

# Plato`s fractal production machine, Neuroscience and Social Theory

Heitor Matallo Junior

May 2021 (revised)

*“In everything there is a share of everything.”*

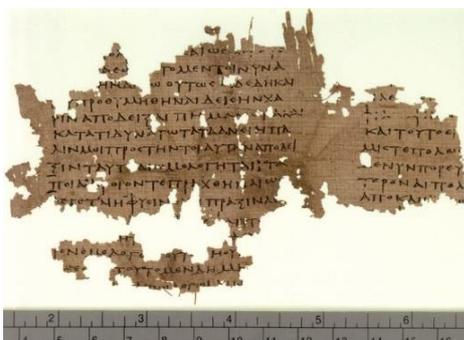
*Anaxagoras*

## Abstract

The objective of this article is to offer an interpretation of the utopian society described in Plato's Republic from a simplified theory of fractals. Plato conceptualizes his Republic as a static society in terms of structure and its components, the people, as having a behavior that can be programmed as linear and not dynamic (LNDS). Based on this analogy, real social functioning (NLDS) is conceptualized, applying the concept of fractal and its corresponding fracton, as the force of attraction that acts in social groups. Thus, social groups obey a fractal geometry, a geometry that reproduces the pyramidal shape, the apex being the crystallization of authority, power or leadership. Modern society, in analogy with Plato's Republic, is also a fractal production machine, replicating pyramid-shaped hierarchical structures and the respective fractons. Individuals are the basic unit of all these fractals. They are the building blocks of all groups at all levels of society. But replication is not self-similar due to fluctuations in cognition and behavior.

## 1. *The Republic* as a Fractal Production Machine

I owe this short paper to a comment made by Oded Busharian to my previous paper entitled *Fractals and Social Sciences: an introductory remark*. In the comment, Mr. Busharian mentioned that the paper reminded him about the Plato`s city-state as a collective person. After reading Busharian`s comment I revisited *The Republic* and started thinking about the Plato`s Utopia and how the perfect city conceived by Socrates should work and, most importantly, how to conceptualize the city-state in terms of fractal structure. It is not my intention to discuss in detail all the philosophical aspects of the *Republic*, but just to apply the fractal analogy to Plato`s Utopia with the objective of taking a step forward in relation to my previous paper mentioned above.



On the side, it can be seen a Plato`s Republic fragment dating from the 3<sup>rd</sup> century AD found in Egypt (P.Oxy. LII 3679). It is a coincidence that it looks like a fractal image. But it is not a coincidence that the city-state conceived by Plato is a fractal production machine. The Republic is, maybe the most perfect and clear situation whereby fractal theory shows its correspondence with a social and political structure. The Republic is a philosophical construction and will be used here as a case to discuss some concepts as education, social classes, and social mobility in the context of the fractal analogy.

The dialog conducted by Socrates in *The Republic*, starts with the conceptualization of two abstract ideas: Justice and Happiness (Books I and II). The narrative is structured having these two ideas as the guiding principles for the entire conception of the Utopian city of Kallipolis (the city of happiness). In principle, all republican citizens should be guided by and aware of these two concepts since these concepts define the status of each individual in the society.

As it is well known, the perfect society for Socrates is a system which organizes the three existing social groups as follows: a) The first-class citizens comprise magistrates and philosophers who are responsible for governing the city, since only they possess all the wisdom that the art of politics requires. The people of this group are expected to prepare themselves for fifty years exercising reason and acquiring knowledge and wisdom, b) the Second-class citizens comprises the soldiers who are aimed to protect the city and to ensure that all individuals follow the rules. They constitute the army and its auxiliaries in public administration, c) The third class of citizens would be dedicated to the most trivial activities related to the city's livelihood, such as land cultivation, handicrafts production, and commerce.

