A general framework for Bitcoin analytics

Massimo Bartoletti¹, Andrea Bracciali², Stefano Lande¹, and Livio Pompianu¹

1 University of Cagliari, Italy
{bart,lande,livio.pompianu}@unica.it
2 University of Stirling, UK
abb@cs.stir.ac.uk

Abstract. Modern cryptocurrencies exploit decentralised ledgers — the so-called blockchains — to record a public and unalterable history of transactions. These ledgers represent a rich, and increasingly growing, source of information, in part of difficult interpretation and undisclosed meaning. Many analytics, mostly based on ad-hoc engineered solutions, are being developed to discover relevant knowledge from these data. We introduce a framework for the development of custom analytics on Bitcoin — the most preeminent cryptocurrency — which also allows to integrate data within the blockchain with data retrieved form external sources. We illustrate the flexibility and effectiveness of our analytics framework by means of paradigmatic use cases.

1 Introduction

The last few years have witnessed a steady growth in interest on blockchains, driven by the success of Bitcoin — the first and most widespread instance of these technologies³. This has fostered the research on several aspects of blockchain technologies, ranging from their theoretical foundations — both cryptographic [4,9] and economic [16,29] — to their security and privacy [1,5,10,12,19].

Among the many research topics emerging from blockchain technologies, one that has received major interest is the empirical analysis of the data stored in blockchains, mostly in that of Bitcoin. Indeed, the Bitcoin blockchain currently contains more than 120GB of data, that only in part are related to currency transfers. Developing analytics on these data allows to obtain several insights on Bitcoin, as well as economic indicators that help to predict market trends. Metadata embedded in transactions offer other opportunities for analysis, as they are often exploited by "smart contracts" which extend the range of applications of Bitcoin beyond simple transfers of currency.

Many relevant works on the analysis of the Bitcoin blockchain have been published over the last few years. Several papers address anonymity issues, either by developing techniques to de-anonymise users [18,19,25,27], by clustering transactions [11,30], or by evaluating the protection offered by anonymising services [22].

³ Considering only the last year, the market capitalization of Bitcoin grew by 400%, passing from ~ 10 to ~ 40 USD billions. Source: http://coinmarketcap.com.

Other analyses address criminal uses of Bitcoin, e.g. by studying denial-of-service attacks [2,32], ransomware [14], and various financial frauds [20,23,31]. Many papers and websites perform statistics on Bitcoin, measuring e.g. economic indicators [15,28], transaction fees [21], the usage of metadata [3], etc.

A common trait of these works is that they usually create *views* of the blockchain which contain all the data needed for the goals of the analysis. In many cases, this requires to combine data *within* the Bitcoin blockchain with data from the *outside*. These data are retrieved from a variety of sources, e.g. blockchain explorers, wikis, discussion forums, and dedicated sites (see Table 1 for a brief survey). Despite many of the operations needed to construct these views are standard (e.g., scanning all the blocks and the transactions in the blockchain, converting the value of a transaction from bitcoins to *USD*, *etc.*), researchers usually have to implement ad-hoc tools to develop their analyses. As far as we know, no general-purpose analytics tools are currently available which allow to combine data in the Bitcoin blockchain with data from other sources⁴.

Several of the above-mentioned works acquire blockchain raw data by using Bitcoin Core⁵ (the reference Bitcoin client), and encapsulate them into Java objects with the BitcoinJ APIs⁶ before processing. However, neither Bitcoin Core nor BitcoinJ are natural tools to analyse the blockchain. Actually, the intended usage of BitcoinJ is to support the development of wallets, and so it only gives direct access to blocks and transactions from their *hash*, but it does not allow to perform forward scans of the blockchain. On the other hand, Bitcoin Core would provide the means to scan the blockchain, but this requires expertise on its low-level RPC interface, and even doing so would result in raw pieces of JSON data, without any abstraction layer. A plethora of tools have been developed to retrieve data external to the Bitcoin blockchain, e.g. by exploiting the APIs of blockchain explorers, or by parsing their HTML pages. However, these tools have not been integrated into general-purpose blockchain parsers, with the consequence that the same features have been implemented again and again as new Bitcoin analytics have been developed, as witnessed by Table 1.

Summing up, exploiting the available tools to access the Bitcoin blockchain and the relevant external data requires a significant programming effort. We believe that a general-purpose tool which provides a suitable abstraction layer for processing the blockchain (and for combining it with external data) would help to reduce this effort.

⁴ A couple of customizable blockchain parsers are discussed in Section 5, but they offer limited built-in support for combining blockchain data with external data.

⁵ https://bitcoin.org/en/bitcoin-core. Another popular tool for accessing the blockchain was Bitcointools (https://github.com/gavinandresen/bitcointools), but is seems no longer available.

⁶ https://bitcoinj.github.io

⁷ No longer online.

