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FORMALIZATION AND MODELING OF CYBERSPACE

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ABSTRACT

FORMALIZATION AND MODELING OF CYBERSPACE

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The cyberspace conceptualization and formal modelling is to enhance the integration of system theory in developing dynamic cyber system modeling framework. Cyberspace and its related network design have been studied in many disciplines and the related literature is intricate. In this dissertation, we study the topological dynamics of cyberspace network design from multidisciplinary perspective integrating graph theory, agent-based modeling and space theoretic mathematical formulation. Our effort examines mainly existing theories and tools to characterize cyberspace. We address the problem of formalizing the topological dynamics of cyberspace entities and investigate how the combination of network design principles and cellular automata modelling approach could be used as a foundation for a new approach of modeling the entities network dynamics. We propose a mathematical formulation that suggest modeling entities in form of layers of networks and incorporates the basic functions for the topological dynamics. Our simple proof of concept experiment shows that the topology of the network, similar to other studies of complex network modeling, exhibit scale free degree distribution explaining where the features of this complex organized network system came from. We also explain the theoretical connections between physical space and cyberspace from both geographic and physics perspectives. Consolidating the available formulation in the literature, we perform extensive multidisciplinary research on this connection to assess the appropriate integration of the related disciplines and to present graph-cellular automata driven cybermap formulation.

Key Words: Formalization of cyberspace, cellular automata, mathematical model

ÖZ

SIBER UZAYIN FORMALIZASYONU VE MODELLENMESI

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Siber uzayın kavramasallaştırılması ve formal olarak modellenmesi, dinamik siber system modeli yapısının geliştirilmesi system entegrasyonunun oluşturulmasıdır. Siber uzay ve ilgili network tasarımı, birçok bilim dalında çalışılmıştır ve bununla ilgili literatür oldukça karmaşıktır. Bu tezde, çizge kuramı, etmen-tabanlı modelleme ve uzay kuramsal matematiksel modelleme alanlarını entegre eden çokdisiplinli bakış açısına göre siber ağ tasarımının topolojik dinamiğini çalışılmıştır. Çabamız, siber uzayı tanımlamak için başlıca var olan kuramları ve araçları incelemektir. Siber uzay elemanlarının topolojik dinamiğini biçimlendirme problemine değinilmiştir. Bununla birlikte; ağ tasarım ilkeleriyle hücresel otomatların modellenmesi yaklaşımının birleştirilmesi yoluyla, ağ dinamiği elemanlarının modellenmesine dair yeni bir yaklaşımın temellerini araştırdık. Ağ katmanları formundaki elemanların modellenmesini öneren ve topolojik dinamiğin temel kuralını da içeren matematiksel bir model önerilmiştir. Basit kavram kanıtlama deneyimi göstermektedir ki, ağ topolojisi -diğer karmaşık network modellemesi çalışmalarına benzer bir şekilde- bu karmaşık, düzenlenmiş ağ sisteminin özniteliklerinin nereden geldiğini açıklayan bağımsız tepe derecesi dağılımını ortaya koymaktadır. Ayrıca, fiziksel uzay ile siber uzay arasında coğrafi ve fiziki bakış açılarına göre var olan kuramsal bağlantılar da açıklanmıştır. Literatürdeki mevcut formülü pekiştirmek adına, ilgili disiplinlerin uygun bir entegrasyonunu belirlemek ve graf-hücresel otomatlar kaynaklı siber haritalar modellemek için, bu bağlantılar üzerine yoğun bir çok disiplinli araştırma gerçekleştirilmiştir.

Anahtar Kelimeler: Siber uzay, Hücresel otomatlar, Modelleme, Network Topolojisi, Çizge, Siber Uzaysal Eleman.

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Anas Mu'azu Kademi
İzmir, 2020

TEXT OF OATH

I declare and honestly confirm that my study, titled "FORMALIZATION AND MODELING OF CYBERSPACE" and presented as a Ph.D. thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Kademi, Anas Mu'azu

Signature

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January 13th 2020

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SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

CPSs Cyber physical systems

GC Generalized cyberspace

MCPS Mobile Cyber-physical system

CPSS Cyber-physical-social system

CPST Cyber physical-social-thinking hyperspace

CA Cellular automata

SYMBOLS:

e_i Cyber object

$P_i^P(t_k)$ Cyber physical system in particular position

$P_i^G(t_k)$ Geospatial position of an object e at time t_k

$d_{i,j}^G(t_k)$ Geospatial distance between entities e_i and e_j at a time t_k

$\mathbb{C}$ Cyberspace geometry

c Cellular automata configuration

Π Probability that a new node will be connected to another node

$\boldsymbol{M}$ Cybermap

A^P Set of all cybermap

R The meta relational map

R_i Relational map

$\mathcal{g}$ Influence function

CHAPTER 1
INTRODUCTION

Cyberspace spectrum is a broad area of research that includes technical, strategic, operational, scientific, philosophical and sociological perspectives, all of which converge at practical and theoretical points. Its primary entity, cyber physical system, is system that integrates the cyberspace with physical world (Baheti & Gill (2011)), and responsible for governing physical systems whose effect unfold in cyberspace. Cyber physical system underlined technological issues relate to specific techniques and procedures. There are also functionalities and events involving relationship between cyber entities and their surroundings.

The technologies of cyberspace come to inhabit all aspects of human endeavor including processes, objects, data and users. The domain is remarkably developing and literatures are added at a high rate. The conception of cyberspace is diversifying and yet not physics centered. In addition, competing ideas and definitions/terminologies struggle for acceptance among scholars. Security-wise, there is continues increase in vulnerability and a growing collection of adversaries who are agile and increasingly strategic; developing an ecosystem of suppliers involved in delivering elements of attack capability, seeking to defraud users, exploit trust, or invade privacy; to misappropriate corporate secrets and intellectual property and disrupt the operation of state or critical infrastructures.

Coined as a fiction (Gibson 1984), Cyberspace is an interdisciplinary contestant terrain which exhibits heterogeneous mathematical characteristics. It is such a complex thing that even the way it is written and used is debatable– “cyberspace” or “cyber space” (Madnick, Chouro & Woon, 2012). The term has seen a diverged perceptions and acceptance (Strate, 1999) —with competing definitions ranging from fantasy to scientific. Cyberspace is believed to have stemmed from the word “cybernetics”– “*control and communication in the animal and the machine*” (Wiener 1948); which is also believed to have been derived from “cybernetique" – *the science of civil government* (Tsien, 1954).

Contemporary cybernetics connect fields such as control systems, neuroscience, electrical network theory, logic design, evolutionary biology, etc. Other fields that cybernetic influenced or are influenced by includes system theory, system dynamics and game theory. Mathematical cybernetics focuses on factors of information, interacting entities of the system and its structure, while in computer science the analysis of information and the control of the entities are important consideration. In engineering, cybernetic concept can be used to analyses cascading failure, small perturbation that leads to huge failure. However, the current high frequency of the usage of cyberspace and cyber-infrastructure supers the use of cybernetics (Umpleby, 2015).

Cyberspace inherit its interdisciplinary nature from cybernetics, a trans-disciplinary approach of exploring system with roots in mathematics fathered by Norbert Wiener, John Von Neumann (cellular automata and its logic) and Walter Pitts; engineering pioneered by the like of Julian Bigelow and Claude Shannon; and Neurobiology with notable scientist like Rafael Lorente de No, Arturo Rosenblueth and Warren MacCulloch. (Abraham,2011). Cyberspace is characterized by the ability to represent many new ideas and phenomena that are emerging, thus becoming flexible and readily mapped to different perceptions.

These variations reflect different understanding, in what Strate (1999) called cyberspaces. The discussions from literatures shows that there is no connection theme across disciplines and that inherent features of cyberspace may be left unexplored. Distinct processes, entities and concepts are involved and remained to be precisely defined. This is because the field can be approached from seemingly complementary but different perspectives. Cyberspace can be analyzed from the viewpoint of contribution it makes— facilitating other systems to achieve their objectives, from its topological and/or geometric structure and characteristics, or from the function it performs. Cyberspace concept is discussed in the context of existing information and communication technology (ICT), the Internet, virtual reality, conventional telecommunications and emerging concepts.

We questioned or seek to explore the availability of a formal way to characterize cyberspace, and to explore existing domain theory for a foundational theory of cyberspace. Finding the right answers will help to understand various features in cyberspace. Example, on the effect of infrastructural attack or simulation of spreading malwares, a formal method and an advanced theory is required. Compared to technical and practical issues, there are only a few theoretical literatures in the field. However, knowledge prospers when the line between practice and theory is blown

1.1. Complex Systems research

Today major interest in Complexity science is complex network theory, with studies of complex network (a network with complex topology in nature, technology and society). The study of complex network aim at at-least one of the following: discover the global properties and device a measure of these properties; Establish a formal model that enable better understanding of the emerging properties and their causes; develop an optimized methods and techniques to improve a given property; or apply a given feature to facilitate and simplify a given solution to a problem (Cheng, Wang, Li, 2014).

Even though complex system across disciplines are correlated at a macroscopic way, they may as well vary at certain level and details, for instance complex system in physics are basically homogenous at the physical properties level (Goldenfeld & Kadanoff, 1999). In engineering and biological systems, the systems are usually inherently complicated, with an evolve structure. However, generally, complex systems share common characteristics, for example the probability distribution of events obeying power laws (Carlson & Doyle, 2000)

Complex system theory: Complexity of phenomena used to be associated with our incomplete knowledge of a system and enormous number of parameters and variables concealing the order of the system. However, with scientific breakthroughs the complexity is now understood to be rooted into the laws of physics. Complex system evolves in a comparable time and scale with its observer (Gregoire & Nicolis, 2007). Complex systems are so important that even some academic institutions are devoted, example, Northwestern institute on complex system, Complex system institute at UNC Charlette, and New England complex system institutes. However, many are not physics centered (Hendrickson & Wrightm, 2006). Complex network systems are perceived as complex systems (Siying, 2006; Newman, 2003; Watts & Strogatz, 1998), sharing common properties of complex system. The complexity of networks is analyzed in a distinct perspective; topological complexity, entities dynamics complexity or mutual relations of these entities and other complex factors (Cheng, Wang, & Li. 2014).

It is possible to relate physical world of complex system to that of information. At basic level, all information flow uses a transmission medium, which is usually a physical object or its properties (Svitek, 2008 & 2015). Complex system theory as a meta-theory also provides a framework for modeling data network (Shahabi, & Banaei-Kashani, 2007). As critical infrastructure can be regarded as an adaptive complex system (Rinaldi et al 2001), so is National critical infrastructure (Chunlei, Lan & Yigi, 2011)

While majority of the early research on complex networks have focused on the characterization of the topological properties, the spatial aspect has received less attention. Some of these networks are those whose nodes can be said to occupy a precise position in two or three-dimensional Euclidean space, and whose edges are real physical connections. It is interesting to note that the topology of cyberspace nodes could be constrained by the geographical embedding. It has been shown that there is a strong correlation between nodes (routers) of the Internet distribution and population density around the world (Yook, Jeong, & Barabási, 2002).

Complex adaptive system (CAS): In addition to having all properties of complex system, complex adaptive systems have adaptability characteristic (Grisogono, 2006). An adaptive system is resilience under perturbation and that the individual and collective behavior evolve and are self-organize, corresponding to the change-initiating micro-event or collection of events (Miller, & Page, 2009; Anish, & Gupta, 2010; Mitleton-Kelly, 2003). The study of complex adaptive system is interdisciplinary and combines ideas from natural to social sciences in order to formulate a model that allows heterogeneous agents and emergent behavior (Auerbach,2016). The examples of CAS are social network, power grid, traffic flows, and Cyberspace etc. Cyberspace— composed, collaborated and governed by users and entities interactions, is also a typical CAS (Phister,2011; Chan, S. (2001). CAS, modeled using agent-based models, is also layered, spatial, and temporal and has a characteristic aspect of self-organization (Holland, 1996).

Multi-level Complex system: Multilevel networks are based on the application of ideas from multilevel analysis (Snijders, & Bosker, 2012) to networks. A general framework for multilevel networks as given by Wang, Robins, Pattison, & Lazega, (2013) can be used to defined network in which nodes (entities) can have any finite number of types (layers or levels) and in which there can be a connection between entities of the same type or between entities that are adjacent. Thus, multilevel networks can fit into multilayer network framework as each level can be considered as a layer (Kivelä, Arenas, Barthelemy, Gleeson, Moreno, & Porter, 2014).

Many interaction and relationships in real world are inherently multi-level temporal and have a characteristic aspect of self-organization (Holland, 1996). Interacting interdependent internet servers (Rosato, Issacharoff, Tiriticco, Meloni, Porcellinis, & Setola, 2008) network structure has multiple levels that are connected to each other in a hierarchical way. The first level of the hierarchy, called the backbone network, serves large regional space. The regional space is partitioned into local areas, which subsequently were partitioned into and are served by switching centers (Ergün, 2013).

Self-organization: The characteristics of self-organization are the spontaneous emergence of new structures and new varieties of behavior in open systems that are not in equilibrium (Capra, 1996). The Internet and the world-wide web are amazing networks—their huge number of nodes allow for a reliable statistical analysis of their topological properties. Such networks are self-organized entities, combining various rules ranging from social needs to the surrounding environmental capabilities in spite of decentralized design.

Cyberspace not only exhibit self-organization but multi-level self-organization of the entities at different levels including physical level (Smirnov, Kashevnik, & Ponomarev, 2015). One of the pioneers of cybernetics, Ashby (Ashby,1957) formulated the principle of self-organization in dynamics system (Ashby, 1947) stating that deterministic dynamics system evolves towards a state of equilibrium, with a constraint that directly implies a form of mutual coordination between the various part of the system. Recently, it was found that self-organization can be regulated for a dynamical system to reach a desired outcome by restricting local interaction between the various part of the system, the emerging discipline of which is called Guided self-organization (Prokopenko,2009), with prospective areas of applications.

A newly formulated framework of information dynamics studies information processing in complex systems (Lizier et al., 2008; 2010; 2012) relating it to critical phenomena, suggesting that analyzing and quantifying information flows in complex systems could be a key to directing the system dynamics towards desirable outcomes.

As a co-relation to cyberspace, self-organization is a property of self-organizing networks that includes scale-free networks and small world networks, and that self-organization is a phenomenon from cellular automata and graph theory (random graph) and optimization methods.

Dynamic system: research characterizes a system whose state at any subsequent time (t+1) is a function of its states at previous time (t). To describe this kind of system, a mathematical formalization is used in the form of system of equations, the solution of which may depends on initial conditions and some variables. Dynamical systems are applied in pattern formation, celestial mechanics, topological dynamics etc. A dynamical system with discrete state and deterministic rule is cellular automata. With origin in Newtonian physics, a dynamical system is manifold with set of evolution function that map a particular state into the state space for any entity in the set of entities.

Robustness: Robustness as the early properties of network to be investigated in complex network works refers to the ability of a network to withstand damage of its fraction part. This has a practical important because directly affects the efficiency of any process running on top of the network. There are studies that show how the attributes of the Internet and WWW changes when some nodes are removed (Albert, Jeong, & Barabási, 2000; Broder et al 2000).)

Scaling and self-similarity: Correlation is also used to characterize complex system, indicating how the effect of perturbation is kept over time and space in the system—small difference in initial conditions resulting in huge change of subsequent behavior (Alberts & Hayes, 2007). Some behaviors are specifically scale free, showing no characteristics time or space scale. This the future indicates self-similarity known as power law or fractal laws. This phenomenon is farther discussed in the subsequent chapters.

Geophysical complexity model: The theory in complex adaptive systems as applicable to spatial analysis suggests that interactions between proximal entities produce complicated spatial entity at a synthesis level. Cellular automata and agent-based modeling are the two essential, complementary spatial modeling tools. From the basic property of CA, regular spatial framework and rules that govern the state of the spatial entity are imposed. And the spatial pattern evolves as time progresses and the entities go through a change of state.

It is often forgotten that the Internet depends, much like other physical networks, on physical infrastructure of different sorts and that critical issues such as efficiency of services, installation cost, and vulnerability to disruption are major concerns for the Internet backbone, similar to infrastructure such as power. The spatial embedding of Internet infrastructure studies about geography focus on how the topology of the Internet relates to physical factors and to other correlated infrastructure networks, for example, places that are well connected by airlines, roads, and other systems tend to be well provided with Internet connectivity (Malecki, 2002). This shows that the interplay between exploratory analysis of whole topology and grounded approaches is vital to comprehensively formulating our concepts in this field.

Pastor-Satorras and Vespignani (2004) provides an extensive survey of studies, particularly statistical network analysis, on the Internet and the geographic aspect of cyberspace as earlier studied by Dodge & Kitchin (2003) and Donert (2000). Cyberspace provides a space of virtual geography underlined by computers and communications (Batty 1997). There is great importance in analysis that take account both network aspect and spatial aspects of social networks (Butts & Acton, 2011), of which cyberspace also relate to social networks.

System science, also called system theory, central argument of which is that in a complex and diverse phenomenon there will always be varieties of organization, which can be explained by principles and concepts independent from that phenomena. In addition, if we are able to disclose these general laws, we could analyze and solve problems in any domain, about any kind of system. The central focus of this approach is the interactions and connectedness of the different parts of a system. Although the systems approach in principle take into account all variations of systems, practically concentrate on the more complex, adaptive, self-regulating systems. Cybernetics together with system science constitutes all traditional disciplines: mathematics, technology, biology, philosophy, social sciences. In recent studies, this domain specifically relates to neural networks, Artificial Intelligence (AI), dynamical systems, chaos, and complex adaptive systems. In essence, cybernetics and systems theory study the same problem. However, systems theory emphasizes more of the structure of systems and their models, while cybernetics deal more with how systems; how they regulate their behavior, how they communicate with one another or with their own parts. However, structure and function of a system are coupled, therefore cybernetics and systems theory essentially two facets of a single approach.

Network Motif: Network motifs are vital for understanding the network dynamics (Alon, 2003) and topological patterns (e.g., network motifs, modules or hubs). Maslov, Sneppen, & Zaliznyak (2004) used topological patterns to detect network feature and identify hierarchical feature of Internet topology. In addition, R. Kiremire et.al (2014) utilized the network motif approach to compare the performances in different Internet topologies. The motifs suggest an underlying process that generated different type of network (Milo et al, 2002).

Cybernetics: Wiener (1948) originated cybernetics to provide a mathematical tool for studying adaptive and autonomous systems, leading to the formulation of theories, which further explain properties of complex system, for instance self-organization. With implications for engineering, systems control, computer science, biology, neuroscience and philosophy. Vinnakota (2013) argued "there is a need to gain knowledge and understand the cyberspaces' influences on enterprises cybernetically in order to deal with cyber-security effectively for enterprises' survival, success and further growth"

Cellular automata: To describe complex dynamic system, a number of model classes can be used such as differential equation, random Boolean networks, chain of oscillation and cellular automata. Dynamical evolving system model can combine cellular automata and element of graph theory (Topa, 2011). This combined method is applied to simulate general class of network system. As classic formalism may fail to model some aspect of the system under consideration (Topa et al 2006), cellular automaton provides a wonderful tool for modelling and simulating complex phenomena with an added advantage of being implementable. General aspect of the system behavior is determined through a model governed by a simple local rule, highlighting a profound insight and information visualization— multi-agent models, cellular automata and games– modeling dynamical system with a deterministic rule and discrete time. Agents based model (Wooldrige 2009) and cellular automata (Graner & Glazierm 1992) are been considered as generalized cellular automata.

Inter-disciplinary methods: As mentioned by Barabási (2012) "Reductionism, as a paradigm, is expired, and complexity, as a field, is tired. Data-based mathematical models of complex systems are offering a fresh perspective, rapidly developing into a new discipline: network science." However, some aspects of networks are peculiar that they cannot be formulated in a classical graph; therefore, different enhancements have to be developed. For instance, heterogeneous information networks were developed as a framework to accommodate multiple types of nodes and edges (Sun & Han, 2013).

Interdisciplinary Cyber Research conference aimed at bringing together research in various disciplines related to information and communication technologies such as computer sciences, political and social sciences, and law, promoting novel research across different domains, centered on technical research concepts. Multi-disciplinary research is needed to characterize cyberspace by appropriate field of knowledge. Network science offers a framework through which different disciplines may coherently interact with each other.

1.1.1. Complex Network Research

Mathematical models of network are the result of structural and dynamics characteristics of complex networks from the discovery of random graphs (Erdös & Rényi, 1960) and small world networks (Watts & Strogatz, 1998) to generating statistical features from the inherent optimization mechanism (Fabrikant, Koutsoupias, & Papadimitriou, (2002) There are various type of complex network ranging from biological to technological represented by graph in the form of node and links.

The Internet is a typical example of complex network with topological structure and dynamics consisting of information and telecommunication networks. Topology generating models, validated by statistical properties, are being developed to characterize the Internet (Pastor-Satorras & Vespignani, 2004; Chen, Wang, & Li, 2014). The statistical characteristics such as average path length, clustering coefficient and average nodes degree distribution have been studied extensively (Fan, 2006). In the evolution of internet, the relatively small average path length, large clustering coefficient and power law degree distribution have been maintained. This is important in developing and validating a new model in an effort to realistically characterize and unravel the hidden pattern that may unfold in the network.

1.1.1.1. Random topology models

The foundation of random graph theory was laid by Erdös and Rényi (1960)–ER, which is the first rigorous and comprehensive notion of modern graph theory after the work by Solomonoff and Rapoport (1951) describing the structure of random networks. The result is that first complex network model of the Internet has no apparent regularities—simple and characterized by lack of understanding of the rules and principles that guide the underlined topology. So, a simple assumption of randomly connecting entities based on some connection probability was made.

In this model, the network G is formed starting from a set of N different entities, which are joined by E links with end connections chosen at random from among N existing entities. A variation of this model Gilbert (1959) developed another version in which the graph is form from a set of N different vertices, where a connection of each of the $\frac{N(N-1)}{2}$ possible edges is based on a probability (connection present: P , connection not present: $1-P$), $P \in (0,1)$. The bigger the value of the P, the denser the resultant network.

In completely random network, it has been shown that the degree distribution follows Poisson degree distribution $P(k)$ of nodes connectivity (Bollobás, & Béla, 2001). and has relatively small Clustering coefficient, C and short average path length, L. But regular ring network has large clustering coefficient (Latora, Crucitti, Marchiori, & Rapisarda, 2003):

$$P(k) = \frac{\mu^k}{k!} e^{-\mu}$$

With the constant μ, referred to as the expectation value

$$L = \frac{\log(N)}{\log(K)}$$

$$C = \frac{k}{N}$$

For N node and K edges.

This shows a characteristic of homogenous network, every node having approximately same degree and so Waxman (1988) proposed the extension of ER model [3]. This simple model has a relatively small size. However, it perfectly depicted Advanced Research Project Agency network (ARPAnet). The model uses a finite lattice space populated with the initial N nodes, and at each time step, two randomly selected nodes n_1 and n_2 are connected with a given probability (also called Waxman probability):

$$\prod(n_1, n_2) = \alpha e^{-d(n_1,n_2)/(\beta)}$$

Where $0 < \alpha, \beta \leq 1$, and the Euclidean distance between node n_1 and node n_2, is given by $d(n_1, n_2)$, the average number of edges (after normalization) is α and β is a parameter determined by the average path length.

The ER and the Waxman's extension whereby the models are reused, generalized and extended for a better, more realistic formulation inspired several other Internet topology generators. For example, a model called configuration model (Jackson, 2010) developed by Bender & Canfield, 1978) is capable of generating a specified degree distribution. The advanced models are more appropriate to characterize real world networks (Newman, 2003).

However, most real-world complex networks are not completely random, i.e., they are generated by some rules. For example, connecting two routers in the Internet by say optical fibers is not a decision made by a coin toss. Furthermore, technological networks are swiftly growing networks with evolutionary dynamics. This is completely different from the fundamental framework of the random graph models, which are static and non-growing, therefore more research to address these issues have been developed, giving raise to other more realistic topological models.

1.1.1.2. Structural topology models

As the networks further evolves, becoming more complex and parallel with the guest to comprehensively understanding its topological features, it was found that the topological structure of the Internet is not a mere random process that resulted a graph of a random type, but rather inherently hierarchical (Zegura, Calvert, and Bhattacharjee, 1996; Doar, 1996). The internet has myriad of interconnected

Autonomous system (AS) in the form of Tiers or Transit-stub (Jaiswal, et al, 2004) – – describing structural connection of AS, or the division of the ISP (International through local). In the same line of research, a hub; some nodes having high number of connections was also discovered (Zegura, Calvert, & Donahoo, 1997; Zhou, & Mondragón, 2004). These and other properties were analyzed in (Pastor-Satorras, & Vespignani, 2004).

The ties topology uses a different procedure to generate the network. First, nodes are randomly placed on finite lattice and connect these nodes as a spanning tree to form the top-level networks (Wide area network), to each of which are at several sporadic tier networks (Metropolitan area Network). Using similar method— but not using minimum spanning tree, other smaller scale network (local area network) are randomly connected to each of the previous intermediate tier network. Then more connections based on inter-node Euclidean distance are added.

The Transit–Stub model similar to the tier model in that it consists of three layers: the top-level layer, the Transit; the Stub domain; and then the smaller scale networks. It is obvious that the Internet has a hierarchy; with backbones and other level of ISPs broken into different "tiers." However, it seems that these hierarchical networks are better modeled by other approach that does not aim at generating the hierarchical structure in the first place (Tangmunarunkit et al, 2002). Furthermore, the degree distributions of the Transit-Stub and Tiers model are not scale free, when it was discovered that the internet has power law degree distribution, the research quest shifted towards power law-based degree generating methods (Faloutsos et al. 1999). This better model captures the large-scale structure of the internet. However, structural topology models were also better in some aspect, for instance, it could be more appropriate for models that includes bandwidth, topology or geography (Tangmunarunkit, et al 2002).

1.1.1.3. Degree based model

The discovery that networks topologies are characterized by the average distribution of node connective triggered the quest for a model that produces this same feature; specifically, the power law that characterized the Internet topology (Faloutsos, 1999) The Small-world and scale-free are two significant properties of internet and complex system that precisely characterizes, in mathematical terms, the hidden regularities of the Internet's structure.

Small world is the small average shortest path length among Internet routers and ASs, making it possible to navigate from one node to another passing through very few intermittent nodes. It also reflects the essential homogeneity of networks, in the sense that all nodes in a network have about the same number of connections to the others, which means that everyone is equally important regarding their roles in the network. This model starts by connecting nearest-neighbor nodes and then use rewiring to connect edges with certain probability and constraint that no loops and parallel edges. The average shortest path length given by P:

$$P = \frac{1}{N(N-1)} \sum_{i,j\, \in V, i \neq j} d_{ij}$$

For the Euclidian distance d_{ij} between node i and j determined by the number of links along the paths.

Small-world model originated from the work of Watts and Strogatz (1998) exhibit high clustering and short average path lengths. The average shortest path length among nodes of the internet graph was found to be very small (Huffaker, Fomenkov, Moore, Plummer and Claffy, 2002; Pastor-Satorras *et al*., 2001; Bu and Towsley, 2002). Generally, random graphs exhibit small-world effect but are not highly clustered, whereas regular network model tend to be clustered but are not small-world. The quest to model heterogeneous networks capturing the important properties simultaneously has increased.

Scale free: In the random network, nodes were connected with same probability, which result in the degree distribution peak at average and decaying exponentially otherwise. It was the work by Faloutsos, (1999) that revealed that internet has power-law distribution both at an AS-level and router-level; it shows the existence of a hubs while most node have few connections. This has inspired a great number of researches on topology characteristics, models, and roles of the Internet (Jin, Chen, and Jamin, 2000; Medina, Matta, and Byers, 2000). However, the research community intrigued to decipher what exactly leads to the emergence of scale free, which was later discovered that preferential attachment is responsible for the emergence of power law of scale free networks; showing the cooperative behaviors of networks nodes.

In an effort to have a model that perfectly validate the power law, degree distribution lots of model were proposed. Chen, Chen & Jamin (2000) proposed a model called Inet and using this and the later version the average path lengths of the Internet from 2000 to 2002 was observed to remain the same. In addition to reflecting the power law degree, the model by Medina et al (2001) shows the hierarchical structure of the internet, this model Called BRITE was relatively much closer to modeling real internet.

Many other models explaining the growth of topology and develop some topology generators are found in literature. For instance, the Internet such as extended scale-free model (Holme, & Kim, 2002; Wang, et. al, 2008); Generalized linear preference model; Tel Aviv Network Generator— combines the Incremental Edge Addition (InEd) model and the Super-Linear Preferential Attachment model; Interactive Growth model (Zhou & Mondragon, 2003); positive feedback preferential model (Zhou & Mondragon, 2004) — based on rich club phenomenon; dynamic and preferential model; incremental edge addition and super-linear preferential attachment model (IEASPA) (Lian-Ming, et al 2011)

The Multi-local world model (MLW) (Chen, Fan, & Li, 2005; Li, Liu, Lu, & Li, 2018), where the Internet was considered as an ensemble of many local-worlds (Li, & Chen, 2003) was proposes to combine the localization effect with the preferential attachment rule. That is with the realization that the Internet hierarchy schematically divided into international connections, national backbones, regional networks and even local area networks. These highly clustered regional networks are then interconnected sparsely by national backbones or international connections
However, which class of model most characterize the real Internet when the large-scale properties of the Interne is considered? The MLW was found to a better model in representing the Internet AS-level topology, as it can capture both the scale-free and small-world features of the real Internet while incorporating the localization effects ((Fan, 2006; Fan, Chen, & Zhang, 2009)

1.1.1.4. Optimization Based and Engineering-based models

Degree based and other topology generators still show our limited knowledge of the Internet, with various assumptions and taken to improve upon the existing models. The models are rather unsatisfactory, from a more basic point of view, when aiming to model, explain, and predict the large-scale properties and behavior of a system on the basis engineering way of system modeling. The preferential attachment used in the other models insufficient. ISPs mostly try to decision-based method to optimize their own competitive advantages instead of preferentially to attaching to giant nodes who have already had most in the network. With this realization, Fabrikant et al (2002) proposed a *heuristically optimized trade-off* (HOT) model. This model explains the highly optimized tolerance mechanism and suggest a new way to produce power–laws by an intrinsic trade-off mechanism.

Most modes attempt to elaborate on network structure, traffic flow, geography, or the economic concepts. However, Holme, Karlin, & Forrest, (2008) worked on discrete agent-based model, which integrate many concepts but with considering the HOT concepts. This model was not intended to be a realistic model of router level topology and that the resulting degree distribution follows a power law only up to a cutoff (Berger, et al 2003).

There is a need for statistical physics model that could explain dynamical evolution rules as the cause of the structural properties of the network. A model based on the realization fact that: The network is a growing network whose number of entities and connectivity increases with time; and connections are placed by following and optimized decision biased by the local properties of nodes. Figure 1.1 shows how complex network and cyberspace are related to graph theory, a mathematical means of depicting network topology.

The internet, the information technology and the networks connecting them are generally comprise of cyberspace. Dictionary definition defined cyberspace as: “the online world of computer networks and especially the Internet” (Merriam-Webster, 2019). The International Telecommunication Union (ITU) uses the term to describe, “systems and services connected either directly to or indirectly to the internet, telecommunications and computer networks.” (ITU, 2011). While the International Organization for Standardization (ISO) perceived cyberspace as “the complex environment resulting from the interaction of people, software and services on the internet, supported by worldwide distributed physical information and communications technology (ICT) devices and connected networks.” (ISO/IEC 27032, 2012). In essence, the internet is an integral and part of cyberspace.

