香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

HKUST VIS

Computational Media and arts Thrust

A Survey of Visual Analytics for Blockchain Data

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2022 – 06 – 28

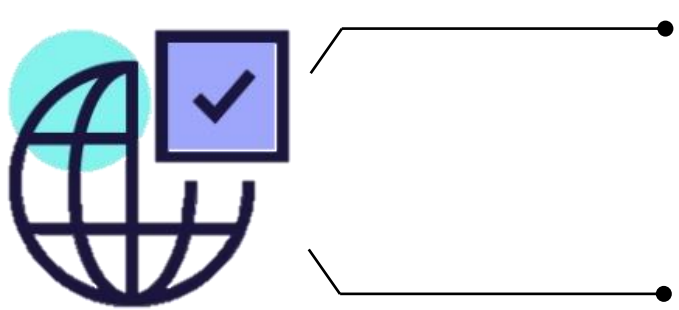
Outline

Motivation - Background

A blockchain, is a distributed and decentralized system that maintains the integrity of data records of all users' peer-to-peer interactions within it.

Distributed Ledger

Immutable Storage



Consensus Algorithms

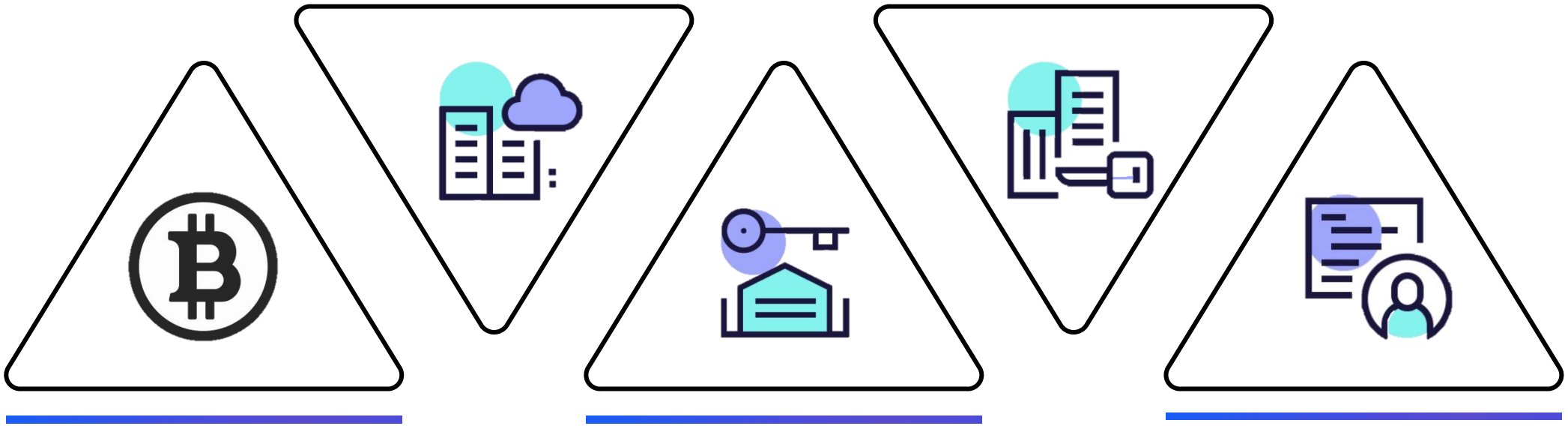
Motivation - Application Scenarios

Ethereum

Underlying Protocols

NFTs

Digital Properties



Cryprocurrency

Bitcoin, ETH

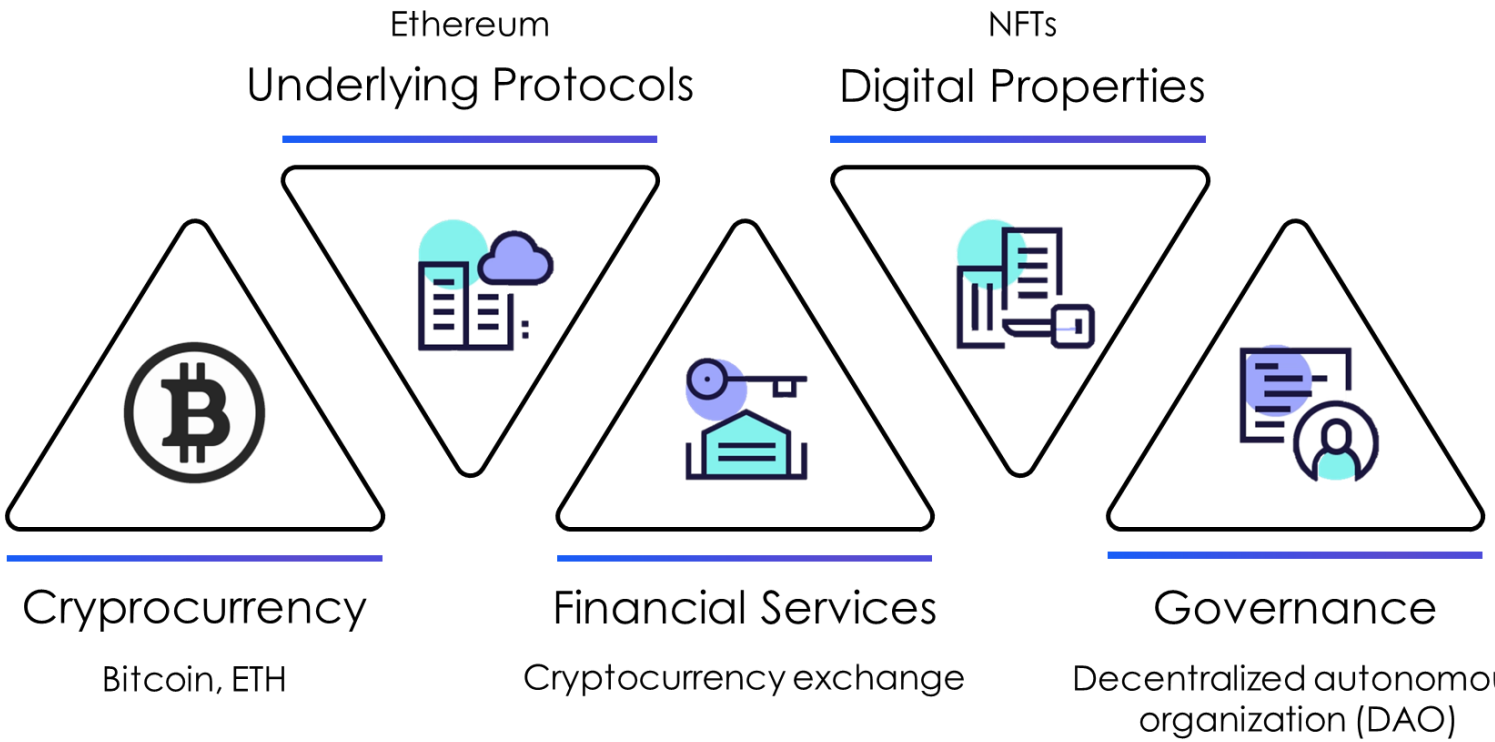
Financial Services

Cryptocurrency exchange

Governance

Decentralized autonomous organization (DAO)

Motivation - Application Scenarios



Blockchain 1.0

Cryptocurrenies

Blockchain 2.0

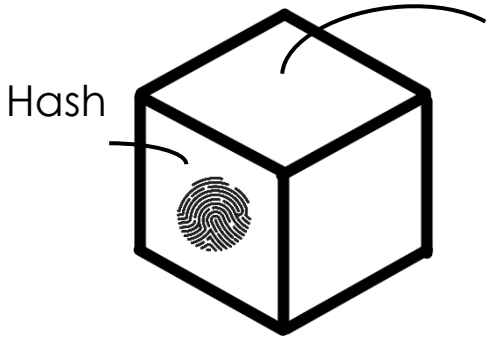
Broader financial services

Blockchain 3.0

Multiple domains

Motivation - Data Properties

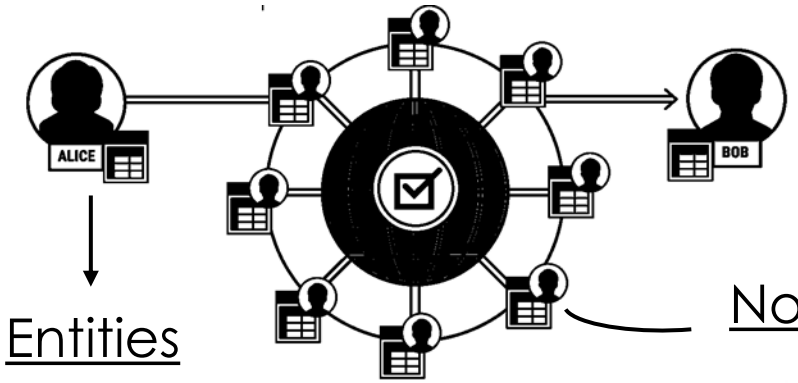
Fundamental blockchain data



From: input **Address(es)**
To: output Address(es)
Amount: transferred values
Timestamp: xxxx

Blocks

Transactions

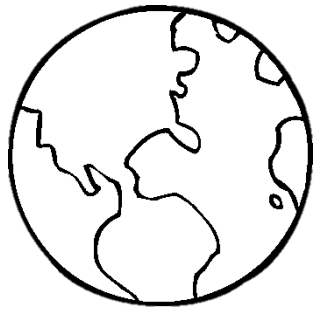


Entities

Nodes

External data

Text



Space

Users' profile data

Muti-media data

Others

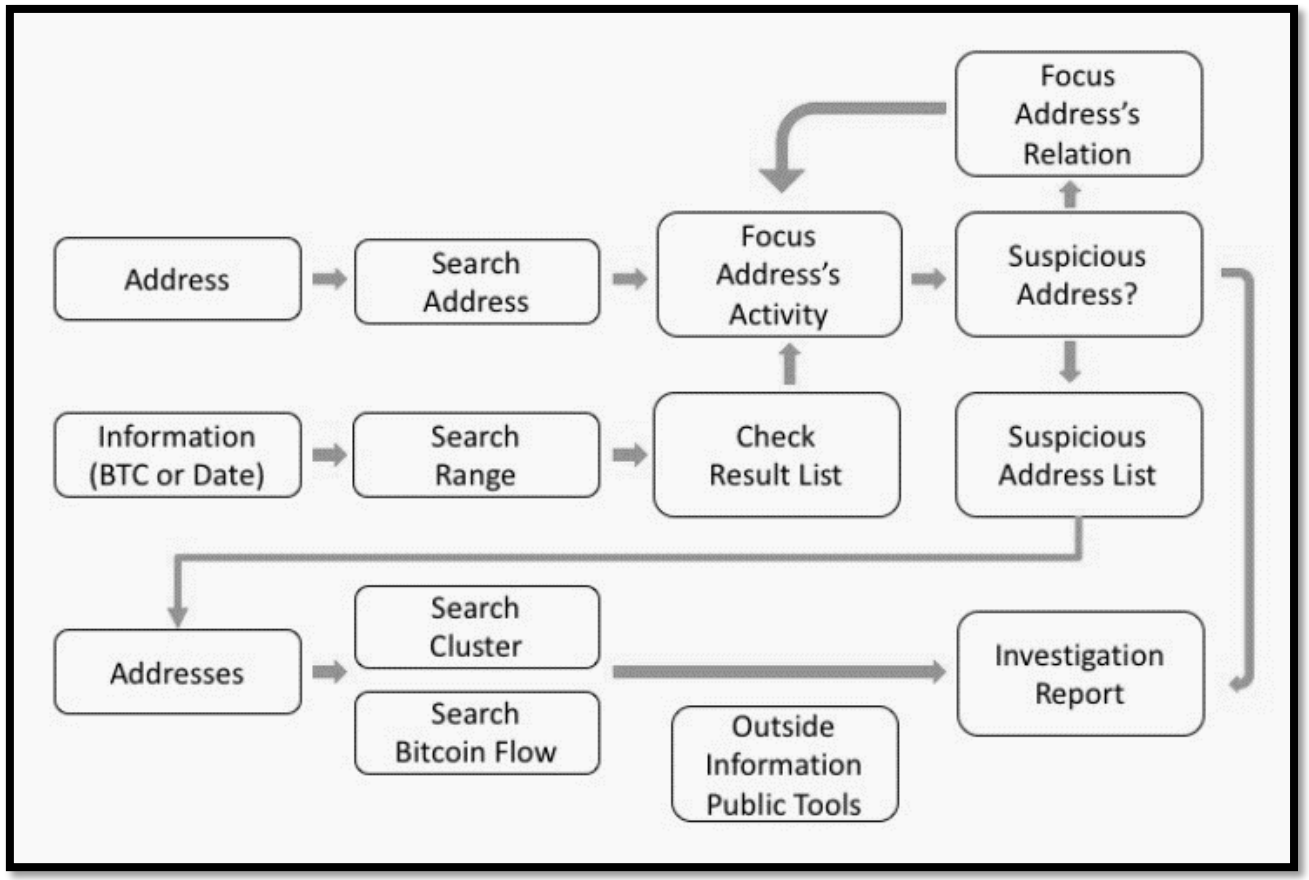
Basic → **Heterogenous**

Challenges

Data

Modeling the substantial, high-dimensional, and pseudonymous blockchain data is challenging.

- **Massive volume**
  - The scalability problem for data processing and representation.
- **Multiple analysis perspectives**
  - Selecting a proper perspective as the start point of drilling down or rolling up is non-trivial.
- **Pseudonymous**
  - It's difficult to involve supplementary external impact attributes.



The Bitcoin analytical process (Kuzuno et al. 2017)

Challenges

Design

Presenting blockchain data in a comprehensive and accessible manner is challenging because of its complicated application scenarios.

- **Information density**
  - Visualization for blockchain data requires a holistic design to present massive information within the limited interface.

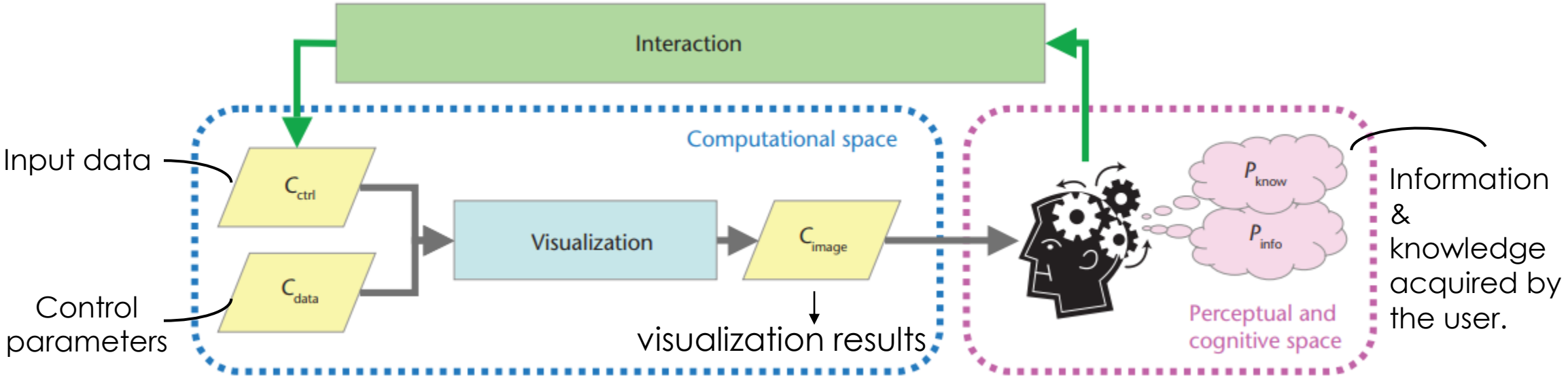
- **User limits**
  - It could be challenging for novice users to understand and extract information from visual analytics of blockchain data.

Blockchain applications (Casino et al. 2019)

Why visual analytics?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

- Replace cognition with perception.
- Balances the computational strength with human expertise.



A typical visualization process, where interaction provides the primary means for reducing the search space in visual exploration (Chen et al. 2009).

Research questions

RQ1

What are the research trends in current blockchain data visualization research?

RQ2

What are the research gaps in current blockchain data visualization research?

RQ3

What are the future research directions for blockchain data visualization?