⁸ https://en.bitcoin.it/wiki/Category:Pool_Operators

⁹ https://en.bitcoin.it/wiki/Trade

¹⁰ https://en.bitcoin.it/w/index.php?title=OP_RETURN&oldid=61694

Analysis Subject Gathered information		Sources		
	Transactions graph	bitcoind [18,19,22,27,30], forum.bitcoin.org ⁷ [27]		
	OP_RETURN metadata	bitcoind [22]		
Anonymity	IP addresses	bitcoin faucet [27], blockchain.info [22]		
	address tags	blockchain.info [18,19,30], bitcointalk.org [18,19,30]		
	address tags	bitcoin-otc.com [30], bitfunder.org [30]		
	Transactions graph	bitcoind [15], blockexplorer.com [28]		
Market analytics	IP addresses	blockchain.info, ipinfo.io [15]		
Market analytics	address tags	blockchain.info [15]		
	trade data	bitcoincharts.com [15]		
	Transactions graph	bitcoind [2,31,32], blockchain.info [14,20]		
	mempool	bitcoind [2]		
	unconfirmed transactions	bitcoind [2]		
	no longer online services	archive.org [31,32]		
Cyber-crime	list of DDoS attacks	bitcointalk.org [32]		
Cyber-erime	mining pools	blockchain.info, bitcoin wiki ⁸ [32]		
	trades on assets and services			
	list of fraudulent services	bitcointalk.org [14,31], badbitcoin.org [31], cryptohyips.com [31]		
	address tags	blockchain.info [31]		
	exchange rate	bitcoincharts.com [14,31], quandl.com [14]		
Metadata	OP_RETURN transactions	bitcoind [3]		
Wicoadava	OP_RETURN identifiers	kaiko.com, opreturn.org, bitcoin wiki ¹⁰ [3]		
	Transactions graph	bitcoind [21]		
Transaction fees	exchange rate	coindesk.com [21]		
	mining pools	blockchain.info [21]		

Table 1. Information gathered by various blockchain analyses.

Contributions. We propose a methodology to create custom analytics for the Bitcoin blockchain. Our methodology consists in two steps: (i) we construct a view of the blockchain as a collection in a NoSQL database; (ii) then, we analyse the collection by using the query language of the database. To support the first step we develop a new Scala library, which allows both to use data contained in the blockchain, and to embed arbitrary external data (e.g., exchange rates, tags, etc.). These views are stored as collections of MongoDB, a NoSQL database which is widely used for the storage and analysis of big data [7].

In Section 3 we illustrate our methodology through a series of real-world use cases. We perform experiments (using consumer hardware) which analyse various aspects of Bitcoin, like e.g. the embedding of metadata on the blockchain, the impact of exchange rates, the evolution of transactions fees, and the usage of address tags. We make available online 11 the source code of our library and use cases, including the Scala scripts used to construct views of the blockchain, the queries in MongoDB, and the results of our experiments. In Section 4 we discuss some implementation details of our library, and we evaluate its effectiveness.

2 Background on Bitcoin

Bitcoin is a decentralized cryptocurrency [24,4], that has recently reached a market capitalization of 40 *USD* billions¹². Bitcoin can be seen as a huge ledger of *transactions*, which represent transfers of bitcoins (*BTC*). This ledger —

¹¹ https://github.com/bitbart/bitcoin-analytics-api

Source: crypto-currency market capitalizations http://coinmarketcap.com

usually called *blockchain* — is maintained by a peer-to-peer network of nodes, and a consensus protocol ensures that it can only be updated consistently (e.g., one cannot tamper with or remove an already-published transaction).

To give the intuition on how Bitcoin works, we consider two transactions t_0 and t_1 , which we graphically represent as follows:

t_0			
in: ···			
in-script: · · ·			
out-script (x) : F_0			
value: v_0			

t_1
in: $hash(t_0)$
in-script: σ_1
$out-script(\cdots):\cdots$
value: v_1

The transaction t_0 contains v_0 bitcoins, which can be redeemed by putting on the blockchain a transaction (e.g., t_1), whose in field is the cryptographic hash of the whole t_0 . To redeem t_0 , the in-script of t_1 must contain a value σ_1 which makes the out-script of t_0 evaluate to true. In its general form, the out-script is a program in a (not Turing-complete) scripting language, featuring a limited set of logic, arithmetic, and cryptographic operators. Typically, the out-script is just a signature verification.

Now, assume that the blockchain contains t_0 , not yet redeemed, when someone tries to append t_1 . To validate this operation, the nodes of the Bitcoin network check that $v_1 \leq v_0$, and then they evaluate the out-script F_0 , by instantiating its formal parameter x to the value σ_1 . If, after the substitution, F_0 evaluates to true, then t_1 redeems t_0 , meaning that the value of t_0 is transferred to the new transaction t_1 , and t_0 becomes no longer redeemable. A new transaction can now redeem t_1 by satisfying its out-script.

Bitcoin transactions may be more general than the ones illustrated by the previous example, in that there can be multiple inputs and outputs. Each output has an associated out-script and value, and can be redeemed independently from others. Consequently, in fields must specify which output they are redeeming. Similarly, a transaction with multiple inputs associates an in-script to each of them. To be valid, the sum of the values of all the inputs must be greater or equal to the sum of the values of all outputs.

