Peirce's "Logic as Semeiotic" and the Design Principles for Semiotic Homologies in Computing Systems

Semiotic Society of America Annual Conference, Oct. 9-13, 2019

Martin Irvine
Communication, Culture & Technology Program
Georgetown University
Washington, DC USA
email: irvinem@georgetown.edu

Outline of Peirce's Program for Logic as Semeiotic (c.1902-1912): Semiotic Design Principles for the Architecture of Computing Systems and Digital Information

1. Peirce's extensive 25-year background in physical science, and his use and *design* of scientific instruments for creating indexical, iconic, and symbolic *correlations to*, and *representation of*, physical phenomena. This knowledge, necessarily combined with his advanced mathematics and logic, was the deep background for his later semiotic philosophy.

2. The discovery of the design Principle of Homology (formal-physical correspondences) that enable a "logical," "calculating," or "reasoning machine" to *be* a *logic* machine subserving all other symbolic functions.

Defining and designing physical homologies for two levels of symbols: symbols for representations (meanings, values, "data"), and metasymbols for operations, relations, and transformations over primary representing symbols: the key is automating *operators* and *operands* in the substrates of a physical *system* architecture.

Cf. design comparisons of diagrams and EGs to "Turing tape."

3. Peirce's descriptions for *physical semiosic actions* with correlated token and index structures in and across material states and time:

Generalizing Peirce's views on the necessary material properties of signs/symbols to the concept of a Physical Substrate Function (material-perceptible sign properties in a medium or continuous substrate) capable of holding invariant patterns of tokens over time.

Extending Peirce's type/token distinction applied in and across physical-electronic substrates: all tokenization is re-tokenization.

4. Conclusions: De-blackboxing Computing Systems as Designed Semiotic Artefacts

The design principles for digital computation and information (data structures) are based on *semiotic design homologies* for serving all our symbolic systems by means of typed tokens and representation substrates in a system architecture of interdependent of levels of subsystems.

The very models of computing systems themselves are based on the capacity for symbolic abstraction and ability to map formal to physical causation.

Peirce began reformulating his logical program as “Logic as Semeiotic” in the late 1890s, and explicitly stated 1902-04.

He worked out this approach consistently in his papers and letters in 1905-1907, and all the way through 1911.

There are at least 50 uses of the phrase “logic as semeiotic[s]” in the papers from 1902-1911.

1902: Transition to “Logic as Semeiotic” in the *Minute Logic* series (MSS 425-434). MS 425, earlier draft of pp.116-117:

> That all our thoughts are signs is an old and familiar doctrine. I show that it is only insofar as thoughts are symbols that they become subjects of logic, and further that all symbols are equally so subject. Logic then is a science of signs, a *semeiotic*; and in particular it treats mainly of symbols. It is a *symbolic*. But a sign may be studied under three relations; first, simply as significant; secondly, in its relation to its object; and thirdly, in its relation to its interpreting sign. For a sign only becomes such by virtue of an interpreting sign.

A few examples:

Carnegie Application Letter, MS L 75 (July, 1902)

12. *On the Definition of Logic* [Final Version]

Logic will here be defined as formal semiotic. A definition of a sign will be given which no more refers to human thought than does the definition of a line as the place which a particle occupies, part by part, during a lapse of time.

[Earlier draft:]
I define logic very broadly as the study of the formal laws of signs, or formal semiotic.

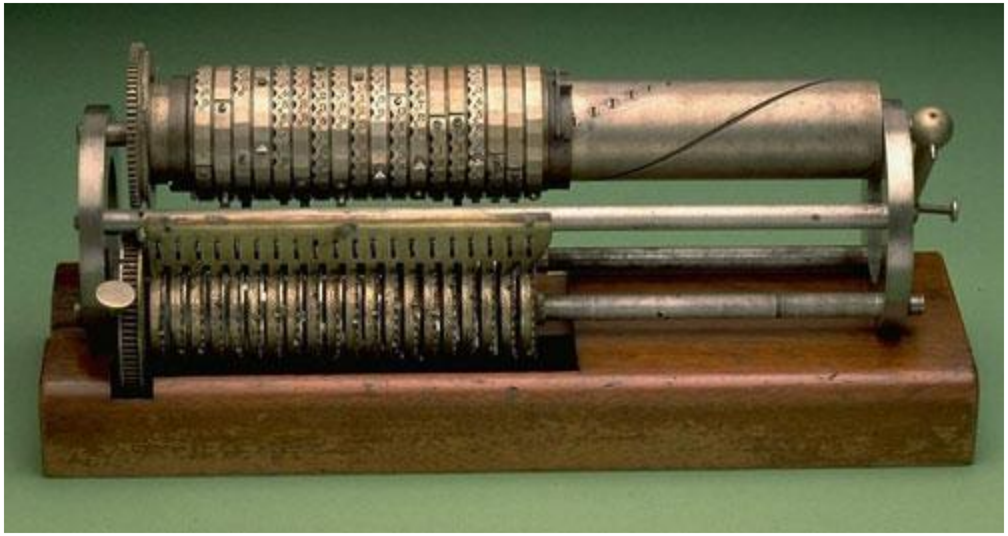
MS 66 (late 1903-early 1904), title page:

Mathematics as it is to be treated in my ~~Pragmati~~ Logic treated as Semeiotics

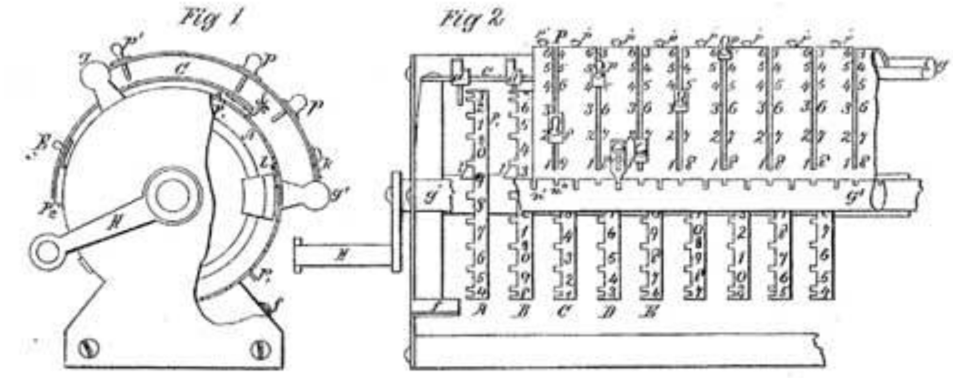
MS 66 consists of a few pages torn from a notebook, and belongs with a series of unpublished papers from 1904 in which Peirce experiments with notations for binary calculations, and algorithms for transforming decimal and binary notations, using ruled paper.

Binary mathematical and logical notation of any kind is a *metasymbolic* and *metalogical* system. For Peirce, it must be included in "Logic as Semeiotic."

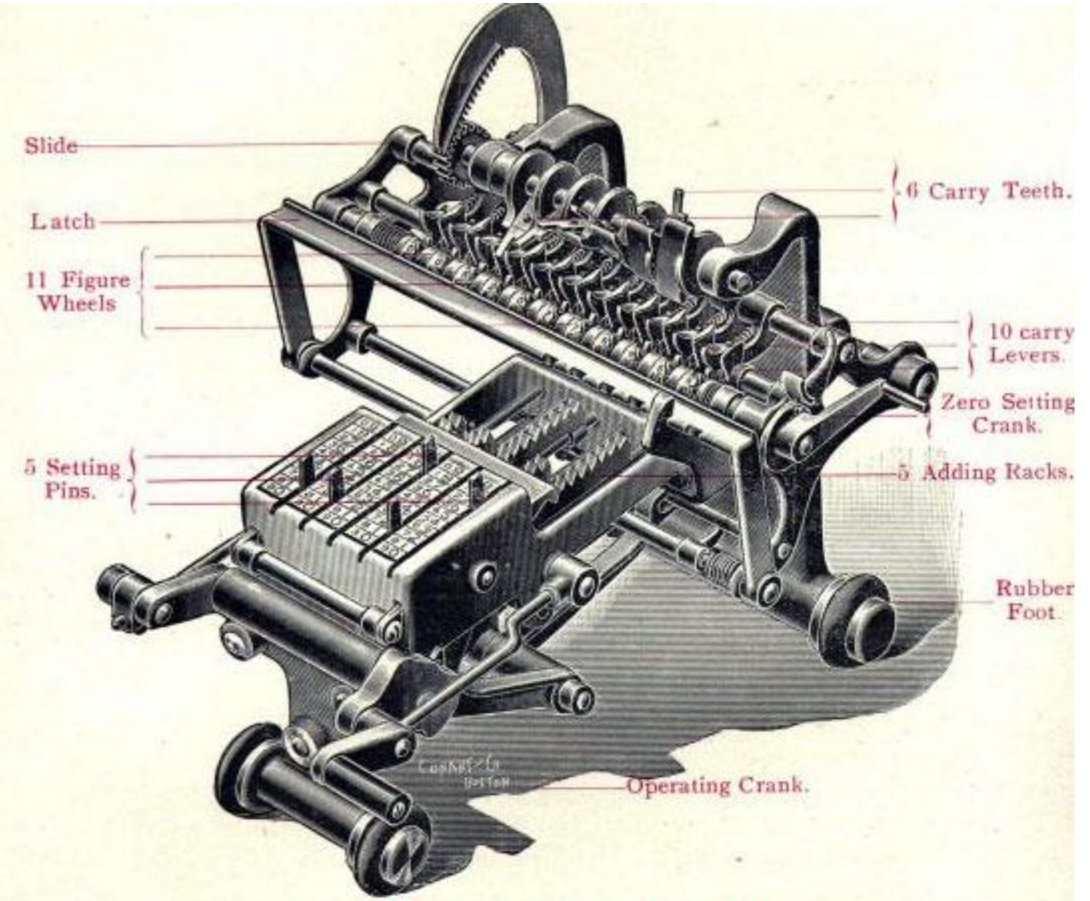
There are hundreds of pages of unpublished experiments in binary notations and binary calculating devices on paper in the Peirce papers from 1904-1912.



