

## Chapter 2

# Introducing the Operator Theory

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*“It seems to be felt in some quarters that the deliberate use of a technique of theorizing involves (in the case of biology) “fitting the facts of life” into some rigid predetermined scheme. Nothing could be further from the truth. Far from making facts conform to a scheme (which in any case would be impossible) we deliberately construct the theoretical system in such a way that it will as faithfully represent the facts as possible”*

(Woodger 1939, p. 74).

**Abstract** The Operator Theory is a new theory about the hierarchical organisation of complexity in nature. The theory is based on the idea that in the space of all possible processes, a small subset exists of highly specific processes through which small objects can integrate to form new, more complex objects. The Operator Theory focuses on this small subset of objects. The processes that the Operator Theory focuses on are referred to as uniform closure of the structural and functional kind. The combination of such closures is called a dual closure. Based on dual closures, and in a step by step way, the Operator Theory identifies a branching hierarchy of kinds of objects that have increasingly complex organisation. Any object of a kind that is included in this hierarchy is called an operator, and the branching hierarchy is called the Operator Hierarchy. Interestingly, there are strong indications that, in analogy with the primary and secondary structure of amino acids, the Operator Hierarchy has a secondary structure. The Operator Theory hypothesises that this secondary structure offers a means to one day predict the structure of future kinds of operators. By offering a stringent classification of the operators of different kinds, from quarks to multicellular animals, the Operator Theory can be used to contribute to discussions about fundamental concepts in science, e.g. individuality, organismality, hierarchy, life and (the prediction of) evolution.

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## 2.1 Introduction

### 2.1.1 *Why Was the Operator Theory Constructed?*

The classical literature about ecological/natural hierarchy offers many different rankings of hierarchy in nature that are based on levels of organisation, or levels of complexity, and that include for example atoms, molecules, organelles, cells, organisms, populations and ecosystems (e.g. von Bertalanffy 1950; Feibleman 1954; Salthe 1985; Simon 1962; Koestler 1967; Jaros and Cloete 1987; Alvarez de Lorenzana 1993).

The above literature offers three dominant classical concepts for analysing hierarchical relationships: meronomy, taxonomy and emergence. Meronomy describes how large physical objects have smaller parts, which in turn can have smaller parts etc. An example of a meronomy is a horse which has a heart that between other things consists of muscles, which in turn consist of muscle cells etc. The second concept, taxonomy, describes conceptual subsets that can be identified inside a larger set. An example of taxonomy is the set of all animals, which includes the set of mammals, which includes the set of dogs etc. The third concept, emergence, focuses on how new systems/objects are formed from the interactions between existing objects. An important aspect when focusing on emergence is that modules, aggregates, or assemblies can scaffold further steps. It is exemplified in Simon's (1962) story about the watchmakers Hora and Tempus indicated, and indicates that existence of modules is an important factor in emergence. From the story: The watchmaker Hora put together his watches from smaller, stable modules. Meanwhile, Tempus worked without using modules. When they were disturbed, Hora had only to rebuild the most recently constructed module. The unfortunate Tempus had to restart the entire assembly of his watch from scratch.

If the aim is to create a stringent hierarchical ranking, one should in principle either use taxonomic rules, meronomic rules, or emergence. And one should stick to the kind of entities that fit the selected rule. Meronomy should include only physical objects. Taxonomy should be based selectively on abstractions called sets, or groups. And emergence should focus on interactions between physical objects.

The demand to focus on a single rule and a single kind of entities is not always respected by classical approaches to hierarchy in nature. To further explore this failing we investigate an example-ranking from atom, to molecule, to organelle, cell, organ, organism, population and ecosystem. The steps of ranking from an atom to an organ and then to an organism can be viewed as ranking ever larger physical parts inside a multicellular organism. Here one can recognise a meronomic ranking inside the organism. The difficulty arises with the term organism. The organism concept is included as a single level, while it refers both to a single physical organism, and to a class that includes all organisms, e.g. a bacterial cell and an elephant. And "above" the organism the ranking shifts its focus from physical objects to conceptual grouping, e.g. populations and ecosystems, which represents a taxonomic approach. As the same ranking includes both meronomic and taxonomic aspects it can be viewed as a mixed approach.

Another aspect of the use of methods such as meronomy—is a part of—and taxonomy—is a kind of—is that such methods start from a specific highest level; they work from the top down. For example, inside a molecule one finds parts called atoms. And of all the animals, a special subset is formed by the dogs. Such a top down perspective does not fit well if the aim is to explain the formation of complexity from the bottom up. For example, one cannot start with an atom and say that a molecule is a part of it. And neither can one start with an atom and say that a molecule is a kind of atom. If the aim is to work from the bottom up, a methodology is needed that is based on emergence and the stability of aggregates such as was proposed by Simon (1962). The wish to construct a conceptual framework based on emergence, that creates a hierarchy of objects that are all formed from the bottom up, became the starting point for the Operator Theory.

While working from the bottom up the Operator Theory had to start with defining low complexity concepts/objects, and uses these as a theoretic foundation for defining more complex concepts/objects. The idea was to create an unbroken chain of theoretic steps, in which ideally every next object/definition is based on already established objects/definitions. The idea that theory must be constructed from the bottom up also can be found in so-called axiomatic approaches in mathematics (Whitehead and Russell 1910, 1912, 1913) and biology (Woodger 1937; Nicholson and Gawne 2014).

The Operator Theory's primary goal thus became the identification and ranking of the building blocks in nature, from the small to the large. Since the Big Bang, increasingly complex building blocks have been formed, such as quarks, hadrons, atoms, cells, cells with endosymbionts, multicellulars, and multicellulars with brains. Based on the idea that each of these special building blocks can be viewed as to operate as a single, countable material unit in its environment, the term *operator* was chosen as a generic name for these building blocks (hence the name Operator Theory). The Operator Theory thus aims at understanding the sequential formation of operators and to analyse this sequence as a special aspect of ontogenesis in the universe. As a secondary goal, the Operator Theory also aims at the description of any material entity in the universe in terms of operators. To achieve these two goals, the Operator Theory had to start with the smallest, lowest complexity objects in nature, which according to current knowledge are the fundamental particles that are studied by particle physicists, out of which all matter in the universe is eventually constructed.

Moreover, it was a goal of the Operator Theory to identify, for every step in the sequence starting with quarks, logical criteria which could offer justification for why a particular kind of system actually represented a next kind of operator. Such criteria should also indicate why this kind of system, and not any other kind, could be accepted as the right kind for the next rung on the complexity ladder.

## 2.2 Introducing Systems and Objects

As a basis for explaining the Operator Theory in the next chapter two concepts need to be explained beforehand: system and object. Interestingly, the concept of a system has proven rather difficult to define, possibly as the result of its many different

applications and interpretations. In some schools of thought, a system is viewed as a synonym for a group of entities that show relationships. Now many things can be a system, e.g. a house, a herd of cows, and the earth. Other approaches are more specific and define a system as something that produces its own limits. Now one could think of an organism, or a soap bubble. Still other schools view a system as an arrangement of things which are arranged such that they help someone to accomplish a specified task. Examples of the latter are an education system, or a factory. Still others speak about systems of interacting agents as complex adaptive systems. In the next paragraph we try to identify a common denominator of all these system concepts.

### ***2.2.1 Existing Ideas About Systems***

When talking about a system, it is important to realise that the concept system represents an abstraction that is man-made and that generally will be imprecise to some degree. That a system always is a man-made model has already been indicated by Bernard (1865) who suggested that “les systèmes ne sont pas dans la nature mais dans l’esprit des hommes”, which says that systems do not exist in nature, but only in the minds of humans. With his statement, Bernard emphasised that humans use their conceptual powers to view chosen objects and chosen relationships in an integrated way as a system. In mathematics such a system of chosen objects and chosen relationships is called a structure. The viewpoint that systems consist of consciously selected objects and relationships can also be found in Checkland and Scholes (1990, p. 22) who in their book about soft systems methodology emphasise that it is “perfectly legitimate for an investigator to say “I will treat education provision *as if it were a system*”, but that is very different from declaring that it *is* a system. This may seem a pedantic point, but it is an error which has dogged system thinking and causes much confusion in the systems literature”. The reason why Checkland and Scholes (1990) call their approach soft systems methodology is that the process of enquiry itself can also be analysed in a systemic way, so to speak as a “soft” system.

### ***2.2.2 The Role of Objects in a System***

When reasoning about a system, the objects in the system have so far only implicitly been included. Yet objects are important, because any systemic analysis presupposes that it is possible to identify objects and their relationships. This leads to the question of how one can determine whether something is viewed as a system or as an object. To answer this question, the Operator Theory suggests using the same strategy as when defining a system, but now with a focus on the intention to wilfully view an entity as an object, instead of as a system. To view an entity as an object,

one must thus make a wilful choice, i.e. the classification is taken as an axiom. Given an object oriented viewpoint, a teacup, an ecosystem, a soil layer, a distant galaxy with millions of stars that are part of it or an imaginary unicorn all can be viewed as objects in one's reasoning. For each object, one must select criteria that allow the identification of the objects' limits. Such criteria can for example be made dependent on functional aspects, such as a specific horizon in a soil where litter is degraded, and on structural aspects, such as when children dance and create a circle-object by holding hands with their neighbours.

### 2.2.3 *Systems and Objects in this Book*

In summary, when discussing systems/objects in this book, the following things are relevant.

- Both a system and an object are viewed as wilful selections. When selecting an object one only needs to decide on the limit of the object. The process of selecting a system is more demanding because it requires: (1) A selection of criteria that limit the volume/edge/extent of the system, (2) A selection of criteria for the identification of different objects inside the volume, and (3) A selection of criteria for relationships between objects that are part of the system that are viewed as being relevant.
- Both an object and a system are subsets of a larger world. This implies that the environment of a system or object is naturally involved if one thinks about a system/object.
- The question of whether something is viewed as an object or as a system cannot be answered by criteria that originate from the entity itself. Instead, the intentions of a person determine whether an entity will be viewed as a system or as an object. Accordingly, Bernard's (1865) statement that systems are in the heads of people, can be extended by adding that a system can only be found in the head of a person who looks at an entity with the intention of analysing it in a systemic way.
- We follow soft systems methodology (Checkland and Scholes 1990) in the suggestion that the methodology of systemic inquiry can itself be looked at as the subject of systemic inquiry.

## 2.3 Introducing Closure

Many years ago, Teilhard de Chardin wrote the following: "First, in the multitude of things comprising the world, an examination of their degree of complexity enables us to distinguish and separate those which may be called 'true natural units', the ones that really matter, from the accidental pseudo-units, which are unimportant.

The atom, the molecule, the cell and the living being are true units because they are both formed and centred, whereas a drop of water, a heap of sand, the earth, the sun, the stars in general, whatever their multiplicity or elaborateness of 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. Secondly, the coefficient of complexity further enables us to establish, among the natural units which it has helped us to ‘identify’ and isolate, a system of classification that is no less natural and universal” (Teilhard de Chardin, 1969).