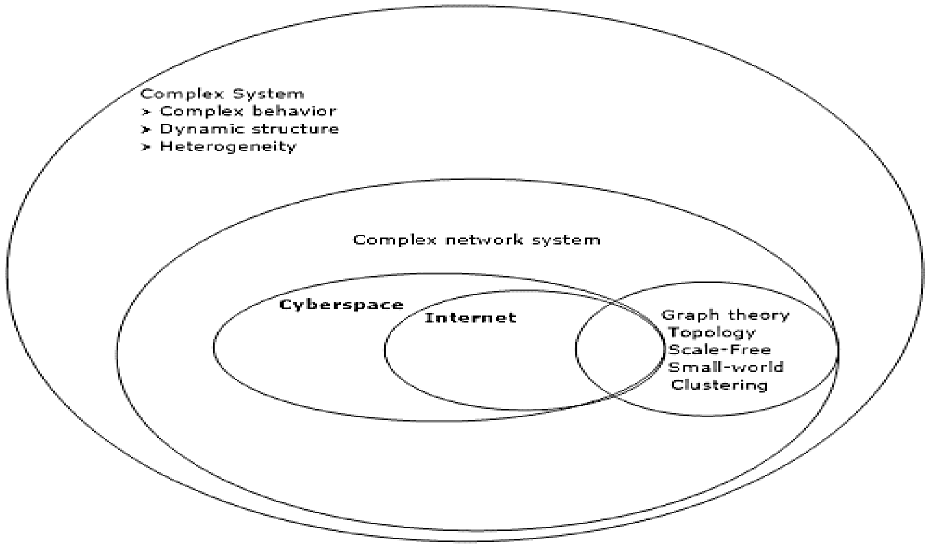


Figure 1.1 Complex system, complex network system and cyberspace relationship

1.1.2. Cyberspace as Complex System

The research methods and tools associated to the field of cybernetics and systems science are applied in the developing "sciences of complexity", also known as "complex adaptive systems", investigating self-organization and heterogeneous networks of interconnected entities, and related studies in the natural sciences like chaos and dynamical systems. the other threads are various advanced computing applications such as artificial intelligence, neural networks, simulation and modeling.

Unfortunately, most concepts and methods in these fields are not connected to the domain of cybernetics as they were used. Areas like complexity, self-organization, connectionism and adaptive systems have already been studied in details, at the time when the concepts of cyberspace started to be used, by scientist and fictioneers such as Wiener, Ashby, Von Neumann and Von Foerster,

Complex systems are ubiquitous, and many associated characteristics are found to be common across fields. These attributes are considered as either necessary and/or sufficient: (disorder, interaction, ensemble of many components) and (Robust order and memory) (Ladyman et al, 2013) respectively. Cyberspace, like other Complex system, exhibit complicated feedback mechanisms and behaviors which cannot be fully explained just from its mere constituents. The components may have mathematically different structures, connected in a variety of ways, most often nonlinearly and/or via a network. Furthermore, local and system-wide phenomena depend on each other in complicated ways. These components form a whole whose behavior can evolve along qualitatively different pathways that may display great sensitivity to small perturbations at any stage. Cyberspace is a complex system as it features exhibit the following (Moffat, 2010; Phister & Paual, 2011).:

- Ensemble of many elements: For interactions— exchange of information, and pattern formation, the system has many similar (in nature) however, different (in properties) elements. The physical entities of cyberspatial system are comparable in size (how big–how much information, how many links?) and some of which may be subjected to some laws of physics in contrast to non-physical components which are similar in behaviors (obey same rules). These entities can be organized in a hierarchical nature reflecting similarity and relations. Hierarchy, which significant features of internet as used in models, is the consequence of scale free and clustering (Ravasz and Barabasi, 2003).
- Interaction: Complex system have the means for its element to interact, showing how the various entities affect each other's behavior by sending or responding to messages. Messages are the means for cyberphysical system to interact and exert force on one another (Bayne, 2008). Message inform of sequence of control packages (bytes, signals impulse) drives cyberphysical objects.
- Adaptive behavior: a special case of complex system whereby the structure and the behavior of the system changes, resulting from adaptive processes—cyberspace is ultimate adaptive system (Olagbemiro, 2015) (Phister, 2011). Innovation, agility, robustness and resilience are used to explore available benefits in the systems environment and to device appropriate response to threats while core functionalities are maintained. This adaptation usually manifest itself in cognitive and social domain. Example, the convergence of technology leading to adaptation among devices, systems and the environment.
- Non-equilibrium order: Interactions between cyberspace elements is far from equilibrium. (Phister, 2011).
- Robust orders: The order in complex systems is robust; being distributed and not centrally managed while stable under perturbations. For example, the response made quickly by router, for example, by updating routing tables for failure point (a dynamical process) is one of the essences in robustness.

- Heterogeneity/ decentralized control: one of the common features with complex system is that large number of components are involved with potentially varieties of scales and structures. These structures are self-organized without any central control. There is no central management that controls the entities functionality in cyberspace. The networked entities have technical and administrative diversity.
- Non-linear. Complex interaction/tipping-point— The spontaneous order is caused from the interactions of individual entities following relatively simple rules. That is, a sudden change in behavior (e.g. from stability to instability). This property adds to limited predictability as minor change of initial condition, which might seem negligible, result in a major dynamic over time. Cyberspace compose of non-linearly interacting entities.
- Simplicity and co-evolutions: entities continuously co-evolve in the dynamics changing system. Resulting from basic local interactions.
- Multi-spatial and temporal: Space and time also critical part of cyberspace. Features significant both in abstract and at high level.
- Emergence: Spontaneous order where behaviors emerge out of interaction between basic elements, the whole is more than the sum of its part—behaviors of a complex system, cyberspace by extension, cannot simply be derived from adding up the behaviors of the individuals.

Many of the features, including previously mentioned, complicate the needed analysis; the presence of heterogeneous variable types, the lack of underlying physics-based "ground truth" to justify a model, highly nonlinear behavior, and the often-erratic effects of social, economic, and human factors. Specifically, for cyber security: non-linear interaction of combat forces and no central coordination of combatant, local actions inducing long range order (Cascading failure can be resulted from localized attack) and collective dynamics. (Moffat, 2010).

Modeling cyberspace concept poses a challenge in mathematical modeling intrinsically different from other complex systems whose components are physical objects. There are no formal bases in the cyberspace theory, and therefore validation of model is problematic, especially with the continues change of the domain. That is, a model become obsolete instantly. Moreover, external factors— particularly, entities heterogeneity and not centrally controlled—affecting system behavior. Without underlying formal description of cyberspace, it is intractably demanding to evaluate models.

1.2. Cyberspace research problems

The advancement, exponential growth and ubiquity of ICTs result in more quest to explain and characterize cyberspace. The technology inhabiting cyberspace are transformative, changing our physical world in a number of ways. Cyberspaces is infinitely mutable, continuously changing as new technology are developed, more entities are added, the infrastructures updated, and the content redefined. As time elapses and new technology develops, the tendency to concentrate on technical and the promises that technological invention offers increases relative to theoretical development.

Cyber research problems stem from the its basic nature: dynamics, complexity, the heterogeneity, vulnerabilities and multi-dimension, multi-disciplinary effects. Whilst majority of the research concentrate on technical and security questions, little consideration has yet to be directed at wider questions concerning the ontological foundation and conceptualization, formalization and the implications from existing domains.

1.2.1. Security research

With growing reliance on cyberspace increasing a wider range of implication and cascading effect on disruption, the vulnerability of the systems allows exploitation and ultimately an attack, necessitating the need for defensive measures—Cyberspace security as preservation of confidentiality, integrity and availability of information in the cyberspace (ISO/IEC 27032, 2012). Addition properties such as authenticity, accountability, non-repudiation and reliability are also included.

With the ubiquity of cyberspace, the exponential growth of cyber-physical systems (CPSs), emerged unprecedented security challenges –diverse range of vulnerabilities, threats, and attacks. New control measures are being devised. However, the heterogeneity of cyberspace and its components and the diversity of cyber physical systems have made it difficult to study the problems with one generalized model.

Among the major challenges of cyberspace and another complex network is s. These models help to: (a) simulate realistic network at different scales for testing controls measures and algorithms for network defense, (b) identify anomalies that are inconsistence from the model and therefore serve to identify network problem for instance, network intrusion. (c) discretize and integrate part of the network graph for more advanced analysis and (d) rigorous sampling of the network statistically (Chakrabarti & Faloutsos, 2006).

There are many security issues that are not covered by current cyber security best practices as a result of gaps in understanding the domain, as well as inadequate communication between the bodies in the cyberspace. This is due to the fact that connected networks and cyber entities underpinning the cyberspace are characterized from multiple disciplines, each with its own theories, concepts and regulatory concerns. The different emphasis placed by each field of study in cyberspace on relevant security issues where little or no consideration is made from another field has resulted in a fragmented state of security for the cyberspace. Thus, a research to address cybersecurity issues focusing on bridging the gaps between different conceptions of cyberspace in various disciplines is timely

1.2.2. Definitions and Conceptualization

The basic characteristic that makes cyberspace puzzling are the problems in definition and delimitation. Cyberspace is characterized by divergence of meanings suggesting that its polysemic feature is connected to its popularity and indicating an interdisciplinary, multi-dimensional and multi-leveled space. There have been many definitions of what cyberspace is from different points of view (from state to individual researchers), and works have been made to defined study cyberspace framework and structure (conceptualization). Yet, there has not been an acceptable model for cyberspace.

To establish range of perception as to what cyberspace is and to derive its ontology, analysis of key elements from the definitions by governments and standardized organization is tabulated in Table 1.1. Indicating that an element is explicitly referred to, denoted by a symbol ●, or implicitly implied by ■. The varying definition cyberspace to at consist of globally internet connected hardware, software, data/information and services but unfortunately, they failed to address dynamic features in time (Ottis, & Lorents, 2010).

	Cyberspace						
	ICT	Inf.	Internet	Network	Virtual space	Users	Connectivity
Merriam-Webster Dictionary	●	■	●	●			
Turkey	●			●			●
Canada	●	●		●	●		●
Estonia	●	●					
Germany	●		●	●	●		●
N. Zealand	●			●			●
UK			●	●	■	●	
USA	●	●	●	●	●	●	●
EU		●			●		
ISO		●	●	●	●	●	●
ITU		●	●	●	●		●
NATO		●		●	●		

Table 1.1 Cyberspace elements in definitions.

Although there is a wide range of definitions, they mostly agree that the fundamental of cyberspace consists of connected networks of hardware, software and information (Rajnovic, 2012). Another aspect, which is implicit and although the immediate theoretical implication may not be apparent, is that humans can interface with cyberspace resulting in social activities. However, in order to better formulate the concepts of cyberspace and understand the topological dynamics, we need further that take into account other factors, for example, time and spatial construct.

Whilst frameworks and various conception of cyberspace are important milestone in the research process, current study has not met the requirement of quantitative description yet. Cyberspace modeling meet with numerous challenges: dissimilarity with many fields for instance, physics space, as cyberspace is not only a material space consisting of various network infrastructures, but also a space that support social behavior and more. Also, even though, graph-theoretic approach has been an essential facet of network modeling, it is potentially capable of only capturing binary relations between homogeneous entities (Halappanavar, et al 2013) — incapable of handling heterogeneous entities and their relationships in cyberspace.

1.2.3. Formalization

The problem is not only lack of cyberspace definition, rather an inadequacy in formality, comprehensiveness and of feasibility in modeling. Most of the challenges would arises from the intrinsic heterogeneity and complexity of cyberspace. For instance, Cyber Physical System integrates diverse subsystems with different mathematical structures, scales and domain-specific, interacting in a complicated feedback mechanism. A mixture of variable types (continues, discrete etc..) connected in different ways.

Inadequate formalization or theoretical perspective is a sign of new domain which also holds in cyberspace and its related areas (cyber warfare, etc.). The development of framework that will support comprehension of different aspect of cyberspaces at both the theoretical and the practical level could solve the problems in lexicon, lack of consensus and provides a ground truth for general analysis and further development. The wider challenge, then, is to defined cyberspace taking in account dynamic features and spatialization of its heterogeneous entities. For instance, some entities have explicit spatial relations and other with an inherently connectivity oriented.

It should be recognized that cyberspace have potentiality of possessing a spatial and geometry features that is dematerialized, dynamic and although may be devoid of the laws of physics, but an inspiration could be drown.

The topologies of the Internet and World Wide Web have particularly been studied intensively, for their complexity and practical importance (Krioukov, et al 2007). No simple model can exhaustively capture the complexity of these structures, but basically are statistically predictable and were both found to be scale- free networks.

1.3. Dissertation Scope

Cyberspace is defined more by the social interactions involved than its technical implementation and scientific formulation (Morningstar & Farmer, 2008). At the very core, cyberspace consist of many heterogeneous entities, the modeling of which is a multifaceted undertaking; one that consists of elements concepts that are philosophical, theoretical, empirical and practical. It is an issue that is extremely difficult to frame exhaustively, therefore our overarching quest seek to find theoretical basis from which to formalize cyberspace, capturing the diverse issues in cyberspace.

We examine the network-based research, geophysics concepts and spatial forms of cyberspace. The central arguments are that cyberspace possesses a cyberspatial mechanics that needs to be examined; that the geo-spatial, info-spatial and socio-spatial relations of cyberspace entities are not randomly produced; and cyberspace is not paraspace but an aspect of cyberspace time as an embodied space. Overall, we seek for a way to characterize cyberspace from a formal basis. It is therefore essential that cyberspace is not perceived as some sort of paraspace. Rather, a conceptualization aimed at rigorous methods.

1.3.1. Research Questions and Hypothesis

This dissertation shall address the lack of cyberspace theory, provides a basis for a vertical development of cyberspace formal perspective. Thus, two broad research questions together with associated hypotheses steer the dissertation:

Research questions:

- ❖ *What is the theoretical basis from which to formalize cyberspace?* Considering other domains theories, how do we define cyberspace with regards to entities that we can call objects?
- ❖ *Which domain theory describes an integrated concept of cyberspace?*

Research hypothesis:

- ✓ *Existing domains, an extension of or a combination can inform a formal model of cyberspace.*
- ✓ *Automata theory– Graph cellular automata formalization as an agent-based model can describe entities dynamic and topology.*

1.3.2. Motivation and Aim

While cyberspace undoubtedly offer an overarching advantage, and as a space in which to explore other spaces, it is recognizable that it is a supplementary new spatial medium and cannot be subsumed as a replacement of a particular space. A key area for research, then, is to examine the ways in which existing theories may be use in cyberspace and how this help better understands the domain. Up to now, this is a problem that is poorly researched, with most studies directed at understanding cyber media (social relations) and technical security. In essence, rather than a list of competing definitions, we need to ask, how should cyberspace be theorized, to identify its salient characteristics.

In response to the never-ending problems, continuous expansion, and an increasing importance of the cyberspace, there is the need of a work to rigorously define and characterize the field. Hence, we aimed at building a common conceptual framework of cyberspace– A formal model. This tends to be distinct from the patch works and prior studies as multi-disciplinary approaches is included.

Objectives

1. Identifying categorical scheme and a ground truth from which to have a point of departure in understanding cyberspace.
2. Develop a model, a theoretical description or characterization of cyberspace: Cellular automata and graph theoretic general model creation for cyber model
3. Define cyber objects and the referential dimensions.

1.3.3. Contribution of the dissertation

In support of creation and generalization of cyber theory, this dissertation suggests an approach in modeling cyberspace. It provides an analytical framework for characterizing cyberspace, expounding on the formation and relation of cyber entities, which are interconnected information systems unit whose effect unfold in both cyberspace and physical space. On a wider academic view, this framework is premised on a cross-disciplinary, theoretically informed and empirical research. Our approach is bounded in the fields of network theory, agent modeling, information theory and geophysical sciences.

There are relatively many studies contributing to describe the concept of cyberspace and various problems, especially security related problems. However, not much attention has been paid to the development of cyberspace-time physics and localization effect of information network, outlining features and functional conception cyberspace. In addition to updating the present research our contributions are:

1) Advancing cyberization process to include theoretical frameworks in the aspect of cyber philosophy, cyber science and cyber information
2) Expanding engineering disciplines to enable cyber entities analysis and design concepts;
3) As Cyberspace also provides new modes of representing and modelling geophysical space, for instance, the interactive three-dimensional models, incorporating (geo)physical sciences, to account for location, interrelationships, and behaviors of entities forming cyberspace topology.

1.3.4. Outline of the dissertation

The thesis consists of five main chapters and a concluding chapter. The first chapter provides a preliminary research issues from complex system systems to cyberspace and of particular interest, the internet as the immediate reference to understanding cyber domain. Some basic concepts, motivations, research question and the related hypothesis as well as the research objectives are presented. In chapter two Cyberspace formal perspectives is given, whereby a paradigm shift from paraspace towards rigorous conceptualization is surveyed and presented.

Relating cyberspace to other bodies of knowledge, chapter three discuses some central insight and questions: to what extent is cyberspace augmented by the theory in physics, network theory and agent modelling paradigms. The notion of cyberspacetime discussed. Following the characterization given in chapter three, chapter four investigate the cyber object formulation and formation.

Chapter five analyses the mathematical dynamics and the cellular automata modeling approach for cyberspace. The modelling formalism of the cellular automata (CA) used is generalized and extended within cybermap algebra. The final result, Cyberspace as “a manifold of cyberspatial entities, whose behavior unfold in cyberspace time and with the topological interactions that are in turn governed by network optimization principles plus, driven by an information exerted and communicated among the entities” is discussed in chapter six.

Finally, the thesis closes with a concluding chapter, giving the summary of the thesis and present suggestions for further works.

CHAPTER 2
CYBERSPACE AND CYBERSPACE(S)

The cyberization process gives rise to a divergence in literature from cyberspaces to general cyberspace; cybermatics to cyberSciTech; and cyber-enabled worlds to cyber-physical-social-thinking hyperspace etc. Cyberspace perception and conceptualization have become more complex through time, due to its scalability and as new and more concepts are being added, leading to continues proliferation and creating a need for simplification/Categorization. Existing theories could be used as basis to better understand the physical social thinking hyperspace notion of cyberspace. Cyberspace is then viewed as a meaningful inter-disciplinary, transdisciplinary, and multi-discipline integration of Cyber psychology, cyber science, and cyber information to present theoretic perspectives on cyberspace. Three main aspects: ontology, topological dynamics, and information form of a message and an entity are respectively considered in terms of philosophy, theory in network science, and information theory.

2.1. Cyberspace Conceptualization

The term "cyber", derives from the Greek word "Kubernao" meaning "to steer" and "to govern", which is the origin of the contemporary word of Cyberspace. It implies the notion of navigation through a space of electronic data, and of control achieved by the operations performed on those data. The word “cybernetique”, the science of civil government (Tsien, 1954), is the root of the cyberspace’s parent term, “cybernetic”, a theoretical study of communication and control processes in complex systems from biological to technological. The term is originally more specific in neurophysiology and linguistics (Wiener, 1948; Lillemose, & Kryger, 2015). Cyberspace was first coined by S. Ussing and C. Hoff as a physical sensory space (Lillemose, & Kryger, 2015), and later popularized by Gibson as a fictional space: “a graphic representation of every computer in the human system” (Gibson 1982 &1984). Gibson's usage of the ward cyberspace is then not a space of passive data; its ‘cyber fiber’ and communication channels connect to the physical environment and allow cyberspace users to interact with this real world.

The word, “space” denotes many aspects. To start with, a space has a virtually infinite extension, including lots of things that is impossible to comprehend at a time. This precisely explain the complexity of the existing massive pool of data presence on the information network. Also, space implies the idea of unrestricted movement, of possibility to be or navigate through a variety of states or places. Most importantly, a space idea as in geometry perspective, implying concepts such as distance, direction and dimension.

The geometry (precisely the topology) of space can be form from the network of links, nodes and their references characterizing a cyberspace time framework (which can be regarded as the most general form for a collection of interlinked entities). One of the challenges in trying to create contemporary network in a Gibson’s idea of cyberspace is to integrate the geometry of 3-dimensional virtual reality, with generalized, yet complex and complicated, infinite dimensionality of hypertext.

Cyberspace as argued by Strate (1999), consist of heterogeneous spaces; it is a myriad of different perspectives of cyberspaces, each providing a relatively distinct form of digital interaction, communication and understanding. Overall, these spaces can be conceptualized into those existing within the technologies of the global network of computer devices—Internet, those within virtual reality, and conventional telecommunications and also new emerging hybrid of spaces. Pointing to the fact that cyberspace has been increasingly studied by researchers in various disciplines such as computer sciences, sociology, geography, physics, psychology etc.

Over the years, many different explanations and understanding of cyber space evolve from individual, official government documents, scientific literatures, groups and dictionaries, cutting across philosophical, scientific and fictional boundaries. It is defined as “A global domain within the information environment consisting of the interdependent networks of information technology infrastructures and resident data, including the Internet, telecommunications networks, computer systems, and embedded processors and controllers “(JP 1-02). Also, defined as manifold where geospatial, info spatial and temporal indices are required to distinguish one its various objectives, allowing actors, both human and synthetic, form socioeconomic networks for the purpose of survival and growth (viability) through exchange of information, goods, and services (Bayne, 2008). Cyberspace as a "time-dependent set of interconnected information systems and the human users that interact with these systems" (Ottis, & Lorents, 2010). In essence there are at least 28 distinct definition of cyberspace with no common definitions at the scientific level (Kramer, Starr & Wentz, 2009) and every nation state uses a different definition. However, the common themes among the definition is that cyberspace is inclusive of globally connected hardware, software, information, and implicit reference to its users.

Subsequently, cyberspace is adopted to associate almost anything that has to do with computer networks (Cyberspace, 2019) and ultimately become synonyms with the Internet and World Wide Web (WWW). Moreover, the prefix "cyber" started to be used to denote newly made terms that are either a duplication of concept or ambiguously used as an adjective. For instance, the use of cyber law, cyber life, cyber economy, cyber ethics etc. to denote something digitally and/or online. Some terms are just a reuse of cyberspace; for instance, Cyber world, Smart world (Liu et al, 2017), Hyperspace and Hyperworld (Ma et al 2005).

2.1.1. Fictional Cyberspace and Factual Cyberspace

Fictional space: Inspired by scientist ranging from engineers to social scientist, Gibson coined the term cyberspace in his novel *Neuromancer* (1984), describing cyberspace as a visual, Cartesian non-space; the existence of a fictional space (para-space defined by Delany (1988) – a visual analogy abstracted from physical space but without tangible material. Following this, computer scientists, referring however partly to Gibson writing, started to actualize this kind of space, initially WWW emerged and then a glimpse of virtual reality applications possible with the aid of the Internet. Cartographers of cyberspace are also using Gibson's spatial metaphors to visualize informational spaces and make them navigable (Dodge & Kitchin,2003).

In this perception there is no 'space', no places and thus no spatiality in cyberspace. Cyberspace is basically a distributed information system that uses a spatial metaphor as its interface and can be accessed independently. Many researchers using the term cyberspace mostly don’t associate it with Gibson original meaning, the imaginary, unreal and fictional space.

Not only imaginary space, cyberspace encompasses digital space of networked information technology accessible from computer screen; a visually observable, evocative, electronic, Cartesian dataspace refers to as ‘The Matrix’ where information’s are exchanged by the entities as they interact. as we use the para-space of cyberspace to connect and communicate it gains a spatiality. Hence, from another perspective spatiality and perceptible places are attributed to cyberspace. As space and information are related, and that space is the nothing more than a set of dimensions for objects and event to be expressed (Benedikt, 2008).

Factual space (Cyberspace time): The traditional or commons sense perception of space, also as highlighted above attributed to cyberspace, does not amount to meaningful scientific concept, therefore in a more rigorous way the basis of cyberspace in contemporary physics is considered. Events and dimensional considered, and the notion of cybernetic, in that it has scientific origin.

As a parallel universe of computers, we also can base our understanding of cyberspace from a logical perspective, as put down by Bolter (1984), cyberspace as an abstract, geometrical and mathematical field in which the data structures are built— an abstract visualization of information. Even though the fictional and factual understanding of cyberspace are wide apart, their boundary is impermeable with regards to science. Lots of work in science start as a fictional, for example, communication satellite (Clarke,1945).

In this view of cyberspace, the proposition that cyberspace may be more accurately described as a part of the physical universe. Finding a relative explanation of cyberspace from physics and geographical understanding our universes. Meaning that cyberspace may follow or object some laws of physics— in the sense of cyberspace mechanics and cyberspacetime (Bayne, 2008). This concept leads to many questions than answers, however, it is hope that some insight will be highlighted.

2.1.2. Physical Cyberspace and Logical Cyberspace

Physical space: Cyberspace is mostly perceived as imaginary space, without much consideration of its underline physical elements. These are the physical circuits, wires, computers and the electronic devices that make the flow and storage of the information possible, called cyber fiber. This is the physical foundation of cyberspace which gives a grounded sense of location—Physical devices existing in this location are within jurisdiction.

The activities from the cyber domain also result in the physical change of our surrounding. The physical place being integrated with information technology, smart homes, smart cities, internet of everything. These physical entities in the form of hardware constitute the main element in understanding cyberspace as physical space. There is an increasing dependence and application of technology in various areas, for examples energy, transportation, military, healthcare, and manufacturing which are directly related to the concept of cyber physical system. The result of the advancements in the information and communication technologies (ICTs) to enhance interactions with physical processes is the integration of these systems into physical space. Cyber physical systems are characterized as networked at multiple and extreme scale; dynamically reconfiguring/reorganizing; cyber and physical components intersection etc. (Shi, et al 2011).

Logical Space: Another conceptual categorization of cyberspace that considers the address space of the cyber entities (Strate,1999). This indicate that "the range of numbers that can be invoked in fetching data" (Bolter, 1984, p.83), the electronic space where information is saved and also as (an abstract, geometrical, and mathematical field in which the programmer can build his data structure (Bolter, 1984, p.243). It is also stochastic, a numerical space. In this context, a map space in form of graphic space based on inherent connection between measurement and dimensions, aid by contemporary analytical geometry (Strate, 1999).

Although integrating recognition with spatiotemporal reasoning improves the overall performance of information retrieval. (Menon, Jayaraman, & Govindaraju, 2011), the widely used notion of cyberspace is attached to our conscious cognition of a space that we can possibly imagine. Novak (1999), studied cyberspace from an abstract angle of architectural field, arguing that it is an imagination and indicating that it has a liquid architecture.

2.1.3. Informational Cyberspace and Social Cyberspace

Information space: Information as stored or transmitted in cyber fiber, can be class a raw data (basically denoting a simple or complex variable such as a sensed parameter of an entity, set of parameters or a message (Grant, 2014)). The content rather than form is of great concern. The form of spatial relationship formed as a result of communication with and through the devices. Aggregation and integration of multiple information, in addition to creating navigation pathways, is bound by rules to organize information

Social Space: With the development of emerging platforms that are associated with the Web 2.0 paradigm, social behaviors are easily facilitated (O'Reilly 2005). Social media can enhance social interaction, making communication between human entities more efficient by making space and time limitation irrelevant and providing social spaces for communication and actions. At the same face, the work on cyberpsychology has also evolved (Barak & Suler, 2008). Social information processing theory, postulated by Walther (1992), propose that users readily provide social background information and also infer relevant social cues in text-based computer mediated communications (CMC. A review social cyberspace shows that with regards to social networking usage, social psychological aspects as well as emotions are related in many ways (Krämer, Neubaum & Eimler, 2016).

2.2. Contemporary Research

The problem of definition consensus is partly due to the novelty of cyberspace itself and the novelty of the evolving concepts therein. The fact that cyberspace boundary is poorly mapped— shifting across philosophical, scientific, social and mental zones, makes empirically competing and equivocal definitions present in the domain.

These kinds of confusion transcend semantic to include syntax. Even the way in which cyberspace is written is debatable– "cyberspace" or "cyber space" (Madnick et al

2012). The usage of derived terms also slightly varied— such as cybercrime or cyber-crime. The variations, especially as semantic problem of definition, leads to what Strate called cyberspace(s) (Strate, 1999) and Ning, et al called “General cyberspace–GC” (Ning et al 2018). This diverged perception and usage of cyberspace and its related terms continues —with competing definitions ranging from fantasy to spatial cognition; none of which is scientific (formal).

The literature converges at a subset of what was coined as cyber-physical-social-thinking hyperspace—(CPST) (Ning et al, 2016) through a process of cyberspace evolution called cyberization (Ning et al 2016; Ma, 2016; Ma et al 2016). A new cyberspace is formed based on the reformation of cyber-enabled world, substantially influencing and revolutionizing the way we conceptualize cyberspace. Fundamentally, cyberspace where cyber-related elements exist pervade different kind of spaces and all aspects of our life.

CPST is form from the merging of Cyberphysical systems (CPSs)— “networked stationary or mobile information systems responsible for the real-time governance of physical processes whose behaviors unfold in cyberspace” (Bayne, 2008) with the Internet of Things (Sun et al 2016). This only emphasizes merging of the paradigms of artificial intelligence and cognitive computing have many areas of application fields.

Related studies have also been carried out with respect to the evolutionary dynamics (Wang, Zhao & Liu, 2016) characteristics (Ning et al, 2016) etc. However, none of these works made a precise definition of Cyberspace in relation to the spatial manifold and existing entities— no attention has been paid to the formal aspects of philosophy, science, and technology of GC, even with the fact that the “space” notion in cyberspace is a significant aspect, and the core issue surrounding its complexity. The space implies the idea of unrestricted movement, of possibility to be or navigate through a variety of states or places. Most importantly, a space idea as in geometric perspective, implying concepts such as distance, direction and dimension.

With the wide penetration of cyberization to the physical environment, Various aspects from related fields and their relationships are increasingly explored for a comprehensive understanding of cyberspace and cyber-enabled spaces as well as sorts of phenomena resulted by the cyberization process. For instance, “CyberSciTech” (Ma et al, 2016) as an inter-discipline, transdisciplinary, and multi-discipline integration of cyber science and cyber technology was studied to explain new conception of cyberspace and the emerging cyber-enabled spaces, empirically adding to ways we understand and study complex phenomena in GC. Similarly, a scientific and systematic discipline to study cyber entities as well as its attributes, properties, behaviors, and practice in GC, called “Cybermatics” (Ning et al, 2016; Ma ,2016) was studied. Although cybermatics looks promising, the research is based on perceptual observation of similar research terms and areas and lacked a real connection theme. The work in (Ning et al, 2017) attempts to link the philosophical concept of cyberspace to cyber science. All these researches mainly studies aspects of minds, Paraspace, communication, and ethics. yet, the fundamental issue of philosophy is about ontological existence, and that of a science is theory.

Most definitions assign cyberspace an empirical spatial quality, despite the fact that traditional nation of space was abandon for a meaningful scientific concept. For example, cyberspace “...as the diverse experiences of space associated with computing and related technologies” (Strate, 1999). In many instances it is perceived in the form of navigation through the space of electronic data, and of control which is achieved by manipulating these data. However, it is more than a space of passive date.; The ‘cyber fiber’ (Gozzi, 1994) and communication channels connect to the physical environment and allow cyberspace users to interact with this real world. Cyberspace's core is particularly the interconnected network of all existing communication channels and information system connecting computer devices, people and machines.

Based on these issues we propose a formalized perception as an addition to the literature and closely related to the work by Ning et al (2018). Their work proposes the definition of general cyberspace (GC), an investigation of cyberspace from three concepts: existence, interactions, and applications/services, in terms of philosophy, science, and technology respectively. Our proposal, the formal cyberspace, then begins by covering four main aspects: (a) The existence of Cyber Entities in Cyberspace underlined by dimensional concept, addressing the theory and methodology of properties and functions for cyberspace and cyber entities from ontology; (b) Cyber-Physical mapping, which is basically concerned with how the cyber physical entities are generally connected;(c) Cyber-informational Conjugation, which is concerned with how information entities are conjugated; (d) Cyber-Physical-Social-Mental Integration is for the possible connection of these multi-disciplinary aspect of dimensional space, network space, and information space entities in FC combine Spaces.

Cyberspace is a contestant terrain, interdisciplinary and exhibits heterogeneous mathematical characteristics. Norbert Wiener originated cybernetics to provide a mathematical tool for studying adaptive and autonomous systems (Wiener, 1948), leading to the formulation of theories which further explain properties of complex system, for instance self-organization. With implications for engineering, systems control, computer science, biology, neuroscience and philosophy. Understanding of cyberspace also has security ramification: “there is a need to gain knowledge and understand the cyberspaces' influences on enterprises cybernetically in order to deal with cyber-security effectively for enterprises' survival, success and further growth” (Vinnakota, 2013).

Over the years, many different explanations and understanding of cyber space evolve from individual, official government documents, scientific literatures, groups and dictionaries, cutting across philosophical, scientific and fictional boundaries. In essence there are at least 28 distinct definition of cyberspace with no common definitions at the scientific level (Kramer, Starr & Wentz, 2009) and every nation state uses a different definition. However, the common themes among the definition is that cyberspace is inclusive of globally connected hardware, software, information, and implicit reference to its users and notion of space.

