Dual Closure: a New Tool for Recognizing Thresholds Between Levels of Organization in Big History

Gerard Jagers op Akkerhuis
Wageningen University and Research, Wageningen, Netherlands

Correspondence | **Gerard Jagers op Akkerhuis** gajm.jagers@gmail.com

Citation | Jagers op Akkerhuis, G. (2023) Dual Closure, a New Tool for Recognizing Thresholds Between Levels of Organization in Big History
Journal of Big History, VI(3); 48–58.
DOI | https://doi.org/10.22339/jbh.v6i3.6305

Keywords: Big History, O-theory, operator hierarchy, dimensions for hierarchy, meta-evolution, thresholds, levels of organisation, complexity, clusters, higher-order periodicity, philosophy of science.

Abstract: Big Historians study the development of the universe and how it passed through different phases. A fascinating trend is the historical increase in the complexity of a part of all systems. To analyse this trend, rankings have been proposed with different scientific and pedagogical aims. For example, they rank epochs, regimes, levels of organisation or dynamic domains. As a result of this variation, the number of levels differs between approaches, while the systems ranked at these levels are the result of unequal processes and belong to different overall types. Such diversity invites a re-examination of the fundamentals involved in these ranking processes. Moreover, if rankings are to be predictive, they must be consistent in their logic. To this end, it would be useful to have a sequence of levels that share a common logic.

As such a common logic, and building on existing systems science and hierarchy theory, a new theory called O-theory proposes the use of a process called 'dual closure'. Each successive dual closure represents a threshold between the old and new types of objects and their respective levels of organisation. In this way a causal logic is obtained, ranking systems from fundamental particles to organisms with brains, all of which are addressed by the generic name of operator. The hierarchy of the operators provides a basic framework that can be used to re-examine existing transdisciplinary classifications and learn more about why they differ in the number of levels they have. It is discussed how big historians might more easily achieve their broad goals if they added the operator hierarchy to their theoretical toolbox.

Introduction

Big historians develop a multidisciplinary historical reconstruction, a timeline, of the phenomena that have shaped the current universe, from the Big Bang to the present. The word history is prominent in the name of the discipline. This has led people to ask whether Big History is an epic, a myth, or a scientific discipline. Science has criteria. Central to it is the construction of theoretical models of the world that support testable predictions. If the predictions can be falsified, the model must be improved. The improved version of the model can then form the basis of new predictions and new tests. The iteration of these steps results in what has become known as the empirical cycle (Geier, 1992). Scientists use this cycle as a tool to construct increasingly accurate predictive models of the world as it was, as it is now, or as it will be in the future.

Building predictive models in Big History is a challenging endeavour for two main reasons. First, the basic data with which to feed a model, or to test the outcome of a model, is always limited because we live in the present, whereas any model of Big History extends into the past and, in the case of predictions, into the future. Fortunately, the past has left traces that can be used as input for modelling and as a reference for checking. Examples include the concentrations of chemicals in rocks of different ages, the layering and folding of rocks, the presence of fossils, the light of ancient stars, or the glow of background radiation in the universe. Second, the processes of cosmic development are inherently complex. The universe contained, and still contains, different types of systems interacting in myriad ways, at different times and on different spatial scales. In addition, new types of systems have emerged from time to time, changing the course of events. The aims of Big History are thus akin to untangling a Gordian knot on the scale of the cosmos.

The challenge of unravelling the cosmic Gordian knot has given rise to a collection of ordering approaches, each with different goals and perspectives. Accordingly, their levels have different names, such as epochs (e.g. Chaisson, 2006), eras or regimes (e.g. Spier, 2015) or dimensions (Henriques, 2003). The following examples show how individual scholars have arrived at their own thresholds and levels.

An early Big History approach is that of Jantsch (1980). He essentially divided all cosmic systems into two large groups, the microstructures, such as atoms and cells, and the macrostructures, such as stars and planets. For each group he offered a timeline of construction steps (summarised in Table 1).

Microstructures	**Macrostructures**
Photons	Superclusters
Leptons	Clusters of galaxies
Baryons	Galaxies
Light nuclei	Stellar clusters
Light atoms	Stars
Heavy atoms	Planets
Molecules	Rock formations
Crystals	Planetary chemo-dynamics
Dissipative structures	Gaia system
Prokaryotes	Heterotrophic ecosystems
Eukaryotes	Societies with division of labour
Multicellular organisms	Groups, families
Complex animals	

Table 1: A timeline of the emergence of increasingly complex systems in the universe. The types of systems are divided into so-called micro- and macro-structures (Jantsch, 1980, Figures 24 (p 94) and 28 (p 132)). Time/complexity increases from top to bottom.

