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Community Detection in Practice: A Review of Real-World Applications Across Six Themes

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Abstract

Community detection in complex networks is widely used across fields, from sociology to biology. Despite its broad applications, there has been limited exploration of real-world experiments involving the use of datasets, algorithms, software, and openly shared code resources. This review addresses this gap by analyzing 88 publications from 2017 to 2023, focusing on the practical implementation of community detection methods. A thematic review (TR) process using ATLAS.ti 23 identifies six key themes: Healthcare, Social Networks, Telecommunications, Economics, Intelligence, and Natural Sciences. The review provides insights into the prevalent use of algorithms, notably the Louvain method, and evaluates their effectiveness across different domains. It also highlights challenges faced in real-world applications, such as scalability, accuracy, and domain-specific limitations. By offering a comprehensive overview of tools, techniques, and resources, this review aims to guide researchers and practitioners in understanding and applying community detection effectively in various real-world contexts.

Keywords: Application Domain, Community Detection, Network Structure, Thematic Review

Introduction

All the data in the real world can be modeled as a network. Networks consists of nodes as an object and edges as the interaction between the object in the communities. The formation of communities from networks is based on nodes that have something in common, such as connections or affiliations, same interests, and shared same material or contents. This network can be from any various systems or scenarios and effectively represent in network

data structure. The knowledge of network data structure is combination of graph theory and mathematics (Dey et al., 2022, Mukhtar et al., 2023). This is helpful to understand over the network in the systems as a great tool (White & Smyth, 2005). One of the important analyses in the network data structure is community detection. Community detection is a process to find relevant communities, modules, clusters, or groups with a high density inside edges and a low density of communities in networks. Most of real-world networks have complicated structures, and community detection can expose the current community structure and provide relevant information (Karatas & Sahin, 2018).

Generally, community detection can be divided into two: static and dynamic community detection. Static community detection methods can be categorized into four types: optimization, spectral, statistical inference, and dynamics (Chunaev, 2020; Fortunato, 2010; Gupta & Sharma, 2017; Javed et al., 2018; Lancichinetti & Fortunato, 2009; Meena et al., 2021; Naik et al., 2022; Su et al., 2024). First, optimization methods seek to discover the maximum or minimum of a quality function that estimates the quality of community structure. One of the most preferred quality functions is modularity (Hairol Anuar et al., 2024). Modularity only operates in undirected, static, non-overlapping networks. It also indicates the dendrogram line and algorithmic useful partitioned values finding. The NP-hard modularity maximization problem requires approximation methods or heuristics. Modularity may miss small and resolution-limited groups. On each run, they may discover distinct communities on the same network, causing instability. To overcome the drawbacks, researchers try to apply spectral methods. Spectral approaches leverage the eigen value spectrum of network matrix representations such adjacency, Laplacian, and modularity matrices (Fortunato & Hric, 2016). They project vertices into metric space using eigen vectors. In an m-dimensional Euclidean space with m eigen vectors, vertex i's coordinates are i-th entries. This is followed by k-means clustering to find communities. However, spectral methods are unreliable in sparse networks because eigenvalue separation is not sharp, and the calculations can be expensive.

For statistics-based methods, data are fit to generative network models using a traditional approach. The Stochastic Block Model (SBM) is the most prevalent network generative model. SBM maximizes the log-likelihood of network communities and requires knowledge of the number of communities in advance, which is often unknown in real-world networks. Another category involves dynamics-based methods. Community structures can be detected in networks using dynamic methods such as diffusion, random walk, and spin dynamics. Label propagation methods use diffusion, while random walk methods rely on the homophily assumption. Spin dynamics methods assign spin variables to network vertices to construct a spin model, and researchers then assign spin values using Hamiltonian distance with minimal values (Abbe et al., 2021; Chien et al., 2019; Yaqoob & Al-Sarray, 2020).

Meanwhile, the dynamic community detection methods can be categories into two: independent and dependent clustering (Elhishi et al., 2019). Independent clustering, also known as a two-stage clustering, is applying static community detection methods to dynamic cases yields this first approach. Then, divide the network's progression into numerous time steps and assign communities to each. Each snapshot detects communities separately and matches them with the ones from the previous stage based on similarity. The matched using a similarity metrics such as Jaccard, Sorensen, and Salton (Dakiche et al., 2019) & (Kadkhoda Mohammadmosaferi & Naderi, 2020). The advantage of this method is directly used to the

dataset without changes and the disadvantage is the result of dynamic community detection are not stable. Dependent clustering is another name for evolutionary clustering.

This eliminates the need to match communities and streamlines the community identification process by requiring the detection of communities at a particular time (present) based on those recognized at a previous period (prior) (Pereira et al., 2021). There are various methods, such as spectral clustering (Chi et al., 2007), non-negative matrix factorization (NMF) based, and multi-objective based (Folino & Pizzuti, 2014). This disadvantage is due to the high temporal complexity. While evolutionary clustering assumes smooth network evolution and incremental clustering uses global community discovery to find changed structures in each network time slice, reducing time complexity.

Literature Review

The idea to study the real-world or practical application in community detection started from the increasing publication of papers by multidisciplinary researchers. There were various application domains that use the community detection method to solve their problem. Depends on system problem modeled as networks, such as in the field of communication (Daher et al., 2020), wireless sensor (Lin & Wang, 2019), telecommunication (Saggese et al., 2020), transportation (Talib et al., 2020), intelligent computing (Abas et al., 2020), data mining (Jiang et al., 2019), healthcare (Damgacioglu et al., 2020), economics (Shrifan et al., 2021), e-commerce (Li et al., 2020), supply chain management (Xueshuo et al., 2021), market segmentation, manufacturing (Jiang et al., 2021), social networks (Zhang et al., 2021), nature (Heinz & Henkel, 2012), agriculture, and aquaculture (Alcácer & Cruz-Machado, 2019) and many more. This shows that the application from sociology to biology uses the method of community detection.

In addition, trending topic analysis and criminal detection also apply the concept of community detection. Most popular, community detection is used in recommendation systems for Netflix, YouTube, Tinder, and Amazon. User selections trigger relevant system suggestions. Additionally, bitcoin network may detect communities. Peer-to-peer networks underpin Bitcoin. Simply put, Bitcoin has no central server or authority. In one of the major Internet peer-to-peer (P2P) networks, Bitcoin users connect directly.

Another example of practical application using community detection is in AstraZeneca vaccine. The science-led biopharmaceutical company's unique medications are used by millions of patients worldwide. Community detection was used to identify communities and ideal intervention locations, uncovering patterns in patient itineraries. Furthermore, bank fraud is a federal crime that involves fraud of the ability of the bank to earn monetary profits. Financial fraud costs banks billions annually. Community detection and similarity helped most top 10 banks discover and recover money crime. 70% of credit card fraud was missed and synthetic identities were bigger challenge. Network analytics with queries and algorithms help to find $10s of millions of frauds in first year of execution plan (Mark Needham, 2021). Another field is in education, community detection can be used to explore and investigate student's physical interaction in peer learning of higher education course (Abal Abas et al., 2022).

As far the authors are aware, few researchers make a summary about practical applications with the community detection method (Abas et al., 2020). One of researcher, Kataras and Sahin, 2018 proposed the taxonomy of community detection and the drawbacks and emphasizes the possible effects of possible improvements in criminal areas (Karatas & Sahin, 2018). Most of research done on social network analysis often focuses on the subject of community detection algorithm due to its connections with data mining and machine learning (Subbian et al., 2016).

Hence, this research review updates the existing review on community detection applications by examining seven years of recent publications through quantitative and qualitative findings. In this study, the focus is on practical applications of community detection rather than simulations or general benchmarks of social networks, such as karate, dolphin, football, LFR, and so on. The primary objective is to identify possible patterns of domains that can be used in community detection. Therefore, this paper aims to answer two key questions for further understanding.

RQ1: What are the current real-world application patterns and statistics in community detection to articles, geographical dispersal, and recommend-journal developed in the publication from 2017-2023?

RQ2: What are the themes that can be generated in the practical application of community detection involved from publication 2017-2023?

This paper is structured as follows: The next section provides a detailed method, examining existing studies on community detection, and identifying the bibliometric analysis of community detection research trends from 2016-2023. The methodology section outlines the research design, including the thematic review concept used to collect publication data. The results section presents the findings from the paper review, highlighting the quantitative and qualitative findings of the bibliometric analysis. Finally, the discussion and conclusion sections reflect on the real-world applications of these findings for community detection experiments.

