transaction is intended for their address, and recovers the private key for this one-time public key to access the funds. [7]

3.1.2 Ring Signatures

In cryptography, a ring signature is a type of digital signature that can be performed by any member of a set of users that each have valid keys. Therefore, a message signed with a ring signature is guaranteed to be endorsed by someone in a particular set of people, but it should be computationally infeasible to tell exactly which member of the group signed the message. Ring signatures were invented by Ron Rivest, Adi Shamir, and Yael Tauman Kalai, and introduced at ASIACRYPT in 2001. [8]

In Monero, a ring signature is used to form the input of a transaction. The public spend key of the actual output being spent in the transaction, as well as the public keys of past outputs, make up the ring signature. [9] This reduces traceability in the Monero blockchain, since it will take substantial time and effort to determine the real input being used in each transaction. Double spending is prevented via the use of key images.

3.1.3 RingCT

Ring Confidential Transactions (RingCT) improves the confidentiality of Monero transactions by hiding the transaction amount. Ring CT was implemented in block 1,220,516 in January 2017. After September 2017, this feature became mandatory for all transactions on the network.

Prior to the implementation of RingCT, Monero required transaction amounts to be divided into denominations. For example, if Bob wanted to initiate a transaction of 12.5 Monero to Alice, this output would be divided into 3 separate rings of: 2, 0.5 and 10. This technique ensured that there was always an ample amount of ring members that could be found on the network, since a ring signature could only ring together outputs that were of the same value. However, the limitation is that, from the perspective of an outside party, they would be able to see the amounts that were being transacted. RingCT gets around this by using the Pedersen Commitment to hide the actual amount being transacted, while still ensuring that the sender has sufficient unspent outputs to cover the input and transaction fees. [10]

3.2 Limitations

Although Monero has been touted as having privacy-by-default, it still has limitation and past transactions are still vulnerable to de-anonymization analysis, usually due to privacy enhancing measures not being enforced in the past. For example, before block 1,009,827, there were no minimum number of mixins (decoy ring members of ring signatures) enforced. A large proportion of transactions from the period have 0 mixins and are thus deducible. This also has a cascade effect where transactions with 1 mixin can become deducible if the only mixin has been marked spent in pervious 0-mixin inputs, and so on. This is known as the 0-mixin attack.

Researchers have also conducted other forms of heuristic-based de-anonymization analysis, such as temporal analysis based on the Guess-Newest heuristic and Monte Carlo Simulation, deducing the real input among a ring signature based on their timestamp.

In Chapter 7, I will be using the 0-mixin attack to conduct anonymity analysis, as it is the most straight-forward to implement, and will reveal the percentage of inputs that are deducible as a result of several rounds of analysis. [11]

3.3 Flow of Monero Transactions

A typical block on the Monero blockchain consists of 2 types of transactions: a coinbase transaction, which contains the miner reward for the block as its output, as well as 0 or more non-coinbase transaction(s), with varying amounts of inputs and outputs. Each input has to originate either as an output of a coinbase transaction or a non-coinbase transaction.

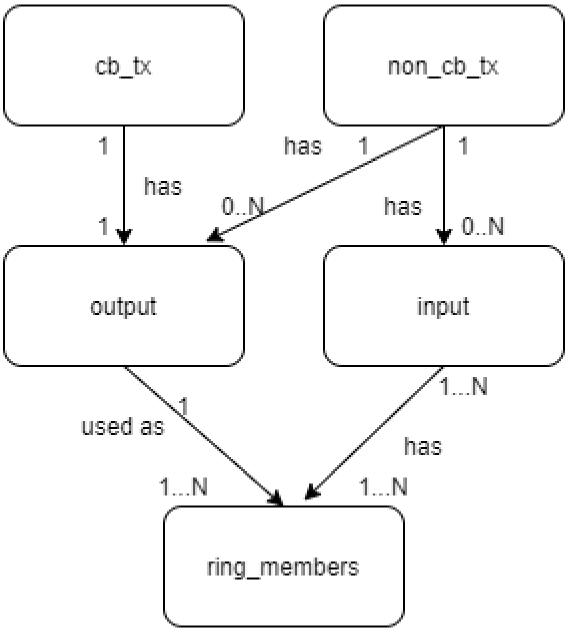


Figure 2: The Monero transaction flow, along with the degrees of relationship, illustrated.

Since each output can only be spent once, if the amount spent as an input is less than the output amount it originated from, the remainder is sent back as change to a new one-time address generated from the public key of the sender.

4 Data Collection

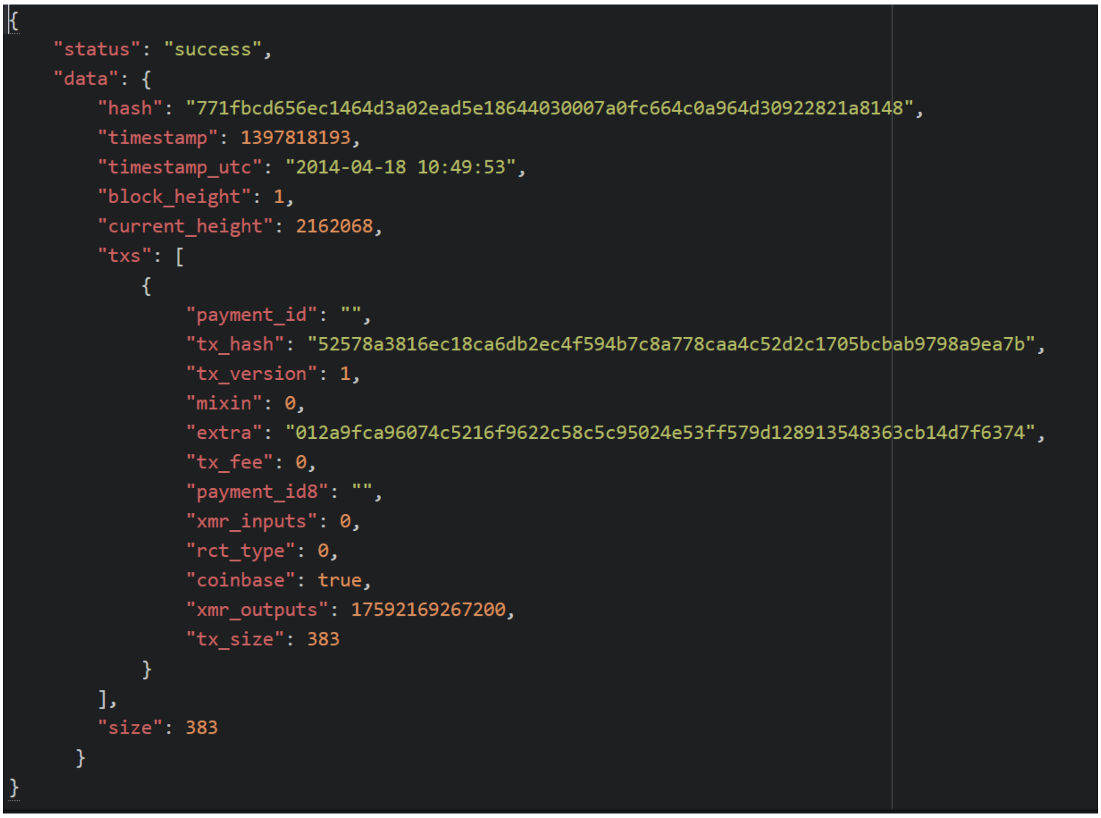
In order to perform network traceability analysis on the Monero blockchain, we must first collect data on Monero transactions, and store it in a format that is easy to retrieve and make amendments to. In this project, it was decided that we would scrape transaction data in the form of JSON objects from the xmrchain.net API endpoint, and store relevant data from the JSON objects in a graph-based database (such as Neo4j or ArangoDB).

4.1 Considerations

Initially, running a Monero node, and extracting data directly from the local blockchain of the Monero node was considered. However, due to the possible limitations and implications of running a Monero node on a NTU server, as well as possible difficulties interacting with a local blockchain, it was decided that scraping data from a public-facing block explorer would be preferable.

4.2 Scraping JSON objects from xmrchain.net

There were 2 types of JSON objects obtained from xmrchain.net: firstly, block JSON objects, which contains data such as block height, timestamp, transactions hashes, as well as miscellaneous data, and secondly, transaction JSON objects, which contains information such as inputs and outputs used in the transaction, mixins used in the inputs, as well as miscellaneous data. A sample JSON block object is shown as follows, and sample JSON block and transaction objects are included in the appendix:



```
{
    "status": "success",
    "data": {
        "hash": "771fbcd656ec1464d3a02ead5e18644030007a0fc664c0a964d30922821a8148",
        "timestamp": 1397818193,
        "timestamp_utc": "2014-04-18 10:49:53",
        "block_height": 1,
        "current_height": 2162068,
        "txs": [
            {
                "payment_id": "",
                "tx_hash": "52578a3816ec18ca6db2ec4f594b7c8a778caa4c52d2c1705bcbab9798a9ea7b",
                "tx_version": 1,
                "mixin": 0,
                "extra": "012a9fca96074c5216f9622c58c5c95024e53ff579d128913548363cb14d7f6374",
                "tx_fee": 0,
                "payment_id8": "",
                "xmr_inputs": 0,
                "rct_type": 0,
                "coinbase": true,
                "xmr_outputs": 17592169267200,
                "tx_size": 383
            }
        ],
        "size": 383
    }
}
```

Figure 3: Sample block JSON object - block 1 JSON data

Data scraping was done using a Python script, *get_json.py*, to iterate through block height in an ascending order, to send GET requests to the http://xmrchain.net/api/block/ endpoint, where block JSON objects are obtained. From the block JSON objects, the individual transaction hashes within the block are obtained. Iterating through the transaction hashes, GET requests are then sent to the API endpoint for transactions, http://xmrchain.net/api/transaction/, where the JSON transaction objects are then obtained. The source code for get_json.py is included in the appendix.

4.3 File structure and archiving txs Directories

The file structure for storing the JSON files are show below, using the example of blocks 0 and 1:

```
data

|-- blocks

|   |-- 0.json

|   `-- 1.json

`-- txs

    |-- 0

    |   `-- c88ce9783b4f11190d7b9c17a69c1c52200f9faaee8e98dd07e6811175177139.json
```

Figure 4: File structure for storing JSON files, pre-archival

Block JSON objects would be stored in the **blocks** directory, with the file name being the block height, while transaction JSON objects would be stored under a newly created directory, with the block height as directory name, and transaction hash as file name.

While in the process of scraping JSON objects from xmrchain.net, I ran into an unusual storage issue: the server that I was running the python script from still had significant storage space unused, but I was getting an error from the python script that indicated there was insufficient storage space. After a brief investigation, the problem was revealed to be that the server had ran out of inodes, which can be thought of as pointers to a file. Usually, the ratio of inodes to storage space is predetermined at time of portioning of storage, so if one needs to store a lot of small files, as in my case, the server would run out of inodes before it runs out of storage space.

The solution I undertook was to write a Python script to archive the directories in txs, as well as to update the *get_json.py* script to archive future txs directories. The updated file structure looked as follows:

```
data

|-- blocks

|   |-- 0.json

|   `-- 1.json

`-- txs
```

Figure 5: File structure for storing JSON files, post-archival

Before this solution, the server would need at least 2 inodes per block – 1 for the block JSON file, 1 for the coinbase transaction file, and 0 or more for the non-coinbase transaction files m(if they exist). This solution ensured that the maximum amount of inodes needed per block was 2 – 1 for the block JSON file, and the other for the archive file of the transaction JSON files. Essentially, the lower bound for the number of inodes needed per block became the upper bound, ensuring that the server would never run out of inodes, based on the highest block height of Monero at that point.

5 Building the Graph Database

After collecting the Monero transaction data in the form of JSON objects from xmrchain.net, we need to store the data in a format that is easier to retrieve and modify. A graph database is ideal because it allows us to explore the relationship between the different parts of Monero transactions, such as the inputs, outputs and mixins.

For this project, ArangoDB was selected as the graph database to be used due to its open-source nature and an abundance of documentation of its API. After a schema for the database was designed, a Python script, *ArangoDB_init.py* was written to implement the schema by initializing the appropriate vertex and edge collections. After which, another

Python script, *json_to_adb.py*, was used to parse information from the JSON objects and write them to the database.