The Bitcoin network is populated by a large set nodes, called *miners*, which collect transactions from clients, and are in charge of appending the valid ones to the blockchain. To this purpose, each miner keeps a local copy of the blockchain, and a set of unconfirmed transactions received by clients, which it groups into *blocks*. The goal of miners is to add these blocks to the blockchain, in order to get a revenue. Appending a new block B_i to the blockchain requires miners to solve a cryptographic puzzle, which involves the hash $h(B_{i-1})$ of block B_{i-1} , a sequence of unconfirmed transactions $\langle T_i \rangle_i$, and some salt R. The goal of miners is to win the "lottery" for publishing the next block, i.e. to solve the cryptopuzzle before the others; when this happens, the miner receives a reward in newly generated bitcoins, and a *fee* for each transaction included in the mined block (the fee of a transaction is the difference between the values of its inputs and outputs). If a miner claims the solution of the current cryptopuzzle, the others discard their attempts, update their local copies of the blockchain with the new block B_i ,

and start mining a new block on top of B_i . In addition, miners are asked to verify the validity of the transactions in B_i by executing the associated scripts. Although verifying transactions is not mandatory, miners are incentivized to do that, because if in any moment a transaction is found invalid, they lose the fee earned when the transaction was published in the blockchain.

3 Analysing the Bitcoin blockchain

We illustrate our methodology through some case studies, which develop custom analytics for the Bitcoin blockchain. All the case studies exploit our Bitcoin Analytics library for processing the Bitcoin blockchain. The APIs provide the following Scala classes to represent the primitive entities of the blockchain:

- BlockchainLib: main library class. It provides the getBitcoinBlockchain method, which allows to iterate over BitcoinBlock objects. In the constructor we can choose between a standard scan of the blockchain, or a "deep" one. In the deep scan we also associate, to each transaction input, the value of the redeemed output¹³.
- BitcoinBlock: contains a list of transactions, and some block-related attributes (e.g., block hash and creation time).
- BitcoinTransaction: contains a list of inputs and outputs and various related attributes (e.g., transaction hash and size).
- BitcoinOutput: transaction outputs. Each output contains a script (the so-called "scriptPubKey"), and the value of the output in BTC.
- BitcoinInput: transaction inputs. Each input contains a script (the so-called "scriptSig"), and the value of the input in BTC (only for deep scans; the value is set to 0 in a standard scan).
- BitcoinScript: the script of an input or an output.

The library constructs the above-mentioned Scala objects by scanning a local copy of the blockchain. It uses Bitcoin Core to have a direct access to the blocks, exploiting the provided indices, and BitcoinJ as a basis to represent the various kinds of objects¹⁴. The APIs allow to export the constructed objects as MongoDB documents. MongoDB¹⁵ is a non-relational database management systems. In MongoDB, a database is a set of *collections*, each of them containing documents. Documents are lists of pairs (k,v), where k is a string (called field name), and v is either a value or a MongoDB document.

¹³ Evaluating input values is a resource-consuming algorithm, since it requires to retrieve data from blocks which be far in the past from the currently scanned one. Hence, a deep inspection is only needed when the target analysis depends on these values (e.g. balances, transaction fees).

¹⁴ As mentioned before, BitcoinJ does not provide methods to navigate the blockchain, but only to recover a block by its hash, using Bitcoin Core.

 $^{^{15}}$ https://www.mongodb.com

```
object MvBlockchain {
         def main(args: Array[String]): Unit = {
         val blockchain = BlockchainLib.getBitcoinBlockchain(
         new BitcoinSettings("user", "password",
val mongo = new MongoDatabase("myDatabase")
                                                                    "8332", MainNet))
         val myBlockchain = mongo.getCollection("myBlockchain")
         blockchain.foreach(block => {
10
              block.bitcoinTxs.foreach(tx => {
11
12
                    myBlockchain.append(List(
                         ("txHash", tx.hash),
("blockHash", block.hash),
13
14
                         ("date", block.date),
("inputs", tx.inputs),
("outputs", tx.outputs)
15
16
17
                    ))
19
              })
20
         1)
21
         }
   }
```

Fig. 1. A basic view of the blockchain.

In Sections 3.1 to 3.5 we develop a series of analytics on Bitcoin, showing the Scala code which builds the needed blockchain views¹⁶.

3.1 A basic view of the Bitcoin blockchain

Since all the analyses shown in Table 1 explore the transaction graph (e.g. they investigate output values, timestamps, metadata, etc.), our first case study focusses on a basic view of the Bitcoin blockchain containing no external data. The documents in the resulting collection represent transactions, and they include: (i) the transaction hash; (ii) the hash of the enclosing block; (iii) the date in which the block was appended to the blockchain; (iv) the list of transaction inputs and outputs.

We show in Figure 1 how to exploit our Bitcoin Analytics APIs to construct this collection. Lines 1-2 are standard Scala instructions to define the main function. The object blockchain constructed at line 4 is a handle to the Bitcoin blockchain. At line 5 we setup the connection to Bitcoin Core, by providing the needed parameters (user, password, and port), and by indicating that we want to use the main network (alternatively, the parameter TestNet allows to use the test network). At line 6 we setup the connection to MongoDB. Since lines 1-6 are similar for all our case studies, for the sake of brevity we will omit them in the subsequent listings. We declare the target collection myBlockchain at line 8.

