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

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Objectives and Scope

Dynamical Systems thinking has been influential in the ways psychologists, cognitive scientists, and neuroscientists think about cognition and development. Growing out of an initial emphasis on motor behavior, dynamic field theory (DFT) has applied the concept of dynamic activation fields to address fundamental questions relating to cognition. Over the last two decades, DFT has been applied to a range of domains from basic processes of visual working memory and the planning of eye movements, to more complex cognitive processes such as word learning and executive function. DFT provides important tools for linking cognition with sensori-motor processes, linking timescales from in-the-moment behavior to learning and development, and linking levels of analysis between neural and behavioral data.

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 and neuronal interaction, generating elementary forms of cognition through dynamical instabilities. DFT has served as a useful tool for not only interpreting and predicting quantitative aspects of behavior, but also interpreting and predicting quantitative aspects of neural activation data. In this way, DFT explains how neural dynamics give rise to cognition over multiple timescales. The concepts of DFT establish links between brain and behavior, helping to provide traction in the dialogue between experimental paradigms and theory development. Behavioral paradigms can be modeled with Dynamic Neural Fields, deriving testable predictions that can be tested against behavioral and neural data.

One obstacle for researchers wishing to use DFT has been that the foundational concepts of DFT are distinct from the standard way of thinking about cognition as comprised of static components. The computational foundations of DFT are also distinct from many traditional computational frameworks that are popular in the fields of cognitive and developmental sciences. Thus, 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 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. In this workshop, we will provide participants with the background needed to think about cognition and development from the perspective of DFT. Additionally, we will take participants through the process of building and simulating to provide the foundation to begin applying concepts from DFT to their own research.

Suggested Readings

(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 6] 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. Perone, S. & Ambrose, J. P. (2015). A process view of learning and development in an autonomous exploratory system [Chapter 11] 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. Buss, A. T., Wifall, T., & Hazeltine, E. (2015). The emergence of higher-level cognitive flexibility: Dynamic field theory and executive function [Chapter 13] 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.

Target Audience

This workshop will not require prior knowledge of the mathematics of programming language used to simulate dynamic systems models or neural networks. The mathematical and conceptual foundations of DFT will be provided during the tutorial. We expect this workshop to appeal to a wide range of individuals interested in computational approaches to cognition and neuroscience.

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 a 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 executive function in children and adults.
4. Case study using DFT to understand the integration of timescales from learning and development – 90 minutes: visual and spatial working memory in infants, children, and adults; spatial precision hypothesis as a developmental mechanism of 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

Aaron T. Buss is an Assistant Professor of Psychology at the University of Tennessee in Knoxville, TN. Prior to arriving at the University of Tennessee, he received a B.S. with Honors from North Central College (Naperville, IL) in 2007 and a Ph.D. in Psychology from University of Iowa in 2013. He is the recipient of the D. C. Spriestersbach Dissertation Award from the University of Iowa. His research examines the development of executive function, dimensional attention, and dimensional labels, with an emphasis on dynamical systems and neural network models of cognition and action. He will lecture on the topics 1-3 above.

Sammy Perone is an Assistant Professor of Human Development at Washington State University. He received his Ph.D. in Psychology from the University of Iowa and recently completed a NICHD postdoctoral fellowship at the Institute of Child Development at the University of Minnesota. He has used DFT to help understand experiential sources of developmental change in several domains, including infant memory, executive function, and word learning. He will lecture on topic 4 above.

Ajaz Bhat is a Senior Research Associate in Psychology Department at the University of East Anglia, UK. His received his PhD in Cognitive Robotics from the Italian Institute of Technology, Genova for his work on brain-inspired constructive semantic-episodic memories, reasoning, causal learning, spatial planning, motor control, skill learning and tool use in robots. His current work employs dynamical systems modelling to understand the developmental processes underlying language acquisition and the role of visual attention and working memory in word learning. Dr. Bhat 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, as well as related publications, lecture material, and interactive simulators can be found at http://www.dynamicfieldtheory.org/.