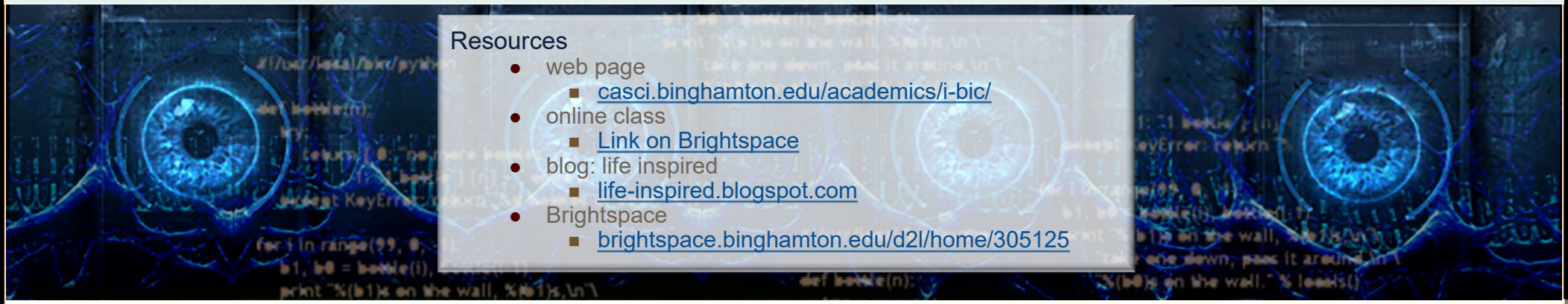
lecture 3


uncertainty-based
Information and
and logic and organization of life
Apex
Midrib
Pinnule(s)
Pinna

evolutionary systems and biologically-inspired computing



Resources

- web page
  - casci.binghamton.edu/academics/i-bic/
- online class
  - Link on Brightspace
- blog: life inspired
  - life-inspired.blogspot.com
- Brightspace
  - brightspace.binghamton.edu/d2l/home/305125

ISE-483/SSIE-583 - spring 2023

luis m. rocha

samer abubaker

office hours:
???
EB K1 and zoom link on Brightspace

office hours:
thursdays 9:00- 11:30am, EB S04
binghamton.zoom.us/my/luismrocha

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casci.binghamton.edu/academics/i-bic

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key events coming up

- Labs: 35% (ISE-483)
  - Complete 5 (best 4 graded) assignments based on algorithms presented in class
    - Lab 0 : January 29th
      - *Introduction to Python* (No Assignment)
        - Delivered by SSIE583 Group 2
    - Lab 1 : February 5th
      - *Measuring Information* (Assignment 1)
        - Delivered by SSIE583 Group 3
- 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 29th
    - Langton, C. [1989]. “Artificial Life” In *Artificial Life*. C. Langton (Ed.). Addison-Wesley. pp. 1-47.
      - Pattee, H. [1989], "Simulations, Realizations, and Theories of Life". In *Artificial Life*. C. Langton (Ed.). Addison-Wesley. pp. 63-77.
        - Presented by Amahury Lopez Diaz
        - Discussion by all