Methodology

This study used ATLAS.ti 23 to implement the thematic review (TR) as shown in (Mnea & Zairul, 2023; Mohd Zairul, 2021; Samsudin et al., 2022; Shahruddin et al., 2020; Zairul, 2022; Zairul et al., 2020, 2023; Zairul & Zaremohzzabieh, 2023; Zakaria & Isa, 2022) where the mechanisms of using the theme analysis approach to complete literature reviews are explained. According to Clarke and Braun, 2013, thematic analysis involves reading extensively to find patterns and themes (Clarke & Braun, 2013). The TR was performed step-by-step to solve the research question on community detection practicability from 2017 to 2023.

It is necessary to find the patterns which exist within the application in community detection domains of network structures. This TR included three stages: identification, screening, and data extraction and reporting. Figure 1 depicts this TR's stages and activities. In the stage of identification, a variety of criteria were used in identifying the selections of articles which would be used. These were: 1) find articles published between the years of 2017 and 2023, 2)

Have at least keyword (s) 'community detection OR community discovery OR community identification', AND 'in', 3) Focusing on the practical application domain used only.

The article that uses the 'general' benchmark networks such as synthetic networks and real-world networks such as Zachary, football, high school, primary school, Facebook and so on were excluded from this process of TR. This is because we want to see the reality of practical applications used in the knowledge of community detection algorithms and we must find patterns and establish categories to comprehend the trends of practical community detection based on article searching. It is worth noting that published works on the subject have been found predominantly within the last 7 years. This subject matter clearly still occupies an exploratory arena and has a great deal of current relevance.

Next, stage two is article screening. The well-known databases used are Web of Science (https://www.webofscience.com/) and Scopus (https://www.scopus.com/) to answer the research questions and discover relevant studies. Both databases filtered 'type of documents', English language, research article only, and the keywords search must appear in the title. We strategized searching keywords of community detection only based on title search because a lot of articles were found, and we need to select the relevant and quality articles. The exclusion criteria are filtered by removing the conference or proceeding articles, book chapters and review article. Also, we removed all the articles that were not related to and were out of range for the year. Then, the articles were then submitted within Mendeley, which was used to efficiently check each article against the previously determined inclusion and exclusion criteria. All the metadata will be checked one by one. The total from Web of Science database is 302 articles, and from the Scopus database are 506 articles. The total articles for both findings are 808 articles. However, after checking for the overlapped (duplicates) articles and the article not eligible according to inclusion and exclusion, the articles left only 88.

Afterward, the third stage is data extraction and reporting. ATLAS.ti 23 was used to analyze the article and find themes in 88 articles. The identifying data for the articles was compiled, which included items such as: title, year of publication, author's name, country of publication, main subject, keywords, and the name of the periodical where it is found. Figure 2 shows the appearance of metadata generated from 88 documents in ATLAS.ti 23.

The selected papers are grouped into quantitative and qualitative findings to collect and synthesize data to answer research questions. The quantitative findings of the paper will answer research question 1 and display the data from a numerical point of view, while the qualitative findings will answer research question 2 and cover the various themes which are being applied within community detection algorithms and real practical application as shown within the articles reviewed. The techniques of community detection, software language used, and link of code/data provided will also be highlighted in this paper for the readers' ease of understanding in the result of discussion. Each article will be categorized with suitable domains based on the dataset used.

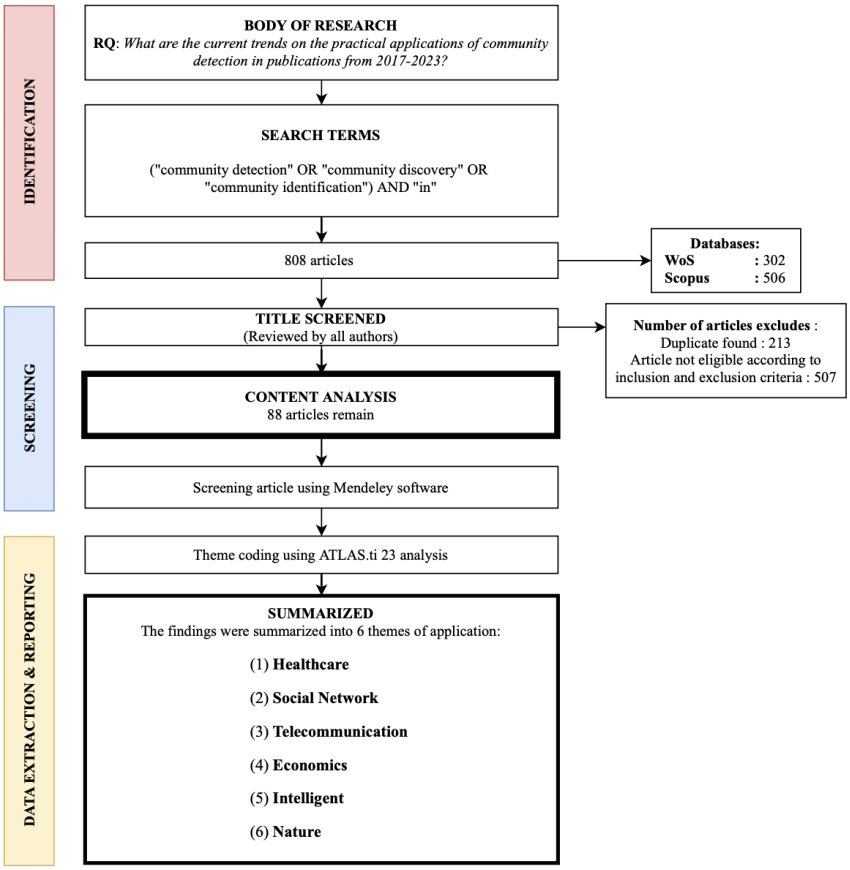

Figure 1: Stages of conducting this thematic review

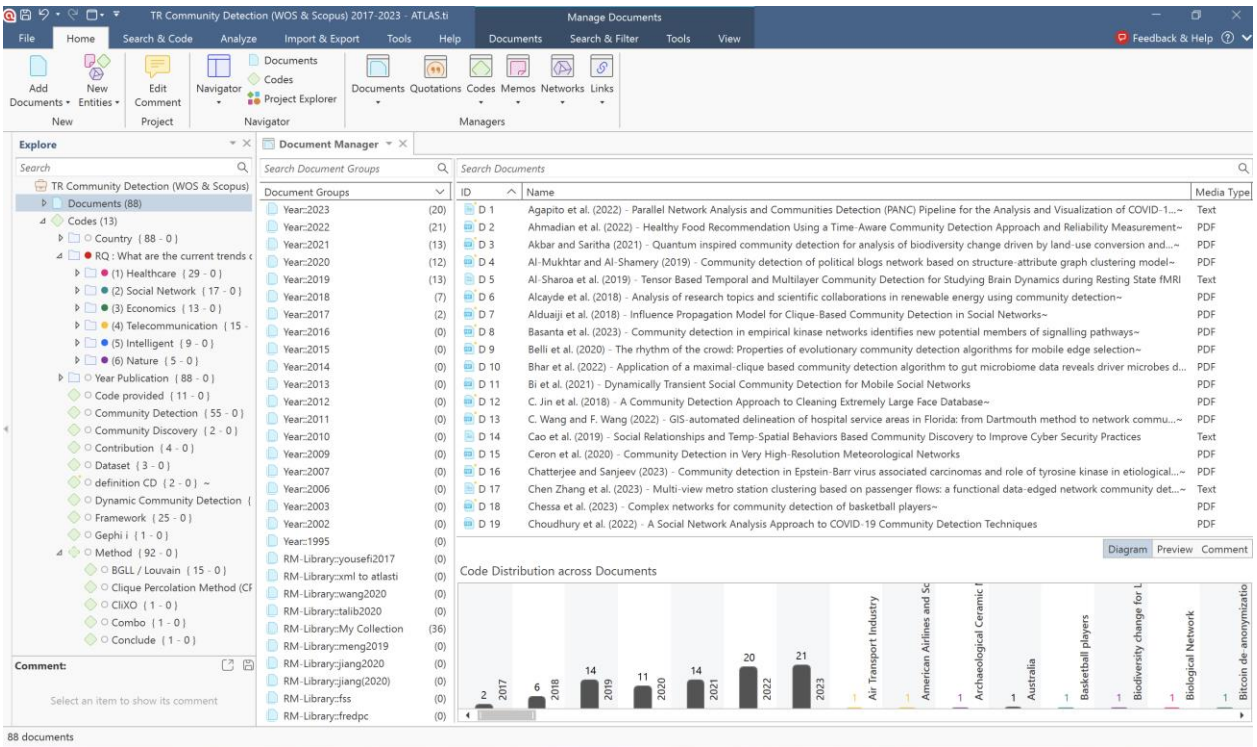

Figure 2: Metadata generated in ATLAS.ti 23.

