William H. Edmondson 2017: The Sequential Imperative. General Cognitive Principles and the Structure of Behaviour. *(Value Inquiry book series.) Leiden, Boston: Brill Rodopi. ISBN: 978-90-04-34289-7 (Pb), 978-90-04-34299-6 (E-book).*

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The core ideas in William Edmondson's contribution *The Sequential Imperative: General Cognitive Principles and the Structure of Behaviour* have a long history. As a matter of fact, they go back to Edmondson's (1986) paper in *Language and Communication* (or likely even further). Already in this paper, he suggested that one of the core functions of grammar – or linguistic cognition – is linearization of cognitive entities into behavior, and de-sequencing of necessarily linear behavior into cognitive entities. More than twenty years later, these ideas were embedded into the more general theory of the "sequential imperative" put forth in Edmondson (2010). The book to be talked about here represents a more in-depth discussion of the theory introduced in the latter article and relates its propositions to several fields of cognitive science.

The book is structured into three main parts, rounded with an introduction and an afterword. The first part, "The sequential imperative and the functional specification of the brain", is about the central propositions of the book referred to as generalized cognitive principles. Edmondson elaborates on these principles drawing on anecdotal evidence as well as evidence from the cognitive and linguistic literature. The main idea (the "sequential

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imperative") is that the task of cognition is to transform (de-sequence) behavior into atemporal entities (representations) during perception and vice versa during production of behavior. Moreover, sequentiality of behavior is presented as an inevitable consequence of physiology.

The main theme of the second part ("Serving the sequential imperative") takes the concepts formulated in the first part to provide a structural account of language (with a focus on phonology). Edmondson presents a structural model which merges several linguistic domains (phonology, syntax, pragmatics at least). Each additional bit of structural (and atemporal) information influences the perception (and production) of sequential linguistic input (output) at the same time.

The third part is called "Behaviour and evolution – on and off planet" and collects several ideas that build on the proposed model but go into slightly different directions. On the one hand it addresses issues of cognitive management (the management of learning and attention and in which way this is related to the sequential imperative). On the other hand, it elaborates on evolutionary questions. Finally, Edmondson closes with a discussion of the (potential) universality of the sequential imperative and a thought experiment about the extent to which the proposed principles may apply to all known (or perhaps also unknown) species.

The style in which the book is written is unorthodox. The book is, as Edmondson points out already in the introduction, meant as "a set of notes for bigger projects to come" (p. IX), and this is also reflected in its structure: sections and subsections within each chapter, often encompassing just a few paragraphs, are mostly not linked explicitly but numbered hierarchically, with a hierarchical depth of up to six levels. The intention of the author is to facilitate jumping from one thought to the next without grappling with laborious transitions and literature reviews.

While this may be true, the lack of subsection headings and signposting sometimes makes it challenging to follow the main argument in each larger section. The reader finds himself jumping back and forth to check which hierarchical level some paragraph one has just read belongs to. This is very much like organizing and reorganizing post-it notes on a board into clusters. So, reading this book is a comparably interactive task and demands a good amount of concentration. Perhaps this experience is intended by the author as well. A second consequence of this style is that the book almost reads like a mathematical text in which every single definition, proposition and example is numbered. Indeed, Edmondson often refers back to particular paragraphs while advancing his thoughts. Repetitions of the key propositions (labeled as GCP1 to GCP8) are very much appreciated.

The book covers many areas relevant to cognition and raises multiple questions. In what follows, I will focus on two main thoughts fleshed out in

the book. The first one is about the nature of cognitive representations. The second one is about language evolution.

As stated before, one of the central propositions in this book is that cognitive representations are strictly atemporal (this proposition is labeled GCP2: "Cognitive entities are [… i]nherently atemporal", p. 23). This is motivated and discussed in depth in chapter 2 (mainly 1(2).5-6). The role of cognition, according to Edmondson, is to de-sequence behavior (which is always sequential) into atemporal cognitive representations (essentially the second part of GCP3: "Perception is de-sequencing", p. 23). Representations are not supposed to be static in the sense that they cannot change, however. Rather they are suggested to be atemporal entities which lack any inherent dynamic properties.

The proposition is particularly interesting as it finds a clear correspondence in artificial neural networks (ANNs; Schmidhuber 2015; LeCun et al. 2015) studied in computational science and mathematics. ANNs can be used to model mappings from sequential objects like speech, sequences of actions or time series, to static – albeit highly dimensional – vector representations. This is often done with recurrent neural networks employing particular types of cells that can store bits of information during processing a sequence (e.g. long short-term memory cells; Gers et al. 1999). The output of these cells is then mapped to multi-dimensional representations in deeper layers of the network (possibly to be further processed for doing specific tasks). Each dimension carries one (potentially condensed) aspect of information. Importantly, the ordering of dimensions does not matter at this point: they are, as Edmondson would probably put it, "atemporal" entities.