5.1 Initial Schema Design

The initial schema design for the database was made based on certain assumptions about the nature of Monero transactions, based on the way that Monero was designed to be used, and based on how rational users would behave if they wanted to maximise their privacy. The schema is as shown below:

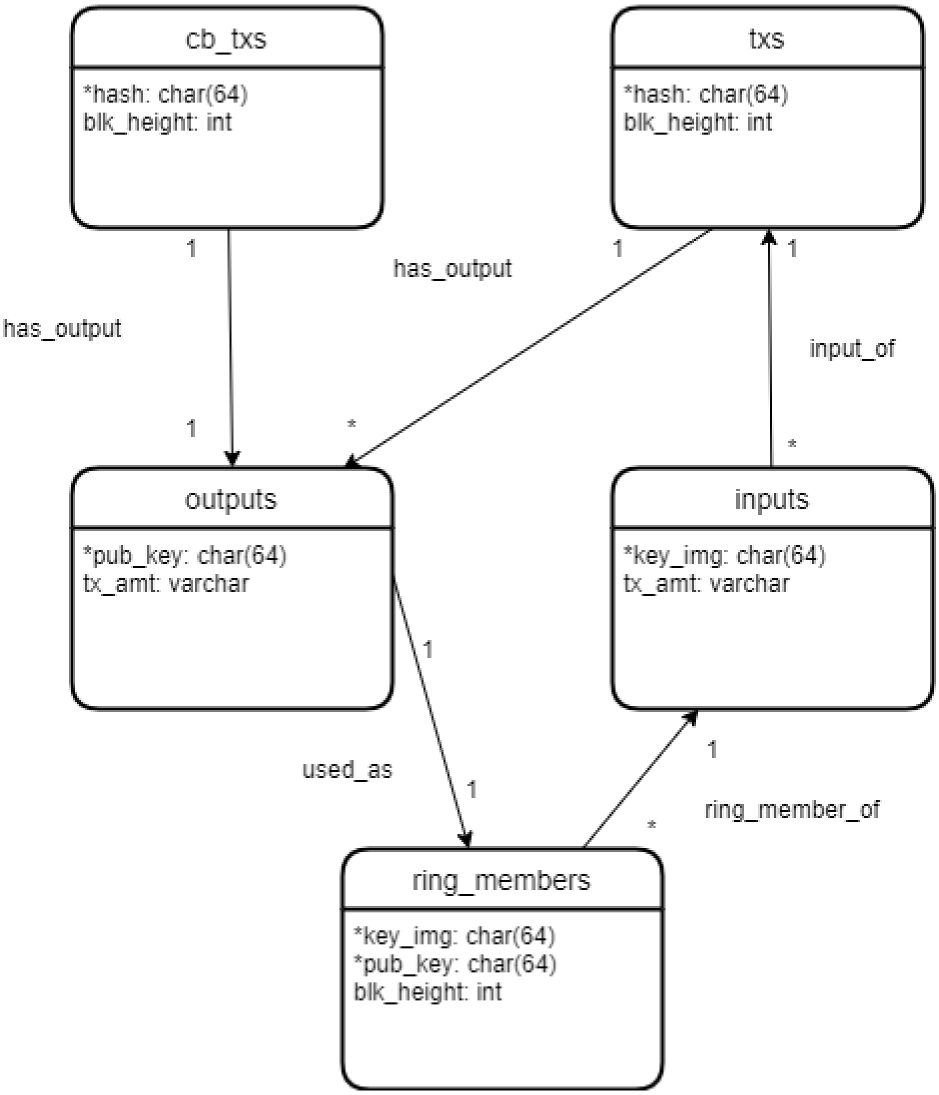


Figure 6: ArangoDB Schema V1

The following assumptions were used to make this schema:

1. Since the public keys generated for receiving a Monero transaction are essentially one-time addresses, they will not be re-used again to receive another transaction, and hence can be used to uniquely identify outputs of transactions. Hence, they are used as keys of the vertex collection *outputs*, and why each output can only belong to coinbase transaction or transacation.
2. Each block will only have 1 coinbase transaction, with each coinbase transaction having only 1 output.
3. Each output can be used as a real input in a future transaction at most once, and can be used as a decoy infinitely many times. However, it will not be used in the same transaction input more than once, since it will defeat the purpose of using mixins by essentially duplicate the candidate inputs. Hence, a combination of the output's public key, and the key image of the input it is used in, should be able to uniquely identify mixins.

However, as we shall see in the next section, there is empirical data to disprove assumptions 1 and 3, and we will have to make changes to the schema to reflect the reality of Monero transactions.

5.2 Anomalies in Data

This section shall explore anomalies encountered during the writing of data from JSON objects to the graph database. These anomalies resulted in the amendment of the graph database schema, as well as the code logic of the *json_to_adb.py* script. We shall explore what these anomalies are, the first instance where they are encountered, as well as possible explanations for these anomalies. These anomalies have been cross-checked with a second block explorer, localmonero.co, to ensure that they are actual anomalies and not just an error/bug with xmrchain.net.

5.2.1 Repeated Output Pubkey

The first anomaly encountered was a repeated output pubkey, or stealth address. This occurred at block 200401, transaction 86c73c157e6fe10aa98c78f25d5a42dbc531e697cd8a366b1292e71cf372b33b, where the pubkey 9b2e4c0281c0b02e7c53291a94d1d0cbff8883f8024f5142ee494ffbbd088071 was re-used from transaction 1a24eea7554d5d2e8f2d5c4fdbbb00bb5ec4ba4718681dd46f0718675d1a5efc from block 200382. This anomaly disproves assumption 1 used in section 6.1 for the initial schema design.

This anomaly affects the schema design of vertex collections cb_txs, txs and outputs, as well as edge collections has_output from cb_txs to outputs and txs to outputs. The changes are listed as follows:

1. An outputs vertex can belong to more than 1 txs or cb_txs vertices.
2. Outputs vertices have a new property, total_inputs which track the total amount of Monero going into the stealth address
3. Txs to outputs and cb_txs to outputs edges have a new property, tx_amt, which replaces the old outputs property.

The new revised schema is shown below:

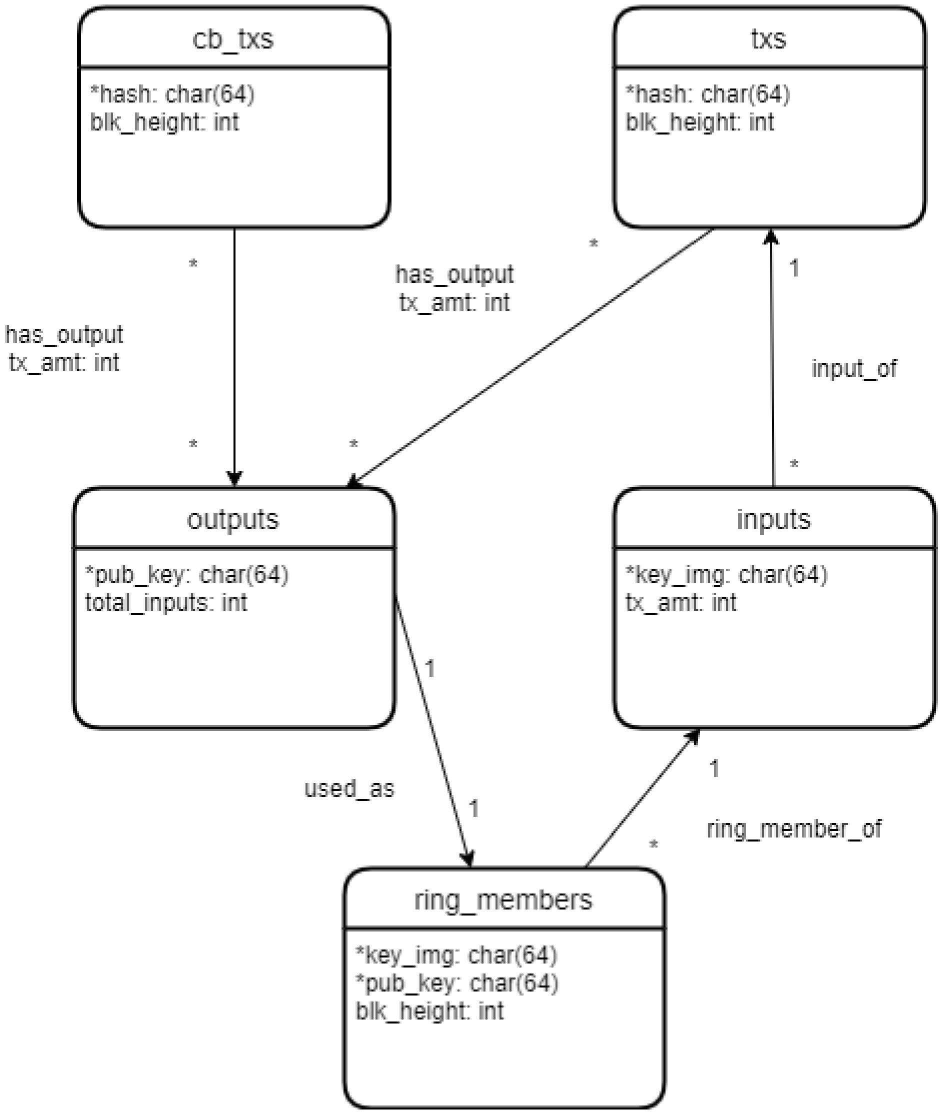


Figure 7: ArangoDB Schema V2

5.2.2 Zero Output Transactions

The next anomaly encountered was 0-output transactions, which were first encountered in multiple transactions in block 202612. The full list of transactions can be found under Table 1 in the Appendix.

5.2.3 Repeated Mixin in Same Input

The third anomaly that was observed was the re-use of a mixin in the same input. This was first observed in block 327 625, transaction

06dfb085e0f5de4cc10b5ab134f06b8c5285887a5cb53c155ec52330887576fd, where the mixin cf216608163fc795aba56d68ab52304a18c0cee62f3b7d0968fea98aede54f79 was used twice in the input 42969704d33bb76decb429235ea8778b4c92e0584afb8a8c680fd62702299c9f. Repeated mixins in the same input are detrimental to reducing the traceability of Monero transactions as they give the appearance of meeting the minimum amount of mixins, but the repeated mixin does not actually contribute to reducing traceability. A possible explanation for the repeated mixin is that there were less outputs of a particular denominations than the required number of mixins, and hence the sender had no choice but to re-use a mixin in order to meet the minimum number of mixins. For example, at block height 327 625, the minimum number of mixins seemed to be 5. It was possible that in the entire history of the blockchain at the time, there were only ever 4 outputs of denomination 0.011111111111 XMR, hence the need to repeat mixins in order to have 5 mixins.

As a result of the discovery of this anomaly, the key image of an input in which a mixin is used in, as well as the public key of the output in which it originated from, can no longer uniquely identify ring members together. As such, a new element must be added to the compound key in order to differentiate repeated mixins. The index of the mixin (since mixins to an input appears as an array in the JSON object) is chosen as this element. In addition, a new property is added to the ring_members collection: ‘duplicate’, a Boolean, which identifies whether the particular mixin is repeated in the same input. The new schema is reflected below:

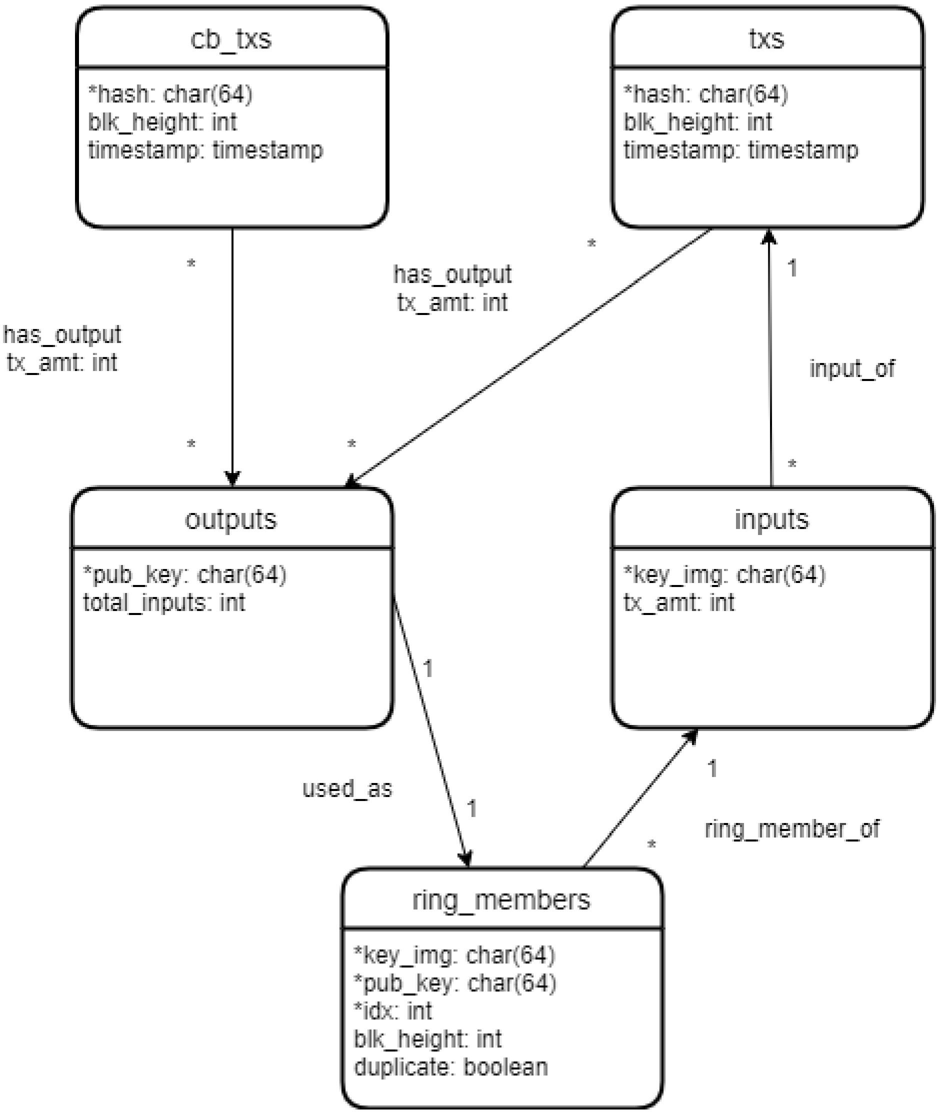
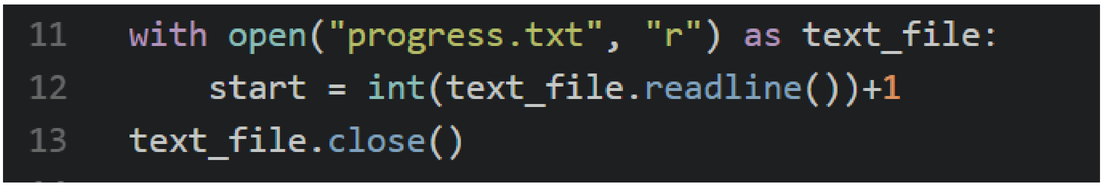


