

CEE 627
MATHEMATICAL PRINCIPLES OF ENVIRONMENTAL SYSTEMS

Instructor: James Uber, 780 ERC, 556-3643, jim.uber@uc.edu

Office Hours: MWF, 1-3PM, or other times as our schedules permit

Course Objectives:

This is an introductory course covering the core concepts in linear and nonlinear dynamic systems, using a few applications that illustrate these concepts and are relevant to environmental engineering and science, such as: population (Predator/Prey) models, algae blooms, river dissolved oxygen depletion, percolation, nonlinear chemical reaction kinetics, biological growth dynamics, fisheries market dynamics, inter-urban migration, etc. Most of the models to be developed and investigated are expressed as systems of differential equations. The analytical solution to linear models is reviewed, while the solutions to nonlinear models are investigated via computer simulation using the Simulink software that is part of Matlab. Emphasis is placed on understanding the characteristics of the solutions, both through graphical (visual) analysis and analytical techniques. Nondimensionalization of models is stressed as a way to generalize results and understand solution behavior. Concepts and techniques relevant to solution stability, or solution behavior under perturbations, are a core concept to be studied, including the classical linearization techniques and linear stability analysis.

“Models are, for the most part, caricatures of reality, but if they are good, then, like good caricatures, they portray, though perhaps in distorted manner, some of the features of the real world.”

M. Kac, *Science*, 166, p. 695, 1969.

Prerequisites:

- multivariable calculus and separable ordinary differential equations.
- some computer programming could be helpful, either by class or by experience (either fortran or C or C++ or Matlab). We will be using the MATLAB software available on the college workstations and PC labs. Matlab manuals are generally well written, and are available from the college of engineering computing office home page.

Text:

The following text is used as a reference for some of the techniques and models discussed:

Steven H. Strogatz, *Nonlinear Dynamics and Chaos, With Applications to Physics, Biology, Chemistry, and Engineering*, Addison-Wesley, 1994.

Electronic Reserves

Reserve materials, some class notes, and homework sets will be available via the www at <http://www.cee.uc.edu/~juber/courses/cee627/cee627.htm>

Grading Policy:

Midterm Exam, (1.5 hour)	35%
Final Exam (2 hours)	35%
Homework MATLAB)	30% (these are either analytical or programming problems using

Course Topics:

Dynamic Systems

- Linear dynamic systems
- The geometry of solutions
- Basic Matlab programming
- Introduction to modeling using Simulink
- 1-D Fixed-points and stability
- 1-D Linear stability analysis
- Linear systems - analytical solutions
- Phase plane analysis/Linearization/Stability
- Application to model and analyze microbial growth dynamics

Parameter Estimation / Model Calibration

- Numerical methods for linear and nonlinear least squares estimation
- Interpretation of the parameter estimates

Space-Time Dynamic Systems (Partial Differential Equations)

1-D Advective-Dispersive equation
Numerical solution techniques
Numerical dispersion

Other Ways to Model Dynamic Systems

Cellular Automata
Application to sorting and mixing of populations, perhaps others as time permits

Some Reference Books for

Numerical Methods in Science and Engineering, and Dynamical Systems

David Kahaner, Cleve Moler, and Stephen Nash, *Numerical Methods and Software*, Prentice Hall, Englewood Cliffs, NJ, U.S.A., 1989. Useful applied approach including quality software.

Thomas Coleman and Charles Van Loan, *Handbook for Matrix Computations*, Frontiers in Applied Mathematics Series, Society for Industrial and Applied Mathematics, Philadelphia, PA, U.S.A., 1988. Good practical text that contains a high level review of fortran, plus modern methods of computation using matrices. It is recommended if you like numerical methods and want to learn more about it.

Golub and Van Loan, *Matrix Computations*, Johns Hopkins University Press, Baltimore, MD, 1983 (more recent addition available). Definitive text on linear algebra computations.

Lapidus and Pinder, *Numerical Solution of Partial Differential Equations in Science and Engineering*, John Wiley, 1982. A thorough reference text on many, many algorithms for solving p.d.e.'s

Davies, *The Finite Element Method: A First Approach*, Oxford, 1980. Good beginning text for finite elements.

Smith, *Numerical Solution of Partial Differential Equations: Finite Difference Methods*, Oxford, 1978. Readable and thorough on traditional topics.

Luenberger, *Introduction to Dynamic Systems*, John Wiley, 1979. Not really a numerical methods book, but a good, readable introduction to analysis of dynamic systems.

Peitgen, Jurgens, and Saupe, *Chaos and Fractals: New Frontiers of Science*, Springer-Verlag, 1992.

Partial Listing of Related Courses In the College of Engineering and Department of Mathematical Sciences

15-025-514

15-025-515

15-025-516 Numerical Analysis I, II, and III.

Taught, naturally, from a more fundamental mathematical perspective, but still applied. You *can* get graduate credit for these courses, as 500 level courses in the College of Arts and Sciences are considered graduate level. Talk to Professor Donald French about current offerings. Good reputation for French's courses.

15-025-561 Numerical Methods in Applied Mathematics.

Same as above.

20-251-780

20-251-781 Numerical Methods in Fluid Mechanics I and II.

Talk to Professor U. Ghia for admission requirements. Good reputation for Ghia's courses.

20-025-376 Applied Mathematics for Engineers

Fourier series, other methods for analytical solution of differential equations in engineering. No numerical methods, but would ideally be a good prerequisite for our course.

20-257-730 Environmental and Hydrologic Systems Analysis

Optimization methods for design and analysis of environmental and hydrologic systems. Significant applications to groundwater remediation design and water distribution systems. Talk to me for further info.

A variety of courses in Electrical and Computer Engineering:

20-260-716 Random Processes and Stochastic Models

20-260-733 Foundations of Applied Systems

20-260-745 Linear Systems

20-260-826 Recurrent Neural Networks
20-260-827 Feedforward Neural Networks
20-260-850 Biological Neural Systems
20-260-854 Complex Systems
20-260-855 Nonlinear Systems
20-260-872 Nonlinear Dynamics in Medicine and Biology
20-256-956 Nonlinear and Self-Organizing Systems

A variety of courses in Chemical Engineering

20-254-780 Process Simulation
20-254-841/842 Process Dynamics and Control