UC Berkeley School of Information

Theorizing Information

Concepts of Information i218
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Itinerary 2/20

Background: what is the "information" of "information theory"

Basic concepts: measuring information

Probability and redundancy

Applications

"The Bandwagon"

The Theory-of-Information Food Chain

A rough but useful distinction: TOFI "Producers" and "Consumers" (Brian Smith)

TOI Producers:

People concerned with "theories or inquiries that address information as a phenomenon in its own right, and who therefore bring forward specific theories about it. … people or theories or investigations that analyse what information is."

I.e., information theory, philosophers, theories of computation, documentalists & information studies,

The Theory-of-Information Food Chain

TOI Consumers (or "developers")

"People, theories, fields, etc.,… which employ the notion of information substantively but who more rely on information itself, or a concept of information, 'being available' for substantive use."

E.g., geneticists who theorize DNA as an information-carrier, psycholinguists who deploy information theory in studies of information processing, economists…

BUT: These theories may be "grounded" in a prior theory of information, linked to it, or rely on it, but usually wind up reinterpreting the notion for their own purposes.(GN)

Two Producers' Theories of Information

Two "producers" of theories of information

- "Information theory" ("mathematical theory of communication).
  - Some applications of MTC
- Philosophical accounts of (semantic) information

Predecessors

information is a very elastic term, and it will be necessary to set up a more specific meaning ...

There must be a group of symbols…the sender mentally selects a symbols and causes the attention of the receiver to be directed ... At each selection there are eliminated all of the other symbols which might have been chosen ... more and more possible symbols sequences are eliminated ... the information becomes more precise ... Inasmuch as the precision of the information depends upon what ... might have been .. Reasonable to hope to find in the number of these sequences the desired quantitative measure .... desirable ... to eliminate the psychological factors involved and to establish a measure of information in terms of purely physical quantities.

R. V. Hartley "The Measurement of Information," 1928


VOLUME VII JULY, 1928 NUMBER 3

THE BELL SYSTEM
TECHNICAL JOURNAL

DEVOTED TO THE SCIENTIFIC AND ENGINEERING ASPECTS OF ELECTRICAL COMMUNICATION

AMERICAN TELEPHONE AND TELEGRAPH COMPANY
NEW YORK

50c per Copy *$1.50 per Year*

Narrowing the problem down

"The word communication will be used here in a very broad sense to include all of the procedures by which one mind may affect another. This, of course, involves not only written and oral speech, but also music, the pictorial arts, the theater, the ballet, and in fact all human behavior."
Weaver, *The Math. Theory of Communication*

Narrowing the problem down

"Relative to the broad subject of communication, there seem to be problems at three levels. Thus it seems reasonable to ask, serially:

LEVEL A. How accurately can the symbols of communication be transmitted? (The technical problem.)

LEVEL B. How precisely do the transmitted symbols convey the desired meaning? (The semantic problem.)

LEVEL C. How effectively does the received meaning affect conduct in the desired way? (The effectiveness problem.)

Cf syntax/semantics/pragmatics; form/meaning/use…

"The technical problem"

The technical problems are concerned with the accuracy of transference from sender to receiver of sets of symbols (written speech), or of a continuously varying signal (telephonic or radio transmission of voice or music), or of a continuously varying two-dimensional pattern (television), etc. Mathematically, the first involves transmission of a finite set of discrete symbols, the second the transmission of one continuous function of time, and the third the transmission of many continuous functions of time or of one continuous function of time and of two space coordinates.

The Mathematical Theory of Communication

Rarely does it happen in mathematics that a new discipline achieves the character of a mature developed scientific theory in the first investigation devoted to it... So it was with information theory after the work of Shannon.

A. I. Khintchin, 1956

Elements of the Theory

"The fundamental problem of communication is that of reproducing at one point a message selected at another point."