Figure 8: ArangoDB Schema V3

5.3 json_to_adb.py Design Justifications and Code Snippets

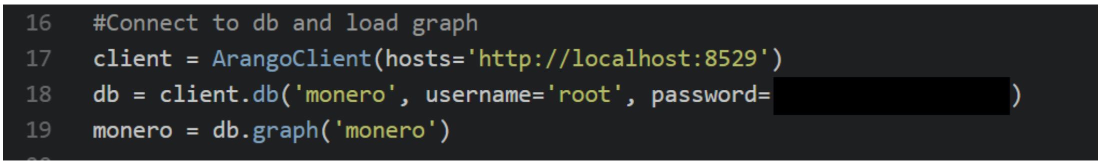
In this section, we will go through a few key snippets of the json_to_adb.py script. The full source code will be made available in the appendix.



```python
with open("progress.txt", "r") as text_file:
    start = int(text_file.readline())+1
text_file.close()
```

Figure 9: Reading start index from text file

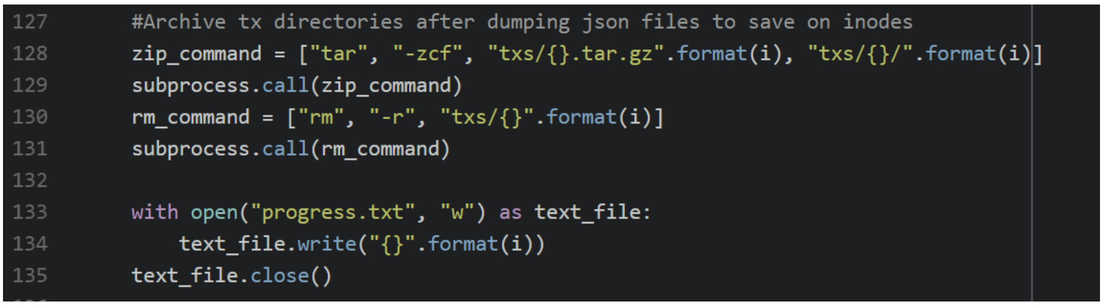
First, we will read in the start index for the for loop from a text file, progress.txt. The reason for doing so is that this script is expected to run for a long time, in the order of days of weeks, and in between, the script might stop running for reasons like unhandled exceptions, running out of memory, or unexpected power failure of the power source powering the server where it is run from.



```python
#Connect to db and load graph
client = ArangoClient(hosts='http://localhost:8529')
db = client.db('monero', username='root', password=[redacted])
monero = db.graph('monero')
```

Figure 10: Connecting to ArangoDB

We then connect to the ArangoDB server on localhost and load the graph. After which, we will enter the for loop, which will extract the archived JSON transaction files by block height, extract the relevant data, and create the appropriate vertex and edge documents and write them to the ArangoDB graph.



```python
    #Archive tx directories after dumping json files to save on inodes
    zip_command = ["tar", "-zcf", "txs/{}.tar.gz".format(i), "txs/{}/".format(i)]
    subprocess.call(zip_command)
    rm_command = ["rm", "-r", "txs/{}".format(i)]
    subprocess.call(rm_command)

    with open("progress.txt", "w") as text_file:
        text_file.write("{}".format(i))
    text_file.close()
```

Figure 11: Re-archiving JSON files, writing index to text file

Once the vertex and edge documents are created for each block, we will re-archive the JSON transaction files and store the current, completed for loop index in the same text file that we read from earlier.

As disruptions to the script can occur in the middle of the for loop, we have created a clean-up script, *cleanup.py*, which is similar to *json_to_adb.py*. In the event that a disruption occurs to *json_to_adb.py* in the middle of a for loop, cleanup.py will be called. For example, if a disruption happens in the middle of writing block 100 data to ArangoDB, the index stored in *progress.txt* will be 99, since the writing to progress.txt happens at the end of the for loop. *Cleanup.py* will then read in the index 99, start the for loop from index 100, and do the writing of block 100 data to ArangoDB, but with try-except block to handle key errors that ArangoDB will throw, due to data that have already been written prior to the disruption happening. After block 100 data has been written, *cleanup.py* will then write the index 100 to *progress.txt*, and exit. We can then call *json_to_adb.py* again to continue. If a disruption happens in the middle of running *cleanup.py*, we will simply call *cleanup.py* again. The full source code for cleanup.py is available in the appendix.

The overall workflow of the *json_to_adb.py* script and its interaction with the JSON files, *progress.txt* and ArangoDB is summarized in the figure below:

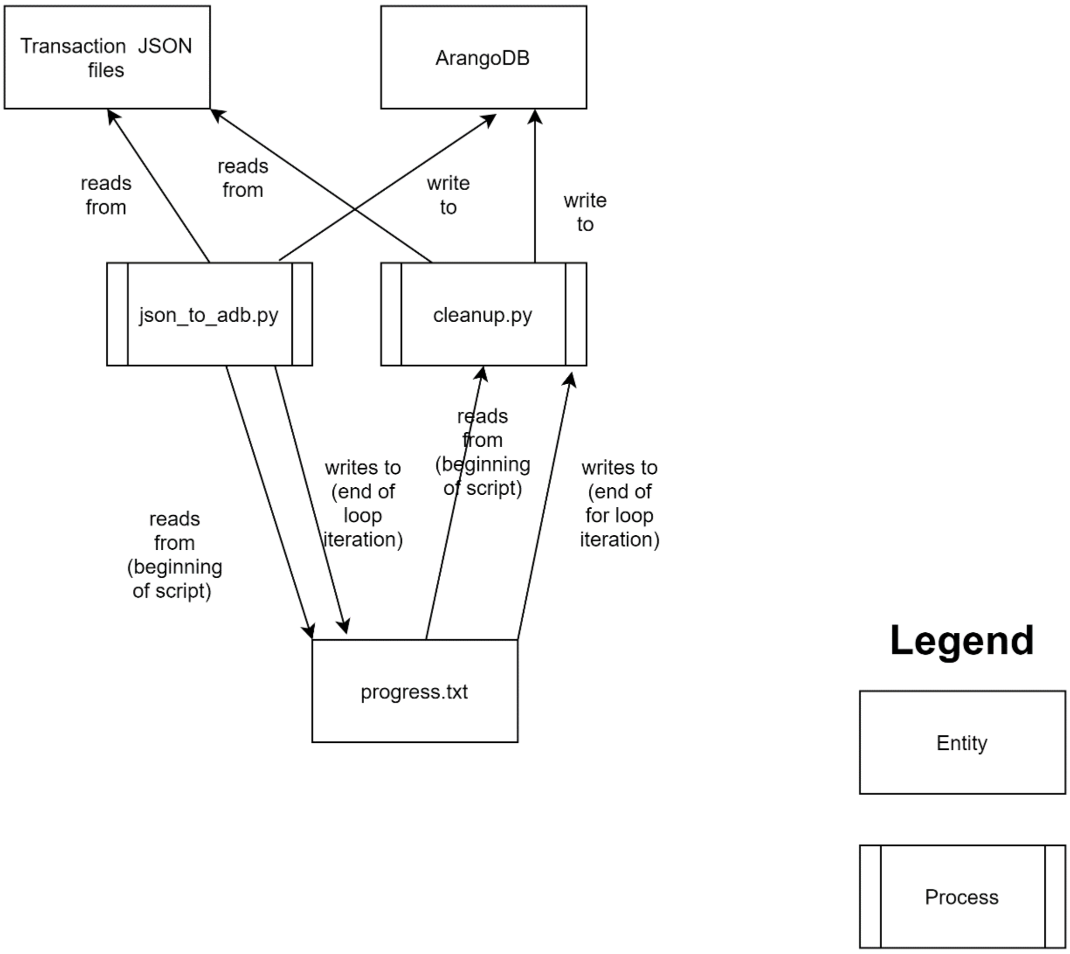

Transaction JSON files
ArangoDB
reads from
reads from
write to
write to
json_to_adb.py
cleanup.py
reads from (beginning of script)
writes to (end of loop iteration)
reads from (beginning of script)
writes to (end of for loop iteration)
progress.txt
Legend
Entity
Process

Figure 12: Workflow of json_to_adb.py

6 Anonymity Analysis

Anonymity analysis will be conducted on the ArangoDB graph of Monero transactions that we have built. The analysis will be conducted through the use of 0-mixin analysis, taking advantage of transaction inputs that have only 1 ring-member and do not use mixins to conceal the true input.

This analysis will be conducted in 2 phases: the first phase, the primary analysis, will mark the only member of the ring signature input of 0-mixin inputs as the real input, as well as the output from which that member originated from, as spent. In the second phase, the secondary analysis, we will filter out inputs where all but 1 member of the ring signature has been marked as spent. We can then conclude with certainty that the only unspent member is the true input, and mark it as such. Once again, we will mark the output that this member originates from as spent. We then repeated this for as long as the project continues, or until no further inputs can be de-anonymized, whichever is earlier.

6.1 Preparation

Before we can proceed with the anonymity analysis, we need to do some modifications to our ArangoDB schema. Looking at ArangoDB schema V3 in the previous section, one might realize that the only way to iterate through inputs to find 0-mixin inputs is to iterate through the *txs* vertex collection, which then points to the *inputs* vertex collection. However, due to the sheer size of the *txs* vertex collection, it is simply not practical to ask the database for the full list of *txs* keys, and them call the database to return the objects. We need a way to iterate through the transactions by using for loop of numbers, not keys, which are not in sequential order. As block height is in running order, and each block can reference transactions, iterating through block heights is a great way to indirectly iterate through transactions and eventually, inputs. Thus, a Python script, *create_blocks.py* is used to add the vertex collection blocks to the ArangoDB graph. This vertex collection will have the integer property, *blk_height*, and will have 2 edges, *has_cb_tx* and *has_tx* connecting it to *cb_txs* and *txs* respectively.

In addition, the following changes need to be made in order to mark true inputs and spent outputs: the addition of Boolean properties *true_input*, *spent* and *deanon* to vertex collections *ring_members*, *outputs* and *inputs* respectively. The *deanon* property simply stores whether an input has been successfully de-anonymized (either in the current or previous rounds of anonymity analysis). The updated, and final schema is reflected below:

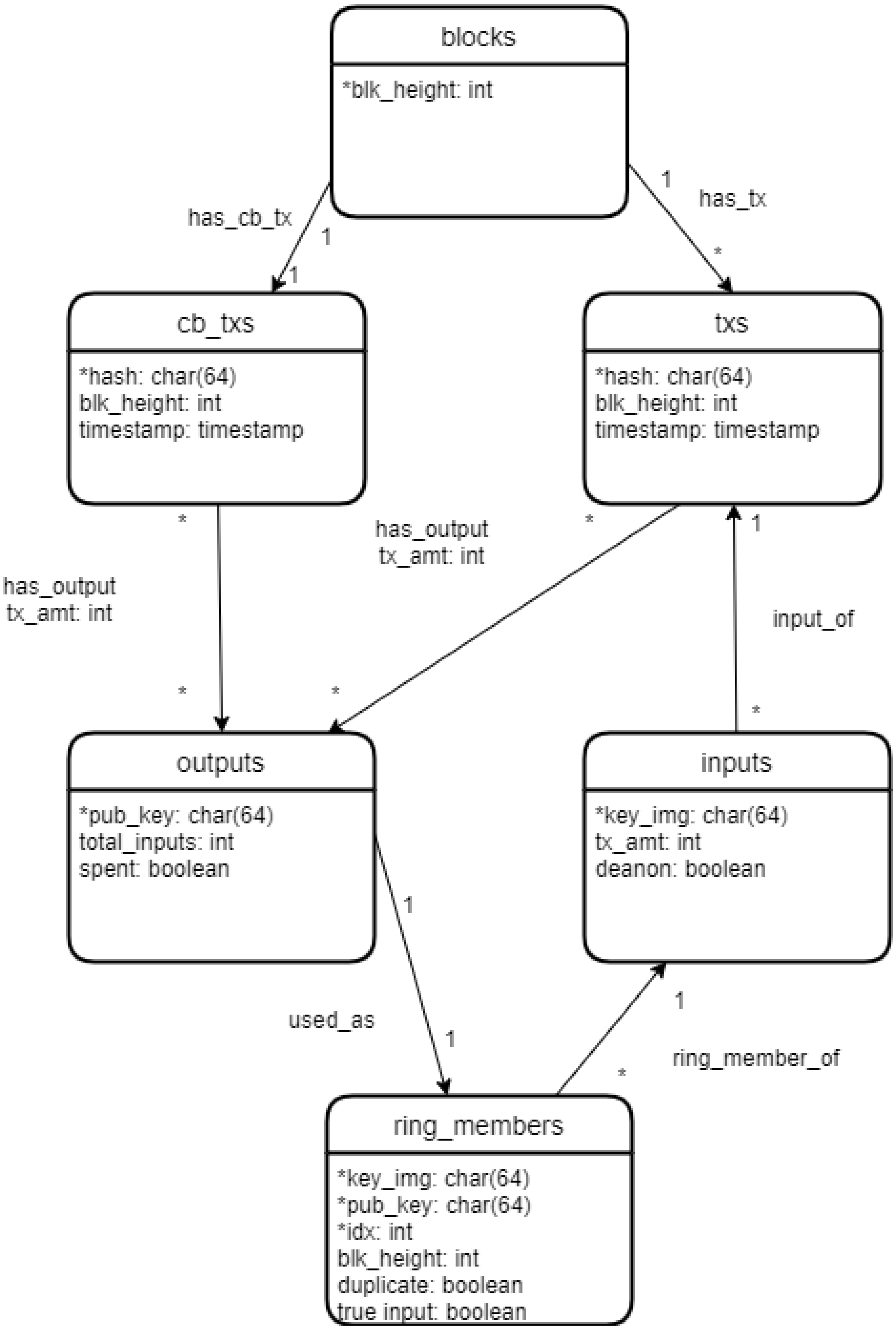
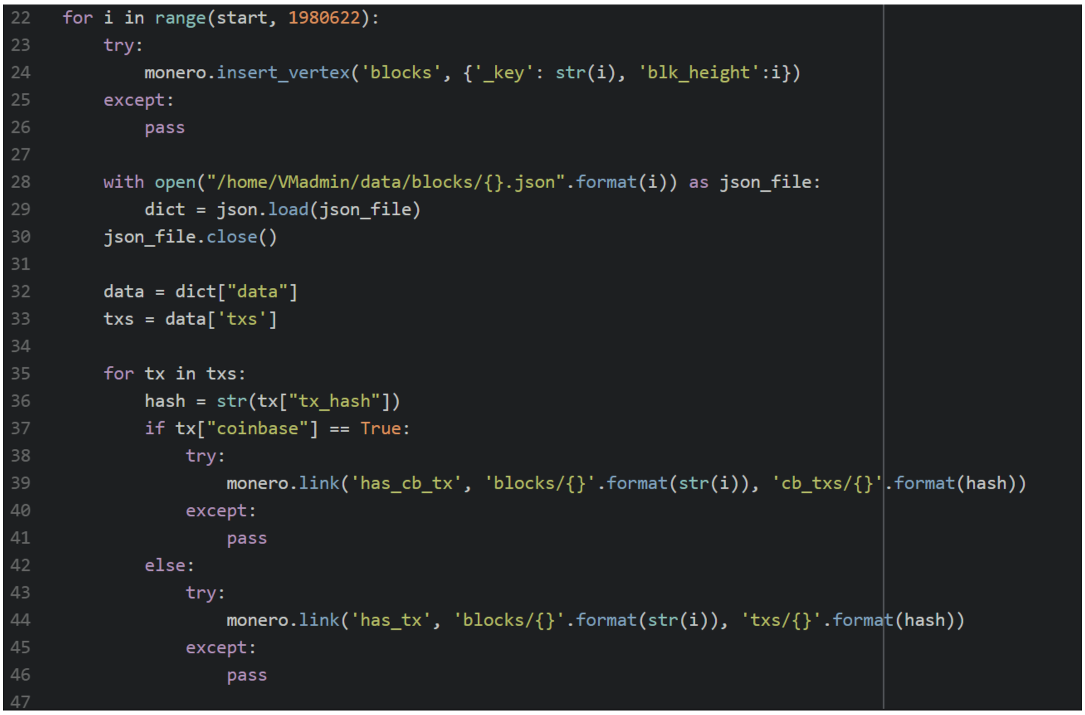