Teilhard de Chardin had an intuitive notion of why certain objects were formed and centred, and other objects did not have such qualities. Yet it remained difficult at that time to offer precise criteria indicating why and when units were formed and centred. The question of what defines unity can also be recognised in the work of other authors including for example the metabolic repair system, and closure to efficient causation (Rosen 1958), autopoiesis (Maturana and Varela 1973), the hypercycle (Eigen and Schuster 1979; Kauffman 1993), the strange loop (Hofstadter 1979), closure (Heylighen 1989a,b, 1990; Chandler and Van De Vijver 2000), quanta of evolution (Turchin 1995) and agency/autonomy (e.g. Ruiz-Mirazo and Moreno 2012; Moreno and Mossio 2015).

Of all these criteria, the concept of closure is viewed in this book as a connecting principle because it can be linked to many of the other concepts. This is the reason why closure has been given a fundamental position in the Operator Theory. In the following paragraphs the concept of closure is explained followed by a discussion of how it is applied in the current book.

### ***2.3.1 An Intuitive, General Explanation of the Concept of Closure***

One of the oldest visualisations of closure is perhaps the ancient symbol of the Ouroboros, the snake that swallows its own tail and by doing so creates a structure of which the beginning and end meet. Closure has gained increasing interest in recent years. The use of the concept of closure in the current book was originally inspired by the works of Goguen and Varela (1979) and Heylighen (1989a,b, 1990). Later an international workshop about closure resulted in a book edited by Chandler and Van De Vijver (2000). Since that time closure has become the subject of an increasing number of publications notably by the group of Moreno, e.g. Mossio and Moreno (2010a,b), Ruiz-Mirazo and Moreno (2012), Mossio et al. (2013), Moreno and Mossio (2015) and the group of Letelier, e.g. Soto-Andrade et al. (2011), Letelier et al. (2003), Luz Cárdenas et al. (2010), Letelier et al. (2011).

Closure can also be expressed in mathematical terms, where it relates, for example, to the situation in which a set is closed for the performance of an operation on its elements. As a case: the set of natural numbers (0, 1, 2, 3, ...) is closed for addition, but is not closed for subtraction, because  $2 - 5 = -3$ , which is not a natural

number. Closure represents a special property of a system because the state space of a closed system has become invariant (i.e. it does not change) under the internal dynamics (e.g. Heylighen 1990; Chandler and Van De Vijver 2000).

In this book the term closure is predominantly used in relation to the closed state that results from the closing process. Closure thus refers to a topology. Closure as a topology creates an intimate link between form and functioning, because specific functionalities of the elements have become unified through the emergence of a closure.

### ***2.3.2 The Utility of Using Closure When Analysing Complexity***

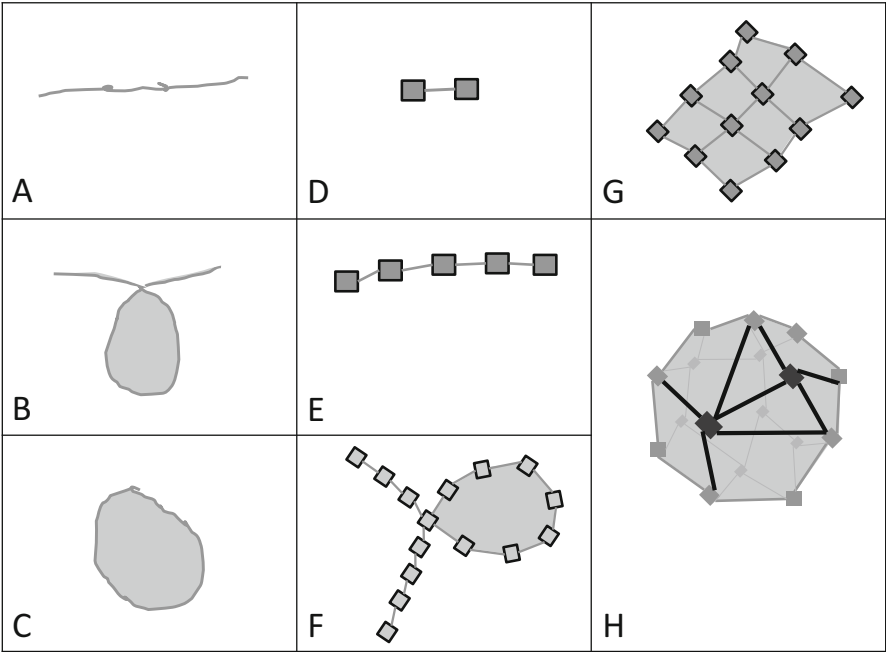
Closure is a potentially very powerful concept when creating a hierarchy of complexity. The reason is that closure has the unique property of unifying all the elements involved into a single entity, either conceptually or materially. This property of closure allows one to identify amidst of all the chaos in the world a select group of elements that together can be viewed as a single countable unit.

## **2.4 Defining Closure as It Is Used in This Book**

The concept of closure in this book is based on the Operator Theory. Before discussing closure in a more formal sense, an intuitive introduction is offered of the concept. For this purpose one can imagine a piece of rope that lies on the table. From this rope different figures can be made, but if a person takes one end of the rope in the left hand and the other end in the right hand, and the ends are pulled apart, the result is a stretched piece of rope (possibly with some small knots) (Fig. 2.1a). Things are different if before stretching the rope, the two ends would have been knotted together. If the knot has loose ends the pulling apart of the rope's ends will result in a short stretch of rope that has a loop of rope dangling from it (Fig. 2.1b). If the knot was very close to the ropes ends, it is no longer possible to grasp the ends of the rope, because the rope has become a close to perfect loop (Fig. 2.1c).

The presence of this loop is what here is called closure. When one takes a two-dimensional picture of the loop, the loop surrounds an area and closes that area off from the area outside the loop. Because the surface inside the loop is surrounded, or enclosed by the rope on its outer edges, the configuration of the rope is named closed, and the part of the rope that creates the loop will be referred to as having closure.

This idea of closure can be generalised to spaces with more than two dimensions. This can be done by imagining that instead of a rope, one would use a sheet of rubber. This sheet of rubber can then be stretched and folded in such a way that (part of it) creates a box, ball or other three- or multi-dimensional shape which surrounds a specific volume of empty space and closes it off from the space outside.



**Fig. 2.1** Explaining closure in an intuitive way. For explanation of examples (a) to (h) see text of Sects. 2.4.1 to 2.5.1

**2.4.1 From a Rope to a Chain of Objects Connected by Relationships**

In the world, things do not generally consist of rope or rubber. This implies that for using the concept of closure in the world, the above examples will have to be generalised into a definition which covers closure in any physical object. For this purpose one can look at the world as if it consists of objects that are related in some way. If an object  $O_1$  has a relationship with object  $O_2$ , the objects can be viewed as being linked by this relationship (Fig. 2.1d). And if an object  $O_1$  links to object  $O_2$ , which links to object  $O_3$  etc. to object  $O_n$ , the resulting chain of links can be viewed as a translation of the open configuration of a physical rope. Accordingly, any linear chain of links between object  $O_1$  to  $O_n$  can be viewed as an open chain of interactions (Fig. 2.1e).

In the same way, one can also create a chain of objects with a loop in it. Let us imagine a chain of objects  $O_i$  with  $i$  ranging from 1 to 15. One now can imagine that the links  $O_5$  to  $O_{12}$  form a loop, because there is a link from  $O_{12}$  back to  $O_5$ , while the links from  $O_1$  to  $O_5$ , and those from  $O_{12}$  to  $O_{15}$  form chains that are open at one end, and that connect to the loop at the other end (Fig. 2.1f). In such a case, the part from  $O_5$  to  $O_{12}$  has closure. As long as a chain of links does not have a loop, it is



viewed as open. Because of this both a linear and a branching chain of objects are viewed as being open.

It is not so difficult to apply the object-based approach to the sheet of rubber that surrounds a volume. For this purpose one can imagine a number of objects that in a two dimensional way are connected to form a sheet (Fig. 2.1g). And this sheet of connected objects can be folded around an imaginary volume (Fig. 2.1h).

### 2.4.2 Closure Caused by One or More Moving Objects

In the above examples it was assumed that the objects had a fixed position in a chain or as part of a sheet. However, it is theoretically advantageous if closure can also be used in the case of one or more objects that move through space, and that follow a path that bends back onto itself (e.g. a planet going around the sun). The path that such an object follows can comply with the above definition of closure, because the path of the moving particle encloses a surface or space.

### 2.4.3 A Definition of Closure

Following the above preparations, a definition of closure can be deduced as follows:

*Closure is the property that one or more entities behave and/or interact in such a way that the result can be viewed as surrounding a space in two (surface), three (volume) or more dimensions.*

## 2.5 Kinds of Closure

The above definition allows for a broad variety of closures. The Operator Theory does not use all such possibilities. Instead it focuses on a limited selection of specific kinds of closures: dealing only with what are called uniform closures of the functional and structural kind.

Uniform functional and structural closures are combined to create dual closure. Dual closure is used in the Operator Theory to identify next-level operators. The identification process starts with fundamental particles after which subsequent dual closures lead to the first kind of operator, and the next etc. In this way next kinds of operators are derived from previous ones in an iterative manner, resulting in the operator hierarchy.

When speaking about the iteration of dual closure, this may bring to one's mind the picture of a linear ranking of steps. However, the rules for dual closure are more intricate and can also lead to a branching pattern. The possibility of a branching

pattern can be understood from an analogy with a ball. Using a ball as the starting point, there are not just one but two options for new closed configurations. One closed configuration is that of two balls that are attached like soap bubbles, with a shared contact surface, and one connected outer surface. Another configuration is that of a small ball inside a large ball. In analogy to the example of the ball, a ranking that is based on dual closures can lead to a linear ladder, but can also diverge into a branching pattern.

Whether or not dual closure leads to one or more different kinds of operators in the next step must be evaluated for every operator. This implies that if one investigates every step locally, which represents a localised, myopic point of view, there is no simple rule that predicts whether branching will occur, or what particular shape the next dual closure will have. When looked at the Operator Hierarchy this way there is no algorithm that allows one to predict the next dual closure. However, as discussed below, the Operator Theory focuses on regularities in the ranking for hypothesising that the overall ranking of all known kinds of operators has a higher order branching structure that may well be the result of an overarching algorithmic logic. The nature of this overall logic is the subject of ongoing research.

The following paragraphs explain further what is meant by the terms uniform closure, functional/structural closure and dual closure. After that, an explanation is offered how dual closures can be used to create the operator hierarchy.

### ***2.5.1 Uniform Closure***

As was said before, the Operator Theory only makes use of uniform closures. To explain what a uniform closure is, it is illustrative to first describe an example of non-uniform closure.

