EXTRAPOLATING A HIERARCHY OF BUILDING BLOCK SYSTEMS TOWARDS FUTURE NEURAL NETWORK ORGANISMS

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ABSTRACT

Is it possible to predict future life forms? In this paper it is argued that the answer to this question may well be positive. As a basis for predictions a rationale is used that is derived from historical data, e.g. from a hierarchical classification that ranks all building block systems, that have evolved so far. This classification is based on specific emergent properties that allow stepwise transitions, from low level building blocks to higher level ones. This paper shows how this hierarchy can be used for predicting future life forms.

The extrapolations suggest several future neural network organisms. Major aspects of the structures of these organisms are predicted. The results can be considered of fundamental importance for several reasons. Firstly, assuming that the operator hierarchy is a proper basis for predictions, the result yields insight into the structure of future organisms. Secondly, the predictions are not extrapolations of presently observed trends, but are fully integrated with all historical system transitions in evolution. Thirdly, the extrapolations suggest the structures of intelligences that, one day, will possess more powerful brains than human individuals.

This study ends with a discussion of possibilities for falsification of the present theory, the implications of the present predictions in relation to recent developments in artificial intelligence and the philosophical implications of the role of humanity in evolution with regard to the creation of future neural network organisms.

Keywords: System hierarchy, evolution, AI, operator hypothesis, building blocks, emergent properties, Constrained Generating Procedures, neural network organisms, memes.

1. INTRODUCTION

There is an old saying: to predict the future one has to know the past. But what should one think of as the past of evolution? How can the evolutionary process be traced back and what can historical steps teach us about the future?

Interpreting evolution in a broad sense, as has been advocated by Laszlo (1994), the evolutionary process has a long history. A history that goes back to a time when the universe showed little differentiation; it was small and extremely hot. It is now widely accepted that after an explosion referred to as the big bang, the baby-universe expanded and cooled down. From that moment onward, the overall universe became increasingly disorganised. Yet, some parts show a process of complexity increase, the occurrence of which is indicated by the subsequent emergence of new types of building block systems and associated interaction systems.

The building block systems are given special attention in the present study. From a beginning with only elementary particles, the universe has gradually become enriched by the emergence of more and more building block systems. Earlier studies focusing on these building blocks and their hierarchy include Feibleman (1949), Simon (1962), Bertalanffy (1968), Teilhard de Chardin (1969), Koestler (1978), Heylighen (1995), Close (1996) and Jagers op Akkerhuis and Van Straalen (1998). At present, the 'ancestral tree' of the building blocks includes the quarks, the hadrons, the atoms, the molecules, the prokaryotic and eukaryotic cells, the multicellular individuals and the multicellular individuals showing a neural network capable of learning.

As is discussed by Jagers op Akkerhuis and Van Straalen (1998) the emergence of any building block adds new aspects to the environment in which it interacts with all other building blocks. This environment consists of interacting building blocks and can for this reason be considered as an 'interaction system'. Examples of interaction systems are galaxies, stars, planets, stones, water, meteors, ecosystems and societies. As is shown in Figure 1, a close relationship can be recognised between the hierarchy of building blocks and the ranking of interaction systems.

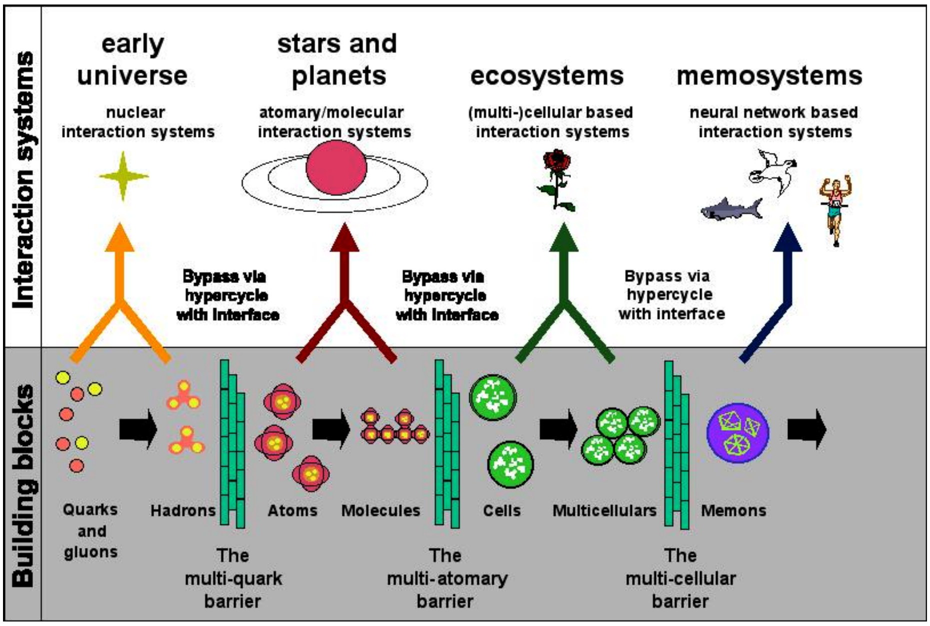

Figure 1. Building block systems and interaction systems. Lower part: *building blocks* and their multistages: quarks and hadrons, atoms and molecules, unicellular and multicellular organisms, and neural network organisms. Upper part: *interaction systems* such as the early universe, stars, ecosystems and societies. Horizontal, black arrows: transitions from a single operator to its multistage. Grey forked arrows: contributions of operators to the interaction systems in which they represent the highest level building blocks. Contributions of operators from lower levels are not indicated separately.

The main aim of this study is the prediction of new life forms via the extrapolation of the hierarchy of the building block systems. In this process we deliberately leave the interaction systems, i.e. stars, planets, etc., out of the discussion. This means that even though interaction systems play an important role as environments that mediate the emergence of new building blocks, the discussion in this study is limited to the formation of the building block systems. The reason is that their subsequent emergence can be ranked in a clear hierarchy offering a unique basis for extrapolations towards future systems.

