FRACTAL THEORY IN MANAGEMENT SCIENCE: TOWARDS FRACTAL-BASED MANAGEMENT

Jan Kalina

Abstract

Fractal phenomena, studied extensively in natural and social sciences, offer valuable insights for management science by revealing patterns and structures observable in organizational systems. Organizations today face transformative shifts driven by the digital economy and advances in artificial intelligence, challenging traditional management theories and highlighting the need for approaches that accommodate dynamic, self-regulating systems. This paper examines how fractal concepts can inform management practices, emphasizing their relevance for understanding complex, adaptive organizations. It outlines the fundamentals of fractals in natural and social sciences, describes the characteristics of fractal organizations, and offers practical recommendations for managers. By integrating fractal theory with cybernetic principles, the paper proposes a framework that helps managers navigate complexity, identify emergent patterns, and make adaptive decisions in evolving organizational environments. This approach underscores the potential of fractal-based thinking to enhance organizational resilience, improve decision-making, and provide a structured lens for addressing the challenges of increasingly interconnected and adaptive systems.

Key words: management science, entropy, fractal organization, political science

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Introduction

Fractal phenomena, explored both theoretically in fractal theory and practically in natural and social sciences, offer valuable insights for management science. The properties of fractals observed in these fields can also be seen in certain organizational structures and systems (Faghih, 2023). Given this, it is logical to consider whether management methods should adapt to these changes in organizations worldwide, especially from a cybernetic perspective as discussed in Peralta and Soltero (2020).

Our society is experiencing profound shifts following the rise of the digital economy, and advancements in artificial intelligence. These changes have significantly impacted various fields, leading to an unstable economy that is increasingly described as fractalized, challenging earlier concepts like general equilibrium (Gonchar, 2023). Additionally, we can perceive an increasing need for a cybernetic approach to management, which emphasizes the dynamic, self-regulating aspects of complex systems (Gosnell et al., 2020). This perspective can help in understanding and navigating the evolving landscape of organizational management in a fractalized world and in the society in an identity crisis.

The aim here is to recall fractals as inspirational concepts for management science and to discuss managerial practice in the context of fractal organizations. We are inspired by recent advances of information-theoretical tools proposed as tailor-made tools for managerial decision making (Kalina, 2014). Section 2 is devoted to fractals in natural and social sciences. Section 3 describes a fractal organization and Section 4 brings examples of more complex fractal systems of organizations. Section 5 is devoted to fractal (fractal-based) management and practical recommendations for managers in the context of fractal organizations.

1 Fractals as a concept in science and society

Fractals are patterns that repeat at different scales, demonstrating self-similarity across dimensions. Attractors are states or behaviors toward which systems naturally tend. In the natural sciences, fractal theory has been used to describe patterns observed in nature, from the branching of trees to the shapes of coastlines. While there is ongoing debate about whether natural phenomena are fully deterministic, random, or a combination of both, fractals remain a key concept, showing how order can emerge from apparent chaos (Fouraharfar, 2020). Although not all phenomena are fractal-based, fractal theory provides valuable insights into the underlying structure and complexity of natural systems. Also cells in living organisms are very complex life elements able to accomplish basic life processes that are characteristic for the organism as a whole; cells follow the same rules as non-living particles to form fractal-like branching structures.

The concept of fractals, stemming from natural sciences, now extends to social sciences as well as economics. The evolving nature of the society defies the traditional law of conservation of entropy, leading to increased complexity and instability, especially after the COVID-19 pandemic. Historical events such as the political and economic transformations in Eastern Europe after 1989 illustrate the fractal structure of history, where periods of upheaval are followed by new orders and reorganizations (Faghih, 2023).

In economics, fractal properties illustrate the unpredictable, nonlinear and uneven development of markets (Gonchar, 2023). Unlike neoclassical economics, which assumes linear input-output relationships, real-world financial markets display irregularities and instability. Classical models fail to capture these complexities, as economic systems often show fractal-like patterns similar to weather systems (Li and Li, 2024). Economic trends act as attractors, representing long-term stability, while short-term market behaviors are chaotic, fluctuating around these stable trends. This fractal-like behavior is evident across various scales, from individual businesses to global economies, blending both stability and volatility in a manner akin to weather and climate dynamics.

