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THERE IS NO COMMON BASIS FOR INTEGRATING ANALYSES OF HIERARCHY IN NATURE. OR IS THERE? HOW O-THEORY CONTRIBUTES TO A THEORY OF HIERARCHIC ORDER

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Abstract

Currently, there is no common basis for integrating analyses of hierarchy in nature. This presents a serious obstacle to developing a general systems theory. To address this issue, O-theory introduced the concept of dual closure, which is fundamental to the formation of systems known as "operators." Using fundamental particles as a basis, dual closure produces the first type of operators. These operators then produce the next dual closure and type of operators. Repeating this process creates a hierarchy of increasingly complex operators. This hierarchy is called the operator hierarchy.

According to the operator hierarchy, complexity can be unraveled in three ways: (1) The emergence of new operators, (2) The parts within an operator, (3) The interactions through which operators cause large systems.

The operator hierarchy was developed for prediction purposes; this goal guided the development of a hierarchy with fixed levels based on dual closure. In contrast, depending on the usage context, there can be many rankings within a single operator and in a large system of interacting operators. These insights provide a new basis for integrating and aligning systemic thinking.

Keywords: O-theory, dual closure, hierarchy theory, transdisciplinary integration, system theory.

Introduction

The literature on analyzing hierarchical organization in nature, features many approaches and perspectives, including hierarchy theory (Simon 1962, Pattee 1973), levels of organization in biology and ecology (Whyte, Wilson & Wilson 1969, Allen & Hoekstra 1992, Campbell 2011), and levels in Big History (Jantsch 1980, Henriques 2003, Chaisson 2006, Spier 2015, Volk 2017). Still other perspectives on levels are represented by the hierarchies of increasingly complex types of 'individuals' proposed by Teilhard de Chardin (1969) and of reductional hierarchy by Oppenheim and Putnam (1958).

The conceptual differences among these approaches touch upon fundamental challenges in systems theory. The challenges include the possibility of adding or removing a level, variation in the number of levels, definitions of levels and their associated entities, and changes in hierarchy depending on the context of use. Currently, there are no signs of an imminent common basis or consensus.

Keeping the above in mind, we propose a new, integrative perspective. To this end, we make use of an innovative theory of hierarchical complexity in nature (Jagers op Akkerhuis and van Straalen 1999). Its current name is the O-theory. Before discussing how this theory can be useful, however, it is important to understand the obstacles to reaching a general solution. Two main obstacles are recognized from the current perspective: (1) inherent complexity and (2) philosophical relativism.

Challenges to creating a general theory of hierarchic order

The first obstacle is that natural systems, including society, are usually complex, especially when viewed broadly. For example, consider society, ecosystems, galaxies, or the universe. In this context, complexity often means that the system in question and its behavior cannot be described or its elements organized according to a single variable or perspective. Complexity therefore urges researchers to apply different perspectives when describing a system of interest (Brooks 2014 , Brooks and Eronen 2018). For instance, an ecosystem can be looked at from the perspectives of a food chain, species diversity, ecosystem engineering, motion of elements, and more. As part of his Living Systems Theory, Miller (1978) presented several fundamental perspectives on organizing complex systems. These perspectives reappeared in a slightly different form in Jagers op Akkerhuis (2008) where they were referred to by the acronym DICE: dispersal (space and time), information, construction, and energy. It is important to note that adopting a different DICE perspective results in a different organization of a system's relationships and parts.

The second obstacle is that contemporary philosophy has deeply integrated the idea that all hierarchies depend on a specific usage context. The upshot of this context dependency is that a ranking that claims prevalence for one reason or another, risk philosophical criticism (Kolnai 1971, Chang 2023). However, there is a twist. Even though all hierarchies undeniably depend on their usage context, the next question is whether different contexts have the same theoretical impact. When applied unilaterally, the principle of relativity does not seem to acknowledge that usage contexts can differ in their theoretical depth.

For example, when speaking to a wide audience, one could provide a grand overview of the emergence of complexity in our universe since the Big Bang. Interesting phenomena to include range from the Big Bang and the formation of solar systems and planets to chemical systems on planets and the emergence of bacterial and archaeal cells. With cells as a basis, the pathway of evolutionary phenomena leads to increasingly complex organisms, including humans. An humans interact to form groups, villages, countries, and so forth. These examples serve to convey the intuitive message of the universe's complexification. Whether an example is added or deleted in a subsequent presentation is not very relevant. Nor do the criteria for identifying any next level, or the entities at that level, need to be of the same overall type. The goal is to offer a broad ranking that speaks to the imagination of the audience, and to do so in a way that is both creative and engaging.

As an alternative to a general overview, one can strive to create a type of order more closely linked to the goal of creating a theoretical framework for a hierarchy of levels of natural organization supporting extrapolation. This is challenging because extrapolation can only be achieved if there is consistency in the transitions between levels and in the types of entities (Jagers op Akkerhuis 2024).

These demands can be illustrated by the following series: II, III, IIII. This series is governed by the rule "add one bar with each successive step." The ranking is consistent in two ways. One, the entities are groups of bars. Two, the transitions depend on the rule "add one bar with each successive step." Because the ranking is consistent, it supports extrapolation; without disturbing mechanisms, the next set of bars would be a group of five bars, or "IIIII." Of course, this is a very simple theoretical example. Finding a similarly consistent ranking in nature is rather challenging.

