Ranking the cognitive plausibility of computational models of metaphors with the Minimal Cognitive Grid: a preliminary study

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Abstract

In this paper, we review the main computational models of metaphors by using the epistemological lens of computational cognitive science: i.e. we aim at analyzing their level of cognitive plausibility and - as such - the explanatory power of their produced output with respect to the existing theories in cognitive science aiming at explaining such a phenomenon. In particular, we analyze and compare the following AI systems: 1) the Structure-Mapping Engine (SME), 2) the AnalogySpace system 3) CogSketch and 4) Large Language Models. The methodological tool adopted for our analysis is the Minimal Cognitive Grid: a pragmatic framework proposed to rank the different degrees of structural accuracy of artificial systems in order project and predict their explanatory power (Lieto, 2021; Lieto 2022). We report the obtained results, discuss the epistemological implications of such analysis and suggest how it can inform the design of the next generation of artificial systems aiming at tackling such cognitive ability.

Extended Abstract

The creation, use and interpretation of metaphors expressed in natural language sentences represents a crucial abstractive capacity of human semantic competence and communication. In the context of computational cognitive modelling, many different systems and approaches have been proposed in oder to endow, with the same ability, artificial systems. In this paper, we review the main, state-of-the-art, computational models of metaphors by using the epistemological lens of computational cognitive science: i.e. with the aim of analyzing their level of cognitive plausibility and - as such - the explanatory power of their produced output with respect to the existing theories in cognitive science aiming at explaining such a phenomenon. More in detail, in this paper we analyze and compare the following AI systems: 1) the Structure-Mapping Engine (SME), developed by Dedre Gentner and Kenneth Forbus, this is one of the most influential systems in the field of analogical reasoning whose underlying principles of identifying systematic correspondences between different domains has also been extended to metaphor understanding, (where metaphors are seen as a form of analogy) 2) the AnalogySpace. This system uses factor analysis to represent general common-sense knowledge in a mathematical space where both analogical reasoning and metaphorical interpretation can occur; 3) CogSketch: an AI system that provides a sketch understanding environment and cognitive modeling tool supporting both visual analogical reasoning and metaphor interpretation, enabling users to draw diagrams that the system interprets, supporting reasoning about both physical and abstract concepts 4) Large Langue Models (in particular GPT-3.5 and GPT-4) used for metaphors comprehension and generation.
The methodological tool adopted for our analysis is the Minimal Cognitive Grid: a pragmatic framework proposed to rank the different degrees of structural accuracy of artificial systems in order project and predict their explanatory power (Lieto, 2021).

The Minimal Cognitive Grid (MCG) considers of three key dimensions that characterize the relationship between a model and its biological or cognitive target system:

- **Functional/Structural Ratio**: This dimension concerns the balance between functional and structural components in the model. It evaluates the extent to which the model relies on abstract functional descriptions versus detailed structural mechanisms. A lower ratio indicates a more mechanistic model, while a higher ratio suggests a more functional approach.
- **Generality**: This dimension assesses the breadth of phenomena that the model can represent. A highly general model can be applied to a wide range of cognitive functions or biological systems, while a narrow model is tailored to a specific task or domain.
- **Performance Match**: This dimension involves a direct comparison between the model's performance and that of the target system. It considers not only the overall accuracy of the model but also the similarity of its errors and execution times to those of the biological or cognitive system. A close performance match suggests a higher degree of psychological or biological plausibility.

We report the obtained results, discuss the epistemological implications of such analysis and suggest how it can inform the design of the next generation of artificial systems aiming at tackling such cognitive ability.

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