Cyberspace is completely unprecedented space which is why in the most recent work studies cyberspace analogue to the traditional Physical, social and thinking space (Ning et al, 2016; Ma, 2016; Ma et al, 2016). The central theme in these and other relevant work is that cyberspace is no longer confined to digital world but extends beyond it to include various concepts of physical, social and even mental space, and this perception needs to be explained in a rigorous way.

Therefore, there is a need to explore theoretical foundation of Cyberspace that highlight the ontology, network theory, and information theory. A novel insight on cyberspace and cyber-enabled spaces as well as open up a wide range of possibilities for further research on scientifically driven cyberspace characterization.

2.2.1. Disciplines

Cyberspace spectrum is a broad area of research that is multidisciplinary; including technical, strategic, operational, sociological, philosophical, scientific, and technological perspectives, all of which has either practical and/or theoretical point of view. The last three of these are necessary but not sufficient to characterize the domain. Cyber philosophy comprises of fundamental issues of cyberspatial entities in CPST spaces of existence; cyber science consists of the cyberspatial entities' systematic testable explanations and predictions in CPST spaces; and cyber information technology consist of cyberspatial information semantics and syntax.

1) ***Cyber Philosophy:***

"conceptual issues arising at the intersection of computer science, information science, information technology, and philosophy" (Ma, et al 2016). In short, intersection of philosophy and computing (Moor & Bynum, 2002). Philosophy of physics and philosophy of social science are instance of metatheories. Philosophy of information is critical investigation of nature and basic principles of information, its dynamics, uses and science or the application of information theoretic and computational methods to philosophical problems (Floridi, 2002). So, the fundamental issue of cyber philosophy, the questions about existence, is still not adequately addressed in detail. To do this, the question of cyber ontology come first.

Ontology: The literature fails to formally address the problem of the ontology of cyberspace. No serious philosophical approaches to ontology of cyberspace have been made; In the work of Heim (1994), a superficial ontology was mention but concisely sets forth the problem: the need to explain how entities exist within cyberspace and the ontological status itself. More comprehensively, the ontological question the need to address the following questions: "What is cyberspace? Is it or does it have dimension? Are there things in cyberspace? Are things in cyberspace properly called objects? Are such objects or is cyberspace itself substance(s) or process(es)? Is cyberspace or the objects in it real or ideal What is the categorical scheme of cyberspace? How should cyberspace fit into a broader categorical scheme?" (Koepsell, 1995).

Cyberspacetime: To define cyberspace, we need to deconstruct a binary opposition of cyberspace to physical space. Basically, cyberspace as a product of dynamic relationship—Presence of energy or field. A dimensional manifold made up of cyberspatial objects (events, entities and process), Therefore, reference frame–cyberspace-time model comprising three spatial dimensions plus time. The dimensions are required to uniquely identify each and every object. Subsequently, cyberfield can be established as a byproduct of the cyberspatial entity network. The formation and evolution of the cluster of the entities is then govern by rules such as topological rules.

Cyberspatial object: There are myriad number of phenomena in cyberspace— material reality, perceptual or conceptual, that can be perceived as objects/entities. For example, computers, cyber physical systems, routers, autonomous system, rational agent, information etc. Cyberspace is then a manifold consisting of these entities. As a meaningful scientific concept, three types are considered: logical entities which exist only in virtue of demarcations induced by human cognition and action, as in application, virtual entities, or simulated objects; physical entities, the material base underlying cyberspace— tangible entities determining a possible pattern of information flow, and the typical operations that can be made. And, also data as an entity, which can be in the form of event or processes. Some of these entities can then be well defined in the spatial embodiment.

Existence: The existence, as a general problem of philosophy, also the substratum of FC, refers to all spaces (physical space, logical space, information space, and cyberspace) and all cyberspatial object in GC. The logical problem of the application of mathematics to the real world is also of great philosophical importance. But, the problem of the existence of entities was reduces simply to that of the existence of terminology or notation, even though existence deprived of application in mathematic is just a meaningless. The logical problem of the existence of entities to the mathematical problem of the existence of entities with certain features, for instance the existence of an entity that has spatial coordinate. The ontological concept of cyber philosophy is given in Fig. 2.1 below.

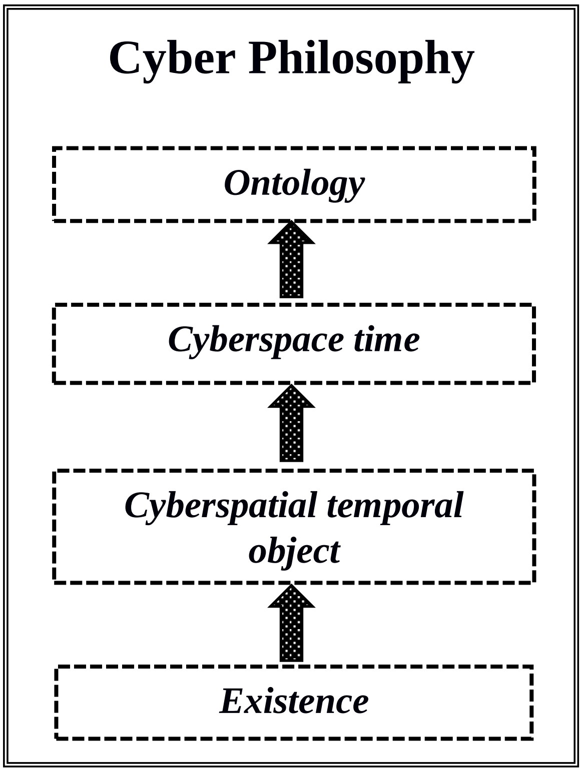


Figure 2.1 Ontological concept of Cyber Philosophy

2) Cyber science:

From Cambridge English dictionary, Science is defined as "the careful study of the structure and behavior of the physical world, especially by watching, measuring, doing experiments, and the development of theories to describe the results of these activities". Cyber science is then study of cyberspatial entities to create systematic information and intelligence about them.

Network science: Communication networks, describing communication devices interaction with each other, through wired or wireless connections, are the core of the modern communication system. To understand this system, we need a deep comprehension about the network behind them. It allows the use of theories and methods including graph theory from mathematics, statistical mechanics from physics, data mining and information visualization from computer science, and social structure from sociology.

Topological dynamics: The natural framework for a precise mathematical modeling of complex network is graph theory. In this case the cyberspatial entities are the nodes and the connection (wired or wireless) as an edge. The ultimate focus of network modeling is towards the definition of increasingly complex rules, incorporating many dynamical characteristics observed in the evolution of real networks, Cyberspace is network of networks (Halappanavar et al, 2013) and therefore its topological structure and the dynamic behavior modeling is promising with network theories. It has been found that the router and/or autonomous system (AS) topology has some defined properties: Hierarchical structure, high clustering, presence of hub, average shortest path etc. (Chen, Wang, & Li ,2014; Fan, 2006).

Rules/principles: Underlined the topology of a network is a principle of its organization. The search for the principles has led to series of quest from random network (Waxman, 1988) to Heuristically optimized trade-off (Fabrikant, Koutsoupias, & Papadimitrioum, 2002; Alderson et al 2006), [39] models of technological network. The baseline is that network is driven by rules and principles.

Interaction: The actual topological structure and dynamics are formed conceptually from individual entities, to pairwise interactions, to local structures, and eventually to the global network as a whole. The interactions among entities and between different levels of the structure of a cyberspace generate many unexpected or unpredictable behaviors, such as power law degree distribution (Siganos et al 2003) emergence and chaos. Figure 2.2 below depicts the Topological formation and interaction of entities.

Dynamic graphs representing the physical connectivity as physical location may provide a vital information in research that correlate the connectivity and performance with the real physical distance among routers (Yook et al 2002). Un top of physical connectivity is the logical interaction, for example a service or a software application running in an enterprise system with link representing pair-wise relationships between them. The relationship between physical entity and logical entity is clear in this regard, that is the services run on a given cyber physical system. From a network perspective, the topological connectivity of entities differs in physical and logical space. With regards to information entity communication, information in cyberspace also forms a network. for instance, the www which is a universe of information formed by linking resources for easier accessibility (Albert et al 1999).

The interaction among different entities is either homogeneous (entities considered with respect to specific spatial domain), or heterogeneous (entities from different spatial domain). The model can uniformly describe homogeneous and heterogeneous entities interacting with their complex relationships in multi-dimensional transdisciplinary cyberspace. This complex interaction could be represented, from a graph theory, as hyper graph H (V, E) (Peng, 2016).

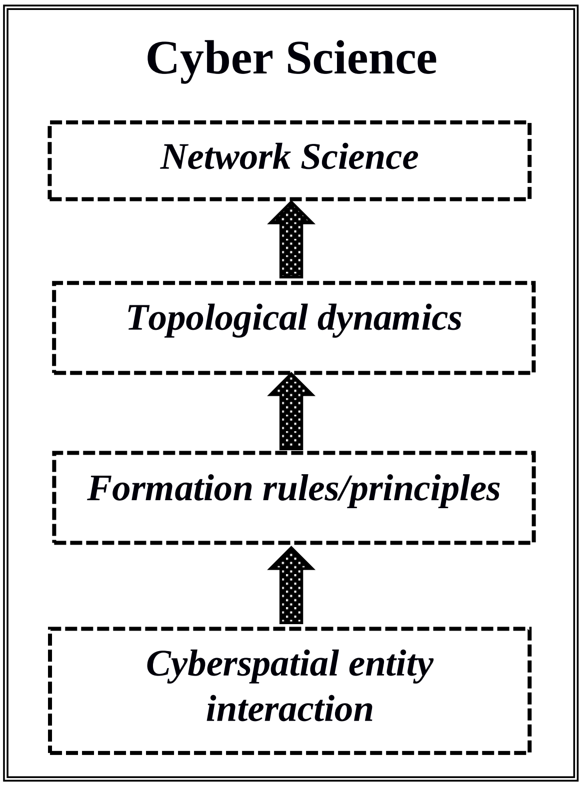


Figure 2.2 Topological formation and interaction of entities.

3**. *Cyber information technology***:

The application of information in the design, development, implementation. use of cyber entities. Our Concern is how to make sense data/information itself, therefore information theory as a measurable reduction in uncertainty is the way to go. Shannon's information theory describes measures for conditional events, streams of messages, and situations. This work is the basis for contemporary information and telecommunications systems, including, telephones, WWW and the Internet which is used for a computable prediction of the system dynamics.

Information theory: Shannon pioneered theory of information, proposing that information can be defined as a change in state (Shannon, 1948). The key elements in a communication system are the source, channel, and receiver, nothing more than the cyberspatial entities—a finite set of information units.

Information syntax and semantics: The general definition of information posit that an instance of information as semantic must consist of a meaningfully well-formed data. The mathematical theories of communication are applied to the data, and the philosophical theories are applied to the semantic (content). Information as being encoded, transmitted and stored is non-negative and additive. The key is to use mathematical theory of communication to give a technical meaning to information instead of using information as an ordinary sense of our thoughts.

Information exertion like an energy: industries. Energy considered from angle of physical and conceptual and social state change the most fundamental sense of information. Energy is what influences changes in systems at all levels in the universe from the subatomic to cosmic. Information is a kind of energy that govern the changes in physical or conceptual states. Energy has basic properties and measures and is understand through the quality and quantity of change it effects. The information; which is exerted like an energy among cyberspatial entities, is shown in Figure 2.3 below.

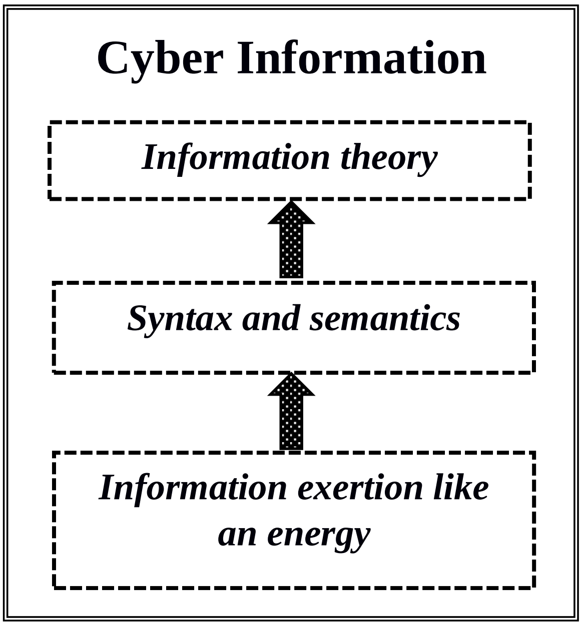


Figure 2.3 Information like a force exerted among cyberspatial entities.

The formal issues arise at the intersection of cyber information, cyber science, and cyber philosophy bridged by Cyberlogic (Ning et al, 2017). More specifically, the existence of space and spatial entities governed by a topological rule and instructional information that the entities used to changes theirs states and the state of other connected entities. Details in Figure 2.4:

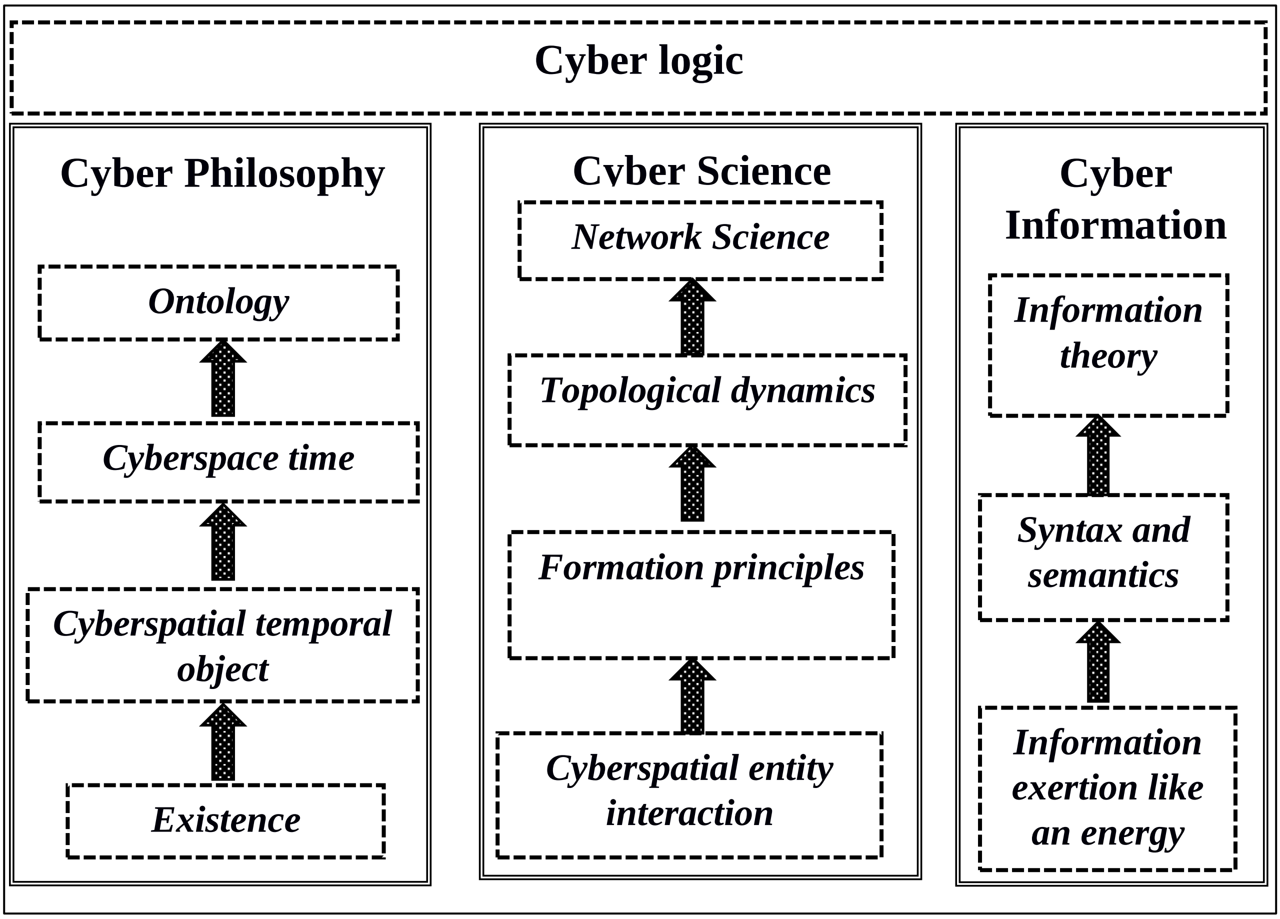


Figure 2.4 Cyberspace disciplines.

2.2.2. General Cyberspace to Formal Cyberspace

Variety of definitions of cyberspace is being given in many documents and mostly posit that the core of cyberspace consists of connected networks of hardware, software and data. In addition, the relationship between these entities is complex and heterogeneous. This emphasis the focus on the cyber part of cyberspace.

However, “space” concept is paramount as well. To define something as a space, a corresponding topology or metric need to be formulated (Kuratowski, 1966). By metric, it implies that the distance measure between entities is explicitly considered so that the corresponding axioms are met (Deza & Deza, 2006). Depending on the underlined spatial theory, different calculation of distance in cyberspace is possible. For instance, shortest path between two nodes from graph theory, geographical distance. Though the later may not be immediately useful.

Three spatial aspect are usually mentioned in literature base on the traditional, physical space, social space and thinking space. CPSs, Mobile Cyber-physical system (MCPS), cyber-physical-social system (CPSS), and cyberphysical-social-thinking hyperspace (CPST) are an instance of convergence these three spaces. The physical space is the real-world space containing geological object, the social space is of social relation of human activities, and the thinking space is a space of though and intellectual activities (Zhu et al, 2016). For a meaningful formal description, we replace social space with logical space, and thinking space with information space. Therefore, present the notion of space, network and information.

The general cyberspace as a unified description of cyberspace and cyber-enabled space is then formally a unified cyberspace and spatial temporal dimensions. A cyberspace occupied by cyberspatial entities, which are distinguish by their spatial coordinate and dynamic in time. This means that users, nodes and connections can appear and disappear, and information is transformed over time.

A typical example of cyberspatial entity is the cyber physical system —System that integrate cyberspace with the physical world, also responsible for governing physical systems whose effect unfold in cyberspace, and its underlined technological issues related to specific techniques and procedures. There are also functionalities and events involving relationship between cyber entities and their surroundings.

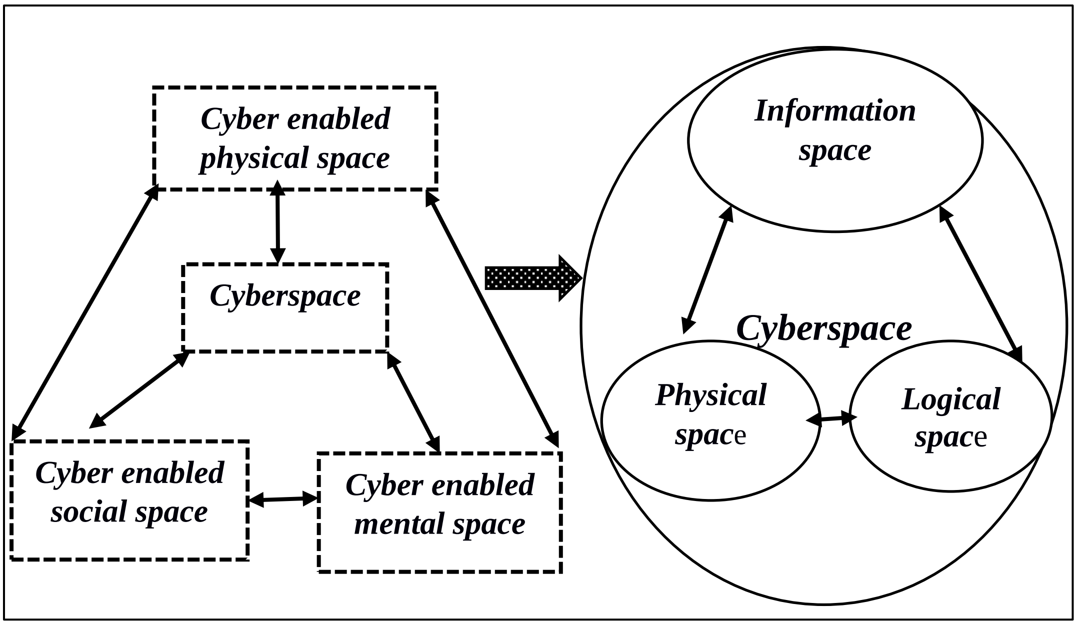


Figure 2.5 Shift from general cyberspace to formal cyberspace.

The spaces are integrated into traditional cyberspace by coupling data/information, and logical cyber interactions, and space-time and/or geospatial manifold. Cyberspace has the following characteristics:

1. Integration: cyberspace as a combination of variety of spaces.
2. Interconnection: cyberspace related with other spaces.
3. Interaction: cyberspace can influence other spaces
4. Interpretation: cyberspace with rigorous meaning

2.2.3. Entities and Spatial Existence

A comprehensive ontology of cyberspace is vital in many aspects. For instance, how the cyber objects are discussed ultimately depends upon choice of ontology of cyberspace. One of the defining characteristics of matter is to occupy a space and a physical existence points to a substance made up of matter and/or energy. Varieties of cyber entities exist, many of which directly correlate to entities in the physical worlds. As result of this, the real entities have a cyber-existence and are interconnected via cyberspace. We then identify and express various forms of existence of space and entities.

A. Space existence

Space is a collection of infinitesimally small places/points/locations where entities may be found. Cyberspace has been considered a ‘parallel’ universe (Grosz,2001), “physical space and cyberspace interpenetrate” (Wellman, 2001)) and that “Space, is a boundless, three-dimensional extent in which objects and events occur and have relative position and direction.” (space,1998). The space consists of some objects that are treated as points, and some relationships between these points. Therefore, we need to specify relevant coordinates, dimensions, objects and their relationships to give the spatial perception of cyberspace. Cyberspace may also be considered as a space since volume, locus, or destination can be implied. It is simultaneously physical, that is tangible and real, and present in geospace (G), informational; which is both logical and virtual, and present in info-space (I), and social; organizational and political, and present in socio-space (S) (Bayne,2008).

- ***Physical space:*** The cyberspace viewed as an entity embedded in physical space and the very existence of cyberspace in physical space is thus investigated. The cyberspace is physical, present in geospace and shares characteristic of physics. The classical three-dimensional Newtonian space-time framework embodied cyber system operates in geospace. The geocentric coordinates which are a system of locating an object in three-dimensions like that of latitude, longitude and altitude may also specify the physical location of an object at a particular time using Cartesian coordinates.

Consider a 3-D manifold, $\mathbb{R}^3$, and let e_i and $P_i^P(t_k)$ be cyber object in a cyberphysical system in particular, and its physical (geospatial) location at time t respectively. The two indexes required are: (i) The geocentric coordinates, a system of locating an object in three-dimensions along latitude, longitude and altitude (x, y, z); (ii) the spherical coordinates defined by using radial, azimuth and zenith angles, r, θ and $\emptyset$ respectively.

$$P_i^G(t_k) = \{x_i, y_i, z_i\}(t_k) \qquad (2.1)$$

Alternatively, the discrete partition model of physical space, a digital earth, could be used to locate cyber object at multiple resolution. For example, Geodetic Discrete Global Grid Systems (GDGGS) (Sahr et al 2008) or Digital Earth Reference Model (DERM) (Vince &Zheng, 2008) allow mathematical operations to be defined on the index, where {x, y, z} refers to the location of a hexagonal region defined by a tessellation on the Earth’s surface.

The addressing of an object, using geospatial *address* (*gsa*), the Pyxis digital earth index, is given in (Bayne, 2007) as:

$$gsa =< dga : dra : dea > \qquad (2.2)$$

Where:

Global Address *dga:* specifies the Resolution 1 index “AN”. The Pyxis DERM Resolution Address *dra:* specifies the higher resolution (>1) indices “N…N.”. The Pyxis DERM Elevation Address *dea:* specifies the thickness (volume) of the cell identified by “ $< dga : dra >$ ” (Bayne, 2007).

- **Logical space:** A network or graph is an abstraction of spatial relationships, most profoundly representing the connectivity between the spatial entities. It is the natural method used to represent the structure of internet. Nodes can be a computer, a router, a host, LAN, an autonomous system, web documents etc. Connectivity among nodes can be depicted accordingly. In this way it is possible to identify and describe part of or an entire underlined structure of internet in an appropriate way.

Mapping of entities has been done at different levels of topological description. It has been possible to have the internet graph by using router adjacencies. At much higher level the internet has also been mapped in a graphical space from autonomous system routing path information. Some factors also influence the structure of network; whereby new connections may emerge with higher probability. Empirical analysis shows that location of routers and autonomous system are related with population density (Yook, Jeon & Barabasi, 2002).

A network consists of some nodes (vertices) connected by some edges (links) in a certain topology (structure). Let V(G) be a given set of points/nodes/entities. Then a topological space is a collection of subsets of V(G), such that every point in V(G) has some neighbors and the interaction of any two neighbors of any point in V(G) Influences the states.

The basic unit of logical space is a pair of points or Logical location of entities and associated with states or values. Formally, the topology space is a function from the set of nodes, occupying a position P, to the set of states (attributes) defined by

$$f: E \rightarrow S \qquad (2.3)$$

$$X = \{(e_i, x(e_i)) : e_i \in E\} \qquad (2.4)$$

Where $e_i \in$E is an entity (cyber object on cyberspatial position) and $x(e_i) \in$S is a state/value.

Vertically an underlying hierarchy can be identified in a logical structure of cyberspace. The network can be partitioned into autonomous systems that are different in size and functions. The autonomous systems correspond to different backbones like Internet Service Providers (ISP), providing connectivity; in national, inter-continental, regional and local areas. A local autonomous system, L, is a subordinate to, and therefore dependent upon national autonomous system, N, which is superior to, and therefore responsible, its subordinates including regional autonomous system, R.

We can identify a logical space, as a framework to specify the location of logical object with respect to its administrative or connectivity role within one or more autonomous systems. Let $P_i^L = \{n_i, r_i, l_i\}$ be the spatial position of logical entity P_i^L. Figure 6 shows the logical coordinate of an entity in 3-dimensions.

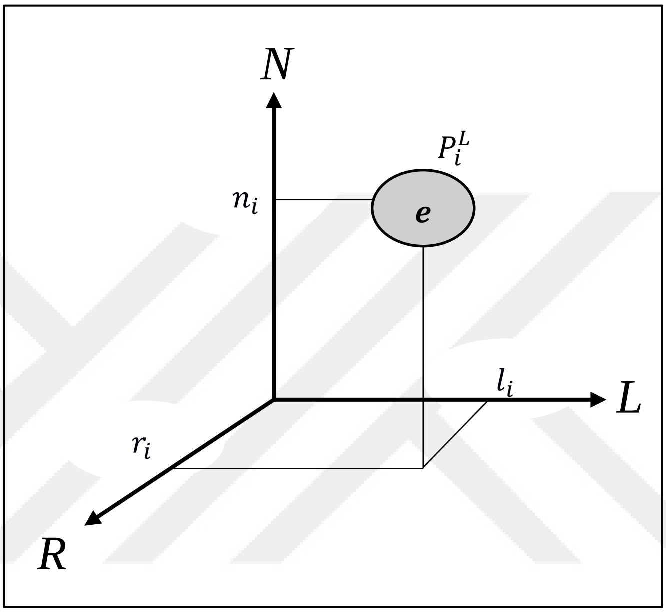


Figure 2.6 Logical coordinate of an entity.

- ***Informational space:*** Semantic information as meaningful data is considered as yardstick to give a framework of information space, although there are many controversies surrounding the ontology of information. Information is then broadly understood, as syntactically well-formed and meaningful data (Floridi, 2019).

A conceptual space can be constructed by processing the data matrix of the observations based on the variable values and class labels (Banaee, 2018) — "A conceptual space is a geo-metrical structure which is defined by a set of quality dimensions. The quality dimensions present the features of objects in the space based on their measured quality values. One conceptual space can consist of multiple domains. A domain in the conceptual space is represented as a set of interdependent quality dimensions which are logically integrated." (Banaee, et al 2018).

The conceptual space models the attributes of concepts for a comprehensive reasoning, and useful as a framework for content determination using semantic inferences. Fuzzy representation of conceptual spaces' elements by integrating conceptual spaces theory with the topic of computing with words is possible (Aisbett et al 2015).

From the work of Banaee et. al. (2018); Raubal (2004); Bechberger (2017) and Peter Gärdenfors (2000), the conceptual information space is considered as 4-tuple〈Q, Δ, C, Γ〉, where Q is a set of quality dimensions which is the framework used to assign properties to objects and to specify relations among them, Δ is a set of domains, C is a set of concepts in the space I, and Γ is a set of instances representing the concepts.

Conceptual spaces theory presents a framework consisting of cognitively meaningful attributes in various domains within a geometrical structure in order to model, categorize, and represent the concepts in a multi-dimensional space (Gärdenfors, 2000). The theory of conceptual spaces is a knowledge representation framework exploring how different information can be formalized, both from a psychological point of view and for developing an artificial system (Gärdenfors, 2004).

Similarly, using 3-D we can identify spatial dimension as framework in which to specify the locations of informational object's location, specifically service access points (SAPs) or the communications ports. Let $P_i^I(t_k) = \{g_i, s_i, a_i\}(t_k)$ be the info spatial location of $e_i$nth SAP at time(t_k). Where, g is the global network address, s is the subnetwork address and, a is the subnetwork's SAP. The Communication system produces a message which can be a function of time and some variables defined in a dimensional continuum (Bayne, 2008).

B. Cyber spatial entity existence

- ***Cyberspatial entities*** which can be events, agents, or processes are objects whose behaviors unfold in *cyberspace*. These objects in physical space, logical space or info space require corresponding indices to distinguish one object from another and, for a given object, one state from another (Bayne, 2007). Cyberspace is thus viewed as occupied by discrete, identifiable entities, each within a spatial reference frame.

- ***Cyber physical object existence****:* In physical space there exist many entities that can be identified and formalized. For instance, cyber physical system is "internetworked information systems responsible for governance of physical processes" (Bayne, 2008). These entities can be identified by their coordinates, geospatial dimension, and can be formalized in such a way that each object composed of unique identity (I), spatial embedment (S), and attributes (A): which can be conceptualized and referenced. Therefore, a cyberspatial physical object or entity P_i^G is formalized with at least 3-tuples $\{i_i, s_i, a_i\}$.The spatial embodiment, $S \in \mathbb{R}^3$, is the geospatial indices and can serve as the objects identity as it is required to distinguish one object from another. This will further be discussed in subsequent chapters.

- ***Cyber logical object existence:*** logical entities exist only in virtue of demarcations induced by human cognition and actions in cyberspace, as in application, virtual entities, or simulated objects. There are many logical entities which are usually represented as a node in the network. Consider an entity $e_i \in E$, for example services, application, documents. In the topology of logical space, $E \neq \emptyset$.

- ***Cyber informational object existence:***

Researchers have proposed quite range conception of information from specific to generic. Information as a product of process (Lose, 2010), the science of information as inter-disciplinary leading to computers and information processing model (Resnikoff, 1989), that electronic media and cyberspace lead to coupling of the classical senses of information (Information as energy, cyber identity, thought and memory, communication process, or as an artifact) (Marchionini, 2010).

Energy is the phenomena that effects changes in systems (subatomic, cosmic, etc.) and information is a sort of energy that drives changes in physical and conceptual states in the form of instructional or imperative information. For instance, electronic, biological, chemical and physical processes use information to effect changes in the state of the corresponding systems. The networks in cyberspace include communications links that guide the flow of energy, the physical entities and the logical entities supported by the physical entities instantiating the rules for information flow.

Data, well-formed information, is an example of information entity. Well-formed means that the data is defined by some rules/syntax that govern the system. Information can be quantified using a fundamental unit; Shannon entropy a measure of the information in a message, measured in bits. The Shannon entropy of a variable X, an entity, is defined as:

$$H(x) = -\sum_{x=1}^{N} P(x)\, log_{2^P}(x) \qquad (2.5)$$

Where $p(x)$ is the probability that X is in the state x, and $p\ log_2 p$ is considered 0 if $p = 0$. (Shannon, 1948). Information in form of a message is defined as $m_{i,j} = \{e_i, e_j, n, l, t_k\}$. Sent from entity e_i to e_j; where l is a payload with a particular action/service selector, $n \geq 1$ and t_k as the time of a "message sent" (Bayne, 2008).

