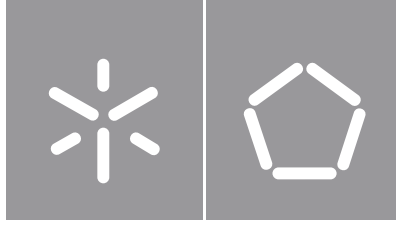


Universidade do Minho
Escola de Engenharia

Pedro José de Araújo Pinheiro

Organizations Diagnosis as Complex
Ecosystems



Universidade do Minho

Escola de Engenharia

Pedro José de Araújo Pinheiro

Organizations Diagnosis as Complex Ecosystems

Doctoral Thesis

Doctoral Degree in Industrial and Systems Engineering

Thesis supervised by

Professor Doctor Goran D. Putnik

STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

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“Everything flows and nothing abides;

Everything gives way and nothing stays fixed.”

Heraclitus

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To my friends.

To my enemies.

Organizations diagnosis as complex ecosystems

Abstract

In highly complex ecosystems, organizations face constant uncertainty where classical management theories prove inadequate. Time and space are interconnected transforming the context and changing life in organizations. Organizations must accept working in networks to overcome adversity, view complexity as an advantage, and transform their behavior into new realities.

After the spread of the Internet and Globalization technologies such as artificial intelligence re-emerged, driven by Cyber-Physical Systems and Industry 4.0, the global entropy of organizations increases if there are no dissipation processes.

Entropy dissipation processes require open systems and, consequently, motivate self-organization processes. Despite the increasing complexity and the dichotomy between redundancy and variability, organizations must present periods of stability revealing self-organization. Therefore, the Thesis assesses the hypothesis that entropy in the interactions of members of an open network organization reaches a value, showing the process of self-organization. However, considering the incompleteness of the entropy, a new hypothesis emerges in the study of self-organization. It tests whether the interactions of members of a complex open network may not follow a pure power law distribution throughout the open network hierarchy while maintaining self-organization.

Two case studies allow the validation of the previous hypotheses: The Arduino Forum network, between 2005 and the end of 2022, and the EEVblog Forum network, between 2009 and the end of 2022. In the analysis of the interactions of the members of these two open networks, the entropy values were stable between 2015 and 2022, in the case of the Arduino, close to 0,7, and between 2010 and 2022, in the case of EEVBlog, close to 0,75. The assessment of the second hypothesis involved developing a formula to examine the stability of one variable. The variable k remained close to 25 in the Arduino between 2015 and 2022 and in the EEVBlog between 2010 and 2017. In the EEVBlog k rose to close to 30 between 2018 and 2022.

KEYWORDS

Complexity, Entropy, Open systems, Organizations, Self-organization

Diagnose de organizações como ecossistemas complexos

Resumo

Em ecossistemas altamente complexos, as organizações enfrentam constantes incertezas e onde as teorias clássicas de gestão se revelam desajustadas. A interligação entre tempo e o espaço transformam o contexto e mudam a vida nas organizações. As organizações devem aceitar trabalhar em rede para superar as adversidades, encarar a complexidade como uma vantagem e transformar o seu comportamento em novas realidades.

Após a disseminação da Internet e da Globalização, o reemergir de tecnologias como a inteligência artificial, impulsionada pelos Sistemas Ciber-Físicos e pela Indústria 4.0, aumentará a entropia das organizações se não existirem processos de dissipação.

Os processos de dissipação de entropia requerem sistemas abertos e, consequentemente, motivam processos de auto-organização. Apesar da crescente complexidade e da dicotomia entre redundância e variabilidade, as organizações devem apresentar períodos de estabilidade revelando auto-organização. Assim sendo, a Tese avalia a hipótese de que a entropia nas interações dos membros de uma organização em rede aberta atinge um certo valor, evidenciando o processo de auto-organização. Porém, considerando as lacunas da entropia, surge uma nova hipótese no estudo da auto-organização. Ela testa se as interações dos membros de uma rede aberta complexa podem não seguir uma lei de potência pura em toda a hierarquia da rede aberta, conservando a auto-organização.

Dois casos de estudo permitem a validação das hipóteses anteriores: A rede Arduino Forum, entre 2005 e o final de 2022, e a rede EEVblog Forum, entre 2009 e o final de 2022. Na análise das interações dos membros destas duas redes abertas, os valores de entropia mantiveram-se estáveis entre 2015 e 2022, no caso do Arduino, próximo de 0,7, e entre 2010 e 2022, no caso do EEVBlog, próximo de 0,75. A avaliação da segunda hipótese envolveu a criação de uma equação para examinar a constância de uma variável. A variável k manteve-se próxima de 25 no Arduino entre 2015 e 2022 e no EEVBlog entre 2010 e 2017. No EEVBlog k subiu para perto de 30 entre 2018 e 2022.

PALAVRAS-CHAVE

Auto-organização, Complexidade, Entropia, Organizações, Sistemas Abertos

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1. Introduction

1.1. Motivation

This thesis investigates the implications of traditional organizational management models, where hierarchical, closed structures that seek to increase efficiency in a hypercompetitive context prevail, compared to open organizations where participation in a complex network of relationships is promoted through dialogue and collaboration.

The organization has been defined in a number of ways. Organization can be defined as a group of individuals who cooperate towards a common goal with the direction of a leader (Davis, 1940); or it can be described as a system of consciously coordinated personal activities or forces (Barnard, 1968).

Despite the efforts, organizations in the face of crises tend to fail, because organizations do not create the crises they face, crises only arise in the face of them (Mitroff, 1988), so other alternative management models to the traditional ones (which idolize efficiency) should be considered. Building an efficient organization is inevitably slow and sometimes costly (Taylor, 1913). In complexity, organizational crises are points of bifurcation of systems or radical disruptive changes where the direction, characteristic, and/or structure of the system deviates from what was anticipated. Crises are natural phases in the development of systems that can lead to a higher level of system operations (Seeger, 2002).

The uncertainty caused by crises is not only related to quantum mechanics. Although uncertainty is the opposite of the purpose of organizations, attempting to reduce uncertainty by increasing rationality increases the organization's energy consumption to achieve certainty (Thompson, 1967). Uncertainty cannot be analyzed only as something undesirable, but as a possibility for change. With each new limitation that arises, new proposals emerge and old ones are abandoned (Barnard, 1968). In this sense, one should not accept the perspective that rationalization – which many authors associate with efficiency – and stability are virtuous characteristics of organizations, when, in fact, they can restrict change, creativity and innovation.

One measure of uncertainty is entropy. Entropy measures the variability of a system's variables. In organizations, this variability is related to the diversity of variables and the connections made between them. For organizations that desire rationality, uncertainty represents darkness and the undesirable

because it creates a series of problems that threaten the organizational order (Shenhav, 2003). However, there are systems, both physical and social, that are clearly described through a finite set of conditions or rules and yet are unpredictable (Cartwright, 1991). For example, the laws of thermodynamics don't fit social organizations because they tend to see systems as closed. Social systems are open and can spontaneously develop into states of greater heterogeneity and complexity (Bertalanffy, 1950). Self-differentiating (or self-organizing) systems that evolve to greater complexity (by decreasing entropy) are, for thermodynamic reasons, possible only as open systems (Bertalanffy, 1968).

Predictability is one of the references of classical management theory and is based on the ability to predict and control the organization. However, the main assumption of complexity is the collapse of the predictability of dynamical systems, where non-linearity makes it impossible to discover the effects caused by change (Lichtenstein, 2000). For example, to simplify, schools offer fixed restrictive programs, or hospitals try to anticipate uncertainty and complex fluctuations in demand (Dooley, 2002; Thompson, 1967).

Simplification becomes an artificial and dangerous tendency. The group effect is not the sum of individual recollections, and organizations stand out during the collaborative process (Weldon & Bellinger, 1997); It is not "because every man is a biped, fifty men are not a centipede" (Chesterton, 1910). The most distinctive part of our (capitalist) economic system is the growth of human knowledge. Without it, one can only aim for adversity, manual labor, and poverty except for those whose income comes from poverty (Schultz, 1961).

The organization behaves like a society or a living organism, and notions such as wholeness, growth, differentiation, hierarchical order, dominance, control, and competition do not appear in conventional physics. Although systems theory is able to deal with these issues, such an approach can culminate in totalitarian states where the human is insignificant (Bertalanffy, 1968).

Despite technological advances, the evolution of knowledge and scientific discoveries, organizations find it difficult to accept change, justifying themselves with rationalization, control and efficiency, and reject a significant part of the system's potential: the human factor, which is imperfect but irreplaceable. The way human beings process information and think, the way they deal with complex problems are crucial qualities for organizations. Large organizations that involve a high level of diversity, uncertainty, or complexity must inevitably have decentralized management (Argyris & Schön, 1978).

Organizations are designed to create stability, predictability, and standardization, and management authority is revealed in the reduction of uncertainty (Shenhav, 2003). However, organizations are

ecological systems, due to the complex and uncertain feedback between the different elements of the system that make up its context, the failure of one element can cause a catastrophe (Levinthal, 1997). Only action and responsibility, through knowledge and freedom, allow us to learn, adapt, collaborate and create organizations prepared to deal with uncertainty and complexity (Bennet & Bennet, 2008). Leaders must allow disruptive patterns that create controversy and encourage novelty through experiences that support collective action (Lichtenstein, 2000).

It is common to find studies on complex adaptive systems, often referred to as “complexity” in the scientific community (Hock, 1995). These concepts are similar to those promoted by Chaordic Systems Thinking (CST), whose principles stimulate the creation of novelty in production systems (van Eijnatten, Putnik, & Sluga, 2007). In organizations, change must be discontinuous, but development efforts are rather reformative than transformative (van Eijnatten & Putnik, 2004). This behavior can create problems adapting to an ever-changing context.

Chaos should not be understood only as disorder. Chaos is an “invisible” order. Chaos is not the result of noise or insufficient knowledge. The beauty of chaos theory applied to management lies in the integration of restlessness between order and disorder, certainty and uncertainty, calm and turbulence (Cartwright, 1991). Considering that predictions for the distant future are virtually impossible for chaotic, dynamic, and evolving systems, because drastic changes can happen unexpectedly, flexibility and adaptability are imperative for the survival of organizations (Levy, 1994).

One of the most important aspects of the chaos and complexity approach is the “holonic characteristic”, i.e., the characteristic of humans acting in the system, which makes them inseparable from the system itself. Thus, the observer and the observed are one, and the same dynamic complex system (van Eijnatten & Putnik, 2004). An organization cannot be seen as a stable structure, but part of a dynamic process (Putnik & Putnik, 2010).

Where there is practical application of knowledge, incentives for interaction and collaboration, deviations are observed as opportunities, and failures as possibilities to learn and improve (Krusche et al., 2017). In these processes, knowledge must provide a continuous readjustment of the organization, with dynamic routines and meta-learning, to build competitive advantages (Lei, Hitt, & Bettis, 1996). Organizations need continuous reorganization because they operate in conditions in an adaptive society, and the larger and more complex the institutions, the more dependent they are on the unequivocal cooperation of all members of the group (Mayo, 2004).

Groups create, through knowledge, an original basis and a higher unity of consciousness that determines their identity (Assmann & Czaplicka, 1995). Knowledge is disseminated through networks of relationships and norms. An infrastructure that facilitates this phenomenon has a positive impact on the effectiveness of the organization (Gold, Malhotra, & Segars, 2001). The main source of value creation in organizations is in informal processes, dialogues, brainstorming and collecting ideas. Formal processes in organizations are important, but they contribute to value creation to the extent that they are in service of informal processes. The rules of participation in education and learning systems are different from the product market and cannot simply compete (Wenger, 2000).

Given the previous arguments, this thesis intends to contribute new knowledge about open organizations' management through Complexity Theory.

1.2. Objectives and Hypotheses

Considering Bertalanffy (1950, 1968), it is intended to evaluate whether open organizations have the propensity to form a complex self-organized system. In this evaluation, the variation of the entropy of normalized Shannon information is used, for 3 reasons: 1) The instantaneous value of entropy may be due to external factors of context and not inherent to the organization; 2) The extensive property of entropy continuously increases the value of entropy with an increasing number of variables or boundaries of a system; 3) No entropy value declares the self-organization of a system because self-organization can be observed in different organizational structures.

In organizational structures, normalized entropy represents total order (when entropy is equal to zero) and total disorder (when the entropy value is one). Since these two extremes seem to be impossible, and like any non-random distribution that implies the organization of a hierarchy, two questions arise: 1) Is there a limit to the evolution of the entropy of a network? and 2) if it is true that this limit exists, does this indicate the presence of self-organization in the open design structure? To verify the previous questions, two hypotheses are posed:

Despite the increasing complexity of production systems and the dichotomy between redundancy and variability, production systems must present periods of stability. Considering that entropy considers redundancy and variability, some hypotheses arise:

Hypothesis 1:

There is some entropy value in the interactions of members of an open network revealing periods of stability and indicating self-organization.

Since the variation in the entropy production (dS) of an open network is the sum of the entropy of the internal production of the network (dS_i) and the entropy flow with the outside of the network (dS_e), and considering that the internal entropy (dS_i), according to the second law of thermodynamics, is always greater than zero, the stability of the system's total entropy production depends on the dissipative structure provided by the network's surroundings (I. Prigogine & Lefever, 1975). Periods of stability in entropy production values in an open network may be a consequence of the self-organization process.

Hypothesis 2:

Interactions of members of complex open networks may not follow a pure power-law distribution throughout the entire network hierarchy while maintaining self-organization.

1.3. Thesis Structure

To answer the research questions proposed above, this thesis, after this introduction, presents from Chapter 2 to Chapter 5 the state of the art and some original contextual contributions, and Chapter 6 and Chapter 7 present the proposed models to diagnose the organizations and validate them, respectively.

Therefore:

Chapter 2 reveals the intrinsic concepts of organizations.

Chapter 3 introduces the precepts of the classical management of organizations, historically framing the economic, social, and technological developments that determined the context in which organizations subsisted. In this chapter, management approaches that emerged after the Second World War are recalled. This period is chosen because, in scientific terms and after the discovery of quantum physics, relevant areas such as game theory, cybernetics, information entropy (also called Shannon entropy),

and artificial intelligence, emerged or stand out, which have changed the management perspectives of contemporary organizations.

Chapter 4 shows complexity as an alternative to traditional management models focused on efficiencies and uncertainty control

Chapter 5 exemplifies how some mathematical concepts can be wrong when they ignore context. It should be noted that all models of organizational management include uncertainty, and that any attempt to control it can be counterproductive. In any closed system, by the second law of thermodynamics, entropy tends to increase.

Chapter 6 describes a proposal for models for the diagnosis of organizations. This assessment considers both complexity management methods and classical management methods.

Chapter 7 includes the evaluation of the research hypotheses set out in this introduction. The examples of the open network formed by the Arduino forum, between 2005 and 2022, of a network that sustains the Arduino program on GitHub, between 2008 and 2021, and of the network formed by the EEVBlog forum, between 2009 and 2022, are used. The dependencies of hierarchy on the efficiency of organizations are also shown. In this assessment, the formulas and concepts described in Chapter 6 are used.

Chapter 8 presents the conclusions and proposals for future work. At the end are the bibliographic references and annexes.

2. Organizations

Organizations are embedded in ephemeral contexts.

Newton's mechanistic analysis was originally concerned with individual systems, which under the action of a certain number of forces are influenced to have certain behaviors, velocities, moments, and accelerations. Generally, this type of analysis is proficient in macro and singular analysis. However, organizations have become specialists of specialists, where the single “generalist” system has become an intricate network of relationships, where each part has a dynamic and uncertain momentum, which prevents it from being determined with the exact distribution of the positions and moments of the system. In addition, we have the second law of thermodynamics and quantum mechanics.

Homeostasis, essential for the existence of any organization, with return channels that prevent oscillations that compromise the balance of the system, keeps the “temperature” within adequate standards. If it were possible to maintain subsistence in some closed system, the organization would depend only on its internal stability, within known limits, with a limited number of constituents. No living system has this ability, not least because there is no permanent generation of Big Bangs. We may not know what started the phenomenon, we may not know part of its manifestation, but we will certainly know its consequences.

2.1. Sociology and organizations

Sociology in organizations emphasizes the production and use of human beings as a source of business. In business, tokenism dominates, revealing that the organization is dependent on symbolism, expression, or interpretation through symbols (tokens), where the manager must have the ability to recognize and master them.

In the sociology of organizations, social thermodynamics and, namely, social entropy, “is a constellation of troubles that a heterogeneous and changeable society” (Bardach, 1977) requires administrators subject to the responsibility of rules to participate in the management game (Bardach, 1977). Social entropy, part of a social game, reveals to the manager that “democracy, as many executives learn, is a lot more fun when you’re going up than when you get there” (Whyte, 2002).

The sociology of organizations unfolds in a dynamic in which flows of events tend to fill time and space. There are no temporal absences that prevent the flow from existing. The non-existence of any event does

not reveal any permanent balance that legitimizes social immobility. If that happened, entropy would extinguish the system. Comte (1875) proposed that “social dynamics” be studied beyond the simple “social statics” that sociology previously named. Thus, he suggested “positive philosophy” as the only correct way of understanding the phenomena that evolved from stages of balance and order (social statics) and progress (social dynamics).

Contrary to “positive philosophy”, which argues the production of the greatest quantity of happiness by the individual, Spencer (1851) considered that this production of happiness depended on the will of others. By proposing social statics and dynamics, Comte projected the balance and determinations through which society advanced toward perfection, consequently legitimizing the extermination of the weakest. In organizational terms, positive sociology, according to Herbert Spencer, limits the happiness of a majority in favor of a particular group.

Pareto (1919) agreed with the proposal of Comte and added the concept of an elite, descendant of an aristocracy, which derives from the Greek *ἀριστος* (aristos) and means great, excellent, or better, i.e., which designates a power that has characteristics that stand out. This idea of the elite does not qualify the goodness of the group to which it belongs and can be related to any species, from thieves to benefactors, it only reports a “set of qualities that favor the prosperity and domination of a class in society”. For Pareto, although this elite prospers in all societies and governs them, even in the broadest democracy, they are not sustainable but in permanent renewal, a phenomenon that he classified as the “circulation of elites”.

The expression “social mechanics”, in addition to being used in physiology and economics in the 19th century, also appeared in sociology. As examples, we have the works of Draper (1878), “Human Physiology, Statistical and Dynamical”, and Andrews (1881), “The Labor Dollar”.

Draper (1878) observes that amidst the automatism that generates structural metamorphoses, there are glimpses of free will that intervene in the connection between structure and habit, even though most actions within the same species are similar. Recognize the republican propensities of ants or the monarchist life of bees; identify the particularities of a polygamous bird in comparison to an annual or eternal monogamous species; realize that buffaloes enjoy the company of their species, while lions do not tolerate competition; reveal that faced with the effect of an external presence, they immediately stimulate the habit of a specific animal attitude and an internal influence dependent on its species, that is, for example, its organization.

According to Andrews (1881), an essential external influence on human organizations is the political economy that creates and appropriates wealth. At this point, the social mechanics of political economy require the precise establishment of the meaning of work. Without this rigor, work is not a scientific magnitude, there are no certainties, and if any energy is expended, as in physics, inconsistent with the organizational purpose, everything is work.

Andrews's idea placed money as a core element in the external influence of any human organization but rejected the monetization of affection. This social mechanics was shared by Pareto (1897, 1917a) when he advocated the social system as a dynamic phenomenon made up of molecules. The term social molecules instills the idea of parts that make up a whole and express the existence of biological agitation.

Hamilton (1999) does not deny the predominance of economic egocentrism in human relations, which does not alter the concept of human nature and which is directly related to the classical idea of social organization, where society is a composition of separate social molecules such as workers, capitalists, and owners. But, in each of the three groups, a system of values is created where individual hedonistic propensities, characteristic of Newtonian mechanics, are altered by external factors such as population growth or technological evolution.

This economic description of sociology, in which people become dependent on money to compete for status, to achieve a social position, to survive, and so forth, converts sociology into a digital mechanism where ambiguities dissipate into the best uplifting result of egocentrism. The risk of sociology simply pointing to the ophelimity proposed by Pareto, in the restrictive senses of value and utility, builds a system that simplifies living organisms into automatons, purely digital, as modeled by von Neumann (1951). However, Neumann noticed that this type of modeling was an excessive simplification of living systems that, in addition to digital mechanisms, living organisms have complex analogies, and it would be absurd to deny their importance.

In organizations, economic sociology encompasses a set of conditioned wills, just as electrons in atoms gravitate around a nucleus and only jump when allowed. The idea of valence, similar to the ability of an atom of an element to combine with other atoms, naturally emerged as a proposal to explain human motivation in organizations. This valence is associated with a context that conditions the particle behavior. This concept was partially shared by Vroom (1995), who corresponded valence to affective orientations towards specific outcomes, where people choose among different alternatives the one they anticipate will maximize their decision. This maximization is inseparable from environmental conditions but is not, in Vroom formulation, limited by them.

Although Vroom mentions Lewin's (1935) concept of teleology and physical vectors, he did not incorporate Galileo's dynamic view that inverted, according to Lewin, Aristotle's teleological explanation of events. In Aristotle's view, every object tends to perfection as long as it does not compete with others. The event is, at the same time, the concept and the goal (τέλος) of the object. This perspective places in the object, or the human, the capacity for artificial production of its existence through its behaviors and desires.

The complexity of sociology is superior to the complexity of physics, which admits the existence of a large number of independent systems of identical nature but differing in phase, that is, in their condition about configuration and speed, and whose behavior depends on the dynamic nature of systems and their phase distribution at the time considered (Gibbs, 1960).

The statistical physics presented by Boltzmann, followed by Gibbs thermodynamics in which particles depend on statistics, rejects the hypothesis that causal and identified laws fully describe systems with the same total energy (Wiener, 1989). When the sociology of organizations tries to understand and modify behaviors under the pretext of "improving" life, it omits that this improvement restricts freedom. If the sociology of organizations ignores their inabilities, as opposed to statistical physics, recognizing their limits, it eventually becomes unnatural and harmful to organizations.

2.2. Relevance of formality in organizations

There is the chimerical notion that formal structure per se impedes the creative activity of the organization. Without formal structure there is no organization and, consequently, no creative activity. The application of the formalization of an organization inevitably conditions freedom, in the same way that a vehicle conditions the behavior of pedestrians, who, with the justification of freedom, are liable to be run over. What defines the good use of the structure of the organization is the person or group of people who are granted the right to command. In the case of the vehicle and pedestrians, the power lies in the driver's ability to drive that vehicle, and in the case of organizations, the power lies with the manager. What can hinder creative activity is the absence of freedom, which is also related to the management policy of organizations.

Formal organization is not just a structure; it is based on rules agreed between the different members, and in order to function effectively it must be based on relationships of trust (Atkinson & Moffat, 2005).

Despite perceptions, organizations often don't have an objective way to describe work. Such a condition means that no worker can be judged with a valid criticism if his or her role has not been properly explained, nor can the organization be evaluated if there are no criteria to evaluate. The absence of an enumeration of what is intended in the work obscures responsibility and makes it difficult to judge those who are at the lower hierarchical levels. An exaggerated ego desires to have no limitations on freedom of decision and to possess unlimited responsibility and simultaneously to be protected from the effect of the unlimited decisions of others (Brown, 1963). The absence of definite attributions of authority and responsibility leaves the government of organizations based on personal prestige and power, on a false formal organization, because if it does not know its principles, all consent is ignorant.

It is unwise not to consider the importance of formality in organizations. Whether in the public or private sector, it is necessary to have clearly defined standards that ensure the cohesion of the organizational structure. When informality and improvisation are emphasized over formality, as an exaltation of a practical organization, organizations are doomed to disintegration, responsibilities dissolve, and organization members are encouraged to exploit private priorities to the detriment of organizational goals (du Gay & Lopdrup-Hjorth, 2016).

Decision is the essence of the manager's work. To deny that management depends on policy-making is to deny the need for a structure to do the work. Confusion between executive, representative, and legislative institutions in an organization deprives all employees of opportunities to participate in policy-making and managers of the necessary responsibility and authority to carry out those policies (Brown, 1963). Brown (1963) held that informal, non-explicit organization does not necessarily improve adaptability, and that explicit or formal organization does not necessarily generate rigidity. From his experience, Brown (1963) interprets the organization as a body and, although he incontestably defends the need for process formalization, he does not ignore the existence of an informal system.

Evidently, without proper adaptation, the formalization of the organization is incomplete. Observe, for example, the information systems, which have hardware and software, of concepts derived from the particularities of biological entities. Formalization should refer to these two dimensions, hardware and software. Without the compatibility of these two qualities, formalization is useless.

2.3. On the formalization of the ego

When organizations formalize their structures and procedures, osmosis formalizes individuals. Ego in organizations is not just reduced to individuals but includes the entire organization as a distinct entity. The ego as an arrogant property that sickly exalts our importance, that forges a sense of superiority (Holiday, 2016) to provide useless recognition, can become a destructive attribute. Organizations instinctively use the formalization of egos to circumscribe the damage from divergent egos.

Hierarchical structures are forms of harmonization of egos, a form of control of individual arrogance. Structures are idealizations incapable of admitting everything, so the consonance of egos is dependent on the organizational capacity to welcome them. Hence, organizations create discord when they tend to reconcile strategy, vision, or goals in a coordination effort, "many leaders default to repeating a message over and over, hoping it eventually sinks in." (Marcum & Smith, 2007). This hypothesis had already been addressed by Davenport and Prusak (1997) who state that "the more an organization knows about a term or concept relevant to its business, the less likely it is to agree on a common term or meaning for it."

An organization without ego is only a theoretical conception; And the bigger the ego is, the more unequal it will be. Therefore, equality depends on the organization's ability to free itself from ego, i.e., on its members renouncing the worthlessness of pride and status. However, the integration of experiences in a process of assimilation, and the particular responses and reactions as a way of accommodating experiences, reveal a permanent formation of the ego (Haan, 1977). The ego belongs to the body.

The status of team members in an organization evolves by mutual influences, and if there were an organization without ego, everyone would have the opportunity to scrutinize everyone's work, which would prevent the establishment of a strong hierarchy. When hierarchy dominates, it regulates criticism and collaboration, but ensures individual control. On the contrary, if in an organization the members work in isolation in cells as "monks", control is lost to individual reputation, and a lack of control of decisions can emerge when there is indifference in the achievement of the group's goals (Weinberg, 1971).

Rationality competes with other decision-making processes, such as defensive reactions against threats to self-esteem or ego-affirmation. Decision-making can also be the expression of the rise in self-esteem, which in Western history and culture has proved to be the dominant force, and which many people consider a right and in which they engage in a never-ending search. People are attracted to the pursuit

of self-esteem and repel threats to their selfishness, but lower rationality is reflected in a cost associated with nurturing these pleasures (Zhang & Baumeister, 2006). Self-esteem can stimulate an artificial consensus that is harmful to the balance of organizations, through a superficial consensus that has latent the true purposes of the ego.

Although there is the possibility that the ego is a serious constraint on the ability to control and self-control in decision-making processes, it is the expression of “a valuable and powerful feature of human selfhood” (Baumeister, Bratslavsky, Muraven, & Tice, 1998). The difficulty of ego management is to properly enhance the value of the ego in creating prosperity.

The individual has creative virtue (Whyte, 2002), and removing this capacity from the ego can incite the “human machine” to work as a team, in an immutable process. Faced with a constantly changing reality, the formalization of the ego can induce the decline of the organization, due to the lack of transformation of the system.

For Bergman (2017) we are “We’ve been brought up on a steady diet of narcissism, but as soon as we’re released into the great big world of unlimited opportunity, more and more of us crash and burn. The world, it turns out, is cold and harsh, rife with competition and unemployment [...] Not surprisingly, that narcissism conceals an ocean of uncertainty.”

2.4. Inequity

Ammon (1895) in an analysis of the works of Friedrich Gauss (1823), Quetelet (1849) and Galton (1892) showed that inequality exists as something hereditary and natural, with statistical associations. The basis of the work rests on the work of Galton (1892), who opposes the sophistry of “natural equality” that children are born almost equal. Not allowing “the great power of education and social influences in developing the active powers of the mind” to be recognized, Galton (1892) warns that only vanity can prevent the recognition of intellectual limitations.

Galton's (1892) work was quite thorough in examining the descent of various illustrious people, of different intellectual pursuits and physical abilities, from painters, musicians, scientists, wrestlers, etc., and with a little statistical analysis at the end. Ammon (1895) represented the data obtained by Galton, in Figure 2.1, which also supported a deeper investigation by Pareto (1897) in assessing economic inequality.

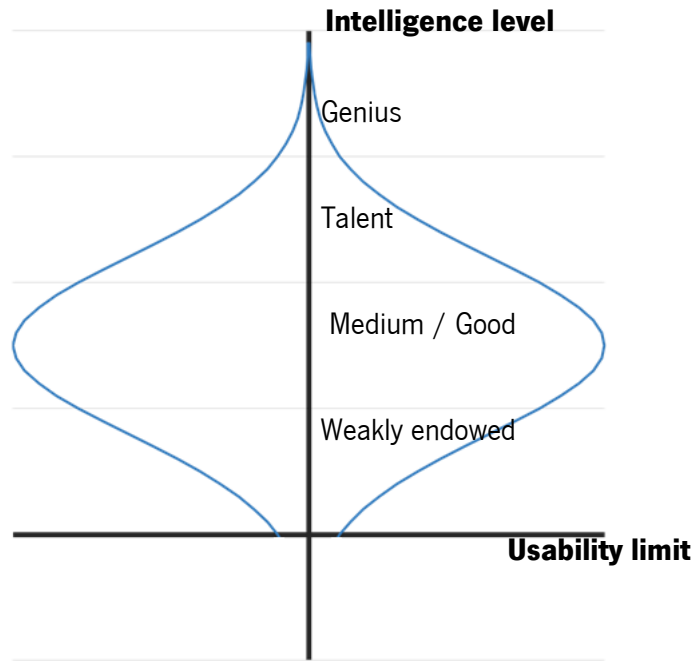


Figure 2.1: True shape of the social pyramid according to Ammon (1895).

The curve presented by Ammon adjusted the values collected by Galton to an apparent normal distribution with Equation 1:

$$x^2 = (Y \times e^{-y^2})^2 \quad (1)$$

where Y is a constant and the elements of both sides are squared to allow the function x to be even. However, when observing that Dalton's values fit the Gaussian curve, randomness is demonstrated in a given group, but Ammon cannot contest and reinforces Whyte's (2002) observation that the elements that stood out in society and, consequently, in organizations "were not necessarily the fittest but, in more cases than not, those who by birth and personal connections had the breaks" (Whyte, 2002). The studies revealed that birth and personal connections influence people's visibility in society, but they do not manifest that they do not exclude the fittest, because a scientific analysis would require providing everyone with the same opportunities.

One can conjecture whether Mozart would have been a musician if his father had not been a musician, one can conjecture whether John Nash would ever get a job if he had not won the Nobel Prize, one can conjecture whether Boltzmann would not have won a Nobel Prize if he had not turned down the dean's post that he lost to Planck. One of the most appreciated characteristics in the science of organizations is the non-presumption and, consequently, the use of a statistic that is completely insensitive to context

(including time). Vilfredo Pareto insinuated that life in societies is flawed and does not depend only on merit. This thought is partly different from Ammon's, because the latter admitted only randomness represented by the curve of the normal distribution. Pareto (1919) gave the example of a bag with a different number of black balls than white balls. Assuming the Pareto model, each individual, group, or population is assigned a certain number of "talents" and "deficiencies" obtained by genetic, economic, social, cultural, or other inheritance.

The results show that a group consciousness (with which the agent interacts) imposes itself on the individual consciousness, which automatically reacts with instinctive dynamics of self-preservation, becoming part of a pseudo-homogeneous mass. Ammon (1895), Pareto (1897), Lorenz (1905), Gini (1912, 1921), Dalton (1920) showed the existence of societies composed of groups and subgroups, on a hierarchical scale, determined by the group will over individual ignorance, imperfection and incapacity. This does not mean that the group is more perfect than the individual, or even that it reveals a synergy that guarantees progress. It only reveals that the inequality of organizations is persevering and is not random. That is why William Whyte's reservations about the predominance of the group over the individual and the consequent sterility of creativity in organizations are not unreasonable.

2.5. Time and organizational architecture

One tries to control everything, but you can't control time, you just use it and spend it. Inadvertently, organizations try to stop time with a sieve.

When man ceased to be nomadic, and with agriculture began to accumulate food, he began a process of control and power that only lasted, because with language he transmits and retains information. Without information, there would be no savings, because there would be no attribution of value. Acknowledging that without language there is no organization, the argument of the divergence of the quality of time in organizations begins.

Information, implicitly, is associated with the dimension of time. Hence the expression of novelty depends on the knowledge of the organization. Only what was unknown is new, and this attribution usually has a distorted temporal connotation, that is, commonly the attribution of novelty occurs through synchrony, which without memory of time, highlights the present and ignores the past. This ignorance, for some, is a form of power.

Power that is based on ignorance does not care where memory is located, although it is known that people have a memory of great capacity (von Neumann, J., 1958).

In organizations, time has a selfish structure, based on a certain space, on a certain operation, on a certain individual, as if it were static and not dynamic, and therefore conditioned everyone. Specific efficiencies are analysed, which then multiply motivate an overall efficiency.

Simon (1962) in the paper “*The architecture of complexity*” wrote a parable about two watchmakers, Hora and Tempus, who had to put 1000 parts together in the manufacture of watches. Hora's business prospered, while Tempus's went bankrupt. Watchmakers had the same skills, but whenever they interrupted their work for any distraction, they had to restart it again. Hora performed the work on subsets of 10 elements, while Tempus performed the integral clock, without any division of its assembly. The description of the two systems adopted can be seen in Figure 2.2.

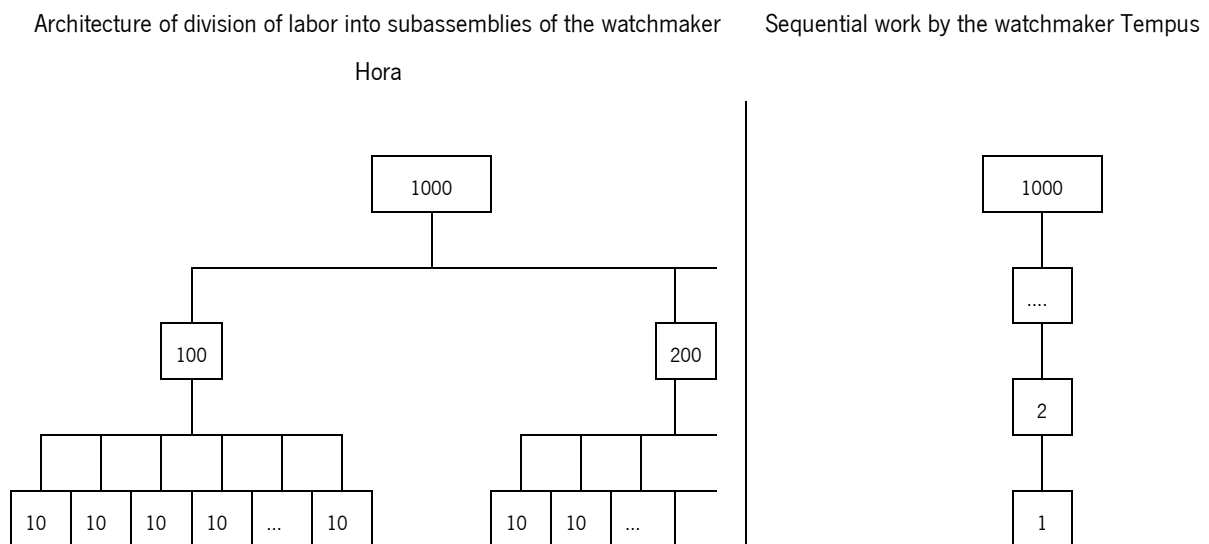


Figure 2.2: Systems of division of labor adopted by the watchmakers Hora and Tempus, presented in the paper “The architecture of complexity” (Herbert A. Simon, 1962).

Whenever the watchmaker Hora was interrupted to answer the phone, whether he was at any stage of manufacturing, he would have to start it over, that is, he would lose time on the subset of 10 pieces he was working on; while Tempus lost all the labor expended in the manufacture of the watch.

Simon (1962) estimated the difference between the manufacturing times between the two watchmakers, considering the possibility of either being interrupted in an operation to be 1%, i.e., the probability of completion of each operation is 99%.

As such, Hora has a $0,99^{10}$ probability of having a subset of 10 pieces successfully completed, while Tempus can only complete a complete clock with a probability of $0,99^{1000}$. Furthermore, taking advantage of the reasoning proposed by Jacobson (1955) and by Setlow and Pollard (1962) on Shannon's information theory, he attributed that on average Tempus loses 100 assembled parts for each interruption, while Hora only loses, on average, 5 assembled parts. However, Hora has to assemble 111 subsets to get a clock, while the Tempus process is unique. Thus, per million attempts, Tempus will produce 43 clocks, while, according to Simon (1962), Hora will produce approximately 4000 times more units than Hora, the result of:

$$\frac{1}{111} \times \frac{100}{5} \times \frac{0,99^{10}}{0,99^{1000}} = 3774,5 \approx 4000$$

Although Simon's calculations are flawed, the fact is that Tempus produces fewer units than Hora.

Considering time as a discrete quantity where each operation has a duration of x_i units of time (ut) and a probability of success p_i , the time spent (t_n) on a set of n operations, where the error in an operation i destroys the previous work, is equal to Equation 2:

$$t_n = X \times \sum_{i=1}^n x_i + \left(\prod_{j=1}^i \frac{nx_i - x_{i-1}}{p_j} \right) \quad (2)$$

Table 2.1 shows a proposal for an alternative resolution on the manufacture of the Tempus clock, using a particular case from the previous equation. It is proposed to consider the method used by the watchmaker Tempus to be a stack of n operations, which develops sequentially in concatenated levels, and which destroys itself whenever the watchmaker is interrupted. Each operation has a duration equal to $X ut$. The probability of success of the operation is equal to p , and the probability of failure is equal to $1-p$.

For 1000 operations, with 1 ut and a 99% probability of success, the application of the formula results in an average time of 2,316 million ut for the completion of the clock, which was the case with the construction made by Tempus.

Table 2.1: Time spent in constructing a watch with n operations and destructive interruptions of all preceding work.

Level	Total time (ut)	
	with equal odds	with different odds
$N=n$	$t_n = X \times \left(\frac{1}{1-p} \right) \times \left(\frac{1}{p^n} - 1 \right)$	$t_n = X \times \sum_{i=1}^n \prod_{j=1}^i \frac{1}{p_j}$
...		
$N=3$	$t_3 = X \times \left(\frac{(1-p)}{p^3} + \frac{(1-p)}{p^2} \times 2 + \frac{(1-p)}{p} \times 3 + 3 \right)$	$t_3 = X \times \left(\frac{1}{p_3 \times p_2 \times p_1} + \frac{1}{p_3 \times p_2} + \frac{1}{p_3} \right)$
$N=2$	$t_2 = X \times \left(\frac{1-p}{p^2} + \frac{1-p}{p} \times 2 + 2 \right)$	$t_2 = X \times \left(\frac{1}{p_2 \times p_1} + \frac{1}{p_2} \right)$
$N=1$	$t_1 = X \times \left(\frac{(1-p)}{p} + 1 \right)$	$t_1 = X \times \left(\frac{1}{p_1} \right)$

For 10 operations and the same 99% probability, the value is 10,573 ut for the average time to build a subset of Hora. He will still have to group 10 sub-sets, into sets of 100 pieces, and finally these sets into a watch of 1000 pieces.

Applying the formula for the sets of 100 pieces, assuming that the subsets will always remain intact, the value for each construction will be 10,573² ut , and for the complete clock 10,573³ ut , i.e., approximately 1182 ut . With this argument, for each clock built by Tempus, Hora will make about 1959 equipment.

Perhaps more important than knowing exactly what the advantage of Hora is over Tempus because it is too significant, it is useful to analyze the curves resulting from n operations with an individual probability of success p .

Figure 2.3 shows the curves on a linear scale, and a logarithmic scale, for 1000 operations and probabilities of success 0,9999, 0,99, 0,98, and 0,95.

The graphs show that works supported by previous achievements lose stability at a certain point, because as Jung (1959) wrote: "No tree, it is said, can grow to heaven unless its roots reach down to hell. The double meaning of this movement lies in the nature of the pendulum."

When you go from a 99.99% probability of success to a 95% probability in each operation, to do a given job with 1000 operations, you go from an average of just over a thousand operations to a number with 23 trailing zeros.

Something wrong, often insignificant, in a system that is sustained by multiple previous operations, can give rise to catastrophic phenomena that, in a chain, break the old idiosyncrasies. Thus wrote Nietzsche (1896) in an attribution to Zarathustra: “If I wished to shake this tree with my hands I could not do so. But the wind which we do not see tormenteth and bendeth it wherever it listeth. By unseen hands we are bent and tormented worst.”

Hence, it must be understood that complexity emerges from the need to use dynamic feedback mechanisms and that we are permanently in a continuous flow of dynamic and chaotic processes, of construction and destruction. As noted by Bai-Lin (1989), despite the difficulty of observing cause and effect, which are often concealed, these mechanisms produce an apparent randomness. This appearance indicates that we should not confuse the unknown with the random.

When thinking about complexity, one must include generative integration which, according to Putnik and Putnik (2010), “is characterised by the ability to create, synthesise or generate the integration”, initially focused on effectiveness and then efficiently. In a dynamic system, all solutions are ephemeral. Hence the importance of pragmatics that guide and formalize information, unify and converge interpretations in the creative process (Putnik & Putnik, 2010). The creative organization can combine the merits of efficiency and effectiveness. However, such an association requires a predictive and predictive analysis of the situations.

2.6. Cyber-Physical Systems as a new organizational trend

In management, the pyramid design still predominates, with a military organizational structure centered on the function. However, Drucker (2011) has warned that this type of structure kills ideas in cognitively and technologically advanced organizations.

The hypothetical fourth industrial revolution, dubbed Industry 4.0, foresees a qualitative change in manufacturing and organizational systems, through digitalization, extensive and intelligent integration of processes and self-organization (Pinheiro et al., 2019). This is an emerging context for industrial activities, dominated by Cyber-Physical Systems, where physical equipment, control processes and information support systems affect each other through feedback loops (Putnik, Ferreira, Lopes, & Putnik, 2019). The necessary integration of these systems brings new challenges to the management of organizations, because the system itself must have the ability to change its behavior to adapt to the inevitable changes caused by new requirements. (Shah & Putnik, 2019).

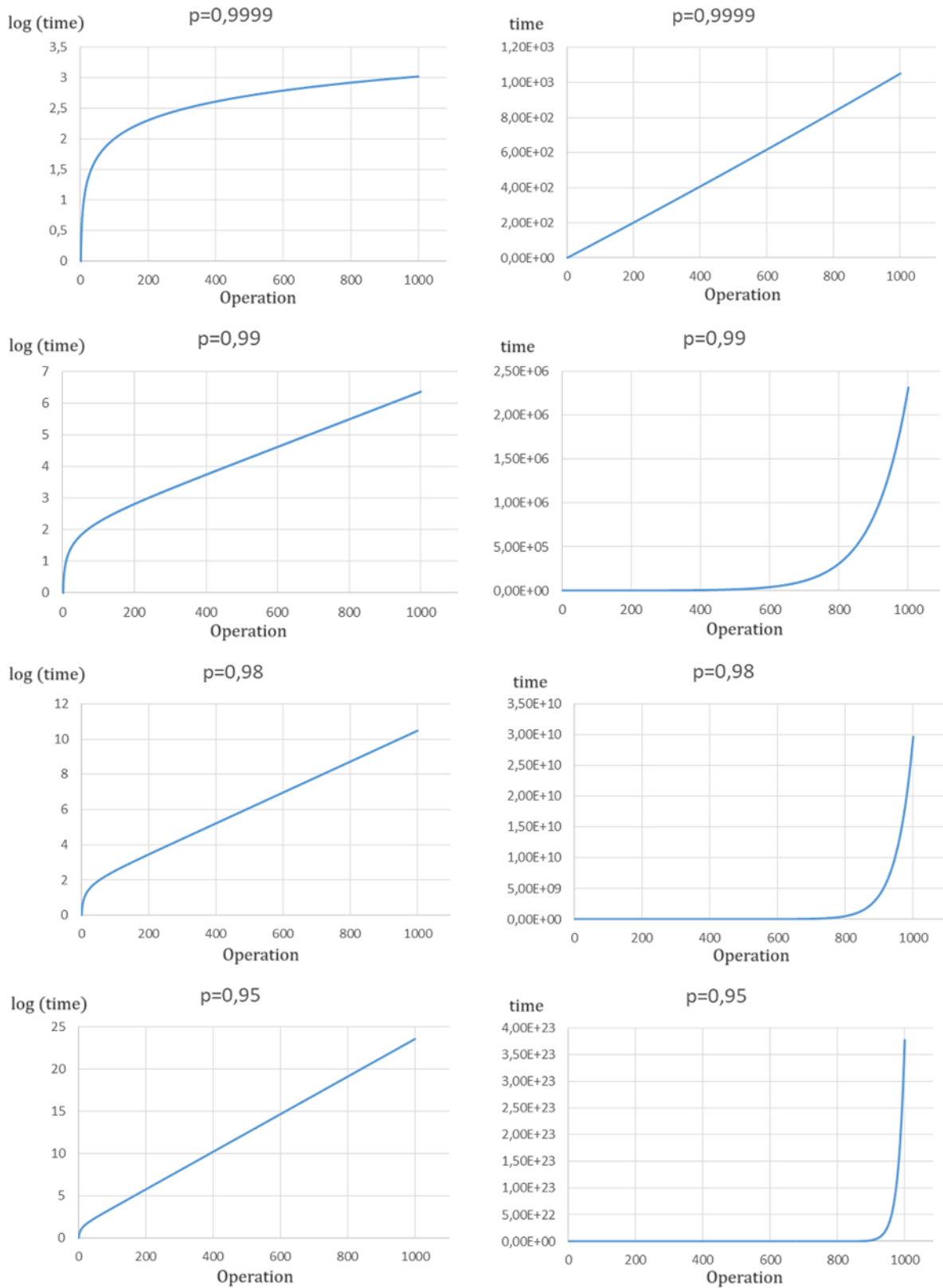


Figure 2.3: Curves on a linear scale and a logarithmic scale, for 1000 operations and probabilities of success 0,9999, 0,99, 0,98, and 0,95.

3. Classical Management Theory

Classical management theories grounded on mechanistic models shaped our conceptions of organization. According to classical management theories, organizational work usually involves routinized and centralized controlled operations, which leads to cross-situational consistency. Organizational functions emerge from an internal set of motivations or objectives. Physical assets are critical competitive resources, and the physical capacity is understood as fixed (Fiol, 2017).

Subchapters 3.14, 3.15, 3.16, and 3.17 contain significant parts of the paper “Organizational efficiency prospects for management in Industry 4.0” (Pinheiro & Putnik, 2021).

3.1. Taylorism

Taylor was a pioneer in stating that the principles of planning and doing are different. German military officers had previously established planning as a separate activity in the early 19th century, but this break had never been practiced in industry (Drucker, 1974).

In his work “Shop Management”, from 1903, Taylor (2003) warned that scientific management could produce beneficial or disastrous results depending on the spirit of those who use the management mechanisms. Planning should ensure that workers are aware of their roles in advance. Taylor (2003) called this procedure a “human mechanism.” “It meant organizing and planning work at least a day in advance.” He highlighted that the main difficulty in planning did not come from workers but from management. Metaphorically, he compared the men's movement to a chess game because they had to be in the right place at the right time.

To realize his system, Taylor (2003) praised the importance of learning. One of the peculiarities he proposed was that no man should be promoted “until after he has trained his successor to take his place.” In this process, he argued that “man must learn to give up his own particular way of doing things, adapt his methods to the many new standards,” while he emphasized that he must first “obey the laws as they exist, and next, if the laws are wrong, to have them reformed in a proper way.”

3.2. Industrial and organizational psychology

After Taylor's work came the contributions of psychology and ergonomics in organizations. The doctoral thesis by Gilbreth (1914), although it was not the first document on these topics, presented, at the time, a complete compilation of the value of psychology in administration, with a focus on efficiency. These works later inspired the expansion of human physical ergonomics to cognitive ergonomics caused by the advent of cybernetics (Newman, 1977), and to organizational ergonomics, a macroergonomics related to the design of organizations (Zink, 2002). At the beginning of the 21st century, organizational ergonomics emerged as a response to the increased complexity of social, economic, cultural, and technological relationships and academically dedicated itself to the optimization of socio-technical systems, including their organizational structures, policies, and processes (International Ergonomics Association, 2021). Without questioning Taylor's scientific management, Gilbreth (1914) warns that this management was undoubtedly associated, usually, only with the organization's management, neglecting part of this vital essence – the best interests of those managed. She regretted the lack of knowledge sharing in the organization, which would enable the maximization of resources and “to receive information with the least waste and expenditure of energy, nor was it recognized that in the industrial, as well as the academic world, almost every man is a teacher” (Gilbreth, 1914).

Münsterberg (1913), in the book “Psychology and Industrial Efficiency” presented three chapters with the suggestive names of “the best possible man”, “the best possible work”, and “the best possible effect” that reveal his interest in improving “a social machinery” for the productivity of organizations. However, he is too critical of standardized education, based on mechanical thinking, capable of guaranteeing organizations the necessary workforce and equal access to all candidates. Faced with the demands of organizations in a competitive context, Münsterberg (1913) warns that, perhaps, “the total result remains a social machinery by which perhaps the elimination of the entirely unfit can be secured.”

Industrial psychology intended to destroy habits because organizations looked at “habit as something detrimental to efficiency. The possession of any and of all habits has at times been regarded as a misfortune” (Scott, 1911).

3.3. The spread of industrial and organizational psychology

After the First World War, many works related to industrial psychology appeared that attested to the contributions of Münsterberg and Gilbreth. Among them are the works of Myers (1927), Watts (1921),

and Swift (1927). Everyone sought to understand human behavior and optimize their industrial production. The concern was not so much the industrial process but influencing people to adapt to the scientific method proposed by Taylor.

Meyers (1927) alluded to the virtues of judgment and intuition because they were “essential in the use and interpretation of vocational tests” and because they encouraged a bright future for “vocational guidance and selection.” Watts (1921) shared some of Myers's ideas, although he was aware of the fragility of industrial psychology “because some of the results of his researches may be ignobly exploited in the service of mean ends and to the great disadvantage of the workers or the community, or both”. At that time, the world experienced a barbaric war that altered some previous political, social, economic, and industrial conceptions. Thus, “the psychologist is deeply interested in what is called scientific management, though not everything that has been done in the name of scientific management can be psychologically justified” to mitigate the “conflicts which have arisen between so-called efficiency experts and organized labour.” The aim “is towards the ideal of constructive co-operation” Watts (1921).

Contrary to Watts's ideology, Swift (1927) observed industrial psychology as an excellent resource for scientifically gaining competitive advantages over competitors. Competitors are everyone who can affect your business. He consciously presented people as machines with economic utility.

Decisions within organizations have limited rationality, but workers act satisfactorily considering time constraints and information availability (Simon, 1947). However, the idea of conditioning and promoting workers' satisfaction and performance by changing the work environment persists, as proposed, for example, by Herzberg et al. (1967). The problem is not in the influence that the elites of organizations exert but in the understanding that workers do not behave like machines. So, the elites try to understand the “human machine” to “improve” it. Intent flows follow the gravity of the organizational pyramid, where few influence many.

3.4. Follett's thinking

At a time when organizational theory worshiped experts who viewed organizations as deterministic structures, Mary Parker Follett conceived of organizations as open, conditioned systems.

Follett (1930) argued against the prominence of experts who determine democracy through binary choices between despots and technicians. Thus, the problems would cease, and “all life would become fair and beautiful. For people, one assumes, will happily agree to become automatons when we show

them all the things - good, solid, objective things - that they can have, abandoning their own experience in favor of a superior race of men called experts" (Follett, 1930). She considered it harmful for society to stick to the superiority of experts' opinions, with hasty reactions, where people are conditioned, as opposed to educating the people and thus integrating them into decisions. Organizations and governments that only observe what experts say, use the goodness of decisions to follow everyone's will. However, this reasoning did not demonstrate any definition of will.

Follett (1918) had already rebelled against class democracy and outlined more of a desire than a defined and scientific analysis of the meaning of democracy. She understood that "democracy, although often considered a centrifugal tendency, is rather a centripetal force." Because this ambition collides with traditional management principles, which discards failure, competition learns from victory and ignores defeat, which does not want to understand a "true democracy" that "infinitely includes". "Democracy must be conceived as a process, not a goal". Against the majority, she argued that "democracy is an infinitely including spirit. We have an instinct for democracy because we have an instinct for wholeness; we get wholeness only through reciprocal relations, through infinitely expanding reciprocal relations. Democracy is really neither extending nor including merely, but creating wholes." (Follett, 1918)

One of the revealing characteristics of Follett's thinking is the rejection of the concept of synergy often used to value integration in organizations. The idea of integration that she defended suggested "something new" that is not necessarily, in quantitative terms, greater but that is qualitatively better. He challenged the tendency of many *Gestalt* psychologists who stated "that the whole is 'more' than its constituent parts" (Follett, 1930). However, "the whole may be different from the parts without being more." (Follett, 1930).

Objecting to the dominant thinking of an elite that used democracy to praise the covert coercion of consensus in formal organizations, Follett demonstrated the merits of a systemic approach to organizations, notably in governments, where all groups should belong. Inevitably, their beliefs met with little acceptance (Cartwright & Zander, 1989).

3.5. The Hawthorne Works experiments

The sociology of organizations research program happened at and by the Western Electric Company in the small town of Hawthorne, which gave its name to the Hawthorne Works industrial complex in

Chicago, United States of America. The Australian industrial researcher, Elton Mayo, headed these experiments.

Although the subjects of this research were already the subject of study, the conclusions were divergent, as previous studies did not adequately consider anthropology, and this continued after the research at the Western Electric Company. The experiments at Hawthorne, which spanned the Great Depression of 1929, showed how human behavior is not a simple and rational variable and that, with mechanistic organizational models, synergy and symbiosis only emerge as opportunistic chimeras.

Mayo (2004) argued that the “scheduling” of tasks assigned to humans is healthy for production and only compares studies that defended or rejected breaks in monotonous work to increase productivity. Mayo does not question the lifelong specialization of the worker and only tries to understand how to control boredom so that the worker is more available and productive. Part of the analysis of monotony in organizations utilized the work of May Smith, and despite making many citations from her work, the experiments failed to rationalize and eliminate any approach to humanity. May Smith (1923) wrote that although it is true that “many descriptions of factory conditions are like skeleton outlines” or reproductions of motion studies, they “lack humanity.” In this chapter on monotony, Mayo (2004) describes an experience in the spinning department of a textile factory, with a high worker turnover compared to other departments. The focus has always been on production efficiency and the incorporated rest periods to increase productivity. Turnover decreased, and production increased (Mayo, 2004), but the study did not isolate the causes.

Roethlisberger and Dickson (2003) detailed three experiments relating to the assembly of relays, the separation of mica, and the assembly of telephone splitters. Production varied and usually increased without knowing the cause. The payment system was mixed, with a fixed part and a variable part depending on exceeding a group goal, called “bogey.” While this objective in other departments brought together groups of one hundred people, in the testing room, it included six workers. Nevertheless, the testing room group did not remain the same throughout the experiment.

During the experiments, there were no permanent formal supervisors, just one researcher, and according to Mayo (2004), the workers internalized it as the absence of supervision. They were naively mistaken because they were “getting closer supervision than ever before,” and the most significant change was only “in the quality of the supervision.” Each worker had a different definition of supervision, as each situation was different, “it was something intimately human, more remote” (Mayo, 2004).

3.6. Sociology at Hawthorne Works

Part of Mayo's (2004) work derives from the work of Durkheim (2005), which revealed that also in 1897, industrial civilization was undergoing rapid development and was prone to suffering from an illness that he called "anomie". For Durkheim (2005), this condition of anomie was caused, at least in part, by economic development, which created a "lack of planning in life," and propagated a systemic quality of both individual and community life, making individuals increasingly nervous, in self-development without plans, in disgust with the "futility of an endless pursuit".

