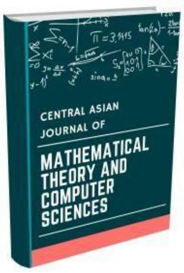

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Article

A Review of Discrete Topological Spaces Using Graph Theory

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Abstract: This review aims to study the relationship between discrete topological spaces and graph theory, focusing on the mechanism of applying topological concepts within the framework of graph theory. This study also provides a comparative analysis of previous works, highlighting the gaps in the current literature, and exploring the positive aspects. This study aims to give the reader a comprehensive understanding of the literature related to discrete topological spaces and the graph field. This review also emphasizes the possibility of making this literature a starting point for future applications, such as in complex networks and large-scale graphs.

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1. Introduction

Topological spaces are fundamental concepts of pure mathematics, allowing them to be understood without relying on traditional geometric concepts such as measuring angles and distances. Among the most important and simplest of these spaces are discrete topological spaces, which are characterized by treating each point as an open set, which allows for the complete separation of each of its elements. Because of this fundamental importance, they serve as a powerful tool for analyzing systems, as they are clear in the arrangement and structure of points or nodes. Discrete topological spaces have many uses and are widely used as models to simplify and explore complex structures across different branches of mathematics, making them useful in fields such as set theory, algebra, and geometry. Discrete topological spaces are important in terms of understanding the relationship between elements and in a way. On the other hand, graph theory is another fundamental branch of mathematics that studies the relationship between entities represented by vertices (nodes) connected by edges (links). Graph theory has countless applications in the fields of networks, computer science, information systems, and cryptography. Discrete topological spaces enable clear distinction between vertices and the determination of the relationship between them in the graph, which facilitates the study and analysis of networks and communication patterns. Studies on topological spaces originated in the early twentieth century and were limited to solving problems related to geometry and differential equations. After that, studies continued to include many applications and many fields such as networks, data analysis, algebra, biology, and computer science. Despite the presentation of several studies that clarified the relationship between topological spaces and graphs, they lack many concepts that clarify the relationship between topological spaces and graphs, especially in the context of complex networks with multiple dimensions. These studies also focused on concepts related to simple binary graphs, ignoring more complex graphs. This study provides a comprehensive and comprehensive review that includes the relationship between discrete topological spaces and graph theory, exploring important and contemporary applications for solving complex problems. It also highlights the gaps in previous work, and recommendations are provided to researchers about future studies that give a more comprehensive concept and broader applications for this literature review.

Review of Literature

Discrete topological space is one of the simplest and most fundamental structures in topology. It is characterized by every point in the space being an open set. This means that each element of the space is completely "separated" from all other elements. More technically, a topological space T=(X,τ) consists of a set X (containing the points of the space) and a collection τ (representing the topology or the open sets). In a discrete space, the topology τ contains all possible subsets of X, including single-point sets (singleton sets). In other words, every subset of X is an open set in a discrete topological space. In contrast, in other topological spaces, not all subsets of X are necessarily open, and specific conditions define which subsets qualify as open. For example, in connected spaces, points cannot be completely separated as they can in discrete spaces. In the real number space with the standard topology, only certain subsets like intervals (a,b) are open, not every possible subset. Discrete topological spaces are essential for understanding more complex topological structures. They are often used as starting points for analyzing connected spaces and more advanced topological concepts. In topological graph theory, vertices and their relationships can be modeled as a discrete space to facilitate a clearer understanding of interactions between nodes.

Graph Theory Basics

A graph is a mathematical abstraction that is widely useful in solving various types of problems. Fundamentally, a graph consists of a set of vertices (nodes) and a set of edges, where an edge connects two vertices. Formally, a graph is defined as a pair G=(V,E), where VVV is a finite set of vertices, and E is a collection of edges, with each edge being a pair (u,v) where u,v∈V. This basic definition of a graph allows flexibility in its interpretation vertices could represent cities with roads as edges, or web pages with hyperlinks as connections.

