The Operator Hierarchy: Evolution Beyond Genes

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A proper understanding of the relationship between evolution, individuality and levels of biological organization, requires a fundamental approach to the recognition of what is an individual and what is a level of organization. Although many biologists have a tendency to focus exclusively on organisms and their genes as the eternal focal point of evolution, a universal perspective on evolution stretches much broader, including inanimate and animate particles alike and covering a continuous sequence of levels of organization, from physical particles, via organisms to future technical intelligences.

In order to rephrase evolution on the basis of a particle hierarchy, the concept of a particle must be clearly defined. Many scientists think of particles as the entities that chemists and physicists investigate, decreasing in size from molecules and atoms to hadrons, quarks and gluons (Close, 1983; Pagels, 1985). Due to this abiotic bias, few regard bacteria as particles, let alone complex organisms such as plants and animals. To reconcile the worlds of physics and biology requires an overarching particle concept that is acceptable to both parties. This need was the reason for introducing a new particle concept that covers abiotic and biotic 'particles': the operator (Jagers op Akkerhuis and van Straalen, 1999).

A fundamental aspect of the use of operators as a comprehensive context for evolution is their identification and subsequent ranking into a strict hierarchy. For a strict ranking of all operators, it is advocated to focus on closure (Heylighen, 1990; 1991; Chandler and van de Vijver, 2000), and in particular the first-next possibility for closure. Closure stands for a fundamental circularity in interactions. Important concepts in system science, such as autopoiesis (which implies self-replication) and the cell membrane depend on the closure of enzyme reactions (autocatalysis, Eigen and Schuster, 1979; Kauffman, 1993) or physical closure. Examples of other closures that define other operators are the exchange of pions between protons and neutrons in the atom nucleus, and the recurrent dependence of cells in a multicellular organism. Essential to ranking operators is that each operator always has exactly one first-next possible closure level separating it from its more complex successor. This requirement assures a refutable hypothesis and allows a strict ranking of physical and biological operators in a single, comprehensive sequence: the 'operator hierarchy' (Jagers op Akkerhuis, 2001; 2008). The operator hierarchy includes quarks, hadrons, atoms, molecules, prokaryotic cells, eukaryotic cells, multicellulars (e.g. plants, fungi), animals and technical 'animals', both called memons (Figure 1). Because of its strictness, the operator hierarchy has valuable applications in various branches of science.

A first application concerns the so-called 'arrow of complexity' (Gershenson and Lenaerts, 2008) indicating the direction of cosmic and biologic evolution. So far, no consensus exists about whether evolution directs the arrow towards higher complexities and how complexity should be quantified. Using the strict ranking of the operator