Another Big History classification is that of Chaisson (2001, 2006). He divides the history of the universe into seven epochs, called (1) particle, (2) galactic, (3) stellar, (4) planetary, (5) chemical, (6) biological, (7) and cultural. Around this time, Henriques (2003) introduced the 'Tree of Knowledge System', which developed a progression and ranking in four abstract dimensions of existence: matter, life, mind, and culture. More recently, he and colleagues discussed how the model relates to the aims of the big history community (Henriques et al., 2019). David Christian and William McNiell (2004) wrote the book 'Maps of Time, an introduction to Big History'. Later, David Christian et al. (2014) proposed the use of eight so-called major thresholds of Big History. These thresholds are: (1) origins of big bang cosmology, (2) first stars and galaxies, (3) formation of chemical elements, (4) earth and solar system, (5) life, (6) what makes humans different? (7) agriculture, (8) the modern revolution. This ranking also inspired the book Big History by the Macquarie University Big History Institute (2016). More recently, and using the logic of 'combogenesis', defined as: 'the birth of new types of entities by the coming together and integration of previous things', Volk constructs a so-called Grand Sequence (Volk 2017, p. 1). This consists of twelve fundamental levels, ranging from (1) fundamental quanta, (2) nucleons (protons and neutrons), (3) atomic nuclei, (4) atoms, (5) molecules, (6) prokaryotic cells, (7) eukaryotic cells, (8) complex multicellular organisms, (9) animal social groups, (10) tribal metagroups, (11) agro-villages, and (12) geopolitical states (Volk, 2017, p. 22). Volk also groups the above levels into three dynamic realms: one of physical laws, one of biological evolution, and one of cultural evolution (Volk, 2017; 2020).

These examples show that authors often look for 'macro-level frames and perspectives … to effectively organize their fields and to situate disciplinary findings in a larger picture of understanding' (Henriques et al., 2019). To reach these goals it has been suggested that a 'convergence model of emergence' may well offer a 'comprehensive map of the time-by-complexity relationship' (Henriques & Volk, this issue).

While working along these lines, authors have used different general logics. This explains why there are different rankings with different numbers of levels, while the types of entities may differ between levels. In this context, the identification of a general logic that would link successive levels would be of great help to integrate different rankings, to discuss the consistency of a ranking, to know if there is a gap in a ranking or to extend a ranking with the aim of predicting systems at future levels. Therefore, from the point of view of the empirical cycle, there is an urgent need to find ways to reconcile differences while seeking integration.

Above all, you need a logic if you want to extrapolate a ranking. But not all rankings lend themselves to extrapolation. In order to extend a ranking in the most probable way, taking into account Ockham's rule, it is best to use the simplest logic. If a ranking has the form I, II, III, IIII, IIIII, one can imagine many ways to continue the ranking, for example by repeating it, but the simplest logic is to assume that you get this ranking by 'adding a bar at each step'. Meanwhile, the systems involved are always 'groups of bars'. Focusing on the simplest explanation, the most likely next levels are IIIIII, IIIIIII, etcetera. A logical ranking with these properties can be considered consistent and can be used in a predictive way.

Of course, a ranking can be consistent without being predictive. An example is the following: ..., 1, *, happiness, K, a picture of a stone, green, ... This example follows the logic that the next object can be anything that a person can think of or observe in the world. However, the resulting sequence provides no information about a particular next object, nor about its properties. In this case, the logical ranking criterion has been made too abstract (in the sense of undefined) for extrapolation. In this case, generality gets in the way of making precise scientific predictions, as Popper urged researchers to do. This suggests that researchers should prefer rankings with a kind of logic that is precise enough to allow extrapolation.

Between 1992 and 1993, during a desktop study, the author's attention was drawn to the challenges of creating rankings in ecology that allow extrapolation (Jagers op Akkerhuis, 2010, pp. 13-17). When analysing complexity in ecology, different authors used different numbers of levels, used levels based on different criteria, even within the same ranking, and placed different types of systems at these levels. The desire to organise things in what might be called a meta-approach inspired the search for a common framework for hierarchy in ecology. In the winter of 1993-1994 the idea was born that a particular framework could provide a consistent ranking with fixed thresholds and levels that could be used in a predictive way. The elaboration of this idea led to the first publication about the subject (Jagers op Akkerhuis & van Straalen, 1999). Since then, more and more new insights have been integrated into the theoretical framework now known as O-theory (the abbreviation O-theory is used to distinguish it from, for example, operator theory in mathematics). The principles of O-theory extend beyond ecology and can therefore be of use to Big History.

Before going into detail, it is important to note that in constructing O-theory it has been necessary to overcome three common prejudices about hierarchy in nature, which can be seen as obstacles to the further development and general acceptance of innovations in hierarchy theory. It is considered relevant to discuss here these prejudices that have been encountered in ecology, as they may also affect the way in which big historians think about hierarchy theory.

Prejudice 1: 'Hierarchy in nature is linear'.

The first prejudice is the idea that complexity in nature follows a linear hierarchy. Linearity here refers to a ranking that has only one dimension. This idea of linearity is closely associated with the part-whole analysis of systems. A focus on parts and wholes implies that if you look at a system from the top down, it is made up of parts, whereas if you look from the bottom up, the parts interact to create a large system. This way of working is sometimes presented as a practical one-size-fits-all solution. But the downside is that this logic leads to rankings that freely mix different types of systems and ranking rules. An example is the ranking from fundamental particles to atoms, molecules, stars and planets, people, families and society. At the lower levels of this ranking, small physical particles combine to form more complex physical particles. For example, atoms combine to form molecules. But at the higher levels, interactions lead to groups. For example, when individual people interact, they form families or societies. The people involved take on a new role as members of a family or society. But a family or society is not a physical entity. The members are not attached. They can go their own way, join other groups and even participate in different groups simultaneously. A family, like other groups, is a mental abstraction. Not a physical particle. These examples show that ranking on the basis of parts and wholes runs the risk of confusing physical particles and groups. To use a popular metaphor, they are mixing apples and oranges.

