# Building neural processing accounts of higher cognition in Dynamic Field Theory

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## Significance of the topic

Dynamic Field Theory (DFT) has now been around now for a good while (Schöner, Spencer, & DFT Research Group, 2016). Formalizing the earlier dynamical systems metaphor, it has been used as a theoretical framework to understand a broad range of sensory-motor behaviors and elementary cognitive processes like metric working memory (Johnson & Spencer, 2016), change detection (Johnson, Spencer, Luck, & Schöner, 2009), cognitive control (Buss & Spencer, 2014), and movement generation (Knips, Zibner, Reimann, & Schöner, 2017).

Dynamic Field Theory postulates that neural populations provide a privileged level of description at which the link between neural and mental or behavioral processes is closest (Schöner, 2019). The forward connectivity between neural populations and the sensory or motor surfaces as assessed in tuning curves constitutes the low-dimensional spaces that are spanned by neural fields, which are thus tightly coupled to sensory-motor processes. On the other hand, activation may be generated entirely within neural fields by regular patterns of intra-field connectivity that make localized peaks of activation attractor states of the implied neural dynamics. This is due to the generic form of connectivity within populations in which neurons tuned to similar feature values are excitatorily coupled, while neurons tuned to dissimilar feature values are inhibitorily coupled. Detection and selection decisions are stabilized by such interactions as is working memory. Active generation of time courses of activation by such neural dynamics are the basis for sequence and movement generation.

Neural fields are essentially strongly recurrent neural networks tuned to low-dimensional features spaces. The emphasis of DFT is on the autonomy of neural processing, in which no "read-out" or other interface with non-neural processing are invoked to generate funtion, ultimately demonstrable on an embodied cognitive agent. A challenge is to understand the autonomous generation of sequences of thoughts or actions characteristic of higher cognition within this framework. Recent work has established first footholds on this road. The perceptual grounding of spatial and movement relations has been demonstrated to emerge from DFT architectures (Richter, Lins, & Schöner, 2017; Lins & Schöner, 2019; Sabinasz, Richter, Lins, Richter, & Schöner, 2020). Mental map formation (Kounatidou, Richter, & Schöner, 2018), learning serial order from demonstration (Tekülve, Fois, Sandamirskaya, & Schöner, 2019), visual search and the autonomous building of scene memory (Grieben et al., 2020), and generating intentional states in an autonomous agent (Tekülve & Schöner, 2019) are other examples.

## Goal of the tutorial

In the tutorial, cognitive scientists will acquire the fundamental concepts of DFT. Advanced topics in DFT including higher-dimensional fields, coupling fields into architectures, and sequence generation will lead to an understanding of how DFT approaches higher cognition. We will facilitate the transition for participants to build their own models in this framework building on the software framework *cedar*.

## Structure and activities in the tutorial

*We will adapt the tutorial format to the virtual nature of CogSci 2020.* Tutorial lectures (40 minute videostreams followed by 15 minute discussion) will introduce the foundational concepts of DFT. Case studies (ca 20 minutes with shorter discussion) will exemplify the use of these concepts to model elements of higher cognition from visual search and sequence generation to the perceptual grounding of relational concepts and cognitive control. Interactive simulators (available at `dynamicfieldtheory.org/cosivina`) will be used to illustrate ideas. Models built in *cedar*, an open source graphical programming framework, available pre-compiled for most operating systems at `cedar.ini.rub.de`), will be demonstrated. Code for all models will be available to participants for their own experimentation. As the virtual format makes "live" hands-on sessions impractical, we will offer individual support to participants upon request outside the CogSci sesssion (see also `dynamicfieldtheory.org`).

1. Tutorial: Foundational concepts of DFT [Gregor Schöner]

2. Case study: A DFT model of motor habituation [Sophie Aerdker]
3. Tutorial: Advanced concepts of DFT: cued selection, binding, coordinate transforms [Gregor Schöner]
4. Case study: Visual search [Raul Grieben]
5. Tutorial: Sequence generation [Jan Tekülve]
6. Case study: Introduction to *cedar* [Mathis Richter, Raul Grieben]
7. Tutorial: Grounding of relational concepts [Mathis Richter, Daniel Sabinasz]
8. Tutorial: Cognitive control [Aaron Buss]
9. Discussion and outlook [All]

## Tutorial organizers and lecturers

**Gregor Schöner** will lecture on the foundations of DFT and its advanced features. He is the Director of the Institute for Neural Computation (INI) at the Ruhr-University Bochum in Germany and holds the chair for Theory of Cognitive Systems there. For the last 30 years, Gregor Schöner has brought to bear his background in theoretical physics on disciplines as varied as movement science, visual psychophysics, cognitive science, neuroscience, cognitive robotics, and computer vision. He contributed scientficially to the dynamical systems account for movement coordination, the concept of the uncontrolled manifold, the counter-change model of motion detection, and the attractor dynamics approach to motion planning. He is one of the originators of Dynamic Field Theory and established its neural grounding through Distributions of Population Activation working with neuroscientists. He has held academic positions in the US, France, and Germany, and has published over 250 scientific articles.

**Aaron Buss** will lecture on using DFT to understand cognitive control and its development. He is an Assistant Professor of Psychology at The University of Tennessee, Knoxville. He received a B.S. from North Central College in 2007 and Ph.D. in Psychology from The University of Iowa in 2013. He is recipient of the D. C. Spriestersbach Dissertation Award from the University of Iowa. His research examines executive function and brain-behavior relationship across the lifespan. He is also trail-blazing the analysis of neural imaging data based on neural dynamic models. His research is funded by NIH (R01HD092485).

**Mathis Richter** is one of the architects of *cedar* and wrote his doctoral dissertation on a DFT account for the grounding of relational concepts. He is currently a postdoc at the INI working on using DFT in neuromorphic systems.

**Sophie Aerdker**, **Raul Grieben**, **Daniel Sabinasz**, and **Jan Tekülve** are doctoral students at the INI and will provide case studies and tutorials based on their ongoing dissertation research in extending the reach of DFT toward higher cognition.

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