Finding

The results are presented in two different subsections. First, the quantitative results are shown in frequencies, and then the qualitative results are the establishes theme elicited and analyzed.

Quantitative Findings

The quantitative results are related to the analysis of the word cloud found within the 88 primary articles. The words with the highest frequency within these articles are community, network, nodes, and detection, respectively as shown in Figure 3.

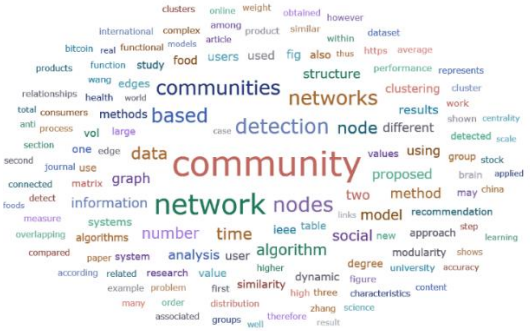

Figure 3: Word cloud generated from 88 articles

Based on our knowledge, there are a few reviews that focus on the practical application domain in community detection. One of the review is in (Karatas & Sahin, 2018). The review has a short overview of the basics of community detection information, including community structure, static and dynamic community detection. We note that many researchers are only partially aware of the relevant studies; this sometimes causes repetition approach. Furthermore, this article up-grades the review from Karatas and Sahin on the application area in community detection with quantitative and qualitative results. The year of publication, research location, and theme subject were used to interpret study trends, which qualitatively resemble community detection patterns.

Figure 4 shows 88 articles by publishing year from the search technique and criteria. The trends of publication papers in community detection increased significantly over the years. In year 2023 reached 20 articles due to the review being undertaken until August 2023. It could be due to global data creation, capture, copying, and consumption.

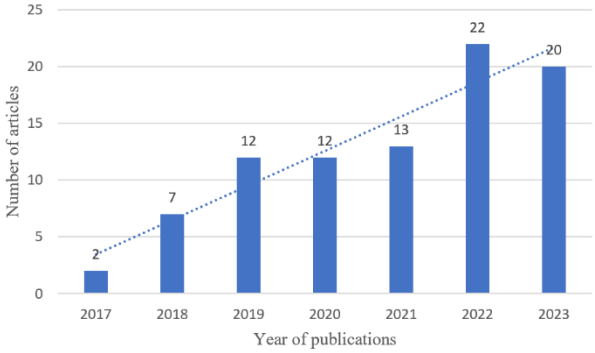

Figure 4: Number of articles by year published

The result of the keywords searching shows that many practical applications apply community detection algorithms to solve certain problems, and we summarized with forming a theme for making valuable information. At the earlier stage of searching, there were found that a few thousand results. However, after focusing on the document title by filtering the keywords, the results significantly drop and more focus on the research objective. This review can be a guide for the beginner researcher that wants to explore in the future about community analytics. They can save time reading or summarizing content interested in the databases by referring to the low and high application areas utilizing community detection. Previous research discussed the usefulness of community detection in real networks based on domains rather than chronological order. However, the quantity that proves the community detection's future practical applicability was not addressed in network structure.

This section elaborates the quantitatively as shown in Table 1, IEEE Access has the most published in community detection articles with eight, followed by Applied Soft Computing with three, Expert Systems with Application with three, and the other journals with two and one article, respectively.

Table 1
Periodical versus year of publications

	2017	2018	2019	2020	2021	2022	2023	Totals
IEEE Access	-	1	5	2	-	-	-	8
Applied Soft Computing	-	-	-	-	1	-	2	3
Expert Systems with Applications	-	-	-	-	1	-	2	3
IEEE Transactions on Neural Systems and Rehabilitation Engineering	-	-	-	1	-	-	1	2
International Journal of Communication Systems	-	-	-	-	1	-	1	2
International Journal of Computational Intelligence Systems	-	-	-	-	-	1	1	2
International Journal of Environmental Research and Public Health	-	-	-	1	-	1	-	2
Social Network Analysis and Mining	-	-	-	-	1	-	1	2
Sustainability (Switzerland)	-	1	-	-	-	1	-	2
Sustainable Cities and Society	-	-	-	-	-	1	1	2
Scientific Report	-	-	-	-	1	-	1	2
Annals of Operations Research	-	-	-	-	-	-	1	1
Applied Sciences	-	-	-	-	1	-	-	1
Applied Sciences (Switzerland)	-	-	-	-	-	1	-	1

Table 2 shows the country distribution of studies, which is very interesting that China produced the most research articles employed the community detection algorithm in real practical application. Proven by Figure 5, the highest publications in China every year, start

from 2018 until today. The practical application in community detection research trends for network structure are reflected in our real problem trends in general. Many researchers prefer to solve problems in healthcare research by employing community detection, as shown in Figure 6. This is because medical data is growing due to digital technology that collects patients' heart rate, respiration rate, temperature, blood pressure and so on. The increment also includes diagnostic information from some disease pattern by dataset of blood tests, genetic tests, culture, and other lab data.

Table 2
Country and number of publications

Country	No. of Articles	Reference	Country	No. of Articles	Reference
China	39	(Zhu et al., 2023) (D. Jin et al., 2020) (Q. Li et al., 2019) (Y. Zhang et al., 2020) (Zhuo et al., 2022) (Liu et al., 2022) (Bi et al., 2021) (Gu et al., 2019) (Cao et al., 2019) (S. Li et al., 2023) (C. Zhang et al., 2023) (Z. Akbar et al., 2021) (Y. Zhang et al., 2019) (Z. Jiang et al., 2020) (Xueshuo et al., 2021) (S. X. Wu et al., 2021) (J. Wang et al., 2022) (J. Wu et al., 2021) (Lu & Dong, 2023) (T. Wang et al., 2023) (Yan & Yang, 2023) (Z. Han et al., 2018) (Zu et al., 2021) (C. Zhang et al., 2023) (Guo et al., 2019) (Huang et al., 2018) (Zhao et al., 2023) (Ding et al., 2022) (W. Wu et al., 2019) (H. Yang & Le, 2021) (X. Han et al., 2022) (B. Yang et al., 2022) (C. Jin et al., 2018) (Qi & Cao, 2023) (Xue et al., 2019b) (J. Li et al., 2018) (S. Zhang et al., 2022) (Xie et al., 2022) (C. Wang & Wang, 2022)	Germany	1	(Bhar et al., 2022)
USA	11	(Kramer et al., 2020) (Al-sharoa et al., 2019) (Mueller et al., 2021) (Karaaslanli et al., 2023) (Rahiminejad et al., 2019) (Kabir et al., 2019) (Torene et al., 2022) (Singhal et al., 2020) (J. Wang & Paschalidis, 2017) (Desai et al.,	Greece	1	(Karyotis et al., 2018)

		2023) (Peeples & J. Bischoff, 2023)			
Italy	8	(Agapito et al., 2022) (Milano & Cannataro, 2020) (Moscato & Sperlì, 2022) (Nicolini et al., 2017a) (Chessa et al., 2023) (Grassi et al., 2021) (Belli et al., 2020) (De Luca et al., 2023)	Brazil	1	(Ceron et al., 2020)
India	6	(Choudhary et al., 2023) (Chatterjee & Sanjeev, 2023) (Nallusamy & Easwarakumar, 2023) (Kannan et al., 2022) (Reddy et al., 2021) (S. Akbar & Saritha, 2021)	Indonesia	1	(Irsyad & Rakhmawati, 2019)
Iran	4	(Ahmadian et al., 2022) (Malekshahi Rad et al., 2023) (Moradi et al., 2021) (Haghbayan et al., 2021)	Iraq	1	(Al-Mukhtar & Al-shamery, 2019)
Spain	2	(Alcayde et al., 2018) (Cotelo et al., 2020)	Korea	1	(Essaid & Ju, 2022)
Taiwan	1	(Sangaiah et al., 2023)	Mexico	1	(Montes-Orozco et al., 2023)
UK	3	(Basanta et al., 2023) (Grant & Ahnert, 2019) (S. Javed et al., 2020)	Portugal	1	(Fernandes et al., 2019b)
Australia	1	(Alduaiji et al., 2018)	South Korea	1	(J.-H. Park & Kwon, 2022)
Egypt	1	(Gaber et al., 2023)	Switzerland	1	(Evans et al., 2022)
Finland	1	(Rostami et al., 2023)	Turkey	1	(Doluca & Oğuz, 2021)