Several important types of graphs are frequently studied:

- *Path,* A simple graph in which the vertices can be arranged in such a way that two vertices are adjacent if and only if they are consecutive in the ordering.
- *Undirected Graph*, A graph in which each edge represents an unordered, transitive relationship between two nodes, typically depicted as a line or arc.
- *Directed Graph (Digraph),* A graph in which each edge represents an ordered, non-transitive relationship between two nodes, usually represented with an arrow indicating direction.

Discrete Topology and Graph Theory:

With the fundamental definitions of discrete topology and graph theory established, it is essential to explore the body of research that has investigated the practical applications of these concepts. Numerous studies have explored how discrete topological spaces can enhance our understanding of graph structures, particularly in the context of complex networks and connectivity patterns. While discrete topology offers a clear way to distinguish between vertices in a graph, its application to more complex, multidimensional networks remains underexplored. Most previous studies have focused on simple, binary graph structures, often overlooking the potential of discrete topological spaces to provide deeper insights into dynamic and large-scale networks. In recent years, however, discrete topology has shown promise in analyzing complex systems in fields such as data science, network theory, and biological systems. The following sections will review key studies that have shaped the development of this interdisciplinary field, highlighting major findings and identifying gaps in the current literature. These studies offer a foundation for future research, particularly in applying discrete topology to more sophisticated graph structures and networks.

" ***Nested Graphs" by Mark Korenblit and Vadim Levit. (2006)[1]*** introduces the concept of a nested graph, which is a special type of two-terminal directed acyclic graph (st-dag) characterized by a unique structure in its minutes. The authors demonstrate that every nested graph is also series-parallel, a well-known class of graphs that can be constructed using simple recursive operations. However, the paper's focus on theory, with limited discussion of practical applications, leaves room for future research to explore how these concepts might be applied to real-world problems.

"Construction of a Topology on Graphs". **(2013)[2]** presents a novel theoretical framework for applying topological concepts to undirected graphs, contributing to both graph theory and topology. Its introduction of the symmetry concept and its focus on graph connectivity offer valuable insights. However, this paper focuses on theoretical concepts with a discussion that is simplistic and insufficient for practical applications. Moreover, these abstract theoretical concepts may pose challenges and difficulties for the reader. We hope that future work will have a significant impact in reducing these abstract limitations by exploring practical applications that contribute to highlighting the effects of topological symmetry in graph theory.

"*Topologies on the Edges Set of Directed Graphs* ".(2018)[3]. The authors of this paper present a new approach by applying discrete topology to the edges of directed graphs, which is a conceptual shift from the previous literature that mainly focused on the set of vertices. They define two types of topologies. The first type includes the compatible edge topology (TCE (D)) based on directed paths with a cavity in the same direction. The second type includes the incompatible edge topology (TIE (D)) which includes neighboring edges in opposite directions. This study summarizes the properties of these topologies such as density and connectivity. It also suggests applications to solve problems related to weighted directed graphs such as improving the features of the routing network. While the research provides definitions, Graphs, and proofs, it is limited to a narrow scope in terms of practical examples and focuses largely on the theoretical side of the research without providing a complete proof that achieves the desired benefit of the proposed topologies.

"ODigraphic Topology on Directed Edges" Hussein A. Neamah, Khalid Sh. Al'Dzhabri [2023][4].

In this paper, the authors introduce a novel approach to studying topology on the edges of directed graphs (digraphs), where they develop a new concept called ODigraphic Topology (τOD**)**. This approach shifts the focus from vertices to edges, unlike previous research that concentrated primarily on vertex sets. The authors prove that this topology is an Alexandroff topology and explore various properties such as connectivity and homeomorphism between isomorphic digraphs.
The paper offers innovative theoretical contributions by linking graph structures with topological concepts. : It lacks practical examples or real-world applications, focusing heavily on theoretical aspects without demonstrating its utility in solving real-world problems.

"A Study of Graph Theory Applications in IT Security"Turkan Ahmed Khaleel. Ayhan Ahmed Al-Shumam.[2020][5].