At this point, we start navigating the blockchain to populate the collection. To do that we iterate over the blocks (line 10) (note that $b \Rightarrow \{...\}$ is an anonymous function, where b is a parameter, and $\{...\}$ is it's body), and for each block we iterate over its transactions (at line 11). For each transaction we

¹⁶ The full code of our case studies, including the MongoDB queries that fetch the analysis results, is available at https://github.com/bitbart/bitcoin-analytics-api

Fig. 2. A query to estimate the average number of inputs and outputs by date.

append a new document to myBlockchain (lines 13-17). This document is a set of fields of the form (k,v), where k is the field name, and v is the associated value. For instance, at line 13 we stipulate that the field txHash will contain the hash of the transaction, represented by tx.hash. This value is obtained by the API BitcoinTransaction.

Running this piece of code results in a collection, which we can process with the query language of MongoDB to obtain several standard statistics, like e.g. the number of daily transactions¹⁷, their average value¹⁸, the largest recent transactions¹⁹, etc.²⁰ Hereafter we consider another kind of analysis, i.e. the evolution over the years of the number of transaction inputs and outputs. To this purpose, we run the MongoDB query is shown in Figure 2. The query first groups the documents with the same date. Then, for each group, it computes the average number of inputs and outputs. Finally, the results are sorted in ascending order.

The results of the query are graphically rendered in Figure 3, which shows the average number of inputs/outputs by date. We see that, after an initial phase, the average number of inputs and outputs has stabilised between 2 and 3. This is mainly due to the fact that most transactions are published through standard wallets, which try to minimise the number of inputs; a typical transaction has two outputs, one to perform the payment and the other for the change. We also observe a few peaks in the number of inputs and outputs, which are probably related to experimentation of new services, like e.g. CoinJoin²¹.

3.2 Analysing OP_RETURN metadata

In this section we analyse the usage of the Bitcoin blockchain as a distributed storage. Actually, besides being used as a cryptocurrency, Bitcoin allows for appending a few bytes of metadata to transaction outputs. This is done preem-

¹⁷ https://blockchain.info/charts/n-transactions

¹⁸ https://bitinfocharts.com/comparison/bitcoin-transactionvalue.html

¹⁹ https://blockchain.info/largest-recent-transactions

Note that one could also perform these queries during the construction of the view. However, this would not be convenient in general, since — as we will see also in the following case studies — many relevant queries can be performed on the same view.

 $^{^{21}\ \}mathtt{https://en.bitcoin.it/wiki/CoinJoin}$

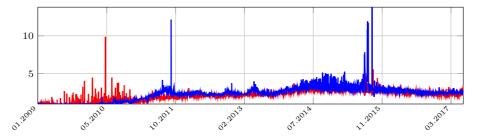


Fig. 3. Average number of inputs (red line) and outputs (blue line) by date.

```
val opReturnOutputs = mongo.getCollection("opReturnOutputs")
   blockchain.start(290000).foreach(block => {
        block.bitcoinTxs.foreach(tx =>
            tx.outputs.foreach(out => {
            if(out.isOpreturn()) {
               opReturnOutputs.append(List(
                 txHash", tx.hash)
               ("date", block.date),
               ("protocol", OpReturn.getApplication(out.outScript.toString)),
("metadata", out.getMetadata())
10
11
12
13
14
15
        })
   })
```

Fig. 4. A blockchain view exposing OP_RETURN metadata.

inently through the OP_RETURN operator of the Bitcoin scripting language²². Several protocols exploit this feature to implement blockchain-based applications, like e.g. digital assets and notarization services [3]. These protocols usually mark their transactions by pre-pending an identifier to each piece of metadata. Hence, a way to analyse the usage of metadata in Bitcoin is to count the transactions of each protocol.

To this purpose, we construct a view of the blockchain which exposes the protocol metadata. More specifically, we build a collection opReturnOutputs whose documents represent transaction outputs, and are composed of: (i) the hash of the transaction containing the output; (ii) the date in which the transaction has been appended to the blockchain; (iii) the name of the protocol that produced the transaction; (iv) the metadata contained in the OP_RETURN script.

Figure 4 shows the Scala code which constructs this collection. At line 3 we scan the blockchain, starting from block 290,000²³. We then iterate through transactions at line 4, and through their outputs at line 5. We append a new document to our collection (lines 7-11) whenever the output of the corresponding transaction is an OP_RETURN (line 6). The method OpReturn.getApplication

 $^{^{22}~{\}rm https://en.bitcoin.it/wiki/OP_RETURN}$

²³ We can discard the initial 290,000 blocks because OP_RETURN transactions were only relayed as standard transactions after the release 0.9.0 of Bitcoin Core.

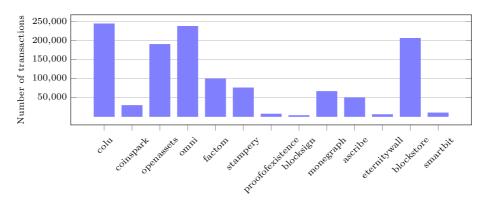


Fig. 5. Number of transactions per protocol (only protocols with > 1000 transactions).

of our APIs takes as input a piece of metadata, and returns the name of the associated protocol. This is inferred by the results of the analysis in [3].