In order to address the challenge of identifying stringent levels, O-theory sought inspiration in ‘circular’ organization. This because a cyclic arrangement integrates the elements involved into one whole entity: the circle. First there are elements, and next these elements are integrated to a whole as a consequence of circular interactions. The circular arrangement is also called ‘closure’ and is discussed in the broad field of closure studies (Bergson 1907, Huxley 1912, Monod 1970, Rosen 1972, Maturana & Varela 1972, Eigen & Schuster 1979, Gánti 1984, 1989, Heylighen 1989, 1990, Kauffman 1993, Chandler & van de Vijver 2000, Hofstadter 2007, Dittrich & Speroni di Fenizio 2007, Letelier, Luz Cardenas & Cornish-Bowden 2011, Soto-Andrade, Jaramillo-Riveri & Letelier 2011, Moreno & Mossio 2015, Ellis 2020). One example of closure is when people hold hands and form a circle. Another example are the cycles of metabolic steps in a cell, including for example the citric acid cycle, which are fundamental to the continuation of metabolism and overall integrity of a cell.

In the context of identifying levels of complexity, closures in the form of a closed cycle of processes, or the closing off of a spatial unit in three dimensions, are valuable tools. This is because there is no closure as long as the elements do not form a closed topology. Only when the elements form a complete cycle or sphere, the system achieves closure. Because of this, closure is either present or absent which allows for a binary yes/no decision. And this binary offers a stringent criterion for the identification of thresholds.

Furthermore, the complexity before closure is lower than the complexity after closure. This is because the closed state of the system creates new ("emergent") properties.

In principle, one can imagine many systems exhibiting some form of closure. For instance, a football is closed, a food chain can be more or less closed, and the electron shell of a molecule is closed across all involved atoms. In a world with so many possible forms of closure, it is important to identify those that are significant from the perspective of natural hierarchy.

To narrow the focus and reduce the number of options, it was decided to in O-theory use a combination of closures. The resulting combination, a ‘double’ closure, received the name of "dual closure" to emphasize that the phenomenon can both be seen as a process of maintaining the closure, and as a state of being closed. Moreover, dual closure also addresses the additional criterion of dependence between the two closures. Simply stated, dual closure occurs when a functional/processual closure (e.g., the metabolism of a bacterium) and a structural/spatial closure (e.g., the membrane surrounding a bacterium) depend on each other dynamically (Figure 1)(Jagers op Akkerhuis and van Straalen 1999).

A bacterium is a simple example of the dependence of the two closures. Its metabolism produces energy, new internal molecules, and membrane molecules, while the membrane prevents metabolic molecules from diffusing into the solute.

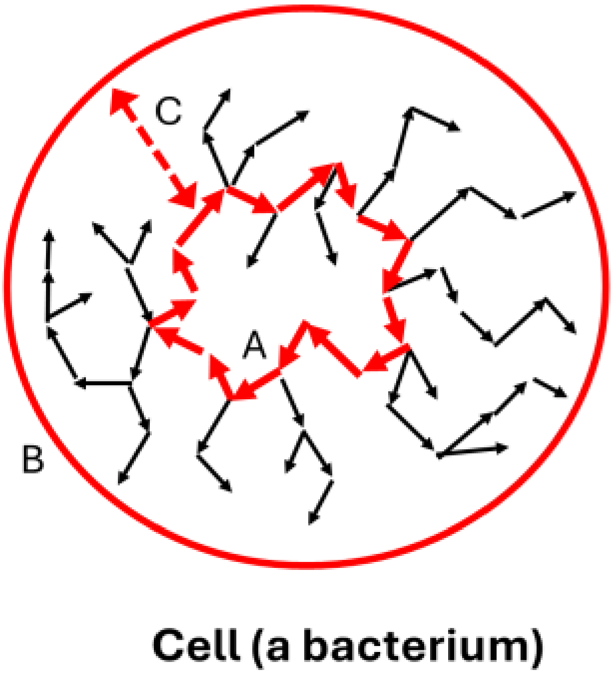

Figure 1: An example of dual closure: The closures of a bacterial cell. A = catalytic closure. B = Spatial closure. C = dependence of A and B.

A system with dual closure is called an "operator," (Jagers op Akkerhuis and van Straalen 1999). The term operator used in this context should not be confused with mathematical operators.

Operators at a given level create the possibility for the next dual closure. Before this occurs, the operators from the highest current level develop a new property. For instance, when molecules form a cell, catalytic reactions are involved in its metabolism. However, not all molecules can carry out catalytic reactions. These reactions depend on three-dimensional properties that alter the state of another molecule. Simple molecules without the necessary three-dimensional structure cannot perform these reactions and are not "selected." Only after more complex molecules formed, could the next dual closure take place. Due to the numerous criteria involved in dual closure, transitions from one level to the next are narrowly defined.

Step by step, and dual closure by dual closure, a hierarchy of levels forms. Each new level is inhabited by a new, more complex type of operator. This results in the operator hierarchy, which has been researched since 1993 (Jagers op Akkerhuis 2010b).