This article explores the applications of graph theory in IT security**,** focusing on two key areas: network security and data encryption using Euler graphs. In network security, graph theory is presented as an effective tool for enhancing encryption techniques and solving security-related problems. The second part examines the potential use of Euler Graphs for encrypting and decrypting messages in Remote Method Invocation (RMI)**,** comparing its performance to algorithms like RSA and 3DES. However, the article has some weaknesses. It lacks a clear problem definition, particularly in explaining why graph theory is superior to traditional methods. The comparative analysis between the Euler scheme and other algorithms is also shallow, with insufficient details on performance and security. Additionally, the proposed solutions are incomplete, as the authors themselves acknowledge the need for improvement without specifying how. The practical application of the algorithm in distributed systems is underexplored, with no discussion of real-world implementation challenges. Furthermore, the limited experimental results do not comprehensively evaluate the algorithm's effectiveness in different contexts.

The article **"Topological Space Generated By Edges Neighborhoods of Discrete Topological Graphs".[2020][6]** introduces a method of transforming topological graphs into discrete topological spaces using adjacent edge neighborhoods. It provides a unique contribution by merging graph theory and topology, introducing a new definition of a partial basis, and using illustrative examples to explain complex concepts. The paper has the potential for generalization, as the methodology could be applied to other graph types, and the use of discrete topology simplifies the theoretical framework. However, the narrow focus on discrete topology limits its impact, and the lack of practical applications reduces its relevance to real-world fields like computer science. Additionally, the complexity of some concepts may be challenging for non-experts, and there is an absence of comparison with previous work, which makes it harder to evaluate the paper's overall contribution. Overall, while the paper is valuable in its theoretical contributions, it could benefit from expanding its scope and providing more practical context.

The research paper "**Ontopological Spaces Generated by Simple Undirected Graphs".[2020][7]** . explores the generation of topologies from simple undirected graphs without isolated vertices. It introduces methods for defining topologies on vertex sets and discusses the conditions for homeomorphism between topological spaces generated by different graphs. This study discusses a number of types of graphs, such as complete and bipartite graphs associated with discrete topological spaces, and also discusses practical examples and clear theories, but it is limited in scope due to its narrow focus on graphs with small and simple boundaries, which lacks practical discussions that are useful to the practical reality. Expanding the scope of this study and exploring its nature would enhance and increase its importance and practical impact

The paper **"On Certain Types of Topological Spaces Associated with Digraphs".[2020][8]** The relationship between discrete topological spaces and bipartite graphs is shown in this study. The authors define two types of open sets, DG sets and DG* open sets, and show how properties of bipartite graphs such as connectivity and networks are translated into topological terms. The paper is distinguished by its mathematical rigor, but it deals with complex and difficult-to-understand definitions for non-specialists, and lacks practical examples. In addition, it does not discuss extended graphs in communication fields such as computer science

The paper **"Total Pitchfork Domination and Its Inverse in Graphs"[2020][9]** This paper deals with two new studies in graph theory, the first is the total pitchfork dominance and the second is the reverse pitchfork dominance, providing upper and lower bounds for both studies and applying them to graphs such as circles and paths. Although this study has made an innovative contribution by expanding the concepts of dominance in the graph, it is not without complexity in the definitions, which requires additional clarification for readers. Moreover, it also lacks practical applications and real-world examples. In general, the study provides a valuable vision for dominance using graphs, which contributes to future applications in various fields such as computer science, modeling, and simulation.

The paper titled "**Stability of Inverse Pitchfork Domination". [2021][10].**This study deals with the effect of changing the reverse fork dominance number mentioned in [9] by adding or removing vertices or edges to and from the graph. This study also shows the importance of dominance in graph theory through new proofs and theories that contribute to moving the subject of dominance to advanced levels. As we mentioned in the previous article [9] this study uses complex terms with definitions that constitute an obstacle to understanding for readers from different scientific circles and lacks comparisons with similar and similar research.