readings

- Class Book
  - Floreano, D. and C. Mattiussi [2008]. *Bio-Inspired Artificial Intelligence: Theories, Methods, and Technologies*. MIT Press. **Preface**.
    - Nunes de Castro, Leandro [2006]. *Fundamentals of Natural Computing: Basic Concepts, Algorithms, and Applications*. Chapman & Hall. **Chapter 1,** pp. 1-23.
- Lecture notes
  - Chapter 1: "What is Life?"
    - posted online @ http://informatics.indiana.edu/rocha/i-bic
- Papers for Presentations
  - Logical mechanisms of life (optional for SSIE 483)
    - Langton, C. [1989]. "Artificial Life" In *Artificial Life*. C. Langton (Ed.). Addison-Wesley. pp. 1-47.
      - Pattee, H. [1989], "Simulations, Realizations, and Theories of Life". In Artificial Life. C. Langton (Ed.). pp. 63-77
- Other Readings
  - Life and Information
    - Dennet, D.C. [2005]. "Show me the Science". *New York Times*, August 28, 2005
    - Polt, R. [2012]. "Anything but Human". *New York Times*, August 5, 2012
  - Optional
    - Gleick, J. [2011]. *The Information: A History, a Theory, a Flood*. Random House. **Chapter 8**.
    - Cobb, Matthew. [2013]. "1953: When Genes Became 'Information'." *Cell* **153** (3): 503-506.
    - Aleksander, I. [2002]. "Understanding Information Bit by Bit". In: *It must be beautiful : great equations of modern science*. G. Farmelo (Ed.), Grant
    - James, R., and Crutchfield, J. (2017). Multivariate Dependence beyond Shannon Information. Entropy, 19(10), 531.
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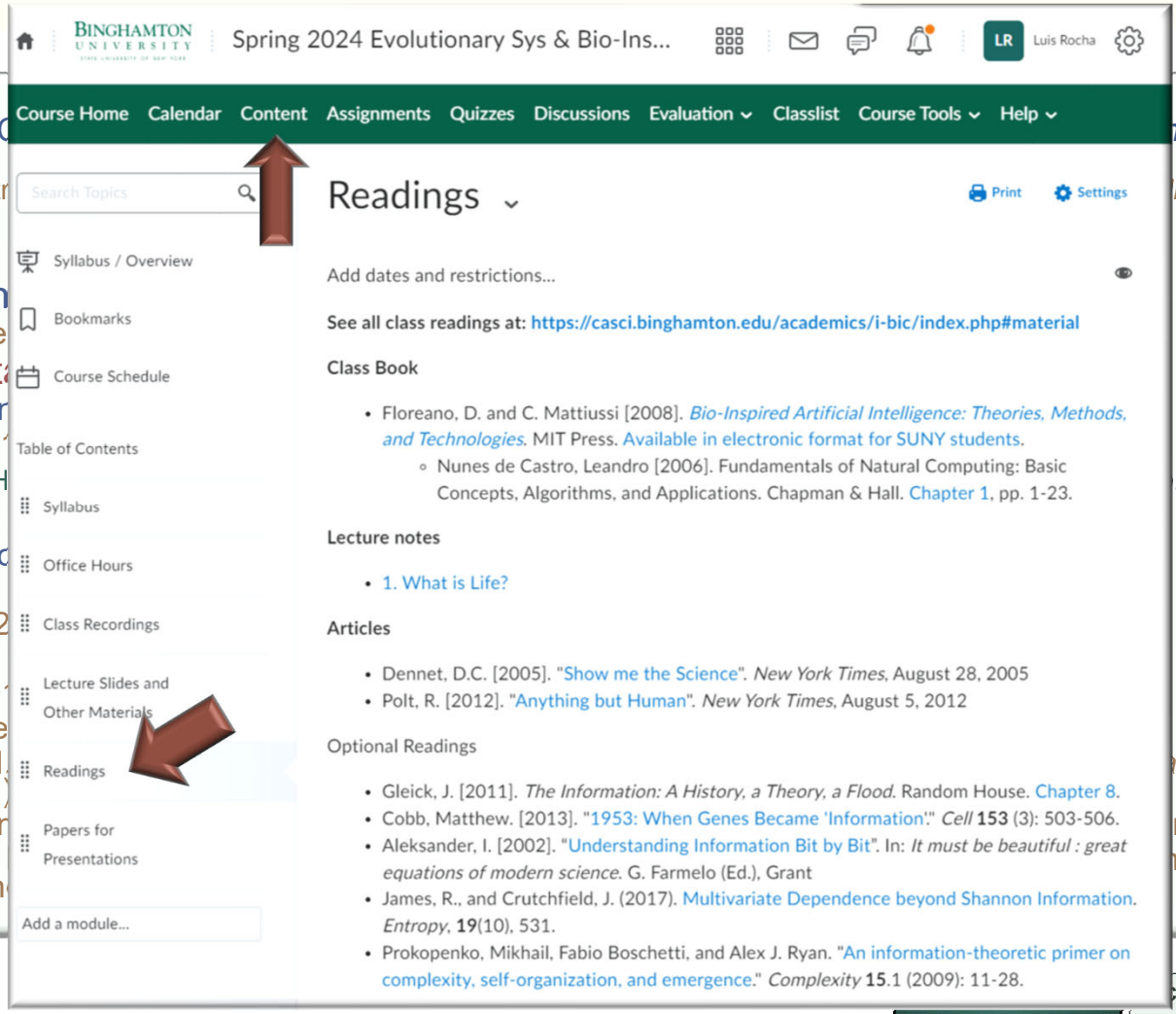


…nologies. MIT Press.

…ications. Chapman & Hall.

. 63-77

…tions of modern science. G.

…ntropy, 19(10), 531.