Faced with the possible scenario of disorder caused by anomie, Mayo (2004) warned of two pieces of evidence. Firstly, "all these colonies present those problems of 'acculturation'". Secondly, "the actuality of anomie may present a serious difficulty or even a threat to the continued existence of a particular community" (Mayo, 2004).

Mayo (2004) uses Tawney's (1920) work "The Sickness of an Acquisitive Society" to note that in "almost the entire area of a man's life the society thinks for him; and he learns only the social responses he must produce in reply to given signals. This is a very restricted method of living, but it is highly integrate and 'functional'; in addition to this it is very comfortable for the individual, who does not need to 'wrestle with a solitary problem'" (Mayo, 2004). This phenomenon places humans as individualities, like a subservient element in society. Considering the role of education and Piaget's (1971) "egocentric" thinking, which in adults is a type of thinking that instantly moves towards synthesis and, in which, things can emerge uncritically as "totalities". When not educated to have sufficient social experience, the adult will not only be socially maladjusted but will simultaneously use inferior logical techniques (Mayo, 2004).

To demonstrate the possible human dichotomy between the individual and the social, which can disrupt the functionality and cohesion of any organization, Mayo cites Pitt-Rivers's (1970) previous speech in 1923 to "The stability and social health of any community, whether a tribe or a nation, however high or low in the scale of culture or complexity, may be reckoned by the degree of integration or disintegration it exhibits, and...every weakening of the tribal tie destroys the social purpose of each member of it" (Mayo, 2004; Pitt-Rivers, 1970). Mayo (2004) assumes that "political action in a given community presumes the desire and capacity of individuals to work together; the political function cannot operate in a community from which this capacity has disappeared." Management depends on the quality of the composition of the administrative group to ensure the preservation of social balance.

Mayo (2004) recalls Pareto (1917a), who mentioned that leadership depends on elites related to aristocracies, although aristocracies do not last. Whatever the causes, it is indisputable that after a period, aristocracies disappear.

History is a cemetery of aristocracies (Pareto, 1917a), stimulating the emergence of changes, a “circulation of elites”, which causes the government to be in a state of slow and continuous transformation, running like a river; today differs from yesterday. Therefore, sudden and violent disturbances occur, similar to river floods (Pareto, 1917a).

Faced with new unprepared elites that stand out from the lower layers, revolutions will emerge (Pareto, 1917a). According to Adams (1913), controlling these revolutions relies on administrators capable of understanding rapid changes with a generalizing consciousness, “which can grasp a multitude of complex relations” (Adams, 1913).

3.7. Criticisms of Hawthorne studies

As previously noted, Mayo's experiments were inconclusive, and Bell (1947) presents multiple critical and discordant arguments regarding the results obtained. Although Mayo's and Taylor's studies focused on efficiency, Mayo's studies were primarily concerned with observing behavior and social relations, while Taylor's work evaluated production on a purely mechanical basis industry

Bell's (1947) first negative assessment highlights the compromised cooperation between industry and universities, which have divergent ideologies. The enterprise values the work of universities due to the availability of research personnel, whose impartiality appears as a source of prestige that benefits them with unions and governments. On the other hand, teachers act as technicians and usually have an ideology focused on necessity. Many consider themselves “human engineers” reconciled with industrial engineers who plan “of work in order to assure greater mechanical efficiency” (Bell, 1947). In this process, the sociologist adjusts the “worker to his job so that the human equation will match the industrial equation” and seeks analogies “to the laws of the physical world, and by and large they give little thought to the fact that they are not operating in the physical world” (Bell, 1947).

Similarly, despite five decades from Hawthorne experiments, Simpson (1989) considered that these experiments changed the “focus away from workers and work, and has transformed our view of the worker from a social to an economic one.” Indeed, Mayo did not alter the conception of the worker to

something similar to a *homo oeconomicus*. Plutocracy is ancestral and was not born with industrialization.

In addition to revealing the problems of changing the social structure, the difficulties of control and communication, and the problems of individual adjustment to the industrial structure (Roethlisberger & Dickson, 2003), Hawthorne experiments named the effect of information tampering that can arise from observation of social behaviors. As the Heisenberg uncertainty effect for particles, the Hawthorne effect applies to the social sciences. The effects share the same principle that observing changes the phenomenon to be analyzed.

In Hawthorne experiments, working conditions changed in one group while the same conditions remained in another, but productivity increased in both groups. In the lighting experience, despite the regression of privileges that were previously the reason for an eventual increase in productivity, productivity continued to increase.

The problem of involuntary interference by the observer in the behavior of the observed creates uncertainty in determining the effects in any community, particularly the industrial one. Eventually, the workers' pride increases when they consider themselves a relevant part of the organization. In this case, it is the act of observation itself that produces the phenomenon in the observed. This effect permeates industrial psychology and appears in all sciences related to human behavior. For example, anthropologists expect observed behavior to be indifferent to the existence of the visiting observer. Through "participant observation," the anthropologist wishes to become "invisible" to people and tries to become part of the existing culture, remaining the culture indifferent to changes (Weinberg, 1971).

However, it is incorrect to admit that the observer (or supervisor) adds to the worker a moral that is positively related to production. In 1937, Rensis Likert tested the hypothesis of the relationship between the eudaemonistic management of workers and their productivity (Whyte, 2002). In a laissez-faire approach, where the supervisor does not lead, workers may like it, and absences and turnover may be low, and if you accept that they produce less, they produce relatively little, i.e., they do what organizations expect from them (Whyte, 2002).

3.8. Hawthorne and the Munchhausen trilemma

The advent of quantum mechanics, with the help of stochastics, allowed the analysis of systems characterized by having distinct qualities. Quantum mechanics showed that observation and evaluation

change systems (Heisenberg uncertainty effect), also recorded in Hawthorne experiments. And such a phenomenon cannot be repressed, as seen in Nietzsche's observations when analyzing the absurdity of Munchhausen's trilemma. Nietzsche (1986) uses an excerpt from some versions of the book "The Adventures of Baron Munchausen", by Rudolph Raspe, which tells how Baron Munchausen was riding a horse and tried to drown. The fictional figure of the Baron describes his self-rescue (Raspe, 1867). Nietzsche clarifies that this illusion of power is motivated by the *causa sui*, which, in his words, "is the best self-contradiction that has been conceived so far, it is a sort of rape and perversion of logic." (Friedrich W Nietzsche, 1986). Nietzsche's caustic remarks about "free will" point to the failure of determinism in Hawthorne experiments, as they created an absurdity that self-constructed, substantiated, and imploded. Already before, for Heraclitus, in ancient Greece, the context is permanently changing, suggesting that "*panta rei os potamós*" (everything flows like a river) (Kahn, 1979). Hawthorne experiments failed because they wanted to compare what was different, and because everyday people and situations were different. As Nietzsche noted, Baron Munchausen's action results from a work of fiction, but Mayo attempted something similar. Stickland (1995) notes, in connection with Hawthorne succession of experiments, that these complex phenomena can "occur in social contexts and organizational systems," and that the situations are still incomplete, as "human activity systems generally have yet to be fully explored" (Stickland, 1995).

3.9. Minorsky's proposal for the control of a system

At the time Fayol (1917) wrote the book, Minorsky (1922) had not yet presented his paper on automatic ship control. On ships, only one man controls the helm or steering wheel as a governor, from the Latin *gubernacúlu*, which is the device that allows to regulate the direction of the ships. In fact, until Minorsky's paper, and despite some earlier work, large boats were controlled only by the dexterity of the helmsman who had to foresee all the conditions of the environment and dock safely. If it had too much speed, the boat would crash and destroy itself against the harbor, if it had too little speed, it would use too much fuel and time.

Minorsky's work presented the formula for what would be called a Proportional, Integral and Derivative (PID) controller, which allows you to automatically adjust the speed of the boat, depending on the distance from the port, using the deviation (or error) as a reference.

Using Minorsky's equations to control the boat and, metaphorically, transpose it to organizations, one can consider:

1st - The impossibility of a synchronic response between the recognition of the error and the effect of the (re)action, due to inertia;

2nd - The dependence on the past in decisions;

3rd - The consequence of the decisions in the future;

Equation 3 shows Minorsky's original equation:

$$A \frac{d^2 \alpha}{dt^2} = -B \frac{d\alpha}{dt} - C(\rho) + D \quad (3)$$

where:

A, B are constants;

$\frac{d^2 \alpha}{dt^2}$ is the angular acceleration;;

$\frac{d\alpha}{dt}$ is the angular velocity;

α is angular momentum;

$C(\rho)$ is the restoration binary due to rudder action;

D is the disordered torque that deflects the boat for any cause such as wind, waves, propellers.

Simplifying the equation proposed by Minorsky, using a linear control instead of an angular control and making the ordinate zero as a reference, we get:

$$\begin{cases} m \frac{d^2 X}{dt^2} = -\kappa X - \beta \frac{dX}{dt} \\ \frac{d^2 X}{dt^2} + 2\alpha \frac{dX}{dt} - \omega X = 0 \\ \alpha = \frac{\beta}{2m} \\ \omega = \frac{\kappa}{m} \end{cases}$$

The formula is similar to that of the pendulum and is easily solved with the Laplace transform (Spiegel, 1965), from which three hypotheses arise.

Equation 4 corresponds to the critically damped motion, with X_0 and V_0 being the initial position and velocity, respectively;

$$(\omega^2 - \alpha^2) > 0 \Rightarrow X = X_0 e^{-\alpha t} \cos \sqrt{\omega^2 - \alpha^2} t + \frac{V_0 + \alpha X_0}{\sqrt{\omega^2 - \alpha^2}} e^{-\alpha t} \sin \sqrt{\omega^2 - \alpha^2} t \quad (4)$$

Equation 5 corresponds to the damped movement;

$$(\omega^2 - \alpha^2) = 0 \Rightarrow X = X_0 e^{-\alpha t} + (V_0 + \alpha X_0) e^{-\alpha t} \quad (5)$$

and Equation 6 corresponds to the ultra-damped movement.

$$(\omega^2 - \alpha^2) < 0 \Rightarrow X = X_0 e^{-\alpha t} \cosh \sqrt{\omega^2 - \alpha^2} t + \frac{V_0 + \alpha X_0}{\sqrt{\omega^2 - \alpha^2}} e^{-\alpha t} \sinh \sqrt{\omega^2 - \alpha^2} t \quad (6)$$

The graphs of each of the previous cases are represented in Figure 3.1, logically assuming that the solution of the dampened motion is the only valid hypothesis in Minorsky's case. However, the solution of damped oscillatory movement may be valid for some organizations, due to the extemporaneous need for quick results, in the same way that it is used permanently in some types of industrial control, such as, for example, temperature.

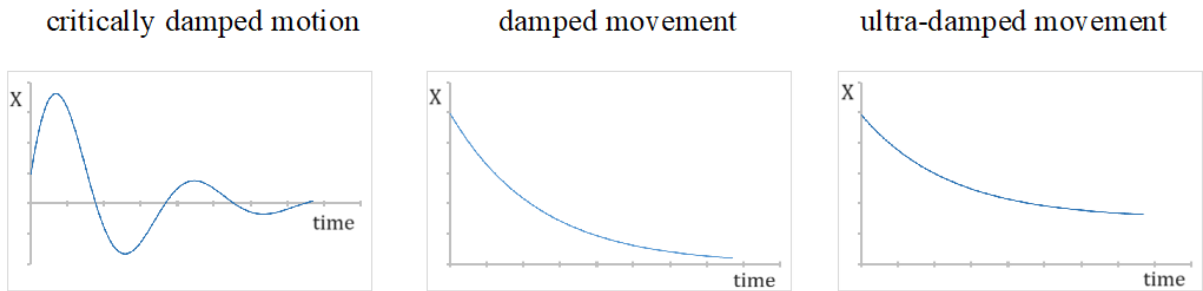


Figure 3.1: PID control functions.

The purpose of this reflection is to demonstrate that primitive proportional control, i.e., binary, which only knows the on and off operations, is still frequently applied in the management of organizations. Control systems, especially in public administration, are "manual" and do not show knowledge of the method proposed by Minorsky, semi-automatic, which only needs to be supplied with data, in order to achieve the control function, which is not only a function of the present (proportional control), but also compares it with the past (integral control) and anticipates the future (derivative control). Logically, the action plan must contain a defined goal, known in advance, so that the deviation from what was previously planned can be properly observed and evaluated. If this is not possible, it should be

investigated whether the plan should be corrected, or whether there are means to ensure adequate data to feed into the system. Therefore, one can adapt Minorsky's equation to create an adhocracy, emphasizing the need for advance knowledge of the design objectives of the organization, product, service.

3.10. Drucker and effective leadership

In World War II, Drucker (1942) warned that organizations would only resist if they had the capacity for self-organization that gave status and social functions to their members on a basis that provided responsibility and independence in decision-making. It was stressful at the time that neither total planning nor the restoration of 19th-century laissez-faire would be viable responses, but local and decentralized self-government to win the war. Drucker's (1942) warning differed from a solution similar to the centralized bureaucratic governments of Europe in the 16th and 17th centuries, preventing a free and functional society essential to any autonomous organization.

3.11. William Whyte and the human

In "The Organization Man," Whyte (2002) presents a portrait of organizations in the 1950s in the United States of America. He refutes the benefit of a consensus constructed as an ideology to ensure trust and stability in the future. This security arose from a growing bureaucracy and a suffocating administrative hierarchy that shaped the individual to create corporate harmony. Essentially, Whyte (2002) criticized the social ethics ideal of a reality in which societal requirements were identical to individual needs, and organizational and social moral goals were aligned. Just as selfish individualism does not work, neither does comprehensive consensus. (Whyte, 2002) warns that there is nothing against conformity; however, "unless one believes in the ennoblement of poverty," there is the danger of the unconsciousness of individual surrender.

Whyte exposes the creation of a specialized elite of qualified leaders who will guide humans indulgently to group membership, which is the second pillar of the attempt to unify society. This desire to belong to a group began in childhood, and schooling reinforced it. According to Whyte (2002), Mayo previously identified this requirement, where the workers belonged to a "social system; the system was informal, but it determined the worker's attitude towards their work," essential engagement was more relevant

than any physical privileges. Thus, the doctrine of human relations that was once a dissident became orthodoxy (Whyte, 2002).

The man in the organization intends to show that the hedonism he promotes and lives in is moral, even when based on the involuntary abstinence of others. It became clear when, in an interview, Whyte (1982) mentioned that many decision-makers hide behind the adage "common good" to shield their decisions when they do not follow any strategy. Whyte (2002) warned of a stultifying climate in education in the United States of America concerned with using engineering tools, applying ideas, knowing the how, and ignoring the why, which contrasted with the teaching of fundamental disciplines in Europe. Whyte (2002) warns that employee specialization becomes a concern in firms when each department develops its lexicon and insufficient overall communication. At each level, there needs to be a kind of "interpreters." Furthermore, participation in defining the organization's global objectives suffers from a lack of ecumenical knowledge.

3.12. Fusion Process

At the same time that Whyte criticized the logic of a social ethic that subjugates the individual to a collective will, a group of researchers developed a theory called the "Fusion Process."

"Fusion Process theory recognizes the existence of separate goal needs of individuals and of the organization

Fusion Process theory recognizes that organization

- is a dynamic activity
- includes formal and informal behavior
- is an open system

Three processes are described:

socializing: activities contributing to organization goals

personalizing: activities contributing to individual actualization

fusion: simultaneous operation of personalizing and socializing" (Pffner & Sherwood, 1960).

One particularity of the ideas associated with the Fusion Process is the conviction that

“the individual and the organization are unique whole entities, and that in the mind of the individual and in the mind of the agents of the organization respectively there is a conception of this wholeness and uniqueness. Both the individual and the agents of the organization, moreover, have a tendency to structure and respond to all stimuli in terms of their impact on the possibility for maintaining, developing, expressing, and realizing this conception of unique wholeness, that is the possibility for self-actualization” (Bakke, 1955)

Argyris (1954b) observed that informal activities were antagonistic to the formal requirements of the organization. Argyris does not suggest resolving the dissociation between formal and informal organizational parts by following a forced socialization process as Ford attempted (Meyer, 1980). In the decision-making process, solving human relations problems separately, as if they were independent of each other, inevitably brings more difficulties (Argyris, 1954a).

Among the main prerequisites for making effective decisions in human relationships, leaders need self-knowledge and self-consciousness. However, it is almost impossible for the executive to be objective. He will tend to see the facts he wants or needs to see (Argyris, 1954a). Another vital rule for the executive making human relations decisions is to know employees' feelings and opinions about problem-solving. Typically, employees are subordinates and dependent on their bosses, even though this dependence is not appreciated because people tend to strive for independence (Argyris, 1954a). Integrating the individual into the organization and the awareness of reciprocity are distinctive in leadership using the Fusion Process, as shown in Figure 3.2.

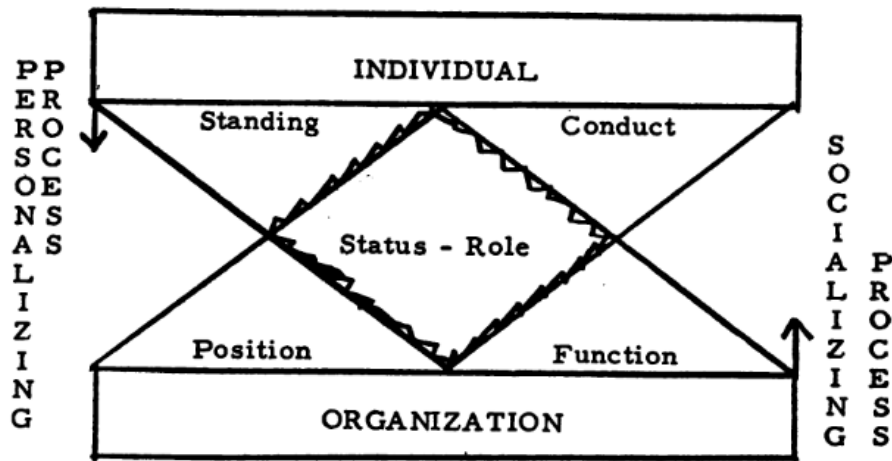


Figure 3.2: The Fusion Process (Bakke, 1955).

3.13. Barnard and cooperation

Sometimes, management assumes that leaders must be indolent, without the ability to manipulate people. The intention of absolute freedom is humanly impossible, while any organization needs laws that maintain a specific order. The ability to induce, persuade, or manipulate others, maybe perversity for some, is an inherent property of the leader's role. As for the ability to influence, after being asked about some riots and getting the jury to support his ideas, Barnard (1946) answered whether his arguments allowed the jury to deliberate the conclusions or whether he did it for them:

"[...] That's the nature of social interaction. That's life in the world. You just can't escape that. [...] What was being done to them was to get their own answers. Get people to answer your problem your way because it makes it their problem and they want it that way. That's the really high art of this thing. Don't get yourself in the state of mind that there's something immoral about trying to persuade people. One of the members of the Graduate School of Arte and Sciences calls Machiavellian because we did try to influence behavior of people. He wrote me about it. I wouldn't say who he was, but I thought that was what he was trying to do. I thought that was the purpose of education" (Barnard, 1946).

The Theory of Human Relations, or School of Human Relations, which emerged after the Great Depression and with the presentation of Hawthorne experiments, is often criticized for its intention to influence people to produce better. As previously emphasized, Follet's ethics should be limited only to the meaning of "better."

Barnard (1946) notes two relevant aspects. Influence exists in all social systems and happens when the group accepts the individual problem. It is the form of acceptance that management must reflect. Acceptance can appear through subjugation, competition, consensus, or integration. But, as Follett (1930) highlighted, only with integration, with full collective consciousness, does acceptance instigate collective responsibility. In other cases, the commitment is mainly because of the behavior of key governance bodies.

For Barnard (1968), authority is an attribute guaranteed by consent, i.e., by individual acceptance of an established domain. This judgment contradicts the generalization of formal organizations that assume intrinsic authority. The manifestation of personal freedom determines the existence of coalition mechanisms that allow organizations to remain coherent. Connection between members occurs through communication, contribution, and a common purpose.

Communication is the process responsible for organizational dynamics. Everyone should be aware of the organization's common goal. However, communication does not constantly require synthesis or feedback to confirm collective formulations. For example, consent to decisions, as revealed by Rivers (1924), in some relatively small groups, is often made and acted upon without explicit formulation. This phenomenon transcends the formal structures of organizations.

While management tries to find jargon for the parties involved in organizations, Barnard (1968) considered everyone a contributor. This reductionist simplification has the advantage of specifying the outcome as the fundamental justification for the participation of some members in a particular process. Thus, individual consent that establishes coordinating authority depends on the success of profits resulting from collective actions. If an individual member feels he achieves more benefits alone than with the organization, he leaves the organization.

After highlighting communication and the desire to contribute (serve), Barnard (1968) proposes purpose as a third aggregating element in organizations. However, one must distinguish between the objective of the organization and the individual motive. "It is frequently assumed in reasoning about organizations that common purpose and individual motive are or should be identical. [...] under modern conditions it rarely even appears to be the case" (Barnard, 1968). The justification of the divergence occurs because the individual motive is internal, personal, and subjective, while the common purpose is external, abstract, and impersonal. It does not mean that individual and organizational purposes are opposites. It only reveals that they belong to different dimensions and are difficult to harmonize.

3.14. Organizational structures and efficiency

The complexity of human social controls requires restrictions. The organization can consume itself in its bureaucracy if there are too many restrictions with too many details and hierarchical levels, whereas the absence of constraints can render the system function useless and on the verge of anarchy. Hierarchical controls arise due to the degree of internal restriction that forces the elements to a simple collective behavior, i.e., independent of the individual dynamic behavior. It is emphasized again that a hypothetical ideal level of restriction cannot be precisely specified but lies between the extremes of strict determinism and stochastic chaos. It is significant that the concept of “autonomy” or “freedom” restricts itself to behavior between these extremes and develops by adding and removing restrictions (Pattee, 1973).

As reality settles between the utopias of total control and the absence of control, all organizations work in a hybrid way that simultaneously contains the properties of open systems and closed systems. In the ambiguity of hybridity, a combination of organizational design archetypes stands out (Skelcher, 2007). Ambiguity emphasizes the tendency of complex structures to be scale-invariant and exhibit a dilation that can apply all scales of an individual to an entire system (Drucker, 2011).

Despite the inherent introduction of inefficiencies, the manufacturing processes proposed by Industry 4.0 cannot exclude the hierarchical organization. All systems, up to Big Data and Artificial Intelligence, work with compression of information to support decision-making. In any organization, the management of these selection processes depends on decomposing social network data into clusters and forming the corresponding hierarchical organizational structure (Enaleev & Tsyganov, 2019). The challenge in organizations is to discern the truth in a context where elements have conflicting goals, and there can be a deliberate distortion of the information circulating in the system. Thus, the need for specific heuristic processes of simplification and semantic transformation allows the emergence of knowledge that improves the quality of the decision.

The inevitable incomplete observation of the system creates uncertainties, requiring organizations to increase contributions and observation points to decrease uncertainties and calculate them more accurately. This requires collaboration that results not from a process of consent, but from conscious integration. Condescending management does not promote learning.

The creation and acceptance of proverbs are perennial, even in science that uses them as commandments. Herbert Simon (Simon, 1946) investigated some of Fayol's (1917) administrative

efficiency principles, namely, that organizational efficiency is dependent on specialization, the exclusivity of authority, and a limited command scope. However, it is possible to refute these three principles:

a) Specialization designates not only function but location as well. Since it is not possible for two people to do the same thing in the same place at the same time, the notion of efficiency through specialization is subjective because two people are always doing different things (Simon, 1946).

b) The concept of authority requires the subordinate to change his behavior regardless of his assessment of the decision's merit. Thus, in the absence of virtuous choices, the principle of a single authority, besides weakening efficiency by the entropic effect of time, always has a lower certification than a collegiate decision as long as it has an odd number of elements. On the face of it, a single authority can make judgments quickly but not more efficiently.

c) While limiting the number of subordinates per foreman is beneficial to the organization's efficiency; on the other hand, as an organization grows, it inevitably increases the number of hierarchical levels, which decreases the overall efficiency of the system.

3.15. Specialization

Specialization increases the need for cooperation between people and between people and machines, forces the creation of groups, and increases the complexity of systems. The existence of teams depends on ethical compliance and may not advocate better results (Whyte, 2002). In management, the term synergy is often a myth.

Specialization itself does not increase the number of hierarchical levels; it can only make them more complex.

In the case of Industry 4.0, the horizontal integration of "things" replaces or assists existing parts at a given hierarchical level. Ultimately, the overall efficiency of an organization's elements depends on the type of integration. In horizontal integration, the efficiency (E_h) of n elements, individually with an efficiency E_{hi} , and a productivity factor x_i , where the sum of x_i is equal to 1, can result in Equation 7 if the processing at this hierarchical level is parallel for different products or services.

$$E_h = \sum_{i=1}^n x_i E_{hi} \quad (7)$$

For example, consider the contribution (x_2) of a robot to a given operation that was previously performed only by the work of one person (x_1). The new total system E_h , in Equation 8, integrates the robot efficiency (E_2) and the efficiency of the previous human work (E_1).

$$E_h = x_1 E_1 + x_2 E_2 \quad (8)$$

As the efficiency and production capacity of the machine is superior to the previous values of exclusively human work, the new total operational efficiency will be close to the value of the robot. Hence the justification for the horizontal integration of cybernetic automatisms in systems is to increase the quantity and quality of production.

However, increased production can have perverse effects on the economy. The horizontal integration of things in manufacturing will have a higher impact on productivity than on efficiency. As x_2 is much larger than x_1 , the sharp rise in production has to be absorbed by the economy. The complexity of the new products will use up some surplus, but the economy has to include the rest, which, due to constant competition, could end up in overproduction. Note that this was one of the reasons for the Great Depression of 1928 (which manifested itself in the October 1929 stock market crash). The risks may come from the slowdown in population rise and the reduction in the consumption of people who do not keep up with the growth of production. While Industry 4.0 can predict manufacturing gains, it can also have catastrophic consequences on the economy and society.

As shown in Equation 9, as serial processing, the efficiency of vertical integration (E_v) results from the product of the efficiencies (E_{vi}) of each of the n hierarchical levels.

$$E_v = \prod_{i=1}^n E_{vi} \quad (9)$$

If the integration of cybernetic automatisms requires new hierarchical levels without changes in the organizational structure, the new total efficiency would always be lower than that of the original system.

Although it does not exclude Simon's argument, the integration of the "things" of Industry 4.0 must be horizontal and parallel so as not to compromise the control of the changes made, since the vertical integration of a new level only fits into the (2). Management must recognize the impact of individual novelties to admit potential synergies. Controlling an integral vertical split requires a new standard, i.e., meaning it belongs to another organization.

Management can model it, but remember Tsyganov (2019) that one of the biggest problems in adopting any innovation in an organization is the impossibility of strategic management to consider all the adversities that only production personnel know during the change process. Ignorance not only increases the “risks, costs and time of innovation but also makes adaptive identification algorithms ineffective.”

3.16. Authority

In his analysis of the “Shop Management” (Taylor, 1911), Fayol (1917) agrees with Taylor (1911) on the need to strengthen chiefs and foremen with a General Staff but disagrees when Taylor doubts the virtues of “military-type” organizations, denies the principle of the command unit, and admits a worker under the orders of two masters. Despite his admiration for Taylor’s work, Fayol does not relinquish the principle of unity of command, and while he acknowledges that it may have worked because of Taylor’s skill, he doesn’t believe in the merits of violating that principle.

Considering Fayol’s thesis, it is possible to verify whether two chiefs (C_1 , C_2) who command the same subordinate (S) improve the accuracy of orders. Table 3.1 shows the result of a similar accuracy of chiefs’ orders. In this case, they have a 95% probability (p) of getting it right.

Table 3.1: Effect on the quality of a decision in the case of a subordinate headed by two chiefs with the preference of one chief (C_1), in the case of a tie.

C_1	C_2	S	Result	Probability of occurrence of an event		
0	0	0	Unwanted	$0,05 \times 0,05 =$	0,0025	5%
0	1	0	Unwanted	$0,05 \times 0,95 =$	0,0475	
1	0	1	Wanted	$0,95 \times 0,05 =$	0,0475	95%
1	1	1	Wanted	$0,95 \times 0,95 =$	0,9025	

0's mean a wrong decision while 1's a good one.

Table 1 reports that the subordinate, in case of a tie, prefers the C_1 . However, the result would be the same if the subordinate had a purely random behavior of 50% preference for each of his chiefs. The probability of getting each chief’s verdict right is equal. Therefore, mathematically, it results in the same

values in case of a tie of contradictory orders. It is also noteworthy that the subordinate behaves like an unconscious actuator that responds to binary decisions.

The result corroborates the saying: “A man with one watch knows what time it is. A man with two watches is never sure” (Bloch, 1977). The proverb, like Table 3.1, highlights that management must reject that more and better are synonymous.

The human organization, which, due to its adaptability and interactivity characteristics, integrates the most complex category known as the self-organized system, reminds us that there are no completely hierarchical organizations. Aware of this situation, the desire to classify the interacting elements of complex systems can constrain the flexibility and adaptive fitness characteristic of self-organized systems (Crumley, 1995).

This self-centered interpretations influence the perception of the environment and, consequently, are applied in communication, negotiation and other similar pragmatic instruments that occur in the implementation of concurrent engineering (Popovic, Putnik, Jasko, & Filipovic, 2013), which share a kind of “efficiency” and whose coordination “implies the common goal of (members) of the engineering/project team” (Putnik & Putnik, 2019). The result in Table 3.1 depends on the human capacity for change. It applies to things like sensors embedded in a network or people who behave like machines.

Deterministically, with chiefs with different abilities and hit probabilities, the most capable element of the group anchors the highest result in the case of a duality. However, with dialogue and collaboration, faced with the inevitable disagreements of complex situations, the result can be better than provided by the best chief. Taylor (1911), according to Fayol (1917), promoted and achieved this.

Table 3.2 shows the improvement in the result of the system when the subordinate receives orders from three chiefs who, equally, have a 95% probability of success in decisions they make.

Although the quality of decision enforcement has improved with three chiefs, it is prudent not to forget that humans are not machines. The dynamism of human systems and egos can make this assumption inconsistent. Hence the importance of ethics and behavior in organizations, from top to bottom.

Table 3.2: Effect on the quality of a decision in the case of a subordinate headed by three chiefs.

C ₁	C ₂	C ₃	S	Result	Probability of occurrence of an event	
0	0	0	0	Unwanted	0,000125	0,725%
0	0	1	0	Unwanted	0,002375	
0	1	0	0	Unwanted	0,002375	
1	0	0	0	Unwanted	0,002375	
0	1	1	1	Wanted	0,045125	99,275%
1	1	0	1	Wanted	0,045125	
1	0	1	1	Wanted	0,045125	
1	1	1	1	Wanted	0,857375	

With the notions presented in Table 3.1 and Table 3.2 and considering n the number of chiefs per subordinate, p the probability of accuracy of the single decision and P the probability of accuracy of the decision made by n chiefs, it is possible to classify the qualities of the decisions through Equation 10 and Equation 11.

If n is an odd number:

$$P_n = \sum_{i=\frac{n+1}{2}}^n \prod_{j=0}^{i-1} \frac{n-j}{j+1} p^i (1-p)^{n-i} \quad (10)$$

If n is an even number $P_n = P_{n+1}$, or:

$$P_n = \sum_{i=\frac{n}{2}}^n \prod_{j=0}^{i-1} \frac{n-j}{j+1} p^i (1-p)^{n-i} - \frac{1}{2} \prod_{j=0}^{\frac{n-2}{2}} \frac{n-j}{j+1} p^{\frac{n}{2}} (1-p)^{\frac{n}{2}} \quad (11)$$

For the reasons indicated in Table 3.1, the second part of Equation 11 disregards half the value in tie situations. Such a situation, humanly, as already mentioned, can be overcome.

(4) and (5) use the same probability of hit decision for all managers. Although this is a simplification, it assumes that, over time, systems tend to be homogeneous, creating stability until they reveal

inconsistencies. The good tends to be associated with good and inept to be associated with inept, and systems tend to balance each other, implying similar probabilities of success for board members in the decision-making process.

Table 3.3 contains some values that show the impact of orders arising from collective decisions.

Table 3.3: Accuracy in decisions made by a collective of n elements with an individual accuracy of 95%.

	Number of chiefs per subordinate						
	1	2	3	4	5	6	7
Probability of getting it right	0,95	0,95	0,99275	0,99275	0,99884	0,99884	0,99981
	0,90	0,90	0,97200	0,97200	0,99144	0,99144	0,99727
	0,80	0,80	0,89600	0,89600	0,94208	0,94208	0,96666
	0,70	0,70	0,78400	0,78400	0,83692	0,83692	0,87396
	0,50	0,50	0,50000	0,50000	0,50000	0,50000	0,50000
	0,30	0,30	0,21600	0,21600	0,16308	0,16308	0,12604

There is symmetry at $p=0,5$ in the discrete distribution resulting from Equation 10 and Equation 11, as observed, e.g., for $p=0,3$ and $p=0,7$. In random decisions, randomness remains.

The graph in Figure 3.3 summarizes these features (symmetry, inflections, and the neutral effect of groups with an even number of elements).

Figure 3.4 shows how a collective decision of four members results. In the representation of p is the accuracy of individual choice, and q is equal to $1-p$.

Events marked with a bold letter represent the tie situations.

Figure 4 confirms the existence of a homothety, a symmetry, and binomial expansion with hierarchical (flagged in the product) and heterarchical (flagged in the sum) characteristics present in Table 3.1 and Table 3.2 and Equation 10 and Equation 11.

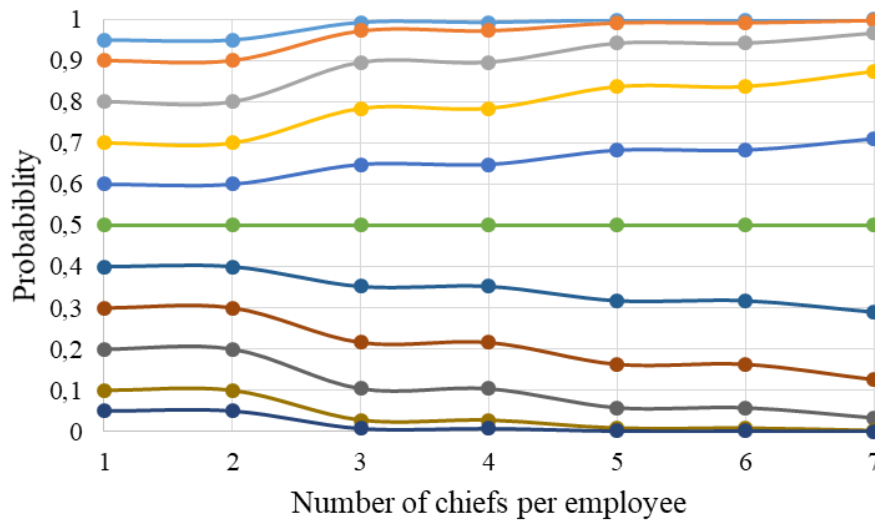


Figure 3.3: Effects of the number of elements in the quality of a decision-making process.

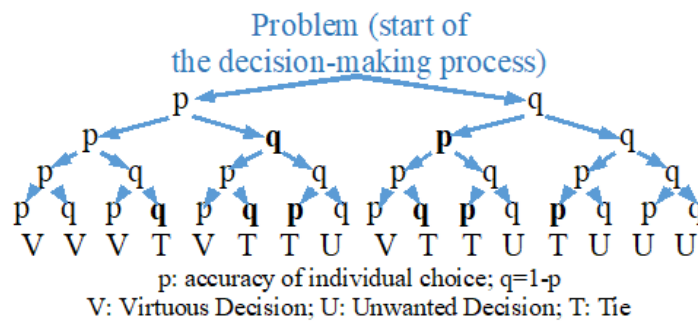


Figure 3.4: Efficiency of a group of 4 decision-making elements.

3.17. Hierarchy efficiency

Until now, the concern was at the top of the hierarchy of organizations. This section looks at the effect of power relations at the bottom.

One of the characteristics of hierarchical levels is the number of subordinates assigned to each chief. However, at the bottom of the organization, the foremen usually commands a higher proportion of workers. In the hierarchical structure shown in Figure 5, each foreman commands six workers. At the following levels, there is a ratio of four subordinates to each leader.

In this example, the total number of base workers (T_n) in the organization is 384, the total number workers (T) is 468, excluding the top level of CEO.

The total number of workers is a geometric distribution (Fayol, 1917) presented in Equation 12.

$$T_w = wc^n \quad (12)$$

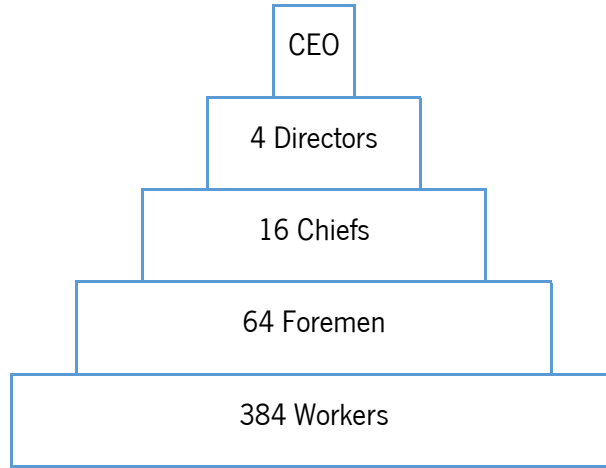


Figure 3.5: Example of an organization's hierarchical structure.

The proportion of workers per foreman, or span of control in the bottom of the hierarchy (w) is the initial value, n is the number of leadership levels, excluding the top level of CEO, and c is the common ratio between leaders.

From Equation 12, one can calculate Equation 13 that is the ratio between the number of workers present in the base and the total number of people in the organization, which, in this document, is called hierarchy efficiency (E_H).

$$E_H = \frac{T_w}{T} = \frac{wc^n}{wc^n + \sum_{i=1}^n c^i} \quad (13)$$

Since, rationally, the number of chiefs is less than the number of workers at the bottom, E_H is limited by Equation 14.

$$\frac{w}{w+1} \geq E_H > \frac{w}{w+2} \quad (14)$$

Keeping the same ratio at the bottom of the hierarchical structure shown in figure 5, i.e., six workers per foreman, Table 3.4 could be filled in with Equation 13.

As two hierarchical levels consider only workers and foremen, the value of E_H is the same, as chiefs only make up the structure above the second level. The value of E_H is the higher limit revealed in Equation 13, i.e., 6/7. For this example, using Equation 14, the minimum value of E_H is 6/8 (75%).

Table 3.4: Hierarchy efficiency in organizations with $w=6$, a different number of hierarchical levels and ratios of headship.

		Number of subordinates assigned to each chief at the top of the hierarchy			
		2	3	4	5
Number of hierarchical levels	2	0,857143	0,857143	0,857143	0,857143
	3	0,800000	0,818182	0,827586	0,833333
	4	0,774194	0,805970	0,820513	0,828729
	5	0,761905	0,801980	0,818763	0,827815
	6	0,755906	0,800659	0,818327	0,827632
	7	0,752941	0,800220	0,818218	0,827595

Table 3.4 also shows that the best E_H results are on the right side, although the damage is negligible when organizations go beyond four hierarchical levels. However, usually, only large companies have more than four levels. In addition to the context benefits, they also benefit from its structure.

Through Equation 14 it is possible to obtain the graph on Figure 3.6 that shows the limits of the relationship between hierarchy efficiency and span of control. The higher the hierarchy efficiency value has, the broader the span of control values will be, which is interlinked with the Promethean's desire to reduce hierarchical layers. However, the solution is not simple.

From Equation 14, one can Equation 15.

$$\frac{E_H}{1 - E_H} \leq w < \frac{2E_H}{1 - E_H} \quad (15)$$

In Equation 15, when E_H approaches 1, w tends to infinity. As E_H also depends on the number of hierarchical layers in the structure, for high values of E_H , the greater the range of possible values for the span of control will be.

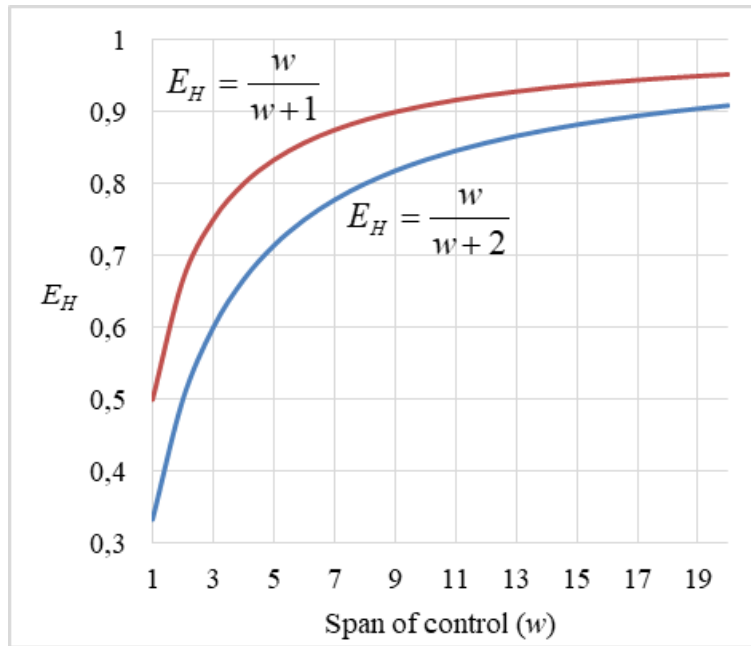


Figure 3.6: The dependence of the hierarchy efficiency on the span of control. Obtained by the interval of Equation 14.

3.18. Cybernetics

Cybernetics, etymologically formed from the Greek κυβερνήτης, meaning governor or helmsman, is dedicated to the study of control and communication in the machine or in the animal (Wiener, 1985). Cybernetics values feedback mechanisms, such as the PID control proposed by Minorsky. The novelty proposed by Wiener in the 40s of the twentieth century was the expansion of the concepts of control and communication, which made it possible to observe the existence of a new ecosystem formed with machines and humans as an “multigenic” network. Thus, decisively, the concepts of thermodynamics invade biology and the concepts of biology are mimicked in mechanics and electronics.

Uncertainty arises not only from the quantum physics discoveries of Heisenberg, Schrödinger, and others, but also from the improbable relationships of different species, living or inert, whose joint properties are probable rather than exact. Faced with the perennial uncertainty in organizations, they only partially understand the past and in a volatile present they can only assume the future. All guarantees are illusory.

In the preface to the book “The Three-Body Problem and the Equations of Dynamics: Poincaré's Foundational Work on Dynamical Systems Theory” (Poincaré & Popp, 2017), from an 1890 translation, it is suggested through Hilborn (2000) that if Poincaré had a computer, the field of nonlinear dynamics

would currently be more developed, i.e., if Poincaré had more technological resources it would have better results. This conjecture, with current knowledge, is impossible to prove or disprove. However, the non-Euclidean geometry and complex dynamical systems impels imagination and creativity, factors that technology, *per ipsum*, does not solve.

3.19. Learning culture

In organizations, homeostasis is not a permanent state, which requires them to possess the faculties of learning and reproduction, characteristics of living systems. Learning reveals the ability to be transformed by the environment, and reproduction the ability to multiply other beings with hereditary similarities (Wiener, 1985). In this sense, learning will only be sustainable in open organizations. The more closed the organization, the more the organization's ability to learn languishes. Organizations in the evolutionary process always undergo transformations and disaggregations and, at the same time, preserve hereditary patterns.

Management must assess the adequacy of the organizational culture, identify dysfunctionalities, and promote its transformation, first by changing its learning assumptions and then applying the beliefs in its culture. In general, people want to contribute and be an active part of the organization, making it imperative that the learning process belongs to the dynamics of the organizational culture. These learning processes can benefit from the adoption of prescriptions regarding structures, processes, and organizational conditions, for example (Argyris, 1999):

- Flat and decentralized organizational structures;
- Open information systems that supply quick feedback systems that enhance organizational transformations;
- Heuristic mechanisms;
- Organizational performance measures;
- Encourage individual learning and collective (organizational) learning;
- Promote continuous learning with openness and boundary-crossing.

The new ways of organizational learning propose to people a holistic experience, in a sustainable, agile and digital ecosystem, with dialogic decision-making processes, which expand the concepts presented by Senge (1994). This organizational way of learning is not a routine dominated by repetition – re-

evaluation, revision, renewal, and new inquiry. It is a practice that does not replicate the same experience, which follows a specific formula. It is a new path based on difference (Deleuze, 1994). However, the value of these thoughts is usually discarded in order to simultaneously correspond to individual and collective interests in organizations (Antonacopoulou, 2019). Learning is a collective and multidimensional process.

The theories and practices that organizations claim to follow often differ from those they use. Organizations almost consistently use single-loop learning, correcting existing methods and policies in a single cycle. There are other ways to learn. Double-loop learning challenges the policies, goals, and values that underlie existing methods, enabling better adjustments to contextual uncertainties. There is also triple-loop learning, presented in the Figure 3.7, an organizational meta-learning, which allows you to reflect on your learning processes and paradigms (Argyris & A. Schön, 1978). In this process, it is possible to find organizational patterns, allowing the organization to change its perspective on learning and opening new paths for understanding and solving problems.

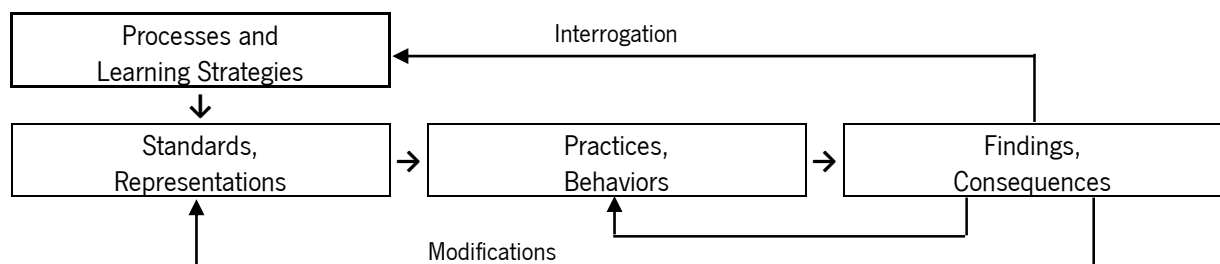


Figure 3.7: Triple loop learning cycle, adapted from (Argyris & A. Schön, 1978)

However, publications with triple-loop learning do not clearly establish an implementation of the process. Thus, it is difficult to state in the modelling that this learning can mutually benefit the different interveners *in situ* and that, at the same time, it is simple to implement (Barbat et al., 2011).

Learning arises in different situations from various forms of organization according to the use of learning, as shown in Table 3.5 (Argyris & A. Schön, 1978).

Learning requires continuous and dynamic interaction between the different components of a system. Interaction encourages open communication and collaboration among employees. Organizations can improve through interactive, collaborative, and group learning, cultivating the free flow of ideas and knowledge.

Table 3.5: The several forms of organization according to the use of learning (Argyris & A. Schön, 1978).

Theories of organizational learning	Approaches associated with learning
1. Organization as a group	Social psychology
2. Organization as an agent	Instrumentalism, Management Theory
3. Organization as a structure	Sociology, Theory of bureaucracy
4. Organization as a system	Cybernetics, Information Theory
5. Organization as Culture	Anthropology, Ethnomethodology, Phenomenology
6. Organization as a policy	Political Theory, Theory of Socio-Political Movements

Learning is recursive and influences the organization's future, with regular feedback and reflection mechanisms that help organizations learn from their experiences. Promotes self-organization, giving employees more autonomy to take initiative and make decisions, creating more agile and resilient organizations. Morin (1992) suggested the Tetralogical cycle, with the Feedback loops shown in Figure 3.8, to help organizations in increasingly complex environments.

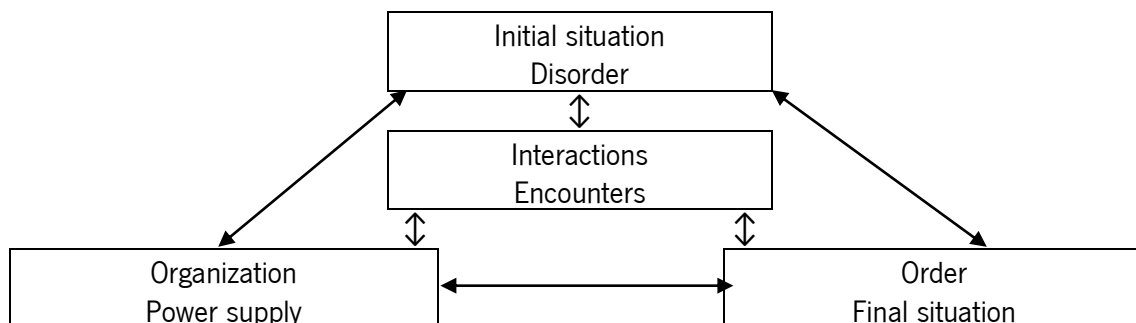


Figure 3.8: Tetralogical cycle according to Edgar Morin (1992).

Parallel to the thought that *Repetitio est mater studiorum* (Repetition is the mother of learning) embodied in the sentence “any book that is at all important ought to be at once read through twice” (Schopenhauer, 2017) emerges the medieval saying *Magister rerum usus; magistra rerum experientia* (Use is the master of things; experience is the owner of things) which posits experience as the path to discovery (Wootton, 2015), since one does not learn to ride a horse or shoot an arrow by reading books. In the case of the book, a second reading creates different and new connections, a new view of each passage, and the

emergence of new meanings (Schopenhauer, 2017). Whatever the origin of knowledge, Plotinus' (2018) thesis that if "Knowledge, if it does not determine action, is dead to us".

Cultural change requires metanoia. Metanoia is a fundamental change in mentality. It is essential for creating an integral learning culture in organizations (Senge, 1994). Leaders are vital in promoting and supporting metanoia, encouraging a culture that values continuous, adaptive learning and reflection in an ever-changing world.

Leadership can influence and shape culture and impact organizational effectiveness and the capacity for change (Schein, 1985). Naturally, rigid organizational structures will be less prone to change. On the contrary, organizations based on adhocracy, with flexible and decentralized government systems (Mintzberg, 1993), facilitate the adoption of a culture that nurtures and is nurtured by dynamic, creative, and agile.

3.20. Technology culture

The culture of technology in classical management theories has evolved for different purposes. Initially, the so-called Scientific Management, proposed by Taylor (1913), focused on individual tasks and worker efficiency. Fayol's (1917) administrative management attempted to improve the organizational structure. In parallel, some supported Weber's (1946) ideas of organizations based on a structured hierarchy and formal rules. On the other hand, Mayo (2004) tried to use technologies to strengthen human relationships and improve worker satisfaction to increase productivity.

After World War II, many scientific areas focused on network studies. Mathematics, Physics, Sociology, and Cybernetics, among others, observe systems as sets of subsystems, which can cause relationships with unpredictable consequences. Thus, the Internet we know today no longer has the same purposes as when it began. Even today, organizations still try to find ways to integrate networks into production systems (in networks of networks).

Technology in classical theory wanted simultaneously to improve machine and human performance to produce more. In teleological terms, the culture of technology in classical theories was to produce more with less. Although there was never a clear intention to make it differently, the natural evolution of contexts has imposed some changes. However, reality requires integrated models that consider parts of autonomous units within other units, i.e, systems within systems (networks within networks).

4. Modern Management Theory based on Complexity

Classical management models are limited in describing current organizational processes, requiring a new set of theories and new metaphors (Fiol, 2017). The classic management idea assumes the organization is like a machine (even trying to mechanize human behavior).

Management theories are emerging that seek to stimulate more decentralized and distributed forms of intelligence, favoring interactions between organizational parts that are less interconnected and, thus, overcoming individual limitations. In these management models, meanings are not imposed a priori from a centralized space; they emerge from the process (Fiol, 2017).

4.1. Complexity

The environment is more complex than the models that organizations use to interpret it in the classical theory. As management recognizes oversimplification as a strategic deception, it needs to understand the complexity. This does not mean the creation of more complex, bureaucratic organizations that compromise a rapid and flexible response to strategic challenges. In this context, organizations must, in addition to the formal structure, consider the systems and relationships that enable an open flow of information. Rules, values, and beliefs must be shared, and inclusive, to take advantage of all the mental and physical abilities of all agents. This entails developing a network of perspectives and flexible relationships in the mind of each agent and in the organization itself (Barlett & Ghoshal, 1990).

Increasingly, managing complexity depends on all the physical, organizational, human, social, and political interfaces that need to remain agile in an ever-changing industrial world (Roucoules & Anwer, 2021).

Figure 4.1 shows the underlying indeterminacy of complex systems. The apparent irregularity of patterns in the different activities depends on the co-evolution of three variables (digitalization, product development, and organizations) (Roucoules & Anwer, 2021).

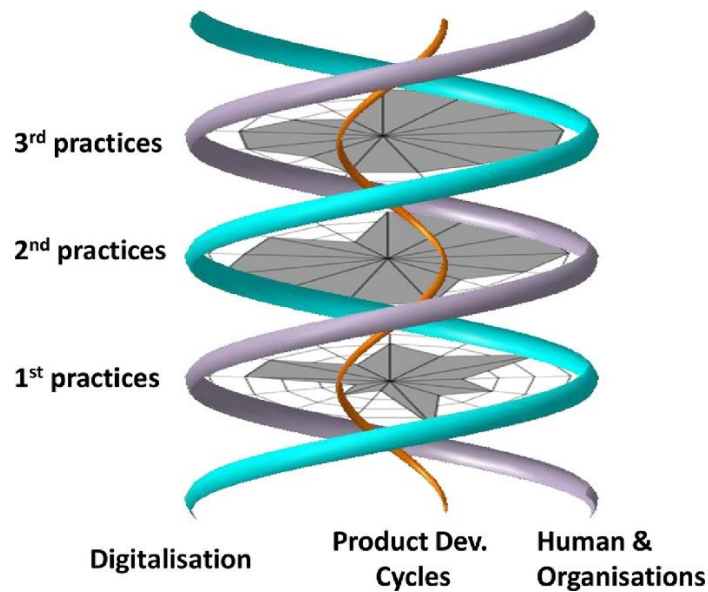


Figure 4.1: Co-evolution of digitalization, product development cycle, and organizations (Roucoules & Anwer, 2021)

For Arthur (2015), complexity is not a theory, but a movement in the sciences that studies patterns. Complexity is about formation—the formation of structures—and how that formation affects the objects that cause it. Complexity questions how individual behaviors can react to the pattern and how changing individual behavior results in the pattern. It is questioned how a process is created from the proposed actions of various agents (Arthur, 2015).

The complexity of organizations is not reduced to the behavior of the organizations themselves. Table 4.1 shows, through the metaphors of following a recipe and raising a child (Westley, Zimmerman, & Patton, 2009), the differences in expected outcomes between simple and complex problems. While in simple problems the context variables (internal and external) are controllable, in complex problems trying to control the context variables can mean a large expenditure of resources with no guarantee of success. In fact, the measure of success is always subjective and circumstantial.

Certainly, given the complexity and flexibility of individual and collective behavior in organizations, no explanatory scheme will be correct all the time (Esbjorn-Hargens, Zimmerman, & Bekoff, 2011).

Table 4.1: Characteristics of a simple process (following a recipe) and a complex process (raising a child) (Westley, Zimmerman, & Patton, 2009).

Following a Recipe	Sending a Rocket to the Moon	Raising A Child
The recipe is essential	Formulae are critical and necessary	Formulae have a limited application
Recipes are tested to assure easy replication	Sending one rocket increases assurance that the next will be OK	Raising a child provides experience but no assurance of success with the next
No particular expertise is required. But cooking expertise increases success rate	High levels of expertise in a variety of fields are necessary for success	Expertise can contribute but is neither necessary nor sufficient to assure success
Recipes produce standardized products	Rocket are similar in critical ways	Every child is unique and must be understood as an individual
The best recipe give good results every time	There is a high degree of certainty of outcome	Uncertainty of outcome remains
Optimistic approach to problem possible	Optimistic approach to problem possible	Optimistic approach to problem possible

A system is made up of parts that manifest their own behavior and can interact with each other. Feedback loops, presented in Figure 4.2, can be present between elements and the interaction and modulation of these elements in different contexts results in a dynamic system, generating a specific output in response to the particularities in the input at a given time.