As mentioned in my paper (Matallo, 2021), fractals in society have an inner attraction force to keep stable the structure. The replication of the structure is ensured by the fracton<sup>1</sup> (common interests, ideology, values, retribution, authority, or a group/corporative culture). In the *Republic*, the division of labor expressed in the three categories as the main classes, implies the existence of predicates attached to individuals and the correspondent class. The perfect functioning of society requires that everyone performs the innate work he or she were born for, meaning, everyone born with unique nature, qualities and skills, and the right thing to do for the perfect society functioning is to keep attached to the respective class and working according to the qualities they were born with. The qualities also include the characteristics of the individual's soul. As mentioned by Jaegwon Kim (1998, 2), according to Plato "each of us has a soul that is simple, divine, and immutable, unlike our bodies, which are composite and perishable. In fact, before we were born into this world, our souls existed in a pure, disembodied state, and...., what we call "learning" is merely a process of recollecting what we already knew in our prenatal existence as pure souls". Therefore, philosophers and magistrates were born to run politics and the entire city through knowledge and wisdom. Farmers and handworkers were born to perform the livelihood activities and commerce, and soldiers were born to protect the city and prevent anyone to do something that it is not according to innate qualities.

The Republic is a hierarchical structure composed by three classes where in the top is the first class (magistrates and philosophers), in the middle the soldiers (responsible for protection and order), and in the bottom the third class (farmers, handworkers, merchants). The social classes are composed by a collection of individuals. This is a particular case where individuals can be considered as fractals since they must have its own fracton. Let's take an example: a carpenter or a farmer. Both have their own innate

---

<sup>1</sup> I choose to create the term "fracton" to refers to a set of common interests, ideology, values, retribution, authority, or a group/corporative culture, which reflects the coercive forces of groups. The concept used in chaos theory is "attractor", which has a specific meaning used in dynamical systems.

skills, their immutable souls, and they are expected to have self-consciousness about their own status in the social structure. Therefore, they cannot expect (or dream) to move to other position, to other class. In the *Republic*, education system is provided by the State and is used to help identifying the innate skills, the nature and quality of souls, and to positioning individuals in their appropriate class. Eventually, education is responsible for training, in particular philosophers, who need many years of learning mathematics and dialectics, which means to recollect what they already know as said Kim (1998) for ruling the government and public affairs. The Philosopher-king represents the totality of the city-state, is the best representant of the fracton, and is placed at the vertex of the structure. Once the individuals grow up, they should be prepared to perform their qualities and skills and to be aware of their status. No social mobility is recognized in the city-state. Mobility is the engine of social destruction.

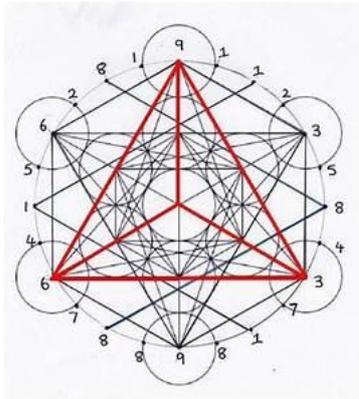
This is the Plato's fractal production machine. A low entropy society perpetuating social classes (three other fractals) through the production of individuals (also fractals) with their respective fractons. Individual's fractons mean be aware of their skills and position in the society, or saying with other words, not intending to be something that doesn't fit with innate qualities. Classes maintain themselves as such because of the values, such as justice and happiness sustaining the structure, as well as because of soldiers, who are trained for overseeing the entire system and to ensure that individuals will not succeed in changing status. The social class self-similarity replicates through individuals performing innate skills and avoiding social mobility. For Socrates, this is the perfect society living with justice and happiness. Plato's recursiveness is linked to a process of production of individuals under the same Fracton. It means that children will reproduce parents fractons. Exceptions will be identified by education system and, eventually children are trained for assuming other fracton, according to the inner skills identified.

*The Republic* is an ideal closed city-state invented by Socrates through Plato's writing, with no social mobility and, therefore low entropy. Considering the class structure, the governance rules, the role of soldiers in maintaining order, and the role of education in shaping individuals, we can follow Karl Popper (2011) and say that the proposed city-state is prone to totalitarianism. The political regime of Plato's Republic is a matter of controversy among philosophers. However, we can say that a system with no mobility, stable classes, rigid overseeing and education, and high level of awareness, produce self-similar individuals, no differentiation, and no conflict. This is what I call a fractal production machine. A machine that generates pre-ordered individuals without any perspective of changing position in the society. Self-similar fractons (adjusted for each class) are aimed to perpetuate the social system through individuals. We can say that the city-state works like a self-reproducing living organism, composed by other organisms as noted by Dirk Vanderbeke (see references).

