CEE556: Hydrocomplexity (4 Credit Hours)

Evaluation

Assignments	Weight
Assignments	50%
Class Participation	5%
Class Project [individual, or groups up to 3]	45%

Project outline
Presentation: Mid March [10%]

Final submission of a publication style draft paper, with presentation day of the scheduled final exam [35%]

Application of complex system science to water cycle and related processes in the atmosphere, ecosystems, critical zone and human systems. The course covers analytical and data driven approaches for characterization and understanding of nonlinear systems, feedbacks and causality, chaos and fractals, complex network science, and emergent behavior. The course emphasizes emerging research frontiers along with traditional foundations through analytical understanding of nonlinear dynamical systems, and their identification and characterization from observations.

Learning Outcomes/Objectives:
- Develop understanding of nonlinear systems and properties of complex systems
- Develop ability to distinguish chaotic systems from other nonlinear behaviors
- Develop an exposure to frontier topics in complex system studies pertaining to ecohydrologic, hydroclimatic and related systems

Topics Covered
- Nonlinear systems analysis
- Chaos and fractals
- Frontier topics: Information theory applications
- Frontier topics: Complex networks
- Emergent behavior in complex systems
- Project discussions, research, and development of report
- Project presentations: preliminary and final

Pre-requisite: Programming experience (e.g., python, R, MATLAB, C++, etc.)

Text (Optional)
> Steven H. Strogatz: Non-linear Dynamics and Chaos (with application to physics, biology, chemistry and engineering), Addison-Wesley Publishing Company), 2001.

Recommended Reading List: The following is a list for additional sources for reading and exploring the implementation of nonlinear systems and will be included in lectures and assignments. They may also serve to inspire ideas for class project.

- Kumar, P., & Gupta, H. V. (2020). Debates—Does Information Theory provide a new paradigm for Earth science?. *Water Resources Research*, 56, e2019WR026398. https://doi.org/10.1029/2019WR026398
- Ruddell, B. L., and Kumar, P. (2009), Ecohydrologic process networks: 1. Identification, *Water Resour. Res.*, 45, W03419, doi:10.1029/2008WR007279.
- Ruddell, B. L., and Kumar, P. (2009), Ecohydrologic process networks: 2. Analysis and characterization, *Water Resour. Res.*, 45, W03420, doi:10.1029/2008WR007280.
- Goodwell, A. E., and Kumar, P. (2017), Temporal information partitioning: Characterizing synergy, uniqueness, and redundancy in interacting environmental variables, *Water Resour. Res.*, 53, 5920– 5942, doi:10.1002/2016WR020216.

- Goodwell, A. E. and Kumar, P. (2017), Temporal Information Partitioning Networks (TIPNets): A process network approach to infer ecohydrologic shifts, *Water Resour. Res.*, 53, 5899– 5919, doi:10.1002/2016WR020218.
- Jiang, P., & Kumar, P. (2019). Using information flow for whole system understanding from component dynamics. *Water Resources Research*, 55, 8305– 8329. https://doi.org/10.1029/2019WR025820
- Newman, M. E. J., The Structure and Function of Complex Networks, SIAM Review 2003 45:2, 167-256, https://doi.org/10.1137/S003614450342480
- Boers, N., Goswami, B., Rheinwalt, A. *et al.* Complex networks reveal global pattern of extreme-rainfall teleconnections. *Nature* 566, 373–377 (2019). https://doi.org/10.1038/s41586-018-0872-x
- Boers, N., Bookhagen, B., Barbosa, H. *et al.* Prediction of extreme floods in the eastern Central Andes based on a complex networks approach. *Nat Commun* **5,** 5199 (2014). https://doi.org/10.1038/ncomms6199
- Faybishenko, B. (2004), Nonlinear dynamics in flow through unsaturated fractured porous media: Status and perspectives, *Rev. Geophys.*, 42, RG2003, doi:10.1029/2003RG000125.
- Duffy, C. J. (1996), A Two-State Integral-Balance Model for Soil Moisture and Groundwater Dynamics in Complex Terrain, *Water Resour. Res.*, 32(8), 2421– 2434, doi:10.1029/96WR01049.
- F. Molz, B. Faybishenko, Increasing Evidence for Chaotic Dynamics in the Soil-Plant-Atmosphere System: A Motivation for Future Research, Procedia Environmental Sciences, 19, 681-690, 2013, https://doi.org/10.1016/j.proenv.2013.06.077
- Molz, F. J., Rajaram, H., and Lu, S. (2004), Stochastic fractal-based models of heterogeneity in subsurface hydrology: Origins, applications, limitations, and future research questions, *Rev. Geophys.*, 42, RG1002, doi:10.1029/2003RG000126.
- May, R. Simple mathematical models with very complicated dynamics. *Nature* **261,** 459–467 (1976). https://doi.org/10.1038/261459a0
- Noy-Meir, Imanuel. Stability of Grazing Systems: An Application of Predator-Prey Graphs. *Journal of Ecology* 63, no. 2 (1975): 459-81. Accessed January 27, 2021. https://doi.org/10.2307/2258730
- Scheffer, M., Carpenter, S., Foley, J. *et al.* Catastrophic shifts in ecosystems. *Nature* **413,** 591–596 (2001). https://doi.org/10.1038/35098000
- Rosas, Fernando; Mediano, Pedro A.M.; Ugarte, Martín; Jensen, Henrik J. 2018. An Information-Theoretic Approach to Self-Organisation: Emergence of Complex Interdependencies in Coupled Dynamical Systems, *Entropy* 20, no. 10: 793. https://doi.org/10.3390/e20100793