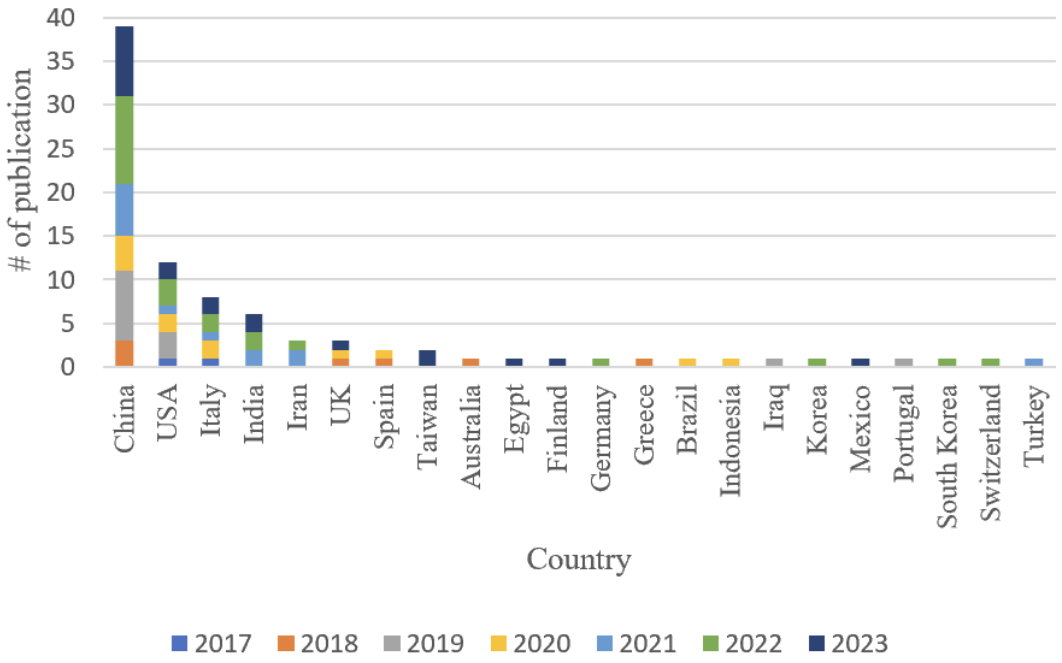

Figure 5: Number of publications versus country

Therefore, the healthcare domain potential of big data is evident and proven by 32% publications. This motivates network analytics researchers to use community detection as data scientists that have the power to anticipate epidemics, prevent diseases, improve health, and reduce fatalities. Social networks are the second most popular subject for practical application in community detection among researchers with 22% publication, and the percentage of publications was followed by 15% is economics, 14% is telecommunications, 11% is an intelligence, and 7% is nature. Overall, this part answers RQ1.

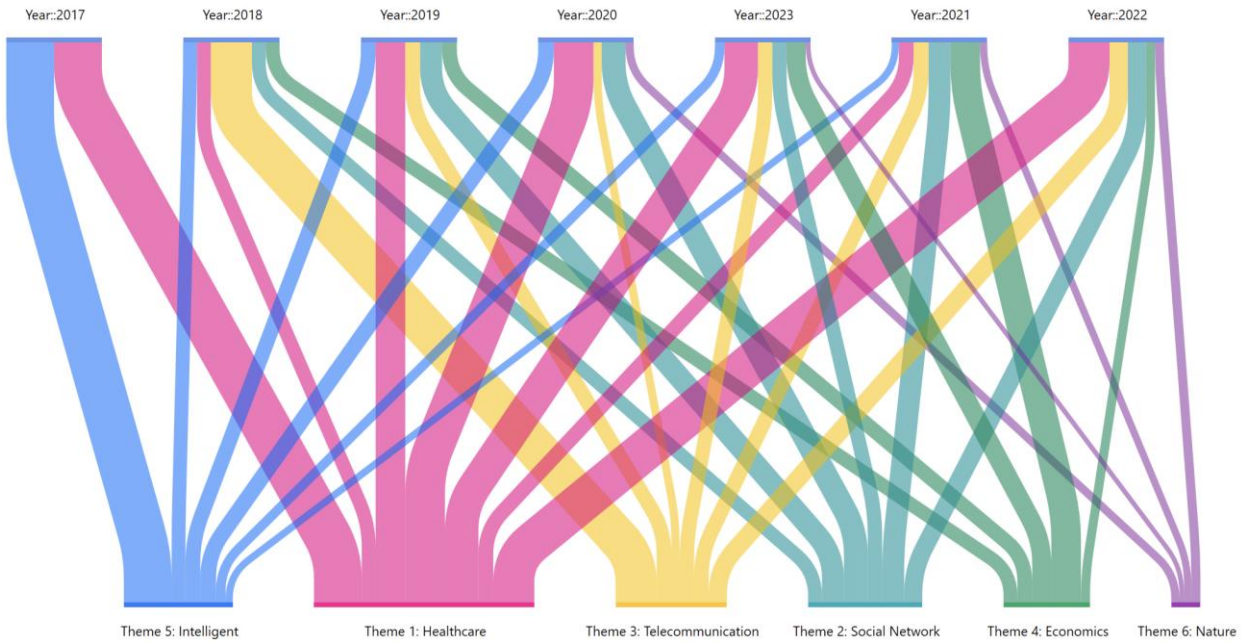

Figure 6: Six themes of the research and publication years

Qualitative Findings

This section answers research question 2 qualitatively by focusing on data extraction topics in the final articles. Summarization of selected articles were identified themes of concern to researcher using a keyword title of community detection. Six themes have been generated, namely Theme 1 (Healthcare), Theme 2 (Social Network), Theme 3 (Telecommunication), Theme 4 (Economics), Theme 5 (Intelligent), and Theme 6 (Nature). An explanation of each theme will be provided below.

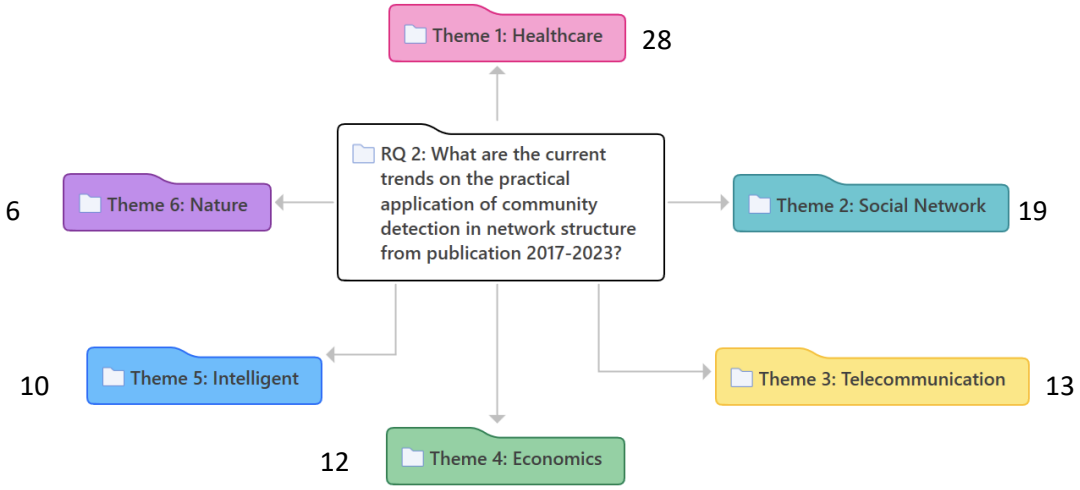

Figure 7: Overall network to answer Research Question 2

Theme 1: Healthcare

Data science has gained popularity for solving medical and engineering problems. One of the methods to analysis the data science is community analytics, and this study focuses on community detection in network structure. Community detection is unique and can be applied to global concerns and address numerous challenges. We reviewed each article selected based on area problem and categorized it into six SubThemes listed below. Table 4 shows the most articles use hierarchical community detection in the healthcare field. Hierarchical community detection is also known as a dendrogram method. It is divided by divisive and agglomerative method. However, agglomerative method is a fast, accurate algorithm and suitable to apply for massive dataset (Anuar et al., 2021). The prevalent community detection algorithm used in the real-word network especially in healthcare field, is Louvain algorithm. This was proven by these qualitative findings.

