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Dynamic Field Theory: Conceptual Foundations and Applications in Cognitive and Developmental Science

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Objectives and Scope

Dynamical Systems thinking has been influential in the way psychologists, cognitive scientists, and neuroscientists think about sensori-motor behavior and its development. The initial emphasis on motor behavior was expanded when the concept of dynamic activation fields provided access to embodied cognition. Dynamical Field Theory (DFT) offers a framework for thinking about representation-in-the-moment that is firmly grounded in both Dynamical Systems thinking and neurophysiology. Dynamic Neural Fields are formalizations of how neural populations represent the continuous dimensions that characterize perceptual features, movements, and cognitive decisions. Neural fields evolve dynamically under the influence of inputs as well as strong neuronal interaction, generating elementary forms of cognition through dynamical instabilities. The concepts of DFT establish links between brain and behavior, helping to define experimental paradigms in which behavioral signatures of specific neural mechanisms can be observed. These paradigms can be modeled with Dynamic Neural Fields, deriving testable predictions and providing quantitative accounts of behavior.

One obstacle for researchers wishing to use DFT has been that the mathematical and technical skills required to make these concepts operational are not part of the standard repertoire of cognitive scientists. The goal of this tutorial is to provide the training and tools to overcome this obstacle. We will provide a systematic introduction to the central concepts of DFT and their grounding in both Dynamical Systems concepts and neurophysiology. We will discuss the concrete mathematical implementation of these concepts in Dynamic Neural Field models, giving all needed background and providing participants with some hands-on experience using interactive simulators in MATLAB. Finally, we will take participants through a number of selected, exemplary case studies in which the concepts and associated models have been used to ask questions about elementary forms of embodied cognition and their development.

A newly published book on Dynamic Neural Field modeling, *Dynamic Thinking: A Primer on Dynamic Field Theory,* covers these topics and more, with interactive simulators available to give hands-on experience to readers. We will take participants through the process of building and simulating models to illustrate key concepts in the case studies we describe in the tutorial.

Suggested Readings

(available online, see Online Resources below)

1. Schöner, G. & Spencer, J.P. (2015). Introduction. [Chapter 1] In G. Schöner, J. P. Spencer, & the DFT Research Group (Eds.), *Dynamic Thinking: A Primer on Dynamic Field Theory*. New York, NY: Oxford University Press.

2. Schöner, G., Reimann, H., & Lins, J. (2015). Neural Dynamics. [Chapter 2] In G. Schöner, J. P. Spencer, & the DFT Research Group (Eds.), *Dynamic Thinking: A Primer on Dynamic Field Theory*. New York, NY: Oxford University Press.

3. Schöner, G. & Schutte, A.R. (2015). Dynamic Field Theory: Foundations. [Chapter 3] In G. Schöner, J. P. Spencer, & the DFT Research Group (Eds.), *Dynamic Thinking: A Primer on Dynamic Field Theory*. New York, NY: Oxford University Press.

4. Johnson, J.S. & Simmering, V.R. (2015). Integrating Perception and Working Memory in a Three-Layer Dynamic Field Architecture. [Chapter 5] In G. Schöner, J. P. Spencer, & the DFT Research Group (Eds.), *Dynamic Thinking: A Primer on Dynamic Field Theory*. New York, NY: Oxford University Press.

5. Simmering, V.R. & Schutte, A.R. (2015). Developmental Dynamics: The Spatial Precision Hypothesis. [Chapter 10] In G. Schöner, J. P. Spencer, & the DFT Research Group (Eds.), *Dynamic Thinking: A Primer on Dynamic Field Theory*. New York, NY: Oxford University Press.

6. Sandamirskaya, Y., Zibner, S., Schneegans, S., & Schöner, G. (2013). Using Dynamic Field Theory to Extend the Embodiment Stance toward Higher Cognition. *New Ideas in Psychology*.