Outline

Introduction

Taxonomy

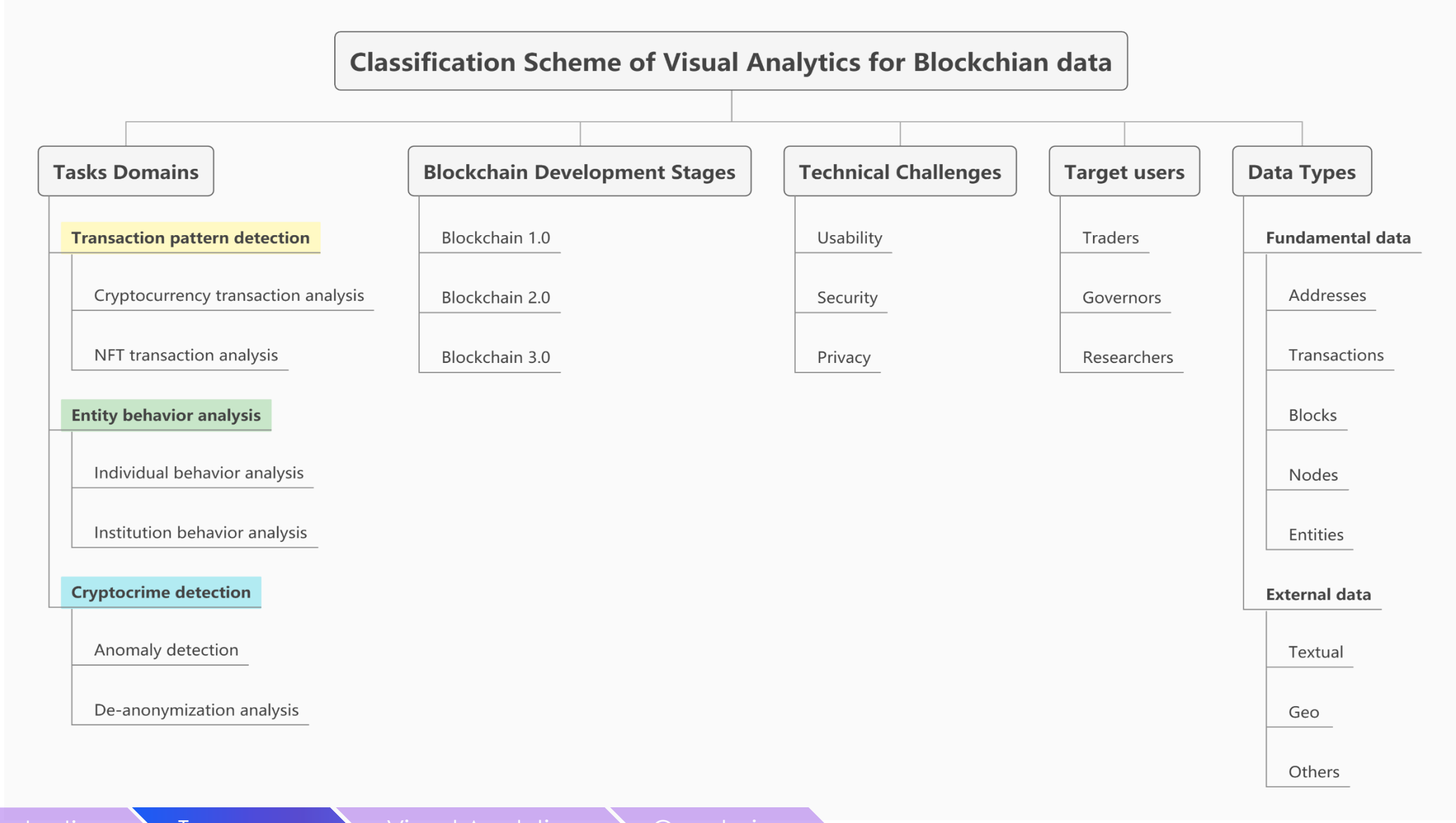
Classification scheme

Category definition

Visual Analytics

Conclusion

Classification scheme

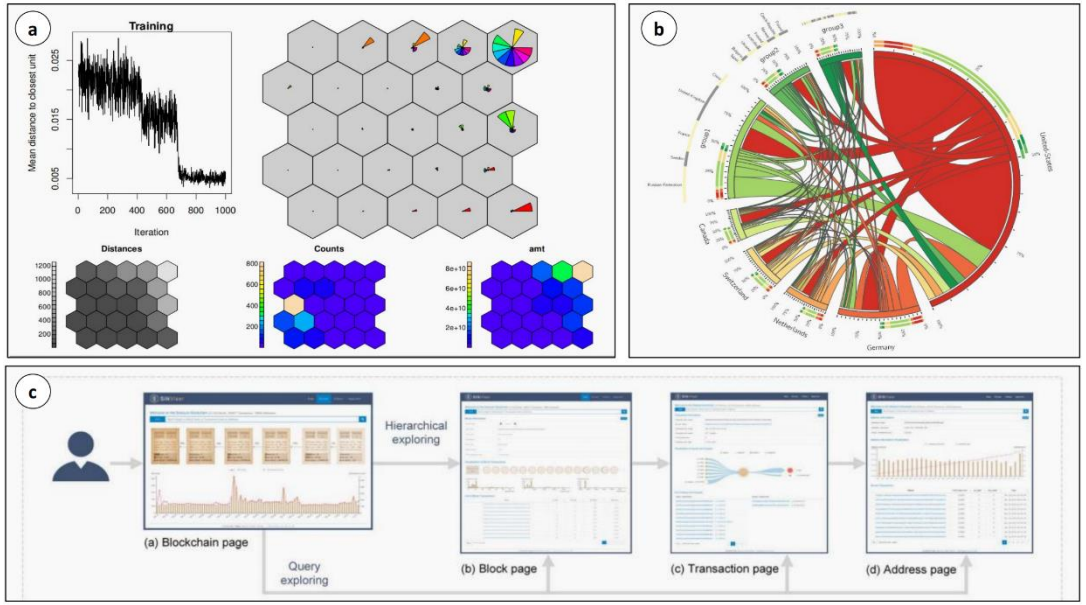


Overview

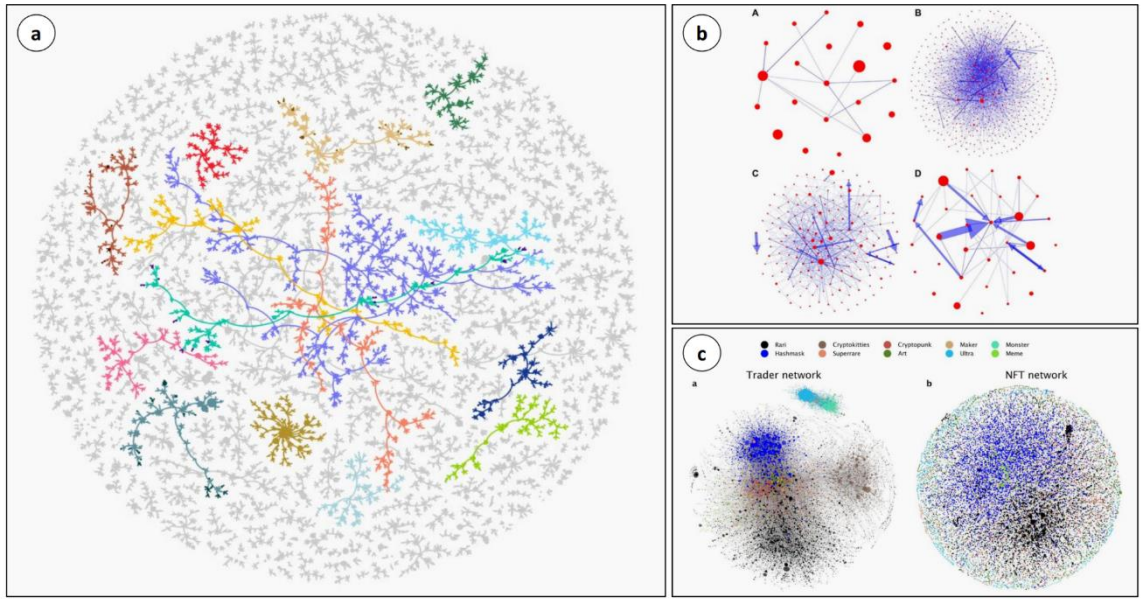
Taxonomy		Related Papers
Transaction Pattern Detection	Cryptocurrency transaction analysis	Bistarelli et al., Oggier et al., Zhong et al., Chawathe, Parino et al., Lischke et al., Chen et al., Chan et al., Jiang et al., Nadini et al., Vasan et al., Dowling, Ante, Mekacher et al., Kapoor et al.
	NFT transaction analysis	
Entity Behavior Analysis	Individual behavior analysis	Sun et al., Kinkeldey et al., Isenberg et al., Kuzuno et al., Xia et al., Tovanich et al., Tovanich et al., Yue et al., Ranshous et al.
	Institution behavior analysis	
Cryptocrime Detection	Anomaly detection	Pham et al., Balthasar et al., Norbutas, Saad et al., Battista et al., McGinn et al., Ahmed et al., Fleder et al., Reid et al., Meiklejohn et al., Biryukov et al., Boshmaf et al.
	De-anonymization analysis	

Category Definition

Transaction pattern detection mainly visualizes the transaction activities between addresses, which could be further distinguished by transferred objects (i.e., cryptocurrencies and NFTs).



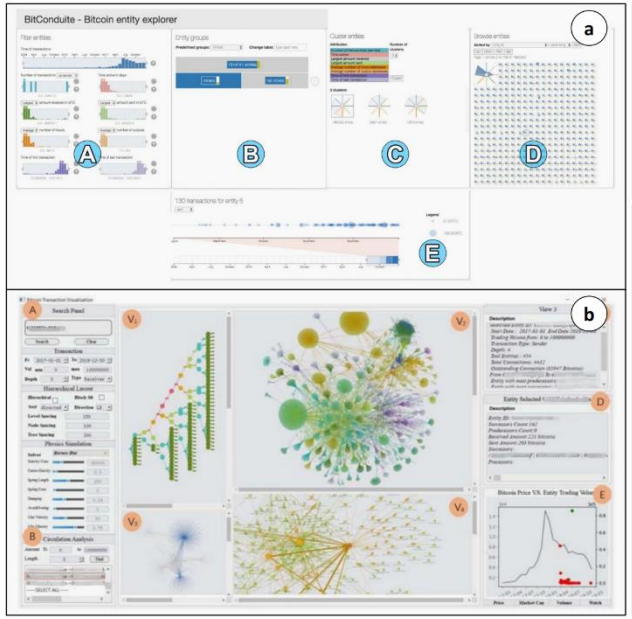
Cryptocurrency transaction analysis



NFT transaction analysis

Category Definition

Entity behavior analysis mainly presents and traces the entities' activities and interactions within blockchain ecosystems, which includes individual behavior analysis and institution behavior analysis.

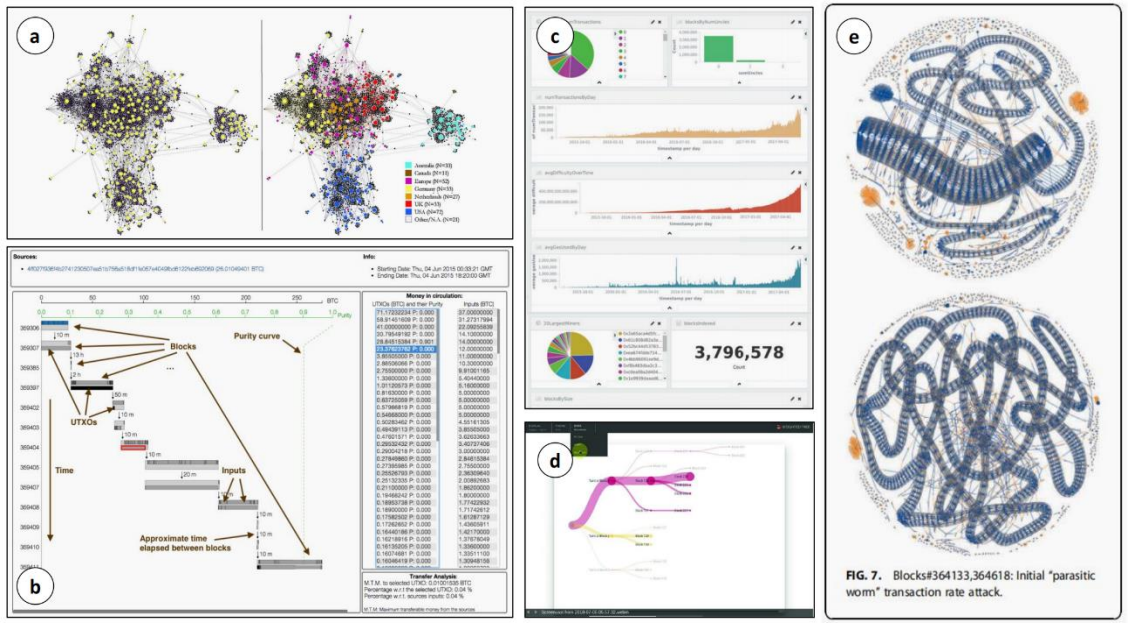


Individual behavior analysis

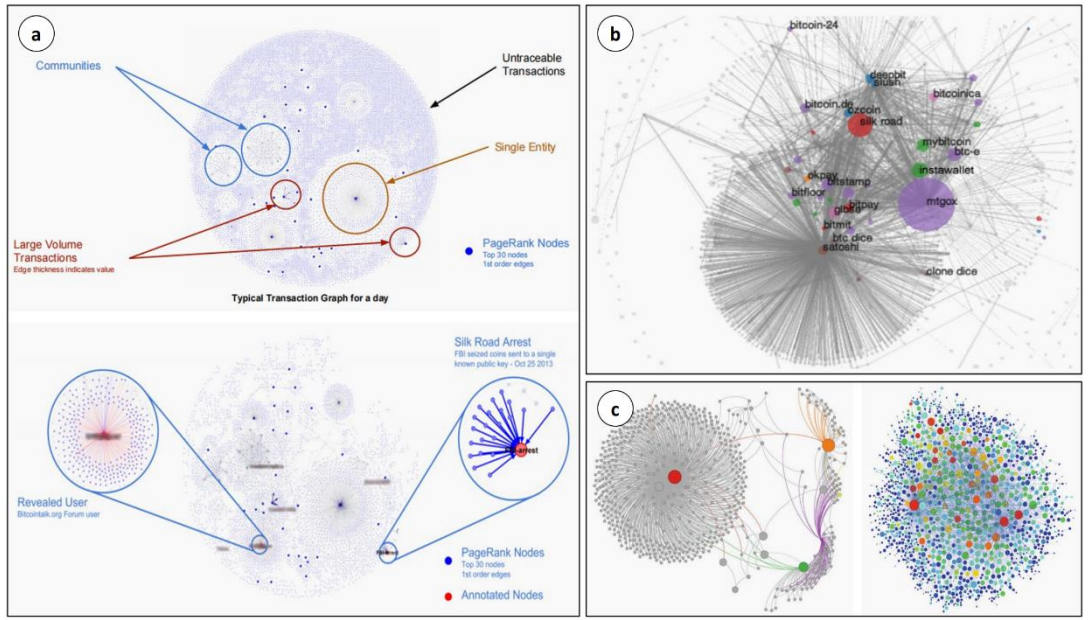
Institution behavior analysis

Category Definition

Cryptocrime detection encompasses two branches: one is to identify suspicious events; another is de-anonymize users to protect their privacy or extract doubtful accounts.



Anomaly detection



De-anonymization analysis

Outline

Introduction

Taxonomy

Visual Analytics

- Transaction pattern detection
- Entity behavior analysis
- Cryptocrime detection

Conclusion

Transaction pattern detection

Transaction Pattern Detection

Cryptocurrency transaction analysis

Network analysis

- Bistarelli et al. (2017)
- Chan et al. (2017)
- Chen et al. (2020)
- Lischke et al. (2016)
- Oggier et al. (2018)

Value flow analysis

- Chawathe (2018)
- Parino et al. (2018)
- Zhong et al. (2020)

NFT transaction analysis

Market trend presentation

- Jiang et al. (2021)
- Nadini et al. (2021)
- Vasan et al. (2022)

Impact attributes extraction

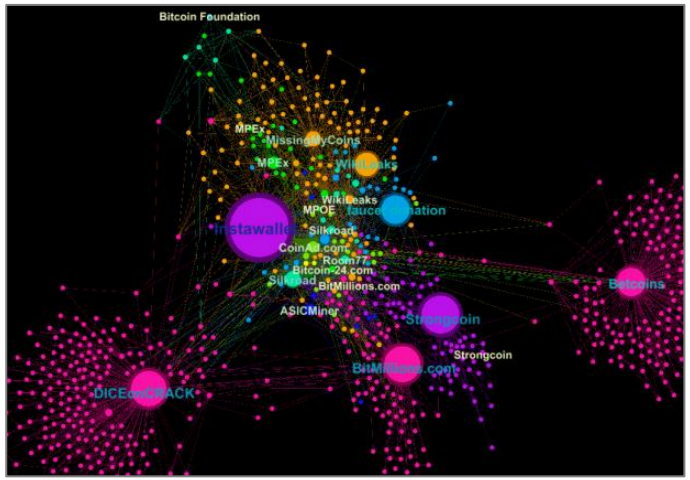
- Ante (2021)
- Dowling (2022)
- Kapoor et al. (2022)
- Mekacher et al. (2022)

Transaction pattern detection

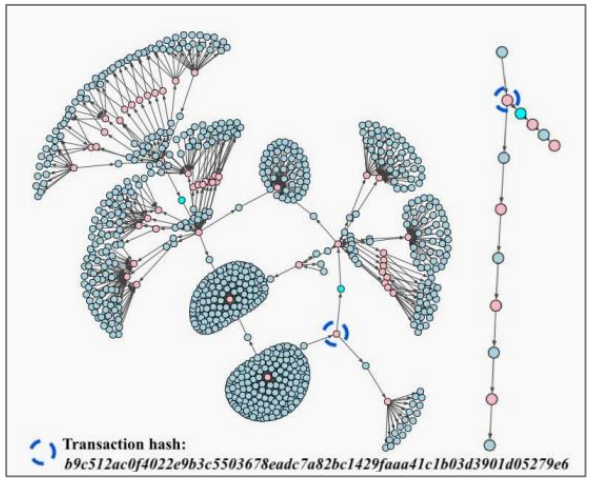
Cryptocurrency transaction analysis

Network analysis

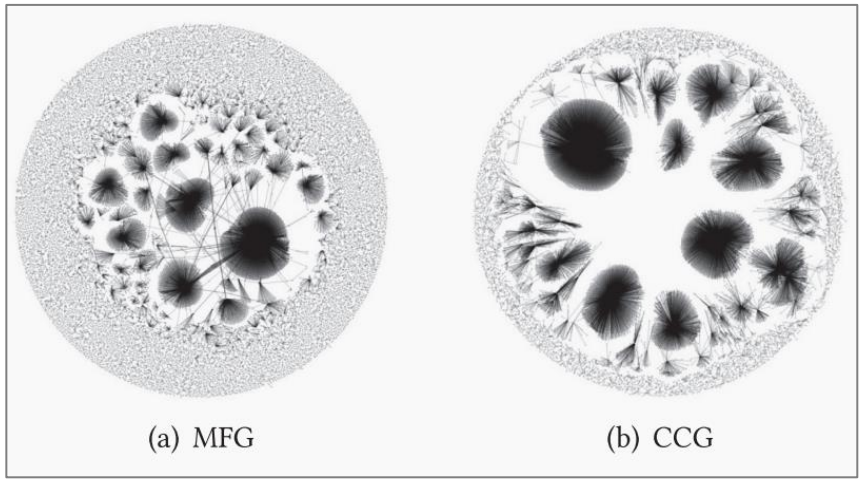
- To filter information out of the massive volumes of data;
- To display the topology structure of clustered addresses;
- To efficiently provide insights for nodes of interests.



Lischke et al. (2016)



Oggier et al. (2018)



Chen et al. (2020)

Contributions: Involved external data.
Limitations: Visual clutter; incomplete tags; no interaction.

Contributions: Subgraph exploration; interactive two mode network.
Limitations: Not friendly to novice users.

Contributions: Extend node types.
Limitations: Visual clutter; no interaction; high cognitive load.

Transaction pattern detection

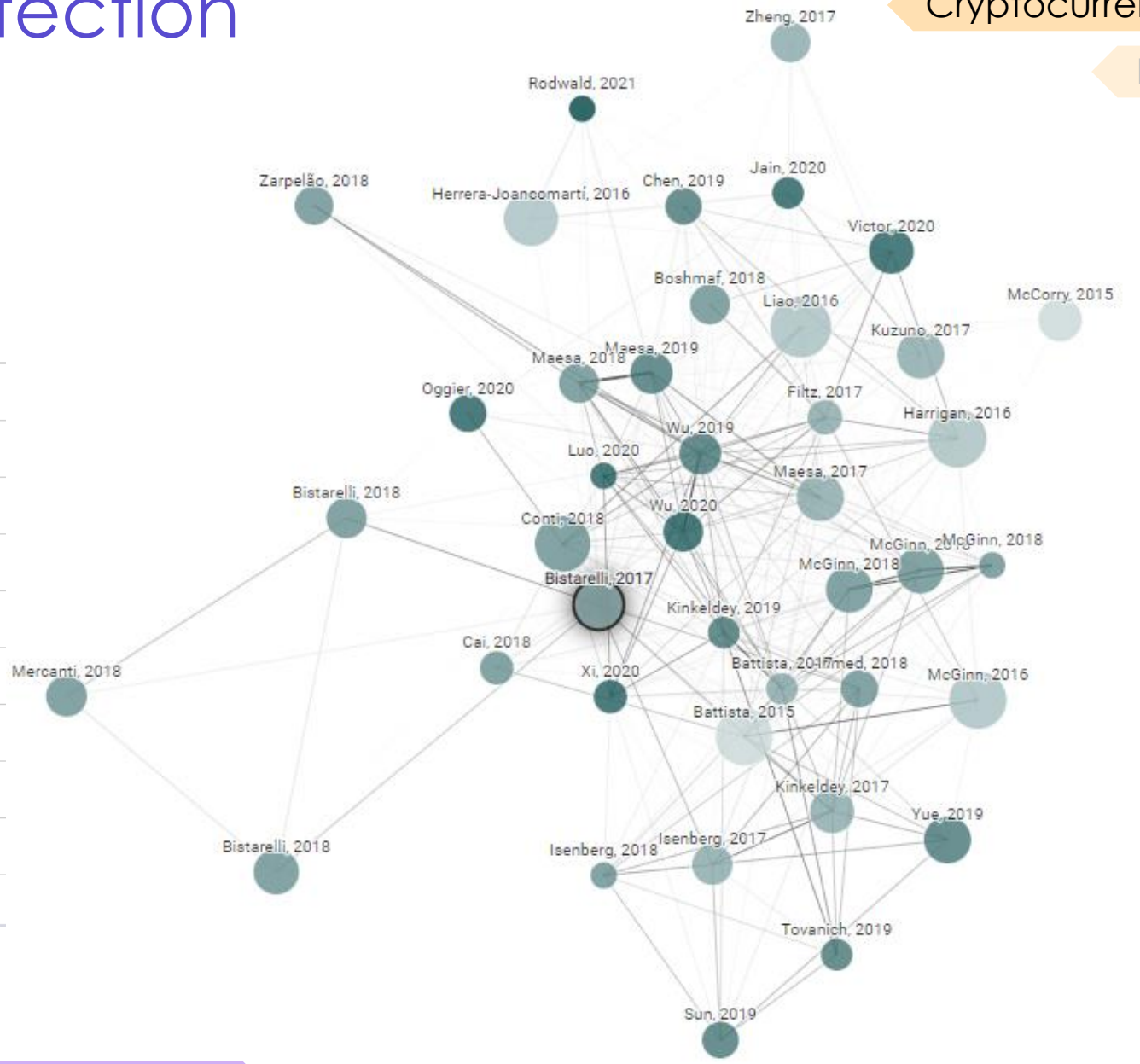
Cryptocurrency

NFTs

BlockchainVis, Bistarelli et al., 2017.