2 Fractal organization

In recent years, the concept of a fractal structure in organizations, such as companies or government offices, has been more specifically defined. This structure, often referred to as a fractal organization (Faghih, 2023), a fractal company (Peralta and Soltero, 2020), or a fractal-inspired organization, emphasizes the application of fractal principles in management. Despite growing interest, the literature has given limited attention to how these principles can be applied to various management tasks, including risk and knowledge management.

Fractal organizations are understood as nonlinear dynamic systems, inherently characterized by fractal properties. For instance, Fouraharfar (2020) discussed the philosophical aspects of fractal organizations and suggested that power structures within these organizations, such as those of managers or politicians, can also be interpreted through a fractal lens. According to the fractal paradigm, organizations exhibit several fractal-like properties, including self-organization, self-similarity, persistence of similarity, symmetrical expansion, and the presence of continuous control processes.

Hoverstadt (2009) was among the first to present a systematic approach to designing fractal organizations, focusing on universal principles for sustainable management and outlining strategies to transition organizational structures toward fractal patterns. More recent studies, such as Fuhao and Qiuhong (2023), compared fractal and traditional structures in emergency organizations and found fractal designs to be more effective. Faghih (2023) examined the employee-organization relationship (EOR) and proposed practical ideas for improvement, arguing that fractal structures naturally satisfy EOR principles developed over the past two decades. Collectively, these works demonstrate the growing recognition of fractal

principles as a practical and adaptable framework for modern organizational design, highlighting their potential to enhance efficiency, resilience, and responsiveness in complex environments.

Fractal-structured organizations are characterized by a decentralized approach maintaining a hierarchical framework. Interestingly, smaller firms often manage more effectively than larger ones. However, decentralization alone is not the sole key to success. A hierarchical structure can still be highly centralized, as exemplified by organizations such as the church or the mafia. While hierarchical and matrix structures are well-established concepts in classical management theory, the idea of fractal-inspired organization is relatively novel. Fractal organizations are inspired by natural patterns and exhibit self-similarity across various levels of the system. In such structures, decision-making is decentralized, occurring at lower levels where departments function as microcosms or 'states within a state.' This fractal approach can be advantageous, particularly for large companies aiming to achieve sustainable growth. Management science has started to describe these patterns after they have begun to take shape. Managers may disrupt existing patterns, allowing new and more efficient ones to develop organically. These new patterns often arise from chaotic conditions, illustrating how order can spontaneously emerge from disorder.

Fractal structures offer significant advantages over centralized ones, particularly in scaling and adapting to change. Innovation often emerges when established patterns are challenged, and key attributes such as autonomy, adaptability, creativity, and flexibility enable organizations to respond effectively to dynamic environments. While these qualities can sometimes introduce complexity, the overall fractal approach supports sustainable growth, decentralized decision-making, and the emergence of efficient organizational patterns from seemingly chaotic conditions.

The critical question is whether centralization or fractalization offers greater effectiveness for organizational management. While excessive decentralization can lead to a loss of control, potentially resulting in management breakdown or chaos, fractalization presents an alternative approach. To effectively implement fractalization, managers must focus on maintaining sustainable growth and preventing abrupt declines following periods of rapid expansion. Ensuring effective information flow within the organization is also vital, as changes in one component can significantly affect others (Gupta and Pandey, 2024).

Following the popular scientific result that patterns emerge even in chaos, it is tempting to propose and enforce more or less random changes in an organization. This will typically lead to an automatic development of new patterns and behaviors as employees adapt.

These emergent patterns can be positive or negative, depending on how the change is managed. While self-organization can lead to creative and efficient solutions, it can also result in inefficiencies, misalignment, or cultural drift if left unchecked. To ensure that new patterns are beneficial, leaders need to provide clear guidance, monitor adaptations, and formalize positive changes while correcting unproductive ones.

3 Fractal organization of a complex system

The fractal structure may be suitable also for complex systems of organizations, for example for national systems for public health, safety, state administration etc. They have been described as systems, which are not deliberately constructed, but are created spontaneously (by themselves) from bottom to top.