Would it be possible to untangle the mixed hierarchies and create a consistent ranking in which the systems at each successive level are always of the same overarching type? O-theory suggests that to achieve this goal, one must first consciously separate the apples from the oranges (Jagers op Akkerhuis & van Straalen, 1999; Jagers op Akkerhuis, 2010). To explain how this can be done, the following example takes an organism, say a horse, as a starting point. From there, three general hierarchies can be imagined, each with its own rules for identifying levels.

The first hierarchy begins with the horse and extends into its interior. Inside the horse you will find smaller and smaller parts of the body, from the abdomen, to the organs, to the tissues, to the cells, to the membranes, to the molecules, and so on. The levels of this classification can be based on conceptual (fiat) thresholds, such as the horse's abdomen, as well as natural (bona fide) thresholds, such as a cell in a tissue. Interestingly, each time you take a different perspective, such as a metabolic, hormonal or developmental perspective, what you see as parts can change, as can their level. In O-Theory, the many possible rankings within a horse are seen as extending along the 'internal dimension'. There is no preferred order along this dimension.

The second type of hierarchy extends from a single horse to the things it interacts with. Here you can create different groupings, each resulting from specific interactions. For example, a focus on mating leads to groupings called herds or species. Other interactions lead to broader groups such as communities, or ecosystems. You can also create hierarchies based on who eats what. These are called food chains. Each time you choose different interactions to determine the groupings, it affects which elements participate in a group. In O-theory, all the different rankings of groupings are considered part of the 'outward dimension'. There is no preferred order along this dimension.

Third, in addition to the inward and outward dimensions, one can imagine another dimension that organises the differences in the major body plans of organisms. Put simply, this runs from simple bacteria to eukaryotic cells, plants and animals. The basic idea of this dimension is that successive processes of integration lead to increasingly complex types of systems. This idea can be found, for example, in the work of Teilhard de Chardin (1946), Oppenheim and Putnam (1958), and the grand sequence of Volk (2017), and is also central to O-theory. It is associated with what is called the 'upward dimension'.

Just as the size of a wardrobe is defined by three independent parameters, length, width and depth, the above examples span three independent dimensions for ranking hierarchies in the organisation of nature. These insights into three dimensions go beyond the assumption of a single linear hierarchy in nature.

There is a caveat here because the steps along the upward dimension do not come out of nowhere. They depend on developments along the outward or inward dimension. For example, the bacterial ancestors of the mitochondria in eukaryotic cells could not just walk into any bacterial host and live there. Instead, it is thought that their current obligate endosymbiotic lifestyle was preceded by a symbiotic aggregate lifestyle. This aggregate is classified as a grouping along the outer dimension. By analogy, the cells of a multicellular organism, such as a plant or fungus, would probably have lived as a group of attached cells before plasma connections were formed between the cells to fuse them into a single unit. But developments need not always and only use the outward dimension. In the course of evolution, complexifying developments can also take place along the inward dimension. For example, special cells will first have developed extensions that allow them to act as neurons. Then, within a multicellular organism, neurons could evolve over many generations to form large networks that, together with sensors such as eyes and ears and activators such as muscles, could eventually form a next-level entity with its proper position along the upward dimension.

With the above argumentation it is possible to let go of the prejudice that there is a single hierarchical, linear natural hierarchy. Instead, three independent dimensions of hierarchy have been discovered.

Prejudice 2: 'Because hierarchy is always context dependent there exists no preferred hierarchy for organizing nature'.

It is widely accepted in philosophy that the construction of any hierarchy depends on the context of its use. The result is that one can imagine as many hierarchies as there are contexts for their use. For this reason, it seems counterintuitive for O-theory to advocate the use of a preferred complexity hierarchy in nature, especially one with fixed levels. How can this paradox be resolved? One solution is to consider that O-theory is a context-dependent theory. The specific context of O-theory is the identification of a fixed ranking of levels of organisation in nature, which shows a logically consistent sequence of levels and types of systems in such a way as to provide a basis for extrapolation. O-theory thus deliberately aims to identify a hierarchy that is appropriate to this very specific context. Recognising this, it is no longer problematic if the approach results in a single ranking with fixed levels. It is a matter of context.

Prejudice 3: 'Hierarchies suggest that complexity can only increase'

As Spier (2022) has pointed out, processes in the universe can lead to complex systems, but they can also lead to destruction and chaos. For example, all complex life on Earth will one day be destroyed when our Sun becomes a red giant and explodes. This shows that not all processes in the universe lead to complexity. Instead, thermodynamic chaos may eventually prevail. In this respect, one must be careful not to interpret a ranking of complexity as a necessary direction of development. A complexity ranking is a logical ordering of organisational types. Systems can gain or lose a level in the ranking. By the same token, a causal ranking of the emergence of increasingly complex types of systems should not be equated with the logic of a timeline. In general, however, the emergence of more complex systems also demands more time.