In the form of the 'operator hierarchy' or 'operator hypothesis', Jagers op Akkerhuis and Van Straalen (1998) discuss the hierarchical relationships of natural building blocks. The building blocks were christened 'operators', for their capacities to operate in an environment and adapt their phenotypes to a broad range of environmental conditions, without losing the most essential aspects of their organisation. As the operator hypothesis holds such an important position in the present study as the basis for all extrapolations, we will begin with a short resume of the operator hierarchy.

2. THE OPERATOR HIERARCHY

The operator hierarchy (Figure 2) is based on a strict, stepwise approach to the complexity of building block systems. Each step is the result of a specific emergent property that causes the transition from building block A at level X to a more complex building block B at level Y. Figure 2 shows that the approach recognises major and minor transitions.

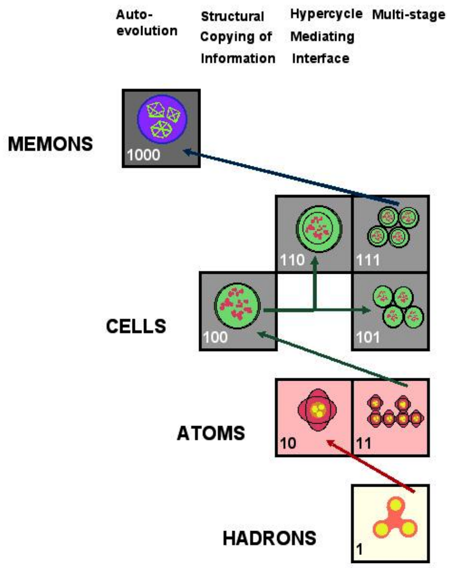

Figure 2. The operator hierarchy. The different evolutionary pathways (lines with arrows) are shown in direct relationship with the emergent properties of the operators (vertical columns). In accordance with the focus on major and minor transitions, the operators are given binary numbers. I: The hadron, I0: The atom, II: The multi-atom, I00: The cell, I0I: The simple multicellular, II0: The eukaryote cell, III: The eukaryotic multicellular, I000: The hardwired memon.

Major transitions

Each major transition, as recognised under the operator hypothesis, creates an entirely new operator type and the beginning of a new major layer (Figure 2). Four examples of operators that according to the operator were created via major transitions are the hadrons (the proton and neutron), the atoms, the prokaryotic cells and the organisms showing a hypercyclic neural network. Of all operators, these four systems are special because each forms the first system of a next row in the operator hierarchy. For this reason they are also called 'first of the row operators'. According to the operator hypothesis, major transitions are always characterised by emergent hypercyclic dynamics. On the basis of enzymatic reactions in cells, Eigen and Schuster (1977) have described hypercyclic dynamics as being cyclic arrangements of elements which themselves are cycles of reactions. A very readable explanation of hypercyclic enzyme reactions in cells can also be found in Kauffman (1993). To define clearly what the operator hypothesis regards as the typical hypercyclic dynamic for each transition, the cycles and hypercycles are shown in Figure 3 and will be discussed in more detail below. With the exception of the hadron, that has such low complexity that

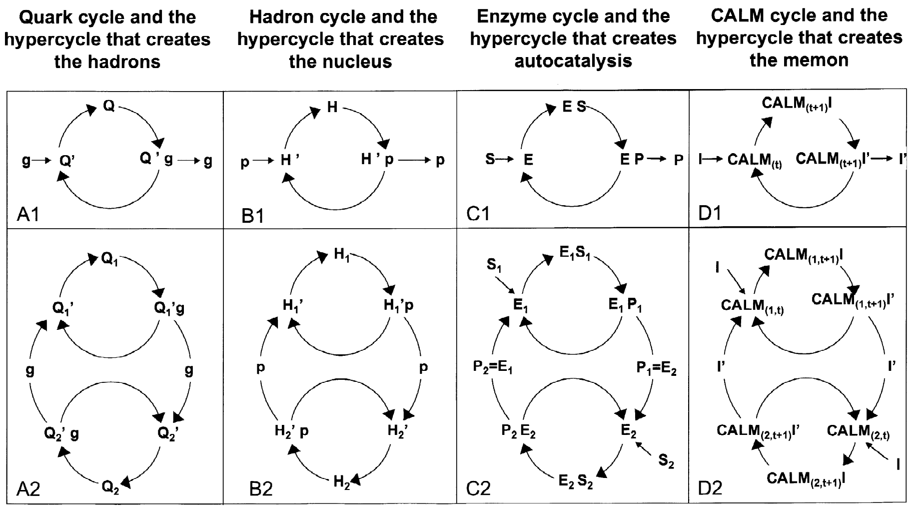

Figure 3. Emergent hypercyclic processes that mark the four major evolutionary transitions. A1: First order reaction cycle of a quark (Q). The quark emits a gluon (g) and becomes a lighter quark (Q'). A2: Second order cyclic process in which two quarks mutually exchange gluons. B1: First-order reaction cycle of a hadron (H). The three-quark hadron (H) emits and absorbs a small two-quark particle (a pion, p). B2: Second-order cyclic process in which two hadrons mutually exchange pions. C1: First-order reaction cycle of an enzyme reaction. The enzyme (E) binds to a substrate (S), transforms it to a product (P), and regains its original form. C2: Second-order cyclic process in which two enzyme reactions mutually create the enzyme for the other cycle. D1: First-order cyclic process on the basis of a group of neurons, called a CALM, because it acts as a categorising and learning module. The $CALM_{(t)}$ receives information (I) and becomes a $CALM_{(t+1)}I$, which can forward information to become the original CALM in a new starting state $CALM_{(t)}$. D2: Second-order reaction cycle in which the perception and release of information proceeds between two or more CALM's.

the multi-property just emerged and containment is not yet possible, all later major transitions are derived from multistage elements and show containment of the hypercyclic dynamics by an emergent interface.