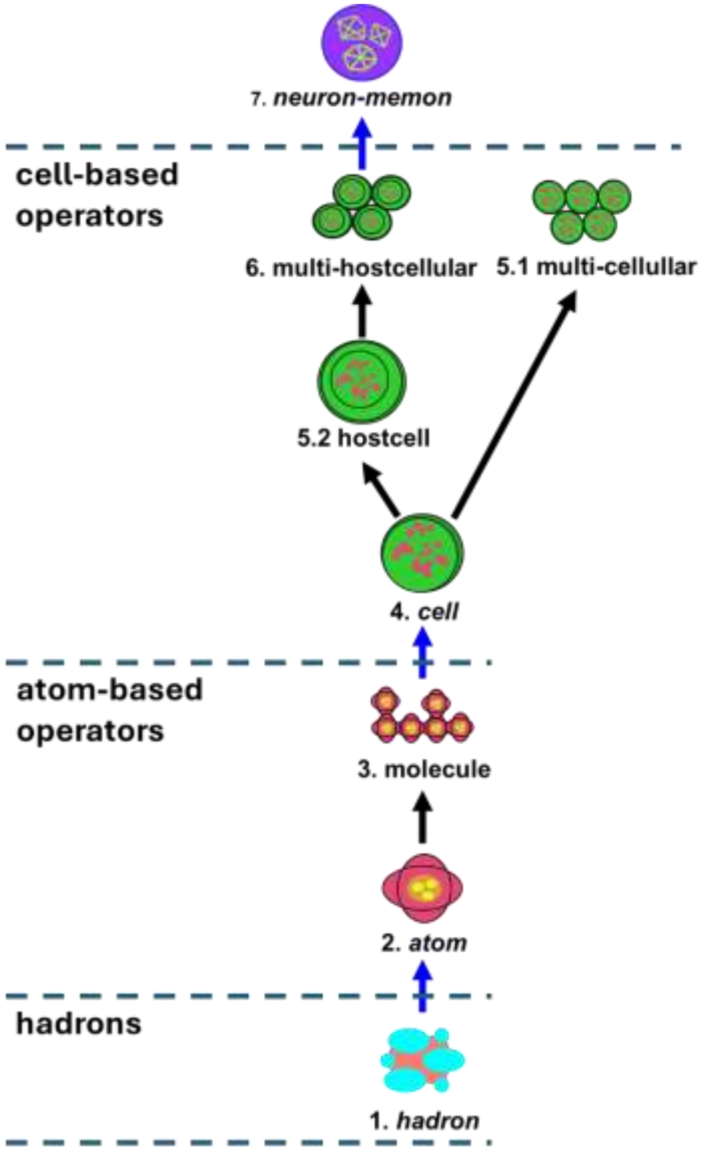

Figure 2. The ranking of all the different types of operators in the operator hierarchy. Dashed lines separate operators in groups, each having a specific operator as its basis. In O-theory the eukaryotic cell is referred to as 'hostcell', and the neural network organism ('animal') as 'neuron-memon'.

Figure 2 illustrates the operator hierarchy, which includes the following types of operators: hadrons, atoms, molecules, and cells (including bacteria and archaea). From the cellular level, there are two possible pathways. One leads to multicellular organisms, such as blue-green algae and streptomycetes. The other leads to eukaryotic cells (in O-theory: 'host cells'), multi-hostcellular organisms, and neural network organisms (the 'neuronmemon')(Jagers op Akkerhuis 2001).

The operator hierarchy is logically consistent in its transitions, which are all dual closures, and in its systems, which are all operators. This consistency makes the operator hierarchy a suitable basis for extrapolation. However, extrapolation and the predictions based on it are not the focus here. These have been addressed in other papers (Jagers op Akkerhuis 2001, 2024) . Here, the focus is on logical consistency because it allows the operator hierarchy to play a fundamental role in systems science. To discuss the contributions of O-theory to systems science, however, requires first discussing the concept of a "system."

What is a system?

Philosophers and system scientists have a long history of discussing the question: "What is a system?" Various domains of systems science have offered different contributions. On the one hand, there are generalist approaches, such as General Systems Theory (GST), proposed by von Bertalanffy (1950). GST is defined as follows: '*General Systems Theory is a logico-mathematical discipline, which is in itself purely formal, but is applicable to all sciences concerned with systems. Its position is similar to that, for example, of probability theory, which is in itself a formal mathematical doctrine, but which can be applied to very different fields, such as thermodynamics, biological and medical experimentation, genetics, life insurance statistics etcetera*.' By analyzing systems as the product of interactions between parts and analyzing those parts as the product of interactions between smaller parts, GST demonstrates a direct link to hierarchy theory. Due to its broad definition, GST considers every entity to be amenable to being analyzed as a system.

In some branches of systems science, the focus has been on systems designed by humans, such as hospitals and educational systems. Soft systems methodology (Checkland and Scholes 1990) specifically addresses this group of systems, and how to manage them. A frequently used perspective on systems is that they can be identified by a unifying function, behavior, or process.

From a philosophical perspective, there has been discussion about whether a system can be considered a physical entity in the world or a conceptual entity in the mind. This question also plagued GST (Guberman, 2004). The viewpoint that an observer imposes -or models- a system's structure as a mental abstraction of an entity's organization suggests that the system is conceptual and does not necessarily offer an exact replica of the entity's organization (Allen, 2001). This stance has already been advocated by Bernard (1865), stating that "*Systems do not exist in nature but only in the minds of people*."

What can we learn from this brief overview as we search for a general, integrative approach? In an attempt to bridge the many perspectives, the following reasoning has been inspired by O-theory (Jagers op Akkerhuis 2024).

