Nombre de la Asignatura: *An introduction to the Philosophy of Cognitive Neuroscience: Epistemic and Metaphysical issues*

Créditos asociados:

Planificación: Primer Semestre

Carácter de la Asignatura: Mínimo.

 Requisitos: Seminario Mínimo.

 Profesor: Dr. Abel Wajnerman Paz.

**General Description**

Cognitive science was one of the dominant approaches to psychological processes during (part of) the second half of the twentieth century. One of its main insights is the hypothesis that mental capacities could be explained through the theoretical tools provided by computer science. Despite its success in accounting for numerous cognitive phenomena, a crucial shortcoming of this research program was its inability to connect the computational and information-theoretic characterization of mental processes to their underlying neurological basis, thus casting doubt on the biological plausibility of its fundamental concepts.

 During the last three decades we have witnessed an unprecedented development of the technological and theoretical tools for manipulating and analysing the neural mechanisms underlying cognitive function and dysfunction, which was considered to constitute a ‘neurocognitive revolution’. Neurocognitive models seem to build a progressively stronger connection between cognition and its biological basis by providing increasingly complex and detailed descriptions of neural mechanisms in computational and/or information-theoretic terms. However, the nature, goals and implications of cognitive neuroscience are still a matter of intense philosophical debate.

 In the first place, there is a discussion regarding the norms of neurocognitive explanation. The mechanistic approach, which has been the dominant view during the last 15 years, identifies the goal of cognitive neuroscience with the modelling of mechanisms underlying cognitive functions. A mechanism is a structure performing a function in virtue of its component parts, component operations, and their organization. Despite its ability to characterize (and evaluate) a relevant part of the explanatory practices in the field, a number of philosophers have recently argued that mechanism constitutes a very narrow view of neurocognitive explanations, failing to account for the explanatory power of, for instance, structural models (which do not refer to causal relations) or dynamical models (which do not describe fixed organizations, components or operations).

 In the second place, there is a widespread metaphysical discussion concerning the cognitive ontology of neural mechanisms, that is, which cognitive properties can be attributed to neural components and activities and organization. A first question is related to the identification of the basic building blocks of neurocognitive processes. The classic view, which is the functional version of the ‘neuron doctrine’, posits that individual neurons are not only anatomical but also cognitive basic components of our mental capacities. On the contrary, a ‘population doctrine’ claims that the contribution of individual cells to cognitive processes can only be understood when neurons are viewed as part of neural assemblies, populations or circuits. A second question is how we should understand these building blocks and the mechanisms they constitute. In this regard, a crucial concern is whether neural processes are better characterized in information-theoretic and computational terms or, on the contrary, cognitive processing can be implemented by network properties that do not involve information or computation. For instance, network neuroscience is a thriving field in which cognitive capacities are often explained by purely graph-theoretic or dynamical properties of neural structures. Finally, there is a debate regarding the relationship between cognitive neuroscience and classic cognitivism. A central issue is whether cognitive neuroscience supports the classic cognitivist view that cognition is representation manipulation. If the kinds of (dynamical, information-theoretic, graph-theoretic or computational) properties implemented by neural structures are inconsistent with a minimal notion of representation, then it is possible that cognitive neuroscience will not contribute to bridging the gap between classic cognitive levels but rather characterize them in a completely new manner.

**Aims**

Upon completion of the course, the students should be able to

* understand the main aspects of the mechanistic approach to neurocognitive explanation, the different problems imposed by dynamic and structural models and the main responses to these problems.
* become familiar with the arguments that support the transition from the ‘neuron doctrine’ to a ‘population doctrine’, the advantages and disadvantages of the different formal frameworks for analysing neural populations and the relationship (or lack thereof) between cognitive neuroscience and classical cognitivism.
* engage in philosophical discussion, look for the relevant literature and construct properly philosophical arguments.
* write a philosophical paper contributing to one of the main addressed debates.