Community detection can track new medical innovations through informal networks in healthcare. Artificial intelligence helps diagnose and predict big sample accuracy. This raising awareness to help health care providers make disease outbreak decisions (Choudhury et al., 2022). Chaoudry et al. proposed employ K-means clustering to examine the patterns of node participation and interaction of user participation of COVID-19 patients to their behavior in Tambaram, India (Choudhary et al., 2023). Two articles used Italian COVID-19 dataset and the study employed the Walktrap community detection to extract communities of hospitalized with symptoms, intensive care, total hospitalized, home isolation, total currently positive, new currently positive, discharged, deceased, total cases and swabs network. This study use graph analytics representation to highlight COVID-19 diffusion similarity among regions (Agapito et al., 2022)-(Milano & Cannataro, 2020). An article examining the microbiome dataset during Influenza A Virus found that the infected group recovered quickly after the second infection. The microbial interaction network applied clique based algorithm to analyze

gut microbiome data from fecal samples collected from both healthy pigs and pigs infected with the IAV at various time points (Bhar et al., 2022). Hence, the beneficial is the healthcare field can find out the gut microbiome and its proteins may help design new antiviral drugs for disease of influenza A.

On the other hand, Chatterjee and Sanjeev, 2023 used Louvain to find communities based on functional similarity characterization in Epstein-Barr virus (EBV)-associated carcinomas network (Chatterjee & Sanjeev, 2023). Another example is tissue phenotyping in colorectal cancer histology images, the evident carried out that the dataset like Gastric cancer (GC), Nasopharyngeal cancer (NPC), Hodgkin's lymphoma (HL), and Burkitt's lymphoma (BL) were found in the disease-gene network (S. Javed et al., 2020). From the communities show that the carcinomas infected by EBV are associated with tyrosine-protein kinase (ABL1) as it was observed through over-representation analysis. ABL1 plays a vital role in 3 out of 9 biological processes. Recently, Cyscape as visualization tools was employed for protein interaction network analysis, disease gene prediction, and drug discovery. Singhal et al., 2020 created CDAPS (Community Detection APplication and Service) and deployed as an app in the Cytoscape platform for network analysis of biological structure (Singhal et al., 2020).

Another finding that stands out from the results reported earlier is in recommendation system subthemes. Community detection based on user graph connections proposes an accurate recommender system. Sangaiah et al., 2023 used Johnson and Louvain community detection to find a set of nodes in the recommendation system about e-healthcare services (Sangaiah et al., 2023). Another best practical application is the meal recommendation systems include a user's diet, recipes, and inclination for healthy eating. Moscato and Sperlì, 2022 evaluated eating habits and physical activities to identify groups with similar lifestyles for improving system performance and the experiment used label propagation algorithm (LPA) as a community detection process (Moscato & Sperlì, 2022). This is linked to a similar case in Rostami et al., 2023 that applied a well-known community detection named as Laplacian. The model recommends healthy foods to the target user based on user preferences and food health factors (Rostami et al., 2023).

In recent years, brain networks as one of the practical applications also have challenged identifying community structures. Neuroimaging analysis most often uses modularity maximization to segment static brain networks into non-overlapping, strongly interconnected modules by maximizing an objective function of modularity. Zhu, Liu and Chong, 2023 examined the block term decomposition (BTD) based on tensor approach applied to epilepsy electroencephalography (EEG) data to analyze and quantify electrophysiological brain network topological dynamics during natural music listening (Zhu et al., 2023). Meanwhile, Mueller et al.,2021 used a heavily sampled female with 30 days of continuous brain imaging and venipuncture measurements to evaluate resting-state community structure across the menstrual cycle using dynamic community identification algorithms (GenLouvain) (Mueller et al., 2021). Also, another evidence can be shown in Jin et al., 2020, where the Louvain was implemented to functional magnetic resonance imaging (fMRI) connectivity (Jin et al., 2020).

From the observation of the protein network, it also can be applied with community detection. Rahiminejad, Maurya and Subramaniam, 2019 proved that Louvain technique detects known core pathways faster than spinglass, CONCLUDE, combo, fast greedy, and

leading eigen for yeast and human protein-protein interaction (PPI) networks (Rahiminejad et al., 2019). Other researcher said that cancer biology and kinase signalling treatments have improved due to the effects of kinase pathways and overactivation on carcinogenesis by using community detection (Basanta et al., 2023). At first, community detection methods locate kinase sub-communities that reflect individual signalling pathways, then empirical kinase-kinase activity markers are utilised to form networks from these subcommunities. It will assist in finding cancer treatments without the most researched mesoscale structure.

One further practical application in community detection is to explore incompatibility of traditional Chinese medicine (TCM) [96]. TCM has been an integral part of Chinese society for hundreds of years, providing both a theoretical and practical framework for addressing medical issues. The TCM includes acupuncture, medicinal wine, formula, and diet (Zhou et al., 2020). The most common use community detection is medical formula, which contains numerous Chinese herbs and the TCM's use label importance-based label propagation algorithm (LILPA).

According to animal scientists, family units were crucial to animal social behavior, which led to the growth of many animal societies (Evans et al., 2022). Evans, Lindholm and König, 2022 shows through social network analysis, researcher can track female mice roles in social groups over time and generations. This understanding led them to study the factors that affect female mice's first litters in their natal group, signaling they will breed there. The evolutionary history and relationships of species in biological networks are studied by phylogenetics. Ding et al., 2022 using Phylogenetic Planted Partition Model (PPPM) dynamic community identification identified these associations (Liu et al., 2022). Please refer Table 3 for more information about the practical application in community detection.

Table 3
Author (Year), Dataset and Community Detection Method for Healthcare Theme

No.	Author (Year)	Dataset	Community detection used	Software used	Link code provided / Link dataset	SubTheme
1	Agapito, Milano and Cannataro (2022)	Italian COVID-19 Data	PANC (Parallel Network Analysis and Communities Detection)	-	-	Disease Network
2	Milano and Cannataro	Italian COVID-19 Data	Walktrap	R	https://github.com/pcmdpc/COVID-19	

	(2020)					
3	Choudhury *et al.* (2022)	Indian COVID-19 Data	K-means	R	-	
4	Bhar *et al.* (2022)	Microbiome data during Influenza A Virus	Maximal-Clique based MCCD-WN	C and R	https://github.com/AniBhar84/MCCD-WN	
5	Chatterjee and Sanjeev (2023)	Disease-gene network linked to Epstein-Barr virus (EBV) using the DisGeNET (v7.0) data	**Louvain**	-	-	
6	Javed *et al.* (2020)	Tissue phenotyping in colorectal cancer histology images	K-Means	-	-	
7	Sangaiah *et al.* (2023)	Digitalization e-Healthcare Services	Johnson and **Louvain**	-	-	Recommendation System
8	Moscato and Sperlì (2022)	eHealth Data (User, Food, Exercise) -MyFitnessPal users	ACLCut based on conductance	Neo4j Microsoft Azure	-	
9	Rostami *et al.* (2023)	Healthy and Time-ware Food Recommender System	LPA	-	www.allrecipes.com and www.food.com	
10	Ahmadian *et al.*	Healthy and Time-ware Food Recommender System	Laplacian	-	www.allrecipes.com/	

	(2022)					
11	Kramer *et al.* (2020b)	REasons for Geographic and Racial Differences in Stroke (REGARDS) dataset	• K-Nearest Neighbors (KNN) • **Louvain** • Leiden • NBR-Clust clustering	-	-	
12	Al-Sharoa, Al-Khassaweneh and Aviyente (2019)	Brain network from Bangor Resting State Functional Magnetic Resonance Imaging (rs-fMRI) dataset	K-Means	-	-	Brain Network
13	Zhu, Liu and Cong (2023)	Brain Functional Networks during Music Listening	Tensor method	MATLAB	-	
14	Mueller *et al.* (2021)	Functional brain networks across a female menstrual cycle	Modularity maximization-GenLouvain	MATLAB	-	
15	Nallusamy and Easwarakumar (2023)	COBRE dataset-Schizophrenia disorder patient from Functional Magnetic Resonance Imaging (fMRI)	**Louvain**	-	-	