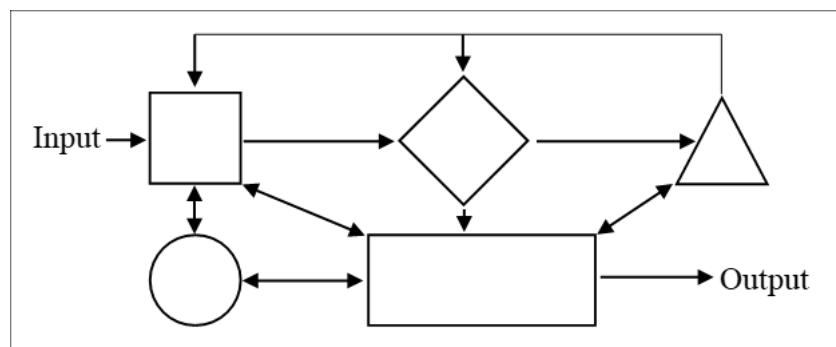


Figure 4.2: System as a composition of different elements that interact with each other (Higgins, 2002).

For Higgins (2002) “complexity is the property of a real-world system that is manifest in the inability of any one formalism being adequate to capture all its properties. It requires that we find distinctly different ways of interacting with systems.” Complexity responds to the constraints of traditional scientific practices, which, despite many impressive advances, observe and explain systems through polarized lenses with a mechanistic, reductionist, restrictive, and limiting view. For example, to study self-organizing systems that require a continuous source of external energy to function away from thermodynamic equilibrium, it is necessary to remove the barriers and constraints that prevent a more comprehensive view of the nature of the systems. These systems dissipate energy to create and maintain order. The development of order decreases the entropy of one system to the detriment of other systems (Higgins, 2002).

Chua et al (2002) point out that if the rules associated with a given system are simple enough, then the system will behave in a purely repetitive manner. However, the combination of very simple rules can lead to the emergence and production of highly complex behaviors in systems (Chua et al., 2002). Although the complexity of a system requires a threshold that is distinct from simple systems, this threshold is usually extremely low.

Senge (1994) warned that the complexity of an organization's design is significantly increased by individual and collective human behavior and the effect of that behavior being part of the system itself. Hence the importance of collaborative leadership and self-organizing systems in the design of organizations.

However, organizations' design models cannot ignore the temporal dimension. A system's structure (form) and behavior pattern (function) are not static but change over time. They fluctuate within a range of probabilities that is part of the complex system (Testa & Kier, 2000), as shown in Figure 4.3.

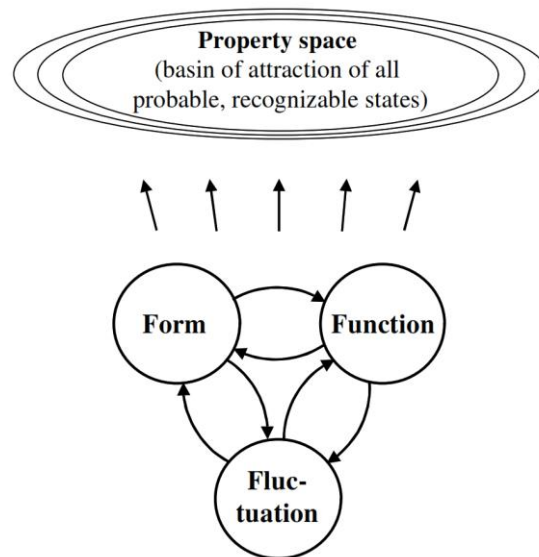


Figure 4.3: Form and function of a system fluctuate to produce a number of formal and functional states (Testa & Kier, 2000).

Understanding complexity requires understanding the interdependence of systems and the existence of patterns. It is an increasingly dominant characteristic in organizations, and influences the decision-making process due to the multiplicity and diversity of agents, variables, and technologies involved. Complexity makes decision-making processes more complex, leading to unique decisions.

Ignoring the complexity, conflict is widespread as a trend, although it is difficult to prove. One of the most intuitively sensible proofs is the economic idea of scarcity. The idea of scarcity is not limited to the availability of resources, but also to the transience of information and the complexity of social relations that, in addition to requiring increasing intellectual and interpersonal capacities, require greater amounts of time. Paradoxically, however, quick decisions are required in increasingly complex environments.

Conceptually, management in a complex environment requires particularities different from classical management models. Table 4.2 shows some differences between classical management models (simple and reductionist) and the model that acts in a complex way on complex management problems.

Table 4.2: Techniques of managing the decision-making process.

	<i>Management Approaches</i>		
	Simple	Reductive	Complex
Question:	What?	Why?	How?
Action	React	Reform	Transform
Change	Conjecture	Structure	System
Paradigm	Control	Learn	Learn to learn (Unlearn)
Evolution	Regression	Progression	Revolution
Position	Submission	Adaptation	Disruption
Thinking	Doxa	Science (Episteme)	Complexity
Behavior	Survival	Competition	Collaboration
Manifestation	Autophagy	Knowledge	Self-Consciousness
Operation	Subtraction	Subtraction/Addition	Differentiation/Integration
Result	Decline	Decline/Progress	Novelty

4.2. Change

The increase in social complexity related to the emergence of change, greater mobility and flexibility, increasing fragmentation of services, professions and products, and the increase in bureaucracy in processes, does not reduce these problems to a clear cause or diagnosis, much less to a specific answer or solution. Social complexity suggests that it is almost impossible for people and organisations to fully master their own world and manage their daily lives due to the numerous challenges, changes, claims, ambiguities, conflicts and pressures involved (van Ewijk, 2017).

Circumstances change. While in the 1950s product personalization was rare, a spontaneous revolt against bureaucracy in the business world with circles of innovation arises, the founder of Visa reveals a book entitled “Birth of the Chaordic Age”, where he designs institutions that combine characteristics of order and chaos (Donahue & Nye, 2004). However, with digitization, digitalization, and a digital transformation where artificial intelligence appears overvalued, it seems that bureaucracy has been unconsciously replaced by a “robocracy”, in which the machine rules. This assertion is based on the

inequality between the prophetic benefits of adopting technologies and the results obtained by IBM's *Watson*. In 2021, IBM open-sourced *Watson* with *Watson OpenScale*, an open platform that shifted from the perspective of closed, proprietary processes to more open approach. This was instigated by Amazon's *AWS* and other open-source technologies, which are more transparent and cheaper and evolve more quickly (Yang, Chesbrough, & Hurmelinna-Laukkanen, 2022).

Therefore, one of the most relevant properties in organizations is the ability to change. Regardless of the process of change, systems evolve and transform (some disappear, others emerge, others adapt) creating new forms and functions as shown in Figure 4.4.

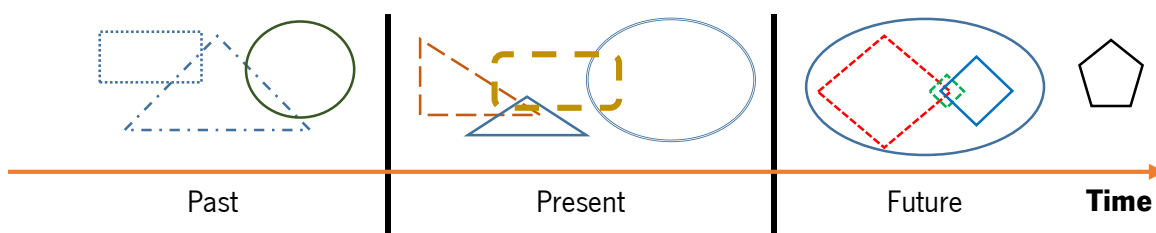


Figure 4.4: Change and creation of new organizational forms and functions over time.

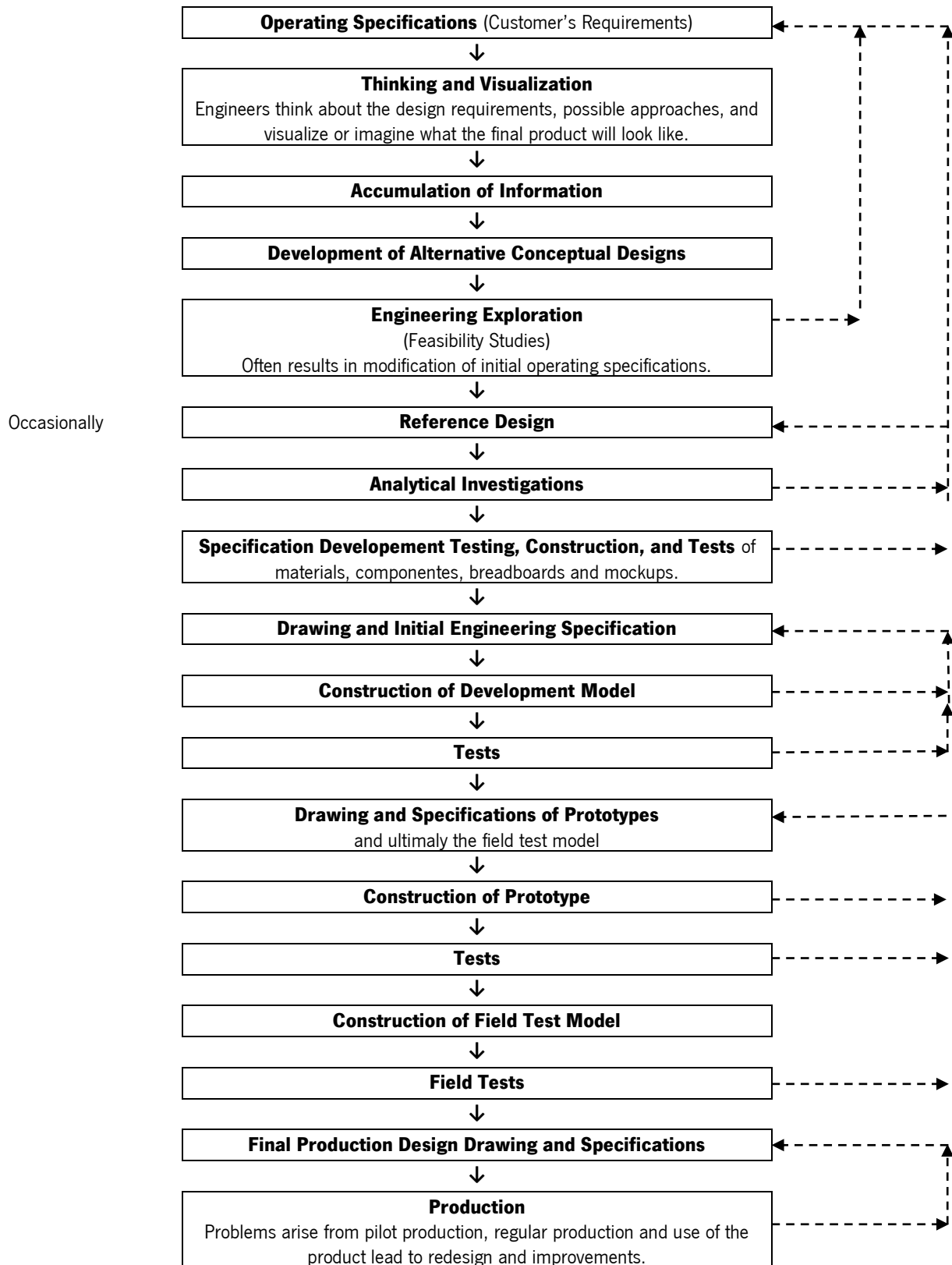
Diversity is increasingly present in organizations, impelling a change in behaviors and actions capable of dealing with rapid technological development and increasing information flows. Increasing organizational complexity significantly reduces our ability to predict and therefore control.

In organizations, technological change alone is not effective. Digital technologies flood the organization with information, and bureaucratic boxes can quickly become overwhelmed. Instead, it should start with an overview and dissipate old mindsets; with strong, agile leadership that drives widespread cultural change across the organization; and a strategy that fosters agility, adaptability, and creativity in the organization. However, not everyone deals with mindset change, which is the most critical barrier to success in any organizational change effort, and not everyone focuses on agile methods in the context of complex systems of rapid adaptability with a bias toward action (Jones, Hutcheson, & Camba, 2021).

Transformation can only be accomplished by the human, and not by the hardware (computers, gadgets, automation, new technologies). Obsolescence does not determine, *per se*, the degradation of an organization, in the same way that experience, without theory, does not guarantee organizations a competitive position in relation to rivals. Experience will answer a question, but the question comes from

theory. Hence, organizations must question permanently. It could just be an intuition or a hypothesis. And it may be wrong (Deming, 2000).

The design of an organization or a product or service is a complex ongoing process, as Schön (1967) observes in Figure 4.5. Organizations are in an ever-changing context that requires adjustments that sustain their existence. Without a reflective attitude, organizations are unsustainable. Thus, organizations need many feedback loops that instigate continuous improvement of the organization/product/service design.



Solid lines indicate main flow of work and information.

Broken lines indicate feeback of information for corrective purposes.

Figure 4.5: Graphical portrayal of the system and product design process (Schön, 1967).

4.3. Creativity

The phenomenon of complexity is universal and independent of the details of specific systems. Although complexity is no rarer in continuous systems than in discrete systems, it has been immensely easier to discover in discrete systems that can normally be investigated in a much more direct manner than with continuous systems (Wolfram, 2002). Thus, it will be easier to study the evolution of system structures through regular discrete quantities (of time, space, actions, relations/connections).

For Whitehead (1979) structural relations acquire intensity from individual experiences, so that the growth of the order of the complex structure of an organization emerges from contrasts. In this way, complexity, as a facilitator of contrasts, establishes a complex of bifurcations of prehensions that comprise divisible realities. These grasps end in a collective social acceptance, but they are born of the individual. Bifurcations consist of the change from one type of attractor to another (Wilber, 2001).

The social duality between the individual and the collective reveals the disjunctive characteristic of complexity in organizations. There are many egos, each ego being a multiplicity, that is, a diversity of units. The individual and the collective share the same "disjunctive diversity" as the joint creativity in the creation of novelty. This incoherence can be defined as a concrescence (growing together) and that only by intuition can one tolerate the "production of novelty" and the existence of a "concrete union" (Whitehead, 1979).

Concrescence "means that integrated contents are decomposed into their elements, which are then synthesized into a new whole," in a process that is neither controlled by some deterministic causality nor derives from a timeless teleology. The nature of the complexity of the process lies in an indeterminate self-creation that indicates an autonomous determination that originates "a non-reducible spontaneity" that is unpredictable for ontological reasons beyond epistemological ones (Koutroufinis, 2014).

A distinction should be made between creativity and innovation. Wallas (1946) in his book *Art of Thought* defined creativity as a process modeled on 5 stages: 1) preparation (reflection that focuses the individual's mind on the problem and explores its dimensions); 2) incubation (unconscious internalization, with apparent external stagnation); 3) insinuation (there is a "feeling" of the emergence of a solution); 4) enlightenment (the creative idea emerges from its preconscious processing to the conscious); 5) verification (the idea is consciously verified, materialized and applied). For Amabile and Pratt (2016), who define creativity as the production of new and useful ideas and innovation as the implementation of these creative ideas. From the two perspectives, it emerges from the second

perspective that innovation exists as a result of the materialization, or synthesis, of creativity. However, in organizations, they are concomitant concepts, as can be seen in Figure 4.6.

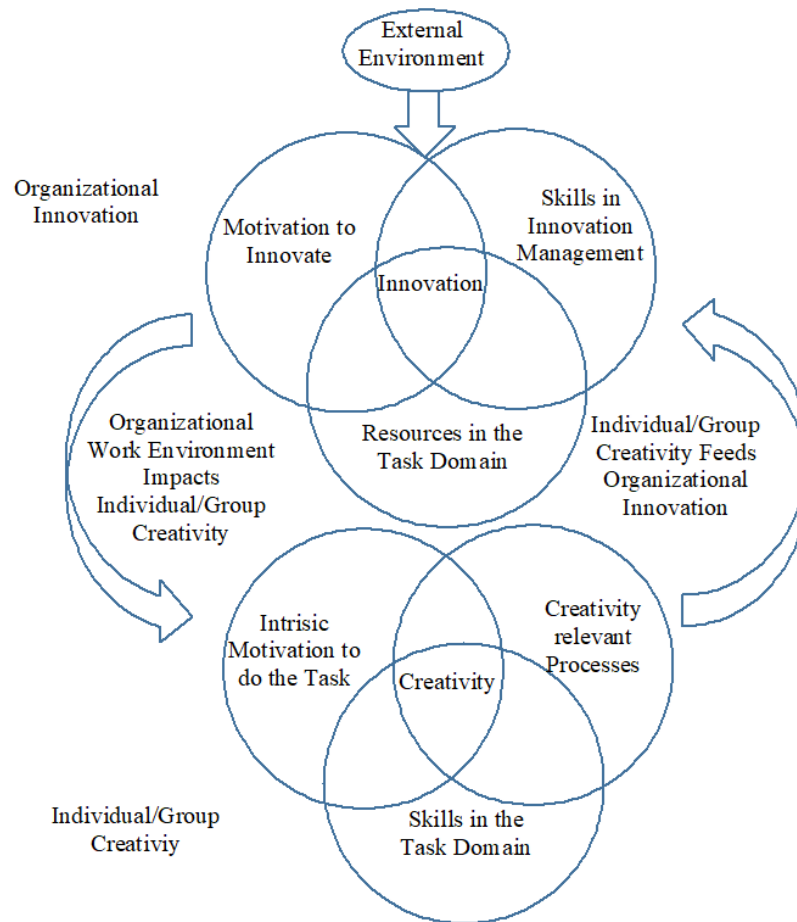


Figure 4.6: An abstraction of the components influencing innovation and creativity and how they interact (Amabile & Pratt, 2016)

Innovation does not necessarily imply organizational improvement. The two situations can converge, but it depends on how the management of the organization involves and encourages the participation of the members of the organization. According to Galbraith and Lawler (1993), organizational improvement can be achieved by stimulating teamwork and systematic analysis of results. However, this behavior can condition innovation, incompatible with the harassment of the control and predominance of the group over individual thought. Organizational improvement and innovation come together when the purposes presented in the meeting of the two groups in the Venn diagram of Figure 4.7. The acceptance of risk, uncertainty, the creation of an environment conducive to learning, the development of collaborative

networks and conditions for dialogue, are some of the characteristics in which innovation and organizational improvement converge.

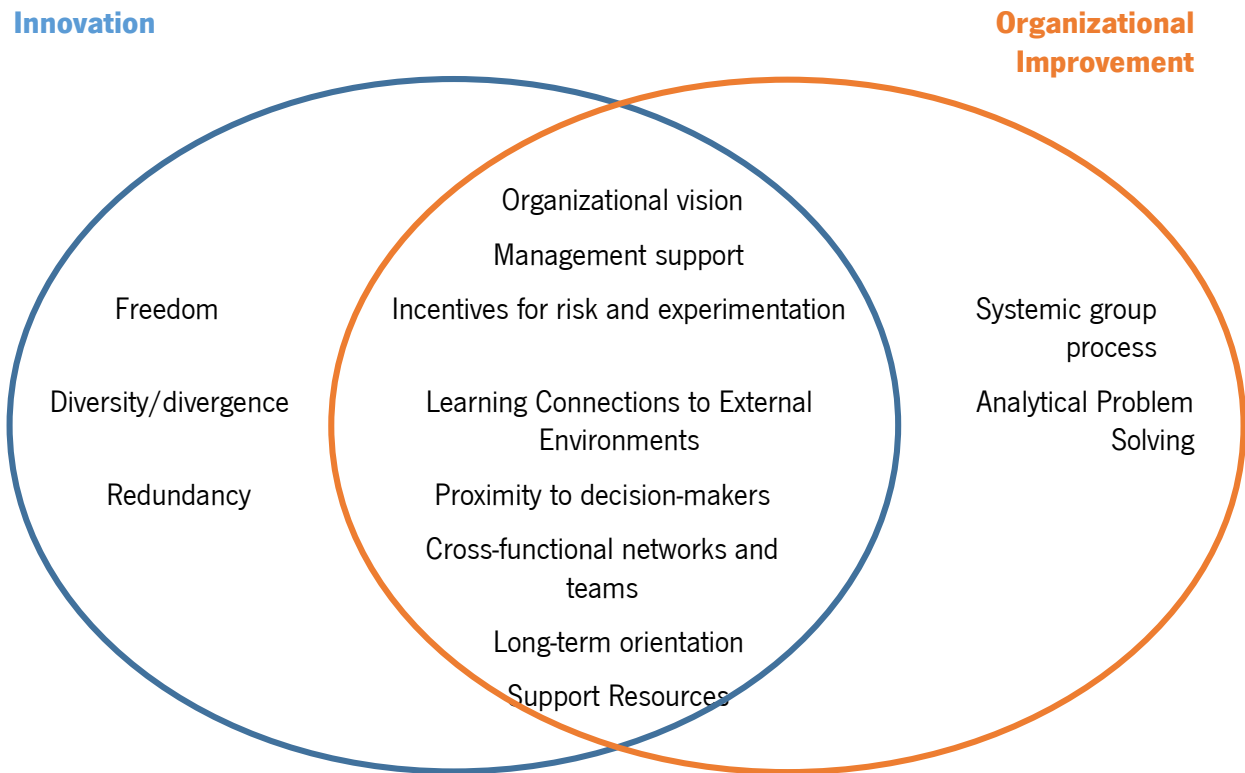


Figure 4.7: Venn diagram of innovation and improvement in organizations, adapted from Galbraith & Lawler (1993).

Innovation and continuous improvement processes in organizations should not depend on mechanical systems, with monotonous Plan, Do, Check and Act (PDCA) cycles. Innovation needs creativity. However, creativity is partially stifled when a “recipe” is applied that guarantees a result. Galbraith and Lawler (1993) propose that organizations should simultaneously create conditions to promote innovation and organizational improvement. As can be seen in Figure 4.5, there is no single, predefined path with absolute PDCA cycles to consummate a design. There are numerous configurations and paths, depending on the context, that allow you to achieve the same result.

4.4. Metaphor

Although controversial in science, metaphors are seen as essential for creativity, innovation, scientific explanation, meaning-making, and the development of personal identity (Zimmerman & Hurst, 1993). Metaphorical perceptions, whether for explanatory or predictive purposes, are intended to be transformative (Tsoukas, 1991). Metaphors relate to fractal structures when 1) they tend to decrease the tensions associated with their formation; 2) build self-similarities through similarities and; 3) destroy the boundaries that delimit them. Figure 4.8 shows the heuristic value of fractal structure in organizations as a metaphor for controlling each of their organizational characteristics (tensions, self-similarity, and boundaries) that influence each other (Zimmerman & Hurst, 1993).

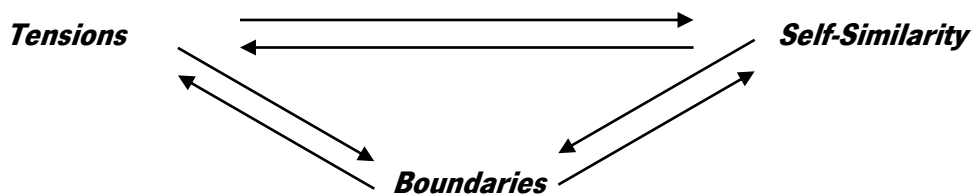


Figure 4.8: Organizations fractal structure as a metaphor for controlling their characteristics (B. J. Zimmerman & Hurst, 1993).

Organizations are systems (internal dimension) within systems (external dimension) where education, health, politics, economics, and engineering, among others, influence each other. The fascination with the metaphor of organization as a machine leads to beliefs that one examines the parts separately and understands their mechanics, allowing one to know them fully. The metaphor of the machine leads one to believe in how the system can be reformed and improved. Any model of organization is an approximation, a simplification of reality. However, these models are of utmost importance because they influence the way people believe the system works and therefore restrict the possible ways of thinking. Using the metaphor of the machine, the belief is that one can increase the inflow without having to proportionately increase the size of the machine (Sanders & Wood, 2019)

4.5. The development of organizations

Science reports “exponential” growth more actively than linear growth. This is not an unthinking predilection, but results from the fact that “the sensibility stimuli increase in geometric proportion; The

very capacity to feel increases only in arithmetic progression” (Pessoa, n.d.). When Fernando Pessoa cites the Weber-Fechner law (Fechner, 1860; Maes, 2021) states that human perceptions follow a logarithmic scale. This type of scaling is observed in other areas, such as the thermodynamic entropy of Clausius and Boltzmann or the ability to transmit information in the so-called Shannon entropy, i.e., there are similar formulations that emerge in different contexts. This also means that humans in organizations do not stand out for their physical capabilities, as activities can be aided with mechanical devices. The differentiating factor of the human being lies in the creative capacity to design these mechanisms. However, the logarithmic sensory scale hinders the ability to differentiate the new paradigms, since variations in equal absolute values manifest themselves more intensely in the case of regression (crisis) than in the case of growth.

As an example, see the Figure 4.9 for the growth of the world population. The world's population grew from 4.85 billion in 1984 to 7.95 billion in 2022 (The World Bank, 2024). This population growth inevitably affects the behaviour of all organizations and the systems that underlie them.

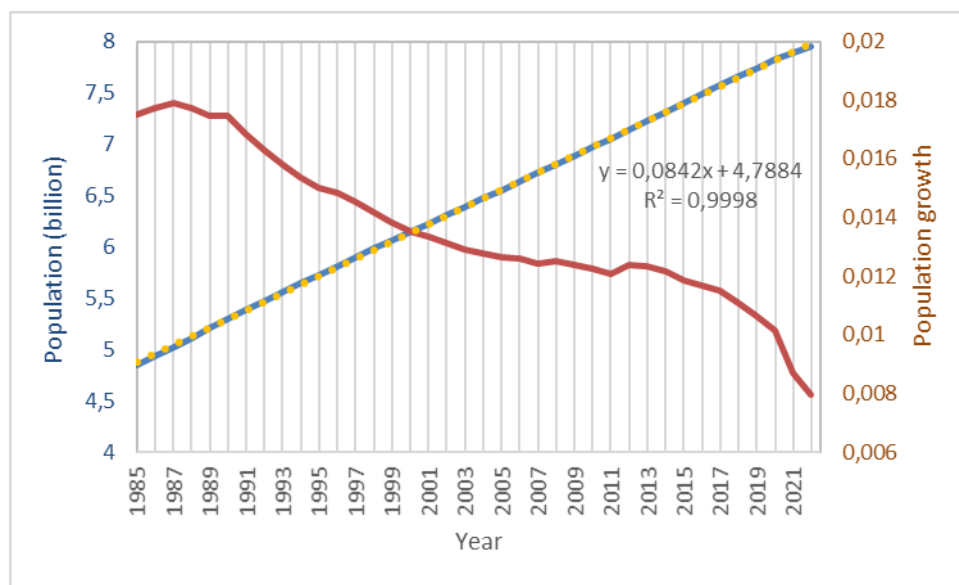


Figure 4.9: World population growth between the years 1985 and 2022.

In the graph in Figure 4.9, while there seems to be a linear growth of the world population (expressed in equation D, with $R^2=0,9998$), this perception is actually false because the population growth (population variation) is not constant, having reduced in the year 2022 to less than half of the value of

the year 1985. It should be noted, therefore, that analyses of the growth of a given phenomenon within a system can easily be misleading despite being statically well adjusted.

Note the case of the publication of papers related to engineering. In a search in the Scopus database, limiting the search of papers to the area of engineering, a search was carried out, between the years 1984 and 2023, considering exclusively the following words contained in the Title Abstract, or Keywords of the papers belonging to the Scopus database:

- 1) Engineering;
- 2) Complexity
- 3) Virtual
- 4) "artificial intelligence"
- 5) Economy
- 6) Entropy
- 7) Self-organization
- 8) "artificial intelligence" and entropy

Naturally, the results of the research should consider the reality represented in Figure 4.10, given that the papers searched in one of the previous issues include or are included, in whole or in part, in the other searches (the values in parentheses represent the total number of papers published).

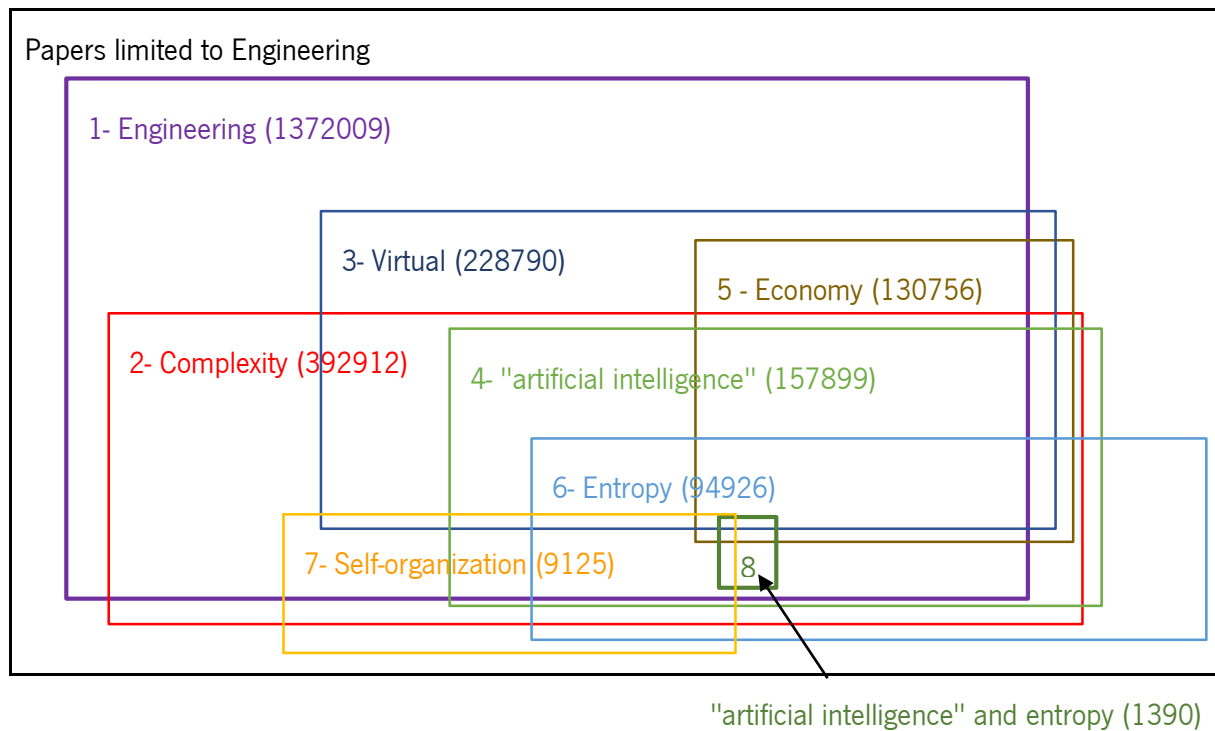
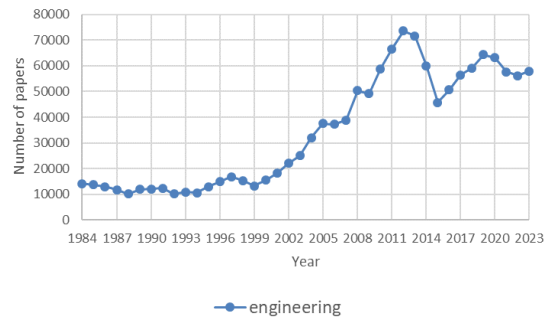
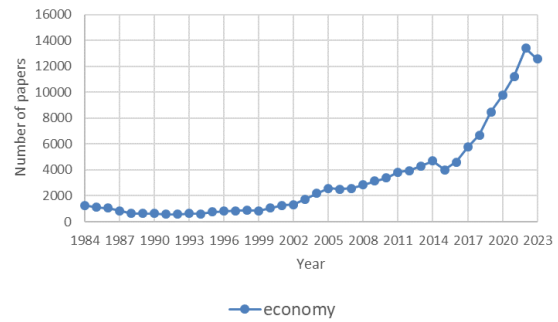


Figure 4.10: Conjecture from a list of groups of articles obtained from Scopus, limited to the area of engineering, between the years 1984 and 2023.

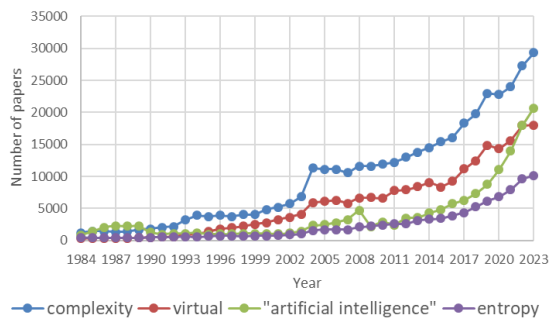
Considering the size of the groups, Figure 4.11 shows the annual evolution of the relevance of the groups of papers mentioned above for the scientific community represented in Scopus.



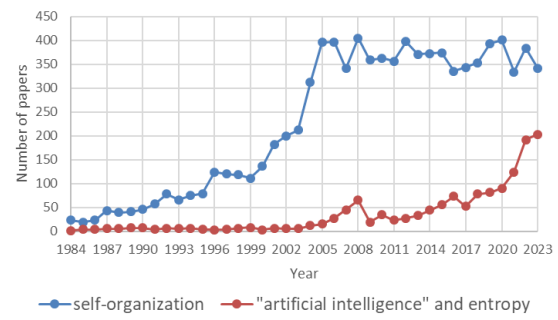
a)



b)



c)



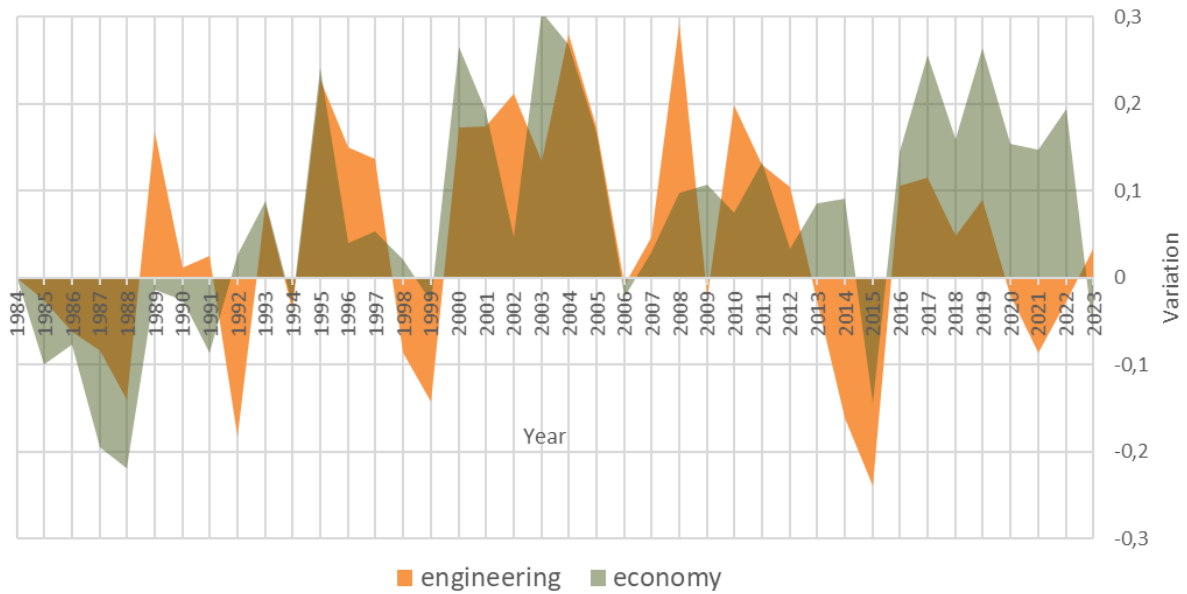
d)

Figure 4.11: Number of papers published annually between the years 1984 and 2023, presented in the Scopus database, with research limited to the area of engineering.

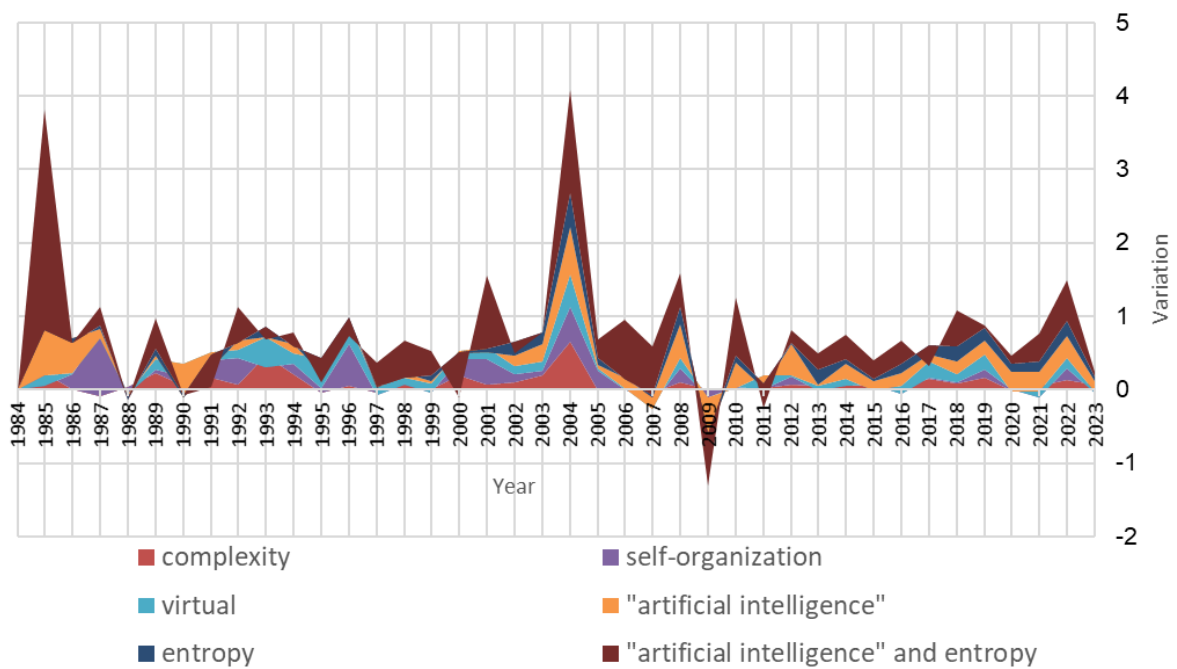
Any analysis that disregards the existence of graph a) of Figure 4.11, for the behavior of graphs b), c), and d) of the same Figure, is very reductive to observing the context and evolution of a given theme/subject in the publication of papers related to engineering. For example, the "exponential growth" apparent in the graph in Figure 4.11c) does not exist until after the year 2012.

An evaluation of the variation in the growth of the graphs present in Figure 4.11 may be more interesting, as shown in Figure 4.12.

The graph in Figure 4.12b) indicates the existence of a greater complexity than the graph in Figure 4.12a). As it is impossible for organizations to be aware of all the variables, it is eventually more useful for organizations to observe and analyze the less "frequent" signs to detect crises and opportunities.



a)



b)

Figure 4.12: Variation in the publication of articles in the Scopus database, with different search words, limited to Engineering, between the years 1984 and 2023.

Insignificant signals, with cyclical fluctuations without great social, economic, productive, or environmental expression, can generate, under certain conditions, a bullwhip effect in the organizational

system. This effect can be further amplified by the system itself when it tries to control the extraordinary phenomenon with a mismatch between the reaction to the phenomenon and the timeliness of that reaction. The effect may arise from the phenomenon presented in the graph in Figure 4.13, which only considers internal temporal feedback in a vibrating system.

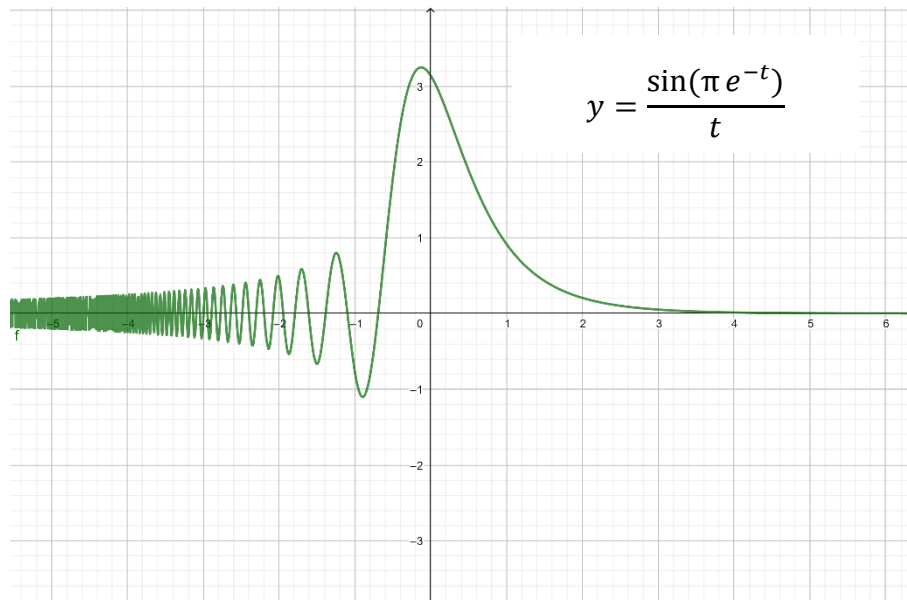


Figure 4.13: Bullwhip effect in the organizational system.

4.6. Chaordic Thinking

Excessive rationalism excludes the chaos indispensable for innovation; condemns creativity, with exaggeratedly detailed plans; promotes efficiency and control through excessive bureaucracy; It fosters large research and development teams, with too many communication channels that compress individual capabilities into a crowd (Quinn, 1985).

The random and chaotic nature of technological change crosses organizational boundaries, and it is prudent to be aware of external trends or capabilities, regardless of the origin (customer, competitor, supplier, ...). However, the innovative process is inherently incremental. Innovation tends to be individually motivated, opportunistic, non-linear, and developed interactively. Despite the planning of goals, surprises are likely to arise. Hence, innovation requires flexible programs for as long as possible (Quinn, 1985).

It is common to find studies on complex adaptive systems, often referred to as “complexity” in the scientific community (Hock, 1995). These concepts are similar to those promoted by Chaordic Systems Thinking (CST), whose principles stimulate the creation of novelty in production systems (van Eijnatten et al., 2007). In organizations, change must be discontinuous, but development efforts are rather reformative than transformative (van Eijnatten & Putnik, 2004). This behavior can create problems adapting to an ever-changing context.

Stengers (1997) argues that complexity is not a general model derived from "complex objects", dissipative structures, or strange attractors that represent "better modeling" for certain problems. For Stengers (1997), complexity is determined by coherent collective behaviors, but with a gravitational factor that, according to context, can be insignificant or change everything. Contrary to the determinism of classical physics, complexity seems to be incapable of challenging the academic isolation and experimental monologue that it stabilizes. “The response to the question of complexity is not theoretical but practical” (Stengers, 1997). This practice only seems to be appropriate if management systems preferentially use dialogue between the elements of the organization (van Eijnatten & Wäfler, 2003).

Sharing the previous ideas, Morgan (2014) considers that there is no organization with a perspective of the future without technology and, particularly, without collective intelligence and collaboration technology. On this subject, Morgan (Morgan, 2014) identified 12 habits for managers to foster the collaborative use of technologies:

- 1) Focus on individual value before corporate value;
- 2) Strategy always comes before technology;
- 3) Learn to get out of the way;
- 4) Lead by example;
- 5) Listen to the voice of the employee;
- 6) Integrate into the flow of work;
- 7) Create a supportive environment;
- 8) Measure what matters;
- 9) Be persistent;
- 10) Adapt and evolve;
- 11) Understand that employee collaboration also benefits the customer;

12) Accept that collaboration makes the world a better place.

Of the 12 habits, the first 3 are clearly linked to complexity, with the third standing out, which may eventually conflict with other habits, namely 6, 7, and 10. In complexity, particularly in CST, “learning to get out of the way” means new ideas that lead to new ways of creating.

Addressing uncertainty, CST uses chaos as a lens and metaphor to understand the dynamics in human organizations (van Eijnatten & Wäfler, 2003).

4.7. Complex adaptive systems

Complex adaptive systems are ubiquitous. Complex implies diversity - a large amount of elements. Adaptable suggests the ability to alter or change – the ability to learn from experience. A system is a set of things that are connected or interdependent. In these systems, things are independent agents that act on the basis of knowledge and the conditions of the context (internal or external). There is no central organism that controls the individual movements of the agent. In their interactions, agents alter the behavior of others and are also influenced by them. Their relationships can generate changes or stability in the system and cause two seemingly identical systems to evolve differently.

Complex adaptive systems exhibit dynamic, emergent, and self-organizing, non-additive, complexly structured behavior. With interactive networks, where agents tend to come together in an ordered state, the consequence is different from the sum of individual behaviors. The large number of agents, their dependencies, and the influence of external forces combine to result in constant and discontinuous changes. Changes are unpredictable, and small mutations in the variables in the system, depending on the context, can have different impacts (Zimmerman, Lindberg, & Plsek, 2009).

In complexity, there are systems that learn from each other and form a co-evolving super-system that discovers, creates, and learns its way into the future. These network systems are ubiquitous in nature. For example, the brain is a complex adaptive system in which neurons are the agents. When humans come together in a group, it creates a complex adaptive system, both biologically and mentally.

4.8. Complexity of human organizations

The complexity of organizations is not a reduction of reality, because it does not generalize and simplify dynamic and uncertain behaviors. On the contrary, instead of reducing them, it displays them. And

although there are contradictory examples, it is preferable to compress reality in order to respond to complex problems, where the present is proclaimed as a permanent concept. In the face of crises, determinism cannot be revoked and, while memory ignores depressive cycles, reality is a binary concept. Similarities are rejected and difficulties are reflected in a context of conflict and repression. The result culminates in competing systems and constant negotiation aimed at satisfying the ego. Crises always lead to changes in the organization. They encourage action.

The 2021 Nobel Prize in Literature, Gurnah (2015), “felt that had been dispossessed of something valuable to see our complicated world so brutally summarized” when he saw a photograph of the neighborhood where he lived as a child. In this case, the word complicated is used as a synonym for complex. Indeterminacies and social connections in photography are excluded.

Despite the possible antagonisms in Table 4.3, organizational structures share hybrid characteristics between hierarchical and heterarchical systems. Productive systems are not technologically "pure" systems that allow the stability of heterarchies, nor are they hierarchies immune to the effects of entropy and power transitions that inevitably change the disposition of the elements that constitute these systems.

Mathematically, systems can be reduced and modeled as inert structures, where hierarchy inspires a stability or persistence of states. However, this is impossible when considering the entropy of closed systems, which imply systems such as organizations with unlimited resources or organizations immersed in total disorder (which contradicts the existence of the idea of organization). Thus, any management system is only viable between the idealizations of total control and full freedom.

Organizations should heed Spinoza's (2018) warning that human beings deceive themselves into thinking they are free. They are conscious of their actions, but ignorant of the causes by which they are determined. Consciousness is the condition of knowing oneself and the environment. All elements of a production ecosystem (e.g., machines, robots, sensors, actuators, conveyors, products, among others) must connect and exchange information automatically with other components or systems. They must also predict the behavior of connected systems, acting and reacting appropriately and optimizing processes (internal and external to the ecosystem), adding, removing, reorganizing, adapting, or updating the network of organizational assets (Anumbe, Saidy, & Harik, 2022).

Table 4.3: Characteristics of hierarchical and heterarchical organizations.

Hierarchy		Heterarchy
Closed, centralized	Structure	Open, decentralized
Pyramidal	Network	Holonics
Conditioned	Communication	Free
Efficiency	Goal	Effectiveness
Economy	Challenge	Social
Slow, by adaptation	Change	Fast, by opportunity
Authority and function	Stratification	Virtually None
Bureaucracy	Instrument of Power	Holacracy
Determinism	System Thinking	Complexity
Top-Down	Decision-making	By innovation
Possessing, Dominating, Limiting, Consenting	Verbs	Giving, learning, knowing, including, integrating
Certainty (as a belief), conviction, restriction, repression, repetition.	Evidence, patterns	Uncertainty, disruption, emergence, coherence, awareness
Eternal. It is not extinguished of its own volition.	Duration	Limited by the achievement of the goal
Classes	Society	Communities

Spinoza's (2018) idea of freedom, therefore, knows no cause for his acts. Transporting this thought to organizations, one can perceive the attempt at ethological control, which is compromised by etiology and which makes teleology an illusory consequence. Organizations can claim “freedom” as a motto for building the future, but they cannot ignore Lorenz's (1972) butterfly effect, where small fluctuations in the system cause major disruptions. There is an equilibrium where a set of variables that interact “systemically” is prone to maintaining a certain pattern of interaction. However, the organization can be

subject to fluctuations that can lead to the creation of a new equilibrium or the disruption of the system (Lasswell & Kaplan, 1950). Some of these issues may involve adopting measures indicated in Table 4.4, which succinctly presents the main characteristics of the Theory of Complexity (Chaordic Thinking).

Table 4.4: Characteristics of Complexity Theory according to Chaordic Thinking.

Characteristics		Chrono	Synonym	What?	How?	Why?
Dissipation		Past Present	Disruption Disturbance	Transformation Metamorphosis	Replace	Unsustainability
Consciousness	Connectivity	Always	Coherence Nexus	Flow Continuity	Opportunity	Intelligence
	Indeterminacy	Future	Uncertainty Perplexity	Event Feasible	Probability Choice	Variety
Emergence		Present Future	Novelty	Diversity	Emerge Create Build	Discovery Reaction to vacuum

4.9. Dissipative structures

It is necessary to be aware that dissipative structures are only capable of “generating” negative entropy if there is an outflow of entropy produced internally. For example, it can be assumed that cities are dissipative structures as long as the harmful impacts of human action (pollution, bureaucracy, destruction of ecosystems) dissipate into the external environment and their consequences are transferred. Open systems have dissipative properties that are beneficial in terms of efficient energy management for the system itself. But eventually, they can degrade the surrounding systems.

Figure 4.14 shows how the process of self-organization and dissipation are correlated in open systems.

Specialization has created more efficient systems with lower entropy. As with dissipative structures, specialization has introduced divergences between the different systems that surround and compose organizations. Management becomes important in the integration of divergences to counteract the extensive property of entropy. In practical terms, we can have structures with very efficient departments and low entropy, but with their languages, autonomous communication systems, which privilege reactive

behaviors, and which cumulatively and through extensive ownership increase entropy in the organization. On the other hand, we can have structures with complex communication systems with high entropy, capable of understanding external systems, making the total entropy of the organization less than the sum of the individual entropies.



Figure 4.14: Correlation of self-organization and entropy dissipation in open systems, adaptation (De Bari, Dixon, Kondepudi, & Vaidya, 2023)

The whole of any organization is more complex than the sum of its elements. Complexity emerges by itself, i.e., it is self-organized. The concept of complexity brings with it the problem of self-reference that links a purpose (Ueda, Márkus, Monostori, Kals, & Arai, 2001), resolving engineering problems more challenging because, without a pre-determined goal, no entity can individually evaluate the evolution of an organization (such as progress or backtracking).

Complexity often refers to a transitory state, limited in space/time, and is an inherent characteristic of the processes present in dynamical systems. It can be observed naturally in snowflake crystals which, although unique, have common features (such as six branches that grow similarly into a structure with self-similarities and details similar to fractal representations). These properties suggest that the growth effect advocated by Whitehead (1979) is not limited to a single science. It is transversal, from Mathematics, Physics, Economics, Sociology, or Biology, among others, but is limited to certain contexts. This delimitation does not have a permanent ordering in space/time: it is ephemeral, with ruptures or transformations very far from stability and typical of dissipative structures (Prigogine, 1987).

4.10. Emergence

Complexity, especially emergence, is based on process philosophy. A dynamic environment, with increasing entropy and the constant transformation of the environment, drives different perspectives and

changes in thinking that allow us to better model the present. Old models, for new challenges, tend to be incoherent.

Any design of a service or product must include all stakeholders as early as possible, sharing experiences and collaborating in the development of the design. Communication between different parties of these systems imitates biological production systems. These systems, with principles of self-growth, self-organization, adaptation, and evolution, deal with unpredictable changes in production environments. Through this process, the design emerges despite an incomplete specification and an unknown/uncertain context (Wiendahl & Lutz, 2002).

Social systems depend on their communication patterns. These patterns are emergent and have properties that, instead of being imposed, emerge *a posteriori*, posing several problems inherent to the analysis of communication networks, highlighting the dimension and complexity inherent to networks with dynamic relationships of their parts. The difficulties increase especially when the parts themselves are complex and changeable and the relationships are not rigid, symbolically mediated, often circular, and with many degrees of freedom, with issues related to the interconnection of the different contexts (internal, external, individual, collective), the pursuit of objectives, or the elaboration and continuous creation of structure, generating a more or less adaptive evolution that creates a mechanics of "control" of self-organization (Richards & Lindsey, 1974). This thought is summed up by (Putnik & Putnik, 2010) who, referring to Saludadez and Taylor (2006), quoted:

"In the communication perspective ..., by contrast, organisation is conceptualised as grounded in a social process of interpretation (). Organisation is created and recreated (..) in and through the everyday sense-making activities of its members (). From this perspective, organisational structure is conceived to be multiple () rather monolithic (); fluid or even fragmented (), rather than fixed; socially constructed (..) rather than static (..); context-sensitive () and historical (..) rather than acontextual or ahistorical; emergent () rather than consciously designed. According to this view, communication and organisation are coconstructing (..). In other words, it is through the process of communication that organisational forms emerge. And communication is in turn framed and informed by organisation." [The original text refers various sources/references which are omitted on assumption that they are not critical in the context of the citation purpose in this paper. Of course the reader could consult them through the original text. The symbol '()' means that on that place is referred a single source, while the symbol '(..)' means that on that place is referred multiple source.]

Complex systems are often illustrated with bifurcation diagrams that manifest the existence of multiple attractors in the system. Figure 4.15 shows a bifurcation diagram corresponding to Lyapunov's largest one-dimensional numerical exponent that summarizes several scenarios that could lead system to the edge of chaos.

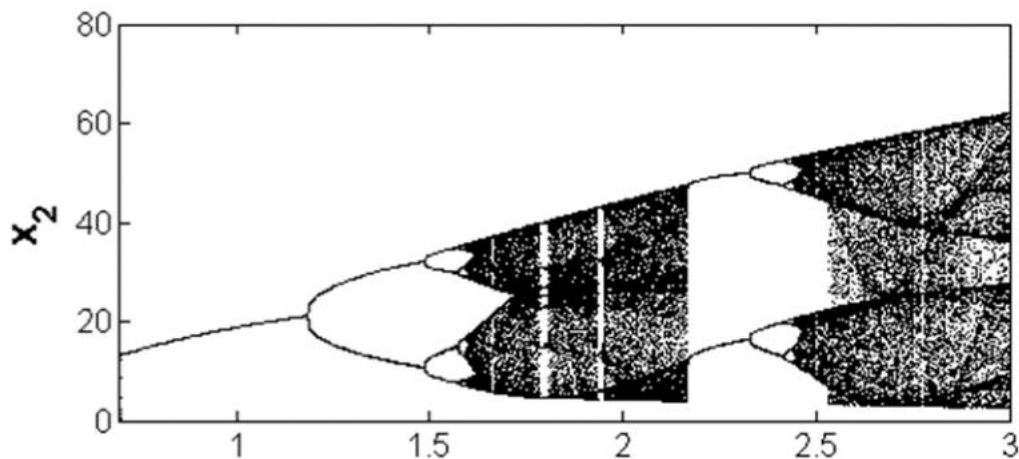


Figure 4.15: Bifurcation diagram of the Colpitts oscillator resulting from the largest one-dimensional Lyapunov exponent (Kamdoum Tamba, Fotsin, Kengne, Kapche Tagne, & Talla, 2015).

Resulting from the Equation 1616161616:

$$\lambda = \lim_{t \rightarrow \infty} \left(\frac{1}{t} \ln dt \right) \quad (16)$$

where

$$dt = \sqrt{\delta_1^2 + \delta_2^2 + \delta_3^2 + \delta_4^2}$$

The first indicator is the bifurcation diagram and the second is the largest one-dimensional numerical exponent of Lyapunov. The calculation of the variational equations is obtained by perturbing the solutions of the sets of $x_i, \dot{x}_i + \delta_i$

Figure 4.15 shows the behavior of a system with one-dimensional dimensional Lyapunov exponent. Despite the complexity and multiplicity of attractors, these models only partially explain the behavior of complex systems. Reality is multidimensional, recursive, and interactive. There is an infinity of emergent systems on the edge of chaos, whose immensity of possibilities results in the indeterminacy of the

behavior of these systems. For example, in the two-dimensional parameter space composed of different cooperative parameters, as in the case of isospike diagrams and bidimensional Lyapunov stability phase diagrams, the scenarios for attractors are more complex, as shown in Figure 4.16.