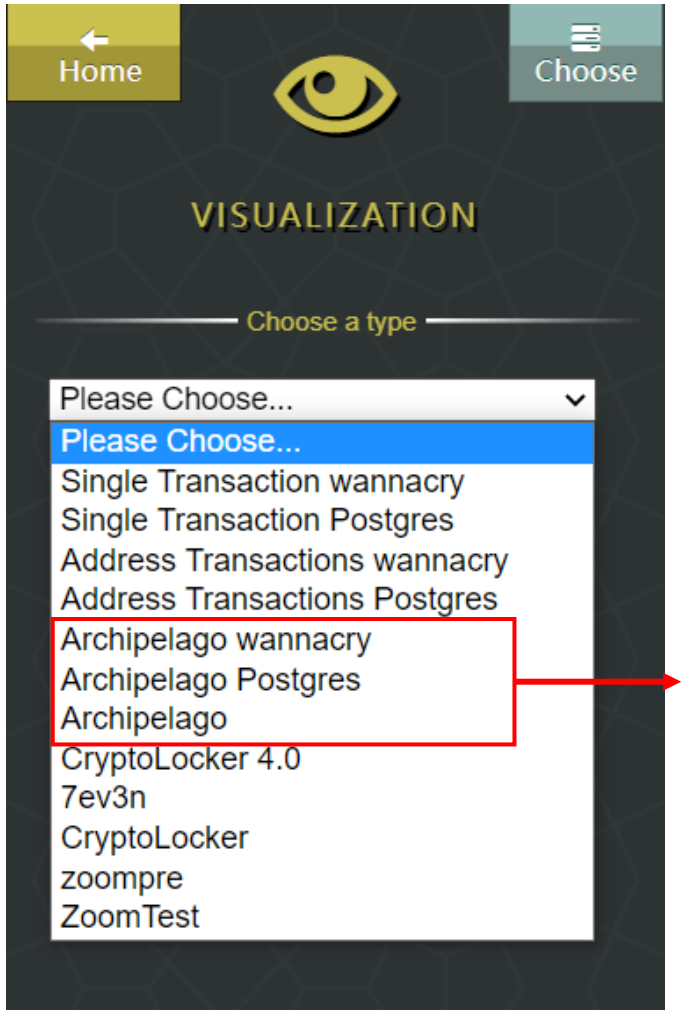
Derivative works:

Title
Visualization of Blockchain Data: A Systematic Review
Visualizing and Analyzing Entity Activity on the Bitcoin Network
Analysis of Cryptocurrency Transactions from a Network Perspective: An Overview
Knowledge Discovery in Cryptocurrency Transactions: A Survey
SilkViser: A Visual Explorer of Blockchain-based Cryptocurrency Transaction Data
SilkViser: A Visual Explorer of Blockchain-based Cryptocurrency Transaction Data
A Survey on Blockchain Anomaly Detection Using Data Mining Techniques
Supervised learning model for identifying illegal activities in Bitcoin
Big data analytics to identify illegal activities on Bitcoin Blockchain for IoMT
SuPoolVisor: a visual analytics system for mining pool surveillance

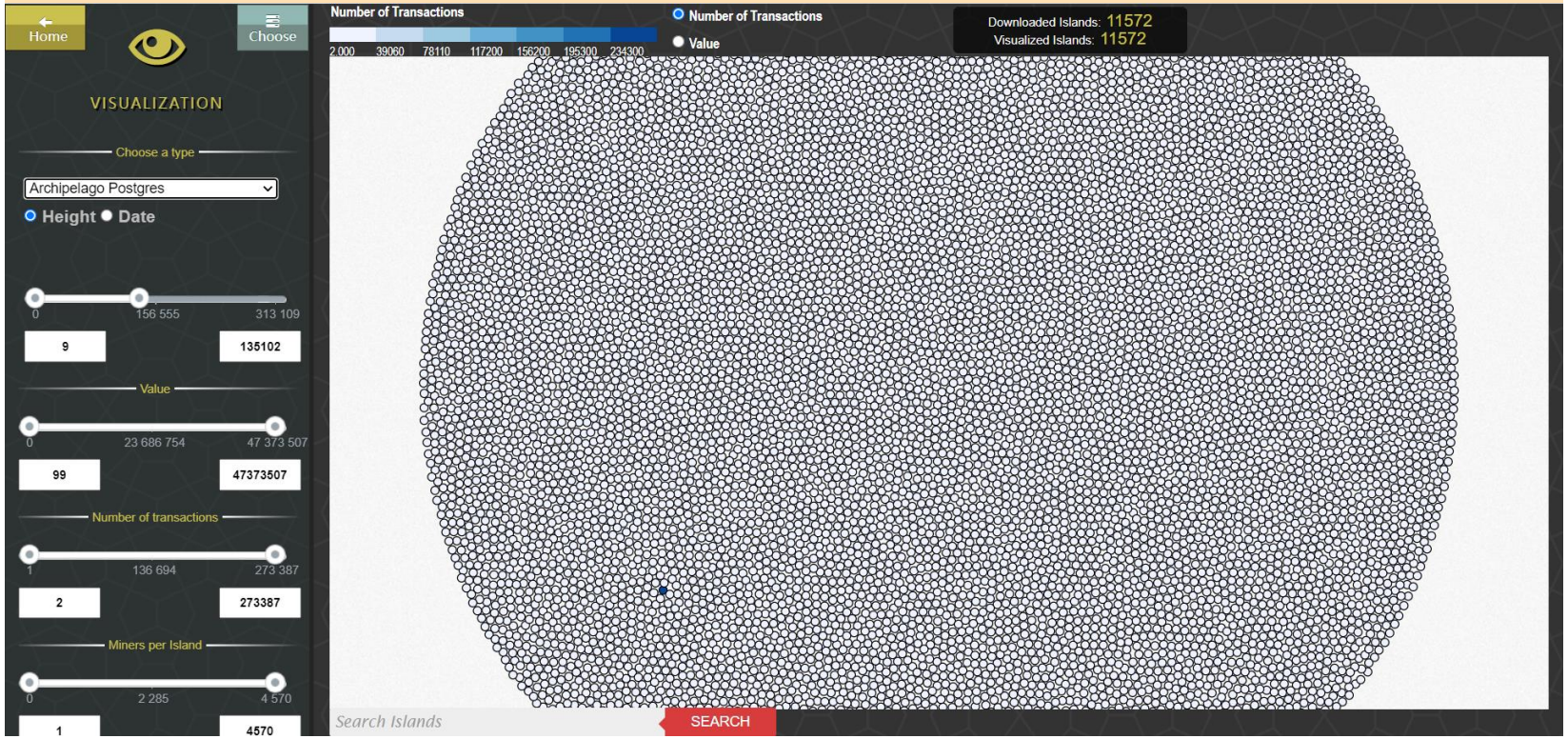


Transaction pattern detection

BlockchainVis, Bistarelli et al., 2017.



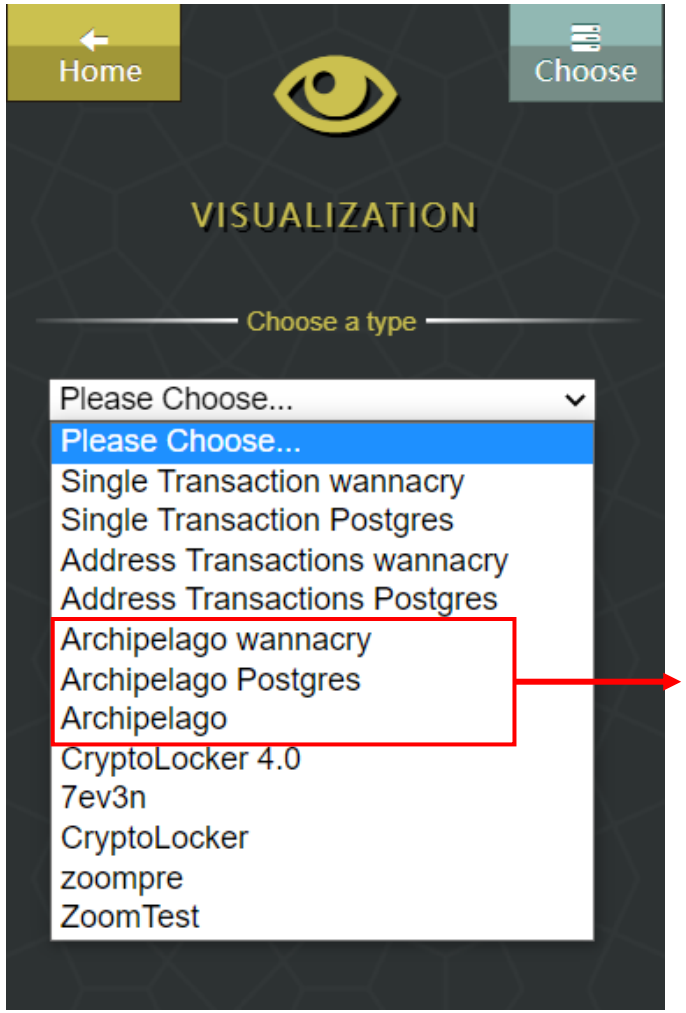
Archipelago visualization



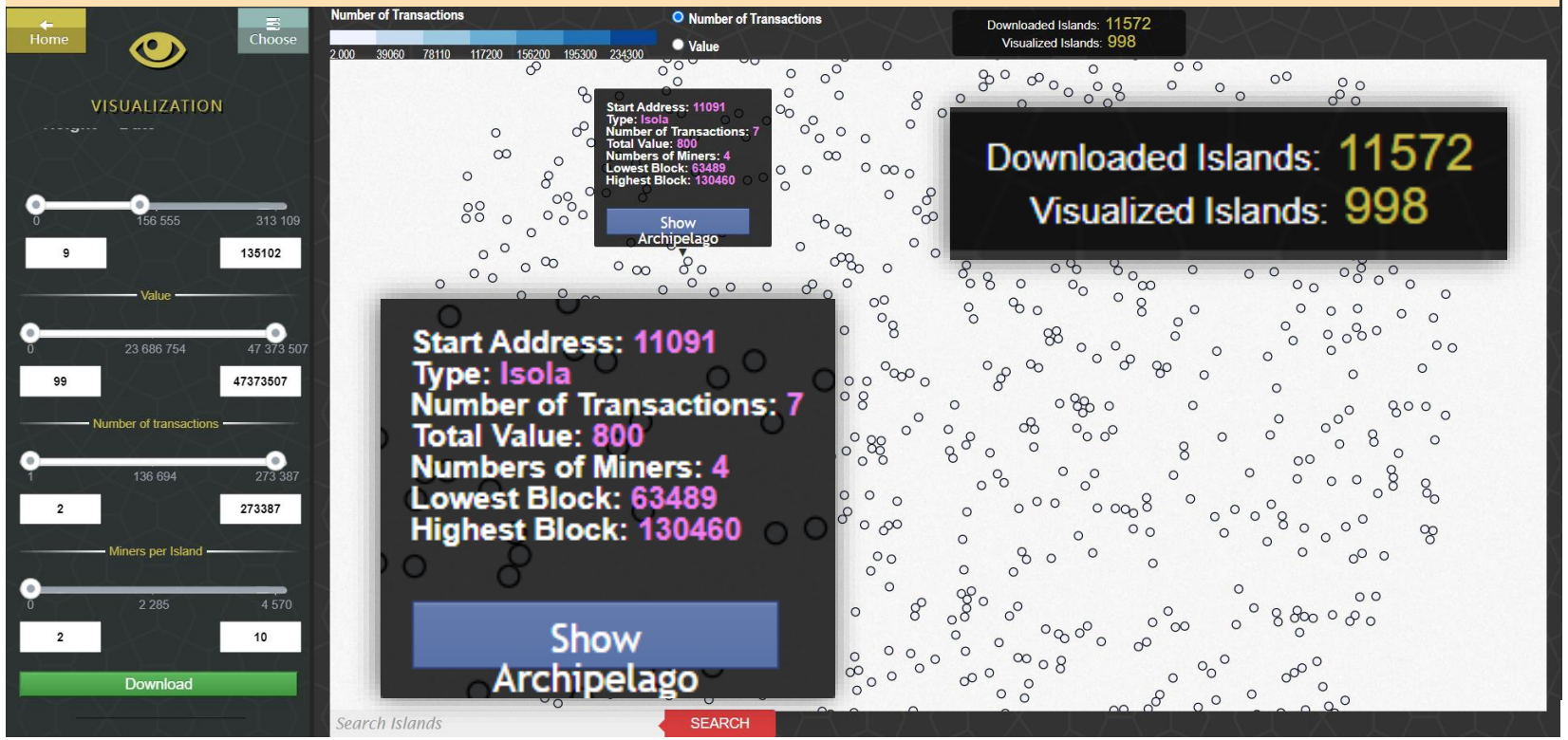
http://normandy.dmi.unipg.it/blockchainvis/vis.php

Transaction pattern detection

BlockchainVis, Bistarelli et al., 2017.

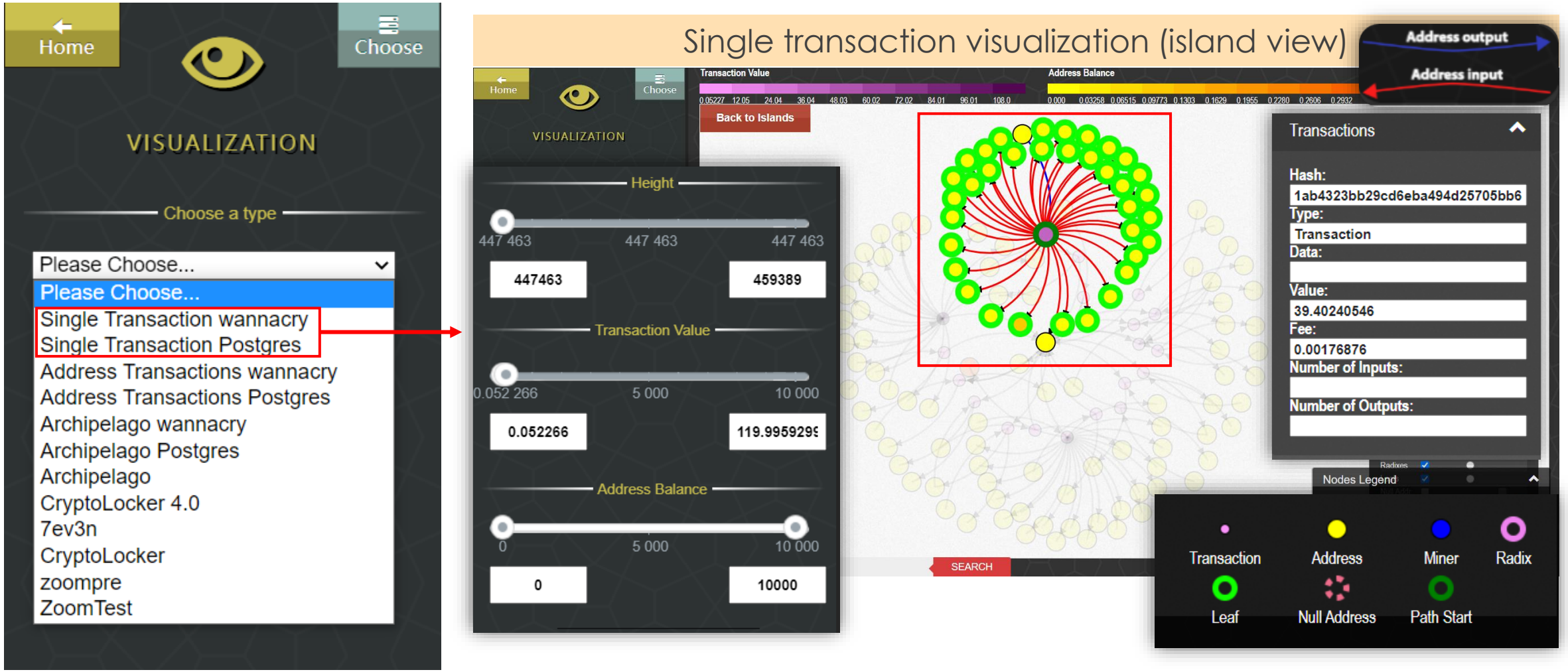


Archipelago visualization



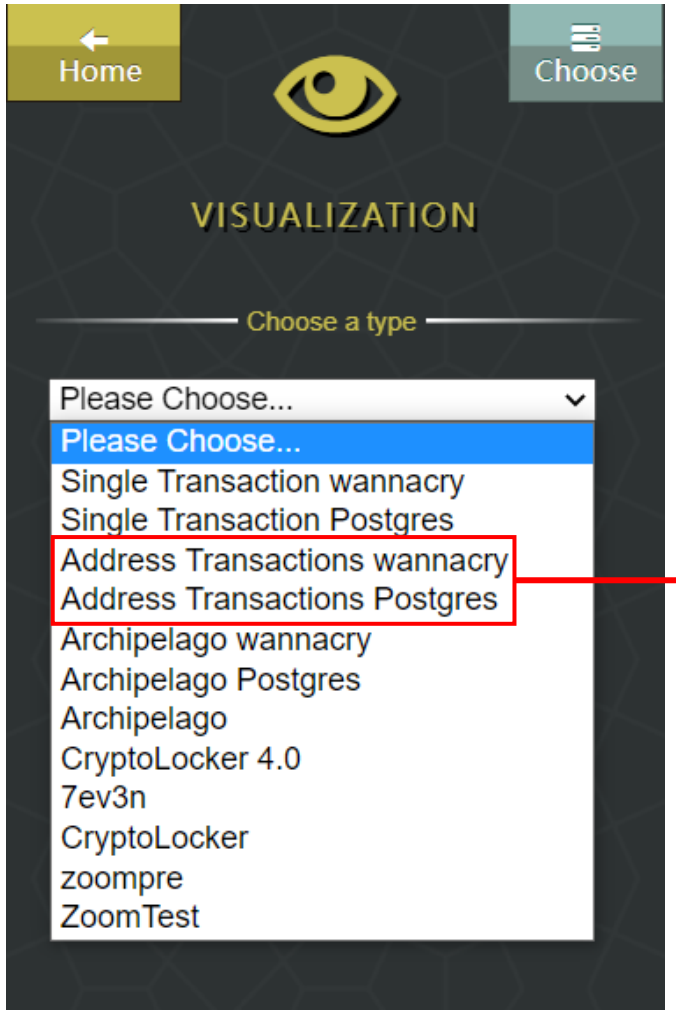
Transaction pattern detection

BlockchainVis, Bistarelli et al., 2017.