Grant Calculating Machine, Centennial Model (from 1876) (courtesy of National Museum of American History)



The patent drawing of the machine of Grant (from 1873)



THE TEN FIGURE MACHINE.

Ten inches square. Weighs ten pounds.

Adds ten columns wide. Multiplies five figures by six.

Divides ten figures by five.

The last calculating machine of Grant (called Grant's grasshopper model because of its appearance) was exhibited by George Grant at the Columbian Exposition held in Chicago in 1893 and was described in the journal *Manufacturer and Builder*, vol. 26, issue 9 (September 1894) (see the figure below). Later on Grant designed an experimental model, designed to incorporate subtraction and division as well as addition and multiplication.

A few other examples:

1904: MS 693, titled *Reason's Conscience: A Practical Treatise on the Theory of Discovery; wherein Logic is conceived as Semeiotic*.

[Important, long document]

1904: MS 336, 337, and 337(s). MSS titled: *Logic viewed as Semeiotics.*

[Uses singular and plural of "semeiotic[s]".]

1908: stated several times in the Welby correspondence

1909: Many statements in the drafts of a "Preface" to his collected papers on pragmatism (MS sequence: 631-640), variously titled *Preface* or *Meaning Preface*.

MSS 634-635

[I]t would seem proper that in the present state our knowledge of logic should be regarded as coextensive with General Semeiotic, the *a priori* theory of signs.
All these essays, as the title-page says, relate to the Meaning of Signs, generally.

MS 637:34-35

Semeiotic, the science of Signs in general, ought to be regarded as the foundation of a liberal education, whether for young men of for young women….

1911: MS 676, *A Sketch of Logical Critics*, p.5

[A logician] ought to study the whole theory of the nature and fundamental varieties of signs; so that **my introductory book might be called "semeiotic."**

“Logic as Semeiotic” includes all sign systems and the design principles of all semiotic artefacts: instruments, devices, and machines

Logic should be regarded as coextensive with General Semeiotic, the *a priori* theory of signs…. All these essays, as the title-page says, relate to the Meaning of Signs, generally....

The present volume, however, contains merely an unsystematic reconnaissance of a part of that broader ground. It considers Signs in general, a class which includes pictures, symptoms, words, sentences, books, libraries, signals, orders of command, microscopes, legislative representatives, musical concertos, performances of these….

MS 634, *Preface (Meaning Preface)*, 1909. Unpublished.

C. S. Peirce's model of semiotic actions in "Logic as Semeiotic"

It is necessary to insist upon the point for the reason that ideas cannot be communicated at all except through their physical effects. Our photographs, telephones, and wireless telegraphs, as well as the sum total of all the work that steam engines have ever done, are, in sober common sense and literal truth, the outcome of the general ideas that are expressed in the first book of the *Novum Organum*.

[The term] "sign" [includes] every picture, diagram, natural cry, pointing finger, wink, knot in one's handkerchief, memory, dream, fancy, concept, indication, token, symptom, letter, numeral, word, sentence, chapter, book, library, and in short whatever, be it in the physical universe, be it in the world of thought, that, whether embodying an idea of any kind (and permit us throughout to use this term to cover purposes and feelings), or being connected with some existing object, or referring to future events through a general rule, causes something else, its interpreting sign, to be determined to a corresponding relation to the same idea, existing thing, or law.

MS 774:4-5 (1904), *Ideas, Stray or Stolen, about scientific writing. No. 1.* Ed. EP 2:326.

The Principle of Homology: Extended to Design of Semiotic Artefacts

Peirce's Definitions:

1889: "Homology," *Century Dictionary*

Homological 1. Pertaining to or characterized by homology; **having a structural affinity**: distinguished from *analogical*, and opposed to *adaptive*.

Homologous [< NL. *homologus*, < Gr. ὁμολόγος [homologos], agreeing, correspondent, < ὁμός [homos], the same, + λέγειν [legein], speak, > λόγος [logos], proportion, etc.] Having the same relative position, **proportion, value, or structure**; having correspondence or likeness. Specifically — (*a*) In *geom*., corresponding in relative position and proportion; also, homological or in homology.

Homology [< Gr. ὁμολογία [homologia], agreement, conformity] The state or character of being homologous; **correspondence**.

1895: MS 165, *Elements of Mathematics,* p.246 (NEM 2:217-218)

Definition 187. ***Homology* is a one-to-one correspondence**; *homologous* is corresponding in a system of one-to-one correspondence. In a more special sense, *homology* is a system of correspondence between two configurations such that to every optical homaloidal place of the one corresponds an optical homaloidal place of the other of the same dimensionality.

Computer Science Design Theory is Everywhere *Intuitively* Semiotic: A Peircean Re-Description Exposes What is Usually Unconscious and Unexpressed

From: Peter J. Denning and Craig H. Martell. ***Great Principles of Computing*****. Cambridge, MA: The MIT Press, 2015: 49-50.**

When we dig a little deeper into how a machine transforms inputs, however, we can see an important aspect of the design of a program that we call ***meaning-preserving***. Consider the addition of two numbers, *a* and *b*. What does it mean to add two numbers? It means that we follow a series of steps given by an addition algorithm. The steps concern adding successive pairs of digits from *a* and *b* and propagating a carry to the next higher pair of digits.

We have clear rules for adding pairs of numbers from the set {0,1,2,…,9} and producing carries of 0 or 1. As we design a program for the algorithm, we pay careful attention that each and every instruction produces exactly the incremental result it is supposed to….

In other words, the design process itself transfers the idea of addition from our heads into instruction patterns that perform addition. The meaning of addition is preserved in the design of the machine and its algorithms.

This is true for any other computable function. We transfer our idea of what it means for that function to produce its output into a program that controls the machine to do precisely that. We transfer our idea of the meaning of the function into the design of the machine.

Generalizing over Peirce's many formulations of:

***representation*,**

***representamen* (that which *performs the function* of representation in a sign relation),**

***token/type*, (for token ⇒ type ⇒ token productivity)**

***medium*, and material properties of signs**

(and many experimental terms)

The function of the ***structured substrate*** required for physical tokenization in time and place by using the material properties of the physical medium for perceptible instances of token structures.

We have a long semiotic continuum of substrates (from speech sounds in acoustic waves and paper inscriptions to digital video files transduced to perceptible features). A substrate must provide a symbolic-system using community with the physical means to instantiate perceptible, identifiable *features* capable of direct inferential mappings to invariant *patterns*, the foundation of our core token → type correspondences for all correlated interpretive actions.

Peirce recognized semiotic homologies in all kinds of designed artefacts: algebraic notation, the calculus, diagrams and his Existential Graphs, and all kinds of scientific equipment and logical machines.

Everything from Euclid's diagrams to the design of reasoning machines involves a *construction* -- a representational form of logico-semiotic relations.

1906: MS 283, 283(s), *The Basis of Pragmaticism*.
[From earlier draft pp. 116-117, not in EP 2]

There is, in fact, no fundamental difference between the writer's general algebra of logic and the differential Calculus, so far as the general nature of their powers is concerned. Neither the one nor the other has any "power" of bringing out any conclusions except **those whose logic was impressed upon it in its very construction**. The routine performances of the differential calculus are very limited, as are those of any algebra of logic. It *is* an algebra of logic, and nothing else. But to say of the one notation or the other that it is of *no use* except for the **working of the machinery of a calculus** is to betray complete ignorance of the method of mathematical research. This is performed by experimentation upon diagrams; and the utility of the notations for this purpose consist in their enabling us to supply the bricks for building the diagrams.

1906: MS 499, 499(s), *On the System of Existential Graphs, considered as an Instrument for the Investigation of Logic* (Unpublished).

A calculus, on the other hand, is a system of symbols by transforming which according to a certain routine one is enabled to pass from a premiss to a conclusion in a particularly speedy and direct way….

[A] calculus, or notation to be transformed according to general prescribed rules, laid down once for all,—which will only differ from a logical machine in that the changes are not effected by mechanical force but by quasi-mechanical rules… [p.6]

"Logical Machines," 1887:168

[W]hatever relation among the objects reasoned about is destined to be the hinge of a ratiocination, that same general relation must be capable of being introduced between certain parts of the machine.

MS 425,
1902

Logic

(73)

we know or care, be a hundred ways of thinking in passing from such a premiss to such a conclusion. But the question is whether, granting that there be such a thing as truth, which can be ascertained at all, such a way of adding conclusion to premiss as that under examination, would lead to the ascertainment of the truth by the speediest path, or not. The whole logical inquiry relates to the truth; now the very idea of truth is that it is quite independent of what you or I may think it to be. How we think, therefore, is utterly irrelevant to logical inquiry.

Reasoning by Machinery.

I must be excused for dwelling on this point, for no other in all logic, though it is a science of subtleties, is so hard to see. The confusion is embedded in language, leaving no words available to epigrammatize the error. Now it is not of fools exclusively, but of the greater part of the thinking world that words are the money. A celebrated treatise is entitled "Logic, or Computation,"

Peirce on the "strata" (layers) of signs and multiple interpretants:

Following the section on "Reasoning by Machinery":

Concepts foundational for the design of computational processes implemented in physical machines

Continuing the study of Speculative Grammar, how, in consequence of every sign determining an Interpretant, which is itself a sign, we have sign overlying sign. The consequence of this, in its turn, is that a sign may, in its immediate exterior, be of one of the three classes, but may at once determine a sign of another class. But this in its turn determines a sign whose character has to be considered. This subject has to be carefully considered, and order brought into the relations of the strata of signs, if I may call them so, before what follows can be made clear.

MS 425, *Minute Logic*, 1902, draft pages unpublished.

This expanded and integrative view opens up the semiotic principles for all kinds of artefacts and actions that are symbolic structures or serve them:

MS 602 (1907), *(M)* (On Classification of the Sciences, Divisions of Logic), pp. 7-8. Unpublished.

[Context: on *stechiology*, first elements of logic as semeiotic:]

Stechiology, the business of which is to analyze reasonings into their ultimate components and to show how these are compounded. But one of the first discoveries of stechiology is that every reasoning is of the nature of a sign…. *Sign* will here be the general name for everything of that sort, whether it be an instrument of music, a mental resolve, a voyage of discovery, or anything else that plays an essential part in the spread of intelligence. Evidently, one group of students [logicians!] can only cover so vast a field on condition of restricting themselves severely to the essential function of signs.