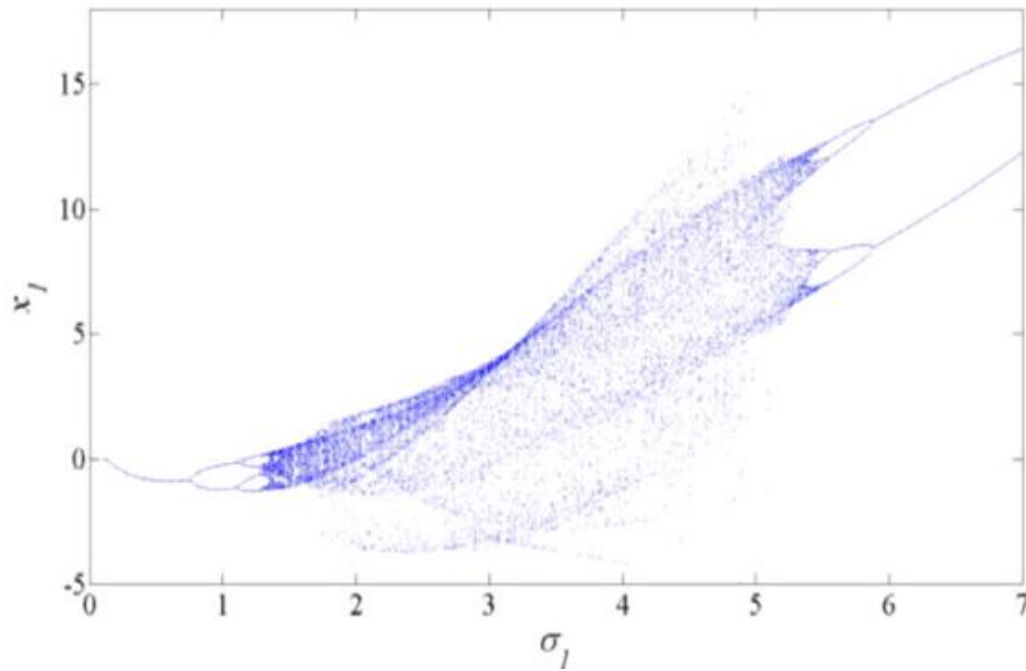


Figure 4.16: A set of bifurcation diagrams along the two lines marked in an isospike diagram (Xu, Chu, & Yang, 2020).

There may be different situations when we consider organizations with agents that are collective entities, e.g., resulting from outsourcing or innersourcing for specific or permanent activities. The intentional common purpose inherent in the value of the organization can extend to meta-agents and meta-organizations.

Considering that the organization of production networks involves a plethora of decisions that establish the channels for the flow of materials, information and financial assets within the network, the way in which a network can organize itself is problematic. According to Váncza *et al.* (2011) open, overlapping and polycentric networks cannot be optimized because there can be no aligned business objectives, no common agenda and, after all, no closed solution space. Váncza *et al.* (2011) argue that:

1) Production networks should be created from a rich fabric of relationships, but who would decide the scope of modeling? How to extend the range of logistics and production management beyond property limits and restrictions? Production networks are not designed, but come into existence; How can this

process be modeled, driven and controlled? Thus, acting together cooperatively can only be an emergent property of the global system.

2) In the business network, the emergency can only be an obstacle to the practical implementation of decentralized solutions. The industry needs both guarantees for the emergence of some useful properties (such as high service levels) and safeguards against undesirable behavior.

3) Any type of communication requires not only a common understanding of the language and protocol used, but also of the underlying conceptual reference model. For a computerized exchange of information, a formal representation, a kind of business ontology, is necessary. In an open and decentralized environment, it is far from clear how partners will be able to reach such a common basis of communication.

Recognizing that there are industrial organizations that do business locally, they are at best doomed to stagnation – e.g. logistic distribution. Váncza *et al.* (2011) designate emergence as a random consequence of a nexus of individual activities. Although it may seem random, if there is connectivity between events, it cannot be said that the events are random and not favorable. Note that emergence and dissipation are two properties that are complementary in complexity. There is no emergency without dissipation. For example, in crises, many lose little and few gain a lot. Normally, those who lose little are already poor, that is, proportionately they lose a lot.

Another example that can be used to refute the idea of the possibility of self-organization and emergence in open systems is the political system. Democracy is the generalized concept to classify the possibility of self-determination and self-organization. The idea of democracy is associated with the possibility of freedom to choose a new organizational design (country, community).

The existence of a common understanding of the language and protocol used in communication processes does not mean that it is impossible to create new codes and new signals that improve systems by taking advantage of emerging technologies. Emergence, as already mentioned, is not a one-dimensional process; The emergency affects the entire organizational ecosystem in different ways. However, the illusion that it is possible to control diffusion models by controlling results in advance continues to dominate production system management models. Perhaps Váncza *et al.* (2011) assumed that the "management of chaos and complexity in organizations", and the "co-creation" approach (the discipline of "co-creation" in fact promotes social construction, which is, by nature, context-dependent), as new paradigms for informing modern design and management, and any planning is virtually impossible as an instrument of control (Putnik et al., 2013). Reality shows that the lack of such a defined

instrument of control is not only destructive. Opportunities arise from crises, learning from errors, discovering from mistakes.

Complexity management must follow organizational contexts (internal and external). It is not possible to fully control ever-changing contexts. Therefore, over-planning is counter-productive. Consider the following metaphor:

A madman plans his escape from the asylum in detail.

- I'm going to go over the gate using a ladder I found in the courtyard. It will be simple!

The next day, the madman is still there and the companion asks:

- Huh, weren't you going to run away?

- Did not happen! The gate was open...

Many opportunities will be missed by following the waterfall pattern, where tasks are sequential and mechanically scheduled.

4.11. Coherence

In the literature, complex networks are often used to designate free-scale networks. The complexity inherent in complex networks is a natural and irreversible process. Complexity arises as part of a natural process that, however, can be mimicked by artificial processes. In these processes, the evolution of design creates new attractors that aim to create order. This order can only be achieved with a new hierarchy, be it technological, economic, political or social.

Human organizations can adapt and evolve to create a new order and coherence. The emergence of a new order and coherence is one of the foundations of complexity management; it allows for new ways of working, forms new relationships and favours the emergence of new structures (Mitleton-Kelly, 2003).

4.12. Intelligence

Intelligence in organizations and in the agents that are part of them suggests a superior ability to acquire knowledge and apply it in practice. The distinction of intelligence over any other concept, such as information or knowledge, does not come from the prescription of a permanent formula. From

etymology, the word intelligence, from the Latin *intelligentia*, emerges from the prefix "*inter*" (between) and "*legere*" (choose, peak out, read). This places the qualification of intelligence as part of a choice, of a game, where the "good" decisions are highlighted.

In organizations, it is normal for the growth of ideas to arise through a process that privileges similarities and neglects the differences between things. In this sense, intelligence can consist in the apprehension of relations when the comparison concerns things of a very different nature. As Gardner(2006) suggests, the existence of multiple intelligences, as already presented in this work, pluralizes the traditional concept. An intelligence is the ability to process a certain type of information, originating in human biology and psychology. Humans have certain types of intelligences that differentiate them from other species, biological or otherwise, with different priorities. An intelligence involves the ability to solve problems that are relevant in a specific context or culture.

The idea of a network arises naturally as a way to increase the "intelligence of the organization", through the "specialization of nodes" and the creation of a communication system that guarantees and stimulates the connections between them. The specialization of an organization's members emerged in the first industrial revolution and continues to be a trend. However, the existence of experts may not bring any positive results to a network if they do not share a common language and collaborate.

As the concept of intelligence is always linked to a subject, Fichte (1994) prefers to use egoity to designate intelligence, as an introspective intellectual intuition that promotes self-knowledge. Fichte's (1994) proposal is instructive, because it suggests that there can be no intelligence without self-knowledge. From this perspective, an agent is free only if he is aware of himself (Higgins & Solomon, 2003) in a context. Thus, the concept of intelligence, egoity, and self-knowledge converge in absolute reciprocity (Ferrer, 2014).

Human intelligence will continue to be an essential element in future production systems. Workers will have to acquire multidisciplinary skills through requalification and upskilling to obtain maximum versatility and adaptability in an increasingly intelligent environment, benefiting from AI and expanded collaboration between humans, robots, and machines to increase efficiency and reduce errors (ElMaraghy, Monostori, Schuh, & ElMaraghy, 2021).

4.13. Networks

Organizations, with internal interactions, form systems that interact with other systems to form a coherent ecology, i.e., a network that is a complex ecosystem.

The success of organizations depends on how quickly they identify changes in the ecosystem and transform the organization to accommodate them. However, the accommodation has become accustomed to a mechanistic frame of reference that tells us that if we work hard enough and carry out a detailed plan, we will know enough about the future and ensure control of the organization. And for survival, we must be able to be better than our rivals; otherwise, we will descend into disorder and anarchy (Stacey, 1996). We enter a vicious circle that requires an intellectual transformation of the organization to get out of it. However, management tries to encourage that we can know what is to come and that reform processes are the most appropriate to face crises. Table 4.5 shows a possibility of adjustment between management proposals and types of organizational structures.

Table 4.5: Management proposals and types of organizational structures.

Management Proposal	Organizational Structure
1. Directing the workers	Linear / Simple
2. Change work Processes	Funcional
3. Modify Structure	Divisional
4. Mediate and seek Change	Strategic Business Unit
5. Join and Convene	Conglomerate
6. Observe Interactions	Matricial
7. Seek Patterns	Network

The complex networks are large, heterogeneous, volatile, and dynamic, with unexpected symmetries that support the emergence of a new design. Observing a pattern (order) that defines the complexity of the network indicates modularity between elements/networks within the complex network. Although modularity allows for the decomposition of problems or networks, complexity can increase substantially when natural system modules are fully decoupled from each other to support parallel design (Topcu,

Mukherjee, Hennig, & Szajnfarder, 2022). Cutting the Gordian knot in complex networks, while often producing unexpected results, can increase complexity (considering that system boundaries resulting from disintegration include all elements of the initial network). It shows that integration in complex networks can be structured with dissipative (entropy) properties. Over time, complex networks can change their physical attributes, for example, self-transforming the nature of their interconnections.

Barnes (1954) defined the concept of “social network”, or social field, as a person's network of contact with other people, some of whom have direct contact with each other, while others do not. He observed inequalities in the ratio of the number of connections made and the number of theoretical maximum connections between small primitive societies, where small networks but with a greater relative number of connections and stronger connections between people, compared to modern, more evolved societies, with expanded networks but with a lower relative number of connections and weaker connections between people (Klason, 1995). The weakening of connections on social networks poses different challenges for organizations. Driven by rapid technological growth, weaker social bonds become pervasive, making it more difficult for organizations to cater to all individual interests.

4.14. Environmental dynamics

Organizations can use different types of environments in order to achieve their goals, as shown in Figure 4.17. The central zone in the Figure 4.17, called complex, is also described as on the verge of chaos or chaordic (referring explicitly to the production/manufacturing management proposal). Traditional management approaches have not proven to be very effective in the , despite being an area of high creativity, innovation and rupture with the past to create new models of action (Zimmerman, 2001).

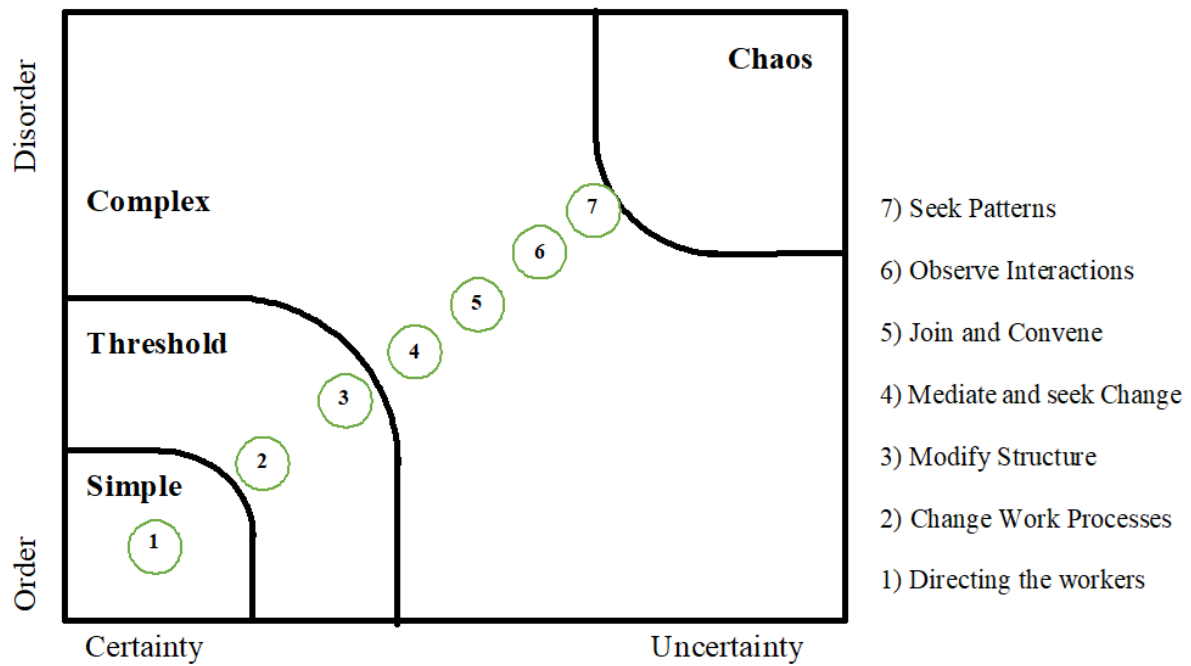


Figure 4.17: Types of organizational environments; adaptation (Stacey, 1996; B. Zimmerman, 2001).

4.15. Holons

The holon is a whole that is part of another whole. Each holon is embraced into a larger holon, existing in nested hierarchies—or holarchies—like atoms in molecules, cells, organisms, and ecosystems. Holarchy includes a balance between hierarchy (with qualitatively classified levels) and heterarchy (with mutually linked dimensions) (Wilber, 2000). The evolution of organizations requires the union of differentiation and integration to materialize in healthy holarchies (Wilber, 2001). According to Wilber (2000), systems fall into four classes: interior, exterior, individual and collective; while the Integral Ecology perspective recognizes levels of complexity in different quadrants: systems, behavior, experience, and culture (Esbjorn-Hargens et al., 2011). Regardless of the different interpretation of complexity, everyone recognizes the simultaneity of all the quadrants that characterize the context and influence the evolution of an organization.

All organizations are Holons, but they are located between Holons, whose contexts permanently condition the results. The reality perceived by human beings is different from the physical reality and this dissociation creates organizational attractors. In physical terms, an attractor is a set of values in phase space to which the system migrates over time (if continuous function) or by iterations (if discrete function). In complexity, namely in CST, “an attractor basin is defined as a kind of valley in conceptual space in which an manufacturing system is directly influenced by an attractor which is delineated as a

force that dictates an manufacturing system to reproduce its specific pattern of behavior, time and again. In complexity science this is a parsimonious way of saying that an manufacturing system cannot surpass design - specification boundaries” (van Eijnatten et al., 2007).

Although the complexity of organizations emerges mainly from social phenomena that presuppose a double complexity (a complexity resulting from the impossibility of artificial isolation, and a complexity due to the fact that social life is a natural phenomenon that presupposes individual mental singularities) (Popper, 1957), it can be described within certain physical values. Given the existence of boundary-creating attractors, any social organization establishes, even if unconsciously, boundaries that define the behavior and cultures of organizational networks. All systems, or organizations, have boundaries where there are relational networks - more stable in closed organizations; and extremely dynamic in open organizations.

Organizational networks relate to holism in which the parts and the whole have an interdependence. However, there are many versions of holism. For Archibald (1992), the most antithetical and individualistic view, identified by Popper (1957) and followed by Agassi (1960), states that “if 'everyone' exists, then they have distinct goals and interests of their own.” Holism, in this sense, reflects the particular interests of a particular set of individuals, where the particular interests of a group exclude, even if unconsciously, the general interests. However, in a network, even with this utilitarian thinking, it is possible to observe a network of networks, selfish, and highly dynamic, that express individual interests and that are formalized in groups with some stability (Archibald, 1992). Thus, Holons' conception does not hinder the analysis of the structures of organizational networks; It requires identification of the elements/groups that share a pattern of stability. This pattern signals the existence of a boundary created by attractors, i.e., the design of Holons is closely related to the design of attractors.

4.16. Self-X

Drucker (2012) suggested that many manufacturers can easily put their parts production on an automatic basis, approaching continuous flow and with self-control. Taking advantage of Drucker's thought, it is necessary to distinguish self-order, self-adaptation, self-control, and self-organization, often used interchangeably. Table 4.6 summarizes in terms of objectives, path, and progression basis implied in these four concepts.

Table 4.6: Distinction between self-order, self-adaptation, self-control, and self-organization.

Initiative	Objectives	Path	Progression Basis
Self-order	Fixed	Determinate / known	Algorithmic
Self-adaptation	Change	Determinate / known	Mimicry / Evolution
Self-control	Fixed	Indeterminate / unknown	Ad-hoc
Self-organization	Change	Indeterminate / unknown	Creativity / novelty / Revolution

4.17. Noise

In self-ordered systems, scale-free correlations are difficult to achieve simply by decreasing the noise in the system. Too low a noise level can cause excessive behavioral inertia, which in turn decreases correlation and overall response. For this reason, criticality is perhaps the most likely scenario for our results. A comparison with physical systems, where much is known about the relationship between correlations and criticality, is significant in this regard. In physics, whenever a continuous symmetry is spontaneously broken, giving rise to a global ordering, it is possible to prove that fluctuations transverse to the order parameter are free of scale (Cavagna et al., 2010). This means that diffusion processes can hardly propagate in a scale-free correlation in closed systems. Moreover, the absence of noise or disruption caused by variability in the system will inhibit any process of self-organization. This means that noise in organizations cannot be overwhelmed because it represents waste. Noise in organizations can incite creativity and novelty.

To Atkinson et al. (2012) Shannon's original theory (Shannon, 1948) identified the “noise” in the system as "destructive." However, variety includes noises that can have a creative property and an asset to the organization promoting change. Noise, redundancy and variability serve and are part of the learning process within the dynamic evolution (adaptation) that defines self-organization over time through the addition of new instruments and the removal of those that are no longer useful. A lack of variety in an organization can lead to hyper-competition and can limit performance by restricting trust; inhibiting collaboration and limiting shared awareness. Variety can allow for better collaboration, a shared consciousness, and the influence of which fosters a self-organization capable of moving an organization, network, society, system to a “higher state” (Atkinson et al., 2012).

Noise instigates turbulence. It allows the generation of self-similarities that occur in time and space, with temporal or spatial power-law correlations that result from dynamical systems and critically self-organized structures with unstable states. Typically, the critical point (attractor) in dynamical systems starts far from equilibrium: the scaling properties of the attractor are model insensitive (Bak et al., 1987). This robustness, for example, emerges in the fractal structures present in nature.

4.18. Paradigm shift - Unlearning

Comparing Socio-Technical Systems Design (STS), a deterministic system that seeks continuous optimization through the imposition of self-regulation, and CST that does not determine a path and does not even indicate where to go, but only allows for reflexive interactions about everything (van Eijnatten & Wäfler, 2003), it is understandable that organizations prefer a paradigm that guarantees false certainty to another that tries to “navigate” uncertainty. Only with a reflective attitude can organizations effectively learn and adapt to complex environments (Schön, 1983).

Faced with uncertainty and disagreement between organizational expectations and reality, the classic double bind intensifies (Bateson, Jackson, Haley, & Weakland, 1956), organizations enter a schizophrenia where through control they try to achieve certainty and produce order. While there are fears that failures in control will lead organizations to anarchy and destruction, traditional referential models show losses of control without anarchy arising. This creates cynicism, disillusionment, anxiety, and hostility within the organization (Stacey, 1996).

A paradigm shift that makes production infrastructure and its supporting ecosystems smarter, faster, and more agile will be worthwhile, employing data as a critical asset for self-optimization, self-adaptation, and collaborative intelligence. Network connectivity, interoperability, collaboration, and learning to learn will define manufacturing processes in the future (Anumbe et al., 2022).

Knowledge mastery in organizations depends on the ability to unlearn. This does not mean a process of forgetting, substitution, or relearning. The process of forgetting discards everything: the good and the bad. The substitution process utilizes the virtue of vice; it forgets an incomplete system and creates another, the degree of incompleteness of which is equally uncertain. In the case of relearning, the agents reform the knowledge, which does not change its accuracy, ignoring the causes, and only observing the consequences. This type of approach is typical of the deutero- learning. "Unlearning" must consist of a process of transforming a system and requires a multiparadigm analysis that implies the use of a

plethora of meanings that allow the understanding of the organization to be refined. According to Edwards (2010), the need to increase sensitivity is justified by the complexity of social events, the diversity of paradigms and theories existing in the literature, and the inclusion of multiple valid conceptual approaches for the construction of an integrative metatheory that includes and requires more "lenses" rather than less.

There are many papers that mention the change of paradigms. It should be noted that paradigms are partial, incomplete, and that when they are replaced there is no certainty of the virtues of their alterations. In addition, futurist Toffler (1971) proposed that "Tomorrow's schools must therefore teach not merely data, but ways to manipulate it. Students must learn how to discard old ideas, how and when to replace them. They must, in short, learn how to learn. [...] A similar strategy can be used to enhance human adaptability. By instructing students how to learn, unlearn and relearn, a powerful new dimension can be added to education." This proposal, although old, remains ignored in organizations, even those related to education. Without unlearning, it is impossible to fully emerge the human creative potential of organizations.

4.19. Self-organization

The design of an organization must expect a transformation in the design, whether of a product or service, of a structure or a process, that determines the "ultimate end" of a given organizational design proposal. Whether supported by a new digital technology, or an advanced strategic plan, any "progress" is determined by what existed before. Design must always have an owner. Typically, those who are better able to "pay" for it will have their perceptions and interests represented more intensely (Tatum, 2004). In self-organized systems, the representation of interests is plural, with a greater diversity of signs and a more usable representation of individual interests. It does not mean that it reduces the inequality of the aphorism "much for the few and little for the many" presented in the power law curve. It requires the integration of individual interests into the objectives of the few at the "top" of the organization in an open network. If the purposes of the lower layers of the hierarchy of self-organized systems were not, somehow, represented in the upper layers, self-organization would disappear and require the expenditure of more resources (energy) in controlling the organization. A self-organizing system can reorganize or adapt without external guidance to meet its needs, with little hierarchical control (Brooks & Roy, 2021).

Self-organization has been an important subject of study in cybernetics and general systems theory, described by systems theorists as autopoiesis (Maturana & Varela, 1980), with the ability of a system to seek new paths of development through successive instabilities (Zimmerman & Hurst, 1993), which can instigate an increase in entropy in the system.

Self-organizing systems require high degrees of interaction between the elements that compose them. For example, in biology, when cells are increasingly concentrated, the average distance between them is shorter. At some critical distance, they create resonance in the system and begin to interact freely with each other, exciting collective modes of organization that can propagate or scale throughout the system (Cisneros, Cortez, Dombrowski, Goldstein, & Kessler, 2010). Whether cells or agents, in a given open organization, with dynamic flows within its boundaries, circumstantial processes of collective excitation can arise that promote self-organization.

The self-organization process occurs in the vicinity of chaotic states that carry states of uncertainty or, more precisely, with probabilities and basic concepts of information theory (where the chance of scarcity of an event stands out) (Haken, 1983). The development of a system occurs by both deterministic and random causes ("forces"), or by "chance and necessity" (Monod, 1972). In exclusively formal organizations, each member acts in a well-defined way under external orders. The behavior regulated in this way is not the result of joint individual interests but rather of a predetermined external purpose (e.g., production needs). In the process of self-organization, even without external orders, the members together, through mutual understanding, participate with individual objectives in the design process (e.g., design a product or a network). In self-organization, internal forces embrace external forces as parts of the system. In this process, principles of biology and general systems theory (Bertalanffy, 1950, 1968) stand out, such as the "flow balance" of the system, with a state of equilibrium existing despite the dynamism of external and internal organizational forces. These principles arose from models of chemical reactions that produce spatial and temporal structures, initiated in the fundamental work of Turing (1952) and developed by others, such as Prigogine (1976, 1977), introducing the principle of "order through fluctuations." Self-organization results from the synergies of internal and external forces that emerge from instabilities that produce excessive entropy. Hence, the importance of early recognition of the instability point in an organization, determining the emergence of a new structure beyond it with new standards (and consequently, the need for new behaviors).

Engineering, influenced by science, lives in cycles of research that contradict each other. For example, until the 1950s, mainstream scientific research denied that a machine could be capable of spontaneous

changes in internal organization. However, using the example of the human being as a strictly determined physicochemical system that can undergo "self-induced" internal reorganizations, resulting in changes in behavior, Ashby (1962) rejects the idea that self-organization cannot be extrapolated to machines. For Ashby (1962), the machine can be at the same time strictly determined in its actions and still demonstrate a self-induced change of organization.

Partially, these assumptions were previously defended by Turing (1948). Thus, any organization can benefit from the introduction of virtual agents that encourage self-organization. Despite the opportunities that can emerge from self-organization, it is reinforced that these processes must be limited in time and subject to processes of (self)destruction/dissipation. Otherwise, virtual agents can take over all the roles of human agents in an organization, making "false" self-organization a consequence of "hog action" and human acceptance in George Orwell's book "Animal Farm".

While there are many claims about self-organization in manufacturing, the variables that determine self-organization are often not spelled out. In many cases, self-organization arises as an implicit consequence of biologicalization in manufacturing systems or the admission of holonic structures with qualities that are difficult to quantify given their dynamism (ElMaraghy et al., 2021). There is therefore no self-organization without dynamic systems, i.e., self-organization requires some degree of openness that renews organizational entropy (in cycles of dissipation and emergence). On the other hand, it will be quite unwise to accept the existence of closed agile organizations, because they react to and are influenced by the external environment, their energy is used only to maintain their internal structure.

Self-organization phenomena in complex systems involve many interacting subunits, with numerous self-organization patterns that guarantee systems' coherence. Despite the controversial status of living beings related to the laws of physics, particularly thermodynamics, the process of self-organization implies a catalyzing amount of interactions between the system's units, which, although they generate fluctuations and modify macroscopic behavior, do not harm coherence. of the networks of relationships of the microscopic units of the system. There may be "competition" between the subsystems or between the internal context and the system's external environment, which propagates fluctuations that lead to instability. These "competitive" processes between systems determine a very accentuated selection, with many "survivors" whose value is higher than their competitors (Nicolis & Prigogine, 1977). Networks' coherence due to fluctuations is not a collaborative phenomenon; it emerges from a destructive, dissipative, and disruptive process. Not only the quantity of units is a relevant assumption in network interactions, but also the value they add to network cohesion.

In closed systems, the governance of the organizational structure is determined at the upper levels of the hierarchy and conditions most of the agents that are part of the lower levels. In open systems, the organization is primarily defined by the lower hierarchical levels, stimulating the behavior of the government of the higher levels. Self-organization is the basis of open organizations. Self-organization drives the becoming, the purposeful self-transformation of the organization. In this process, the participation of human agents is differentiated from other non-human agents (such as elements of the "Internet of Things") that intensify in organizational networks. In the latter, consciousness is programmed by an algorithm defined *a priori*. Human precedents and experiences are not fully glimpsed by the machine, although many, such as Turing (1948) admit this possibility. However, the existence of Holons and attractors, created by a perceived reality, increasingly narrows physical and virtual realities and opens up new research opportunities.

In a network production system, an agent can also represent a functional entity such as a production company, a production unit, a software system, interacting with each other according to simple control rules, creating self-organization capabilities and allowing the entire production system quickly redesign the system and govern the system's actions (Dan, Li, Zhang, Guo, & Zhou, 2005). Due to the demanding renewal of resources that support these networks, networked production systems require high degree of openness.

Self-organization happens in many contexts. From 1946 to 1993, Kowloon Walled City, shown in Figure 4.18, existed without explicit government control (either from Chinese or Hong Kong authorities) over an area of 0,026 square kilometers (just over 100 by 200 meters). A unique urban structure grew and developed without imposed planning. Amid the apparent disorder, from an almost arid place, at its climax, there was a solid mass of buildings with an average height of 14 floors and a population exceeding 35 thousand inhabitants (Lambot, 2017).



Figure 4.18: Kowloon Walled City, China (Kolkman, 2012)

The evolution of Kowloon Walled City showed that the growth of an organization does not just imply specialization of the parts of the whole, requiring integration. Figure 4.19 can display it. In Kowloon Walled City, there were more than 650 registered buildings in the early 1960s, while 300 remained in 1987 (Lambot, 2017).

The development and growth of Kowloon Walled City did not indicate the existence of more parts. It needs the dissipation of old parts and the emergence of new ones.

“It is a common misconception that the City was not subject to any government control or service” (Prudence, Lawrence, & Daniel, 2018). For example, aviation safety conditioned the height of buildings. Another prejudice is that the organization of space favored the spread of criminal and cartelized activities. In interviews with 30 builders, they pointed out that the market for private redevelopment was highly competitive, and there was no sign of a cartel (Prudence et al., 2018). Lack of knowledge or non-enforcement of laws does not mean the absence of laws.

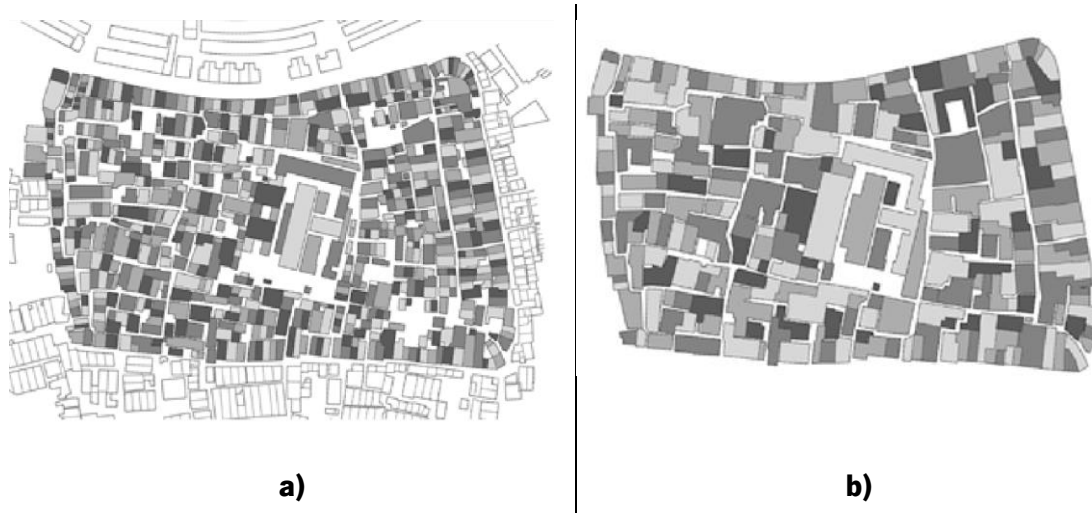


Figure 4.19: Kowloon Walled City: a) in the early 1960s, and b) in 1987 (Lambot, 2017).

The Kowloon Walled City's distinction was diplomacy, not ethnicity. Diplomacy successfully accommodated diversity. The differences were integrated and assimilated. The notion of *xiao zhong jian da* (to see the large within the small) appears to have guided the creation of the Kowloon Walled City (Harter, 2000).

The Hong Kong government demolished Kowloon's urban structure in 1993, and the space later became a park (Lambot, 2017).

4.20. Open systems

At the end of the 20th century, the manufacturing framing perspective was summarized in relation to six central propositions (Clark, 1996):

- (1) there are many ways to compete;
- (2) companies cannot be all things to all people;
- (3) there are trade-offs in production decisions about structure and infrastructure;
- (4) production strategy is defined by the pattern of decisions in many categories of structure and infrastructure;

(5) the success of a production strategy is determined by the coherence of the pattern between decision categories and the correspondence between the strategy, other functions and the business in general; and finally

(6) In the long term, a production strategy is successful because it guides the business in building essential capabilities to achieve the company's chosen competitive advantage.

Although these propositions are robust in certain dimensions, they do not include production dimensions in global open systems, which is the reality for most current organizations (Karlsson & Sköld, 2007).

A system is considered to be open when it is capable of exchanges of energy, information, matter. The influxes of energy, information, matter, produce gradients throughout the system. In some systems, these forces and flows drive self-organizing processes that produce spatial, temporal, or spatio-temporal structures, producing work that drives self-organization through dissipation (De Bari et al., 2023).

Systems, although open, produce entropy. However, they have the ability to dissipate entropy in the surroundings.

A network has costs and benefits and is dependent on the agents who participate in it. There is a statistical value for every agent, just as in economics there is the statistical value of a life. However, as Friedman (2020) points out, there are painfully obvious flaws when this methodology is applied to capitalism. Thus, when this work presents open networks as a proposal for the development of engineering, which are structures of social, cultural and economic expansion, it is not ignored that the human is a predominantly selfish agent. Without a transformation in these behaviors, open networks will only feed the economy of those who already have power and will not reduce inequalities or cultural intolerances.

However, we must be aware that open environments are subject to countless feedback loops that are very challenging to tune and control. For example, notice in Figure 4.20 that an open system (A_0) with “infinite” production capacity depends on external properties (B). The universe that includes the two systems (A) summarizes what happens when A_0 interacts with B . In this case, we only have one feedback loop defined by B .

To discover A , considering negative feedback, that is, B restricts the ability to produce:

$$O = A_0 \cdot (I - B \cdot O)$$

$$A = \frac{O}{I}$$

$$A = A_0 \cdot (1 - BA)$$

$$A = \frac{A_0}{1 + B \cdot A_0}$$

$$\text{if } A_0 \gg B \Rightarrow A \approx \frac{1}{B}$$

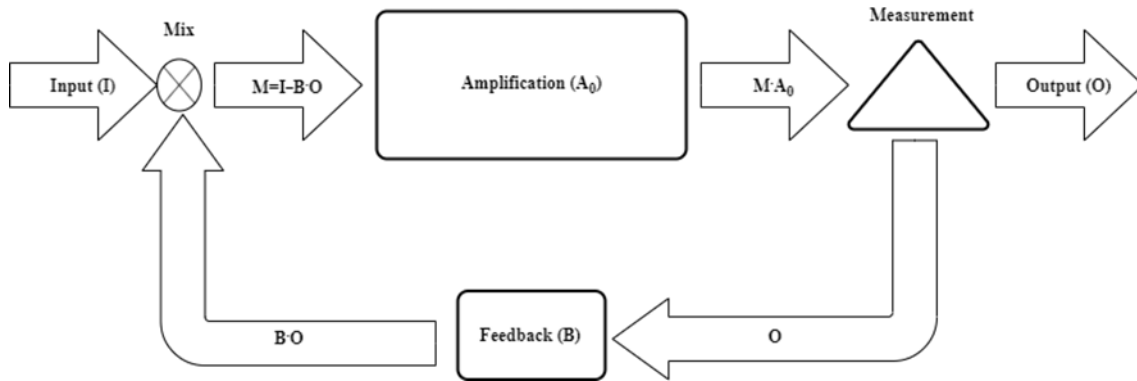


Figure 4.20: Open system (A_0) with simple feedback circuit.

An open system in negative feedback means, metaphorically, being within an unproductive universe, and its use is harmless. An open system depends on the characteristics of the external context (fluidity, agility, capacity, information, intelligence, technology, knowledge, collaboration, diversity)

In the case of positive feedback, the sign of the denominator in changes to negative, as shown in Equation 17.

$$A = \frac{A_0}{1 - B \cdot A_0} \quad (17)$$

Positive feedback can cause instability. However, a delay in positive feedback can allow control of the system that prevents the existence of resonance. On the other hand, in some events, the delay may be so high that the phenomenon has already occurred but is perceived as occurring, such as, e.g., observations in astronomy.

4.21. Open Design

Fostering competition creates abundance and scarcity. At the same time that it build options, it increases inequalities (Black, 1975). Thus, it is essential to apply design to develop alternatives to competition. The order created by design must provide for a balanced distribution of resources.

The need to invent and create is the only way for organizations to thrive without the domination or subjugation of others. Clark (1921) argued that an incomplete definition of wealth is usually proposed, because in the Euclidean capitalist model "the capacity to produce does not exist apart from the power to retain." For example, "an invention, once made public, is not 'productive,' and the inventor is not a productive factor, with respect to any past invention, except insofar as he retains patent rights which enable him to retain it from the market, and therefore right to place it on the market." Just considering the idea of "capitalist" organization, open organizations are not productive. However, open organizations whose design is not constrained by the patent economy stimulate new idiosyncrasies about power, equality, and freedom, compared to traditional closed organizations.

Open design encourages collaboration and feedback from agents/ users/ members/ makers. Having full access to the artifact design empowers users' conscious contributions to create new paradigms/designs. This integrative property promotes the expansion of product families that leverage manufacturing. Creating a network allows users to access personalized products and manufacturing benefits from contributions that improve design faster.

Open design entails issues of choosing a business model and technology strategy. In reality, the distinction between "open" and "closed" is only a matter of definition and degree. There are different degrees of openness between companies. Organizations can decide which pieces of knowledge can be opened and which remain proprietary (Bogers, Chesbrough, Heaton, & Teece, 2019). The complex nature of deciding which business model fits the design you intend to disseminate requires understanding the exact mechanisms that determine the success or failure of open design.

Open organizations have boundaries. Although tenuous, like hierarchy, the boundary defines the scope of a given structure, and is itself made up of changing internal boundaries (organic transformations within holons that change their internal context). Open organizations depend on the context (individual, collective, internal, external). Open organizations are difficult (or even impossible) to conceive of in closed societies, economies, cultures. Closed contexts negatively amplify boundaries, closing them. Open organizations are not free. Open organizations have costs (time, energy, money, technologies, ...) and

depend on work (voluntary or rewarded) that must be composed of several specialties. Open organizations need networks with diversity (quantity) and variety (quality) of members. To ensure connections and resilience, the organization must be able to have a great capacity for renewal through a large number and a great variability of members that guarantees sufficient agility for the constant changes and requests of the context.

4.22. Collaboration

Any digital transformation strategy in organizations is likely to go unnoticed if it does not consider the importance and adoption of flexible and open structures. As the open organization requires an open business model, it is only feasible based on a relational vision built on agile collaboration, promoting mutual trust between agents and facilitating the transfer of knowledge across organizational boundaries (Sjödín, Parida, Jovanovic, & Visnjic, 2020).

Business strategies are increasingly digital and driving greater diversity in operating models, trying to increase the “just-in-time” model with “just-in-case” scenarios and using new strategic collaboration and partnership networks. Business strategies attempt to ensure more effective scalability of organizational capabilities by sharing distributed resources among many customers (ElMaraghy et al., 2021). The decentralization of risks allows organizations greater resilience in the face of increased uncertainty.

The collaboration will always involve some participatory action-research involving the agents as subjects and co-researchers (Argyris, 1999). Even IoT or IIoT devices must have some degree of autonomy, allowing them to be part of new networks. Without the ability to integrate and expand, systems are not flexible. Consequently, the complexity of the network depends on the ability of its agents to take on multiple roles.

Collaboration requires interaction, interoperation, integration, distribution, decentralization, and networking, implying greater complexity resulting from the large quantity and diversity of data/information shared and the consequences of this sharing between collaborating entities in the network, e.g., machines and humans, in a context of an expanded production environment. (Varela, Putnik, & Romero, 2022).

Collaborative organizations must use Collaborative Engineering. “Collaborative Engineering is the engineering design process (practice) within an intentionally developed community as a complex network, created to promote and maximize the individual and shared learning of its members, through

ongoing interaction, interplay, dialogue and collaboration among the community's members to achieve common goals of collaborative learning on design and creation of novel design" (Putnik et al., 2021). Although collaboration promotes an unpredictable outcome, unknown in advance, it increases the probability of new developments emerging, limiting the possibility of repression and subjugation of the individual interests of the organization's members. Singular interests do not accompany but are part of collective (organizational) interests.

4.23. Adhocracy

Baber (1983) specified the conception of a post-industrial society where organizations are conditioned by six characteristics: 1) transience, 2) complexity, 3) conflict, 4) integration, 5) professionalization, and 6) technocracy. Given the first characteristic, the concept of transience emerges from five distinct contexts proposed by Toffler (1971): 1) rapid obsolescence of material things, 2) and increased geographical mobility, 3) which weakens the connections of human relations, 4) causing a rapid devaluation of information, 5) and encouraging the formation of temporary organizations (adhocracies).

Adhocracy (an agglutination of the Latin ad hoc, meaning for a specific end or for a purpose, plus the suffix cracy), as opposed to bureaucracy, shows in Figure 4.21 that organizations are incapable of establishing only one permanent strategy, given that the change in context requires the emergence of strategies disaggregated from those initially intended (Mintzberg & McHugh, 1985).

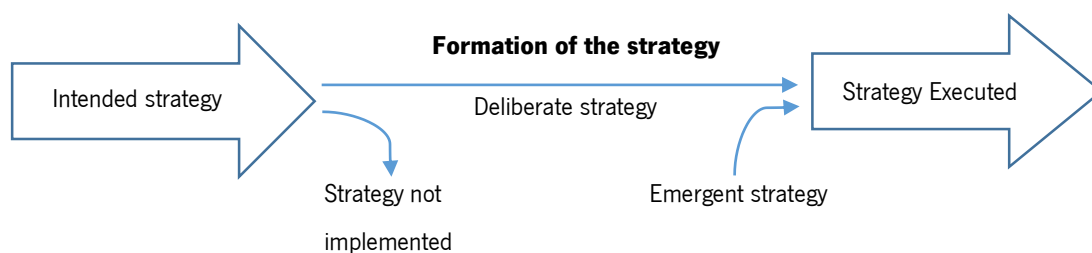


Figure 4.21: Basic Forms of Strategy Action (Mintzberg & McHugh, 1985)

4.24. Learning Culture

Argyris (1999) argued that any organization must transform its basic assumptions into “learning assumptions” and promote them in its culture. Among the main learning assumptions is that people want to contribute and are trusted to do so, thus spreading the responsibility for learning and making it part of the culture, promoting its creation through cultural diversity. The sequential conceptual model can be applied in organizations without difficulties if learning purposes are known in advance. In classical management, these purposes are defined by the top of the management hierarchy, assuming organizational and ignoring individual interests.

CST sees organizations as systems with life cycles (van Eijnatten et al., 2007). Although life cycles are natural processes, transversal to all organizations, organizations insist on using learning as a competitive factor rather than a self-conscious process. Classical learning models are unlikely to allow for less social unrest. Some reasons are worth noting:

- The difficulty for organizations to abandon their attractors;
- The difficulty for organizations to accept ephemerality;
- Organizational narcissism that prevents the adoption of new ideas.
- The illusion that an organization requires only physical control, i.e., the monolithic internal organizational context defines (illusorily) the organization’s boundaries.

Complexity theory in the management of organizations warns of the action of learning. It partly shares Argyris’s positions on the multiple roles that different organizational agents can assume. However, one of the most relevant actions is unlearning, i.e., the ability of organizations to transform their models (with the dissipation of old ones and the emergence of new ones) and enable mechanisms to discover new paths to new unknown attractors.

The learning culture in organizations must consider the increase in the complexity of systems, benefiting the creation of an authentic novelty, defined as something entirely new and characterized by a lack of prior knowledge of the object and the process for its creation (Putnik & Putnik, 2012), as shown in Figure 4.22.



Figure 4.22: Real novelty defined as something completely new, characterized as unknown in advance both the what (the subject matter to be created) and how (the process by which the subject matter is to be created) (Putnik & Putnik, 2012).

Manufacturing systems based on ubiquitous manufacturing, cloud manufacturing, social manufacturing networks, and open manufacturing, among others, promote the systemic occurrence of interactions between many independent agents, leading the system to spontaneous self-organization and learning through feedback loops. The success of new production systems depends on new ideas, techniques, and agile methodologies nurtured by the CST (Putnik & Putnik, 2012). Models that adopt the principles of complexity in the organizational learning culture allow the dissipation of old ways of thinking and doing to enable the emergence of new ones.

4.25. Technology culture

Han (2017) recalls the prophecy of Vilém Flusser that today's human being, equipped with digital devices, already lives the "immaterial life". In the immaterial future, the human being will not be defined by a worker, Homo Faber (Arendt, 1958), but as a player - Homo ludens. Homo digitalis - will not be a man of action (Han, 2017). Such a view can place the human in a subservient position if Mckeeon's (2016) position is accepted, which states that power is initiative and that there is no power except the power exercised.

In the 21st century, the VUCA (Volatility, Uncertainty, Complexity, and Ambiguity) world is under enormous pressure to change and needs a high capacity for transformation and innovation. This fundamental change requires new collaboration models with high flexibility and a strong capacity for the self-organization of systems. Holacracy, collegial leadership, empowerment, or agile organization emerge with centralized and hierarchical structures changing to heterarchical and open structures (Burchardt &

Maisch, 2019). These structures try to benefit from the Internet of Things or Industry 4.0 with more information transparency and using participatory approaches, such as Open Innovation, achieving new work cultures that aim for greater autonomy, agility, and self-realization of human beings. Meanwhile, people's social behavior is changing the use of digital technologies. The focus is no longer on the power and knowledge of individual executives but on collegial decisions anchored in the organization's subsystems. The objective is to develop and use the potential of all people in the organization and anchor this implementation as a cultural asset. An open and participatory culture is noteworthy, "because "culture constrains strategy," a company must analyze its culture and learn to manage within its boundaries or, if necessary, change it" (Schein, 1985).

Decisions can benefit from real data to back them up. But we must attend to the circumstances. For example, IBM promoted Project Watson, creating a medical diagnostic assistant software that provided a list of various potential diagnoses, with decreasing probability ratings (Lohr, 2015). However, this technology erred in the quality and quantity of data that fed the system (Yang et al., 2022).

Another example shows that organizations that adopt data-driven decision-making achieve 5 to 6 percent higher productivity than could be explained by other factors, including investment in technology (Brynjolfsson, Hitt, & Kim, 2011). In contrast to traditional management thinking based on "experience and intuition", decisions based mainly on "data and analysis" are still minimal. Brynjolfsson argues that "the technology is well ahead of the management culture" (Lohr, 2015).

Featherstone (2007) refers to postmodernism from several perspectives: a new post-industrial order, which replaces universalism with localism; cultural practices and changes in the power balances of groups involved in production, classification, circulation and consumption; emerging cultural complexes that attempt to create a new cultural order. However, in modern technological societies where no individual has mastered all scientific skills, there is a considerable division of labor, with specialists, with scholastic formats for the transmission of knowledge and explicit standards for evaluating success (Gardner, 2011). Thus, in organizations the risk of misunderstanding and oppression of cultures with different standards increases.

Organizations must leverage technological resources to support and adapt to digital strategies and top management capabilities. Many organizations have made smart investments but have not achieved the expected returns. Technology changes the business model and the business constantly requires new technologies that adapt to new structures. Technology is a means that changes the structure (X. Zhang,

Xu, & Ma, 2022). Therefore, organizations must know how to properly leverage the value of these tools and the compatibility between the new technologies and the "new" organization.

While it can be safely stated that the use of advanced computer technologies is contributing to further improve the efficiency of the (integration) system, the contribution of the "technology-driven" approach is sometimes less obvious, if not downright harmful. Such a situation alerts us to the fact that "tools by themselves do not promote success; the proper use of the tools does" (Putnik & Putnik, 2010). In addition, "the social, cultural and organisational aspects play more decisive roles than technology itself" (Liu, 2000).

Halevi suggests that production planning in organizations is a very complex task, not least because of rigid organizational structures that try to solve disruptions by mathematics rather than technology. It also states that large organizations will dominate the automation of production processes and that smaller companies will have more difficulty competing with them due to the high investment cost of technology (Halevi, 2017).

The rapid circulation of information also accelerates the circulation of capital. The tide of information we are exposed to is interfering with our ability to reduce things to their essence. Thinking necessarily involves negativity: discernment, discrimination, and selection. More information doesn't necessarily lead to better decisions. According to Han (2017), the growing mass of information diminishes our higher faculty of judgment.

5. Mathematical models

There is a tendency to delimit formalization in science, and in a more consistent way in mathematics. However, the attempt to formalize the systems collides with the improbable certainty of empirical induction processes.

5.1. Formality in Mathematics

Gödel (1986) proved “that in every consistent formal system that contains a certain amount of finitary number theory there exist undecidable arithmetic propositions and that, moreover, the consistency of any such system cannot be proved in the system.” Thus, formalization emerges as an incomplete process, uniquely defined as any mechanism for the production of formulas, called probable formulas.

Although the complexity of the behavior of many systems has underlying rules that are much simpler than one might intuit, complexity has fundamental limitations in the idea of central proof in traditional mathematics, and the limitations of Gödel's principle persist (Wolfram, 2002).

In the presentation of his work, when he received the Nobel Prize in physics, Wilhelm Wien, in 1911, showed the importance of abduction in scientific research and the advances that science has achieved with this methodology. He assumed that “to be allowed to idealize, we must neglect all non-essential secondary phenomena, while considering only everything indissolubly connected with the processes under examination” (Wien, 1911). Thus it was that “Boltzmann derived from thermodynamics the law, previously empirically formulated by Stefan, that the radiation of a black body is proportional to the fourth power of the absolute temperature” (Wien, 1911). Although the Stefan-Boltzmann formula cannot be refuted with another process, science often denies abduction.

Thus there remains the deduction hostage to the known universal, capable of guaranteeing an (uncertain) secure formalization of general theories that conform the parts into a homogeneous whole.

Formality in mathematics is not as comprehensive as the diffusion of its attributes immersed in the pragmatism of an exact science. The discovery was not always governed by rules, because some were only defined later. Practice has often instituted the rule. As an example, Benjamin Peirce recalled that following Euler's formula that relates π , e , and i , that a professor of his at Harvard, in the middle of the nineteenth century, faced with the disconcerting equality $e^{\frac{\pi}{2}} = \sqrt{i}$ said: “Gentlemen, that is surely true, it is absolutely paradoxical, we can't understand it, and we don't know what it means, but we have

proved it, and therefore we know it must be the truth” (Archibald, Lowell, Byerly, & Chace, 1925). This thought reflects how even in logic there are many research opportunities for use in organizations.

5.2. On formalization of systems

Some argue that the possibility of formalizing Hilbert, von Neumann, and Turing, in mathematics, or Peirce and Saussure, in linguistics, in which all organizational processes can be replaced by computing systems, with autonomous control, without the intervention of human imagination and creativity. Others assume the impossibility of formalization with the limitations of algorithms, the incompleteness thesis proposed by Gödel, and the behavior of dynamical systems.

Reality can be constructed or interpreted, in the same way that, by quantum physics, light can be interpreted as a wave or a particle, depending on how the observer is faced with the phenomenon. The process of interpretation conditions the analysis and evaluation of any system.

Systems should have monitoring and remediation tools that can anticipate problems and provide solutions. These instruments should not, by default, be sources of problems caused by entropy of information, lack of return channels, or inadequacy of systems. Such instruments, therefore, must be carefully formalized. Perhaps the greatest difficulty is the assessment of the adequacy of the criterion.

As proposed by Minorsky (1922) for the control of the rudder of a ship, although the problem of anticipating some probable developments in the near future or theoretically predicting the appearance of an eventual disturbance is meaningless, one should not underestimate the practical consequence in reducing the effects of crises on society when using predictive models.

The organizational dynamic system involves multiple oscillations that, when neutralized, reduce the final vibratory effect and do not represent a threat to the organization. However, if some oscillations occur in the same direction, their overlapping effects add up and can generate significant consequences, with periods typically called prosperity when referring to progress and crisis when referring to a recession. These events are characteristic of the life inherent in an organization where there is a cure for everything except death (Pareto, 1917b).

Mathematics is able to reveal that there are elements that condition the development of systems. Organizations such as cellular automata can be considered as irreversible discrete dynamic systems. The order merges with time and, successively, following trajectories that become concentrated in attractors that usually contain a tiny number of possible states. This limited attraction of arbitrary initial

states fosters a self-organizing behavior that evolved from seemingly structureless realities. Thus, “the nature of the attractors determines the form and extent of such structures” (Wolfram, 1984). Attractors are examples of the regimes or organizing forces of social holons and their inherent teleological attraction to the pattern, without which a holon could not identify itself and simply would not exist (Wilber, 2001).

In a cybernetic analysis that disregards the mental processes relating to living things, potentially “all the physical and chemical laws that apply to the inanimate universe apply also without exceptions or restrictions to the living organisms” (Rosenblueth, 1970). One can therefore develop, through abstraction, a formal mathematical model that reveals, in logical terms, the idealization of a relatively simple situation that shares the structural properties of the original system. It should be noted that this type of analysis does not consider the indeterminacy of systems defended by Arthur Eddington, Werner Heisenberg, or Erwin Schrödinger, among others, and that it can cause catastrophic events in the systems, because, although statistically irrelevant, these are not impossible. Hence, mathematical formalization has limits, and it must be recognized that “the main tool of science is the human mind and that the human mind is finite” (Rosenblueth & Wiener, 1945).

The study of organizational behavior benefits model simulations of system dynamics using feedback loops. Managing complexity in organizations requires a systemic approach capable of predicting and analyzing the behavior of complex systems, which helps to identify behavior patterns and implement more effective policies (Forrester, 1961). Organizations operate in environments characterized by uncertainty and complexity. Organizations must adapt their structures according to the specificities of their technologies and environments, as no single organizational structure is ideal for all situations (Thompson, 1967). Organizational effectiveness depends on environmental and technological contingencies, implying continuous adjustments and changes in organizational structures and processes. Any mathematical formalization must understand organizational dynamism.

Science, like organizations, likes to assume its actions as grounded in true foundations. The presumption of truth is debatable as a persistent reality because this kind of truth is temporally insensitive. Hence, perhaps, grammar will remain proscribed from the theory of organizations, since it would reveal the inconstancy of truth. “There are no whole truths; all truths are half-truths” (Whitehead & Price, 1954).

5.3. Algorithmic information content

According to the classical physics of a century ago, accurate knowledge of the laws of motion and the configuration of the universe at any moment in time would, in principle, make it possible to predict the entire history of the universe. We now know that this is quite false. The universe is quantum-mechanical, implying that even if its initial state and the fundamental laws of matter are known, only a set of probabilities for different possible histories of the universe can be calculated (Gell-Mann, 1995b).

One of the concerns of organizations is to reduce the time it takes to solve a given problem. In computing, programmers call the problem "computational complexity" the shortest possible time to find a solution. Contextual dependencies emerge from the technology and the algorithm, as presented in Figure 5.1. In the 1960s, the concept of information content emerged, which showed that computational complexity depends on the entropy of the algorithm (Gell-Mann, 1995b).

Chaitin (1994), one of the creators of algorithmic information theory, calls a program "elegant" if no smaller program produces the same output. Algorithmic information theory is an elegant theory of complexity, perhaps the most significant, but as von Neumann warned, pure mathematics is easy compared to the real world (Chaitin, 1994).

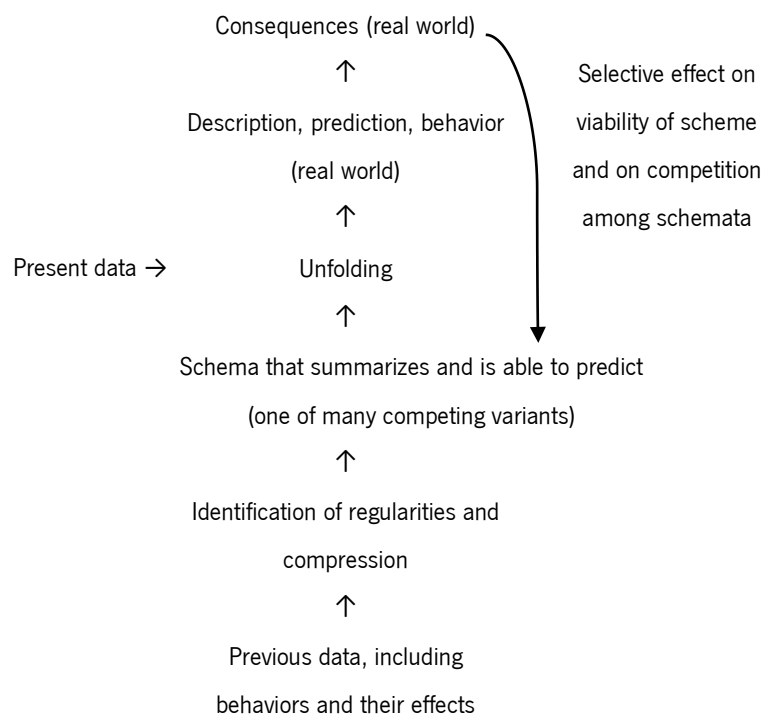


Figure 5.1: How a complex adaptive system works (Gell-Mann, 1995b).

