The computational modeling of inferential and referential competence

Fabrizio Calzavarini[1,2], Antonio Lieto[1,2]
[1]University of Turin, Italy, [2]Center for Logic, Language, and Cognition (LLC)

Introduction

In philosophy of language, a distinction has been proposed between two aspects of lexical competence, i.e. referential and inferential competence (Marconi 1997). The former accounts for the relationship of words to the world, the latter for the relationship of words among themselves. The distinction may simply be a classification of patterns of behaviour involved in ordinary use of the lexicon. Recent research in neuropsychology and neuroscience, however, suggests that the distinction might be neurally implemented, i.e., that different cognitive architectures with partly distinct neural realizations might be responsible for cognitive performances involving inferential and referential aspects of semantics. This hypothesis is strongly consistent with patient data supporting the notion of a functional double dissociation between inferential and referential abilities, and with a set of direct cortical mapping studies and neuroimaging experiments suggesting that inferential and referential abilities are underpinned by at least partly different regions of the human brain (e.g., Marconi et al. 2013; review in Calzavarini 2017).

The initial hypotheses formulated in the setting of the philosophy of language, along with the neuropsychological experimental evidence (about how referential and inferential competences may be neurally instantiated) can be the input to computational modelling activities involving the inferential and the referential aspects of lexical competence. The aim of the talk is to offer a critical discussion of the kind of formalisms that can be used to model the two aspects of lexical competence, and of the main difficulties related to the use of these computational techniques.

Inferential (=symbolic) vs referential (=connectionist) formalisms

The first conclusion of our discussion is that the distinction between inferential and referential semantics is instantiated in the literature of Artificial Intelligence by the distinction between symbolic and connectionist approaches. On the one hand, symbolic formalisms (e.g., meaning postulates, semantic networks, frames, distributional models) are successfully utilized to model a variety of inferential semantic tasks like semantic inference, definition naming, synonym judgments, word-word matching, and so on. The symbolic approach to inferential competence is not immune from problems. For instance, it is know that symbolic formalisms have difficulty in modelling prototypical knowledge and deafasible inference, two essential aspects of human lexical inferential competence (Lieto et al. 2012). The critical point here is that, for conceptual reasons, none of the symbolic formalism appears to be able to model the referential aspect of human lexical competence, i.e. our ability to apply words to objects in the world through perceptual recognition, particularly to visual recognition (Marconi 1997; Harnad 1980).

On the other hand, connectionist approaches (i.e. neural networks, including deep neural networks) are today very effective in modelling referential tasks like visual recognition and naming and are the most widely adopted framework in artificial vision (e.g., Szeliski, Springer, 2010). Differently from symbolic representations, neural networks receive input data directly coming from sensory systems, as images, signals, and so on, and thus the problem of grounding representations to entities in the external world is in some sense alleviated. The importance of neural networks for symbol grounding has been discussed by Harnad in a seminal paper (Harnad 1980). From this point of view, the main advantage of deep neural networks, and in particular of Convolutional Neural Networks, is that they are even closer to sensory data, and therefore they need less or no preprocessing of input data. Among the problems that affect this class of formalisms, however, is that one of not being able to model inferential mechanisms such as taxonomic relations and semantic composition (Lieto, Lebiere, & Oltramari 2018).

The need of integration

The second conclusion of our discussion is that the modelling of lexical competence needs the advent of hybrid models integrating symbolic and connectionist frameworks. Such integration is hard to obtain at this state of knowledge (and this can provide, we claim, further indirect evidence for the cognitive reality of the inferential/ referential distinction). While, in fact, existing hybrid systems and architectures such as CLARION (Sun 2006) or ACT-R (Anderson et al. 2004) are able to combine different kinds of representations, nonetheless this kind of integration is usually ad hoc based (Chella, Frixione, & Gaglio, 1998) or, as we will try to show in our presentation, is only partially satisfying. Our hypothesis is that Conceptual Spaces, a framework developed by Gärdenfors (2000) more than fifteen years ago, can offer a lingua franca that allows to unify and generalize many aspects of the representational approaches mentioned above and to integrate "inferential" (=symbolic) and "referential" (=connectionist) computational approaches on common ground (Lieto, Chella & Frixione 2017). The integration referential/inferential integration via Conceptual Spaces seems nowadays more viable due to the enhancements provided by the existing systems. In particular, we claim that a straightforward way for such integration could combine the overall visual architecture provided in Chella, Frixione & Gaglio (2003) with the grounding mechanisms between conceptual spaces and symbolic representations available in the system DUAL-PECCS (Lieto et al. 2015).

References

Anderson, J.R., Bothell, D., Byrne, M.D., Douglass, S., Lebiere, C., Qin, Y.: An integrated theory of the mind. Psychological review 111(4), 1036 (2004) 2.

Calzavarini, F.: Inferential and referential lexical semantic competence: A critical review of the supporting evidence. Journal of Neurolinguistics 44, 163–189 (2017) 3. DOI: https://doi.org/10.1016/j.jneuroling.2017.04.002

Chella, A., Frixione, M., Gaglio, S.: A cognitive architecture for artificial vision. Artificial Intelligence 89(1), 73–111 (1997) 5. DOI: https://doi.org/10.1016/S0004-3702(96)00039-2

Chella, A., Frixione, M., Gaglio, S.: Anchoring symbols to conceptual spaces: the case of dynamic scenarios. Robotics and Autonomous Systems 43(2), 175–188 (2003)

Frixione, M., & Lieto, A. (2012). Representing concepts in formal ontologies. Compositionality vs. typicality effects. Logic and Logical Philosophy, 21(4), 391-414.

Gardenfors, P.: Conceptual spaces: The geometry of thought. MIT press (2000)

Harnad, S.: The symbol grounding problem. Physica D: Nonlinear Phenomena 42(1-3), 335–346 (1990)

Lieto, A., Radicioni, D. P., & Rho, V. (2017). Dual PECCS: a cognitive system for conceptual representation and categorization. Journal of Experimental & Theoretical Artificial Intelligence, 29(2), 433-452. DOI: https://doi.org/10.1080/0952813X.2016.1198934

Lieto, A., Chella, A., & Frixione, M. (2017). Conceptual spaces for cognitive architectures: A lingua franca for different levels of representation. Biologically inspired cognitive architectures, 19, 1-9. DOI: https://doi.org/10.1016/j.bica.2016.10.005

Lieto, A., Lebiere, C., & Oltramari, A. (2018). The knowledge level in cognitive architectures: Current limitations and possible developments. Cognitive Systems Research, 48, 39-55. DOI: https://doi.org/10.1016/j.cogsys.2017.05.001

Marconi, D.: Lexical competence. MIT press (1997)

Marconi, D., Manenti, R., Catricala, E., Della Rosa, P.A., Siri, S., Cappa, S.F.: The neural substrates of inferential and referential semantic processing. cortex 49(8), 2055– 2066 (2013) DOI: https://doi.org/10.1016/j.cortex.2012.08.001

Sun, R.: The CLARION cognitive architecture: Extending cognitive modeling to social simulation. Cognition and multi-agent interaction pp. 79–99 (2006)