Figure 5 shows the number of transactions associated with the most used protocols (only those with at least 1000 transactions). The protocol with the highest number of transactions is Colu²⁴, which is used to certify and transfer the ownership of physical assets. The second most used protocol is Omni²⁵, followed by Blockstore²⁶, a key-value store upon which other protocols are based.

3.3 Exchange rates

Several analyses in Table 1 use exchange rates for quantifying the economic impact of various phenomena (e.g. cyber-crime attacks, transaction fees, business activities). In this section we analyse how the value transferred in transactions is affected by the exchange rate between *USD* and *BTC* over the years. Since exchange rates are not stored in the Bitcoin blockchain, we need to obtain these data from an external source, e.g. the Coindesk APIs²⁷. Using these data, we construct a blockchain view where each transaction is associated with the exchange rate at the time it has been appended to the blockchain.

More specifically, we construct a MongoDB collection whose documents represent transactions containing: (i) the transaction hash; (ii) the sum of its output values (in BTC); (iii) the date in which the transaction has been appended to the blockchain; (iv) the exchange rate between BTC and USD in such date.

Figure 6 shows the Scala code which builds this collection, using our APIs (we omit the declaration of the main method, already shown in Figure 1). At line 1 we declare the collection that we are going to build, txWithRates. At lines 3-4 we iterate over all the transactions in the Bitcoin blockchain. For each

²⁴ https://www.colu.com/

²⁵ http://www.omnilayer.org/

²⁶ https://github.com/blockstack/blockchain-id/wiki/Blockstore

²⁷ http://www.coindesk.com/price/bitcoin-price-index/

Fig. 6. A view of the blockchain including exchange rates.

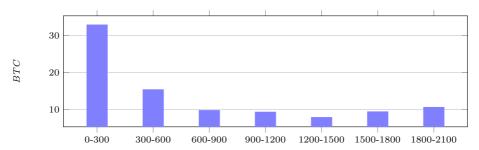


Fig. 7. Average value of outputs (in BTC) by exchange rate.

one, at lines 5-9 we add a new document to txWithRates. The total amount of BTC sent by the current transaction is stored in the field outputSum (line 8). The exchange rate is obtained by invoking the method Exchange of our APIs (line 11). This method takes a date as parameter, and retrieves from Coindesk the exchange rate BTC/USD in that date.

We can analyse the obtained collection in many ways, in order to study how exchange rates are related to the movements of currency in Bitcoin. For instance, one can obtain statistics about the daily transaction volume in USD^{28} , the market capitalization²⁹, the list of richest addresses³⁰, etc. Hereafter, we measure the average value of outputs (in BTC) of the transactions in intervals of exchange rates. The diagram in Figure 7 shows the results of this analysis, where we have split exchange rates in 7 intervals of equal size. In the first five intervals we observe the expected behaviour, i.e. the value of outputs decreases as the exchange rate increases. Perhaps surprisingly, the last two intervals show an increase in the value of outputs when the value BTC has surpassed 1500 USD. This may be explained by speculative operations on Bitcoin.

3.4 Transaction fees

In this section we study *transaction fees*, which are earned by miners when they append a new block to the Bitcoin blockchain. Each transaction in the block

 $^{^{28}\ \}mathtt{https://blockchain.info/charts/estimated-transaction-volume-usd}$

²⁹ http://blockchain.info/charts/market-cap

 $^{^{30}}$ https://bitinfocharts.com/top-100-richest-bitcoin-addresses.html

Fig. 8. A blockchain view exposing transaction fees.

pays a fee, defined as the difference between its input and output values. While the values of outputs are stored explicitly in the transaction, those of inputs are not: to obtain them, one must retrieve from a past block the transaction that is redeemed by the input. This can be obtained through a "deep" scan of the blockchain, which is featured by our library.

We show in Figure 8 how to construct a collection which contains, for each transaction: (i) the hash of the enclosing block; (ii) the transaction hash; (iii) the fee; (iv) the date in which the transaction was appended to the blockchain; (v) the exchange rate between BTC and USD in such date. The extra parameter true in the BitcoinSettings constructor (missing in the previous examples), triggers the "deep" scan. When scanning the blockchain in this way, the library maintains a map which associates transaction outputs to their values, and inspects this map to obtain the value of inputs³¹. The methods getInputsSum (resp., getOutputsSum) at line 11 returns the sum of the values of the inputs (resp., the outputs) of a transaction.

The obtained collection can be used to perform several standard statistics, e.g. the daily total transaction fees³², the average fee³³, the percentage earned by miners from transaction fees, etc. Hereafter we focus on the so-called whale transactions [13], which pay a unusually high fee to the miners³⁴. To do that, we first compute the average \bar{x} and standard deviation σ of the fees in all transactions: in USD, we have $\bar{x}=0.41$, $\sigma=12.09$. Then, we define whale transactions as those which pay a fee greater than $\bar{x}+2\sigma=24.58$ USD. Overall we collect 242,839 whale transactions; those with biggest fee are displayed below.

³¹ Since inputs can only redeemed transactions on past blocks, the map always contains the required output. Although coinbase inputs do not have a value in the map, we calculate their value using the total fees of the current block and the block height (reward is halved each 210,000 blocks).