Minor transitions

The minor transitions are associated with emergent properties that occur within a major layer. The operator hypothesis states that these minor transitions reflect the emergent properties of major transitions occurring earlier. The names of the minor transitions are shown on top of the columns in Figure 2. How the properties of major and minor transitions are linked is explained in short in the following lines.

The formation of the hadron is the first major transition. The hypercyclic dynamics in the hadron (see Figure 3A1 and 3A2) create a system that shows emergent multiness of elementary particles. Multiness, as an emergent property, recurs from now on at each higher level, in the form of the last minor transition in every row.

The second major transition leads from the hadron to the atom (Figure 2) In addition to a hypercyclic nucleus (Figure 3B1 and 3B2), the atom shows an electron shell as interface that mediates the interactions of the nucleus with the world. This property is called a hypercycle-mediating interface (HMI). With the latter naming I deviate from Jagers op Akkerhuis and Van Straalen (1998) where this property is called internal information compartmentation (IIC). The reason is that more emphasis should be put on the emergent occurrence of the interface. From this moment on, the HMI property will show up in higher levels immediately before a multistage.

Some atoms may show a minor transition and become a multistage: i.e. a molecule, a metal grid, etc. Only a selection of these multistages, notably enzymatic catalists, can show a reaction cycle that can be linked in hypercyclic dynamics (Figure 3C1 and 3C2). The latter marks the next major transition from molecules to cells.

Besides their hypercycle and containment, cells show the capacity to structurally auto-copy the information in their hypercycle. As can be seen at the top of Figure 2, this property is called Structural (auto-)Copying of Information. The SCI property can be seen to recur, at any higher level, before the HMI stage that in turn precedes the multistage. From the prokaryotic cell, a minor transition may lead directly to the prokaryote multistage, as can be observed in bluegreen algae. A different route leads first to the gaining of a hypercycle-mediating interface and then to the eukaryote multistage.

Within the multicellular environment, certain cells, the nerve cells, have gained the capacity to let thin cell extensions construct recurrent activation/inhibition interactions. In this way small units of cells are formed, showing a unit structure that in artificial neural network research has become known as ‘categorising and learning modules’ or CALM’s (Murre *et al*. 1989, 1992). These CALM’s show a recurrent interaction and thereby a first order interaction-cycle. If these CALM’s are coupled again, creating a next recurrent connection, this results in a hypercyclic cirquit (Figure 3D1 and 3D2). The surrounding of these neural circuits by an interface of sensory/activation cells fulfills the requirement of the operator hierarchy for a next major transition; from multicellular individuals *without*, to multicellular individuals *with* ‘’brains’’. Multicellulars with hypercyclic brains have been named ‘memons’ by Jagers op Akkerhuis and Van Straalen (1998) to which study we also refer for a more in-depth explanation of the latter transition. The word memon is selected as a general term for individuals that show an emergent hypercyclic neural network with interface. It should be noted that the group of memons includes all animals with a brain that, at least locally, shows hypercyclical activity. This implies that most animals and human individuals are included, but no plants or fungi.

How the memon may develop via minor transitions to more complex life forms is discussed below as part of the present extrapolations.

3. HOW TO QUANTIFY EMERGENT PROPERTIES

All emergent properties in the operator approach are based on changes in the organisation of the systems involved. A simple quantification of an emergent property is, therefore, not possible, because an emergent property implies a new system configuration, and its new property cannot be quantified in terms of the old configuration. This forms a serious obstacle for attempts at quantification. This general problem of emergent properties is discussed by Holland (1998) in his recent book 'Emergence'. We strongly support his proposal for a solution by defining emergent properties on the basis of special models called 'constrained generating procedures' (CGP's). With respect to CGP models, Holland (1998) says: "The models …are dynamic, hence *procedures*; the mechanisms that underpin the model *generate* the dynamic behaviour; and the allowed interactions between the mechanisms *constrain* the possibilities, in the way that the rules of a game constrain the possible board configurations." Thus, when basic functional elements, the mechanisms, create a constrained interaction pattern, a new system is created which, as an individual entity, may show unprecedented functional properties: the emergent properties. In line with the reasoning by Holland (1998) and Simon (1969) a CGP that shows persistent dynamics, may itself act as a building block for the creation of higher level CGP's. In the latter case, CGP's can be used as the building blocks of multilevel CGP hierarchies. This is exactly the way in which the present study deals with building blocks and emergent properties. By selecting persistent physical building blocks that themselves can act as the building blocks for the next level system, such as atoms, molecules, cells, etc. a continuous hierarchy can be recognised. On the basis of CGP's it is possible to formulate a mathematical description for any emergent property, as is discussed in Chapter 7 of Holland (1998).

A few words should furthermore be directed to those that expect quantitative predictions from the present approach. In principle I regard the presence of a hypercycle as a quantitative aspect, namely as the prediction of a specific CGP, the structure of which can be quantified in terms of the links between the contributing mechanisms. Further quantitative predictions are not aimed at during the present extrapolations. The reason is that aspects regarded as quantitative, such as the weight, colour or DNA structure, are not very relevant in this context. The weight may help to describe a particular atom 'species' but different atoms can vary considerably in weight, ranging from helium to the trans-urane elements. A specific weight, therefore, is not a group property. Another example is given by unicellular organisms. These change weight/colour/precise DNA structure during their lives and/or between generations. Again, the weight/colour/DNA are not essential aspects of their group property, which is their existence as a cell. The observations that all species of atoms are atoms and all species of unicellular organisms are unicellular organisms are based on common properties shared by all members of the group. These *group properties* form the focus of the present study.

4. PREDICTIONS

The working hypothesis of this paper is that the internal logic of the operator framework (illustrated in Figure 2) can be extrapolated to more complex systems than hardwired memons. As can be deduced from Figure 2, all evolutionary stages that are presently predicted are memons. This implies that it may be wise to discuss some concepts regarding memic systems before we proceed, so that no confusion will arise when in a later stage exotic memic properties are discussed.

