Anecdotes

Origin of the Term *Bit*

In the January 1981 *Annals* (Volume 3, Number 1, p. 72), Werner Buchholz described the origin of the word *byte* from its appearance in an internal memo in 1956 to its first published use in 1959. Because *byte* is defined in terms of *bits*, it was obvious that the next etymological effort should be directed toward the origin of *bit*. Robert Price, of the late Sperry Research Center in Sudbury, Mass., undertook the inquiry, and he has supplied the pieces of the story for this department. We start the saga with the following from the *Supplement to the Oxford English Dictionary* (Oxford, Clarendon Press, 1972, Volume I, p. 272).

> **bit** (bit), *sb.*[4] [Abbrev of **binary digit.*] A unit of information derived from a choice between two equally probable alternatives or 'events'; such a unit stored electronically in a computer.
> **1948** C. E. SHANNON in *Bell Syst. Techn. Jrnl.* July 380. The choice of a logarithmic base corresponds to the choice of a unit for measuring information. If the base 2 is used the resulting units may be called binary digits, or more briefly *bits*, a word suggested by J. W. Tukey.
> **1952** *Sci. Amer.* Sept. 135/1. It is almost certain that 'bit' will become common parlance in the field of information, as 'horsepower' is in the motor field.

As noted in the OED excerpt, the first appearance in print of the word *bit* as a technical term was in "A Mathematical Theory of Communication," by Claude E. Shannon in the *Bell System Technical Journal* (Volume 27, Number 3, July 1948, p. 380); in a Bell Labs classified memorandum of September 1, 1945, "A Mathematical Theory of Cryptography," he had employed the noun *alternative* as the binary-choice measure. The pertinent portion of the landmark 1948 work is reproduced here. Incidentally, Shannon's 1945 cryptography memorandum contains what may well be the first documented appearance of the expression *information theory* (see "A Conversation with Claude Shannon," F. W. Ellersick (ed.), *IEEE Communications Magazine*, Volume 22, Number 5, May 1984).

Biographies of the major characters in our saga are as follows.

Brockway McMillan (B.S. 1936, Ph.D. 1939 MIT) served in the U.S. Navy at Dahlgren and Los Alamos during World War II. He joined Bell Telephone Laboratories in 1946 as a research mathematician. He became assistant

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A Mathematical Theory of Communication

By C. E. SHANNON

INTRODUCTION

THE recent development of various methods of modulation such as PCM and PPM which exchange bandwidth for signal-to-noise ratio has intensified the interest in a general theory of communication. A basis for such a theory is contained in the important papers of Nyquist[1] and Hartley[2] on this subject. In the present paper we will extend the theory to include a number of new factors, in particular the effect of noise in the channel, and the savings possible due to the statistical structure of the original message and due to the nature of the final destination of the information.

The fundamental problem of communication is that of reproducing at one point either exactly or approximately 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. The system must be designed to operate for each possible selection, not just the one which will actually be chosen since this is unknown at the time of design.

If the number of messages in the set is finite then this number or any monotonic function of this number can be regarded as a measure of the information produced when one message is chosen from the set, all choices being equally likely. As was pointed out by Hartley the most natural choice is the logarithmic function. Although this definition must be generalized considerably when we consider the influence of the statistics of the message and when we have a continuous range of messages, we will in all cases use an essentially logarithmic measure.

The logarithmic measure is more convenient for various reasons:

1. It is practically more useful. Parameters of engineering importance such as time, bandwidth, number of relays, etc., tend to vary linearly with the logarithm of the number of possibilities. For example, adding one relay to a group doubles the number of possible states of the relays. It adds 1 to the base 2 logarithm of this number. Doubling the time roughly squares the number of possible messages, or doubles the logarithm, etc.

2. It is nearer to our intuitive feeling as to the proper measure. This is closely related to (1) since we intuitively measure entities by linear comparison with common standards. One feels, for example, that two punched cards should have twice the capacity of one for information storage, and two identical channels twice the capacity of one for transmitting information.

3. It is mathematically more suitable. Many of the limiting operations are simple in terms of the logarithm but would require clumsy restatement in terms of the number of possibilities.