Computing systems and digital media (in design and implementation) are part of the semiotic *artefactual continuum*

That mysterious thing called Reason which, without the exercise of any force…, **only acts through signs, spoken or written or "scribed" or imagined**. That which has made all our wonderful **engines, wireless telegraphs, telephones, phonographs**, and a thousand other wonders possible, has been the differential calculus, by which scientific men are instructed how to make the experiments that will be important. What is this "differential calculus"? **It is a system of *signs*** invented by the great philosopher Leibniz....

Reason is in itself, -- whether it is anything all by itself, -- we cannot say. It is mysterious. It is what makes man's life noble. It is what gives a man self-control. **It acts through words or other signs**.

From MS 514 (Misc. pages) (c.1911), unpublished.

Peirce: Sign actions, tokenization, interpretants in electrical signals

Every thought, or cognitive representation, is of the nature of a sign. "Representation" and "sign" are synonyms. The whole purpose of a sign is that it shall be interpreted in another sign; and its whole purport lies in the special character which it imparts to that interpretation. When a sign determines an interpretation of itself in another sign, it produces an effect external to itself, a physical effect, though the sign producing the effect may itself be not an existent object but merely a type. It produces this effect, not in this or that metaphysical sense, but in an indisputable sense.... Thinking is a kind of action, and reasoning is a kind of deliberate action....

Consequently, the whole purport of any sign lies in the intended character of its external action or influence. Some signs are interpreted or reproduced by a physical force or something analogous to such a force, simply by causing an event; as sounds spoken into a telephone effect variations or the rate of alternation of an electric current along the wire, as a first interpretation, and these variations again produce new sound-vibrations by reinterpretation.

MS 1476, Drafts of a review of Herbert Nichols' *A Treatise on Cosmology* (1904, pp. 5-6; p.4, second sequence of drafts). Unpublished.

Peirce wrote several drafts of this section. In an earlier draft of this page, he words it this way:

> Some signs are interpreted in actual physical effects or in relations analogous to such effects; as when sound vibrations of speech before a telephone transmitter cause variations in the rate of alternation of an alternating current along the wire, this series of variations making up a sign that interprets, i.e. translates, the acoustic sign, and in its turn setting up new acoustic vibrations in the receiver, as a reinterpretation.
>
> MS 1476, 1904, p. 5, sixth sequence of drafts. Unpublished.

This statement is a prelude to the formulation of the mathematical theory of information inaugurated in Bell Labs by Hartley, Nyquist, and Shannon in the 1920-30s.

The next step in symbolic homological automation is metasymbolic formalization:

Operators (operator signs and notations) must be converted into sign actions (operations) over and set of token *operands*

"Logic begins" with a metasymbolic, metacognitive step (MS 547, 1886).

"Logic begins when we treat signs as the objects of our study."

"The mathematician conceives **an operation as something itself to be operated upon**" (MS 1288, 1898).

MS 1147 (1901): Logic and mathematics treats "symbols themselves as the objects of symbols." and "operations and relations of all kinds [as] objects to be operated on."

Baldwin's *Dictionary* (2:651): Symbolical. Relating to an algebraical method in which **operations are denoted by letters and made the subject of operations.**

(Also in MSS 56, 813, and 968: "Architecture of Theories," 1890-91.)

Peirce's Type/Token Distinction, from 1906 on:
Signs/Symbols Signs are what can be instantiated in tokens (earlier term, "replicas")

The proof or test of whether something perceptible *is* a sign or symbol (instantiates a symbolic function) is whether the features ⇒ pattern structure can be re-instantiated in another place and time in any perceptible medium.

> By a Type, I mean a general form which can be repeated indefinitely and is in all its repetitions one and the same sign. Thus the word *the* is a Type. It is likely to occur over a *score* of times on a page of an English book; but it is only one word twenty times repeated. The distinction between a Type and a Token is obvious.
>
> MS 399, Logic Notebook, April 2, 1906, f. 276r

> [A] "word" does not exist: it has a higher mode of being than existence, since it is a form that imparts utility to the existing matter in which it gets embodied. I term any sign having the mode of being of a form a *type*, and any sign which is a single existent object or single collection of objects, or which is a single actual occurrence, a *token*. . . . . A token which represents a type, by embodying it, such as any particular *the* on a single line of a single page of a single copy of a book, I will call for the present an *instance* of that type. (MS 292:17, 1906)

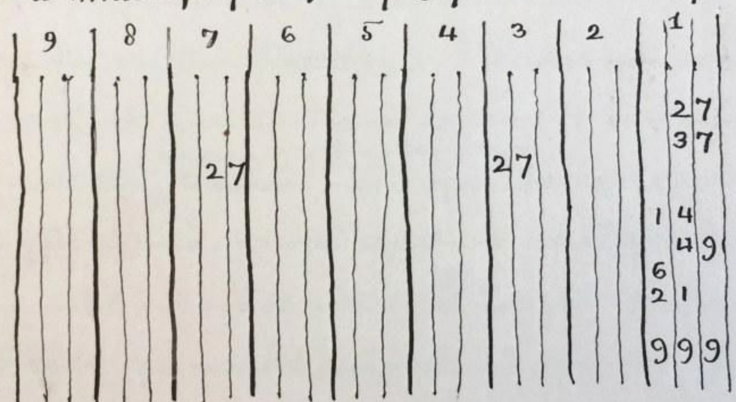
A digital system is a set of positive and reliable techniques…for producing and re-identifying tokens, or **configurations of tokens, from some prespecified set of types**.

Haugeland, John. *Artificial Intelligence: The Very Idea*. Cambridge, MA: MIT Press, 1985: 53

1904: MS 1262, *Garrulities of a Vulgar Arithmetician*. Cf. MS 685.
History of "Arabic" numerals, decimal 10-place arithmetic, abacus constructions, algorithms, and methods of computation, 12th c. to 19th c.

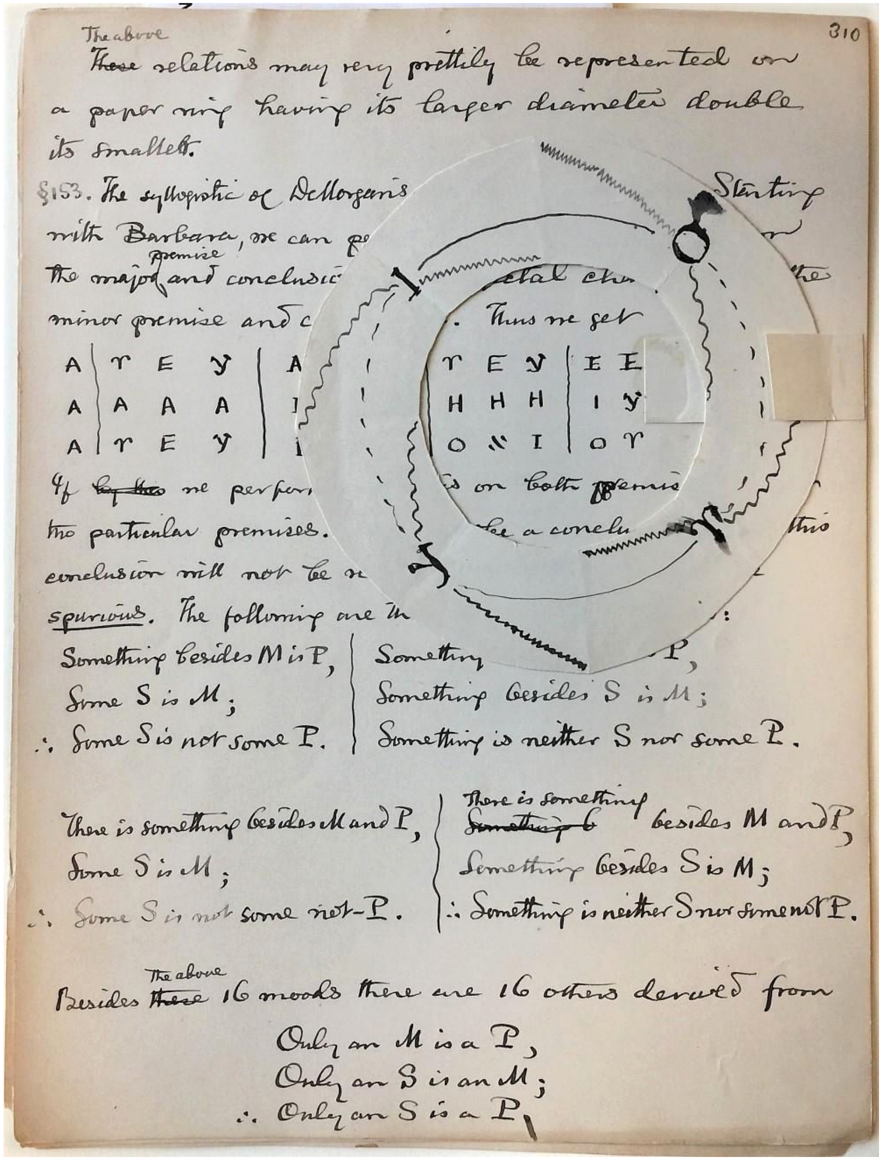
"**No invention lasts longer than a fundamental improvement in computation**." (p.50)

54 abacus was adapted to a pedagogical purpose. Now what does he mean by saying that the borrowing of the counters by the 27 divisions of the abacus would express either the multiplication or the division of them by each of the numbers? It seems to me that what is meant is, for example, that a beginner would be taught to multiply 27 by 37 in this shape:



There are nine columns, each having a units' place, a tens' place, and a hundreds' place; and for the beginner a number placed in any column denotes the product of that number multiplied by the digit at the head of the column. [At a later stage of the instruction, it may denote the quotient of the number entered divided by the heading digit.] The beginner, then, first places counters to repre-
... 27×7 and 27×30 by putting 27