Imagine a set of three objects: a bicycle, an apple and a molecule. The relationships between these objects can be many, but one can for example imagine that the bicycle rides over the apple and crushes it, that the apple releases a molecule of a volatile apple-oil, and that this oil-molecule condenses onto the bicycle. In principle, the relationships from the bicycle, to the apple, to the molecule, to the bicycle can be viewed as representing a closure. In an example like this, however, both the objects and the relationships between the objects vary, and it is hard to identify an overall logic which binds the diverse elements together. One might therefore call a closure like this one, with different kinds of objects and different kinds of relationships non-uniform closure.

In contrast to a non-uniform closure, which can be based on objects and relationships of (very) different kinds, a uniform closure is based on objects which are all of the same kind, while the relationships between the objects are also all of the same kind. This statement begs the question: when are objects, respectively processes, of the same kind? The criteria for identifying the kinds of objects and processes that play a role in the Operator Theory are explained later on, for example in Sects. [2.5.4](#), [2.6.1](#) and [2.6.3](#).

### 2.5.2 *Functional Versus Structural Closure*

On top of only dealing with uniform closures, the Operator Theory also limits itself to functional and structural closures.

In a functional closure the objects are connected through links that can be viewed as unidirectional transformations. During a unidirectional transformation a first object alters the physical construction of a second object through a physical interaction, in such a way that the interaction either changes both objects, or only the second object. One can visualise successive unidirectional transformations as a chain of links represented by arrows from the first to the second object, the second to the third etc. Such a chain has functional closure when at some point the chain loops back onto itself and thus creates a closure of the process chain. This definition implies that a functional closure has a minimum size of two objects connected by two processes (arrows).

An example of a functional closure is given by a set of for example three catalytic molecules ( $M_1$  to  $M_3$ ) which transform substrate molecules to catalytic molecules that are part of the set. In this set,  $M_1$  catalyses the production of  $M_2$ ,  $M_2$  that of  $M_3$  and  $M_3$  that of  $M_1$ . The relation between catalysts and molecules produced through catalysis forms the loop required for closure.

The other kind of closure that plays a role in the Operator Theory is the structural closure. Structural closure implies that a group of objects interact in a non-transformative way while their locations are confined by the formation of a closure. The closure can have two different forms: one form is that of a two dimensional surface that completely surrounds a volume, as in the case of a rubber ball where the rubber surrounds a volume of air. The other form is that of one or more moving objects whose paths create a closed shape. An example of the latter is an electron that is part of an atom. In this case, structural closure can be seen to occur in two ways. (1) When the electron returns to a point it was at before, thus closing a loop and (2) the set of its possible locations creates a sphere known as the electron shell, which completely surrounds the nucleus. Due to Pauli's exclusion principle, the electron shell has physical relevance, because the electron shells of two atoms experience increasing resistance when their electron orbits approach each other and overlap.

### 2.5.3 *Dual Closure*

Of all objects with closure, the Operator Theory deals selectively with objects that were formed through the combination of a functional and a structural closure, referred to as dual closure (addressed in singular).

There are two reasons for suggesting the use of dual closure. Firstly, and in analogy to the exclusion of non-uniform closures from the current approach, it is necessary to avoid that subsequent steps are based haphazardly on either functional or

structural closure. After all, the goal here is not to end up with a ranking that is based on a mixture of rules, which could be viewed as representing a logically inconsistent ranking. Secondly, the aim is to create a ranking that selectively includes physical objects. On the one hand this goal immediately excludes entities defined by functional closure, because such entities are conceptual. On the other hand, if a ranking is based selectively on structural closures the ranking can include all sorts of enclosed objects, such as soap bubbles, hollow glass spheres, fatty acid vesicles and children holding each other's hands while dancing in a circle.

Through the use of dual closure the Operator Theory limits the options for any next kind of closure to a single next possibility, or to a few possibilities which are all based on the current dual closure.

### ***2.5.4 The Use of Dual Closure in the Operator Hierarchy***

The goal of the Operator Theory is to create a ranking that is also an ontogenesis for kinds of objects. For this purpose, the Operator Theory identifies a sequence of dual closures in such a way that every new dual closure is of a new kind, and defines a new kind of object. Every object of a kind that is included in this sequence is called an operator, and the sequence is called the Operator Hierarchy.

One of the goals of the Operator Theory is to create constancy in the naming of the kinds of operators. For this purpose the dual closure of a specific operator is used as an anchor for the naming of the kind of the operator, and sub-kinds.

A new operator is created through a new kind of dual closures that connect two or more operators of the current kind, thus creating the next operator in the hierarchy. The operators in the operator hierarchy refer to kinds of objects, not to specific objects. This means that any configuration of operators of the current kind which are linked through one or more dual closures of the new kind is an operator of the same new kind, i.e. any such object is placed in the same position in the operator hierarchy. The above generalisation can be understood more intuitively by comparing an operator with a brick structure and a dual closure with cement. In that case, the above principle says that the term brick structure is a general term that refers not to a specific structure, but to any structure made out of bricks that are held together with cement. Thus, any object made of the same kind of operator and the same kind of dual closure can be seen as being of the same operator kind. Accordingly, if atoms are the bricks and covalent bonds are the cement, both a diatomic structure, such as  $H_2$  or  $O_2$ , is a molecule, the long chain of atoms in some fats or in lignin is a molecule, a sheet of connected atoms such as in graphene is a molecule, and a spherical structure of carbon atoms, a fullerene, is a molecule.

The sequence of all dual closures and associated kinds of operators follows the order in which they were first formed, and starts with cosmogenesis. The first kind of particles that currently are known to have been formed during the Big Bang are the particles that are studied by particle physics, the so-called fundamental particles that are described by the so-called standard model (Close 1983; Oerter 2006). In the

Operator Theory, all fundamental particles are seen as belonging to the same kind. The idea that they are of the same kind is not new. It is also the idea behind M-theory (Rickles 2014), which is more popularly known as string theory and which sees all fundamental particles as small strings. Whether fundamental particles have closures, and of what kind such closures are is currently unknown. For this reason the Operator Theory does not detail their closure, but accepts fundamental particles as the starting point for constructing a hierarchy of dual closures.

Generally speaking, the dual closure of the operator of the current level can be used to identify the dual closure of operator(s) of the next level. The single exception to this rule is the atom. In atoms the functional closure of the atom nucleus is based on hadrons, which represent operators. Meanwhile, the structural closure of the electron shell is based on one or more electrons, which represent fundamental particles instead of hadrons. Apparently, electrons have been the highest lower level possible for creating the structural closure of the electron shell, while at all higher levels it has been possible to create the next dual closure of the operators of the immediately preceding kind.

There is one final aspect of the use of dual closure that has to be explained, namely that the criterion of dual closure does not always lead to a single option for a next operator. In some cases two or more dual closures can be based on the current one. In such a case, the two new kinds of operator that are created out of the present one cause a branching of the ranking. And the new kinds of operator after the branching will be different, but will all reside at the next level in the hierarchy. As explained in the next chapter, the possibility that dual closure can lead to a branching of the ranking of the operators suggests that the ranking of all the kinds of operators follows higher-order logic.

## 2.6 Primary Structure and Secondary Structure of the Operator Hierarchy

All the transitions in the Operator Hierarchy are summarised in Table 2.1 and the steps in the table are explained in an accessible way in the accompanying text. For additional information on this topic the reader is referred to earlier publications on this subject (Jagers op Akkerhuis and van Straalen 1999; Jagers op Akkerhuis 2010a, pp. 37–55).

### 2.6.1 *Primary Structure of the Operator Hierarchy*

In Table 2.1, one finds all the kinds of operators, and the dual closure (functional and structural) on which they are based. The table also includes a distinction between the structural closure called interface and the functional closure called hypercycle. When separate, the interface and hypercycle do not represent an

operator, because they only refer to a single closure, not a dual closure. Even though these uniform closures do not represent operators, the interfaces and pre-operator hypercyclic sets are included in Table 2.1 because they will play an important role in later analyses of the secondary structure of the ranking.

Even though the concept of dual closure in principle does not demand this, it is relevant to remark that dual closure can in practice frequently be identified because it involves an “advanced” property of the interacting operators. The advanced operators have a new property that adds something special to the repertoire of their interactions.

For example, of all the fundamental particles with mass, the quarks not only have mass, but are also known to emit and reabsorb (at high frequency) small force-carrying particles, called gluons. Gluons are relatively complex, because they convey a property that is known as “colour”, which is conveyed as a combination of colour and anti-colour. This complex feature later became the basis for the functional closure of gluon exchange. Another example can be observed in neural networks. While all the cells of a multicellular touch their neighbouring cells and interact with them through plasma connections, a special new property of a subset of advanced cells was that they could connect cells that are not direct neighbours. This special property later formed the basis for the functional closure of the neural network.

The dual closures in Table 2.1 are explained in detail in the following sections.

The quarks are viewed as primitive objects, of which the kind of closure is unknown.

Quarks can interact through the exchange of other small fundamental particles, notably gluons. In this way quark–gluon plasma can be formed. When the quark–gluon plasma cooled, during the expansion of the universe, the gluon force-field became relatively strong, and the quark–gluon interactions condensed into small bundles of two or three quarks, a process called confinement. The exchange of gluons and the confinement represent a functional and structural closure, respectively, and thus a dual closure. The resulting kind of operator is called a hadron. Examples of hadrons are the proton and the neutron.

Protons and neutrons can emit and reabsorb small hadrons that consist of two quarks, and that are called pions. In the same way as quarks can exchange gluons, the hadrons can exchange pions, and in this way create an emission-absorption cycle. Bound protons and neutrons together are also viewed as a nucleus. The capturing of an electron shell creates a structural boundary around the nucleus. The combination of the nucleus and electron shell represents a new dual closure, and is called the atom.

