Chapter 2
Representation of Neuro–Information and Knowledge

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ABSTRACT

Human cognition integrates grounding, productivity and dynamics. This chapter discusses how combinatorial structures can be created by forming temporal interconnections between grounded representations of concepts (words). Specific architectures are required so as to allow these temporal connections to be formed. A crucial aspect of these architectures is that they do not copy and transport symbols. Instead, the representations they use remain “in situ”, such that each representation of a concept used in a combinatorial structure is always the same grounded representation of that concept. These architectures therefore combine productivity of cognition with grounding of representations. Because they consist of neural structures, they are also inherently dynamic, which ensures the ability to interact dynamically with the environment. Grounded representations as constituents in combinatorial structures provide both local and global information. As constituents, they can affect specific (local) combinatorial structures, but without losing their embedding in the global information structure of which they are a part. The constraints that grounding, dynamics and productivity impose on each other have consequences for processing, learning and development. These consequences will be discussed and illustrated.

INTRODUCTION

There is clearly a close relation between our ability to learn and the way information (knowledge) is stored in the brain. On the one hand, our learning capacity determines what knowledge is stored and how it is stored. But, on the other hand, the way the brain represents knowledge also determines what we can learn and how we learn.

Representation of knowledge in the brain is affected by (at least) three important features that underlie human cognition. These features are the productivity of human cognition, our ability to interact dynamically with the environment, and
the fact that our conceptual representations are grounded in perception, action, associations and semantic relations. Because these features influence the way information is represented, they would also influence the interaction between learning and representation.

One can assume that each of these features (productivity, dynamics and grounding, for short) evolved as a response to specific constraints imposed on cognition. Productivity of cognition refers to the ability to combine learned knowledge to form and process combinatorial structures, as found in language, reasoning, planning or navigating in (visual) environments. With productivity, we can process and produce much more information that we can learn in a lifetime. For example, we can understand (or produce) more sentences than we could ever learn. In this way, a community of people can share each others knowledge, and humans can pass their knowledge on to later generations (e.g., in a written or verbal form). So, with productivity we can accumulate knowledge over time (evidence of that can be found in any library). Our ability to interact dynamically with the environment ensures that we can process information about events in the real world as they unfold. This is an essential feature of cognition because the dynamics of events in the outside world are mostly beyond our control. Grounding entails that our conceptual knowledge is determined by the way we interact with our environment and other people. It also ensures, as I will argue, that our conceptual knowledge is activated in a direct way by the information we receive and process, and that conceptual knowledge can steer our actions in a direct way as well.

Although productivity, dynamics and grounding are each important features of cognition, it is in particular their combination that is important. Indeed, it may be their combination that sets human cognition apart from cognition as found in animals or artificial systems. Dynamical interaction is quite clearly an important feature of animal cognition, and grounding can be achieved with associative neural networks, as found in animal brains as well. Productivity, on the other hand, is clearly found in artificial forms of information processing, as in digital computers. However, productivity to the extent of human cognition is not found in animals, and dynamics and in particular grounding are missing in artificial forms of cognition.

The purpose of this chapter is to illustrate that when productivity, dynamics and grounding are combined, they impose constraints on each other that require specific systems (architectures) for their combined implementation. Because these architectures are different from the symbolic architectures of classical cognitivism, I will briefly discuss symbolic architectures first. This also serves to illustrate that the lack of grounding in artificial cognition is related to the symbolic way information is represented and processed in these systems.

**BACKGROUND**

The classical theory of cognition, or classical cognitivism for short, arose in the 1960s. It emphasized the importance of productivity for human cognition, and the demands it imposes on cognitive architectures (e.g., Anderson, 1983; Newell, 1990). Classical cognitive architectures achieve productivity because they use symbol manipulation to process or create compositional (or combinatorial) structures.

Symbol manipulation depends on the ability to make copies of symbols and to transport them to other locations. Newell (1990) argued that symbols are needed for cognition because only a limited amount of information can be stored physically at a given location. The symbol token is then needed to obtain more information when that is required for a given process. In Newell’s words:

*The symbol token is the device in the medium that determines where to go outside the local region*
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