16	Nicolini, Bordier and Bifone (2017)	Brain network-fMRI Connectivity	• **Louvain** • Asymptotical Surprise optimized with PACO • Infomap	C++ in MATLAB, Octave, Python.	https://github.com/carlonicolini/lfrwmx	
17	Jin, Li and Xu 2020 (b)	Brain network-fMRI Connectivity	**Louvain**	-	http://www.nitrc.org/ projects/nyu trt/	
18	Karaaslanli *et al.* (2023)	Epilepsy electroencephalography (EEG) data	Modularity maximization	Python	https://github.com/SPLab-aviyente/MLModularityForEEG	
19	Li *et al.* (2019)	Herb network-Traditional Chinese Medicine (TCM)	ANti-community detection algorithm based on the Degree and the RaTio (ANDERTION)	C	--	Medicine Network
20	Zhang *et al.* (2020)	Chronic glomerulonephritis (CGN) data and core herbs in TCM	LILPA	-	https://github.com/yunzhangwww/TCM-literature-corpus	
21	Rahiminejad, Maurya and Subramaniam	Yeast and human protein-protein interaction (PPI) network	• **Louvain** • Spinglass • CONCLUDE • Combo	R	https://thebiogrid.org/	

	(2019)		• Fast Greedy • Leading Eigen			Protein Network
22	Zhuo *et al.* (2022)	Non-coding RNA (ncRNA)–Protein Interactions (NPI)	Graph Neural Network (GNN)	-	-	
23	Basanta *et al.* (2023)	Kinase network	Modularity maximization	Python	https://github.com/celiaccb/KinasesCommunityDetection	
24	Doluca and Oğuz (2021)	Yeast and human protein-protein interac-tion (PPI) network	• CPM • COPRA • Neighbourhood-Inflated Seed Expansion (NISE)	-	-	
25	Grant, Ahnert and Estrada (2018)	Protein Data Bank	Infomap	MongoDB database	-	
26	K. Kabir *et al.* (2019)	Template-Free Protein structure prediction	• **Louvain** • Greedy Modularity Maximization (GMM).	Python	-	
27	Evans, Lindholm and König	Female house mice preferentially breed	**Louvain**	-	-	Biological Network

	(2022)					
28	Liu *et al.* (2022)	Phylogenetic Evolution	DCD Phylogenetic Planted Partition Model, PPPM	-	-	

Table 4
Author (Year), Dataset and Community Detection Method for Social Network Theme

No.	Author (Year)	Dataset	Community detection used	Software used	Link code provided / Link dataset	SubTheme
1	Al-Mukhtar and Al-Shamery (2019)	Twitter-Political web-blogs	Structure-Attribute Similarity (SASCluster)	Python	-	Online Social Network (Twitter)
2	Alduaiji, Datta and Li (2018)	Twitter, Facebook, and Amazon	Temporal interactions biased (TIB) Clique-based overlapping	-	-	
3	Cotelo *et al.* (2020)	Twitter written in Spanish of political domain	Spectral Biclustering	-	-	
4	Irsyad and Rakhmawati (2020)	Twitter about Indonesian presidential election process	**Louvain**	-	-	
5	Torene *et al.* (2022)	Twitter and Parler	**Louvain**	-	-	
6	Kannan, Mannathazhathu and	Online social networks	Hybrid honey badger	-	-	

	Raghavan (2022)		optimization-based African vulture algorithm (HHBA)			
7	Bi *et al.* (2021)	Mobile phone records from Massachusetts Institute of Technology Trace Data	Dynamic transient social community (DTSC)	-	-	Mobile Social Network
8	Gu, Liu and Wang (2019)	Mobile Social Networks	Attributes and node interests	-	-	
9	Malekshahi Rad *et al.* (2023)	Social Internet of Things (SIoT)	Modularity maximization	-	-	
10	Cao *et al.* (2019)	Social relationships, temp-spatial distribution, and behavioral pattern characteristics.	Non-negative matrix decomposition (NMF)	-	-	
11	Moradi, Mohasefi and Mahdipour (2021)	Routing in mobile social networks	Adaptive community detection	-	-	
12	Park and Kwon (2022)	Cyber security intelligence (CSI) data	**Louvain**	Neo4j	-	Cyber Network

13	S. Li *et al.* (2023)	BotFinder	**Louvain**	-	https://security.bytedance.com/fe/ai-challenge#/sec-project?id=2&active=1	
14	Alcayde *et al.* (2018)	Scopus Database - Publication about Renewable Energy and scientific	Modularity maximization	Gephi	-	Collaboration Network
15	Zhang *et al.* (2023)	Collaboration network for statisticians	Edge Cross-Validation (ECV)	-	-	
16	Akbar, Liu and Latif (2021)	Social applications network from business perspective	Modularity maximization	-	-	
17	Yunlei Zhang *et al.* (2019)	Online forum Reddit and academic cooperation network DBLP	Dynamic topical community detection (DTCD)	Python	-	
18	Jiang *et al.* (2020)	Football Matches of 2018 FIFA World Cup	Bottom-up community detection mechanism (BPCD) trajectory-based	-	-	Sport Network
19	Chessa *et al.* (2023)	Basketball players	**Louvain**	-	-	

Theme 2: Social Network

Social networks now influence people's opinions, decisions, and lifestyles. Therefore, with the rapid growth of social network data, more reliable for community detection are needed. Research challenge in network science is finding and prioritizing key nodes (Mukhtar, Abal Abas, et al., 2023). In Table 4 show the patterns in Theme 2 with five SubThemes.

Facebook, Twitter, and LinkedIn are significant social networks that use community detection. Political web-blogs based on Twitter dataset were analyzed using temporal interactions biassed (TIB) clique-based overlaps to determine their interactions, density, subjects, and size-activity connection over time (Alduaiji et al., 2018). Cotelo et al., 2020 illustrated the overall twitter written in Spanish about political using spectral biclustering (Cotelo et al., 2020).

Twitter lets users send short messages to interested parties. Twitter is also a vast laboratory of information and connections that can be used to analyze opinions on any topic and test sociological ideas (Cotelo et al., 2020). In the results, some communities support traditional Spanish parties. It is also vital to remember that a community tied to a social movement that led to the birth of a new political party may be able to forecast the future. Knowledge of user relationships improves social recommendations. Other researchers, Zhang et al. integrated node interaction transience and social links to examine how social features affect behavior patterns [41]. Bi et al., 2021 proved that the contact model was based on actual and social contact, and the similarity formula was used to detect community based on DTSC (Bi et al., 2021).

Park and Kwon, 2022 works the relation of cyber security intelligence (CSI) user list, phrase list, tweets written by the users in CSI and List and news articles were analyzed using community detection to detect cyberattack (J.-H. Park & Kwon, 2022). Further research by S. Li et al., 2022, used Louvain in BotFinder to detect social bots. The study defined BotFinder and examined eight million records of users. Such dataset is used to extract social bot traits using machine learning and graph approaches. To produce account node vectors and apply unsupervised approach, they used Louvain to diffuse labels to improve graph performance (S. Li et al., 2023). Another researcher applies community detection in collaboration network. Alcayde et al. study the issue renewable energy as a research topic and scientific collaboration. This approach automatically retrieves bibliographic data from scientific papers using the Scopus Database API Interface and analyses it utilizing modularity community recognition algorithms and graph visualization in Gephi. The findings indicate that renewable energy research fields and collaboration network structures can be identified.

We also found there are certain problems in the sport network which applied the use of community detection. This is proved by Chessa et al., 2023 for the 2020–2021 National Basketball Association (NBA) regular season. (Chessa et al., 2023). Basketball players can use statistical analysis to make short- and long-term decisions using the presented strategy. Complex networks can detect NBA players in communities, according to the investigation.

Theme 3: Telecommunication

A significant challenge associated with telecommunication theme in the community detection is the mobile network. The increased availability of mobile devices with rich sensors and short-

range communication interfaces has enabled participatory and opportunistic Mobile CrowdSensing (MCS) (Capponi et al., 2019). This work focuses on crowd or co-location trace rhythm. Co-location traces report the identifier of devices in proximity with a timestamp. In Table 5 show the authors, dataset and community detection have been used.

Some researchers have focused on network-wide traffic control strategies including perimeter control and route directing in metropolitan networks, based on macroscopic fundamental diagram (MFD) theory, to reduce or delay congestion. Congestion hotspots are discovered using community detection theory (Guo et al., 2019). Based on Haghbayan, Geroliminis and Akbarzadeh, 2021, day-to-day traffic congestion in big urban networks can vary (Haghbayan et al., 2021). A cost-effective method using Infomap community detection was utilized to get communities near roadways to consider cluster homogeneity, contiguity, and compactness in a shorter computing time. This method's principal taxi system divides cities into homogenous, connected regions.

