FRESHMAN SEMINAR PROPOSAL

The Information Revolution: Insights into Technology, Language, and Biology

Information exchange and transfer are basic to human existence and are common to a variety of technological, physical, chemical, biological, and social processes. For example, much of the information technology that has dominated the technological landscape of the late 20th and early 21st centuries is designed to enable these functions. Moreover, humans use spoken, written, and symbolic languages to communicate in many diverse ways. On the other hand, in the biological context, information exchange at the cellular level involves chemical signaling, and is basic to many biological processes including the transfer of genetic information from generation to generation. Irrespective of the means of communication, the primary goal of all information exchange is the reliable transfer of information. In its highest form, the theory of reliable communication encompasses sophisticated mathematical ideas. However, the fundamental concepts at the heart of this theory, developed in the 1940s by the renowned engineer and mathematician Claude Shannon, are both intuitive and general enough to be understood by a wide audience.

Shannon introduced three basic concepts to characterize information transfer and used them to develop his fundamental theory of reliable information transfer. These concepts are: *entropy*, a quantitative measure of the information in any system; *coding*, a method of introducing redundancy to information to achieve reliable communication; and *compression*, a technique for reducing information to its minimal form in order to transmit or store it as efficiently as possible. The contributions of Shannon and his successors over the past half a century led to an *information revolution* and an explosion of innovative new technologies to communicate, process, and store information. Today's ubiquitous wired and wireless communication networks, as well as the computers, media players and storage devices that are an inseparable part of our daily lives, are testaments to the application of Shannon's fundamental ideas. Further, the universality of Shannon's concepts has led to their application in a variety of other areas such as linguistics, genomics, neurosciences, quantum mechanics, and cryptography.

In this seminar, we will study Shannon's fundamental ideas and the insights they bring to a wide variety of fields, such as those noted above. We will first discuss the basic concepts of entropy, coding, and compression. Then, we will examine a series of examples from linguistics, biology, finance, history, genetics, and modern digital communications, to illustrate these concepts and to demonstrate their power and simplicity in characterizing the primary objective of communications: reliable information transfer.

Classroom activities will include the presentation and discussion of the fundamental concepts of information and communication, discussion and analysis of a selection of examples and reading materials, interaction with guest lecturers, and student presentations. Also included will be two hour-long interactive experiments, one at the beginning of the course and the other towards the end of the course, that demonstrate the fundamental principles discussed in the course. The mathematical tools required for this seminar are basic and should be accessible to all Freshmen with knowledge of high-school calculus.

Preliminary Reading List:

Books

- Hans Christian von Baeyer, *Information: The New Language of Science* (Harvard University Press: Harvard, 2005).
- David Leunberger, *Information Science*, (Princeton University Press, Princeton, 2006).
- Keith Ball, *Strange Curves, Counting Rabbits, and Other Mathematical Explorations*, (Princeton University Press: Princeton, 2003).
- Simon Singh, *The Code Book: The Science of Secrecy from Ancient Egypt to Quantum Cryptography* (Anchor: New York, 1999).
- Tom Standage, *The Victorian Internet: The Remarkable Story of the Telegraph and the Nineteenth Century's On-line Pioneers* (Berkeley Books: New York, 1998).
- Gerard Holzmann and Björn Pehrson, *The Early History of Data Networks* (Wiley-Interscience: New Jersey, 2003).
- John Bray, *Innovation and the Communication Revolution*, (Institute of Electrical Engineers: London, 2002).
- Fred Rieke, David Warland, Rob de Rutyer van Steveninck, William Bialek, *Spikes: Exploring the Neural Code*, (The MIT Press: Jun 1999).
- Willaim Poundstone, *Fortune's Formula: The Untold Story of the Scientific Betting System that Beat the Casinos*, (Hill and Wang, 2006).

History and Biography

- Biography of C. E. Shannon: http://www.research.att.com/~njas/doc/shannonbio.html
- Erico Marui Guizzo, *The Essential Message: Claude Shannon and the Making of Information Theory*, MIT Masters Thesis, 2003.
- Neil Sloane and Aaron Wyner, *Claude Elwood Shannon: Collected Papers* (IEEE Press: New York, 1993)
- Irving Reed, "*Brief History of Computers and Error-Correcting Codes and My Work With Gus Solomon*," IEEE Pacific Rim Conference on Networking, Vol. 2, 20-22, Aug. 1997.

Journals and Articles

Technology:

- Claude Elwood Shannon, "*A Mathematical Theory of Communication*," *Bell System Tech. Journal*, 27:379-423, 623-656, 1948.
- AMS Archive: Digital Revolution (I), (II), (III), The Mathematics of Communication.
- *The Electromagnetic Spectrum. What are Electromagnetic Waves?* http://science.hq.nasa.gov/kids/imagers/ems/waves2.html

- Kees Immink, *Shannon, Beethoven, and the Compact Disc*, http://www.exp-math.uni-essen.de/~immink/
- Robert G. Gallager, "*Claude E. Shannon: A Retrospective on His Life, Work, and Impact*," IEEE Transactions on Information Theory, Vol. 47, No. 7, Nov. 2001.

Biology:
- F. Werblin and B. Roska, "*The Movies of Our Eyes*," Scientific American, 2007.
- S. A. Altmann, "*The sociobiology of rhesus monkeys*," Journal of Theoretical Biology: no.8, pp. 490-522.
- R. Ferrer i Cancho and D. Lusseau, "*Long-Term Correlations in the Surface Behavior of Dolphins*," Europhysics Letters, 74 (6), 2006.
- Joseph J. Atick, "*Could Information Theory Provide an Ecological Theory of Sensory Processing*," link to article via the Course Materials link on Blackboard. Read Sections 1, 2 (ignore the last part of 2.2 on the last half of page 218), 2.3, 3.1.

Language:
- Claude Elwood Shannon, "*Prediction and Entropy of Printed English*," Bell System Tech. Journal, 50:50-64, 1951.

History:
- Joachim Hagenauer, Zahir Dawy, Bernhard Goebel, Pavol Hanus, and Jakob Mueller, "*Information Theory Helps Historians*", Information Theory Newsletter September 2005.

Genetics:
- Pavol Hanus and Joachim Hagenauer, "*Genomic Analysis using Methods from Information Theory*", in Proceedings of the IEEE Information Theory Workshop, October 2004.
- Pavol Hanus, Bernhard Goebel, Janis Dingel, Johanna Weindl, Juergen Zech, Zaher Dawy, J. Hagenauer, and Jakob Mueller, "*Information and Communication Theory in Molecular Biology*", Springer Series, vol. 90, number 2, December 2007.
- Zaher Dawy, J. Hagenauer, Pavol Hanus, and Jakob Mueller, "*Mutual Information Based Distance Measures for Classification and Content Recognition with Applications to Genetics*", in Proceedings of the IEEE International Conference on Communications, May 2005.

Finance:
- Thomas Cover, "*Portfolio Theory: Publications*," http://www.stanford.edu/~cover/portfolio-theory.html.