The choice of a logarithmic base corresponds to the choice of a unit for measuring information. If the base 2 is used the resulting units may be called binary digits, or more briefly *bits*, a word suggested by J. W. Tukey. A device with two stable positions, such as a relay or a flip-flop circuit, can store one bit of information. N such devices can store N bits, since the total number of possible states is 2^N and $\log_2 2^N = N$. If the base 10 is used the units may be called decimal digits.

[1] Nyquist, H., "Certain Factors Affecting Telegraph Speed," *Bell System Technical Journal*, April 1924, p. 324; "Certain Topics in Telegraph Transmission Theory," *A. I. E. E. Trans.*, v. 47, April 1928, p. 617.

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

Published in *Bell System Technical Journal*, Vol. 27 (July, October 1948), 379–423, 623–656. Reprinted with permission from Bell Telephone System Monograph B-1598, pp. 1–2.

director of systems engineering in 1955 and was named director of military research in 1959. From 1961 to 1965 he was with the U.S. Air Force as assistant secretary for research and development and then undersecretary of the Air Force. He rejoined Bell Labs in 1965 and retired in 1979 as vice-president for military development. He is an IEEE Fellow, past president of SIAM, and member of several mathematical organizations. He lives in Sedgwick, Maine.

Robert Price (A.B. 1950 Princeton; Sc.D. 1953 MIT) was at the MIT Lincoln Laboratory from 1951 to 1965. He then joined the Sperry Research Center as a department head with responsibilities in electronic systems innovation, and in 1977 became staff consultant there for the communication sciences. In 1983 he was appointed chief scientist of M/A-Com Linkabit, Inc. Recently he published a potpourri of historical notes on secret communications. He has served on national engineering committees and is an IEEE Fellow and a member of the International Union of Radio Science (URSI).

John W. Tukey (Sc.B in chemistry 1936, Sc.M. 1937 Brown; M.A. 1938, Ph.D. 1939 Princeton) has been associated with Princeton University since 1939, first as an instructor of mathematics and now (in the Department of Statistics) as Donner Professor of Science. Concurrently, he has been at AT&T Bell Laboratories since 1946, since 1961 he has been an associate executive director in research (for communication and information sciences) there. He has served on national and international scientific boards and has received numerous awards and honorary degrees for his work in statistical analysis, including the IEEE Medal of Honor in 1982.

Robert Price offered to write to John W. Tukey and ask for his recollections. Excerpts from Price's letter are as follows.

Professor Herman Goldstine of the Institute for Advanced Study has told me you originated this use of "bit" around 1946, in discussions during the planning of the IAS computer. I have recently talked with Dr. Brockway McMillan, now retired, and he recalls your coming up with "bit" at a Bell Labs lunch table. He also remarked that Lancelot Hogben complains that this usage of "bit" is a bit too slangy.

Though I presume your coinage was for computer hardware rather than information theory, Dr. Claude Shannon naturally adopted it. In an extremely thorough and perceptive study in the history of science done for his dissertation, Dr. F. W. Hagemeyer refers to your coinage in a footnote (p. 433) and to Shannon. Hagemeyer also cites your January 9, 1947, Bell Labs memorandum. . . . Hagemeyer further seems to indicate (p. 359) that Professor George Stibitz came close to coining "bit" in the early 1940s. (Hagemeyer, Friedrich-Wilhelm, "Die Entstehung von Informationskonzepten in der Nachrichtentechnik," Free University, Berlin, 1979).

Price noted that the citation for Tukey's memorandum was given by Hagemeyer as: "Tukey, J. W. (9.1.1947): 'Sequential Conversion of Continuous Data to Digital Data,' BAA; 9.1.1947" [BAA = Bell Labs Archives]. Tukey has approved publication of part of the memo here.

Sequential Conversion of Continuous Data to Digital Data[1]

January 9, 1947

MEMORANDUM FOR FILE

1. Summary

Information which is to be presented *accurately* to a person or a computing device can best be handled digitally. Continuous computers (often called analog computers) and persons can use an accuracy of 1 in a thousand with considerable difficulty and 1 in a 100 with moderate care. Accurate information available in continuous form, therefore, may need conversion to digital information. This may be done in two ways:

(A) once-for-all conversion—as by counting fringes in an interferometer,

(B) repeated measurement in finer and finer steps, essentially fixing another digit at each step.