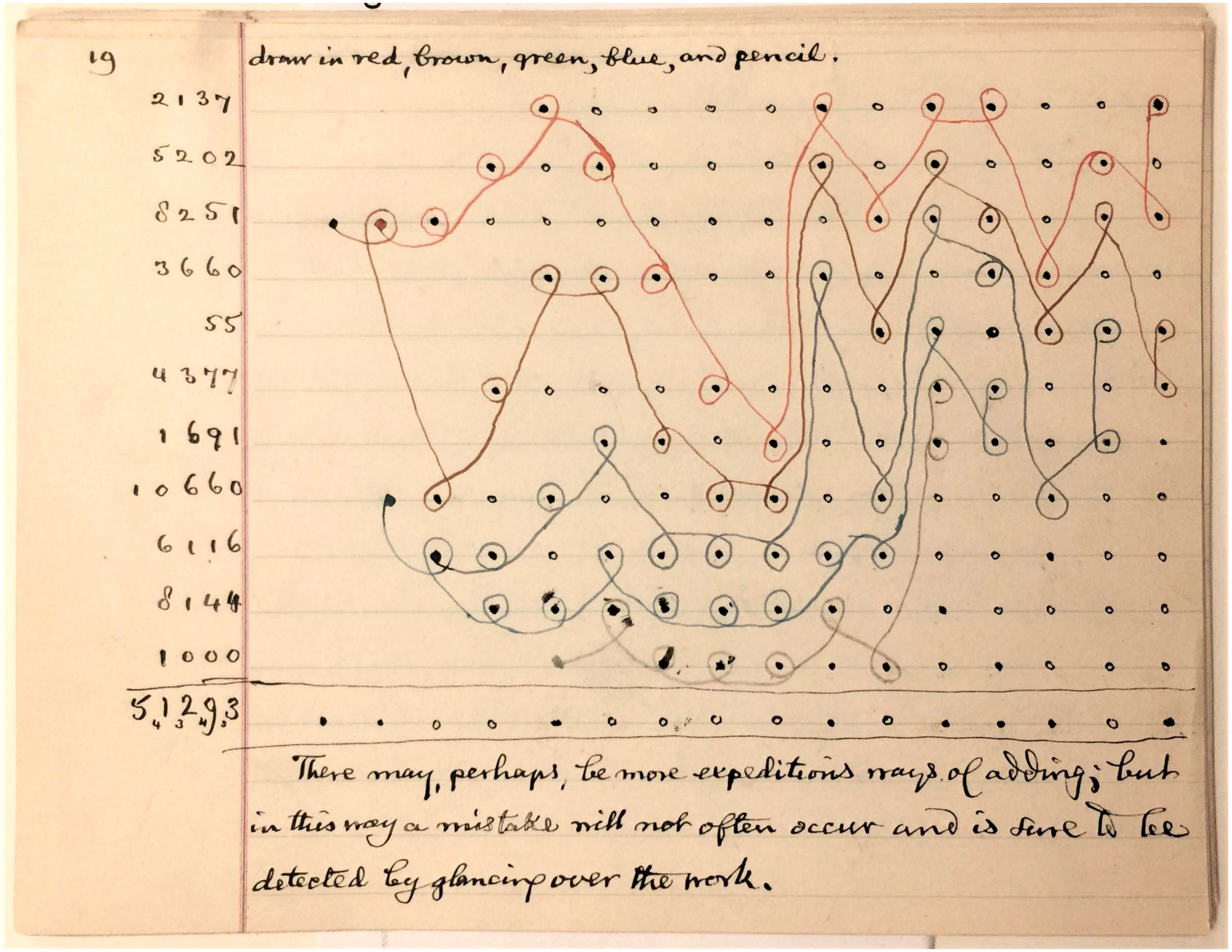
Peirce and homological devices for automating reasoning:
"Paper Devices" for Logic Machines and Binary (Base-2) Computations



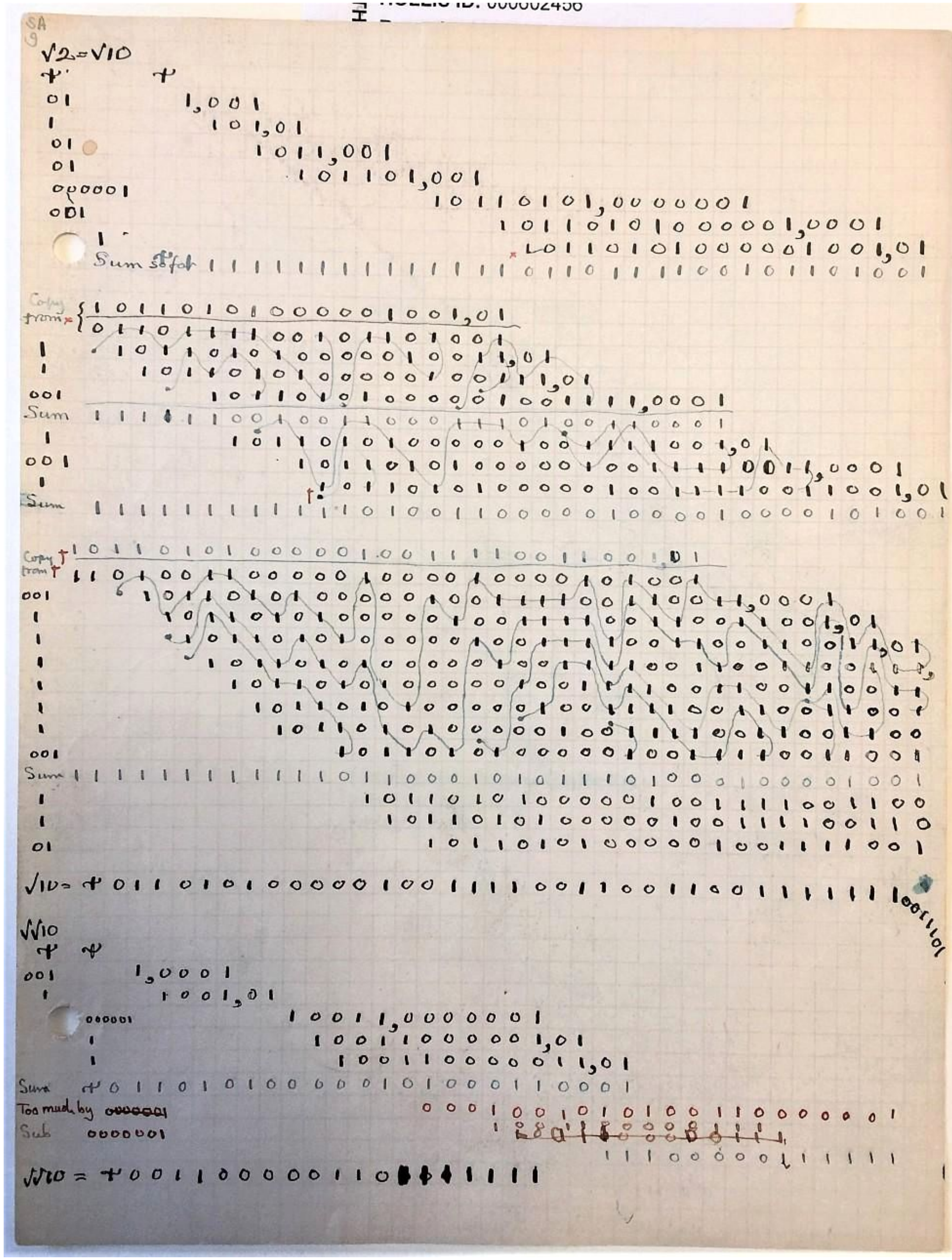
Peirce's manuscripts and notebooks contain hundreds of pages of diagrams and devices for computation, and for representing necessary reasoning processes in designed artefacts ("constructions," devices, and aids for "diagrammatic reasoning").

MS 415, *De Morgan's Propositional Scheme* (1890). Paper "logic machine" (marked slide wheel) for demonstrating valid syllogisms.

Peirce and devices for automating reasoning:
Devices and Schema for Binary (Base-2) Computations



MS 1, *On the Simplest Possible Branch of Mathematics"* (1904), p. 19.
Methods for computing in binary (base 2) arithmetic.



MS 57 (1906),
***Essay on Secundal Augrim*.**
Dedicated to J. M. P.

[“Secundal” = “binary, base-2”]

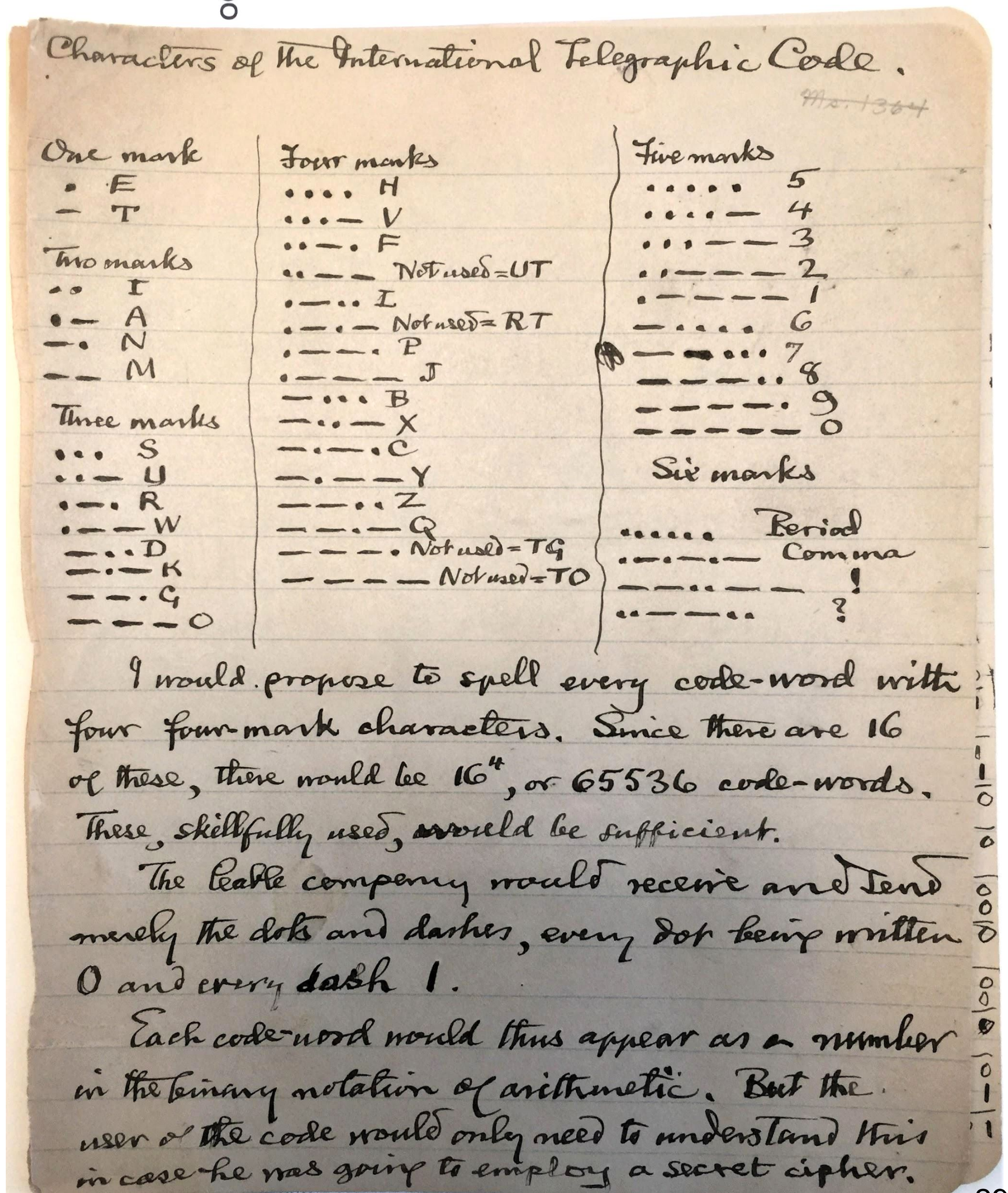
MS has many pages of computations on graph paper, which was called “computer paper” in the 19th c.