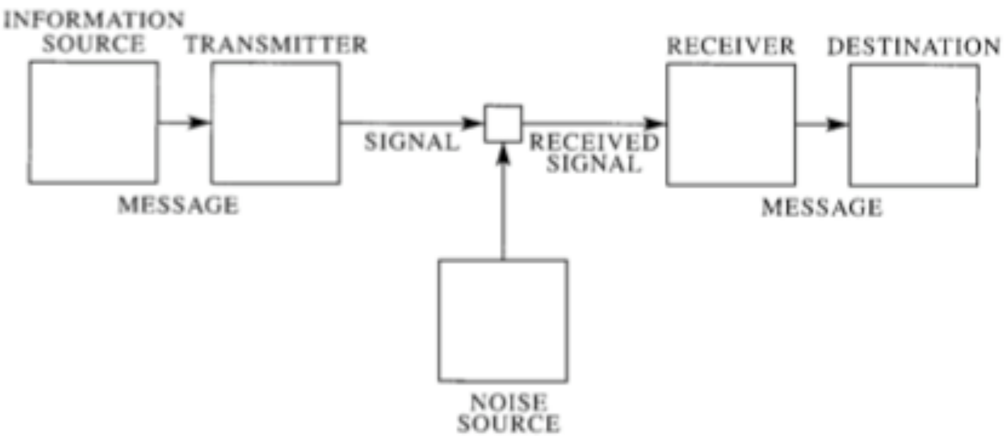
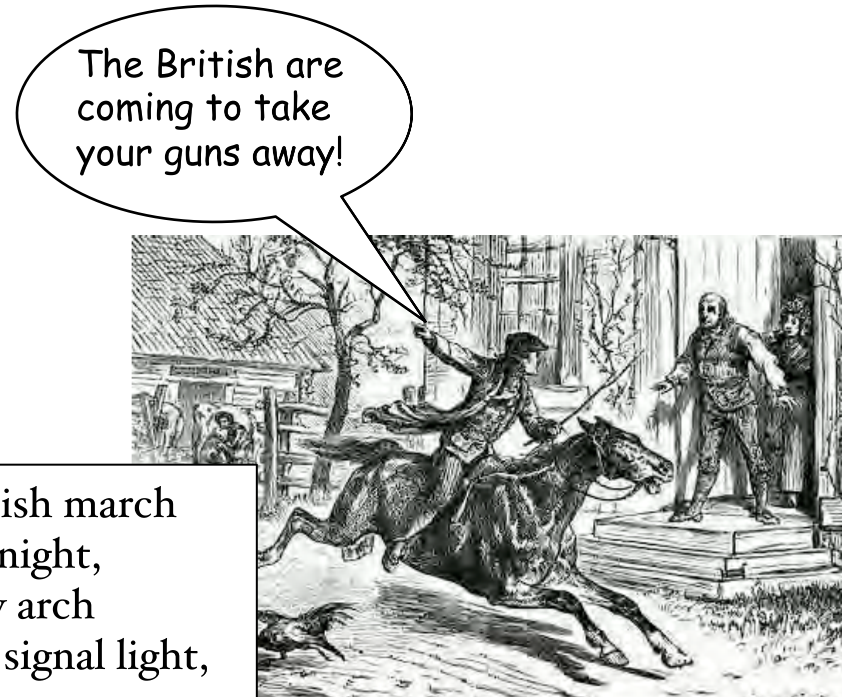


Fig. 1—Schematic diagram of a general communication system.

Varieties of Signals

Form of signal and channel is irrelevant; matters only if signal is discrete or continuous.

Varieties of Signals



He said to his friend, "If the British march
By land or sea from the town to-night,
Hang a lantern aloft in the belfry arch
Of the North Church tower as a signal light,
--One if by land, and two if by sea;
And I on the opposite shore will be,
Ready to ride and spread the alarm
Through every Middlesex village and farm...

Reducing Uncertainty

Information is that which reduces uncertainty in a choice situation.

Weaver: "… in this new theory the word information relates not so much to what you *do* say as to what you *could* say. That is, information is a matter of your freedom of choice when you select a message."

Anti-semantics

"The fundamental problem of communication is that of reproducing at one point a message selected at another point. Frequently the messages have meaning; that is they refer to or are correlated according to some system with certain physical or conceptual entities. These semantic aspects of communication are irrelevant to the engineering problem. The significant aspect is that the actual message is one selected from a set of possible messages." Shannon, 1948

I.e., "Communication" ends when it is determined ***which*** message was sent.

Anti-semantics

First off, we have to be clear about the rather strange way in which, in this theory, the word "information" is used; for it has a special sense which... must not be confused at all with meaning. It is surprising but true that, from the present viewpoint, two messages, one heavily loaded with meaning and the other pure nonsense, can be equivalent as regards information.