First, we assume that concepts form the basis of our thinking. We use these concepts to describe and classify our experiences, as well as the connections between these experiences and entities in the world and all their properties. Our "worldview" is conceptual. The link with entities in the world is never exact, but should be good enough to recognize an entity in the world as an instantiation of a specific concept.

The development of the conceptual worldview begins when a child learns to name things. Names are concepts for things, such as "cat," "car," or "house"; properties, such as "red"; and dynamics, such as "meowing," among others. In O-theory, every subset of the universe that is represented in our minds as a single, countable unit is referred to as an "object." This includes a cow, a river, or a cat's heart, as well as a factory, a galaxy, or an educational system with all its buildings, students, teachers, and computers. It also includes the reflection of light on water or the continent of Australia. While the world is full of things, the associated mental representations are objects.

Second, the -mental- object can be transformed to a system through a "gestalt switch." This switch involves shifting the focus intentionally from a single, countable object to its elements and potential interactions. Interactions can be within the object's limits and may extend to the world outside the object's limits. Due to this gestalt switch, the object transforms conceptually into a system. In O-theory, the term "Sysob" highlights the object-system pair (Jagers op Akkerhuis 2018, 2024).

With the Sysob approach, the limit chosen for an object automatically defines the limit of the associated system. Since objects are conceptual, the limits of both objects and their associated systems are also conceptual. While conceptual, a limit can exhibit more or less physical realism. For instance, the limits of a cubic meter of air, a galaxy, a company, or an educational system lack a clear physical basis. In contrast, the conceptual and physical limits of a cell membrane or a football's leather correspond closely.

The above approach to defining systems offers a way out of 'wholeness' discussions, because it allows for the creation of subsets that emphasize specific wholes, in relation to applications, functions, behaviors, feedbacks, or goals. Additionally there is no need anymore for disagreements about which subsets qualify as systems or which discipline has the most appropriate system definition. Nor should acceptance of different definitions of systems in different subsets hinder interdisciplinary understanding. With the Sysob approach as a starting point, dedicated system types can be identified, such as feedback systems, closed systems, open systems, social systems, and others. Each type is relevant in its own context.

In summary, this text advocates viewing a system as an abstraction associated with the intentional, systemic analysis of an object as if it consists of elements and their interactions. The terms "object," "system," "element," "interaction," and "limit" are all conceptual. They relate to entities ("things") or dynamics ("phenomena") in the world. In principle, thoughts about systems can also be studied as parts of the world because they have a physical basis in the brain's neural network. Now that the concept of a system has been discussed, it can be applied to the discussion of O-theory's contributions to a system-based, integrative analysis of hierarchy in nature.

O-theory as a basis for systems-theoretic integration.

When considering the use of O-theory as the basis for an integrated systems theory, two major aspects deserve attention:

(a) How a succession of dual closures defines operators of increasingly complex types which

can serve as a general basis for distinguishing different types of hierarchy.

(b) How O-theory suggests a top-level ontology for systems;

(a) Ranking increasingly complex operators in the operator hierarchy.

O-theory introduces a fundamental hierarchy for all operators, shedding new light on natural hierarchy. It is noteworthy that, because of its focus on dual closure, the operator hierarchy has a single, stringent ranking. As it includes operators of increasing complexity—from hadrons to organisms with neural networks—the hierarchy is transdisciplinary in scope. This allows one to analyze natural organization using operators as "building blocks," comparable to how LEGO bricks can be used to build houses, trains, cities, and more. In this sense, the operator hierarchy occupies a fundamental, transdisciplinary position in systems science.

Now that the operator hierarchy has been established, it can serve as a foundation for distinguishing two additional types of hierarchy. The first type refers to the various forms of hierarchy within an operator. In O-theory, these hierarchies are considered "inward." One example of an "inward" hierarchy is the progression from a cat to its heart to muscle tissue to muscle cells to mitochondria, and so on. Another example is the hierarchy from the cat's brain to its nerves to its eyes.

The second type refers to hierarchies in systems produced by interacting operators, such as ecosystems, societies, and the universe. These hierarchies exist outside the operators and are considered "outward." One example of an outward hierarchy is the ranking from a pack of wolves to the local wolf population and the community that includes their prey. Another example is a food chain involving plants, mice, cats, and birds of prey. In both examples, all levels involve mental groupings.

(b) Top-level ontology:

Because thinking is conceptual, concepts are the root level. At the next level, O-theory uses the Sysob pair—suggesting the concepts of "object" and "system" are two sides of the same coin—as the highest level of systemic analysis (Jagers op Akkerhuis 2024). However, one could argue that calling everything a Sysob takes the "color" out of systems analysis. To restore color, O-theory identifies several major subgroups. First, fundamental particles are considered the lowest level of organization and the smallest objects. Next, the large set of systems built from fundamental particles (referred to as 'multiparticle systems') is divided into operators and interaction systems. Finally, the set of interaction systems is subdivided into composite objects and groups (Figure 3).