Meme concepts

In this study, the concept of a memon is used for any operator within the memic layer, e.g. all systems that show an emergent hypercyclic neural network and interface. The memons that emerge first will show a hardwired neural network that is based on autocatalytic cells, the nerve cells or neurons, or that is based on technical hardware. Higher level memons may also show a programmed neural network. Memons are involved in the copying of various memic entities, which we will define in more detail here. Firstly, the concept "functional-meme" (or f-meme) could stand for the actual neural network that in its structure harbours learned knowledge and, therewith, abstract memes. Secondly, a "coding meme" (or c-meme) could be used to define any string of codes that contains the information to construct a certain neural network. In fact, a coding meme codes for a neural network architecture and associated knowledge much in the same way as a gene code for a catalytic molecule playing its role in the survival of the cell. Thirdly, they may exchange ideas. We suggest using the concept "abstract meme" (or a-meme) for such abstractions, for example melodies, ideas and jokes that may reside in functional meme networks and can be transmitted from memon to memon in the process of communication. This is closest to the meme concept as introduced by Dawkins (1976). Finally, memons will actively create physical "traces" of their thoughts, such as books, houses, computers, radiowaves, etc. These could best be indicated as "physical meme models" or physical memes (p-memes), because these entities represent "real world" models of the concepts represented by abstract memes.

Which rationale can be used for extrapolations?

The operator hierarchy offers a structured basis for extrapolations (Figure 2). Yet, it can be deduced that there is an aspect of the predictions for which the historical data does not give full information on future possibilities. The reason for this lies in the question of whether or not the emergent properties are independent. In principle, each time an independent emergent property is added, this would double the number of possible system types. The operator hierarchy (Figure 2) shows that for hadrons, there is only multiness. For atoms, there is a single degree of freedom, which leads to two system types: single atoms and multi-stages. Next, prokaryotic cells have two degrees of freedom, which leads to four system types: prokaryotic cells, eukaryotic cells and their multistages. However, even though the latter indicates two degrees of freedom, it cannot be deduced from this example whether the four system types are the result of dependent or independent combinations of the two degrees of freedom. For the next level, the memic level showing three degrees of freedom, this implies that it is not possible to predict whether six or eight memic system types will emerge. Independence of the emergent properties would result in a total of eight possible system types, e.g. 2*2*2=8 combinations, dependence would lead to a total of six, because any next minor transition would only be possible following the immediately preceding minor transition.

Now that we have discussed some basic aspects of the present predictions the time has come to predict properties of future memons.

Prediction 1. The memic multistage: a robust prediction

Our first prediction is based on a conservative approach that selectively uses the most obvious aspects of the operator hierarchy: the major transitions. Major transitions are a robust basis for extrapolations because each time the multistage is reached, a major innovation, e.g. the creation of a new building block type, is obligatory for the continuation of evolution. For this reason, the iteration between 'first of the row' operators and their multistages forms a robust principle on which to base predictions.

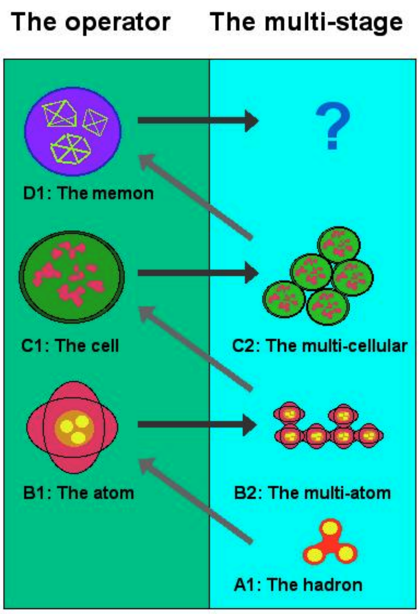

Figure 4. The lowest and the highest complexity operators that are based on systems showing the same type of hypercycle. A1: the hadron, a quark multistage. B1: The atom. B2: The atomic multistage. C1: The cell. C2: The cellular multistage. D1: The individual with hardwired hypercyclic neural network called the 'memon'.

Focusing on major transitions only, the operator hierarchy can be summarised as is shown in Figure 4. From this starting point, two predictions on future system types are available. The first prediction is that some day systems will evolve which show a multistage that is based on elements showing neural network architecture. The second prediction is that this multistage will form the basis for a new cyclic interaction, which will lead to the next hypercyclic interaction forming the basis of the next evolutionary level.

As the above conservative prediction is strictly based on the most fundamental aspects of the operator hierarchy, there is a large probability that the prediction of a future multistage is correct. But how much information is gained with such a prediction? In fact, the information is limited, because insight is still lacking on the specific properties of the memons that form the building blocks of the multistage. A most serious error, which is easy to make at this stage, is to start considering how, for example, human brains, as a neural network type of considerable complexity, can be imagined to function as a multistage. To do this would deny the possibility of stages in between any newly formed building block and its multistage (see Figure 2). This may not seem problematic for the step from the atom to the multi-atom stage, because this step leaves no room for additional system types anyway. But serious problems arise for cells, which may be prokaryotic or eukaryotic, each creating its proper type of multicellularity. Prokaryotes have given rise to multicellular blue-green algae. Eukaryotes have formed fungi, plants and animals. There is a world of difference between the intercellular communication in blue-green algae on the one hand and that of fungi, plants and animals on the other. The lesson from this is that the complexity of the building blocks has a major influence on the potential complexity of the multistage. The assumption that human neural networks would be the building block for the multistage leads to the imagining of a multistage with ridiculously primitive properties. The error would be similar to explanations of multicellular life on the basis of prokaryotic units only. As will be shown in the following text, the solution to this problem lies in the recognition of the other steps of complexity increase that the operator theory helps to recognise between any newly emerged operator and its multistage.

