ECE 642
Information Theory and Source Coding

Prof. Mark R. Bell

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Course Information

Instructor: Prof. Mark R. Bell
Course Location: BHEE 226 (TR: 3:00–4:15pm)
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email: mrb@purdue.edu
Course Home Page: https://engineering.purdue.edu/~mrb/ (We will ***not*** be using Brightspace.)
Zoom Office Hours: Monday: 10:30–11:30am, Thursday: 11:00am–Noon, or by appointment.

Course Web Page: The course webpage, reachable from the ECE642 drop-down menu on my Purdue Personal Webpage (**https://engineering.purdue.edu/~mrb**), will be used for distributing all course materials. A Brightspace page will *not* be used in this course. All homework assignments, homework solutions, and course lecture slides (posted after each lecture) will be downloadable from the web page.

Text: T. M. Cover and J. A. Thomas, *Elements of Information Theory,* 2nd Edition, Wiley, 2006.

Grading Policy: There will be 2 midterm exams worth 25% of the final grade each, a final exam worth 40% of the final grade, and homework worth 10% of the final grade.

Make-Up Exam Policy: There will be no make-up exams (except in extreme circumstances); in general, if you miss a midterm exam your final exam score will be used in its place. If you are going to miss a midterm exam and want your final exam score, used in its place, you must tell me *before* the midterm exam.

Homework Collaboration Policy: I allow and encourage collaboration on homework. However, I expect you to write-up your own solutions and understand what you hand in.

A Note on Homework: Homework will be collected and spot checked, but not graded in detail. Detailed solutions will however be posted to the course website after the homework due date. Homework should be submitted as a pdf scan on or before the homework due date to mrb@ecn.purdue.edu, with the email subject line "ECE642: Homework N" (with N replaced by the homework assignment number.) In cases of borderline grades, your homework solutions will be scrutinized to determine the final course grade. I recommend that you keep a copy of your homework solutions for study purposes.

Course Outline: A brief outline of the course is as follows:

1. Introduction and Mathematical Preliminaries
2. Noiseless Source Coding
3. Channel Coding Theorem for Discrete Memoryless Channels
4. Channel Coding Theorem for the Gaussian Channel
5. Source Coding with a Fidelity Criterion (Rate Distortion Theory)
6. Source-Channel Coding Theorems
7. Source Coding Techniques

Additional References: A number of additional books, available in the Purdue Libraries, will be useful in the course. These include:

1. R. G. Gallager, *Information Theory and Reliable Communication,* Wiley, 1968.
2. R. J. McEliece, *The Theory of Information and Coding,* Addison-Wesley, 1977.
3. R. Ash, *Information Theory,* Wiley, 1965. (Reprinted as a Dover book)
4. R. Blahut, *Principles and Practice of Information Theory,* Addison-Wesley, 1987.
5. N. S, Jayant and P. Noll, *Digital Coding of Waveforms,* Prentice-Hall, 1984.
6. A. Gersho and R. M. Gray, *Vector Quantization and Signal Compression,* Kluwer, 1992.
7. D. J. C. MacKay, *Information Theory, Inference, and Learning Algorithms,* Cambridge, 2003. (free pdf available at http://www.inference.phy.cam.ac.uk/makkay/itila/book/html)

Academic Dishonesty: As graduate students, you are expected to behave with honesty and academic integrity in this course. In this respect, any action that would give any student an unfair grade advantage in this course will be considered *academic dishonesty*. Any case of academic dishonesty may result in a grade penalty on the assignment or in the course, as well as being reported to the Student Office of Rights and Responsibilities. Examples of academic dishonesty include, but are not limited to the following:

- Sharing information during an exam;
- Using forbidden material or a forbidden device during an exam;
- Viewing or working on an exam before or after the official time allowed;
- Requesting a regrade of work that has been altered;
- Submitting work that is not your own.

Emergency Procedures: Purdue is a relatively safe campus, however, we want to emphasize our emergency procedures for evacuation and shelter in place incidents in the event they are needed. To this end, we review the following procedures:

- To report an emergency, call 911. To obtain updates regarding an ongoing emergency, sign up for Purdue Alert text messages and view the current emergency status at **www.purdue.edu/ea**.
- There are approximately 300 Emergency Telephones distributed across campus and in parking garages. These connect directly to the Purdue University Police Department (PUPD). To use these, push the button on the phone and you will be connected to the PUPD immediately.
- If a fire alarm goes off during class, class will stop immediately. Evacuate the classroom immediately and head outdoors. Do not use the elevators.
- If we are notified during class of a Shelter in Place for a Tornado Warning, we will suspend class and shelter in the basement.
- If we are notified during class of a Shelter in Place for a hazardous material release, or a civil disturbance—including a shooting or other use of weapons, we will suspend class and shelter in the classroom, shutting and locking the doors and turning off the lights.
- Please review the Emergency Preparedness website for additional information: http://www.purdue.edu/ehps/emergency_preparedness/index.html

In the event of a major campus emergency, course requirements, deadlines and grading criteria are subject to changes that may be required by changes in the semester calendar or other circumstances. In such an event, information will be provided by email and the ECE642 course website.