Thus, two of the central propositions (GCP2 and GCP3) are conceptually supported by computational research. On the neurophysiological level, things are less clear. In section 1(2).6, Edmondson defends his propositions against potential neurophysiological criticism, mainly drawing on literature from the 1960s. The crucial question is this: is there neurological evidence for temporal patterns of cognitive representations? The author discusses related issues like temporal patterning in auditory studies (1(2).6.2.1.2), neuronal speed of response (1(2).6.2.1.3), and brain waves (1(2).6.2.1.4). It is then concluded that (with the exception of the latter) "it makes no sense to seek to align measures of temporal activity and patterns measured in the brain with temporal structure in behaviour and perception" (p. 37).

I would like to contest this conclusion by referring to hippocampal replay phenomena. In a couple of studies it was demonstrated that temporal patterns of brain activity are replayed in the hippocampus during subsequent rest or sleep (see e.g. Frankland and Bontempi 2005, for an overview). This was shown in humans (Huber et al. 2004) and other animals. More specifically, for example, Lee and Wilson (2002) have demonstrated

that neuronal activation patterns of rats associated with spatial movement are replayed during slow wave sleep, thereby retaining activation ordering. The behavioral sequence was compressed in time by a factor of 20. They take their finding as evidence for the formation of long-term memories of sequential events.

The crucial point here is that replay is broken down to the neural level and that there is a clear alignment of temporal neuronal activity (albeit compressed) and temporal patterns of behavior. This correspondence is too tight to be discarded as being not relevant. Do these temporal patterns on the neuronal level correspond to temporally structured representations? Or are they mapped – through the proposed de-sequencer perhaps – to atemporal cognitive representations conceptually similar to static vector representations in (computational) artificial neural networks discussed before? The answer is not clear; in any case, the book fulfils its purpose of initiating interesting discussions and thoughts.

Let us turn to the second topic I want to address. Chapter 8 ("Issues in evolution and language") focuses on discussing the evolutionary consequences of GCP3 ("Behaviour is sequencing; Perception is de-sequencing", p. 141). Interestingly, it seems that Edmondson conceptualizes cultural evolution (e.g. the evolution of languages) as epiphenomenon of the evolution of a cognitive device. For example, right in the introduction of Chapter 8 Edmondson states the following: "[o]ne particular misconception we need to sweep away is that 'a behaviour' evolves – it doesn't; the behavioural apparatus evolves" and "[it] is behaviour which *changes*, because the potential for sequencing and de-sequencing *evolves*" (both p. 140; emphasis as in the original). Based on these assertions it seems that it is solely biological evolution driving the evolution of cognition (the cognitive apparatus) which in turn drives behavioral change (such as linguistic change). Referring to Jackendoff (2002), Edmondson continues to argue that a behavior "such as language does not evolve in the sense of interest to us here. [… T]hey are already languages – and it is how we got that far that is of interest here" (p. 142). I would like to question this argument.

To begin with, there is quite some research on cultural evolution not referred to in this book, starting with Dawkins' (1976) and Hull's (1988) work on Generalized Darwinism (see also Aldrich et al. 2008). Basically, they argue that it is the same set of evolutionary mechanisms which operate in biology and the cultural domain. The theory of Generalized Darwinism was extended later to the linguistic domain particularly by Croft (2000) and Ritt (2004), among others. When discussing the history of the design of screws (blade to cross-head), Edmondson, for example, argues that "[t]alk of evolution in the design of screws is loose talk [and t]alk of 'evolution of language' is loose talk in the same way [… because] the focus is on the superficial 'observables'

and not on the underlying capability" (p. 145). This would not be supported by Generalized Darwinism, since in this paradigm evolution does not require any underlying capability but just (cultural or biological) replicators.

Now, research on cultural and in particular linguistic evolution has shown that studying cultural change is indeed relevant to understanding cognition. This is because by investigating the history and change of cultural replicators one can identify cognitive biases and constraints, i.e. properties of cognition (Kirby, Dowman, and Griffiths 2007; Evans and Levinson 2009). So, studying behavioral change can shed light on how the cognitive apparatus evolved, to begin with.

Finally, Edmondson seems to assume a unidirectional relationship between biology and behavior when he says that "complexities in the processes of sequencing and de-sequencing [...] change as brains evolve" (p. 161). This may not be exclusively so. For instance, Ferretti and Adornetti (2014: 316) argue that "[i]f it is true that external scaffoldings [e.g. language] are used to reduce the computational cost of the brain, it is also true that they represent a new commitment for the brain". That is, linguistic behavior represents a selection pressure in the biological evolution of the brain.

As Edmondson states repeatedly, the book understands itself as a prolegomenon to a discussion rather than a finalized theory (interestingly enough, the same term that Edmondson used in his 1986 kick-off paper). The fact that Edmondson manages to let the reader's thoughts flow to yield new ideas and to provide novel views and angles on certainly well-studied phenomena is probably the biggest strength of this book.

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