Recent examples of fractal systems include the work of Zincă et al. (2021), who proposed a fractal structure for the whole system of healthcare providers in Romania. The authors suggested to build the whole healthcare system as a fractal system, which would ensure the optimal outputs. Peralta and Soltero (2020) discussed manufacturing systems, i.e. the whole industry as a self-organized ecosystem developed from fractal theory. The paper applied fractal concepts to the framework of industry 4.0 and proposed fractal models for manufacturers, which are inspired by properties of fractal structures. Accou and Reniers (2019) proposed a fractal model for a national system for safety management, particularly for investigating accidents. The effect of corporate governance on management of working capital in India across the whole economy was explained by tools of fractal geometry in Gupta and Pandey (2024).

Fractal systems have found their place also in political science. For example, Li and Li (2024) described a decentralized form of government using the terminology of fractals and discussed its advantages. Maillet et al. (2023) described the health organization in Canada again to have a fractal structure. Political scientists generally favor decentralization, as it aligns with the idea that radical changes can be detrimental and that extremism should be avoided. However, the concept of fractals, which emphasizes fluctuations and variations, presents a different perspective. In a fractal view, change is seen as an inherent and dynamic process. Politicians with limited authority often support only those changes that are likely to occur regardless of their involvement, thereby avoiding significant disruption. This approach aligns with a more cautious and incremental view of change, contrasting with the fractal idea of embracing and managing variability.

4 Fractal-based management: The practice in a fractal organization

This section explores the principles and practices of fractal-based management, focusing on the qualities required of managers, the analytical tools and budgeting techniques that support decision-making, and strategies for implementing change and fostering innovation within fractal organizations.

4.1 Fractal-based management: Concepts and managerial qualities

While the topic of fractal organizations, as discussed in Section 4, has received some attention in the literature, there are no established practical management recommendations specifically related to the context of fractal organizations. Fractal management can be described as a universal response to changes in organizational structure (Gosnell et al., 2020). Fractal-based management, which has not been formally defined, involves understanding and adapting to the conditions of a fractal organization. It implies a need for flexibility and adaptability in response to structural changes and variability within the organization (Peralta and Soltero, 2020). Understanding the conditions and requirements of a fractal organization is crucial for effectively applying fractal-inspired management practices.

The specific context of fractal organizations imposes unique demands on the essential qualities of managers. Managers must be capable of learning from experience and adapting over time; they cannot be entirely inexperienced or too young. Experience in managing smaller organizations is beneficial, as understanding an entire large firm can be challenging due to evolutionary limitations (Maillet et al., 2023). Extremes can be harmful, so a balanced approach is necessary. While caution is important, managers must also possess the courage to embrace change and manage stress, as people often fear instability and change.

Effective management necessitates the efficient handling of daily tasks, a principle emphasized by Carnegie's time management strategies and the concept of focusing on immediate, everyday priorities, akin to the Biblical notion of daily bread (Matthew 6:11). Time itself can be conceptualized as fractal in nature (Faghih, 2023). Managers should apply logical reasoning while being cautious of the potential drawbacks of digitalization, which can sometimes undermine critical thinking. Additionally, the increasing prominence of Big Data in decision-making requires managers to maintain a holistic perspective of the organization (Kalina and Rensová, 2015). While intuition plays a significant role, it is essential for managers to be adept in statistical tools to support informed decision-making amidst uncertainty.

4.2 Management tools and budgeting practices in fractal organizations

Furthermore, it is essential to explore managerial practices within a fractal organization under fractal conditions (Gupta and Pandey, 2024). Managers should view every creative idea as an opportunity, even if it initially appears flawed or impractical, recognizing that innovation often involves trial and error. In managing a fractal organization, it is crucial to account for economic uncertainty and always consider multiple solutions to a given problem. This approach helps in adapting to dynamic conditions and making informed decisions e.g. in the field of financial management amidst uncertainty. We recommend creating multiple budget scenarios:

1. Optimistic budget: This scenario assumes the best possible outcome, i.e. strong revenue growth, increased demand, or favorable market conditions.
2. Moderate budget as a realistic, middle-of-the-road or base case scenario. It is typically based on the most likely outcomes, considering historical data, trends, and market forecasts.
3. Pessimistic budget accounting for worst-case outcomes, i.e. economic downturns, supply chain disruptions, market contraction, or competitive pressures.