This memorandum discusses the second possibility and concludes that circuitry now being developed for electronic arithmetic computers makes such sequential conversion quite possible.

2. Introduction

Consider a device for measuring a continuously variable quantity which is constant during the measurement, and expressing the measured value in a digital code. For definiteness, consider the measurement of the diameter of a shaft and its expression in decimals of an inch. In very general terms, the device must work on one of two ways (indicated here rather than accurately described):

(A) the device may choose a unit, say 0.00001 inch, and, while shifting from one side of the shaft to the other, it may add up the number of units that it has to move,

(B) the device may first determine the first decimal in the shaft diameter, then the second, and so on.

The present memorandum is concerned with devices analogous to (B) and with the interpreting part rather than the measuring part. How the measuring part operates will clearly depend on the nature of the measurement. There seems to be little reason for a unified discussion. But the discussion of the nature of a digital system in the next section shows that an interpreting part for a (B) device has to meet certain essential difficulties arising out of the nature of a digital system. It turns out that these can be rather easily circumvented by

(1) the temporary use of a redundant digital system,

(2) the use of electronic arithmetic circuits to convert from the redundant system to a more normal digital one.

[1] From AT&T Bell Laboratories Archives.

The methods proposed are not known to be the best, but it is clear that their simplicity cannot be greatly improved.

The discussion is naturally based on the scale of 2 rather than the scale of 10, and it seems advisable to begin with some definitions and parallelisms. We shall use a *binary place-value system* under three different conditions. This means that when a character is shifted one place to the right, its value is halved, and that the value of the whole is the values of the characters. Thus

$$0.001\ 010\ 111 = 1/8 + 1/32 + 1/128 + 1/256 + 1/512 = 87/512 = 0.169992\ldots \text{ (in decimal notation).}$$

We shall use this for the ordinary binary system, with characters 0 and 1, and for certain less usual systems with other characters. The *place-value* of a character is the value of 1 written in the same place.

All further numbers will be in the binary system unless otherwise indicated. An unspecified number will sometimes be written out in such form as

CBA.abcd,

where A, B, C are the characters of place-value one, two, and four, respectively, while a, b, c, and d are the characters of place-value one-half (0.1), one-quarter (0.01), one-eighth (0.001), and one-sixteenth (0.0001).

We shall find it helpful to list corresponding words for the decimal and binary systems, as in the following table:

Decimal System	*Binary System*	*Definitions*
Decimal point	Binary point	Divides characters with integral place-values from those with fractional place-values
Digit	Bit	Individual character
k-digit number	k-bit number	Number given by characters of k successive place-values
Decimal	Binary	Individual character of fractional place-value
k-decimal number	k-binary number	Number given through the character of k-th fractional place-value

Since $2^{10} = 1024$ (Decimal system), the approximation

10-bit accuracy = 3-digit accuracy

is good enough for most purposes.

—*John W. Tukey*

Price suggested that in the absence of a written reply from Tukey, Brockway McMillan might agree to write up his version of the story. McMillan prefaced his recollections with the following: "Helped and encouraged by the relentless and ever-tactful Bob Price, I have put down my comments on the origin of *bit*. I have conversed only with Tukey and Price. What I say is, I believe, consistent with what Price learned from Tukey."

I cherish the memory that I was present when the word *bit* was launched on its technical career. The launching went like this. A group of us at Bell Laboratories, probably over lunch, were discussing the awkwardness of, and the hint of internal inconsistency in, the term *binary digit.* We deplored the lack of a suitable substitute. John Tukey joined us at about this point, and heard our complaint. With a characteristic grin, and equally characteristic down-east inflection, he asked, "Well, isn't the word obviously *bit*?" And it was.

Several persons must have been present, but memory identifies only Tukey; he disclaims any recollection. Inference points strongly to R. W. Hamming, and to Claude Shannon perhaps, as witnesses.