³² https://blockchain.info/charts/transaction-fees

 $^{^{33}}$ https://bitinfocharts.com/comparison/bitcoin-transactionfees.html

The first whale transaction is supposed to be a mistake, so the mining pool offered to refunded the user. http://www.coindesk.com/accidental-136000-bitcoin-mining-pool/

```
val outWithTags = mongo.getCollection("outWithTags")
   val tags = new Tag("path\\input.txt")
   blockchain.foreach(block => {
     block.bitcoinTxs.foreach(tx => {
        tx.outputs.foreach(out => {
          out.getAddress(MainNet) match {
            case Some(add) =>
               tags.getValue(add) match {
                 case Some(tag) =>
10
                   outWithTags.append(List(
11
                      ("txHash", tx.hash),
                      ("date", block.date),
("value", out.value),
("address", add),
13
14
15
                      ("tags", tags.getValue(add))
16
                 case None =>
19
              7
20
            case None =>
21
        }) }) })
```

Fig. 9. A view of the blockchain associating transaction outputs with tags.

Fee (USD)	Date	Transaction hash
136243.37	2016-04-26 14:15:22	cc455 ae816 e6c dafd b58 d54 e35 d4f46 d860047458 eacf1 c7405 dc634631 c570 d
56493.50	2017-01-04 20:01:28	d38bd67153d774a7dab80a055cb52571aa85f6cac8f35f936c4349ca308e6380
39502.15	2017-05-31 14:28:51	cb95ab3aef378c14bc59d0db682d96202b981c1f8fad7d66e23e0be06f2a00c4
25095.71	2017-05-31 14:28:51	8e12a1aba87e4657f5fabec1121ed57f706805ad6d4ffe88c6fce78596bd9b75
23518.00	2013-08-28 10:45:17	4 ed 20 e 0768124 bc 67 dc 684 d57941 be 1482 ccdaa 45 dad b 64 be 12 afba 8 c 8554537

3.5 Address tags

The website blockchain.info/tags hosts a user-generated list of associations between bitcoin addresses and tags which briefly describe their usage³⁵. Table 1 shows that address tags are widely adopted. Cyber-crime studies retrieve addresses tagged as scam or ransomware on forums. Market analysis exploit tags for recognising addresses of business services. Anonymity studies tag the addresses that seems to belong to the same entity. In this section we construct a blockchain view where outputs are associated with the tags of the address which can redeem them (we discard the outputs with untagged addresses). More specifically, we construct a collection whose documents represent transaction outputs containing: (i) hash of the enclosing transaction; (ii) the date in which the transaction has been appended to the blockchain; (iii) the output value (in BTC); (iv) the address receiving the payment; (v) the tag associated to the address.

Figure 9 shows the Scala script which builds this collection. We retrieve tags from an external source, the blockchain.info website. While in the previous case studies we have retrieved external data by querying the source (e.g. the

For instance, (i) the address 1Archive1n2C579dMsAu3iC6tWzuQJz8dN is associated to the tag *Internet Archive* (https://archive.org/donate/bitcoin.php); (ii) the address 1PQCrkzWweCw4huVLcDXttAZbSrrLbJ92L is associated to the tag *Linux Mint Donations* (http://www.linuxmint.com/donors.php).

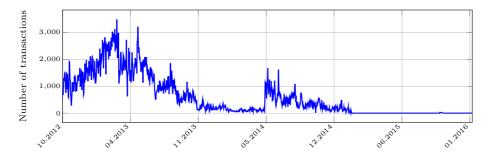


Fig. 10. Number of daily transactions to addresses tagged with SatoshiDICE*.

Coindesk APIs), in this case we query a local file in which we have stored the data fetched from blockchain.info. At line 2, given the file containing tags, the Tag class builds a Map which associate each address to the correspondent tag. At lines 4–6 we iterate over all the transaction outputs. At line 7 we try to extract the address which can redeem the current output. If we find it (line 8), then we search the map for the associated tag (line 9); if a tag is found (line 10) we add a new document to outWithTags (lines 11–16).

Since it is often possible to infer the business of an address from its \tan^{36} , the obtained collection allows to get some insights on several transfers of bitcoins. For instance, one can aggregate transactions on different business levels [15] to obtain statics about the total number of transactions, the amount of BTC exchanged, the geographical distributions of tagged service, etc. Hereafter, we aggregate all addresses whose tag starts with SatoshiDICE, and then we measure the number of daily transactions which send BTC to one of these addresses. The diagram in Figure 10 shows the results of this analysis. The fall in the number of transactions at the start of 2015 may be due to the fact that SatoshiDICE is using untagged addresses.

4 Implementation and performance evaluation

We implement our library by exploiting the RPC interface of Bitcoin Core. While Bitcoin APIs only allow the programmer to retrieve a block by its hash, Bitcoin Core's interface exposes calls to do so by its height on the chain. Furthermore, Bitcoin Block objects do not carry information about block height and the hash of the next block (they only have backward pointers, as defined in the blockchain), which can be fetched by using Bitcoin Core. Our APIs allows to navigate the Bitcoin blockchain by iterating over these steps: (i) get the hash h of the block of height i, by using Bitcoin Core; (ii) get the block with hash h, by using Bitcoin J; (iii) increment i. By default, the loop starts from 0 and stops at the last block. The methods blockchain.start(i), and blockchain.stop(j) allow to scan an interval of the blockchain, as shown in Section 3.2.

