uncertainty-based Information and the logic and organization of life.
Lab Assignments: 35% (ISE-483), 25% (SSIE-583)
- Complete 5 (best 4 graded) assignments based on algorithms presented in class
  - Lab 0: January 30th
    - Introduction to Python (No Assignment)
  - Lab 1: February 6th
    - Measuring Information (Assignment 1)

SSIE – 583 -Presentation and Discussion: 25%
- Present and lead the discussion of an article related to the class materials
  - Enginet students post/send video or join by Zoom
- First presentation January 30th
  - Mike Magid
  - Discussion by all
- Next Presentations February 13th
  - Presented by Grant Aguinaldo
Class Book

Lecture notes
- Chapter 1: “What is Life?”
  - posted online @ casci.binghamton.edu/academics/i-bic

Papers and other materials
- Life and Information
- Logical mechanisms of life (optional for SSIE 483)
    - Pattee, H. [1989], "Simulations, Realizations, and Theories of Life". In Artificial Life. C. Langton (Ed.). pp. 63-77
- Optional
  - Aleksander, I. [2002]. “Understanding Information Bit by Bit”. In: *It must be beautiful : great equations of modern science*. G. Farmelo (Ed.), Grant
uncertainty, about outcome. How much information is gained when symbol is known

- **on average**, how many yes-no questions need to be asked to establish what the symbol is
- “structure” of uncertainty in situations

Shannon’s entropy formula

\[
H_S = - \sum_{i=1}^{n} p(x_i) \log_2(p(x_i))
\]

For one alternative

\[
H_S \in [0, \log_2|X|]
\]

Uniform distribution
English entropy (rate)

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<th>Letter</th>
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Entropy: **4.14225193**

http://www.macfreek.nl/memory/Letter_Distribution

Hartley Measure: **H(26) 4.7004397**

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Entropy: **4.0849451**
entropy and meaning

- entropy quantifies information (surprise), but it does not consider information content
  - semantic aspects of information are irrelevant to the engineering problem in Shannon's conception

\[ H_S = - \sum_{i=1}^{n} p(x_i) \log_2(p(x_i)) \]

Holdin' me back
Gravity's holdin' me back
I want you to hold out the palm of your hand
Why don't we leave it at that?
Nothin' to say
When everything gets in the way
Seems you cannot be replaced
And I'm the one who will stay, oh

In this world, it's just us
You know it's not the same as it was
In this world, it's just us
You know it's not the same as it was
As it was, as it was
entropy according to probabilistic model

0th order model: equiprobable symbols

\[ H(A) = \log_2 |A| \]

Hartley Measure
\[ H(127) = 4.7548875 \]

1st order model: frequency of symbols

\[ H_s(A) = -\sum_{i=1}^{n} p(x_i) \log_2 p(x_i) \]

\[ H_S = 4.08 \]

2nd order model: frequency of digrams

Most common digrams: th, he, in, en, nt, re, er, an, ti, es, on, at, se, nd, or, ar, al, te, co, de, to, ra, et, ed, it, sa, em, ro.

3rd order model: frequency of trigrams

Most common trigrams: the, and, tha, ent, ing, ion, tio, for, nde, has, nce, edt, tis, oft, sth, men

4th order model: frequency of tetragrams

\[ H_S = 2.8 \]

including more structure reduces surprise

http://pages.central.edu/emp/LintonT/classes/spring01/cryptography/letterfreq.html
http://everything2.com/title/entropy+of+English
uncertainty

other measures to infer structure and organization in nature and society

- **Mutual Information**
  - Amount of information about one variable that can be gained (uncertainty reduced) by observing another variable

- **Information Gain (Kullback-Leibler Divergence)**
  - Difference between two probability distributions $p$ and $q$,
    - average number of bits per data point needed in order to represent $q$ (model approximation) as it deviates from $p$ (“true” or theoretical distribution)

- **Transfer Entropy**
  - transfer of information between two random processes in time
    - Amount of information (in bits) gained, or uncertainty lost, in knowing future values of $Y$, knowing the past values of $X$ and $Y$.