The electron shell of an atom normally contains the same number of electrons as there are protons in its nucleus. The electron shell of cell is built up in layers. The electrons orbit the nucleus and can be anywhere in their layer at any one time. Each layer can contain only a limited amount of electrons. For example: the innermost layer can only hold 2 electrons and the next two layers 8 each. A new layer is formed outside the previous one, but only when the previous layer is full. Apart from this layering, there is another important property, namely that electrons in the electron shell want to pair up with another electron. Atoms have a tendency to want to have

**Table 2.1** The functional and structural closure that together allow a transition from an operator of a lower level kind to an operator of a higher level kind

Operator (or system kind)	Advanced property	Functional closure (transformation)	Structural closure (shape)	Operator	Operator code
Fundamental particle		First closure?		No	
Quark–gluon plasma		Gluon exchange between quarks		No	
Hadron	Quarks emit gluon carrying colour and anti-colour	Gluon exchange between quarks	Confinement (at low enough temperature)	Yes	1
Nucleus		Hadron–pion hypercycle		No	
Atom	Exchange of pion as two-quark object	Pion exchange between hadrons	Electron shell	Yes	10
Multi-atom (e.g. molecule, metal grid)	Orbit with an unpaired electron allowing for the formation of an orbit with paired electrons	Exchange of electron pairs between atoms	Coupled electron shell of shared pair of electrons	Yes	11
Auto-catalytic set		Catalytic hypercycle		No	
Cell (e.g. bacteria and archaea)	Molecules capable of catalysing molecular reactions	Set-wise autocatalysis	Cell membrane	Yes	100
Endosymbiont cell (e.g. protozoa, eukaryote cells)	Free living endosymbiotic cells	Obligate interaction between host cell and the endosymbiont	Cell membrane of the host cell	Yes	101
Multicellular (e.g. blue-green algae)	Developmental history with pluricellular stage	Plasma connections with neighbouring cells	Shared membrane after connection of the plasma	Yes	110
Endosymbiont multicellular (e.g. plants, algae, fungi)	Developmental history with pluricellular stage	Plasma connections with neighbouring cells	Shared membrane after connecting of the plasma	Yes	111
Self-referential system		Signal transduction hypercycle		No	
Hardwired memon	Cells or other “agents” that transfer signals to other cells or agents	Second order cycle of connections that alter the signal transduction of the receiver	Sensors	Yes	1000

the outer layer of their electron shell to be full. One way they can do that is by a pairwise sharing of some of the electrons in that outer layer with those of another atom. For example: the oxygen atom has 8 protons in its nucleus, and hence 8 electrons in its electron shell. The first layer therefor contains two electrons, while the second, and in this case outermost, layer contains 6 out of a possible 8. This means this layer is lacking 2 electrons. This lack can be solved by a pairwise sharing of two electrons in this layer with another oxygen atom. This sharing creates the more stable oxygen molecule, made up of two atoms. Electrons that are paired up in such a way can then orbit both atoms. The sharing of electrons in this way is known as a covalent bond which keeps the atoms close together. When the outer layer of an atom's electron shell is already full, it will not form covalent bonds with other atoms, and thus will never be part of a molecule. Such atoms are known as the noble gasses, which are therefore inert.

Molecules come in many varieties. Some of these can catalyse a reaction in which a substrate molecule is transformed into another molecule. A functional closure now emerges if, in a chain of catalytic reactions, the set of molecules created by the reactions is the same as the set of molecules that catalyse the reactions. Such a set of molecules is known as an autocatalytic set. At the same time, some products of the reactions of the catalytic cycle may form a vesicle that surrounds a volume of liquid in which the catalytic processes take place. When this happens, the catalytic cycle and the vesicle together represent a dual closure. The resulting system is the operator of the kind cell. Examples of this operator are the bacteria and the archaea.

The next operator is based on the interaction between cells. But now there are two topological possibilities for structural closure. A cell can interact with another cell that is attached to it, or with one that is inside it.

If a cell interacts with a cell that is attached to it, a dual closure emerges when the cells are linked through plasma connections across their membranes. Due to the plasma connections two or more cells interact in a transformative way, by the exchange of plasma, hereby creating a functional closure. And the plasma connections also create a connected outer surface, which represents a structural closure. The resulting kind of system is called the multicellular operator. Multicellularity of a group of cells thus implies that any cell is linked to at least one other cell in the group through plasma strands, and that every cell contributes to the functioning of one or more cells of the group in the context of maintenance of all the cells in the group as a multicellular organism. An example of this kind of operator is represented by the blue-green algae.

If a cell interacts with a cell inside it, the functional closure is realised through the obligatory dependency of the host cell on the metabolic activity of the endosymbionts, while the endosymbionts depend for their metabolism on the host cell. The structural closure involved is that of the membrane of the host cell, which acts as an interface for the endosymbionts with the outer world. The resulting kind of system is called the endosymbiont operator. Examples of this kind of operator are the protozoa.

By analogy with the multicellular operator, endosymbiont cells can, through a dual closure, create an endosymbiont multicellular operator, such as a plant, an alga and a mushroom.



From the endosymbiont multicellular operator a next dual closure can be reached in the following way. First, single cells connect through long extensions with other cells than their neighbours. These extensions connect multiple cells into groups that, through a first-order interaction cycle can act as information storage. A second order interaction cycle emerges when such first-order cyclic groups are connected to other such groups. The interactions between such groups represent a new kind of second-order functional closure. For a dual closure, the interacting groups of neural cells still need structural closure, which because of the demand of uniformity, has to be based on multicellular units. It is suggested for this reason that structural closure is represented by the groups of interacting neural cells that act as sensors. The combination of the hypercyclic interactions and the sensory interface is viewed as the hallmark of a new kind of operator, which has been named the memon. When analysed in this way, the tissues in which the neural system and interface are embedded, the 'body' that 'surrounds' the memon, becomes a kind of 'vehicle' for the memon. The memon as a neural entity depends strongly on feedback with its multicellular vehicle, because the interaction between both aspects is needed for maintenance of the entire construction. Because of this close interaction, the current text will generally use the concept of a memon as if it extends to the entire physical body in which the memon resides. For example, when a human is called a memon, this refers not just to the neural network, but includes the human body as the vehicle of the neural network. Accordingly, a memon will also be addressed as a neural network organism.

It is furthermore relevant to remark that in nature the first memons could only develop as a special kind of organs in multicellular organisms. For the Operator Hierarchy it is not necessary, however, that the agents that carry out the informational hypercycle are cells. In principle technical analogies of cells may perform processes that conceptually can be viewed as identical.

### 2.6.2 *Secondary Structure of the Operator Hierarchy*

By analogy with the way amino acids can be viewed as the primary structure, and the helix as the secondary structure of DNA, the Operator Theory also theorises that the ranking of the operators has a primary structure and a secondary structure.

The primary structure depends on the pairs of kinds of operators before and after a dual closure, e.g. hadron and atom, atom and molecule, molecule and cell, and cell and endosymbiont cell. (see Table 2.1). The secondary structure depends on patterns that recur in the kinds of transitions and the kinds of operators they connect. The following discussion of the secondary structure involves two steps. The first step focuses on transitions from one kind of operator to the next. The second step pays special attention to a number of closures that occurred before the first operator emerged.

## Secondary Structure in the Ranking of All the Operators

Here it is hypothesised that the ranking of all the operators of different kinds has a secondary structure. This hypothesis has its roots in the observation that kinds of operators can be arranged in groups, each group being limited at the low end by a new kind of operator, and at the high end by an operator that consists of multiple attached operators. Inside such a group all the operators can be viewed as being constructed from the first operator of that group. For example, the atom is a new kind of operator at the lower end of the group, and the molecule is the operator that consists of attached atoms, and that forms the higher end of the group. One can also observe in Table 2.1 (third column, grey rows) that the first kind of operator in every group of the kind that is discussed here is preceded by a hypercyclic closure with interface.

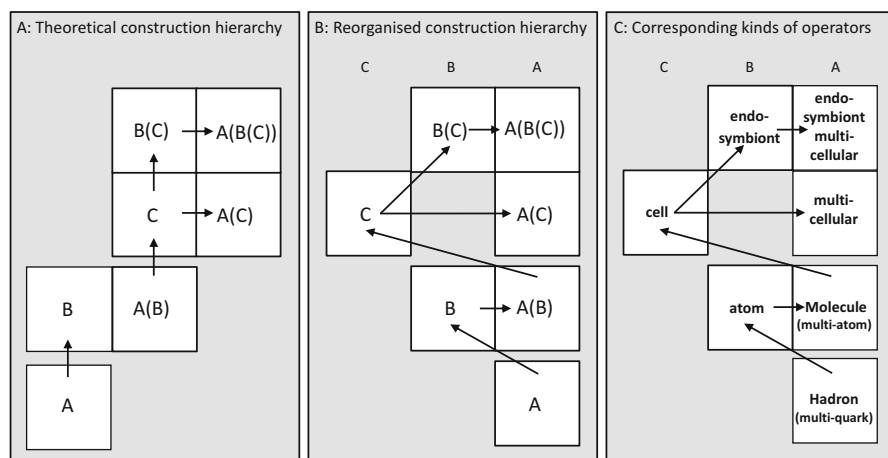
The above groups of kinds of operators can include just a single operator kind, or can include two or more kinds of operators. Using Table 2.1 one can identify three examples of such groups:

1. The hadron, which represents the first and only operator kind in this group.
2. The atom and the molecule either are atoms or consist of atoms.
3. The cell, the multicellular, the endosymbiont cell, and the endosymbiont multicellular, which all are cells or consist of combinations of cells.

The above groups differ in the number of members, either a single or two or four, while the increase in the number of kinds of operators per group suggests an exponential pattern. The Operator Theory assumes that this exponential pattern is not an artefact of the way of analysing organisation, but that it can be viewed as representing a special kind of regularity in the organisation of nature. If this assumption is correct, there are two questions that need to be answered. The first is: What kind of regularity can describe a pattern like this? And the second is: What kind of mechanism can be found that can explain the emergence of such regularity? This section focuses on the first question. The second question is discussed in the thermodynamics chapter of this book.

One of the hypotheses of Operator Theory is that the exponential pattern in the number of kinds of operators per layer can be described by means of a simple abstract logic that is based on the following two rules. 1. The first rule is that the dual closure of any next kind of operator must always be of a new kind. Due to this rule, the dual closure of the current operator can never be of the same kind as that of the next operator. 2. The second hypothetical rule assumes that after a new kind of operator has formed, any next new kind of operator will have a dual closure that repeats, at a higher level, all the closure kinds at the preceding level.

The way these two rules work is demonstrated by the following example. If the current operator has dual closure of kind A, the first rule implies that the next operator must have dual closure of kind B (Fig. 2.2a). Given an operator of kind B, the second rule implies that the next new operator must have a dual closure that differs from B while repeating the kind of closure of A. Accordingly, the next new operator will have dual closure of the kind A(B), which coding indicates that a new kind of



**Fig. 2.2** Hypothetical algorithm for the second order ranking of the different kinds of operators. Part (a): The construction of increasingly complex kinds of operators based on a combination of the two hypothetical rules, the logic of which is explained in the text. Symbols  $A$ ,  $B$  and  $C$  indicate different kinds of dual closure. Part (b): A reorganised representation of the ranking in part (a). Dual closures are sorted according to columns with a recurring similarity in the kinds of dual closure, indicated as  $C$ ,  $B$  and  $A$  on top of a column. At the same time, every position in the hierarchy has its proper kind of dual closure. While the arrows seem to follow a different pattern in Fig. 2.2a than in 2.2b, this is an artefact of the new kind of ranking. Part (c): The mapping of real operators that correspond with the position in part (b)

dual closure  $A$  is formed that is based on the dual closure of operators of the kind  $B$ . Now all possible combinations based on  $B$  have been filled in, and because a next kind of operator must have a new kind of dual closure, this implies that the next new operator must be of kind  $C$ . For a proper understanding of the use of dual closure it is relevant that every next operator is based on the dual closure of the preceding operator, but that this does not necessarily imply that a next operator must always be constructed physically from operators of the preceding kind.