Warren Weaver, 1949

Reducing Uncertainty

Hartley: Information content is proportional to the number of symbols, size of the set of possibilities.

$$H = n \log s$$

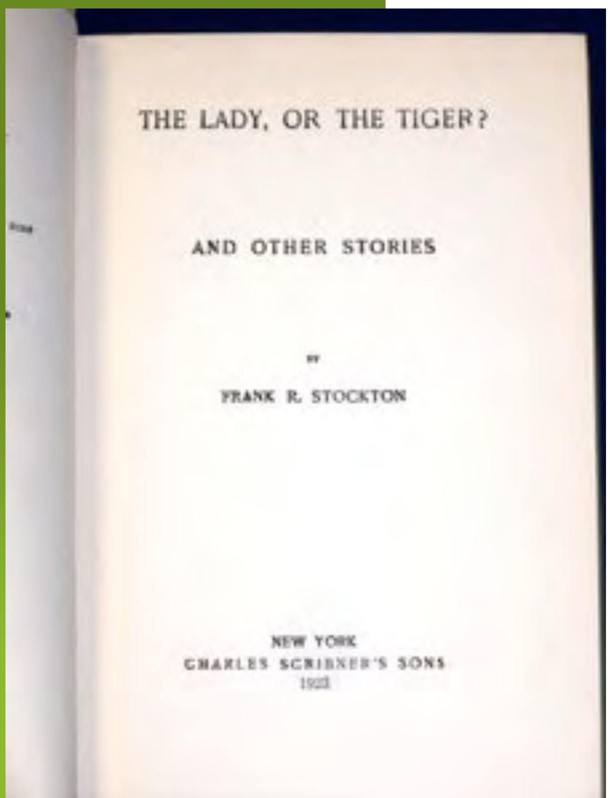
Where H = amount of information, n = number of symbols transmitted, and s = size of the "alphabet" (dot-dash, alphabet, Chinese logographs, etc.)

E.g., Information in all possible 3-letter strings =

$3 * \log_2 (26) = 3*4.7 = 14.1$ bits

Why "*log* s"?

A simple instance



In the very olden time there lived a semi-barbaric king, whose ideas, though somewhat polished and sharpened by the progressiveness of distant Latin neighbors, were still large, florid, and untrammeled, as became the half of him which was barbaric...
"The Lady or the Tiger," Frank Stockton, 1882

A simple instance

"Did the tiger come out of that door, or did the lady?"

"The Lady and the Tiger," Frank Stockton, 1882

Arm up → right door
Arm down → left door

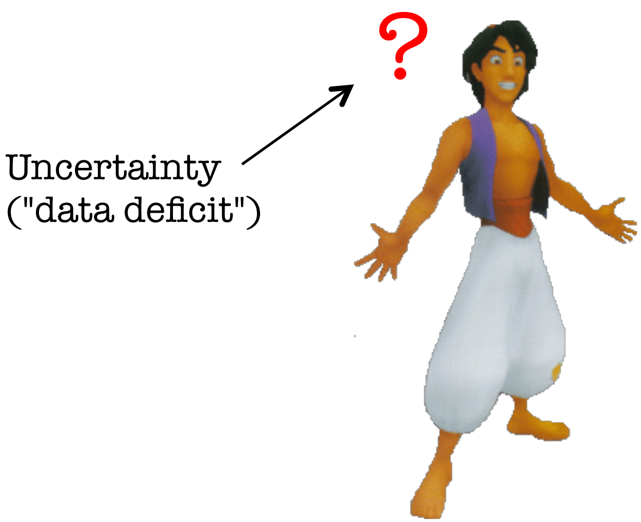
A simple instance

Arm up → right door
Arm down → left door

...the amount of information is defined, in the simplest cases, to be measured by the logarithm of the number of available choices. It being convenient to use logarithms to the base 2... This unit of information is called a 'bit' ... a condensation of 'binary digit'.