Consider M as the set of all messages $\{m^1, \dots, m^w\}$ possible for X, and $p(x)$ is the probability of some $x \in M$, then the entropy of X would be defined as

$$H(X) = E_x(I(x)) \qquad (2.6)$$

Where $I(x)$is the entropy contribution of an individual message (Floridi, 2005).

To sum up, the traditional or common-sense perception of space attributed to cyberspace does not amount to meaningful scientific concept, therefore the basis of cyberspace in contemporary physics is considered for it represents more rigor. As a parallel universe of electronic devices and infrastructures, we ca base our understanding of cyberspace from well-defined perspective, for example as put down by Bolter (1984) that a cyberspace as an abstract, geometrical and mathematical field in which the data structures are built. In this view of cyberspace, the proposition that cyberspace may be more accurately described as a part of the physical universe holds true that the cyberspace may follow or object to some laws of physics. Unfortunately, this concept leads to many questions than answers, however, existing theories may highlight some insights.

CHAPTER 3
CYBERSPACE FORMAL MODEL INTEGRATION

Underlined every spatial representation is an implicit model of space. Such models are more useful if they can be fully interactive and dynamic for exploratory purposes and based on actual data. Spatio-temporal capability, simplicity, and parallelism of cellular automata has helped modeling approaches move from the systems of differential equations and the realm of pure abstractions to that of potentially qualitative, implementable tool. Such models could be fully interactive for exploring quite range of complex systems, and they can be based on more realistic models of systems and actual data. Cyberspace perception and conceptualization has become more complex through time, due to its scalability and as new and more concepts are being added, leading to an endless proliferation and creating a need for simplification/Categorization. We show that many of its concepts can be derived from a well-established foundation in physical space. Relating cyberspace to other bodies of knowledge, we analysis some central insight and questions: to what extent is cyberspace augmented by the theory in physics, the network theory and agent modelling paradigms. Does the concept of absolute and relative space help to explain and/or advance the theory of cyberspace? what concepts of network theory can be readily re-appropriated? And can the network-based agent model help to describe the cyber spatial object dynamics? and what hint can be used to have an integral explanation of the cyber domain?

3.1. Cyber Inspired from Physical Space

Philosophically, physical space is understood mainly in terms of a dichotomy—relational and absolute space. In absolute notion (Aristotelian, Newtonian), space is generally perceived and considered as a phenomenon filled with objects/events, from this view Aristotelian conceive space as static, hierarchical, and concrete; and Newtonian, regards space as ‘a kind of absolute grid, within which the objects are located and events occur’ (Curry, M. 1995). Meanwhile, in relational view of space (Leibnizian and that of Kantian), space is understood as the consequence of interrelationships between objects. Leibnizian hold a space to be relational and defined entirely in terms of those established relationships; while Kantian conceptualized space as ‘a form imposed on the world by humans’ (Curry, M. 1995).

Another concept of space that binds space and time so tightly is Einstein's Space-Time in which Space-time behaves relationally but exists absolutely. And basically, modern space-time theories are now built in a similar way as such even "empty space" is populated by matter in the form of virtual particles, zero-point fields and more (Overduin, J., 2007). A theory posits a manifold of events and then assigns structures to those events to constitute the content of space-time.

Space then taken to be the collection of places (location where an object is positioned) or events (occurrences in a particular location in an instant of time). The collection of these locations is assumed to be structured, various relation to be defined on them. This assume a dimensional reference frame is whereby the object in consideration have relative location and direction. That is, a metric space; with Euclidian geometry as the basic structure. In a similar but different setting, it has been shown that cyberspace can assume Euclidian formalism— a compacted space of at least three-dimension: geospace, infospace, and sociospace. (Bayne, 2008).

Physical space and cyberspace has been analytically argued to be equivalent in the sense of four concepts; place, distance, size and route, and that even though cyberspace exhibits some characteristics from physical space theories (absolute, relational, Einsteinian and Kantian), although it can't be subsumed under one particular theory (Bryant, 2001). Coyne (1995) argued on ontological stand of cyberspace, he contended that cyberspace is a "world", a space, and a place.

A configuration of cyberspace objects brings about the very structure and form. The initial configuration and the set of rules point out a space of potentialities. The object can assume states and the totality of which comprise as space. Also, the sense of coordinate and to some extent measurable space can be implied: Object in cyberspace gets into a particular relationship with one another, such as; adjacency (direct/indirect link), connectivity (e.g. Peering), etc. and a location of an object can be specified arguably in at least three-dimensional space having referential coordinates. This enable object's where about to be found, using this reference frame in terms of address or URL. With this introduction of dimensional coordinate, we can account for objects distance, in more network theoretical perspective, the sequence of edges length regarding the number of objects traversed. Hence, Cyberspace shares some absolute features of physical space in that it is conceivably measurable and identifiable. That is, some aspect of cyberspace can be abstracted on spatial plot.

As in physical space, entities relation is formed by some spatial concepts. Object in space and their reference frame are organized in relation to a spatial logic underlined by some factors. Although cyberspace makes the concept of physical distance in terms of social relations of entities obsolete (Cairncross, 1997), the abstract spatial concern is still relevant— entities are relatively located, physically where they could take advantage of population distribution, economic strength or services rendered.

Cyberspace as an embodiment of a “world”, this a world with myriad of entities and various categories of this objects are observed, such as the physical infrastructure of hardware components, the services. Thus, the collection of cyber physical systems is the subset of the physical space. Furthermore, the cyberspace supports the space of various enterprises. The implication of this is to help derive some properties of cyberspace from the features of these entities. This embodiment entails rules bounded by the entities, practices and the possibilities they permit. The possibility for certain event to occur— resulting from the interaction between much bigger cyber physical system and the smaller cyber objects

Cyberspace reshape the conception of our surrounding. For example, the effect of proximity or distance in our physical world and services which has been changed or made irrelevant—direct and instant exchange of information and service. A constraint of time, which regulate access to resources, is in more effect then a that of a distance as in cyberspace (Harvey & Macnab, 2000). Therefore, many aspects pose challenges relating Cyberspace to physical space. Thus, Cyberspace goes beyond just purely spatial to include another concept as it is a Spatio-temporal dynamic system that evolves and in continues development.

To match our understanding of distance, time plays a critical role. Cyberspace, in addition to the spatial dimension, has temporal dimension. The first thought to include time might be to take hid from relativistic space-time continuum, and the time as another coordinate as a measure of entities, or the speed of the message signals. Therefore, the cyberspacetime has to only make use of some relativistic concepts.

Cyberspace exhibits characteristics associated with physical space and beyond. With regards to absolute space, cyberspace is characterized as having (Bryant, 2001):

(i) Irreducible Cyberspatial entities occupying positions

(ii) Cyberspace may exist in the absence of information, but cyber objects depend on cyberspace for their existence— the possibility to transmit information is still there even if cyber objects were to be obliterated.

(iii) Cyberspatial reference frame.

Space-time can be plausibly inferred in cyberspace as it is a manifold populated by entities and the spatial relations between these entities are manifested in it. In physical space, the energy or force which is the result of dynamic relationships can have a similar notion in cyberspace, as cyber space is never an empty container (fundamentally formed by the movement of electrons, and forces exerted by information in the form of messages flowing among cyberspatial objects). Thus, the Cyberspacetime as the totality of events involving relationships between entities. Emphasizing the relational aspect of cyberspace, an aspect of cyber field is established through a simple dyad. Hence, we can at least further our understanding of physical basis of cyberspace by considering the basis of our conception of physical space.

An important consideration is the mathematical abstraction of the space relating the set of objects, allowing the basic rules of their interaction and the operation carried out (example, information transmission, locating entities) based on these rules. The need for an implicit model of space which has underlined spatial representation and can be realized in conceptual and/or abstract way. From the conceptual point of view, space is either set of locations/spatial distribution with properties or set of objects having spatial attributes. The distribution is as a function from spatial framework to attribute domain, and the referential object is characterized by some attributes and populate the space. Mathematically, geometries provide formalisms that represent abstract properties of structures within space. Euclidean geometry provides a view of physical space by setting up a coordinated frame consisting of fixed, distinguished points also called locations. A function assigns a value to each location in a spatial reference frame of at least one dimension, with an additional dimension representing time. A graph is an abstracted model of spatial relationships and allows us to represent connectedness between objects of the space– network-based field, where each location is associated with a discrete object in physical space.

Euclidian geometry can provide a referential model of space, while graph, which is a highly abstracted model of spatial relations, inherently represents network model. As cyberspace is multifaceted, within and beyond physical space concepts, we may have to extend our conceptualization of cyberspace to a theoretical framework that is combinatorial: Combinatorial Euclidian space for instance which is "…finite and discrete structures that arise in combinatorial topology are highly suitable for representation in computer-based data structures" (Worboys & Duckham, 2004) and that "This model can be also used to describe space-time of dimension bigger or equal to four in physics." (Moa L. 2011 Pg. 154).

In this thread we have examined the relevant of cyberspace to physical space. Our central arguments are that cyberspace share some properties with physical space and that the well-established theories may give some hints to further explain cyberspace. That is, cyberspace is treated in context of cyberspacetime rather than paraspace.

3.1.1. Absolute Space and Relative Space

This part explores the questions: "Is cyberspace a kind of space" as put forward by Adams and Warf (1997, p. 141), and a supported by Grosz (2001, p. 76): "cyberspace has been considered a 'parallel' universe to our own". Other view is that cyberspace is neither absolute nor relative (Wang et al. 2003), rather it is an excitingly new medium that exhibits characteristics associated with many theories (Bryant 2001).

Cyberspace is an inherently geographic metaphor' (Graham 2013, p. 178) in that it is spatially and materially based through its physical space infrastructure (Zook et al. 2004), and it interacts with this physical environment (Light 1999; Graham 1998). It also exhibits representations of real space through maps, and graphs, important for the study of real space and for navigation (Zook and Graham 2007; Zook et al. 2004).

These various perceptions may be considered as complementary, so that cyberspace may be viewed as constituting a virtual, physical, interactive, conceptual and metaphorical spatial entity. This is what Strate's (1999, p. 383) termed as cyberspaces suggesting that cyberspace is 'better understood as a plurality rather than a singularity'. The broad adoption of spatial terms in cyberspace somehow substantiate the process of spatialization (Kellerman 2007), implying space as a metaphor for cyberspace and its operation. Assuming cyberspace as Euclidian and compact with perpendicular axes, implies that the orthogonal Euclidean 3-space vectors produce zero dot products, and that system behaviors could be isolated so as to realize compact functional designs–an important system design principle. A hint is given below for the geometrical structure.

3.1.1.1. Geometrical Structure

Let the structure of $\mathbb{C}$, describing cyberspace be characterized geometrically by a tuple $\mathbb{C} = (\mathrm{C}, \mathrm{L}, \Omega, \mathrm{V})$, Where

- C is assumed Euclidian and compact of primarily 3 dimensional (Physical (P_i^P), logical (P_i^L), and information (P_i^I)) plus time.
- L is a connection on C. Its torsion which is the rate of change of the direction of the unit vector, is assumed zero. The **Torsion** is the value τ(L)=0
- Ω, as a differentiable 1-form field on C, as a point set with neighborhoods homeomorphic with the Euclidean space, Such that Ω≠0.
- V is as vector field on C. Such that each point of the manifold $\mathbb{C}$ is an entity or an "event" which is characterized by their instant and point in time and place of occurrence. Two events/process $p, q \in \mathbb{C}$ occur at the same place in the space if and only if they belong to the same of address.

Each point of the manifold $\mathbb{C}$ is a potential entity/object of the cyberspacetime. The structure should allow one to "stratify" the manifold $\mathbb{C}$ into succession of three-dimensional spaces, so that each object is characterized by its instant and the layer (place) of its occurrence. We then need to explore the existence of cyberspatial object.

3.2. Cyberspace Time References

To describe the dynamics behavior of cyberspatial object, at least 2 primary dimensions are needed. Inspired from classical space-time in physics, Bayne (2007) proposed a cyberspace-time reference frame consisting of 2 dimensions plus time. The geospatial and infospatial dimension each considered to have 3 dimension— unfolding seven-dimensional manifold: plus, time. Physical space, however, is conceived to have three-linear dimension, describing objects and event relative position and direction, plus time as in modern space-time, we have boundless four-dimensional continuum. Cyberspace include profiles of system users and administrators and their relationship to critical factors (US DOS, 2013), therefore, adding one more dimension to account for this profile will extend the dimension similar to physical space: cyberspace as primarily consisting of four-dimensional extents (cyberspace and time). Proposed by Bayne (2007), we highlight and re-appropriate these coordinates below:

3.2.1. Geospatial Dimension

From the layered description approach, set of cyberspatial objects in physical layer are tangible and real. This category of object is present in geospace, meaning that a given dimension is required to identify the physical coordinate of the object. These are physical component of the network that includes hardware and infrastructures. This dimension also is the first point of reference used to determine the geographical location and relevant jurisdiction.

We are interested in an object's placement within biosphere, a reasonable depth below and altitude above the sea level. In this vicinity, the object can be able to be located, tracked, identified and reported. We therefore seek a way to indexing the dynamics of the object, a conceptual framework capable of detailing the statics and dynamics (in place and time) characteristics of mammoth number of these objects. A digital representation of geospace is needed

Analogue Reference system: Using geocentric coordinate which is a system of locating object in three-dimensions along latitude, longitude and altitude. To describe the location of an object on earth surface, which is spheroid, a natural way is to use curvilinear coordinates, specifically spherical coordinate: defined by using radial, azimuth and zenith angle coordinates, $r, \theta,$ and $\emptyset$ respectively. The azimuthal angle in x y-plane from x-axis with $0 \leq \theta < 2\pi$, The zenith angle, $\emptyset$ is the polar angle from the positive z-axis with $0 \leq \emptyset \leq \pi$, and r is the radius (distance). With the coordinate system uses a cartesian system (x, y, z), $\emptyset$ is the geocentric latitude and θ is the longitude (denoted λ). Therefore, these two notations are related as follows (Weisstein, 1999): The spherical coordinates $(r, \theta, \emptyset)$ are given by:

$$r = \sqrt{x^2 + y^2 + z^2}$$

$$\theta = \tan^{-1}\left(\frac{y}{x}\right)$$

$$\emptyset = \cos^{-1}\left(\frac{z}{r}\right)$$

Alternatively,

$$tan\,\lambda = y/x$$

$$tan\emptyset = z/\sqrt{x^2 + y^2 + z^2}$$

Where $r \in [0, \infty)$,$\theta \in [0, 2\pi)$ and $\emptyset \in [0, \pi]$

The Cartesian coordinates $(r, \theta, \emptyset)$ are given by the following, as also shown in Figure 3.1:

$$x = rcos\theta sin\,\emptyset$$

$$y = rsin\theta sin\,\emptyset$$

$$z = rcos\,\emptyset$$

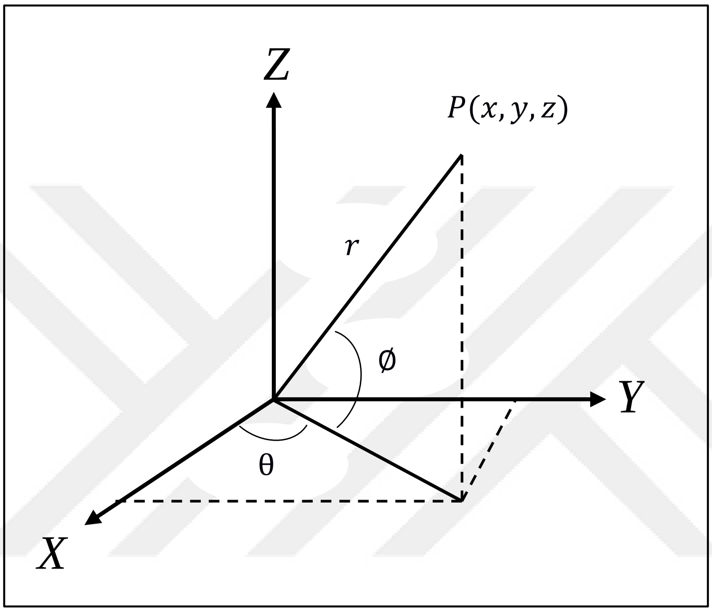


Figure 3.1. Static geocentric position of cyberspatial object

The above is sufficient to describe stationary object (physical immobile in place and time). However, other objects are mobile, as the earth is also in motion, and so time is introduced. If the coordinate change with time, the basis vectors change with a given angular velocity.

In geospace we can therefore specify the physical location of an object at a particular time using geocentric Cartesian coordinate. To use the same coordinate used in navigation, it may be more convenient to employ geodetic coordinate as the earth is slightly flattened at the poles and that the same latitude and longitude are used in navigational maps. However, both systems use three index and can therefore be symbolically generalized. Shown in Figure 3.2, Let $P_i^G(t_k) = \{x_i, y_i, z_i\}(t_k)$ be the geospatial location/position of an object e at time t_k.When the object change position then its coordinate changes, for example, from $P_0^G(t_0)$ to $P_1^G(t_1)$ at time t_0 and t_1 respectively.

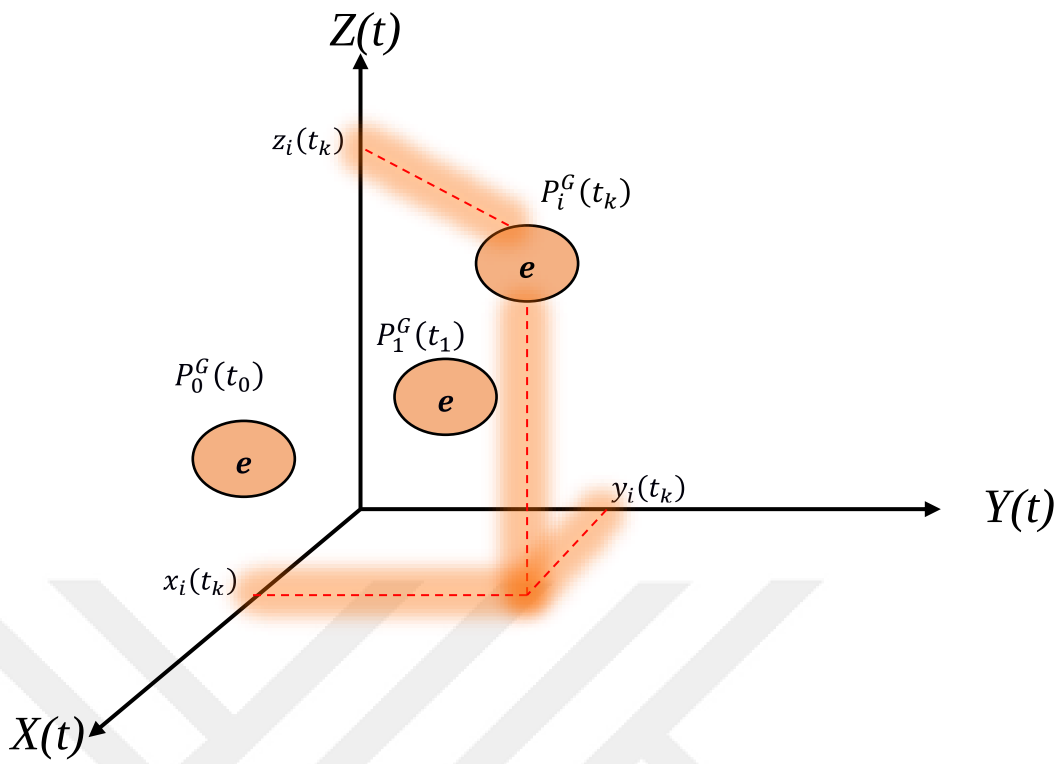


Figure 3.2. Dynamic position of cyberspatial object in time.

The most important concern in this approach are the notion of physical distance which play a critical role in signal transmission, and physical location of cyber object influenced by economic and demographic factors. Given two objects e_i and e_j at a time t_k we can find the distance as follows:

$$d_{i,j}^G(t_k) = \sqrt{(dx(t_k)^2 + dy(t_k)^2 + dz(t_k)^2)}$$

$$d_x(t_k) = x_i(t_k) - x_j(t_k)$$

$$d_y(t_k) = y_i(t_k) - y_j(t_k)$$

$$d_z(t_k) = z_i(t_k) - z_j(t_k)$$

Digital Reference Model:

Almost all aspects of information fabric are digital and therefore more capabilities can be included if we can look beyond model built base on continuum of points. By defining discrete pieces, in resolution of pixels, of partition of space, where the cyberspatial object are referenced. And practically, the placement of ISP infrastructure may utilize different methods, for example Base transceiver station (BTS) towers uses grids system to enable mobile object's wireless transmission of signals. Therefore, particular tessellation, for instance hexagonal tessellation can be employed in the addressing the object physical location. Digital Earth Reference Model (DERM) is a grid of cell modeling the earth, thus the location of cyberspatial object. It provides a mathematical framework defining relationship and operations between the cells. It is extensible and includes multi-resolution index. Multi-spatial and temporal scale, allowing entities related information to be located and indexed at different granularity.

Discrete Global Grid Systems induced by the latitude–longitude does not have equal-area cell regions, which complicates statistical analysis on this particular type of grid. Geodesic Discrete Global Grid Systems (GDGGS) offers a regular grid of cells a representation of surface (Goodchild 2000, Sahr et al. 2003). These cells are usually triangular, quadrilateral (squares or diamonds) or hexagonal. Hexagonal cells are particularly desirable due to their unique characteristics, such as the capable of forming a uniform adjacency and reduced quantization error (Sahr 2011, Snyder et al. 1999). Whilst square tessellation has two kinds of adjacency: between adjacent side and where vertices meet, hexagonal representation can be used for discrete dynamic model. However, an orthogonal framework is widely used for systems. In addition, generalized balanced ternary, as structure on hexagonal tessellation is extensively to multi-dimension, and provide layered indexing of Euclidian space (Herring, 1994). The coordinate can be transformed between Cartesian coordinate (Van Roessel, 1988).

A hexagonal coordinate system is defined as a triple (O, U, V). Where O is the origin centered on a chosen hexagon and U and V are two basis vectors with 120-degree difference (Mahdavi-Amiri et al 2015).

3.2.2. Infor-spatial Dimension

Besides the physical location of an object, we also need to specify the service access points (SAP) of an object— A part of network address that identify distinct application on a host, sending or receiving a packet. This enable different services and application to be distinguished. This is a logical point (conceptual location) rather than physical at which one OSI layer can request the services of the other.

For a network object, when using OSI network system, the bases for this address is Network Service Access point (NSAP). Using Internet Protocol version-six (IPv6) standard, which is 128 bits long and has a theoretical space of 2^{128} $(3.4*10^{38})$ addresses: about 340 trillion, trillion, trillion. Comparatively, the earth surface is about 540 trillion square meters and if a typical node is assumed to occupy a physical space of tenth of square kilometers, we would only need tiny fraction of the address to mapped to physical space, and even with a composite entity (virtualization of entities to have multiple nodes), we still have a stack of *1 x* 10^{10} on the surface of the earth. Therefore, with physical and virtual entities, $3.4*10^{38}$ entities can be theatrically identified. With 128 total bits, we have a full 45 bits reserved for network prefix (global network), 16 bits for site subnet, and 64 bits to use for the interface identifier, which is called host ID under IPv4. Hence, it is imperative that three addresses are used to reach to an object e_i access point at a time t_k , as also hinted by Bayne (2008): global network address, subnet address and access point itself, denoted by g_i, s_i and a_i respectively. Let $P_i^I(t_k) = \{g_i, s_i, a_i\}(t_k)$ be the infospatial location of an object in the entire network space at time t_k. For an object e_i and e_j with and access points *n* and *m* respectively, the distance between this object in infospace, depicted in Figure 3.3 is given below (Bayne, 2008).

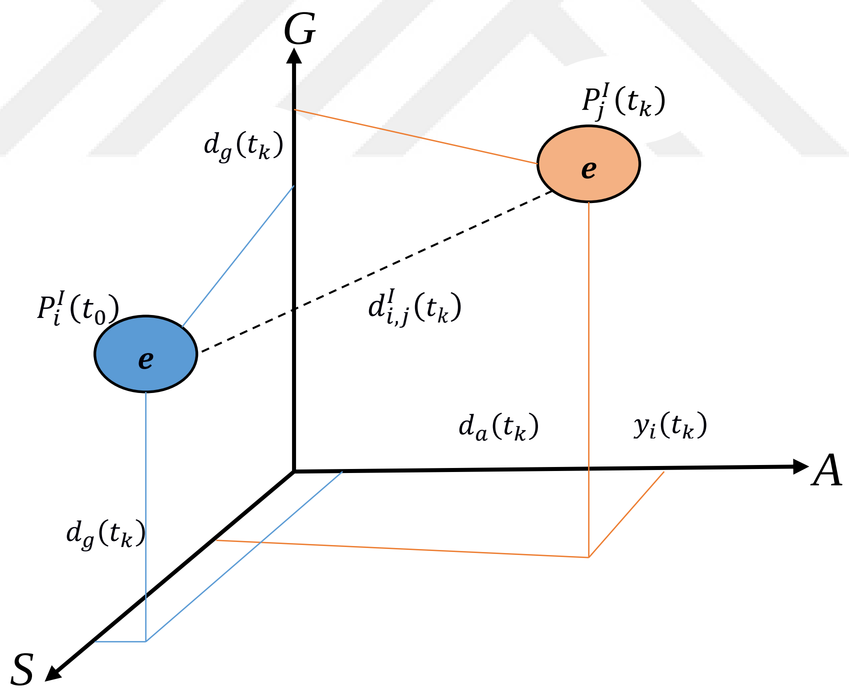


Figure 3.3. Info spatial distance.

$$d_{i,j}^I(t_k) = \sqrt{(dg(t_k)^2 + ds(t_k)^2 + da(t_k)^2)}$$

$$d_g(t_k) = g_i(t_k) - g_j(t_k)$$

$$d_s(t_k) = s_i(t_k) - s_j(t_k)$$

$$d_a(t_k) = a_i(t_k) - a_j(t_k)$$

3.2.3. Socio- spatial Dimension

The cyber-physical-social system (CPSS) is the inclusion of social space to the cyber physical systems involving cyberspace and physical space, whereby humans, machines and entities interact and complicate the complexity of the system as humans are intrinsic part of the system, integral part of effective cyber-physical-system design and operation. Social space includes that information from human and activities and social events such as supervision, organization and coordination. It addresses the aspects of control management, operational role relationships and human behavior formalization. The social rule is then established through cyber persona and other cyber entities coexistence. The architecture specifies the location of cyber entities with regards to operational role within enterprises system (Bayne, 2006)

Integration of technology has transformed military and civilian organizations — changing their structures and forming more dynamic and complex interaction. The real-time enterprise governance and its requirements for a service oriented command and control architecture able to improve interoperability between and among interdependent enterprises is given by a theory, the "theory of enterprise command and control" (Bayne,2006), which offers a logical and technical framework for integrating concepts and requirements for network-centric operations within and among different enterprises; governmental or commercials, public or private military or civilian (Bayne & Paul, 2004).

The cyberspatial objects are defined in terms of two functions and operate in three-dimensional space (Bayne, 2006). The valued added services and governance structure function determining the object's regulatory control structure function and regulating the object's behavior respectively. Cyberspatial object operate in communities of mutual interest, ecosystems called federations (f), the enterprise position in supply chain—Production axis (p), and the enterprise's position accountability axis—command chain (c). The enterprising object, $CPS_{f,p,c}$ is member of at least one "root "federation {f = 1} (Bayne,2008), a dimension of which is shown in Figure 3.4.

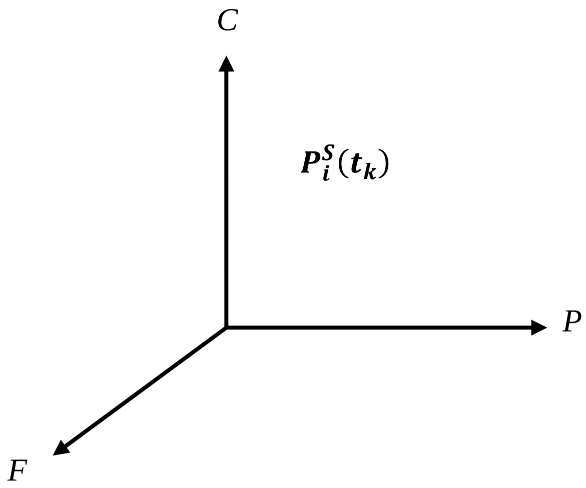


Figure 3.4. Enterprises Socio-spatial dimension.

The position of socio-spatial object at a time, $\boldsymbol{t_k}$ is given by $\boldsymbol{P_i^S}(\boldsymbol{t_k}) = \{\boldsymbol{f_i}, \boldsymbol{p_i}, \boldsymbol{c_i}\}(\boldsymbol{t_k})$ For simplification, this definition is implicit of superior-subordinate relationships as defined by Bayne and Paul (2004), however a given enterprising object interact with multiple producers; the service providers and the client enterprises.

3.2.4. Time Dimension

Cyberspace is dynamic and the spatial objects are either static or dynamic (change in of state and behavior with respect to space and time). Time considered in cyberspace is relative to network accessible clock(s). Time according to network time protocol (NTP) and simpler non-averaging (SNTP), which are used to synchronize the time for Internet hosts, routers and devices to Coordinated Universal Time (UTC), is concerned with the relation between times reported by various network-connected observers, which are generally servers (an instance of cyberspatial objects), describing events of shared interest.

The concept of time is important in order to understand the dynamics of cyberspatial objects therefor time is discrete and defined by incremental offset from reference clock, where $dt = t_m - t_{m-1}$ is the lapse between the timestamps t_{m-1} and t_m. Therefore, events unfold successionally in time. If $t_x < t_y$, an event $\boldsymbol{x}$ at time t_x precedes event $\boldsymbol{y}$ at time t_y. More assumptions for events $\boldsymbol{x}, \boldsymbol{y}$ and $\boldsymbol{z}$ are also taken to be true as follows (Lamport, 1978):

- If $\boldsymbol{x}$ precedes $\boldsymbol{y} \Rightarrow \boldsymbol{x} \rightarrow \boldsymbol{y}$. Establishing a partial relation between

- Let $\boldsymbol{x}$ and $\boldsymbol{y}$ be the events that denotes sending of a message by $\boldsymbol{e_i}$ and the receipt of the same message by $\boldsymbol{e_j}$, then $\boldsymbol{x} \rightarrow \boldsymbol{y}$. Where $\boldsymbol{e_i}$ and $\boldsymbol{e_j}$ are cyberspatial object ore Process
- If $\boldsymbol{x} \rightarrow \boldsymbol{y}$ and $\boldsymbol{y} \rightarrow \boldsymbol{z}$ c, then $\boldsymbol{x} \rightarrow \boldsymbol{z}$. Two distinct events $\boldsymbol{x}$ and y are said to be concurrent if $\boldsymbol{x} \nrightarrow \boldsymbol{y}$ and $\boldsymbol{y} \nrightarrow \boldsymbol{x}$.
- $\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z} \in \mathbb{C}$

An ordered sequence of processes P_1, P_2, and P_3 with their physical clock "tick lines" aligned and the offset error ε given in Figure 3.5 (Bayne, 2008; Lamport, 1978). With the space in horizontal axis and the time presented in vertical axis. The events are the dots denoted by P_{11} to P_{35} of different processes. Message is then sent as shown with wavy lines and it is clear to see that $\boldsymbol{x} \rightarrow \boldsymbol{y}$, which may additionally be interpreted as event $\boldsymbol{x}$ casually affecting event $\boldsymbol{y}$.