Memory, and some verifiable facts, serves to fix an approximate date for this launching. In January 1947, Tukey entered a memorandum into the files of Bell Laboratories in which, without apology or discussion, the word *bit* is explicitly defined as the analog, in writing numbers in binary notation, of *digit* as used in decimal notation. I remember well both hearing Tukey describe the clever ideas in this memorandum and reading, later, a draft of the document. These events preceded the January date, but possibly not by much, since the ideas seemed rather exciting to several of us and we were pressing for copies. Say, then, that I read the draft in November 1946. As of that reading, use of the word *bit* evoked no reaction that I can remember. Therefore, *bit* became a part of my lexicon after July 1, 1946, when I joined Bell Laboratories, and before late November of that year.

Observe that *bit*, in Tukey's memorandum, is the generic name of a coefficient in the expansion of a number as a sum of powers of a base, as is *digit.* It is a natural adaptation, but a significant extension, of either term to use *number of bits* or *number of digits* to count the number of independent choices, between two alternatives or among ten possibilities, required to identify a unique individual from among a specified population. Shannon uses the word *bit* in this latter meaning, and of course even extends that meaning, in his fundamental paper of 1948, crediting the term to Tukey. Shannon's paper is probably the first open publication to use *bit* in a technical meaning, albeit a meaning different from Tukey's original one. Tukey does not, and I cannot, from memory identify specific discussions of this new meaning for *bit.* From my memory of the general spirit that prevailed at the time, I am certain that such discussions did take place, probably within each of the possible subsets of sufficient cardinality of the set: Tukey, Shannon, Hamming, D. P. Ling, and McMillan.

Marcel J. E. Golay, as of 1954 (*Proc. IRE 42*, 9, September 1954), notes the usefulness and popularity (his words) of *bit* as a unit of information, and deplores the awkwardness of *binary digit* as the name of a coefficient. He proposes *binit* for the latter, unaware, of course, of Tukey's original use of *bit.*

Robert Price points out that in the Van Nostrand *International Dictionary of Applied Mathematics* (Princeton, N.J., 1960), the word *bigit* appears, defined as the name of a coefficient, leaving *bit* as the binary unit of information.

The synthetic words *binit* and *bigit* never flew. *Bit* did. The word *bit* is a common English word. One of its common meanings relates, in a logical and amusing way, to its technical meaning. Perhaps these virtues account for its general acceptance. But acceptance has not been universal. Lancelot Hogben wrote: "The introduction by Tukey of *bits* for *binary digits* has nothing but irresponsible vulgarity to commend it." (L. Hogben and M. Cartwright, *The Vocabulary of Science*, New York, Stein & Day, 1969, p. 146). Should Tukey byte back?

—*Brockway McMillan*

That's the end of the story so far. We'd like to express our thanks to Tukey, McMillan, and Price—and our hope that we'll hear from others who may be able to tell us more about the origin of the term *bit*.

—*Henry S. Tropp*

The Soviets and the ENIAC

John Grist Brainerd's note is not only an interesting anecdote, but also a first-hand representation of the state of electronic computing at a time when a major change had taken place in the international political environment. Since the ENIAC was a classified project, it would not have been possible for the Russians to have visited the Moore School during the period of construction. The logbook at Harvard does contain evidence of Russian scientific visitors during World War II, however, which is consistent with Brainerd's comment regarding activity and interest in computing involving nonelectronic devices.

The ENIAC—the first general-purpose electronic digital computer—was completed in December 1945 and dedicated in February 1946. In the U.S.S.R., which of course had been under great strain during the war, there was much activity—both theoretical and practical—in the computer field (as there was in the United States, in the nonelectronic computer field), but none in electronic computers. This is attested by the following quotation from the extensive article by Ershov and Shura-Bura: "There were no hints in these papers [a group published in 1946] of electronic computing machinery."[1]

[1] Andrei P. Ershov and Mikhail R. Shura-Bura, "*The Early Development of Programming in the U.S.S.R.*," in N. Metropolis, J. Howlett, and G. C. Rota (eds.), *A History of Computing in the Twentieth Century*, New York, Academic Press, 1982, pp. 137–196 (esp. p. 140).