Useful References:
- Juan G. Roederer, Information and its role in nature, Springer, 2005.
- Garnett P. Williams: Chaos Theory Tamed, National Academy Press, 1997.
- Donald L. Turcotte: Fractals and Chaos in Geology and Geophysics, Cambridge University Press, 1997.
- Luca Rodilfi, Paolo D'Odorico and Francesco Laio, Noise Induced Phenomena in the Environmental Sciences, Cambridge Univ. Press, 2011.
- Scott Camazine, Jean-Louis Deneubourg, Nigel R. Franks, James Sneyd, Guy Theraulaz, & Eric Bonabeau, Self-Organization in Biological Systems, Princeton Univ. Press, 2003.
- Henry D. I. Abarbanel: Analysis of Observed Chaotic Data, Springer, 1996.
- Holger Kantz and Thomas Schreiber: Non-Linear Time Series Analysis, Cambridge University Press, 1997.

Popular Books:
  Exploring Complexity: An Introduction by Gregoire Nicolis, Ilya Prigogine, W.H. Freeman & Company (October 1989)
  Ricard V. Solé, Phase Transitions, Princeton Univ. Press, 2011.
  Marten Scheffer, Critical Transitions in Nature and Society, Princeton Univ. Press, 2009.
  Mark Buchanan, Nexus: Small Worlds and the Groundbreaking World of Networks, W. W. Norton and Co., 2002.
  Alberto-Laszlo Barabasi, Linked: How Everything is Connected to Everything Else and what it Means, Plume Book, 2003.

Software Tools:
  - For analytical approach to nonlinear dynamical systems: use matlab, python, or mathematica [see Heikki Ruskeepaa, Mathematica Navigator, Academic Press, 2009.]
  - For use of information theory to geoscience: https://github.com/HydroComplexity/TIPNet [See also https://geoinfotheory.org/software/]

Late Assignment Policy
Late assignments will be accepted up to 24 hours after the due date without penalty. If you need an additional extension on an assignment, contact me before the assignment due date.

ChatGPT and other LLMs and AI tools

For this class, keep the following three principles in mind: (1) An AI cannot pass this course. (2) AI contributions must be attributed and true. (3) AI use should be open and documented.

ChatGPT and other LLMs can be useful tools but should not be used to replace critical thinking. As engineers, it is important that you can stand behind your work. You are taking full responsibility for your assignments and the results and conclusions that you present. All ideas must be accurately attributed, and facts must be true. If you decide to use AI tools to help with your assignments, you must include a section describing how you used AI.

This statement is developed, in part, with help from The Sentient Syllabus Project (2022) http://sentientsyllabus.org

Academic Integrity

The University of Illinois Urbana-Champaign *Student Code* should also be considered as a part of the syllabus. Students should pay particular attention to Article 1, Part 4: Academic Integrity. Read the Code at the following URL: http://studentcode.illinois.edu/.

Academic dishonesty may result in a failing grade. Every student is expected to review and abide by the Academic Integrity Policy: https://studentcode.illinois.edu/article1/part4/1-401/. Ignorance is not an excuse for any academic dishonesty. It is your responsibility to read this policy to avoid any misunderstanding. Do not hesitate to ask the instructor(s) if you are ever in doubt about what constitutes plagiarism, cheating, or any other breach of academic integrity.