\[
I(X; Y) = \sum_{i=1}^{n} \sum_{j=1}^{m} p(x_i, y_j) \log_2 \frac{p(x_i, y_j)}{p(x_i)p(y_j)}
\]

\[
I(X; Y) = H(X) + H(Y) - H(X, Y)
\]

\[
IG(p(X), q(X)) = \sum_{i=1}^{n} p(x_i) \log_2 \frac{p(x_i)}{q(x_i)}
\]

\[
T_{X \to Y} = H(Y_t | Y_{t-1:t-L}) - H(Y_t | Y_{t-1:t-L}, X_{t-1:t-L})
\]
Mutual Information
- Amount of information about one variable that can be gained (uncertainty reduced) by observing another variable

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$I(X; Y) = H(X) + H(Y) - H(X, Y)$

$IG(p(X), q(X)) = \sum_{i=1}^{n} p(x_i) \log_2 \frac{p(x_i)}{q(x_i)}$

$T_{X \to Y} = H(Y_t | Y_{t-1:t-L}) - H(Y_t | Y_{t-1:t-L}, X_{t-1:t-L})$
Information as decrease in uncertainty.

\[
H(A) = \log_2 |A|
\]

- Measured in bits
- Number of Choices


Including more structure reduces surprise

Information is surprise

\[
H_S(A) = - \sum_{i=1}^{n} p(x_i) \log_2 (p(x_i))
\]

- Measured in bits
- Probability of alternative

Holdin' me back
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As it was, as it was
Aren't you the guy who tried to
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“syntactic” surprise But what about function and meaning (semantics)?

rate of removing uncertainty of each symbol
how to identify it?

**List of properties**
- Growth
- Metabolism
- Reproduction
- Adaptability
- Self-maintenance (autonomy)
- Self-repair
- Self-assembly
- Reaction
- Evolution
- Choice

**Threshold of complexity**
- Closure (metabolic, functional)
  - Categorization and Control
  - Function (self-reference)
- Open-ended evolution
- (genomic) Information

Is life Fuzzy?

---

Is there a synthetic criteria? How general can it be?

---

viruses
candle flames
the Earth
hurricanes
robots
self-assembling wires?

---

rucha@indiana.edu
casci.binghamton.edu/academics/i-bic
Chris Langton

- Artificial Life can contribute to theoretical biology by locating life-as-we-know-it within the larger picture of life-as-it-could-be
- life as a property of the organization of matter, rather than a property of the matter which is so organized
  - The way information is processed
- Whereas biology has largely concerned itself with the material basis of life, Artificial Life is concerned with the formal basis of life.
  - views an organism as a large population of simple machines
  - Synthetic approach or emergent behavior


- The logical mechanisms of life
- Chris Langton
- Artificial Life can contribute to theoretical biology by locating life-as-we-know-it within the larger picture of life-as-it-could-be
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- life-as-it-could-be
scientific approaches of life

alternative concepts of mechanism

- **Analytical**
  - Reduction to (non-living) components
    - Reductionism
    - *Material* mechanism
    - Life is complicated chemistry
    - Tied to specific materiality
    - Does not allow emergence
      - Function, control, measurement, categorization, information are unnecessary "illusions"

- **Synthetic**
  - Construction from components
    - Holist
    - *Logical* mechanism
    - Life is *Organization*
      - Networks of components
    - Universal or implementation independent
    - Emergence
      - "bottom-up" approach
what is non-life-as-it-could be?

criteria for deciding good simulations or realizations?

- **Alife must be compared to something**
  - What is the formal/logical threshold of complexity?
    - **Hard Alife** must provide a set of rules to distinguish Alife from artificial matter
    - **Weak Alife** needs to be able to test design principles of life with simulations
      - Bio-inspired computing needs only to produce good results in engineering problems
  - Comparison to “life-like” behavior is too subjective

- **theories of life**
  - Alife methodology requires existing theories of life to be compared against
    - constrained by our theories or “fiction”
  - contributes to the meta-methodology of Biology
    - test and improve beyond material constraints, such as the incomplete fossil record or measurement of cellular activity

---

readings

- **Class Book**

- **Lecture notes**
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  - Chapter 2: The logical Mechanisms of Life
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