

## COMPLEX SYSTEMS AND DATA SCIENCE

<https://www.uvm.edu/cems> (<https://www.uvm.edu/cems/>)

### OVERVIEW

The College of Engineering and Mathematical Sciences provides an educational program in Complex Systems and Data Science (CSDS) that includes education offerings at three levels:

1. A 5 course Graduate Certificate in Complex Systems that may be taken by any graduate student at UVM to augment their degree.
2. An MS in CSDS which is a 2-year degree with optional disciplinary tracks, and which UVM undergraduates may initiate through an Accelerated Master's Program.
3. A PhD in CSDS which will allow students to fully develop a deep portfolio of published research, thereby opening the door to high level research positions in, for example, government, industry, or academia.

The educational program naturally complements UVM's undergraduate degree in Data Science but also thematically connects with many fields across the university.

The program's overall goal is to help students become protean data scientists with eminently transferable skills. Students are provided with a broad training in computational and theoretical techniques for (1) describing and understanding complex natural and sociotechnical systems, enabling them to then, as possible, (2) predict, control, manage, and create such systems. Students will be trained in: Industry standard methods of data acquisition, storage, manipulation, and curation; visualization techniques, with a focus on building high quality web-based applications; finding complex patterns and correlations through, for example, machine learning and data mining; powerful ways of hypothesizing, searching for, and extracting explanatory, mechanistic stories underlying complex systems—not just how to use black box techniques; combining the formulation of mechanistic models (e.g., toy physics models) with genetic programming.

### DEGREES

Complex Systems and Data Science AMP (<http://catalogue.uvm.edu/graduate/complexsystemsdatascience/complexsystemsdatascienceamp/>)

Complex Systems and Data Science CGS (<http://catalogue.uvm.edu/graduate/complexsystemsdatascience/complexsystemsdatasciencecgs/>)

Complex Systems and Data Science M.S. (<http://catalogue.uvm.edu/graduate/complexsystemsdatascience/complexsystemsdatasciencecems/>)

Complex Systems and Data Science Ph.D. (<http://catalogue.uvm.edu/graduate/complexsystemsdatascience/complexsystemsdatasciencephd/>)

### FACULTY

**Allgaier, Nicholas;** Assistant Professor, Department of Psychiatry; Ph.D., University of Vermont

**Bagrow, James;** Associate Professor, Department of Mathematics and Statistics; PHD, Clarkson University

**Bongard, Joshua C.;** Professor, Department of Computer Science; PHD, University of Zurich

**Danforth, Chris;** Professor, Department of Mathematics and Statistics; PHD, University of Maryland College Park

**Dodds, Peter Sheridan;** Professor, Department of Computer Science; PHD, Massachusetts Institute of Technology

**Galford, Gillian Laura;** Research Assistant Professor, Rubenstein School of Environment and Natural Resources; PHD, Brown University

**Garavan, Hugh P.;** Professor, Department of Psychiatry; PHD, Bowling Green State University

**Hébert-Dufresne, Laurent;** Assistant Professor, Department of Computer Science; PHD, Université Laval, Québec, Canada

**Mahoney, John Matthew;** Assistant Professor, Department of Neurological Sciences; PHD, Dartmouth College

**Niles, Meredith;** Assistant Professor, Department of Nutrition and Food Sciences; PHD, University of California-Davis

**Pespeni, Melissa H.;** Assistant Professor, Department of Biology; PHD, Stanford University

**Price, Matthew;** Associate Professor, Department of Psychological Science; PHD, Georgia State University

**Ricketts, Taylor H.;** Professor, Rubenstein School of Environment and Natural Resources; PHD, Stanford University

**Young, Jean-Gabriel;** Research Assistant Professor, Department of Computer Science, PHD, Université Laval

### Courses

#### CSYS 266. QR: Chaos, Fractals & Dynamical Syst. 3 Credits.

Discrete and continuous dynamical systems, Julia sets, the Mandelbrot set, period doubling, renormalization, Henon map, phase plane analysis, and Lorenz equations. Prerequisite: MATH 122 or MATH 124. CS 020 or CS 021 recommended. Cross-listed with: MATH 266.