Introducing O-theory

The development of O-theory occurred in the context of trying to make sense of the many frameworks used to analyse levels of organisation in ecology. To reduce the complexity of the task, it was decided to focus initially on small systems such as atoms, molecules or cells. The visionary work of Teilhard de Chardin (1946), Oppenheim and Putnam (1958) and, more recently, Jantsch (1980) had already suggested a distinction between small and large systems. As a criterion for small systems, Teilhard de Chardin used their 'formedness' and 'centredness'. Formedness is about having a surrounding layer. Centredness depends on a unifying internal organisation. The large objects did not have these qualities. Teilhard de Chardin (1946) said: 'The atom, the molecule, the cell and the living organism are true units because they are both formed and centred, whereas a drop of water, a pile of sand, the earth, the sun, the stars in general, however complex or elaborate their structure, seem to possess no organisation, no 'centricity'. However imposing their extent, they are false units, aggregates arranged more or less in order of density'. These new discoveries allowed him to group together atoms, molecules, cells and multicellular organisms and to arrange them according to the order of their formation.

Oppenheim and Putnam's approach was based on functional reduction and aimed to provide a framework that would unite all the different branches of science. They described their approach as follows "We offer, therefore, a system of reductive levels chosen so that a branch with the things of a given level as its universe of discourse will always be a potential micro-reducer of any branch with the things of the next higher level (if there is one) as its universe of discourse" (Oppenheim & Putnam, 1958). In order of progressive reduction, Oppenheim and Putnam distinguished the following levels in their model: social groups, (multicellular) living things, cells, molecules, atoms and finally fundamental particles. Because in later years people have associated the levels of organisation in Oppenheim and Putnam's model with the layers of a cake, their model has also become known as the 'layer cake model'.

The works of Teilhard de Chardin and Oppenheim and Putnam were concerned with systems science and preceded the theory of Big History by several decades. Perhaps this is why these works are rarely referred to by big historians. For example, when Jantsch (1980) divided systems into two groups, the microstructures and the macrostructures, and ranked the systems in these groups separately, this shows a marked similarity to these historical publications.

A challenge when working with so-called small systems is the identification and definition of their causal sequence of emergence. This is also recognised by Volk, who proposes as a solution the use of combogenesis, which he defines as 'the birth of new types of entities by the coming together and integration of previous things' (Volk, 2017, p. 1). O-theory suggests an equivalent approach, based on a logic called 'dual closure', originally referred to as 'hypercycle formation' and 'compartmentation' respectively (Jagers op Akkerhuis & van Straalen, 1999) and elaborated in e.g. Jagers op Akkerhuis (2010, 2016). In O-theory, the systems resulting from dual closure are called operators. We can now define O-theory as follows: with dual closures as the basic processes and operators as the basic elements produced by the dual closures, O-theory describes in an abstract causal way how a series of operators of increasingly complex types has emerged in nature. This series is named the operator hierarchy. The levels of complexity resulting from dual closure can also be used as a classification. But this use is only secondary.

In O-theory the construction sequence starts from quarks. Quarks are regarded as fundamental objects that do not themselves exhibit dual closure. For this reason, a quark is not an operator. Volk uses similar reasoning to deduce that quarks precede his grand sequence (Volk 2017, p. 34). With quarks as the basis, every dual closure involves the first possible combination of two closures, a so-called new process cycle and an associated spatial envelope. Both the new process cycle and the spatial envelope have their own definitions.

The new process cycle can be defined as: The first possible, new type of circular process in which the objects change each other's states through an advanced type of dynamic interaction. It is through the advanced interaction that existing entities create the new type of process cycle.

	Dual closure			
Complex property that allows process closure	**Creation of new type of process closure based on transformations**	**Addition of new type of spatial closure causes physical unity**	**Operator type resulting from dual closure:**	**Level**
Quarks emit and absorb gluons	Cycle of mutual transformation through the exchange of gluons between quarks (causes the strong force)	Confinement surrounds the quarks (induced by sufficient space)	**Hadron** (e.g. a proton, neutron or pion)	1 (the first operator)
Hadrons emit and absorb light mesons called pions	Cycle of mutual transformation through the exchange of pions between hadrons (causes the nucleus)	Electron shell surrounds the nucleus	**Atom** (e.g. Helium)	2
'Vacant' positions in electron shells allow for the exchange of electrons	Cycle of mutual transformation through the exchange of electron pairs (molecules) or as a sea (metals) between the atoms	Shared electron shell or electron sea surrounds the atoms	**Multi-atom** (e.g. molecules, metals)	3
Special molecules allow for catalytic reactions	Cycle of mutual transformation through catalytic reactions between molecules	Cell membrane surrounds the plasma with autocatalytic set	**Cell** (e.g. bacteria and archaea)	4
Clonal cells develop plasma connections	Cycle of mutual transformation through plasma exchange between neighbouring cells	Shared membrane surrounds the connected plasma	**Multicellular** organism (e.g. blue-green algae)	5.a
Some cells develop physiological symbiosis.	Cycle of mutual transformation through (obligate) physiological interactions between hostcell and guestcells	Cell membrane of the hostcell surrounds both cells	**Endosymbiont cell** In O-theory: **hostcell** (e.g. protozoa)	5.b
Clonal hostcells develop plasma connections	Cycle of mutual transformation through plasma exchange between neighbouring hostcells	Shared membrane surrounds the connected plasma	**Multihostcellular** organism (e.g. plants, algae, fungi)	6
Some cells develop signal transduction to other cells	Cycle of mutual transformation through information exchange between groups of neurons.	Shared interface consisting of sensors and activators surrounds the neural network	**Neuronmemon** (e.g. horses, humans)	7

Table 2: Overview of how a sequence of dual closures can be seen as causal for the emergence of increasingly complex operators. First, there are lower level entities (quarks or operators) some of which show or develop an advanced interactive property (column 1). Second, this property is causal to the emergence of a new process closure (column 2). Next, the process closure is contained by an associated spatial closure (column 3). The combination results in an operator of a new type (column 4). The last column shows the binary code given to each operator type (modified from Table 2.1 of Jagers op Akkerhuis, 2016, p. 37).