According to what we discussed, Plato's *Republic* is a Linear and Non-Dynamic System (LNDS) in terms of its structure. The structure reproduces itself as a fractal machine producing individual fractals, (and the respective fractons) as self-replicant biological entities designed to accomplish the system's goals defined by the philosopher-king.

Therefore, the Republic is a LNDS because individuals behave as LNDS living organisms sharing one single fracton according to the social classes the individual belongs.

Assuming Plato's Utopia as a LNDS, we can refer to such kind of system as a totalitarian political order since the vortex of the entire society, understood as a pyramidal fractal, is occupied by the philosopher-king, representing the state, as the only source of authority which ensures the stability of the entire fractal system – classes and individuals - and the respective fractons related to the classes, which are shared by each individual of the same social class. In modern terms, the one direction information flow, a unique source of authority, concentration of power by a leader, rigid control of the state, and an armed force to service the leader are the basis of a totalitarian society.



But there is something else. Plato's conception has four elements: a) Society, the wholeness, and b) three classes. Using the geometrical platonic analogy, this configuration is the red tetrahedron in the side figure. Individuals would be inside the tetrahedron in the respective level. In the upper vertex is supposed to be the Philosopher-king. It is a complex figure but still linear since each element is in its own place and no move is expected to happen or, at least, no move in terms of classes.

It is interesting to notice that Plato's cosmivision associates the universe as made by five types of matter: earth, air, fire, water, and cosmos and each type of matter is also associated to a geometrical form. The Earth is associated to a cube. Gabor Domokos et alli (2020) conducted a research on the fragmentation of rocks and concluded that in average they end up as cubes. It seems that Plato was not wrong. In Domokos (2020, 18178) words, "We live on and among the by-products of fragmentation, from nanoparticles to rock falls, to glaciers to continents. Plato envisioned Earth's building blocks as cubes, a shape rarely found in nature. If you take three-dimensional polyhedral shape, slice it randomly into two fragments and, then slice these fragments again and again, you get a vast number of different polyhedral shapes. But in an average sense, the resulting shape of fragments is a cube". Still on the same, Domokos (2020, 18184) stresses out that "our findings illustrate the remarkable prescience of Plato's cubic Earth model. One cannot, however, directly "see" Plato's cubes; rather, their shadows are seen in the statistical averages of many fragments". This is another coincidence, that the Earth is a fractal made up of cubes, statistically speaking!

I mentioned (Matallo, 2021) that in a conflictive situation, different social fractals behave through replication and dominance and I've taken political parties as example. The Republic is a utopia based on fractal replication and cooperation, where fractons are not in conflict just because every individual knows exactly its position (and the respective fracton) in the social structure. Therefore, there is no space for conflict and fracton disputes. In a hypothetical situation where someone from the third-class for instance is looking for power aimed to run the Republic, this would open a conflict with

the first-class and the philosopher-king, and eventually would end up in a disruption of the entire society. In case that individuals, let's say farmers or merchants, want to actively participate in governance, replacing the philosopher-king or sharing his power, this would create an endogenous fractal conflict, creating a dispute for dominance (Matallo, 2021). It means that the conflict would be created inside the fractal (Individual versus social class in this case). However, political conflict and dispute are primarily fractal conflict and is partially or entirely solved through dominance, meaning, convincing, election, agreement, law enforcement, or brutal force in radical situations.

All these dominance elements can be used to keep the fractal configuration unchanged. In case a dissented idea emerges from an individual fractal (an individual conflict against the social class), the individual can convince others and create a different and conflictive fractal inside the previous one. The expansion of the emergent set of fractals (set of individuals) would establish a social conflict within the social class and a fight for dominance. This could make the social class to enter in conflict with other social classes and two options would be at stake: changing the Republic to other political regime (timocracy, oligarchy, or democracy, or tyranny), or to suffocate the conflict by the second-class soldiers and re-establishing the Republic's order (totalitarian society under the modern conception).

