Architectures of Intelligence
Assignment 5

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Different levels of abstraction

In this assignment, cognitive architecture as well as cognitive models and connected arguments, fields and frameworks, are discussed.

Cognitive architectures specify the structure of the brain at a certain level of abstraction which is needed to explain the function of the mind [1]. Before the introduction of cognitive architecture, it was common to either focus on the structure of the brain or be concerned with its functionality. However, to understand the mind it is important to define the relationship between the two in a cognitive architecture [1]. Cognitive models also play an essential role in order to understand the working of the brain [2]. In contrast to cognitive architecture, they describe computationally how the brain operates when performing different tasks such as thinking [3]. To do that, cognitive models divide cognition into components which each serve a certain functionality [2]. Newell argued, that in order to fully understand how different parts of the brain interact, it is important to construct computational models instead of just focusing on a single phenomenon. Even though he was very satisfied with the quality of psychological experiments, he thought that the scientific community at his time was too focused on binary questions such as "[..] nature versus nurture, [..] central versus peripheral, [..] serial versus parallel" [4]. In his opinion, hypothesis testing needs to be supported by the construction of computational models in order to verify how the examined functionality actually works in the context of an information-processing mechanism [2].

Three scientific fields, cognitive science, computational neuroscience and artificial intelligence all contribute to cognitive models in their own way, following different goals. Cognitive science targets to retrieve useful information from brain data, building computational models backed by prior knowledge and empirical evidence, while computational neuroscience is concerned with the modelling of actual biological neurons with the help of mathematical models. The last field, artificial intelligence, combines functions to achieve intelligent behaviour. In the recent past, the achievements in the field not only improved because of an increase in computational power but also because of the use of deep neural networks and cognitive-level symbolic models. Overall, each scientific area provides useful additions to cognitive models on a different level of abstraction [2].

For cognitive brain models, at least two different levels of abstraction can be obtained. On the one hand, there is the high-level abstraction of cognitive science, which decomposes computations into smaller functions and therefore results in a representation independent of the brain's implementation. This also means these types of models don't need to concern with components on neurobiological levels. There are three classes of cognitive models originating in some of the scientific fields mentioned above. In cognitive science, the Bayesian model is widely used to describe optimal brain behaviour in situations where sensory input is already present. With the use of statistical calculations, Bayesian models achieve inference, providing insight into processes such as decision making and judgment, all operating on a higher level of abstraction. Another cognitive model is that of production systems. These models are based on logical components, with productions that get selected based on a control structure [2]. ACT-R is a typical example of a production system, having productions that are selected on an if-then basis. Another type of cognitive model is reinforcement learning. This approach describes how an agent can learn through rewards obtained by interaction with its environment.

On the other hand, there is a lower level of abstraction of a neural network model. In contrast to cognitive brain models, these models describe functions on a level closer to the workings of the brain and are therefore unable to occupy with high-level processing in a way that cognitive models can. These neural network models are created using linear and nonlinear functions with millions of parameters which naturally make them more complex and unable to describe complex traits of intelligence [2]. An example of a framework to implement neural networks is Nengo. The python framework makes it able to create individual nodes, define how the input and output signals should be mapped and combined and therefore represents information on the level of individual neurons and clusters of neurons. Comparing Nengo and ACT-R, one can instantly see, that the if-then structure of the production system ACT-R can recreate far more complex tasks, but works on a higher level of abstraction than Nengo which is able to work with individual Neurons.

Besides the models at the abstraction levels of ACT-R and Nengo, there are also other, much lower levels of abstraction. An example is Markam's Blue Brain Project. **Figure 1** shows a graph of biological and cognitive fidelity. In contrast to cognitive models and neural networks, the Blue Brain Project has a much higher biological fidelity, with a cognitive fidelity close to zero. Following the trend indicated above, I would suggest that it is not possible to use the Blue Brain Project for sophisticated cognitive tasks. Since the abstraction level is very low, the resulting model probably has a wide array of parameters with a highly complex interaction. On the contrary, because of its fine granularity, elementary functions and processes can be modelled very precisely. Due to cognitive architecture being used to explain the function of the mind[1], using the Blue Brain Project would, because of its level of detail, fail to provide a good cognitive architecture and general insight into our cognitive system. For lower levels of abstraction and research tasks close to the neuronal layer, the Blue Brain Project is better suited to generate important insight into our minds.

For further engagement with cognitive models, I would propose a research question: Normally, people learn to write using pen and paper. However, humans can instantly use a keyboard to produce texts when confronted with one. How is the human mind able to transfer the learned writing approach to the digital domain so quickly? To answer the question, I would use a higher level of abstraction and a production system like ACT-R to implement it, because it describes a complex cognitive task using remembering and transfer of knowledge and is therefore impossible to describe with lower abstraction.

References

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A. Assignment 5

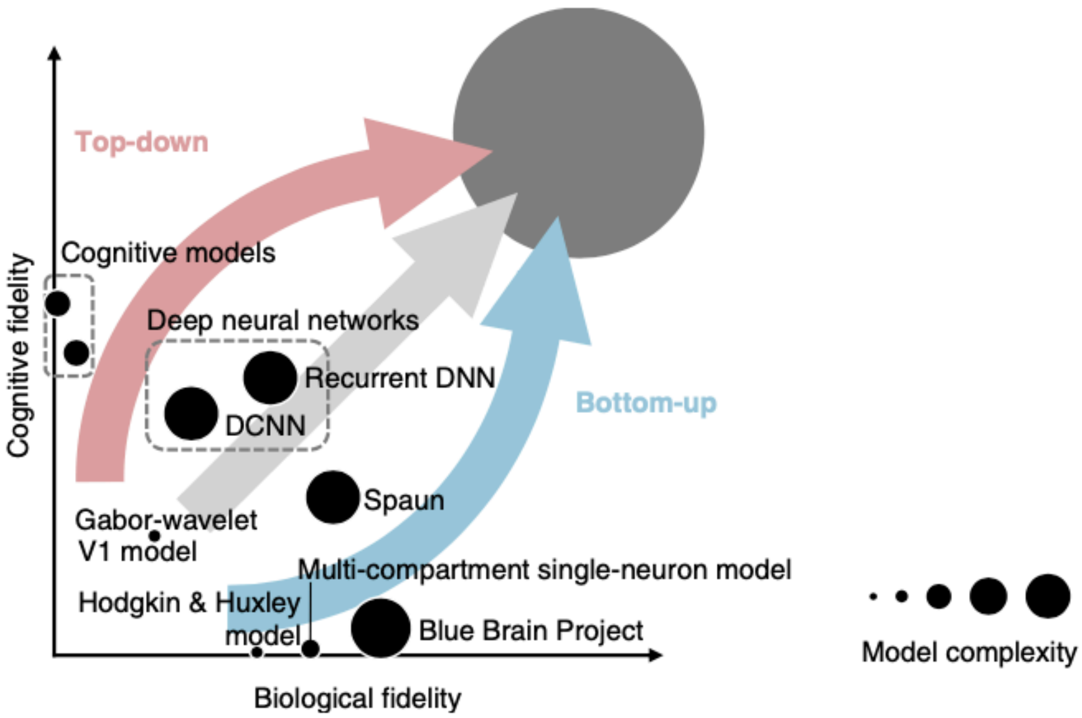

Figure 1: *Illustration depicting a graph of cognitive brain models in terms of cognitive and biological fidelity. Source. [2]*