Another public transport is the rail transit route network. Ding et al., 2023 employed Louvain to assess and optimize rail network structure (Ding et al., 2022). China Railway data has fully adopted online ticketing, initiating e-commerce. Users can check the passenger train timetable, ticket price, remaining tickets, and more on the website. For years, Louvain measured train network community numbers. Amazingly, infrastructure or transport-related networks can be an aviation network. Wu et al., 2019 find community structures in airport and airline networks (W. Wu et al., 2019). Alot of the work that has already been done in this area is helpful for developing our modelling approach. Network community detection based on airport distance is less reliable than route-traffic-based community detection. Because it analyses how airlines handle travellers switching routes. Airlines' hubs are communities' core airports. Geographically uncertain airports, such as those in the catchment area of multiple major airports, can be classified more clearly. This simplifies airport relationships research. This community discovery uses low-order node and edge connectivity patterns and a traffic-driven weighted network indicator.

In advanced, a high-order connection is frequently a sub-network, a graph within a larger graph whose vertex and edge sets are subsets of the node and edge sets, respectively. A clique is a full network subgraph. It is a basic graph theory topic and network topology class. Yang and Le, 2021 proposed a clique-based community to address the highly interrelated regions of a weighted network (H. Yang & Le, 2021).

Table 5
Author (Year), Dataset and Community Detection Method for Telecommunication Theme

No.	Author (Year)	Dataset	Community detection used	Software used	Link code provided / Link dataset	SubTheme
1	Belli *et al.* (2020)	ParticipAct Data- Mobile CrowdSensing project	• iLCD • in fomap • TILES	-	-	Mobile Network
2	Gaber, Abdelbaki and Arafa (2023)	Mobile network-Radio Access Network (RAN)	• Base stations (BSs) clustering	-	-	
3	Zhang, Zheng and Tsung (2023)	Origin-Destination (O-D) Path Flow Data in Hong Kong and Singapore	Functional factorization	-	-	Public Transport Network
4	Guo *et al.* (2019)	Urban road network-Jinan City in China	Fuzzy C-Means	-	-	
5	Haghbayan, Geroliminis and Akbarzadeh (2021)	Urban road network-Shenzhen, China and San Francisco, USA	Infomap	-	-	
6	Huang *et al.* (2018)	Taxi System urban in Shanghai and Beijing	Combo algorithm Walktrap	-	-	
7	Zhao *et al.* (2023)	Taxi trajectories in New York City	Infomap	Pyhton	https://opendata.cityofnewyork.us/	
8	Ding *et al.* (2022)	Evolution of the China Rail Transit Route Network (CRTRN)	**Louvain**	Gephi	-	
9	Wu *et al.* (2019)	American Airlines and Southwest Airlines	Clauset-Newman-Moore (CNM)	-	https://www.oag.com and https://www.light-	

					stats.com on American Airlines (AAL) and Southwest Airlines (SWA	
10	Yang and Le (2021)	Air Transport Industry- Top 10 airline groups by passengers carried in 2019, including American Airlines Group, Delta Air Lines, Southwest Airlines, United Airlines, Ryanair, China Southern Airlines, Lufthansa Group, China Eastern Airlines, International Airlines Group (IAG) and Air China Group	Clique Percolation Method (CPM)	-	https://www.oag.com/	
11	Han *et al.* (2022)	Power Grid- Electrical power systems (IEEE-39 bus and 118-bus test systems)	Di-Ag Dynamic commnity detection	-	-	Power Grid Network
12	Yang *et al.* (2022)	Power Grid Partition for Voltage Control	Balanced-depth-based	-	-	
13	Zu *et al.* (2021)	Service Function Chain online placement and migration problem in the cloud datacenter.	**Louvain-**Online two-stage heuristic (OTSH)	MATLAB	-	

Theme 4: Economics

In economic analysis, it's very important to understand how communities in a network are put together (Mukhtar, Abas, Rasib, Anuar, Zaki, Abidin, et al., 2023). Communities are

distinct from nodes and the network. These traits can impact network events. The reviewed list of economics' article is in Table 6. Since it combines cryptography, e-money, and blockchain, it has garnered the most bitcoin interest. Bitcoin is the most popular blockchain cryptocurrency and application (Xueshuo et al., 2021). Bitcoin's job is to share the ledger's record of balances among the actors. Peer-to-peer (P2P) computers that run the Bitcoin protocol build a flat, decentralised mesh network on top of the Internet. Nodes deliver and consume services in P2P networks.

Wu et al., 2021 examined community detection in blockchain networks (Wu et al., 2021). The researcher uses bitcoin and ethereum networks to demonstrate how spectral clustering community discovery has multiple applications. They modified community detection for the bitcoin network and applied it to the transaction social network to cluster like users. They created a smart contract-based bipartite social graph for Ethereum.

It is impossible to create a marketing strategy for each customer due to budgetary and logistical constraints, thus it is vital to group them and follow the same consumption habits. Traditionally, the corporation has focused exclusively on its optimization instead of its network. Co-marketing refers to strategic collaborations or partnerships. In recent years, retail and petroleum chains in Portugal have collaborated to retain customers and expand market share. Such partnerships exist in Portugal, such as the combined marketing between food retail chains Continente and Pingo Doce, and fuel brands Galp and BP (Fernandes et al., 2019b).

Certain consumers have related product needs. In 2021, Wu et al.'s findings on co-purchased product associations and their limitations, including redundancy of the extracted association rules, the potential to miss novel and interesting associations hidden in shopping behaviours, and neglect of several important influential factors. This study finds product communities using CFinder, COPRA, and Demon.

Outsourcing industrial production creates more complex business collaboration relationships, which overlap and blurs supply chain network enterprise communities. Assembler and supplier sequencing orders must be better understood to coordinate supply chain partner participation due to network complexity. For supply chain network architecture, Lu and Dong, 2023 developed a gravitation-based hierarchical community detection algorithm (GHSCA) (Lu & Dong, 2023).

T. Wang et al., 2023 pulled historical prices from 762 Chinese A-share market stock prices using AkShare, an open-source financial technology (T. Wang et al., 2023). Similar stock prices interact. KG and GCN combinations were suggested to improve stock price forecast accuracy. The data implant community detection using a GCN leverages modularity as the loss of stock clustering and reverse error transfer to improve clustering outcomes. Finally, a multivariate time series prediction model receives similar stock price data from the k-means clustering method to help understand the target stock's fluctuation trend and anticipate its stock price trend.

Additional observation in mechanical engineering field which applied the knowledge of Fast Newman (FN) community detection. Module partitioning of mechanical computer-aided

design (CAD) assembly model based on FN. FN, a quick and hierarchical approach for network community structure detection, can be used to locate modular structures in mechanical CAD assembly models by discovering communities in correlation connections networks for assembled parts.

Table 6
Author (Year), Dataset and Community Detection Method for Economic Theme

No.	Author (Year)	Dataset	Community detection used	Software used	Link code provided / Link dataset
1	Essaid and Ju (2022)	Bitcoin Transaction Network (Cryptocurrency)	K-Means	-	-
2	Xueshuo *et al.* (2021)	Bitcoin de-anonymization	AWAP	-	-
3	S. X. Wu *et al.* (2021)	Blockchain Social Network	Spectral clustering	-	http://vo.elte.hu/bitcoin
4	Fernandes *et al.* (2019)	Co-marketing multilayer network	LART	-	-
5	Grassi *et al.* (2021)	International Trade Network-Wold Trade Dataset	CPM)	-	-
6	J. Wang *et al.* (2022)	Jobs-housing Route: The case of Beijing	**Louvain**	-	-
7	Wu *et al.* (2021)	Construction of a Co-demanded Product Network	• CFinder • COPRA • Demon	-	Alimama (https://tianchi.aliyun.com/dataset/dataDetail?dataId=649).
8	Lu and Dong (2023)	Smart phone battery production for structuring the supply chain network	GHSCA	Python	-
9	Montes-Orozco *et al.* (2023)	Employment in Mexico during COVID-19 Pandemic	• Robust coloring problem (RCP) • Vertex cover probl	-	-

			em (VCP)		
10	T. Wang *et al.* (2023)	Large-scale Stock Price Prediction	• K-means • GCN	Java and Python	https://github.com/Gjl12321/KG_GCN_Stock_Price_Trend_Prediction_System
11	Yan and Yang (2023)	New York Stock Market	Spectral clustering	-	-
12	Han *et al.* (2018)	CAD assembly	FFN	MATLAB	-

Theme 5: Intelligent

Building massive face datasets from Internet photographs is easy now. Video, text, and image data are growing every second. In real problem is time consuming to process the large images in database. Table 7 shows the real-world application used (dataset used) in community detection was reviewed in the intelligent theme. Jin et al. 2018 proposed to eliminate mislabeled photos using facenet community detection and deep convolutional neural network (CNN) model (Jin et al., 2018).

