Information

Reading: Complexity: A Guided Tour, Chapter 3
Recap: Core disciplines of the science of complexity

**Dynamics:** The study of continually changing structure and behavior of systems

**Information:** The study of representation, symbols, and communication

**Computation:** The study of how systems process information and act on the results

**Evolution:** The study of how systems adapt to constantly changing environments
Information

Motivating questions:

• What are “order” and “disorder”?  

• What are the laws governing these quantities?  

• How do we define “information”?  

• What is the “ontological status” of information?  

• How is information signaled between two entities?  

• How is information processed to produce “meaning”?  

Energy, Work, and Entropy

• What is energy?

• What is entropy?

• What are the laws of thermodynamics?

• What is “the arrow of time”?
Maxwell’s Demon

James Clerk Maxwell, 1831-1879

See Netlogo simulation
Szilard’s solution

Leo Szilard, 1898-1964
Bennett and Landauer’s solution

Rolf Landauer, 1927–1999

Charles Bennett, b. 1943
Entropy/Information in Statistical Mechanics

- What is “statistical mechanics”?

- Describe the concepts of “macrostate” and “microstate”

Ludwig Boltzmann, 1844-1906
Entropy/Information in Statistical Mechanics

• What is “statistical mechanics”?

• Describe the concepts of “macrostate” and “microstate”.

• Combinatorics of a slot machine
  Possible fruits: apple, orange, cherry, pear, lemon
  – Microstates
  – Macrostates

Macrostate: “Three identical fruits”
  – How many microstates?

Macrostate: “Exactly one lemon”
  – How many microstates?

Macrostate: “At least 2 cherries”
  – How many microstates?
Boltzmann’s entropy, $S$

$$S = k \log W$$
Boltzmann entropy of a macrostate: \textit{natural logarithm of the number of microstates (W) corresponding to that macrostate} (you can ignore the “k”).
Boltzmann entropy of a macrostate: **natural logarithm of the number of microstates** \((W)\) **corresponding to that macrostate** (you can ignore the “\(k\)”).

Aside: What is a “natural logarithm”? 

\[ S = k \log W \]
Boltzmann entropy of a macrostate: *natural logarithm of the number of microstates* \( (W) \) *corresponding to that macrostate* (you can ignore the “\( k \)”).

Aside: What is a “natural logarithm”?

Examples from slot machine.
Boltzmann entropy of a macrostate: **natural logarithm of the number of microstates** \((W)\) **corresponding to that macrostate** (you can ignore the “\(k\)”).

Aside: What is a “natural logarithm”?

Examples from slot machine.

**Boltzmann entropy:** the more microstates that give rise to a macrostate, the more probable that macrostate is. Thus high entropy = more probable macrostate.
Boltzmann entropy of a macrostate: **natural logarithm of the number of microstates** \((W)\) **corresponding to that macrostate** (you can ignore the “\(k\)”).

\[
S = k \log W
\]

Aside: What is a “natural logarithm”?

Examples from slot machine.

**Bolzmann entropy**: the more microstates that give rise to a macrostate, the more probable that macrostate is. Thus high entropy = more probable macrostate.

**Second Law of Thermodynamics** (à la Boltzmann): Nature tends towards more probable macrostates
Boltzmann’s entropy, $S$

What does this have to do with the “arrow of time”?
Quick review of logarithms

- $\log_{10}$
- $\ln$
- $\log_2$
- $\log_a b = \log_{10} b / \log_{10} a$
  
  $= \log_n b / \log_n a$ for any $n$
Shannon Information / Entropy

What were his motivations for defining/studying information?

What is a “message source”?

Claude Shannon, 1916-2001
Boltzmann Entropy

\[ S(state) = k \ln W \]

Measured in units defined by \( k \) (often “Joules per Kelvin”)

Shannon Information

\[ H(message \ source) = -\sum_{i=1}^{N} p_i \log_2 p_i \]

Measured in “bits”

Message source has \( N \) “microstates” (or “messages”, e.g., words).

\( p_i \) is the probability of message \( i \).
$H(Nicky) = -\sum_i p_i \log_2 p_i$
$H(Jake) = -\sum_i p_i \log_2 p_i$
Netlogo Information-Content Lab
Go over Week 2 homework
Projects Schedule

• By Tuesday, October 18: Project “abstract” due

• By Thursday October 20: Feedback from me

• Week of October 24: Present project abstract to class

• Month of November: Time in class for help on projects

• December 9: Final paper due
Brainstorming on projects