Prediction 2. The hardwired memon and its multistage

The most straightforward detailed prediction is that the I000-memon, or hardwired memon, develops directly to a multistage (memon 1000 and 1001 in Figure 5). This results in a primitive multistage having limited prospects for becoming of any evolutionary importance. The reason is that the transition to this multistage will be difficult and slow, especially for memons based on cells. This is caused by two major drawbacks of these systems. The first drawback is that genes code for the structure and quality of cellular neural networks that, for this reason, can only evolve over many generations, via reproduction and selection. A second drawback is that their bodily construction and interfaces are based on organic cells, with many limiting consequences for the way in which they can become physically linked into a multistage and for the way in which the linked individuals can exchange information. The construction of a technical hardwired memon may improve on this situation, because its technical construction and interface would bring more powerful ways within reach for physical connection and communication with other memons.

Prediction 3. The SCI-memon and its multistage

Much more promising are the prospects for the pathway towards the structural (auto-)copying of information (SCI) multi-stage. For this pathway, a hardwired memon first evolves to the SCI-state before it evolves to a multistage (memon 1100 and 1101 in Figure 5).

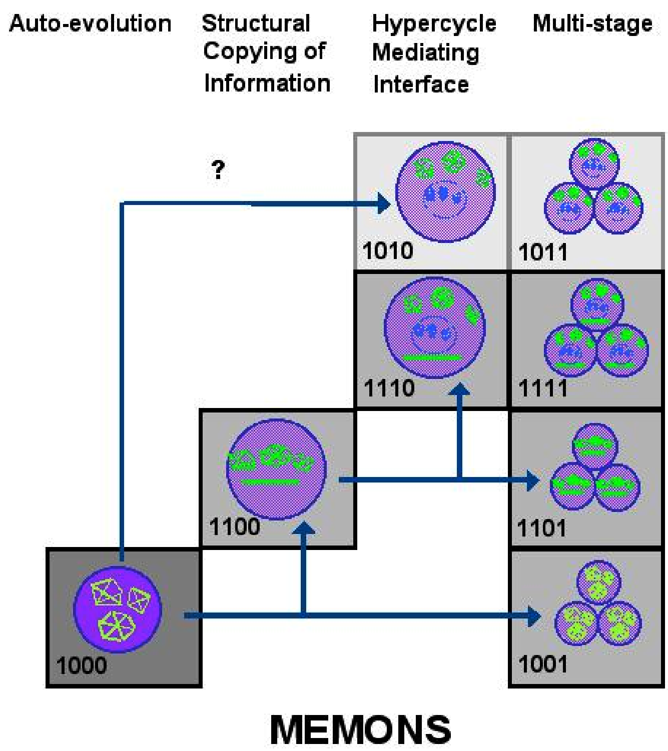

Figure 5. Predictions of future memons. I00I: Predicted multistage of the hardwired memon. II00: Predicted memon with the SCI (structural copying of information) property. II0I: Predicted multistage of the SCI memon. III0: Predicted memons showing SCI and Hypercycle Mediating Interface (HMI) properties. IIII: predicted multistage of the III0 memon. I0I0: Predicted HMI memon. I0II: Predicted multistage of the I0I0 memon.

The SCI property has occurred earlier in evolution in cells. Here autocatalysis implies that a full structural copy of the information in the cell is produced, which, in present day cells is for the largest part allocated in DNA and/or RNA. The auto-copying process for neural network information does not involve DNA. Yet, it requires that the memon can copy the architecture of all neurone connections and the interaction strengths of all synapse connections. This leads to the very strict requirement that it must have access to all this information. There is no way in which a memon can (auto-)copy its neural network without full information about the architecture and interaction strengths. It is hard to imagine how a cellular memon could do this. This would require sensory cells which by some means find out what cells are connected to each other and in addition measure the strength of each synapse and report this to the individual. Apart from the physical tour de force to host large amounts of additional sensory cells in the brain, we consider the chance that this evolves naturally extremely small if not impossible. Even genetic manipulation may prove an insufficient tool to reach such a complex goal.

The prospects that computer based memons gain insight into the exact state of their brain are much better. The only thing they need is an extra interface that helps them read the arrays with information about their cell-cell contacts and synapse strengths, which information is kept off record anyway in programmed memons. From the moment that network structure and interaction strengths between cells can be examined, a whole world of new properties opens up, which allows a number of exciting predictions.

The first prediction based on the SCI property is that, for reasons discussed above, SCI-memons would with very high probability be technical constructions. Accordingly, the SCI-property strongly guides predictions in the direction of computer-based entities. Despite its technical construction, the SCI-memon and human beings have a similar basis for their neural network structure. In principle this allows for ‘human’ processes, such as intelligence, creativity, curiosity, etc. But a technical construction will also imply important differences with respect to energy procurement and living environment. Energy procurement will focus on electricity. And, because a technical memon does not breathe air, they can colonise underwater environments, planets without an atmosphere, or even a free position in space, supposing that other resources for normal functioning are available.

That SCI-memons most likely show a technical basis is furthermore of marked importance for the evolutionary debate. The reason is that SCI-memons cannot evolve as a special case of organic life. As they are technical constructions, it is simply impossible that they evolve as offspring from cellular parents. Instead, SCI-memons have to be built either by cellular memons, as a special kind of tool (a p-meme!) that starts defining its proper goals in life, or by technical memons, as a special kind of constructed offspring.

The moment that SCI-memons can copy their knowledge structurally this will cause an earthquake in memic evolution, the importance of which can hardly be overestimated. As an exploration of the possibilities, the text below gives some examples:

1. SCI-memons can for the first time in memic evolution reproduce their whole personality by simply producing a structural copy of their neural network. This copy will automatically contain all learned knowledge. Note that despite discussions about

cloning, human beings absolutely lack a similar option. Humans cannot perform a structural reproduction of their whole personality, e.g. of all nerve connections and interaction strengths, simply because they lack access to the network topology and interaction strengths. What human beings copy upon reproduction is the genetic coding for a human being which will show a mixture of parental phenotypic properties and which upon birth has a neural network showing a good deal of genetically based pre-structuring, but which is devoid of learned knowledge. This means that the body and the overall network structure are roughly copied, but without even a trace of anything the parents have learned. As the structural copying of the parental knowledge is blocked, the transfer of knowledge to the offspring requires a long detour via many years of education. For SCI-memons reproduction of their complete knowledge can take place almost overnight as long as an appropriate technical device is available to which the information can be copied and in which it can become operational. This shows that if the intelligent technical memon has taken shape, it is but a small step to a whole population of such memons. In fact, technical memons will find that the copying of a full parental network is costly in terms of energy and time. The parental memon may therefore consider the production of small network-vehicle combinations with the best possible capacities for learning and maintenance, and the capacity to actively enlarge their bodily and memic construction to develop into fully-grown memons themselves.