Figure 13: ArangoDB Schema V4

6.2 Primary Analysis

While the block vertex collection, and its corresponding edge collections are created in the earlier section, the creation of the actual vertex and edge documents will be done just prior to the first round of anonymity analysis, in the same Python script. This is done to save runtime. A code snippet of the script, update_adb.py, showing the creation of the appropriate documents is attached below, with the full version in the appendix.



```python
for i in range(start, 1980622):
    try:
        monero.insert_vertex('blocks', {'_key': str(i), 'blk_height':i})
    except:
        pass

    with open("/home/VMadmin/data/blocks/{}.json".format(i)) as json_file:
        dict = json.load(json_file)
    json_file.close()

    data = dict["data"]
    txs = data['txs']

    for tx in txs:
        hash = str(tx["tx_hash"])
        if tx["coinbase"] == True:
            try:
                monero.link('has_cb_tx', 'blocks/{}'.format(str(i)), 'cb_txs/{}'.format(hash))
            except:
                pass
        else:
            try:
                monero.link('has_tx', 'blocks/{}'.format(str(i)), 'txs/{}'.format(hash))
            except:
                pass

```

Figure 14: Creating the relevant ArangoDB documents

The code logic for the primary anonymity analysis is too long to be shown as a snippet, and the source code of update_adb.py should be referenced in order to gain an understanding of the implementation of the primary anonymity analysis.

6.2.1 Setup

Similar to the process of writing data from JSON files to ArangoDB, the script for primary analysis is expected to have a long runtime of days to weeks, and hence we will also need text files to store and retrieve variables, as well as a clean-up script. A Python script, *update_adb.py* will be used to update the ArangoDB schema from V3 to V4, as well as perform primary analysis. This time, however, there needs to be 3 variables that need to be stored and retrieved from text files – the index of the for loop, which will be stored and retrieved from *progress.txt*, the total number of inputs so far, which will be stored and retrieved from *inputs_count.txt*, as well as the total number of traceable inputs so far, which will be stored and retrieved from *deanon_inputs.txt*. There will also be a clean-up script, *update_adb_cleanup.py*.

We also managed to automate the process of cleaning up and restarting the *update_adb.py* script. This is achieved through another Python script, *check_status_restart.py*, which sends the command 'pgrep -f update_adb.py'. If there is no Process ID returned, it means that the *update_adb.py* script is not running. We then check *progress.txt* to see if the script has stopped running because the for loop index has reached the last value. If that is not the case, we then call the *update_adb_cleanup.py* script, before restarting the *update_adb.py* script. We set the *check_status_restart.py* to run every minute via crontab, thereby minimizing the downtime of the *update_adb.py script*.

In addition, we also implemented a Telegram bot which reports on the progress of the *update_adb.py* script. This is done by calling the *bot.py* script every 4 hours through crontab. The *bot.py* script then reads from *progress.txt*.

The overall setup is summarized in the figure below:

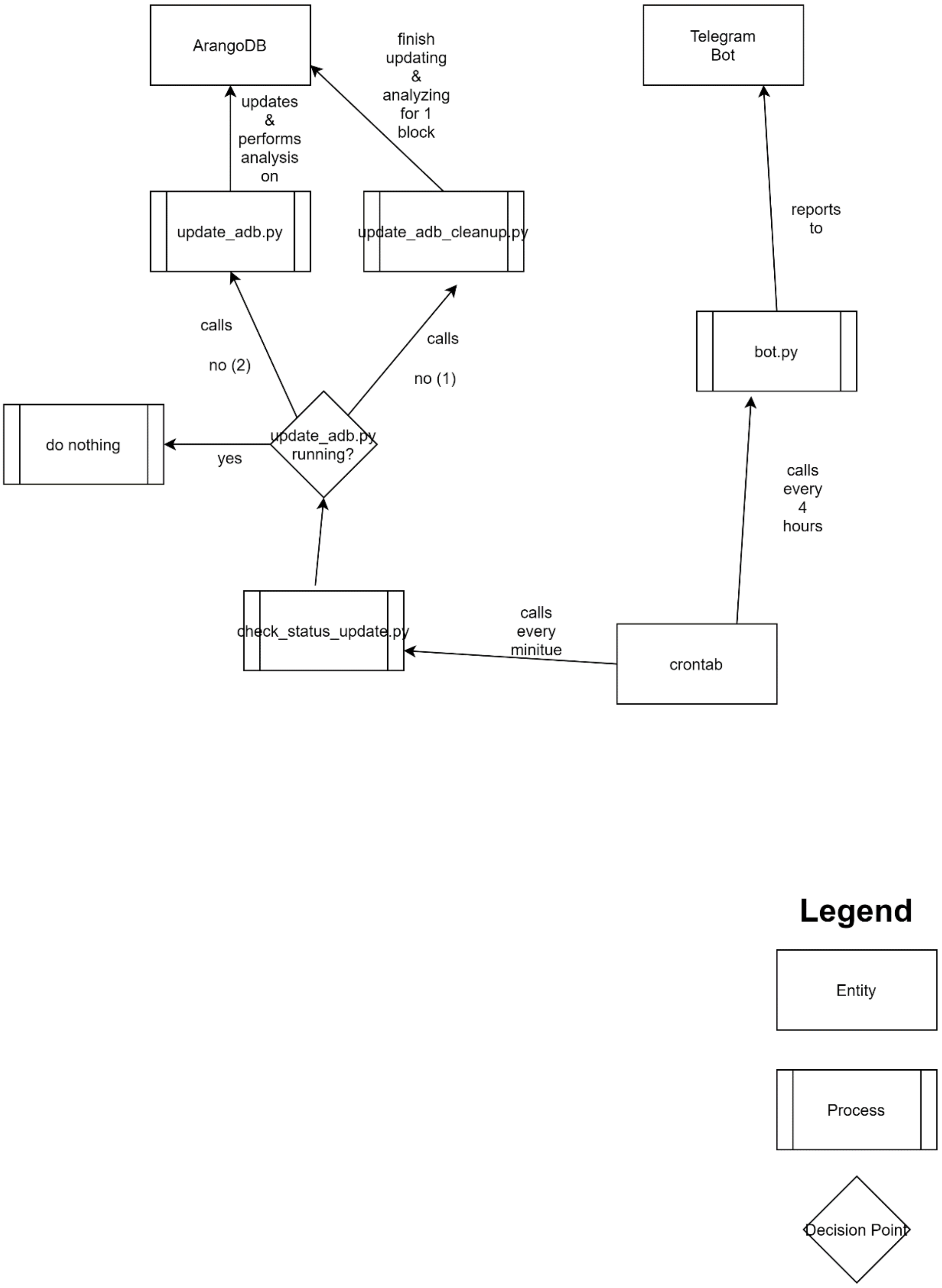


Figure 15: The overall setup of performing primary analysis,

6.2.2 Results

At the end of primary analysis of the first 1980622 blocks, the ratio of traceable inputs is 0.399738639. Unfortunately, the Python script for primary analysis did not include code logic to store the deanonymization ratio at regular block intervals, so we have to rely on data that is reported from the Telegram bot. The following is the plot of cumulative deanonymization ratio (CDR) across block heights.

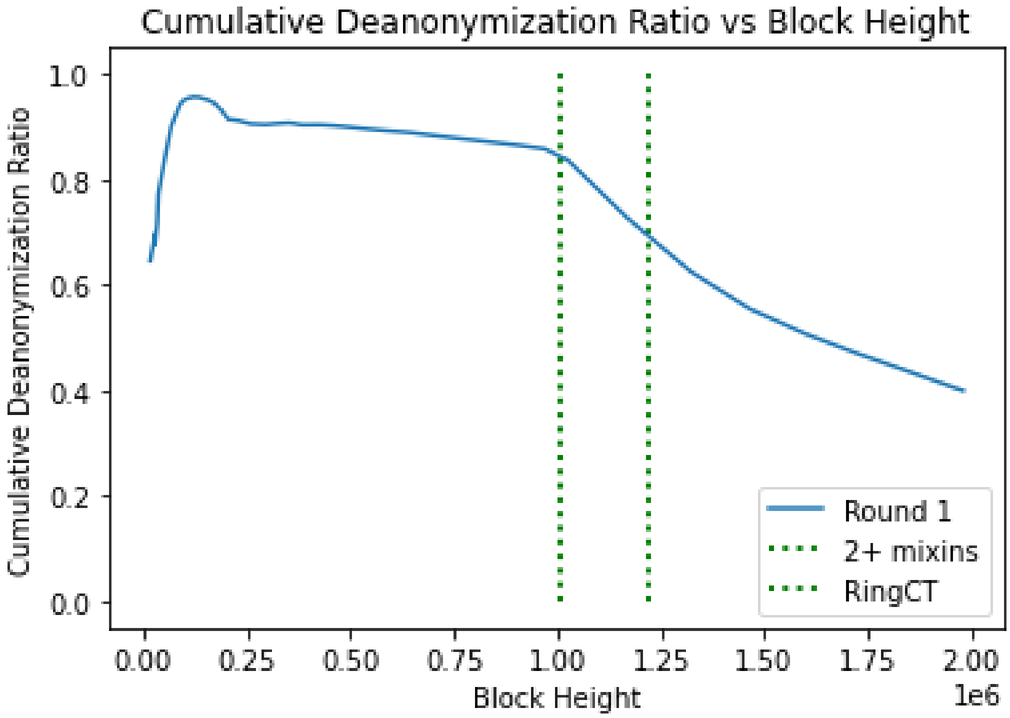


Figure 16: Cumulative Deanonymization Ratio vs Block Height

As we can see from the above figure, the CDR drops substantially after a minimum of 2 mixins is enforced, and even more so after RingCT is implemented. Since primary anonymity analysis relies solely on 0-mixin inputs, it should not come as a surprise that CDR drops after 2+ mixins is enforced, since there should be no more 0-mixin inputs after that.

6.3 Secondary Analysis

Using a similar setup to that in 6.1, we perform secondary analysis as discussed in section 6. The Python scripts involved, anon_analysis.py and anon_analysis_cleanup.py are available in full in the appendix.

Unfortunately at the time of writing of this report, we have only managed to perform secondary analysis till block 1768000. However, this time, we managed to collect CDR data at a regular interval of every 1000 blocks. The results will be discussed in the section below.

6.3.1 Results

Secondary analysis ended with a CDR of 0.551860605 at block 1768000. The following is a plot of CDR over block height, compared with CDR from primary analysis.