…mplexity, self-organization,

what it measures

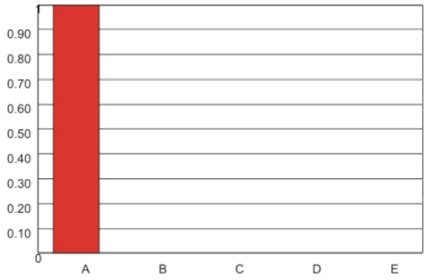
uncertainty, about outcome. How much information is gained when symbol is known

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

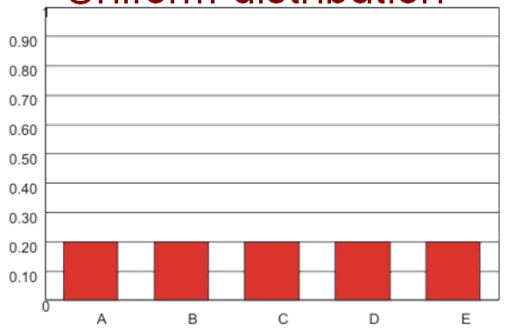
$$H_S \in= -\sum_{i=1}^{n} p(x_i)\log_2\left(p(x_i)\right)$$

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

For one alternative



Uniform distribution



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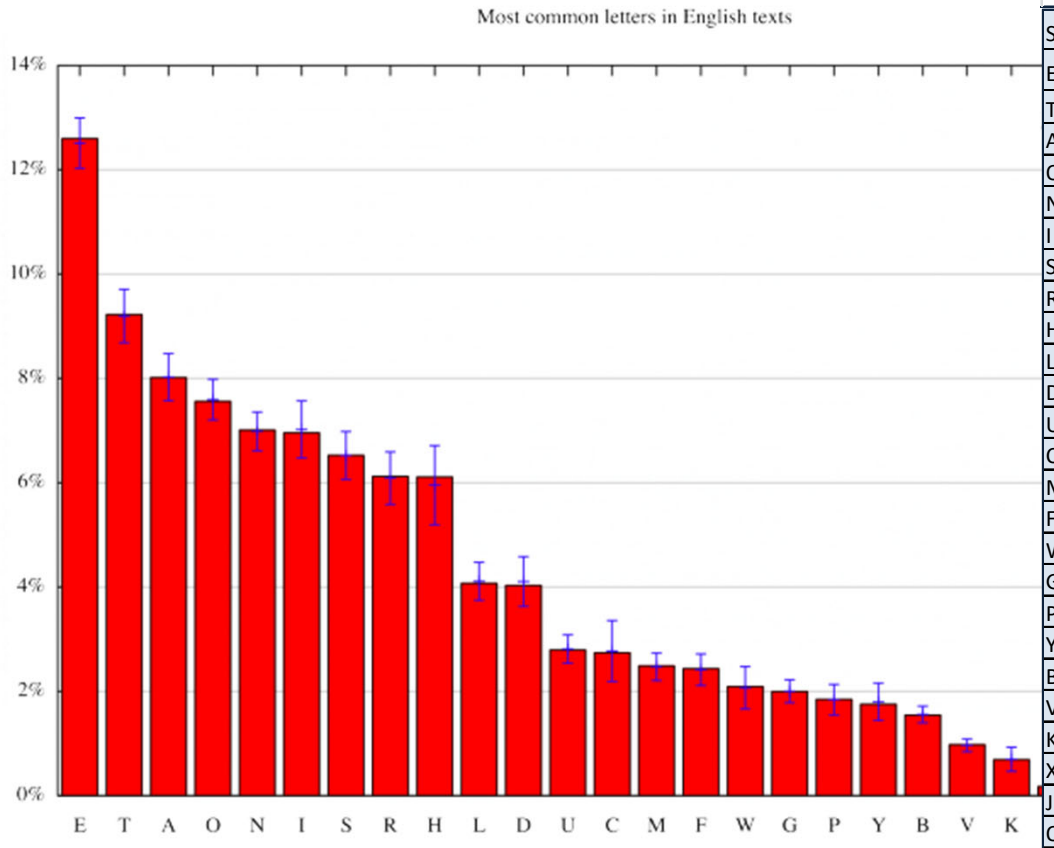
from letter frequency

	p(x)	log2(p(x))	-p(x).log2(p(x))
e	0.124167	-3.0096463	0.373698752
t	0.096923	-3.3670246	0.326340439
a	0.082001	-3.6082129	0.295877429
i	0.076805	-3.7026522	0.284382943
n	0.076406	-3.7101797	0.283478135
o	0.07141	-3.8077402	0.271908822
s	0.070677	-3.8226195	0.270170512
r	0.066813	-3.903723	0.260820228
l	0.044831	-4.4793659	0.200813559
d	0.036371	-4.7810716	0.173891876
h	0.035039	-4.8349111	0.169408515
c	0.034439	-4.8598087	0.167367439
u	0.028777	-5.11894	0.147307736
m	0.028		094755
f	0.023		220629
p	0.020517	-5.6211617	0.114205704
y	0.018918	-5.7240814	0.108289316
g	0.018119	-5.7863688	0.104842059
w	0.013523	-6.2084943	0.083954364
v	0.012457	-6.3269343	0.078812722
b	0.010658	-6.5519059	0.069830868
k	0.00393	-7.9911852	0.031406876
x	0.002198	-8.8294354	0.019409218
j	0.001998	-8.9669389	0.017919531
q	0.000933	-10.066609	0.009387113
z	0.000599	-10.705156	0.006412389
		Entropy	**4.14225193**