Family Educational Rights and Privacy Act (FERPA)

Any student who has suppressed their directory information pursuant to *Family Educational Rights and Privacy Act* (FERPA) should self-identify to the instructor to ensure protection of the privacy of their attendance in this course. See http://registrar.illinois.edu/ferpa for more information on FERPA.

Mental Health

Significant stress, mood changes, excessive worry, substance/alcohol misuse or interferences in eating or sleep can have an impact on academic performance, social development, and emotional wellbeing. The University of Illinois offers a variety of confidential services including individual and group counseling, crisis intervention, psychiatric services, and specialized screenings which are covered through the Student Health Fee. If you or someone you know experiences any of the above mental health concerns, it is strongly encouraged to contact or visit any of the University's resources provided below. Getting help is a smart and courageous thing to do for yourself and for those who care about you.

- Counseling Center (217) 333-3704
- McKinley Health Center (217) 333-2700
- National Suicide Prevention Lifeline (800) 273-8255
- Rosecrance Crisis Line (217) 359-4141 (available 24/7, 365 days a year)

  If you are in immediate danger, call 911.

  *This statement is approved by the University of Illinois Counseling Center

Community of Care

As members of the Illinois community, we each have a responsibility to express care and concern for one another. If you come across a classmate whose behavior concerns you, whether in regards to their well-being or yours, we encourage you to refer this behavior to the Student Assistance Center (217-333-0050 or http://odos.illinois.edu/community-of-care/referral/). Based on your report, the staff in the Student Assistance Center reaches out to students to make sure they have the support they need to be healthy and safe.

Further, as a Community of Care, we want to support you in your overall wellness. We know that students sometimes face challenges that can impact academic performance (examples include mental health concerns, food insecurity, homelessness, personal emergencies). Should you find that you are managing such a challenge and that it is interfering with your coursework, you are encouraged to contact the Student Assistance Center (SAC) in the Office of the Dean of Students for support and referrals to campus and/or community resources.

Students with Disabilities

To obtain disability-related academic adjustments and/or auxiliary aids, students with disabilities must contact the course instructor as soon as possible and provide the instructor with a Letter of Academic

Accommodations from Disability Resources and Educational Services (DRES). To ensure that disability-related concerns are properly addressed from the beginning, students with disabilities who require assistance to participate in this class should apply for services with DRES and see the instructor as soon as possible. If you need accommodations for any sort of disability, please speak to me after class, or make an appointment to see me or see me during my office hours. DRES provides students with academic accommodations, access, and support services. To contact DRES, you may visit 1207 S. Oak St., Champaign, call 217-333-1970, e-mail disability@illinois.edu or visit the DRES website at https://dres.illinois.edu/. Here is the link for information to apply for services at DRES, https://dres.illinois.edu/information-before-you-apply/application-process/ .

Disruptive Behavior

Behavior that persistently or grossly interferes with classroom activities is considered disruptive behavior and may be subject to disciplinary action. Such behavior inhibits other students' ability to learn and an instructor's ability to teach. A student responsible for disruptive behavior may be required to leave class pending discussion and resolution of the problem and may be reported to the Office for Student Conflict Resolution (https://conflictresolution.illinois.edu; conflictresolution@illinois.edu; 333-3680) for disciplinary action.

Emergency Response Recommendations

Emergency response recommendations and campus building floor plans can be found at the following website: https://police.illinois.edu/em/run-hide-fight/. I encourage you to review this website within the first 10 days of class.

Religious Observances

Illinois law requires the University to reasonably accommodate its students' religious beliefs, observances, and practices in regard to admissions, class attendance, and the scheduling of examinations and work requirements. Students should complete the Request for Accommodation for Religious Observances form should any instructors require an absence letter in order to manage the absence. In order to best facilitate planning and communication between students and faculty, students should make requests for absence letters as early as possible in the semester in which the request applies.

Sexual Misconduct Reporting Obligation

The University of Illinois is committed to combating sexual misconduct. Faculty and staff members are required to report any instances of sexual misconduct to the University's Title IX Office. In turn, an individual with the Title IX Office will provide information about rights and options, including accommodations, support services, the campus disciplinary process, and law enforcement options.

A list of the designated University employees who, as counselors, confidential advisors, and medical professionals, do not have this reporting responsibility and can maintain confidentiality, can be found here: wecare.illinois.edu/resources/students/#confidential.

Other information about resources and reporting is available here: wecare.illinois.edu