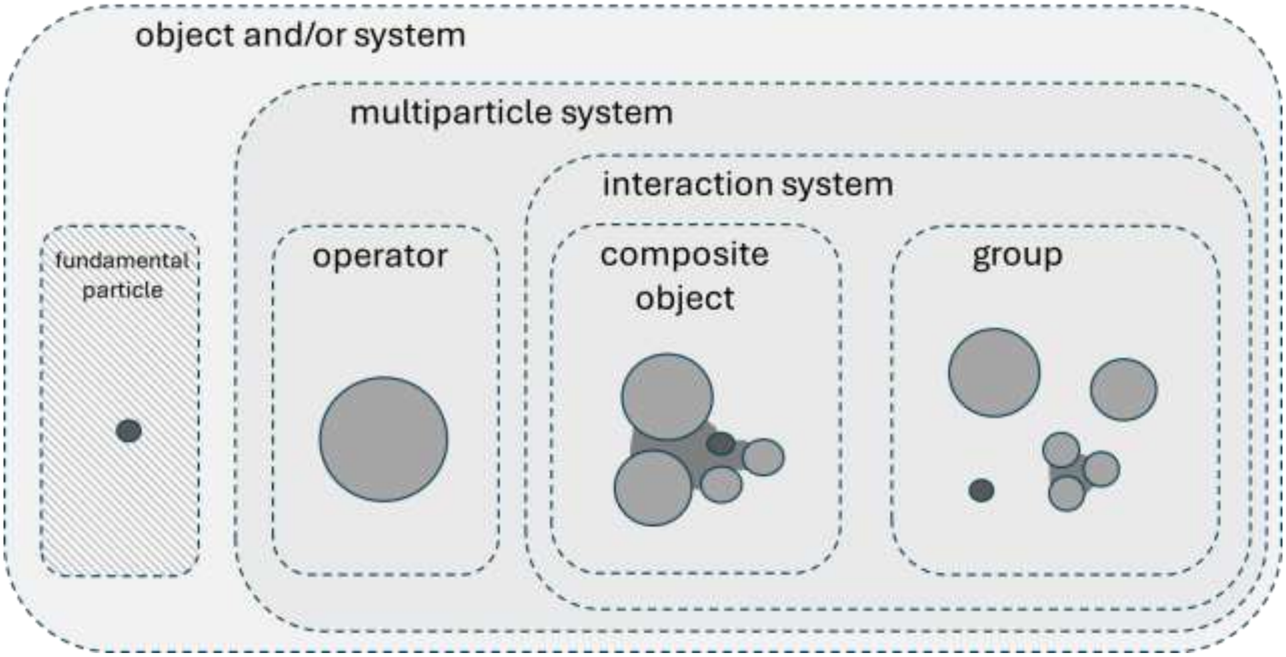

Figure 3: A top level ontology based on the operator theory. The top level is based on the Sysob pair, combining the perspectives of object and system. Concepts are explained in the text.

Operator: Because they are organized by dual closure, all the operators are considered singularly countable objects.

Interaction system: Any system that includes operators without classifying as an operator. The domain of complexity science largely focuses on interaction systems of some sort, such as flocks of birds, a company, society, or the universe.

Composite object: The parts of a composite object can be fundamental particles, operators or composite objects themselves. The parts are more strongly linked to each other than to the environment. Examples of composite object are: a football, a car, an alarm clock, a brick, a crystal, a car, or a slug of a slime mold. The definition is relative to the environment. A drop of water in oil or a raindrop in the air is a composite object. The same drop in the ocean, however, is an indistinguishable part of it. Because the composite object is defined in a relative way, it has limit cases (Jagers op Akkerhuis 2024).

Every composite object can be seen as a system. This includes a car and all its parts. However, functionally oriented perspectives on what is a system might exclude the car's radio when it's off or may not recognize the car as a system if there is no driver behind the steering wheel. These limitations show that such approaches can be seen as subsets of the current system definition.

Group: Examples of groups include the board and pieces of a chess set, a football team, a cloud of water droplets, celestial objects in a galaxy, the plasma of a star, and animals in a population. The entities of a group are separate in space. They are not attached (if they were attached, they would classify as a composite object). This implies that they are more like "elements" or "members". The limits of the group are set by the definition of the object. The members of a group may be fundamental particles, operators, and/or composite objects. Entities can be elements of several groups at the same time, or can change groups over time, e.g. a person can be part of a family, a football team, etc.

Discussion

The absence of a shared foundation for integrating analyses of hierarchy in nature poses a significant challenge to the development of a comprehensive systems theory. To address this issue, O-theory introduces the concepts of dual closure, operator, and the operator hierarchy. Starting with the operator hierarchy as a foundation allows one to subsequently analyze hierarchies within operators or interaction systems. Recognizing three domains of hierarchy analysis can help systems scientists to work towards a consistent use of rankings, and to prevent that an overall hierarchy mixes elements of the three domains and in this way suffers from inconsistent logic. For example, if a hierarchy begins with bacteria, then eukaryotic cells, eukaryotic multicellular organisms, neural network organisms (i.e., animals), and finally populations, communities, and ecosystems, it connects steps that follow the operator hierarchy (i.e., from bacteria to animals) and steps that represents outward grouping (i.e., mental aggregates such as populations and communities).

A notable example of mixed logic is the set of Major Evolutionary Transitions introduced by Maynard Smith and Szathmary (1995). It proposes eight transitions. These either represent a collection, or a series of steps in a hierarchy, from the small to the large. Assuming a hierarchy, the logic behind it must be demonstrated. The original eight transitions can be ranked as follows:

(1) From unlinked replicators to chromosomes

(2) From replicating molecules to populations of molecules in compartments;

(3) From RNA serving as both a gene and an enzyme to DNA and proteins;

(4) Prokaryotes to eukaryotes;

(5) From asexual clones to sexual populations;

(6) Protists evolved into animals, plants, and fungi.