Considering the computational complexity, the best solution is between order and disorder, as can be seen in Figure 5.2.

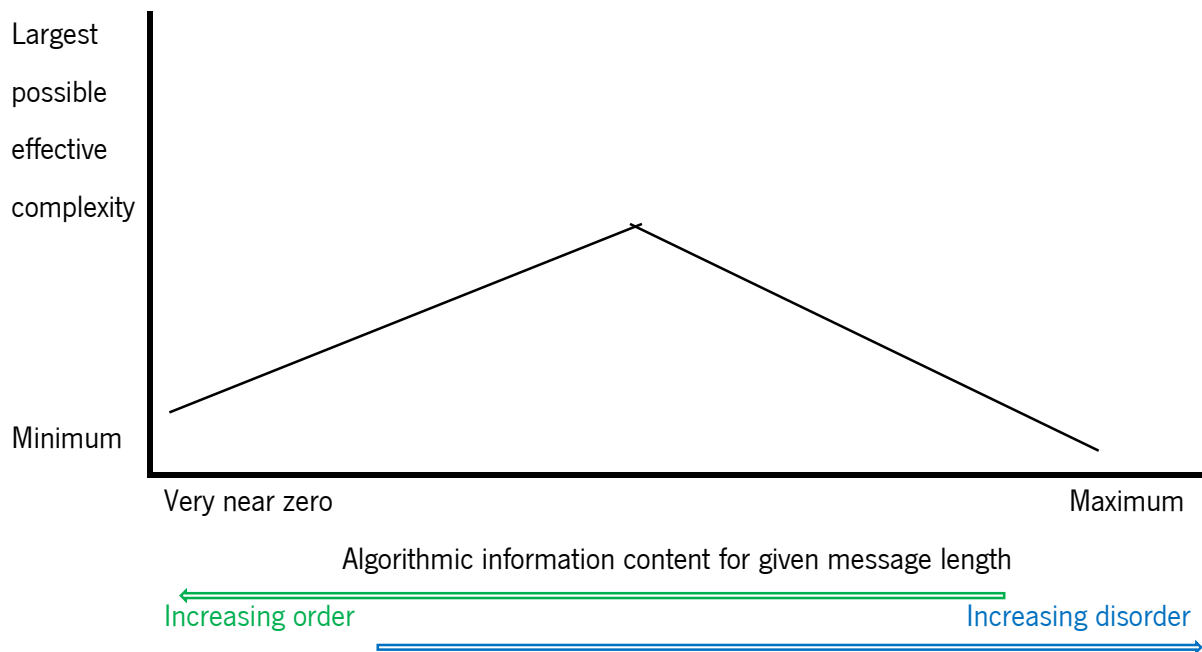


Figure 5.2: A sketch showing roughly how the largest possible effective complexity varies with algorithmic information content (AIC) (Gell-Mann, 1995b).

Simplicity refers to the absence (or near absence) of complexity. Gell-man assigned the word plectics as a branch of complexity, which shares the etymological root plexus, meaning “braided”, originally “braided together” (Gell-Mann, 1995a). Complex nonlinear systems may exhibit simplicity, but only emergent and not obvious from the outset (Gell-Mann, 1995b).

Now almost all classical or modern physics is statistics, where chaos and complexity are emphasized and systems can behave unpredictably. Although it is still strongly established that mathematics is eternal, static, and perfect, in fact, there is a new field of mathematics, called metamathematics, which claims to know what the limitations of mathematical reason are (Chaitin, 1999). Transferring this reality to the management of organizations, it seems to be imperative to create a meta-management capable of recognizing the limitations of current management models, especially in manufacturing.

5.4. Algocracy

While algocracy may appear to have built-in bureaucratic structures, the system is driven by the algorithm, or more deeply, by binary code. System formulas are not bureaucratic, but rather mathematical, even when a programmer codes bureaucratic controls into a software system. This means that algocracy can codify not only bureaucratic governance, but also non-bureaucratic and less hierarchical governance, as seen in peer-to-peer programming schemes or open-source development projects. The notion of algocracy implies, therefore, an “algorithm rule” or a “code rule” and not a bureaucratic surveillance system (Aneesh, 2009). It is possible, therefore, to have a self-organized open system under the rule of an algocracy that distinguishes the variety of activities/agents and their relationships in digital schemas, in a programming code that allows the emergence of a global organizational space.

The use of PID control as a way of governing complex organizations is limited to the existence of a dynamic environment (internal and external) that constantly changes organizational purposes (individual and collective). Thus, management based on algocracy is limited to small and basic human organizations whose objectives and the path to achieving them are known in advance (allowing the creation of an organizational management algorithm).

5.5. Power law

Power law distribution spans many disciplines, from physics, biology, engineering, and computer science to economics, political science, sociology, and statistics. Well-founded methods for analyzing power-law data have not yet taken root across science, and hypothesized distributions are imprecise concerning the data. For example, the common practice of identifying and quantifying power law distributions by the approximately linear behavior of a histogram on a doubly logarithmic plot is unreliable. Such linear behavior is a necessary but insufficient condition for “true” power law behavior (Clauset, Shalizi, & Newman, 2009).

Let $p(x) dx$ be the fraction of quantitative data between x and $x + dx$. If the histogram is a straight line on log-log scales, then $\ln p(x) = -\alpha \ln x + c$, where α and c are constants. (The minus sign is optional). Taking the exponential of both sides, this is equivalent to Equation 18.

$$p(x) = Cx^{-\alpha} \quad (18)$$

with $C = e$. Distributions of the form in Equation 18 are said to follow a power law. The constant α is called the exponent of the power law. (The constant C is mostly uninteresting; once is fixed, it is determined by the requirement that the distribution $p(x)$ sum to 1) (Newman, 2005).

There are many different mechanisms for producing power laws. Such systems self-organize up to a critical point (attractor). Due to phenomena associated with the self-organized criticality concept, the systems totally or partially lose their scale factor as they diverge (Newman, 2005). Divergence can leave the system without an appropriate scale factor to define the size of some measured quantity, i.e., the quantity follows a power law (dimensionless or scaleless).

Power law distributions occur over a wide range of phenomena, e.g., populations in cities, the sizes of earthquakes, the size of lunar craters, the size of solar flares, the size of computer files, frequency of use of words in any language human nature, the number of articles scientists write, the number of citations the articles receive, the number of hits on web pages, the sales of books, musical recordings, and almost all other commodities, and the annual incomes of people. Power law distribution appears under names such as the 80/20 rule and scaleless distribution, highlighting two physical mechanisms: 1) The Yule process, which states that there is a propensity for the rich to get richer, and 2) The phenomena of the critically self-organized system in which a system scale factor diverges, either because we tune the system to a particular critical point in its parameter space or because the system automatically heads to that point by some dynamic process (Newman, 2005).

5.6. Exponential growth versus Power Law

Empirically, we can assume that the design evolution follows an exponential distribution or power-law. Although commonly confused as equals, they are only approximate.

To clarify this idea, observe the evolution of the power law $p(t)$ curve in Equation 19 and the exponential $r(t)$ curve in Equation 20 with $c_1 = 2$ and $c_2 = 3$, shown in Figure 5.3. Informally, the exponential term characterizes the behavior of the two functions.

$$p(t) = c_1 c_2^t - c_1 \quad (19)$$

$$q(t) = c_1 t^{c_2} \quad (20)$$

Nevertheless, the growth of $p(t)$ is the power law. An exponential growth approximation does not significantly change the conclusions when a network is small or temporally constrained.

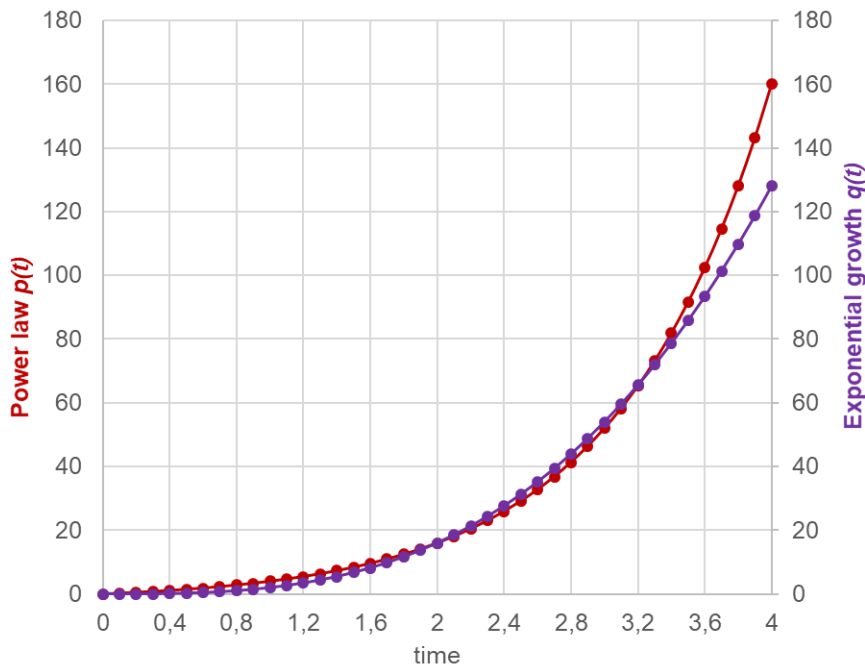


Figure 5.3: Comparison of the growth of power-law and exponential functions.

However, the growth effect cannot be underestimated when analyzing a time-expanded sample where the $\dot{p}(t)$ is higher than $\dot{q}(t)$. Sometimes the word exponential is misleading to characterize the growth or composition of a network.

Expanding the number of connections and communications (information transfer) in an organization can contribute to increasing organizational intelligence, as it amplifies the number of choices. In fact, this concept has been debated among physicists, mathematicians and applied in production, logistics or management of organizations. However, it is important to distinguish between exponential growth and

power law growth. In small networks, the type of network growth is almost indistinct, as shown in Figure 5.3.

5.7. Engineering and Design

“True” engineers are designers (creators). The Greek word *techne* (art or craft) encourages an engineer to overcome binary thinking and accept that design is simultaneously science and art (Mozota, 1998, 2003). Furthermore, in addition to engineering *techne* is very close to the *Episteme* (Parry, 2024; Rawlins, 1950), which is highly appreciated in current science.

As an effect of pragmatics, semiotics generates ambiguity. While engineering is full of paradoxes, it tends to ignore them. It is not only human action that increases complexity, but human behavior of ignoring the unknown does not benefit from decreasing entropy in systems. On the contrary, it increases it. And the result is yet another paradox: the human does not like ambiguity, but contributes to its increase (Putnik, Putnik, Pinheiro, & Alves, 2022).

It was at the beginning of the 20th century that the need to adjust the needs of users to the design of products and the design of production systems was assumed. However, it was only later that they found a "real connection" in engineering with TRIZ (Altshuller & Shapiro, 1956) and axiomatic design (Suh, 1990). "True connection" means that these methodologies provide tools that allow for the systematic interpretation of design problems briefly through "ideal end result" and "contradictions" in the case of TRIZ and "functional requirements" and "design parameters" in the case of Axiomatic Design. The tones, measures and shapes, with TRIZ and Axiomatic Design, found message converters - translators - between the user (abstract thinking) and the engineer (pragmatic thinking), which improve the communication process and the artifacts. These methodologies can be implemented by a person or in a collaborative process, protecting intellectual property or promoting the expansion of open source. The open design network will achieve faster results as long as self-organization has been achieved beforehand. Self-organization allows, in the context (internal and external), to create a balance between energy expended and results obtained, i.e., the reaction does not seek the optimal result, but the best achievable result, because no optimal result is eternal.

The activity closely associated with design is synthesis, for which there is no commonly recognized form of reasoning (Cross, 1989). Therefore, we emphasize abduction. According to Peirce (Peirce, 1998): “Deduction proves that something must be, Induction shows that something actually is operative,

Abduction merely suggests that something may be.” This characteristic of intuitive design, based on subjective thinking, is transferred to engineering (Cross, 1989).

Design includes not just engineering. Design must be the central reason for organizations, justifying their existence. As shown in Figure 5.4, it centralizes the relationships between manufacturing, engineering, human resources, and marketing, being the link between all resources and organizational elements.

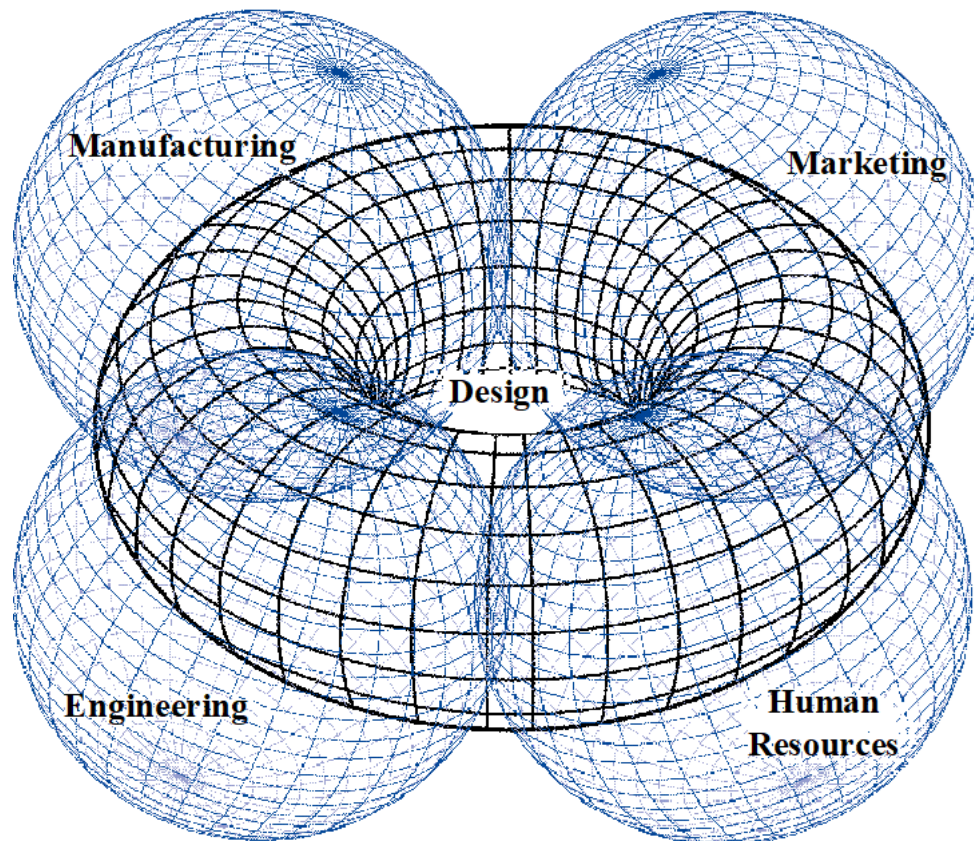


Figure 5.4: Design as an aggregator of disparate parts in organizations.

From Plato and Aristotle, the distinction between theoretical thought and technological activity was established, where words such as machine or engineer emerge, which do not refer to rational knowledge, but to cunning and convenience. The idea is not to efficiently replicate natural processes, “but to deceive nature, to "machinate" against it – that is, to work wonders and create effects extraneous to the "natural order" of things”. (Prigogine & Stengers, 1984) This was augmented by the Newtonian synthesis which systematically combined “manipulation” and theoretical understanding. Organizations must also be able to create an alternative order to the pseudo-fatalism of the natural order.

While there are no organizations without structure, and structure only exists with design, often the design of organizations is ignored. To emphasize this perspective, take as an example the role of leadership, which is heavily emphasized in traditional organizations. Metaphorically, Senge (1994) wrote:

“The neglected leadership role is that of the designer of the ship. No one has a more sweeping influence on the ship than the designer. What good does it do for the captain to say, “Turn starboard thirty degrees,” when the designer has built a rudder that will turn only to port, or that takes six hours to turn to starboard? It’s fruitless to be the leader in an organization that is poorly designed.

Translating the role of designer from the context of an engineering system to that of a social system is tricky. As leaders in organizational contexts, we are not designing a thing, something separate from ourselves. When we think of ourselves as designers, it might even be tempting to think of the organization as a sort of machine, one that somehow needs to be redesigned. But, we are participants in the system not outsiders, and you do not redesign a living system as you would redesign an automobile.”

5.8. Innovation pattern

The results of the organizations summarize the synthesis between the adaptation of their purposes and their surroundings. This adaptation includes the type of innovation adopted. Three types of innovation are distinguished: incremental, radical, and disruptive. They all share the intention to promote change. Essentially, it's the kind of change that distinguishes them.

Not all discontinuous or radical innovations are disruptive innovations. Technological discontinuities do not always have disruptive effects on organizations. (Dan & Chieh, 2008).

The innovation pattern is stunningly consistent. Whether the technology was radical or incremental, expensive or cheap, software or hardware, component or architecture, competence-enhancing or competence-destroying, the pattern was the same. The disruptive innovations were technologically straightforward. On other hand, advanced technology development in the industry was always to sustain established trajectories of performance improvement to reach capital higher-performance. Many of these technologies were radically new and challenging, although were not disruptive (Christensen, 1997).

Although the organizational technological process leads, from the simplest to the most radical innovation, the organizations that led in all cases of development and adoption of disruptive technologies were newcomers to the industry, not its incumbents. Leadership in these cases required unique

technological capabilities, that is, radical changes rather than incremental innovations (Christensen, 1997).

The purpose of organizations should not be to maintain old ideas/products but to create new ones and introduce them to the market when product cycles reach maturity. Organizations should not think in a product cycle but rather in interdependent cycles, which summarize the parts worth keeping and abandoning the others, as shown in Figure 5.5.

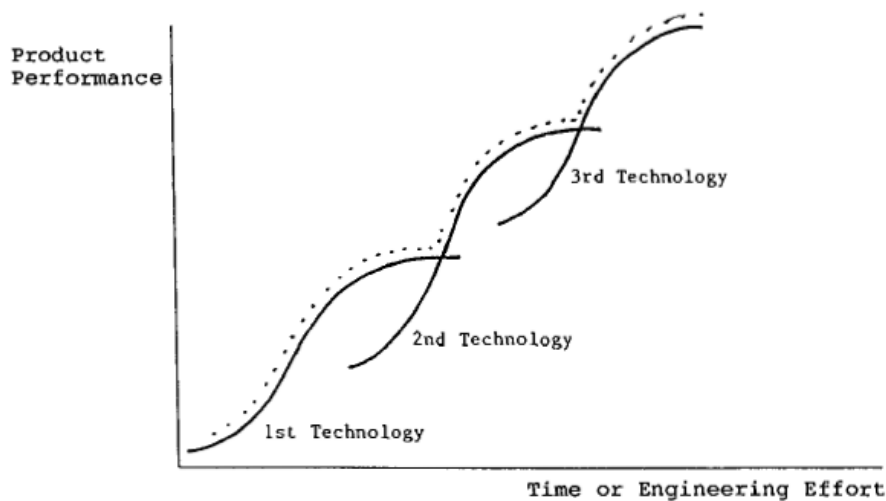


Figure 5.5: Limits of the Technology (Christensen, 1992).

5.9. Diffusion of innovation

Innovations don't just depend on time. The relationships that enable innovation are more complex than a one-dimensional context, for example, which only considers time). Figure 5.6 shows how the innovation process can evolve with time and distance. Distance can be a metaphor, for instance, of the proximity of scientific knowledge. Adding additional dimensions to models improves their representation of reality. However, more dimensions can make models indecipherable, making it difficult to decode system patterns.

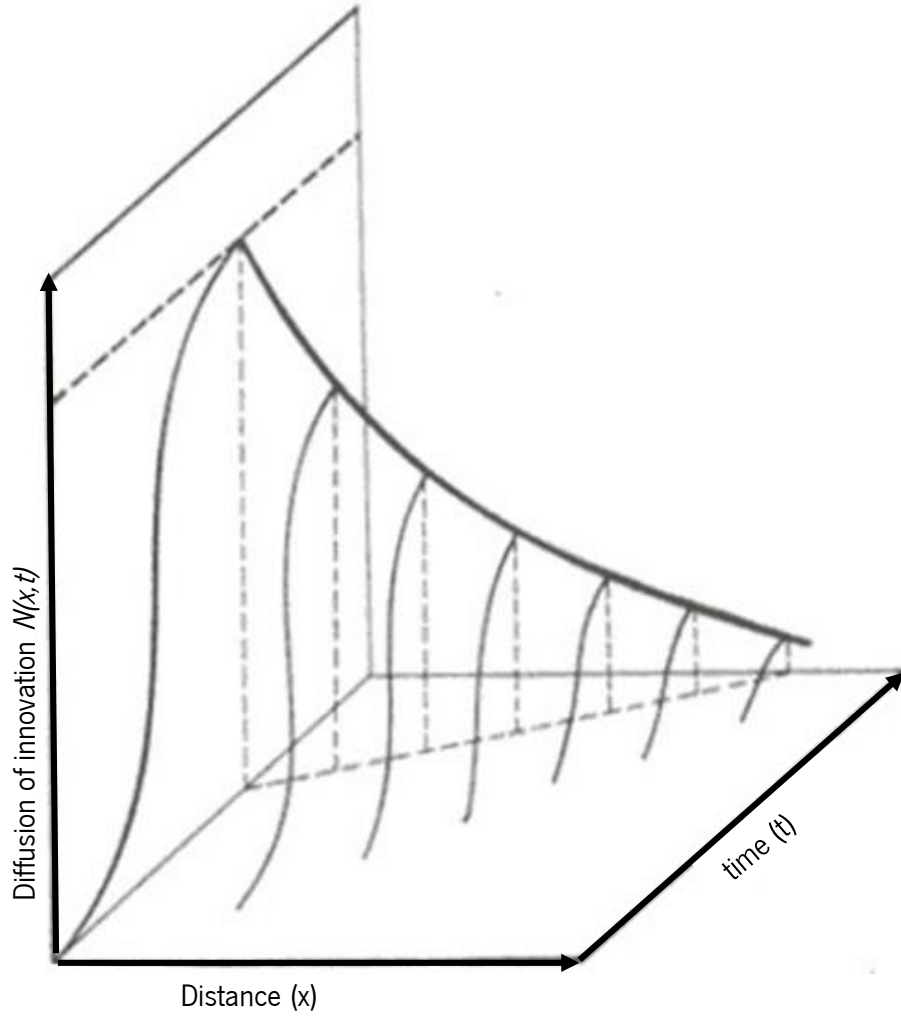


Figure 5.6: Diffusion of innovation as a function of time and distance (Mahajan & Peterson, 1985).

Figure 5.6 arises from Equation 21:

$$N(x, t) = \bar{N} \frac{\bar{N}(x) - \frac{a(x)(\bar{N}(x) - N_0(x))}{a(x) - b(x)N_0(x)} e^{-(a(x)-b(x)\bar{N}(x))(t-t_0)}}{1 + \frac{b(x)(\bar{N}(x) - N_0(x))}{a(x) - b(x)N_0(x)} e^{-(a(x)-b(x)\bar{N}(x))(t-t_0)}} \quad (21)$$

$N(x, t)$ represents the diffusion function of innovation with respect to distance x and time t . The function $a(x)$ is defined as an indicator of mimicry or internal induction and reflects the interaction of earlier adopters $N_0(x)$ with potential adopters $(\bar{N}(x))$. The $b(x)$ function is a representation of the effect of horizontal communication channels, decentralized or not, structured and informal. Adopters are those who follow, accept, and use a particular innovation.

5.10. The laws of physics and complexity

Classical physics has an adage that assumes that all actions have a reaction as a result. With the work of Clausius and Boltzmann on entropy, it was verified, by the second law of thermodynamics, that inactions also have reactions, due to the effect of time degradation. Later, Heisenberg shows that phenomena are subject to an uncertainty caused by the observer. These unique phenomena are related in organizations through a concept – complexity.

The previous examples used physics to characterize part of the concept of complexity, but it requires a broader perspective, encompassing other areas of the exact and natural sciences. Complexity is not analyzed as synonymous with complicated, and it has peculiarities that distinguish it from other approaches used in the management of organizations.

Ergodic theory (from Greek *ἔργον* (ergon), “work”, and *ὁδός* (hodos), “path”,) is a branch of mathematics that studies dynamical systems, and assumes entropy and statistics as fundamental tools. This theory reveals that in their evolution, ergodic systems tend to abandon their initial state with a stochastic and uncertain dynamic.

The fact that evolution reveals that more organized systems develop over time may contradict the concept of organization applied in thermodynamic entropy. However, these highly developed systems can be organized by a process of meeting rather than a process of creation. When using entropy, aware that it is subject to a temporal scale, represented between the past and the future, one must consider the system in isolation. The distortion of isolation can generate organization, with the collection and drainage of other neighboring systems (Eddington, 1935). This misrepresentation, legitimate as long as it is expressed, is often used in the analysis of the dissipative structures of cities, among other open systems. In these cases, the entropy of one system decreases at the expense of other systems.

Meetings inevitably need an aggregating element, an attractor that orders the actions, which in organizations must be the responsibility of the management elements. Generally, only a fragment of Lorenz's (1972) example of the "butterfly effect" is presented that justifies the agglomeration that culminates in adverse weather events. Figure 5.7 shows an example of the growth of Lorenz attractors. Unlike Minorsky's PID control, in which the target is known, in the case of Lorenz's equations the attractor is unknown at the outset, and small variations in circumstances can radically alter the results.

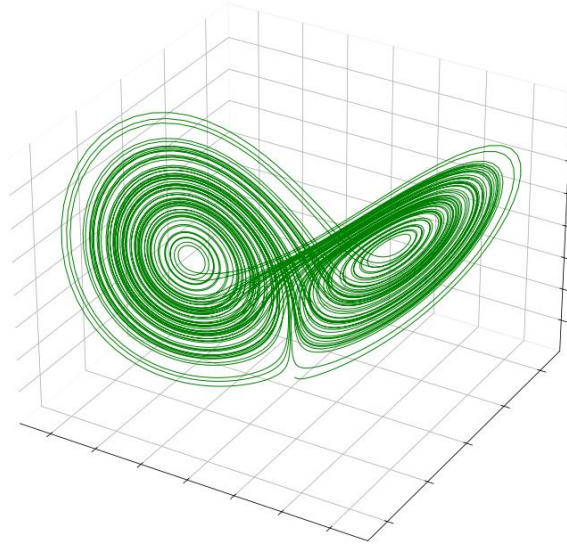


Figure 5.7: Example of growth of Lorenz attractors.

Lorenz's (1972) theory is composed of two propositions:

1. "If a single flap of a butterfly's wing can be instrumental in generating a tornado, so also can all the previous and subsequent flaps of its wings, as can the flaps of the wings of millions of other butterflies, not to mention the activities of innumerable more powerful creatures, including our own species."
2. "If the flap of a butterfly's wings can be instrumental in generating a tornado, it can equally well be instrumental in preventing a tornado."

Both propositions lead us to the complexity of systems; and they make us part of them. Uncertainties are not only due to the behaviors of others; the consequences are not the result of a "butterfly"; They emerge from a combination of interests that includes us. At the same time, we are the cause and the solution.

Quantum physics has revolutionized science to the extent that it has simultaneously challenged casualism and determinism, which forces physicists to get rid of prejudices. The concepts of quantum mechanics have destroyed determinism and although almost a century has passed since the work of Wilhelm Wien, Max Planck, Satyendra Bose, Albert Einstein, Werner Heisenberg, Erwin Schrödinger, John von Neumann, Paul Dirac, or Wolfgang Pauli (Wheeler & Zurek, 1983), among others, the provocation of Richard Feynman's (1985) speech is still pressing:

"There was a time when the newspapers said that only twelve men understood the theory of relativity. I do not believe there ever was such a time. There might have been a time when only one man did,

because he was the only guy who caught on, before he wrote his paper. But after people read the paper a lot of people understood the theory of relativity in some way or other, certainly more than twelve. On the other hand, I think I can safely say that nobody understands quantum mechanics.”

5.11. The uncertainty of life time

Sometimes the life of organizations is compared to a game, events are analyzed and time is ignored. All events are sequential and therefore conditioned. In terms of energy, as mentioned earlier, when you make a certain "deal" between a seller and a buyer, something has to dissipate the energy: the seller, the buyer, or the environment that also includes the rest of society. This means that there are no inert relationships and that in these relationships control and domination prevail for the purpose of self-preservation. Time is part of the game and it is wrongly assumed that it is the owner of a homogeneous property. Time is an integral part of uncertainty.

It is reinforced that time is an antagonist to the ability to anticipate, because any trace of the future requires a control that converts related parts, e.g., a change in the acceleration of an airplane must be converted, first into a change of speed and then into a change of position, in order to be effective (Wiener, 1985). This procedure is not inconsequential, because it takes time which, even if infinitesimal, will always belong to a hypothesis confined to an interval of probabilities.

5.12. Markov and information relations

Usually, in network analysis, the power law is highlighted, presenting a non-linear distribution. One of the most relevant studies was carried out by Markov (1913) who, using two chapters from Pushkin's (1943) book "Eugene Onegin", compared the incidence of vowels in a sequence of 20,000 letters, excluding the letters **l** and **h** which are not read independently. Markov observed that the incidence of letters was uneven, with few letters having a regular high presence.

In the study, Markov (1913) divided the 20,000 letters into 200 subsets of 100 consecutive letters, and then grouped 200 subsets into 40 sets of 500 consecutive letters. As Link (2006) notes, the relationship of objects in the macroscopic world seems uncertain, but it is only concealed at the microscopic level in a network of interacting parts. In the Markov exercise, this occurs to the extent that the end of one sequence influenced the next, i.e., the past in an imperceptible way influenced the future.

5.13. Shannon's Information Theory

Shannon (1948) had the intelligence to use the works of Markov (1913), Nyquist (1924), and Hartley (1928) to complete the formula that revolutionized information systems as shown in Equation 22.

$$H = -k \sum_{i=1}^n p_i \times \log p_i \quad (22)$$

where:

H is the entropy of information

k is a constant

n is the number of possible values for a variable

p_i is the probability of occurrence of the variable

A peculiarity in Shannon's work is the indistinct use of the words uncertainty and entropy to qualify H . “no one knows what entropy is, so in a debate you will always have the advantage” (Campbell, 1982), was the advice John von Neumann gave to Claude Shannon to name his formula. Campbell (1982) notes that Shannon intended to use the term uncertainty instead of entropy for his measure of information, but was convinced by von Neumann with the former argument. Despite being a colloquial conversation, entropy has been a staple of many habits of science since Boltzmann and “generations of practical scientists have used the concept of entropy, just as they have used the concept of probability, without giving a moment's thought to the unsteadiness of its theoretical underpinnings” Campbell (1982). Thus, despite the numerous interpretations of the term entropy, it can be idealized as a measure of uncertainty, variability/redundancy, depending on the context.

Nyquist (1924) wrote, before Shannon (1948), Equation 23 relating the speed of transmission of intelligence (W) and the number of possible values for each unit of information (m).

$$W = k \times \log m \quad (23)$$

where k is a constant.

Using the example of Nyquist (1924), compare sending a word with 3 voltage levels and 3 elements (ternary system with 3 units of information), and sending a variable with 2 voltage levels and 5 elements (binary system with 5 bits). Considering the constant time of sending a unit of information, the sending

of information in the first case is 1,67 times faster than in the second, resulting in a quotient of 5 by 3. However, the first example can form 27 words, or 3^3 , while the second example can form 32, or 2^5 , which applying to an “intelligence” ratio of the Nyquist formula gives a value of 1,58, a result of $(\log 5 / \log 3)$. Thus, Nyquist (1924) asserted that “the figure 1,67 for the relative speeds of transmission of characters and the figure 1,58 for the relative speeds of transmission of intelligence are not incompatible.” Now, that was obvious because:

$$\frac{3^3}{2^5} = \frac{27}{32} \Rightarrow \frac{3 \times \log 3}{5 \times \log 2} = \frac{\log 27}{\log 32} \Rightarrow \frac{5}{3} = \frac{\log 3}{\log 2} \times \frac{\log 32}{\log 27}$$

Nyquist had the merit of qualifying information as “intelligence” by demonstrating the advantages of multilevel transmissions, namely in digital transmission with analog signals, recalling that not all information has the same value.

However, Hartley (1928) observed that transmission channels limit the amount of information that can be transmitted. In this, Equation 24 shows that the amount of information (H) is related to the number of possible symbols for each unit of information (s) and the number of symbols that make up a word (n).

$$H = \log_b s^n = n \times \log_b s \quad (24)$$

The basis of the logarithm (b) only applies if the unit of information is fixed. In the case of transmitting 9 different symbols, 3,17 bits ($\log_2 9$) would be required, and in the case of 30 words with 9 different symbols, the minimum number required would be 30 times 3,17, i.e. 95,1 bits. Hartley's observation gave rise to the fractionation of the unit of information, which to a certain extent turned a discrete quantity into a continuous magnitude.

Hartley kept the symbols as discrete units, although little was left to transform the formula. Adjust the example of rolling a die with m faces, with probabilities of occurrence on either side equal to $p = \frac{1}{m}$. By Hartley's formula:

$$H = \log_2 m = m \times \frac{1}{m} \times \log_2 m = m \times p \times \log_2 \frac{1}{p} \Rightarrow H = \sum_{i=1}^m p_i \times \log_2 \frac{1}{p_i}$$

Shannon took the seeds of knowledge, applied the probabilities of events to the formulas of his predecessors, and arrived at the formula of information uncertainty, although this is not explicit in his paper.

An interesting explanation of Shannon's formula is given in Stone's (2015) book which gives as an example the flip of a rigged coin that comes up heads 90% of the time. This means that it will be a "surprise" when it appears tails, as there is only a 10% chance of that happening. Shannon's formula uses the $(-\log p)$ to demonstrate this "surprise".

In the case of flipping a normal coin, with the application of Shannon's formula, we have:

$$H = \sum_{i=1}^n p_i \times \log_2 \frac{1}{p_i} = \sum_{i=1}^2 0,5 \times \log_2 \frac{1}{0,5} = 1 \text{ bit}$$

Because there is the same 50% probability of coming up heads or tails.

In the case of flipping a biased coin with a 95% probability of coming up heads and a 5% probability of coming up tails, we have Shannon's formula:

$$H = \sum_{i=1}^n p_i \times \log_2 \frac{1}{p_i} = 0,95 \times \log_2 \frac{1}{0,95} + 0,05 \times \log_2 \frac{1}{0,05} = 0,286 \text{ bit}$$

It is shown that a rigged coin has a lower "intelligence" than the normal coin because it needs fewer bits and consequently produces fewer "surprises" for similar processes. The use of Nyquist's term "intelligence" is associated with Stone's "surprise" to emphasize the term uncertainty, i.e., a normal coin is associated with greater uncertainty than a vitiated coin.

Although the importance of what Shannon revealed in his 1948 paper is undeniable, the way he did it and the association between entropy and uncertainty left remnants. When the paper was published, it had a negative review stating that "the discussion is suggestive throughout, rather than mathematical, and it is not always clear that the author's mathematical intentions are honorable" (Doob, 1948). Despite this criticism, the paper was published, and when confronted with this appreciation, in an interview Shannon replied "you can write mathematics line by line with each tiny inference indicated, or you can assume the reader understands what you are talking about. I was confident I was correct, not only in an intuitive way but in a rigorous way. I knew exactly what I was doing, and it all came out exactly right" (Nahin, 2017).

Because it is little appreciated by most science, the criticism of the adequacy of the word entropy that was used in information theory and its dimension in communication has faded. However, some, such as Baecker (2007), refute the use of entropy to characterize the uncertainty of a communication. The criticism is based on the impossibility of the evolution of the system, which makes the analysis poor in semantic terms because his concept of the theory of communication signals works with the premise of a certain selection range. According to Baecker, in Shannon's formula information is a measure of the uncertainty of the occurrence of events, which takes on larger values, between 0 and 1, the higher the order an event suggests. Therefore, "the greater the probability of inferring other objects and states in the selection area of a message, the greater the redundancy of its request" (Baecker, 2007). However, for Baecker (2007), entropy is the opposite of redundancy.

5.14. The entropy of a "bit"

As a paradigmatic example of the entropy dimension, it is the incorrect assumption that digitalization is energy-neutral and that, therefore, the exponential growth of information has no implications in terms of consumption. Landauer (1961), using Boltzmann's law of entropy, assumes that the entropy associated with the elimination of 1 bit in a computer "cannot decrease; hence this entropy must appear elsewhere as a heating effect, supplying $0,6931 kT$ per restored bit to the surroundings. This is, of course, a minimum heating effect, and our method of reasoning gives no guarantee that this minimum is in fact achievable" (Landauer, 1961). The storage and transmission of information entails large flows of energy, which are evident and generally ignored.

5.15. Entropy and the internal energy of organizations

Organizations must be aware that not all energy can be transformed, that is, waste is produced in all processes. This concept of thermodynamics appears in the formula

$$U = U_0 + Q - \omega$$

In which the internal energy U depends on the initial energy U_0 , the amount of heat Q that is transmitted to the body, and (ω) the external ergon that is produced as the body transforms from the initial energy condition (U_0) to its current energy condition U (Clausius, 1867). Entropy (or in colloquial terms, disorder) emerges as a natural consequence of evolution. The term entropy was coined in 1865 by Clausius

(1867), who used the “Greek word τροπή, transformation. I have intentionally formed the word entropy so as to be as similar as possible to the word energy; for the two magnitudes to be denoted by these words are so nearly allied in their physical meanings”.

Organizations have an internal energy, an energy that cannot be fully transformed into useful energy, due to entropy. Organizations cannot expend all the available energy because part of it belongs to their structure and is dependent on the environment. The concepts of internal energy and entropy are important for organizations to understand that there are no optimal results, nor repeatable results. These concepts of thermodynamics relativize the importance of efficiency, as it depends on the "thermal agility" of the organization. We can have very efficient organizations established in precarious structures, as well as less efficient organizations with robust structures, which can withstand a superior "thermal agility" that guarantees their preservation. Although less efficient, organizations with higher thermal "agility" prove to be more competitive.

For example, the population (P) grows at an exponential rate with an exponent representing a certain growth rate(s), when the available resources are considered infinite, or in the real case, much higher than those necessary for the existence of a given species. It is added that this is true if there are no predators or threats to their existence, which will only be limited by biological phenomena such as, for example, telomere chain degradation, which are internal and determined properties of individuals.

$$P = e^s$$

Now, if we consider social, economic, or cultural factors that influence the birth rate of a species, we have to multiply the growth rate by a constant (c), leaving the formula:

$$P = e^{cs}$$

$$s = \frac{1}{c} \ln(P)$$

$$s = k \times \ln\left(\frac{1}{p}\right)$$

This speculative reasoning leads us to a formula similar to Boltzmann's entropy formula, in which the rate of growth becomes entropy and the population becomes a probability. Using this metaphor, if the rate of population increase (inevitably) increases entropy, i.e., the number of possible relationships. None of this can be praised as innovative, in the same way, that this analogy does not indicate anything about the quality of the system for the human being, even if we consider entropy as an intensive physical property, because it refers to a quantity decontextualized in time and space. This is because, 1) “the

energy of the universe is constant”, and 2) “the entropy of the universe tends to a maximum” (Clausius, 1867), finite resources (energy) tend towards chaos (due to increased entropy).

The previous reflection brings two more hypotheses. The first suggests the impossibility of correctly determining the quality of a work without temporal variation. The second questions the achievements of a given population, because while the number of elements legitimizes the increase in relationships, even when they are realized, they do not refer to useful work but to energy consumption. Thus, in the study of organizations, it is beneficial to refer to entropy variation and useful work rather than the regular process of circumstantial evaluation of the moment in which competitors are compared. Not presenting the full space-time context prevents the organization from correctly determining its intents.

Complex structures are not just a consequence of living structures. They become rapidly visible in living structures through evolution, adaptation, and competition. However, complexity also appears in inorganic structures due to the degeneration effect of entropy.

6. Proposal of models for diagnosing organizations

Considering the issues discussed previously, it is worth making a synthesis that allows us to understand the evolution of open organizations. Understanding open organizations as complex networks that feed the diversity and integration of cultures into continuous learning networks, the investigation continues through the quality and quantity of relationships between the parts that make up these networks.

6.1. Diversity

It is well known that, despite the apparent diversity and complexity of different systems, there may exist similar fundamental dynamic principles (Zipf, 1949). These principles depend on logarithmic distributions visible in, e.g., Lorenz, Pareto, or Zipf.

Teachman (1980) argues that population diversity is “the distribution of population elements (which are not limited to humans or the characteristics of humans) along a continuum of homogeneity to heterogeneity with respect to one or more variables”. It is not uncommon to find measures referred to as diversity or variability by one researcher "inverted" by another researcher to measure concentration or redundancy (multiplying by -1 or subtracting the maximum value) (McDonald & Dimmick, 2003).

There is little distinction in the literature between variability and diversity, often being differentiated only in the categories they represent (diversity in biosciences and variability for inanimate things). Nevertheless, diversity and variability represent the singularity of the parts in a set, considering mathematical or metaphysical implications. Despite these singularities having several distinct features, they provide the emergence of a collective singularity (in organizations' structures representing fractals or holons). Diversity displays the proportion of elements assigned to a given category concerning the set of all categories in a system (McDonald & Dimmick, 2003), as shown in Table 6.1. Conceptually, diversity represents the distribution of interactions between groups of components, members, or parts in a given context (spatially and/or temporally limited).

Table 6.1: Measures of diversity and their formulas, adapted from McDonald & Dimmick (2003).

Measure	Formula
Probability-based measures	
Simpson's D	$D = 1 - \sum p_i$
Simpson's D_z	$D = 1 - \sum \frac{p_i^2}{1 - \frac{1}{k}}$
Les and Maher's Ω	$\Omega = \sum p_i p_j$
Les and Maher's Ω_z	$\Omega = \sum \frac{p_i p_j}{1 - \frac{1}{k}}$
Junge's H	$H = (1 - \sqrt{k}) \left(\sqrt{k-1} - \sqrt{k \sum p_i^2 - 1} \right)$
Kvalseth's OD	$OD = \left(1 - \sum p_i^2 \right)^{-1} - 1$
Fager's S	$S = \sqrt{\frac{k \sum p_i^2 - N^2}{k(k-1)}}$
Logarithm-based measures	
Shannon's H	$H = - \sum p_i \log_2 p_i$
Brillouin's H	$H = \frac{1}{N} \log \frac{N!}{N_1! N_2! \dots N_k!}$
Gleason's D	$H = \frac{(k-1)}{\log N}$
Rank based measures	
Hall and Tideman's TH	$TH = \frac{1}{2 \sum r p_i} - 1$
Fager's NM (Number of Moves)	$NM = \frac{N(k+1)}{2} - \sum r_i n_i$
<p>Note. For all the above, p_i is the proportion in the ith category where categories = i through j, k is the number of categories in the distribution, N is the number of observations in the sample, n_i is the number of observations in the ith category, and r is the rank of the ith category (ranked with 1 as the largest category).</p>	

Technology can bring diversity that changes cultural reality, making society more decentralized with more small communities, but with sophisticated interconnection systems. Due to decentralization, the emergence of a greater quantity and diversity of channels, with a greater potential number of information sources, the more difficult it becomes to limit and control the flow of information. Despite Toffler's (1971) perspective that the greater the diversity, the more difficult it will be to restrict and permanently falsify information, it appears that decentralization and diversity have a threshold beyond which falsification can occur as an expression of chaos. At least this seems to be a characteristic of the organization of some contemporary societies. The possibility of maximizing freedom in the future requires the construction, in the present, of a greater diversity of information channels (Martin, 1978).

When a community's culture fosters complexity, it allows its members to participate in many ways with complementary roles. These communities have flourished with the Internet and will become even more abundant as the capabilities of the Internet develop. The relaxation of size and proximity restrictions provided by the network increases the diversity of its members (Wellman, 2001). After an indeterminate size, any online community appears to be an unstructured mob. However, the network must have a structure that prevents its disintegration. This structure emerges from the self-organization of the communities that belong to the network.

Whether the human is a producer or a consumer, variety is a permanent requirement. Therefore, it is necessary to analyze the effect of the number and variety of members that make up an organizational network in order to inquire about its possibilities of evolution.

6.2. Entropy

Two types of dispersion metrics stand out: variance in Equation 25, calculated as a mean squared deviation, and entropy in Equation 26, which is calculated as a theoretical index of information redundancy (Richards & Lindsey, 1974).

$$\sigma^2 = \frac{\sum_1^N (x_i - \mu)^2}{N} \quad (25)$$

$$H = \sum_1^N -p_i \log_2 p_i \quad (26)$$

In the case of network analysis, in the search for patterns of behavior, or in the attempt to recognize similarities between structures (qualitative evaluation of a given distribution, verification of the existence of fractal structures, determination of redundancy/variability of information), the value of variance is negligible. Relative to absolute entropy, due to the extensive quality of entropy, the growth of a network will always increase the entropy value, even if the pattern of structure or behavior repeats itself. Hence, the analysis of the dispersion of the behavior of agents in a network through normalized entropy, shown in Equation 27 whose values are limited between zero and one, is preferred in this thesis.

$$H = \sum_{i=1}^N -p_i \log_N p_i \quad (27)$$

Entropy is a useful concept when trying to approximate a model to nature, considering that certain information about the closed system is important and the rest is ignored. When important information is discarded in the selection process, entropy, which represents ignorance of important information, tends to increase (Gell-Mann, 1995b)

Shannon's communication entropy is a measure of the efficiency of codes and the degree of information compression. This type of evaluation reduces the data to a utility function which implies that the lower the entropy value, the less waste (and more efficient) the system is.

However, with increasing complexity, which introduces more quantities simultaneously with more qualities into the organizational environment, the stabilization of normalized entropy can mean that despite increasing variability, while maintaining efficiency, we increase organizational creativity, flexibility, agility, and resilience. From this perspective, the entropy examination may be more useful if it does not focus on maximizing the energy use of the system but rather on assessing the degree of sustainability of the organization. Hence, organizational entropy can be a measure of self-organization if it has a pattern (e.g., staying constant).

The concept of self-organization is often used as an ideal process to respond to the increasing specialization of manufacturing systems and the complexity of design structures in manufacturing organizations. With self-organization, new design processes emerge, behaving quickly to the dynamism and uncertainty of the context (internal, external, individual, collective). According to complexity theory, to increase the potential for novelty creation, the system must be complex, based on many agents interacting in a way that leads to self-organization (van Eijnatten & Putnik, 2004; van Eijnatten et al., 2007).

By (ElMaraghy et al., 2021), when an online community reaches an undetermined size, it becomes an unstructured crowd. Nevertheless, “unstructured” could mean self-organized.

Self-organization emerges as a dynamic, collective, autonomous, spontaneous, and conscious process due to positive and negative feedback loops (communication, information, and learning) in which agents share the same language and interests and freely become members of (and recognize themselves as part of) a system, e.g. design and manufacturing network.

Without consciousness, any system results from a pre-programmed evolutionary process of adaptation to environmental changes. Without an intentional purpose, the system is self-ordered (Abel & Trevors, 2006). Self-organization has no meaning when applied to inanimate things. Without the prescribed intention of human autonomy, one converges with the position of ElMaraghi et al. (ElMaraghy, Kuzgunkaya, & Urbanic, 2005; ElMaraghy, ElMaraghy, Tomiyama, & Monostori, 2012; 2003), which does not give manufacturing the ability to self-organize. Furthermore, according to Ashby (1962), self-organization in a closed system cannot exist because it depends on external context and is subject to “random” environmental factors. Therefore, self-organization is only possible in open-design organizational structures. It implies that the self-organization process requires a sufficiently redundant organizational structure that responds to and resists a decrease in external redundancy. Thus, it suggests self-organization arises from continuous disorganization followed by reorganizations with more complexity and less redundancy [14], i.e., with higher variability. It does not make sense to say open without explicitly including a network.

In addition to entropy, the power law distribution (Newman, 2005) arises as a second measure for identifying the self-organization of open and large complex networks. Considering that “few real-world distributions follow a power law over their entire range” (Newman, 2005), other models are considered, such as truncated power law distribution, according to Gonzalez et al. (2008). Gonzalez et al. (2008) argue that self-organizing patterns are often truncated power law, i.e., have an exponential attribute in the function of power law.)

Often associated with uncertainty, randomness, disorder, or as a measure of the complexity of a system, in our proposal, entropy measures the variability of the organization's design (i.e., higher variability means less redundancy and vice versa). Specifically, in manufacturing, Shannon entropy, presented in equation 1, usually is one measure of the system's complexity.

The normalized entropy H shown in Equation 1 represents the variability of the participation distribution of all active network members (n) in a given period. The probability of occurrence of a post $p(x)$ is the

ratio between the number of posts made by the member and the total number of posts. (“post” is a synonym of a single communication, activity, or interaction of a network member. The term appears in the science of Internet communication).

In any system with no dissipative property, i.e., closed, entropy increases with time progression. The diversity of interactions that characterize self-organizing systems suggests dynamical systems, requiring continuous interactions between members at hierarchical lower levels that support and develop the organization (Camazine et al., 2001). Considering a complex network where hierarchical structures emerge (Dehmer & Mowshowitz, 2011), a significant part of the entropy of network dissipation depends on the lower hierarchies, and trying to reduce it can mean the destruction of self-organization.

Since the entropy produced in a system has a limit (Prigogine, 1977), the entropy associated with the participation of network members should reach a critical level that indicates the existence of self-organization and the transition to a new point of stability in the network, i.e., a new attractor.

6.3. Power law distribution

Concerning the power law distribution, the linearity in the log-log distribution, in our case of posts by different active members over the years, suggests that we are facing a heavy tail distribution. However, as mentioned by (Clauset et al., 2009), linear behavior is a necessary but insufficient condition to ensure a power law distribution. It does not deny the scale-free networks related to self-organization (Cavagna et al., 2010) but emphasizes a holonic hierarchy, with systems within systems, that creates a new order. When the concentration of members of a given organization increases, reducing the average distance/interaction between them, a critical distance will arise in which they begin to interact in a self-organized way (Cisneros et al., 2010).

Conceptually, Salmador et al. (2021), using the ideas of phase transition, limit, bifurcation point, and critical value to identify the point where a system passes from the linear additive state to a multiplicative state, that is, non-linear, reported that companies with behavior that follows the power law, with an interdependent, highly scalable and non-linear environment, and has prominent potential to better organizational results.

When analyzing companies listed in the S&P 500 stock market index, Salmador et al. (2021) tried to prove that there is a point that separates companies with behavior that follows the power law and the majority of companies that follow “linear” behavior. To illustrate this, they use Figure 6.1, in which they

place the majority of organizations in the Gaussian World (with linear behavior) while the remaining few reveal Paretian behavior that follows the power law distribution. However, this reasoning has some inaccuracies:

- 1) Looking at Figure 2.1, the Gaussian world is not linear (although it may appear that way when defining the logarithmic scale);
- 2) For samples with a small number of data, as shown in Figure 5.3, Gaussian exponential distributions and the Paretian power law can have tuning parameters that make them almost indistinct. It happens because there is always a group representing few units because many have little or because few have a lot.

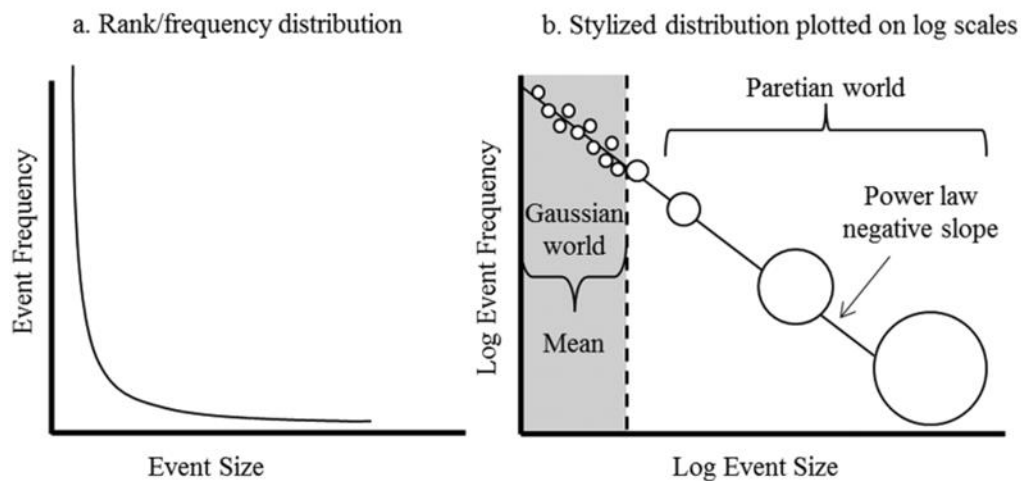


Figure 6.1: Stylized rank/frequency distribution (Maria Paz Salmador & Bill McKelvey, 2021).

However, the work of Salmador et al. (2021) has the virtue of splitting the complex reality and treating the group that has many units differently from the group, i.e., that has few units, which implies different parameters but not necessarily different distributions.

6.4. Center of mass

Considering that the entire network could be not a pure power law function (e.g., truncated power law), a solution to improve the models is to divide the network into two parts using the network's center of mass proposed by Fu et al. (2017) and defined by Equation 28.

$$cm_x = \frac{\sum_1^n U_n \times P_n}{\sum_1^n P_n} \quad (28)$$

Where:

c is the number of members of the center of mass;

U_n represents the accumulated number of members that have made n posts;

P_n represents the number of posts held by U_n ;

and $\sum_1^n P_n$ represents the total number of posts made by all members.

The network mass center splits the network into “higher” and “lower” layers of the network hierarchy. Higher and lower layers classify the groups of members with more and fewer posts, respectively. If these two hierarchical layers have very different power law distributions, it shows two concurrent scale-free networks in the same network structure.

6.5. Application of Shannon's Information Theory to Complexity assessment

In view of the indeterminacies about entropy and its consequences, particularly with regard to the use of the word entropy in Shannon's studies on information and its transposition to the evaluation of the complexity of a system, it is appropriate to inquire about the convenience of the studies. In this sense, the article “Operation-based configuration complexity measurement for manufacturing system” (Guoliang, Aiping, Giovanni, Liyun, & Xuemei, 2017) is used as an example, which insists on stating that the hypothetical “entropy of information”, *per se*, represents the complexity of a system.

Figure 6.2 shows the four examples of numbered workstations that were presented in the article by Guoliang *et al.* (2017), in which they use the formulas proposed by Shannon. The activities unfold from right to left and the letters represent the operations.

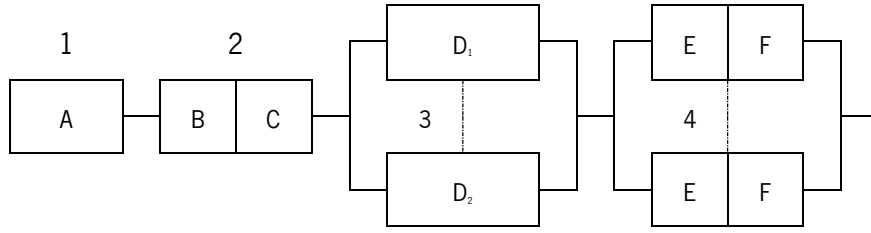


Figure 6.2: Multiple Types of Workstations in an Organization.

The authors proposed to compute the system complexity using efficiency as a measure of the probability of occurrence of the state. With Shannon's formula, where p_x is the probability of success and $(1-p_x)$ is the probability of failure of operation X, for example, for the proposed calculation for the complexity (h) of station 1, we have Equation 29.

$$h_1 = p_A \log_2 \frac{1}{p_A} + (1 - p_A) \log_2 \frac{1}{(1 - p_A)} \quad (29)$$

Now, this little formula represents what Shannon used to determine the capacity of the transmission channel, as noted above, and whose function is symmetric at the value 0.5. This implies that the supposed complexity of a system with a 90% efficiency is equal to the complexity of a system with a 10% efficiency.