Peirce, MS 1361, c.1902

On telegraphic code converted to binary, and a cypher in binary for Morse Code

In 1898, Peirce wrote to Henry Cabot Lodge just after the Spanish-American War broke out, offering his method for encrypting Morse code (which may be the technique described in here in MS 1361):

“My ingenuity ought to be rendered serviceable. I cannot make it so without backing. I could make a machine which would write a **cipher dispatch**, as secure as a combination lock, and as readily as an ordinary typewriter, and **a companion machine would translate it as fast as a stock ticker**, -- every dispatch in a different cipher which the machine itself would discover. This would be valuable to merchants in war times.” (MS L 254)



Characters of the International Telegraphic Code.

~~Ms. 1361~~

One mark
• E
— T

Two marks
•• I
•— A
—• N
—— M

Three marks
••• S
••— U
•—• R
•—— W
—•• D
—•— K
——• G
——— O

Four marks
•••• H
•••— V
••—• F
••—— Not used = UT
•—•• L
•—•— Not used = RT
•——• P
•——— J
—••• B
—••— X
—•—• C
—•—— Y
——•• Z
——•— Q
———• Not used = TG
———— Not used = TO

Five marks
••••• 5
••••— 4
•••—— 3
••——— 2
•———— 1
—•••• 6
——••• 7
———•• 8
————• 9
————— 0

Six marks
•••••• Period
•—•—•— Comma
——••—— !
••——•• ?

I would propose to spell every code-word with four four-mark characters. Since there are 16 of these, there would be 16^4, or 65536 code-words. These, skillfully used, would be sufficient.

The cable company would receive and send merely the dots and dashes, every dot being written 0 and every dash 1.

Each code-word would thus appear as a number in the binary notation of arithmetic. But the user of the code would only need to understand this in case he was going to employ a secret cipher.

Peirce on mathematical-logical homologies:

> 1. The principal part of a code for telegraphing consists of a classification of ideas. This is so no matter what the plan of it may be. This work is about the most difficult task that can be set to a logician, and no other man is fit to undertake it.

[Note the method for converting telegraphic dot-dash code into binary 1s and 0s, and for the cryptographic system using prime numbers:]

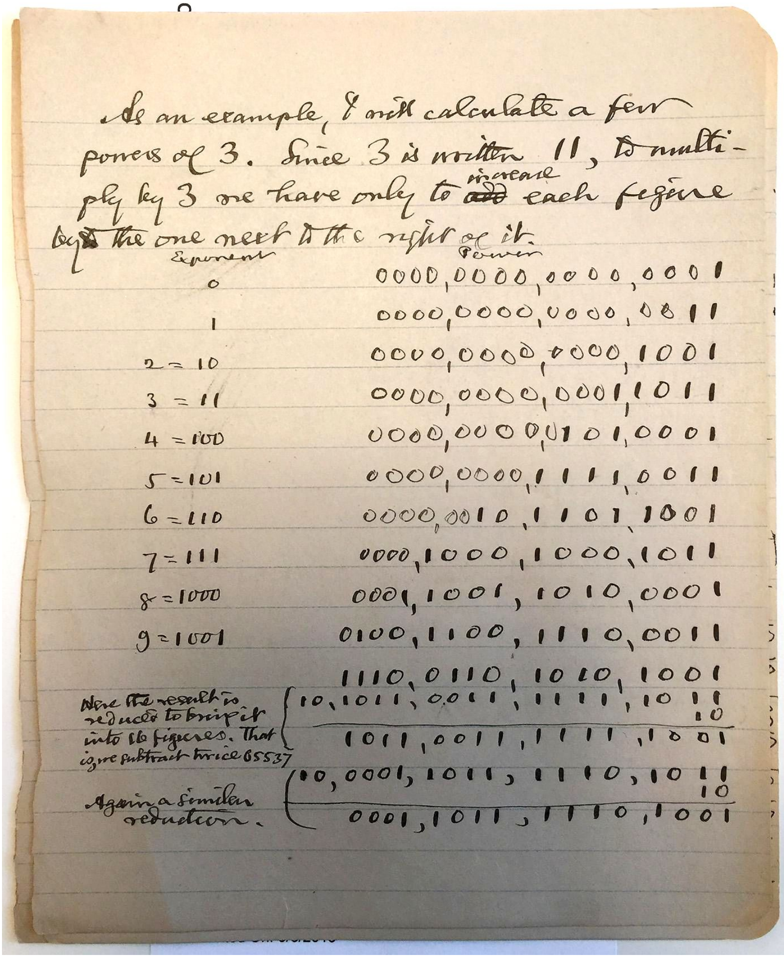
I would propose to spell every code-word with four four-mark characters. Since there are 16 of these, there would be 16^4, or 65536 code-words. These, skillfully used, would be sufficient.

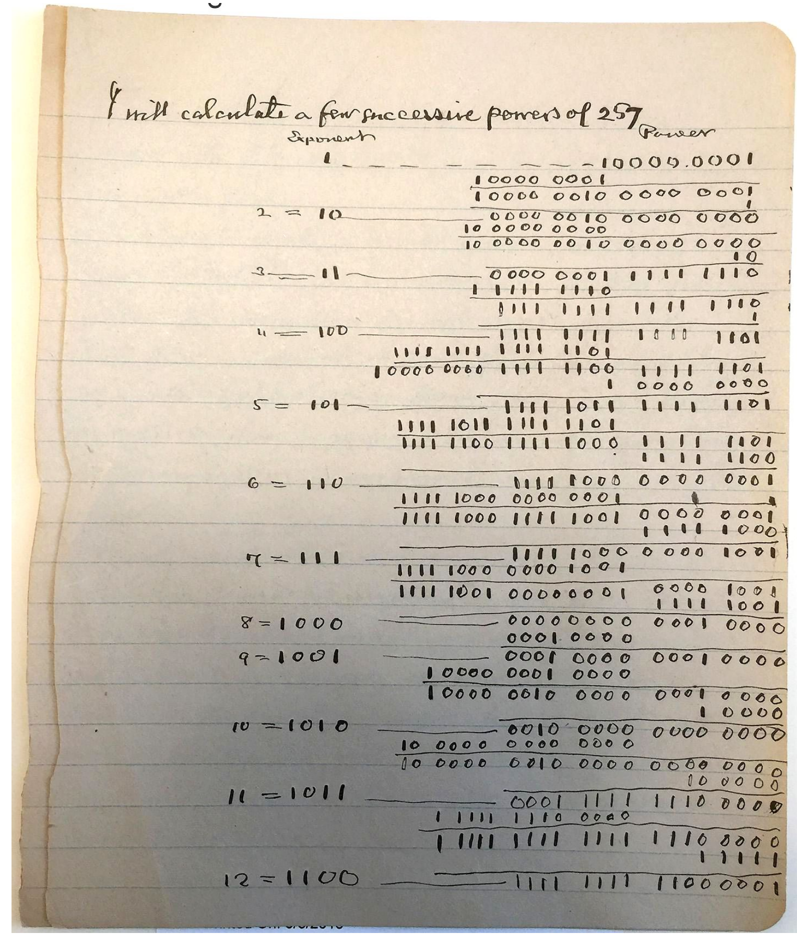
The Cable company would receive and send merely the dots and dashes, every dot being written 0 and every dash 1.

Each code-word would thus appear as a number in the binary notation of arithmetic. But the user of the code would only need to understand this in case he was going to employ a secret cipher….

In order to make a secret cipher, it should be agreed between the correspondents, that the sender after getting his code-words should treat them as numbers and perform a certain arithmetical operation on each and that the receiver should perform the inverse operation. The *binary system is excessively easily and rapidly worked.*

Peirce outlines an encryption scheme for telegraph code in binary form, and method for using prime numbers as "keys" -- 32 years before similar use in WWII

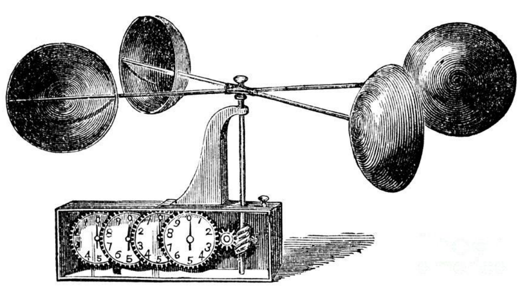




Peirce understood the technique for encoding/decoding alphanumeric characters in **binary strings**, a method underlying all digital text representations from the first computers with teletype keyboards, to standardization on ASCII, and now in Unicode, the international standards for byte-code representations for all written languages (no contemporary text software would work without it). Again, these are formal-physical homologies for tokening and re-tokening written signs as instances in physical substrates.