$Log_2\ 2 = 1$ (i.e., $2^1 = 2$)

Signal contains 1 bit of information ("informativeness," "surprisal")



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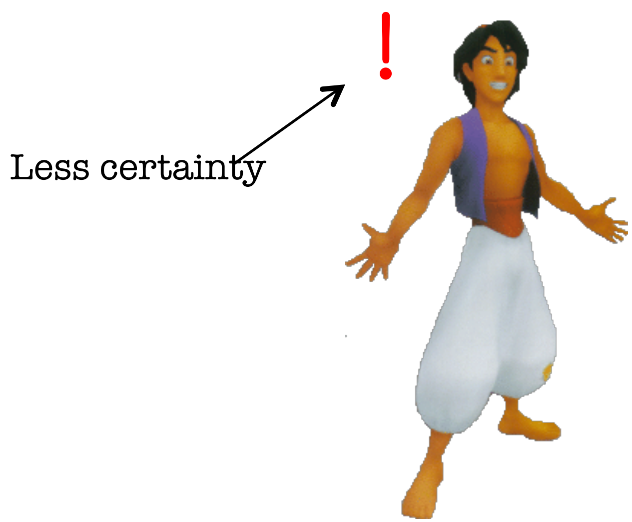
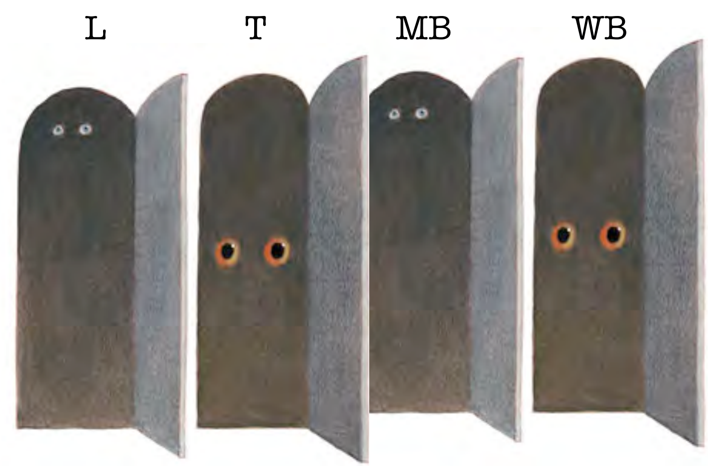


Reducing Uncertainty

"Did the tiger come out of that door, or did the lady, or did the wild boar, or did the mortgage broker?"

$\log_2 4 = 2 \rightarrow$ 2 bits of information (i.e., $2^2 = 4$)

L down R up → door 1
L up R down → door 2
L down R down → door 3
L up R up → door 4



It's not about semantics

"The significant aspect is that the actual message is one selected from a set of possible messages."

Arm up → one signal
Arm down → another signal

The effects of probability

Signals are not equiprobable…

_ _ _   _ _ _   _ _ _   _ _ _ _

The effects of probability

Signals are not equiprobable…

_ I _   _ _ _   _ _ _   _ I _ S

The effects of probability

Signals are not equiprobable…

K _ X   _ _ _ _ _ _   K _ _ _

The effects of probability

Signals are not equiprobable…

Freq. of initial letters of English words

T	15.2%
A	11.4%
H	8.5 %
W	7.0%
F	3.5 %

Knowing that a message begins with T reduces the set of possible messages by 84.8%

Knowing that a message begins with F reduces the set of possible messages by 96.5%

→ #F__ is more informative than #T___

The effects of probability

What every "Wheel of Fortune" viewer knows:

_o_e_ _   a_e   _e_ _   i _ _o_ _a_ i _ e   _ _a_
_o_ _o_a_ _ _

The effects of probability

What every "Wheel of Fortune" viewer knows:

_o_e_ _ a_e _e_ _ i _ _o_ _a_ i _ e _ _a_ _o_ _o_a_ _ _

V_w_ls _r_ l_ss _nf_rm_t_v_ th_n c_ns_n_nts

The effects of probability

What every "Wheel of Fortune" viewer knows:

_o_e_ _ a_e _e_ _ i _ _o_ _a_ i _ e _ _a_ _o_ _o_a_ _ _

V_w_ls _r_ l_ss _nf_rm_t_v_ th_n c_ns_n_nts

How long would it take to finish a game if the answers were Polish surnames? Licence-plate numbers?

The effects of probability

Morse(?)-Vail Code: (roughly) fewer bits for most common letters:

A: .- B: -... C: -.-. D: -.. E: .