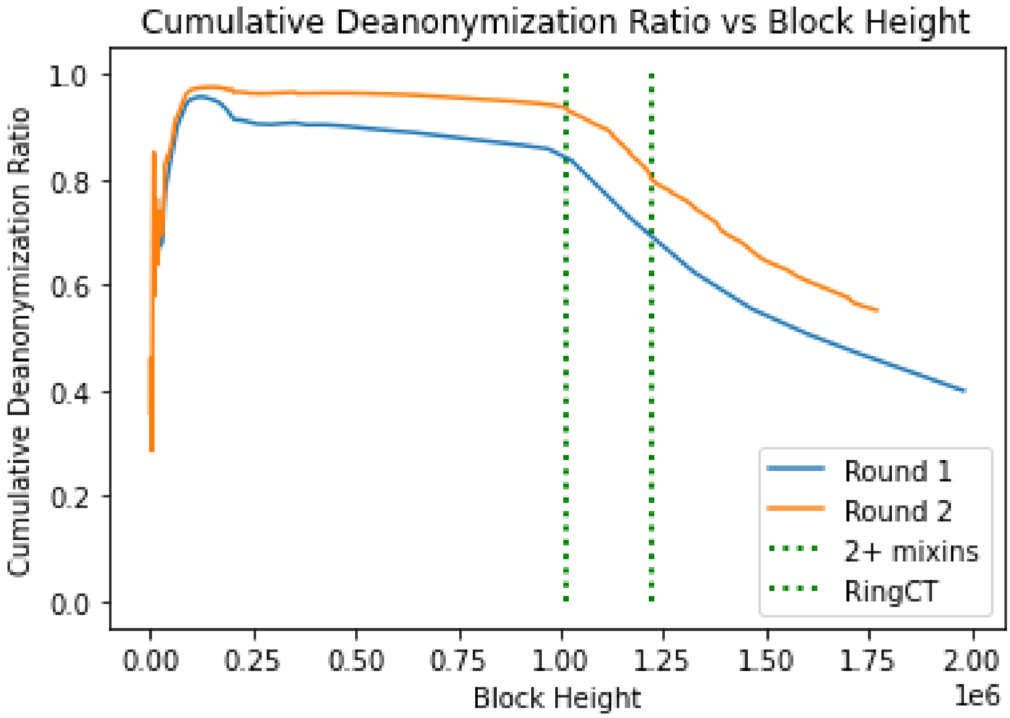


Figure 17: CDR vs Block height, Round 1 vs Round 2

As expected, the CDR obtained from secondary analysis is greater than or equal to that obtained from primary analysis across all intervals.

7 Conclusion

In conclusion, Monero is not as private and untraceable as we would like to think it is. However, as a minimum number of mixins has been enforced, and the number of non-0-mixin inputs increase and becomes a larger proportion of inputs over time, the traceability of Monero should decrease over time. Increasing the minimum number of mixins, while increasing transaction sizes, could help decrease the traceability of the Monero network.

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Appendix

1.1 Sample Block JSON data

```
{
    "status": "success",
    "data": {
        "hash":
"771fbcd656ec1464d3a02ead5e18644030007a0fc664c0a964d30922821a8148",
        "timestamp": 1397818193,
        "timestamp_utc": "2014-04-18 10:49:53",
        "block_height": 1,
        "current_height": 2162068,
        "txs": [
            {
                "payment_id": "",
                "tx_hash":
"52578a3816ec18ca6db2ec4f594b7c8a778caa4c52d2c1705bcbab9798a9ea7b",
                "tx_version": 1,
                "mixin": 0,
                "extra":
"012a9fca96074c5216f9622c58c5c95024e53ff579d128913548363cb14d7f6374"
,
                "tx_fee": 0,
                "payment_id8": "",
                "xmr_inputs": 0,
                "rct_type": 0,
                "coinbase": true,
                "xmr_outputs": 17592169267200,
                "tx_size": 383
            }
        ],
        "size": 383
      }
}
```

1.2 Sample Transaction JSON data

```
{
    "status": "success",
    "data": {
        "payment_id": "",
        "inputs": [
            {
                "amount": 7000000000000,
                "mixins": [
                    {
                        "public_key":
"de00acad5a0df1c52ef51637cb89ae1c991c877acf6152252529009d6e51adbc",
                        "block_no": 2
                    },
                    {
                        "public_key":
"1b6367f72a1cdbc7a21aa37e0ab2155529e404c2efaadd72ca7702e42bc96640",
                        "block_no": 6
                    },
                    {
                        "public_key":
"1e4f2708aa04f52d4607d98ba18bf0f87b5045ff74df71f45649975093d19a12",
                        "block_no": 7
                    },
                    {
                        "public_key":
"d1468a64e2703489fcd7d759bb0ca2a93d4acbdda3aaa77c103f5eb4424ed6b9",
                        "block_no": 24
                    },
                    {
                        "public_key":
"feca0b1c0266f02eed4fb19f97bc077171de836d5dcca99280367f9c94ed05e8",
                        "block_no": 31
                    },
                    {
                        "public_key":
"3c65dd846c83fb48036cd978d4d40c35065de407d20df34234332e5db49c6fde",
                        "block_no": 32
                    }
                ],
                "key_image":
"f254220bb50d901a5523eaed438af5d43f8c6d0e54ba0632eb539884f6b7c020"
            }
        ],
        "tx_hash":
"beb76a82ea17400cd6d7f595f70e1667d2018ed8f5a78d1ce07484222618c3cd",
        "tx_version": 1,
        "rct_type": 0,
        "extra":
"01d34f90ac861d0ee9fe3891656a234ea86a8a93bf51a237db65baa00d3f4aa196"
,
        "outputs": [
            {
                "public_key":
"f9c7cf807ae74e56f4ec84db2bd93cfb02c2249b38e306f5b54b6e05d00d543b",
                "amount": 9000000
            },
            {
                "public_key":
"b6abb84e00f47f0a72e37b6b29392d906a38468404c57db3dbc5e8dd306a27a8",
                "amount": 90000000
            },
            {
                "public_key":
"cfc40a86723e7d459e90e45d47818dc0e81a1f451ace5137a4af8110a89a35ea",
                "amount": 900000000
            },
            {
                "public_key":
"6b19c796338607d5a2c1ba240a167134142d72d1640ef07902da64fed0b10cfc",
                "amount": 9000000000
            },
            {
                "public_key":
"1f6f655254fee84161118b32e7b6f8c31de5eb88aa00c29a8f57c0d1f95a24dd",
                "amount": 90000000000
            },
            {
                "public_key":
"3321af593163cea2ae37168ab926efd87f195756e3b723e886bdb7e618f751c4",
                "amount": 900000000000
            },
            {
                "public_key":
"95ed2b08d1cf44482ae0060a5dcc4b7d810a85dea8c62e274f73862f3d59f8ed",
                "amount": 1000000000000
            },
            {
                "public_key":
"dc50f2f28d7ceecd9a1147f7106c8d5b4e08b2ec77150f52dd7130ee4f5f50d4",
                "amount": 5000000000000
            }
        ],
        "timestamp_utc": "2014-04-18 12:13:09",
        "tx_fee": 1000000,
        "payment_id8": "",
        "block_height": 110,
        "xmr_inputs": 7000000000000,
        "confirmations": 2144114,
        "mixin": 6,
        "timestamp": 1397823189,
        "coinbase": false,
        "current_height": 2144224,
        "xmr_outputs": 6999999000000,
        "tx_size": 776
    }
}
```

2 Source Code for get_json.py

```python
'''Script to get json objects from xmrchain.net'''
import requests
import json
import os
import datetime
from time import sleep
from requests.adapters import HTTPAdapter
from requests.packages.urllib3.util.retry import Retry
```

```
import subprocess

#parsed at block 2112472, approx 03-06-2020 1952hrs

session = requests.Session()
retry = Retry(connect=3, backoff_factor=0.5)
adapter = HTTPAdapter(max_retries=retry)
session.mount('http://', adapter)
session.mount('https://', adapter)

print("Starting script at {}".format(datetime.datetime.now()))

for i in range(2112473):    #monero block height starts at 0
    response =
session.get("https://xmrchain.net/api/block/{}".format(str(i)))
    block = json.loads(response.content)

    with open('blocks/{}.json'.format(i), 'w') as f:    #dump block
data as json
        json.dump(block, f, indent=4)

    data = block["data"]
    txs=[]

    if not os.path.exists("txs/{}".format(i)):
        os.makedirs("txs/{}".format(i))

    for tx in data["txs"]:
        txs.append(tx["tx_hash"])

    for hash in txs:
        response =
session.get("https://xmrchain.net/api/transaction/{}".format(hash))
        tx = json.loads(response.content)
        with open('txs/{}/{}.json'.format(i, hash), 'w') as f:
#dump tx data as json
            json.dump(tx, f, indent=4)

    #Archive tx directories after writing json files to save on
inodes
    zip_command = ["tar", "-zcf", "txs/{}.tar.gz".format(i),
"txs/{}/".format(i)]
    subprocess.call(zip_command)
    rm_command = ["rm", "-r", "txs/{}".format(i)]
    subprocess.call(rm_command)
```

3.1 Source Code for json_to_adb.py

```
'''
Script to dump json data into ArangoDB.
To be run from directory ~/data
'''
import subprocess
import os
import json
import csv
from arango import ArangoClient

with open("progress.txt", "r") as text_file:
    start = int(text_file.readline())+1
text_file.close()


#Connect to db and load graph
client = ArangoClient(hosts='http://localhost:8529')
db = client.db('monero', username='root', password=[redacted])
monero = db.graph('monero')

for i in range(start, 2112473):   #Final value: 2112473
    #Extract json files from archive
    extract_cmd = ["tar", "-zxf", "txs/{}.tar.gz".format(i)]
    subprocess.call(extract_cmd)

    #Handle missing json files

    if not os.path.isdir("txs/{}".format(i)) or
len(os.listdir("txs/{}".format(i)))==0:

        with open('missing_data_log.txt', 'a') as logfile:
            logfile.write('Missing files at block{}\n'.format(i))
        logfile.close()
        with open("missing_data.txt", "w") as file:
            file.write(str(i))
        file.close()
        re_get_cmd = ["python", "re_get_json.py"]
        subprocess.call(re_get_cmd)
        extract_cmd = ["tar", "-zxf", "txs/{}.tar.gz".format(i)]
        subprocess.call(extract_cmd)
        txs = os.listdir("txs/{}".format(i))
        if len(txs)>0:
            with open('missing_data_log.txt', 'a') as logfile:
                logfile.write('Successfully re-got json tx files\n')
            logfile.close()

    txs = os.listdir("txs/{}".format(i))

    for tx in txs:
        with open("txs/{}/{}".format(i,tx)) as json_file:
            dict = json.load(json_file)
        data = dict["data"]

        hash = data["tx_hash"]
        blk_height = data["block_height"]
        timestamp = data["timestamp"]

        if data["coinbase"] == True:
            monero.insert_vertex('cb_txs', {'_key': str(hash),
'hash': hash, 'blk_height': blk_height, 'timestamp': timestamp})
        else:
            monero.insert_vertex('txs', {'_key': hash, 'hash':hash,
'blk_height': blk_height, 'timestamp': timestamp})

        if data["outputs"]:
            for output in data["outputs"]:

                pub_key = output["public_key"]
                amt = output["amount"]
                outputs = monero.vertex_collection('outputs')

                #If pubkey already exists, add new edge with tx
amount, and update total inputs.
                if outputs.has(str(pub_key)):

                    existing_total_inputs =
outputs.get(str(pub_key))['total_inputs']
                    new_total_input = existing_total_inputs + amt

                    if data["coinbase"] == True:
                        monero.link('has_output',
'cb_txs/{}'.format(str(hash)), 'outputs/{}'.format(str(pub_key)),
data = {'total_inputs': amt})
                    else:
                        monero.link('has_output',
'txs/{}'.format(str(hash)), 'outputs/{}'.format(str(pub_key)), data
= {'total_inputs': amt})

                    outputs.update({'_key': str(pub_key), 'pub_key':
pub_key, 'total_inputs': new_total_input})

                else:
                    outputs.insert({'_key': str(pub_key), 'pub_key':
pub_key, 'total_inputs': amt})
                    if data["coinbase"] == True:
                        monero.link('has_output',
'cb_txs/{}'.format(str(hash)), 'outputs/{}'.format(str(pub_key)),
data = {'total_inputs': amt})
                    else:
                        monero.link('has_output',
'txs/{}'.format(str(hash)), 'outputs/{}'.format(str(pub_key)), data
= {'total_inputs': amt})

        else:
            with open('zero_output_txs.csv', 'a') as zo_file:
                csv_writer = csv.writer(zo_file, delimiter=',',
quotechar='"', quoting=csv.QUOTE_MINIMAL)
                csv_writer.writerow([blk_height, hash])
            zo_file.close()



        if data["inputs"]:
            for input in data["inputs"]:
                ki = input["key_image"]
                amt = input["amount"]
                monero.insert_vertex('inputs', {'_key': str(ki),
'key_img': ki, 'tx_amt': amt})

                monero.link('input_of', 'inputs/{}'.format(str(ki)),
'txs/{}'.format(str(hash)))

                mixins = input["mixins"]
                pks = [mixin['public_key'] for mixin in mixins]

                for idx, mixin in enumerate(mixins):

                    pk = mixin["public_key"]
                    blk_height = mixin["block_no"]

                    if pks.count(pk)>1:
                        duplicate = True
                    else:
                        duplicate = False

                    key = str(ki)+','+str(pk)+','+str(idx)
                    monero.insert_vertex('ring_members', {'_key':
key, 'key_img': ki, 'pub_key': pk, 'idx': idx, 'blk_height':
blk_height, 'duplicate': duplicate, 'true_input': False})

                    monero.link('ring_member_of',
'ring_members/{}'.format(key), 'inputs/{}'.format(ki))
                    monero.link('used_as',
'outputs/{}'.format(str(pk)), 'ring_members/{}'.format(key))

        json_file.close()


    #Archive tx directories after dumping json files to save on
inodes
    zip_command = ["tar", "-zcf", "txs/{}.tar.gz".format(i),
"txs/{}/".format(i)]
    subprocess.call(zip_command)
    rm_command = ["rm", "-r", "txs/{}".format(i)]
    subprocess.call(rm_command)

    with open("progress.txt", "w") as text_file:
        text_file.write("{}".format(i))
    text_file.close()
```