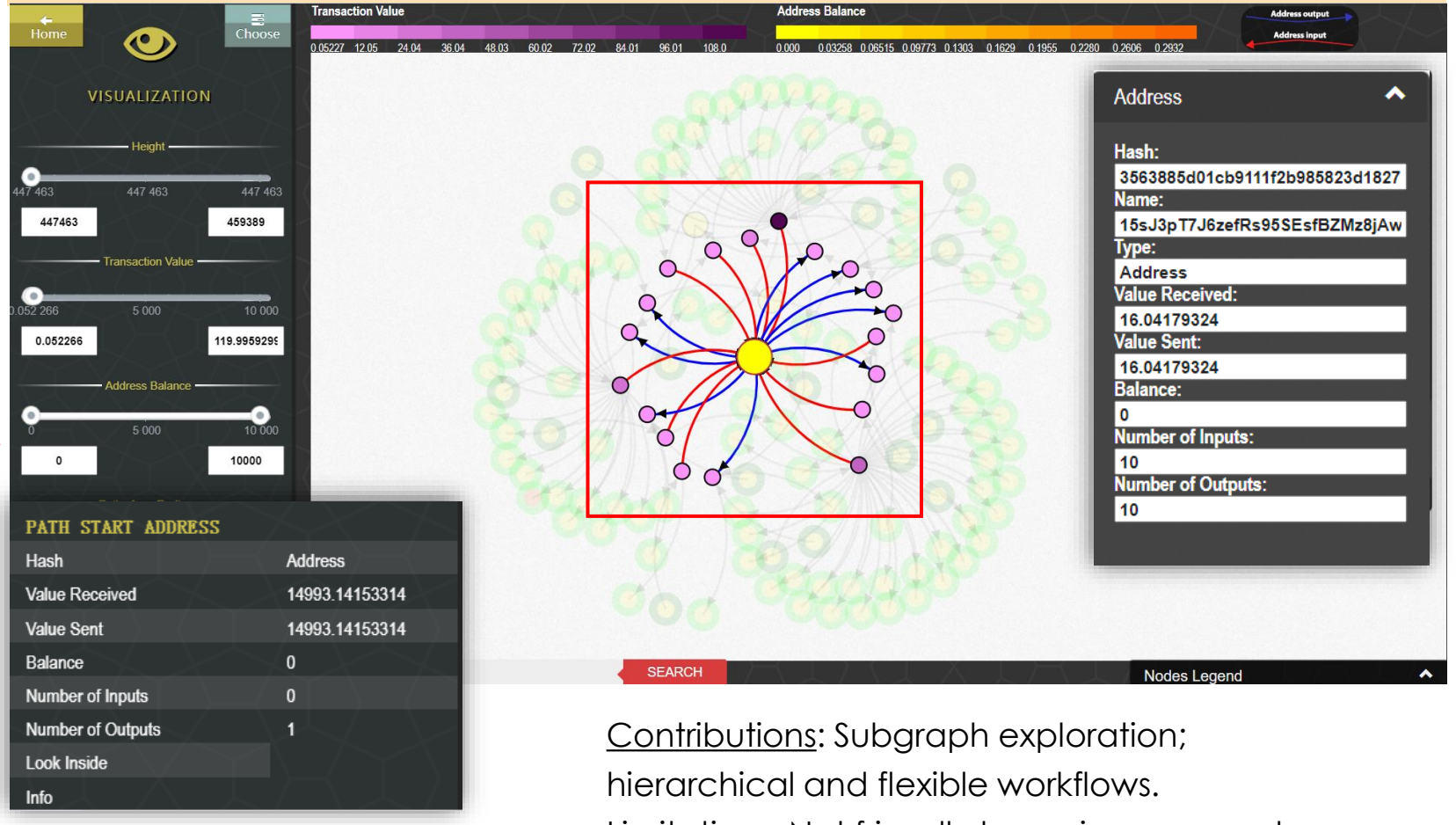


Transaction pattern detection

BlockchainVis, Bistarelli et al., 2017.



Address transaction visualization (Island view)



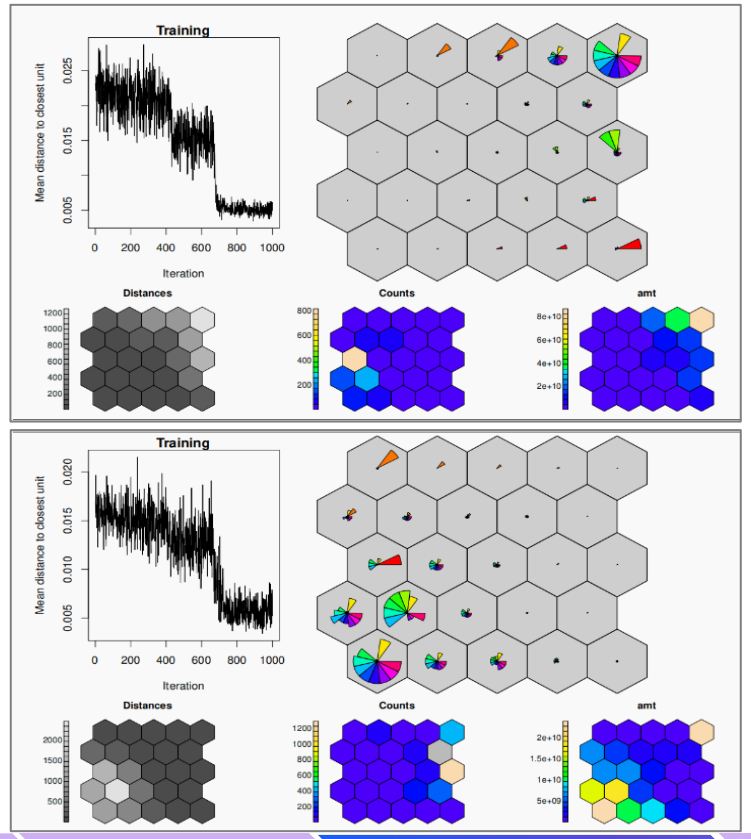
Contributions: Subgraph exploration; hierarchical and flexible workflows.
Limitations: Not friendly to novice users; not involve external data; learning curve is steep.

Transaction pattern detection

Cryptocurrency transaction analysis

Value flow analysis

- To illustrate details of value flow during cryptocurrency transactions;
- To compare cryptocurrency transactions by visualizing related attributes.



Chawathe (2018)

Contributions:

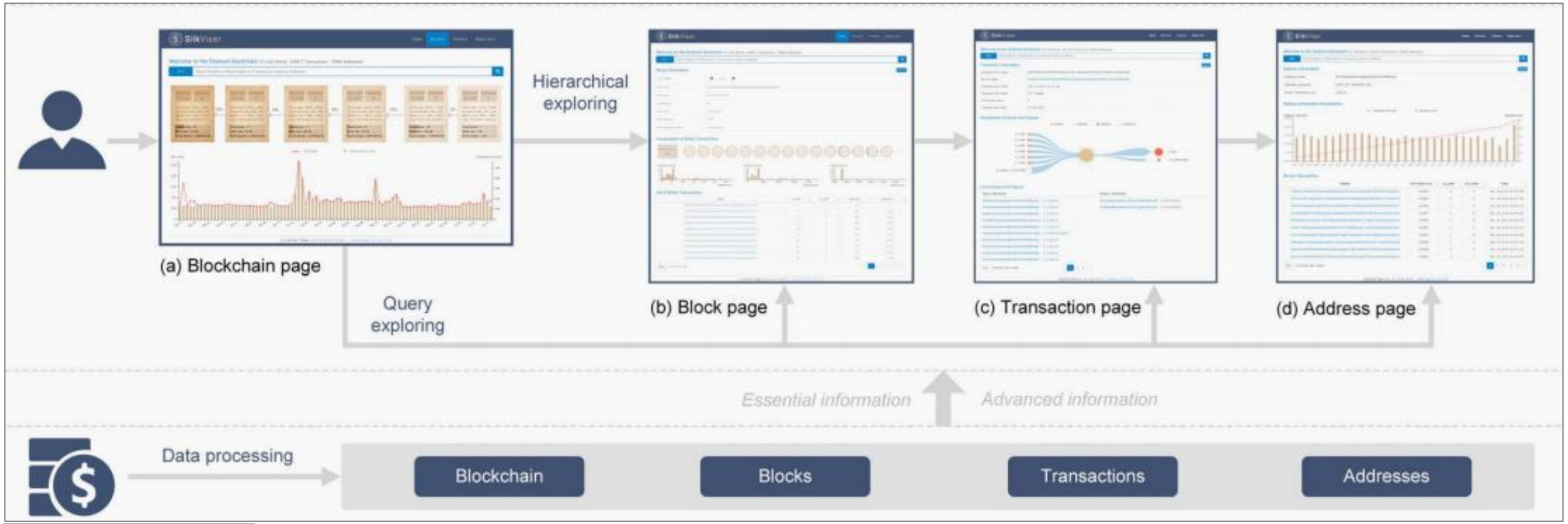
- Allow autonomous visualization generation;
- Easy to compare;
- Provide details for every single transactions.

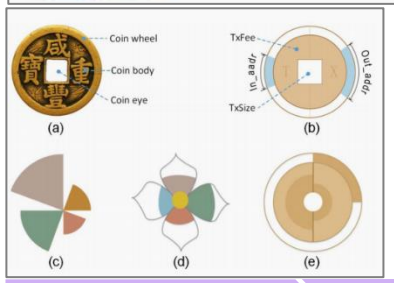
Limitations:

- Steep learning curve;
- Cannot provide insights Independently;
- Interaction is limited;
- No evaluation.

Transaction pattern detection

SilkViser, Zhong et al., 2020.





Contributions:

- Metaphoric glyphs;
- Friendly to novice users;
- Light interactions and clear workflow.

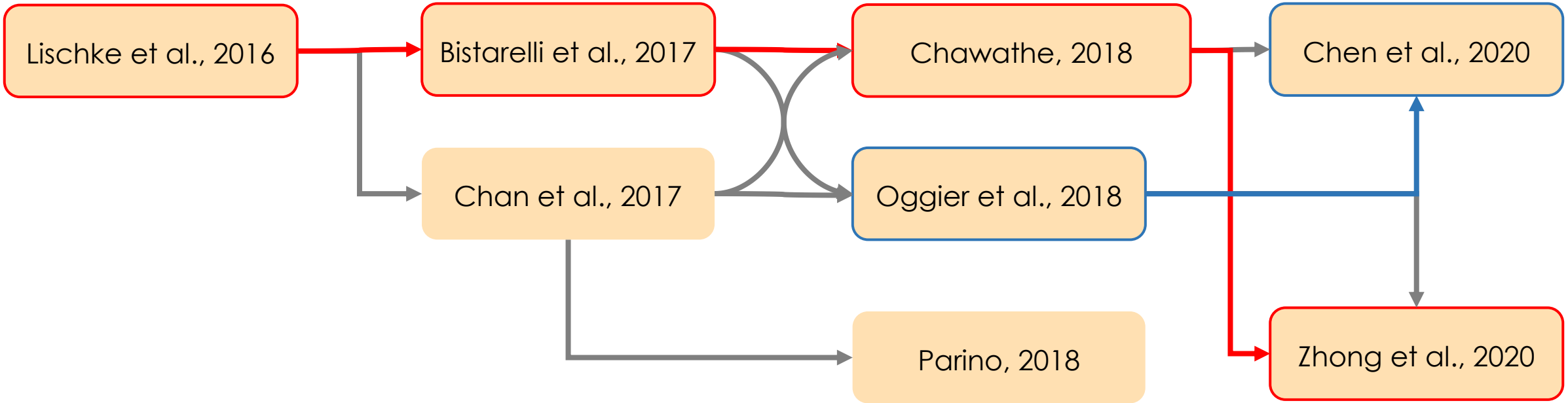
Limitations:

- The interface suitable issues;
- Cross culture communication issues;
- Scalability;
- Cannot support in-depth and complicated analysis.

Transaction pattern detection

To summarize

- The number of comprehensive and interactive VA systems is limited, while statistical analysis works comprise the majority.
- The most frequent interaction techniques are query, filter, and zoom in, which require a user to obtain essential knowledge about blockchain data properties.
- Many works (except Zhong et al.) did not involve domain experts or at least external users to participate in the evaluation and case study section.



Transaction pattern detection

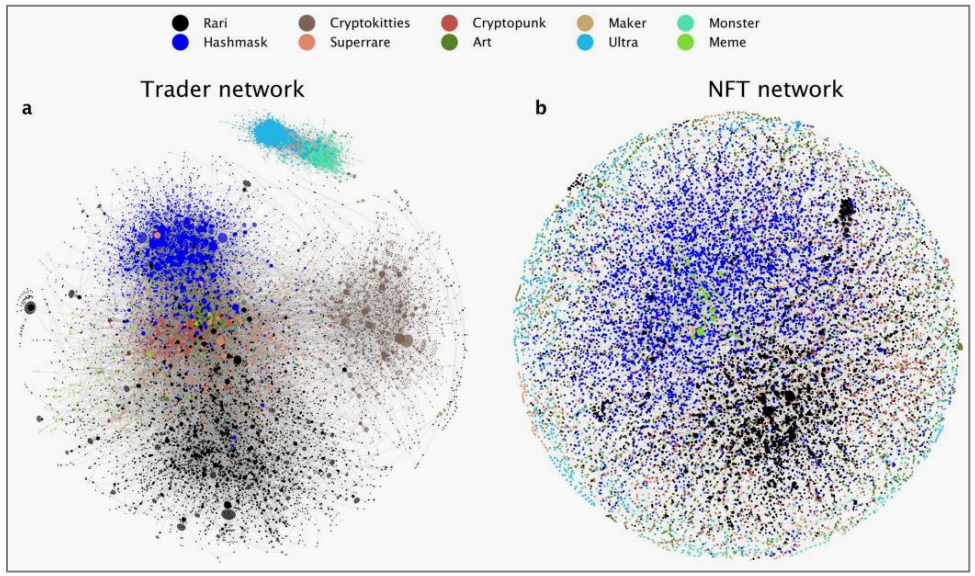
NFT transaction analysis

Market trend presentation

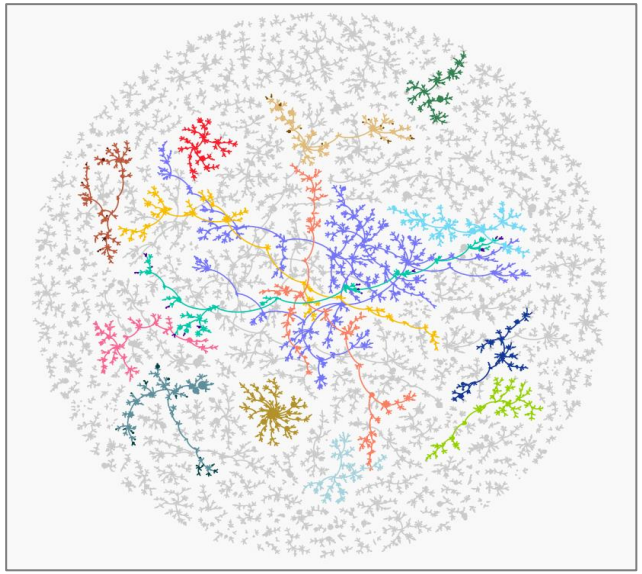
- To present the revolution of NFT marketplaces;
- To display stakeholders' (e.g., traders, artists, and players) interaction networks.

Contributions:
Multi-facet network.

Limitations:
- Mixed various participants into single networks.
- Induce visual clutter.
- Obscure analysis focus.
- No evaluation.



Nadini et al. (2021)



Vasan et al. (2022)

Contributions:
- Clear research focus.
- Cluster artists' social committees.

Limitations:
- Cannot provide insights Independently.
- Visual clutter.
- No evaluation.

Transaction pattern detection

NFT transaction analysis

Impact attributes extraction

- To detect the significant impact attributes of NFT marketplaces through visualization charts.

Ante (2021)	Investigate the interrelationships between NFT sales, NFT users (unique active blockchain wallets), and the pricing of Bitcoin and Ether by VECM method (cointegrated VAR).
Dowling (2022)	Wavelet coherency graph to show how NFT pricing relates to cryptocurrency market pricing. (A spillover index shows low spillover between cryptocurrencies and NFTs).
Kapoor et al. (2022)	This work gauges the impact of social media on NFT collectibles' virality, and predict assets' value via machine learning and deep learning models accordingly
Mekacher et al. (2022)	This work quantify Non-fungible token (NFT) rarity and investigate how it impacts market behaviors.

Conrtibutions:

- Clear statistical analysis;
- Inspiring for the nascent NFT analysis domains.

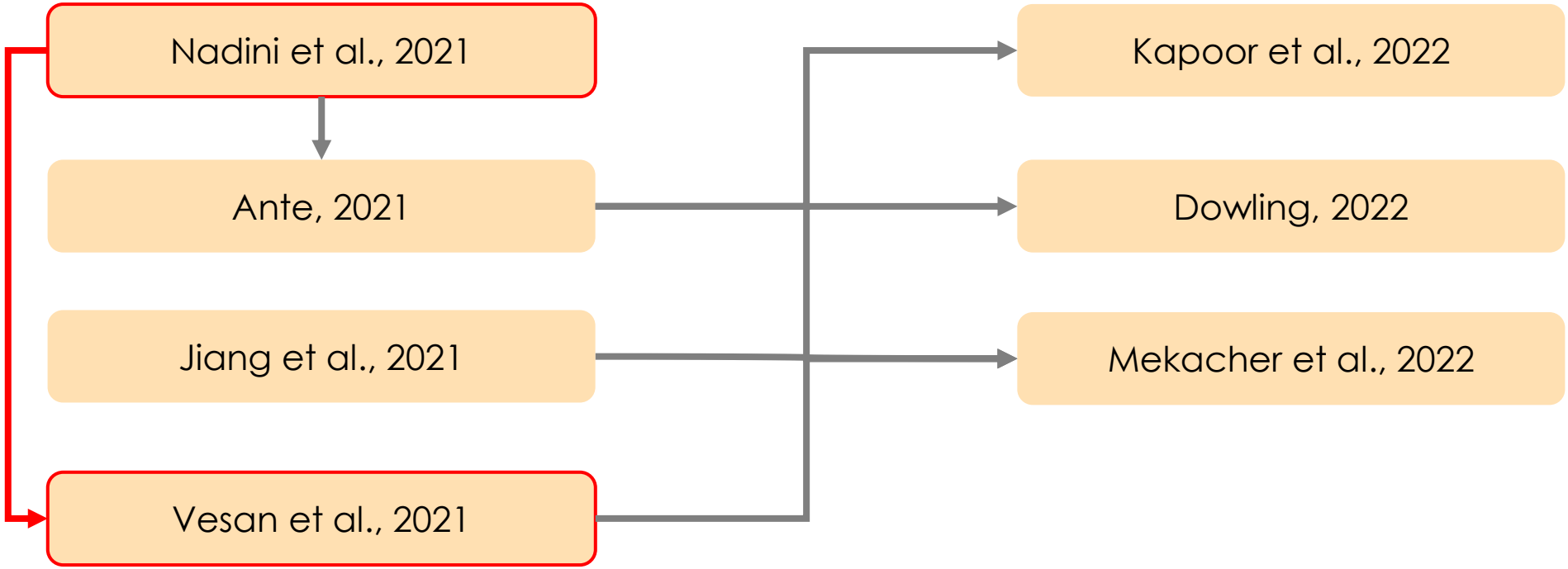
Limitations:

- Did not differentiate the categories of diversified NFT-tied assets;
- No interactions and cannot support exploratory analysis;
- Only detect single kind of impact attribute.