**Contents**

1. **Cognitive Science and the ‘neurocognitive revolution’**

**Mandatory Readings.**

1. Bechtel,W. (2001). Cognitive neuroscience: Relating neural mechanisms and cognition. In P. Machamer, P. McLaughlin, & R. Grush (Eds.), *Philosophical reflections on the methods of neuroscience*. Pittsburgh, PA: University of Pittsburgh Press.
2. F. Boone, W., & Piccinini, G. (2016). The cognitive neuroscience revolution. *Synthese*, 193(5), 1509-1534

**Further Readings.**

1. Craver, C. F. (2007). *Explaining the brain: Mechanisms and the mosaic unity of neuroscience*, ch. 1. Oxford University Press.
2. Baars, B. J., & Gage, N. M. (2010). *Cognition, brain, and consciousness: Introduction to cognitive neuroscience*. Burlington, MA: Academic Press/Elsevier.
3. McClelland, J. L., & Ralph, M. A. L. (2015). Cognitive Neuroscience. In James D. Wright (Ed.), *International Encyclopedia of the Social & Behavioral Sciences*, 95–102. doi:10.1016/b978-0-08-097086-8.56007-3
4. **Explanation in CN: The mechanistic approach**

**Mandatory Readings.**

1. Machamer, P., Darden, L., & Craver, C. F. (2000). Thinking about mechanisms. *Philosophy of science*, 67(1), 1-25
2. Craver, C. F. (2007). *Explaining the brain: Mechanisms and the mosaic unity of neuroscience*, ch. 4. Oxford University Press.

**Further Readings.**

1. Woodward, J. (2005). *Making things happen: A theory of causal explanation*. Oxford university press.
2. Pearl, J. (2009). *Causality: Models, Reasoning, and Inference*, second edition, New York: Cambridge University Press.
3. Piccinini, G., & Craver, C.(2011). Integrating psychology and neuroscience: Functional analyses as mechanism sketches. *Synthese*, 183(3), 283–311.
4. Craver, C.F., & Darden, L. (2001). Discovering mechanisms in neurobiology: The case of spatial memory. In P. Machamer, R. Grush, & P. McLaughlin (Eds.) *Theory and method in the neurosciences*. Pittsburgh: University of Pittsburgh Press.
5. Craver, C. F. (2014). The Ontic Conception of Scientific Explanation. In Andreas Hütteman and Marie Kaiser (Eds), *Explanation in the Special Sciences: The Cases of Biology and History*, Dordrecht: Springer, pp. 27–52.
6. Bechtel, W. and A. Abrahamsen (2005). Explanation: A Mechanistic Alternative. *Studies in History and Philosophy of the Biological and Biomedical Sciences*, 36: 421–441.
7. Levy, A. (2013). Three kinds of new mechanism. *Biology & Philosophy*, 28(1), 99-114.
8. Levy, A. and W. Bechtel (2012). Abstraction and the Organization of Mechanisms, *Philosophy of Science*, 80: 241-261.
9. Machamer, P. (2004). Activities and Causation: The Metaphysics and Epistemology of Mechanisms, *International Studies in the Philosophy of Science*, 18: 27-39.
10. **Explanation in CN: non-causal and dynamic explanation**

**Mandatory Readings.**

1. Chirimuuta, M. (2017). Explanation in computational neuroscience: Causal and non-causal. *The British Journal for the Philosophy of Science*, 69(3), 849-880.
2. Rathkopf, C. (2018). Network representation and complex systems. *Synthese*, 195(1), 55-78.

**Further Readings.**

1. Craver, C.F. and Kaplan, D. (2018) “Are More Details Better? On the Norms of Completeness for Mechanistic Explanations.” *British Journal for the Philosophy of Science*.
2. Burnston, D. (2019). Getting over Atomism: Functional Decomposition in Complex Neural Systems, *The British Journal for the Philosophy of Science*, axz039, https://doi.org/10.1093/bjps/axz039
3. Wajnerman Paz, A. (2017). A mechanistic perspective on canonical neural computation. *Philosophical Psychology* 30 (3), 209-230.
4. Zednik, C. (2018). Models and mechanisms in network neuroscience. *Philosophical Psychology*, 1–29. doi:10.1080/09515089.2018.1512090
5. Bechtel, W., & Abrahamsen, A. A. (2013). Thinking dynamically about biological mechanisms: Networks of coupled oscillators. *Foundations of Science*, 18(4), 707-723.
6. Craver, C.F. and Povich, M. (2018) “The Directionality of Distinctively Mathematical Explanations.” *Studies in the History and Philosophy of Science*.
7. Craver, C. F. (2016). The explanatory power of network models. *Philosophy of Science*, 83 (5), 698–709.
8. Green, S., Şerban, M., Scholl, R., Jones, N., Brigandt, I., & Bechtel, W. (2018). Network analyses in systems biology: new strategies for dealing with biological complexity. *Synthese*, 195(4), 1751-1777.
9. Meyer, R. (2018). The Non-mechanistic Option: Defending Dynamical Explanations. *The British Journal for the Philosophy of Science*. doi:10.1093/bjps/axy034
10. **Cognitive ontology in neuroscience. Building blocks: From the Neuron Doctrine to the Population Doctrine**

**Mandatory Readings.**

1. Barlow, H. B. (1972). Single units and sensation: a neuron doctrine for perceptual psychology?. *Perception,* 1(4), 371-394.
2. Eichenbaum, H. (2018). Barlow versus Hebb: When is it time to abandon the notion of feature detectors and adopt the cell assembly as the unit of cognition?. *Neuroscience letters*, 680, 88-93.

