Introduction to Dynamic Systems in Cognition

Cognitive Science Q580

Spring 2012

Instructor: James T. Townsend

Volunteer: Dynamic Systems Graders: Devin Burns

Course Texts:

1. Elementary Differential Equations and Boundary Value Problems by Boyce & DiPrima; Wiley, 2005. Required. **NOTE**: Newest revision not necessary.
2. Mathematics for Dynamic Modeling by Beltrami; Academic Press, 1998.
3. Dynamical Systems with Applications Using Maple by Lynch; Birkhauser; Boston Press, 2000, or comparable software. Recommended.

General Recommended Reading: 1. Mind as Motion: Explorations in the Dynamics of Cognition, R. F. Port and T. van Gelder (Eds.), MIT Press, 1995. 2. Dynamical Cognitive Science, L. Ward, MIT Press, 2002. 3. Nonlinear Dynamics: Techniques and Applications in Psychology, R.A. Heath, Erlbaum, 2001.

Other Extra Readings: Given specifically below.

Ancillary Material: *Applications and Examples: Are signified by A & E.*

Course Philosophy: My philosophy in this course is to give participants a solid introduction to dynamic systems. Given the massive size of the field and the limited time, we have to carefully select the topics to cover. Because I believe that the student cannot really comprehend nonlinear systems without a pretty thorough understanding of linear systems, that is where we start: first order, 1-dimensional, homogeneous, continuous time, linear systems. As the former indicates, we focus on continuous time systems. If one understands these, it is relatively easy to learn discrete time systems, but the converse is not so true. The other terms will be defined throughout the course. In fact, we very early categorize the various types of dynamic systems, particularly within the realm of differential equations, but as time goes on, a brief introduction to the concept of topological dynamics (not constrained to differential equations) is offered. Unfortunately, we will not likely have time to peruse stochastic dynamic systems, despite their considerable importance. Perhaps sometime we can offer a course specifically devoted to that topic, given sufficient interest. In any case, after some work with homogeneous and non-homogeneous, n-dimensional, time variable and time invariant, linear systems, we go on to autonomous nonlinear systems, emphasizing at first 2-dimensional systems. From here, we take up more general nonlinear systems and learn about Lyapunov's two methods and various kinds of stability (generalized, naturally to nonlinear systems). We also study catastrophe theory (a subset of bifurcation theory). Finally, a brief introduction to chaos theory is given. Here we violate the 'continuous time' policy and scrutinize nonlinear difference equations that can produce chaos. Because the abstract math is usually much harder than reading applications, the lectures emphasize the former. However, a few examples of use in psychology and cognition will be discussed.

Course Duties: Weekly homework plus a paper applying dynamic systems to a topic in cognitive science. The employment of some kind of software for examples and some homework problems will be indispensable. There are many of these now available, from the simple PHASER to the powerful MATLAB or again, the routines associated with Maple and Stephen Lynch's book.

Outline (Giving the order, but not the durations of occupation with a topic). Readings will be indicated by initials of the authors, B&DP, or B, along with chapter and/or page numbers. I will typically indicate chapters rather than specific sections or pages. The specific topics should be obvious. The match with lectures will not be perfect, since I put together what I consider to be the most important panoply of topics from many sources, but it should help a great deal. The symbol # will denote readings. :

I. First order, linear, homogeneous differential equations and extension to the non-homogeneous variety along with interpretation. Taxonomy of dynamic systems. General first order, ordinary differential equations and proof of existence of solutions. Inputs, state transition operators and convolution integrals. # B&D, Chapters 1, 2.

A&E: 1. Busey, T. A., & Loftus, G. R. Sensory and cognitive components of visual information acquisition by *Psychological Review*, 1994, 446-469.

2. *The Mathematics of Marriage* by Gottman et al. (2002). Bradford/MIT.

3. McClelland, J. L. On the time relations of mental processes: An examination of systems in cascade. *Psychological Review, 86,* 1979, 287-330.

II. Second order, linear differential equations and interpretation in terms of mechanics, electrical, and hypothetical cognitive situations. Higher order systems. Certain methods of solution. More on state transitions and convolutions. Transforming n-dimensional systems to an n-th order, 1-dimensional system and vice versa. #B&D, Chapters 3, 4, 7.

A&E: 1. An Introduction to Neural Networks by J. A. Anderson, chapter 6.

2. Approach-Avoidance: Return to dynamic Decision Behavior (1989) by J. T. Townsend and J. Busemeyer in Current Issues in Cognitive processes by C. Izawa (Ed.). Read up to page 121.

3. Usher, M., & McClelland, J. L. (2001). The time course of perceptual choice: The leaky accumulator model by *Psychological Review, 108, 550-592.*

III. Laplace transform, Fourier transform and brief introduction to feedback control systems. # B&D, Chapter 6.

1. Read in *Control Theory for Humans* by R. Jagacinski & J. M. Flach (2003). Erlbaum

IV. Introduction to non-linear dynamic systems, Lyapunov's two methods and stability in general systems. Classical examples of these. # B&D, Chapter 9; B, Chapters 1, 2 (these former are primarily review), 3 (new stuff).

A&E: 1. Nonlinear Neural Networks: Principles, Mechanisms, and Architecture (1988) by S. Grossberg in Neural Networks.

2. Approach-Avoidance: Return to dynamic Decision Behavior by Townsend &

Busemeyer; Chapter in Current Issues in Cognitive Processes, C. Izawa (Ed.); Erlbaum, 1989.

V. Limit cycles, bifurcation, gradient systems, catastrophe theory and topological dynamics. # B&D, Chapter 9.7; B, Chapters 6,7.

A&E:

1. *Space-Time Behavior of Single and Bimanual Rhythmical Movements: Data and Limit Cycle Model (1987) by B. A. Kay, J. A. S. Kelso, E. L. Saltzman and G. Schöner in Journal of Experimental Psychology: Human Perception and Performance.*

2. *Introduction to topological dynamics by R. S. Sibirsky. Leyden: Noordhoff, 1975.*

VI. A brief introduction to chaos theory. # B, Chapter 8.

A&E:

1. *Chaos Theory: A Brief tutorial and Discussion by Townsend; Chapter in From Learning Theory to Connectionist Theory, Healy, Kosslyn & Shiffrin (Eds.); Erlbaum*, 1992.

2. Notes from first chapters in *Chaotic Dynamical Systems, Delaney, Benjamin/Cummings Publ. Co., 1986 or later version.*