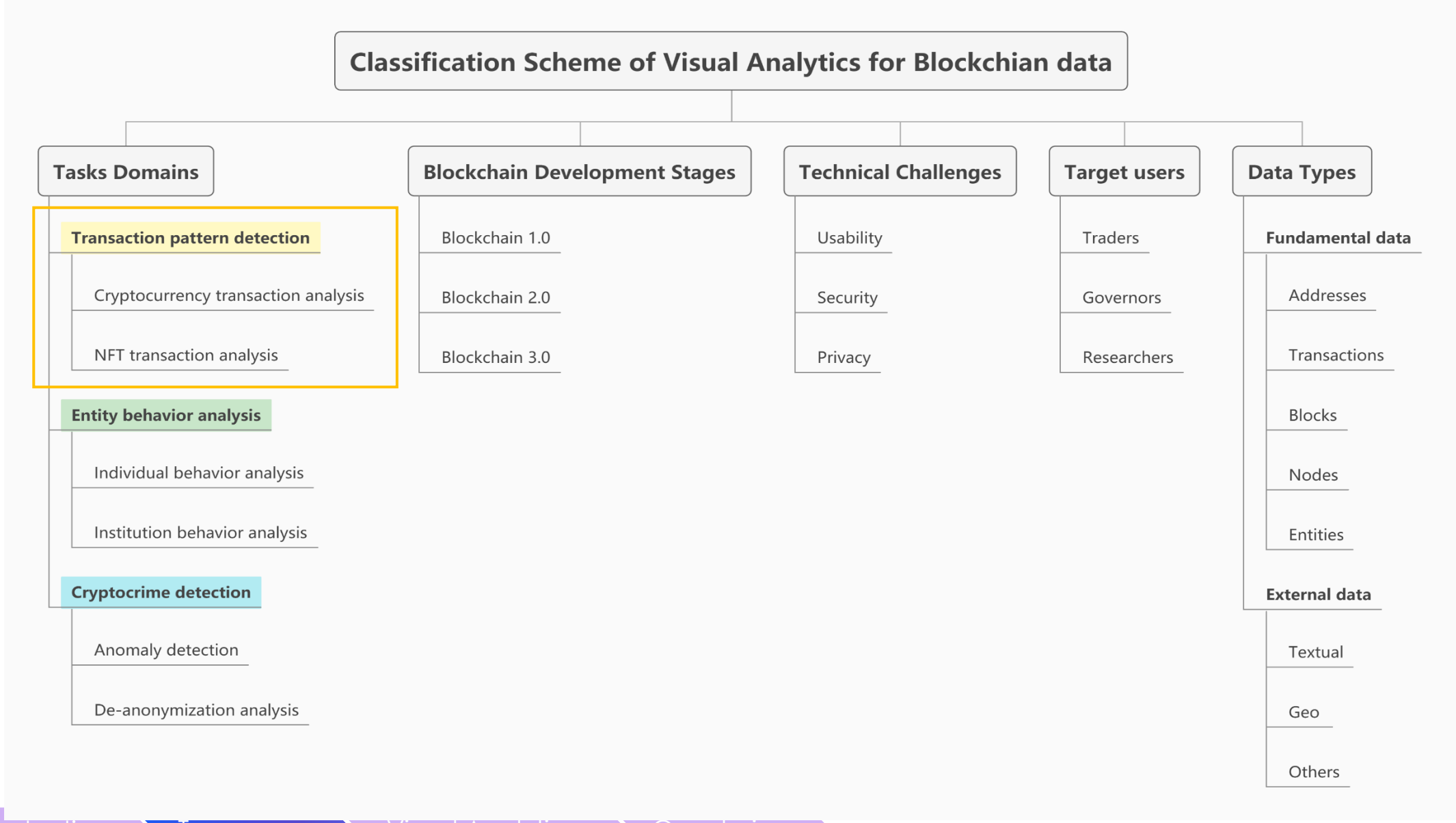
Transaction pattern detection

To summarize

- The number of investigations of NFT marketplaces is increasing rapidly.
- The scope of studies is polarized, either focusing on the micro impact attributes or the macro market trend.
- Current network graphs for NFT stakeholders induce visual clutter for viewers, and thus cannot fulfill the
- Efficiency during analysis or insights generation.



Classification scheme



Transaction pattern detection

Task Domains	Subtasks	Surveyed papers	Stages	Technical Challenges	Target Users	Data types	Data Mining	Visual Analytics
Crypto-currency transaction analysis	Network analysis	Lischke et al. (2016) Bistarelli et al. (2017) Chan et al. (2017) Chen et al. (2020) Oggier et al. (2018)	1.0	Usability	Traders & Researchers	Fundamental + External	✓	✓
	Value flow analysis	Chawathe (2018) Parino et al. (2018) Zhong et al. (2020)					✓	✓
NFT transaction analysis	Market trend presentation	Jiang et al. (2021) Nadini et al. (2021) Vasan et al. (2022)	2.0		Researchers		✓	O
	Impact attributes extraction	Ante (2021) Dowling (2022) Kapoor et al. (2022) Mekacher et al. (2022)					✓	?

✓: interactive visual analytics | O: static visual analytics | ?: no visual analytics

Entity behavior analysis

Entity behavior analysis

Individual behavior analysis

- Isenberg et al. (2017)
- Kuzuno et al. (2017)
- Sun et al. (2019)
- Kinkeldey et al. (2021)

Institution behavior analysis

Exchanges centered

- Ranshous et al. (2017)
- Yue et al. (2018)

Mining pools centered

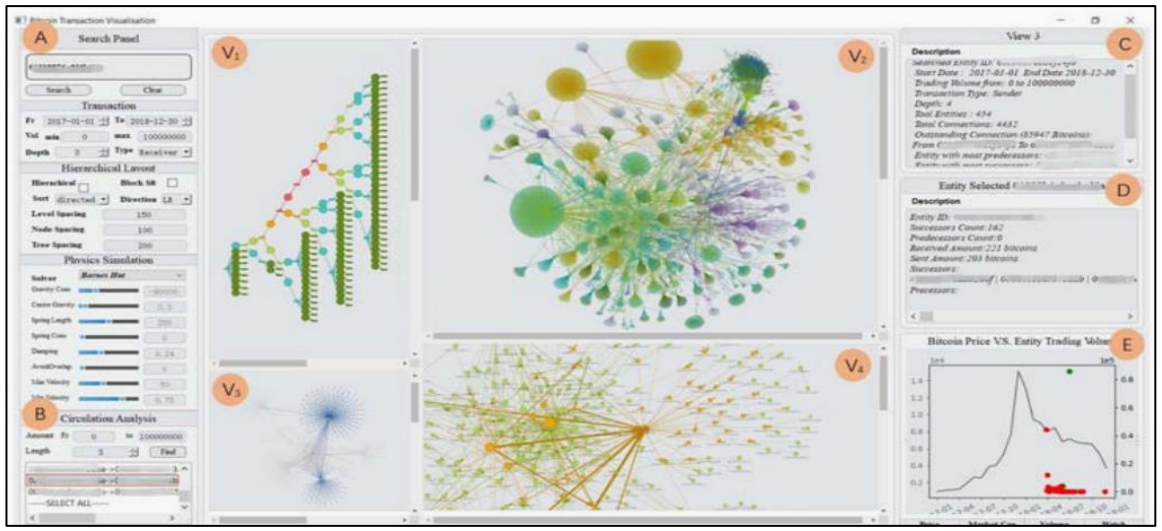
- Xia et al. (2020)
- Tovanich et al. (2021)
- Tovanich et al. (2021)

Entity behavior analysis

Individual behavior analysis

- The most granular task among all visual analytics tasks of blockchain data.
- It is worth noting that the individual entities are aggregated from co-occurred addresses.
- The research object for individual behavior analysis is hypothetical clients instead of single transaction addresses.

Isenberg et al.et al. (2017)



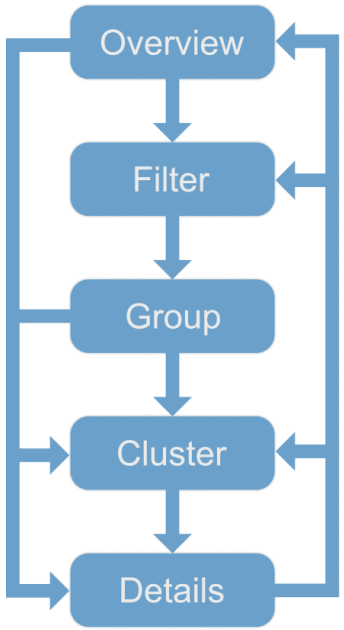
Sun et al. (2019)

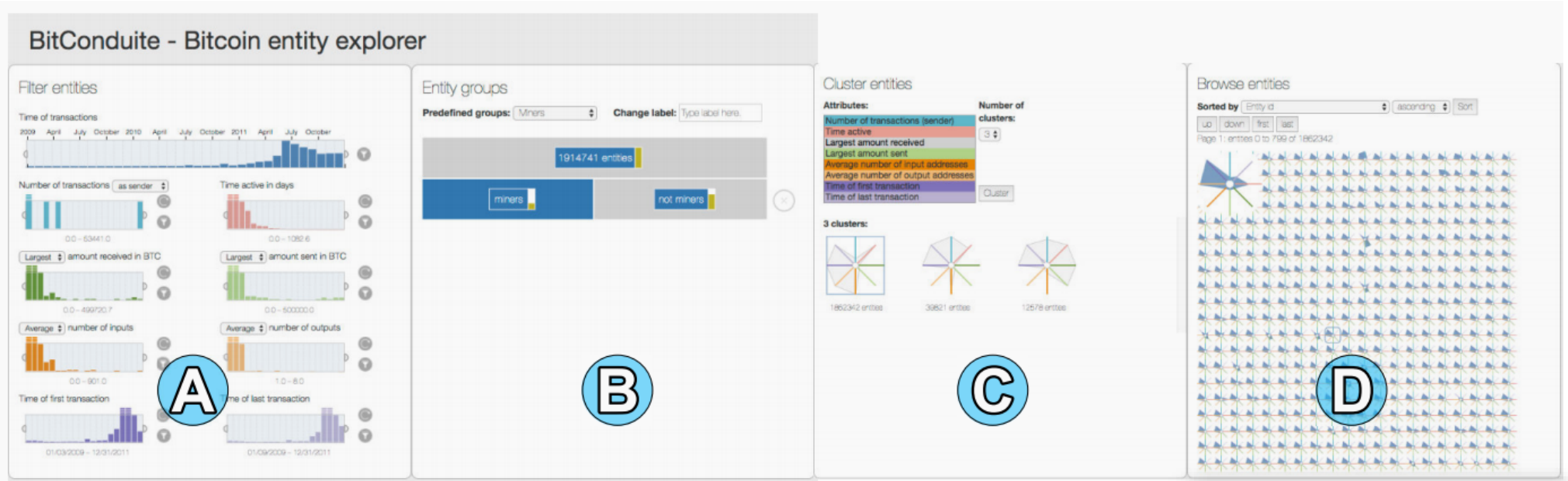
Contributions: Clear interactive interface; low cognitive load.
Limitations: Cannot support in-depth and complicated analysis.

Contributions: Facilitate fast and convenient account-based bitcoin activity analysis; provide multi-facet details than previous works.
Limitations: Visual clutter; scalability.

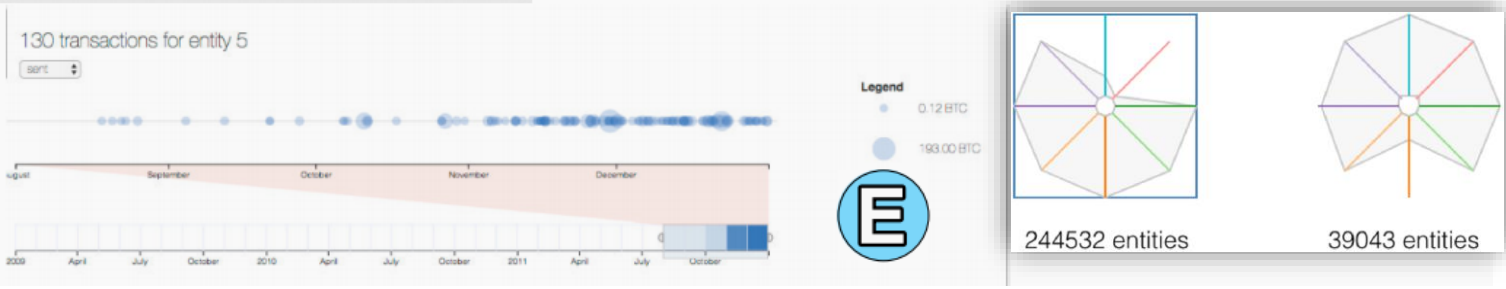
Entity behavior analysis

Bitconduite, Kinkeldey et al., 2021.



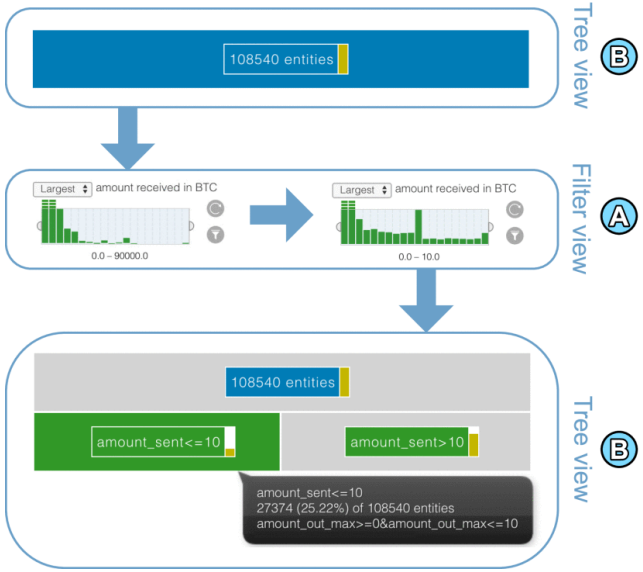


Measure	Color	Description	Definition
num_txs		Number of transactions (as sender / as receiver)	Overall number of transactions per entity.
time_first		Time of first transaction	Point in time, from which an entity was active.
time_last		Time of last transaction	Point in time, until which an entity was active.
time_active		Time active in days	Duration: last minus first transaction of an entity.
amount_rec		Amount received in BTC: s/a/l	Amount of Bitcoin an entity received.
amount_sent		Amount sent in BTC: s/a/l	Amount of Bitcoin an entity sent.
num_inputs		Number of inputs: s/a/l	Number of input addresses per transaction.
num_outputs		Number of outputs: s/a/l	Number of output addresses per transaction.

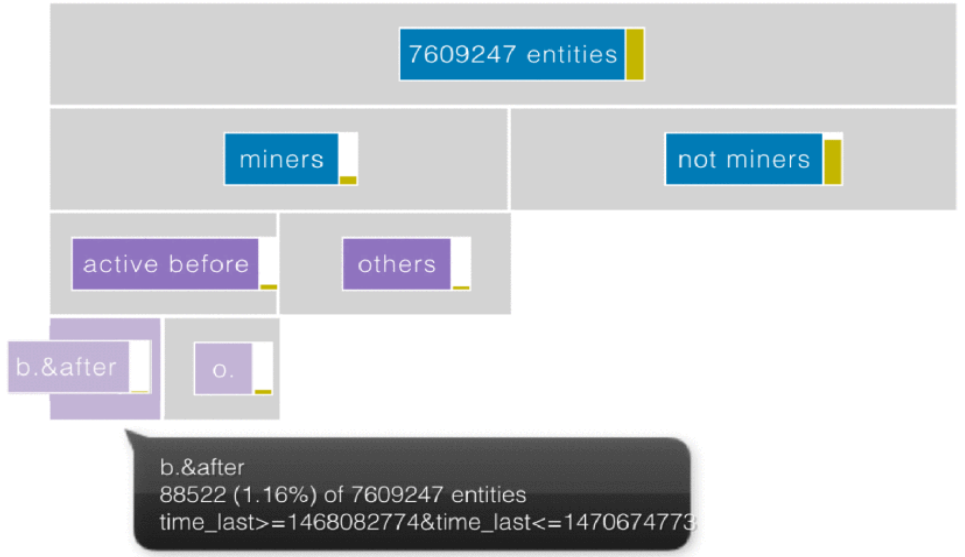


Entity behavior analysis

Bitconduite, Kinkeldey et al., 2021.



Principle of the entity group tree



Group of entities that were active as miners

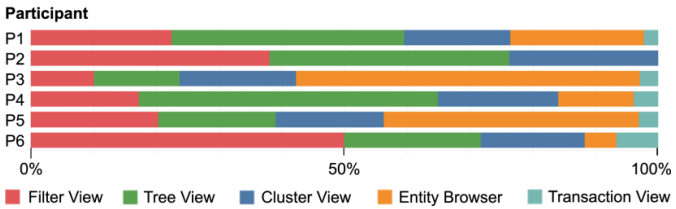
Contributions:

- Lower the threshold of Bitcoin analysis.
- Help with a deeper analysis for social scientists.

Limitations:

- Cannot identify the entities in reality;
- Scalability limitations due to computing latency;
- No methods to measure entity aggregation quality;
- Not friendly for novice users.

Category	Questions
Exploring specific entities (known entities)	Does Kraken have liquidity issues? (P2) How many [B]itcoins does Satoshi own? (P2)
Exploring specific entities (other entities)	*Do [entities] [exchange] money with the same people? (P1) Who are the 10 main owners of Bitcoin and how much [do] they own? (P3)
Linking and relationships between entities	*Do [entities] send small amounts to 1 person (or the opposite = large amount[s] to multiple)? (P1) Do mining pools interact with each other directly? (P1) *Explore and link multiple entities to a single one based on its behavior (P1)
Exploring trends (behavior)	*Which factors affect pools of miners dynamics? (P1) *What happened to BTC exchange platforms during trouble periods? (P6)
Exploring trends (temporal)	*Are there daily users that are non-miners / non-professionals? (P1) Is there any seasonality in the use of BTC? (P5)

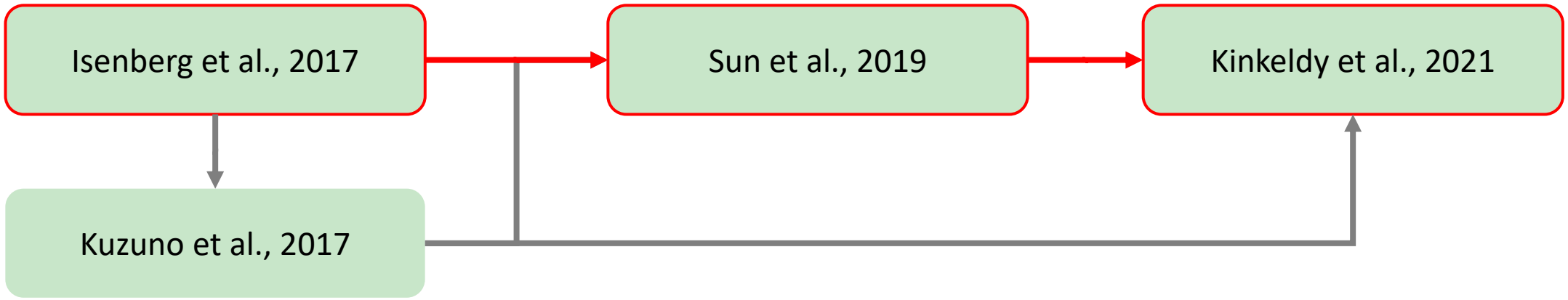


Evaluation

Entity behavior analysis

To summarize

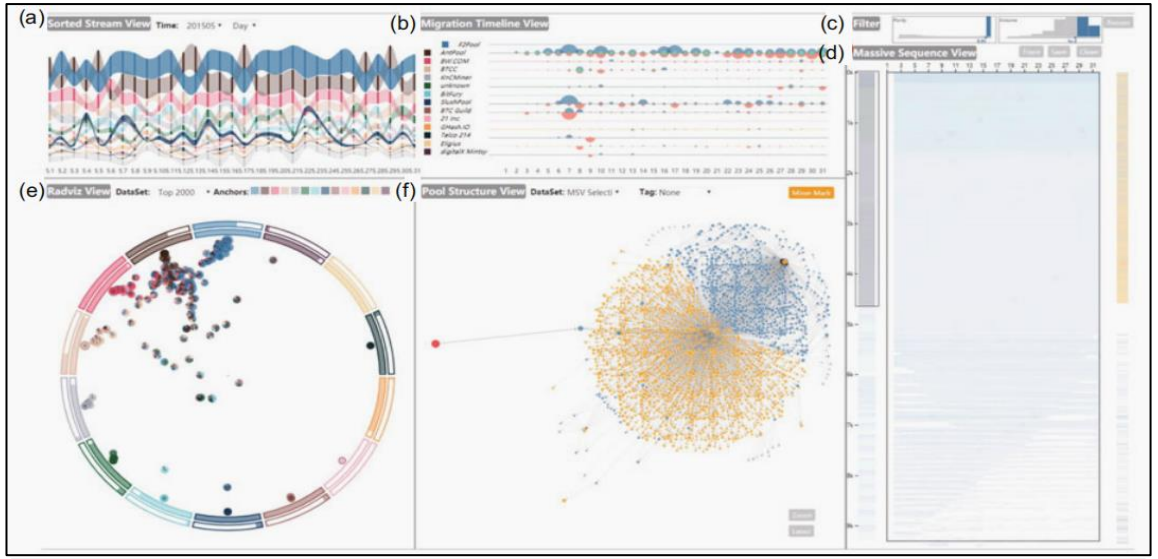
- Addresses directly connect users and are the most micro analysis units, which are the start points for analysis.
- Researchers applied diversified interaction techniques to support investigations.
- The clients detected by aggregating addresses are uncertain and cannot be quantified.