## **2. Society, Fractals and Non-linear Dynamic Systems**

Moving from utopia to real life, societies are not Linear Non-Dynamic Systems (LNDS) as assumed under Plato's conceptualization of the *Kallipolis*. Societies are primarily dynamic, non-linear, and changing structures (NLDS) where individuals look for differentiation and mobility, which make them the source and the engine of change and novelty. Societies and Individuals are both complex non-linear entities (Guastello, 2011), (Cloutier, see references). Because complexity is a universal phenomenon, non-linear properties accompany all complex systems at all levels, from individuals, family structures, groups, to communal, national, and global systems.

Fractals are everywhere in nature as well as in society and individuals (Taylor & Spehar, 2016). As mentioned by Claude Cloutier (see references), "the essential nature of our atoms, molecules, cells, organs, and higher-level structures all the way to the biosphere can be described in classical physics terms as fundamentally electromagnetic, electro-chemical, and/or electro-mechanical. These structures exhibit nonlinear dynamics and have fractal properties, particularly organisms".

Following Cloutier (see References), the NLDS is a property to be applied to all existing systems, from atoms and cells to global society. Societies and organisms share the same behavior as NLDS. Maybe it is not the case to consider society as organisms, as Spencer (1820 – 1903) did in his time<sup>2</sup>. The important thing to be recognized here is that when it comes to NLDS, all existing entities have the responsiveness and adaptability

---

<sup>2</sup> This could be an option to be better developed with contemporary eyes. The Spencer's organicism could be re-evaluated under the new social neuroscience developments. Maybe his thoughts are meaningful for modern social thinking.

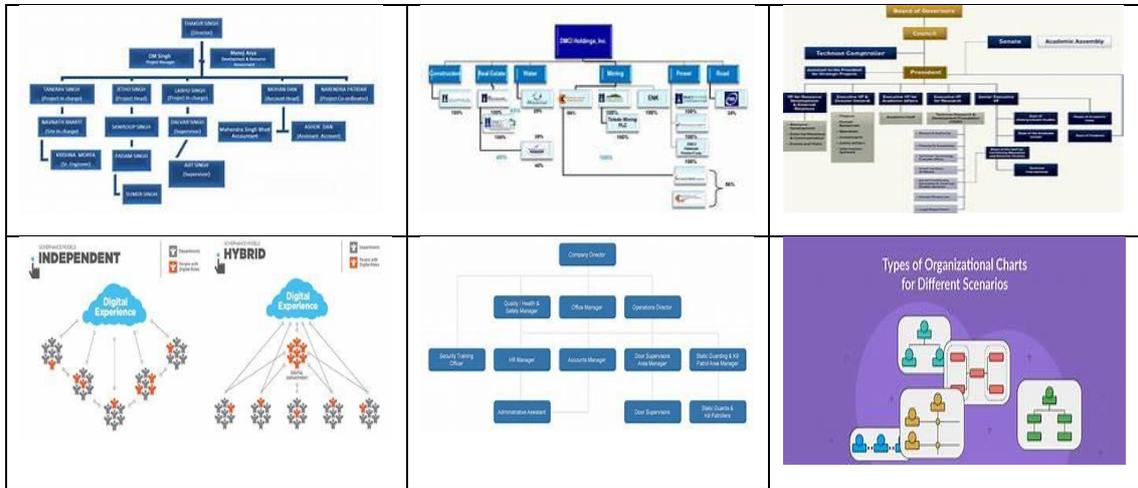
properties, and these things are not predictable, being nature, organisms, or society. The way responses are taken, and the course of adaptability are both not predictable.

As a general definition, a human society consists of a collection of people involved in a network of relationships, meaning that individuals and social groups (institutions, parties, trade unions, families, and other small groups) share a common culture, recognized by the members as part of the whole group, and perform a set of dynamic inter-relations and socio-economic and political processes, whereby individuals play a role according to their personal attributes and personalities as well as their acquired experience (Giddens, 2006; Lindsey & Beach, 2004; Farley, 1998). The network of relationships is embedded in a particular social structure. Individuals, social groups, society, also nations, are immerse in the surrounding environment which has no definite border, at least in modern western society. It goes from the immediate ecological environment to a rural or urban cultural group until the entire planet. Modern societies kept nation`s border but have surpassed their economic and cultural boundaries in almost all the cases. Even in environmental terms, there is no boundaries for the global environmental issues.