Proposing multiple budgets offers several advantages, including better preparedness, risk mitigation, increased stakeholder confidence, and valuable insights into how different factors such as market changes and cost fluctuations affect the organization. By creating various budget scenarios, organizations can better anticipate and respond to potential uncertainties.

Nevertheless, constructing and maintaining multiple budgets is time-consuming and requires frequent revisions. An alternative approach is using flexible budgets, which adjust dynamically based on actual performance and changing conditions. To enhance the analysis of multiple budgets, incorporating quantiles can be particularly useful. Quantiles divide the data into intervals with equal probabilities, helping to identify how different budget scenarios perform across various levels of expenditure. A robust version of regularized quantiles was exploited in Kalina et al. (2019). In the context of budget forecasts, examining regression quantiles can provide insights into the distribution of outcomes, highlight potential risks, and improve decision-making by revealing how different factors impact different budget scenarios. This approach not only streamlines the budgeting process but also offers a more detailed understanding of financial variability and risk. This method also supports adaptive decision-making, allowing managers to respond quickly to unexpected changes and align resources with shifting organizational priorities.

4.3 Managing change and fostering innovation in fractal structures

Radical and abrupt managerial interventions can be essential in specific situations, particularly when addressing significant challenges or implementing strategic shifts. However, such actions come with considerable risks and complexities. Managers must balance centralization with flexibility, embracing change while mitigating associated risks. Analytical tools, such as quantiles, can support decision-making by revealing patterns in budgetary and financial data. Recognizing and leveraging the fractal nature of complex systems helps develop more effective strategies and understand the dynamics driving societal and economic transformations.

Rapid decision-making and the ability to adapt swiftly to changing conditions are essential. Key strategies include appointing effective leaders, optimizing resource allocation, and employing delegation techniques such as "divide and conquer" (Accou and Reniers, 2019). Establishing clear expectations while avoiding excessive interference contributes to success. Directors should focus on interactions with their closest subordinates to ensure the chain of command is respected and decisions are executed efficiently. Balancing significant change with careful management practices ensures transformation is effective and sustainable.

Managers in fractal organizations should aim for a balance between enforcing necessary changes and avoiding change overload. Necessary changes align with strategic goals or improve key processes, while excessive changes can create confusion, resistance, or burnout. Instead of imposing changes directly, managers often act as facilitators or influencers, using collaboration, communication, transparency, and phased implementations to guide transformation (Fouraharfar, 2020).

It is important to monitor the pace of change and understand how much teams can absorb without negatively affecting productivity or morale. The focus should be on making change manageable, securing buy-in, and ensuring alignment with broader organizational goals. In fractal structures, where direct control is limited, the ability to influence, communicate, and collaborate is more critical than top-down enforcement. Introducing new elements to increase flexibility can disrupt routines and challenge the status quo, fostering innovation and adaptation. While this shift requires courage, it can motivate teams and help maintain dynamism within the organization, supporting long-term resilience and adaptability.

Conclusion

This paper provides a concise exploration of two concepts, fractal organization and fractal-based management, which have received limited attention in the literature. Section 4

examines the increasing fractalization of organizations, leading to the practical recommendations for managers presented in Section 5. These recommendations draw on the literature while remaining highly relevant due to the growing emphasis on fractal principles in organizational contexts. Managers must balance centralization with flexibility, embracing change while managing its risks. Analytical tools, such as quantiles, can support decision-making by providing deeper insights into budgetary and financial patterns. Recognizing and leveraging the fractal nature of complex systems can lead to more effective strategies and a better understanding of the dynamics driving societal and economic transformations.

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Contact

Jan Kalina
The Czech Academy of Sciences, Institute of Computer Science
Pod Vodárenskou věží 2, 182 07, Prague 8, Czech Republic
& Charles University, Faculty of Mathematics and Physics
Sokolovská 83, 186 75 Prague 8, Czech Republic
kalina@cs.cas.cz