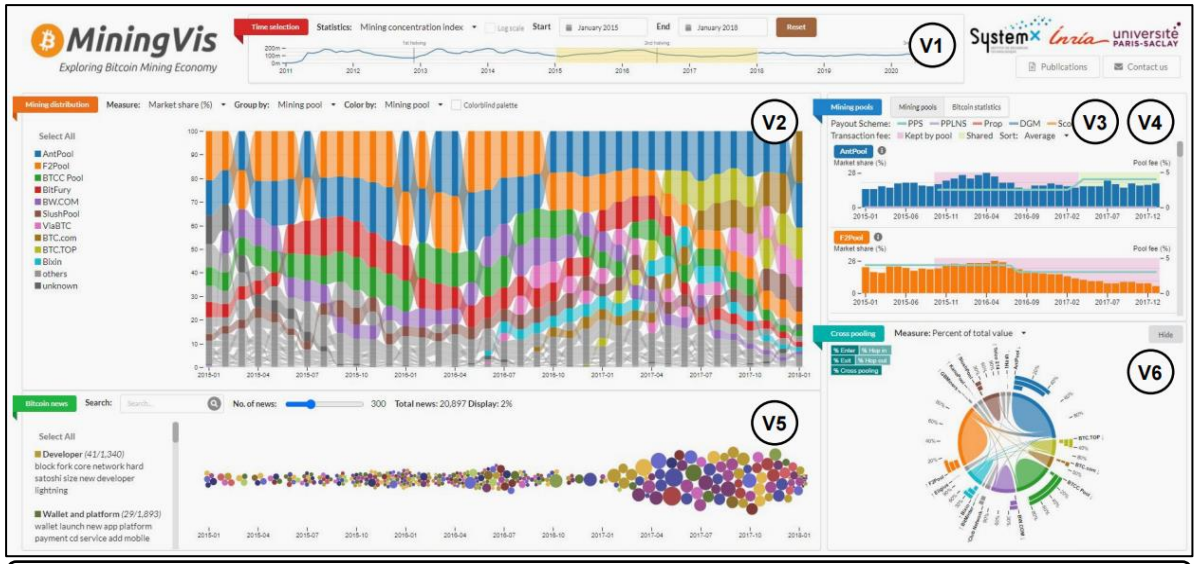
Entity behavior analysis

Institution behavior analysis

- Mining pools and exchanges rapidly developed among the organizations and affected many other blockchain applications and businesses.
- To understand and monitor these organizations.



Xia et al.et al. (2020)



Tovanich et al. (2021)

Contributions: A comprehensive visual surveillance system for mining pools from pool level and address level.
Limitations: Huge and messy force-directed graph; too colorful.

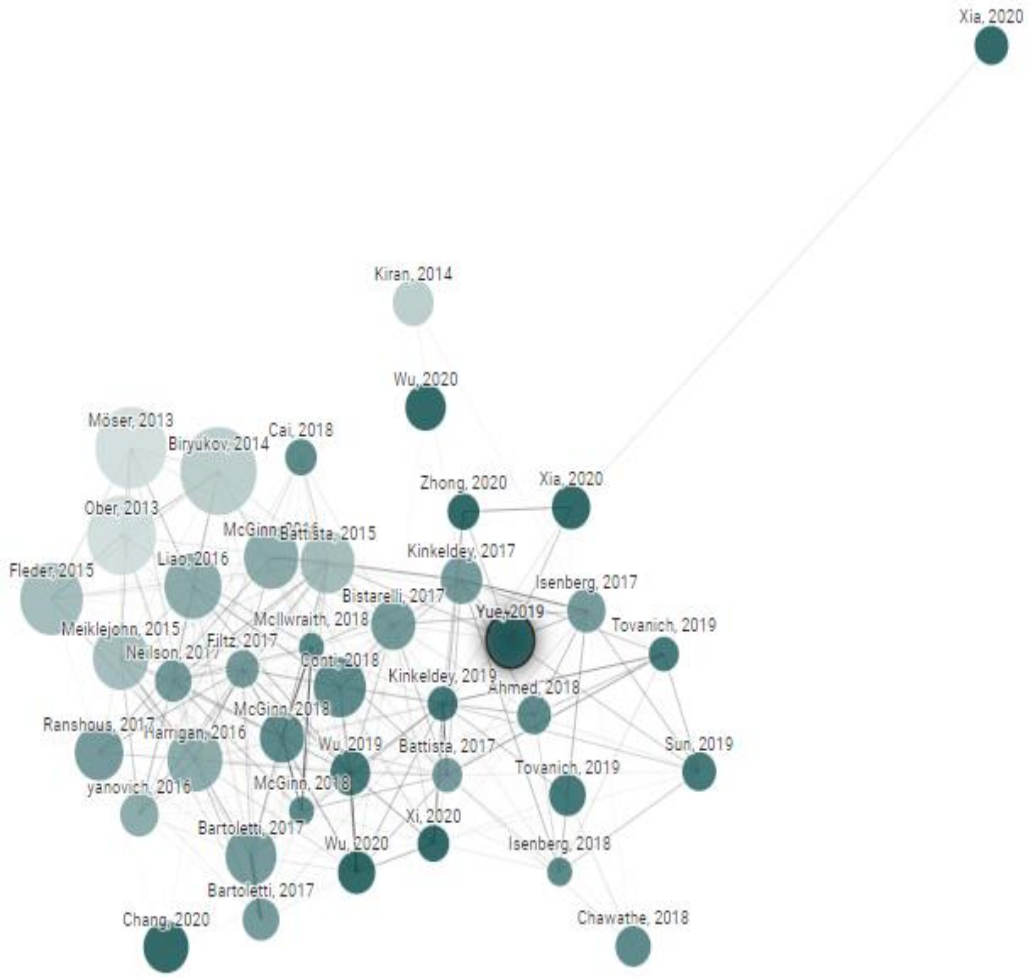
Contributions: Tackle the research gap of a lack of tools and systems that help to analyze Bitcoin mining in detail.
Limitations: A lack of real-time data; hard to extract insights from the textual data.

Entity behavior analysis

BitExTract, Yue et al., 2018.

Derivative works:

Title	Last author	Year	Citations	Graph references
Visualization of Blockchain Data: A Systematic Review	P. Isenberg	2019	8	15
Knowledge Discovery in Cryptocurrency Transactions: A Survey	C. Tse	2020	16	13
SilkViser: A Visual Explorer of Blockchain-based Cryptocurrency Transaction Data	Ronghua Shi	2020	0	12
SilkViser: A Visual Explorer of Blockchain-based Cryptocurrency Transaction Data	Ronghua Shi	2020	2	12
SuPoolVisor: a visual analytics system for mining pool surveillance	Wei-ping Wang	2020	11	12
Visualizing and Analyzing Entity Activity on the Bitcoin Network	P. Isenberg	2019	1	9
Analysis of Cryptocurrency Transactions from a Network Perspective: An Overview	Zibin Zheng	2020	16	9
BitVis: An Interactive Visualization System for Bitcoin Accounts Analysis	Kwok-Yan Lam	2019	4	8
A Survey on Blockchain Anomaly Detection Using Data Mining Techniques	Xi Chen	2019	5	8
BitExTract: Interactive Visualization for Extracting Bitcoin Exchange Intelligence	Siyuan Liu	2019	27	8



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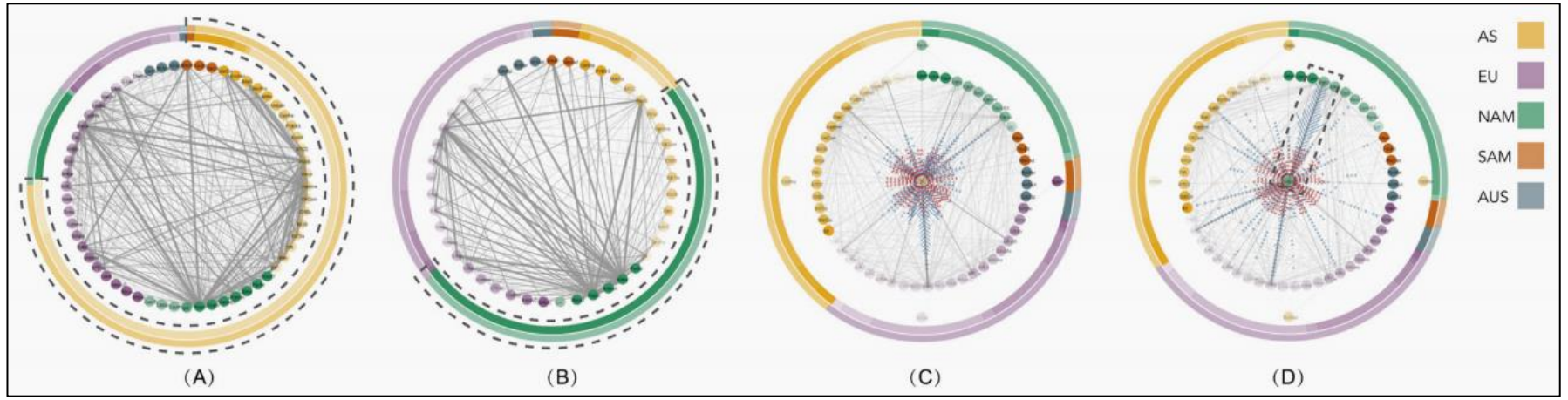
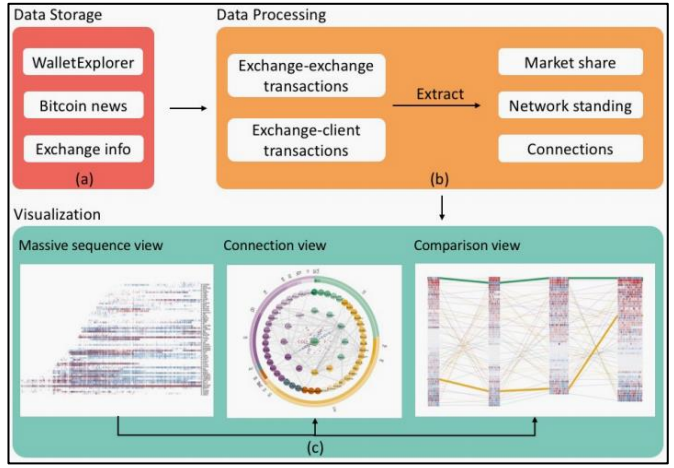


Exchange network patterns on connection view



System Overview

Contributions:

- The first attempt to explore the evolutionary transaction patterns of Bitcoin exchanges from two perspectives, namely, exchange vs exchange and exchange vs client.
- A new dynamic timeline visualization combined with parallel bars that demonstrates time-varying, multi-variable transaction data features for comparison between exchanges.

Limitations:

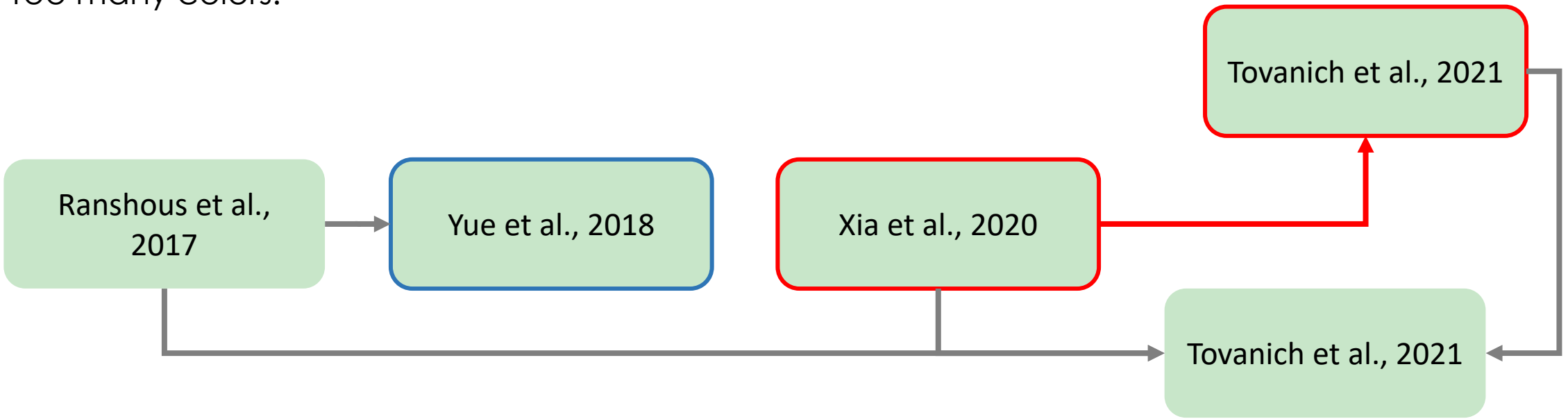
- Complicated design and steep learning curve;
- Scalability issues of showing over 10 months transactions in comparison view, or showing over 60 exchanges in massive sequence view;
  ➡ (Filter interaction)
- Data uncertainty due to anonymity properties of blockchain data;
- Possible visual clutters in connection view.

A common issue

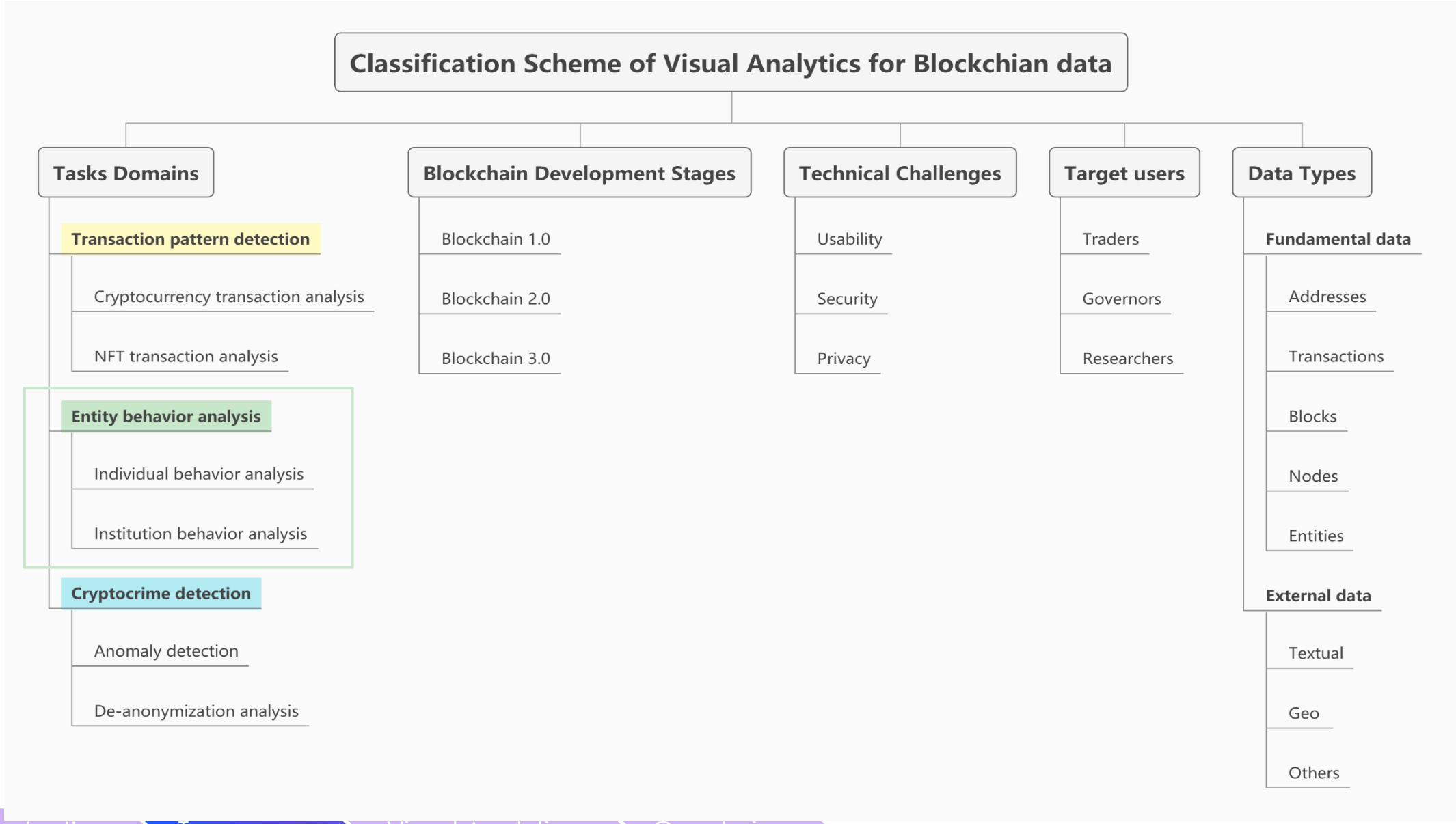
Entity behavior analysis

To summarize

- More comprehensive and support multi-dimensional, hierarchical workflows.
- Support diversified data sources and data types for exploration.
- Scalability limitations and visual clutters.
- Too many colors.