Indexical, Iconic, and Symbolic Functions in the Homological Design of Measuring Devices

THE ROBINSON ANEMOMETER.



It is true, however, and highly important in the development of exact logic, that the different kinds of symbols are connected in certain ways. An index points to its object in certain respects, and it must refer to some icon of those respects. A Robinson's anemometer is a purely physical representamen, or index, of the wind. It may be arranged to record upon a chronograph the instant at which every ten miles of air has passed by it. The chronograph record is thus made the interpretant of the anemometer, in a purely physical way. Now, the intervals between the records on the chronograph-fillet constitute an icon of the behaviour of the wind. A little reflection will enable the reader to convince himself inductively that an icon is thus connected with every index. In like manner, a symbol cannot existentially denote anything, without appealing to an index to represent the individual denoted.

MS 1147 (Drafts of entries for Baldwin's Dictionary) (1901), pp. 10-11. Unpublished.

Orders of Symbols and the correspondence between "operator" metasymbols ("signs of operations") and *operations* as actions or processes that must occur physically in time and place

***Century Dictionary*, Operation (1888-89):**

(b) In *math*., the substitution of one quantity for another, or the act of passing from one to the other, the second quantity being definitely related to the first, either in value or in form. An *operation* must not be confounded with the *process* by which the operation is effected. Thus, there is but one operation of extracting the cube root of a number, but there are several different processes.

Working toward disclosing many kinds of sign actions, holding a non-psychologistic and a *non*- or *re*-anthropomorphizing point of view

I am not anthropomorphic enough in my account of logic as a science of signs and in describing signs without making any explicit allusion to the human mind.

A line of bricks stand on end upon a floor, each facing the next one of the line. An end one is tilted so as to fall over upon the next; and so they all successively fall. The mechanical statement of the phenomenon is that a portion of the sum of the energy of motion that each brick had at the instant its centre of gravity was directly over its supporting edge, added to the energy of its fall is transformed into an energy of motion of the next brick. Now I assert no more than this, but less, since I do not say whether it was mechanical energy, or what it was that was communicated, when, applying my definition of a Sign, I assert (as I do) that each brick is a Sign (namely, an Index), to the succeeding bricks of the line, of the original effect produced on the first brick. I freely concede that there is an anthropomorphic constituent in that statement; but there is none that is not equally present in the mechanical statement, since this asserts all that the other form asserts. Until you see this, you do not grasp the meaning that I attach to the word "sign."

MS 293, *Prolegomena for an Apology for Pragmatism* (1906):3. Ed. NEM 4:313-14.

This analogy doesn't quite work on Peircean principles, but it is a good analogy for describing signal re-tokenization in digital electronic information transmission and computer data representations.

From: **Michael S. Mahoney, "The Histories of Computing(s)" (2005).**

"**Recall what computers do. They take sequences, or strings, of symbols and transform them into other strings.** The symbols and the strings may have several levels of structure, from bits to bytes to groups of bytes to groups of groups of bytes, and one may think of the transformations as acting on particular levels. But in the end, computation is about rewriting strings of symbols….

Any meaning the symbols may have is acquired and expressed at the interface between a computation and the world in which it is embedded. The symbols and their combinations express representations of the world, which have meaning to us, not to the computer. **It is a matter of representations in and representations out**.

What characterises the representations is that **they are operative**. We can manipulate them, and they in turn can trigger actions in the world. What we can make computers do depends on how we can represent in the symbols of computation portions of the world of interest to us and how we can translate the resulting transformed representation into desired actions."

These statements can be completed with a Peircean semiotic re-description, though they are intuitively correct.

“Symbol” and “Token” in classical computer science, 1970-80s:

Allen Newell and Herbert Simon, “Symbol Manipulation.”

In Anthony Ralston, ed., *Encyclopedia of Computer Science, 2 Vols.* (New York: Petrocelli/Mason Charter Books, 1976). Definition reproduced in 4th edition, John Wiley & Sons, 2003.

The power of a modern computer derives from its being more than an arithmetic calculator. It is, in fact, a general-purpose symbol-manipulating system.

A symbol token is a pattern that can be compared by an information processing system with some other symbol token and judged equal with it or different from it. The basic test for equality of tokens incorporated in an information processing system determines the fundamental alphabet of symbols it is prepared to recognize and distinguish. A symbol, then, is a class of equal tokens with respect to this basic test.

The key characteristic of symbols for an information processing system is their ability to *designate*, i.e., to have referents. This means that an information process can take a symbol token as input and use it to gain access to a referenced object in order to affect it or be affected by it in some way: to read it, modify it, build a new structure with it, and so on. Hence, three concepts are central to understanding symbol manipulation: information processing system, symbol structure, and designation.

Key Texts by Peirce on Logic/Reasoning Machines & Semiotic Foundations

C. S. Peirce, "Logical Machines," *The American Journal of Psychology* 1, no. 1 (1887): 165–70.

Cites:

Babbage's analytical engine

Stanley Jevons's machine

Alan Marquand's "vastly more clear-headed contrivance"

Peirce clearly understood design homologies for logic.

Logical Machines.

In the "Voyage to Laputa" there is a description of a machine for evolving science automatically. "By this contrivance, the most ignorant person, at a reasonable charge, and with little bodily labor, might write books in philosophy, poetry, politics, laws, mathematics, and theology, without the least assistance from genius or study." The intention is to ridicule the Organon of Aristotle and the Organon of Bacon, by showing the absurdity of supposing that any "instrument" can do the work of the mind. Yet the logical machines of Jevons and Marquand are mills into which the premises are fed and which turn out the conclusions by the revolution of a crank. The numerous mathematical engines that have been found practically useful, from Webb's adder up to Babbage's analytical engine (which was designed though never constructed), are also machines that perform reasoning of no simple kind. Precisely how much of the business of thinking a machine could possibly be made to perform, and what part of it must be left for the living mind, is a question not without conceivable practical importance; the study of it can at any rate not fail to throw needed light on the nature of the reasoning process. Though the instruments of Jevons and of Marquand were designed chiefly to illustrate more elementary points, their utility lies mainly, as it seems to me, in the evidence they afford concerning this problem.

The machine of Jevons receives the premises in the form of logical equations, or identities. Only a limited number of different letters can enter into these equations—indeed, any attempt to extend the machine beyond four letters would complicate it intolerably. The machine has a keyboard, with two keys for the affirmative and the negative form of each letter to be used for the first side of the equation, and two others for the second side of the equation, making four times as many keys as letters. There is also a key for the sign of logical addition or aggregation for each side of the equation, a key for the sign of equality, and two full stop keys, the function of which need not here be explained.[1] The keys are touched successively, in the order in which the letters and signs occur in the equation. It is a curious anomaly, by the way, that an equation such as A═B, which in the system of the transitive copula would appear as two propositions, as All A is B and All B is A, must not be entered as a single equation. But although the premises outwardly appear to be put into the machine in equations, the conclusion presents no such appearance, but is given in the form adopted by Mr. Mitchell in his remarkable paper on the algebra of logic. That is to say, the conclusion appears as a description of the universe of possible objects. In fact, all that is exhibited at the end is a list of all the possible products of the four letters. For example, if we enter the two premises All D is C, or D═CD, and All C is B, or C═BC, we get the conclusion in the following shape, where letters in the same vertical column are supposed to be logically multiplied, while the different columns are added or aggregated:

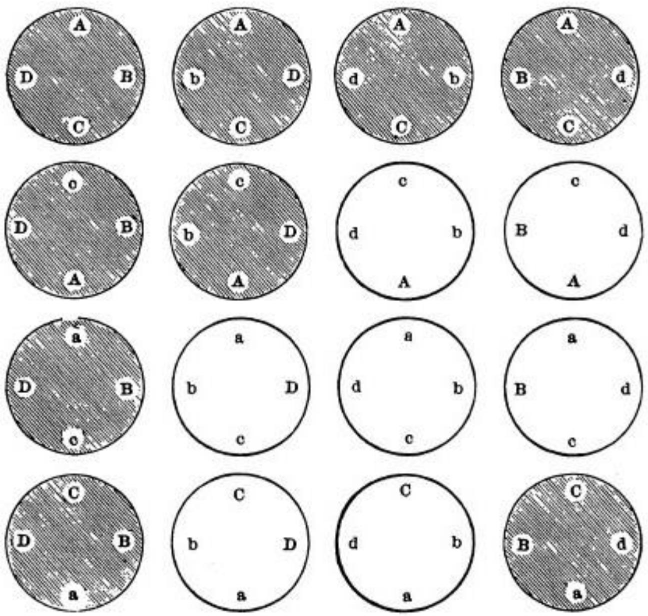
A	A	A	A	a	a	a	a
B	B	B	b	B	B	B	b
C	C	c	c	C	C	c	c
D	d	d	d	D	d	d	d.

[1] Phil. Trans. for 1870.

The capital letters are affirmatives, the small letters negatives. It will be found that every column containing D contains B, so that we have the conclusion that All D is B, but to make this out by the study of the columns exhibited seems to be much more difficult than to draw the syllogistic conclusion without the aid of the machine.