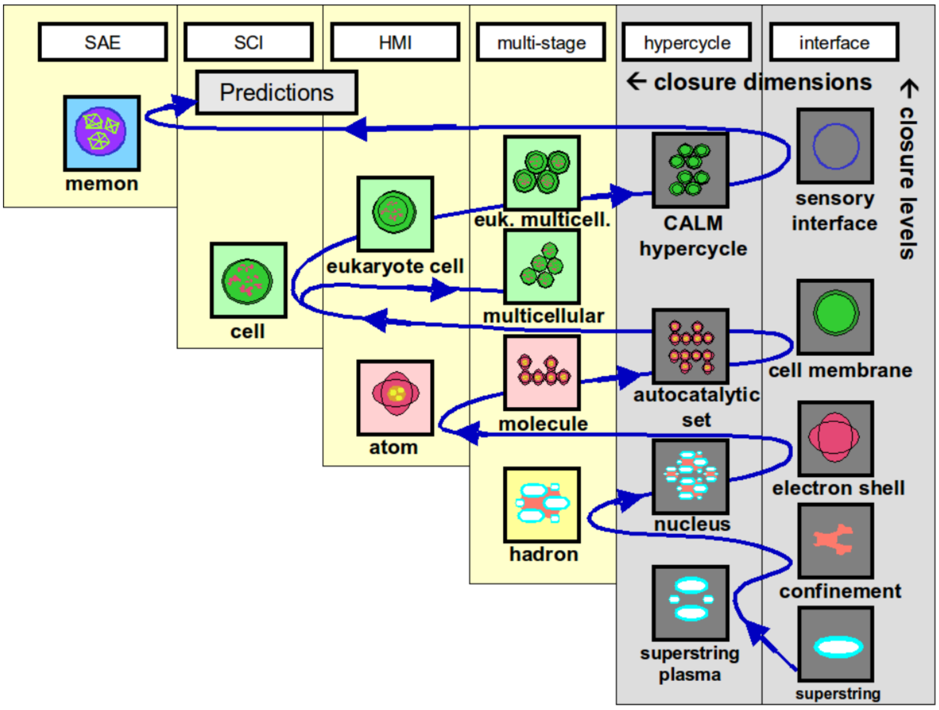

Figure 1: The evolution of particles of increasing complexity as represented by the operator hierarchy. The blue line shows the historical pathway by which successive closures created successive operators. The gray columns indicate closures that only in combination create operators. Explanation of abbreviations: SAE ('Structural Auto Evolution') = the property of an operator to autonomously evolve the structure that carries its information. SCI ('Structural Copying of Information') = the property of an operator to autonomously copy its information (genes, learned knowledge) by simply copying part of its structure. HMI (Hypercycle Mediating interface) = a closure creates an interface that mediates the functioning of the hypercycle. Multi-state = operator showing closure between multiple units of exactly one lower closure level. Hypercycle = closure based on emergent, second order recurrent interactions. Interface = closure creating an emergent limit to an operator. CALM (Categorizing and Learning Module) = a minimum neural memory. For further explanation of the operator hierarchy see (Jagers op Akkerhuis and van Straalen, 1999; Jagers op Akkerhuis, 2001; 2008, and the authors website www.hypercycle.nl)

hierarchy as a yardstick offers a potential solution. Due to the requirement of closure, evolution has little choice but to either remain at the same closure/complexity level, to fall back to a lower level or to create a next level. Focusing on the occurrence of next levels, closure directs complexity's arrow.

A second application is relevant for exobiology and artificial intelligence with respect to discussions about future operators. On earth the so-called 'memon' (represented by the animals) is the most complex operator and is characterized by its neural network. About what will be the next step in evolution, biologists and artificial life scientists hold different opinions that include more complex organisms and robots, respectively (Popa, 2003). The operator hierarchy now speaks in favor of technical intelligence, because the position of the next operator is associated with a property called 'structural copying of information'. The latter property indicates the capacity of a memon to copy its learned information by means of replicating the structure of its brain, just as a cell copies its survival information by replicating its DNA. The passing on of information via learning is insufficient for this property! It is unlikely, if not impossible, that memons based on organic cells will ever develop the structural copying of information property, because structural copying requires that the memon autonomously identify all of its cells and their connections with other cells and precisely measure the connection strengths of these connections. In contrast, the brain of a technical memon relies on computer files, which are easy to copy. This reasoning implies that the next memon must show technical intelligence, a conclusion that tears down the walls between biology and robotics and places artificial intelligence at the heart of evolution on earth.

A third application concerns the definition of life. Despite many years of discussion (Popa, 2003; Ruiz-Mirazo et al., 2004; Bedau, 2007; Cleland and Chyba, 2007; Koshland, 2002; Morales, 1998), a consensus definition still does not exist, which has slowed theoretical progress in various disciplines such as exobiology, artificial life, biology and evolution. The seeming hopelessness of the situation has made certain scientists adopt the rather pessimistic, pragmatic viewpoint that a solution will not be found (Emmeche, 1997). Assuming that life represents a generic concept that applies to a range of configurations of matter the operator hierarchy suggests a definition for life as 'matter with the structure of an operator, and that possesses an equal or higher complexity than the cellular operator' (Jagers op Akkerhuis, forthcoming). It is absolutely crucial that this definition excludes everything that is not an operator. Moreover, by including all future technical memons the definition allows a full merger of organic and artificial life. The definition also solves problems with facultative aspects, such as metabolism, growth and reproduction that frequently cripple existing definitions, because facultative aspects can be absent in non-reproducing, frozen or desiccated organisms. Also discussions about 'life as we do not know it' (Bedau, 2007; Ward, 2005) may profit from the operator hierarchy. The reason is that cosmological observations have shown that all operators from quarks to molecules have a universal existence. Extending this observation to higher-level operators and assuming the general validity of the closure rules defining the operator hierarchy, this implies that the shape of life everywhere in the cosmos is limited to that of operators.

The above shows that the operator hierarchy contributes in different ways to important scientific topics. Therefore, the historical emergence of the operators deserves a prominent position in the evolution debate.

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