Understanding modern society according to our analogy means to consider individuals as fractals, inside fractals, inside fractals... . Individuals, family members, small group members (school, clubs, work, party), social class members, communities, and country affiliates. All these situations imply to share common basic values. In western democratic countries, the core global values are expressed by the so-called fundamental rights adopted in most countries. This is also called the "Rights Agenda". Right for education and health care, right of free expression at all levels, political, cultural, and religious, and economic freedom. These are the first level fracton in modern society (Devaney, 1990; Crossman, 2019). There are also institutions (which are also fractals) to ensure the prevalence of the main fracton in case some individuals or groups threaten it. The interesting thing here is what happens at the other levels of the fracton. Apart from the main attraction force (the main fracton), there are other different sub-level fractons, according to the subgroup individuals are voluntarily or compulsorily attached to. As in Plato`s Republic, modern society is also a fractal machine production, but with some key differences: societies are non-linear multi-systems. All the sub-systems are surrounded by external environment, where individuals are all under the same rule of differentiation and unpredictability, reproducing themselves as fractals inside fractals and all connected with several other fractals. It means that fractal reproduction through individuals and groups are ubiquitous.

From what has been said, one question immediately comes up: What is reproduced as fractal? The answer is: the pyramidal structure (Matallo, 2011). Every social group is based on authority, which are based on leadership, prestige, economic power, or social status attributed by knowledge or other predicate and all the mentioned predicates are distributed as a pyramid in the social structure. I took from Internet 6 images searching for "Models of institutions structure", "models of companies structure" and "models of social groups structure" and I choose randomly some images that can be seen below.

These images are examples of different organigrams, but all cases show the same logical model. The top manager in the vertex and the group members distributed in the various levels according to their respective role in the structure. Each level corresponds to a different level of power, prestige, status, and financial retribution.



Source: Google.

The prevalent geometry of these structures is pyramidal and follow the Domoko's cubes conception (Domoko et al., 2020), meaning that statistically speaking they are pyramidal structures. In all of them the vertex concentrates the power and the representation of the fracton. Other levels are responsible to ensure the transmission of the fractons and this is an important characteristic of the structures. The fact that they must disseminate the fracton. However, the interpretation of fractons is not homogeneous. There are interpretative fluctuations, leading individuals to differentiating themselves and establishing instability inside the fractal. This is due to differences in the adoption of values, ideologies, ideas, or interests by individuals. Finally, the fractal production machine in modern societies generates similar but not equal fractals (individuals). Individuals are different in personality, and cognition, and learning skills, which means that they react differently to social situations (Prigogine, 1984; Wheatley, 1994).

The fractal reproduction happens under the signal of fluctuations. This is a changing mechanism leading to individual differentiation and, therefore, to new possibilities for fractal differentiation. Individual fluctuations cause social systems to respond and eventually lead to an accumulation and growth of such fluctuations, causing macro changes or even disruption in the structure and eventually the emergence of a new higher order, particularly in institutional situations (Csanadi, 2004).

Fluctuations in Individual's brain<sup>3</sup> do not exist out of social structure, and, at the same time, social structure is shaped by how creativity, learning and memory perform in

<sup>3</sup> There is a long and length discussion about the differences between brain and mind. The scope of this paper does not allow such kind of discussion. For our purposes here, both brain and mind will be considered as performing the same things, meaning, the activities comprising perception, cognition, and learning. One possible difference between both is: Brain is a conglomeration of nerves, cells, blood vessels

individual mind. Social structures are open to the environment, information processing, and matter (Csanadi, 2004). They are dissipative systems whereby fluctuations are a key element for the emergence of new levels of complexity and order (Van de Leeuw, 2020).

At individual level, brain is designed for keeping uninterrupted feedback between perception, cognition, and learning (Mind attributes). This is the foundation of information flow, knowledge, and human activity. The cycle starting with perception of the external world, going to cognition, and then leading to learning, is the genesis of fluctuations. At the same time, there is no way to predict the brain response to any kind of external stimuli, and as consequence, a certain level of uncertainty is integral part of human behavior and response to the social systems at all levels (small groups or the society as a whole). As mentioned by Skarda and Freeman (1990), “the brain is a chaotic system, intricately related by internal feedback that must be analyzed. Small internal uncertainties are amplified over time, making long term predictions of brain activity impossible. Furthermore, its chaotic activity creates new solutions, an internal process critical to learning”.