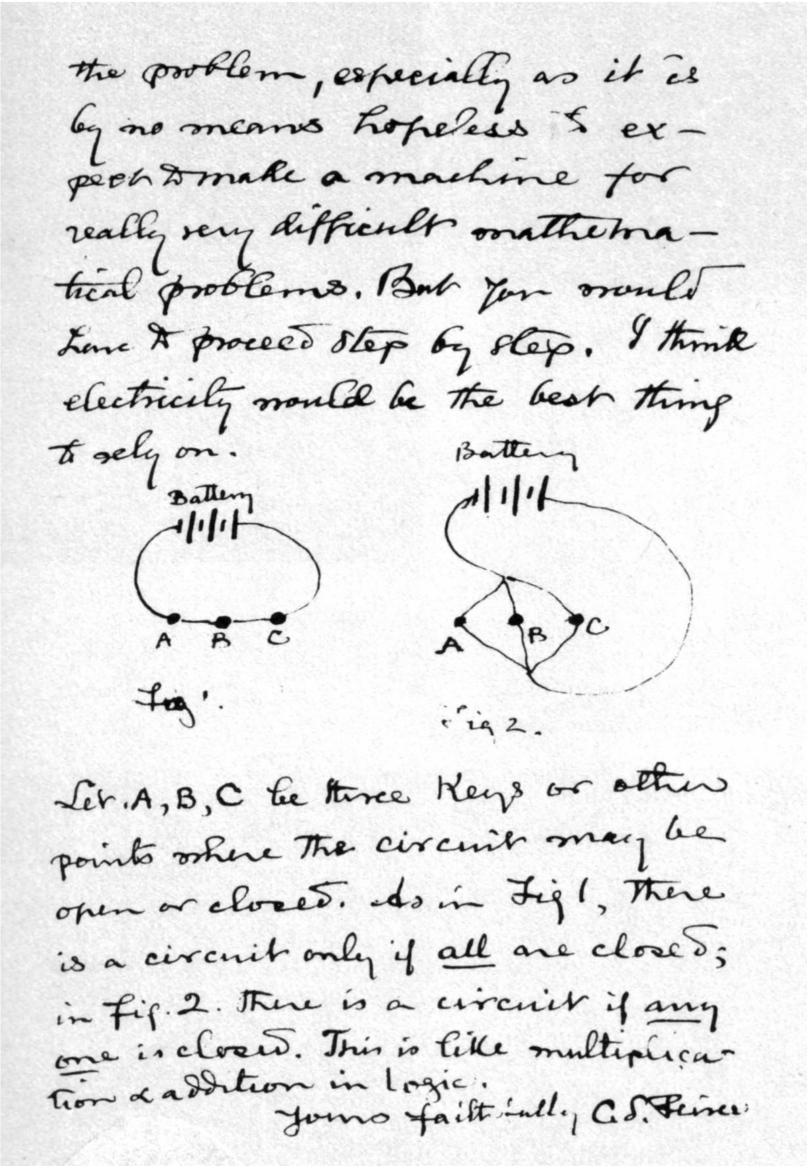
Mr. Marquand's machine is a vastly more clear-headed contrivance than that of Jevons. The nature of the problem has been grasped in a more masterly manner, and the directest possible means are chosen for the solution of it. In the machines actually constructed only four letters have been used, though there would have been no inconvenience in embracing six. Instead of using the cumbrous equations of Jevons, Mr. Marquand uses Professor Mitchell's method throughout.[1] There are virtually no keys ex-

[1] It would be equally true to say that the machine is based upon Mrs. Franklin's system. The face of the machine always shows every possible combination; putting down the keys and pulling the cord only alters the appearance of some of them. For example, the following figure represents, diagrammatically, the face of such a machine with certain combinations modified:



This face may be interpreted in several different ways. First, as showing in the shaded portions—

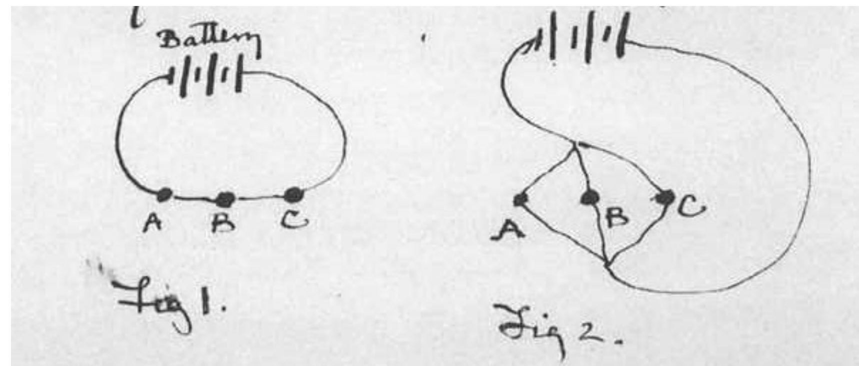
C. S. Peirce: Logic Machines and First Diagram of Boolean Electronic Logic Switches (Gates) (1886)


the problem, especially as it is by no means hopeless to expect to make a machine for really very difficult mathematical problems. But you would have to proceed step by step. I think electricity would be the best thing to rely on.

Let A, B, C be three keys or other points where the circuit may be open or closed. As in Fig 1, there is a circuit only if all are closed; in Fig. 2. there is a circuit if any one is closed. This is like multiplication & addition in Logic.

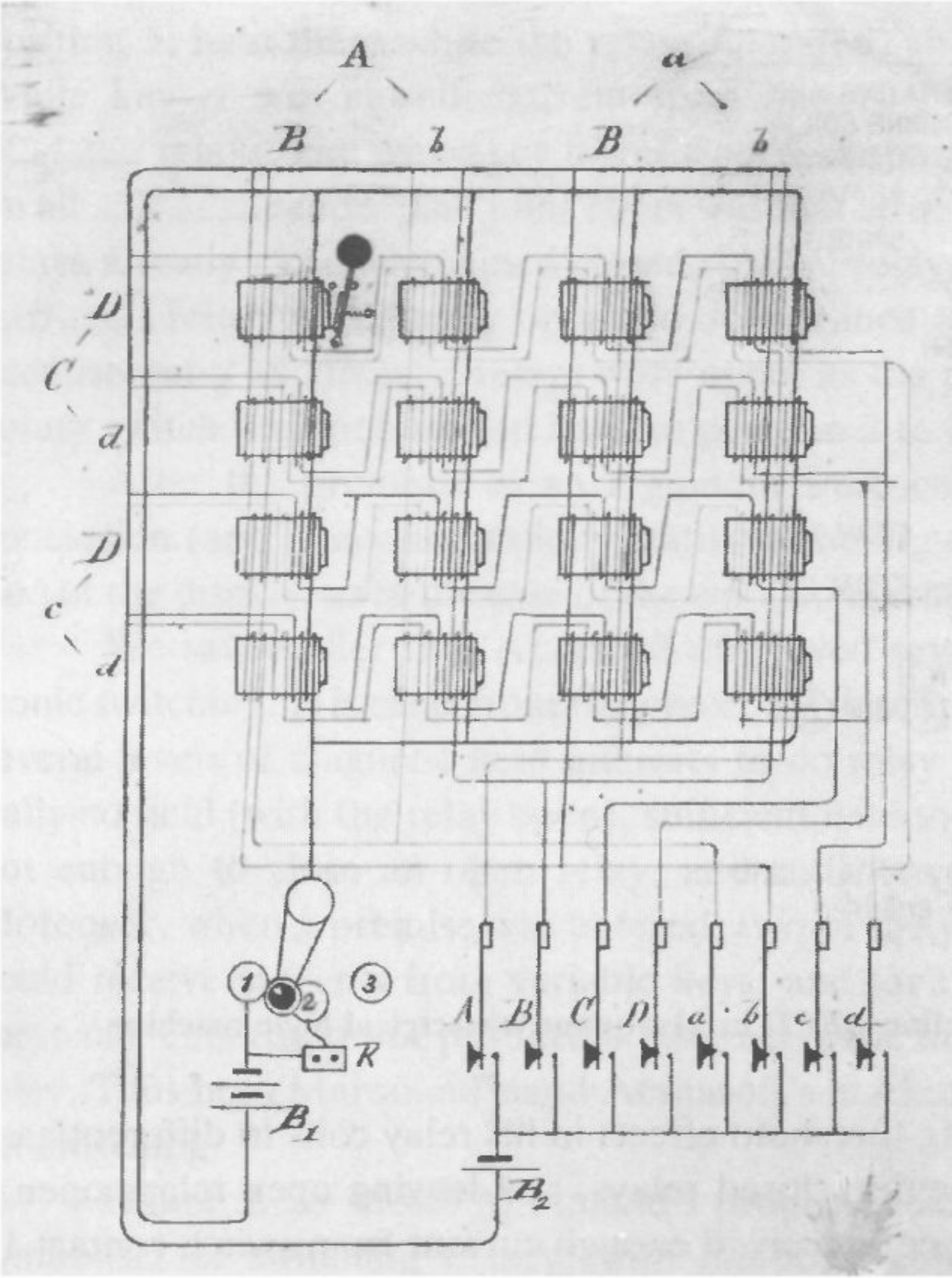
Yours faithfully, C. S. Peirce

"I think you ought to return to the problem [of building your reasoning machine], especially as it is by no means hopeless to expect to make a machine for really very difficult mathematical problems. But you would have to proceed step by step. I think electricity would be the best thing to rely on.



Let A, B, C be three keys or other points where the circuit may be open or closed. As in Fig 1, there is a circuit only if all are closed; in Fig. 2. there is a circuit if any one is closed. This is like multiplication & addition in Logic."

(Peirce, Letter to Allan Marquand, 1886, W 5.421-22)



Peirce’s diagram for improving Alan Marquand’s electromagnetic switched logic machine, c. 1886.

16 switches for 4-term syllogisms, set by keys to select syllogistic form.

From Alan Marquand Papers,
Firestone Library, Princeton University

Claude Shannon,
Design for Combining Switching Circuits Modeled on Boolean Symbolic Logic

(1) *A Symbolic Analysis of Relay and Switching Circuits* (MIT Thesis, 1936-37)

(2) "A Symbolic Analysis of Relay and Switching Circuits." *American Institute of Electrical Engineers*, 57, no. 12 (December 1938): 713–23

(1) Drawing from MIT Thesis (1936-37), p. 5

hinderance of the circuit formed by connecting the circuits a-b and c-d in parallel. A relay contact or switch will be represented in a circuit by the symbol in Fig. 1, the letter being the corresponding hinderance function. Fig. 2 shows the interpretation of the plus sign and Fig.3 the multiplication sign.

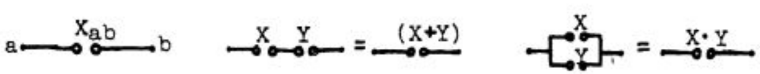


Fig. 1 Fig. 2 Fig. 3

This choice of symbols makes the manipulation of hinderances very similar to ordinary numerical algebra.