The paper "**An Inverse Triple Effect Domination in Graphs**".**[2021][11].** The study presents a new approach to the dominance of the inverse triple effect referred to in [9], [10] which introduces a new concept and approach to dominance using the graph. This study also presented many proposals and theories and applied the concept of dominance to many properties of the graph such as the bipartite and complete graphs. Despite its mathematical rigor, the paper's focus is largely theoretical with limited practical applications, and its specialized scope might limit its appeal to a broader audience. Additionally, the introduction of complex terminology without simplified explanations could challenge non-expert readers. Overall, the paper makes a valuable theoretical contribution but would benefit from exploring real-world applications and providing clearer examples for broader accessibility.

The paper "**The Neighborhood Topology Converted from Undirected Graphs**".**[2022][12]** presents a method for generating neighborhood topology from undirected graphs, introducing **a** novel subbase definition that includes vertex neighborhoods. The study demonstrates the application of discrete topology to graphs**,** with clear examples aiding in understanding. While the research offers valuable theoretical insights, it lacks discussion on real-world applications and focuses primarily on discrete topology, missing opportunities to explore other types. Additionally, the mathematical details provided may be too brief for readers interested in computational depth. Overall, the paper contributes to the intersection of graph theory and topology, but expanding its focus could enhance its impact.

The article "**Concepts Of Bi-Supra Topological Space Via Graph Theory**"**[2022][13]** introduces the concept of bi-supra topological spaces. The paper defines how graphs can represent topological structures, using vertices and edges corresponding to open and closed sets. It presents several theorems and examples to clarify these concepts and introduces new definitions such as bi-supra open subgraphs and graph closures. While the study provides valuable theoretical insights and bridges two fields, it is primarily focused on the theoretical framework, with limited discussion on practical applications. Expanding into real-world contexts could enhance its relevance and appeal

The article "**Arrow Edge Domination**"**[2022],[14]** introduces a novel concept in graph theory that expands traditional domination models by applying the idea to edges instead of vertices. The paper covers a wide range of standard graphs, such as path, cycle, and complete graphs, demonstrating the versatility of arrow edge domination. The authors validate their findings with rigorous mathematical proofs, including significant results like the discovery that certain graphs lacking an arrow vertex dominating set can still possess an arrow edge dominating set. However, the study's lack of practical applications and limited explanations of new concepts might make it difficult for non-expert readers. Additionally, the model's restrictions to specific graph types and its narrow focus on standard graphs reduce its flexibility and real-world relevance. Overall, while the paper makes a solid theoretical contribution, it would benefit from exploring complex graphs and discussing practical uses

The paper "**The Graph Of Some Types Of Topological Spaces** "**[2022],[15]** deals with the relationship between discrete, non-discrete, finite, and multiple topological spaces using graph applications. It also proposes a new method and an innovative contribution to reconstructing a topological space from its graphical representation, mentioning these positive aspects that this study addressed, but it lacks practical application. There is also complexity in the concepts and definitions presented, which represents a challenge for non-specialists. Overall, this study can be improved by employing the concepts and going to the broader scope of practical applications.

The article "**O Digraphic Topology On Directed Edges**"**[2023][16]** by Hussein A. Neamah and Khalid Sh. Al'Dzhabri introduces a novel topological structure on directed graphs called ODigraphic Topology**.** The study provides innovative definitions and establishes a strong connection between graph isomorphism and homeomorphic topologies, enhancing the understanding of graph structures through topology. However, the paper is largely theoretical, with limited practical applications or real-world examples, and it focuses solely on directed graphs**,** without exploring undirected graphs or other graph types. Additionally, the lack of comparative analysis with existing topologies limits the broader understanding of its advantages. Overall, the paper contributes significantly to theory but would benefit from practical examples and broader generalization.

The paper "**Outtopological Digraph Space and Some Related Properties,**"**[2023][17]** is a novel concept connecting graph theory and topology through a new topological structure based on subbases of vertices and edges. The authors develop several theorems and provide examples to illustrate their ideas. The paper's strengths lie in its innovative concept and the development of new theorems, alongside clear examples that help clarify complex ideas. However, its complex mathematical terminology may be difficult for non-specialists, and it lacks practical applications in real-world fields like computer science. Additionally, some core concepts are not fully explained, making the paper harder to follow for readers without a deep background in the subject. Overall, it contributes valuable theoretical insights but could benefit from improved clarity and real-world relevance.