Using the two above rules, and based on the dual closure of the kind  $C$ , there are now three options for a next new kind of dual closure, namely  $A(C)$ ,  $B(C)$  and  $A(B(C))$  (Fig. 2.2a). For example  $A(C)$  can be interpreted as a repetition of the  $A$  kind of dual closure based on operators of the kind  $C$ . Due to this logic, a ranking emerges that includes an exponential increase in the number of kinds of dual closure per layer, from 1 to 2 to 4 to 8 etc. While this hypothetical pair of rules describes a logic that can be matched with the pattern in the sequence of kinds of operators, it is still an open field of scientific inquiry to identify all the mechanistic explanations that create such patterns. Furthermore, based on the current understanding it cannot be excluded that in analogy to the system kind  $A(B(C))$  producing a next series of systems, also  $A(C)$  can become the basis of next systems. At present, however, no known examples seem to exist of systems that fit into this hypothetical extension, due to which such an option is no more than a theoretical speculation.

In Fig. 2.2a the different kinds of operators are grouped based on dual closures of kind A, B or C. However, the way in which the kinds are organised does not offer a transparent overview of when a dual closure is new, and when it repeats a dual closure of a lower level operator. To improve on this situation, it was decided to rearrange the kinds of dual closure in a column-wise way (Fig. 2.2b). Since the repetition of the dual closure of kind A is always the last option before a new kind of dual closure is required, these closures are viewed as the most complex in the series, and are placed at the right side of the figure (Fig. 2.2b). In this way the “ladder” of dual closures of Fig. 2.2a is folded to highlight its column-wise regularity in Fig. 2.2b.

So far, the Fig. 2.2a, b depict relationships based on hypothetical rules. The link with real kinds of operators becomes apparent in Fig. 2.2c. It can be observed that every dual closure in the rightmost vertical column is of the kind A, and correspond with operators that consist of multiple attached objects of a uniform kind: the hadron, the molecule and the multicellular. In the hadron, the attached objects are quarks. In the molecule the attached objects are atoms. In the multicellular organisation the attached objects are either cells or endosymbiont cells. One column to the left, all the operators share a kind of dual closure that is associated with the character B. This dual closure involves an interface. In the atom the interface is the electron shell, and in the endosymbiont cell, the membrane of the host cell acts as an interface for the endosymbiont cell. Finally the cell has a new property (of kind C) which according to the Operator Theory is the capacity called the structural copying of information.

Apparently it is possible to relate the abstract rules and the ranking of specific operators. This suggests that nature fills in a regular pattern of positions in state space. These positions have also been referred to as slots in state space by Diedel Kornet (personal information).

## Extending the Secondary Structure Below the Level of the Hadron

So far, the attention was focused on the ranking of the operators, of which the hadron is the least complex kind. A typical property of all the operators is their dual closure. However, the demand of dual closure excludes systems that lack the required pair of closures. To also include in the logic of the Operator Hierarchy the kinds of objects that preceded the hadrons, analyses must also include objects having a single closure dimension. A focus on such objects implies that structural and functional closures must be analysed independently of each other.

The early universe was filled with plasma of fundamental particles of different kinds. Some of these particles represented matter and others conveyed forces. The matter particles are either leptons (e.g. the electron) or quarks.

Here it is assumed that the particles in the standard model really represent the most fundamental level of organisation. Based on string-theoretical models for quarks, every quark presumably exists as a self-interacting field that rolls up to a closed space, creating an interface between the quark and the world. The new kind of (single) closure that is introduced by quarks was for this reason named the interface closure.

Fundamental particles split off and reabsorb virtual particles, such as virtual photons, in a process called self-interaction. A special property of quarks is their capacity to emit and reabsorb force carrying particles of the kind gluon. The emission and reabsorption of a gluon can be viewed as a cyclic process. A cycle of cycles or second order cycle is formed when a quark splits off a gluon which is absorbed by a second quark, which splits off a gluon which then is absorbed again by the first quark. The Operator Theory refers to this second order cycle as a hypercycle. Any hypercyclic arrangement of gluons now represents the kind of (single) closure indicated as a hypercyclic closure. As the interactions in this cycle are of a transformative kind, they comply with the criteria for functional closure.

In the early universe all forms of hypercyclic closure between quarks were embedded in the quark–gluon plasma. When the universe expanded, however, the temperature dropped because the energy was dispersed over a larger space. And at lower temperatures the gluon field becomes relatively strong. If, at current temperature, one pulls two quarks apart, the gluon field stretches like an elastic band. When it snaps, the energy that is released is transformed into new quarks on either side of the breakpoint. As the result of this mechanism quarks always occur in bundles of two (mesons) or three (baryons). It is said that the gluon field confines the quarks. This confinement of quarks by the gluon field is viewed by the Operator Theory as a new kind of closure that repeats the interface kind of closure of the individual quarks (Fig. 2.3). Confinement can be viewed as a structural container around the functional process of gluon exchange, and complies for this reason with the criteria for structural closure.

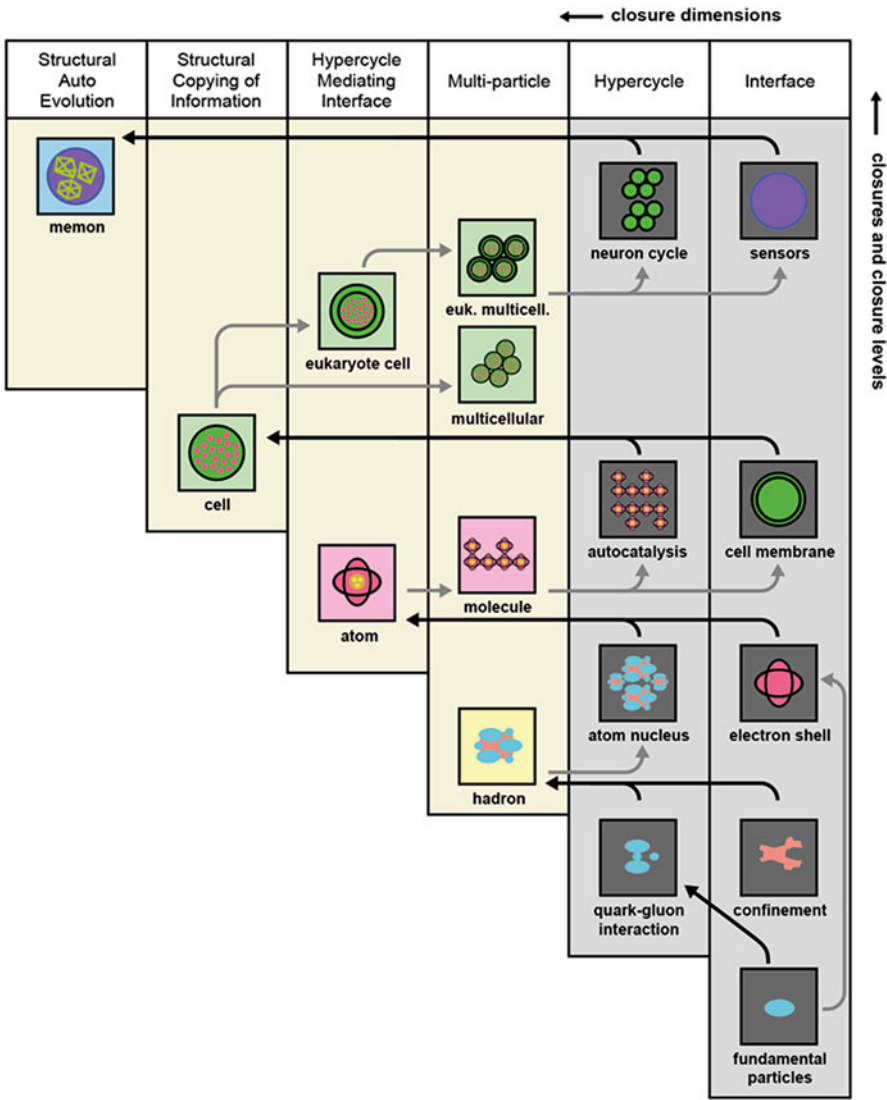
By combining the hypercycle closure (functional) and the interface closure (structural), one obtains the first dual closure, which is typical for the hadrons (particles such as protons and neutrons). From this moment onwards one can continue with the logic of dual closure steps that was discussed above.

The above explorations have demonstrated that it is possible to identify two kinds of single closure that emerged during the first closure steps from quarks to hadrons. It is interesting to add this information to the scheme of Fig. 2.2.c. The result is a new scheme that starts with the first single closures and continues with the dual closures (Fig. 2.3).

At this place, the names of the closure dimensions on top of the columns in Fig. 2.3 are not discussed. This topic is detailed in Sect. 18.8 in relation to predictions of future operators.

Using Table 2.1 and Fig. 2.3 one can now define both the transitions between operator layers (BOL) and the transitions between operator kinds (BOK).

Examples of BOL transitions are all transitions in the operator hierarchy that introduce truly new kinds of closure. At the same time, every truly new kind of closure can also be viewed as opening up a new dimension. There are many examples of the early dimensions, notably the closure dimensions of the interface, the hypercycle, and the multi-particular state. For this reason, the structures of these closure dimensions are relatively well understood (see the right columns in Fig. 2.3). The more recently a dimension has emerged, the fewer examples of it are known and the more difficult it becomes to perform secondary analyses and to identify the general factor that is typical for the dimension.



**Fig. 2.3** The secondary structure of the Operator Hierarchy. *Grey columns*: conceptual stages that precede the formation of the first kind of operator at a next layer (pre-operator hypercyclic set, and interface). *Yellow columns*: operators and their closure dimensions. *Black arrows*: transitions towards the first operator at the next layer, named a BOL transition. *Grey arrows*: transitions towards new kinds of operators within a layer, named a BOK transition. Arrows that reach across two or more columns, do not indicate a gap in the logic, but are the result of the figure representing a two-dimensional projection of a higher dimensional logic

In the operator hierarchy the following six BOL transitions (a) and related closure dimensions (b) can be recognised:

1. First BOL transition: the fundamental particles.
  - (a) Here scientists still speculate about the closures. A potential explanation based on string theory is the rolling up of a field-sheet to a long tube and the closure of the tube to a finite system; the torus of the closed string.
  - (b) Fundamental particles are assumed to have the closure dimension of the interface, which is the first kind of closure of the operator hierarchy. Higher level pre-operator systems which also have the interface closure are: gluon confinement, pion exchange, the cell membrane, and the sensory interface.
2. Second BOL transition: The hypercyclic quark–gluon plasma.
  - (a) This is represented by the second order process of quark–gluon exchange that connects two quark–gluon cycles in a hypercyclic arrangement.
  - (b) The new closure dimension that is introduced is the hypercyclic closure, or hypercycle. At levels above the quark–gluon plasma this kind of closure can also be recognised in the pion exchange in the nucleus, in the set-wise autocatalysis and in the informational interactions between groups of neurons in neural networks. Set-wise autocatalysis differs from normal autocatalysis in the sense that in normal autocatalysis a catalyst changes a substrate into a copy of itself. Meanwhile, when set-wise autocatalysis occurs, the catalysts involved change substrate to other catalysts than themselves in such a way that if each of two catalysts would produce the other, they would together sustain the pair of them, and realise auto-catalysis of the set that is represented by the two atoms.
3. Third BOL transition: The hadron.
  - (a) This is the first step in which dual closure occurs. The hadron combines the closures of the superstring hypercycle and the confinement of the quarks through gluon fields.
  - (b) The new closure dimension that is introduced is that of the multi-particle. Examples of multi-particles at levels above that of the hadron are: the multi-atom (e.g. a molecule or a lump of metal), the multicellular organisms, and the endosymbiont multicellular organism.
4. Fourth BOL transition: The atom.
  - (a) The dual closure is based on the nuclear hypercycle and the electron shell.
  - (b) The new closure dimension that is introduced is that of the hypercycle mediating interface. Based on only two examples it is deduced that what is important about this dimension is the spatial separation of a hypercycle and a mediating interface. This interfacing is repeated in the endosymbiont unicellular.
5. Fifth BOL transition: The cell.
  - (a) The dual closure is based on the catalytic hypercycle and the cell membrane.