(7) Solitary individuals evolved into colonies.

(8) Primate societies evolved into human societies.

One can now apply the three domains introduced by O-theory to analyze these transitions. Each transition is given a code depending on the type of hierarchy: I = inward, O = outward, and U = upward. After this is done, Maynard Smith and Szathmary's ranking shows the following sequence (levels 1 to 8): U, I, I, U, O, U, O, O.

This classification of the major evolutionary transitions clearly shows that if the examples are viewed as a series , this mixes different types of hierarchies. Assuming the major transitions do represent a series, not just a collection, this suggests that, even though the concept of Major Evolutionary Transitions is intuitively appealing, their overall ranking requires restructuring to improve consistency (Jagers op Akkerhuis 2024).

Philosophizing about the operator hierarchy

A philosophical approach to hierarchical rankings acknowledges that they are, by definition, always relative to a specific goal or context of use. This relativism underscores a fundamental property of complex systems and prevents people from adopting one-sided viewpoints. However, the idea that all rankings are relative does not mean that all rankings have equal theoretical weight. To evaluate theoretical weight, one must consider conceptual generality and logical consistency. In other words, the philosophical evaluation process has two tiers: (1) taking inventory of different perspectives and (2) comparing and ranking their broad theoretical relevance.

Now that O-theory suggests that the operator hierarchy is a foundational framework for systems science, philosophers naturally ask questions such as: How can we ascertain that the operator hierarchy encompasses only the current levels and not others? How can we be confident that there are no other rankings with comparable theoretical relevance? Have important past theoretical achievements in systems science been integrated into O-theory?

The first of these questions is relatively easy to answer. Remember that the rationale behind developing the operator hierarchy was to create an extrapolative ranking. Extrapolation requires consistent logic in transitions between levels and in the overall type of all entities involved. To meet these requirements, the dual closure process was chosen as the criterion for advancing to the next level. Since every step in the operator hierarchy depends on dual closure, the hierarchy's structure is strictly limited to the current levels and the selective inclusion of operators.

The second question is more difficult to answer. After all, one could conceive of an infinite number of theoretical rankings, at least in principle. Therefore, an equally relevant theoretical ranking could exist outside of the current knowledge. To determine the best option, we can compare O-theory with other proposed rankings, focusing on logical consistency, correspondence with real systems, efficiency (Ockham's razor), and transdisciplinary scope.

The third question focuses on whether past systems-theoretic insights have been incorporated. The answer is "yes and no." The "yes" part refers to the broad range of classical approaches that were studied during the development of O-theory. Particular attention was given to approaches focusing on hierarchy, including those of von Bertalanffy (1950), Feibleman (1954), Oppenheim & Putnam (1958), Simon (1973), Turchin (1977), and Salthe (1993). The "no" part emphasizes that O-theory offers a new perspective by aiming to extrapolate a hierarchy into the future. This viewpoint requires focusing on logical consistency in ranking, a topic that classical systems theorists only explored to a limited extent. Among the exceptions are Huxley's (1912) work, which distinguishes between internal differentiation (e.g., brain formation in multicellular organisms) and aggregate differentiation (e.g., multicellularity), and Teilhard de Chardin's (1946) work, which discusses "formed" and "centered" systems.

Theoretical contributions

The innovations suggested by O-theory touch on a variety of philosophical and systems-theoretical themes.

One fundamental theme is the question which types of things can be used as basic units to analyze hierarchical organization in nature. Various of such units have been proposed. For example, Huxley (1912) defined these units as "individuals," Koestler (1967) defined them as "holons," and Whitehead (1929) defined them as "organisms" (with a different meaning than the term "organism" in biology). By its focus on dual closure, O-theory provides a precise definition of a new type of basic unit: the "operator." As dual closure is closely associated with the physical organization of entities in the world, the abstraction of the operator represent a relatively *bona fide* description of a group of natural entities.

With the operator definition in place, several related challenges can be addressed. One such challenge is identifying a type of building block system that can be used at all levels of science. The various types of operators and their ranking in the operator hierarchy offer a relevant solution in this regard.

Another challenge involves defining organisms and life. Using the operator hierarchy as a basis can simplify these tasks. First, all operators that are equally or more complex than bacterial or archaeal cells in terms of dual closures can be labeled as organisms (Jagers op Akkerhuis 2010a). Second, if we consider life to be a general property, then life can be defined as the presence of a dual closure that is at least as complex as a cell's. Only operators labeled as organisms comply with this criterion.

Furthermore, O-theory contributes to systems science by proposing a top-level ontology in which the object/system pair, called a Sysob, is at the apex (Jagers op Akkerhuis 2019). From this level down, subgroups are defined as operators, composite objects, and groups. This way of analyzing the world also suggests a general definition of a system: an object exhibits a gestalt switch to a system when studied in a systemic way. In other words, its elements and interactions become the focus of attention. This definition allows us to identify subsets of specific types of systems.