F: ..-. G: --. H: .... I: .. J: ---.

K: -.- L: .-.. M: -- N: -. O: ---

P: .--. Q: --.- R: ._. S: ... T: -

U: .._ V: ...- W: .-- X: -..- Y: -.-- Z: --..

1-BIT	2-BITS	3-BITS	4-BITS
E,T	I,A,N,M	S,U,R,W,D,O,G,K	H,V,F,L,P,J,B,X,C,Z,Q,Y

The effects of state-dependence (transitional probabilities)

Signals are not ergodic (zero-memory).

Overall frequency of *h* = .06

Overall frequency of s = .06

But probabilities are not the same after an initial t:

P(h) /#t__ > P(s) /#t__

i.e., a signal string beginning with *Ts*… is more informative than one beginning with *Th*…

The effects of probability

Signals are not equiprobable…

…if we are concerned with English speech, and if the last symbol chosen is “the,” then the probability that the next word be an article, or a verb form other than a verbal, is very small. This probabilistic influence stretches over more than two words, in fact. Weaver, *Math. Theory of Comm.*

The effects of probability

How to accommodate probability?

Hartley's formulation for equiprobable symbols:

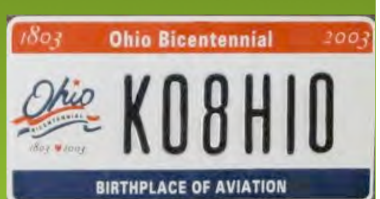
$$H = n \log s$$

Shannon's formulation for stochastic processes:

$$H = -\sum_{p_i} \log_2 p_i$$

Uncertainty = the weighted sum of the (log of) improbabilities of messages.*

- If average $p_i = 1$, $H = 0$
- If average $p_i = .5$, H reaches maximum of 1 ($\log_2 .5 = -1$)
- If the set of symbols/messages is larger, H increases.
- Contrast info in letters & numbers)



*"*It is misleading (though sometimes convenient) to say that one or the other message conveys unit information. The concept of information applies, not to the individual messages (as the concept of meaning would), but rather to the situation as a whole." Weaver p9*

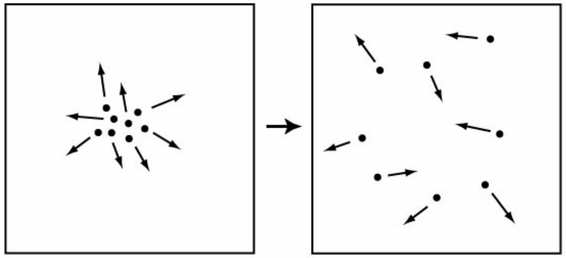
The entropy connection

The informativeness of a message varies inversely as its probability:

$$H = -\sum_{pi} log_2 p_I$$

H is the "entropy" of the message.

> The quantity which uniquely meets the natural requirements that one sets up for "information" turns out to be exactly that which is known in thermodynamics as *entropy*. [. . .] Thus when one meets the concept of entropy in communication theory, he has a right to be rather excited—a right to suspect that one has hold of something that may turn out to be basic and important. Shannon

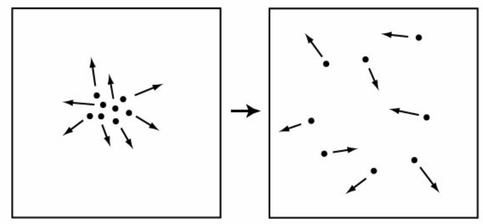


The entropy connection

An informative desk

Why the connection? Information and disorder

$H = -\sum_{pi} log_2 p_I$



Consequences of low entropy

Low entropy = more predictability

Redundancy permits compression

*abc* _ _ _

Consequences of low entropy

Redundancy permits compression

dabchick

Consequences of low entropy

Redundancy permits compression

dabchick

These are the times that try men's souls.

Thes ar th time tha tr men' soul

The ar th tim th tr men' sou

Redundancy & pattern permits compression

Cf Dictionary compression: "small bits"

chromate
chromatic
chromatin
chromatogram
chromatograph
chromatography
chrome
chromic
chromium
chromosome (= 86 characters)

Redundancy & pattern permits compression

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chromatogram
chromatograph
chromatography
chrome
chromic
chromium
chromosome (86 characters)

→ chromate F7ic F8n F7ogram FBph FDy F5e F5ic F6um F5osome (27 characters)

Compressing ZIP codes?