³⁶ For instance, the *Internet Archive* and *Linux Mint Donations* tags are related to donations, while the *JackpotDICE* tag is related to gambling.

We carry out our experiments using consumer hardware, i.e. a PC with a quad-core Intel Core i5-4440 CPU @ 3.10GHz, equipped with 32GB of RAM and 2TB of hard disk storage. The following table displays the size of the blockchain view, and the time required to construct and query it.

Case study	Size (GB)	Creation time (h)	Query time (s)	Updated to
Basic view of the blockchain	300	9	2860	2017-06-27
OP_RETURN metadata	0.5	2	0.5	2017-06-27
Exchange rates	30	15	477	2017-06-27
Transaction fees	23	35	448	2017-06-27
Address tags	0.8	10	1.8	2017-06-27

Note that the size of the blockchain view constructed in Section 3.1 is more than twice than the current Bitcoin blockchain. This is because, while Bitcoin writes scripts in binary format, our library writes them as strings, so to allow for constructing indices and performing queries on scripts.

5 Related works and conclusions

We have presented a framework for developing custom analytics on the Bitcoin blockchain. Its main component is a Scala library which allows to construct views of the blockchain, possibly integrating blockchain data with data retrieved from external sources. Blockchain views are represented as NoSQL databases, which can be analysed by using the query language of MongoDB.

Our APIs are closely related to a few projects that are available on online repositories. BitIodine³⁷ is a modular framework to parse the Bitcoin blockchain and retrieve external information (e.g. exchange rates and tags). However, according to its website, this project is no longer actively developed, and it does not work with the recent Bitcoin blockchain. The projects blockparser³⁸ and rusty-blockparser³⁹ implement blockchain parser which work on Bitcoin-based blockchains. These tools allow to perform full scans of the blockchain, and to define custom listeners which are called each time a new block or transaction is read. Compared to our Scala library, these tools offer limited built-in support for combining blockchain and external data. Comparing the performance of these two tools against ours would be a relevant question for future work. A preliminary (rather approximate) comparison can be obtained by observing the performance data reported in the rusty-blockparser's website. They say that a full scan of the blockchain took about 70 minutes on January 2016. This is not too far from the the construction of our quickest view, that took about 2 hours, considering that the blockchain has grown from $\sim 55 \text{GB}$ to $\sim 120 \text{GB}$ by then.

Although our framework is general enough to cover most of the analyses reported in Table 1, it has some limitations that can be overcome with future extensions. In particular, we note that some analyses, addressing e.g. information

³⁷ https://github.com/mikispag/bitiodine

³⁸ https://github.com/znort987/blockparser

³⁹ https://github.com/mikispag/rusty-blockparser

propagation, forks and attacks [6,8,17,26], require to gather data from the Bitcoin network, besides that from the blockchain. To support this kind of analyses one has to run a (customized) Bitcoin node. We believe that this kind of extension would also be helpful to obtain on-the-fly updates of the analyses.

References

- 1. Androulaki, E., Karame, G., Roeschlin, M., Scherer, T., Capkun, S.: Evaluating user privacy in Bitcoin. In: Financial Cryptography and Data Security. LNCS, vol. 7859, pp. 34–51. Springer (2013)
- Baqer, K., Huang, D.Y., McCoy, D., Weaver, N.: Stressing out: Bitcoin "stress testing". In: Financial Cryptography Workshops. LNCS, vol. 9604, pp. 3–18. Springer (2016)
- 3. Bartoletti, M., Pompianu, L.: An analysis of Bitcoin OP_RETURN metadata. In: Bitcoin Workshop (2017), also available as arXiv preprint 1702.01024
- 4. Bonneau, J., Miller, A., Clark, J., Narayanan, A., Kroll, J.A., Felten, E.W.: SoK: Research perspectives and challenges for Bitcoin and cryptocurrencies. In: IEEE S & P. pp. 104–121 (2015)
- Bonneau, J., Narayanan, A., Miller, A., Clark, J., Kroll, J.A., Felten, E.W.: Mixcoin: Anonymity for Bitcoin with accountable mixes. In: Financial Cryptography and Data Security. LNCS, vol. 8437, pp. 486–504. Springer (2014)
- 6. Decker, C., Wattenhofer, R.: Information propagation in the Bitcoin network. In: P2P. pp. 1–10. IEEE (2013)
- Dede, E., Govindaraju, M., Gunter, D., Canon, R.S., Ramakrishnan, L.: Performance evaluation of a MongoDB and Hadoop platform for scientific data analysis. In: Proc. 4th ACM workshop on Scientific cloud computing. pp. 13–20. ACM (2013)
- 8. Donet, J.A.D., Pérez-Solà, C., Herrera-Joancomartí, J.: The Bitcoin P2P network. In: Financial Cryptography Workshops. LNCS, vol. 8438, pp. 87–102. Springer (2014)
- 9. Garay, J.A., Kiayias, A., Leonardos, N.: The Bitcoin backbone protocol: Analysis and applications. In: EUROCRYPT. LNCS, vol. 9057, pp. 281–310. Springer (2015)
- Gervais, A., Karame, G.O., Wüst, K., Glykantzis, V., Ritzdorf, H., Capkun, S.: On the security and performance of proof of work blockchains. In: ACM SIGSAC Conference on Computer and Communications Security. pp. 3–16. ACM (2016)
- 11. Harrigan, M., Fretter, C.: The unreasonable effectiveness of address clustering. In: UIC/ATC/ScalCom/CBDCom/IoP/SmartWorld. pp. 368–373. IEEE (2016)
- 12. Karame, G.O., Androulaki, E., Roeschlin, M., Gervais, A., Capkun, S.: Misbehavior in Bitcoin: A study of double-spending and accountability. ACM Trans. Inf. Syst. Secur. 18(1), 2 (2015), http://doi.acm.org/10.1145/2732196
- Liao, K., Katz, J.: Incentivizing blockchain forks via whale transactions. In: Bitcoin Workshop (2017)
- 14. Liao, K., Zhao, Z., Doupé, A., Ahn, G.: Behind closed doors: measurement and analysis of CryptoLocker ransoms in Bitcoin. In: APWG Symp. on Electronic Crime Research (eCrime). pp. 1–13. IEEE (2016)
- 15. Lischke, M., Fabian, B.: Analyzing the Bitcoin network: The first four years. Future Internet 8(1), 7 (2016)
- 16. Luu, L., Saha, R., Parameshwaran, I., Saxena, P., Hobor, A.: On power splitting games in distributed computation: The case of Bitcoin pooled mining. In: IEEE Computer Security Foundations Symposium. pp. 397–411. IEEE (2015)

