Teaching and learning guide for: Dynamical systems theory in cognitive science and neuroscience

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1 | INTRODUCTION

Cognitive science is commonly viewed as having a widely accepted set of commitments (e.g., cognition as information processing). Although neuroscience research can be understood as focused more on ‘hardware’ implementation (e.g., neurons), it is fair to view subfields such as the cognitive and computational neurosciences as sharing many of the same commitments as cognitive science. Starting in the 1990s, philosophers of cognitive science and mind began calling these core assumptions into question via appeal to dynamical systems theory (DST). DST is a branch of mathematics that assesses systems that change over time. The concepts and methods of DST provide a rich alternative framework for investigating and explaining cognition (e.g., continuous and not discrete). This approach underlies the ‘dynamical hypothesis’, specifically, the claims that cognition is and can be understood as dynamical systems. For the past 20 years, cognitive science and neuroscience have seen increased applications of DST to investigations ranging from physiologically fundamental single-neuron activity and neuronal networks to behaviorally complex decision making and sensorimotor coordination. This work raises many topics of philosophical significance across areas such as philosophy of cognitive science (e.g., representations), philosophy of mind (e.g., boundaries of cognition), and philosophy of science (e.g., explanation).

2 | AUTHOR RECOMMENDS

2.1 | Classics

Kelso, J. A. S. (1995). Dynamic patterns: The self-organization of brain and behavior. Cambridge, MA: The MIT Press. This book synthesizes Kelso's pioneering work applying dynamical systems theory to various forms of behavior and cognition. The central claim is that the structure and function of brain and behavior are the result of self-organization via coordination dynamics. It is a paradigmatic example of the mutual development and application of theory and experiment.

This collection presents applications of dynamical systems theory across various sciences, such as artificial life, cognitive science, and linguistics. In doing so, it demonstrates the central role time plays in phenomena such as attention, decision making, neural activity, and perception-action.


This book synthesizes the authors' research on cognition and action in order to present a comprehensive account of human development centered on dynamical systems theory.


This book provides an overview of the various ways dynamical systems theory can be applied in cognitive science. It is a bit more mathematically technical than the others, but remains accessible. This work is particularly noteworthy for its discussion of the pervasiveness of fractal structure—that is, $1/f$ noise, also known as $1/f$ scaling or pink noise—in cognitive phenomena, which would come to play a larger role in the cognitive sciences and neurosciences of later years.


Central to debates concerning dynamical systems theory in cognitive science and philosophy of cognitive science are van Gelder’s seminal papers. His 1995 paper (cited below) set the terms of the debate in philosophy. His 1998 target article paper gained a broader audience and allowed for various perspectives on the issues to be presented and debated.

2.2 | Contemporary


In this article, Chemero and Silberstein present an excellent overview of central philosophical and theoretical issues in the cognitive and neural sciences, many of which concern dynamical systems theory. In particular, issues concerning the dynamic nature of cognitive and neural systems and the kind of explanatory style that results from appealing to dynamical systems theory.


This journal special issue includes articles demonstrating cutting-edge applications of dynamical systems theory in investigations of cognitive systems. Topics include big data approaches, complex adaptive systems, decision making, neural networks, nonlinear methods (e.g., fractal analysis), social dynamics, and team cognition.


In this article, Kaplan and Craver provide forceful arguments against the claim that dynamical systems theory alone can provide explanations in neuroscience. To be explanatory, dynamical accounts—like other mathematical approaches—must fulfill a model-to-mechanism-mapping constraint.

In this article, Ross pushes back against Kaplan and Craver’s claims by discussing the ways mathematical models provide explanations in dynamical systems neuroscience. Ross discusses Izhikevich’s pioneering work on dynamical models of single-neuron activity to demonstrate how such dynamical approaches are explanatory in their own right. This is accomplished in part by appealing to Batterman’s account of minimal model explanations.


This book presents an account of cognition-action-perception as continuous forms of mental activity. In addition to applying dynamical systems in his own research, Spivey demonstrates how numerous other behavioral and neurophysiological studies display continuous temporal dynamics across phenomena such as attention, language comprehension, and visual perception. This book is especially noteworthy for its incorporation of representations in a dynamical systems theory approach, which are typically treated as antithetical in the relevant literatures.

### 2.3 Online materials

**PhilPapers: Subcategory: Dynamical Systems**: https://philpapers.org/browse/dynamical-systems

This is an excellent resource for papers on numerous relevant topics from various disciplines (e.g., cognitive science and philosophy). There are also links to other categories of interest, such as Connectionism and Neural Networks, Cybernetics, and Neurophilosophy.

**Scholarpedia: Dynamical Systems**: http://www.scholarpedia.org/article/Dynamical_systems

A short introduction to dynamical systems, as well as links to other relevant Scholarpedia articles on topics such as attractors, bifurcations, and partial differential equations.

**Society for Chaos Theory in Psychology and Life Sciences: Resources for Professionals and Students**: https://www.societyforchaostheory.org/resources/

This website provides resources about dynamical systems theory, including definitions of key concepts, and links to articles, software, and videos.

**Nonlinear Dynamics and Chaos: Steven Strogatz, Cornell University**: https://www.youtube.com/playlist?list=PLbN57C5Zdl6j_qJApARjnKsmROzPnO9V


**Dynamical Systems Magazine**: https://dsweb.siam.org

This online magazine from the Society for Industrial and Applied Mathematics includes articles about dynamical systems theory and its application in various fields, book reviews, information on conferences and workshops, and links to software and training.

### 2.4 Sample syllabus

Dynamical systems theory can be included in various philosophy courses, such as Philosophy of Mind and Philosophy of Science. The following provides an example of where dynamical systems theory could be placed in a Philosophy of Cognitive Science course.
2.4.1 | Part I. Introduction and traditional cognitive science

Weeks 1 through #
Topics: During the first half of the course, students could be introduced to the history of cognitive science and what many view to be its central theoretical and methodological commitments. Topics include the cognitive revolution, computational and representational approaches to investigating and explaining cognition, and artificial intelligence.

Readings:

2.4.2 | Part II. Alternative investigative and explanatory frameworks

Topics: During the second half of the course, students can be introduced to alternative approaches to investigating and explaining cognition. Connectionism is typically the first alternative to be discussed. Other approaches that can be covered in this part of the course include ecological psychology, embodied cognition, and enactivism. Dynamical systems theory can be suitably placed between connectionism and those other approaches.

Topic: Dynamical systems theory.

Week 1: Introduction to dynamical systems theory in cognitive science
Readings:

Week 2: Critiques of dynamical systems approach and responses
Readings:
3 | FOCUS QUESTIONS

1. What kind of explanation(s) does a dynamical approach provide (e.g., covering law, mechanistic, its own unique type, etc.)?
2. Is a dynamical systems approach necessarily antithetical to traditional commitments in cognitive science, such as computational and representational conceptions of cognition?
3. When applied to cognitive science and neuroscience, does dynamical systems theory give reasons to question the boundaries of cognition (i.e., cognition as located in brains, embodied, extended, etc.)?
4. Are dynamical systems approaches commensurable with reductionist or antireductionist approaches to investigating cognition?
5. Do dynamical systems approaches provide reasons to support claims of emergent phenomena in cognitive science and/or neuroscience?

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