The paper "**Some Properties of Topological Spaces Generated from Simple Undirected Graphs**"**[2023][18]**This study explores the construction of graphs using discrete topological spaces. It explores several new concepts such as accumulation points and relative hub topology. It also provides clear conditions for T0, T1, and Hausdorff spaces. This is one of the positive aspects of this study, but its concepts rely heavily on previous studies without providing new insights. It also needs more for practical applications.

This paper discusses "**Some Dominating Results of the Join and Corona Operations Between Discrete Topological Graphs**"**[2023][19]** for dominance sets and dominance numbers of great importance in graphs and their application to discrete topological spaces as well as join operations using coronas. This paper is comprehensive in its theoretical analysis, presenting new results on inverse dominance and including many useful examples, but it lacks broader practical applications and clearer concepts.

This paper, "**Constructing New Topological Graph with Several Properties**"**[2023][20]**, presents a new approach to studying discrete topological spaces using graphs as embedding complete subgraphs and inferring new properties such as degree, diameter, and clique count. This paper is characterized by simplicity, as it focuses largely on familiar properties, but its scope is narrow and does not cover other types of graphs and topological spaces.

In this study, "**Construction of Graphs from the Complement of Discrete Topological Space**"**[2024][21]**, a new method for calculating the complement of a discrete topological space is used to construct graphs. A comprehensive analysis of some graph properties such as color number, independence number, perimeter, and many other properties is presented, as they play an effective role in various fields such as coding theory and computational biology. Although this paper has valuable theoretical advantages and contributions, it lacks extensive scientific applications, in addition to repetition in examples without comparing the method used with previous works.

This article**,**" Using Graphs to Depict Relationships among Elements in Various Topological Spaces"[2024][22], discusses a novel method for representing discrete topological spaces, including discrete ones, using graphs. It provides a comprehensive analysis of graph properties such as color number and group number, supported by comprehensive proofs, and valuable theoretical insights. However, the language of this article is challenging for non-expert readers, and the examples are repetitive, in addition to the comparison with previous works.

This paper "**Text Encryption with Graph Theory Based Key Generation**"**[2024][23**] presents a new method for graph encryption using matrix operations. The study deals with the use of monoalphabetic substitution ciphers and graph-based transformations to convert plain text into encrypted form using tools such as Kruskal's algorithm and adjacency matrices to ensure that the encryption process is more complex. The paper provides a valuable theoretical contribution to the great importance of encryption at present, but it lacks practical applications or actual studies in the current reality.

The study **"Prediction nullity of graph using data mining**"**[2023][24]**explores the use of machine learning techniques to predict the nullity of graphs, offering a practical alternative to traditional methods with high computational complexity. Strengths include introducing innovative features for classification and prediction, achieving high accuracy (97.08% for binary classification), and low error rates with the M5P tree model. The research also addresses time efficiency issues associated with large graphs. However, it faces challenges such as imbalanced datasets between zero and non-zero nullity samples and the potential for improved performance with broader and more balanced datasets. The study highlights the significance of graph algorithm innovation while suggesting further improvements for better generalization.

2. Materials and Methods

This study was documented through an extensive search in well-known global academic data repositories to document and include sources directly. Data repositories such as Google Scholar, IEEE Explore, Springer Link, and JSTOR were used to expand the study concepts to ensure more comprehensive results. Many keywords were dealt with to cover the research aspects including discrete topological spaces, properties and axioms of separation in topological spaces, and connectivity in graphs to ensure the accuracy and scope of the research. This study was restricted to the literature of the previous ten years to make the most of the latest studies and theories. Old articles were excluded unless they were considered basic references and necessary sources in providing knowledge related to the scope of the research. In addition, the literature published in international peer-reviewed scientific journals was restricted to ensure that all references included are subject to professional academic review, enhancing the results' credibility and reliability. This study focused on articles that combined the applied and theoretical aspects of the relationship between discrete topological spaces and graphs while excluding studies that lacked direct analysis. A strategic review of the comprehensive literature on engineering and network studies was conducted, and aspects that had not been previously addressed were highlighted. Citations were analyzed through the citation feature in academic data repositories as an indicator of their quality and importance, and to track studies that have received wide interest from readers in this field.

