Werner Callebaut & Diego Rasskin-Gutman (eds.), *Modularity. Understanding the Development and Evolution of Natural Complex Systems,* Cambridge: MIT Press, 2005.

The Vienna Series in Theoretical Biology (MIT Press) generally honours integrative and cross-disciplinary research on the "theoretical foundations of biology" (vii). Its latest volume is an extensive study of how thinking in terms of *Modularity* adds to our understanding of the *Development and Evolution of Natural Complex Systems.*

Now that today's biological research entered the post-genomic era, modularity – or the attempt to view systems as integrations of partially independent and interacting units – may prove itself to be extremely helpful in finding a middle road between the massive increase of data on the diverse building blocks of living organisms on the one hand and the quest to understand the organism as a functional whole on the other. In how far this middle road will serve as a general conceptual background or as having a methodological or even experimental nature is explored in the eighteen papers collected by Werner Callebaut (a philosopher of science and scientific manager of the Konrad Lorenz Institute for Evolution and Cognition Research, Vienna) and Diego Rasskin-Gutman (a researcher in biological sciences at the Salk Institute for Biological Studies). These papers not only illustrate how the concept of modularity takes form in disciplines as diverse as philosophy, mathematics, computational science, physics, chemistry, biology, psychology, cognitive science and economics. Through their division into separate chapters, they also put the usefulness of thinking in terms of modularity to the test with regard to specific themes, in the volume respectively labelled *Evo-Devo: the making of a modular world*, *Evo-Patterns: working toward a grammar of forms*, and *Modularity of mind and culture*. Ultimately, the book aims to clarify "what modules are, why and how they originate and change (develop, evolve), and what this implies for the respective research agendas in the disciplines involved" (xv).

The volume opens with a foreword by the late Herbert A. Simon, "the master of modularity thinking" (xvi). He wrote this foreword in 2000 for the Altenberg workshop in Theoretical Biology out of which the other papers of the volume originate. Simon recapitulates his longstanding interpretation of modularity in terms of near decomposability[1], i.e. "the frequencies of interaction among elements in any particular subsystem of a system are an order of magnitude or two greater than the frequencies of interaction between the subsystems" (x). Because systems displaying near decomposability are evolutionary more fit "than when there is mutual dependence of design" (xi), it is argued that the complex systems known to us generically display a hierarchical near decomposability at virtually all levels of their organization.

That complexity and modularity go hand in hand and are ubiquitous is also argued in Callebaut's introductory chapter. Taking the observational regularities that Kepler attributed to our solar system as a starting point, Callebaut goes on to review several other contexts in which scientists invoke(d) modularity in order to disentangle various meanings of the concept and to provide a general definition. This definition adds to Simon's that "the strength or weakness of interactions is a matter of degree" (6), making modularity a gradual property. It stresses that modules "persist as identifiable units for long enough time spans" (9), and that they form "reusable building blocks" (9) of larger wholes. Refining the concept of modularity, Callebaut points out that it can tell us something about a system's (physical or organisational) structure or about its (functional) processes. In this, attention should be paid to the notion of "weak modularity" (17) in that the same module may belong to several processing systems, and *vice versa*. Modularity also may serve both as an *explanans* and as an *explanandum*. Here it is argued that "once a module has been established, its constituent parts become irrelevant" (11-12), while the interactions among modules become all the more important. Although this idea logically is tempting, its concrete value depends on the possibility of 'establishing a module'. Complex systems typically show a dynamic turnover of parts, while subsystems hold on to a more stringent identity. But while this may be easy to recognize in morphological cases, in a process-minded view the task to decipher modules from each other may be much harder to do.

[1] Cfr. H. Simon (1962), The sciences of the artificial, *Proceedings of the American Philosophical Society*, 106, pp. 467-482.

A process-minded view serves as a welcome background in the second chapter, placing the concept of modularity in a larger biological perspective including evolution *and* development. As such, it enters the domain of Evo-Devo, the “now fashionable field of evolutionary developmental biology” (29). More specifically, possible mechanisms involved in the evolutionary origin of diverse kinds of modules are explored. Günther Wagner and his co-authors here argue for a “mechanistic plurality” (43) of modular kinds. In the case of left and right forelimb buds, this means that one needs to recognize two different “developmental modules” (35) that are part of the same “evolutionary module” (*ibidem*). On the basis that both buds express the same genetic information, such modules also can be interpreted in terms of genetic networks (i.e. strongly integrated sets of genes).