**Further Readings.**

1. Yuste, R. (2015). From the neuron doctrine to neural networks. *Nature reviews neuroscience*, 16(8), 487.
2. Maldonado, P. (2007). What we see is how we are: New paradigms in visual research. *Biological research*, 40(4), 439-450.
3. Saxena, S., & Cunningham, J. P. (2019). Towards the neural population doctrine. *Current opinion in neurobiology*, 55, 103-111.
4. Schneidman, E. (2016). Towards the design principles of neural population codes. *Current opinion in neurobiology*, 37, 133-140.
5. Fairhall, A. (2014). The receptive field is dead. Long live the receptive field?. *Current opinion in neurobiology*, 25, ix-xii.
6. Barlow, H. B. (1961). Possible principles underlying the transformation of sensory messages. *Sensory communication*, 1, 217-234.
7. Barlow, H. (2001a). The exploitation of regularities in the environment by the brain. *Behavioral and Brain Sciences*, 24(4), 602-607.
8. Barlow, H. (2001b). Redundancy reduction revisited. *Network: computation in neural systems*, 12(3), 241-253.
9. Barlow, H. B., Parker, A. J., Singer, W., & Thorpe, S. J. (2009). Barlow's 1972 paper. *Perception*, 38(6), 795-807.
10. Page, M. (2000). Connectionist modelling in psychology: A localist manifesto. Behavioral and Brain Sciences, 23(4), 443-467.
11. Bowers, J. S. (2017) Grandmother cells and localist representations: a review of current thinking, *Language, Cognition and Neuroscience*, 32:3, 257-273, DOI: 10.1080/23273798.2016.1267782
12. Bowers, J. S., Martin, N. D., & Gale, E. M. (2019). Researchers Keep Rejecting Grandmother Cells after Running the Wrong Experiments: The Issue Is How Familiar Stimuli Are Identified. *BioEssays*, 41(8), 1800248.
13. **Cognitive ontology in neuroscience. Basic properties: Information-theoretic, computational, dynamical and graph-theoretic approaches**

**Mandatory Readings.**

1. Piccinini, G., & Scarantino, A. (2011). Information processing, computation, and cognition. *Journal of biological physics*, 37(1), 1-38.
2. Sporns, O. (2014). Contributions and challenges for network models in cognitive neuroscience. *Nature neuroscience*, 17(5), 652.
3. Bressler, S. L., & Kelso, J. A. (2016). Coordination dynamics in cognitive neuroscience*. Frontiers in neuroscience*, 10, 397.

**Further Readings.**

1. Piccinini, G. and Bahar, S. (2013). Neural Computation and the Computational Theory of Cognition. *Cognitive Science* 37 (3), 453-488.
2. Piccinini, G. (2007). Computing Mechanisms, *Philosophy of Science*, 74: 501-526.
3. Elber-Dorozko, L., & Shagrir, O. (2019). Integrating computation into the mechanistic hierarchy in the cognitive and neural sciences. *Synthese*. doi:10.1007/s11229-019-02230-9
4. Sporns, O. (2014). Contributions and challenges for network models in cognitive neuroscience. *Nature neuroscience*, 17(5), 652.
5. Colombo, M. (2013). Moving forward (and beyond) the modularity debate: A network perspective. Philosophy of Science, 80(3), 356-377.
6. Rubinov, M., & Sporns, O. (2010). Complex network measures of brain connectivity: uses and interpretations. *Neuroimage*, 52(3), 1059-1069.
7. Fornito, A., Zalesky, A., & Bullmore, E. (2016). *Fundamentals of brain network analysis*. Academic Press.
8. Bertolero, M. A., & Bassett, D. S. (2019). On the nature of explanations offered by network science: A perspective from and for practicing neuroscientists. arXiv preprint arXiv:1911.05031
9. Bressler, S. L., and Kelso, J. A. S. (2001). Cortical coordination dynamics and cognition. *Trends Cogn. Sci*. 5, 26–36. doi: 10.1016/S1364-6613(00)01564-3
10. Kelso, J. A. S. (2012). Multistability and metastability: understanding dynamic coordination in the brain. *Philos. Trans. R. Soc. Lond. B Biol. Sci*. 367, 906–918. doi: 10.1098/rstb.2011.0351
11. **Cognitive ontology in neuroscience: Neural Representations**