New means that the specific interactions have never occurred before in cosmic history.

The new interactive process is caused first by quarks and then by increasingly complex operators. Because nature can only build more complexity out of what already exists, low-level operators first became part of the next operator. However, because dual closure is an abstraction, becoming a part is not essential. High-level operators can also enable the new process closure in other ways.

The associated spatial envelope can be defined in more detail as: The first possible new type of boundary layer enveloping the elements of a process closure. A cell's spatial closure, for example, specifically mediates the process closure, i.e. the autocatalytic set of molecules that sustain a cell through their concerted activity. The spatial closure should not be considered as impermeable. For example, the ability of food to enter a cell and waste molecules to leave a cell is obligatory for its activity.

At low levels of complexity, spatial closure may not seem very 'material'. For example, a plasma of freely moving quarks exchanging gluons would drift apart as space expands. However, a very strong force, called the colour force, confines groups of quarks to small volumes. In this process, spatial closure is little more than a local force field that did not already exist in the quark plasma, but took shape as space expanded. At higher levels, the spatial closure increasingly takes on a material form. An example of this is the membrane of a cell. As a distinct material layer, the membrane is the interface of the catalytic processes of the cell's process closure.

All the process closures and spatial closures involved in O-theory, as well as the operators they create, are listed in Table 2 (previous page).

Since nature can only build with what is already there, subsequent dual closures up to level six are brought about by the physical integration of objects of the highest possible preceding level, either fundamental particles or operators. The common dual closure logic of all these steps can be explained using the example of the atom.

The process cycle of the nucleus can form because the protons and neutrons have a complex, new property. They can emit and absorb particles called pions, which are themselves hadrons made up of two light quarks. The exchange of pions creates a strong force that binds the protons and neutrons involved, quantum-mechanically linking their states. The resulting process closure stabilises the neutrons, which would otherwise decay with a half-life of about fifteen minutes. The new process that adds the spatial closure is the following. At temperatures below 3000^{o}K, the positive charge of the proton(s) can attract and bind low energy electrons. Due to their particle/wave duality, the electrons settle into a probability space around the nucleus, known as the electron shell.

In combination, the process cycle of the nucleus and the associated spatial envelope of the electron-shell define the atom. The example of the atom is also chosen to illustrate why the definition of dual closure speaks about the 'highest possible' preceding level(s). When a nucleus attracts electrons, these are fundamental particles. This implies that the immediately preceding level of hadrons is skipped. In principle the highest preceding level is the cause of the next dual closure. However, since a spatial envelope of hadrons is physically impossible, the remaining option is that of the next lower preceding level of fundamental particles.

Successive dual closures define a subset of systems which - through their history of emergence - are all members of a large family, the family of operators. Since dual closure is present or not present, the ranking of successive types of operators has fixed levels. The sequence of dual closures results in the following types of operators at the following levels: hadrons (level 1), atoms (level 2), molecules (level 3), cells, such as bacteria and archaea (level 4), multicellular forms, such as the bacterial blue-green algae (level 5a) followed by hostcells, such as protozoa (level 5b) and multi-hostcellular organisms, such as plants, fungi and algae (level 6). The final category is that of the so called neuronmemon (level 7).

What is a neuronmemon? A neuronmemon is a multi-hostcellular organism with a neural network of sufficient complexity to exhibit dual closure. Such organisms are conventionally placed in the taxon Animalia, the animals. However, the term animal in biology also includes the sponges and placozoans, which lack neurons, as well as early evolutionary forms and/or developmental stages that may have a neural network without dual closure. In relation to the focus on dual closure, the new term neuronmemon is introduced to allow a specific focus on organisms with neural dual closure (see also Table 2). The term memon is chosen to honour the meme concept introduced by Dawkins (1976). He discussed the evolutionary dynamics of (mentally) copyable elements of thought, the ideas or, as Dawkins called them, memes, in analogy to the dynamics of genes. Such dynamics are typical of organisms with neural networks or analogous constructions. The shorter term ‘memon’ is used in O-theory to refer generically to all possible types of memons, neuronmemons being a special subset.

Because the neural network of a neuronmemon develops from within a multi-cellular organism, it may seem that this dual closure does not follow the logic of previous dual closures, where operators of the highest preceding level are physically integrated to produce the next dual closure. For example, atoms integrated to form molecules and molecules integrated to form cells. In contrast, whole plants or fungi did not integrate to form a neuronmemon. That the neuronmemon does not deviate from the overall logic is because, as explained above, dual closure always refers to an organisational state. It is an abstraction. Therefore, the new state of dual closure does not have to develop through the cooperation of whole operators, i.e. through integration along the outward dimension. Instead, the dual closure of the neuron-memon evolved like a new organ in an existing multicellular organism. Integration in this case took place along the inward dimension. This was possible because some of the cells in a multi-hostcell organism developed extensions that could send signals to other cells, allowing a neural network with a new process closure to form. At the edges of the neural network, sensors and activators developed to form the spatial closure. The body of a multi-cellular organism simply provided the most efficient scaffold for innovation.

