Dynamic Field Theory: Conceptual Foundations and Applications in the Cognitive and Developmental Sciences

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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, therefore, 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. We will review robotic implementations to make the ideas concrete. 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.

The interactive simulators will be available at the tutorial.

Suggested Readings

(available at online, see below)

1. Spencer, J.P., Perone, S., & Johnson, J.S. (2009). The dynamic field theory and embodied cognitive dynamics. In J.P. Spencer, M.S. Thomas, & J.L. McClelland (Eds.) *Toward a Unified Theory of Development: Connectionism and Dynamic Systems Theory Re-Considered.* Oxford University Press, pages 86-118
2. Schutte, A.R. & Spencer, J.P. (2009). Tests of the dynamic field theory and the spatial precision hypothesis: Capturing a qualitative developmental transition in spatial working memory. *Journal of Experimental Psychology: Human Perception and Performance*, **35**:1698-1725.
3. Johnson, J. S., Spencer, J.P. & Schöner, G. (2009): A layered neural architecture for the consolidation, maintenance, and updating of representations in visual working memory. *Brain Research* **1299**:17-32
4. Sandamirskaya, Y. & Schöner, G. (2010): An embodied account of serial order: How instabilities drive sequence generation. *Neural Networks* **23**:1164-1179
5. Samuelson, L.K., Smith, L.B., Perry, L.K. & Spencer, J.P. (2011). Grounding Word Learning in Space. *PLoS One*, **6**, e28095.
6. Lipinski, J., Schneegans, S., Sandamirskaya, Y., Spencer, J.P. & Schöner, G. (2012). A neuro-behavioral model of flexible spatial language behaviors. *Journal of Experimental Psychology: Learning, Memory, and Cognition* **38**:1490-1511.
7. 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* (in press, 2013)

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.

Material covered in the course

1. Conceptual foundations of Dynamical Systems Thinking and Dynamical Field Theory (DFT): 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: 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; Categorial 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 embodied cognition and its development: visual and spatial working memory in children and adults; spatial precision hypothesis as a developmental mechanism in spatial recall, position discrimination, and change detection; mapping of DFT to functional neuroimaging with children.

4. Case study using DFT to understand brain-behavior relations in humans with functional neuroimaging: 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.

5. Case study using DFT to understand how flexible action sequences can be generated: Dynamics of serial order and behavior organization; Coupling to real sensor and motor systems; Stability and flexible timing of actions in a sequence; Autonomy and executive control in neural and robotic systems.

Lecturers

John P. Spencer is a Professor of Psychology at The University of Iowa and 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 teach the tutorials on development and functional neuroimaging (numbers 3, 4 below).

Gregor Schöner holds the Chair for Theory of Cognitive Systems and is the Director of the Institut für Neuroinformatik, Ruhr-Universität Bochum, Germany. Following his PhD in 1985 in theoretical physics at the University of Stuttgart, he held positions at the Center for Complex Systems of Florida Atlantic University, the Institut für Neuroinformatik, and the Center for Cognitive Neuroscience of the CNRS in Marseilles, France before returning to Bochum, Germany in 2001 to assume his current position. Dr. Schöner has received funding from different agencies in the US, Germany, France, and the European Union. He has published over to 200 scientific articles and chapters. Dr. Schöner is considered one of the world's experts on dynamic systems theory within the fields of Psychology and Cognitive Science, and is also a pioneer in the application of Dynamic Neural Fields to autonomous robotics. He will teach the conceptual and mathematical tutorials (numbers 1, 2 below).

Yulia Sandamirskaya is a Post-Doctoral researcher at the Institut für Neuroinformatik, Ruhr-Universität Bochum, Germany. She obtained her PhD (Dr.rer.nat.) in Physics for her work on embodied sequence generation within DFT. In her research, Dr. Sandamirskaya develops DNF models and robotic implementations of DNF architectures for sequence generation, behavior organization, and spatial language. Her work has been published in three journal articles, several conference proceedings, and a book chapter. Dr. Sandamirskaya will lecture on autonomy and sequence generation in DFT and present robotic implementations that demonstrate how concepts of DFT can lead to autonomous behavior in real environments (number 5 below).

Schedule

1. Conceptual foundations of Dynamical Systems Thinking and Dynamical Field Theory (DFT): 30 minutes

2. Dynamical Systems and Dynamic Field Theory Tutorial: 90 minutes

3. Case studies using DFT to understand embodied cognition and its development: 60 minutes before and 60 minutes after the lunch break

4. Case study using DFT to understand brain-behavior relations 60 minutes

5. Case study using DFT to understand flexible action sequences 60 minutes

Computer use

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

Online resources

Publications, lecture material, and interactive simulators can be found at our DFT Summer School websites `http://www.robotics-school.org` and `http://www.uiowa.edu/delta-center/research/dft`