Open-source software (OSS) ecosystem understanding can be gained through community detection. OSS involves voluntary cooperation amongst scattered developers using open-source platforms like GitHub. In the last 20 years, millions of software developers have used the git control version system to keep track of their projects and make it easy to share their work. GitHub is a prominent version control system that offers free online git repositories (De Luca et al., 2023).

Sensor networks will be larger and more diverse in future smart cities, collecting data from multiple services and constructing more complex topologies. During the Internet of Things (IoT) era, huge, distributed sensor networks will generate large amounts of different types of data, which will increase the need for efficient and effective processing. A novel data clustering framework for massive sensory data from IoT applications was proposed by Karyotis et al., 2018 (Karyotis et al., 2018). It's important to accurately detect and analyze the community structure in large internet protocol (IP) networks to optimize and secure them. CDSCB community detection based on similarity of behavior in IP networks was employed by Zhang et al., 2022 (Zhang et al., 2022).

Table 7
Author (Year), Dataset and Community Detection Method for Intelligent Theme.

No.	Author (Year)	Dataset	Community detection used	Software used	Link code provided / Link dataset
1	Jin *et al.* (2018)	Original MSCeleb-1M image dataset	Facenet	Python and Gephi	https://github.com/davidsandberg/facenet
2	De Luca *et al.*, 2023)	Repository Mining - Github Dataset	K-Means	Python in Google Colab	-
3	Qi and Cao (2023)	Open-Source Software Ecosystem-Github Dataset	• Canopy • Meta-path based for Heterogeneous community detection (METHODS)	-	-
4	Reddy, Kolli and Balakrishnan (2021)	Malware detection	Machine learning	-	-
5	Singhal *et al.* (2020)	Bioinformatic in Cytoscape App.	• CliXO • BGLL / Louvain • Infomap • OSLOM	Java	https:// github.com/cytoscape/cy-community-detection https://github.com/cytoscape/communitydetection-rest-server
6	Wang and Paschalidis (2017)	Botnet traffic captured in the Czech Technical University	Modularity maximization	-	-
7	Xue *et al.* (2019)	Cold Start Recommendation System	Incremental community detection	Python	https://github.com/ChuanyuXue/Incremental_GroupSpecific_Recommender_System

8	Li *et al.* (2018)	Mobile Internet of Things (IoT)	• Dynamic trustworthiness overlapping community detection scheme (D2-TOC) based on improved random walks and • Seeds expansion algorithms	MATLAB	-
9	Karyotis *et al.* (2018)	FIESTA-IoT federation and SmartSantander Data	Girvan-Newman Algorithm-Hyperbolic embed	MATLAB	https://github.com/netmode/CREDIT_FIESTA-IoT_OC1_experiment
10	Zhang *et al.* (2022)	Internet Protocol (IP) networks	CDSCB	-	-

Theme 6: Nature

Next-generation studies should use graph theory-based community, centrality, path, and connectivity analytics to understand network structure (Hairol Anuar et al., 2024)-(Delmas et al., 2019). Recent complex network research focused on community detection in human and animal species interaction networks to understand many social phenomena (Bialek et al., 2012; Gao, 2021; Lijcklama à Nijeholt, 2020; Liu & Qiu, 2019; Ou et al., 2007; W. Zhang et al., 2019). In other kind of nature such as biodiversity, meteorological and archeological also get more attention in network analysis, refer Table 8 below.

Ceron et al., 2020 demonstrates the use of a (geo)graph approach to assess the system's community structure using radar-derived rainfall data (Ceron et al., 2020). The results suggest an influence of both digital elevation model (altimetry) and land use/land cover on the community structures. In 2023, Desai et al. employed digital elevation models (DEM) and Interferometric synthetic aperture radar (InSAR) slope and displacement snapshots for geographic information (Desai et al., 2023). Using these two data kinds, a multilayer network estimated rheology. The study tests if the community detection algorithm identified Mud

Creek's geometry and location. After achieving success, community persistence was analysed over time to create a metric that predicts failure.

The Louvain community discovery algorithm was used to the reverse slope, slope of Xiaodongcao, China. Based on reservoir water level change, Xie et al., 2022 partitioned slope deformation. The slope displacement cloud map and three ArcGIS geological geometric characteristic factor zoning maps were layered on the deformation characteristic zoning result. An open-source software called ArcGIS divides the bank slope's geological properties by elevation, slope, and aspect.

Table 8
Author (Year), Dataset and Community Detection Method for Nature Theme

No.	Author (Year)	Dataset	Community detection used	Software used	Link code provided / Link dataset
1	Akbar and Saritha (2021)	Biodiversity change for Landscape based dataset and Number of Tiger	Modularity maximization	-	[https:// bigca tsindia. com/ tiger-census- 2018/
2	Ceron *et al.* (2020)	Meteorological Networks-Radar-Derived Rainfall at Serrana Region of Rio de Janeiro State, Brazil	Walktrap	-	-
3	Desai *et al.* (2022)	Geophysical Satellite Data- Interferometric synthetic aperture radar (InSAR) in a region near the 2017 Mud Creek, California landslide	GenLouvain	-	-
4	Xie *et al.* (2022)	Reservoir Water Level in Xiaodongcao slope	**Louvain**	ArcGIS	-
5	Peeples and J. Bischoff (2023)	Archaeological Ceramic Network Data in the U.S. Southwest/Mexican Northwest from the cyberSW project online database	**Louvain**	R	-
6	Wang and Wang (2022)	GIS-automated delineation of hospital service areas in Florida	• **ScLouvain** • **ScLeiden**	GIS	https://faculty.lsu.edu/fahui/news/2021/book-gis-hsa- by-crc.php

In Peeples and Bischoff, 2023, the archaeologist used a huge settlement and material culture database from the U.S. Southwest/Mexican Northwest (ca. 1000–1450 CE) separated into short temporal intervals to explore material cultural similarity networks (Peeples & J. Bischoff,

2023). The work defines and evaluates key scales using Louvain community detection. Critical scales are geographic/spatial scales linked with sudden network connection changes. Critical scales are geographic scales where tiny scale changes cause substantial network property changes.

Natural integration with healthcare is possible. GIS analyses and displays spatially referenced data. It employs unique location-based data. The Florida hospital service area GIS-automated delineation research integrated the system. Since the Dartmouth Hospital Service Areas (HSAs) were developed three decades ago, significant research has examined geographic heterogeneity in U.S. health care for system effectiveness and policymaking. Applying ScLouvain and ScLeiden to network community detection (C. Wang & Wang, 2022).

Conclusion

This innovative study helps explain research trends in healthcare, social networks, telecommunications, economics, intelligence, and nature by examining the dataset used in the research context and community detection methods. The resources of the code also have been provided. As previously mentioned, this thematic review (TR) used two separate approaches when reviewing the 88 articles selected by this research. The quantitative component answers research question 1 by presenting ATLAS.ti 23 data numerically. While the second approach is the qualitative section and answer research question 2 for regarding the trends or themes of practical application in community detection that has been completed within the last seven years.

Six main themes were listed in this study as the trend patterns of community detection approaches for the various application domain in network structure. The trends of practical application in community detection shows that the descending themes that researchers used were (1) Healthcare, (2) Social Networks, (3) Telecommunication, (4) Economics, (5) Intelligent, and (6) Nature. Healthcare theme is a major area of interest within the field of community detection. And the lowest article produces from nature theme. These all fields are commonly used in community detection as a potential method to analyze and solve their problem when it is heterogeneous network. The nature theme is not a new field applying community detection, but less researcher explores.

The Louvain algorithm is commonly employed in recent studies to identify communities in network topology due to its speed, effectiveness, and simplicity, as shown by data collecting from various themes. Interestingly, as shown in the findings, we can see that the pattern varies the term of community detection depending on the field. Thus, this study has made a key contribution to the field by examining the available literature both quantitively and qualitatively, and then synthesizing that information for ease of comprehension. One recommendation is that since Leiden has outperformed Louvain since 2019, researchers can attempt using it for upcoming research.

Amazingly, China has the highest frequency of articles on publication. This review provides the interested researcher with an up-to-date and self-contained view of the existing data, the community detection used, and with the links to state-of-the-art algorithms. As a result, the outcome helps learners in network research by providing them with a short overview of the

goals of community detection across different domains. We can propose that in the future, community detection research on the field's natural subject be expanded upon.

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Conflict of Interest
The authors declare that there is no conflict of interest regarding the publication of this paper.

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