Consequences of low entropy

Redundancy facilitates error detection and signal recovery in noisy channels

Redundancy facilitates processing

I know that the boy will come.

I know the boy will come.

I know that she will come.

I know she will come.

Applications

Applications of Information Theory

An example: "Optimizing information density through syntactic reduction" (Roger Levy & Florian Jaeger)

Assumption (per Shannon): speakers structure utterances to minimize information density (amount of information per utterance unit). I.e. speakers try to spread out the surprisal.

"speakers structure their utterances in ways that buy them time to prepare difficult words and phrases."

Cf effects on contraction, speech rate, etc.

Phonetics: speakers lengthen syllables of less familiar words. *antimetabole* vs *antidepressant*…

Applications of Information Theory

An example: Optimizing information density through syntactic reduction (Roger Levy & Florian Jaeger)

Syntactic reduction:

(1) How big is [NP the family$_i$ [RC (*that*) you cook for i]]?

Assume information density is higher when relativizer is omitted. (because then the 1st word of the rel. clause does double work.)

Then "full forms (overt relativizers) should be used more often when the information density of the RC *would be high if the relativizer were omitted.*"

1. I believe (that) that drug makes you sleepy.
2. I believe (that) this drug makes you sleepy.

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Table 1 Rate of optional that (% OPT) before pronoun that and this in CCs

	WSJ		BC		SWBD		Total	
Subject	% OPT	Total	% OPT	Total	% OPT	Total	% OPT	Total
Pronoun this	26%	39	58%	19	18%	50	28%	108
Pronoun that	2%	41	33%	6	9%	675	9%	722
Fisher's Exact		**p<0.01**		**n.s.**		**p<0.05**		**p<0.001**

Predicting word-length choices

"Speakers actively choose shorter word in predictable contexts" Mahowald et al. 2012

supportive-context: Susan was very bad at algebra, so she hated... 1. math 2. mathematics (67%)

neutral-context: Susan introduced herself to me as someone who loved... 1. math 2. mathematics (56%).

Applications of Information Theory

Assume information density is higher when relativizer is omitted. Then "full forms (overt relativizers) should be used more often when the information density of the RC *would be high if the relativizer were omitted.*"

Contrast the effects of pronoun case…

I believe (that) she took the test.

I believe (that) the girl took the test.

… and NP complexity:

I believe (that) the student who failed the test has dropped the course.

I believe (that) the student has dropped the course.

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Development of MTC

Development of information theory in mathematics, engineering, computer science

e.g., work on compression, IR, etc.

Influence/cross-fertilization w/ biology & physics ("It from Bit")

The "information" explosion

"Information Please,"
NBC Radio

The 50's moment: cybernetics, game theory, generative grammar..

Information theory also has influence in economics, psychology, linguistics, sociology and anthropology, sometimes lasting, sometimes temporary...

> Information theory is alive and well in biology, engineering, physics, and statistics, although one rarely sees Shannon's information theory in contemporary psychology articles except to the extent of the late John W. Tukey's term *bit*, which is now a permanent word of our vocabulary. Duncan Luce, 2001

> The mathematical theory of information ... is irrelevant [to computation] although computer programs are often said to be information-processing mechanisms. Aaron Sloman

"The Bandwagon"

Information theory has, in the last few years, become something of a scientific bandwagon. Starting as a technical tool for the communication engineer, it has received an extraordinary amount of publicity in the popular as well as the scientific press. In part, this has been due to connections with such fashionable fields as computing machines, cybernetics, and automation ; and in part, to the novelty of its subject matter. As a consequence, it has perhaps been balloned to an importance beyond its actual accomplishments. … Applications are being made to biology, psychology, linguistics, fundamental physics, economics, the theory of organization, and many others. In short, information theory is currently partaking of a somewhat heady draught of general popularity…What can be done to inject a note of moderation in this situation? Claude Shannon, 1993

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Next Time…

Fred I. Dretske. 1983."The Epistemology of Belief." *Synthese* 55 (1):3 - 19.

Background

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