The emergence of the theoretical features relating genetics and social structures and how they can influence each other (Harmon-Jones & Winkielman, 2007) is a new challenge to social sciences in terms of the scope of its subject as well as its explanatory capacity. According to this new scientific branch, nature (environment), individuals, groups, and the entire society have a multifractal behavior (Cloutier, see References), (Lipton, 2020), (Persaud and O’Leary, 2015), (Taylor & Spehar, 2016). All these mentioned entities are complex systems which are in some way connected and influencing each other. The acceptance of this multi-level complexities (Morales & Delgado-Gracia, 2015) originated the new scientific branch of Social Neuroscience (Cacioppo & Berntson & Decety, 2010, Harmon-Jones & Winkielman, 2007). As pointed out by Cacioppo and associates (2010) “Social neuroscience seeks to specify the neural, hormonal, cellular, and genetic mechanisms underlying social behavior, and in so doing to understand the associations and influences between social and biological levels of organization”.

Modern society is a fractal production machine system, replicating hierarchical pyramidal shape structures and the respective fractons. Individuals are the basic unit of all these fractals. They are the building blocks of every group at every level in society. But replication is not self-similar due to what has been mentioned earlier, the fluctuations in cognition and behavior. The linkage of individuals to a particular sub-group (formal or informal) means that the person has a specific way to bond to these sub-groups in terms of adaptability and this means differentiation. Individuals are marked by differentiation and adaptability in terms of responses and these characteristics has to do with brain development (Royce, J. R. & Powel, 1983).

Social structure is a set of all-connected fractals (individuals, families, social classes, working groups, clubs, army, etc) with their respective Fractons. Fractons change due to

---

and the like. Mind is a conglomeration of thoughts, memories, emotions, and the like (<https://www.differencebetween.com/difference-between-mind-and-brain/>)

the interpretative and behavioral individual fluctuations as well as due to collective fluctuations and the conflictive and/or competitive nature of fractals relationships in society. Competition for resources, energy, and matter (Prigogine, 1984) are the driving forces for change at global level and individual brain fluctuations are the driving forces at micro level. Brain, as the rest of the human body, is fractal in nature, therefore unpredictable. It is influenced by the external environment and the social structure. The tri-components – environment, social structure, and brain - is subject of epigenetics adaptations. As mentioned by Bello-Morales & Delgado-Garcia, 2015, “epigenetics has been considered as the climax in the process of “socialization” of biological and neurobiological concepts as well as the last frontier in the development of a narrative about the sociality of the brain, and the discovery of a mechanism mediating between environmental exposures, gene expression and neuronal development”.

This is an overly complex issue to be considered in this short paper. But it has a heuristic potential and should be explored in the future. Maybe the next step should be deepening the research on the tri-above-mentioned issue (environment-social structure-brain) under the epigenetics general idea and the concrete role neuroscience play to understand some concrete situations in society. I think that it is possible to find historical situations where this approach could be tested and perfected. I started the paper considering Plato`s Republic as our subject. But *the Republic* is a hypothetical situation invented by a philosopher more than two thousand years ago. It is time to take a step forward and consider concrete historical situations to test the appropriateness of the analogy, in particular in those situations whereby totalitarian order is running or is a concrete possibility due to economic and political circumstances. I hope this paper could inspire some further research on this topic.

## References

Bello-Morales, R. and Delgado-García, J.M. (2015). The social neuroscience and the theory of integrative levels. Front. Integr. Neurosci. 9:54.

Cloutier, C. (no date). Non-Linear Dynamical Systems (NDS) Exploration of the Fractal Nature of Binary Conflict in Human Systems, retrieved from <https://fielding.academia.edu/ClaudeCloutier>

Crossman, A (2019). Chaos Theory, Retrieved from <https://www.thoughtco.com/chaos-theory-3026621>

Csanadi, M. (2004). A comparative model of party-states: the structural reasons behind similarities and differences in self-reproduction, reforms and transformation, KTK/IE Discussion Papers 2004/7 Institute of Economics Hungarian Academy of Sciences, Hungary.