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COPY

THE GOVERNMENT PURCHASING COMMISSION
OF THE
SOVIET UNION IN THE UNITED STATES OF AMERICA

3355 16th St., NW
Washington, D. C.

In reply refer to

16-1/292

April 5, 1946

Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, Pa.

Gentlemen:

We would appreciate your advising us as to whether you can accept our order for manufacturing the Robot Calculator.

If so, we would like to see your representative in our office for discussing the above matter.

Very truly yours,

/s/ A. P. Malyshev
Engineering Department

APM:aoe

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April 8, 1946

Dear General Barnes:

I am enclosing herewith the original and carbon of a letter which I have just received from The Government Purchasing Commission of the Soviet Union in the U.S.A. The question which the writer, Mr. A. P. Malyshev, poses, is whether we can accept an order for the manufacture of the Robot Calculator, by which he evidently means the ENIAC.

I have serious doubts as to whether the Moore School should even consider the building of another ENIAC, but if the Ordnance Department approves, it might be to our mutual advantage to at least have a preliminary conversation with Mr. Malyshev.

Should the Ordnance Department approve of our talking with Mr. Malyshev, and should our conversation with him indicate that it might be to our advantage to make a contract with the USSR, we would make it very clear to him that we would do nothing which would interfere in any way with the work that is now under way for the Ordnance Department. A possible arrangement might be that we would take the contract and sub-let the actual construction of the machine to some competent firm, and we on our part, would provide only the consulting engineering talent.

I would appreciate your returning for our files the original of Mr. Malyshev's letter.

Very truly yours,

Dean.

Major General Gladeon M. Barnes
Chief of Research and Development Service
Office of the Chief of Ordnance
War Department, Washington, D. C.

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There seems little question, however, that there was much work in nonelectronic devices and that there existed a receptive mood for innovation. That this was so is further evidenced by the two letters published herewith. The first is a copy (made in the Moore School) of an inquiry from the Soviet Government Purchasing Commission concerning the manufacture of "the Robot Calculator." This inquiry, dated within two months of the dedication (and removal of some of the classification) of the ENIAC, tends to show that the Soviet computer scientists were on their toes at the time. They recognized the potential of the ENIAC and succeeded in convincing their government officials to provide funds—presumably the inquiry from the Soviets was backed by ability to pay—in remarkably short time.

The letter from Dean Harold Pender of the Moore School to General Barnes never elicited a written reply, but conversations took place, of course. As a result, the letter from the Purchasing Commission was, to the best of my knowledge, never answered.

John G. Brainerd
Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104

Addenda

In our Special Feature on Colossus (Volume 5, Number 3, July 1983), we inadvertently omitted a reference to a report written by I. J. Good on T. H. Flowers's 1981 Colossus lecture (Volume 4, Number 1, January 1982, pages 53–59).

The footnote on page 387 of Volume 5, Number 4 (October 1983) should note that C. H. Gaudette is listed as the second author of "Lincoln Utility Program System" in the 1956 WJCC *Proceedings.*

Self-Study Questions

This fourth occurrence of the Self-Study Questions department concentrates on some hardware issues and some early appearances of a few common terms in software.

The basic description of this department's intent and method of presenting material is given in the Annals, Volume 5, Number 3, July 1983, page 302. Readers are encouraged to send suggested questions (and their answers), as well as any comments or disagreements on previous answers, to the department editor (whose address is shown on the masthead). *—Jean E. Sammet*

Questions

1. Name several different bases used for floating-point arithmetic and the early computers they were used on.
2. What type of storage device was used as both main and *secondary* memory with the early computers? What type of storage replaced it and approximately when?
3. Why were hybrid systems (composed of analog and digital computers) created? Where and when were the early attempts?
4. What is the relationship between analog computers and programming languages?
5. Where, when, and in what context did the term *software engineering* seem to appear first?
6. To what does the phrase *mythical man-month* refer?
7. What is clearly the earliest reference to a language "Tower of Babel" and where did it appear?

Answers are on pages 164–165