**Mandatory Readings.**

1. Piccinini, G. (2018). Computation and Representation in Cognitive Neuroscience. *Minds and Machines* 28(1): 1-6.
2. Constant, A., Clark, A., & Friston, J. (2019). Representation Wars: Enacting an Armistice through Active Inference [Unpublished]

**Further Readings.**

1. Bechtel, W. (2016). Investigating neural representations: the tale of place cells. *Synthese*, 193(5), 1287-1321.
2. Wajnerman Paz, A. W. (2018). An efficient coding approach to the debate on grounded cognition. *Synthese*, 195(12), 5245-5269.
3. Martínez, M. (2019). Representations are Rate-Distortion Sweet Spots. *Philosophy of Science*, 86(5), 1214-1226.
4. Hutto, D. & Myin, E. (2018). Much ado about nothing? Why going non-semantic is not merely semantics, Philosophical Explorations 21 (2):187-203.
5. Kuokkanen, J. & Rusanen A.M. (2018) Making too many enemies: Hutto and Myin’s attack on computationalism, *Philosophical Explorations* 21 (2):282-294.
6. Colombo, M. (2014). Explaining social norm compliance. A plea for neural representations. *Phenomenology and the Cognitive Sciences* 13 (2): 217-238.
7. Morgan, A., & Piccinini, G. (2017). Towards a Cognitive Neuroscience of Intentionality. *Minds and Machines*, 28(1), 119–139. doi:10.1007/s11023-017-9437-2

**Methodology**

Encouraged participation in the seminar is expected, and students should arrive having carefully read the assigned material, and having prepared their thoughts and questions about the readings in advance. For this purpose, students are required to circulate at least 1 and a maximum of 2 pages of double-spaced writing before 7:00 p.m. the night before each seminar session at the latest. These texts should concern the readings scheduled for the session that will take place on the following day. The students must send their texts to the group as email attachments. The aim of these written exercises is to deal with the mandatory readings. The students can do this in the way that is most useful to them, summarizing the material, criticizing one of the arguments or defending the author of a possible criticism. These documents will not be given any marks, but students must send them all to pass the course.

**Assessment**

-Two individual oral presentations of selected texts (weight: 20% each).

-A written research essay (weight: 60%).

**Bibiliography**

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Craver, C. F. (2014). The Ontic Conception of Scientific Explanation. In Andreas Hütteman and Marie Kaiser (Eds), *Explanation in the Special Sciences: The Cases of Biology and History*, Dordrecht: Springer, pp. 27–52.

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Piccinini, G., & Craver, C.(2011). Integrating psychology and neuroscience: Functional analyses as mechanism sketches. *Synthese*, 183(3), 283–311.

Piccinini, G. (2007). Computing Mechanisms, *Philosophy of Science*, 74: 501-526.

Piccinini, G., & Scarantino, A. (2011). Information processing, computation, and cognition. *Journal of biological physics*, 37(1), 1-38.

Piccinini, G. and Bahar, S. (2013). Neural Computation and the Computational Theory of Cognition. *Cognitive Science* 37 (3), 453-488.

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Saxena, S., & Cunningham, J. P. (2019). Towards the neural population doctrine. *Current opinion in neurobiology*, 55, 103-111.

Schneidman, E. (2016). Towards the design principles of neural population codes. *Current opinion in neurobiology*, 37, 133-140.

Sporns, O. (2014). Contributions and challenges for network models in cognitive neuroscience. *Nature neuroscience*, 17(5), 652.

Wajnerman Paz, A. (2017). A mechanistic perspective on canonical neural computation. *Philosophical Psychology* 30 (3), 209-230.

Wajnerman Paz, A. W. (2018). An efficient coding approach to the debate on grounded cognition. *Synthese*, 195(12), 5245-5269.

Woodward, J. (2005). *Making things happen: A theory of causal explanation*. Oxford university press.

Yuste, R. (2015). From the neuron doctrine to neural networks. *Nature reviews neuroscience*, 16(8), 487.

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