3.2 Source Code for cleanup.py

```
import subprocess
import os
import json
from arango import ArangoClient
import arango
import csv

#Connect to db and load graph
client = ArangoClient(hosts='http://localhost:8529')
db = client.db('monero', username='root', password=[redacted])
monero = db.graph('monero')

with open("progress.txt", 'r') as text_file:
    i = int(text_file.readline())+1
text_file.close()


#Extract json files from archive
extract_cmd = ["tar", "-zxf", "txs/{}.tar.gz".format(i)]
subprocess.call(extract_cmd)

#Handle missing json files
if not os.path.isdir("txs/{}".format(i)) or
len(os.listdir("txs/{}".format(i)))==0:

    with open('missing_data_log.txt', 'a') as logfile:
        logfile.write('Missing files at block{}\n'.format(i))
    logfile.close()
    with open("missing_data.txt", "w") as file:
        file.write(str(i))
    file.close()
    re_get_cmd = ["python", "re_get_json.py"]
    subprocess.call(re_get_cmd)
    extract_cmd = ["tar", "-zxf", "txs/{}.tar.gz".format(i)]
    subprocess.call(extract_cmd)
    txs = os.listdir("txs/{}".format(i))
    if len(txs)>0:
        with open('missing_data_log.txt', 'a') as logfile:
            logfile.write('Successfully re-got json tx files\n')
        logfile.close()

txs = os.listdir("txs/{}".format(i))

for tx in txs:
    with open("txs/{}/{}".format(i,tx)) as json_file:
        dict = json.load(json_file)
    data = dict["data"]

    hash = data["tx_hash"]
    blk_height = data["block_height"]
    timestamp = data["timestamp"]

    if data["coinbase"] == True:
        try:
            monero.insert_vertex('cb_txs', {'_key': str(hash),
'hash': hash, 'blk_height': blk_height, 'timestamp': timestamp})
        except Exception as e:
            print(e)
    else:
        try:
            monero.insert_vertex('txs', {'_key': hash, 'hash':hash,
'blk_height': blk_height, 'timestamp': timestamp})
        except Exception as e:
            print(e)

    if data["outputs"]:
        for output in data["outputs"]:

            pub_key = output["public_key"]
            amt = output["amount"]
            outputs = monero.vertex_collection('outputs')

            #If pubkey already exists, add new edge with tx amount,
and update total inputs.
            if outputs.has(str(pub_key)):

                existing_total_inputs =
outputs.get(str(pub_key))['total_inputs']
                new_total_input = existing_total_inputs + amt

                if data["coinbase"] == True:
                    try:
                        monero.link('has_output',
'cb_txs/{}'.format(str(hash)), 'outputs/{}'.format(str(pub_key)),
data = {'total_inputs': amt})
                    except Exception as e:
                        print(e)
                else:
                    try:
                        monero.link('has_output',
'txs/{}'.format(str(hash)), 'outputs/{}'.format(str(pub_key)), data
= {'total_inputs': amt})
                    except Exception as e:
                        print(e)
                try:
                    outputs.update({'_key': str(pub_key), 'pub_key':
pub_key, 'total_inputs': new_total_input})
                except Exception as e:
                    print(e)

            else:
                try:
                    outputs.insert({'_key': str(pub_key), 'pub_key':
pub_key, 'total_inputs': amt})
                except Exception as e:
                    print(e)
                if data["coinbase"] == True:
                    try:
                        monero.link('has_output',
'cb_txs/{}'.format(str(hash)), 'outputs/{}'.format(str(pub_key)),
data = {'total_inputs': amt})
                    except Exception as e:
                        print(e)
                else:
                    try:
                        monero.link('has_output',
'txs/{}'.format(str(hash)), 'outputs/{}'.format(str(pub_key)), data
= {'total_inputs': amt})
                    except Exception as e:
                        print(e)

    else:
        with open('zero_output_txs.csv', 'a') as zo_file:
            csv_writer = csv.writer(zo_file, delimiter=',',
quotechar='"', quoting=csv.QUOTE_MINIMAL)
            csv_writer.writerow([blk_height, hash])
        zo_file.close()

    if data["inputs"]:
        for input in data["inputs"]:
            ki = input["key_image"]
            amt = input["amount"]
            try:
                monero.insert_vertex('inputs', {'_key': str(ki),
'key_img': ki, 'tx_amt': amt})
            except Exception as e:
                print(e)
            try:
                monero.link('input_of', 'inputs/{}'.format(str(ki)),
'txs/{}'.format(str(hash)))
            except Exception as e:
                print(e)

            mixins = input["mixins"]
            pks = [mixin['public_key'] for mixin in mixins]

            for idx, mixin in enumerate(mixins):

                pk = mixin["public_key"]
                blk_height = mixin["block_no"]

                if pks.count(pk)>1:
                    duplicate = True
                else:
                    duplicate = False

                key = str(ki)+','+str(pk)+','+str(idx)
                try:
                    monero.insert_vertex('ring_members', {'_key':
key, 'key_img': ki, 'pub_key': pk, 'idx': idx, 'blk_height':
blk_height, 'duplicate': duplicate})
                except Exception as e:
                    print(e)
                try:
                    monero.link('ring_member_of',
'ring_members/{}'.format(key), 'inputs/{}'.format(ki))
                except Exception as e:
                    print(e)
                try:
                    monero.link('used_as',
'outputs/{}'.format(str(pk)), 'ring_members/{}'.format(key))
                except Exception as e:
                    print(e)

    json_file.close()


#Archive tx directories after dumping json files to save on inodes
zip_command = ["tar", "-zcf", "txs/{}.tar.gz".format(i),
"txs/{}/".format(i)]
subprocess.call(zip_command)
rm_command = ["rm", "-r", "txs/{}".format(i)]
subprocess.call(rm_command)

with open("progress.txt", "w") as text_file:
    text_file.write("{}".format(i))
text_file.close()
```

4 Zero Output Transactions

Table 1: Complete List of Zero Output Transactions

Block Height	Transaction Hash
202612	fe4b08727d96d282184ff6667991b377c1c744e62d281068e8791f011dec4c57
202612	ef42a0ebfb06e029b0bea886920ca35b2673982ac6c8e137f55368923d17884e
202612	2ca13518b91e0526e1b0ed4c0e1e78a10f6ffea0cdaffdf6de62d8a57302dfb4
202612	577ed79b3aed71d4ded13145ce554a75abe6a11a1d1f95eb85f1a15c9c4b539c
202612	54c5a623fd32a3a97b0bdc5303e6d0354bdded5c82a6b0b863b811a1c2627a38
202612	71f927d6235a5ec86598d3ec285d31f8897b97550db8a3347d20235c9cc3e6d8
202612	6cbe2e5a048dc7088e6cce38ab1d4774da7dc6c85be3d1178d41aa75a1180824
202612	84cfd8f79b260109021f2c85373173ab8b59bad3f55ddea4bb1514c0c1448536
202612	cb65e3dbc36a4c756d742b30bc1877b4df8132ecc899608a4d96f1fae0a34b96
202612	5322b5a07660d7bc266f38d66a9b485123e69467b7abd10c59e9afa29b5fccf7
202612	290a70f599936b97d9682c490d0f74469295912e53de9ba36c3311449df36f80
202612	b5b742b3639e8677e197d29f5e0e45c887994d2710d1614201b68b255180f521
202612	1db8e164de5f4bcb2c0ffd1601bcda6fdd7f8457c51f06f4af2ea2a65844292c
202612	2690de1beac7e3d99c224b8395874f5c18f8a0911317f43584f209eb59e33431
202612	073b66aea877496d27dd61f9231ae835d66a0c8beddb21fb953caef8b1c6868a
202612	7ca27510637674c373e463b45170e603e5e38171a3b022f499ac44ffeea4ede9
202612	2d1b3752f130bb9a3d7ac04e0526a2db6f24664250b93fd8799e737bf62813b7
202612	9e29b0a51f61cc2bf162d9f82ae22b429670a8a6ebf1a909628c53ae2798b656
202612	96b05f723620a7a72e7da9b0cb43e1ab842dcbc17959247d944c74b9ef380c51
202612	54b7d694e18ae2c04bf24cabd236ab9d1504b0061d48477e8581aecf4f855eec
202612	cb27ff9bda1998b608311e6a7d1edbf1c83aff291257f03b4e33bbea150a370f

202612	76f21afb5f402a4366c65311b8134d8ff41a7566d1628fa8c937c0186dd7f03d
202612	57ca150f68d99eb813b85202a6c09f5884aacee58729afbfc3074ce07517683f
202612	fa142203f6c2f153a3448b18b20314a79c3e64425b9c69cc80b899c2d3c143ec
202612	b78c267ded6c7fccd9cfaa849a7feec0775401c2c8cf5849757aa1de923efa05
202612	02fbc8463ae3f6514a88a53cdcc1bec4aa439df57e084c5ca5cf507fd720301b
202612	4221dac24449d9d67d3ca5dccc443a744a5c3b272fa74a42d348eb7809964dd8
202612	2948e30bf789c414d06bed34a917cfc6a62dcd335a2b983acc999942f4594148
202612	f3c25408e55e53ff7a6aa81551eb295a939f72f9f2272120513df7f3942c0761
202612	73c73e26ab2d4bbe7f749298cd05a54afd814cc7389c358c92e4ca5528498395
202612	dfbdc61da434133aa78f7b38590c0cc64a989b609435444ca125de4e3208359c
202612	c531bccca8d555aa3e5d438a86971846f2d07f21192c604eaf21b25f8b5c695e
202612	33207e284ba346dc3f7f6e7aaa984a085cdb36e3030ff830b26d79cce48d4720
202612	e44f6749da932b62ea700c6eb5e1b32735aa0095e0da1a0db4505ef8e094b408
202612	34757b4181d6a77f8bb97e8d5d2e9db4b781c3f3515b179cee562721b574e51f
202612	0ca8eb6a90c5b90ba05723c18da60d20725d54502529f2486761b4afa257c67e
202612	06f27a6f3435147911981dae7d2b806ececa0e572927ce1451682a6bcd8ffa3d
202612	e7998d5ed9f1bc9e1a4338ff7a8d1a92b6b664a8b162308de29a13e2f7ea83d4
202612	ba6076371e1920af1e6e14fba0b690b5bd4d5f950dc9f828a55e321243a43b8b
202612	e9b57dc41159825dff888371ad4cf8a023676fff9468b3b664f78190167293d6
202612	dbb1333debc933640e6ba5abe580a636bd4508e5bf00e68c85faf5efb9cd5867
202612	aa717003a756f2d917372c5135cd33e924a32044e12a1440f85ad7590140cd51
202612	b59f2814d2bdd41a5f6156c14da5eb0c06be76f6afdbea8496217be019444737
202612	af2216a4df96f9fb629d0aea30ac9ba40c3e6ad8f81ab36c2d004a4ff4d8fe9c
202612	c56a9052d92373e8acc1c7f52a4c9bba4eddef16928da803fe69fd95cf66b041
202612	ef3d8eab3084f17c19dad187b65670dd1a0f04800819f0afcd7cb733b8f65e29
202612	e2cb95fc2f63cdbcb7eed3502b7acc07b09714e6220f421c66389d7dd289d738
202612	862f2141095027802553d235acaadebbc3ee595f53a51df939beadad9e46fc6d
202612	a6166d7657cf1c44ee5474d8d3b3866e571d1ac298194b80ac92fd16dd5fc365
202612	c2f9bc724c7ce9b56947f12390162dae5ec571ca782d9f59aa56817e8d242abd
202612	d5b05f64c030fe06ad5497b115efddfbcd11debd08401c8218c118d60b2d66d1
202612	b077b5008168528a4265da050822d37f39ee37d920a89a04b5820cad71f5125d
202612	5ba89b51b5b41565046420c2215f8b4d6aae1a5ac3d76d5e6531677fcc1dedb7
202612	871d003793be4a129ccdcd6a55c1c5f5f9269923efc8aeae9fef6691bac92987
202612	30d2028790eb706c1d7f2ca439efddaccbcc8dfff38f8ae1bcb08d40a6391019
202612	c7aab9f217fdedce123d1d59aec4348bc1082ee1155bfc7e1d855f9a0618fb6b
202612	79e2b2431a62ed77f069e81351b3ddae218352aec1df772823d67f35b99a8fee
202612	ee79d808f3f95a39e11ed93a92393617d7bf89c78cb8a87d1731da13d5347f9a
202612	2470929d49730ea7795360a54a8046f637ea8f956352fe1a7ead454bd05fe9a3
202612	e8aadb6617f3c37dda37c22791c1687bfe07fa1d1d2c03302c3ecbca0fb65c72
202612	952f0893913181df09f976fab16a1881aafdf22d5c6edb9b630f49ff284ee84d
202612	a3604d1af063189becce88cbacb8cc56a9592a20c11ca0b512566c8c9927e86b
202612	c9d6c869b8141fb3b29644a1b6f09d7a46c401429e45dfec38401b20f3ba42be
202612	97cc3e85bcb7c0ac1b27ea009de1a02e3da71c13dda31b559e7068e93fd17a49
202612	333dd623cd245186be98edde0a3687381231faaa4012eaba0fa49cd72df73d32
202612	ff676a7aa6847a61cc97ce4856fcf2bd3ece00dd0dcaa2cf6bbbe82acd6ddb3e
202612	1afff53b9e0aa6fc2bc912d64fb15ba9574b626ed50c66e7de171d09dbb9b69a
202612	871089a5edbbe5515ce8ad0ca49790e2e59a7585c67b60cffff543e45c8e3a04