2. The working with and/or copying of network topologies will require some kind of coding to handle the information about the topology and the interaction strengths of the neural connections in the copied network parts. As discussed above, these code-strings hold a position in memons, which is similar to the DNA in cells. Where specific regions on the DNA, the genes, code for specific proteins, it will now become possible to recognise specific regions of coding, which code for network structures with certain properties.

3. SCI-memons can use the access to their own neural network to create one or more shunts of network parts, in each of which they can introduce small modifications to study which network configuration yields the best results. This implies that real-time, goal-oriented improvement of network configurations has become reality. In fact, not only the configuration of such networks can evolve. Several other features too may evolve, including the signalling procedures between neurons, the integration functions via which the neurones decide whether or not to signal subsequent nerve cells and the ways in which coding memes are coding for neural network constructions.

Further aspects of technical memons that follow more or less from the above three points are also interesting. In order to stay focused on the major aspect of this study and prevent technical details, we will only shortly mention these aspects without going into details. These aspects are: the possibility of meme trade, the accelleration in memons of thinking speed with computing speed, the tendency towards the development of modular network architecture and the capacity of technical memons to integrate very different technical equipment directly into their interface.

SCI-memons have a much better chance of reaching multicellularity than the hardwired memons (I000 in Figure 5). The main reason being, of course, that they may show very high evolution speed, due to properties such as: a programmed network structure, the possibility of internal experimenting with network parts, the creation of similar copies, the acquisition of informed network parts via trade and the possibility of programmed interfaces. Increasing competition for living space on earth and available resources in new environments, such as local networks of a company or a spaceship and larger networks, such as the global inter-net, will force SCI-memons to cooperate for survival. In some cases this will drive SCI-memons to dependence on cooperation and to structural connection, marking the transition to the SCI-multi-memon state.

Prediction 4. The HMI-memon and its multistage

The next predictable property of a future memic operator is that of Hypercycle Mediating Interface (HMI) (memon 1110 and 1111 in Figure 5). Figure 2 shows that the HMI property has occurred earlier in evolution, i.e. in atoms and eukaryotic cells. In atoms, the Hypercycle Mediating Interface emerges for the first time in the form of the electron shell. In eukaryotic cells the situation is more complex. Here, a new interface is added to the already existing interface around the cell, creating a second interface: the nuclear envelope.

In cells, large 'libraries' of information are stored in the form of DNA/RNA. In prokaryotic cells the unpacking of the information and the functioning of the coding for enzymes occur in the same compartment. In eukaryotic cells, the storage part of the information has become sequestrated to the nucleus, from where coded information is transported through pores in the nuclear envelope to the soma before it is (transcribed) to functional enzymes. This shows that the nuclear membrane separates the cell into two compartments. In the nucleus the information of the cell is for the largest part handled in a coded form. Outside the nucleus the information is active in the form of enzymes. Accordingly, the HMI property is associated with an extra internal interface that separates different levels of the expression of the information.

This observation offers information about possibilities for future system configurations, because the continuation of this sequence would imply a three-layer HMI in future memons. But, assuming that this extrapolation is valid, it remains in our opinion quite hard to imagine at the present state of the understanding of the operator hierarchy what the second layer would look like in practice. Starting simply, two situations will be visualised showing an extra interface. These can then be combined to create a tentative prediction of a two-layer IIC-memon.

Imagining only a single layer, as in prokaryotic cells, it would be quite natural to assume that the HMI-memons find increasing use for coding memes, in the shape of code-strings that represent the topology and strengths of all the neural connections of modular network parts. The reason for the popularity of c-memes is that they offer a highly efficient method of coding to store away all information that via experience and learning was gathered in the neural networks. This implies that, by using c-memes, little energy is required to maintain large reservoirs of knowledge, of which only a minor part would have to be unpacked and used in response to specific environmental conditions, after which it could be packed away again in its new, more experienced form. In contrast to networks and code strings that are stored temporarily in the active working memory of the memon, a more profound storage of c-memes would imply that these are stored away in a form which is not directly accessible, for example in a high capacity data-storage medium. A potential candidate for this process is the threedimensional storage in crystals that are programmed and read by means of laser beams. But the storage and retrieval of large amounts of c-memes will require a special interface to decode the information. The new coding and the related interface would imply an additional Hypercycle Mediating Interface.

There is another way, via which an additional interface could evolve in these future memon systems. To understand this, we have to place ourselves in the situation of an SCI-memon that has just copied its network structure into a new vehicle. Unfortunately, this imaginary new vehicle which is furnished with a lot of new technical properties, differs in many aspects from the previous one. This implies that the memon has to go through a long process of revalidation and practice with its new 'body' for adjusting its neural circuitry to the new phenotypic properties. Such a practice period could be made a lot shorter, and larger differences between the old and the new vehicle could be allowed, if the neural network of the memon possessed translation interfaces allowing a rapid adjustment of the memon's 'proper' interface to various types of vehicles. It will probably be most efficient to have only a selection of such interfaces active, namely those that yield the highest survival value under given circumstances. Other interfacing networks can then remain stored as c-memes in the central meme library.

The combination of an internal c-meme library with a translation interface would, in principle, allow a two-level Hypercycle Mediating Interface.