Classification scheme



Entity behavior analysis

Task Domains	Subtasks	Surveyed papers	Stages	Technical Challenges	Target Users	Data types	Data Mining	Visual Analytics
Individual behavior analysis	-	Isenberg et al. (2017) Kuzuno et al. (2017) Sun et al. (2019) Kinkeldey et al. (2021)	1.0	Usability	Traders & Researchers	Fundamental	✓	✓
Institution behavior analysis	Exchanges centered	Ranshous et al. (2017) Yue et al. (2018)	2.0	Usability + Security	Traders & Researchers & Governors	Fundamental + External	✓	✓
	Mining pools centered	Xia et al. (2020) Tovanich et al. (2021) Tovanich et al. (2021)					✓	✓

✓: interactive visual analytics | O: static visual analytics | ?: no visual analytics

Cryptocrime detection

Cryptocrime detection

Anomaly detection

Taint flow presentation

- Battista et al. (2015)
- Ahmed et al. (2018)

Attacks identification

- McGinn et al. (2016)
- Pham et al. (2016)
- Saad et al. (2019)

Illegal business analysis

- Balthasar et al. (2017)
- Norbutas (2018)

De-anonymization detection

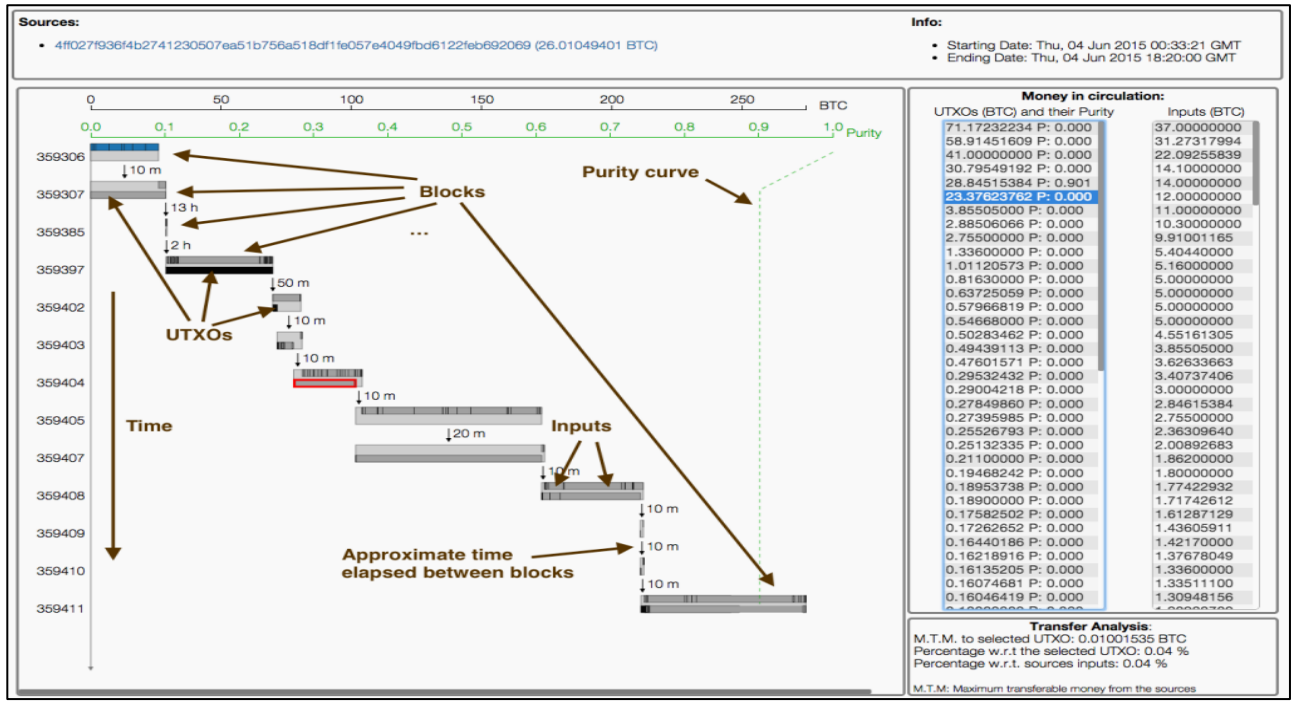
- Meiklejohn et al. (2013)
- Reid et al. (2013)
- Biryukov et al. (2014)
- Fleder et al. (2015)
- Boshmaf et al. (2019)

Cryptocrime detection

Anomaly detection

Taint flow presentation

- To trace the flow of stolen cryptocurrency;
- To detect the change of "purity" within transactions.



Battista et al. (2015)

Contributions:

- A VA system with high-level metaphors for the representation of the graph and the size and characteristics of transactions.
- The first graphical tool for the analysis of flows in the blockchain.

Limitations:

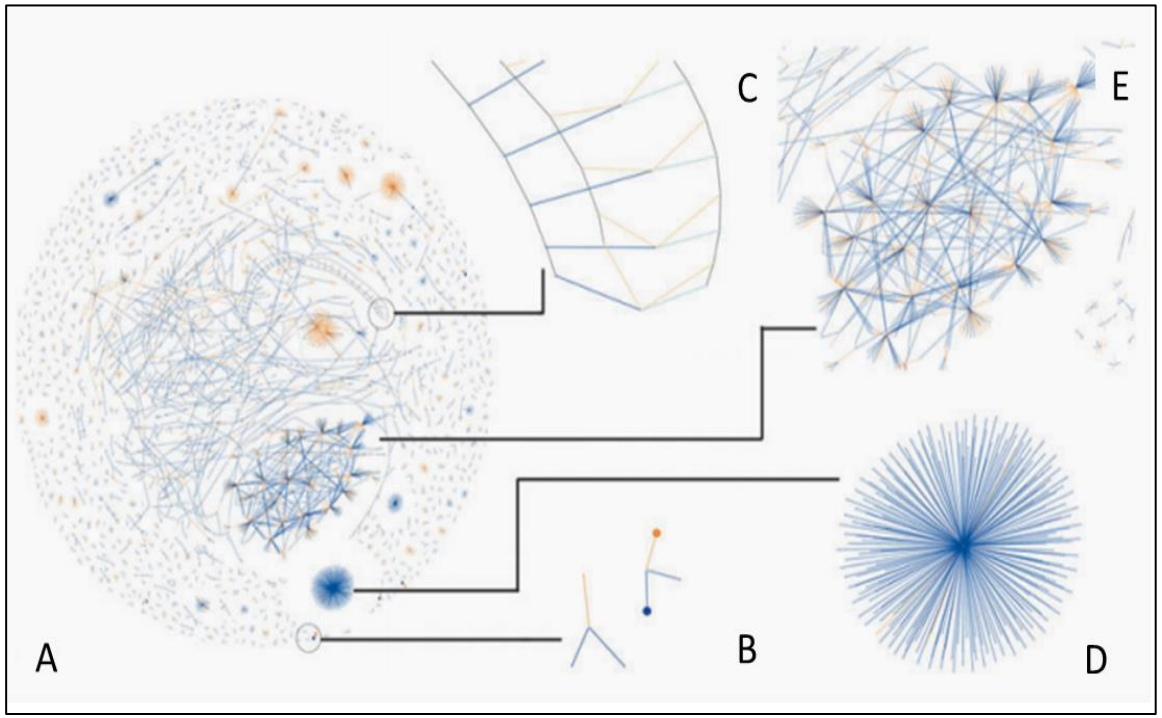
- Scalability issues when the BitCone contains more blocks than can comfortably fit on the screen.
  - (A clustering mechanism that groups together consecutive Blocks.)
- Restrict to a limited time interval.
- Hard to compare;
  - (Morph new and older selected BitCone to preserve users' mental map.)
- Cannot support high-grained explorations within a selected block.

Cryptocrime detection

Anomaly detection

Attacks identification

- To extract suspicious events, such as algorithmic denial of service attacks, partitioning attacks, fraud, and unusual spikes in transactions.



McGinn et al. (2016)

Contributions:

- An effective force-directed graph visualization employed in the large-scale data observation facility to accelerate this data exploration and derive useful insight among domain experts and the general public alike.
- A high-resolution large-scale observatory for users to physically conduct a fine-grained analysis of one particular anomaly, while maintaining the context of the whole picture.
- Real-time data.

Limitations:

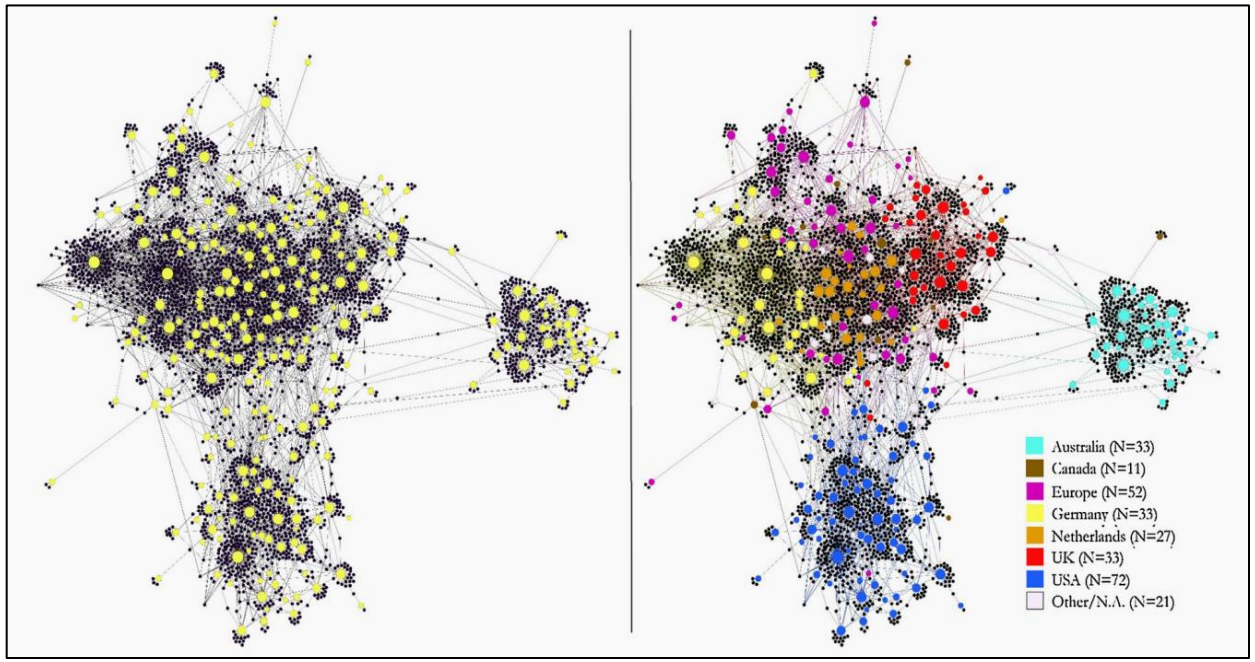
- Steep learning curve and cannot be interpreted by general public independently.
- High requirement for the presentation devices.
- Visual clutter of the network.

Cryptocrime detection

Anomaly detection

Illegal business analysis

- To analyze the transaction patterns of criminal organizations (e.g., Bitcoin laundry service providers and illicit drug dealers).



Norbutas (2018)

Contributions:

- Analyze the structure of a complete cryptomarket trade network with a focus on the role of geographic clustering of buyers and sellers.
- Use descriptive social network analysis and Exponential Random Graph Models (ERGM) to analyze the structure of the trade network.

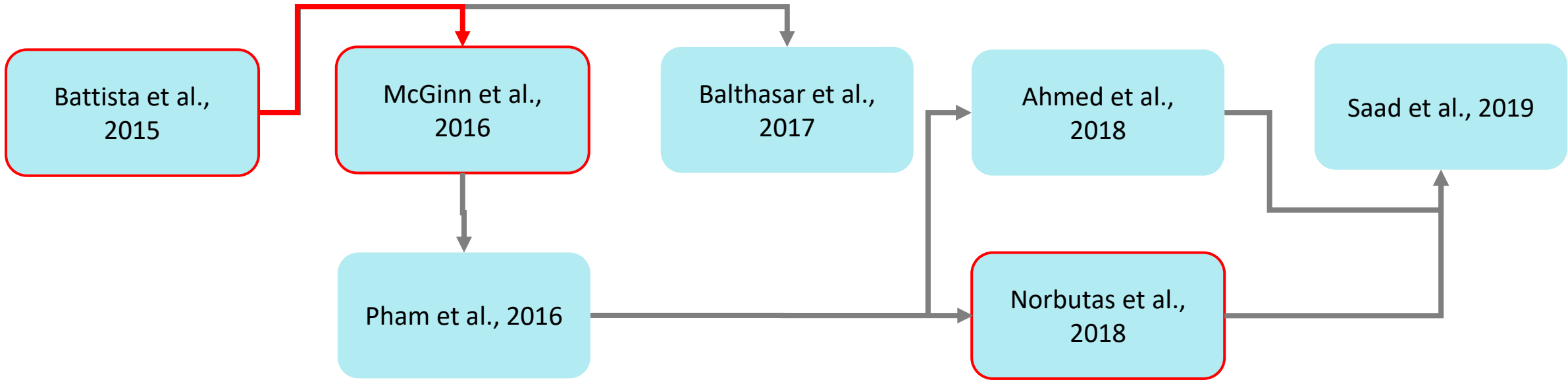
Limitations:

- Unable to evaluate insights directly, since buyers' geographic locations were not available in the cryptomarket website.
- Visual clutter, and the nodes distribution is not aligned with the geographic locations;
- The research target is a relatively small market and thus the insights can not be directly generalized to other cryptomarket.
- No interactions.

Cryptocrime detection

To summarize

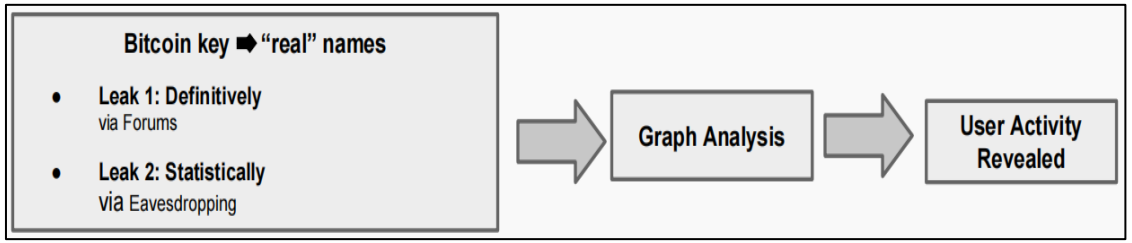
- Draw interests of researchers from diversified disciplines and governors of blockchain applications.
- Could be generalized to similar financial domain tasks with the related dataset.
- Hard to verify because of the pseudonymous characteristics of blockchain data.

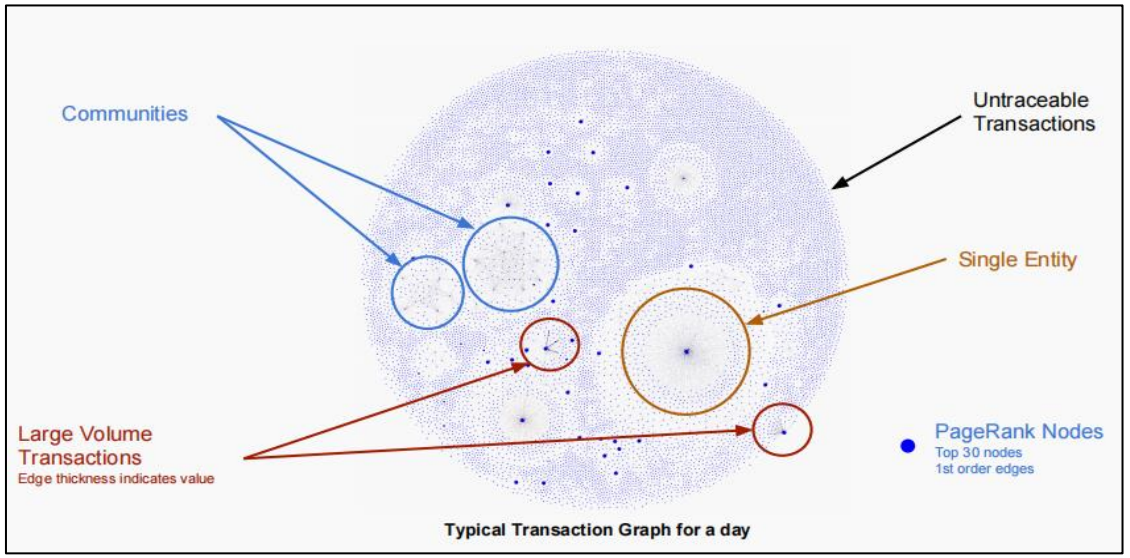


Cryptocrime detection

De-anonymization detection

- To identify owners of multiple addresses;
- To further detect criminal activities for surveillance.





Fleder et al. (2015)

Contributions:

- Developed a graph analysis framework in order to de-anonymize users' identities given publicly available information such as scraped bitcoin forum users, and bitcoin transaction information.
- Use PageRank as a guide to determine the most interesting nodes, or users in the user graph to further investigate their linkage with known forum users.

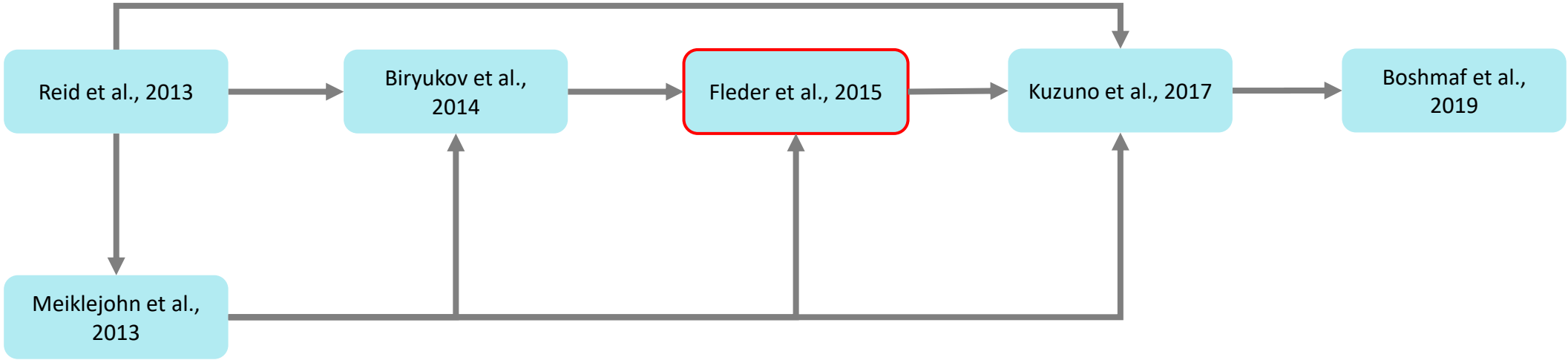
Limitations:

- The uncertainty in taking rough information regarding transaction time and value and matching it to an exact transaction in the blockchain.
- A limited time interval (only 24-hour period).
- The user network is not quite indicative of the true user network as several public key addresses that may have appeared out of the time interval are not used to link addresses.
- Visual clutter without any interactions.