- 17. McCorry, P., Shahandashti, S.F., Hao, F.: Refund attacks on Bitcoin's payment protocol. In: Financial Cryptography and Data Security. LNCS, vol. 9603, pp. 581–599. Springer (2016)
- 18. Meiklejohn, S., Pomarole, M., Jordan, G., Levchenko, K., McCoy, D., Voelker, G.M., Savage, S.: A fistful of bitcoins: characterizing payments among men with no names. In: Internet Measurement Conference. pp. 127–140. ACM (2013)
- 19. Meiklejohn, S., Pomarole, M., Jordan, G., Levchenko, K., McCoy, D., Voelker, G.M., Savage, S.: A fistful of Bitcoins: characterizing payments among men with no names. Commun. ACM 59(4), 86–93 (2016)
- 20. Möser, M., Böhme, R., Breuker, D.: An inquiry into money laundering tools in the Bitcoin ecosystem. In: APWG Symp. on Electronic Crime Research (eCrime). pp. 1–14. IEEE (2013)
- Möser, M., Böhme, R.: Trends, tips, tolls: A longitudinal study of Bitcoin transaction fees. In: Financial Cryptography Workshops. LNCS, vol. 8976, pp. 19–33. Springer (2015)
- Möser, M., Böhme, R.: Anonymous alone? Measuring Bitcoin's second-generation anonymization techniques. http://informationsecurity.uibk.ac.at/pdfs/MB2017_AnonymousAlone.pdf (2017)
- Möser, M., Böhme, R., Breuker, D.: Towards risk scoring of Bitcoin transactions.
 In: Financial Cryptography Workshops. LNCS, vol. 8438, pp. 16–32. Springer (2014)
- 24. Nakamoto, S.: Bitcoin: a peer-to-peer electronic cash system. https://bitcoin.org/bitcoin.pdf (2008)
- 25. Ober, M., Katzenbeisser, S., Hamacher, K.: Structure and anonymity of the Bitcoin transaction graph. Future Internet 5(2), 237–250 (2013)
- Pappalardo, G., di Matteo, T., Caldarelli, G., Aste, T.: Blockchain inefficiency in the Bitcoin peers network. CoRR abs/1704.01414 (2017), http://arxiv.org/abs/1704.01414
- 27. Reid, F., Harrigan, M.: An analysis of anonymity in the Bitcoin system. In: Security and privacy in social networks, pp. 197–223. Springer (2013)
- 28. Ron, D., Shamir, A.: Quantitative analysis of the full Bitcoin transaction graph. In: Financial Cryptography and Data Security. LNCS, vol. 7859, pp. 6–24. Springer (2013)
- 29. Schrijvers, O., Bonneau, J., Boneh, D., Roughgarden, T.: Incentive compatibility of Bitcoin mining pool reward functions. In: Financial Cryptography and Data Security. LNCS, vol. 9603, pp. 477–498. Springer (2016)
- 30. Spagnuolo, M., Maggi, F., Zanero, S.: Bitiodine: Extracting intelligence from the Bitcoin network. In: Financial Cryptography and Data Security. LNCS, vol. 8437, pp. 457–468. Springer (2014)
- 31. Vasek, M., Moore, T.: There's no free lunch, even using Bitcoin: Tracking the popularity and profits of virtual currency scams. In: Financial Cryptography and Data Security. LNCS, vol. 8975, pp. 44–61. Springer (2015)
- 32. Vasek, M., Thornton, M., Moore, T.: Empirical analysis of Denial-of-Service attacks in the Bitcoin ecosystem. In: Financial Cryptography Workshops. LNCS, vol. 8438, pp. 57–71. Springer (2014)