- (b) The new closure dimension that is introduced is that of the structural copying of information. Here the deduction of the closure dimension is difficult, because there is only a single example that can be used. It can, for example, be assumed that the new property the cell allows for is the structural copying of information in the cell. Another option could be to focus on unit-wise information processing.

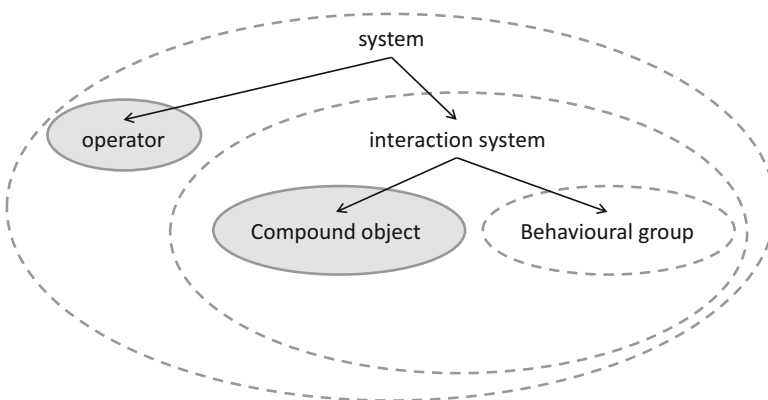
6. Sixth BOL transition: The memon.

- (a) The dual closure is based on the neural hypercycle and the sensory interface.
- (b) The new closure dimension involved is deduced to be structural auto-copying of information.

It must be noted that the closures of BOL transitions (interface, hypercycle and the combination of interface and hypercycle) are dealt with separately when analysing them from the point of view of system organisation. At the same time, however, these two closures have generally occurred simultaneously during the natural processes that formed an operator.

### 2.6.3 *Systems That Include Two or More Operators: The Interaction Systems*

Because it has dual closure, an operator always represents a countable, structural and functional whole, and a physical unity. For this reason, an operator can function in the Operator Theory as the basic building-block for analysing systems that consist of multiple operators (Fig. 2.4). Any such system (the system concept has been



**Fig. 2.4** The fundamental ontology that the Operator Theory uses for the identification of major kinds of organisation. *Dashed circles indicate conceptual entities. Circles with grey shading indicate physical units*



discussed in Sect. 2.3) that includes two or more operators, and that does not represent an operator itself, will be viewed as an interaction system (Jagers op Akkerhuis 2008, 2014). Examples of interaction systems are a population, a family, a society, a car and a football.

The concept of an interaction system is defined by invoking set theory. An interaction system and its material objects are associated with a set which has at least two entities, named the elements of the set. The number of members of an interaction system decreases when two or more objects integrate physically. Inside the large set of all possible interaction systems one can create subsets of various kinds. The reason why many subsets can be created is that one can imagine many criteria and combinations of criteria for deciding which objects will belong to a specific subset. Criteria can be spatial, e.g. all organisms in a specific area. Or criteria can be based on taxonomy, e.g. all the organisms of the same species (which concept requires further criteria to be specified). Criteria can also be based on social interactions, e.g. the wolves that cooperate as a pack, the mating of organisms, and the giving birth to offspring. Many more selections can be envisioned. Of all the possibilities, two special subsets are the compound objects and behavioural groups.

Compound objects are highlighted because, just like operators, they represent countable physical/material unities. In the literature about knowledge representation compound objects have also been referred to as chunks, in the interpretation of continuous pieces of matter (e.g. Bennett et al. 2000; Davis 1993, and Needham 2002). A compound object consists of operators and/or compound objects which are more closely attached to each other than to their environment, and which can be displaced as a structural unity relative to the environment (as explained in Jagers op Akkerhuis 2008), e.g. a stone, a drop of water in oil, a piece of cloth, and a car. The term compound object is never used for an operator. Complex compound objects can be formed through the lumping of less complex compound objects. A special kind of compound objects is formed through the attachment of single celled organisms, leading for example to the slug of the cellular slime mould *Dictyostelium discoideum* and the eight-cell stage of the human embryo. The reason why these are called compound objects, and not organisms, is that the cells lack the plasma connections required for dual closure. Instead of as an organism, the Operator Theory views the slug and the early embryo as *pluricellular compound objects*.

Another special kind of interaction system is the behavioural group, which is defined as a consciously made selection of organisms which are not attached and which can be viewed as being united through some kind of interactive relationship. Making a conscious choice about which organisms belong to the group and which do not is necessary for three reasons. Firstly, as long as one talks about individually dwelling organisms, the interactions do not define a form of material unity. For this reason the criterion of attachment cannot be used to identify the members of a group. Secondly, the number of possible relationships that an organism can have with entities in its environment is almost infinite. This implies that one has to consciously select specific relationships between specific organisms when defining a behavioural group. For example, in a specific environment wolves will eat mice, dig burrows, mark their territory and have many more interactions, but only the social interactions

with some other wolves are selected for the identification of the wolves that are a member of a specific pack. Thirdly, if one uses a functional criterion without additional spatial criteria, this can have marked consequences. For example if one uses the potential to mate as the criterion for membership of the global population of a species, this leads to problems in the cases of ring species where all neighbouring individuals can mate, but where at the geographical edges of the population at least two groups of individuals exist that can not mate or can not produce fertile offspring.

A property of interaction systems is that the objects involved can be grouped according to fully or partially overlapping subsets. For example horses can be grouped according to herds or populations, as wild horses or as riding horses. Additionally, and in a (partially) overlapping way, the individuals of different species that are present in a specific area can be grouped according to more inclusive criteria, which results for example in communities and ecosystems. Another example of overlapping criteria is the participation of a person in different groups, such as a company, a family, a debating club and a tennis club. The subsets of people in the different clubs are not the same, and may show some overlap, for example when a single person participates in two or more groups. At the same time, there may also be several colleagues of this person, who participate in the same tennis club, but not in the other groupings.

## 2.7 Discussion

### 2.7.1 *General Remarks*

The Operator Hierarchy is based on the concept of dual closure. Dual closure adds a novel perspective to existing system theories about objects and hierarchical levels of organisation, e.g. by Von Bertalanffy (1950), Simon (1962), Turchin (1977), Koestler (1978), Miller (1978), Salthe (1985), Heylighen (1990), Alvarez de Lorenzana (1993) and others. It is important to realise that the functional and structural aspects of dual closure are always the results of underlying dynamics, and that for this reason the Operator Theory is not just an administrative classification of closure kinds but also a mechanistic ranking.

An object that has (dual) closure, can of course lose its closure. This happens for example when the construction and/or dynamics are reduced to below a specific minimum for the kind of closure, for example, an atom that is heated stops to be an atom when it loses the last electron shell, or a multicellular organism can be starved and loose its capacity of maintenance, and finally die and disintegrate.

While closure is an absolute necessity for activities/processes such as metabolism and maintenance, this logic cannot automatically be inversed, as the example of crows illustrates. Most crows are black birds, but this does not imply that most black birds are crows. By analogy, while the metabolism of organisms requires functional closure of the processes involved, this does not imply that a system that is not metabolically active does not have closure. An example is a frozen bacterium. As long as all the molecules are preserved that are involved in the autocatalytic

closure, and as long as the membrane of the bacterium is intact, dual closure is present, and the frozen bacterium can be thawed and become fully functional again. This is the reason why such a frozen state has been called viable lifelessness. A consequence of this unidirectional logical relationship is that closure can be viewed as being more fundamental than metabolism because one needs closure for metabolism, while as the example of the frozen bacterium illustrates- metabolism is not necessary for closure.

At the end of this paragraph special attention is asked for the non-classical naming that the Operator Theory introduces. The classical indication that the bacteria and the archaea represent prokaryotes can be viewed as an approach that has worked towards increasingly small objects. For a long time it had been impossible to observe structures much smaller than those of eukaryote cells. And when the first microscopes finally offered a view of the bacterial world, these were classified as prokaryotes, the organisms that do not have a nucleus in their cells. As the Operator Hierarchy reasons from the bottom up, a system that resides at a higher level in the operator hierarchy, such as a eukaryotic cell, cannot serve as a reference as long as it still has to be constructed. A similar logic applies to the single celled organisms that belong to the group that classically is named Protozoa. In the Operator Hierarchy the Protozoa are classified as endosymbiont cells. They are called endosymbiont cells (and the cells living inside them are called endosymbionts) because the Operator Theory emphasises the dual closure that is associated with the endosymbiont cell(s) that live inside an endosymbiont cell. When identifying the next step after the cell, the Operator Theory emphasises the presence of the endosymbionts instead of the presence of the karyos. The operator theory focuses on the presence of the endosymbiont, because the structure of the karyos is not present in all stages of the life cycle of all eukaryotic species. During cell division, the karyos of many species temporarily dissolves. The advantage of focusing on the presence of endosymbionts is that the endosymbionts in a cell can never disappear, because they are part of an obligatory interaction with the host cell. Finally, the Operator Theory does not in all cases use the word animal. The reason is that the concept of the animal in the classical naming system can equally well be applied to single celled protozoa such as *Paramecium* as to multicellular animals. To prevent confusion when using the concept of the animal in this way, and in accordance with the dual closure of the neural network, the Operator Theory makes use of a new concept, the memon for the class of neural network organisms. Accordingly, all memons are animals, but not every animal is a memon.

### ***2.7.2 Using the Operator Hierarchy for Defining the Organism Concept***

As has been indicated in the general introduction the debate about how the organism concept can be defined does not seem to have ended yet. About the role of the organism concept in the life sciences Nicholson (2014) says the following: “Although

organisms were deemed to have been explained away, in retrospect a more accurate assessment is that they were merely abstracted away. In molecular biology, the complexity of the organism's organization was taken for granted as the experimental focus shifted towards the detailed mapping and analysis of metabolic pathways, signalling cascades, and the regulation of gene expression. Likewise, in the Modern Synthesis view of evolution, the agency and autonomy of organisms were not even recognised as theoretical problems but were simply presupposed in the models of population genetics and behavioural ecology."