202612	8301074787649e7e905ab135a172ab5d0ecac0383f064364b9c7c84b1b621d7c
202612	846e64dbb06769cd43774ecc7bbfc08510ec2feeb03984732a79088e6c1e45d1
202612	99f34952fa352e23dbb95931df1123e32749f4bd50700b99b352b5820c4af578
202612	488d0a8dd835ed1143c750f14b179e8fb5f0b451d00fafe05723dbbf7e5b931f
202612	4b400a63e35d410f175b25e865a225ae7a85d1c5fe1d9467689361efcd49a955
202612	7480ec78eaec6075dbbc1f9dba9ed6e7719cdd508ae00171fd8bd7cbeb922432
202612	2742c25bcaa49d4930e454a49bb15b6a6be04d57dfa50b920dca5c7bd0a70970
202612	d226266378415f181a37ef2833118304cd0e505c229d8e6d6aecba8c35859659
202612	c0dfd58b8bde7e23b5fddccb508843ee1be53b8b28c783ad2c3b302f0335cbc0
202612	64f96c08c21da0fa4048f91f118c89e10707538c89bde3ce48f7bd0e691e6cea
202612	b98a8c8984b3311d0c294845acf13b39fb164c725f938cd52ba3fe0ad64021bd
202612	ba7a52b19a1a834ae037ddb688f1b368b4c945ea50c88941bfe707f75f917691
202612	83a054f48698eab23cdd88ea309fe6608d3a94dc5345e7b196723ef8c16e7b86
202612	3c6ae81848d6779f1556d4aa365805c719f4cc44860d8733633d251c210af65a
202612	01215c58138820199faaa56b540ec0274d2f02080cba82be5c8c00ca088b19e9
202612	7912413b7f8ebe362a4b1485e8566740fc030764164db64ecc6d970f1f51978c
202612	95386e2cdeeaa6eb0d36a13ee67e390c0417432a89a614bdda122680930401f4
202612	8653ca847121d3eaf8a04221f4ad227ab430fae7b7ab73925c1043a59bf7af3f
202612	0e543108a3f901d53234bb3d5b0b3c0c33998dd580968bd47caf245a30a15e7a
202612	e8a860d9e96e8222cd5f794269852359babc557b2079f379d2ea08ea557a0418
202612	07c01f8d0fa885a16b8a719cde738da238b4b7f4c0622a6bb6ce88b09b3204c4
202612	43ade7774efd22c71c92eb34700bd72993383ba264d6caddd49c678ff859ab2e
202612	3f3c7e9cdfb1ec719e943a58db3f9a3748f6b574c9d362851ee9e93d6b8666ae
202612	d0c629b37a1bf258135d7a8e8ddbb72da9122e0c56e506b0da2ea547ad286fbc
202612	c0e53e5a81c13c716b5600c265619b9670e44f6e879b8800ba18000fea4cfebb
202612	90d7ebe6c7cee16d24c9349f0c3b4ccdadae48967266d0001f5115fbe44dc5be
202612	5cc2af701a10bb06075f880cd024d69b3d30dfb80fa6dfebab3b765ff912d421
202612	63ce9d40b49564a840a6286e524195c44c7638d5ab60c808f9fd49ede97aa3c0
202612	ec0032f33f7ff5de39b8a76797a6b9142f2a9e11d8b78dd7a8ac5f0ca089d58f
202612	eb56ec440616fcad9d72ffef8c3092c2d93082181397c2c0fe516ef3b32339fc
202612	16ba10e985bf5aa566964722808119fdbcbf0dd12675c2a1bcbf83ee75e54a46
202612	0b931afbac2a7145f7e74e7bfba306da065f92bae91660652a69f46950625ee8
202612	f4471c9d4108c96f4db7bdeb68b27bc2f30293d027a7ffbbb9206a86461b9ef7
202612	efeac81ddc7f3b2b7cf4a7baca33b8f3f0f38da3abda076fed36bd6ad6f2c917
202612	34bf07dc525d8e416cc82e85809a884f87b819693a720aaf6ee1cbaba6eb0e1f
202612	69912107b38ca3870c0f15eb81595286a3d0e8d5ce54b0c5a9eb92d9b378a9f8
202612	5c5a4a93bc1a20c77c872aec71af8ac11c563d5809a3addf8a6766b5f97b6bdd
202612	6e6e4404bd830e8dc39a90287163c1f594abe1933aef3bb059921667bd8d4dec
202612	eeb76421e3690ec2e48ffc6817ef65a32079f5a30e81992a8df74cb8c708f17b
202612	a14378375cc95a8293e3659493b26f5008818662ecdec7302e4e4d74a0455621
202612	d9487bd9c5f665b1e9584382b9531c8680aeb059103193a94f0dfc2908230bc3
202612	e11f86fcf7efbbfe6218567e269f86f7aa84e21e7442ef1d1198743430a53267
202612	fdf42f2078d8fd1127905cd94ad034b4407383f54301838da88fd7b198dcb59d
202612	16bf4002e5a5c1d1d21cbb3ec879454108b2710030b898d9f139e09a24785363
202612	d4a09ea799b980f7464f6f13ed095b08e9aecaf471085fc2157510ceb9863522
202612	365751dc015a7303d7c5af762793a62f6eb0e373337aff03347b552e8f97ee66

202612	6e04157e5953d6502b5244481a039cc0785018c7f296306bc64aa778ffa98d77
202612	fd1d1f7ea3c395e106f31e409044f731d769bc0d9ae3dca2600ab62c261b5e7b
202612	3d50102352822a7959a6461761482e0789a97675dad23b01ee2612eb4ca47767
202612	a022a5867af095300286bbb3e9c01f8e7a286be7dcdf2ffecf87125c042e8757
202612	235b50431a0a0c23a054137f364a4de18ce701677abeb0033e785d9ea73d7e6c
202612	48e65dd5117e9face756201429c08700dd0e77a63dfbd4f7c42bea07671f2665
202612	0d4d48195a8359b3de164093d0db2df51a65b379aba2cdf170e5a05e6cade3d1
202612	00dbc84e96d00a547132d6268a71f15f0b387a8553ca3cb1e7bc60b33fee1285
202612	d2959930d9a44f955455f0400cecd809fb99fb9884d0103c1918f2ac9b288021
202612	68684c5971ead0aed7220d0e7bbeb55159161de3f37a888a9bbd27c00764159e
202612	ec94570ca062599746c028b7a3bebbf722de2c5933370f99da0e59934bbef6c8
202612	5a11fa0f01ab37a04b91ab3d8e7f05fac7a894ee33296a5ee2b5f74a2502a39a
202612	4a403e1d2b28f9bd2204a24cd0a12ed99d3e171edd89afe54c2ab1a4bd9ec00d
202612	1f73d7ac3e617dbc8135bb610139a2bd53f0b3e4ab722c93ec13e6b5274c089c
202612	2366dfa041e9ce0be812e1c84b17bc613f4d6a89b242990826d30b7b8012d10e
202612	c29f627877f11cab3825881ccf74bebdc49a23ebf6759322660332ac8e3b8a29
202612	268af973df48c1f5c80a9b95c241a6ed27779dd58b0c4e9b8cd50de7ae5d161d
202612	c35e23f40c3f0f424daa94df58788328192a6ad75f8c7d0d4d6388cf560acb17
202612	e4b5832eb35692f132f82ee408ea14f4475ef4d703e9b670aadd45e5681f3328
202612	d9a8313eecfe692b3e935a3b1432d69757a0c8f43783d598fc772d7538d614ff
202612	e041cd6b7f232257001a391ee342d5bed8d2e641e284739d98781527c507eb34
202612	faf1b465426f987f000e75ef43892f31e024e21145c442e40586776bc52980b4
202612	0b0e7eb4f3a9b04b04d34cee48dd91aaef830e90a041869d4526041ad3f35d20
202612	f8f1e24aca97db18f0230b92bc581ac454d4c1e2956f27f7875ec40b0b797fbd
202612	73583e678a352aa965d5978ca0f5385dbf83255bc52401c1859fed2295b8c2a2
202612	b2e48c210596fa90ec1bd1e235cf84edcc90b29b6b6ae3834649fc8701a72e18
202612	29b6b5044a181bf0d645087fea19b5e2f7337d7a1dfb3fd5e2db332ed03f023b
202612	fb9e2263981448f2595575724c9e76356c7e27907ab35d5e69733e45ab1cb4ae
202612	dbd132a9d082d539d39a71cac2903a3ec5c0ba1fe65f7b26309e7aca3f63a58e
202612	b82db1fa094fef7cd453576998f7d39edce77ea31ad3ba846a30a1244d67e26e
202612	697c3da49f2b79ca6ffdd7a349af87331bc80ba0ab1a5e271c7a7aad77132e6c
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202612	0d06228c9cd7fc0d51b685f3ac880220fbcb6f20763b206beed5c570be319363
202612	13516d0d901e6098a302599c60bbaca7d494c9deb90f1c102a3c8ef0787e6630
202612	74d740655a45c14d535564541f611741dd24ba9186d780dd5488728f382b2423
202612	c83f0868bc451f1dbc2237ca216fd7621bd83dc60fac80fc485931654f03b154
685498	c34a3b726bed1c13cd66accb184d4a0f3f51238b2d2c1733dd99e9f5d74ae7d1
761389	01b257e003e8686d3b153331480a558f19eb323379e7eb6484efb9c089b4b9e8
770439	ee55915c178b9961c89d81f0059a9a3b54026e2be069d0d2e6dae12119bc0f69
775584	3a64c998b7abd2144d2bfde04fdeb631d0034db04ea30bf5b4400425d02d8742

782657	c83a2107e32b366704b9b747de2dfb1e008bf5cfcb0668f60132d5e2f8843848
844742	2c81d050f135e387d5d5f72fac9da88960926dc8af5b5fd7be92a48c57b27d6a
894416	4d282799872b46712f6cc6387d8286a76174cc3f195b645408a5dd7a0f9530d4
914263	5c58a204bf8b559118cefc4d65ede74fc45b009ae255fad29cd92aa65670e059
923755	8e5dac538c0efb357828a6a739605e8da4499a734a3ade177ba306d11f2604d6
950311	b1681099ffb5157d6f7057daf9f6f6090463d6e33716430a6141a0a0456de851
954707	a1e7aac4f34901c9394048eec9621e805b0d16b9d817255fe5a11863ac99d89d
954851	c1912d0d3dbdf7132a36f0abb4883b7873f9404a880efd24a374179b8a216981
960504	2ac32c2a3cdecec9d9e46ef3a606f334a607b3e41847f4805df7d6f2f2ef0fc1
960583	712037dc6cca4bef5eabfc4ab53a0316cd5066155030146a3d0f26f43889fa83
960591	36600922fa908d1cc32d5912e89a676932b93a944ebb086e0e785eba04d4e9aa
964973	2ba329cf242ce689ee0969a05fe859c0ed3365686b0f7619a3bda20edd3bf3b9
979604	c6e7cfc1b2d8d95bfc6a88b941071bd7f2cd02be51d039951410e194ec7dc796
982072	30bbc9f4bf951f011f823d048a91d29be544f636aa00a6b78d72a660e6efc0cd
990283	695d3fa1b7411f877f8ac8574a160c5c24da1f0f4505fc39e936c798d020098b
995534	32d8d17f8ecc6c8f7556039793c50f7def0f5eb9573321f31d482d6ca00df13d
1006680	785d320a94a1a515300a820e73b5ca713358aa2a3f45ccd3a6aed584669cb864
1006680	30f97c54470b57dfe8aa94a4097d645fbb864cb50ea756b436bb5c0bc69c8f45
1164055	f6b1637c4d4c95db5f16a872dc678849346ca7324aef2711406fff25ad213108

5.1 Source Code for update_adb.py

```
'''
Script to update ArangoDB graph to schema V8.
1st round of de-anonymization- get % of 0-mixin inputs; mark true
inputs.
To be run from directory ~/data
'''
import subprocess
import os
import json
import csv
from arango import ArangoClient

with open("/home/VMadmin/data/progress.txt", "r") as text_file:
    start = int(text_file.readline())+1
text_file.close()


#Connect to db and load graph
client = ArangoClient(hosts='http://localhost:8529')
db = client.db('monero', username='root', password=[redacted])
monero = db.graph('monero')

for i in range(start, 1980622):
    try:
        monero.insert_vertex('blocks', {'_key': str(i),
'blk_height':i})
    except:
        pass

    with open("/home/VMadmin/data/blocks/{}.json".format(i)) as
json_file:
        dict = json.load(json_file)
    json_file.close()

    data = dict["data"]
    txs = data['txs']

    for tx in txs:
        hash = str(tx["tx_hash"])
        if tx["coinbase"] == True:
            try:
                monero.link('has_cb_tx', 'blocks/{}'.format(str(i)),
'cb_txs/{}'.format(hash))
            except:
                pass
        else:
            try:
                monero.link('has_tx', 'blocks/{}'.format(str(i)),
'txs/{}'.format(hash))
            except:
                pass

            ec = monero.edge_collection("input_of")
            ec1 = monero.edge_collection("ring_member_of")
            vc = monero.vertex_collection("ring_members")
            vc1 = monero.vertex_collection("inputs")
            vc2 = monero.vertex_collection("outputs")

            with open("/home/VMadmin/data/inputs_count.txt", "r") as
text_file:
                inputs_count = int(text_file.readline())
            text_file.close()

            with open("/home/VMadmin/data/deanon_inputs.txt", "r")
as text_file:
                deanon_inputs = int(text_file.readline())
            text_file.close()

            inputs = ec.edges("txs/{}".format(hash),"in")['edges']
            inputs = [str(input['_from']) for input in inputs]

            for input in inputs:

                inputs_count+=1

                ring_members = ec1.edges(input, "in")['edges']
                ring_members = [str(ring_member['_from']) for
ring_member in ring_members]
```

```
                mixin_count = len(ring_members)

                if mixin_count == 1:

                    deanon_inputs+=1
                    rm = vc.get(ring_members[0])
                    rm['true_input'] = True
                    vc.update(rm)

                    ip = vc1.get(input)
                    ip['deanon'] = True
                    vc1.update(ip)

                    pk = rm['pub_key']
                    op = vc2.get(pk)
                    op['spent'] = True
                    vc2.update(op)

            with open("/home/VMadmin/data/inputs_count.txt", "w") as
text_file:
                text_file.write("{}".format(inputs_count))
            text_file.close()

            with open("/home/VMadmin/data/deanon_inputs.txt", "w")
as text_file:
                text_file.write("{}".format(deanon_inputs))
            text_file.close()

    with open("/home/VMadmin/data/progress.txt", "w") as text_file:
        text_file.write("{}".format(i))
    text_file.close()
```