In reaction to Richard Lewontin and John Bonner’s work, Robert Brandon adds that the *existence* of evolutionary modules is not explained by the argument that adaptive evolution *requires* quasi-independent genetic networks. Indeed, instead of showing necessary relations in the world, such “transcendental arguments” (52) may simply reflect our limited understanding of it. Likewise, *why* modularity is attained is not directly explained by the *post hoc* recognition that forelimbs-becoming-flippers-or-wings refer to similar developmental modules but different functional modules. Brandon acknowledges the need for empirical hypotheses, verifiable by direct observation, in order to explain modularity. Thus, whereas conceptual analyses via convention set out the “proper domain” (57) of a theory of modularity, empirical hypotheses aim to explain modularity in terms of underlying mechanisms.

The discussion on the unit(s) and/or levels of selection is also tackled in this chapter. Rasmus Winther examines how discussants of this debate usually apply a *competition perspective*, putting the role of modules in selective processes to the fore. Instead, Evo-Devo adherents use an *integration perspective*, stressing the involvement of modules in mechanistic processes. This not only has consequences for the research methodologies, but also for the gene concept used. In Moss’ terminology[2]: modularity in Evo-Devo involves 'genes-D' (or developmental genes), one among many kinds of physical developmental resources, defined by its specific molecular sequence. In the levels of selection debate, 'genes-P' (or phenotypic genes) and their statistical changes in frequencies stand central, stressing a direct relationship to a phenotype instead of a specific molecular nature or context.

The papers by Lee Altenberg on modular genotype-phenotype mapping, by Lauren Ancel Meyers and Walter Fontana on computational models on modularity in RNA, and by Gerhard Schlosser on the evolution of amphibians, further investigate under which conditions modularity provides evolutionary advantages. Schlosser concludes that structurally and functionally quasi-independent modules can serve as units of evolution, but not necessarily so. Similarly, not all units of evolution need to be modular.

The third chapter analyses *morphological* and *architectural* aspects of modularity in order to find more rigorous criteria for the decomposition of wholes into parts. This is illustrated by Gunther Eble's paper on how morphological modules causally participate in the structure and evolution of ecological and genealogical systems, and by Roger Thomas's paper on how metazoan skeletons evolved as modular-but-hierarchically-integrated structures because of "scaling considerations and rates of physical processes" (239).

Whereas Callebaut reminds of the quest for universal rules catching the "logic of organic form" (181), the remainder of this chapter elaborates on making sense of modularity "as a recognizable, observable feature in nature" (*ibidem*), or said differently, experiencing modularity in terms of recurrent patterns. Daniel McShea and Carl Anderson focus on patterns in the evolutionary transition from fee-living single cells to full multi-cellular organisms. They hypothesize that the emergence of a higher-level entity with functional capabilities is ordinarily accompanied by "the loss of part types within the lower-level organisms that constitute it" (185) and by the transformation of lower-level organisms "into

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[2] L. Moss (2001), "Deconstructing the gene and reconstructing molecular developmental systems", in: Oyama, S., Griffiths P.E., Gray R.D., (eds.), *Cycles of Contingency: Developmental Systems and Evolution* (pp. 85-97), Cambridge (Mass.), MIT Press.

differentiated parts within the higher-level entity" (*ibidem*). As size increases, intermediate parts emerge between these lower-level and higher-level entities, amounting to a "repartification" (199) or a "remodularization" (*ibidem*) in the physiology or behaviour of the organism. Here, the idea that "individuation is the result of selection for functional capability" (186) shines through.

Diego Rasskin-Gutman next argues how modular processes can be iterated, leading to segmentation, symmetries and other specific morphologies. Taken as a "set of construction rules" (209) with self-organizational properties, he assumes modularity to elucidate how evolution moves from one region of morphospace into another. Hereby the neo-Darwinian view on modularity as the end product of natural selection is shaded, which implicitly brings back in the debate on how natural selection and self-organization relate to one another and in how far they can be isolated into separate components of evolution.