One of the things that may have blocked the road towards consensus about a definition of the organism concept is that classical approaches start with inventories of different kinds of things that are viewed as organisms such as bacteria, viruses, archaea, protozoa, sponges, corals, plants, algae, fungi, lichens and animals. After this inventory has been made, criteria are sought that can cover all these cases. What is special about such an approach is that the examples were selected more or less haphazardly, based on a loose collection of criteria that roughly coincide with properties that organisms generally have. For example, one may have used reproduction as a criterion for considering an example as an organism. Indeed most of the examples may potentially reproduce. But the technical aspect that is relevant for a definition is, whether or not reproduction offers a necessary and sufficient criterion? Can it be confirmed that every example that is considered as an organism can always reproduce (think of a single animal that is locked up in a cage)? And is it always true that if a system cannot reproduce it can never be an organism (think of a sterilised cat, or a mule)? Similarly, one could focus on the use of metabolism as a criterion for whether or not an entity represents an organism. Now it is easy to on the one hand indicate many things that have some form of metabolism but are not organism-like, such as a flame, or a compost heap. And on the other hand, there exist things that are organisms but that do not have metabolism, such as a frozen bacterium. The use of reproduction and metabolism as criteria also leads to questions about what *exactly* is meant with these concepts. If one uses for example reproduction or metabolism as criteria for deciding whether or not an object belongs to the set of organisms the next challenge becomes to define precisely what the criterion means, because any variation in the interpretation of reproduction or metabolism will lead to a different selection of objects.

The Operator Theory now offers an alternative approach to defining the organism concept that contributes to resolving the above discussions. As was discussed in Jagers op Akkerhuis (2010b, 2012a, b), the Operator Theory offers a basis for defining the organism concept in two steps. The hierarchy of all the operators serves as the first step. And as the second step, one can choose to -by definition- only select as organisms those kinds of operators that are at least as complex as the cell. If one uses these two steps, the organism concept is defined from the bottom up. Based on this approach, only the following kinds of operators represent organisms: the cell (conventionally called a prokaryote), the (prokaryote) multicellular (e.g. blue-green algae), the endosymbiont cell (conventionally called a eukaryotic cell, but named differently by the Operator Theory because of the relevance of the endosymbiont), the endosymbiont multicellular (e.g. a plant) and the organism with neural network (the so-called memon, see Fig. 2.3).

As has been discussed for example in Jagers op Akkerhuis (2010b, 2012a,b) using the Operator Hierarchy as a basis for defining the organisms, offers clarity about which entities are organisms and which are not. The operator-based criteria allow one to identify the operators that are organisms amidst of the many other systems which are not an operator, such as the slug of a slime mould, symbiotic relationships, herds, colonies and bee hives. As a consequence of this approach some of the classical examples of organisms, such as viruses, sponges and lichens have to be set aside. And the classical criteria such as reproduction, metabolism and response to stimuli will have to be reconsidered. When using the new definition, only specific kinds of complex operators are viewed as organisms, and the essential property of an organism has become its level-dependent kind of dual closure. This novel approach implies a major re-conceptualisation of the discussions in this field.

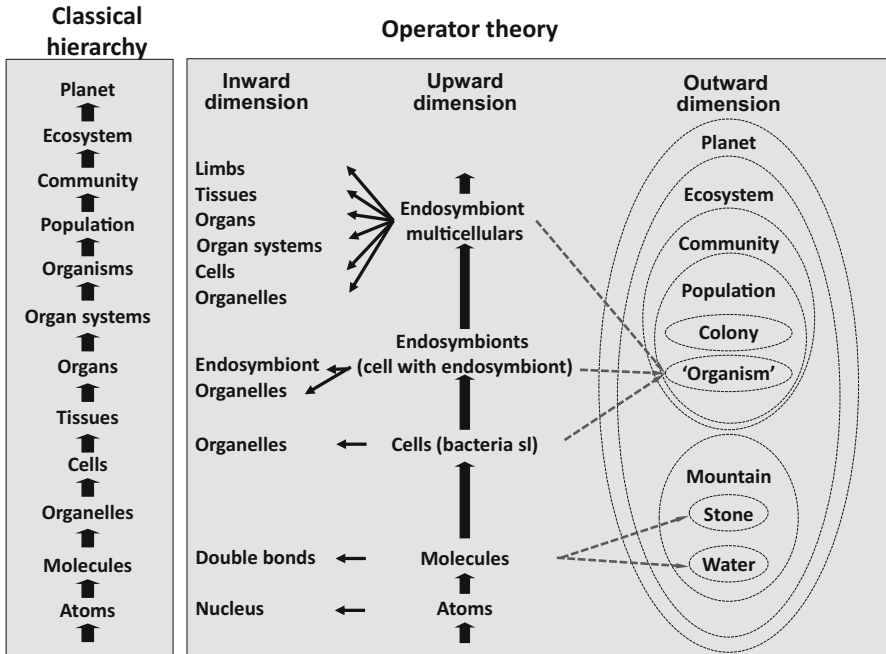
The operator theory also clarifies the difference between cell theory, and organismal theory (e.g. as discussed by Nicholson 2010; Nicholson and Gawne 2014, 2015). It does so by emphasising that a cell has dual closure, and that combinations of cells can also have dual closure. Both a cell, and a group of cells that have dual closure, are viewed as an organism. This indicates that in a single cell the criteria for dual closure and the criteria for being an organism are in full overlap. In systems that consist of multiple cells, however, the cells have one particular kind of dual closure and the multicellular organisation has another particular kind of dual closure. And for the Operator Theory it is the highest level closure that determines the kind of the operator.

### 2.7.3 *Relating Classical Hierarchy and the Operator Theory*

Those readers who are familiar with classical approaches in natural hierarchy, in biological/ecological hierarchy and in ecotoxicology, will have noticed that such approaches generally make use of a linear ranking, a “ladder”, in which lower level elements are subordinate in some way to higher level elements. However, the Operator Theory offers tools to allow that more complex hierarchies can be thought of, as is also suggested by the following citation of Bickhard and Campbell (2003) stating that: “The important point ... is that ratchets of stability of emergent forms can form ladders and more complex hierarchies—hierarchies of some kinds of new organizations and emergents that make possible other kinds of organizations and emergents. Such hierarchies impose an organization on the potentialities of progressive emergence: these hierarchies constitute intrinsic constraints on the possible courses of cosmology and evolution”.

As a supplementation of classical approaches that are based on a linear ranking, the Operator Theory proposes a conceptual framework for synchronic observations that works along three complementary lines, called dimensions (see Fig. 2.5). These dimensions are:

1. The Operator Hierarchy (the ranking of all the kinds of operators along the upward dimension).



**Fig. 2.5** A comparison of the classical hierarchy (*left*) based on a single dimension, and the new approach of the Operator Theory (*right*) based on three dimensions. *Dashed circles* indicate abstract conceptual groupings of increasing inclusiveness. Classical approach: levels are connected by *thick solid arrows*. Operator Theory: *Thick solid arrows* indicate the levels of the Operator Hierarchy along the upward dimension. *Thin solid arrows* indicate parts along the inward dimension. *Dashed arrows* indicate the belonging of specific operators to one or more conceptual groupings along the outward dimension

2. The organisation inside any individual operator (the inward dimension).
3. The organisation of systems that consist of interacting operators (the outward dimension).

In fact, it can be suggested that changes over time can potentially be viewed as adding a fourth dimension, representing the diachronic perspective.

The motivation for this multi-dimensional viewpoint is that each of the dimensions leads to a specific kind of ranking that is based on a specific kind of entities and ranking rules. For example the upward dimension selectively ranks operators of increasingly complex kinds, e.g. atom, molecule and cell. while the ranking rule is based on dual closures. The inward dimension focuses on an operator, and studies the material construction inside (e.g. organs and tissues in a multicellular organism). The outward dimension ranks increasingly general subsets of objects.

While the upward dimension has a stringent ranking that is based on (dual) closures, the ranking of objects along the inward and outward dimension is sensitive to the perspective that is used during the ranking process. For rankings along the

inward or outward dimension, one can choose different viewpoints that can be grouped according to the following major properties: Displacement, Information, Construction, and Energy. These different perspectives for analysing organisation have been indicated with the acronym DICE (Jagers op Akkerhuis 2008). The following paragraph offers some examples of how DICE can be applied to the inward and outward dimension.

When studying organisation along the inward dimension the following example demonstrates how DICE can be applied, Displacement can for example focus on the way that vessels and veins transport blood, and the way blood cells transport oxygen. Informational relationships can focus for example on how ribosomes read the DNA and how messenger RNA is produced, and transcribed resulting in amino acids. Construction relationships can focus on organs in multicellular organisms, and on the way organs are constructed. And energy relationships can focus on the uptake of food, and the different ways energy from the food is used in the body.

Along the outward dimension one can identify many different groupings of objects. Examples of such groupings at increasing levels of abstraction are for example a population, a community and an ecosystem. Or one can identify grouping of increasing size, such as hamlets, towns, cities and mega-cities. Many different perspectives can be used for the ranking of objects into groups. While such perspectives can be ranked using the dimensions of the DICE approach, also other approaches can be selected. Using DICE one can for example analyse an ecosystem as follows. When using feeding relationships, which belong in part to the construction dimension of DICE, and in part to the energy dimension, one can rank organisms into food chains. And when using displacement interactions, one can create a classification in which objects are transported either by wind or water, or by insects, birds, humans etc. And constructional relationships can be used to develop a tree of interactions in which for example bacteria grow on the skin of a mosquito larva, which lives in the water in the heart of a bromeliad, which grows on a tree, which grows in the soil.

The Operator Theory thus recognises three dimensions, upward, outward and inward, and suggests that classifications along the inward and outward dimension always depend on the perspective that is chosen, while these perspectives can be grouped according to DICE. In this way, the Operator Hierarchy helps creating awareness about the use of distinct kinds of concepts and ranking rules.

As an example of how the viewpoint of the Operator Theory contributes to classical approaches, one can look at the following example of a classical ranking: cells, organs, organisms, populations. In this ranking the objects are of different kinds: cells are either operators or parts of an organism, organs are always parts of an operator, the organism represents a conceptual class that may include various bacteria, protozoa, plants and animals, and a population represents a conceptual grouping of selected objects. Besides that ranking of the Operator Theory organises the different kinds of objects, it also organises the broad range of ranking rules. For example, the step from cell-to-organ, and from organ-to-organism will generally take place in an inverse direction, namely from a small multicellular organism with specialised cells, to a large multicellular organism that has multicellular organs. Finally,



the step from organism-to-population represents the conceptual step from a single element to a conceptual grouping of consciously chosen elements.

The three dimensions discussed so far are all synchronic dimensions, in the sense that they focus on the organisation of system at a specific moment. Of course one can also focus on the change or development of systems over time, using a diachronic perspective. The diachronic approach could be viewed as a new dimension that analyses things in a forward way. Along such a forward dimension one can analyse how organisms during their development change from one developmental stage to the other, and how interactions in ecosystems change, e.g. during succession.

