CS 295 **Information & Complexity** **Spring 2007**

Course Syllabus

Instructor: Robert R. Snapp, 353 Votey, 656–0735, snapp@cs.uvm.edu.

Office Hours: Tue. 9:30–11:00 AM; Wed. 2:00–3:00 PM; and by appointment.

Lectures: T & Th, 8:00 – 9:15 AM in 307 Votey.

Web Page: www.cs.uvm.edu/~snapp/entropy/

Description: *Information and Complexity* describe a broad theoretical framework that can be applied to a variety of problems in computer science, engineering, statistics, and other disciplines. Claude Shannon extended Ludwig Boltzmann's concept of *entropy* to describe the amount of computer memory that is required to store a random *message*, as well as the maximum rate at which it can be reliably transmitted over a given communication channel. Andrey Nikolaevich Kolmogorov (1903–1987) developed *algorithmic information theory* to measure the *complexity* of a *message* as the "size" of the smallest computer program that generates it. This course will develop, analyze, and apply these and other measures of information and complexity in a variety of contexts, including communication theory, complex systems, computer science, finance, physics, statistics, and complex systems.

Prerequisites: A course in probability or statistics, e.g., STAT 141, 143, 151, or 153.

Textbook: Thomas M. Cover and Joy A. Thomas, *Elements of Information Theory*, 2nd edition, Wiley, New York, 2006. (*EOIT*)

Homework: Homework exercises will be assigned on a regular basis.

Term paper: One 20 page term paper that relates information and complexity to a problem of interest, e.g., turbo codes, capacities of neural network (associative) memories, portfolio management, physics of computation, quantum measurement theory, fractal-based image compression, games of chance, coding schemes for disk arrays, etc. More explicit guidelines for the paper will be distributed in the near future. Term papers are due on ***May 7***.

Exams: Two take-home midterm exams will be given, one from ***February 22*** to ***27***, and the other from ***April 19*** to ***24***.

Final Exam: The final exam period for this course is scheduled for 11:45–2:45 PM, Monday, ***May 7***. Instead of a customary final exam, each student will give a 20 minute oral presentation on their term paper topic.

Grading Policy: The course grade will be based on

- Homework (30%),
- Exam #1 (25%),
- Exam #2 (25%),
- Term Paper (20%).

Students entitled to special accommodation must notify the instructor by the second week of the semester.

Collaboration: You are *encouraged* to share your knowledge, discoveries, and ideas with other students outside of class. All work (e.g., ideas, opinions, analyses, algorithms, data, and source code) generated by others should be properly cited.

Absolutely no collaboration or unauthorized material is allowed during any quiz or exam. All violations will be forwarded to the University Coordinator of Academic Honesty, following the *new* policy of Academic Integrity posted at

http://www.uvm.edu/cses/code_ai.html

Topics

The following topics are subject to change.

- Review of probability & statistics.
- Entropy: from Boltzmann to Shannon.
- Relative Entropy and Mutual Information.
- Asymptotic Equipartition Property.
- Kelly Gambling and Portfolio Management.
- Channel Capacity.
- Error Correcting Codes.
- Entropy of continuous random variables.
- Gaussian Channels.
- Rate Distortion Theory.
- Method of Types & Fisher Information.
- Data Compression.
- Kolmogorov Complexity.
- Thermodynamics of Computation.

References: There are many useful reference books dedicated to puzzles and games. The following is my personal list of favorites, and is certainly not complete. Many of them are in the Bailey-Howe Library. The rest are available through interlibrary loan.

1. William Feller, *An Introduction to Probability Theory and Its Applications*, Vol. 1, 3rd edition, Wiley, New York, 1968.

2. A. I. Khinchin, *Mathematical Foundations of Information Theory*, Dover, New York, 1957.
3. A. N. Kolmogorov, *Foundations of Probability*, 2nd English Edition, Chelsea, New York, 1956.
4. Bernd-Olaf Küppers, *Information and the Origin of Life*, MIT Press, Cambridge, MA, 1990.
5. Ming Li and Paul Vitányi, *An Introduction to Kolmogorov Complexity and Its Applications*, 2nd edition, Springer, New York, 1997.
6. Robert J. McEliece, *The Theory of Information and Coding*, Cambridge University Press, Cambridge, UK, 2002.
7. John R. Pierce, *An Introduction to Information Theory: Symbols, Signals and Noise*, 2nd revised edition, Dover, New York, 1980. [A very accessible introduction to information theory, written for the layman by a former Bell Labs director, and Caltech professor.]
8. William Poundstone, *Fortune's Formula: The Untold Story of the Scientific Betting System that Beat the Casinos and Wall Street*, Hill and Wang, 2005.
9. Alfréd Rényi, *A Diary on Information Theory*, Wiley, New York, 1984.
10. Claude E. Shannon, "A Mathematical Theory of Communication," *Bell Syst. Tech. J.*, vol. 27, (1948), pp. 379–423.
11. Claude E. Shannon, "Communication in the Presence of Noise," *Proc. IRE*, vol 37, (1949), pp. 10-21.
12. Claude E. Shannon, "Prediction and Entropy of Printed English," *Bell Syst. Tech. J.*, vol. 30, (1951), pp. 50–64.
13. Claude E. Shannon and Warren Weaver, *The Mathematical Theory of Communication*, University of Illinois Press, Urbana, IL, 1949. [This book is essentially a reprint of Shannon's 1948 paper on information theory, prefaced by Weaver's introduction.]
14. Hans Christian von Baeyer, *Information: The New Language of Science*, Harvard University Press, Cqmbridge, MA, 2003.
15. Ian H. Witten, Alistair Moffat, and Timothy C. Bell, *Managing Gigabytes: Compressing and Indexing Documents and Images*, 2nd edition, Morgan Kaufmann, San Francisco, 1999.
16. Wojciech H. Zurek, *Complexity, Entropy, and the Physics of Information*, Addison-Wesley, Redwood City, CA, 1990. [Proceedings of a Workshop, from May 29 to June 2, in Sante Fe, NM, organized by the Sante Fe Institute.]