#### CSYS 287. QR: Data Science I. 3 Credits.

Data harvesting, cleaning, and summarizing. Working with non-traditional, non-numeric data (social network, natural language textual data, etc.). Scientific visualization using static and interactive "infographics". A practical focus on real datasets, and developing good habits for rigorous and reproducible computational science. Project-based. Prerequisites: CS 020 or CS 021; STAT 141 or STAT 143 or STAT 211; CS 110 and MATH 122/124 recommended. Cross-listed with: CS 287, STAT 287.

**CSYS 300. Principles of Complex Systems. 3 Credits.**

Introduction to fundamental concepts of complex systems. Topics include: emergence, scaling phenomena and mechanisms, multi-scale systems, failure, robustness, collective social phenomena, complex networks. Students from all disciplines welcomed. Pre/co-requisites: calculus and statistics required; Linear algebra, differential equations, and computer programming recommended but not required. Cross-listed with: MATH 300.

**CSYS 302. Modeling Complex Systems. 3 Credits.**

Integrative breadth-first introduction to computational methods for modeling complex systems; numerical methods, cellular automata, agent-based computing, game theory, genetic algorithms, artificial neural networks, and complex networks. Semester team-based project. Prerequisite: Graduate standing. Pre/Co-requisites: Computer programming in any language; calculus. Linear algebra recommended. Cross-listed with: CS 302.

**CSYS 303. Complex Networks. 3 Credits.**

Detailed exploration of distribution, transportation, small-world, scale-free, social, biological, organizational networks; generative mechanisms; measurement and statistics of network properties; network dynamics; contagion processes. Students from all disciplines welcomed. Pre/co-requisites: MATH 301/CSYS 301, calculus, and statistics required. Cross-listed with: MATH 303.

**CSYS 352. Evolutionary Computation. 3 Credits.**

Theory and practice of biologically-inspired search strategies including genetic algorithms, genetic programming, and evolution strategies. Applications include optimization, parameter estimation, and model identification. Significant project. Students from multiple disciplines encouraged. Pre/co-requisites: Familiarity with programming, probability, and statistics. Cross-listed with: CS 352.

**CSYS 354. Deep Learning. 3 Credits.**

Introduction to Deep Learning algorithms and applications, including basic neural networks, convolutional neural networks, recurrent neural networks, deep unsupervised learning, generative adversarial networks and deep reinforcement learning. Includes a semester team-based project. Prerequisite: CS 254. Cross-listed with: CS 354.

**CSYS 369. Applied Geostatistics. 3 Credits.**

Introduction to the theory of regionalized variables, geostatistics (kriging techniques): special topics in multivariate analysis; Applications to real data subject to spatial variation are emphasized. Prerequisites: STAT 223; CS 020 or CS 021; or Instructor permission. Cross-listed with: CE 369, STAT 369.

**CSYS 387. Data Science II. 3 Credits.**

Advanced data analysis, collection, and filtering; statistical modeling, monte carlo statistical methods, and in particular Bayesian data analysis, including necessary probabilistic background material; a practical focus on real datasets and developing good habits for rigorous and reproducible computational science. Prerequisite: STAT 287 or CS 287 or CSYS 287 or Instructor permission. Cross-listed with: CS 387, STAT 387.

**CSYS 390. Internship. 1-18 Credits.**

On-site supervised work experience combined with a structured academic learning plan directed by a faculty member or a faculty-staff team in which a faculty member is the instructor of record, for which academic credit is awarded. Offered at department discretion.

**CSYS 391. Master's Thesis Research. 1-9 Credits.**

Masters thesis research under the supervision of a graduate faculty member. Prerequisite: Instructor permission.

**CSYS 392. Master's Project. 1-6 Credits.**

Masters Project under the supervision of a graduate faculty member. Prerequisite: Instructor permission.

**CSYS 393. Independent Study. 1-18 Credits.**

A course which is tailored to fit the interests of a specific student, which occurs outside the traditional classroom/laboratory setting under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

**CSYS 394. Independent Graduate Research. 1-18 Credits.**

Graduate student work on individual or small team research projects under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

**CSYS 395. Advanced Special Topics. 1-18 Credits.**

See Schedule of Courses for specific titles.

**CSYS 491. Doctoral Dissertation Research. 1-18 Credits.****CSYS 494. Independent Graduate Research. 1-18 Credits.**

Graduate student work on individual or small team research projects under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

**CSYS 496. Advanced Special Topics. 1-18 Credits.**

See Schedule of Courses for specific titles.