### ***2.7.4 Relationships with the Major Evolutionary Transitions Theory***

The Operator Hierarchy is closely related to the Major Evolutionary Transitions theory that has been proposed by Szathmáry and Maynard Smith (1995). The Operator Theory adds new insights concerning the use of structural criteria and the classification of kinds of transitions. Firstly, all the major evolutionary transitions are based on the select use of three functional criteria (cooperation, competition reduction and reproduction as part of a larger unit), while the Operator Theory elaborates this viewpoint by suggesting the use of structural criteria in addition to functional criteria. Secondly, in the Major Evolutionary Transitions theory, all transitions that fit the criteria are viewed indiscriminately as major evolutionary transitions. The Operator Theory adds to this that the transitions that are referred to as major transitions differ in their kinds, and can be named according to these kinds. The Operator Theory also indicates that some transitions are relatively more complex than others, such as the BOL transitions, and that transitions may on the one hand lead to new kinds of operators (atoms, molecules, cells etc.), while on the other hand they may lead to new kinds of systems consisting of interacting operators (populations, societies). Studying the relationships between the Operator Theory and the Major Evolutionary Transition theory is relevant, because the relationships offer a basis for discussing how the use of structural criteria can contribute to the creation of hierarchical rankings. The relationships between the two approaches are discussed in detail in Chaps. 8–11.

### ***2.7.5 Using the Operator Theory for an Ontology of Artefacts***

From an ontological perspective, the Operator Theory primarily offers a hierarchy of kinds of operators. When looking at ontology from a causal perspective, this hierarchy itself represents a causal ranking of what came first and what came later. For example the formation of a cell necessarily must precede the formation



of a multicellular. In the same way, one can create a conceptual classification of different operators or interaction systems that could form because a specific operator was involved. For example, a farm can be viewed as a physical system that intelligent beings have constructed to produce agricultural products in an efficient way. This implies that one first needs intelligent beings, before there can be a farm. Basically, if one uses the logic of the Operator Theory, a farm classifies as an interaction system.

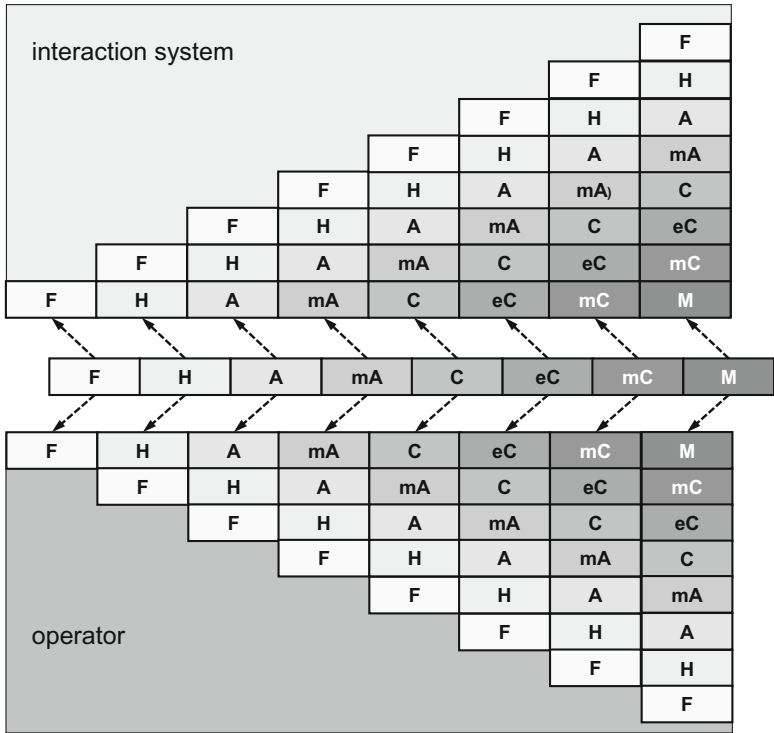
One can even be more precise in the classification of a farm as a system kind. In Jagers op Akkerhuis (2008) it was explained that the Operator Theory classifies interaction-systems after the highest-level operator that is involved in the system. And the most complex entities involved in a farm-system are either the farm animals or the owner of the farm as a human animal. Animals with a neural network are also called memons by the Operator Theory. This implies that a farm classifies as a memic interaction system. A scheme which organises all the causal relationships that lead to different kinds of operators and different kinds of interaction systems is offered in Fig. 2.6). As it is designed by humans, who classify as memons, a farm is viewed as a memic system of memic origin (Fig. 6.2: an interaction system of the kind  $M \rightarrow M$ ). Likewise, if humans modify a bacterium by means of genetic engineering, such a bacterium would classify as an operator of the kind cell, of memic origin. Similarly, a hammer would classify as a molecular interaction system of memic origin (in Fig. 2.6:  $M \rightarrow mA$ ) because the hammer is constructed by memons, and because the most complex operators involved in the construction of the hammer are of a molecular kind (the wooden/metal handle and the metal head). Likewise, a lignin molecule would classify as a molecular operator of multicellular origin (in Fig. 2.6:  $mC \rightarrow mA$ ).

### 2.7.6 *Summarising What Is New About the Operator Theory*

The Operator Theory has been the inspiration for some marked innovations in the thinking about objects and hierarchy.

Firstly, the Operator Hierarchy suggests that, because it involves a mixture of kinds of objects and kinds of ranking criteria, it may be profitable to re-conceptualise the classical perception of (ecological) hierarchy that is based on a single dimension. For unravelling which different kinds of objects and relationships are involved, a new approach is suggested which uses three independent dimensions (Jagers op Akkerhuis and van Straalen 1999; Jagers op Akkerhuis 2008):

1. An upward dimension for all the vertical transitions from quarks to neural network organisms.
2. An inward dimension for the levels of organisation inside an operator, such as organelles in a unicellular organism, and organs in a multicellular organism.
3. An outward dimension for analysing complexity in interaction systems, such as populations.



**Fig. 2.6** A causal classification of operators of different kinds, and the operators and interaction-systems they produce. *Middle*: a ranking of operators of increasingly complex kinds. *Top*: a ranking of interaction systems produced by operators. *Bottom*: a ranking of operators produced by operators. *Abbreviations*: *F* fundamental particles, *H* hadrons, *A* Atoms, *mA* multi-atoms (“molecules”), *C* cells (“prokaryotes”), *eC* endosymbiont cells (“eukaryotes”), *mC* multicellulars, *M* memons (neural network organisms)

Secondly, dual closure is brought forward as a general criterion for the hierarchical ranking of systems which are all of the same major kind, namely that of the operator. The use of dual closure also offers a basis for a stringent ranking of levels of (a specific kind of) complexity.

Thirdly, in close relation with the three dimensions for hierarchy, the Operator Theory allows a stringent top-level classification of major system kinds as operators and interaction systems (Jagers op Akkerhuis 2008).

Fourthly, the logic of the Operator Theory can be used to name developmental histories and life cycles after the highest kind of organisation included. Consequently, a bromeliad, a mushroom, and kelp classify as being part of a multicellular life cycle, while a tiger is part of the neural network life cycle.

Fifthly, the operator hierarchy offers a novel solution to the long standing challenge of defining the organism concept: only operators from the level of the cell and up are viewed as an organism.

### 2.7.7 *Current Status and Future Goals*

The Operator Theory is linked to the hypothesis that topological rules have guided nature through a long and specific sequence of increasingly complex operators. It seems as if there is a law in nature that limits the complexity of the operators to specific steps, that are guided by dual closure. In order to assess the validity of the Operator Theory one can examine the validity of the assumptions that underlay every individual transition. As another test, one can examine the secondary structure of the Operator Hierarchy, or the predictions that result from extrapolating the Operator Theory towards future kinds of operators.

While the Operator Hierarchy can be viewed as an interesting innovation that offers a foundation for exciting theoretic developments, it cannot be excluded that other ways may be found for creating a structured overview of the foundations of the organisation of the universe. How can one choose between such alternatives? To answer this question one can use Ockham's razor for comparing the effectiveness of the criteria of alternative hypotheses.

Focusing on the Operator Theory from an axiomatic perspective, there is an interesting observation to be made. Primarily, the goal of the Operator Theory is to develop a reasoning that results in an ontology that can be constructed from the bottom up. Such ontology should start at the beginning of the universe, and should describe all kinds of systems that formed over time, until finally organisms with brains emerged who can reason and construct a conceptual framework for analysing complexity in nature. A particularly challenging task that remains is to express the logic of the Operator Hierarchy mathematically, in all its detail, for example by using a framework based on topology. Such a framework should enable the prediction of every single step in the Operator Hierarchy and should also produce the hierarchy's secondary structure. The use of mathematics may assist in resolving some aspects of the theory which currently are not understood in full depth, such as the following aspects that still demand technical and conceptual elaboration: 1. The question of what exactly are the multicellular units that form the basis of the step from the multicellular to the memon, 2. The question of whether the hypothetical existence of unicellular organisms with multicellular endosymbionts is relevant for the structure of the Operator Hierarchy, or falls in the class of 'endosymbionts of any kind' which applies for example to the endo-endosymbiont cells, 3. In the electron shell of an atom the electrons originate from two levels below the level of the atom, which is in contrast with all other steps in the Operator Hierarchy where the next dual closure involves the operators of the preceding level, and 4. The challenge of predicting accurately any next kind of operator above the level of the hardwired memon. While these four points still pose challenges, the Operator Theory in its current status can be viewed as providing a framework that suggests many novel pathways for theoretical and practical research in system science.

Interestingly, while in the universe all entities were formed in a long sequence of processes, it is not possible to use that same sequence as an axiomatic basis for thinking about the universe. The reason is that most of the time there was no one present to identify and classify the things that happened or were formed such that

they could be used for the construction of an axiomatic ontology. Things just happened. A possible solution to this problem is to accept that—with hindsight—one acts as if one can observe and classify the developments in the universe as through the eyes of an independent observer. And it is the role of this independent observer to construct a representation that suits the criteria of an axiomatic ontology, which finally includes sentient beings, and their thoughts about the world. As soon as a specific ontology includes sentient beings, and their thoughts, the ontology can use these entities as a basis for including conceptual representations. Subsequently, every object in the world can be described by means of a conceptual representation. From this point onwards, an intelligent being can work with a conceptual axiomatic ontology, representing his/her thoughts about what happened in the universe before the existence of intelligent beings capable of thinking about the universe. In fact, when talking about the Operator Hierarchy its structure represents the latter viewpoint. The Operator Hierarchy offers a conceptual representation that describes and ranks all the construction steps in the universe that are based on (dual)closure, and the kinds of objects that are produced by such steps.

The Operator Theory is a new theory. The earliest conceptual drawings of it stem from 1994. Since that time, the approach has offered a starting point for many challenging theoretical developments, such as those discussed in the following chapters of this book.

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