In conclusion

By the end of the nineteenth century, mathematics was in a foundational crisis. To solve this problem, mathematicians like Hilbert (1923) began envisioning a comprehensive mathematical framework. Although Gödel (1931) demonstrated that no mathematical approach could be proven true within the context of its own axioms, this search helped integrate mathematics. In some respects, one can draw parallels between the current state of the natural sciences, which are also seeking integration. By challenging the widely accepted notion that there is no common ground on which to integrate analyses of hierarchy in nature, O-theory advances integration in systems science.

However, it should be noted that operator theory is not a theory of everything. Rather, it is a theory about the hierarchical emergence of all types of operators. Nevertheless, one can develop many interesting innovations in general systems science based on this foundation. For instance, novel perspectives have been proposed regarding the concepts of organisms and life, as well as the three domains used to analyze hierarchy. Additionally, the logic of the operator hierarchy can be extrapolated to reveal unknown unknowns by -at least partially- filling in the dual closure types of future operators. Thus, operator theory paves the way for a transdisciplinary theory of hierarchical order and the exploration of unanswered—and even unanticipated—questions in systems science.

References

Allen, J.F. (2001). https://web.archive.org/web/20011218001638/http://isss.org/hierarchy.htm).

Allen, T. F. H., & T. Hoekstra, T. (1992). *Toward a unified ecology*. Columbia University Press.

Bergson, H. (1907). *L'Évolution créatrice*.

Bernard, C. (1865). Introduction à l'étude de la medicine expérimentale. Nombreuses rééditions, p.ex.: 1943, Paris, Librairie Joseph Gibert (col. 'Chefs-d'oeuvre philosophiques', 308, 175.

Brooks, D.S. (2014). *The concept of levels of organization in the biological sciences,* Department of Philosophy, Bielefeld University, Ph.D. thesis. https://pub.uni-bielefeld.de/publication/2786539

Brooks, D.S., & M.I. Eronen (2018). "The Significance of 'Levels of Organization' for Scientific Research: A Heuristic Approach" in *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences Vol. 68–69*, 34-41.

Chaisson, E. (2006). *Epic of Evolution: Seven ages of the cosmos*. New York: Columbia University Press.

Chandler J.L. R., & van de Vijver, G. (2000) Closure. Emergent organizations and their dynamics. Volume 901. Annals of the New York Academy of Sciences.

Chandler, J. L. R. & Van de Vijver, G. (Eds.) (2006), Closure: emergent organizations and their dynamics. *Annals of the New York Academy of Sciences 901*.

Chang, H. (2023). *Realism for Realistic People. A New Pragmatist Philosophy of Science.* University of Cambridge.

Checkland, P., & Scholes, J. (1990). *Soft systems methodology in action*. John Wiley & Sons. Chichester.

Dittrich. P., & Speroni di Fenizio, P. (2007) Chemical organization theory. *Bulletin of Mathematical Biology, 69*, 1199-1231

Eigen, M., & Schuster, P. (1979). *The hvpercycle: a principle of self-organizalion*. Springer, New York.

Ellis, G. F. R. (2020). The causal closure of physics in real world contexts. *Foundations of Physics, 50*, 1057-1097.

Feibleman, J.K. (1954) Theory of integrative levels. *British Journal Philosophy Sci. 5*, 59-66

Gánti, T. (1984) Chemotonelmélet I. A fluid automaták elméleti alapjai (1984), OMIKK, Budapest. (Chemoton Theory. Vol. I. Theory of Fluid Machineries (2003), Kluwer Academic/Plenum Publishers, New York).

Gánti, T. (1989) Chemotonelmélet II. Az élő rendszerek elmélete (1989), OMIKK, Budapest. (Chemoton Theory. Vol. II. Theory of Living Systems (2003), Kluwer Academic/Plenum Publishers, New York).

Gödel, K. (1931). Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme, I. *Monatshefte für Mathematik und Physik 38:* 173–198.

Guberman, S. (2004). Reflections on Ludwig von Bertalanffy's "general system theory: foundations, development, applications". *Gestalttheory.net*

Henriques, G. R. (2003). The Tree of Knowledge System and the theoretical unification of psychology. *Review of General Psychology 7*, 150-182.

Heylighen, F. (1989). Self-organization, emergence and the architecture of complexity. In *'Proceedings of the 1st European conference on System Science'*, (AFCET, Paris).

Heylighen, F. (1990). Relational Closure: a mathematical concept for distinction-making and complexity analysis. In R. Trappl (Ed.), *Cybernetics and Systems '90*. World Science, Singapore.

Hilbert, D. (1923). "Die logischen Grundlagen der Mathematik", *Mathematische Annalen 88*: 151–165. Lecture given at the Deutsche Naturforscher-Gesellschaft, September 1922. Reprinted in Hilbert (1935, 178–191). English translation in Ewald (1996, 1134–1148).

Hofstadter, D. (2007). *I am a strange loop*. Basic books.

Huxley, J. S. (1912). *The Individual in the Animal Kingdom*. Cambridge University Press.

Jagers op Akkerhuis, G.A.J.M. (2001). Extrapolating a hierarchy of building block systems towards future neural network organisms. *Acta Biotheoretica, 49,* 171-189).

Jagers op Akkerhuis, G.A.J.M. (2008). Analysing hierarchy in the organization of biological and physical systems. *Biological reviews, 83,* 1-12.

Jagers op Akkerhuis, G. A. J. M. (2010a). Towards a hierarchical definition of life, the organism, and death. *Foundations of Science, 15*, 245-262.