Prediction 5. From the hardwired memon, via the HMI-memon without SCI properties towards to multistage

Assuming independence of the minor emergent properties, a comprehensive discussion of the possibilities for future memons, should also include the route from hardwired memons to HMI-memons, without the intermediate stadium of the SCI-memon (the route from memon 1000 via 1010 towards system type I0II in Figure 5). Even though it could be a theoretical possibility, the direct transition from hardwired memons to HMI memons must be expected to suffer from technical problems due to a low rate of evolution. The reason is that hardwired memons cannot read their neural network state. If the HMI-memon without SCI properties will arise at all, it will certainly have problems reaching a multistage. The contribution of this option to the mainstream of operator evolution must, therefore, be considered minimal, and the existence of these type of operators be considered more of theoretical importance.

5. CONCLUSIONS AND DISCUSSION

The above extrapolations present a panorama of possibilities for future organisms. First of all, it appears that the most likely next stages will be technical neural network organisms, because this is by far the most likely option for constructing a system type that can show structural auto-copying of information. The reason is the structural copying of information requires that the network structure and synapse strengths can be assessed by the organism itself and copied. Even if genetic manipulation were to proceed far beyond the present level, it is hard to imagine that brains could be developed showing extra cells in-between present brain cells, that can analyse the neural network structure and report this to the individual. Secondly, the predictions strongly suggest that man must create the next stage in the operator hierarchy, because it is hard to imagine the development of a technical construction from a cellular basis. The predictions also show that, one day, neural network organisms can be created that can copy themselves. For this purpose one could simply imagine a "body factory" constructing phenotypes that can be bought by any existing memon for the purpose of copying a neural network structure onto the new phenotypes computer space. From that moment onwards, humanity will have to live amongst such intelligent technical 'organisms'. Thirdly, the operator framework depicts evolution as an open, ever-extending process, in which the next major transition coming will be based on a hypercyclic interaction between multimemic elements, most likely within the 'environment' of a multi-memic organism that is supported by a technical vehicle. Fourthly, the operator approach suggests that if technical memons are not constructed, this will block, on earth, the evolutionary sequence that leads from one operator to the next. We stress that this does not affect the evolution of cellular organisms, including cellular memons, which, of course, will continue.

One may now ask what the novelty is of the above insights, especially because there is a growing awareness that technical developments will before long create machines that will compete for resources with cellular life as we know it. For example Kelly (1994) in his book 'Out of control' uses citations of C. Langton to convince the reader that:

> 'There are these other forms of life, artificial ones that want to come into existence. And they are using me as a vehicle for its reproduction and its implementation'. … 'By the middle of this century, mankind had acquired the power to extinguish life. By the end of the century, he will be able to create it. Of the two, it is hard to say which places the larger burden of responsibility on our shoulders'.

The new life-forms are frequently expected to become a threat. Warwick (1997) makes the following three statements in his book 'The march of the machines' in a chapter, which is called 'Mankind's last stand?'

> '1. We humans are presently the dominant life form on Earth because of our overall intelligence. 2. It is possible for machines to become more intelligent than humans in the reasonably near future. 3. Machines will then become the dominant life form on Earth'.

A last example of predictions of intelligent future life forms is given from Kurzweil (1999) who in his book 'The age of spiritual machines' presents a time line of the evolution of the universe. In the time-line section about the year 2099 he writes the following:

> 'Machine-based intelligences derived from extended models of human intelligence claim to be human, although their brains are not based on carbon-based cellular processes, but rather electronic and photonic equivalents'. … 'The number of software-based humans vastly exceeds those still using native neuron-cell-based computation'.

These predictions show that the idea of computer based intelligence has become a generally accepted subject amongst leading scientists. Also the present study shows that for our human successors, a life amongst technical memons simply represents the next stage in evolution.

Yet, in comparison to the above-cited deductions, there are several aspects in the present study, which offer exciting novel points of view. First of all, the just cited predictions lack a structural rationale. They reach as far as the extension of existing trends in computer speed, hardware capacity and programme complexity, but lack a backup by a hypothesis for the evolution of system complexity, for which we apply the operator hierarchy. The use of the operator hierarchy allows descriptions of structural properties of future system types and the indication of goals for construction efforts. Secondly, it is of importance that the aspects of the operator hypothesis are open to scientific inquiry and/or falsification. This holds both for the assumptions that underlay the steps in the hierarchy and for the overall rationale dividing emergent properties in major and minor transitions. Thirdly, by indicating a pathway for further development showing the structural aspects of future evolution, the question of how fast developments will go can be dealt with in a more precise way. Finally, the evolutionary rationale of the operator hierarchy shows that the coming into existence of the next system type is part of a larger evolutionary context. Accordingly, the present approach indicates the necessity that the human beings on earth start considering whether or not they want to live amongst technical memons. In addition it extends this reasoning to considerations about humankind's role in the case where the decision is made not to produce these systems and therewith block the major evolutionary pathway on earth. All these statements deserve more attention and are discussed in detail below.

Degrees of freedom in the operator hierarchy

A question, which is left unanswered by the operator hierarchy, is whether the minor transitions represent independent degrees of freedom. In other words, can the properties of a layer, such as multiness, internal information compartmentation (HMI), structural copying of information (SCI) and auto-evolution, occur in random combinations or do they occur in sequence? The present understanding of the operator hierarchy does not allow a conclusive decision. This leaves an interesting field for further development.

Putting the operator hypothesis to the test

The most important assumption of the operator hierarchy is that hypercyclicity forms the major requirement for the major transitions in evolution. Furthermore, the containment of the hypercycle is also required for all operators of a higher complexity than the hadron, whilst both properties occur as emergent properties immediately after a multistage has been reached. This aspect is open to falsification both with respect to existing and future system types. The hypercycles and their containment have been discussed in the above text. For the transitions from hadrons to atoms and from molecules to cells there are no problems with the recognition of the just mentioned emergent properties. For the transition from multicellular units to the neural hypercycle the proof is still rather thin. If more evidence becomes available that the self-learning capacity of present day neural network organisms, such as humans, is strictly and only possible because of a hypercyclic coupling of neurons, this will support the theory. Turning the argument around, a proof for self-learning intelligence without hypercyclic circuits would falsify the present approach. Likewise, the assumption that the operator hierarchy includes all possible operators can be tested for validity. Proof that an additional operator exists in-between the steps of the present operator sequence would falsify the operator hypothesis.