In fact, this formula is the result of the truth Table 6.2, in which what Shannon called entropy or uncertainty, is calculated as a binary sequence of states (success, represented by logical level 1, and failure, represented by logical level 0).

Table 6.2: Truth table that represents Shannon's entropy for a station with one operation.

Operation A	Result	p_x	$h = -p_x \log_2 p_x$
0	Failure	$(1 - p_A)$	$(1 - p_A) \log_2 \frac{1}{(1 - p_A)}$
1	Success	p_A	$p_A \log_2 \frac{1}{p_A}$

In the case of station 2, the proposal is to calculate the total efficiency of the workstation by multiplying the efficiencies of the operations and, with this efficiency, apply the previous equation. The question arises about the sequence of operations because there is the commutative property of multiplication, which, theoretically, allows exchanges without changing the result.

In the case of station 3, with two operations in parallel, the proposal is to apply the truth Table 6.3 in which variables, in this case, the operations D (D_1 and D_2), can each have two states, which together determine the probabilities to be applied in the Shannon formula.

Table 6.3: Truth table representing Shannon's entropy for two stations with a parallel operation.

D_1	D_2	p_x
0	0	$(1 - p_D)^2$
0	1	$(1 - p_D) \times p_D$
1	0	$p_D \times (1 - p_D)$
1	1	p_D^2

Getting the Equation 30.

$$h_3 = (1 - p_D)^2 \log_2 \frac{1}{(1 - p_D)^2} + 2 \times (1 - p_D) \times p_D \log_2 \frac{1}{(1 - p_D) \times p_D} + p_D^2 \log_2 \frac{1}{p_D^2} \quad (30)$$

In the case of workstation 4, the cases of station 2 and station 3 are combined.

The critique of the work of Guoliang et al. (2017), whose formulas are summarized above, is based on the already discussed distorted semantic assumption of the concept of entropy, on the symmetry of the function that gives rise to it and on the inexistence of the variable time that in the original formula of entropy is found in the variable energy. Therefore, the values obtained in this article are not disputed, the only question is what their meaning is.

In the paper they tried to approximate the concept of complexity to algorithms, whose definition of average complexity can be summarized as the “average time” for the best algorithm to solve a problem (Barthelmy, Cohen, & Lobstein, 1996). The complexity assessment proposal of the article could only be

used remotely to characterize what they call complexity in algorithms, since the efficiency is dimensionless and has no associated “code” that allows evaluating the redundancy of the “instruction” (which in this case is the operation). The authors were aware of this when they stated that “Complexity theory is an effective method to measure diversity and uncertainty and is used to measure the uncertainty of production system in manufacturing system” (Guoliang et al., 2017). However, efficiency measures neither diversity nor uncertainty; Eventually, it may represent a pattern between systems, which defeats the purpose of the study. In part this view was shared by Kolmogorov (1956), who did not question the term entropy used by Shannon, but insisted “that the fundamental concept, which admits of generalization to perfectly arbitrary continuous information and signals, is not directly the entropy concept but the concept of the quantity of information”, i.e., the number of signals is not important. The most relevant thing is what they represent.

7. Assessment of research hypotheses

Following the complex thinking of this Thesis, the hypotheses presented are also complex. They relate self-organization in the Arduino Forum and EEVBlog Forum open networks using normalized entropy and power law distribution. Entropy and power law distribution arise from calculating the size of networks and the explicit number of interactions of the members that compose them. Some of the results presented in this research were published in the paper “Self-organization in open and very large and complex design and manufacturing networks through entropy and power law distribution” (Putnik, Pinheiro, Varela, & Alves, 2024).

7.1. Research hypotheses

Considering that the informational content of an organization seems 1) “destructive” when entropy decreases and 2) “autonomy-producing” when entropy increases (Atlan, 1974), the formal definition of an organization must involve a balance between maximum redundancy and maximum variety. As Atlan (1974) points out, the organization concept can involve two contradictory trends. Traditionally, the organization is a regulated system where the order is superimposed, which is seen essentially as a repetitive order, that is, redundancy (ideally a perfect crystal). In the other perspective, on the influence of information theory, the organization is maintained as a non-repetitive order, measured by the information content in the sense of Shannon's theory (Shannon, 1948), i.e., a degree of unpredictability directly related to variety and lack of homogeneity. Although entropy can be a measure of self-organization, due to several shortcomings of entropy as a measure (Prigogine & Lefever, 1975), other measures are needed.

Despite the increasing complexity of production systems and the dichotomy between redundancy and variability, production systems must present periods of stability. Considering that entropy considers redundancy and variability, some hypotheses arise:

Hypothesis 1:

There is some entropy value in the interactions of members of an open network revealing periods of stability and indicating self-organization.

Since the variation in the entropy production (dS) of an open network is the sum of the entropy of the internal production of the network (dS_i) and the entropy flow with the outside of the network (dS_e), and considering that the internal entropy (dS_i), according to the second law of thermodynamics, is always greater than zero, the stability of the system's total entropy production depends on the dissipative structure provided by the network's surroundings (Prigogine & Lefever, 1975). Periods of stability in entropy production values in an open network may be a consequence of the self-organization process.

Hypothesis 2:

Interactions of members of complex open networks may not follow a pure power-law distribution throughout the entire network hierarchy while maintaining self-organization.

7.2. Research design

Using the research onion proposed by Saunders et al. (2019), shown in Figure 7.1, postmodernism was a more influential philosophy of this Thesis.

Considering complexity as a central issue in studying open organizational networks, abduction naturally emerged as the predominant logical inference.

Several original databases were created from open data collection on the Internet using web scraping, making it possible to assess the self-organization process. There are two principal databases with data about posts made in two open Internet forums related to electronic industrial technologies (open and proprietary):

1) the Arduino forum network, with 225292 active members identified between July 2005 and the end of 2022, and

2) the EEVBlog forum network, with 53368 active members identified between October 2009 and the end of 2022.

The first case study served as a definition of the model. The second case study concerns model validation.

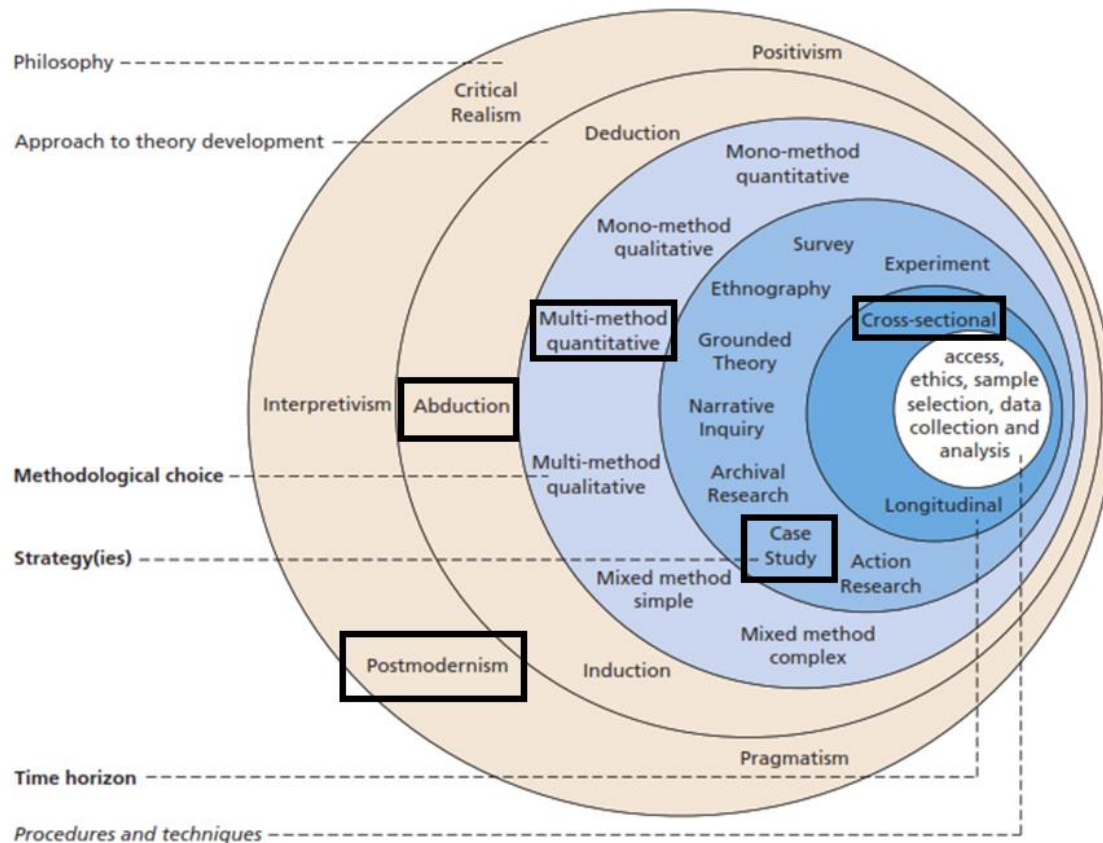


Figure 7.1: The research onion, adapted from Saunders et al. (2019).

The computation of normalized entropy changes and variations in power law distributions in the years included in different databases aimed to evaluate the self-organization process in open organizational networks.

7.3. Arduino and EEVBlog ecosystems

Arduino is the brand of an open prototyping platform. It designs, manufactures, and supports the hardware and software of electronic devices, enabling everyone to easily access advanced technologies and create artifacts that interact with the physical world (Arduino Team, 2021). The EEVblog claims to be “one of the world's largest and most active forums for electronics engineering professionals, students, hobbyists, hackers and makers [...] The site is essentially a self-moderated forum, and people lead by example” (EEVblog Electronics Community Forum, 2023).

The Arduino forum network emerged in a turbulent context that motivated the creation of a specific design. Circumstances determined design and design changed circumstances.

The Wired and Arduino Uno printed circuit boards, one of the most recognized in the Arduino family of products, are shown in Figure 7.2.

As Barragán (2016) states, the initial design purposes of Arduino (initially Wired) did not include any purpose of a unifying design for the IoT or IIoT. However, today, most IoT and IIoT devices can be associated with the Arduino design.

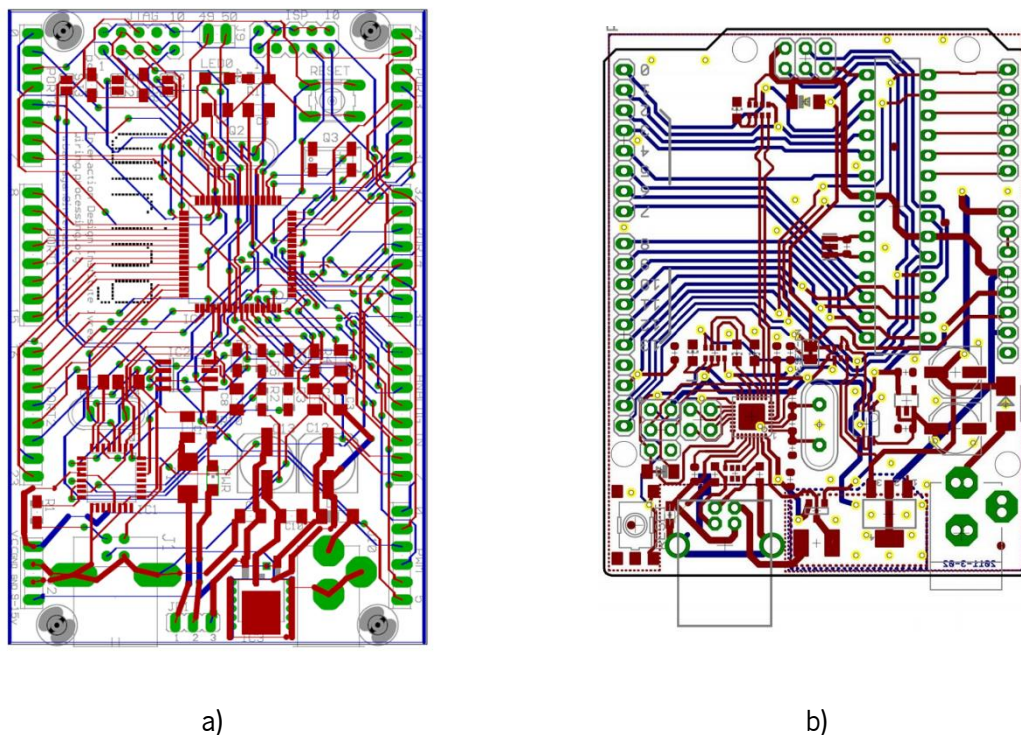


Figure 7.2: The a) Wired and b) Arduino Uno printed circuit boards.

The EEVblog Forum is broader than the Arduino Forum, with funding provided by Internet advertising. Figure 7.3 shows that the EEVBlog Forum has various topics that apply electronics, from beginners or product development to manufacturing applications. It is, therefore, not as restrictive in terms of design because it does not promote any specifically, being a more open network than the Arduino Forum.

Electronics	
	Beginners  A place for electronics newbies to ask questions. Include detail & what you have already done to find the answer.
	Projects, Designs, and Technical Stuff  Show off your projects you are working on. Talk about designs or ideas, ask technical questions, and share technical information.
	Repair  Ask for repair help or describe how to repair equipment
	Microcontrollers  Microcontroller hardware or software. Use the Embedded Computer section for single board computers like RPi etc
	FPGA  Everything programmable logic related. FPGA's, PLD's, VHDL, Verilog etc
	RF, Microwave, Ham Radio  RF, Microwave, and Ham Radio designs, projects, and discussions.
	Metrology  Everything metrology & Calibration related. This is where the Voltnuts hang out.
	Power/Renewable Energy/EV's  Power related discussions, Renewable Energy, energy storage, Electric Vehicles etc.
	Open Source Hardware  A community section to discuss Open Source Hardware (OSHW) projects or anything OSHW related.
	Manufacturing & Assembly  Discuss PCB or product manufacture or assembly. Home brew PCB's, Pick & Place machines, soldering, reflow etc
	Mechanical & Automation Engineering  Machining, Fabrication, Robotics, CNC and other automation.
	PCB/EDA/CAD  General discussion on Electronics Design PCB, CAD and EDA software. Child Boards: KiCad, Altium Designer, DIPtrace, Circuit Studio, Eagle, Proteus
Products	
	Test Equipment  Test Equipment reviews, teardowns, discussion etc. This is the biggest T&M forum on the interwebs! Use Search to find products.
	Thermal Imaging  Everything to do with thermal imaging and cameras

Figure 7.3: Part of the EEVBlog Forum page (<https://www.eevblog.com/forum/>).

Figure 7.4 shows an amplified part of the polycentric Arduino and EEVBlog networks in 2022. Despite having an open and decentralized structure, it presents a representative hierarchy of inequality in the participation of members in a network of networks (system of systems).

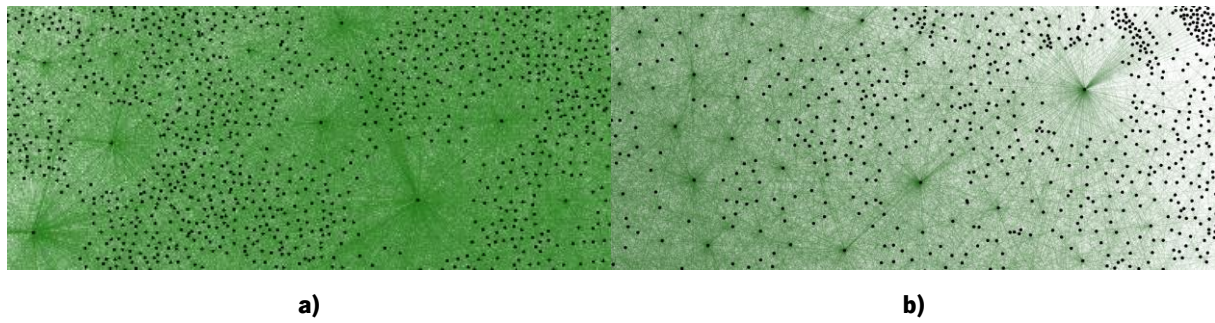


Figure 7.4: Amplified part of the polycentric networks a) Arduino and b) EEVBlog, in 2022.

7.4. Arduino on GitHub

Git is a tool that allows collaboration between the author and the committer. Although the same person can play both roles (author and committer), different people often play these roles. The author is the person who originally wrote the patch, while the committer is the person who last applied the patch. Therefore, when you submit a patch to a project and one of the core members applies the patch, both will receive credit (Chacon & Straub, 2014). A patch is a set of changes to a computer program or its supporting data designed to update or repair it. This includes bug fixes to remove security vulnerabilities and errors. Patches are often written to improve a program's functionality, usability, or performance. Furthermore, with *Git*, the patch can be used in different designs that would not initially be foreseen.

For one of the most successful versions of the Arduino software, release 5640, 320 members contributed between 2009 and 2021. Of the 320 members of Arduino release 5640 on GitHub, there were 252 registered members across 37 different nationalities. The geographical origin of 68 members could not be identified. The data is in Annex 10.1.

The geographical distribution of the authors and committers of GitHub's network open software of Arduino, release 5640, did not appear to have a very different distribution of the distribution of the world's development, presented in Figure 7.5. Partly it seems that opportunity is an essential element for the growth and success of the network. The success of the network progress can also depend on the culture (capitalist, competitive) mainly implanted in the world's northern hemisphere, as shown in Figure 7.6. Thus, the quality of diversity of agents/members, essential for the prosperity of a network, appears to have boundaries that prevent the participation of elements external to the network's culture. Despite being open, networks have limits (social, economic, technological, scientific, ...), which, although not explicit, are implicit.

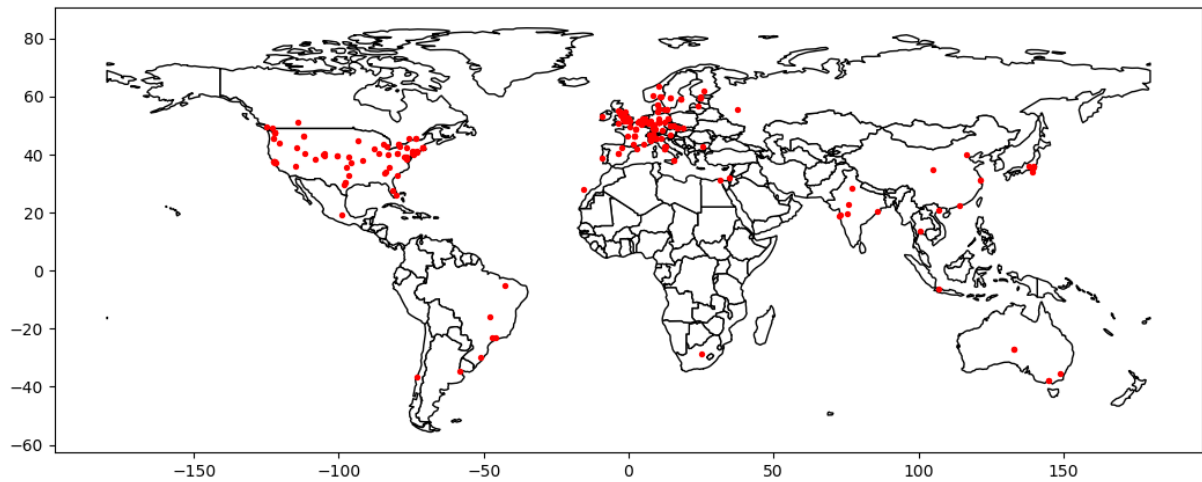


Figure 7.5: Geographical distribution of the authors and committers of the open software of Arduino, release 5640.

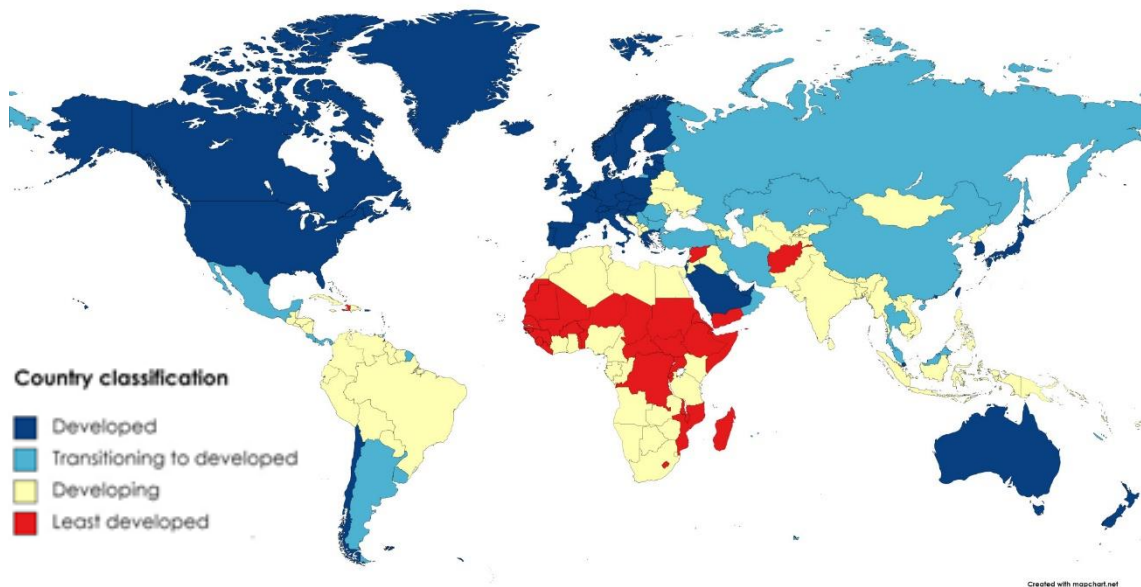


Figure 7.6: Development of countries, in 2021 (Maps on the Web, 2021).

Figure 7.7 shows that the collaboration in creating the Arduino software, version 5640 on GitHub, between 2009 and 2021, had a great diversity of members and continuous renewal. Figure 7.7 shows that, as Whyte (2002), some members like to work alone while others work in teams, depending on the circumstances (individual and collective, internal and external).

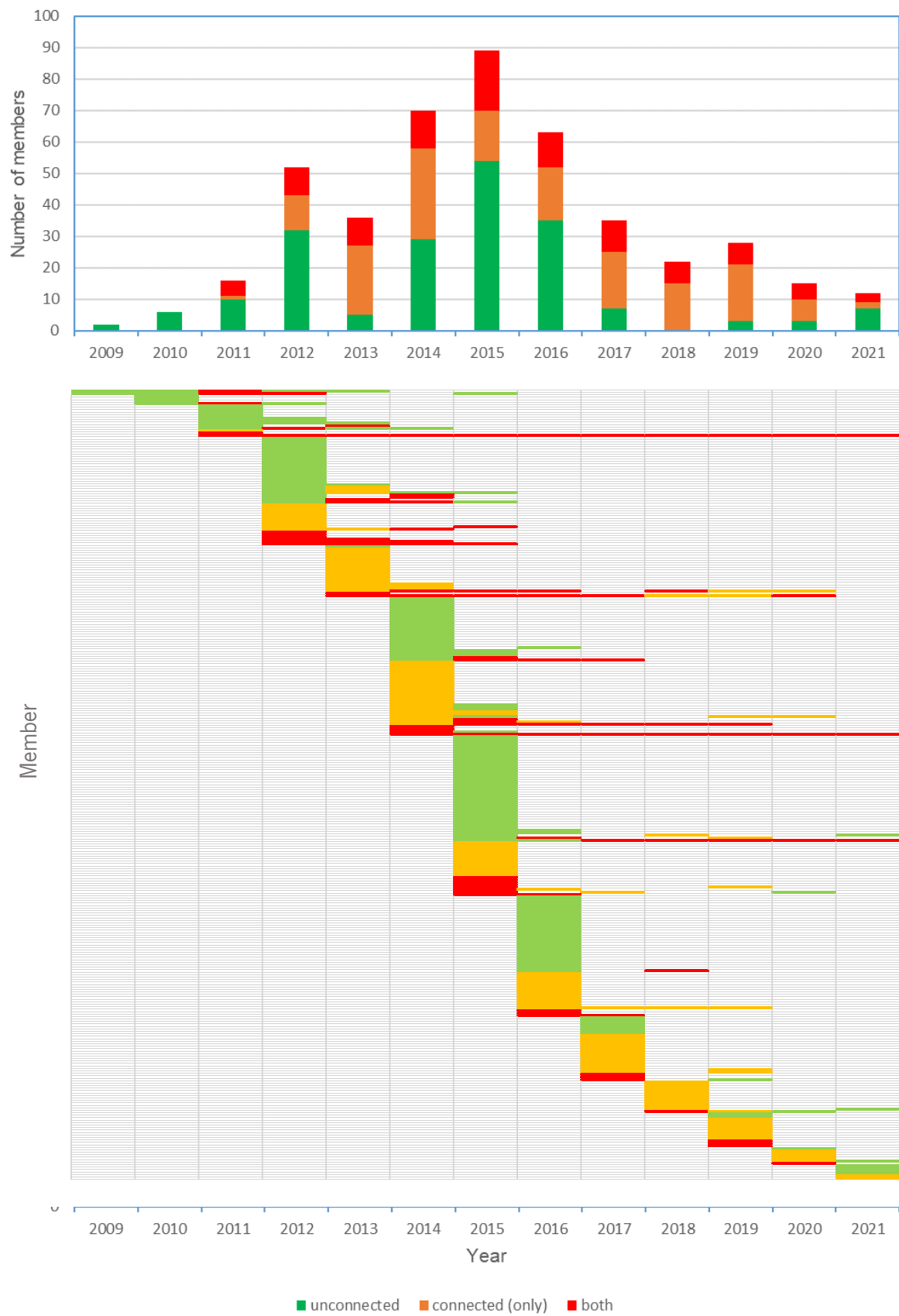


Figure 7.7: Evolution of Arduino software release 5640 on GitHub, between 2009 and 2021.

7.5. Arduino Forum network

In the Arduino forum network study, 225292 active members were identified between July 2005 and the end of 2022. An active member is a user registered on the forum network who has made at least one post. An active member in a given year involves making at least one post on the Arduino Forum. The Table in Annex 10.2 shows data from the Arduino Forum network. The renewal rate of network members stands out, i.e., presenting a large influx of new members (from 2015 to 2022 with values close to 80%). Figure 7.8 shows that most network users were only there for one day.

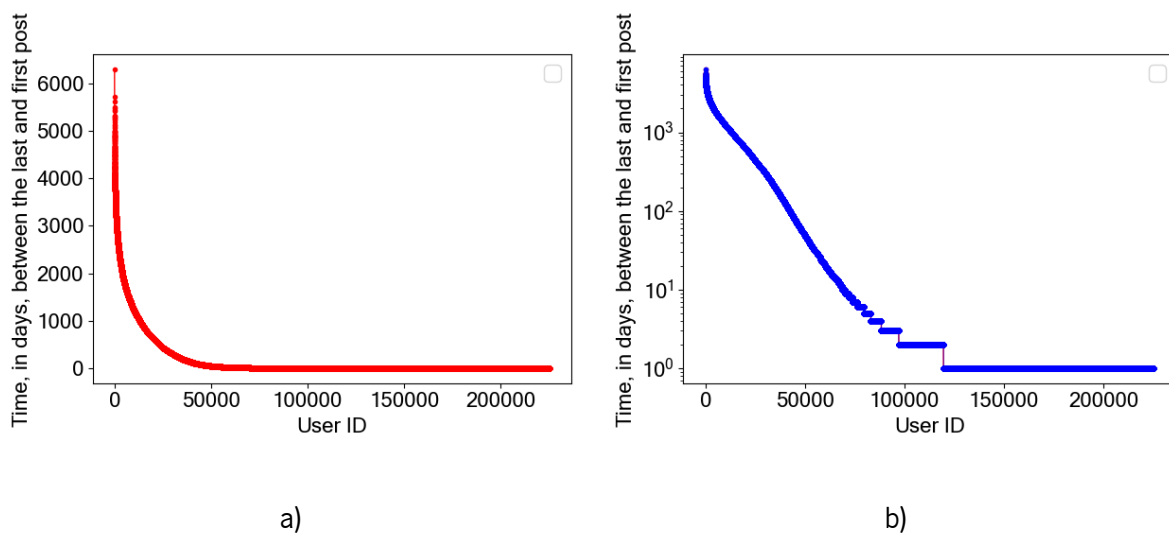


Figure 7.8: Time difference, in days, between users' first and last posts in the Arduino Forum network considering a) linear scales and b) log-log scales.

Therefore, when analyzing Figure 7.9, it must be considered that the values are a consequence of networks formed mainly by new elements, as already observed in Figure 7.7.

Figure 7.9 shows a stabilization of the entropy value at around 0,7, between 2015 and 2022, while after 2017 there is a decrease in the number of members that make up the network. Despite a large variation in the number of network members and, through Figure 7.10, in the number of posts made, the network organization has an entropy of close to 0,7. According to the graphs in Figures T and G, there is an excessive amount of posts compared to the number of users in the network. In the Table in Annex 10.3, the values of posts per active user exceeded a hundred between 2007 and 2012, suggesting some disturbance in the network. The disturbance results from the user's system. This user is a bot. A bot is a software program operating on the Internet and performing repetitive tasks.

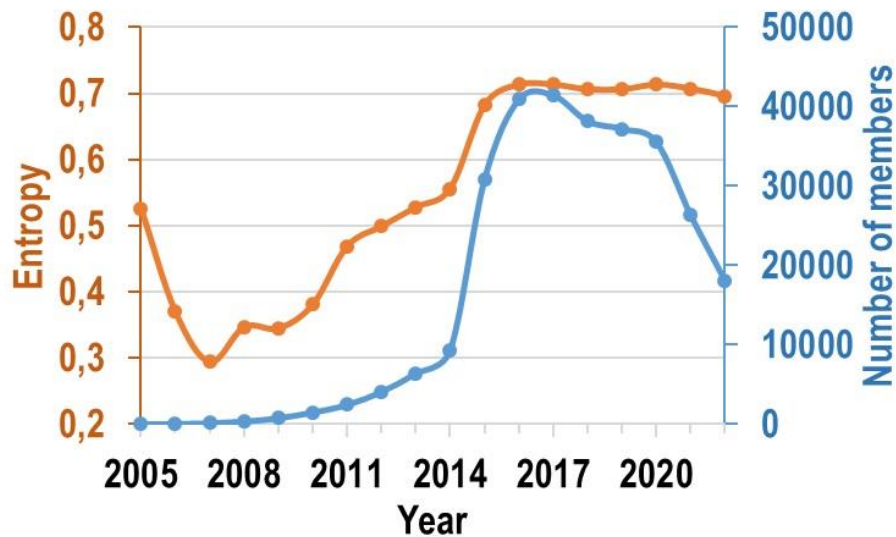


Figure 7.9: Entropy and number of members in Arduino Forum network.

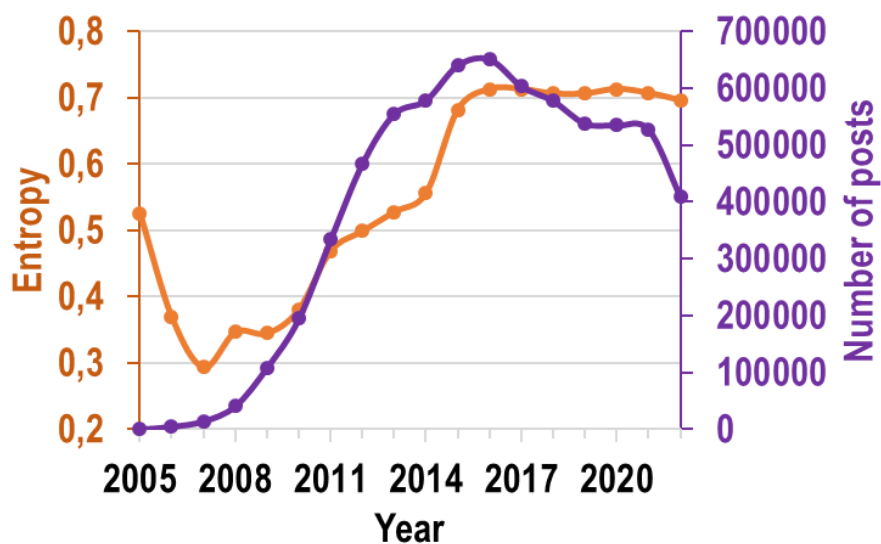


Figure 7.10: Entropy and number of posts in Arduino Forum network.

One of the topics on the Arduino Forum is "Who is the 'system' user?". Answering:

"The system user is a special account that is automatically created by Discourse. It is used for performing some automated functions on the site. It is also used as the API user if you make API requests with the All Users API key."

"One of the tasks of this automated account was creating all the posts that no longer had a user account attached."

“Even though we have very dedicated moderators, that would have been a herculean task to do manually. Much better to let the robots handle the boring stuff they are so good at so us wetware can focus our time on the things we do better.” (Forum Arduino, 2021)

Given the role of this special user called *system*, Table in Annex 10.3 excluded all user *system*'s data from the Arduino Forum network. Between 2005 and 2022 the bot system aggregated 1,120469 million posts.

Figure 7.11 shows that the system decreases the entropy value of the Arduino Forum network organization, except in 2005, 2020, 2021, and 2022 when the values are similar.

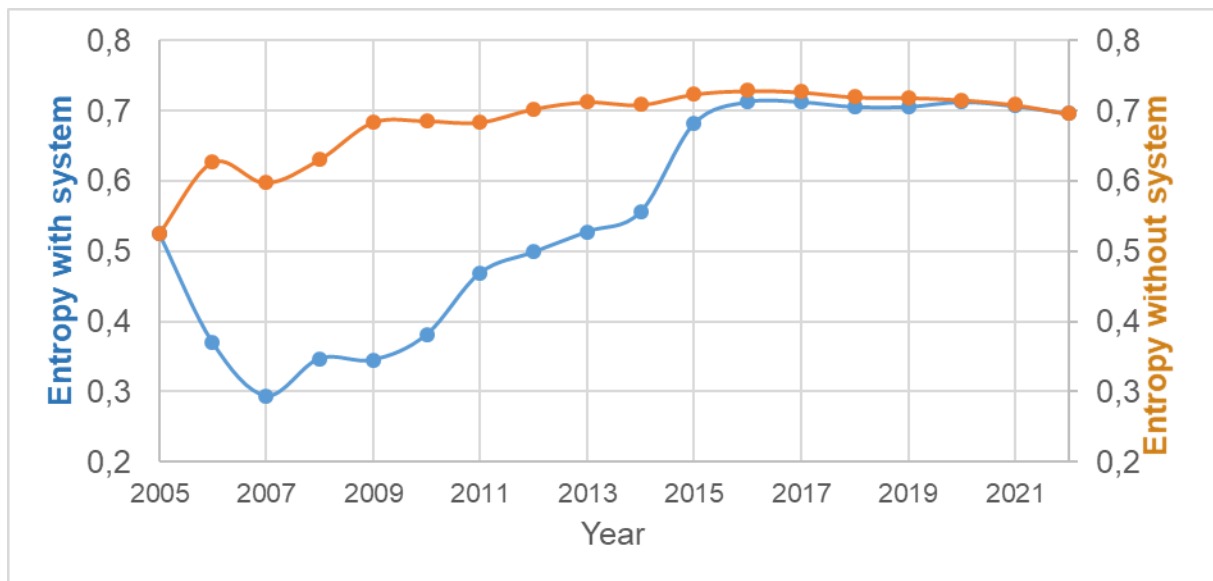


Figure 7.11: Comparison of entropy values for the Arduino Forum network, between 2005 and 2022, with and without the user “*system*”.

One aspect revealed by Figure 6.1 is that the distribution of elements in an open (complex) network has different properties depending on the hierarchical level it occupies. In this study, each network member's participation (number of posts) affects their hierarchical position.

Figure 7.12 presents the distribution of network members by their level of participation in the network and, using Equation 28 divides members into two hierarchical layers (a higher layer with members who have made the most posts and a lower layer with members who have made fewer publications). Considering Figure 5.3 when there are small sets any adjustment by either the power law or the exponential distribution is almost indistinct. Therefore, the two hierarchical layers fitted in Figure 7.12 only use the power law distribution.

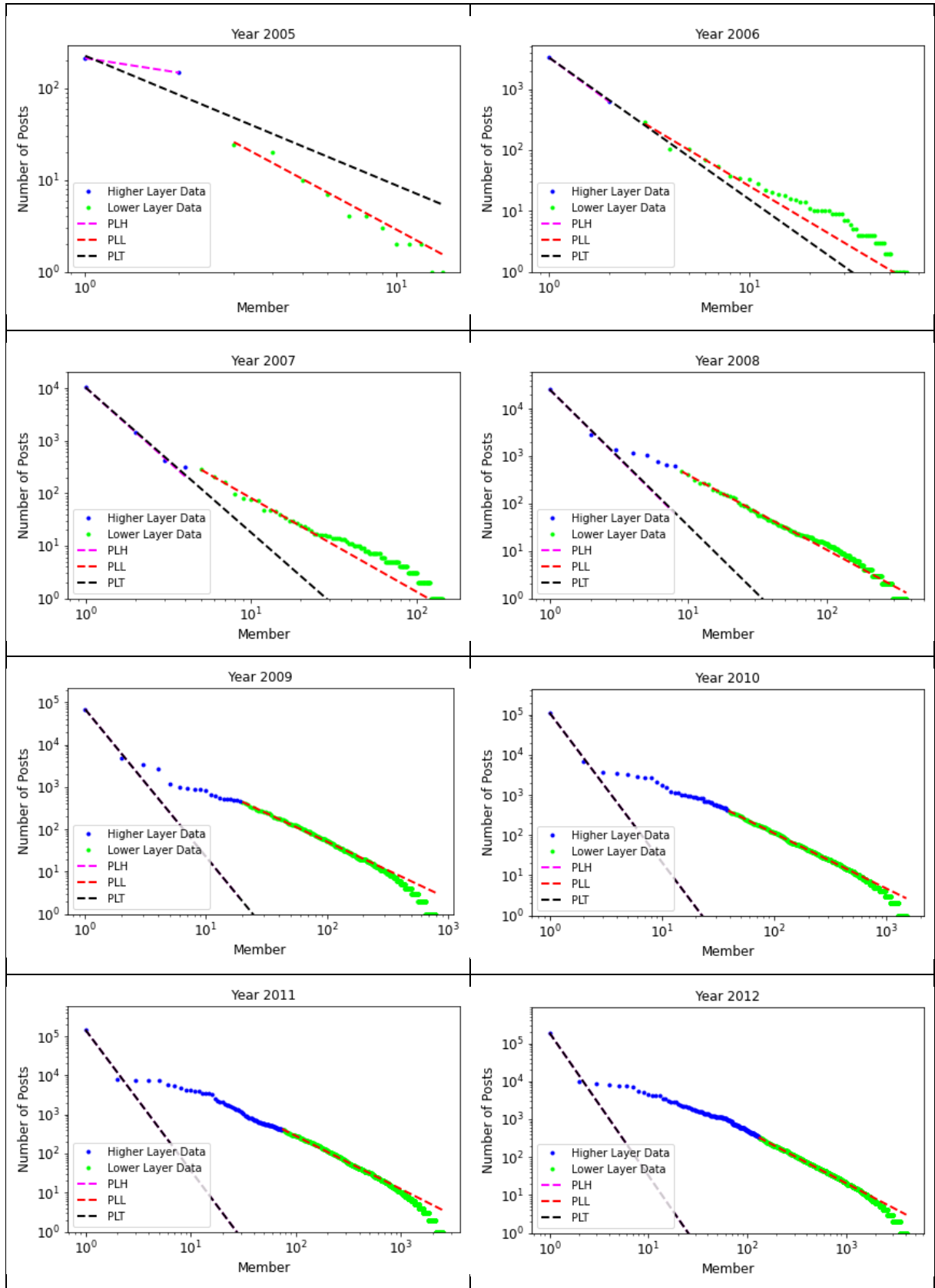


Figure 7.12: The higher hierarchical layer (PLH), lower hierarchical layer (PLL), and total (PLT) of the Arduino Forum network are fitted by a power law distribution.

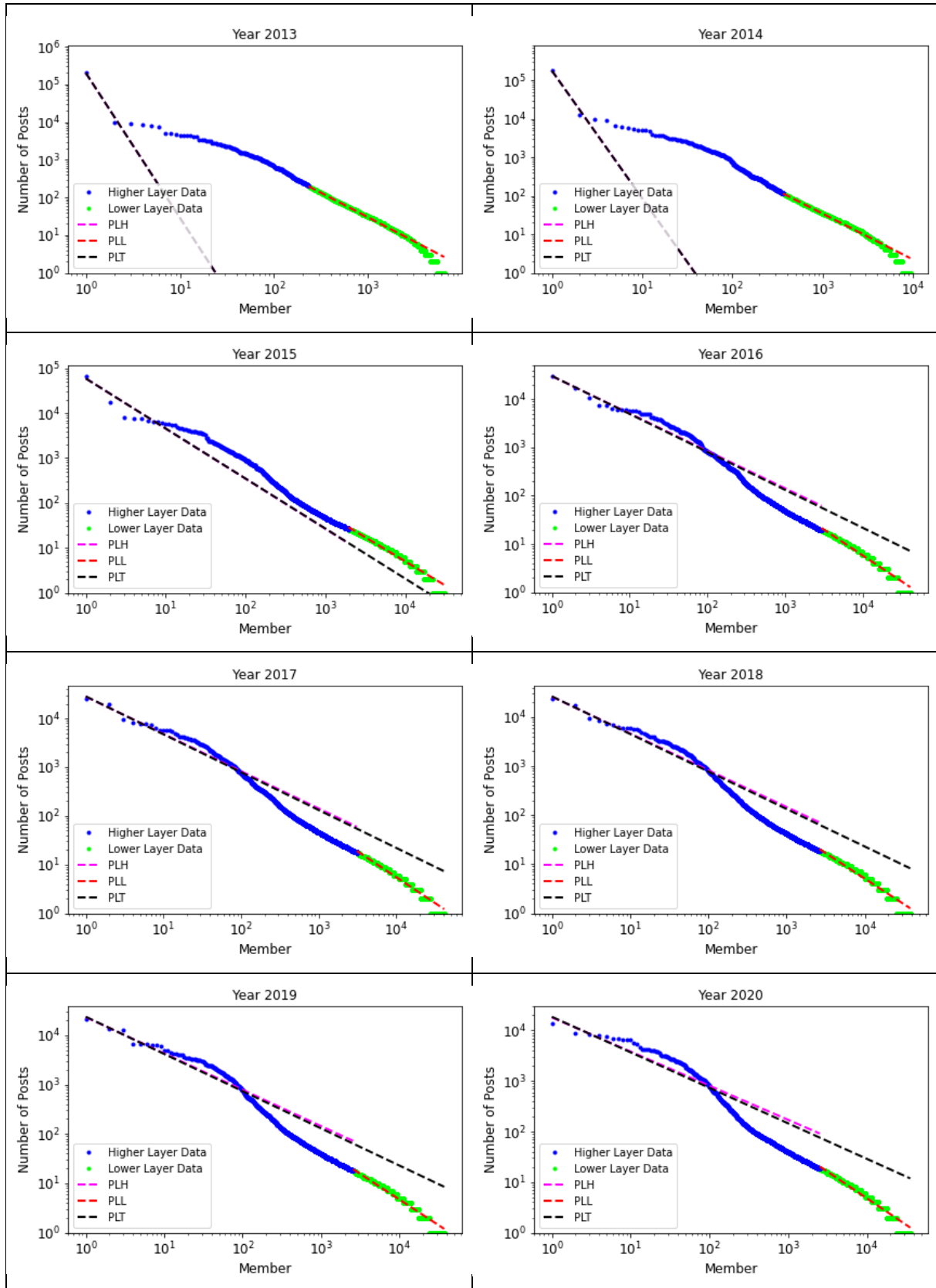


Figure 7.12: The higher hierarchical layer (PLH), lower hierarchical layer (PLL), and total (PLT) of the Arduino Forum network are fitted by a power law distribution (continuation).

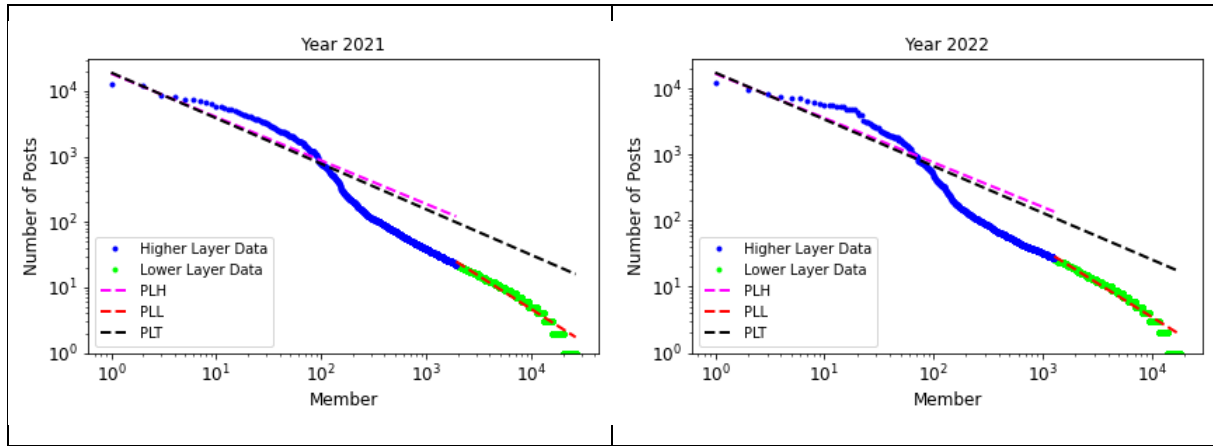


Figure 7.12: The higher hierarchical layer (PLH), lower hierarchical layer (PLL), and total (PLT) of the Arduino Forum network are fitted by a power law distribution (continuation).

Annex 10.5 contains the values of the constants of the power law fittings curves in the graphs presented in Figure 7.12. These values show irregular behavior in the power law curves adjusted for the higher hierarchical layer of the network, which significantly influences the result of the entire network.

The data shows *system's* significant influence on the network's evolution. The graphs in Figure 7.13 do not consider the user *system*.

Without the influence of user *system*, the values of the power law distribution constants, shown in Annex 10.6, for the higher hierarchical layer of the network present greater regularity, ensuring the stability of the network's total results.

Figure 7.12 and Figure 7.13 show that the higher layer of the network hierarchy has a determining role in the power law distribution of the entire network. The size of the deviation on a log-log scale is not linear, so although the network-wide power law curve fit appears to not account for the lower layers, Figure 7.12 and Figure 7.13 show that often the power law curve values of the entire network have a number slightly higher than the values of the power law curve fitted to the higher layer of the network. The first years of the network's evolution did not respect this principle, particularly until 2015, considering the user *system*.

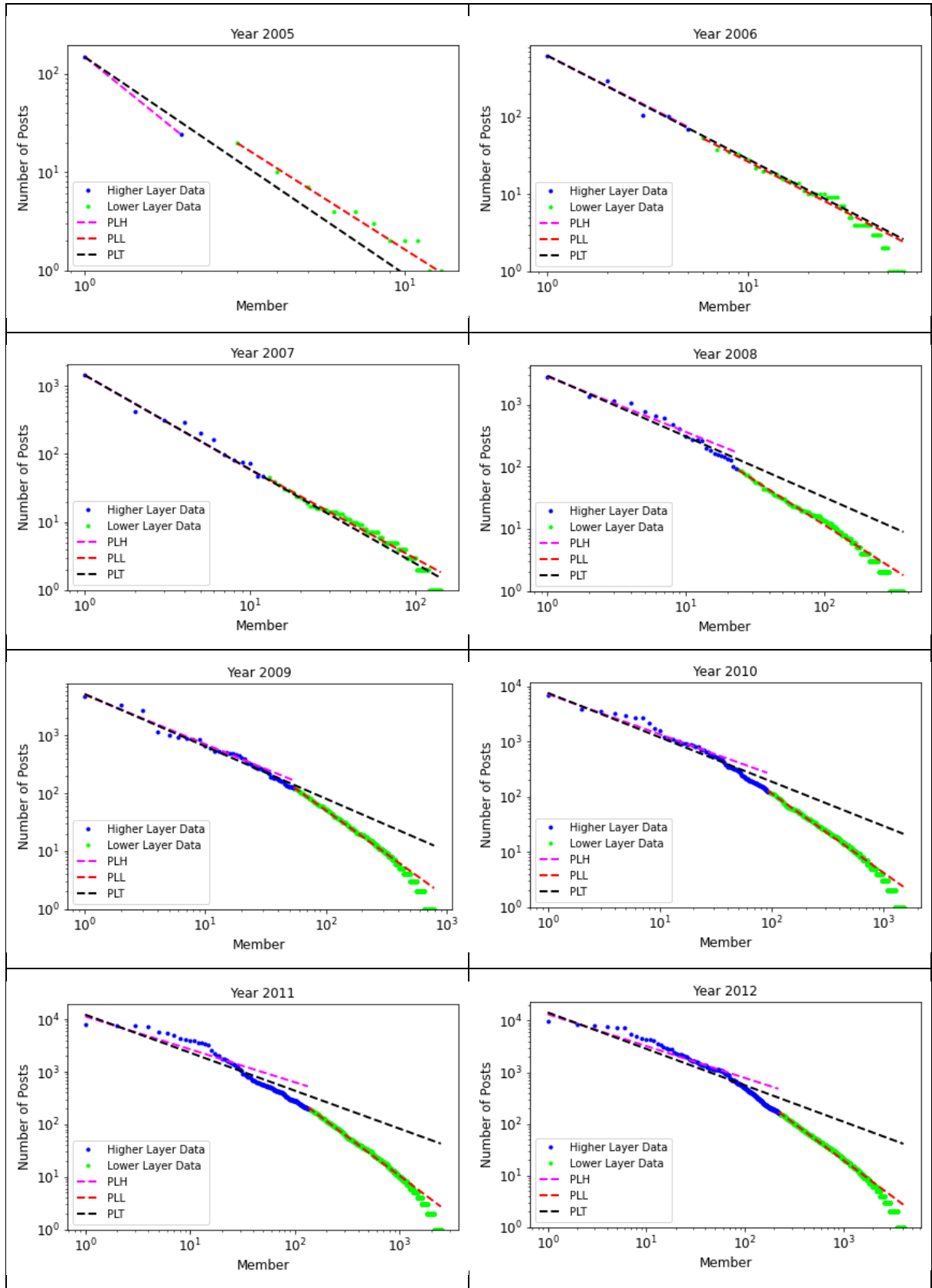


Figure 7.13: The higher hierarchical layer (PLH), lower hierarchical layer (PLL), and total (PLT) of the Arduino Forum network, without the user *system*, are fitted by a power law distribution.

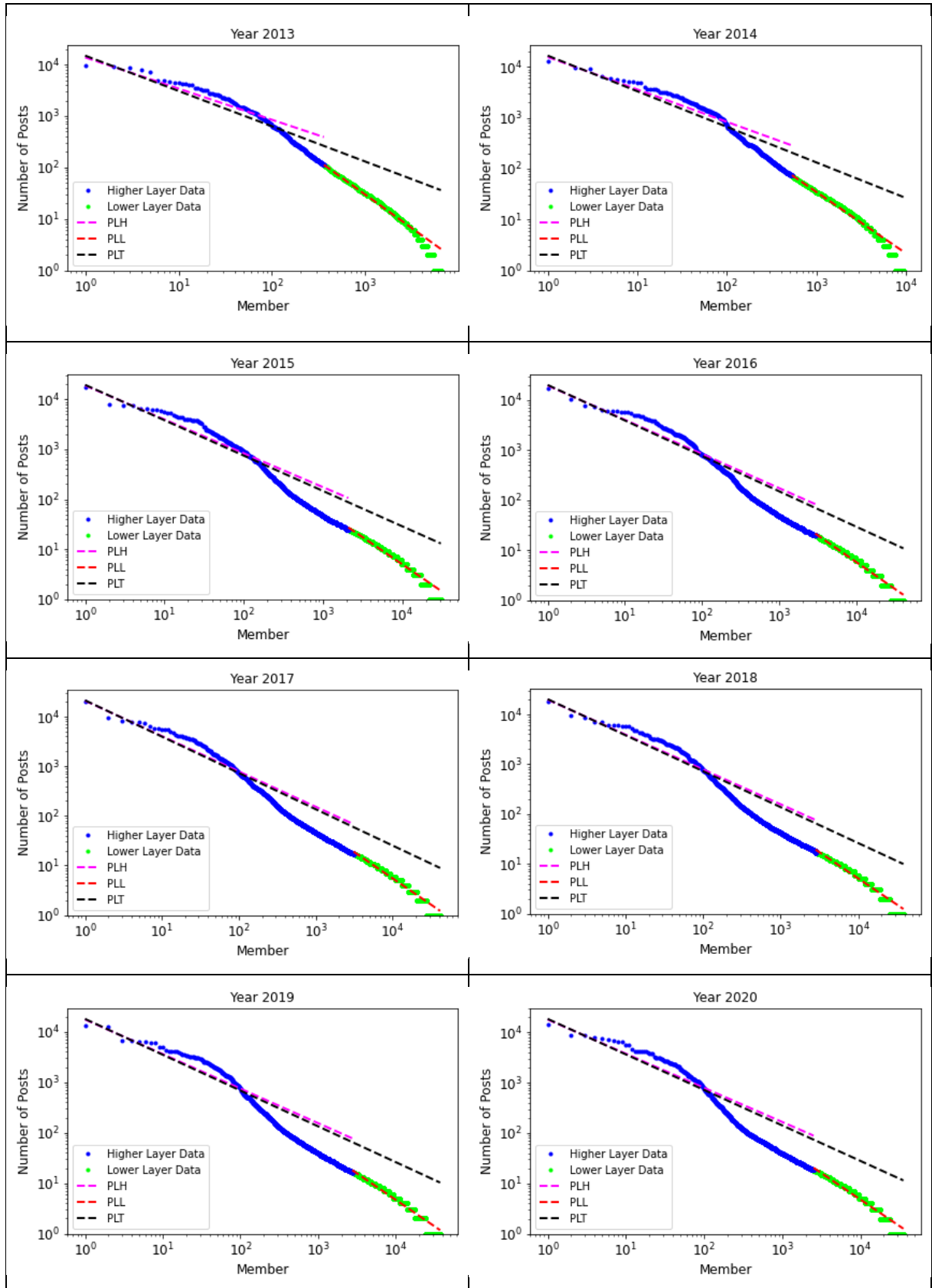


Figure 7.13: The higher hierarchical layer (PLH), lower hierarchical layer (PLL), and total (PLT) of the Arduino Forum network, without the user system, are fitted by a power law distribution (continuation).

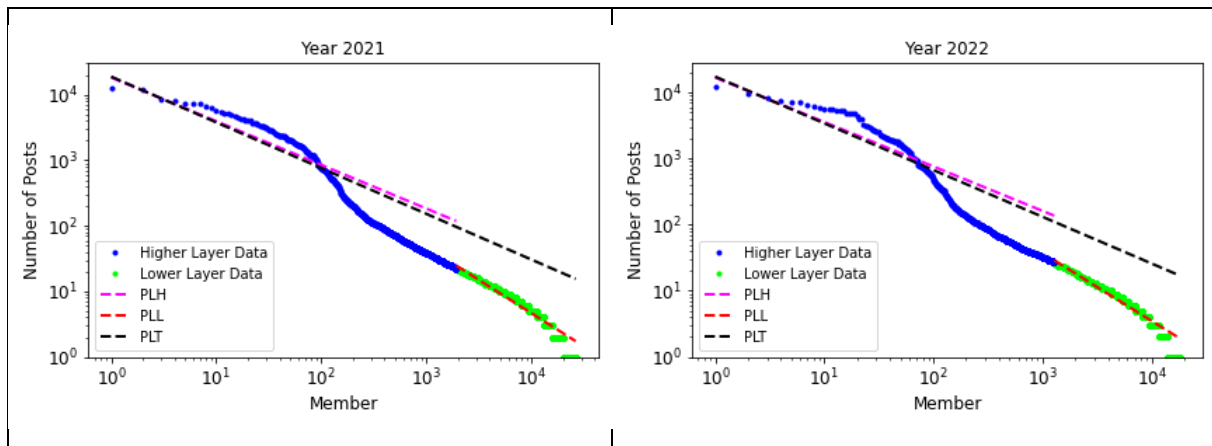


Figure 7.13: The higher hierarchical layer (PLH), lower hierarchical layer (PLL), and total (PLT) of the Arduino Forum network, without the user system, are fitted by a power law distribution (continuation).