Domokos, G., Jerolmack, D. J., Kun, F., Török, J. (2020). Plato’s cube and the natural geometry of fragmentation, PNAS August 4, 2020, 117 (31) 18178- 18185;

Elżbieta Gabryś, Marek Rybaczuk, Alicja Kędzia. Fractal models of circulatory system. Symmetrical and asymmetrical approach comparison in Chaos, Solitons & Fractals Volume 24, Issue 3, May 2005, Pages 707-715.

Farley, J (1998). Sociology, Prentice Hall, Upper Saddle River, New Jersey. USA

Gabrielle Lipton, The fractal nature of almost all things, retrieved from <https://news.globallandscapesforum.org/43195/fractals-nature-almost-all-things/>

Giddens, Antony (2006). Sociology, Polity Press, Cambridge, UK.

Gleick, J. (1997). *Chaos: Making a New Science*, Penguin Books, NY.

Guastello, S. (2011). Nonlinear Dynamical Systems Applications to Psychology and Management, in The SAGE Handbook of Complexity and Management. Eds. Peter Allen, Steve Maguire and Bill McKelvey. Los Angeles: SAGE Publications <https://doi.org/10.1073/pnas.2001037117>

Harmon-Jones, E. & Winkielman, P. (2007). A Brief Overview of Social Neuroscience in Social Neuroscience: Integrating Biological and Psychological Explanations of Social Behavior, Edited by Eddie Harmon-Jones and Piotr Winkielman, Guilford Publications, NY.

Jaegwon Kim (1998). Philosophy of Mind. Westview Press A Subsidiary of Perseus Books, L.L.C, NY. USA

John T. Cacioppo, Gary G. Berntson, Jean Decety (2010). Social Neuroscience and Its Relationship to Social Psychology, in Social Cognition, Vol. 28, No. 6, pp. 675–685

Karmeshu, V. P. Jain (2003). Non-Linear Models of Social Systems, Economic and Political Weekly, Vol. 38, No. 35, pp. 3678-3685 (8 pages), Economic and Political Weekly (<https://www.jstor.org/stable/4413965>).

Kersgaard, E. (2020). *How fractals are the building blocks of systems from the galaxy to society*. <https://medium.com/illumination/lifes-universal-patterns-e534475aabf6>.

Linda Lindsey & Stephen Beach (2004). Sociology, Prentice Hall, Upper Saddle River, New Jersey. USA

Mandelbrot, B. (1983). *The Fractal Geometry of Nature*, W.H. Freeman and Company, NY.

Merton, R.K. (1949). Social Theory and social structure.

Parsons, T. Social Structure and personality.

Persaud-Sharma D. and O'Leary J.P.(2015). Fibonacci Series, Golden Proportions, and the Human Biology. Austin J Surg. 2015;2(5): 1066.

Popper, K. R. (2011). The open society and its enemies, Routledge Classics, NY. USA.

Prigogine, I. & Stengers, E. (1984), Order out of chaos, Bentam Books, New York.

Richard P. Taylor and Branka Spehar (2016). Fractal Fluency: An Intimate Relationship Between the Brain and Processing of Fractal Stimuli in The Fractal Geometry of the Brain Springer, Germany.

Royce, J. R. & Powel, A. (1983). Theory of personality and individual differences: Factors, systems and processes, Prentice-Hall, New Jersey.

Skarda, Christine A. and Freeman, Walter J. (1990). Chaos and the New Science of the Brain in Concepts in Neuroscience vol. 1, no. 2 p275. March 1990.

Turner, J. (2013) Theoretical sociology, SAGE publications, USA

Van der Leeuw, S. (2020). Social Systems as Self-Organizing, Dissipative Information-Flow Structures. In *Social Sustainability, Past and Future: Undoing Unintended Consequences for the Earth's Survival* (New Directions in Sustainability and Society, pp. 144-156). Cambridge: Cambridge University Press.

Vanderbeke, D. Of Parts and Wholes: Self-similarity and Synecdoche in Science, Culture and Literature, retrieved from Academia.edu.

Warnecke, H. & Hüser, M. (1993). *The Fractal Company: a Revolution in Corporate Culture*, Springer-Verlag, Berlin.

Wheatley, M. (1994). Leadership and new science: learning about organisation from an orderly universe, Duke University Libraries, San Francisco.