ECE 642: Information Theory and Source Coding

1.1

- Prerequisite: ECE 600
- Tools:
  - Probability and Random Variables
  - Basic Analysis (limits, convex functions, etc.)
  - Some mathematical sophistication (proofs)
  - A little combinatorics

ECE 642: Information Theory and Source Coding

- Text: Cover and Thomas, *Elements of Information Theory*, 2nd Ed., Wiley, 2006.
- (The first edition can also be used.)
- We will take material from other books and papers.
- The book gives a very broad and up-to-date coverage of information theory and its application areas.

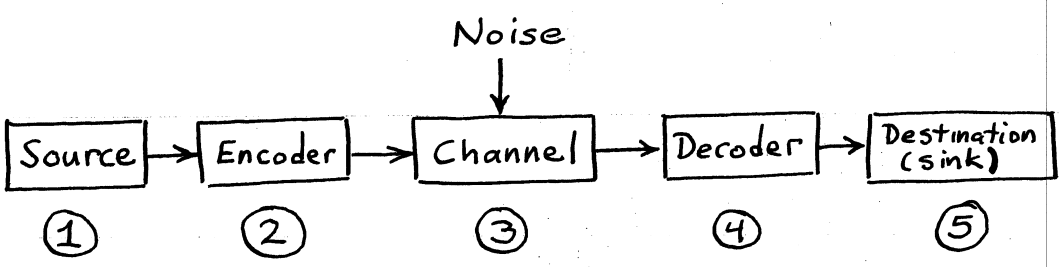
- Course Title: *Information Theory* and *Source Coding*
  Part 1 of course Part 2 of Course
- Information theory is the primary tool for the theoretical analysis of source coding.
- What is Information Theory?

  "The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point." — *C.E. Shannon*

- *A/The Mathematical Theory of Communication* — Shannon

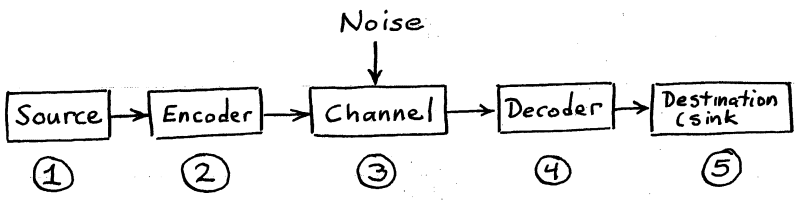
- Information Theory does many things:
  - It describes how to measure information (as a quantity)
  - It provides bounds on achievable rates of communication in the presence of noise
  - It provides bounds on the minimum amount of information required to represent an *information source*
  - *It is **not** a constructive theory*. It does not tell you how to (practically) construct codes that achieve the capacity of a channel, but it does supply some hints.

A Typical Communication System



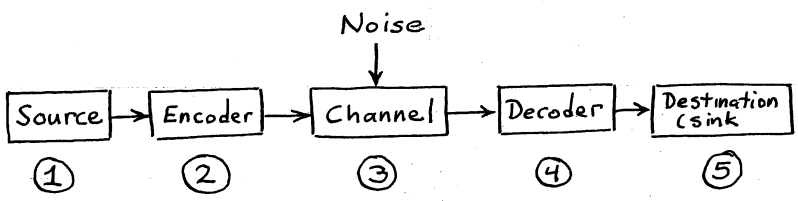
1 **Source**: Origin of information to be communicated

(e.g., voice, images, computer data, DNA sequences, physical measurements, etc.)

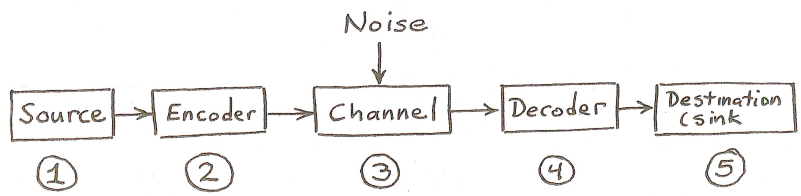


③ <u>Channel</u>: Physical Medium across which information must be transfered.

(e.g., microwave link, optical fiber, free-space (MW or optical), magnetic storage medium (disk or tape) optical storage medium (CD or DVD) phonograph record, telephone line, tin-can telephone string, etc.)



⑤ <u>Destination (sink, user)</u>: This is where the information is used. (Could be CRT/display, human visual system, human ear, computer system, etc.)



② **Encoder**: Provides necessary processing (coding) of source output before transmission through channel.

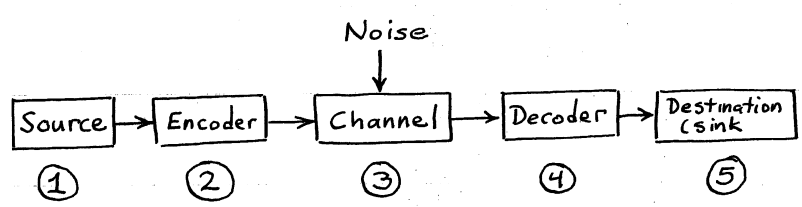
"Matches source to channel"

Example: Suppose you have a source that produces a message using a 4-letter alphabet and you want to send it over binary channel!