The two closing papers of this chapter bridge disciplinary boundaries by discussing the role of modularity in art. Slavik Jablan generally interprets modularity as a "universal principle of economy in nature" (259), *i.e.* through recombination, a finite and restricted set of basic elements can lead to a diversity and variability of structures. This principle appears to be abundantly present in art. Unfortunately, it remains unclear how our "understand[ing of] the anthropological, social, cognitive, and communicational senses of ornaments" (278-279) will gain from a reconstruction of the process by which modular ornaments were made. Jablan equally does not elaborate on the difference between the *static* modules in the diverse geometrical arts he discusses and the more *dynamic* modules found in biology. Angela Buscalioni and co-authors do pay attention to this with their distinction between a module as either a static concept or a real entity (with structural and spatial, changing properties). They relate modularity to a "conscious necessity to reduce the complexity of natural organization into a more comprehensible world" (283). A modular system thus cannot be conceived of without a model that "orders the system through the underlying relations and/or interactions between modules" (294).

With the exception of a paper on the division of labour and market selection (i.e. the creation and coordination of modules) by economists Luigi Marengo and co-authors, the final chapter addresses the value of a modular conception of the mind and/or brain. This conception played overtly in the quest to discover the physical location of human consciousness, language and symbolic thought. Today, it continues to play in evolutionary psychology, which views the mind as composed of adaptive, innate and quasi-independent "special-purpose computational modules" (305) processing distinct types of information and having specialized functions. Because evolutionary psychologists wrote none of the papers, a real discussion remains out in this volume. Instead, all contributions tend to shade evolutionary psychology. Raffaele Calabretta and Domenico Parisi, for example, reject evolutionary psychology's panadaptationism, as well as the traditional mind/computer analogy used in computational cognitive science. They argue in favour of an "evolutionary connectionism" (309), which relies on structural and functional aspects of the nervous system and which models the mind as a large physico-chemical neural network. In this model, the mind – genetically speaking – only inherits a general and constrained capacity to learn from experience. The eventual rising of modules (as parts of a neural network) then results from further development and learning.

Methodologically, Fernand Gobet's paper illustrates that computer simulations (like artificial life simulations of evolving populations of neural networks) has become a powerful tool in cognitive science. Also speculative conceptual schemes play heavily in this research area. Reference can be made to Kimbrough Oller's proposal of a natural logic of communicative possibilities, which in the emergence of language supposedly forms a triad with the biological predispositions and the environmental input (and learning) of the organism. Still, speculations and conceptual schemes need support from experimental data. Boris Velichkovsky's clear review of empirical research on memory and perception shows that modularity at best offers an incomplete model of human cognition. Instead, more attention should be paid to how "levels of processing" (356) involved in experimental manipulations relate to the different architectures and mechanisms that evolved in the human brain.

In conclusion, this volume explores the concept of modularity and its possible roles in the development and evolution of (mainly biological) complex systems. It draws on clarifying the diverse disciplinary meanings of this concept and the theoretical input these may offer to several ongoing debates in philosophy, biology and cognitive science. In this, three aspects stand out. First, most contributions work towards or start from a 'trans-disciplinary' and abstract definition of modularity and/or modules. This leaves unanswered the question of how specific disciplinary differences in meaning and use of the concept may lead to a more concrete and refined 'inter-disciplinarity'[3]. Second, and partially countering the first remark, whereas the separate papers do not directly react to each other or defend antagonistic views, Callebaut's introductory paper and the guiding editorial notes at the beginning of each chapter bring extra synergy to the volume by putting some of the larger topics discussed throughout the volume together. Third, although both experimental and computational data are not eschewed, this volume demonstrates that – in Schlosser words – "we still need to broaden our empirical basis and combine detailed experimental studies" (166) in order to rigorously establish the importance and exact ontological and epistemological meaning of modules in complex systems. This collection thus presents interesting work in progress, inspiring both to academic students and researchers working in philosophy of science, biology and cognitive science, and to researchers willing to push the interdisciplinary challenge offered by complex systems further.

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[3] See also S. D. Mitchell (2006), Modularity – More than a Buzzword?, *Biological Theory* 1(1), pp. 98-101.