ECE 611: Advanced Digital Communications

General Description:
An introduction to digital communications, entropy, mutual information, rate distortion function, lossless and lossy source coding, communications with AWGN interference, standard modulation techniques, performance analysis, channel capacity and coded modulation, block and convolutional codes including without limitation linear block codes, low density parity check codes, turbo codes, and polar codes, decoding algorithms, applications to and interactions with deep learning.

Materials on information quantities and lossy coding will help you understand deep learning better and provide a basis for designing robust and widely deployable deep neural networks.

Prerequisites: Probability theory and elementary stochastic processes.

Textbook: Course notes for E&CE 611 available online; J. G. Proakis, *Digital Communications,* fourth edition, McGraw–Hill, 2001.

Reference: R. G. Gallager, *Principles of Digital Communication,* Cambridge University Press, 2008.

Course Outline

1 Introduction (3 hours)
- Overview of digital communications
  - Network of networks
  - Bigger pipes, more pipes, and better pipes
- A digital communication block diagram
- Mathematical models for communication channels
- Review of probability theory
- Review of stochastic processes

2 Source Coding (7 hours)
- Mathematical models for information sources
- Entropy and mutual information
- Lossless data compression
  - Coding for discrete sources
  - Huffman coding and adaptive Huffman coding
  - Run-length coding
  - Arithmetic coding

  - The context weighting algorithm
  - The Lempel-Ziv algorithm
  - Grammar-based coding
  - Yang-Kieffer algorithms
- Lossy data compression
  - Rate distortion function
  - Scalar quantization
  - Vector quantization
- **Applications to and interactions with deep learning**

3 Communications with AWGN Interference (7 hours)

- Vector communications with AWGN interference
- Waveform communications with AWGN interference
- Digital modulation methods
- Probability of Error for various digital modulation methods
- Comparison of digital modulation methods

4 Channel Capacity and Coded Modulation (7 hours)

- Channel models and channel capacity
  - Channel models
  - Bandwidth, dimensionality, and channel capacity
  - Achieving channel capacity with orthogonal signals in the case of infinite bandwidth
  - Channel reliability function
- Coded modulation—a probabilistic approach
  - Random coding based on M-ary binary coded signals
  - Random coding based on M-ary multiamplitude signals
  - Comparison of R_0^* with the capacity of the AWGN channel

5 Block and Convolutional Channel Codes (12 hours)

- Linear Block codes
  - The generator matrix and parity check matrix
  - Some specific linear block codes
  - Cyclic codes
  - Optimum soft decision decoding of linear block codes
  - Hard decision decoding
  - Comparison of performance between hard decision and soft decision decoding
  - Bounds on minimum distance of linear block codes
  - Interleaving of coded data for channels with burst errors
  - Serial and parallel concatenated block codes
  - Low density parity check codes

  - Polar codes
- Convolutional codes
  - The transfer function of a convolutional code
  - The Viterbi algorithm
  - Probability of error for soft decision decoding
  - Probability of error for hard decision decoding
  - Distance properties of binary convolutional codes
  - Other decoding algorithms for convolutional codes
  - Optimal decoding of linear codes for minimizing symbol error rate—the BCJR algorithm
  - Parallel and serial concatenated convolutional codes—Turbo codes