Hartley Measure
H(|26|) 4.7004397



	p(x)	log2(p(x))	-p(x).log2(p(x))
Space	0.18288	-2.4509943	0.448249175
E	0.10267	-3.2839625	0.337152952
T	0.07517	-3.7336995	0.280662128
A	0.06532	-3.9362945	0.257125332
O	0.06160	-4.0210249	0.247678132
N	0.05712	-4.1298574	0.235897914
I	0.05668	-4.1409036	0.234724772
S	0.05317	-4.2332423	0.225081718
R	0.04988	-4.3254212	0.215748053
H	0.04979	-4.3281265	0.215478547
L	0.		63015644
D	0.		61811184
U	0.02276	-5.4574834	0.124201198
C	0.02234	-5.4844363	0.122504535
M	0.02027	-5.6248177	0.113990747
F	0.01983	-5.6561227	0.112164711
W	0.01704	-5.8750208	0.100104113
G	0.01625	-5.9435013	0.096576215
P	0.01504	-6.0547406	0.091082933
Y	0.01428	-6.1301971	0.087518777
B	0.01259	-6.3117146	0.079456959
V	0.00796	-6.9728048	0.055511646
K	0.00561	-7.4778794	0.041948116
X	0.00141	-9.4709063	0.013346416
J	0.00098	-10.001987	0.009754119
Q	0.00084	-10.222907	0.008554069
Z	0.00051	-10.929184	0.005604998
		Entropy	**4.0849451**

Hartley Measure
H(|27|) 4.7548875

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

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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

We were good, we were gold
Kinda dream that can't be sold
We were right 'til we weren't
Built a home and watched it burn

Mm, I didn't wanna leave you
I didn't wanna lie
Started to cry, but then remembered I
I can buy myself flowers
Write my name in the sand
Talk to myself for hours
Say things you don't understand
I can take myself dancing
And I can hold my own hand
Yeah, I can love me better than you can

$$H_S \in= -\sum_{i=1}^{n} p(x_i)\log_2\left(p(x_i)\right)$$

wdeo eog geWl ewr e deorw
aainhmta d rettoeKandl dsbc
eeeier ntw hWttr ewrgliwe
oriaedatmht ndc lwn thuaBeuib

eanm dtaI vewdi nl o unMay
al indn nItawde i
cl rettedtebrmSrb reemntuy da oth e
uolrawe blnffmsyylc es
niWe dty ne rsehmntiama
arem TIl ssytrfu fkoooh
nyoh e gdodudtnaraustsi tnynS
atf Ik emcnegyn snlicad a
hmhydcndAwannoo n dl I a
tlhI eatta nom Ybrueny h ee oaavn cce

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entropy according to probabilistic model

0th order model: equiprobable symbols

$$H(A) = \log_2 |A|$$

Hartley Measure
H(|27|) 4.7548875

XFOML RXKHRJFFJUJ ZLPWCFWKCYJ FFJEYVKCQSGXYD QPAAMKBZAACIBZLHJQD

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

OCRO HLI RGWR NMIELWIS EU LL NBNESBEYA TH EEI ALHENHTTPA OOBTTVA NAH BRL

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.

ON IE ANTSOUTINYS ARE T INCTORE ST BE S DEAMY
ACHIN D ILONASIVE TUCOOWE AT TEASONARE FUSO
TIZIN ANDY TOBE SEACE CTISBE

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

IN NO IST LAT WHEY CRATICT FROURE BERS GROCID
PONDENOME OF DEMONSTURES OF THE REPTAGIN
IS REGOACTIONA OF CRE

4th order model: frequency of tetragrams

H_S = 2.8

THE GENERATED JOB PROVIDUAL BETTER TRAND THE
DISPLAYED CODE ABOVERY UPONDULTS WELL THE
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including more structure reduces surprise

http://pages.central.edu/emp/LintonT/classes/spring01/cryptography/letterfreq.html

http://everything2.com/title/entropy+of+English

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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.

