Information, Energy and Machine Learning
Spring 2023 — Special Topics Course Proposal

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Course Content

The course will focus on the ideas that power recent spectacular advances in Machine Learning: Information theory, Statistical Mechanics, Bayesian methods and related subjects.

The course will have two threads: theory and algorithms, including implementation. Our focus will be on algorithms that are deemed to be "artificially intelligent", which, by definition, means achieving near-human performance on complex tasks that are usually performed by humans. The bulk of examples will come from recent research by the instructor in the area of Optical Character Recognition (OCR), which is a traditional field of Artificial Intelligence. OCR is one of the most complex AI systems that is in common use, but with many outstanding problems, such as machine-reading documents with complex layouts and off-line handwriting recognition. The current research by the instructor is motivated by the problem of automated processing of medical forms on a national scale, with immediate applications to overhaul the organ transplant system, which is a joint project with the College of Medicine.

Specific topics will include:

- Data compression, block and stream codes, the Shannon entropy bound.
- The noisy channel model, its usefulness in surprising contexts, and methods of correcting errors.
- Connectionist models of Machine Learning, neural networks (NN); layered NN, DAG NN, recurrent NN, general graphical models.
- Specific applications: image classification, semantic segmentation, sequence-to-sequence and sequence-to-label mapping.
- Applications to OCR.

The course will illustrate the theory with code samples written primarily in MATLAB. A tutorial introduction to the MATLAB Machine Learning framework is a part of the course. In contrast with Python or R, MATLAB is suitable for building industrial strength software and has excellent, mathematically rigorous documentation. There will be programming assignments aimed at providing a competitive skillset for industrial jobs.

Learning Outcomes

The student will gain a working knowledge of information theory and develop the ability to apply it in machine learning type algorithms. In particular, the student will be able to:

- Understand definitions, theorems and examples from information theory.
- Master the fundamentals of machine learning theory.
- Formulate and solve problems using neural networks.
- Build basic Machine Learnig applications in MATLAB.

Course Information

Textbooks and other course materials The freely downloadable book "Information Theory, Inference, and Learning Algorithms" by David J.C. MacKay. Additional course materials will be provided by the instructor in electronic form.

Assignments and Exams This course will be project oriented. The grade in the course will be based on a number of assignments and small-to-medium programming projects (dozens to hundreds lines of code). The grade will be based on 5 homework assignments and a final project.

Prerequisites Senior-level Linear Algebra, Calculus and Probability, Numerical Methods. Ability to program in a high-level programming language (such as MATLAB, Python or R). Ability to transfer programming skills to MATLAB, which will be the main software used in the course.

Contact information Please contact the instructor by e-mail at **rychlik@arizona.edu**.

Approximate Schedule

Week	Topics covered
1	Data Compression:: The Source Coding Theorem. Symbol Codes. Stream Codes.
2	Noisy Channel Coding:: Dependent Random Variables. Communication over a Noisy Channel. Information and Entropy. The Noisy-Channel Coding Theorem.
3	A tutorial Introduction to MATLAB:: Emphasis will be given to Toolboxes: Statistics, Image Processing, Machine Learning, Vision and Deep Learning.
4	Probability and Inference:: Clustering. Maximum Likelihood. Exact Marginalization.
5	Probabilities and Inference:: Exact Marginalization.
6	Neural Networks:: Introduction. Perceptron layer, activation function, loss (energy) function.
7	MATLAB Deep Learning Framework:: A tutorial. Layers. Layers as classes. Automatic differentiation. DAG networks.
8	Neural Networks in MATLAB:: Layers: input ,fully connected, sigmoid and ReLu, convolutional, transposed convolutional, softmax, classification, regression. Recurrent neural networks.
9	Neural Networks in MATLAB:: Implementation and examples.
10	Neural Networks in MATLAB:: More advanced examples.
11	Optical Character Recognition:: Review of problems and approaches.
12	Optical Character Recognition:: Image processing, segmentation, filtering, binarization.
13	Optical Character Recognition:: Neural Nets for OCR.
14	Review:: Main ideas. Outstanding problems.