When O-theory speaks about an operator, the focus is on dual closure. For example, O-theory views the living hostcells connected by plasmodesmata as the most important aspect of the organisation of a tree. Strictly speaking, only these connected cells are the operator. This means that the heartwood and bark, which are made up of dead cells, are not included. In biology, however, the focus is generally on the whole phenotype of the tree. It is of practical importance that these two views can be reconciled. Theoretically, O-theory makes a distinction between the operator and its extensions. The living cells of a tree are the operator, and the heartwood and bark are the extensions. The phenotype studied by biologists thus combines the operator and its extensions. And when the neural network and sensors in a multi-hostcellular embryo develop into a neuronmemon, the rest of the tissues change status to become extensions. But in practice, the term operator is also used to denote the operator with its extensions. Whether a text refers to a phenotype, an organism or an operator (with or without extensions) will be easy to understand in most contexts. If necessary, the exact status can be clarified in a short explanation..

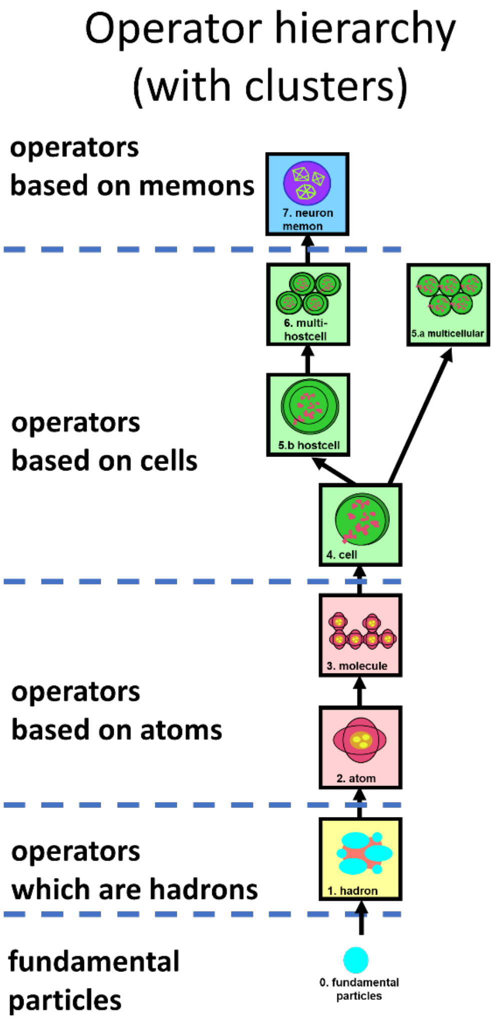

Figure 1: A simple representation of the operator hierarchy. Complexity increases from bottom to top, one dual closure at a time. Dashed blue lines and colour differences separate operators in clusters. All operators in a cluster are combinations or elaborations of the basic operator of the cluster (the first in the cluster). A new term is introduced for the most complex operator: neuronmemon. Simply put, this term refers to an animal with a neural network with dual closure.

A basic graph of the emergence of all types of operators is shown in Figure 1.

A unique result of the logic of dual closure is that the ranking it produces shows a branching pattern, because after the level of the cell (e.g. bacteria and archaea) there are two options to continue the hierarchy. One option is to go towards multicellular forms of bacteria (such as cyanobacteria). The other option is to continue in the direction of cell-in-cell construction of the eukaryotic cell. O-theory prefers to use the term hostcell rather than eukaryotic cell. This is because in many cases the nucleus of the cell, the 'karyos', is lost during cell division, only to be rebuilt later in each daughter cell. However, the cells that are part of the obligatory endosymbiotic relationship, such as mitochondria and chloroplasts, always remain present during cell division. This makes them better candidates as criteria for use in O-theory.

Once the hierarchy of the operators has been constructed, it can be used as a basis for analysing the organisation of all other systems resulting from interactions between operators, which in O-theory are called interaction systems.

How the use of dual closure can contribute to Big History

A major scientific goal of Big History is not only to organise historical knowledge, but also to create predictive models of cosmic development. As a basis for prediction, one needs a consistent model of levels of complexity. Dual closure provides such a model. Because of the dual closure, the operator hierarchy has fixed levels, while the systems involved are always operators. This means that the hierarchy is consistent in terms of both rules, levels and entities. Consistency also means that different people using dual closure will in principle always arrive at the same basic hierarchy.

Now that the operator hierarchy provides a ranking with a continuous series of fixed levels, one can consider extending this ranking to future types of operators. To extend a hierarchy one always needs some kind of periodicity. The study of periodicity in the operator hierarchy is an extensive topic that has been explored in previous work by the author (Jagers op Akkerhuis & van Straalen, 1999; Jagers op Akkerhuis, 2016). O-theory starts with dual closure steps as the first-order periodicity, and from this basis recognises higher-order periodicities.

One fundamental higher order periodicity is that of clusters. Put simply, all the operators in a cluster share the same type of building block. For example, in the cluster of atoms and molecules, all systems are either atoms or made up of atoms. Similarly, in the cluster of cellular operators, all systems are cells or are derived from cells, such as multicellular organisms, hostcells and multihostcellular organisms. Finally, in the memon cluster, only the neuron-memon has evolved so far (see Table 2).