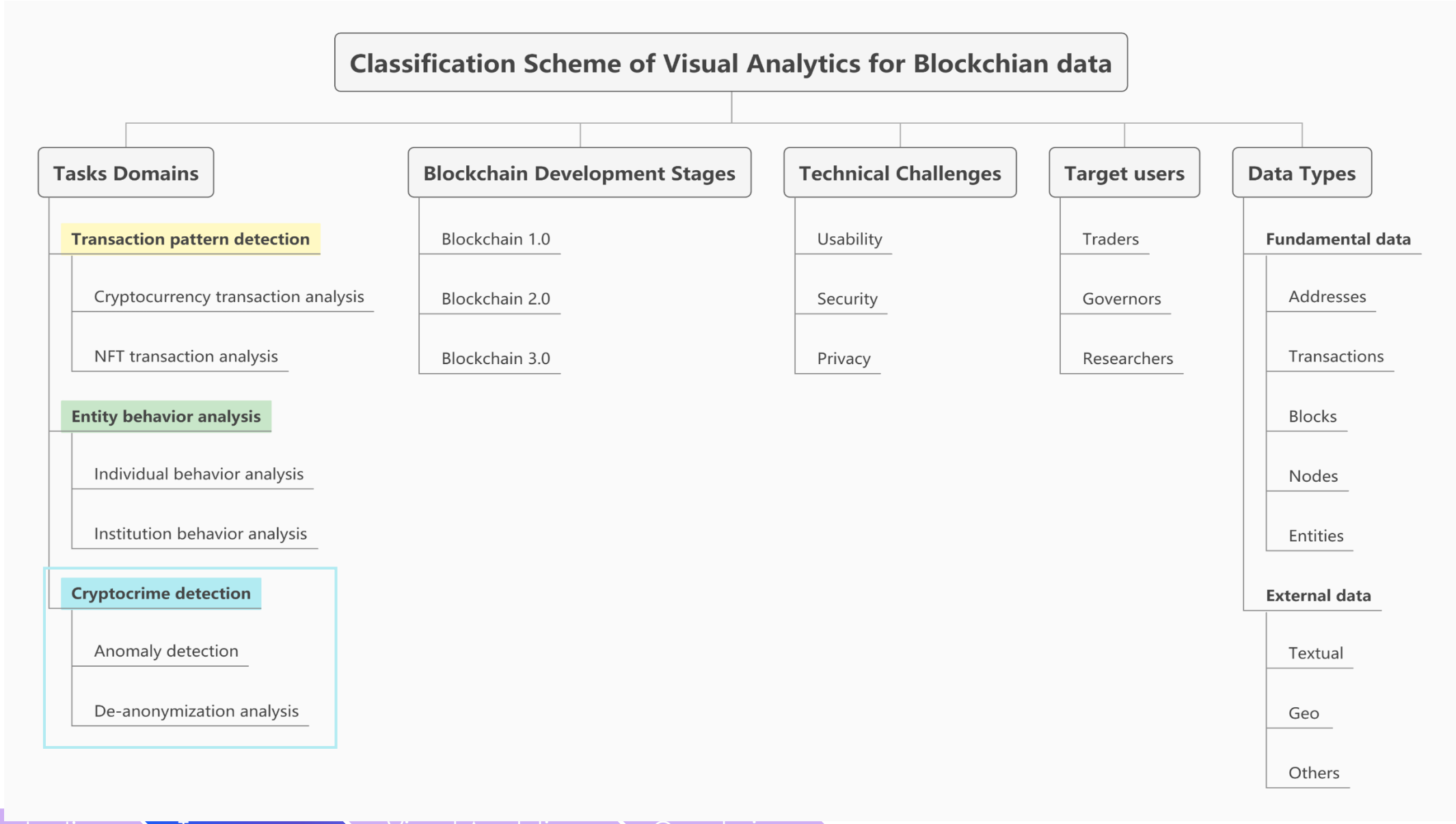
Cryptocrime detection

To summarize

- Visual analytics for de-anonymization detection is an essential topic for researchers and governors.
- Identifying clients' identities and profiles requires external information, which is hard to evaluate.
- No interactive VA system yet focusing on de-anonymization detection.
- The visualization designs are most node-link diagrams, which causes much visual clutter.



Classification scheme



Cryptocrime detection

Task Domains	Subtasks	Surveyed papers	Stages	Technical Challenges	Target Users	Data types	Data Mining	Visual Analytics
Anomaly detection	Taint flow presentation	Battista et al. (2015) Ahmed et al. (2018)	1.0	Security	Governors & Researchers	Fundamental	✓	✓
	Attacks identification	McGinn et al. (2016) Pham et al. (2016) Saad et al. (2019)				Fundamental	✓	O
	Illegal business analysis	Balthasar et al. (2017) Norbutas (2018)				Fundamental + External	✓	O
De-anonymization detection	-	Meiklejohn et al. (2013) Reid et al. (2013) Biryukov et al. (2014) Fleder et al. (2015) Boshmaf et al. (2019)		Security + Privacy	Researchers & Governors	Fundamental + External	✓	O

✓: interactive visual analytics | O: static visual analytics | ?: no visual analytics

Outline

Introduction

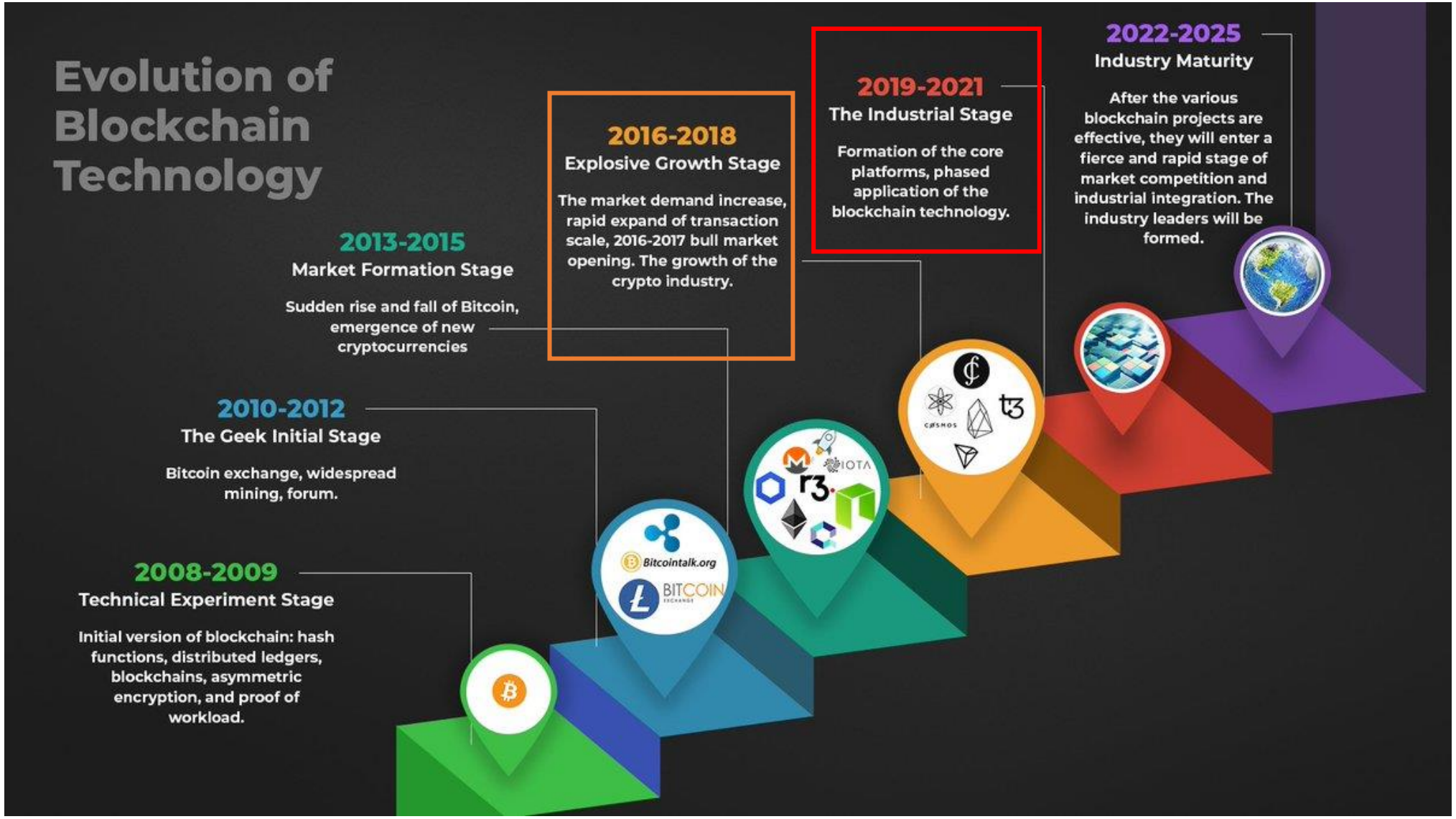
Taxonomy

Visual Analytics

Conclusion

- Research trend
- Future Directions

Research trend



Research trend

Explosive Growth Stage

The industrial Stage

Tasks	Subtasks	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Transaction pattern detection	NFT transaction analysis									Ante, Jiang et al., Nadini et al.	Dowling, Vasan et al., Kapoor et al., Mekacher et al.
	Crypto-currency transaction analysis				Lischke et al.	Bistarelli et al., Chan et al.	Oggier et al., Chawathe, Parino et al.		Chen et al., Zhong et al.		
Entity behavior analysis	Individual behavior analysis					Isenberg et al., Kuzuno et al.		Sun et al.		Kinkeldey et al.	
	Institution behavior analysis					Ranshous et al.	Yue et al.		Xia et al.	Tovanich et al.	
Crypto-crime detection	Anomaly detection			Battista et al.	McGinn et al., Pham et al.	Balthasar et al.	Ahmed et al., Norbutas	Saad et al.			
	De-anonymization detection	Meiklejohn et al., Reid et al.	Biryukov et al.	Fleder et al.				Boshmaf et al.			

Research trend

Tasks	Subtasks	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
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	Institution behavior analysis					Ranshous et al.	Yue et al.		Xia et al.	Tovanich et al.	
Crypto-crime detection	Anomaly detection			Battista et al.	McGinn et al., Pham et al.	Balthasar et al.	Ahmed et al., Norbutas	Saad et al.			
	De-anonymization detection	Meiklejohn et al., Reid et al.	Biryukov et al.	Fleder et al.				Boshmaf et al.			

Focus shift

The focus of research tasks is shifting from cryptocrime detection, entity behavior analysis, to transaction pattern detection, which echoed with the three development stages.

Extended data types

The data types involved in visual analytics extend from blockchain components (e.g., addresses, transactions, and blocks) to heterogeneous data types (e.g., social media and multi-media data).

Research gaps

Task Domains	Subtasks	Surveyed papers	Stages	Technical Challenges	Target Users	Data types	Data Mining	Visual Analytics
Crypto-currency transaction analysis	Network analysis	Lischke et al. (2016) Bistarelli et al. (2017) Chan et al. (2017) Chen et al. (2020) Oggier et al. (2018)	1.0	Usability	Traders & Researchers	Fundamental + External	✓	✓
	Value flow analysis	Chawathe (2018) Parino et al. (2018) Zhong et al. (2020)					✓	✓
NFT transaction analysis	Market trend presentation	Jiang et al. (2021) Nadini et al. (2021) Vasan et al. (2022)	2.0		Researchers		✓	O
	Impact attributes extraction	Ante (2021) Dowling (2022) Kapoor et al. (2022) Mekacher et al. (2022)					✓	?

Task Domains	Subtasks	Surveyed papers	Stages	Technical Challenges	Target Users	Data types	Data Mining	Visual Analytics
Individual behavior analysis	-	Isenberg et al. (2017) Kuzuno et al. (2017) Sun et al. (2019) Kinkeldey et al. (2021)	1.0	Usability	Traders & Researchers	Fundamental	✓	✓
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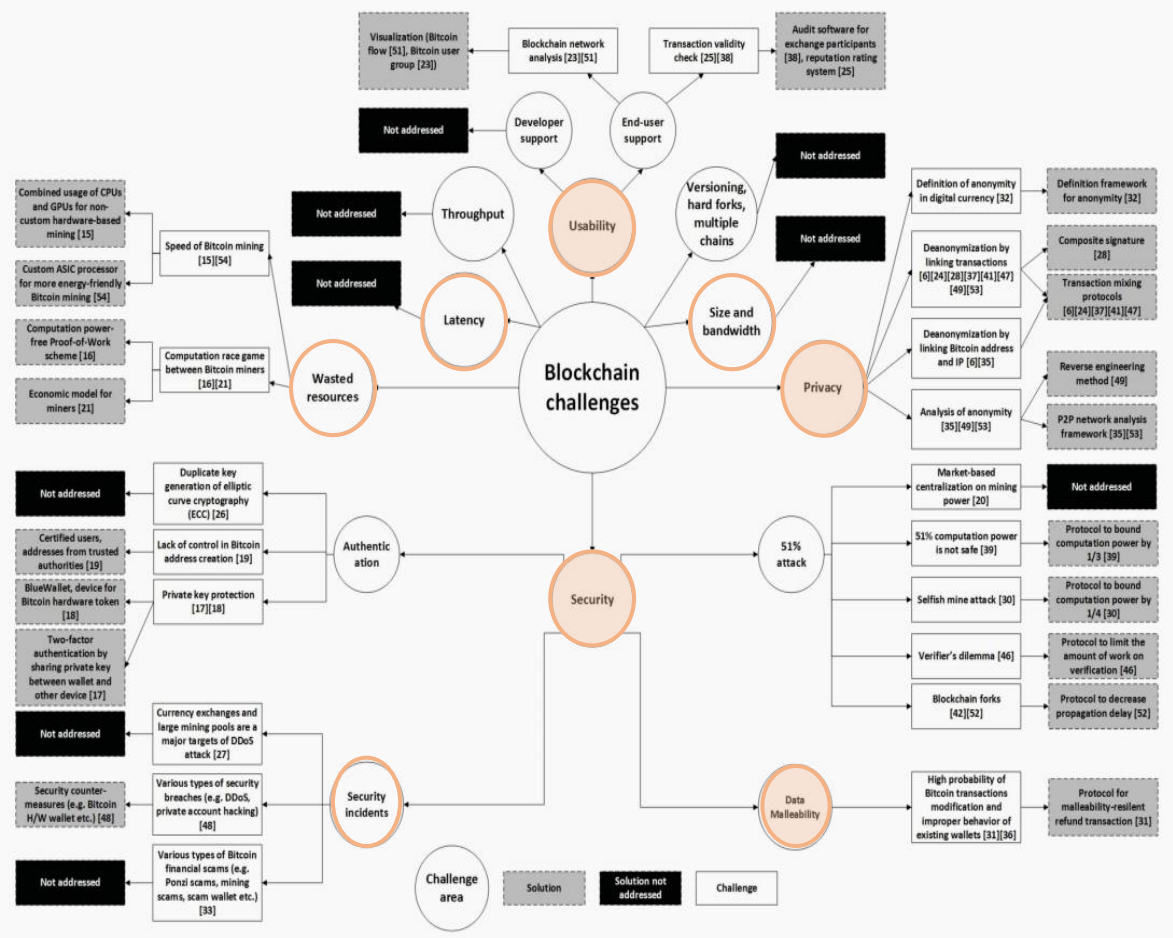
✓: interactive visual analytics | O: static visual analytics | ?: no visual analytics

- There are not many interactive, comprehensive VA systems for blockchain data.
- Scalability issues due to the massive volume of transactions data (no state-of-the-art solutions).
- Design challenges (e.g., too many colors, easily induce visual clutter, too many similar node-link diagrams).
- Uncertainty issues of identifying clients.
- Steep learning curve, specifically for novice users.

Future directions

Underexplored challenges



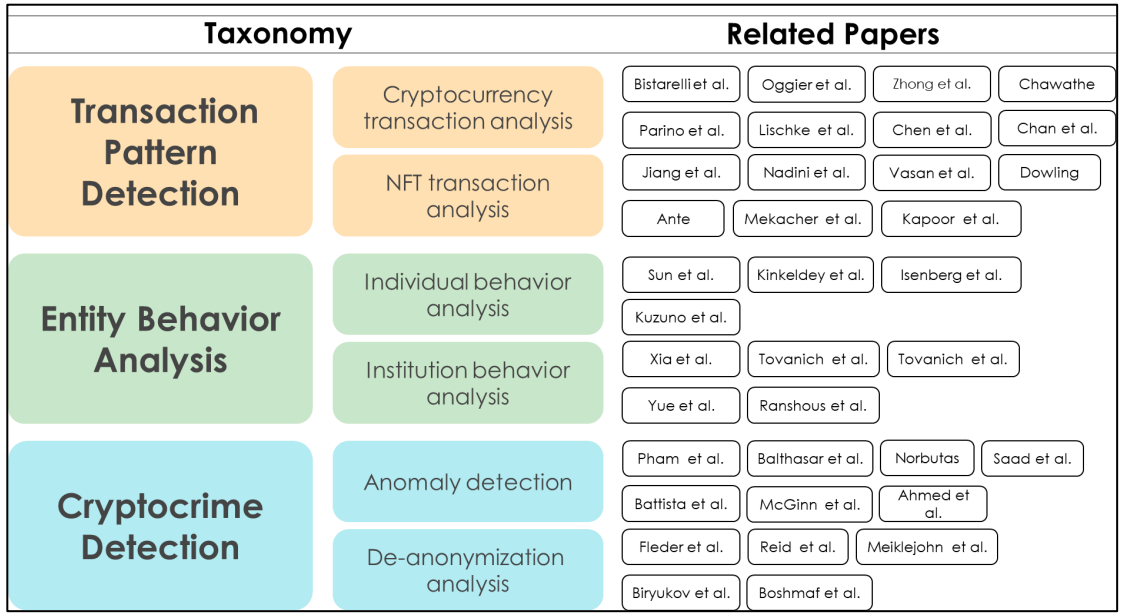
Summary of the identified challenges and solutions of Blockchain
(Yli-Huumo et al., PLOS ONE 2016)

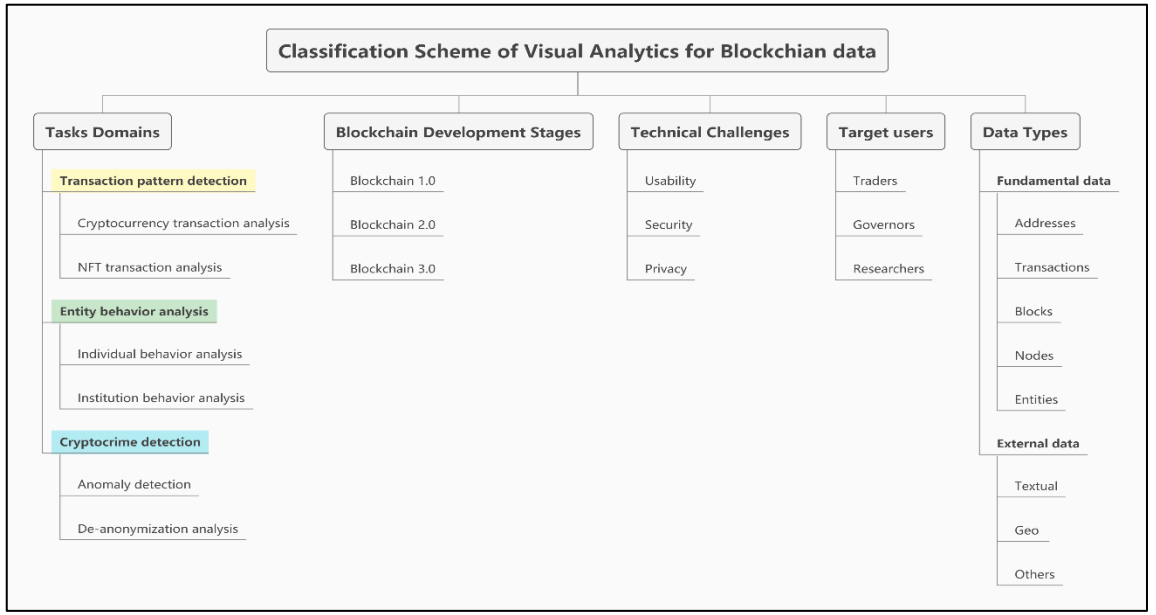
Underexplored applications

Application	Description	Examples
Underlying Infrastructure	Underlying protocols, decentralized application ecosystems, IoT architecture.	*Ethereum Blockstack, IoTA*
Currency	Payment services, internal currencies and utility tokens.	*Bitcoin, Dash, Kin*
Financial Services	Asset management, investment trading, and crowdfunding.	*Ripple OpenLedger Swarmfund*
Proof-as-a-service	Notaries, registers and attestation, supply-chain management.	*Blocknotary Chronicled, Everledger*
Property and Ownership	Digital rights management, copyright and ticketing services.	*Creative Chain Blockphase Aventus*
Identity Management	Self-sovereign digital identity, and authentication.	*Civic, Blockchain Helix, Bitnation*
Governance	Voting services, distributed autonomous organisations (DAO's).	*Followmyvote, Backfeed Crowdjury*

Typology of seven classes of blockchain applications
(Elsden et al., CHI 2018)

Q & A





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