Source → Encoder →

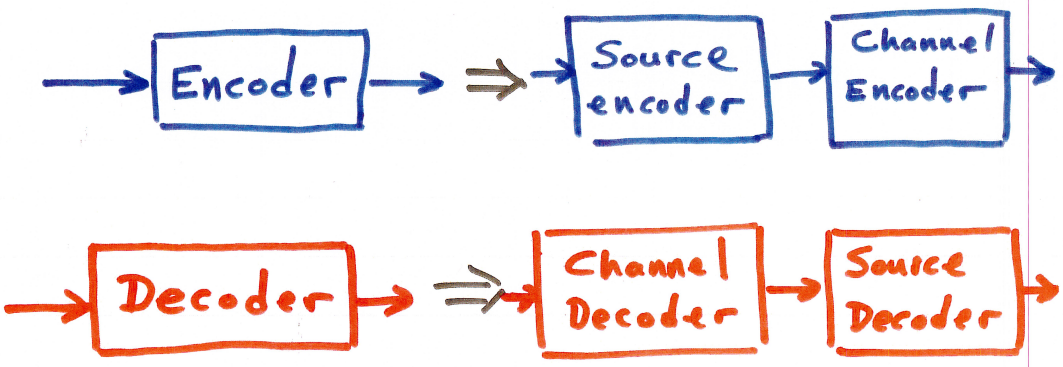
$a_1 \mapsto 0$ $\quad a_3 \mapsto 110$

$a_2 \mapsto 10$ $\quad a_4 \mapsto 111$



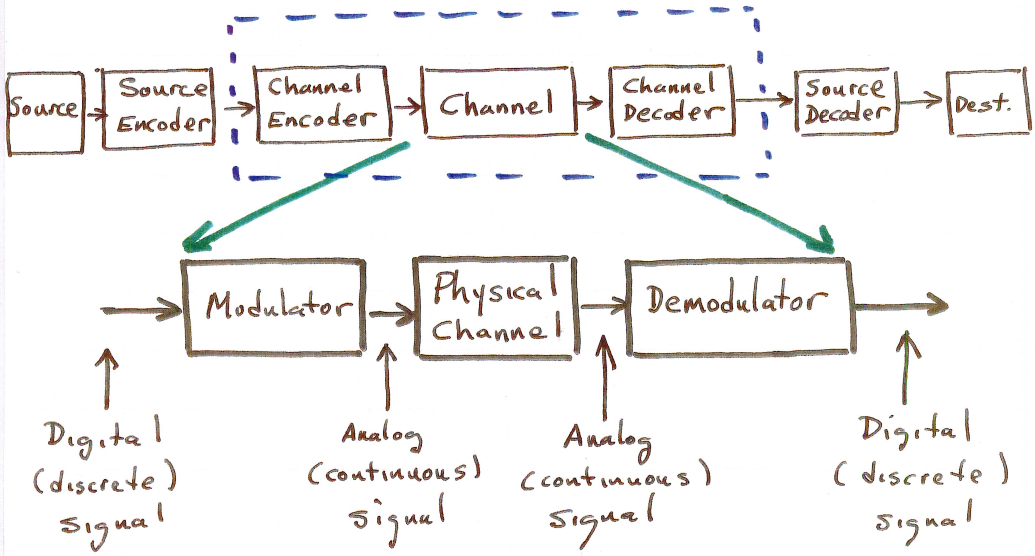
④ **Decoder**: Processes the channel output with the goal of producing an "acceptable" replica of the source output.

Sometimes the encoder and decoder are broken into two parts (each)



We will see that we can always do this decomposition and still achieve optimal performance if we encode in large blocks (asymptotically).

When this decomposition is done, the communication system appears as follows:



In light of this...

1. Think about how a digital audio CD system would fit into this framework

2. Think about how a deep-space probe (e.g. Voyager) sending images back to earth fits into this framework.

Mathematical Preliminaries

Probability:

Defn: A probability space $(\mathcal{S}, \mathcal{F}, P)$ is a triple consisting of

$\mathcal{S}$ = sample space

$\mathcal{F}$ = event space (σ-field)

P = probability measure

- $\mathcal{S}$ = set of all outcomes
  (one and only one outcome occurs when the random experiment is performed.)

- An <u>event</u> $A \subset \mathcal{S}$. We say that an event A occurs if outcome $w \in A$.

- The <u>event space</u> $\mathcal{F}$ is a collection of events satisfying closure properties:
  1. If $A \in \mathcal{F} \Rightarrow \bar{A} \in \mathcal{F}$
  2. If $A_1, \ldots, A_n \in \mathcal{F} \Rightarrow \bigcup_{i=1}^{n} A_i \in \mathcal{F}$
  3. If $A_1, \ldots, A_n, \ldots \in \mathcal{F}$
     $\Rightarrow \bigcup_{i=1}^{\infty} A_i \in \mathcal{F}$.