Another fundamental higher order periodicity is that of so-called closure families. Across clusters, closure families group operators that share a common property. For example, hadrons (hadron cluster), molecules (atom cluster), multicellulars, and multihostcellular organisms (cell cluster) are all recognised as members of the so-called multi-operator closure family, because they always represent groups either of quarks (in the case of hadrons) or of preceding level operators (in all other cases).

The opportunity to explore the ability of higher order regularities to predict future operator types is new. However exciting it is, the derivation of accurate predictions remains a challenging area of research. It is beyond the scope of this paper to go into detail here, as higher order regularities would first need to be properly introduced and then combined to produce accurate predictions. How this can be done has been explored in previous work by the author (e.g. Jagers op Akkerhuis, 2001; Jagers op Akkerhuis, 2016; pp. 271-275). This is all work in progress. Simply put, the results so far suggest that the memon cluster will one day house a total of eight types of memon, the more complex of which are all technical in nature.

O-theory is not a theory of everything. Dual closures restrict the theory to operators. This allows three contributions to classical problems in Big History: (1) the classification of systems into two large non-overlapping groups, one containing the operators and the other containing all systems without dual closure, the so called interaction systems, (2) the construction of a consistent hierarchy with fixed levels of increasingly complex types of operators, (3) deductions leading to predictions of future memons. With the possibility of predicting future memons, O-theory provides big historians with a methodology for complying with the empirical cycle.

With the new approach, the operators, classically called small systems, can be organised in a consistent way. The challenge that remains is to organise what are classically called large systems, such as galaxies, black holes, stars, planets, meteorites, ecosystems and societies. All these systems are made up of interacting fundamental particles and/or interacting operators and are called interaction systems for this reason.

Both the operators and the interaction systems play their part in the development of the universe. It is therefore not possible to separate these systems causally. However, a conceptual separation is possible. In the context of Big History, I have proposed in previous work to distinguish between a 'phenotypic' and a 'genotypic' perspective (Jagers op Akkerhuis, 2019 p 67). The phenotypic perspective of the universe focuses on how the world as a whole appears to us. This perspective is represented by interaction systems. Observations of phenomena of interaction systems play a leading role in many epochal approaches in Big History. First there is a universe filled with plasma. Then clouds of matter form, which contract to form galaxies. Within the galaxies, black holes, stars and planets form. And then, on the planets, you can see ecosystems forming. Finally, in some ecosystems, roads, factories and cities mark the rise of culture. It will be intuitively clear that this focus on the world as a whole is complemented by a focus on the emergence of the operators. In retrospect, the naming of a phenotypic and genotypic perspective is confusing, as it has strong associations with biology. It may therefore be better to speak simply of interaction systems and operators. This is also closer to the use of macrosystems and microsystems proposed by Jantsch (1980, see also Table 2).

Obviously, interaction systems and operators offer inseparable perspectives on universal dynamics. At the same time, each perspective triggers its own thresholds. First, when focusing on interaction systems, they go through stages of development that result from different processes and can be viewed from different perspectives. For example, a star begins its life as a cloud of cosmic dust. The cloud contains fundamental particles, hadrons, as well as hydrogen and helium nuclei and atoms. Gravity then pulls the dust together. Depending on the amount of dust, a star or a black hole is born. The processes can take different paths. Inside stars, nuclear fusion produces larger types of atoms. Over time, a 'young' star can become an 'adult' star, and eventually an 'old' star. This may become a red giant before exploding. New secondary or even tertiary stars can form from the debris. Planets can also form. Once formed, a planet remains a planet. But on the planet, new processes can lead to the emergence of bacteria, followed by eukaryotic cells and eukaryotic multicellulars. These new inhabitants change the 'type' of the planet as a whole from a chemical system to an ecological system. Within these patterns of change, many different thresholds can be identified, caused by different processes and leading to different sequences and/or cycles of events. Secondly, by focusing on dual closures, the analyses are guided into a step-by-step approach to thresholds, each associated with the next type of operator. The use of dual closure implies that there is only one perspective. Depending on the perspective chosen, either interaction systems or operators, what is seen as a threshold is different.

Combining the interaction system and operator viewpoints opens up new possibilities. For example, based on operators and their hierarchy, interaction systems can be ranked according to the most complex operator present or dominant in the system. This is also logical from a functional point of view, as the most complex operator will generally tend to drive the salient processes that characterise the system. For example, a planet may change from being a chemosystem, hosting atoms and molecules, to an ecosystem, once it has also become home to bacteria. The 'type' of planet may then change again the moment eukaryotic cells appear. In this way, the operator hierarchy provides a tool for fine-tuning the classification of the type or 'developmental stage' of celestial bodies.

Discussion

How can O-theory contribute to Big History? Two contributions can be suggested here. The first focuses on the general approach taken by Big Historians. It starts with the question of what Big History is and what are the foundations of the discipline. Big History is often described as a scientific discipline that examines history from the Big Bang to the present, is multidisciplinary, looks for universal patterns or trends, and places humanity in a universal context. Given these characteristics, Big History can be seen as a broad canvas that connects well-known academic disciplines such as quantum physics, chemistry, biology, sociology and robotics. Researchers in each of these disciplines look for empirical evidence and cause-and-effect relationships that allow them to construct models and make testable predictions. In this way they follow the empirical cycle. Each discipline already covers its own local part of the broad canvas that connects all the sciences. This means that the contributions of Big History lie in the area of integrating frameworks and overarching patterns. What is the unique contribution of Big History to achieving such goals?