When will technical memons become reality?

An important aspect of hypercyclic neural networks is that science has no means to predict the skills of any newly developed neural network architecture. This implies that it remains unclear how to construct the potent neural networks that will finally allow technical memons to become intelligent. As the functional properties of neural networks cannot be predicted, skilled networks will have to be created via technical evolution, which implies the testing of large numbers of randomly constructed, simulated memons, the selection of the best as parents for a new series of networks, etc. The necessity of using trial and error when developing future intelligent neural networks represents the Achilles heel of computer intelligence. How soon computer based neural networks will become intelligent, and finally more intelligent than mankind, depends on how much the processes for the evolution of artificial brain-structures can be accelerated. There are prospects for acceleration, because nature has already shown that an architecture on headlines, which at this moment is offered by genes, offers enough manageable modularity to produce human intelligence. The use of genetic codes as a basis for the evolution of brain structures can be imitated, also for technical neural networks. How this can be done has been shown by Happel (1997) and requires a smart combination of special genetic algorithms for neural network structure, efficient selection strategies and fast computers. As these aspects are all available, the evolution of intelligent neural networks can be expected in the near future.

From practical questions about survival amongst technical memons to philosophical questions about our impact on the major evolutionary pathway when the global population decides not to create them.

One of the major questions which is discussed in the recent literature (Kelly, 1994; Kurzweil, 1999) is whether humanity should develop intelligent technical memons if it is unpredictable how they will behave towards us. As they may become faster and more intelligent than human beings and, because they will also require resources for their functioning, it is likely that they will compete for resources with human beings and manipulate the behaviour of humans for their purposes. A little precaution in constructing ‘them’ may therefore be a good thing.

It remains an open question, though, whether it will at all be possible to stop scientific activities that finally lead to their construction. Given the more or less autonomous process of scientific innovation and development, it can be expected that even when the required knowledge is not specifically or purposefully developed, it will be developed indirectly.

So far the aspects deal only with the consequences of the interaction between human beings and technical memons, not with more philosophical aspects of the choice (not) to create technical memons. This choice can be approached from at least two sides, a systems viewpoint and a religious viewpoint. From a systems viewpoint the operator sequence simply reflects a universal self-organisation process which proceeds as the blind consequence of earlier phases in the process. We can recognise a direction, but no goal. In this case evolution can be blocked without problems, because there is no reason why any next stage should be reached.

On the other hand, the evolutionary sequence of the operator hierarchy can be regarded as the reflection of some kind of larger plan. As it will be hard to prove the existence of such a plan, I regard this a religious viewpoint. Yet, under the assumption of a larger plan, it becomes extremely difficult to find valid arguments that give us the right to act against evolution.

The above shows that the question of whether or not technical memons should be developed is a complex case on which the last words have not been spoken. The operator hierarchy certainly deserves a place in this discussion.

6. IN CONCLUSION

The present paper has examined possibilities for the prediction of future organisms. For this purpose we began with a short resume of the structure of the operator hierarchy. Subsequently, the logic of the operator hierarchy was extended yielding several predictions of future memic individuals, for which the operator hypothesis strongly suggests that they will be of technical construction.

The present approach can be considered unique in its contribution to comparative system hierarchy because of the level of detail with which it predicts structural details of future organisms. I consider it an exciting challenge to develop this field further and thereby improve the understanding of the cosmic evolution process and our capacity to predict more and increasingly detailed aspects of future organisms. The most direct practical value of the present predictions lays in the suggestion of hypercyclic neural networks as the basis of artificial intelligence. The fact that the operator hierarchy reflects a universal evolutionary process may also have some spin-off in the field of philosophy. I sincerely hope that the ideas presented in the above text will stimulate creative suggestions for elaboration and improvement.

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REFERENCES

Bertalanffy, L. von (1968). General System Theory. Braziller, New York.

Close, F. (1983). The cosmic onion: Quarks and the nature of the universe. American Institute of Physics, USA.

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

Eigen, M. and P. Schuster (1977). The hypercycle: a principle of natural self-organisation, Part A: The emergence of the hypercycle. Naturwissenschaften 64: 541.

Feibleman, J.K. (1954). Theory of integrative levels. British Journal for the Philosophy of Science 5: 59-66.

Happel, B.L.M. (1997). Principles of neural organisation: Modular neuro-dynamics. PhD thesis, 125 pp.

Heylighen, F. (1995). Systems as constraints on variation. A classification and natural history of metasystem transitions. World Futures 45: 59-85.

Holland, J.H. (1998). Emergence from chaos to order. Oxford University Press, Oxford.

Jagers op Akkerhuis, G.A.J.M. and N.M. van Straalen (1998). Operators, the Lego bricks of nature: evolutionary transitions from fermions to neural networks. World Futures 53: 329-345.

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

Kelly, K. (1994). Out of control. The rise of neo-bological civilisation. A William Patric Book. Addison Wesley Publishing Company, Reading.

Koestler, A. (1978). Janus, a summing up. Hutchinson & Co., London.

Kurzweil, R. (1999). The age of the spiritual machines. When computers exceed human intelligence. Viking, New York.

Laszlo, E. (1994). From GUT's to GET's: Prospects for a unified evolution theory. World Futures 42: 233-239.

Simon, H.A. (1962). The architecture of complexity. Procedings of the American Society for the Philosophy of Science 106: 467-482.

Teilhard de Jardin, P. (1969). The future of man. Editions de Seuil V, Paris, (1946).

Warwick, K. (1997). The march of the machines. Why the new race of robots will rule the world. Century Books Ltd., London.