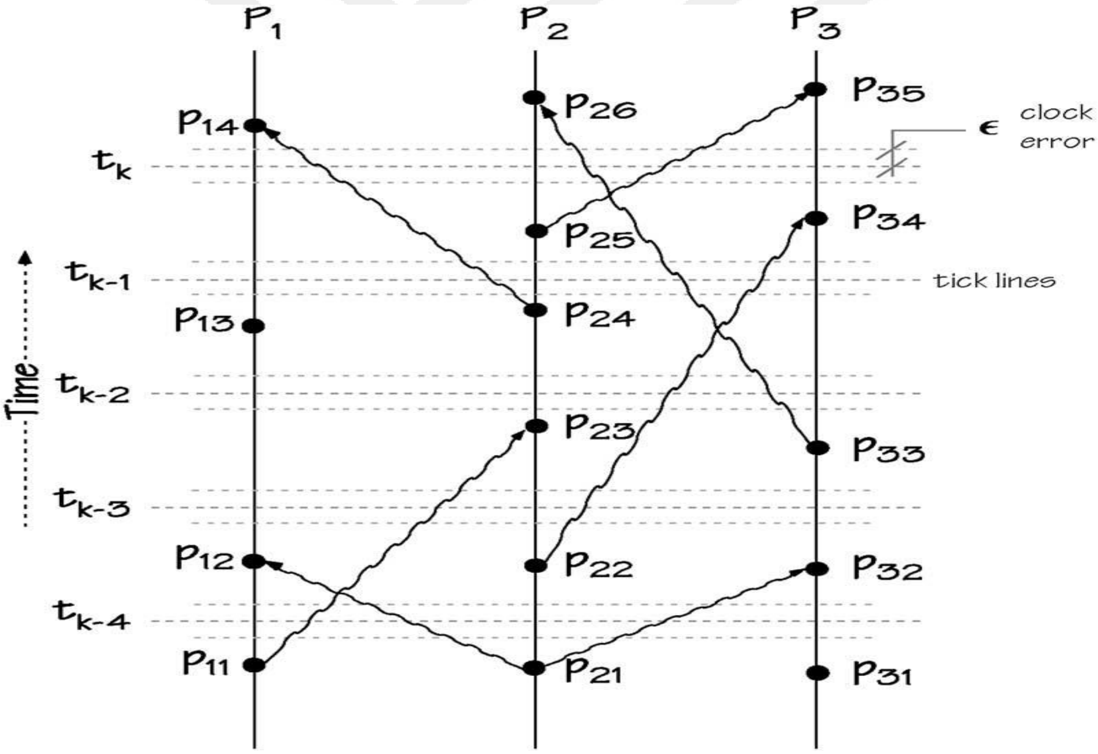


Figure 3.5. Space-Time Spatial (Bayne, 2008).

3.2.5. Reference Frame (place and time)

As cyberspatial object behaviors unfold in both cyberspace and time, it requires geospatial and infospatial and sociospatial dimensional indices to be described terms. Using the above concepts, cyberspatial object therefore can be identified with its presence in geospace (G), infospace (I), and sociospace (S) at a particular time. The space consists of three primary dimensions represented as points in this system as (G, I, S), where G, I and S are separate coordinates in three orthogonal (perpendicular) directions. To index cyberspatial object therefore:

$$\{G, I, S\} = \{\{x, y, z\}, \{g, s, a\}, \{f, p, c\}$$

Figure 2.4 shows two cyberspatial objects $\boldsymbol{e_i}$ and $\boldsymbol{e_j}$ at respective positions interacting in a region of cyberspace. They influence each other's state through their communication by means of messages. Each occupies a certain location {G, I, S} at a point in time. Therefore, the cyberspatial object have a unique identity.

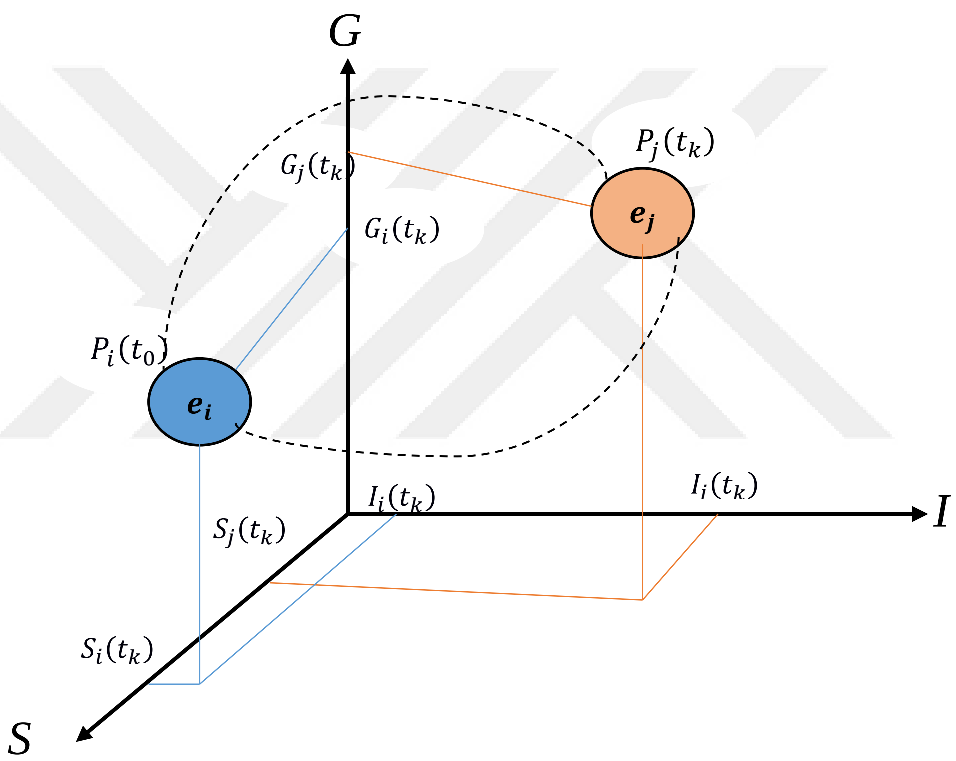


Figure 3.6. Cyberspace-time continuum.

3.3. Cyberspace Graph Theoretic Features

A *network* is a sketch map/depiction of a system or structure which consisting of some *nodes* (vertices) connected by some *edges* (links) in a given topology (structure). A *graph*, however, is a formal notion that represents only the structure of a network without physical details (Chen, Wang, & Li, (2014). We use these terms interchangeable in this work referring to a formal notion, Large scale topological structure of cyberspace entities and their formation.

Network science has been an essential field used to describe complex system (Barabási, 2009 & 2013; U. Brandes, G. Robins, A. McCranie, and S. Wasserman, (2013)) and a modeling approach whereby objects (nodes) and their relationship are explained and explore in a coherent way is a graph. Graph theory (Bollobás, 2013; West, 1996) is a natural framework for a precise mathematical modeling of complex networks and, formally, a complex network can be represented as a graph (Boccaletti, et al 2006; Newman, 2003; Albert, & Barabási, 2002; Strogatz, 2001; Costa, et al 2007; Dorogovtsev, & Mendes, 2002).

Cyberspace consist of independent information technology infrastructures, together with the Internet, telecommunication networks, computers, and embedded processor & controllers. Its modeling mainly depicted as graph that reproduce the topological properties or the dynamic process that is observed from the underlined Autonomous System (AS) or router level topology.

A series of observation and objectives lead to different models of a complex topology of network system. For instance, to realize the static structure of networks, or to reproduce relevant layered or hierarchical maps many approaches based on random process were proposed. However, most of the complex system–including communications networks are the result of growth process, and this leads to shift of paradigm to evolutionary mechanism that causes the network dynamics. Earlier on, preferential placement of node links was responsible for some observed statistical distribution of the nodes (Barab´asi & Albert 1999). Although the preferential attachment characterized a big category of models, it was then observed that many systems optimize certain objectives and not preferentially formed (Carlson & Doyle, 1999), including the internet (Fabrikant, Koutsoupias & Papadimitriou, 2002).

Although the network is dynamically evolving— rapidly and continuously growing and restructuring, some fundamental characteristics have never changed, or typically do not change, during the evolution. For instance, relatively small average path length, relatively large clustering coefficient, power–law distribution of node degrees, etc. in the Internet models.

3.3.1. Topological Characterization

Complex networks are depicted lying in an abstract space, and in a cyberspace the position of vertex is vital as it influences the network evolution— where the position of entities, for instance, routers, can be localized in a map and the edges between them correspond to real physical entities, such as fiber optics. Networks that connect points in geographic space, including the Internet was found to have strong signatures and patterns, giving the networks shapes (Gastner, & Newman, 2006).

The topology model of complex information system network is determined using two methods: a probe of the system under consideration or using topology generating models, that combine statistic or technical validation methods. To use the last approach, the entities has to be defined in the first place. Autonomous system (AS), and router level topology are the two widely studied and model using graph theories.

The quantitative description of networks attributes provides fundamental framework for classifying both theoretical and real networks, and statistical network properties are essential as a direct or supplementary tool in many network investigations, including representation, characterization, classification and modeling. Many real networks show some universality in their topology (Albert, & Barabási, 2002; Dorogovtsev, & Mendes, 2002). An essential universal character of these networks is given by their scale-free degree distribution which is a general property of a majority of complex systems (Barabási, & Albert, 1999).

Currently, topological characterization has been used in static model, whereby the change in topology is hardly been incorporated. As internet evolves in time with new competitively and nodes addition and removal, as a result of which the topology also evolves in time. This dynamical behavior, when included in the model, is important in evaluation and analysis (Wang and Longuinov, (2010). If such dynamics are involved, it seems that no existing model can adequately capture such features. Therefore, away of generalizing this internet model to have more dynamic features is needed.

3.3.1.1. Power Law and Scaling Free Behavior

Real networks, including communication system network, biological and social network are characterized by heterogeneous degree distribution (Chen, Wang, & Li, 2014, pg. 114) — their node degree distributions are independent of scale, also refers to “scale-free” implying notions about the spatial, geometric, or topological features of the network under consideration. It is being used to describe complex systems from many naturally occurring and man-made networks. Many statistical features of graph structures have been researched: the size of the largest connected component, link density, node degree relationships, the graph diameter, the characteristic path length, the clustering coefficient, and the betweenness centrality. However, the most widely considered property is the node degree distribution, which is validated by finding a particular pattern, for example, power law.

A finite *sequence* ***s = (s_1, s_2, . . ., s_n)*** of real numbers, assumed to be ordered such that **$s_1 \geq s_2 \geq . . . \geq s_n$,** is said to have ***a power law or scaling relationship*** if

$$K = cyk_k^{-\alpha}$$

where *k* is the *rank* of **s_k, c** is a fixed constant, and α is called the *scaling index*. Since ***log k = log(c) − α log(s_k)***, the relationship for the rank ***k*** versus ***s*** appears as a line of slope $-\alpha$ when plotted on a log-log scale.

For a network with *n* nodes, let d_i = deg(i) denote the degree of node i, $1 \leq i \leq n$, and call $D = \{d_1, d_2, ..., d_n\}$ the *connectivity sequence* of the network, which is assumed without loss of generality to be ordered $d_1 \geq d_2 \geq . . . \geq d_n$. Then it is said that a network/graph has *scaling degree sequence D* if for all $1 \leq k \leq ns \leq n$, *D* satisfies a *power law size-rank relationship* of the form $k\, d^{\alpha}_k = c$, where $c > 0$ and $\alpha > 0$ are constants, and where *ns* determines the range of scaling (Mandelbrot & Stewart, (1998). Since this definition is simply a graph-specific version of $K = cyk_k^{-\alpha}$ that allows for deviations from the power law relationship for nodes with low connectivity, it can be recognized that logarithmic plots of *dk* versus *k* yield straight lines of slope $-\alpha$, at least for large *dk* values.

The ubiquitous recognition of power laws in engineering, geophysics, biological, astrophysics, technology etc. is seen as a proof of self-organized criticality and edge of chaos concepts (Waldrop, 1993; Kauffman, 1993; Stallings, 1998, Faloutsos, 1999, Scroeder, 2009). Power laws are intrinsic in interconnected system; these two features are not the only origin of power law.

3.3.1.2. Clustering

Clustering defined the average fraction of pair of neighbors of node that are also neighbors of each other. That is a ratio between the actual number of edges of a given node among its neighbors and its maximum passible number. For node $\boldsymbol{i}$ with $\boldsymbol{k_i}$ edges connecting node $\boldsymbol{i}$ to other $\boldsymbol{k_i}$ nodes, maximum edges of $\boldsymbol{k_i(k_i-2)/2}$ is possible among neighbors of $\boldsymbol{i}$. The clustering coefficient is given by:

$$\boldsymbol{C_i} = \frac{\boldsymbol{2e_i}}{\boldsymbol{k_i(k_i-1)}}$$

That is the probability that two neighbors of node $\boldsymbol{i}$ are also neighbors/connected.

Given the value of $\boldsymbol{C_i}$ of node $\boldsymbol{i}$ for all nodes, since $\boldsymbol{C}$ is just the average of $\boldsymbol{C_i}$ over all $\boldsymbol{i}$, the clustering coefficient of the whole network of ***N*** nodes is given by:

$$\boldsymbol{C} = \frac{1}{N}\sum_{\mathrm{i}\epsilon\mathrm{v}} \mathrm{c_i}$$

C≤1 and ***C=1*** if the network is fully connected.

3.4. Agent-based Model

As previously reviewed, there are basically three interdependent and complementary ways of describing cyberspace — the dimensional manifold space, the network space and the information space (Chen, Feng, Zhang, Jiang, & Liao, 2016; Benedikt, 2008). However, individually, the dimensional model may not performance zero time and zero distance operation, the network space has limitation in explaining various aspect of cyberspace and the information space model does not consider the infrastructural constituents of cyberspace.

A combined model is a model that combine basic capabilities and attempt to integrate these three or more concepts. Considering our conception of physical space, cyberspace has geographical components incorporated–nodes having positions in space, and the topological structure can be best described by network(graph) theory and the dynamic processes by any theory that has space and time as its core feature— Cellular automata (CA) in this case. Therefore, space and dynamics in time are critical to describe cyberspace. Graph and cellular automata however are different in terms of structure and relational influences between nodes, which necessitate relaxation of the core construct of one of the two modeling techniques. Generalized relaxation of classical cellular automata, Proximal model, by Couclelis (1997) not only make it possible to use graph formalization but relate absolute and relational model of space.

3.4.1. Cellular automata

Cellular automata (CA) is a discrete modeling tool consisting of a space (often a grid), a set of allowed cell states, and a transition rule specifying changes in cell state which occur at discrete time steps. Each cell's state is determined at each time step according to its own current state and the state of neighboring cells in the cell space. It is considered as parallel processing device and has the potential for implementation and extensive formalism. Such potential features make it suitable as a basis for agent models. Global structure in a CA system is often seen to emerge out of purely local interactions between cells. A tool for modeling spatially extended decentralized system consisting of many agents— for instance, cyberspace. As a computational mode, the computation is carried out by cells which evolve in discrete time steps. The state transitions and the definition of neighborhood is defined by the rules of the CA (Wolfram, 1984). A formal definition of one-dimensional CA with a range r and with variables σ_i is defined as follows:

$$\sigma_i(t+1) = \phi\big(\sigma_{i-r}(t), \sigma_{i-r+1}(t), \dots, \sigma_{i+r}(t)\big)$$

Where each cell takes a finite set of symbols $\sum$ and$|\sum| = k.$ The dynamics of this system is given by a local transition rule $\sigma: \sum^{2r+1} \rightarrow \sum$ (Lindgren & Nordahl, 1990). In one-dimensional CA, the neighborhood is defined as the perimeter r, and by the local transition rule σ, a global mapping of the cellular automaton is defined.

A CA of one-dimension with $r = 1$ and $k = 2$ is called the Rule 110 automata and this automaton is also called "elementary cellular automata". It has proven to be Turing-complete and universal in the work of Matthew Cook in 2004 (Cook, 2004). A CA can be of arbitrary dimension and the neighborhood can be defined on n-dimensional grids as well (Arrighi & Grattage, 2010; Arrighi & Nesme, 2009;).

The power of the CA as defined by the following important properties, which are potentially exploitable in this research: Evolutionary structure, Self-organization, Self-repairing, distributed computation.

- The structure of the cellular automata is evolved by the rules. In every advancement of the automaton, the patterns of neighborhoods are created. This nature of the CA provides with the evolutionary structure to the computation.
- Self-organization and self-reproduction were first considered in the computational systems by John von Neumann in 1947. This 29-state automaton, given time, reproduce itself from scratch. Though the aim was not to construct a malware, this theoretical model of cellular automaton is accepted as the world's first computer virus in the computer society.
- Self-repairing of an automaton is to take the self-reproduction idea to a step further. Assuming that a cellular automaton with a malfunctioning cell, the automata can reproduce and fix this cell from the closest working copy. Security-wise this automatic repairing can be quite dangerous as well as being useful since a malicious attempt to change the rules for distributing a virus on the system can be fatal.
- A CA can be considered as a distributed computational machine. Every cell on the CA is computing a small part of a complex and bigger computation.

Aforementioned characteristics have shown that, cyberspace is a very complicated domain to define within just one theory or just one basic definition that covers all the aspects of it. One might perceive the aspects as connectivity and topology related or the other might perceive as a big information flowing space where the flowing speed is defined by one's hardware. Modeling with a CA is generally an effort to develop patterns of a computation through a space of cells and a global rule. Therefore, two approaches that are presented below are those that yield to patterns that could explore the properties of cyberspace.

Model 1 – Physical Approach

Cyberspace is an electronic medium where the entities are connected and where all the communications occur. Cyberspace has an emerging nature, every network card, router and switch have very similar functions in a practical and an abstract manner. However, the communications create a space that has peculiar characteristics and properties and this space evolves in time and forms the cyberspace.

An analogy can be made with the emergent properties and characteristics of cyberspace and a cellular automaton. For example, basically, considering the layer 2 and layer 3 of the OSI network model, forwarding and dropping functions of network packets and calculation of routes can be modeled on a Cellular Automata by defining a CA space that is formed from a graph and global rules defined by the rules of router and/or switch. In CA the space is discrete and quantized by cells and in cyberspace nodes and their connections worldwide; the time is defined by timestamps that are attached to each and every packet on a network provides with the synchronization of events.

Model 2 – Connection Establishment Approach

On an overall approach, on every second, tens of thousands of connections are established and disappear on the Internet through network devices. A protocol can be implemented to a graph CA for evaluating the configuration of connectedness and creating/destroying new connections on the space. Those connections can be modeled onto a CA as neighborhood properties. The new connections of such type would create the network evolution to a complex system.

These models, however, mostly stop at using standard CA—– uniform rules and neighborhood, regular grids, binary cells state. To develop more realistic model while preventing more sophisticated relaxation of CA model from being computationally expensive and theoretically intractable, a Generalized-CA, taking leap out of standard CA models were studied. The neighborhood now is abstracted by relations of closeness between spatial objects, and the closeness in turn depends on both adjacency and influence, which are spatial and functional respectively.

This is because cellular automata in its classical form are rather limited in their application and generally too restrictive, however, their simplicity is fascinating. For a realistic model, Various extensions have been made to enhance the model and accommodate wide field of applications, however at the expense of simple, generic and elusive insight of the classical CA formalism. For instance, graph cellular automata or network cellular automata, which is a hybrid modelling method that uses cellular automata theory and graph theory element. Several relationships between the two approaches are defined: cellular automata as the basis to construct graph (Topa, 2011), the underlined structure as a graph while a dynamical process as cellular automata running on the graph (O'Sullivan, 2001).

This irregular CA (also called graph-based cellular automata, graph-CA, GCA, or network automata) basically extend the neighborhood of cell (relationships of node) across the space to be different for each cell. These kinds of relaxation have also been used in urban and regional models by Couclelis, (1997) for proximal spatial model of physical space. O'Sullivan (2001) generalized this concept, again an application of physical space. As cyberspace is equally physically present in geospatial space, we adopt the same conceptual framework towards its formalism. This provides some useful conceptual tools to decipher what may be of the relationship between structure and processes, form and function of cyber entities.

Graph-cellular automata model by O'Sullivan (2001), though applied to urban and regional modeling, is used to define the dynamic of cyberspace. In this regard, the topology of cyberspace is depicted using graph (proximal space) and the dynamic as a cellular automaton process running on the graph–instead of using only cellular automata or graph. This permits simultaneous usage of the underlined formalism to describe the model topology, structure and the relationship between the two. Incorporating concept of space, the proximal model notion, such that neighborhood (localized entity/node based on influence) correspond to key notions in absolute space—referenced position of cyber entity, and relative space— relation between an entity to another.

Research has shown that CAs, as pattern analysis and formal tool, can be integrated with networks in order to analyses topological properties of complex systems, of which cyberspace is also complex adoptive system. For example, works on small-world networks shows CAs density Classification capability in small-world topologies (Watts, D. J, 2000; Tomassini, M. Giacobini, M, & Darabos, C. 2005). Marr & Hutt, M. T. (2009 & 20012) examined the dynamics of evolving networks using CAs. These shows a possibility of using CA in network model, for instance as entropy measures can be obtained from the Spatio-temporal patterns and the degree distribution of a network. In addition, CA has also been used to model the dynamic process taking place on a network (Shuai & Shuai, 2008; Marr & Hütt, 2009 & 2012,).

3.5. Integrated Modeling

Our argument started by using the notion of “cyberspaces” From Strate (1999), where many conceptions of cyberspace are categorized into various form of spaces— first order through third order. These addressed the cyberspace’s ontology—cyberspace-time notion, basic infrastructural building block entities and the synthesized result of these entities’ relationship within themselves and the users.

Placing cyberspace concept in the spectrum of fictional setting and/or contemporary scientific basis, the ontology is a meta-theoretical notion of cyberspace that question material reality of cyberspace, the structure and behavior of the abstract element that made up cyberspace corresponding to space-time concepts, On the other hand, there are the fictional perception of cyberspace, as the term initially coined from a fictional context by William Gibson. However, science is established in factual setting and therefore cyberspace basis in objective reality based in science is more reasonable and therefore, Cyberspacetime triumphed over the para-space conception. A physics of cyberspatial object (events, agents, processes) whose behavior unfold in cyberspace and effect manifested in physical space establishing a formal basis of cyberspace, consistent with rigorous conception of physical space, inferred as cyberspace time—4-dimensional extent made up of objects located in space and events occurring in cyber time.

Beside the cyber objects, cyberspace is also characterized by complicated, interactive events and processes (Wang, Zhang, Che, Zhang, Zhao, & Yang, 2015). Cyber event, which is basically an action that happens at a particular time in cyberspace, is resulted from entities interaction and in turn influence the related entities. For instance, security related events which can be detected from the intrusion detection system, supervisory control and data acquisition etc. Let’s denote the set of events I which relate to various entities E and occur at a particular time as:

$$I = \{ID_n^t, IDg, [E]\}$$

Where ID_n^t is the serial number of events with value n at time t, ID_g is the group of events related in time of behavior and $[E]$ is the set of entities affected.

We can also talk about cyberspace in terms of tangible aspect of our physical world, the structure and behavior of the physical element that made up cyberspace, our cognitive understanding of it and something in-between— the basic construct of cyberspace. The tangible networked entities, cyber-fiber, determines the possible pattern of signals and electronic flow, messages in other words, and the operations that facilitate functioning of infrastructures. The individual entities, physical cyber-object, is referential in a space and therefore somewhat characteristically expressive in absolute space notion. The conceptual cyberspace, which deals with cognitive recognition of entities, can be related to the tangible entities as logical address and storage space can be inferred. Virtual aspect is different, in that they can only be explored by the mind, yet metaphorically relate to sensory experience, therefore entities existence is imaginary, hyper real, or simulated and lack bases in physics.

There is also the synthesis of cyber space object, when a new medium is introduced, which adds some functionality to and thereby changing the environment and changing the relationships between objects—cyber media. The communication with and through devices generates s sense of space which concerned the formal element to communicate information (states, data, ideas, emotions). However, in terms of information theory the concerned may be more of content rather than form.

3.5.1. Proximal space

The proximal space attempts to accommodate both place and situation conception of physical object in a notion of neighborhood. The place is the absolute site that an object occupies while the situation describes an object states relative to another object. In essence, the spatial information of an object as geo-referenced in absolute space and spatially related is incorporated in the neighborhood defined in proximal space. This neighborhood can be further abstracted and define closeness between spatial objects which in turn depends on adjacency and functional influence. The entities neighborhood therefore consists of all those entities that may influence this particular entity’s state

From geographic modelling, proximal space presents an incredible approach for an exploration of the properties of space, fundamentally its effects on some dynamic processes. This model of space is a bridge between absolute and relative space and is theoretically able to embody graph and cellular automata models (foundation for generalized cellular automata). Neighborhood along with the notion of nearness/influence are the fundamental concept in proximal model. As CA does, the neighborhood refers to a localized node, and at the same time embodies the notion of influence or proximity–a relation between the elements. This allows non-contiguous neighborhoods base on relations of influence between the objects. Moreover, integration of functional and spatial relations, and of fuzzy concepts and phenomena are made possible.

Cellular geography developed by Tobler (1979) and Hägerstrand (1967) and geo-algebra developed by Takeyama and Couclelis (1997) are the mathematical foundation of proximal space models. Geo-algebra extends classical CA to allow irregular cells neighborhoods. Thus, each cell in this framework can have neighborhood formed according to the relations between whatever spatial objects to be modelled. The underlined spatial structure of the models is mostly described and understood as a graph.

To sum up, the notion of absolute space embodied as referenced node, and that of relative space as the spatial relation. Whether expressed in continues (dimensional) space or restricted (network) space, the essence of space in cyberspace is the referenced entity. The integrated approaches as it relates to various concept and converging at cellular automata model is illustrated in Figure 3.7.

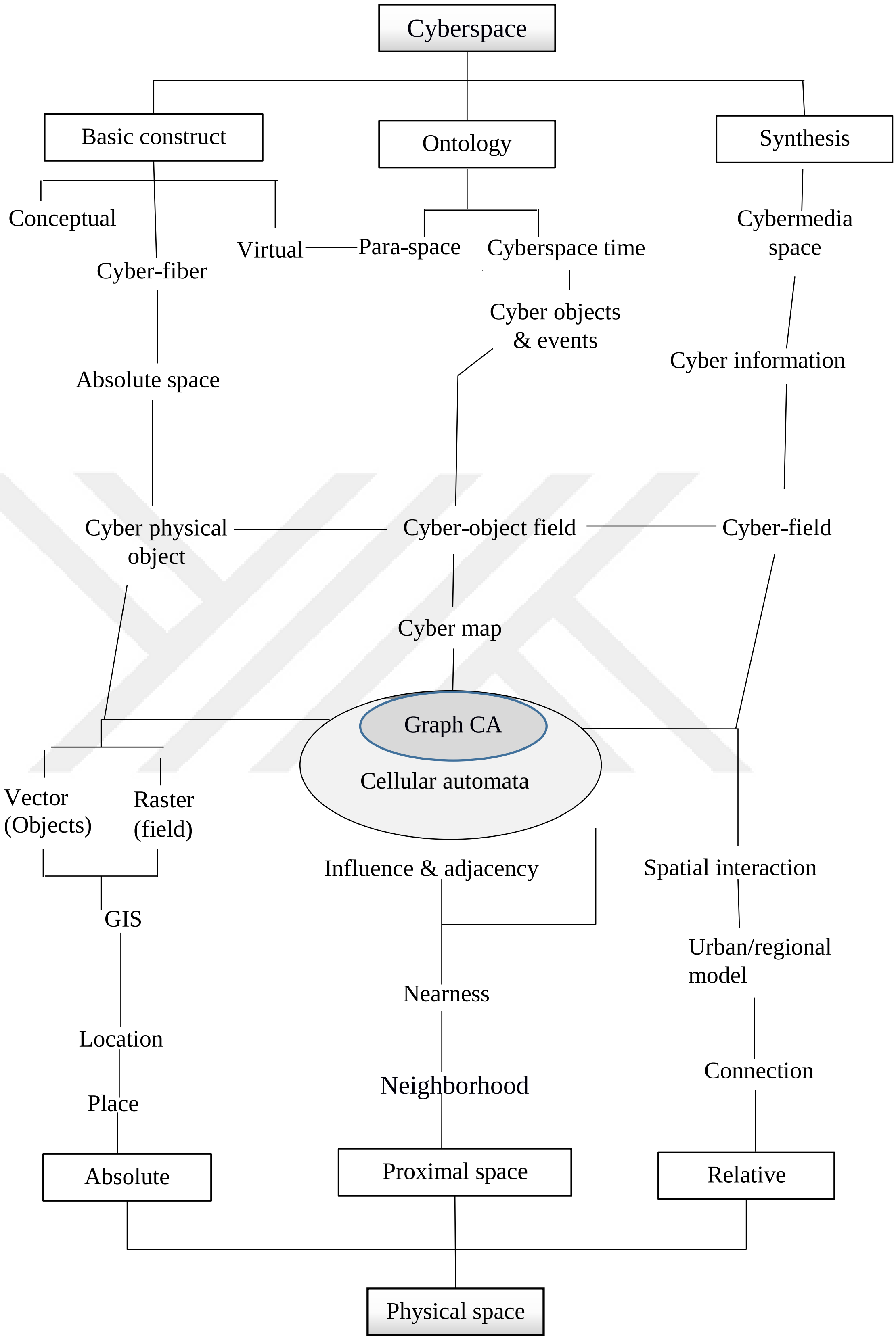


Figure 3.7. Integrated cyberspace conception.

CHAPTER 4
CYBERSPACE REPRESENTATION

This chapter investigates cyberspatial object formulation, formation and evolution. The main concern is cyberspace information representation; particularly the definition categorization, and dynamics of objects in cyberspace. These homogeneous and heterogeneous entities interact through complex relationships. The model of network and computerized system are multi-layered, with a high-level system-independent conceptual model of the application domain further supported by system-oriented models underneath. Object-oriented representation is considered at each of these layers.

Cyberspatial objects (events, agents, processes) whose behaviors unfold in cyberspace and whose state requires description in geospatial, infospatial and socio-spatial terms are discussed in two broad classes of models; The object-based cyber information representation treating the information space as populated by well-defined cyber entity– discrete, identifiable entities (objects), each with a cyber-reference. And The field-based cyberspace information representation that treats such information as spatial distributions (Worboys 1995; Coucleli,1992), whereby each distribution may be formalized as a mathematical function from a spatial framework (two, or three dimensions' reference, with an additional dimension of time) to an attribute domain.

Field and object models have gained acceptance as two approaches for conceptualizing and modelling various phenomena (Couclelis 1992, Worboys 1995). Field model is a conceptual model and a basis for many scientific and geographical modelling (Goodchild 1997) where each location in a spatial framework is associated with a set of features. The object conceptual perspective is much compatible with object orientation in software engineering (Gahegan and Roberts 1988, Frank and Egenhofer 1992, Worboys 1994).

4.1. Object-based Cyberspace

Cyberspace, when viewed from an object perspective, can be seen as a manifold consisting of entities. At least two basic categories can be observed as meaningful scientific concept: logical entities which exist only in virtue of demarcations induced by human cognition, as in application, virtual entities, or simulated objects. On the other hand, there are material base underlying cyberspace (Phelan, (1996) — the tangible entities that determine pattern of information flow, and the typical operations that can be made. That is, a boundary conceptualized as a genuine discontinuity in cyberspace, as in physical node. The latter category can generally be well defined in their spatial embodiment.

This approach attempts to formalize the cyber information space as occupied by discrete, identifiable entities, each within a cyberspatial reference frame— More importantly an agent which is distinguished from ill-defined cyberspatial objects (events, processes). Cyberspatial object/entity, therefore, is a stationary or mobile entity existing, and whose behavior unfold, in cyberspace. Mobile objects are able to change position in space and time, communicate and are characterized by both state and behaviors. Cyber physical systems, considered as primary cyberspatial object, are information system whose behaviors are defined in cyberspacetime and responsible for locating, identifying and controlling cyberspatial objects (object/ agent, process, services or events).

Object-oriented models decompose an information space into objects and each object must be identifiable, describable and relevant (Mattos ***et al.*** 1993). Therefore, cyber entity/object composed of:

- Unique identity(I),
- Spatial embedment(S),
- Attributes (A), and
- Operations/interaction(O):

Which can be conceptualized in n-dimensional space. Let's a cyberspatial object or entity (CSO_i) be defined by $e_i = \{i_i, s_i, a_i, o_i\}$. Cyber object comprises of its information, the totality at any time of which constitute its state, and the dynamics part—its functionality which is its response to messages and its surrounding. Cyberspatial object has state and functionality.