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

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

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

$$T_{X\to Y} = H(Y_t|Y_{t-1:t-L}) - H(Y_t|Y_{t-1:t-L}, X_{t-1:t-L})$$

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other measures to infer structure and organization in nature and society

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  - n)
  - m processes in time
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Tuyrtsfq&Wjfinslx?%

Uwtptujspt1&R rpmfmq&Kfgnt%Gtxhmjyyn&fsi%Fqj}%D3&W~fs3%'Fs%
nsktwr fyrts%ymjtwjyh%uwr jw&ts%htr uqj}ny~1&xjq&twlfsnjfyrts1%
fsi%jr jwljshj3'Htr uqj}ny~6:36%755>.?%6627=3

Ofr jx1&W3&fsi%Hwzyhmknjq1&D3%756<.3%R zqxn{fwfyj%Ijujsijshj%
gj~tsi%Xmfssts%Nsktwr fyrts'3%Jsywtu~1%6>65.1&:863

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

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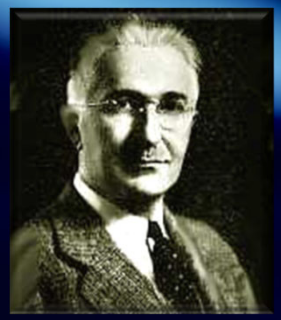
information as decrease in uncertainty .

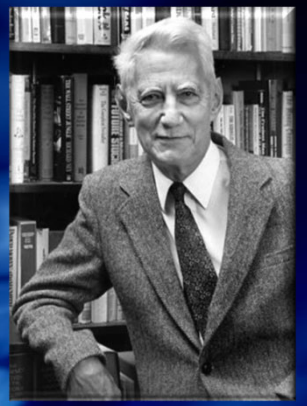


$$H(A) = \log_2 |A|$$

Measured in bits

Number of Choices

Hartley, R.V.L., "Transmission of Information", *Bell System Technical Journal*, July 1928, p.535.



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

Measured in bits

Probability of alternative

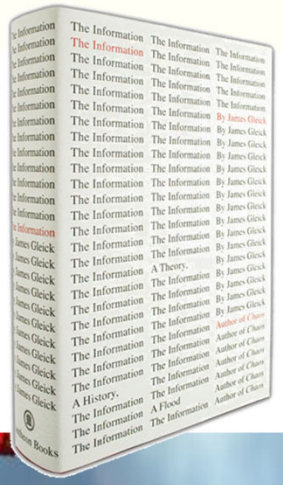
including more structure reduces surprise

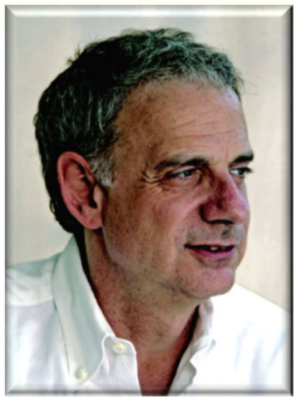
information is surprise

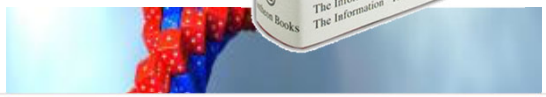
C. E. Shannon [1948], "A mathematical theory of communication". *Bell System Technical Journal*, **27**:379-423 and 623-656

information of sequential messages

rate of removing uncertainty of each symbol





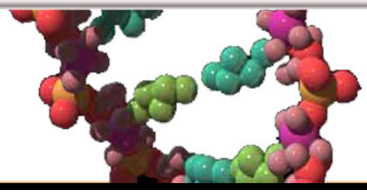


Holdin' me back
Gravity's holdin' me back
I want you to hold out the palm of your hand
Why don't we leave it at that?
Nothin' to say
When everything gets in the way
Seems you cannot be replaced
And I'm the one who will stay, oh

Tuyrtsfq%Wjfinslx?%

Uwtptujspt!%R rpmfnq%Kfgnt%Gtxhmjyyn%fsi%Fqj}%O3%W~fs3%Fs%
nsktwr fyrts%ymjtwjyh%uwnr jw%ts%htr uqj}ny~!%xjdk%twlfsn{fyrts!%
fsi%jr jwljshj3'Htr uqj}ny~6:36%755>.?%6627=3

Ofr jx!W3!%fsi%Hwzyhmknjq!%O3%756<.3%R zqn{fwfyj%Ijujsijshj%
gj~tsi%Xmfssts%Nsktwr fyrts'3%Jsywtu~!%>-65.!%:863



"syntactic" surprise But what about function and meaning (semantics)?

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