Dynamic Field Theory: Conceptual Foundations and Applications in Developmental Science

John P. Spencer (j.spencer@uea.ac.uk)
School of Psychology, University of East Anglia, Norwich NR4 7TJ, United Kingdom

Larissa K. Samuelson (l.samuelson@uea.ac.uk)
School of Psychology, University of East Anglia, Norwich NR4 7TJ, United Kingdom

Iliyana Trifonova (iliyana.v.trifonova@gmail.com)
School of Psychology, University of East Anglia, Norwich NR4 7TJ, United Kingdom

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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 and developmental 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, python, and CEDAR. 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 published book on DF 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. & the DFT Research Group (2016). *Dynamic Thinking: A Primer on Dynamic Field Theory*. New York: Oxford University Press.
2. Bhat, A., Spencer, J.P. & Samuelson, L.K. (2021). Word-Object Learning via Visual Exploration in Space (WOLVES): A Neural Process Model of Cross-Situational Word Learning. *Psychological Review,* https://doi.org/10.1037/rev0000313.
3. Spencer, J. P. (2020). The development of working memory. *Current Directions in Psychological Science*, doi/10.1177/0963721420959835.

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 and development 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; categorial vs. graded mode of operation.
3. Hands-on introduction – 60 minutes: practical implementation of DFT in simulators; interactive simulation using CEDAR 'drag-and-drop' model building; introduction to COSIVINA framework for simulations in MATLAB and PYTHON.
4. Case study using DFT to understand visual working memory and its development – 90 minutes: visual and spatial working memory in infants, children, and adults; spatial precision hypothesis as a developmental mechanism supporting visuospatial cognition; scaling up WM architectures to include attention, change detection, and binding of object features.
5. Case study using DFT to understand early word learning – 90 minutes: cross-situational word learning as an exemplary case; using and implementing large-scale neural architectures; WOLVES model and simulation of adult and developmental data.

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 be the primary lecturer.

Larissa K. Samuelson is a Professor of Psychology at the University of East Anglia in Norwich, UK. Dr. Samuelson received a BS with honors from Indiana University in 1993 and a joint Ph.D. in Psychology and Cognitive Science from Indiana University in 2000. From 2000-2015 she was in the Psychology Department at the University of Iowa. She is the recipient of the J.R. Kantor Graduate Award, and in 2010, she received the American Psychological Association Distinguished Scientific Award for Early Career Contribution to Psychology in the area of developmental psychology. Her research examines processes of cognitive development with a focus on early word and category learning and incorporates neural network and dynamic neural field models. She has had continuous funding from the National Institutes of Health since 2004. She is an affiliate of the DeLTA Center at the University of Iowa.

Iliyana V. Trifonova is a Senior Research Associate at the University of East Anglia in Norwich, UK. Dr. Trifonova has Bachelor's degrees in Psychology and English Philology (Veliko Turnovo University) and Master's degrees in both Cognitive Science (New Bulgarian University) and Human Resource Management (Sofia University). She received a Ph.D. in Psychology from the University of Warwick, UK. She was awarded an Early Career Fellowship from the Institute of Advanced Study, University of Warwick. Before joining the School of Psychology at the University of East Anglia, Dr. Trifonova worked as a postdoctoral Research Associate at the University of York. Her research interests include dynamic field theory, computational modelling, visual word recognition, and face recognition.

Computer Use

Participants who bring laptops with python or MATLAB installed (student version is sufficient) will be able to follow demonstrations by actively working with the COSIVINA simulator during lectures. We will also use the CEDAR platform which can be downloaded and installed during the workshop.

Online Resources

Publications, lecture material, and interactive simulators can be found at our DFT website:

http://www.dynamicfieldtheory.org/