In attempting to answer this question, it is relevant to mention another discipline with a broad scope called systems science. Systems scientists study abstract commonalities between systems of all kinds, extending the scope to the universe and everything in it. This overlap suggests that

Big History and systems science are natural partners. Potentially, then, collaboration with systems scientists could help big historians achieve their goals of extracting large patterns, building overarching frameworks, and using their insights to guide scientific predictions. Because O-theory is rooted in systems science, it can help connect Big History with this broad discipline.

The second contribution of O-theory is in the area of thresholds. It has been suggested that ‘the concept of thresholds in Big History is fatally flawed and ought to be abandoned’ (Spier, 2022). This criticism is underpinned by four claims. The first is that there is no clear definition of what a threshold is. The second is that there are no clearly defined scientific criteria for setting a threshold. The third is that the proposed thresholds cannot be used to structure the whole of Big History. The fourth is the focus on increasing complexity while ignoring its decrease.

O-theory can help big historians translate the above criticisms into an advanced view of thresholds. To illustrate how this can be done, the four points raised by Spier can serve as an example. Using O-theory, there is clarity about what a threshold is, because each threshold is defined by a dual closure that leads from operators at level X to a more complex kind of operator at level X+1 (point 1). The way in which the dual closure distinguishes thresholds is abstract, but has its basis in both physics and systems theory (point 2). It is also relevant that O-theory does not exaggerate its goals. It focuses primarily on the operators and their hierarchy of emergence as a result of dual closures. It does not aim to organise the whole of Big History. Any broader application, such as considering an analysis of Big History based on interaction systems, can always refer to the ranking of the operator hierarchy as a basis (point 3). After all, what the operator hierarchy provides is an abstract, causal ranking. This ranking classifies systems according to the number of dual closures required for their emergence. By gaining or losing a dual closure, systems can move up or down this ranking. Both the possibility of gaining and losing dual closures are natural options in O-theory (point 4). These arguments show that O-theory can solve problems with the definition and interpretation of thresholds.

In summary, O-theory analyses phenomena in the universe from a systems perspective, which means that it uses the system concept as a mental tool. However, it does not generalise to a level where all things are systems. Instead, it distinguishes between types of systems, mainly operators and interaction systems. Starting from fundamental particles, increasingly complex operators result from dual closures. By offering a singular, causal perspective based on dual closure, the operator hierarchy provides a means of solving the problem that the rankings in Big History generally differ in the number of levels of complexity, in the types of entities, and in the rules for moving from one level to the next. The proposal is therefore to add the operator hierarchy to the theoretical toolbox of Big History. Next, the operators and their ranking can be used to analyse the world of interaction systems, which can be seen as the appearance of the universe at large. Since the ranking proposed by O-theory is logically consistent because it is based on dual closures, it offers possibilities for predicting future types of operators. Given all these new possibilities, the use of O-theory could help big historians to make their discipline not only an integrative, causal and transdisciplinary science, but also a predictive one.

Acknowledgements: The author gratefully acknowledges the constructive comments of Prof. Tyler Volk, which contributed to the quality of this paper and its suitability for Big History.

References

Chaisson, E. (2000). *Cosmic evolution: The rise of complexity in nature*. Harvard University Press.

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

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

Christian, D. (2004). *Maps of time: An introduction to big history.* University of California Press.

Dawkins, R. (1976). *The selfish gene*. Oxford University Press.

Geier, M. (1992). *Der wiener kreis: Mit selbstzeugnissen.* Original 1929. Rowohld Taschenbuch Verlag.

Henriques, G. R. (2003). *The tree of knowledge system and the theoretical unification of psychology. Review of General Psychology*, 7, 150-182.

Henriques, G. R., Michalski, J., Quackenbush, S., & Schmidt, W. (2019). *The tree of knowledge system: A new map for big history. Journal of Big History*, III(4), 1-17.

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. (2010). *The operator hierarchy. A chain of closures linking matter, life, and artificial intelligence. Alterra Scientific Publications*, 34.

Jagers op Akkerhuis, G. A. J. M. (2016). *Evolution and transitions in complexity. The science of hierarchical organization in nature.* Springer Nature.

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

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.

Macquarie University Big History Institute. *(2016). Big History.* Dorling Kindersley.

Oppenheim, P., & Putnam, H. (1958). *Unity of science as a working hypothesis. Minnesota Studies in the Philosophy of Science*, 2, 3-36.

Spier, F. (2015). *Big history and the future of humanity.* Wiley-Blackwell.

Spier, F. (2022). *Thresholds of increasing complexity in big history: A critical review. Journal of Big History,* 5(1), 48-58.

Teilhard de Chardin, P. (1969). *The future of man*, pp 109-110 (Editions du Seuil V, p. 137; 1946).

Volk, T. (2017). *Quarks to culture: How we came to be.* Columbia University Press.

Volk, T. (2020). *The metapattern of general evolutionary dynamics and the three dynamical realms of big history. Journal of Big History*, 4(3), 31-53.