3. Result and Discussions

This section aims to evaluate how previous studies on discrete topological spaces and graph theory have contributed to this field and identify gaps that require further analysis and exploration. As we explained in the previous literature section, many studies have examined discrete topological spaces using graphs. However, there is still great potential to explore their application to more complex systems, especially large-scale multidimensional graphs.

Leveraging Previous Research:

Previous studies have provided a solid foundation by applying discrete topological spaces to simple graph models, usually focusing on binary or undirected graphs. These studies have provided important insights into the connectivity between vertices and have shown that discrete topological spaces allow for the formation of graphs that lead to new conclusions. However, the dominant feature of this study is that it lacks sufficient insights into network behavior and lacks the treatment of graphs with complex dimensions as well as the temporal changes of networks, there is limited research exploring how discrete topological spaces might enhance our understanding of dynamic graphs that evolve, such as social media networks or biological systems where connections continuously change.

Suggestions for Further Research:

To address these gaps, it is crucial to explore how discrete topological spaces can be applied to more complex and evolving networks. While the application of discrete topology in graph theory has thus far yielded meaningful results in simple structures, the following areas remain underexplored:

Multidimensional Graphs

Existing studies have focused predominantly on 2D or basic 3D graph structures, yet real-world applications often involve multidimensional networks, where nodes can be connected based on several attributes (e.g., social relationships, geographic proximity, and interests). Expanding the analysis to these more complex graphs can reveal insights into how discrete topology handles multiple layers of connectivity.

Although prior studies have focused on the binary and undirected graph representations, we propose expanding research into multidimensional graphs that reflect real-world networks with multiple overlapping relationships. Such exploration can offer new perspectives on how discrete topology can manage complex connectivity patterns."

Temporal or Dynamic Graphs

Another largely overlooked area involves dynamic networks, where node connections change over time. For example, networks in communication systems, financial markets, and epidemic propagation models evolve dynamically over time. Although discrete topologies provide powerful tools for discrete nodes, their application in temporal analysis requires further study. Current research focuses primarily on static graphs. Therefore, we recommend that future studies explore how discrete topologies can be applied to dynamic or evolving networks. Exploring how discrete topological concepts interact with time-varying graphs may provide important insights into the behavior of networks under changing conditions

The added contribution to this study:

Unlike previous work that focused primarily on the simple binary relationship between discrete topological spaces and graphs, this study aims to introduce an analytical dimension that has not been fully explored: spaces with complex graphs with multi-layer dimensions. This approach also enhances the efficiency and capability of algorithms that analyze large and complex networks.

Recommendations for Future Work:

In addition to the treatments mentioned above, this review urges that future studies focus on:

- The impact of discrete topological spaces on the simulation of large-scale networks, especially in distributed computing environments
- Studying how discrete topological spaces can be combined with other mathematical models such as algebraic topology, can open up new approaches to the hybrid networks. These models also enable researchers to study both large-scale and dynamic ones, which opens up new horizons for understanding complex systems.

4. Conclusion

This paper highlights the previous literature, including contributions to topological spaces and graph theory concepts, and what these concepts have provided in analyzing mathematical structures, especially in network analysis. Discrete topological spaces have also provided a powerful tool for studying individual elements within a group, reflecting their importance in graph-based models representing nodes and edges. However, this study still has gaps, especially in a deeper understanding of the basic structure and behavior of the discrete topological spaces under study on more complex graphs. This paper also leaves a large scope for further discoveries in dynamic networks and large-scale systems that evolve. This study also urges researchers to use topological spaces to develop new analytical algorithms and tools, such as social network analysis, biological systems, and distributed computing.

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