Identity: In addition to socio spatial indices, Geospatial, infospatial and temporal indices are required to distinguish one object from another and, for a given object, one state from another. The identity defined to reasonable level of precision, object's spatial extent at a time. Cyberspatial position is defined by its coordinates as explained by the frame of reference.

Spatial embedding: Cyber objects, are referred to as 'cyberspatial' because they exist inside 'space' which is an important construct. Many features of a spatial object depend upon the structure of its embedding space which dictate the type of operation that can be performed. An object in an abstract space can be represented as a node/entity. This object, represented in a plane, have a unique value and understood as represented in at least two space, geospace and infospace space (G and I). Cyberspatial object state requires description in either or both of geospatial, logical space or and infospatial terms ((Bayne, 2008). For dynamic cyberspatial object its behaviors unfold in both cyberspace and time. With the addition of time, the position of cyber entity, e_i, at time, t_k, is given as $P_i(t_k)$.

Geospace provides framework for specifying the physical location of an object. The geospatial location of CSO_i at time *tk* is $P_i^G(t_k) = \{x_i, y_i, z_i\}(t_k)$. Where x_i, y_i and z_i are the altitude, latitude and longitudinal coordinates. The Infospace, on the other hand, is a framework in which the locations of an object's service access point, through which object interact with each other gets specified which is denoted $P_i^I(t_k) = \{g_i, s_i, a_i\}(t_k)$, with global network address, subnet address and access point port respectively

The dimensionality is broadly classified in to two compounds namely, space and time. An object is dynamic in space and time if it changes position between time t_{k-1} and t_k, which implies changes in some attributes. Figure 4.1 shows dynamic object e_1 changing position at time t_1, t_2 and t_3. At t_1, e_1 changed in all dimension, at t_2, e_1 did not change in infospace ($P_1^I(t_1) = P_1^I(t_2)$). At t_3 however, e_1 changed in infospace but did not change in geospace ($P_1^G(t_2) = P_1^G(t_3)$). The static objects, e_2, e_3, e_4, e_5 and e_6 remain the same in their respective spatial reference points.

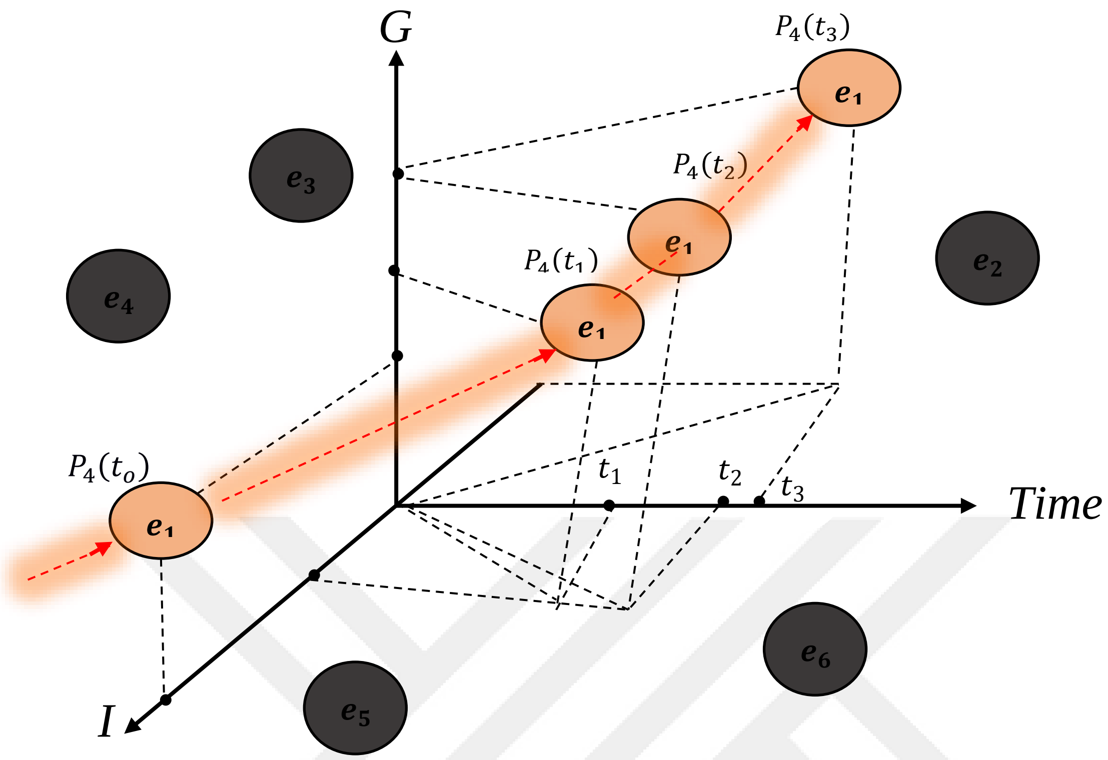


Figure 4.1 Minimum cyberspace dimension in space and time.

Attributes**:** These are properties measured on an appropriate scale. Static aspect of an object is expressed by a collection attributes, each of which may take a value from a pre-specified domain. The totality of attribute values for a given object at any time constitutes its *state*. The state of an object is collection of attributes and describes the static aspects or properties of the object.

$$St(t) = \sum_{n=1}^{N} A_n \leq 1$$

Where $St(t)$ define a state as a function of time of an object such that at most one of the attributes $A_n \in \{A_1, A_2, A_3, \dots A_n\}$ should hold at any one time. The dynamic, which is the behavioral side of an object is then determined by a set of operations that the object can perform under appropriate conditions. This for example is represented by procedural functions (methods) that can be invoked on the object. Thus, Objects encapsulate state and behavior and communicate via messages which initiate from info space. The static or dynamic is defined in terms of two interdependent functions which are:

a. The processes through which they interact with and influence other objects
b. The internal governance structure through which the behavior is regulated.

Objects with similar behaviors and functions are organized into *layers*. Thus, the behavior consists of a collection of operations that can be performed on objects in a layer. At system level, however, describing the behaviors of CSO (and their CPS containers) requires a set of performance measures. Comparing behaviors of these interacting CSO necessitate that that these metrics be generalized and be scalable. This indicate a further research gap.

Interaction/Operations: In order to be integrated in the complex cyber environment, objects have to self-organize, learn, react and interact. Interaction denotes the object's ability to converse with the user and or other object in terms of input, output, control, and feedback--governing the dynamics by means of exchanging messages.
Some of geographical information system operations performed on areal objects like object addition, deleting, updating, movement, and transformation are proposed to be performed on cyber-object modeling. In addition, object-based analysis functions like spatial query, node pattern analysis, distance calculation, network analysis, cluster analysis, spatial similarity analysis, and location modelling are envisioned.

4.1.1. Cyber Objects and Layers

Cyberspace consists of many different and overlapping networks, along with the nodes (any entity or logical location which can be identifiable) on those networks, and the information supporting them. Cyberspace can be described in terms of three major categories of entities and three layers: physical entities layer, logical entity layer, and information entity layer. The major constructs of cyberspatial object-based representation are discussed from layered viewpoint and in the context of graph theoretic information handling.

a) **Physical entities:** These are physical devices(hardware) and agents as cyber Objects: Cyberspace consists of physical networks and computing hardware all of which are part of geo-physical entities, the physical medium where the information is transmitted, processed and stored. The collection of connected network infrastructure components such as cyber physical system, routers, servers, switches, firewalls, communication lines, terminal devices etc. are the physical entities. All the dependencies between these components, like connectivity, containment, location, and other relations, represent the topology of at these layers.

In addition, an intelligent agent is also physical agent such as persona as cyber object. Users and virtual entities interacting with cyberspace objects as a higher level of abstraction than the physical and information objects in cyberspace; these "persona" objects use logical rules applied to information and data objects develop a digital representation of an individual or entity identity in cyberspace.

b) **Logical entities:** These are software, services and applications as cyber objects, describing different logical components and their dependencies between them. For instance, an application software might contain many subcomponents; an operating system manages and supports applications. A logical entity has attributes different from other entities, for example functional class of the component. A different system could be built by taking a different approach to the logic of interconnection of logical entities using same physical entities

c) Information and data as Cyber Objects: Information and data are the cyber objects which are transmitted, processed and stored by the physical objects in cyberspace. While information entity in cyberspace may take many forms, its usage such as creation, capture, storage and processing is central.

Layers/hierarchy of cyberspatial objects

From the biological to technological, most networks are multi-layered (D'Agostino & Scala, 2014; Boccaletti, et al 2014;) i.e. they are formed by many interacting networks. Layers are an organization of entities into separate functional components that interact in some way, with each layer assumed to implicitly relate to its immediate layer– the layer above or below it. Despite the diverse perception, cyberspace is generally represented to comprise of multiple layers (Wang et al 2015; Clark, 2010; Jakobson,2011) and networked system (Jinhua et al, 2013; Klimburg, 2012; McCarthy).

Layering is a traditional approach to understand, design or define a system, most importantly complex system. Not only layering is important for describing complex system, it makes it possible to differentiate entities- different portion of cyberspace can be evolved separately. Cyberspace entities have been mapped to at most 5 layers, with majority of research using 3 layers (Strate 1999, Clark 2010, Jinhua et al 2013 and Wang 2015). Halappanavar et al (2013) proposed a three-layered network of network (NoN) model for an *enterprise* cyber system; where the first layer is physical (Hardware) layer on top of which is Logical (Software; Functional) layer and followed by layer three Social (User; Computer). Cyberspace can also be described in three layers consisting of physical network, logical network, and cyber persona (U.S. Department of Defense, 2018).

Telecommunication networks can have various facilities based on the needed functionalities. These types of networks are referred to as multi-level networks where distinct regions serve as levels to the telecommunication network model (Local access to backbone or local service provider to International backbones). Moreover, these networks may have several technologies and protocols along with multiple layers and therefore composing multi-level and multi-technology networks called multi-layer networks (Lehman et al, 2011; Ergün, 2013). The multilayer network design problem involves designing the network layers in an integrated way which is complex and cannot be solved with general purpose integer programming methods.

The layering concept of cyberspace can thus be described by; (a) the number of layers assumed (heterogeneous entities), and (b) Homogenous entities in a layer. Hence, the set $L = \{E_1, E_2, E_3, \dots E_M\}$ where M is the number of layers assumed, such that $(1 \leq \mathrm{M} \leq 5)$, For now $M = 3$ i.e. three layers of cyberspace entities. Thus, we have physical (geo-spatial or base layer), Logical layer, and information layer (Infor-spatial). An entity in a given layer will be affected by the behavior of other entity in the same layer as they interact and will send/receive feedback to/from a relative entity from an immediate/subsequent layer.

A Cyberspace multilayer network of entities is a pair $\mathrm{T} = (\mathrm{L}, \mathcal{C})$ where $\mathrm{L} = \{\mathrm{G}_\alpha;\ \alpha \in \{1, \dots, \mathrm{M}\}\}$ is a family of graphs $\mathrm{G}_\alpha = (\mathrm{E}_\alpha, \mathrm{C}_\alpha)$ forming layers or subnetworks of T and;

$$\mathcal{C} = \{\mathrm{E}_{\alpha\beta} \subseteq \mathrm{E}_\alpha \times \mathrm{E}_\beta; \alpha, \beta \in \{1, \dots, \mathrm{M}\}, \alpha \neq \beta\}$$

is the set of interconnections between entities of distinct layers G_α and G_β with $\alpha \neq \beta$. The elements of $\mathcal{C}$ are crossed layer connections, the elements of each C_α are intralayer connections of the topology T and the elements of each $E_{\alpha\,\beta}$ $(\alpha \neq \beta)$ are interlayer connections.

The set of entities of the layer G_α will be given by $E_\beta = \{E_1^\alpha, \dots, E_{N_\alpha}^\alpha\}$ and the influence given by the adjacency matrix of each layer G_α is given by:

$A^{[\alpha]} = \left(a_{ij}^\alpha\right) \in \mathbb{R}^{N_\alpha \times N_\alpha}$ where

$$a_{ij}^\alpha = \begin{cases} 1 & if\ (E_i^\alpha, E_j^\alpha) \in C_\alpha \\ 0 & otherwise \end{cases}$$

For $1 \leq i, j \leq N_\alpha$ and $1 \leq \alpha \leq M$. The interlayer adjacency matrix $C_{\alpha\,\beta}$ is the matrix $A^{[\alpha,\beta]} = a_{ij}^{\alpha\beta} \in \mathbb{R}^{N_\alpha \times N_\beta}$

$$a_{ij}^{\alpha\beta} = \begin{cases} 1 & if\ (E_i^\alpha, E_j^\beta) \in C_{\alpha\beta} \\ 0 & otherwise \end{cases}$$

The map of the network of T is the graph *map (T)* $= E_\tau, C_\tau$ where

$$E_\tau = \bigcup_{\alpha=1}^{M} E_\alpha,$$

$$C_\tau = \left(\bigcup_{\alpha=1}^{M} C_\alpha\right) \cup \left(\bigcup_{\substack{\alpha=1 \\ \alpha\neq\beta}}^{M} C_{\alpha\beta}\right)$$

With this definition the model simultaneously takes into consideration the connectivity in the distinct networks; the features of the connections and the relationships between entities that belong to various layers, and the particular entities belonging to each layer involved. As shown in figure 4.2, we assumed three layers of cyberspace entities;

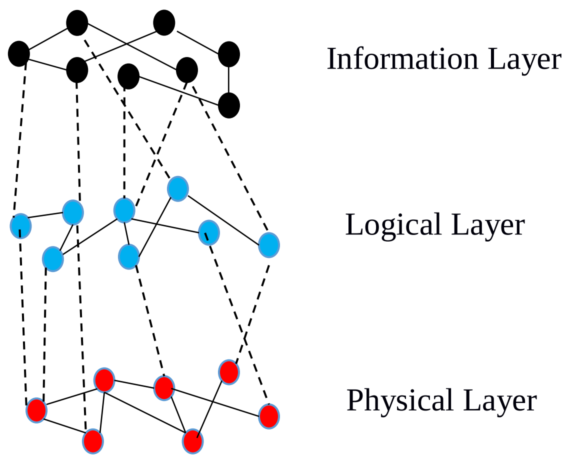


Figure 4.2 Layers of cyberspace entities

Physical layer

This layer comprises of the network topology that consists of entities that are interconnected via physical devices such as switches and routers to the enterprise backbone. Based on network-theoretic perspective the *connectivity* of the nodes at this layer is fundamentally different from other layers. For instance, let distinct routers be denoted as vertices, and connections between any two routers via certain physical links be the network edges, then all the entities connected to a central node for instance switch will form a fully connected component. Physical layer entities further formed a hierarchical structured given by the three-layer transit-stub (Calvert et al, 1997) or tiers topology (Doar, 1996)

Consider $\mathrm{G}_{\alpha} = (\mathrm{E}_{\alpha}, \mathrm{C}_{\alpha})$ with $\mathrm{E}_{\alpha} = \{\mathcal{E}_1, \ldots, \mathcal{E}_N\}$ when all the layers have the same nodes, $\mathrm{E}_1 = . . . = \mathrm{E}_M = E$ and $\mathrm{C}_{\alpha\beta} = \{(\mathcal{E}, \mathcal{E});\ \mathcal{E} \in \mathrm{E}\}$ for every $1 \leq \alpha \neq \beta \leq \beta$.

The network design at physical layer involves finding an optimal configuration of network elements, which are hardware set on the nodes and links connecting these nodes in order to satisfy traffic demand. There are two basic objectives that the design problem tries to achieve: minimizing costs of network operation or installation or optimizing the network performance (Ergün, 2013).

The geodesic distance between two nodes is given by the length of the shortest path, where a path length is taken as the number of links forming the path. Shortest path lengths obviously average and distribution determines the overall clustering of a network.

Logical layer

Various models are possible, for example distinct software applications and/or services running in an enterprise system as a graph. In this case the nodes would correspond to different services and edges would show pair-wise relationships between them. Security-wise, an attack *graphs* (Ammann, et al 2002) can be represented to depict vulnerability dependencies and system exploits forming a network at logical layer. The relationship with the physical layer can be as simple as services running on specific hardware. The connectivity structure of networks at this logical layer varies from those at the physical layer. For example, attack graphs basically use directed edges from an attack source to the target.

Information layer

In the information layer, differently from the other layers, each node contains information. This information ranges from the smallest unit, bite, to the collection of documents and instructions. The world wide web, as a better subset, is a continuously growing repository of information that can naturally be decomposed and studied at different level of granularity. However, not level of details is necessary for the analysis of the topology. At the web-page level a node corresponds to a web-page and the hyper-links are mapped into directed links between nodes. In this case, the degree of a node is made of incoming and outgoing connections. Another possible resolution is the site level, where a node corresponds to a site having a collection of Web pages, and two nodes are connected by undirected edges when there exist hyper-links between Web pages in the corresponding sites.

Although it may seem chaotic in nature, the Web is statistically structured and graph theoretic tools can help to understand the structure of the Web at macroscopic and microscopic level (Hayes, 2000). It was found that the webs nodes degree distribution, both the in-degree and out-degree, follow power-law distribution (Albert et al, 1999; Broder et al, 2000; Kumar et al 1999). Assuming undirected links, the clustering coefficient is higher than that of random network. In general, the WWW information network exhibits small world and scale free features.

4.1.2. Cyber Objects Relationships

It is not the entities that creates the phenomenon we call cyberspace. It is the interconnection between these entities that makes cyberspace— homogenous and heterogeneous interconnections within and between layers/hierarchy of entities. This allows Inter-object communication. The interconnection between the entities and network systems form a network of networks in which the interdependencies play a vital role in discerning emerging functions and performances. A higher connectivity allows faster information exchange and also critical for the robustness and resilience.

This conception can uniformly describe homogeneous and heterogeneous entities interacting with their complex relationships in multi-layer cyberspace. Through decomposition of cyberspace into the layered network of cyberspace cyber entities, we can discriminate three types of connections:

a) Interlayer connection, this a connection between heterogeneous entities in adjacent layers.
b) Intra-layer connection, a connection between homogenous entities of same layer.
c) Super-layer connection, a connection between entities that are either in adjacent layers, or in the same layer.

4.2. Field-based Cyberspace

The field-based conception and modelling has its origin from classical physics and is useful for modelling physical properties, such as gravity, whose value is dependent on its spatial location. The field concept has been extended in geographic Information Science to include any properties whose magnitude (value) is dependent on its spatial location (Kemp 1997, Goodchild 1997). To describe ill-defined cyberspatial objects (services, processes), we need cyber fields rather than cyber objects. Defined as a collection of particulars (points, or domain) providing an objective framework of spatial reference. Each field defines the spatial variation of an attribute in the relation as a function from the set of locations (spatial framework*)* to an attribute domain. Here the function is the field. Spatial framework is a set whose individual elements are called locations. Cyber information that have no inherent spatial properties are then mapped onto the defined spatial framework and subsequently to the cyberspatial object. Spatial framework/distribution is a discretization of the given cyber model into a finite tessellation of spatial objects based on mathematical model of space. The individual components of the partition are what we called cyberplace/*locations or* points, occupied by cyber object. For example, a cell in two-dimensional Euclidian space, often grids of square, triangles, or hexagonal tilling.

Cyber field model is based upon spatial framework S and consists of a finite collection of n spatial fields $\{f_i: 1 = i = n\}$. The spatial framework s is a finite tessellation of space of at least 2 dimensions. We therefore have the function $f : S \rightarrow V$, where $V = V(f)$ is the set of values characteristics of the field. For $1 = i = n$, each spatial field f_i is a computable function from set S *to* a finite attribute domain A_i. From this perspective, every place/point in a spatial framework is associated with a set of attributes measured on a variety of scales.

Furthermore, a field can be understood as a mapping between a locational reference frame and an attribute set (Worboys 1995). Therefore, as a single valued function of space with each point being assigned to a value. Presumably, the set of place/locations in a field is infinite. More points can be accommodated or extended in order to make space for more entities or for analysis or measurements. The spatial frame of reference can broadly be of one, two, or three dimensions, defending on the frame of reference consideration. With an additional dimension of time, the notion of cyberspacetime could be included. Time in spatial modelling context, generally, is either discrete or continuous. As most of the concepts in cyberspace are assuming discrete notion, discrete time slice in a field might be easier to handle. It is possible to think about the possibility of cyberspace as a field.

Field are commonly captured in three ways, as a scalar type, vector type, or tensor. Field as scalar, every location is assigned a scalar value from an attribute domain. As a vector, every location in space is mapped to a set of values describing the position of a node at that point according to its dimensions. In geographical information system, for example, Vector field are used to represent land surface gradients like slope, or dynamic phenomena on the land surface like wind, water, and fire. Under similar observation, the dynamic phenomena of cyberspace like effects of attacks, change of node clusters are roughly envisioned.

Tensor field are common in representing multiple directions using a matrix at every location. However, additional challenge comes as field has to be approximate, since we cannot store an infinite number of place due to computational practical restrictions. Spatial tessellations (regular, irregular, or hybrid) are the most common means for representing field-based models. Some critical issues in using a tessellation is the meaning of the value in a spatial unit

4.2.1. Cyber Field of Spatial Object

Cyber *field-based* model treats cyberspace information as spatial distributions, where each distribution may be formalized as a mathematical function from a spatial framework to cyber object domain, acting as the attribute. The spatial framework, S, consist of finite collection of n spatial fields (s_i) , each of which is a function from the spatial framework F to a finite cyber object domain e_i.

Therefore, to model cyber field of spatial object, the following constructs are required:

1. Suitable model of the underlying space to act as the spatial framework, *S*. The spatial framework, for example, may be based upon an arbitrary mathematical model of space. From object model, Euclidean space was used as the reference frame. And extension of Euclidian space is needed to include the networked properties of cyberspace. Assuming *Combinatorial space (ƇG),* a union of mathematical spaces (V_1; R_1), (V_2; R_2), · · ·, (V_m; R_m),) for an integer m, with underlined graph structure G where $V(G) = \{V_1, V_2, \ldots V_m, \}$, $E(G)=\{(V_i, V_j) \mid V_i \cap V_j = \emptyset \ , 1 < i, j < m\}$

   $$ƇG = \left(\bigcup_{i=1}^{m} V_i \bigcup_{i=1}^{m} R_i\right)$$

   For example, a combinatorial Euclidean space is a combinatorial system ƐG of Euclidean spaces R^n with an underlying structure G. Therefore, a *spatial framework here* is a partition of the given cyberspace region into a finite tessellation of spatial objects. It is sufficient to approximate the locations by points or nodes.
2. An appropriate domain for the cyber object such that $1 = i = n$ for e_i . That is finding a computable function from S to e_i.
3. Specify the phenomena/process under consideration at the cyberplaces in the spatial framework, to construct the spatial field functions.
4. Analyses of the dynamics by computing with the spatial field functions.

We then need to represent an object's spatial embedding. Using binary field, we can define whether the cyber-object is present or absent at each location in cyber-field with a function that operate upon cyberplace vector (**x**). $S = \{(\mathbf{x}, f\ (\mathbf{x})) | \mathbf{x} \in R^n, f\ (\mathbf{x}) \in \{0, 1\}\}$. To represent fuzzy objects, the function *can* not to be defined on a discrete field, a continuous field on some interval, say 0 to 1, is required. This allows an object to be present at a given location to a certain degree— for cyber object that can be present in more than one location.

The dimensionality and observable properties of cyber-objects are constrained by the space (model) in which they are embedded. So, cyber field model may allow operations like classification, statistical analysis, map algebra etc. While object-based model may allow operations like cluster analysis, movement, update, transformation etc.

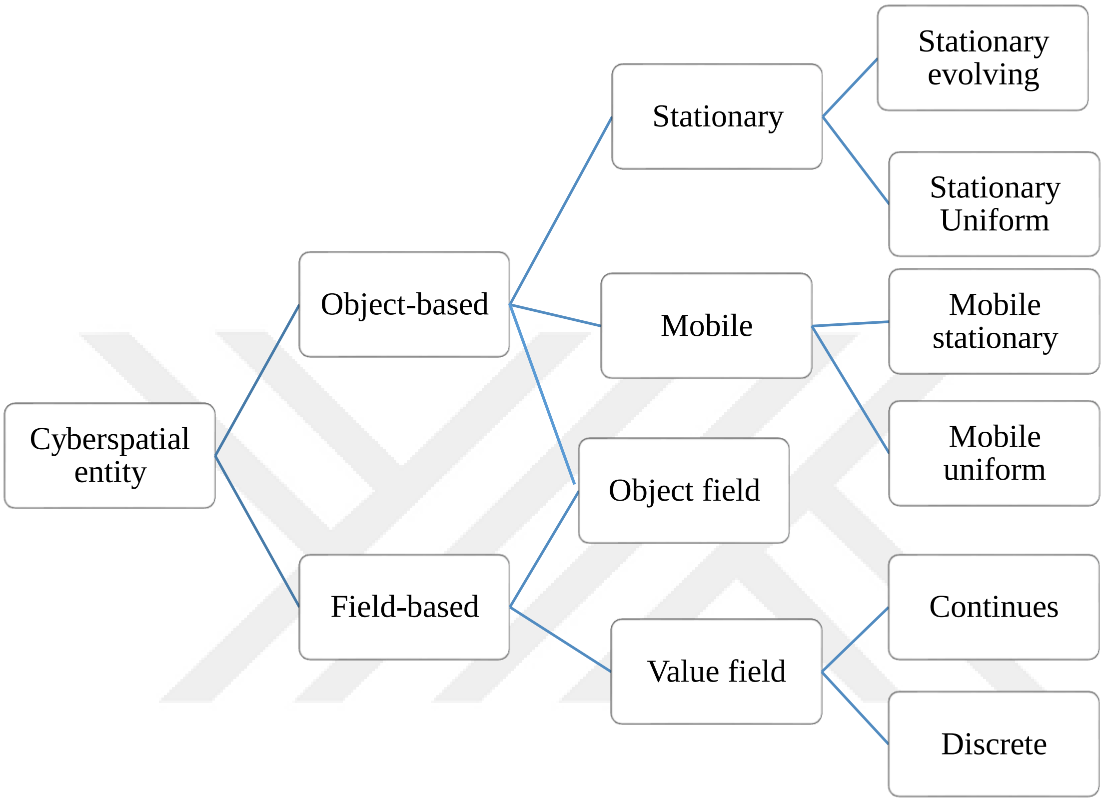


Figure 4.3 Basic of cyberspatial entity conceptualization

Figure 4.3 summarizes the proposed concepts of cyberspatial object theory, aggregated into cyber-fields and cyber-objects and the further abstraction in terms of dynamics and attributes for both. The cyber-object may be stationary or mobile, which may be considered to change functionality through time— evolving or remain unchanged—uniform. For the field, the attribute domain may contain values that are distinguished from the continuous or discrete field function

4.3. Cyber Object Network Design and Formation

Due to multilayered nature of cyberspace, there is yet no single topology that reflect its structure at large. Each set of entity and protocols induces its inherent graph representing the connectivity amongst its constituents. For instance, the router-level network topology depicts a type of physical connectivity, the autonomous system-level topology reflects a kind of organizational connectivity, whereas the web graph represents some virtual overlay connectivity. Although, all these topologies exhibit roughly similar statistical features, in general the features of each graph are quite different and there is no direction correlation between them. We therefore focus on network design problems which is an optimization problem of finding an appropriate configuration of network elements, the entities set on a node and edges connecting these nodes so as to satisfy a given objective, for instance traffic demand.

A classical problem of network design involves decisions for nodes location, suitable hardware and links, capacity allocation of links and traffic flow routing. Multilayer network design together with the emergence of new technology add more decisions and objective to the problems. Recently, due to the complexity in modeling multi-layer network, the network design problems are solved and modeled for single layer networks integrating the design of different layers of the network jointly.

Formulations and algorithms for centralized computer networks was reviewed by Gavish (1982), further work of which studies local access networks relating network design problems to network optimization problems with solution methods for these problems (Gavish, 1991; Minoux,1989; Ergün, 2013)

4.3.1. Multi-layered Network Design Problem

Cyberspace entities network is a multi-technology networks, it also has hierarchical structure called multi-level. The multi-layer network representation is a multi-network model and multi-technology network that represents each layer by a distinct network and subnetworks, each layer involves a particular technology and facility type (Lehman et al 2011). and the networks in are organized in a manner that a subnetwork is built on top of another subnetwork and the physical components of the networks constituting the base network. Each subnetwork in may have its own technology and protocol (Orlowski & Wessäly 2004).

The basic concepts of the multilayer networks include the connectivity/links (both physical and logical), traffic demands, node devices, cost, and routing (Orlowski, 2009; Orlowski & Wessäly 2004). Three-layered network of cyberspace consists of three subnetworks: a physical, logical and information network layer. The information layer network nodes may be contained in logical layer network nodes which further form a subset of those in the physical layer. Every edge in the logical layer is defined by a path in the physical layer. Therefore, Subject to all constraints a network configuration consists of:

a. A given subset of nodes and edges.
b. An object (e.g. hardware) placement at the nodes.
c. A capacity installation on edges, and
d. A routing of the traffics within the link capacities,

The goal is to find a feasible network configuration that optimizes a given objective, for instance, cost. When designing a network, or when adapting a preexisting network, these sorts of a network design problems are encountered. Compared to links, node is not widely taken into account because node cost is generally smaller than link cost in optimization, even though the cost of multilayer networks is incurred from nodes and links.

The two main objectives of network design problem are strategic decisions or operational decisions to optimize operation cost or performance measure respectively. Many of the studies and design are focused on strategic decisions, particularly minimizing the installation costs. However, network performance decisions with objective functions such as minimization of delay and minimization of lost traffic are more technology dependent.

Multilayer network design problem includes the following sub-problems for high-capacity optical backbone network (Stanojevic, 2005; Ergün, 2013):

a) Physical topology design problem: Determining the physical nodes allocation, its capacity and type etc.
b) Logical topology design problem: Determining number of logical links possible between node pairs and traffic routing
c) logical links routing problem: determining routing of links on the logical topology.

Traditionally due to computational intractability, sequential methods were used to find solutions to these problems. However, integrated solution of multiple sub-problems is possible; physical topology design, logical topology design and logical links routing problems can be solved jointly (Lehman et al 2011; Orlowski & Wessäly 2004; Orlowski, S. 2009). As network optimization problems are main tools for modeling the telecommunication network design problem, the algorithms and solution procedures of the two are closely related (Ergün, 2013).

The multilayer network design problem is on $\mathrm{G}_{\alpha} = (\mathrm{E}_{\alpha}, \mathrm{C}_{\alpha})$ where E_{α} is the set of entities such that $\mathrm{E}_{\alpha} = \{\mathrm{e}_{\alpha}: \mathrm{e}_{\alpha} = 1, \dots, n\}$ where n is the number of potential entities locations, and C_{α} is the set of edges such that $\mathrm{C}_{\alpha} = \{\{i, j\}: i, j \in \mathrm{E}_{\alpha}\}$

- Links represent the transmission environment between the nodes.
- Capacity of entities is the capacity of the node device.
- Cost of the devices located at the nodes is the node costs.
- Capacity of links is the number of wavelengths that can be transmitted.
- Cost of links is determined by the distance cost and capacity of the link.

With this similar assumptions Ergün (2013) uses a single network to model all of the network layers instead of distinct networks for each layer for network flow, applicable to the multi-layer networks. It was shown that ATM-over-SDH-over-WDM network can be modelled using the network flow formulation.

4.3.2. Multicenter network optimization

Considering a multicenter network optimization problem which is equivalent to the network design problem of choosing locations of backbone nodes, terminal nodes assignment and their topology. Basically, the network design problem is to assign terminal nodes to backbone nodes, which may be several root nodes with different capacity. Although, several problems may have to be solved jointly, the main objective is to find the least cost connection between a given set of user and backbone nodes (centers), with each subtree satisfying the capacity restriction of the node.

Given the of terminal nodes, the possible backbones locations and the traffic requirements, the topological design of computer network problems is in short the problem of determining the network topology, capacity assignment of both nodes and link and traffic routing to optimize certain objectives, most notably to minimize the total system cost. With the objectives known, some constraints are imposed such as connectivity, reliability etc. Due to the complexity of the problem, finding an exact solution is intractable, heuristic solutions are required for problems with more than 25 nodes (Altinkemer,1989; Boorstyn, & Frank, 1977). One of the solution methods is to breakdown the problem into subproblems that are solved sequentially, and yet these subproblems are very difficult to solve. For instance, lets assumes N locations to be assign the entities. There are $N(N-1)/2$ possible edges and $2N(N-1)/2$ potential topologies.