5.2 Source Code for update_adb_cleanup.py

```
'''
Script to update ArangoDB graph to schema V8.
1st round of de-anonymization- get % of 0-mixin inputs; mark true
inputs.
To be run from directory ~/data
'''
import subprocess
import os
import json
import csv
from arango import ArangoClient

with open("/home/VMadmin/data/progress.txt", "r") as text_file:
    start = int(text_file.readline())+1
text_file.close()


#Connect to db and load graph
```

```
client = ArangoClient(hosts='http://localhost:8529')
db = client.db('monero', username='root', password=[redacted])
monero = db.graph('monero')

for i in range(start, start+1):
    try:
        monero.insert_vertex('blocks', {'_key': str(i),
'blk_height':i})
    except:
        pass

    with open("/home/VMadmin/data/blocks/{}.json".format(i)) as
json_file:
        dict = json.load(json_file)
    json_file.close()

    data = dict["data"]
    txs = data['txs']

    for tx in txs:
        hash = str(tx["tx_hash"])
        if tx["coinbase"] == True:
            try:
                monero.link('has_cb_tx', 'blocks/{}'.format(str(i)),
'cb_txs/{}'.format(hash))
            except:
                pass
        else:
            try:
                monero.link('has_tx', 'blocks/{}'.format(str(i)),
'txs/{}'.format(hash))
            except:
                pass

            ec = monero.edge_collection("input_of")
            ec1 = monero.edge_collection("ring_member_of")
            vc = monero.vertex_collection("ring_members")
            vc1 = monero.vertex_collection("inputs")
            vc2 = monero.vertex_collection("outputs")

            with open("/home/VMadmin/data/inputs_count.txt", "r") as
text_file:
                inputs_count = int(text_file.readline())
            text_file.close()

            with open("/home/VMadmin/data/deanon_inputs.txt", "r")
as text_file:
                deanon_inputs = int(text_file.readline())
            text_file.close()

            inputs = ec.edges("txs/{}".format(hash),"in")['edges']
            inputs = [str(input['_from']) for input in inputs]

            for input in inputs:
                inputs_count+=1

                ring_members = ec1.edges(input, "in")['edges']
                ring_members = [str(ring_member['_from']) for
ring_member in ring_members]

                mixin_count = len(ring_members)

                if mixin_count == 1:

                    deanon_inputs+=1
                    rm = vc.get(ring_members[0])
                    rm['true_input'] = True
                    vc.update(rm)

                    ip = vc1.get(input)
                    ip['deanon'] = True
                    vc1.update(ip)

                    pk = rm['pub_key']
                    op = vc2.get(pk)
                    op['spent'] = True
                    vc2.update(op)

            with open("/home/VMadmin/data/inputs_count.txt", "w") as
text_file:
                text_file.write("{}".format(inputs_count))
            text_file.close()

            with open("/home/VMadmin/data/deanon_inputs.txt", "w")
as text_file:
                text_file.write("{}".format(deanon_inputs))
            text_file.close()


    with open("/home/VMadmin/data/progress.txt", "w") as text_file:
        text_file.write("{}".format(i))
    text_file.close()
```

5.3 Source Code for check_status_restart.py

```
import requests
import os
import subprocess
import locale
import datetime

cmd1 = ['pgrep', '-f', 'anon_analysis.py']

#Function to check if process is running
def check_proc(cmd):
    proc = subprocess.Popen(cmd, stdout=subprocess.PIPE,
stderr=subprocess.PIPE)
    o, e = proc.communicate()
    return o.decode('ascii')!=''

if not check_proc(cmd1):
    with open('/home/VMadmin/data/progress.txt') as file:
        n = int(file.readline())
    file.close()
    if n!=1980622:
        os.system('python
/home/VMadmin/data/anon_analysis_cleanup.py')
        os.system('python /home/VMadmin/data/anon_analysis.py &>
anon_analysis.out &')

        with open("/home/VMadmin/data/logs/restart_log2", 'a') as
file:
            file.write("Restart at
{}\n".format(datetime.datetime.now()))
        file.close()
    else:
        pass
```

5.4 Source Code for bot.py

```
import requests
import os
import subprocess
import locale
import datetime

locale.setlocale( locale.LC_ALL, '' )

def telegram_bot_sendtext(message):

    bot_token = [redacted]
    chatID = [redacted]
    send_text = 'https://api.telegram.org/bot' + bot_token +
'/sendMessage?chat_id=' + chatID + '&text=' + message
    requests.get(send_text)

    return

cmd1 = ['pgrep', '-f', 'anon_analysis.py']
cmd2 = ['df', '-h']
cmd3 = ['df', '-i']

#Function to check if process is running
def check_proc(cmd):
    proc = subprocess.Popen(cmd, stdout=subprocess.PIPE,
stderr=subprocess.PIPE)
    o, e = proc.communicate()
    return o.decode('ascii')!=''
```

```
def check_mem(cmd):
    proc = subprocess.Popen(cmd, stdout=subprocess.PIPE,
stderr=subprocess.PIPE)
    o, e = proc.communicate()
    return o.decode().split()[23]

def get_status():

    with open("data/progress.txt", "r") as text_file:
        count = int(text_file.readline())
    text_file.close()
    count_str = locale.format("%d", count, grouping=True)
    dumped_percent = float(count)/2112472*100

    script_status = ('Running' if check_proc(cmd1) else 'Down')
    mem_usage = check_mem(cmd2)
    inode_usage = check_mem(cmd3)

    with open("data/inputs_count.txt", "r") as text_file:
        inputs_count = int(text_file.readline())
    text_file.close()

    with open("data/deanon_inputs.txt", "r") as text_file:
        deanon_inputs = int(text_file.readline())
    text_file.close()

    deanon_ratio = float(deanon_inputs)/float(inputs_count)

    if script_status == 'Down':
        with open("data/anon_analysis.out",'r') as file:
            try:
              error_msg = file.readlines()[-1]
            except: error_msg = "No error msg"
        file.close()
        timestamp =
datetime.datetime.fromtimestamp(os.path.getmtime("data/anon_analysis
.out"))
    else:
        error_msg = 'NIL'
        timestamp = 'NIL'

    return "================================\nAnonymity analysis
untill block {} ({}%).\n\nAnonymity analysis script status:
{}.\n\nDeanon ratio: {}\n\nError message: {}\n\nTimestamp:
{}\n\nMemory usage:
{}\n================================".format(count_str,
dumped_percent, script_status, deanon_ratio, error_msg, timestamp,
mem_usage)

telegram_bot_sendtext(get_status())
```

6.1 Source Code for anon_analysis.py

```
'''
Subsequent rounds of de-anonymization
'''
import subprocess
import os
import json
import csv
from arango import ArangoClient

with open("/home/VMadmin/data/progress.txt", "r") as text_file:
    start = int(text_file.readline())+1
text_file.close()


#Connect to db and load graph
client = ArangoClient(hosts='http://localhost:8529')
db = client.db('monero', username='root', password=[redacted])
monero = db.graph('monero')

for i in range(start, 1980622):

    with open("/home/VMadmin/data/blocks/{}.json".format(i)) as
json_file:
        dict = json.load(json_file)
    json_file.close()

    data = dict["data"]
    txs = data['txs']

    for tx in txs:
        hash = str(tx["tx_hash"])
        if tx["coinbase"] == True:
                pass
        else:

            ec = monero.edge_collection("input_of")
            ec1 = monero.edge_collection("ring_member_of")

            vc = monero.vertex_collection("ring_members")
            vc1 = monero.vertex_collection("inputs")
            vc2 = monero.vertex_collection("outputs")

            with open("/home/VMadmin/data/inputs_count.txt", "r") as
text_file:
                inputs_count = int(text_file.readline())
            text_file.close()

            with open("/home/VMadmin/data/deanon_inputs.txt", "r")
as text_file:
                deanon_inputs = int(text_file.readline())
            text_file.close()
            inputs = ec.edges("txs/{}".format(hash),"in")['edges']
            inputs = [str(input['_from']) for input in inputs]

            for input in inputs:

                input_json = vc1.get(input)
                inputs_count+=1

                if 'deanon' in input_json.keys() and 
input_json['deanon']==True:
                    deanon_inputs+=1
                else:

                    ring_members = ec1.edges(input, "in")['edges']
                    ring_members = [str(ring_member['_from']) for 
ring_member in ring_members]
                    unspent = []

                    for ring_member in ring_members:
                        pk_str = ring_member.split(',')[1]
                        pk_json = vc2.get(pk_str)
                        if not 'spent' in pk_json.keys() or 
pk_json['spent'] ==False:
                            unspent.append(ring_member)

                    unspent_count = len(unspent)

                    if unspent_count == 1:

                        deanon_inputs+=1
                        rm = vc.get(ring_members[0])
                        rm['true_input'] = True
                        vc.update(rm)

                        ip = vc1.get(input)
                        ip['deanon'] = True
                        vc1.update(ip)

                        pk = rm['pub_key']
                        op = vc2.get(pk)
                        op['spent'] = True
                        vc2.update(op)

            with open("/home/VMadmin/data/inputs_count.txt", "w") as 
text_file:
                text_file.write("{}".format(inputs_count))
            text_file.close()

            with open("/home/VMadmin/data/deanon_inputs.txt", "w") 
as text_file:
                text_file.write("{}".format(deanon_inputs))
            text_file.close()

    if i%1000==0 or i==1980622:
        with open("/home/VMadmin/data/inputs_count.txt", "r") as
text_file:
            inputs_count = int(text_file.readline())
        text_file.close()

        with open("/home/VMadmin/data/deanon_inputs.txt", "r") as
text_file:
            deanon_inputs = int(text_file.readline())
        text_file.close()

        deanon_ratio = float(deanon_inputs)/float(inputs_count)

        with open('/home/VMadmin/data/round2.csv', 'a') as file:
            csv_writer = csv.writer(file, delimiter=',',
quotechar='"', quoting=csv.QUOTE_MINIMAL)
            csv_writer.writerow([i, deanon_ratio])
        file.close()

    with open("/home/VMadmin/data/progress.txt", "w") as text_file:
        text_file.write("{}".format(i))
    text_file.close()
```

6.2 Source Code for anon_analysis_cleanup.py

```
'''
Subsequent rounds of de-anonymization
'''
import subprocess
import os
import json
import csv
from arango import ArangoClient

with open("/home/VMadmin/data/progress.txt", "r") as text_file:
    start = int(text_file.readline())+1
text_file.close()


#Connect to db and load graph
client = ArangoClient(hosts='http://localhost:8529')
db = client.db('monero', username='root', password=[redacted])
monero = db.graph('monero')

for i in range(start, start+1):

    with open("/home/VMadmin/data/blocks/{}.json".format(i)) as
json_file:
        dict = json.load(json_file)
    json_file.close()

    data = dict["data"]
    txs = data['txs']

    for tx in txs:
        hash = str(tx["tx_hash"])
        if tx["coinbase"] == True:
                pass
        else:

            ec = monero.edge_collection("input_of")
            ec1 = monero.edge_collection("ring_member_of")

            vc = monero.vertex_collection("ring_members")
            vc1 = monero.vertex_collection("inputs")
            vc2 = monero.vertex_collection("outputs")

            with open("/home/VMadmin/data/inputs_count.txt", "r") as
text_file:
                inputs_count = int(text_file.readline())
            text_file.close()

            with open("/home/VMadmin/data/deanon_inputs.txt", "r")
as text_file:
                deanon_inputs = int(text_file.readline())
            text_file.close()

            inputs = ec.edges("txs/{}".format(hash),"in")['edges']
            inputs = [str(input['_from']) for input in inputs]

            for input in inputs:

                input_json = vc1.get(input)
                inputs_count+=1

                if 'deanon' in input_json.keys() and
input_json['deanon']==True:
                    deanon_inputs+=1
                else:

                    ring_members = ec1.edges(input, "in")['edges']
                    ring_members = [str(ring_member['_from']) for
ring_member in ring_members]
                    unspent = []

                    for ring_member in ring_members:
                        pk_str = ring_member.split(',')[1]
                        pk_json = vc2.get(pk_str)
                        if not 'spent' in pk_json.keys() or
pk_json['spent'] ==False:
                            unspent.append(ring_member)

                    unspent_count = len(unspent)

                    if unspent_count == 1:

                        deanon_inputs+=1
                        rm = vc.get(ring_members[0])
                        rm['true_input'] = True
                        vc.update(rm)

                        ip = vc1.get(input)
                        ip['deanon'] = True
                        vc1.update(ip)

                        pk = rm['pub_key']
                        op = vc2.get(pk)
                        op['spent'] = True
                        vc2.update(op)

            with open("/home/VMadmin/data/inputs_count.txt", "w") as
text_file:
                text_file.write("{}".format(inputs_count))
            text_file.close()

            with open("/home/VMadmin/data/deanon_inputs.txt", "w")
as text_file:
                text_file.write("{}".format(deanon_inputs))
            text_file.close()

    if i%1000==0 or i==19806220:
        with open("/home/VMadmin/data/inputs_count.txt", "r") as
text_file:
            inputs_count = int(text_file.readline())
        text_file.close()

        with open("/home/VMadmin/data/deanon_inputs.txt", "r") as
text_file:
            deanon_inputs = int(text_file.readline())
        text_file.close()

        deanon_ratio = float(deanon_inputs)/float(inputs_count)

        with open('/home/VMadmin/data/round2.csv', 'a') as file:
            csv_writer = csv.writer(file, delimiter=',',
quotechar='"', quoting=csv.QUOTE_MINIMAL)
            csv_writer.writerow([i, deanon_ratio])
        file.close()

    with open("/home/VMadmin/data/progress.txt", "w") as text_file:
        text_file.write("{}".format(i))
    text_file.close()
```