Target Audience

No specific prior knowledge of the mathematics of dynamical systems models or neural networks is required as the mathematical and conceptual foundations will be provided during the tutorial. An interest in formal approaches to cognition is an advantage.

Schedule of Material Covered in the Tutorial

1. Conceptual foundations of Dynamical Systems Thinking and Dynamical Field Theory (DFT) – 30 minutes: embodied and situated cognition; stability as a necessary property of embodied cognitive processes; distributions of population representation as the basis of spatially and temporally continuous neural representations.

2. Dynamical Systems and Dynamic Field Theory Tutorial – 90 minutes: concept of dynamical system; attractors and stability; input tracking; detection, selection, and memory instabilities in discrete neuronal dynamics; Dynamical Fields and the basic instabilities: detection, selection, memory, boost-driven detection; learning dynamics; categorical vs. graded mode of operation; practical implementation of DFT in simulators; interactive simulation; illustration of the ideas through robotic implementations;

3. Case study using DFT to understand brain-behavior relations in humans with functional neuroimaging – 60 minutes: mapping of neural activation patterns in dynamic neural fields to the hemodynamic response measured with fMRI and fNIRS; case study on the neural processes that underlie visual working memory in children and adults.

4. Case study using DFT to understand embodied cognition and its development – 90 minutes: visual and spatial working memory in infants, children, and adults; spatial precision hypothesis as a developmental mechanism visuospatial cognition

5. Case study using DFT to understand higher cognition – 90 minutes: integrating location and feature information to form working memory representations of visual scenes; linking spatial language to visual perception

Lecturers

John P. Spencer is a Professor of Psychology at the University of East Anglia in Norwich, UK. Prior to arriving in the UK, he was a Professor of Psychology at the University of Iowa and served as the founding Director of the Delta Center (Development and Learning from Theory to Application). He received a Sc.B. with Honors from Brown University in 1991 and a Ph.D. in Experimental Psychology from Indiana University in 1998. He is the recipient of the Irving J. Saltzman and the J.R. Kantor Graduate Awards from Indiana University. In 2003, he received the Early Research Contributions Award from the Society for Research in Child Development, and in 2006, he received the Robert L. Fantz Memorial Award from the American Psychological Foundation. His research examines the development of visuo-spatial cognition, spatial language, working memory, and attention, with an emphasis on dynamical systems and neural network models of cognition and action. He has had continuous funding from the National Institutes of Health and the National Science Foundation since 2001 and has been a fellow of the American Psychological Association since 2007. He will lecture on the topics 1-3 above.

Vanessa R. Simmering is an Assistant Professor of Psychology at the University of Wisconsin – Madison. She obtained her B.S. with Honors in Psychology from the University of Iowa in 2001 and a Ph.D. in Psychology from the University of Iowa in 2008. Her research takes a dynamic systems approach to understanding cognition and development, with particular emphasis on how visuospatial cognition relates to other developing skills during early childhood. She will lecture on topic 4 above.

Sebastian Schneegans is a postdoctoral researcher in the Department of Psychology at the University of Cambridge. He obtained his PhD (Dr.-Ing.) at the Institut für Neuroinformatik, Ruhr-Universität Bochum, for his work on visual working memory, spatial cognition and spatial language within the framework of DFT. He is now developing population code models of visual working memory and testing them in psychophysical experiments. His work has been published in seven journal articles, six book chapters, and numerous conference contributions. Dr. Schneegans will lecture on mechanisms for feature binding and spatial transformations in DFT. He will lecture on topic 5 above.

Computer Use

Participants who bring laptops with Matlab installed (student version is sufficient) will be able to follow demonstrations by actively working with the simulator during lectures.

Online Resources

We will use simulators from the free Matlab toolbox Cosivina for demonstrations. Installation instructions and documentation for the toolbox can be found on the website. Related publications, lecture material, and interactive simulators can all be found at our website, http://www.dynamicfieldtheory.org/.