7.6. EEVBlog Forum network

In the EEVBlog forum network study, 53368 active members were identified between October 2009 and the end of the year 2022. An active member is a user registered on the forum network who has made at least one post. An active member in a given year involves making at least one post on the EEVBlog Forum. The Table in Annex 10.4 shows data from the EEVBlog Forum network. The network's membership renewal rate has gradually decreased from 94.2% in 2010 to 44.9% in 2022. The user renewal rate on the EEVBlog Forum Network is substantially lower than the new user rate on the Forum Network Arduino. Perhaps this data will allow open networks to achieve self-organization more quickly, even though they are two different networks. The EEVBlog network deals with broader subjects (Projects, drawings, and technical material to mechanical engineering and automation) with multiple technologies while the Arduino Forum Network considers more specific projects. However, Figure 7.14 shows that many network users were only there for one day.

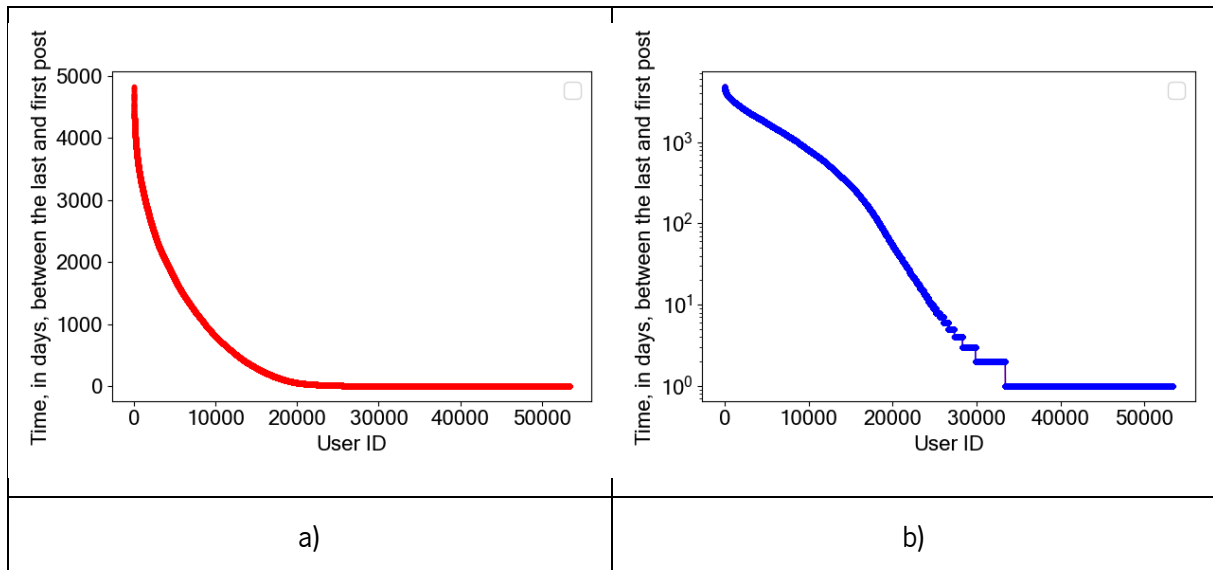


Figure 7.14: Temporal difference, in days, between users' first and last posts in the EEVBlog Forum network considering a) linear scales and b) log-log scales.

Figure 7.15 shows that after the initial growth in user participation in the network, the number of active users per year remained close to 10000 between 2017 and 2021 (9154 users in 2022).

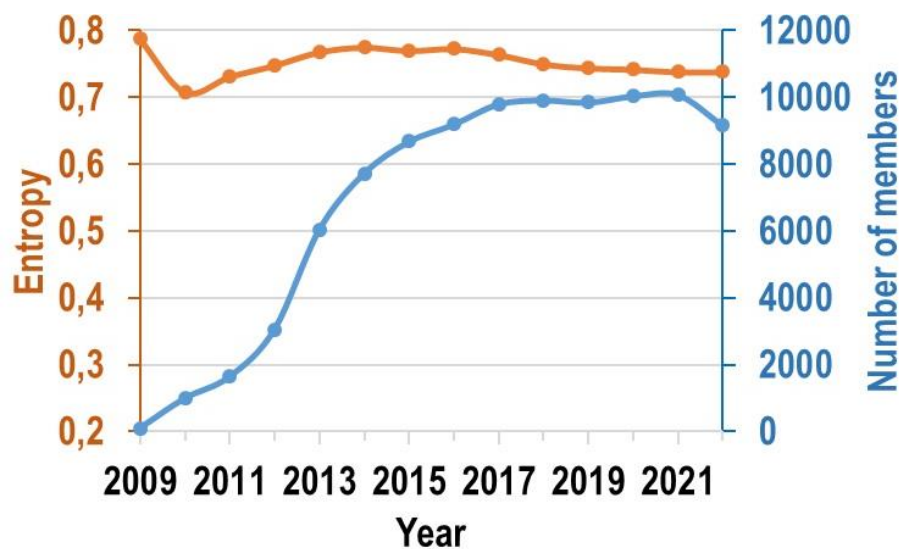


Figure 7.15: Entropy and number of members in the EEVBlog Forum network.

Figure 7.16 shows that the annual variation in the number of posts does not present a similar pattern to the number of active users on the network. A characteristic that influences this phenomenon is the variation in the average number of posts made per active user, which in 2022 was 29,9, while in 2011 and 2012, it was 35,5.

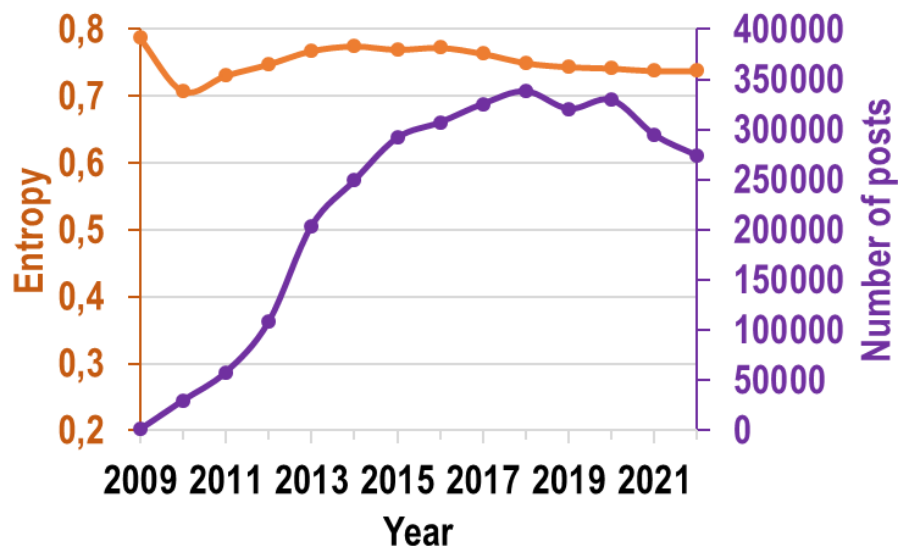


Figure 7.16: Entropy and number of posts in the EEVBlog Forum network.

As was done in the case of the Arduino Forum network, Figure 7.17 shows the distribution of members of the EEVBlog Forum network by their level of participation in the network and, using Equation 28, dividing the members into two hierarchical layers (a higher layer with members who made the most posts and a lower layer with members who made fewer posts) fitted only by the power law distribution.

Appendix 10.7 contains the values of the constants of the power law fitting curves in the graphs shown in Figure 7.17. The values of k for the higher layers of the network hierarchy are consistently lower than the numbers of the lower layers.

Figure 7.17 suggests, by its downward concavity of the curve and inflection before the center of mass, that the EEVBlog network curve follows a truncated power law. However, as previously mentioned, the purpose is not to verify the actual curve that characterizes an open network (because there are multiple possible configurations) but to assess the self-organization process and observe points of disruption that show changes in the state of the network. The values in Annex 10.7 point to two networks within a network that, despite having different characteristics, are indispensable for the self-organization process. The following subchapter will analyze these values in more depth.

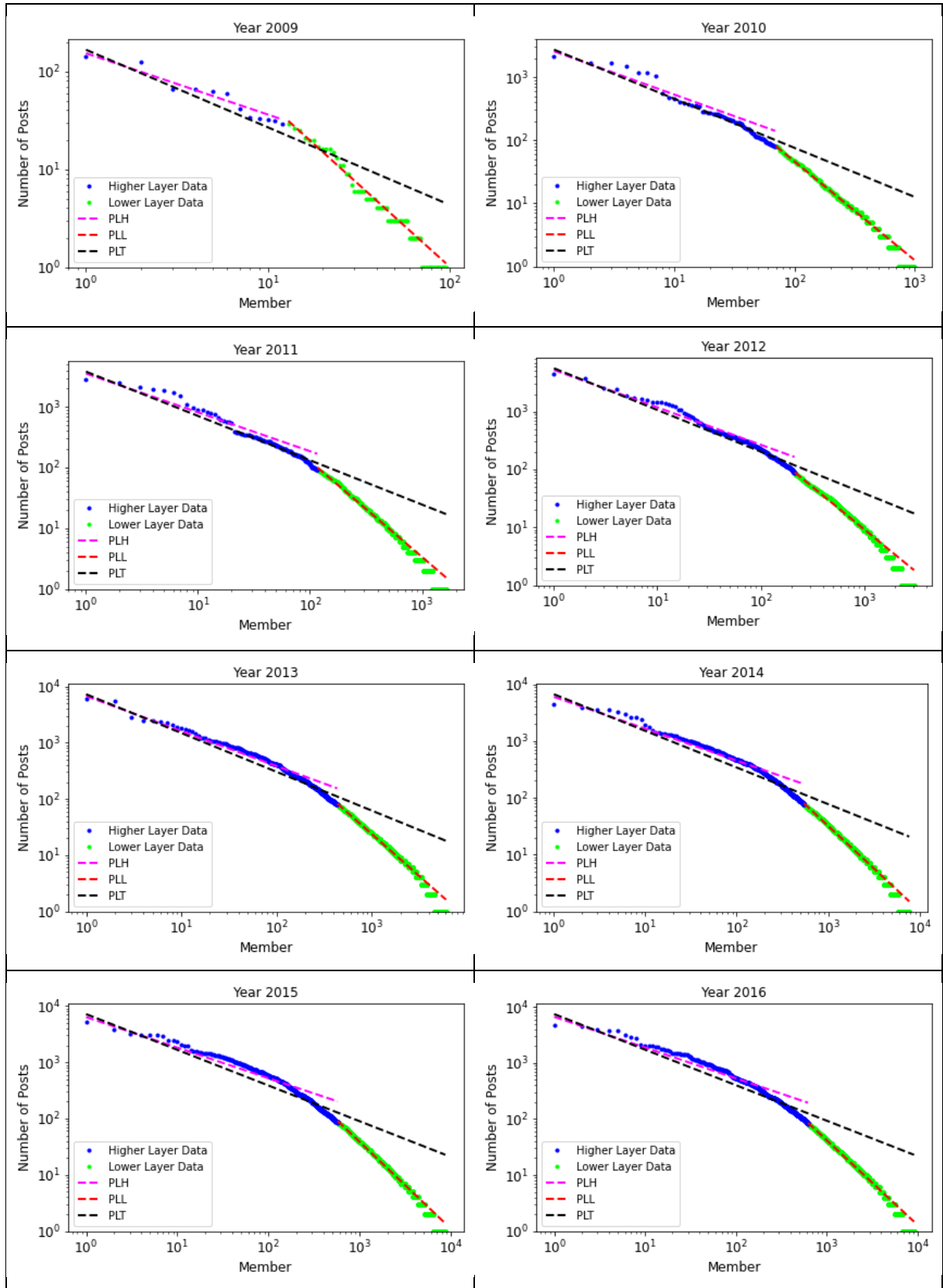


Figure 7.17: The higher hierarchical layer (PLH), lower hierarchical layer (PLL), and total (PLT) of the EEVBlog Forum network, are fitted by a power law distribution.

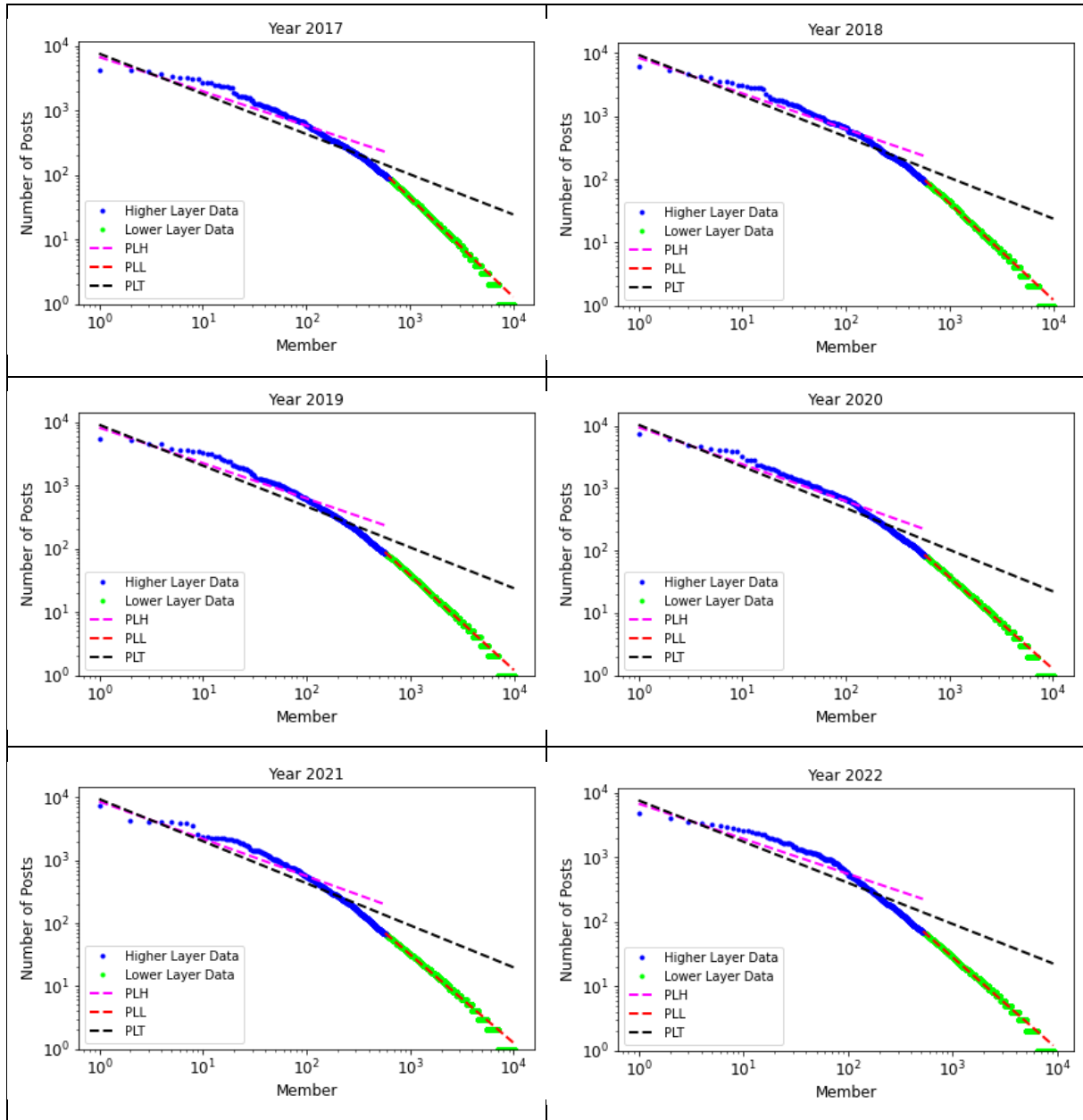


Figure 7.17: The higher hierarchical layer (PLH), lower hierarchical layer (PLL), and total (PLT) of the EEVBlog Forum network, are fitted by a power law distribution (continuation).

7.7. Analysis of Arduino Forum and EEVBlog networks behavior.

Based on the results shown in Figure 7.9 and Figure 7.15 for the Arduino Forum and EEVBlog Forum networks, respectively, there is a balance of Entropy values with values close to 0,7 (between 2015 and 2022) in the case of Arduino and 0,75 in the case of EEVBlog. These values are relevant if we observe the constant renewal in these open networks, where most participants often were new members. (Between 2019 and 2022, the EEVBlog network renewal rate was less than 50%). However, the almost

constant values of entropy, as already mentioned, seem to be limited in determining that networks are in a process of self-organization.

Observing the numbers presented in Annex 10.5, Annex 10.6, and Annex 10.7 and the graphs in Figure 7.12, Figure 7.13, and Figure 7.17, the division of the Arduino Forum and EEVBlog Forum networks showed similar patterns. Excluding the first years of the evolution of the Arduino Forum network, the power law distribution fit numbers of the member participation distribution curve in the two networks show that considering the a_n, k_n distribution, considering the hierarchy layer h :

The values of the constant k for the lower layers of the hierarchy are often more elevated than the numbers of k for the higher layers of the network hierarchy.

The constant y depends on the size of the number of elements that make up the network (which previously also influenced the coordinates of the network's center of mass).

Crossing the previous patterns with the circumstance that this regularity occurs with post-communications between elements of the higher hierarchical layers and the lower hierarchical layers of the network, as can be seen in Annex 10.12 and Annex 10.13, which show the edges and nodes of the Arduino Forum and of the EEVBlog Forum, for the year 2022, suggests some relationship between the two hierarchical layers of the networks (with holonic behavior) and the total behavior of the networks.

Assuming that the number of posts made by each active member determines its position in the network's hierarchical ranking, it is conceivable to model the number of posts accumulated by each group (y) as a function of its hierarchical ranking in the network (x). (This proposed hierarchical network model assesses only the quantity and not the quality of the posts.) By abduction, the function takes into account the following:

- The existence of two power law distributions (by $f(x) = ax^{-\alpha}$) in the first diagram of figure 3;
- The power-law exponent α should consider the center of mass (cm_i) as the inflection point between the two different ranks;
- The power law exponent α should be standardized and consider the number of groups that are different;
- Power law exponents are different and must be proportional (k);
- Power-law distributions' coefficients are different, although they may be related (a_i and a_j);

- There is an initial value of posts made by the group of members who made only one post (y_0);
- Across the entire network dimension, y is always positive.

Thus the function is defined as Equation 31:

$$y = y_0 + a_1 x^{\left(\frac{x}{cm_x} - 1\right)} + a_2 x^{k\left(\frac{x}{cm_x} - 1\right)} \quad (31)$$

During the first simulations, the fitting between Equation 31 and data collected from the networks implies that:

The term a_1 is negative and a_2 was inversely proportional to a_1 ;

Thus, the Equation 31 could be rewritten in Equation 32.

$$y = y_0 - ax^{\left(\frac{x}{cm_x} - 1\right)} + \frac{1}{a} x^{k\left(\frac{x}{cm_x} - 1\right)} \quad (32)$$

Where a and k are the signature values of the function.

This function formed by a difference of pseudo power law functions causes huge variations in y with a small variation of x , around the center of mass. It shows that the state at the threshold of instability/chaos is a characteristic of open organizations. However, the process of self-organization inherent in complex organizations ensures apparent equilibrium.

Figure 7.18 and Figure 7.19 present the correspondence of the cm_x , y_0 , a , and k change over the years, for both networks. In the calculations, the value of k was limited to 40. It must therefore be assumed that the k values, presented in the case of the Arduino Forum network, in the period between 2012 and 2014, exceed 40.

The center of mass in both the Arduino Forum and the EEVBlog Forum networks follows almost proportionally the y_0 curve. This proportionality is much more evident in EEVblog networks, with the center of mass values between 3,1 and 3,8 times greater than the y_0 numbers. In Contrast, in Arduino, the proportionality of the center of mass for y_0 varies between 2,6 and 6,9.

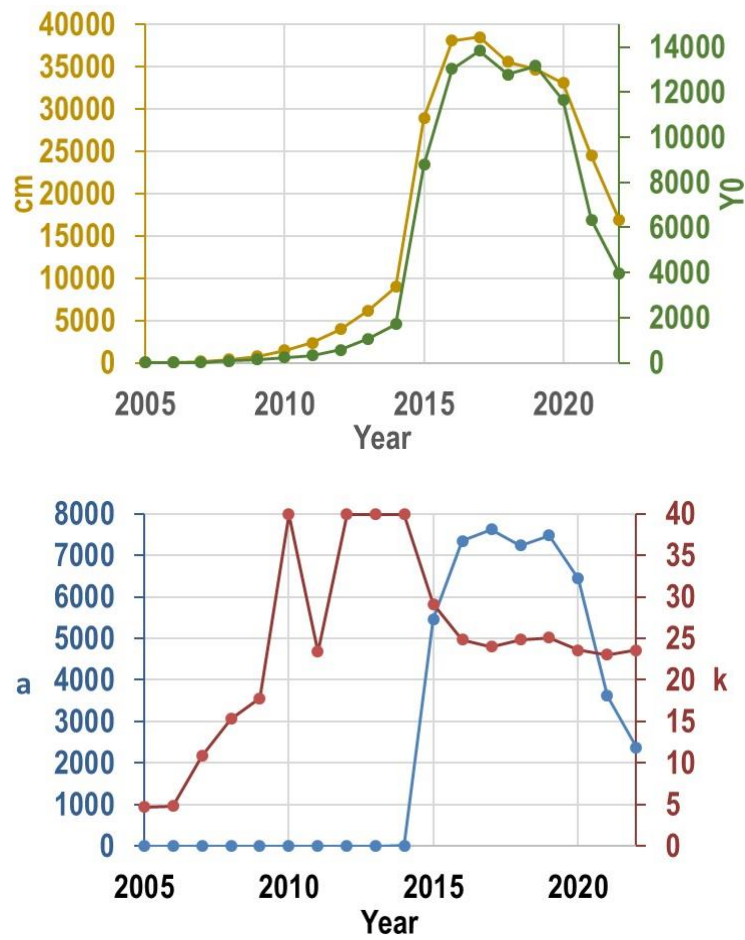


Figure 7.18: Correspondence of the cm , and y_0 , and a and k change over the years for Arduino Forum network.

The value of the constant a also varies with the size of the networks, so it will not be an indicator of self-organization. As for the constant k , its values stabilized from 2015 to 2022 in the case of Arduino and the EEVBlog between 2010 and 2016 close to 25 and in the EEVBlog between 2018 and 2022 at a value close to 30. In Arduino, the stability of k coincides with the occasion in which the entropy variation is less, indicating an (internal) organization process. In EEVBlog, the entropy variation was low almost from the beginning. However, from 2018 onwards, the entropy value in EEVBlog was always lower than 0,75, which could mean a new state of self-organization that coincides with the lower renewal of network members.

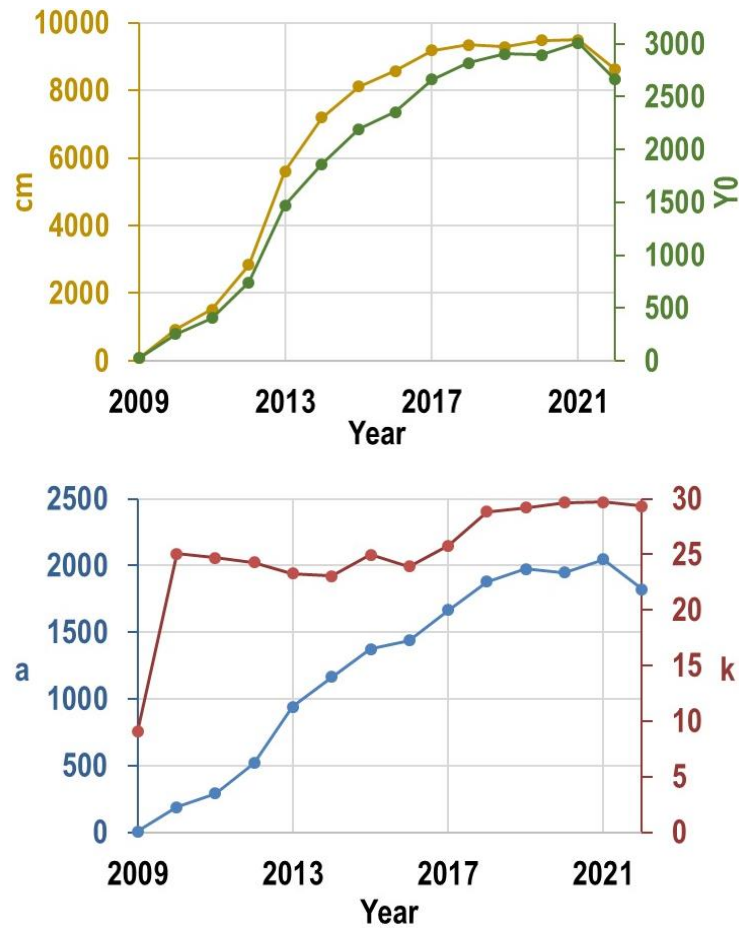


Figure 7.19: Correspondence of the cm_s and y_0 and a and k change over the years for EEVBlog Forum network.

Using the actual values of cm_s and y_0 , and the a and k values that best-fit equation 4, Figure 7.20 shows real and modeled graphs for the Arduino Forum network for each year.

Until 2015, errors associated with fitting Equation 32 to the Arduino Forum network curve were high. These errors arise for two reasons:

In the first years, the size of the network is small;

The existence of a member of the network that has such disparate participation concerning the other members that until 2015, the Arduino Forum network curve appears to have a horizontal asymptote close to zero.

As previously stated, this member is the bot *system*, and one of his tasks was not to lose posts from users who did not identify themselves on the network. Thus, users who participated a few times, due to their large number, helped a super user, *system*, to increase his position in the network, reducing the system's entropy and virtually distancing it from the self-organization process.

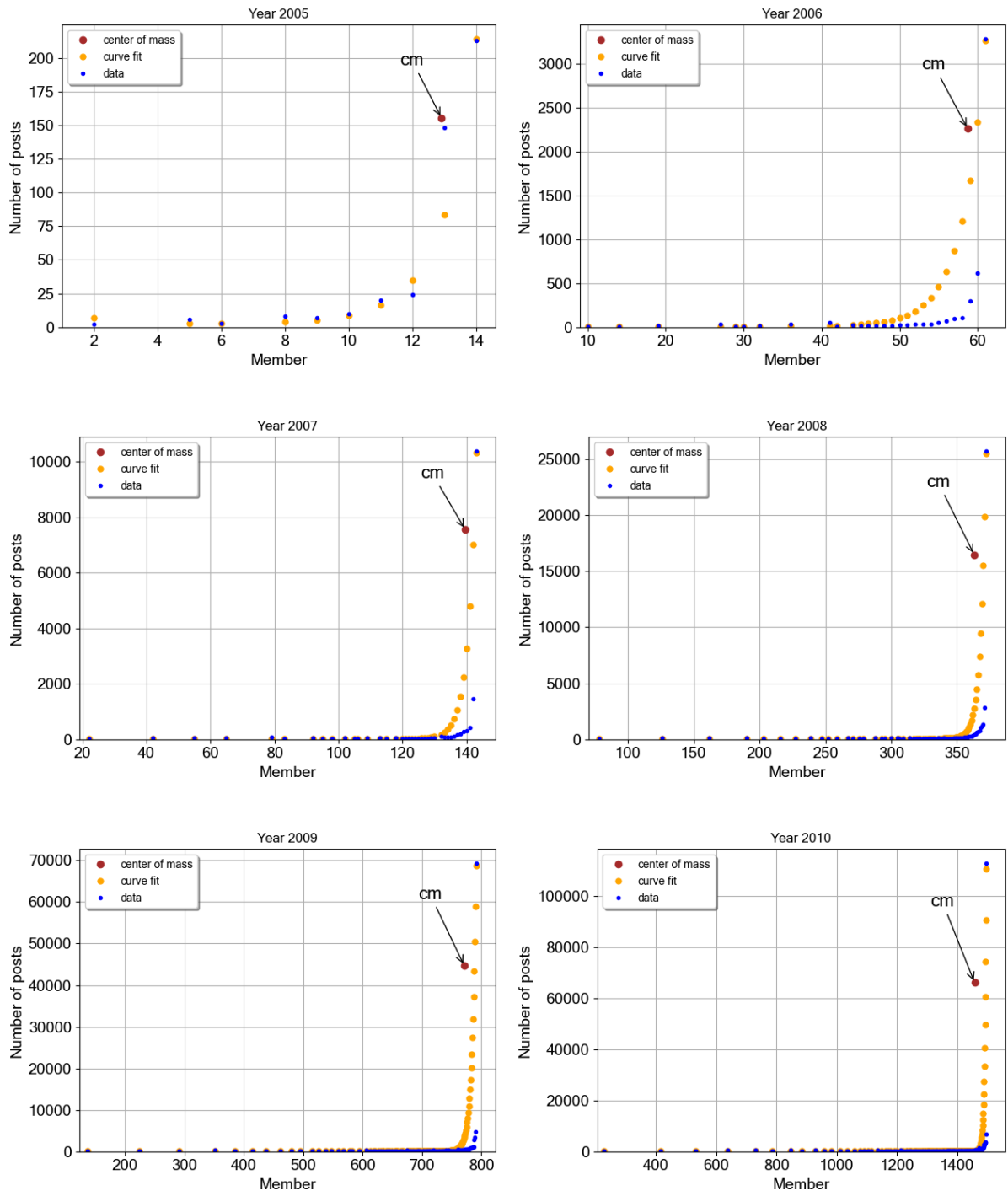


Figure 7.20: Comparison of modeled and real behavior of the Arduino Forum network, between 2005 and 2022.

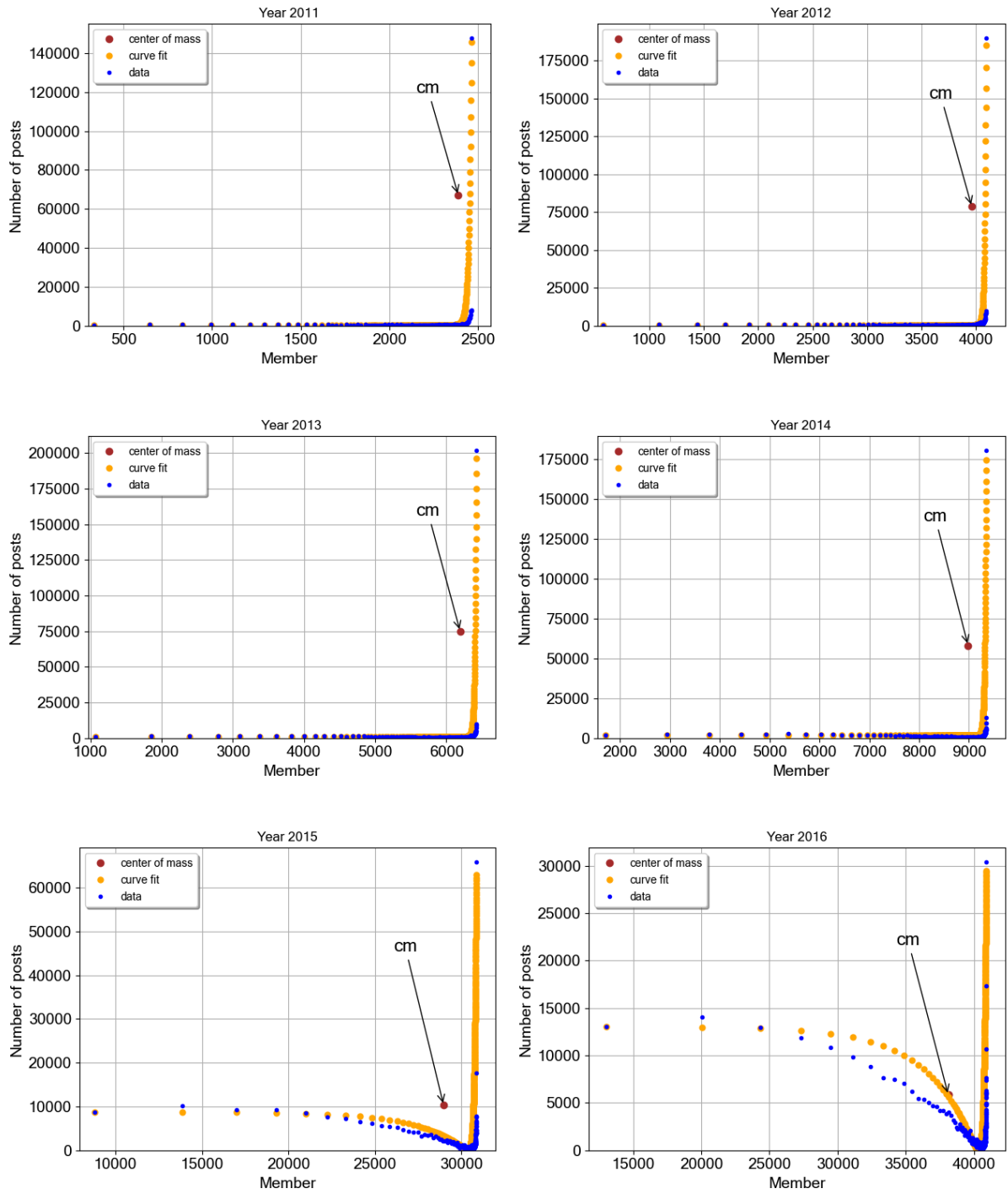


Figure 7.20: Comparison of modeled and real behavior of the Arduino Forum network, between 2005 and 2022 (continuation).

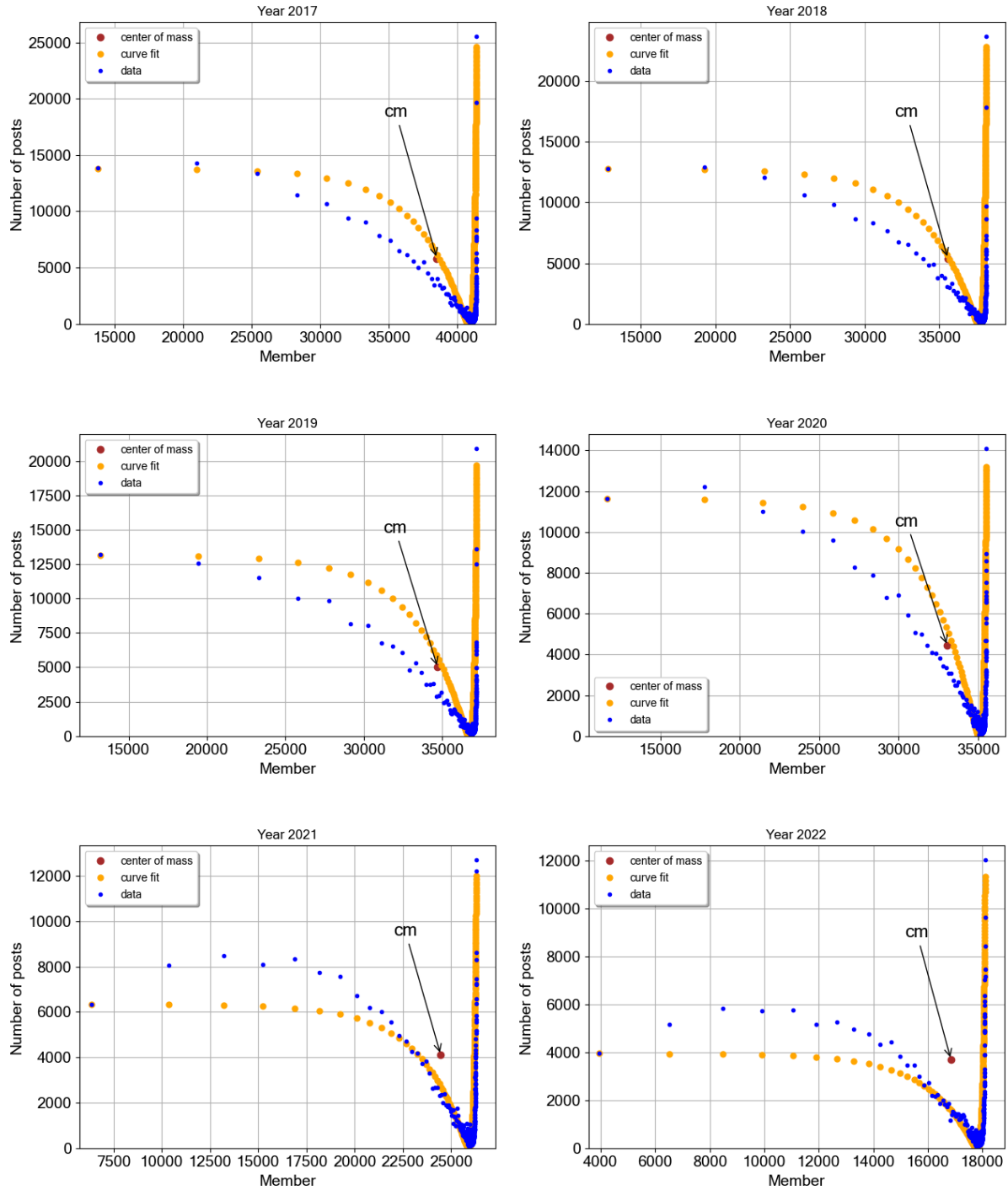


Figure 7.20: Comparison of modeled and real behavior of the Arduino Forum network, between 2005 and 2022 (continuation).

Considering the disparity in entropy values presented in Figure 7.11, it is relevant to observe the behavior of the Arduino Forum network disregarding the user *system*. Despite the influence of the user *system* on the number of posts and interactions on the Arduino Forum network, the bot's participation has a residual change in the center of mass, as shown in Figure 7.21.

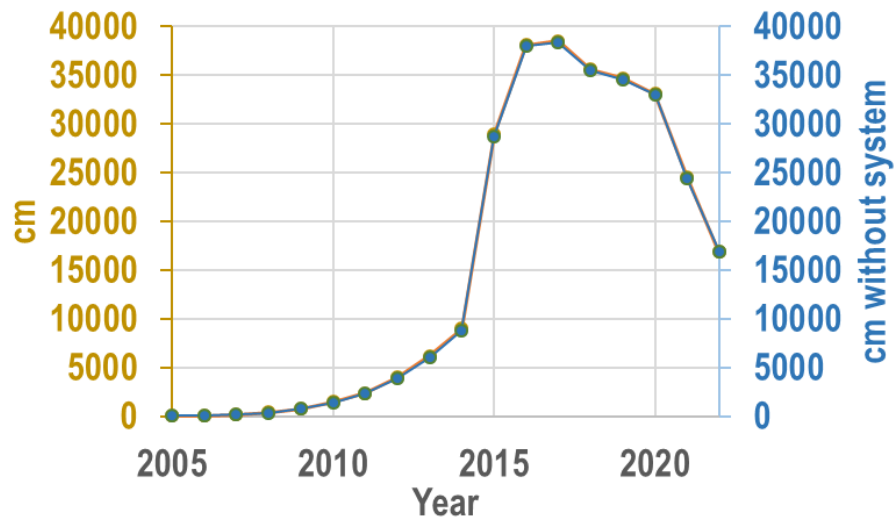


Figure 7.21: Center of mass cm , of the entire Arduino Forum network and disregarding the user *system*.

Figure 7.22 shows that parameter a is an insignificant variation between considering or not considering the user *system* in the network.

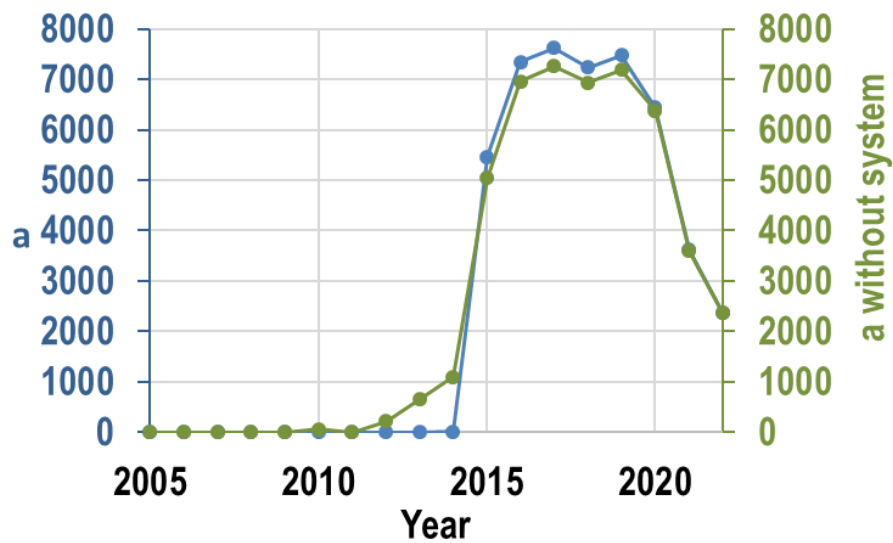


Figure 7.22: Parameter a of the entire Arduino Forum network and disregarding the user *system*.

Figure 7.23 shows that parameter k follows a similar pattern regardless of whether the user *system* is considered in the network. However, k values without the user *system* are smaller when compared to the k values in the total network.

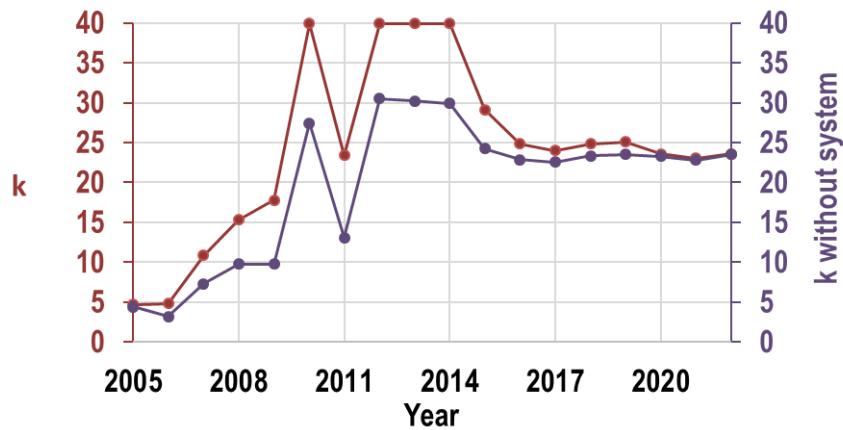


Figure 7.23: Parameter k of the entire Arduino Forum network and disregarding the user *system*.

The variation in k may be due to the significant number of posts attributed to the Pedro bot, as illustrated in Figure 7.24.

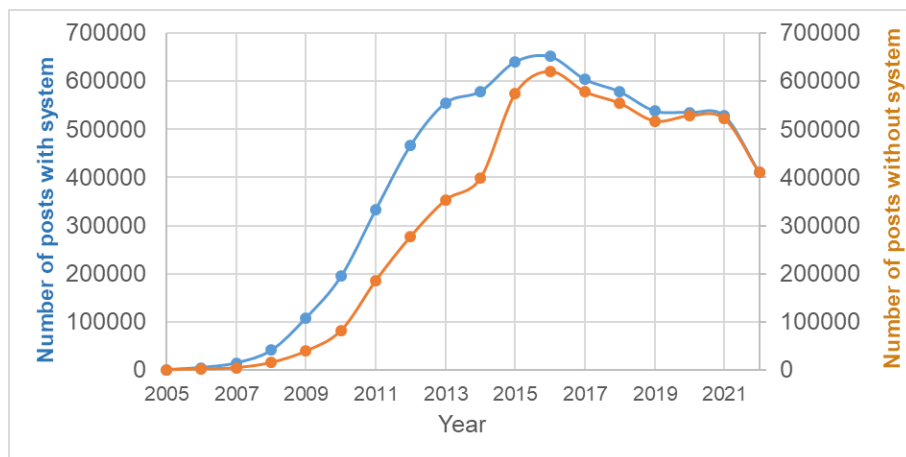


Figure 7.24: Number of posts made on the Arduino Forum network, with and without the user *system*.

Figure 7.24 effectively shows that the massive participation of the bot system in the Arduino Forum network occurred until 2015. Considering also Figure 7.11, which shows that one of the consequences of the *system* bot's participation in the organization was artificially reducing the value of normalized entropy, the absence of user *system* may have helped the system quickly enter the self-organization process. So far, perhaps contrary to mechanistic prejudices, self-organization emerges from systems with entropy values close to 0,7 (typically between 0,6 and 0,8), as opposed to highly efficient systems with low redundancy.

To confirm whether the absence of user *system* improves the results of the adjustment of Equation 32 on the Arduino Forum network, Figure 7.25 shows the adjustment of Equation 32 with the interactions of groups belonging to the Arduino Forum network, between 2005 and 2022, without incorporating the user *system*.

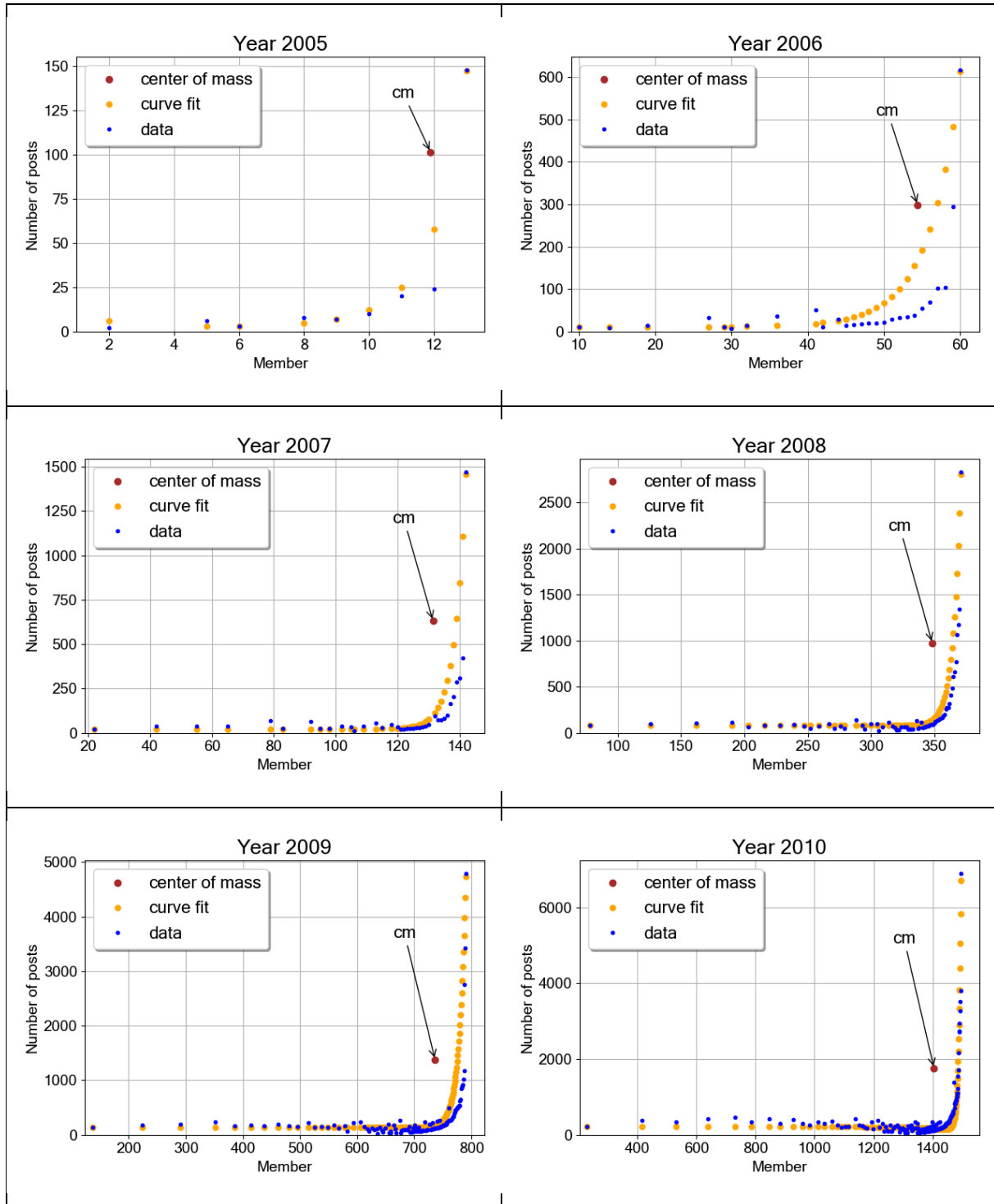


Figure 7.25: Comparison of the modeled and real behavior of the Arduino Forum network without user system, between 2005 and 2022.

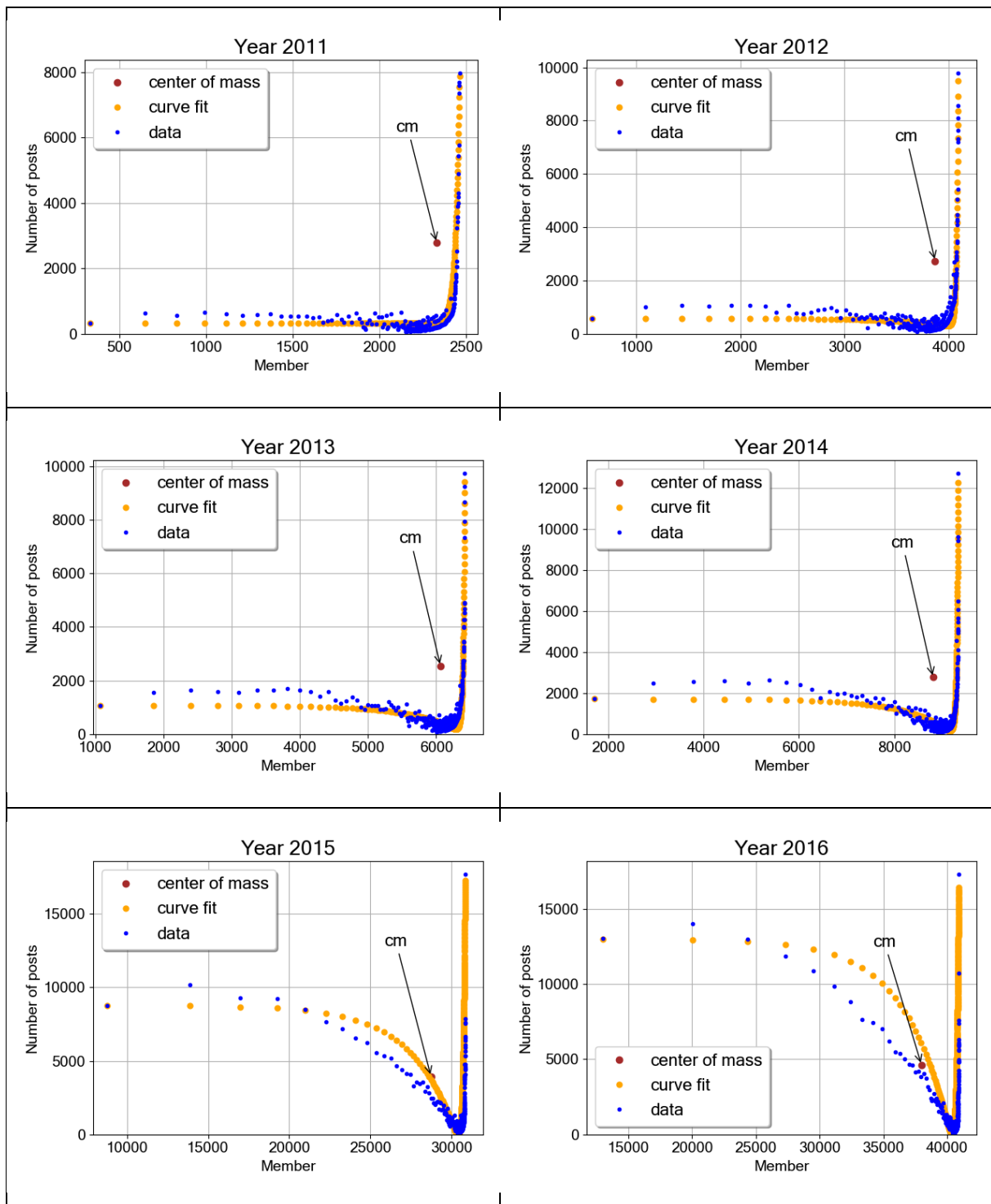


Figure 7.25: Comparison of the modeled and real behavior of the Arduino Forum network without user system, between 2005 and 2022 (continuation).

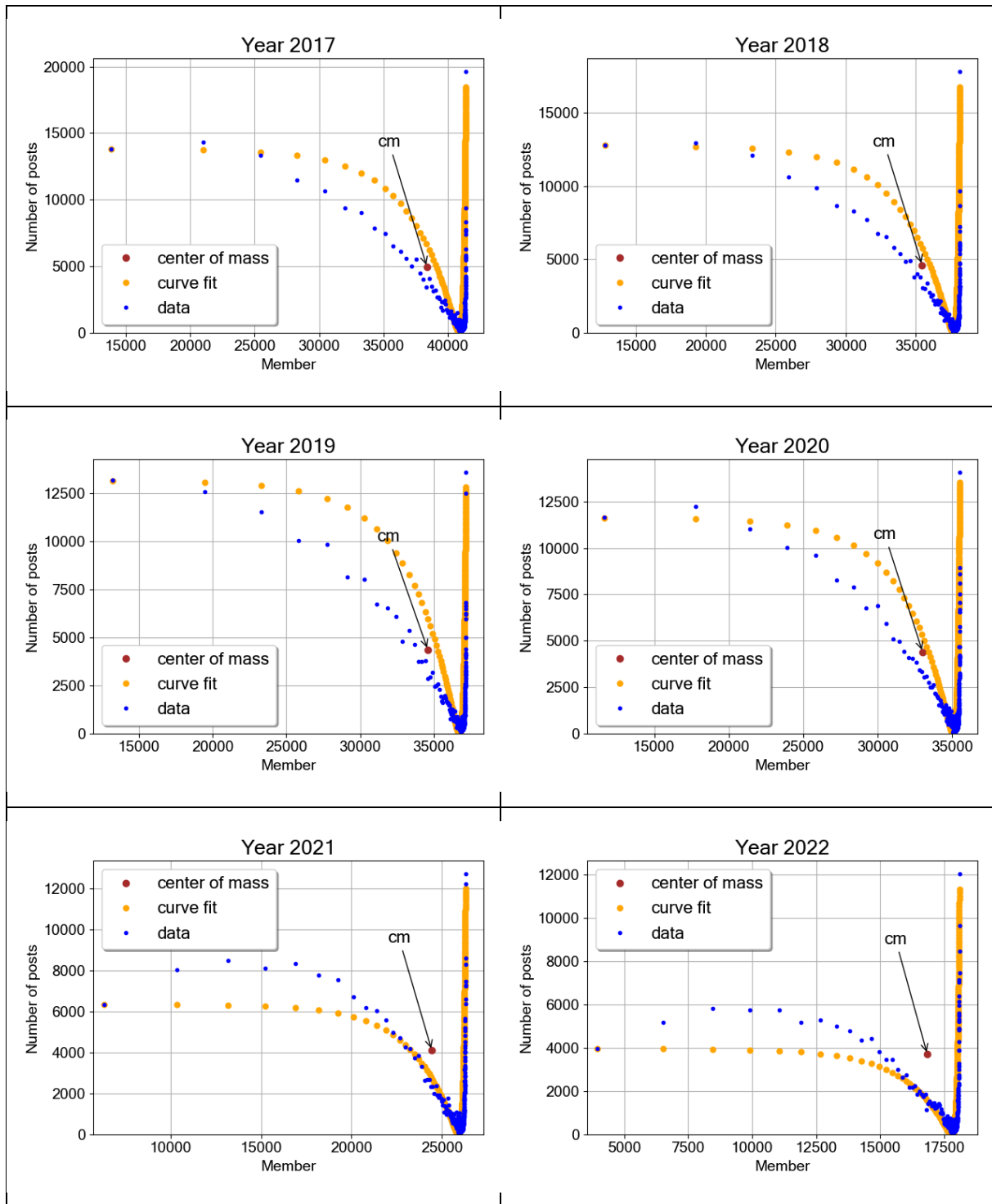


Figure 7.25: Comparison of the modeled and real behavior of the Arduino Forum network without user system, between 2005 and 2022 (continuation).