Using integer programming formulation, the multicenter network is to formulate a network, here subtree, with root at one of the backbone nodes that minimize total cost of the links such that each subtree generate does not exceeds the maximum traffic as formalized below. With y_{ij} *as* binary variables which are equal to one if link (i, j) or (j, i) is used in the final, and zero otherwise.

$$min \quad z = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} C_{ij} y_{ij}$$

Subject to:

a) Each node connecting to some other node in the network

$$\sum_{i=1}^{i=1} y_{ij} + \sum_{j=i+1}^{N} y_{ij} \geq 1 \quad i = B+1, \ldots, N-1$$

b) The node N has connection to at least one node

$$\sum_{i=1}^{N-1} y_{jN} \geq 1$$

c) Capacity of the network ensured and that no loop in the final solution

$$\sum_{i \in s} \sum_{\substack{j \in s \\ j > i}} y_{ij} \leq |S| - L_S \qquad \forall S \subseteq \{B+1, \ldots, N\} |S| \geq 2\, y_{ij} = 0 \; or \; 1$$

$$i = 1, \ldots, N-1 \;\; and \;\; j = i+1, \ldots N$$

d) To ensures that there will be certain number of arcs in the final solution, For instance, $N - B$

$$\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} y_{ij} = N - B$$

Where B is the number of backbones, $N - B$ number of terminal nodes, K is the maximum traffic on the subtree, $t_i$is the expected traffic at location $i: i \in \{1, \ldots, M\}$, L_S is the optimal solution to one dimensional bin packing problem (Eilon, &

Christofides 1971) with K as the bin length and d_i, $i = B + 1, ... N$ are the length of the items that have to be packed to those bins. and C_{ij} is the cost of connecting location i to location j C_{ij}. The bin packing is NP-complete

The problem is NP hard as the cost might be backbone node dependent because different capacities for backbone nodes may exist on different locations. Altinkemer (1989) uses Parallel savings heuristic to for the network with 100 nodes with varying arc capacity, and two to seven number of backbones. A generalized multicenter was considered using iterated tour partitioning heuristic and optimal partitioning heuristic by Gavish, Li, & Simchi-Levi (1992).

Multicenter network optimization problem is equivalent to the network topology problem which is also similar to multi local world topology model if the network fundamental feature such as scale free and linear growth of nodes a are considered. The network topology problem consists of deciding on Network control processors (NCP) locations and the set of links connecting them (Gavish, 1991). The backbone network consists of backbone lines and nodes. The backbone nodes contain network control processors (NCPs).

The network design process and subproblems can be grouped into 2 main types s as backbone network design and local access network design which we took as local world, with network expansion as an important process in the dynamics. The design process involves a number of decisions which are related to the subproblems. These subproblems are mostly NP-hard (Gavish, Li, & Simchi-Levi 1992). These problems can be related as given in the following flow of steps:

Network design process and subproblems

Choosing nodes location
- Location of backbones
- Potential network control processors sites
- Multi-level network design problems
- Assign network control processors in selected location

→ **Local access network design**
- Concentrator location problems
- Telpak problems

→ **Terminal nodes Interconnection**
- Terminal assignment problems
- Terminal layout problems
- Clustering of nodes

→ **Backbone network design**
- Backbone routing and capacity assignment problems

→ **Interconnect backbone nodes**
- Dimensioning; determines links and their capacity
- Connecting the backbones to other each other

→ **Evaluate the network for performance and other objectives**
- Cost evaluation
- Security evaluation
- Response time and efficiency
- Reliability and availability

→ **Network optimization**
- Network expansion
- Capacity expansion problem
- Network upgrade

A particular network model called Multi local world (MLW) captures the structural topology of the internet better than previously proposed models in terms of essential features of the generated networks (Fan, Chen, & Zhang, 2012). The model can produce a large clustering coefficient, it captures both the scale free and small world features of internet model. The MLW model is closer to the real Internet than all other models in comparison (Fan, Chen & Zhang, 2009; Fan, 2006)

4.3.3. Heuristically Optimized Trade-off Model of Multi-local World

It was observed that at the autonomous system level, the actual Internet hierarchy, which is basically one of the widely studies complex system is conceived into levels: International connections; national Connections; regional connections, and local networks connections. These together form the topology and justified by the operational activities, the different levels internet service providers (ISPs). The nodes in the regional networks are closely connected, producing quit high clustering coefficients. These highly clustered regional networks are then interconnected sparsely by national backbones or international connections. This observed structure inspired the new approach of evolving network topology; the Multi-Local-World model, which is based on the following theoretical considerations:

- ***Backbones and terminal nodes addition and removal****:* It is obvious that the networks such as Internet, World Wide Web etc. continues to expand in an accelerated growth speed after formation. For instance, from data collected by the route Server of Oregon university the number of autonomous system (AS) in the Internet was increased from 4320 in 1998 to 9520 in 2000, and to over 50,000 in 2016 (Irl.cs.ucla.edu., 2016). As the birth rate of ASs are larger than the death rate at the same instant, the event of death of ASs is not usually considered in the MLW model.
- ***Addition and removal of Edges***
  When new node is added into the network, it creates a certain number of links to the existing nodes in the network—new interconnections called "birth" of link between the preexisting nodes emerge.
- ***Edge Rewiring***
  The dynamics of the network requires that a node may rewire one of its links to connect with other nodes for more efficiency or other benefits, for instance, minimizing the distance from an ISP to other nodes in the network. However, edge rewiring does not play a significant role in the evolution of the Internet AS topology and thus may not necessarily be considered in MLW model.
- ***Localization***
  A network is Considered to have a schematic hierarchy division into international connections, national backbones, regional networks, and local area networks. At some level, for example, regional networks, a tight connection can be observed which is evident by its high clustering coefficient. These clustered networks are then interconnected sparsely by much high-level connections. The notion of localization point to the ability that a node in a particular network can attract link from the newly added node may depend primarily on its position relative to the other nodes within the same network, but not to the entire multilevel network.

- ***Attachment:***

  Shown by Vázquez, Pastor-Satorras, & Vespignani, (2002), newly added nodes actually create new links by a preferential attachment rule, which confirmed by research of Yook, Jeong, & Barabási, (2002). This influences the MLW model, whereby the linear preferential attachment rule is used to determine the probability of existing node receiving a new connection from a newly added node. However, decisions made by Internet Service Providers (ISPs) play a fundamental role in the formation and evolution of cyberspace topological structure and the topology affects complexity of the design problem. We therefore use a decision-based node attachment to optimize certain objective, the kind of topology model dubbed the *heuristically optimized trade-off* (HOT) / *highly organized tolerance (HOT)* or *heuristically Optimal Topology* model proposed by Fabrikant et al (2002).

4.3.3.1. Heuristically optimized trade-off (Hot) Model

The widely known preferential attachment mechanism, leading to power–law degree distributions of scale-free network models conforms with the *cooperation* traits manifested among the nodes in networks. However, beyond cooperation, the real networks have much *competition* traits *which* implies that preferential attachment becomes less convincing. This is because, intuitively, nodes usually try to optimize their own advantages and strengths in while connecting and behaving and do not necessarily prefer to attach to giant.

The heuristically optimized trade-off modelling approach attempts to explain the highly optimized tolerance mechanism for power–law distributions in designing a network, proposed by Carlson and Doyle (1999), and point out a more engineering approach to produce power laws by an intrinsic trade-off mechanism. Generally, in designing a complex system and Specifically network, basically conflicting objectives are encountered; consequently, trade-off among these objectives is indispensably, while various optimizations toward the objectives are being performed. Elaborating the importance of design, structure, and optimization, this modeling approach provides a framework in which the observed highly variable event in systems optimized by engineering design are the results of tradeoffs between yield, cost of resources, and tolerance to risk/failures.

From the statistical physics models—such as percolation lattices, cellular automata, and spin glasses—HOT places itself to use a simple model that take into account the importance of design or evolution in creating highly structured configurations, power laws, self-dissimilarity, scale-richness, etc. The emphasis in the HOT view is on ***organized complexity***, which differ with the view of ***emergent complexity*** that is much considered in the other areas of research. The HOT perspective has wide range of application from biology to technology, and the models typically basically optimizing functional objectives of the system as at large, depending on constraints on their components, mostly with an explicit source of uncertainty against which solutions must be tolerant, or robust. The focus on function, constraints, optimization, and organization clearly differentiate HOT from SF approaches. HOT systems have the following features:

- Power-law degree distribution.
- High efficiency, performance and resilience to perturbations considered in the design.
- Hypersensitivity to design laws and unexpected perturbations.
- Structured and specialized configuration.

Constraints and functional Objectives

The features of HOT are a result of optimization of the network design objectives under uncertainty and subjected to several constraints. The other network, self-similar structures, rarely satisfy the objectives of specialized design choices. When designing system, especially engineering systems, many design decisions have to be made. For our research we first ask what really matters when it comes to topology modelling; what needs to be optimized— the objective function. Real networks evolve over time in response to changes in their environment (Alderson, et al 2006) due to the following factors that we call “demand”:

- *Technology:* Changes on network configuration, and redundancy/survivability constraints—bandwidth and number of connections. *link costs, router technology. Traffic*, constraints on traffic patterns
- *Economics:* budget constraints, arc costs (both installation costs and variable use costs),

- *Regulations:* Deregulation of the industries, service introduction and competitions
- *Geography:* population and demand, customer requirements and service requirements.

Initial models assumed that there are fixed number of nodes, that are then randomly connected (Erdos & Renyi, 1959; (ER model)), or reconnected (Watts & Strogatz, 1998;(WS model). However, real-world networks grow, i.e. they form by the continuous addition of new nodes to the system. Second, subsequent models assume that two nodes are connected randomly and uniformly according to probabilities or preferentially attachment (Chen, Wang & Li 2014; Lian-Ming, et al 2011). In contrast, most real networks nodes are connected based on certain objectives. Therefore, we proposed Multi-local world with Heuristically optimized trade-off (MLW-HOT) model defined in two basic steps outlined as follows:

1. **Growth:**

- Let G_l ($G_l \geq 1$) be the initial isolated local-worlds, (E_l(($E_l \geq 1$) be isolated nodes in each local-world such that each local world can be identified. For the network $G_l = (E_l, C_l)$.
- *New local word creation: birth of local access network/AS*: Base on demand, ***a***, a news local world G_l is design which contain E_l, and C_l connections
- *New terminal node added to the existing local world—Birth of end user node*: Base on demand, ***b***, a new node is added to an existing local world, along with its C_1 new edges connecting to the nodes within the same local world. That is a local world G_Ω is chosen and in it node is chosen based on the following mean field probability dependent on demand;

$$\Pi(k_i) = \frac{k_i + \alpha}{\sum_{j \in G_\Omega} (k_j + \alpha)}$$

The probability Π that a new node will be connected to node i depends on the connectivity k_i of that node, and the parameter $\alpha > 0$ which is the "suitability" of node i which is used to determine the probability for the new nodes to attract new edges. This task is repeated C_1 times.

2. **Heuristic attachment**

- *Links added with a chosen local world:* Base on demand, $\boldsymbol{c}$, C_2 connections are added within a selected local world. Meaning that repeated C_2 times a local world G_{Ω} is randomly chosen and an edge is connected between a randomly chosen node and other nodes inside G_{Ω} according to the given mean field probability.
- *links deleted within a chosen local world— edge rewiring:* Base on demand, $\boldsymbol{d}$, C_3 connections are removed within a selected local world. Whereby a local world G_{Ω} is arbitrarily chosen and then one end of an edge is randomly chosen while the other end is chosen depending on the following probability: This

process is done C_3 times.

$$\Pi'(k_i) = \frac{1}{N_{G_{\Omega}}(t) - 1}\,(1 - \Pi(k_i))$$

Where $N_{G_{\Omega}}(t)$ is the number of nodes within the $G_{\Omega}th$ local-world in the network at the present stage t, $\Pi(k_i)$ is from the node addition. And -1 represent the exclusion of the node under consideration.

- Links added between different local world: Base on demand, $\boldsymbol{e}$, C_4 connections are added between distinct local worlds. Done C_4 times: a local-world is arbitrarily chosen; then a node in this local-world is randomly selected according to the addition mean field equation. Same is done to choose the second local world to be connected.

The parameters, a,$\boldsymbol{b}$,$\boldsymbol{c}$,$\boldsymbol{d}$ and $\boldsymbol{e}$ satisfy the design objectives, and for probability consideration $0 \le \boldsymbol{a}, \boldsymbol{b}, \boldsymbol{c}, \boldsymbol{d}, \boldsymbol{e} \le \mathbf{1}$ and $\boldsymbol{a} + \boldsymbol{b} + \boldsymbol{c} + \boldsymbol{d} + \boldsymbol{e} = \mathbf{1}$ (Fan, Chen, & Zhang, 2009).)

To simplify the model, we assume a simple connected acyclic graph (i.e., a tree) starting from one local world representing root node, which is the core of the network, while the other nodes arrive uniformly distributed in space; node ***i*** attaches itself to the node ***j*** according to the weighted sum of the demands objectives (Fabrikant et al, 2002):

$$\text{Min}_{j<i}\ \alpha d_{ij} + h_{ij}$$

Where d_{ij} is the normalized Euclidean distance between node ***i*** and node ***j*** and h_{ij} is some measure of the “centrality" of node j such as one of the following:

- The average shortest-path length from *j* to all the other nodes in the network; average number of hops
- The maximum shortest-path length from *j* to any other node in the network; maximum number of hops
- The shortest-path length from *j* to a fixed "central" node

To measure the relative significant of the objectives, a parameter $\boldsymbol{\alpha}$ as a function of the number of nodes $\mathbf{n}$ is used. However, its value is critical in determining the behavior of model:

- For $\boldsymbol{\alpha} < \mathbf{c}$, the Euclidean distances are not important, and star topology is formed. where $\mathbf{c}$ is a constant depending on the region?
- For $\boldsymbol{\alpha} \geq \sqrt{\mathbf{n}}$, the Euclidean distance is too important, resulting in a variety of Euclidean minimum spanning tree.
- For $\mathbf{c} < \boldsymbol{\alpha} < \sqrt{\mathbf{n}}$, the power law degree distribution is formed.

The two objectives objective in this model aimed to minimize the last mile costs and the operational costs due to communication delays respectively. The scale free features point out that preexisting nodes are preferred by new nodes because they have high degree and a low operational cost. This is a result of local optimization subjected to certain constraints. In this model, power laws are the result of an optimized and reliable design base on ISP decision in spite of constraints and uncertainty. At the basic level, the trade off to deal with is bandwidth and number of connection subject to costs constraint. Hence, the first term of the objective formalization optimizes the cost of establishing physical connection between the newly added node and the existing nodes *by* minimizing the Euclidean distance. The second term tries to minimize the hop distance of node *j* to the "centrally located" node in order to maximize the information transmission efficiency. The model generates a sequence of node degrees that follows are consistent with observed scale degree distribution.

The simple model can explain the basic features of spatial entities networks, including their dimension, in accordance with design decisions such as location influenced by Euclidean distances between nodes or abstractly the graph distances. Assuming that the cost of designing and maintaining the network is proportional to the total length of all its edges and transmission cost:

$$min \quad f_i(j) = \sum_{edges(i,j)} d_{ij} + \sum_{\substack{j\in s \\ j>i}} h_{ij}$$

Subject to:

a) Each node connecting to some other node in the network

$$\sum\nolimits_{i=1}^{i=1} y_{ij} + \sum\nolimits_{j=i+1}^{N} y_{ij} \geq 1 \quad i = B+1, \dots, N-1$$

b) The node N has connection to at least one node

$$\sum_{i=1}^{N-1} y_{jN} \geq 1$$

c) Capacity of the network ensured and that no loop in the final solution

$$\sum_{i\in s} \sum_{\substack{j\in s \\ j>i}} y_{ij} \leq |S| - L_S \qquad \forall S \subseteq \{B+1, \dots, N\} |S| \geq 2\, y_{ij} = 0 \; or \; 1$$

$$i = 1, \dots, N-1 \;\; and \;\; j = i+1, \dots N$$

d) To ensures that there will be certain number of arcs in the final solution, For instance, $N - B$

$$\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} y_{ij} = N - B$$

Where y_{ij} as binary variables which are equal to one if link (i,j) or (j,i) is used in the topology, and zero otherwise.

$$y_{ij} = \begin{cases} 1 & if \; (E_i^{\alpha}, E_j^{\alpha}) \in \; C_{\alpha} \\ 0 & otherwise \end{cases}$$

Some complex networks models are assumed in an abstract space such that the location of vertices has no particular meaning. in contrast, there are several networks where the position of node is particularly vital as it influences the network's evolution. The Internet, for example, such that location of the network entity such as routers can be localized in a map and the edges between them correspond to physical entities such as fiber cables. More practically the design of the network corresponds to the following steps:

STEP 1: Decide the distribution of the AS and the coverage area. This choice may be based on the Geography (population density) or driven by service requirement and/or market competition. The initial generating algorithm follows the MLW model.

STEP 2: Design a general or for each AS an access network.

- The underlined technology assumptions.
- Choose (probabilistic) distributions for bandwidth demands.
- Formulate an optimization objective to obtain a heuristically optimal local topology.

STEP 3: Design a topology to support traffic between the ASs.

- The underlined technology assumptions.
- Formulate the backbone networks design problem as a constrained optimization.

STEP 4: Consider the complex network features for a validation of the model.

STEP 5: Compute theoretical performance of the network as a whole (e.g. throughput, utilization) under initial assumptions.

A simple way to generate spatial networks is by placing n nodes at random in a two-dimensional space and connect them with a given probability or based other considerate that is dependence on the distance. The network formation may start with a few nodes as new nodes and connections are added at each subsequent time step — spatial growth. Such a model is capable of generating different network topologies including small-world and linear scale-free networks (Kaiser, & Hilgetag, 2004).

Dynamics of evolving dynamical networks, network with active topology (nodes and connectivity) and the dynamic processes, are coupled—interdependent. However, most of the research mainly focus on how the network behavior is influenced by its static topology.In majority of the real networked systems, including the telecommunication and information network, the connectivity varies in time and is inherently dependent on the dynamics of nodes and links, and vice versa. Thus, for an interdependent dynamical entities and evolving topology, the topology is augmented with another formalism we called Cybermap. In general, how the network topology evolves, according to some optimization objectives, is formulated. Then, in the following chapter the dynamics of the network governed by the associated dynamical mapping will be described. The topology evolution and network dynamics representation allows one to adequately describe different collective behaviors in cyberspace.

CHAPTER 5
CYBERSPACE DYNAMICS

A generalize graph-cellular automata (graph-CA) spatial model of cyberspace dynamics is investigated. Inspired from the understanding that cyberspace has presence in geo-space, dynamics of cyberspace is described in graph-CA context. Use of graph as a network's structural properties defined in terms of relationships between subsets of nodes/cells and generalization of classical cellular automaton (CA) which enable more realistic descriptions of network as a coupling of structure, dynamics and function. This pave a way for further development of realistic types of models that explain not only topological or functional dynamics, but entities interrelations. The benefits of graph-CA from both the graph and CA formalisms allows the simultaneous use of formal ways of describing networks model structure and process dynamics, and that these help in the research towards cyberspace theories. In essence, this chapter analyses the mathematical dynamics and the cellular automata modeling approach for cyberspace. The modelling formalism of the cellular automata (CA) is used, generalized and extended.

Three key concepts are considered: cyberspace having a spatiality that needs to be analyzed; the spatial geometries and forms of cyberspace are entirely produced; and that cyberspace is an embodied space. Cyberspace is inherently spatial, a digital space in which many relations are developed. Its structure and operation are generally built on the premises that often depend on spatial metaphors. Its infrastructures have materiality that can be mapped onto physical space. These infrastructures are accessed and used by agents located within physical space. Therefore, the characteristics and location of the agents using the services in cyberspace can to reveal important features such as the demographic information of cyberspace.

The maps of cyber infrastructure used to be static map of network architecture, for example the original ARPANET network— where nodes are the sites and the links are the edges. This and other similar static maps convey only a limited amount of information and are closed to inquiry, and thus more sophisticated representations, the interactive map, were explored. Subsequently a dynamic map of the infrastructure, for example the trace route— reporting the route that data packets traversed, and the time taken between all the nodes along the route.

Contrary to mapping of the materiality of cyberspace, cyberspace information with no inherent spatial properties is also mapped onto a defined spatial framework for analysis and better understanding. This is the network topology map which is abstract in nature in a way that the physical location of the infrastructure may not be vital because the topology is aimed to express other kind of information, most often the connectivity and the routing. Here a system of relative location can be assumed. The spatialization takes on an almost celestial character, with the nodes and connections floating in an abstract space, like stars in galactic clusters.

5.1. From Cybermap to Cybermap-Algebra

There have been few attempts to model spatialization of cyberspace. Dodge (1997) discussed the concepts of 'cybermaps' into physical space metaphors, conceptual maps, and topology maps etc. Jiang and Omerling (1997), categorized maps of virtual reality spaces in terms of navigation, cyberspatial analysis, and persuasion. Dodge (2003) proposed mapping of cyberspace in four-fold; physical space referent, the infrastructures of cyberspace; material and immaterial spatial forms; and map/spatialization form (static, animated, interactive, dynamic). In general, the mappings of cyberspace vary as a function of physical space reference, spatial form/attributes, and materiality of the information that is mapped. However, all these failed to take into account the dynamic map of cyberspace and comprehension of different concepts of cyberspace theoretically.

"Cybermap", is a spatial framework for defining and organizing numerous aspects of cyberspace, such as, physical locations of entities, traffic situation and so on (Dodgem 2003; Jiang, & Ormeling 1997). The World-Wide Web formed a universe of information logically linked and residing in cyber entities; thus, information may be considered to have its own location, mapped on domain location maps.

While cybermap provides an interesting framework to visualize many aspects of cyberspace, it has some significant deficiencies in expressing spatial models. Cybermap does not clearly defined spatial relations and interactions among locations, which are key concepts in cyberspatial modelling. The spatial interaction expresses the influence of one location to another and cyber map lack the structure to represent arbitrary interactions and operations involving these interactions. This can be formulated with a formalized notion below.

The formalize Cybermap extends the original concepts of cybermap by including spatial interactions as well as recursive operations for dynamic modelling of complex cyberspatial processes. It opens up new ways of investigating cyber spatial modelling framework. In accordance with formal algebra, the structure of Cybermap consists of sets of operands and the operations defined on these sets. We assume that the operands are: Cyberspatial location, attributes, cybermap influence, relational influence, and meta-relational influence. The operations are divided into local and global operations, with the basic operations as unary and binary local operations. The local operations are related to and carried out on and between the maps while global operations constitute operations between cybermaps and meta-relational influence and local influence function.

Cybermap consists of pairs of position/location P, defined as a subset of n-dimensional space, and associated attributes/values (of any appropriate date type) A. This is the essential unit of cyberspace representing any information at a position. Given $P$and A, the cyberspace unit is denoted by $P \times A$ and therefore the cybermap is a function from a set of locations or positions in a reference frame to a set of attributes/values A, $\boldsymbol{M}: P \rightarrow A$ defined by:

$$\boldsymbol{M} = \{((p_i), m(p_i)): p_i \in P, \qquad m(p_i) \in A\}$$

Where cyberspatial position $p_i \in P$ is the position that cyber object e_i is located and $m(p_i) \in A$ is the attribute/state/value of the object at that position, which may be any set of complex structures representing the current states at those positions. The set of all A attributes cybermaps on P is given by A^P. Any spatial structure may be defined to accommodate the set P; Conceptually as a continues field of discrete domain, for example, two-dimensional space (a regular grid) having the limit determined by $\times$ ($P = R \times R$ for the set of reals, R) or restricted network domain. The set of values may be set of integers, real number, binary numbers, characters, set of characters or a complex structure–provided they are well-defined, giving the current states of nodes. The aggregate properties of these units then form the global state of cyberspace.

For multiple states/attributes (multi-variate situation), where a position takes multiple entities and/or attributes simultaneously, the set of state is the set product of these states/attributes, and therefore;

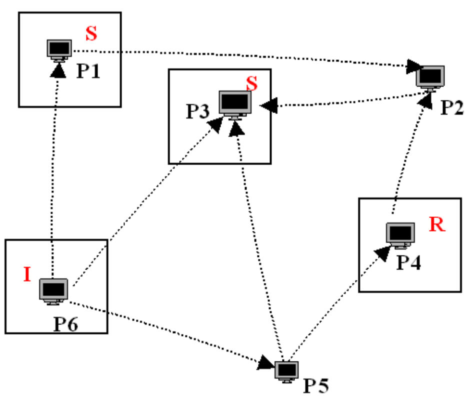
$$A = \prod_{i=1}^{z} A_i$$

A simple operation, unary operation for example, is then defined at each position p_i, which is influential on a global state of cyberspace, $\boldsymbol{M}$. This local operation is formalized from a local function f' on the state of cyberspace at each position in P:

$$f(\boldsymbol{M}) = \{[p_i, f'[m(p_i)]]\}$$

Characteristic function $\mathscr{b}\colon \mathrm{A}^{\mathrm{P}} \to \{0,1\}^{\mathrm{P}}$ representing a binary cybermap for an attribute value $\mathscr{b}\colon A \to \{0,1\}$ calculates whether the attributes at each position is included in a given set $\boldsymbol{\mathcal{S}}$. Similar to biological system, a scale-free network can model such a virus spread— a cyberspace devices unit (AS, router, or PC) defined as a node in a network, linked together by edges, in a certain topology. Let $\boldsymbol{\mathcal{S}}$ have values of SIR (Susceptible, Infected, Recovery) epidemic model $\boldsymbol{\mathcal{S}} = \{\boldsymbol{S}, \boldsymbol{I}, \boldsymbol{R}\}$. Then a cybermap $\boldsymbol{M}$ is transfigured into a cybermap : $\mathscr{b}^{\boldsymbol{\mathcal{S}}}(\boldsymbol{M})$ by a characteristic function $\mathscr{b}^{\boldsymbol{\mathcal{S}}}$ as shown in figure 5.1. Accordingly, any local operation between cybermaps is induced by an operation on an attribute set A.

$\boldsymbol{M}$



$\mathscr{b}^{\boldsymbol{\mathcal{S}}}(\boldsymbol{M})$

	P1	P2	P3	P4	P5	P6
P1	**1**	0	0	0	0	0
P2	0	0	0	0	0	0
P3	0	0	**1**	0	0	0
P4	0	0	0	**1**	0	0
P5	0	0	0	0	0	0
P6	0	0	0	0	0	**1**

Figure 5.1 Cybermap characteristic function application

The local operations at each node e_i at position p_i can be extended to have a global influence (a function from a local rule on the value of mapping at each location in P). This pave a way to include effect of influence (spatial relations) between entities on P, this in essence is vital to depicts neighborhoods structure and subsequently the cellular automata formalism. Defining the influencing positions is achieved using metarelational cybermap (R), where each position is assigned a relational cybermap (R_i)—set of all nodes in P influencing node p_i is associated with each node $p_i \in P$. For example, to represent connectivity, a binary map on the set of nodes P can be assumed such that R_i is populated with binary values— 1 as presence of connection or influence and 0 otherwise. The situational information of each position is expressed with the relational map. The meta relational map is then given by:

$$R = \{(p_i, R_i)\}$$
$$R_i = \{\big(p_i, r_i(p_i)\big): r_i(p_i) \in \{0,1\}, \qquad \forall p_i \in P\}$$

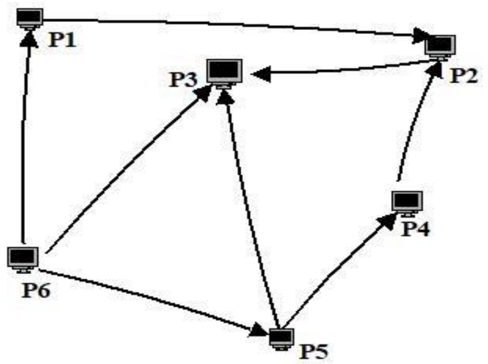
Therefore, a relational cybermap represents the situational information for each position. It expresses any arbitrary neighborhood or influence associated with a location. Metarelational cybermap is in essence a way in which each nodes space, as a part of cyberspace (a space which node is part of), can be related with each node. A global configuration may be computed from metarelational cybermap. This generalization requires a step from the basic unit of information map to a medium level metarelational cybermap, $M \otimes R$, in which each location p_i is associated with the set of values from influencing nodes. The global cybermap function is then a function on $M \otimes R$, representing the attributes of influencing positions:

$$M \otimes R = \{(p_i, Y_i)\}$$
$$Y_i = \{\big(p_i, y(p_i)\big): y_i(p_i) = m(p_i) r_i(p_i)\}$$

The CA space is then allowed to be represented by a metarelational cybermap R_{CA} , where nodes relational cybermap can now be defined by the CA's neighborhood operator. Therefore, function on the previously valued metarelational cybermap is substituted as the transition rule, Giving a new cybermap at time $t+1$ from the previous map, at time t:

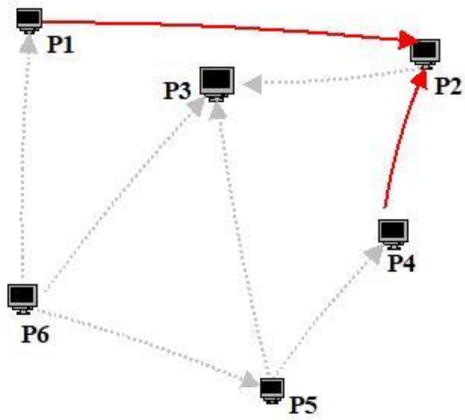
$$M_{t+i} = f(M \otimes R_{CA})$$

Thus, the entity set, the state value set and the metarelational map– P, A and R respectively, add with the rules set constitute a dynamic map of cyberspace. With edges non-uniformly distributed (irregular neighborhood across cells as in CA), the map is capable of depicting this generalization. Thus, relational and metarelational cybermapping can express influential or situational information in the forms of cybermaps, and the potentiality to define set of operations within and between different set of entities, in order that the topological and situational based information can be integrated and processed.



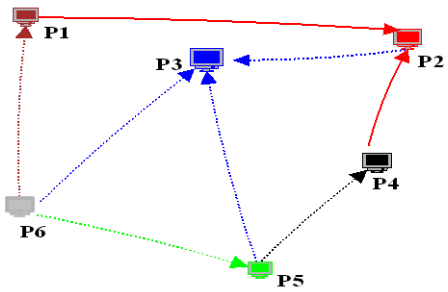
	P1	P2	P3	P4	P5	P6
P1	0	1	0	0	0	0
P2	0	0	1	0	0	0
P3	0	0	0	0	0	0
P4	0	1	0	0	0	0
P5	0	0	1	1	0	0
P6	1	0	1	1	0	0

1) Cybermap interaction and Connectivity



	P1	P2	P3	P4	P5	P6
P1	0	**1**	0	0	0	0
P2	0	0	0	0	0	0
P3	0	0	0	0	0	0
P4	0	**1**	0	0	0	0
P5	0	0	0	0	0	0
P6	0	0	0	0	0	0

2) Influence on position **P2**



	P1	P2	P3	P4	P5	P6
P1	0	1	0	0	0	0
P2	0	0	1	0	0	0
P3	0	0	0	0	0	0
P4	0	1	0	0	0	0
P5	0	0	1	1	0	0
P6	1	0	1	1	0	0

3) Metarelational cybermap for Cybermap interaction

Figure 5.2 Cybermap, relational map and metarelational cybermap

5.1.1. Cybermap in Time

The dynamic of cybermap is described by introducing time. Cybermap, therefore, consists of position/location P, a time T and associated attributes/values A. The cyberspace unit is denoted by $P \times \mathrm{T} \times A$ and the cybermap as a function from a set of locations in a reference frame at a certain time $P \times \mathrm{T}$ to a set of attributes/values A, $\boldsymbol{M}: P \times \mathrm{T} \rightarrow A$ defined by:

$$M = \{((p_i, t), m(p_i, t)): (p_i, t) \in P \times A, \qquad m(p_i, t) \in A\}$$

For cyberspatial position $(p_i, t) \in P \times A$ in time $t \in \mathrm{T}$, and attribute/state/value $m(p_i, t) \in A$ of the object at that position.

