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 at this operational level do not form 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 and demonstrable. 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. We will also give participants access to generic production-level simulators of Dynamic Field Models that can be expanded by participants to simulate and evaluate Dynamic Field Models that they may develop in their own work.

Target audience The tutorial will introduce participants to the area. 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. Because dynamical systems tools are not standard in Cognitive science, researchers with prior experience in connectionist or computational modeling may be interested in the tutorial as well.

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 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 with possibility for students to follow along on their own computers; Illustration of the ideas through robotic implementations;

3. Case studies using DFT to understand embodied cognition and its development: Spatial working memory in children and adults; Spatial precision hypothesis as a developmental mechanism;

4. Case studies using DFT to understand basic cognitive and behavioral processes in infants; generalization of mechanisms of discrimination and change detection along metrically organized dimensions in adults to infant looking

paradigms; Integration of real and developmental time scales; Role of autonomous visual exploration and multi-agent interactions in the developmental of stable individual differences.

Lecturers

The tutorial leader will be *Gregor Schöner*, who holds the Chair for Theoretical Biology and is the Director of the Institut für Neuroinformatik at the 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 close to 100 refereed journal articles and over 70 book chapters and refereed proceedings papers. 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 above).

Anne Schutte is an Assistant Professor at the Department of Psychology of the University of Nebraska-Lincoln. She obtained her PhD in Psychology from the University of Iowa with work on the development of spatial working memory. In her published work and her current research agenda she combines experimental and modeling approaches structured by the concepts of Dynamical Field Theory. Dr. Schutte has published 11 refereed journal papers and a book chapter. Dr. Schuttes work has been funded by the National Institutes of Health (NIMH and NICHD). She will lecture on case studies using DFT concepts to design, analyze and interpret experiments on the development of spatial working memory (number 3 above).

Sammy Perone is a doctoral candidate in developmental science at the University of Iowa working under the supervision of Dr. John Spencer. His dissertation uses Dynamic Neural Fields to examine the common mechanisms by which, in some task contexts, memory formation affects looking at stimuli that vary along metrically organized dimensions and, in other task contexts, how looking at such stimuli affects memory formation. Sammy has won numerous awards and fellowships at the University of Iowa, has published 5 journal articles on topics in infant cognition and Dynamical Systems Theory, and has published several conference proceedings and book chapters. Sammy will lecture on the use of DFT concepts to study infant cognitive development, as well as design and analyze experiments in the context of infant looking (number 4 above).

Schedule

1. Conceptual foundations of Dynamical Systems Thinking and Dynamical Field Theory (DFT): 30 minutes
2. Dynamical Systems 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 studies using DFT to understand basic cognitive and behavioral processes in infants 120 minutes

Suggested readings

(available online at: http://www.uiowa.edu/∼icdls/dft/dft-publications.html)

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

Johnson, J. S., Spencer, J., Luck, S., Schöner, G.: A Dynamic Neural Field Model of Visual Working Memory and Change Detection. *Psychological Science* **20**: 568-577 (2009)

Schöner, G.: Dynamical Systems Approaches to Cognition. In: The Cambridge Handbook of Computational Psychology, Ron Sun, (ed.), Cambridge University Press (2008), pages 101-126

Schöner, G. (2009): Development as Change of System Dynamics: Stability, Instabilty, and Emergence. In: *Toward a Unified Theory of Development: Connectionism and Dynamic Systems Theory Re-Considered*. J.P. Spencer, M. Thomas, & J. McClelland (Eds.), Oxford University Press, pages 25-47

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.

Spencer, J.P. & Perone, S. (2008). Defending qualitative change: The view from dynamical systems theory. *Child Development* **79**:1639-1647.

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

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