Conceptual and Computational Models of Cognition: The Case of Predictive Processing

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Abstract. Cognitive scientists typically assume that Marr's levels of description (computational, algorithmic, and implementational) are sufficient to explain cognitive phenomena. This paper disputes this assumption by arguing that models of cognition are two-fold, comprising a conceptual model and a computational model. Whereas conceptual models act as minimal ontologies that are part of the construction assumptions of scientific models, computational models are the representational media embodying such ontologies. In contrast to Marr's levels, this distinction offers a solution to the gap between computational and algorithmic level descriptions with implementational accounts. This paper takes the predictive processing framework in cognitive science as a case study to justify these claims, showing that treating PP and related theories either as computational or algorithmic is misleading. Furthermore, such theories are not implementational accounts, remaining only as empirically adequate. Based on the distinction between computational and conceptual models, this paper treats PP theoretical entities as scientific constructs that are part of the construction assumptions of process models of cognition. Rather than being accurate representations of cognitive phenomena, they enable prediction and control.

Keywords: Predictive Processing, Scientific Modelling, Conceptual Models, Computational Models.

1 Introduction

Scientific frameworks furnish theories and models with the basic premises, analogies, or metaphors that guide research. Through all of them, scientists can conceptualize, represent, visualize, control or predict the behavior of systems. This is particularly evident in cognitive science, understood as the scientific study of the mind, cognition, or intelligent behavior. Since these target systems are not directly observable, scientists employ various constructs that allow them to collect data, make visualizations or define variables that make such systems amenable to research. Perhaps the main contribution of frameworks in cognitive science is to provide the basic analogies that characterize cognitive phenomena in general terms and, by extension, orientate the design of models of cognition. The most used analogy in cognitive science associates mental to computing processes. This analogy favors the use of computational models and simulations for exploring cognitive phenomena in disciplinary research.

Cognitive science's literature emphasizes its interdisciplinary character. As cognition is a complex multifaceted phenomenon, a single discipline cannot fully explain it [1]. Such interdisciplinarity confers scientific frameworks an additional role: the analogies these frameworks establish between cognitive processes and, e.g., ruled-base systems, neural networks, or dynamic couplings are referents providing unity to otherwise disparate disciplinary research. If predictive processing (PP) is a framework in cognitive science, it must provide a unifying referent to disciplinary research. That seems to be the case: concepts from PP and related theories (e.g., the free-energy principle, active inference, and the Bayesian brain) are employed in disciplinary research in neuroscience, biology, and cognitive psychologists, to name just a few of them.

Interestingly, the transfers of concepts among PP and related theories have received little attention. Philosophers of science studying PP and related theories have been mainly interested in whether these concepts designate natural kinds. Though this may be true, they are still scientific constructs playing a role in interdisciplinary research. This paper explores how should the interdisciplinary transfer of concepts in cognitive science be understood, considering the case of PP. A typical answer to this question follows Marr's levels of analysis [2], considered to be sufficient for characterizing the types of explanations delivered by theories and models of cognition. The three levels are a) the computational, which defines the cognitive task and specifies its elements in terms of mappings from inputs to outputs; b) the algorithmic, which specifies the rules these mappings follow; c) the implementational, which explains the instantiation of the other two in physical systems such as brain networks.

Interdisciplinarity in cognitive science, following Marr's levels, occurs because disciplinary accounts provide explanations at different levels, constructing a complete explanation of cognitive phenomena. However, frameworks in cognitive science do not easily accommodate Marr's levels (e.g., the cognitivist framework dismisses the implementational level). Also, accounting for PP by appealing to Marr's levels is problematic: for some authors, PP is a computational theory [3]; for others, it is algorithmic or implementational [4]. The same holds for models widely employed in PP and related theories, such as Bayesian models, since authors disagree on whether they are computational or algorithmic [5].

In contrast to views of PP as a complete explanation of cognition [6, 7], this paper proposes that interdisciplinarity in PP is not driven by the attempt to construct a full-fledged explanation of cognition [8, 9]. Instead, the integration of disciplinary research develops through transfers of conceptual models within PP and related theories [10, 11, 12]. Conceptual models act as theoretical umbrellas that integrate disciplinary research by finding overlapping points of knowledge. This paper suggests that predictive processing integrate Bayesian models as representational media embodying its conceptualization of cognition in scientific models that provide tractability and enable the interpretation of neural data. Also, following Colombo, Elkin, and Hartmann [16], the paper distinguishes Bayesian from mechanistic models because they model information processes and not the instantiation of such processes in cortical networks.

With respect to the FEP, the paper argues that it is not critical to PP because it extends its scope to biological systems, but serves rather as a heuristic principle [13, 14, 15]. The argument is that the principle does not target biological organisms but formal systems. If the principle is a conceptual model, it provides an understanding of life and cognition that may not add specific constraints to PP scientific models.

This paper has four sections: the first introduces Marr's levels and the distinction between conceptual models and computational templates. The second addresses the interdisciplinarity of cognitive science frameworks, comparing cognitivism, connectionism, and PP. The third and fourth sections introduce Bayesian models of cognition and the free-energy principle, respectively, discussing their roles in PP.

References

1. Bermúdez, J. L. Cognitive Science. An Introduction to the science of the mind. 3rd edn. Cambridge University Press, Cambridge, New York (2020).
2. Marr, D.: Vision. A computational investigation into the human representation and processing of visual information. W. H. Freeman and Company, New York (1982).
3. Keller, G., Mrsic-Flogel, T.: Predictive processing: a canonical cortical computation. Neuron 100(24), 424–35 (2018).
4. Kogo, N, Trengove, C.: Is predictive coding theory articulated enough to be testable? Frontiers in Computational Neuroscience 9, 1–4 (2015).
5. Cao, R.: New labels for old ideas: predictive processing and the interpretation of neural signals. Review of Philosophy and Psychology 11(3), 517–46 (2020).
6. Friston, K. J.: The free-energy principle: a unified brain theory? Nature Reviews Neuroscience 11(2), 127–38 (2010).
7. Hohwy, J.: The predictive mind. Oxford University Press, Oxford (2013).
8. Harkness, D., Keshava, A.: Moving from the what to the how and where – bayesian models and predictive processing. In Metzinger, T., Wiese, W. (eds.) Philosophy and Predictive Processing. MIND Group, Frankfurt am Main (2017).
9. Gładziejewski, P.: The mechanistic unity of the predictive mind. Theory and Psychology 29(5), 657–75 (2019).
10. Andersen, H.: Collaboration, interdisciplinarity, and the epistemology of contemporary science. Studies in History and Philosophy of Science Part A 56, 1–10 (2016).
11. Knuuttila, T, Loettgers, A.: Magnets, spins, and neurons: the dissemination of model templates across disciplines. The Monist 97(3), 280–300 (2014).
12. Herfeld, C., Lisciandra, C.: Knowledge transfer and its contexts. Studies in History and Philosophy of Science Part A 77, 1–10 (2019).
13. Friston, K. J.: A theory of cortical responses. Philosophical Transactions of the Royal Society B: Biological Sciences 360(1456), 815–36 (2005).
14. Friston, K. J., Stephan, K.: Free-energy and the brain. Synthese 159(3), 417–58 (2007).
15. Friston, K. J., Daunizeau, J., Kiebel, S. Reinforcement learning or active inference? PLoS ONE 4(7) (2009).
16. Colombo, M., Elkin, L., Hartmann, S.: Being realist about bayes, and the predictive processing theory of mind. The British Journal for the Philosophy of Science 72(1), 185–220 (2021).