With time explicitly defined, the cybermap is considered as a series of time shot of slices. Formally, a time shot of a cybermap **M** at a time $t_i \in T$ is now $\boldsymbol{M}: P \times \mathrm{T} \rightarrow A$ to $P \times \{t_i\}$, Precisely $m_{t_i}: P \times \{t_i\} \rightarrow A$ such that $m_{t_i}(p_i, t) = \mathrm{m}(p_i, t)$: for$(p_i, t) \in P \times \{t_i\}$

The notion of cybermap time shot allows the description of cybermap dynamics: $(\{T, A^P, (A^P)^P, (\{0,1\}^P)^P\}, \{\circledast, g\})$ where g is the dynamic universal influence function given by $m_{t+p_i} = g(m_t \circledast R)$

The cybermap slice at time t_0+k is recursively determined from the initial cybermap at time t_0 by : $m_{t_0+k} = g(\ldots(g(g(m_{t_0} \circledast R) \circledast R)\ldots) \circledast R)$ this formed as series of cybermap time shots $m_{t_0} m_{t_0+1} m_{t_0+2} \ldots m_{t_0+k}$ which we named ***dynamics behavior of cybermap dynamics.***

5.1.2. Cybermap Open Dynamics

The cybermap dynamics $(\{T, A^P, (A^P)^P, (\{0,1\}^P)^P\}, \{\circledast, g\})$ is capable of expressing any Cellular automata and extend the formalism to model dynamic processes. While classical CA restrict the space in a regular space, cybermap dynamics is not limited by this restriction. In addition, a both continues, and discrete set of positions and attributes can be assumed with the dynamic map. Furthermore, the neighborhood defined by metarelational influence goes beyond the classical neighborhood. These and other additional extensions play a vital role in the framework that can be used to model dynamic in which entities may not necessarily be regularly placed and the rules and interactivity may be different from network to network.

The space in the classical formalism is generally taken to be a single plane corresponding to a particular attribute under which to be modelled, which does not take in to account the interactions among multiple number of attributes. To deal with dynamic interactions among multiple map layers corresponding to multiple variables

and attributes, an extension of the framework of a cybermap dynamics into a multi-layer (or multi-variate) map dynamics is required. Given the set of attributes or the entities:

$$A = \prod_{i=1}^{z} A_i$$

The multilayered cybermap is given by:

$$m: P \to \prod_{i=1}^{z} A_i$$

and the multilayered cybermap in time is given by:

$$m: P \times T \to \prod_{i=1}^{z} A_i$$

Where $m = (m_{t_0}, m_{t_0+1}, m_{t_0+2} \dots m_{t_0+m-1})$ and $m_{t_j} = m|p \times \{t_j\}$

External input and influence affect the dynamic of cyberspace, for instance power outage on a national grid or backbone cables cut. Whereas conventional CA is a closed a system, dynamic cybermap consider the external data input. Assuming that the data input at the initial cybermap, the map dynamic is better defined as open map dynamic which allows new different concepts to be defined into the framework in addition to the spatial information modeling and conceptualization.

5.2. Graph Cellular Automata Approach

It is based on relaxing neighborhoods restriction by the classical cellular automata, whereby cells can have different neighborhood. This enable establishment of various relations between the spatial entities of the model. “The spatial structure underlying such CA models is most conveniently described and understood as a graph” (O'sullivan, 1999).

Recall that a Cyberspace multilayer network of entities is a pair $\mathrm{T} = (\mathrm{L}, \mathcal{C})$ where $\mathrm{L} = \{\mathrm{G}_\alpha;\ \alpha \in \{1,\ldots,\mathrm{M}\}\}$ is a family of graphs $\mathrm{G}_\alpha = (\mathrm{E}_\alpha, \mathrm{C}_\alpha)$ forming layers or subnetworks of T and;

$$\mathcal{C} = \{\mathrm{E}_{\alpha\,\beta} \subseteq \mathrm{E}_\alpha \times \mathrm{E}_\beta; \alpha, \beta \in \{1,\ldots,\mathrm{M}\}, \alpha \neq \beta\}$$

is the set of interconnections between entities of distinct layers G_α and G_β with $\alpha \neq \beta$. The elements of $\mathcal{C}$ are crossed layer connections, the elements of each C_α are intralayer connections of the topology T and the elements of each $\mathrm{E}_{\alpha\,\beta}$ $(\alpha \neq \beta)$ are interlayer connections.

Considering single layer of cyber physical entities as a homogenous set of cyber entities, then the network G_α will be given by $G = (E, \mathrm{C})$ where $E = \{\mathrm{e}_1, \mathrm{e}_2 \ldots, \mathrm{e}_n\}$ is an ordered non-empty finite set of the entities, and $\mathrm{C} = (\mathrm{e}_i, \mathrm{e}_j)$ is the connectivity or the set of edges as finite pair of element in E ; two entities are said to be adjacent (or neighbors) and hence influence each other if the edge between them exist. The adjacency matrix of the entities network is $A = \left(a_{ij}\right) \in \mathbb{R}^{N\times N}$ where

$$a_{ij} = \begin{cases} 1 & if\ (\mathrm{e}_i, \mathrm{e}_j) \in \mathrm{C} \\ 0 & otherwise \end{cases}$$

For $1 \leq i, j \leq N$ and $1 = \alpha = M$.

The neighborhood of an entity $\mathrm{e}_i \in E$, $\mathrm{N}_{\mathrm{e}_1}$, is the set of all entities of G which are adjacent to e_i, that is, $\mathrm{N}_{\mathrm{e}_1} = \{\mathrm{e}_j \in E$ such that $(\mathrm{e}_i, \mathrm{e}_j) \in C\}$. The degree of a node e_i, de_i, is the number of its neighbors.

In general, cellular automata defined on a network G is a 4-tuple $CA = (E, S, N, f)$ where

- The set $E \subseteq \mathbb{Z}^d$ is a d-dimensional space which defines the cellular space of the CA such that each cell is of the form $\mathrm{e} = (e^1, e^2, \ldots, e^d)$ where each coordinate $e^i (i = 1,2, \ldots, d)$ is the reference frame and for simplicity represented as an integer
- S is a non-empty finite set of states that can be assumed by the entities at each time t. The state of an entity e_i is denoted by $s_i^t \in S$ generated according to transition function f.

- N is a neighborhood function which assigns to each entities its neighborhood

  $N: E \rightarrow 2^{E}$

  $e_i \rightarrow N(e_i) = N_{e_i} = \{e_{i1}, e_{i2}, \ldots, e_{id_{ei}}\}$

  where each coordinate e is a vector of d integers.

- f is a transition rule/function $f: S^k \rightarrow S$ which is defined as:

$$s_e^{t+1} = f(s_{e_{i1}}^t, s_{e_{i2}}^t \ldots, s_{e_{id_{ei}}}^t) \in S,$$

where $s_{e_{id_{ei}}}^t$ is the state of the entity $e_{id_{ei}}$ at time t

In addition, a configuration of a cellular automaton is a function $c = E \rightarrow S$ given by:

$$c = \{(e_i, c(e_i)) | e_i \in E\}$$

Where $c(e_i) \in S$ therefore $c(e_i) = s_{e_i}$. A configuration of a CA expresses the assignment of an automaton state to every cell of the CA space and represents a global state obtained by simultaneous sum of the local transition function to each cell.

Given a set of all configurations, S^e for Given cellular space, E, position, P and $e \subseteq \mathbb{Z}^d$, a universal transition function F is a rule $F: S^e \rightarrow S^e$ defined as:

$$F(c)(e) = f(c(e + e_{i1}), \ldots, (c(e + e_{id_{ei}}))$$

Implying that the concurrent application of local transitions rules f to all cells of the space result in a universal function.

Axiom: Cybermap is homomorphic to CA.

Consider any $CA = (E, S, N, f)$ and a cybermap $M = \{(p_i, m(p_i)): p_i \in P,\ m(p_i) \in A\}$ and lets functions h_1 and h_2 be $h_1: E \rightarrow P$ and $h_2: S \rightarrow A$. That is, the set of positions and the attributes set are defined such that these two functions are injective. For every coordinate of e of the cellular space and every location $p_i \in P$ of the cybermap, $h_1(e) = h_1(p_i) \rightarrow e = p_i$. Then a mapping between the CA's configuration and the cybermap can be induced $ḩ: \rightarrow S^E \rightarrow A^P$, defined by:

$$ḩ(c) = \{(h_1(e_i), h_2(c(e_i))) | e_i \in E\}$$

Where A^P, is the set of all cybermap

Which point out that any configuration of the CA, c is equivalent to the cyber map, m as the functional relation is maintained.

Given h_1 and h_2, any neighborhood $N_{e_i} = \{e_{i1}, e_{i2}, \dots, e_{id_{ei}}\}$ is also equivalent to the metarelational influence map $R = \{(p_i, R_i)\}$, $R \in (\{0,1\}^P)^P$ defined by:

$$R_{p_i}(p_j) = \begin{cases} 1 & p_i = h_1(e_i) \; and \; p_j \in \{h_1(e_{i1}), \dots . h_1(e_{id_{ei}})\} \; for \text{ some } e_i \in E \\ 0 & otherwise \quad p_i, p_j \in P \end{cases}$$

In a similar way, we establish a correspondent between transition rule f and local influence function, a function which transforms each cybermap value associated with each position in R_p into a new value at the position p_i: denoted by g_p. Where g is the universal influence function computed from the parallel application of the local functions to all the positions of a relational cybermap, which can be spatially homogeneous or heterogeneous. The values at each of the influencing locations area computed from a combine operation between the cyber map m and the meta relational map R, resulting in an integrated new R denoted $g(M \otimes R)$. Therefore, an arbitrary transition rule f can be mapped to an influence function g_{p_i} as given by:

$$g_{p_i}(M \otimes R_{p_i}) = \begin{cases} h_2\left(f\left(c(e + e_{i1}), \dots, c\left(e + e_{id_{ei}}\right)\right)\right) \; for \text{ some } e, & p_i = h_1(e) \\ 0 \quad otherwise & p_i \in P \end{cases}$$

Clearly $g(m \otimes R)$ =ẖ $(F(c))$ and thus, the **universal influence function simulates** precisely the same behavior as that of the CA. As such, for any arbitrary cellular automaton $CA = (E, S, N, f)$, we can have a dynamics model $(\{T, A^P, (A^P)^P, (\{0,1\}^P)^P\}, \{\circledast, g\})$ which is homomorphic M. Table 5.1 below shows the correspondence.

Cellular Automata		Cyberspace dynamics	
Elements		Elements	
Cellular space	$E \subseteq \mathbb{Z}^d$	Cyberspatial position	P
States	S	Attributes	A
Configuration	c	Cybermap	$\boldsymbol{M}$
Neighborhoods	N	Meta relational topology	R
Local rules	f	Local influence function	g_p
Universal rules	F	Universal influence function	g

Table 5.1 Graph space and cyberspace.

CHAPTER 6
RESULT AND DISCUSSIONS

Cyberspace have integrated structural topology, dynamics and functional processes, and not well defined and delimited. In order to support the generalization of cyberspace theory a formalization and a solid foundation are essential. To introduce a formal proof and development of rigorous terminologies, it is paramount to formally define the domain considering the topology, functional process and dynamics in time. These could solve the problems in lexicon, lack of consensus and provides a ground truth for general analysis and further development.

Most complex systems, even biological ones, exhibit a layered structure which comes useful in deciphering the complexity at least in an understandable level. It is pointed here that cyberspace can be represented as a layered structure of entities and hierarchy of terms. This perception is chosen as the basis for a formal cyberspace framework and characterization, and subsequently offered a formalization consisting of a topological characterization guided by the network formation rules. The framework is a mathematical definition presented on cellular automaton principles highlighting the potential set of rules.

The layered approach describes the heterogeneous interacting entities whose effects unfold in cyber domain. We describe cyberspace as *a manifold of cyberspatial entities, whose behavior unfold in cyberspace time and with the topological interactions that are in turn governed by network optimization principles plus, driven by an information exerted and communicated among the entities"*. This chapter discusses the results obtained from the formulation performed with the created model.

6.1. Model Description

The model is based on the original idea of the heuristic optimization trade-off approach that recreate network topology at router. Since the observation that the node degrees of the graph of Internet at different level obey to power-law (Faloutsos, M., Faloutsos, P. and Faloutsos, C. 1999), the approaches to model network model has been re-assessed. And, while the degree-based models assume certain random processes, our model accordingly derives an implicit assumption from an engineering perspective of network model.

We first introduce the agent-based model using netlogo and the basic functions used to manage the analyses and experiments. The graphic user interface (GUI) of netlogo basically consists of the visual representation of the netlogo, *buttons*, and *sliders* to control the model and *monitors* and *plots* to show the result generated, as shown in figure 6.1. The netlogo environment is made up of agents, beings that can be controlled. Four types of agents are available in netlogo: turtles, patches, links, and the observer. Turtles are agents that move around in the world. The space is two dimensional and is divided into a square grid of patches, where turtles can move. Links are agents that connect two turtles. The observer is a special agent that gives instructions to other agents.

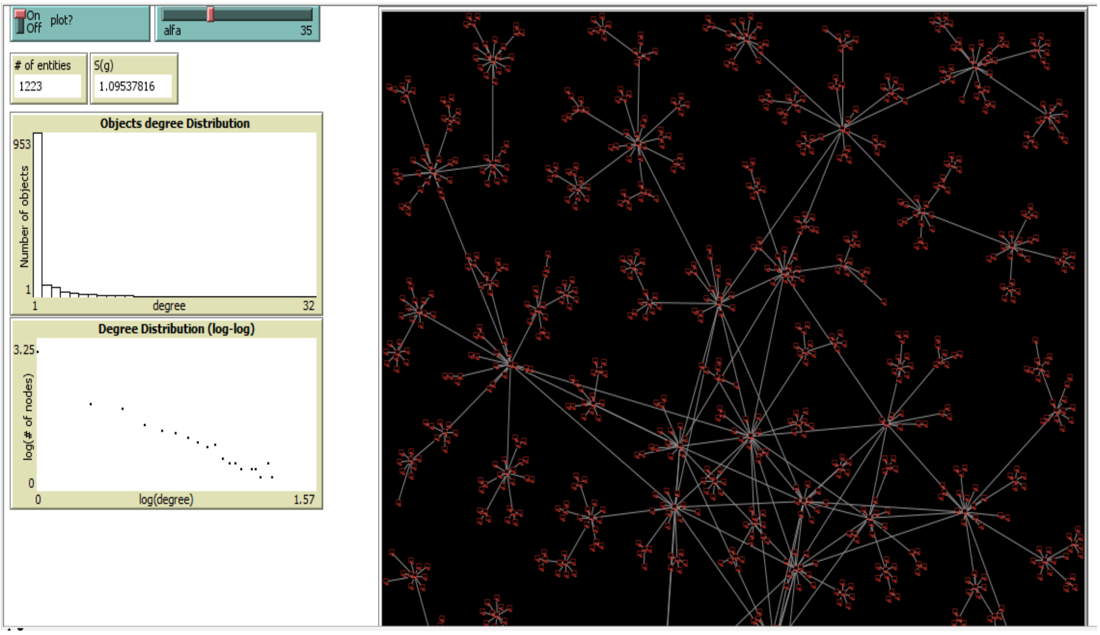


Figure 6.1: The Netlogo interface with the models of the network topology formation.

We exclusively consider one type of cyberspatial objects, an agent, whose behaviors unfold in the space. The basic behavior exhibited by the object are that of addition, deleting, updating, and movement: with much consideration on object addition in the physical topology design problem. The model in this dissertation consists of a network topology evolution which simulates the evolution of a network's structure based on the heuristically optimized trade-off model of multi-local world described in chapter four. The structure of a simulated network is controlled by one parameter, **α**, as a function of the number of nodes.

This model does not claim to be exhaustive, but establishes, in a different way, the principles by which a network topology with a robust design, which is subjected to objectives and constraints, can be formed. Therefore, the results are a "proof of concept" in the development of models of cyberspace network of entities topology, which is a foundation of the defined cellular automata formalism. In general, the model demonstrates important points. Primarily, it is relatively simple engineering design way to generate a network topology that conforms to core network design principles and trade-off faced by ISPs.

6.2. Topology and Degree Distribution

We now examine the generated topology of the model in pursuit of the answer to the question on how we can define cyberspace with regards to its entities. It has been shown that cyberspace consists entities and that these entities form a structure, which is not a mere co-incident, but a result of a highly organized tolerance based on design objectives.

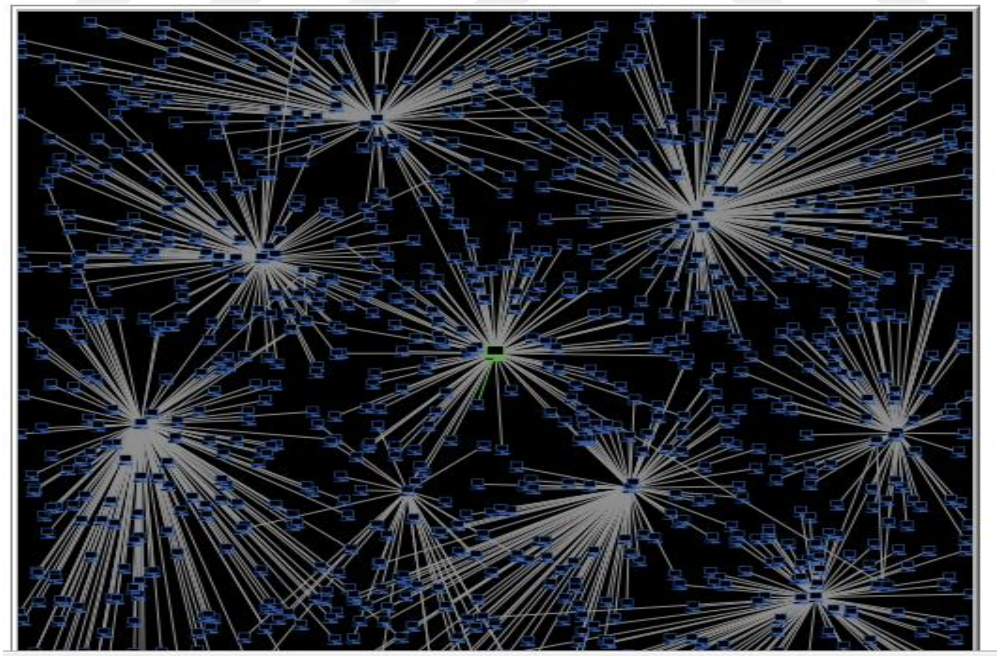


Figure 6.2: Topology of 1000 entities and 10 local world at **α** = 6

The small-world property of networks reflects the homogeneity of a networks, in such a way that that nodes in such network equal number of connections to the others. The essence of this property is that every node is as vital as the other in terms of their functionality in their network. In contrast, heterogeneity of the cyberspace entities network, where a few nodes have a considerable large amount of connections whereas the majority of nodes have small number connections each. And These nodes with large number of edges, refers to as *hubs*, tend to connect to one another and therefore play more significant roles in the network. This kind of nodes are shown in figure 6.3.

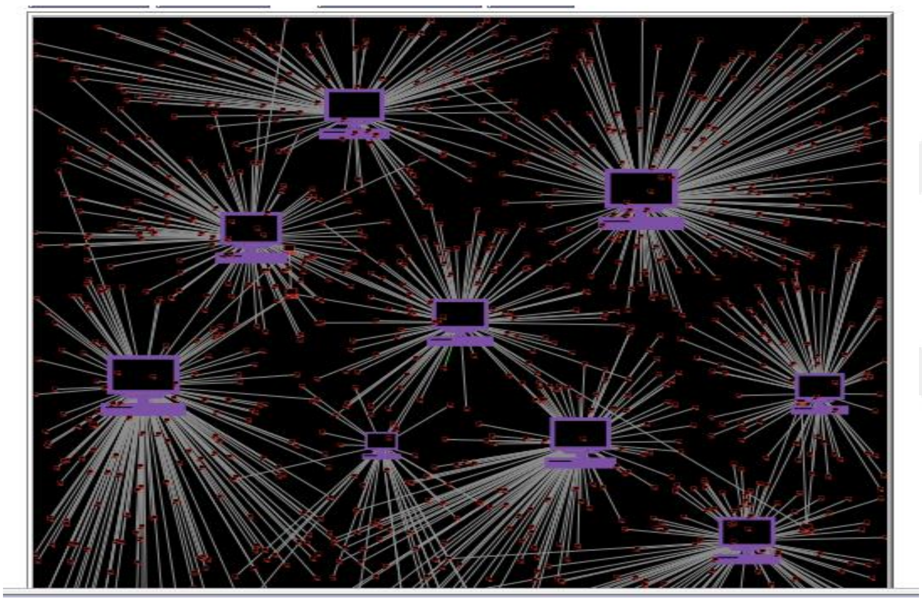


Figure 6.3 Topology of 1000 entities and 10 local worlds at $\boldsymbol{\alpha} = 6$ and the hub nodes shown in purple.

The models that uses multi-local world only has the limitation of being random attachment while the real network is bound to the topology choice for a given application; also the pure HOT model assumptions a single local world which does not consider the choice of a core nodes connected to be connected. Therefore, are barely justifiable within the network generation principles. Another limitation in literature is the inability to realize power-law distribution appropriately, which normally based on a given degree sequence. These render the model lacking in many ways and unable to have predictive power.

The model here attempts to create a topology that reflect the multi-local world and the design objectives making adding to the literature of the generative model. It starts with an arbitrary number of initial nodes, placed in a random position in the space, and subsequently the networks grow. The result is a topology of entities with power-law in node connectivity. This is shown in Figure 6.4. As the value of the parameter is critical in determining the behavior of the model, the Euclidean distances are not important, and star topology is formed as in Figure 6.2 when $\boldsymbol{\alpha} < \mathbf{c}$, where $\mathbf{c}$ is a constant depending on the region. For $\mathbf{c} < \boldsymbol{\alpha} < \sqrt{\mathbf{n}}$, the power law degree distribution is generated.

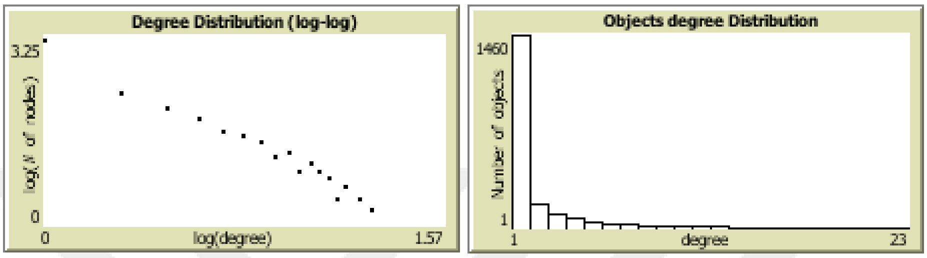


Figure 6.4 The degree distribution of 2000 entities, 10 local worlds at $\boldsymbol{\alpha}$ = 49.

6.3. The Cyberspace Tuple

The concept of cyberspace can be analyzed from different perspectives: its function, its structure and behavior, and our cognitive experience, which are complementary. In terms of its structural topology and behavioral dynamics, cyberspace is considered to have set of entities and their interconnection (links) (Jakobson, 2011).

The framework of cyberspace is then described by; (a) the number of layers (heterogeneous entities), and (b) Homogenous entities in a layer, defined by the set $L = \{E_1, E_2, E_3, \dots E_M\}$ where M is the number of layers assumed, such that $(1 \leq \mathrm{M} \leq 5)$, for now $M = 3$ i.e. three layers of cyberspace entities.. An entity in a layer will be affected by the interaction behavior of other entity in the same layer and will send/receive feedback to/from a relative entity from an immediate/subsequent layer.

The interconnection can be categorized using the following futures

a) Connectivity— whether entities are related, symmetric or asymmetric
b) Types of connection (homogeneous, heterogenous)
c) Order of connection (weight)

To have an instance of cyberspace, we have three possibilities; a snapshot of cyberspace topology at an instance of time, collecting and analyzing set of data (trace rout for example), or from the of rules which entities and their interrelations are founded. Viewed horizontally as a composition of networks, vertically as functional layers enabling platform upon platform development, cyberspace is seen from the later perspective. Thus, a different level of abstractions, which determined the granularity of the cyber entities, can be used. For instance, models of bits and how the dynamics and topology of electronic circuitry arise from intersections between micro entities, models of cyber objects and how the behaviors and/or topology of cyberspace resulted from their interaction, or the model of how a cyberspace can be characterized from less abstract modules that represent a complete subsystem.

Formally, therefore, four major classifiers to characterize the nature of cyberspace is used in this paper: topology, the rule set, initial configuration, and the constraint. These form the basis of the formalization in which the dynamic rule set is to be employed using automata theory.

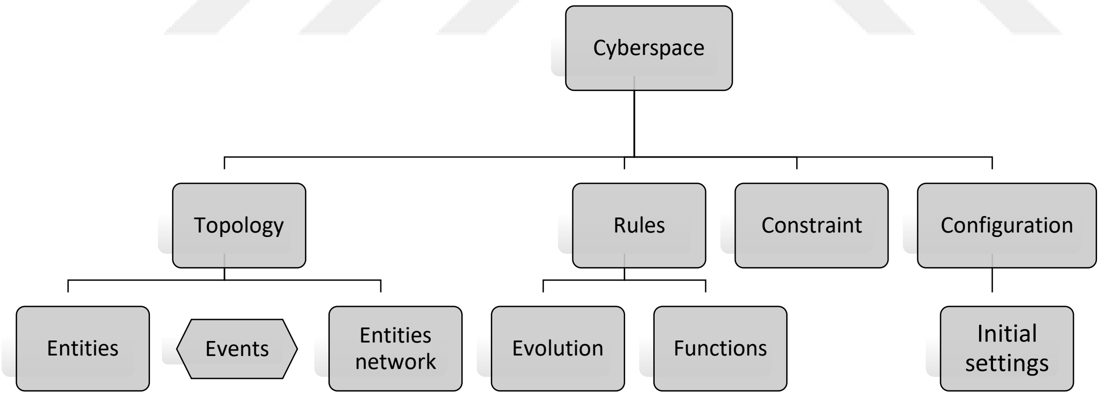


Figure 6.5 The cyberspace constructs.

Hence, Cyberspace is proposed to be defined as a four tuple: the set of microscopic rules, the topology, the configuration and the constraint. The topology which is also a tuple consisting of the precondition of cyberspace (entities and their network). The entities are defined by the layers. Their interconnection encompasses a set of relation between an entity. say, a source entity ($\mathbf{S_{k,\,i}}$) and another, say, the destination entity

($t_{m,\,j}$). Source entities are the set of entities which can initiate the exchange of information with the destination node. The set of rules are the topological evolution rules and functional dynamic rules. The information regarding the nodes and their interconnection (weight, link existence etc.) can be stored in an adjacency matrix, and the evolution function is regarded as the process that alter the element within this matrix. The dynamics depends on the topology because the topology evolves as some process take place on the network simultaneously.

Cyberspace (ℂ) as a tuple

ℂ = (T, ҩ, A, G)

Topology $\mathbf{T} = (\mathbf{L}, \boldsymbol{\mathcal{C}})$

Layers of Entity **L= {E_1, E_2, E_3…. E_K} ||L||=3**

Entities per layer **E_k= {$e_{k,\,i}$}** *ith entity in layer k*

The connectivity **C = {$S_{k,\,i} \rightarrow t_{m,\,j}$} 1≤ k, m ≤ K**

Source entity **$S_{k,\,I}$ = {$e_{k,\,i}$}**

Constraint

a) Each node connecting to some other node in the network

$$\sum_{i=1}^{i=1} y_{ij} + \sum_{j=i+1}^{N} y_{ij} \geq 1 \quad i = B+1, \ldots, N-1$$

Configuration **G (0) = {E(0), I(0), N(0) }**

Initial state of entities **E(0)**

Initial state process/activity **I(0),**

Initial local thresholds and neighborhood **N(0)**

Rules set ҩ = {er, nr}

er = Evolution rules

nr= Functional dynamics rules

Network of entities in cyberspace in general while design to be robust to perturbation of the designed principles are also vulnerable to other kind of perturbation. Every single unit is bound by the rules. However, the presence of feedback control loop, the system tolerate scalability while abiding by the constraints, ensuring robustness and reliability in functionality. As much as the system is robust to random failures, removal, and attack; it is equally fragile to targeted on highly connected components (Doyle-

Willinger et al., 2005). To understand these features, a perspective that integrate layering, rules and protocols is required. In essence, this may suggest that the robust, yet fragile behavior is a result of design choice and evolution rather than the connectivity of the graph itself.

To sum up, it can be stated that the formulated descriptions of cyberspace represents in satisfactory manner the basic networks topology and dynamics, as it conforms to the theoretical foundation of well-established disciplines and is able to illustrate the principles behind the network and produce the expected results with a simple simulation. Moreover, it can be noted that compared to the previous attempts such as the cyberspatial mechanics of Bayne (2008), our formulation has the advantage of having a multi-disciplinary approach, dynamic predictive power and turn out to be generic, although at the cost of being restricted and computationally demanding since we can only show some of the characteristics of networks.

CHAPTER 7

CONCLUSION

Cyberspace is inherently spatial, dynamic and time dependent. Its conception and usage are founded on its spatial features: Basically, as it produces unique space–time compression, or because it provides distinct spaces in which quiet range of relations thrive. In addition, its topology and dynamics are largely built on bases that often depend on spatial metaphors. Cyberspace has been conceptualized in many ways from different disciplines and approaches. However, none of the precious attempt formally characterize the domain, in a way that established a physics driven foundation. The dynamics, complexity, multidimensional and multi-disciplinary effects, explored in this dissertation, are what shape the characteristics of cyberspace. This approach reveals that cyberspace is exhibits features within and beyond many fields and thus existing disciplines can help formalized cyberspace. Based on the formulation and the results obtain it can be stated that:

- ✓ *A multi-disciplinary approach is required to formalize cyberspace.*
- ✓ *Cyberspace is occupied by discrete, identifiable entities, each within a spatial reference frame, and whose behaviors unfold in cyberspace.*
- ✓ *Graph-cellular automata can describe an integrated concept of cyberspace: graph theory and agent-modeling are the foundational formal tools for a sound topology and dynamics model respectively. Hence, a combined graph-cellular automaton formalized and describe entities dynamic and topology.*
- ✓ *Graph theory is the foundational formal method for a sound topology, and the dynamics required an agent-based modelling approach. Hence, a combined graph-cellular automata formalization as an agent-based model can describe entities dynamic and topology.*
- ✓ *Cyberspace is a manifold of cyberspatial entities, whose behavior unfold in cyberspace time with the topological interactions that are in turn governed by networking principles such as optimization rules driven by an information exerted and communicated among the entities.*

7.1 Cyberspace as Having objects with Structure and Behaviors

Our main findings and contributions can be summarized as below:

- We provide an extended survey and classification of cyberspace.
- Our survey on general cyberspace unifies the concept of cyberspace to a formal concept.
- We propose a unique graph-CA representation for the cyberspace dynamics.
- Provide an integration of highly optimized tolerance model and multi-local world model.

7.2 Open issues and Future research directions

Justifying the optimization approach in the formation physical entities of cyberspace, our simulation model does not claim to be exhaustive, rather explores the principles by which a network of cyber entities having important properties (Reliability/Robustness, Efficiency, Scalability, modularity and evolvability), which depend on objectives and constraints, can be defined. Even though the simulation is operational, it is not applicable to general entities networks. In addition, hierarchy of sub-networks is not explicit, and there are many abstractions made. Therefore, there are number of improvements that can be made in subsequent research such as:

- Investigate the relationships between distinct edges and nodes such as the core and terminal nodes.
- Develop further implementation of the distribution for general networks.
- Include other parameters characterizing the real network graph such as population density.
- Further development of cyberspacetime.
- Relativistic effect: Velocity of objects speed of light.
- Unification of cyberspatial reference frames.
- A model expressing the performance of cyberspatial objects.
- Inter-object integral distance.
- Further cyberspatial mechanics

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