Jagers op Akkerhuis, G. A. J. M. (2010b). The operator hierarchy. A chain of closures linking matter, life and artificial intelligence. Alterra Scientific Contributions 34.

Jagers op Akkerhuis, G.A.J.M. (2018). Een realistische, trans-disciplinaire ontologie voor de empirische basis van de wetenschap: bijdragen van de operator theorie. [A transdisciplinary realist ontology for the empirical basis in science: contributions of the operator theory]. https://doi.org/10.13140/RG.2.2.12851.12321

Jagers op Akkerhuis, G. A. J. M. (2019). *ScienceBites – A fresh take on commonly used terms in science.* Wageningen Academic Publishers, 142 pp.

Jagers op Akkerhuis, G.A.J.M. (2024). *The third law of evolution and the future of life. A systems approach to natural philosophy.* Springer, 348pp.

Jagers op Akkerhuis, G.A.J.M., & van Straalen, N. M. (1999). "Operators, the Lego-bricks of nature, evolutionary transitions from fermions to neural networks." *World Futures, The journal of general evolution 53*, 329-345.

Jantsch, E. (1980). *The self-organizing universe. Scientific and human implications of the emerging paradigm of evolution*. Pergamon Press.

Kauffman, S. A. (1993). *The origins of order: Self-organisation and selection in evolution*. (Oxford University Press, Oxford) (709 pp).

Koestler, A. (1967). The ghost in the machine. Macmillan, New York.

Kolnai, A. (1971). The Concept of Hierarchy. *Philosophy 46*, 203-221. doi:10.1017/S0031819100018970

Letelier, J.-C., Luz Cardenas, M., & Cornish-Bowden, A. (2011). From L'homme machine to metabolic closure: steps towards understanding life. *Journal of Theoretical Biology 286*, 100-113.

Letelier, J.-C., Marin, J., & Mpodozis, J. (2003). Autopoietic and (M, R)-systems. *Journal of theoretical biology, 222*, 261-272.

Maturana, H. R., & Varela, F. J. (1972). Autopoiesis and cognition: the realization of the living. *Boston studies in the philosophy and history of science*. Dordrecht: Reidel.

Miller, J. G. (1978). *Living Systems*. New York: McGraw-Hill.

Monod, J. (1970). *Le hasard et la nécessité*. Editions du Seuil (Translation: Toeval en onvermijdelijkheid. Proeve van een natuurfilosofie van de modern biologie. Bruna & Zoon. Utrecht/Antwerpen. 1971).

Moreno, A., & Mossio, M. (2015). Biological autonomy. A philosophical and theoretical enquiry. *History, philosophy and theory of life science. Vol. 12*. Springer, Dordrecht.

Oppenheim, P., & Putnam, H. (1958) “Unity of Science as a Working Hypothesis.” *Minnesota Studies in the Philosophy of Science 2*, 3-36.

Pattee, H. H. (ed.)(1973). *Hierarchy theory: the challenge or complex systems*. Braziller, New York.

Reece, J. & Urry, L. et al. (2011). *Campbell Biology*. Pearson.

Rosen, R. (1972). Some relational cell models: the metabolism-repair system. In: R. Rosen R. (Ed.), *Foundations of mathematical biology*. Academic Press, New York.

Salthe, S. N. (Ed.)(1993). *Development and evolution. Complexity and change in biology*. MIT Press, Cambridge.

Simon H.A. (1973). The organization of complex systems. In: *Hierarchy theory* (ed. H.H. Pattee). George Braziller, New York.

Simon, H. A. (1962). The architecture of complexity. *Proceedings of the American philosophical society 106,* 467-82.

Soto-Andrade, J., Jaramillo-Riveri, S., & Letelier, J.-C. (2011). *Ouroboros avatars: A mathematical exploration of self-reference and metabolic closure*. ECAL 2011.

Spier, F. (2015). *Big History and the Future of Humanity*. Second Edition. Chichester, West Sussex, U.K., Malden, MA, Wiley-Blackwell.

Spier, F. (2022). Thresholds of Increasing Complexity in Big History: A Critical Review. *Journal of Big History 5,* 48-58.

Stokes Brown, C., Benjamin, C., & Christian, D. (2014). *Big history: between nothing and everything*. McGraw-Hill education.

Szathmáry, E., & Maynard Smith, J. (1995). The major evolutionary transitions. *Nature, 374*, 227-232.

Teilhard de Chardin, P. (1969). *The future of man* (Editions du Seuil V, 1946)

Turchin V.E. (1995). A dialogue on metasystem transitions. In: Heylighen, F., Joslyn, C., and Turchin, V. (eds.). *The quantum of evolution. Towards a theory of metasystem transitions.* (Gordon and Breach Science Publishers, New York)(Special issue of ‘World Futures; the journal of general evolution’, volume 45)

Volk, T. (2017). *Quarks to Culture: How We Came to Be*. New York, Columbia University Press.

Von Bertalanffy, L. (1950). An outline of general system theory. The *British Journal for the Philosophy of Science, 1*, 134-166.

Whitehead, A. N. (1929). *Process and Reality: An Essay in Cosmology*. 1979 corrected edition, edited by David Ray Griffin & Donald W. Sherburne,

Whyte, L. L., Wilson A. G., & Wilson D. (eds.)(1969*). Hierarchical structures*. American Elsevier, New York.