Figure 7.25 shows, as expected, that the curve fitted to the Arduino Forum network leaves the zero horizontal asymptote before the center of mass more quickly, significantly reducing the errors associated with the constants a and k , as indicated in Annex 10.9. However, it is crucial to acknowledge the importance of the bot *system* in the Arduino organization. The *system* worked as a debugger and not as

an eraser, which is why it played a fundamental role in the self-organization process of the Arduino Forum network.

Using the real values of cm_x and y_{θ_i} and the a and k values that best-fit equation 4, Figure 7.26 shows real and modeled graphs for the EEVBlog Forum network, between 2009 and 2022.

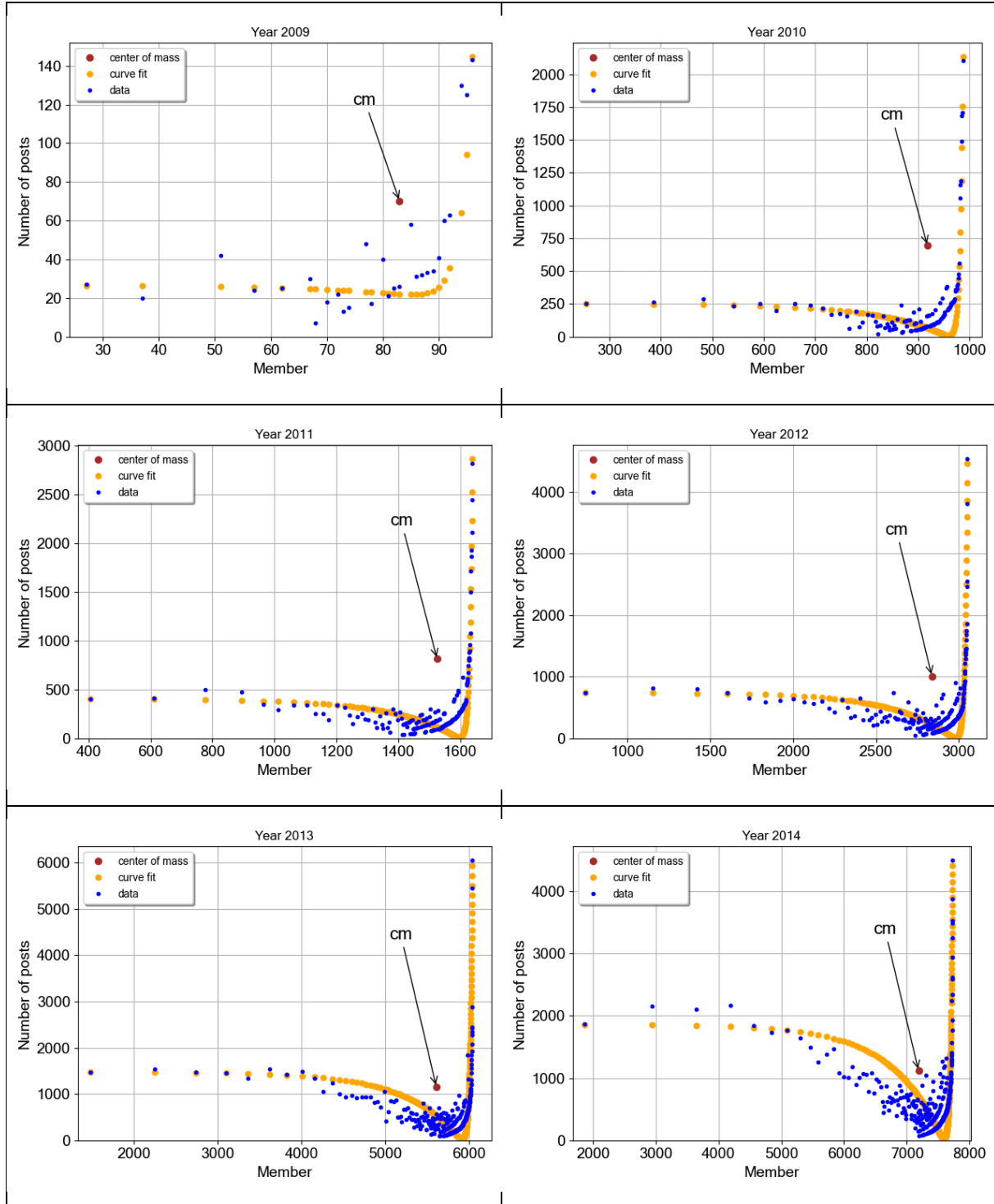


Figure 7.26: Comparison of modeled and real behavior of the EEVBlog Forum network, between 2009 and 2022.

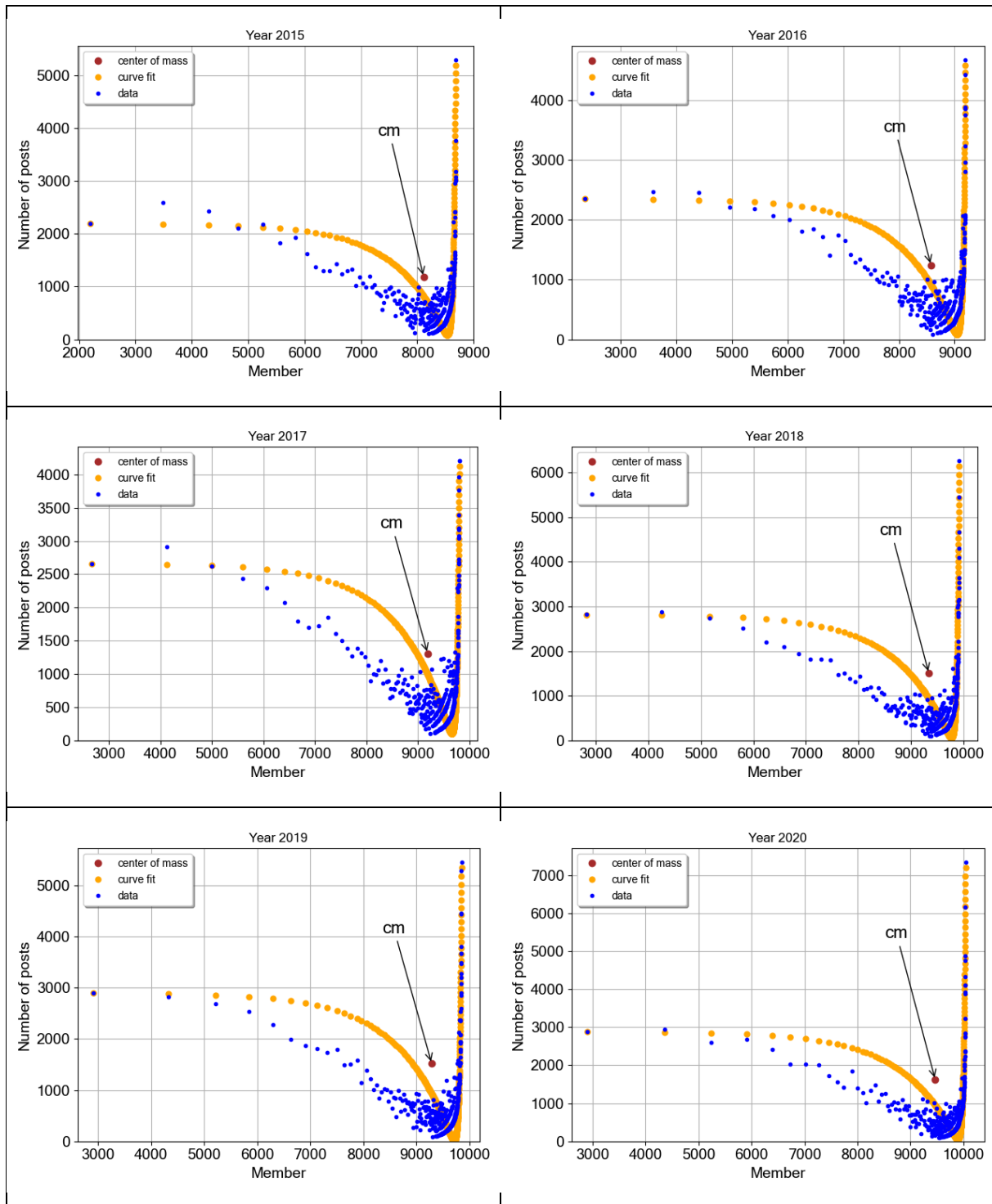


Figure 7.26: Comparison of modeled and real behavior of the EEVBlog Forum network, between 2009 and 2022 (continuation).

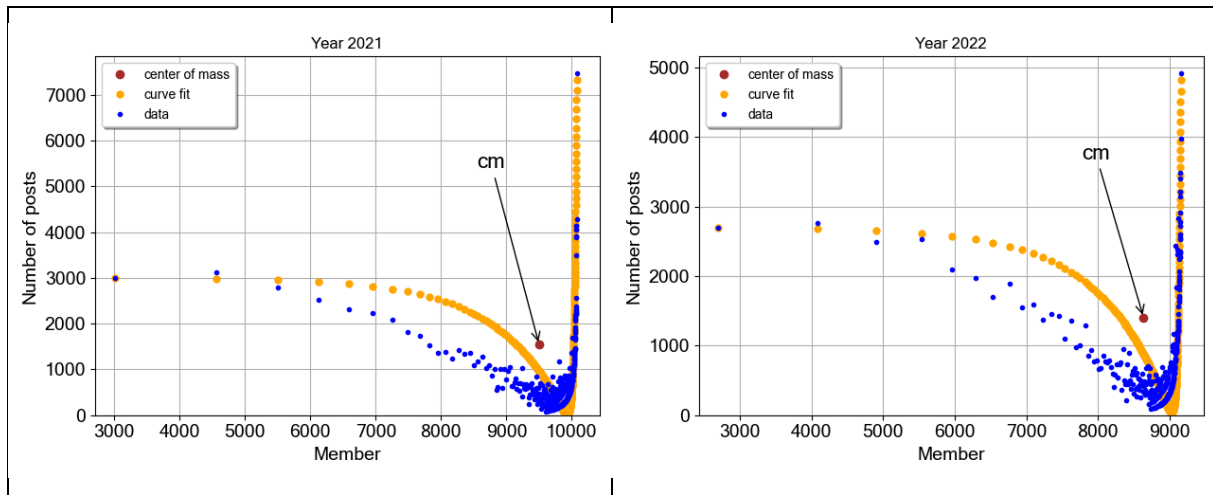


Figure 7.26: Comparison of modeled and real behavior of the EEVBlog network, between 2009 and 2022 (continuation).

The graphs shown in Figure 7.26 suggest that the EEVblog Forum network achieved the self-organization process faster than the Arduino Forum Network. b and k constants b and k present in Appendix 10.10 have low associated error values compared to the errors of the Arduino Forum network. The error values associated with k are surprisingly low, which from 2012 onwards are less than $\pm 0.4\%$ and approaching $\pm 0.2\%$ with the increase in the size of the EEVBlog network.

The maximum values of the number of posts axis in the graphs shown in Figure 7.26 considered the network's member that made the most posts. As a result, the size and quality of the networks determine the axes of all graphs. This condition allows us to observe the displacement of the center of mass during the years of the study. The center of mass approached the fitted curve of the EEVBlog Forum network until 2017 and then moved away. It is a pattern also seen on the Arduino Forum network. This phenomenon occurred on dates close to the change in the variation in the value of k when this variation approached zero. In the EEVBlog Forum network, this happened when k went from values close to 25 to close to 30 in the transition year of 2017, as shown in Figure 7.19.

The existence of two periods with reduced values of annual variation of k in the EEVBlog Forum network could mean a rupture in the network that passes from one self-organization process to another. This process may have occurred due to changes in the functioning of the open network through, for example, changes in the themes and organization of the Forum, the entry of new elements that led to a change in the Forum's communication culture, or through requests for the external environmental context lacking communication technologies such as IoT, IIoT and the maturation of Cyber-Physical Systems.

7.8. Application of entropy in virtual environments

When virtual agents interact in open networks with humans, they can change the value of network/system entropy, as shown in Equation 33.

$$H(S) = \sum_i^n p_i \log_n p_i^{-1} \quad (33)$$

where

$$p_i = \frac{I_i}{I_T}$$

p_i is the probability of agent i interacting;

I_i is the number of interactions carried out by agent i ;

I_T is the total number of interactions carried out by all agents;

$H(S)$ is the normalized entropy generated in system S

n is the total number of agents in the system

However, achieving entropy is possible by employing Equation 34 and Equation 35.

$$H(S) = H(G_R) + \frac{I_R}{I_T} H(R) \quad (34)$$

$$H(S) = H(G_v) + \frac{I_V}{I_T} H(V) \quad (35)$$

where

$H(V)$ is the entropy generated by virtual agents (machines/artificial)

$H(R)$ is the entropy generated by (real) human agents

I_R total number of interactions carried out by human agents

I_V total number of interactions performed by virtual agents

$$H(R) = \sum_i^{n_r} \frac{I_i}{I_R} \log_n \frac{I_R}{I_i}$$

$$H(V) = \sum_i^{n_v} \frac{I_i}{I_V} \log_n \frac{I_V}{I_i}$$

where

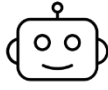
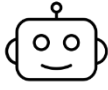
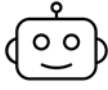
n_h is the number of human agents;

n_v is the number of virtual agents;

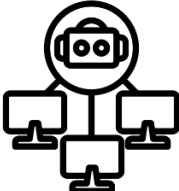
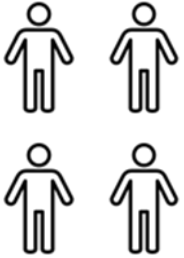
I_h is the total number of interactions carried out by human agents;

I_v is the total number of interactions carried out by virtual agents.

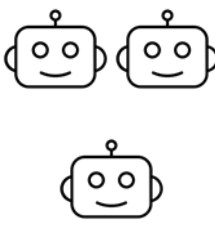
Figure 7.27 shows that the point of view of a system does not change the value of entropy. Changes the perception of the organization. When the elements of a set are brought together, they create a more ordered system without being less complex.

						
3	4	9	2	11	25	13
$H(S)$						

a)

					
		$H(R)$			
39	4	9	2	13	
$H(G_v)$					

b)

					
		$H(V)$			
28	3	11	25		
$H(G_h)$					

c)

Figure 7.27: The effect of recursion on entropy considering: **a)** the system S as a whole, **b)** virtual agents as a system within S, and **c)** human agents as a system within S.

The normalized entropy of the system, presented in Figure 7.27, and considering the previous equations, can be computed in three different ways:

- Consider each agent in the system as a distinct part of the system.

According to the computation presented in Annex 10.11, the system normalized entropy value is 0,855.

- b) Consider all virtual agents as a meta-agent and, recursively, each of these agents as a distinct part of the system.

According to the computation presented in Annex 10.11, the normalized entropy value remains at 0,855. However, the group of virtual agents has an entropy value of 0,604. There may be a perception that the entropy value drops when improving the ordering of elements. The system 's entropy only drops with the destruction/dissipation of the system itself, or by transferring entropy outside the system.

- c) Consider all human agents as a meta-agent and, recursively, each of these agents as a distinct part of the system.

According to the computation presented in Annex 10.11, the normalized entropy value remains at 0,855. However, the group of human agents has an entropy value of 0,600. The illusion caused by the creation of groups does not change the value of the total entropy of the system, as seen in situation b).

Another example is presented in Figure 7.28, which shows a system consisting of 3 human agents (real agents) and 1 virtual agent. Humans are part of a subsystem, called R (composed of “real” agents named as Ra, Rb, and Rc), while the virtual agent Va can interact to ensure a certain entropy value.

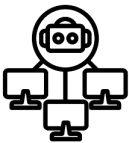
System				
	V _a	R _a	R _b	R _c
Interactions	?	2	4	8

Figure 7.28: System with three human agents (real agent) and one virtual agent.

Using the recursive property of entropy, it can be seen in Table 7.1, that the virtual agent participating in the system can increase or decrease the perceived value of entropy generated only by humans.

Table 7.1: The entropy of the interaction of real and virtual agents.

	Human Agents			Virtual Agent	Entropy		
	R_a	R_b	R_c	V_a	$H(R)^*$	$H(G_R)$	$H(S)$
Number of interactions	2	4	8	none	0.689	none	0.689
	2	4	8	10	0.689	0.490	0.892
	2	4	8	28	0.689	0.459	0.689
	2	4	8	100	0.689	0.269	0.353

* Considering only the interactions of human agents and entropy with the base-4 logarithm.

The virtual agent, in addition to the situation in which it does not participate in the network, can have a neutral behavior in entropy in the system. Considering the example shown in Figure 7.28 and the graph in Figure 7.29, the virtual agent has a neutral participation in relation to the total entropy of the system when it performs 28 interactions.

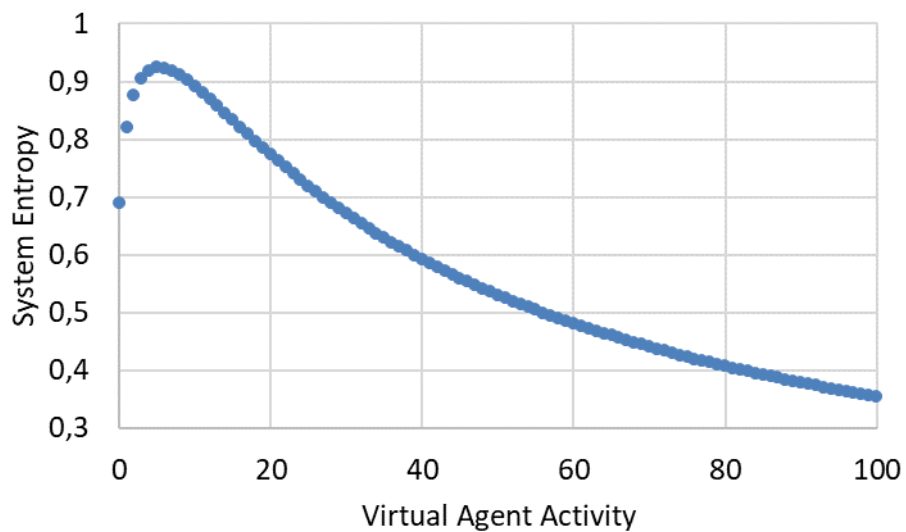


Figure 7.29: Influence of a virtual agent's activity on the entropy of a system composed with three human agents.

8. Conclusions and proposals for future work

This thesis studied some classic forms of organizational management, from the formalization of processes and Taylor's fascination with efficiency or through Fayol's hierarchical organization to Weber's sociological and bureaucratic interpretation. All models presented excellent results until the Great Depression of 1929. Until that moment, the purpose was to produce more, and the market would appear. This model did not prove to be sustainable. Just before this economic model showed its weaknesses, Mayo's work and Hawthorne experiments extended the purpose of incorporating humans into machine efficiency by creating an environment that motivated human participation in production competition. However, Parker Follett advocated other management models, viewing organizations as complex entities that benefited little from fierce competition processes.

At the same time that the Great Economic Depression emerged, in Physics, the theory of quantum mechanics emerged; in Mathematics, Whitehead proposed the philosophy of the process and the principles of what Shannon called information entropy. In the face of the crisis, these scientific advances changed how science understands systems and allowed changes in management thoughts.

Some mathematical models can adapt to classic management practices in organizations. These models include Minorski and the principles of hierarchy efficiency supported by Fayol's thoughts. However, these models require prior and well-determined knowledge of organizational objectives based on the assumption of rigid contexts and structures and a one-dimensional mechanistic reality.

Despite possible criticisms, formal models are relevant in describing organizations. The models, although compressed reality, allow decision-making. However, some information fades in the information compression process, such as through Shannon entropy. In these processes, small signals can quickly create disruptive situations, as seen by the Lorenz butterfly effect. In the face of uncertainty, decision-making processes in organizations must continue with criteria that can allow for a broad range of alternatives. Without alternative proposals, the decision-making process is a useless administrative act.

Organizations cannot overvalue social ethics over individual work in the decision-making process. Theory shows a greater probability of reaching a good decision if it is a collective process. However, this assumption is valid only if the members of the deciding network have similar intelligence. Whyte warned that creative designs follow individual goals or can emerge as collaborative efforts. Thus, organizations must simultaneously recognize the ability of their members to work individually and collectively, not disregarding anyone who, for example, is individualistic. true

Organizations try to find management principles to combat uncertainty (contingencies) and systemic approaches that highlight the need for organizations to learn, promoting feedback cycles that feed the organization's individual and collective cognitive systems.

Chaordic Thinking is one approach to dealing with organizational complexity. It encourages organizations to achieve new designs without pre-conceived paths or objectives. Chaordic Thinking requires collaborative tools that allow them to abandon old attractors. One of these tools is unlearning, which goes against the grain of the still dominant school models. Classical learning models comprise a deterministic teleology. While unlearning conceives a teleology based on cybernetics and the uncertainty of the network of probabilities.

Inequality is a natural physical reality. It is present in nature and allows systems to be resilient. So far, there is no indication that organizational systems with uniform distributions are sustainable. On the contrary, sociological, biological, semiotic, physical, and cybernetic models show extraordinarily unequal realities. This inequality is frequently referred to as exponential, often using the Gaussian distribution or power law, typically called Lorenz's law (economics) or Pareto's law (engineering), which further emphasizes the power of elites and the nature of inequality.

Organizations are composed of many egos that have different languages. Metaphors allow you to associate and unify different realities and enhance dialogue, sharing, and the creation of new learning opportunities.

Faced with complex environments, organizations must work in networks and try to imitate the complex environments that surround them. These mimicry processes can help them understand the context (internal, external, individual, collective) and also influence it. The networks need to be open for it to happen.

The existence of recursive components in organizations frequently described as holistic allows organizations to support complexity. These components may create the illusion that they contain information that is not very useful, but these elements describe extraordinarily complex patterns.

To grasp the context, organizations need a learning culture that views technology as a tool rather than a goal.

There are many ways to exercise governance in organizations. Faced with constantly changing contexts that create new challenges, organizations must enable adhocracy more frequently. However, following the expectations of technologies, organizations tend to prefer the scientific commitments of algocracy.

Technocentric organizations, when they improve the structures of technological systems, can fail if they disregard human creative systems, placing technology as an agent equal to humans. It is assumed that virtual agents can play the role of human agents in a generalized way. Despite mathematical validation, more interdisciplinary research is needed to understand the evolution of the boundaries and structures of complex organizational networks.

Diversity comprises various behaviors and cultures, allowing organizations more flexibility and agility to abandon an (old) attractor and create a new reality (with new behaviors). However, no organization can completely exclude borders or do away with hierarchical structures. Borders limit the “space” of the organization, allowing its hierarchical structures to have a degree of specialization among its members and maintain levels of efficiency that provide them with sustainability.

Normalized entropy in organizations evaluates the variables associated with an organization's members/agents, revealing the degree of inequality present in these variables (e.g., monetary income, productivity, participation, and effort). Normalized entropy in organizations evaluates the variables associated with the members/agents of an organization, revealing the degree of inequality present in these variables (e.g., monetary income, productivity, participation, and effort). Given that inequality appears to be a perennial characteristic, this thesis made a diachronic assessment of the evolution of the organizational context (external and internal) since the end of the 19th century. Sometimes, efficiency and specialization in organizational structures, per se, do not guarantee better performance.

The greater hierarchy efficiency in organizations (shown in Figure 3.6) requires high values for the span of control. However, these values are conditioned, among others:

Worker super-specialization leads to the formation of new knowledge clusters;

Shorter product design cycles;

Products with rapid obsolescence;

Globalization and the Internet have led to fierce competition in open markets.

To overcome these challenges, it will help:

Network structures that cover different areas of knowledge;

Collaborative structures and tools that promote greater sharing and flow of information;

Open organizational structures that mimic and combine with the context that surrounds them.

Self-organization emerges as a dynamic, collective, autonomous, spontaneous, and conscious process due to positive and negative feedback loops (communication, information, and learning) in which agents share the same language and interests and freely become members of (and recognize themselves as part of) a system, e.g., design and manufacturing network.

The open-design organization is a complex network with the capacity for self-organization and, consequently, a greater capacity for creating novelty than organizations with classical and bureaucratic management.

Analysis of Arduino and EEVBlog member networks corroborates the normalized entropy constraints when organizations reach maturity. Self-organization maintains equilibrium in the network despite a high rate of member replacement and a high influx of new members. The tiny variation in entropy values between 2016 and 2022 in the Arduino network and between 2010 and 2022 in the EEVBlog network establishes this. Open-design networks create “strange” structures of network organization that self-replicate without any perceived control. It suggests that when there is no entropy convergence, any self-organizing system becomes counterproductive to the networks of design and manufacturing systems. Despite the high volatility of the members of an open network, the new members that emerge re-establish the pattern of network structure, demonstrating Hypothesis 1.

Although the activities of the members of the open networks Arduino and EEVBlog do not follow a pure power-law distribution, e.g., truncated power law distribution, throughout the network hierarchy, there are signs of self-organization in the networks, i.e., manifested through the k -value. In the Arduino network, the k value stabilized in the period between 2016 and 2022 at a value close to 25, while in the case of the EEVBlog network's k -values present two periods of stability, between 2010 and 2016, with a value close to 25 and between 2018 and 2022, with a value close to 30, see the diagrams of k in Figure 7.18, Figure 7.19, and Figure 7.23 which confirms the Hypothesis 2.

One of the most important conclusions is related to the high sensitivity of the open network behavior, which could be verified by the variation of parameters a and k , implying the possibility of control and optimization of the open design and manufacturing networks, opposing the idea that “open, overlapping and polycentric networks cannot be optimized because there can be no aligned business objectives, no common agenda, and after all, no closed solution space” (Váncza et al., 2011).

In general, in complex networks, there are a large number of agents and interactions/activities. Thus, it is not unlikely that complex open networks will create and self-organize sustaining clusters of clusters,

and systems within systems, revealing polycentric networks that suggest holonic structures. The results focused on the number of agents and the relationships of their interactions. Thus, in future studies, open networks should be qualitatively investigated to recognize the communication patterns between the holons that make up these organizations.

As mentioned earlier complex networks are systems within systems, representing a holonic structure, where agents can be networks as parts of networks. An example is the Arduino design development network (hardware and software). The network is decentralized, containing several networks, simultaneously, working for the same project, and agents can intervene simultaneously in the (different) networks assuming different roles (developer, user, maker, contributor, author, committer, ...). This feature gives members of open networks the possibility of ubiquity and fairness (being everywhere at once, contributing as much as they want).

The Equation 32 formed by the difference of two pseudo-law functions of power presents enormous variations in the state of the network around the center of mass, that is, subtle variations in the composition of the organizational structure can cause a huge distortion in the organization (positive or negative). In both cases, on the networks of the Arduino forum and the EEVBlog forum, the organization exists on the threshold of instability/chaos. However, the stability of entropy values in the two organizations has slightly different values. This, in addition to inducing the possibility of the existence of a process of self-organization in open networks that ensures the balance and inherent sustainability of their structures, suggests that there is an infinity of viable structures. This means that a model of self-organization feasible in one open network may be completely destructive and unfeasible in another. Although the process of self-organization is internal, it depends on the quantity and quality of flows (agents, activities, interactions, energy, information, resources, ...) between the internal and external context of the organization. These flows were partially studied (about the agents) but, taking advantage of the results obtained, it is possible to investigate the implications in the connections of different flows in the process of self-organization in complex networks.

During the analysis of the participation of members of the Arduino Forum network, a user called System emerged. It is a bot. Although it affects the fit of any distribution, it reinforces confidence in the results. As expected, the bot system artificially decreases the network's entropy and creates conditions for more robust self-organization. The managers of the Arduino Forum network do not want self-organization as a goal. They use it as a means of sustainability of an open design network.

If an agent can create conditions to get the self-organization process, it can also boost the rejection of the self-organization state. Any intervention in an open organization depends on uncertain variables related to the organization's contexts (internal and external), which determine the culture, forms of learning, structures, or relationships (between the different parts - physical/virtual, individual/social, machines/humans). Thus, any intervention in an open organization to enhance self-organization must generate new (unique) structures. If the intention is not to create new and adapt to an always different context, self-organization is not distinctive, so *nomen est omen* does not make sense.

During self-organization emergence, facilitators and controllers may emerge that favor a context that enhances self-organization. The instruments of the engineering process include facilitators such as human resources and other elements of manufacturing and organization (Roucoules & Anwer, 2021). One of the main instruments of control could be the introduction of virtual agents in networks (towards the policies of digitalization, virtualization, and autonomy in Industry 4.0).

The results presented in this thesis may appear in future work, such as incorporating virtual agents in organizations that improve (optimize) and control the establishment of self-organized structures. Furthermore, research can expand to find other parameters that define the self-organization process, stimulating actions that increase agility, flexibility, and adaptability and face the growing instability in the environment of production systems. Identifying these instruments and parameters would enable effective and efficient design and implementation of future design and manufacturing systems based on open large and complex networks.

This thesis drives several opportunities for future research:

- Study the effect of introducing virtual agents on self-organization in all or just some parts of the organization.
- Improve the model that results in Equation 32, checking whether there are alternatives for the center of mass in the partition of complex network hierarchies.
- Relate Equation 15, Equation 18, Equation 27, and Equation 32 to understand the link between the efficiencies of classical organization hierarchies and open network organizational structures and understand the differences in entropy change and inequality that can exceedingly enable large closed organizations relationships can create relationships that are on the threshold of self-organization.
- Identify and qualify the internal and external contexts that condition (positively or negatively) the existence of self-organization in open organizational structures by analyzing resource flows

and agent behavior. Such a model will not rely on such a large amount of data over a long time to observe whether a system is prone to self-organization.

9. References

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10. Annexes

10.1. Country of origin for Arduino GitHub members, release 5640

Country	
USA	72
Germany	27
Italy	21
United Kingdom	21
France	11
Canada	8
Netherlands	7
Sweden	7
Belgium	6
Czech Republic	6
Denmark	6
India	6
Australia	5
Brazil	5
China	5
Japan	5
Spain	5
Norway	4
Switzerland	4
Estonia	3
Finland	2
Argentina	1
Austria	1
Bulgaria	1
Chile	1
Egypt	1
Indonesia	1
Ireland	1
Israel	1
Mexico	1
Portugal	1
Russia	1
Slovakia	1
South Africa	1
Thailand	1
Vietnam	1
Latvia	1
Total	252

Latitude	Longitude
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56.946285	24.105078
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55.75696945	37.61502075
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55.67024900	10.33332830
55.604981	13.003822
55.600147	13.013337
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54.913811	9.792178
54.906869	-1.383801
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53.40547190	-2.98053930
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52.95497710	-1.15110660
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52.489471	-1.898575
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51.73433130	0.46908880
51.5429715	-1.7714294

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42.88645	-78.87837
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40.73059910	-73.98658120
40.7241971032	-73.9895960416
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40.65010380	-73.94958230
40.62886700	-74.13201790
40.55085270	-105.06680850
40.44169410	-79.99008610
40.440624	-79.995888
40.416775	-3.703790
40.41670470	-3.70358250
40.343899	-74.660049
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40.296898	-111.694649
40.07573840	-74.40416220
40.014984	-105.270546
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39.916668	116.383331
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39.613319	-105.016647
39.29086080	-76.61080730
39.203714	-76.861046
39.1974437	-96.5847249
39.047409	-77.495762
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38.50928920	-76.67968410
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38.19375710	15.55420820
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37.95135750	-91.77179200
37.77927680	-122.41927040
37.77492950	-122.41941550
37.733795	-122.446747
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37.38747400	-122.05754340
37.36883010	-122.03634960
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35.69797400	139.73924870
35.65713670	-97.46490380
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33.75891880	-84.36408290
32.78760120	-79.94027280
32.77627190	-96.79685590
31.894756	34.809322
31.22534410	121.48889220
31.224361	121.469170
31.037933	31.381523
30.27112860	-97.74369950
30.26758957	-97.74298859
29.70261730	-98.12562630
28.61389670	77.21595620
28.13100052	-15.44359970
27.66482740	-81.51575350
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22.54309600	114.05786500
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-15.793889	-47.882778
48.402880	11.741185
-35.2381609	149.0840869

10.2. Table with data from the Arduino Forum network, by year.

Year	2005	2006	2007	2008	2009	2010
N_users	14	61	143	372	791	1496
New Users	14	51	114	291	578	1039
Nodes	13	51	121	305	640	1200
Edges	14	81	185	614	1524	3031
Rate new users	1	0,836	0,797	0,782	0,731	0,695
N_posts	441	4989	14598	40973	108505	194535
Posts per user	31,5	81,8	102,1	110,1	137,2	130,0
Entropy	0,526	0,370	0,294	0,347	0,345	0,381
X_center_mass	12,9	58,7	139,6	363,2	771,2	1457,6
Y_center_mass	155,4	2262,9	7562,2	16445,7	44681,2	66131,2
cm_entropy_sup	0,393	0,240	0,178	0,180	0,179	0,171
cm_entropy_inf	0,254	0,199	0,161	0,171	0,175	0,170
cm_ratio_users	0,857	0,951	0,972	0,976	0,975	0,974
lim_max_cm_users	13	59	140	364	772	1458
lim_min_cm_users	12	58	139	363	771	1457
cm_ratio_posts	0,181	0,159	0,138	0,155	0,159	0,154
lim_max_cm_posts	228	1088	2324	6857	17750	30418
lim_min_cm_posts	80	794	2014	6369	17302	29997

Year	2011	2012	2013	2014	2015	2016
N_users	2464	4093	6421	9348	30859	40910
New Users	1604	2604	3885	5670	24136	31847
Nodes	2171	3641	5591	8109	25677	34668
Edges	7943	14908	22407	28942	67677	81967
Rate new users	0,651	0,636	0,605	0,607	0,782	0,778
N_posts	333530	467351	554838	578917	640277	651019
Posts per user	135,4	114,2	86,4	61,9	20,7	15,9
Entropy	0,469	0,499	0,528	0,556	0,682	0,713
X_center_mass	2389,7	3960,7	6192,5	8982,3	28966,2	38120,5
Y_center_mass	66907,7	78714,4	74934,5	58157,5	10310,7	5832,9
cm_entropy_sup	0,189	0,188	0,187	0,188	0,238	0,254
cm_entropy_inf	0,188	0,187	0,186	0,187	0,235	0,248
cm_ratio_users	0,97	0,968	0,964	0,961	0,937	0,928
lim_max_cm_users	2390	3961	6195	8987	29006	38167
lim_min_cm_users	2389	3960	6192	8982	28930	37965
cm_ratio_posts	0,174	0,172	0,169	0,168	0,214	0,226
lim_max_cm_posts	58549	80763	94307	97660	139085	151215
lim_min_cm_posts	58139	80429	93662	97075	137033	147175

Year	2017	2018	2019	2020	2021	2022
N_users	41401	38147	37191	35518	26309	18093
New Users	33086	30160	29183	27503	19937	13590
Nodes	35280	33332	32317	30689	23749	16354
Edges	79324	75953	71896	69930	65455	54534
Rate new users	0,799	0,791	0,785	0,774	0,758	0,751
N_posts	603660	577966	538074	535026	527768	410199
Posts per user	14,6	15,2	14,5	15,1	20,1	22,7
Entropy	0,713	0,706	0,706	0,713	0,707	0,696
X_center_mass	38508,3	35563,0	34701,0	33053,9	24463,4	16839,3
Y_center_mass	5815,3	5394,4	4996,9	4426,3	4116,7	3699,3
cm_entropy_sup	0,257	0,255	0,253	0,259	0,252	0,250
cm_entropy_inf	0,251	0,250	0,248	0,253	0,247	0,246
cm_ratio_users	0,925	0,931	0,931	0,929	0,927	0,929
lim_max_cm_users	38540	35668	34776	33144	24499	16860
lim_min_cm_users	38315	35510	34612	32983	24397	16808
cm_ratio_posts	0,229	0,228	0,226	0,231	0,224	0,223
lim_max_cm_posts	142125	134897	124466	126603	120675	92860
lim_min_cm_posts	138075	131895	121514	123544	118329	91456

10.3. Table with data from the Arduino Forum network, by year, without bot system.

Year	2005	2006	2007	2008	2009	2010
N_users	13	60	142	371	790	1495
New Users	13	51	114	291	578	1039
Nodes	13	51	121	305	640	1200
Edges	14	81	185	614	1524	3031
Rate new users	1	0,850	0,803	0,784	0,732	0,695
N_posts	228	1706	4219	15303	39266	81746
Posts per user	17,5	28,4	29,7	41,2	49,7	54,7
Entropy	0,525	0,627	0,598	0,631	0,684	0,686
X_center_mass	11,9	54,4	131,4	348,3	736,4	1404,6
Y_center_mass	101,5	298,7	631,1	974,8	1376,6	1754,3
cm_entropy_sup	0,415	0,348	0,285	0,254	0,273	0,248
cm_entropy_inf	0,323	0,322	0,264	0,249	0,270	0,247
cm_ratio_users	0,846	0,900	0,915	0,938	0,932	0,939
lim_max_cm_users	12	55	132	349	737	1405
lim_min_cm_users	11	54	130	348	736	1404
cm_ratio_posts	0,246	0,272	0,222	0,221	0,250	0,226
lim_max_cm_posts	80	518	1029	3478	9922	18604
lim_min_cm_posts	56	464	935	3386	9798	18478

Year	2011	2012	2013	2014	2015	2016
N_users	2463	4092	6420	9347	30858	40909
New Users	1604	2604	3885	5670	24136	31847
Nodes	2171	3641	5591	8109	25677	34668
Edges	7943	14908	22407	28942	67677	81967
Rate new users	0,651	0,636	0,605	0,607	0,782	0,778
N_posts	185890	277540	353151	398452	574447	620655
Posts per user	75,5	67,8	55,0	42,6	18,6	15,2
Entropy	0,684	0,703	0,713	0,709	0,724	0,729
X_center_mass	2330,7	3870,1	6062,0	8816,6	28749,2	37984,1
Y_center_mass	2787,2	2734,7	2545,1	2763,4	3948,3	4632,8
cm_entropy_sup	0,243	0,237	0,230	0,227	0,256	0,265
cm_entropy_inf	0,242	0,235	0,229	0,227	0,252	0,259
cm_ratio_users	0,946	0,946	0,944	0,943	0,932	0,928
lim_max_cm_users	2331	3874	6064	8820	28847	38167
lim_min_cm_users	2330	3870	6061	8815	28748	37965
cm_ratio_posts	0,226	0,218	0,210	0,206	0,230	0,237
lim_max_cm_posts	42208	61136	74526	82426	134875	151215
lim_min_cm_posts	42008	60488	74190	82061	132400	147175

Year	2017	2018	2019	2020	2021	2022
N_users	41400	38146	37190	35517	26308	18092
New Users	33086	30160	29183	27503	19937	13590
Nodes	35280	33332	32317	30689	23749	16354
Edges	79324	75953	71896	69930	65455	54534
Rate new users	0,799	0,791	0,785	0,774	0,758	0,751
N_posts	578146	554297	517196	528152	521929	409874
Posts per user	14,0	14,5	13,9	14,9	19,8	22,7
Entropy	0,727	0,720	0,719	0,716	0,709	0,696
X_center_mass	38380,7	35452,7	34600,5	33021,8	24442,7	16837,8
Y_center_mass	4946,0	4614,1	4355,8	4394,5	4097,5	3702,0
cm_entropy_sup	0,268	0,260	0,257	0,262	0,254	0,250
cm_entropy_inf	0,261	0,255	0,252	0,256	0,250	0,247
cm_ratio_users	0,925	0,926	0,926	0,929	0,927	0,929
lim_max_cm_users	38540	35510	34612	33144	24499	16860
lim_min_cm_users	38315	35340	34443	32983	24397	16808
cm_ratio_posts	0,239	0,232	0,229	0,234	0,227	0,223
lim_max_cm_posts	142125	131895	121514	126603	120675	92860
lim_min_cm_posts	138075	128835	118641	123544	118329	91456

10.4. Table with data from the EEVBlog Forum network, by year.

Year	2009	2010	2011	2012	2013	2014	2015
N_users	96	987	1639	3052	6043	7729	8679
New Users	96	930	1265	2282	4442	4977	5160
Nodes	53	639	1131	2063	3988	5288	6013
Edges	103	3161	6936	13628	28345	38724	45988
Rate new users	1,000	0,942	0,772	0,748	0,735	0,644	0,595
N_posts	1170	30009	58127	108245	203789	249174	291803
Posts per user	12,2	30,4	35,5	35,5	33,7	32,2	33,6
Entropy	0,788	0,708	0,731	0,748	0,768	0,775	0,770
X_center_mass	83,0	918,2	1524,9	2837,9	5611,5	7187,6	8111,3
Y_center_mass	70,1	694,0	812,4	1006,6	1154,5	1118,2	1184,1
cm_entropy_sup	0,428	0,279	0,279	0,272	0,270	0,265	0,262
cm_entropy_inf	0,388	0,274	0,277	0,271	0,267	0,265	0,260
cm_ratio_users	0,865	0,930	0,929	0,930	0,928	0,930	0,934
lim_max_cm_users	85	920	1525	2838	5612	7188	8116
lim_min_cm_users	83	918	1523	2837	5605	7187	8108
cm_ratio_posts	0,359	0,254	0,261	0,254	0,250	0,249	0,245
lim_max_cm_posts	478	7779	15340	27598	51517	62061	72287
lim_min_cm_posts	420	7617	15156	27512	50957	61984	71599

Year	2016	2017	2018	2019	2020	2021	2022
N_users	9195	9802	9916	9850	10042	10074	9154
New Users	5116	5399	5115	4833	4981	4665	4107
Nodes	6308	6188	6082	5844	5997	5777	5352
Edges	47248	47283	44472	39101	38100	32976	30607
Rate new users	0,556	0,551	0,516	0,491	0,496	0,463	0,449
N_posts	307237	325720	338190	320714	329588	294728	273967
Posts per user	33,4	33,2	34,1	32,6	32,8	29,3	29,9
Entropy	0,773	0,764	0,750	0,744	0,742	0,738	0,738
X_center_mass	8575,1	9187,4	9340,7	9287,5	9469,8	9498,5	8634,9
Y_center_mass	1242,4	1309,3	1504,3	1521,0	1622,5	1547,5	1407,0
cm_entropy_sup	0,263	0,259	0,250	0,245	0,243	0,240	0,238
cm_entropy_inf	0,262	0,258	0,248	0,244	0,242	0,239	0,236
cm_ratio_users	0,932	0,937	0,942	0,943	0,943	0,943	0,943
lim_max_cm_users	8576	9193	9347	9289	9473	9501	8635
lim_min_cm_users	8572	9187	9339	9285	9468	9496	8629
cm_ratio_posts	0,246	0,244	0,234	0,229	0,227	0,222	0,219
lim_max_cm_posts	76033	79880	79901	73818	75091	65642	60320
lim_min_cm_posts	75697	79334	79165	73482	74671	65307	59906

10.5. Table of a and k coefficients of power law curve regression ax^k for the Arduino Forum network

Year	$a_{low\ layer}$	$k_{low\ layer}$	$a_{high\ layer}$	$k_{high\ layer}$	a_{total}	k_{total}
2005	193,2	1,828	213,0	0,525	225,6	1,413
2006	2336,9	1,960	3283,0	2,412	3279,2	2,326
2007	4955,8	1,785	10378,2	2,815	10372,5	2,761
2008	15232,1	1,582	25627,4	2,902	25620,9	2,879
2009	25024,6	1,344	69184,3	3,490	69184,0	3,489
2010	63305,2	1,378	112728,7	3,723	112728,7	3,723
2011	148266,6	1,360	147471,4	3,597	147471,4	3,597
2012	256990,8	1,365	189662,1	3,759	189662,1	3,759
2013	237884,4	1,302	201547,5	3,845	201547,5	3,845
2014	130145,6	1,192	180194,1	3,316	180194,1	3,316
2015	96869,0	1,071	59475,7	1,116	59439,5	1,114
2016	113420,0	1,073	30158,5	0,775	30482,7	0,787
2017	97632,6	1,062	27939,9	0,765	28247,7	0,777
2018	74115,0	1,041	26143,7	0,750	26517,9	0,766
2019	67094,0	1,039	23225,4	0,736	23615,3	0,754
2020	77827,8	1,052	18136,8	0,675	18653,6	0,702
2021	53677,5	1,016	18480,8	0,665	19085,1	0,696
2022	45091,7	1,027	16835,6	0,672	17389,8	0,707

10.6. Table of a and k coefficients of power law curve regression ax^k for the Arduino Forum network, without user *system*.

Year	$a_{low\ layer}$	$k_{low\ layer}$	$a_{high\ layer}$	$k_{high\ layer}$	a_{total}	k_{total}
2005	189,6	2,064	148,0	2,625	147,2	2,207
2006	579,9	1,340	623,7	1,314	625,4	1,340
2007	1249,8	1,319	1443,4	1,393	1442,1	1,387
2008	8061,6	1,423	2834,5	0,893	2922,2	0,979
2009	50818,9	1,500	5122,9	0,857	5241,0	0,905
2010	85657,5	1,438	7279,5	0,729	7641,7	0,806
2011	317013,0	1,494	11443,1	0,628	12319,0	0,725
2012	359925,1	1,419	13363,0	0,617	14453,5	0,705
2013	245338,0	1,306	13771,6	0,606	14909,7	0,686
2014	145713,9	1,207	15705,6	0,638	16706,6	0,700
2015	110560,2	1,086	19013,7	0,678	19617,8	0,708
2016	113335,7	1,073	19698,4	0,684	20224,4	0,709
2017	97492,5	1,062	20955,1	0,713	21363,4	0,732
2018	83840,4	1,054	19831,5	0,700	20282,2	0,723
2019	75128,2	1,051	17582,6	0,685	18038,9	0,710
2020	77737,1	1,052	17962,1	0,678	18462,6	0,705
2021	53619,9	1,016	18382,4	0,667	18970,8	0,698
2022	44994,5	1,027	16836,3	0,672	17389,8	0,707

10.7. Table of a and k coefficients of power law curve regression fit ax^k for the EEVBlog Forum network

Year	$a_{low\ layer}$	$k_{low\ layer}$	$a_{high\ layer}$	$k_{high\ layer}$	a_{total}	k_{total}
2009	2296,8	1,677	152,9	0,626	166,0	0,791
2010	62434,4	1,566	2561,8	0,685	2718,8	0,778
2011	183474,5	1,579	3536,2	0,640	3798,5	0,730
2012	228190,6	1,463	5215,0	0,645	5579,7	0,720
2013	734012,0	1,496	6759,2	0,622	7280,6	0,690
2014	999059,6	1,498	5997,7	0,562	6660,2	0,645
2015	1624889,2	1,542	6364,4	0,544	7181,5	0,635
2016	1446303,8	1,512	6684,6	0,549	7467,4	0,634
2017	1898332,9	1,545	6785,5	0,534	7642,4	0,625
2018	1656583,6	1,533	8506,9	0,566	9418,3	0,650
2019	1174812,6	1,499	8156,0	0,561	9034,7	0,647
2020	1018734,9	1,477	9494,8	0,593	10350,4	0,668
2021	531384,0	1,407	8624,7	0,593	9406,3	0,669
2022	535354,5	1,426	6848,8	0,545	7677,3	0,640

10.8. a and k values from the Arduino Forum network behavior model

Year	a	$\pm a_{err}$	k	$\pm k_{err}$
2005	0,013	0,003	4,67	1,047
2006	0,001	0	4,793	1,096
2007	0	0	10,823	2,1
2008	0	0	15,323	2,558
2009	0	0	17,759	2,512
2010	0,02	0,016	39,92	4,532
2011	0,002	0,001	23,372	2,47
2012	0,356	0,364	39,92	3,836
2013	2,079	2,408	39,92	3,713
2014	16,435	22,128	39,92	3,735
2015	5462,248	684,605	29,143	0,254
2016	7347,586	346,14	24,824	0,124
2017	7619,909	309,754	24,005	0,115
2018	7230,443	288,333	24,837	0,118
2019	7473,295	245,708	25,075	0,109
2020	6443,368	150,599	23,591	0,086
2021	3614,579	108,006	23,05	0,088
2022	2376,504	95,14	23,556	0,104

10.9. a and k values from the Arduino Forum network behavior model, without user *system*.

Year	a	±a_err	k	±k_err
2005	0,02	0,004	4,407	0,807
2006	0,006	0,001	3,172	0,633
2007	0,013	0,005	7,296	1,186
2008	0,016	0,005	9,76	0,941
2009	0,025	0,011	9,775	0,977
2010	62,11	15,359	27,462	0,559
2011	0,044	0,01	13,09	0,565
2012	220,812	16,801	30,48	0,178
2013	654,785	20,869	30,204	0,082
2014	1101,782	45,838	29,88	0,108
2015	5038,664	164,823	24,255	0,097
2016	6962,183	177,354	22,879	0,085
2017	7265,925	226,849	22,555	0,097
2018	6929,167	203,496	23,355	0,097
2019	7192,664	146,743	23,521	0,081
2020	6378,404	158,031	23,288	0,089
2021	3596,664	109,562	22,783	0,089
2022	2379,165	95,365	23,546	0,105

10.10. a and k values from the EEVblog Forum network behavior model

Year	a	$\pm a_{err}$	k	$\pm k_{err}$
2009	5,06	3,235	9,07	1,043
2010	188,469	12,146	25,047	0,175
2011	292,031	11,603	24,691	0,107
2012	517,068	18,112	24,271	0,092
2013	941,327	28,01	23,297	0,081
2014	1164,271	18,142	23,048	0,056
2015	1373,265	23,21	24,977	0,064
2016	1439,831	18,906	23,936	0,053
2017	1667,583	19,277	25,77	0,059
2018	1878,095	24,621	28,826	0,06
2019	1972,86	22,643	29,211	0,06
2020	1946,029	29,328	29,679	0,065
2021	2044,448	33,582	29,715	0,071
2022	1820,919	22,605	29,319	0,066

10.11. The effect of recursion on entropy

Case a)

$$\begin{aligned} H(S) &= \frac{1}{I_T} \sum_i^n I_i \log_n \frac{I_T}{I_i} = \frac{1}{67} \sum_i^7 I_i \log_7 \frac{67}{I_i} = \\ &= \frac{1}{67} \left(3 \log_7 \frac{67}{3} + 4 \log_7 \frac{67}{4} + 9 \log_7 \frac{67}{9} + 2 \log_7 \frac{67}{2} + 11 \log_7 \frac{67}{11} + 25 \log_7 \frac{67}{25} + 13 \log_7 \frac{67}{13} \right) \\ H(S) &= 0,855 \end{aligned}$$

Case b)

$$\begin{aligned} H(G_v) &= \frac{1}{I_T} \sum_i^{n_{gv}} I_i \log_n \frac{I_T}{I_i} = \\ \frac{1}{67} \left(39 \log_7 \frac{67}{39} + 3 \log_7 \frac{67}{3} + 11 \log_7 \frac{67}{11} + 25 \log_7 \frac{67}{25} \right) &= 0,604 \end{aligned}$$

$$\begin{aligned} H(V) &= \frac{1}{I_V} \sum_i^{n_v} I_i \log_n \frac{I_V}{I_i} = \\ = \frac{1}{39} \left(3 \log_7 \frac{39}{3} + 11 \log_7 \frac{39}{11} + 25 \log_7 \frac{39}{25} \right) &= 0,431 \end{aligned}$$

$$H(S) = H(G_v) + \frac{I_V}{I_T} H(V) = 0,604 + \frac{39}{67} \times 0,431 = 0,855$$

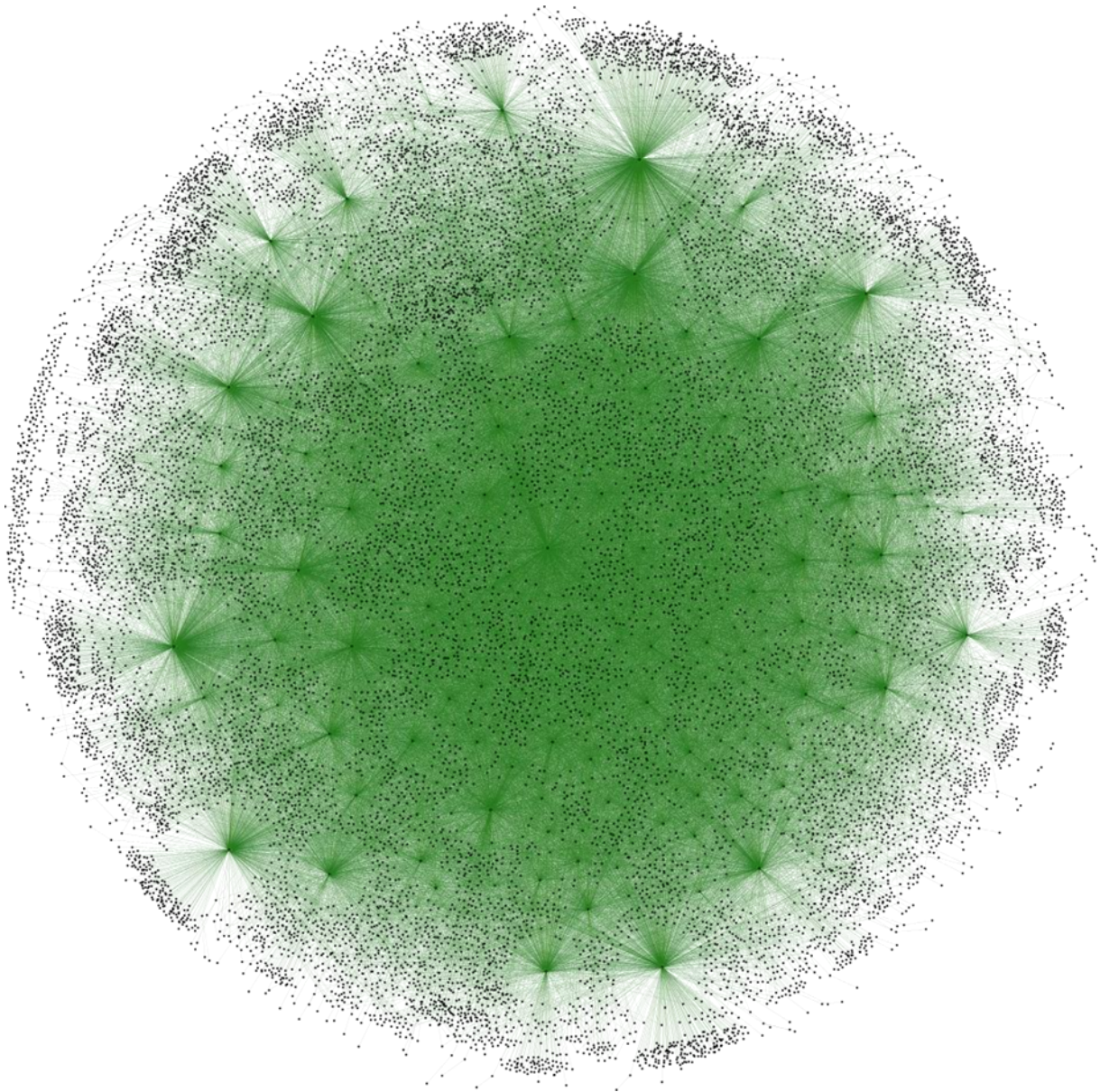
Case c)

$$\begin{aligned} H(G_R) &= \frac{1}{I_T} \sum_i^{n_{gr}} I_i \log_n \frac{I_T}{I_i} = \\ \frac{1}{67} \left(28 \log_7 \frac{67}{28} + 4 \log_7 \frac{67}{4} + 9 \log_7 \frac{67}{9} + 2 \log_7 \frac{67}{2} + 13 \log_7 \frac{67}{13} \right) &= 0,600 \end{aligned}$$

$$\begin{aligned}
H(R) &= \frac{1}{I_R} \sum_i^{n_r} I_i \log_n \frac{I_R}{I_i} = \\
&= \frac{1}{28} \left(4 \log_7 \frac{28}{4} + 9 \log_7 \frac{28}{9} + 2 \log_7 \frac{28}{2} + 13 \log_7 \frac{28}{13} \right) = 0,610
\end{aligned}$$

$$H(S) = H(G_R) + \frac{I_R}{I_T} H(R) = 0,600 + \frac{28}{67} \times 0,610 = 0,855$$

10.12. Arduino Forum Network in the year 2022.



10.13. EEVBlog Forum Network in the year 2022.