(2) Published version, 1938

THEOREMS

In this section a number of theorems governing the combination of hindrances will be given. Inasmuch as any of the theorems may be proved by a very simple process, the proofs will not be given except for an illustrative example. The method of proof is that of "perfect induction," i.e., the verification of the theorem for all possible cases. Since by postulate 4 each variable is limited to the values 0 and 1, this is a simple matter. Some of the theorems may be proved more elegantly by recourse to previous theorems, but the method of perfect induction is so universal that it is probably to be preferred.

$$X + Y = Y + X \quad \textbf{(1a)}$$

$$XY = YX \quad \textbf{(1b)}$$

$$X + (Y + Z) = (X + Y) + Z \quad \textbf{(2a)}$$

(3*b*), however, is not true in numerical algebra.

We shall now define a new operation to be called negation. The negative of a hindrance X will be written X' and is defined as a variable which is equal to 1 when X equals 0 and equal to 0 when X equals 1. If X is the hindrance of the make contacts of a relay, then X' is the hindrance of the break contacts of the same relay. The definition of the negative of a hindrance gives the following theorems:

$$X + X' = 1 \quad \textbf{(6a)}$$

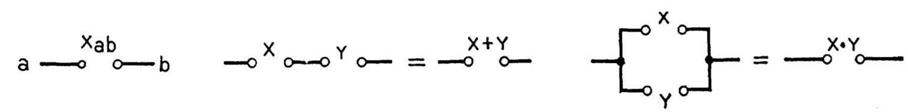


Figure 1 (left). Symbol for hindrance function

Figure 2 (middle). Interpretation of addition

Figure 3 (right). Interpretation of multiplication

Peirce's conception for logic switches was re-discovered by Shannon in the 1930s.

Shannon's “analogy” = *homology* (a design for “structural affinity”)

Our notation is taken chiefly from symbolic logic. Of the many systems in common use we have chosen the one which seems simplest and most suggestive for our interpretation….

We shall limit our treatment to circuits containing only relay contacts and switches, and therefore at any given time the circuit between any two terminals must be either open (infinite impedance) or closed (zero impedance)....

This choice of symbols makes the manipulation of hindrances very similar to ordinary numerical algebra.

[I]it is evident that **a perfect analogy** exists between the calculus for switching circuits and this branch of symbolic logic. Due to this analogy any theorem of the calculus of propositions is also a true theorem if interpreted in terms of relay circuits.

Shannon, *A Symbolic Analysis of Relay and Switching Circuits* (1936-37)

Homology **is more precise: “one-to-one” correspondence.**

Shannon's Bibliography

References

1. A complete bibliography of the literature of symbolic logic is given in the *Journal of Symbolic Logic*, volume 1, number 4, December 1936. Those elementary parts of the theory that are useful in connection with relay circuits are well treated in the two following references.

2. THE ALGEBRA OF LOGIC, Louis Cauturat [sic, for *Couturat*]. The Open Court Publishing Company.

3. UNIVERSAL ALGEBRA, A. N. Whitehead. Cambridge, at the University Press, volume L book III, chapters I and II, pages 35-82.

4. E. V. Huntington, *Transactions of the American Mathematical Society*, volume 35, 1933, pages 274-304. The postulates referred to are the fourth set, given on page 280.

Peirce's works on logic in the Bibliography cited by Shannon:

"A Bibliography of Symbolic Logic," *The Journal of Symbolic Logic*, Vol. 1/4, (Dec., 1936), 123-155.

28. C. S. PEIRCE.

* *1. On an improvement in Boole's calculus of logic* (presented 12 March 1867). ***Proceedings of the American Academy of Arts and Sciences,*** vol. 7 (1865–8), pp. 250–261. Reprinted in ***Collected papers of Charles Sanders Peirce,*** ed. by Charles Hartshorne and Paul Weiss, vol. 3 (Cambridge, Mass., 1933), pp. 3–15. "Let $a+,b$ denote all the individuals contained under a and b together. The operation here performed will differ from arithmetical addition in two respects: 1st, that it has reference to identity, not to equality; and 2d, that what is common to a and b is not taken into account twice over, as it would be in arithmetic."

2. Upon the logic of mathematics (presented 10 Sept. 1867). Ibid., pp. 402–412. Reprinted in ***Collected papers,*** vol. 3, pp. 16–26. "These considerations, together with those advanced on page 293 (112) of this volume, will, I hope, put the relations of logic and arithmetic in a somewhat clearer light than heretofore."

3. Grounds of validity of the laws of logic: Further consequences of four incapacities. ***The journal of speculative philosophy,*** vol. 2 (1868–9), pp. 193–208. Reprinted with corrections in ***Collected papers,*** vol. 5 (Cambridge, Mass., 1934), pp. 190–222.

* *4. Description of a notation for the logic of relatives, resulting from an amplification of the conceptions of Boole's calculus of logic* (communicated 26 Jan. 1870). ***Memoirs of the American Academy of Arts and Sciences,*** n.s. vol. 9, part 2, pp. 317–378. Reprinted in ***Collected papers,*** vol. 3, pp. 27–98. "Boole's logical algebra has such singular beauty, so far as it goes, that it is interesting to inquire whether it cannot be extended over the whole realm of formal logic, instead of being restricted to that simplest and least useful part of the subject, the logic of absolute terms, which, when he wrote, was the only formal logic known."

* *5. On the algebra of logic. Chapter I.—Syllogistic. Chapter II.—The logic of non-relative terms. Chapter III.—The logic of relatives.* ***American journal of mathematics,*** vol. 3 (1880), pp. 15–57. Reprinted with corrections in ***Collected papers,*** vol. 3, pp. 104–157.

* *6. On the logic of number.* Ibid., vol. 4 (1881), pp. 85–95. Reprinted with corrections in ***Collected papers,*** vol. 3, pp. 158–170.

7. Brief description of the algebra of relatives. 1882, 6 pp. Reprinted in ***Collected papers,*** vol. 3, pp. 180–186.

8. Remarks (on an article by B. I. Gilman). ***The Johns Hopkins University circulars*** (Baltimore), vol. 1 (1879–82), p. 240.

* *9. A theory of probable inference. Note B. The logic of relatives.* ***Studies in logic by members of the Johns Hopkins University,*** Boston, Mass., 1883, pp. 187–203. Reprinted in ***Collected papers,*** vol. 3, pp. 195–209.

* *10. On the algebra of logic: A contribution to the philosophy of notation.* ***Amer. jour. math.,*** vol. 7 (1885), pp. 180–202. Reprinted in ***Collected papers,*** vol. 3, pp. 210–238, with addition of *Note*, pp. 239–249. "Let v and f be two constant values, and let the value of a quantity representing a proposition be v if the proposition is true and be f if the proposition is false."

11. The critic of arguments. I. Exact thinking. II. The reader is introduced to relatives. ***The open court*** (Chicago), vol. 6 (1892), pp. 3391–3394, 3415–3418. Reprinted in ***Collected papers,*** vol. 3, pp. 250–265.

12. Review of Schröder's ***Vorlesungen über die Algebra der Logik,*** vol. 3, contained in two articles, *The regenerated logic,* ***The monist*** (Chicago), vol. 7 (1896–7), pp. 19–40 and *The logic of relatives,* ibid., p. 161–217. Reprinted in ***Collected papers,*** vol. 3, pp. 266–287, 288–345.

13. Insolubilia. ***Dictionary of philosophy and psychology,*** ed. by J. M. Baldwin, vol. 1 (New York and London 1901), p. 554. Reprinted in ***Collected papers,*** vol. 2 (Cambridge, Mass., 1932), pp. 370–371.

14. Logic (exact). Ibid., vol. 2 (New York and London 1902), pp. 23–27. Reprinted in ***Collected papers,*** vol. 3, pp. 393–399.

15. Relatives (logic of). Ibid., pp. 447–450. Reprinted in ***Collected papers,*** vol. 3, pp. 404–409.

16. Symbolic logic. Peirce's contribution to an article of that title, ibid., pp. 645–650. Reprinted in ***Collected papers,*** vol. 4 (Cambridge, Mass., 1933), pp. 320–330.

17. Existential graphs. ***A syllabus of certain topics of logic,*** Boston 1903, pp. 15–23. Reprinted in ***Collected papers,*** vol. 4, pp. 331–340.

18. Nomenclature and divisions of dyadic relations. c. 1903. Reprinted in ***Collected papers,*** vol. 3, pp. 366–387.

19. Prolegomena to an apology for pragmaticism. ***The monist,*** vol. 16 (1906), pp. 492–546. See corrections, ibid., vol. 17 (1907), p. 160. Reprinted in ***Collected papers,*** vol. 4, pp. 411–463.

20. Some amazing mazes. [Conclusion.] Ibid., vol. 18 (1908), pp. 416–464. Reprinted in ***Collected papers,*** vol. 4, pp. 485–537.

* *21. A Boolian algebra with one constant* (c. 1880). ***Collected papers,*** vol. 4, pp. 13–18. "The apparatus of the Boolian calculus consists of the signs, $=$, $>$ (not used by Boole, but necessary to express particular propositions), $+$, $-$, $\times$, 1, 0. In place of these seven signs, I propose to use a single one."

22. Second intentional logic (1893). ***Collected papers,*** vol. 4, pp. 56–58.

23. The logic of quantity (1893). ***Collected papers,*** vol. 4, pp. 59–131.

24. The simplest mathematics (1902). ***Collected papers,*** vol. 4, pp. 189–262.

25. On existential graphs, Euler's diagrams, and logical algebra (c. 1903). ***Collected papers,*** vol. 4, pp. 341–397.

26. The gamma part of existential graphs (1903). ***Collected papers,*** vol. 4, pp. 398–410.

27. Notes on the list of postulates of Dr. Huntington's Section 2 (c. 1904). ***Collected papers,*** vol. 4, pp. 263–267.

28. Analysis of some demonstrations concerning definite positive integers (1905). ***Collected papers,*** vol. 4, pp. 281–289.

29. An improvement on the gamma graphs (1906). ***Collected papers,*** vol. 4, pp. 464–470.

See also C. J. Keyser 118***15***, E. V. Huntington 122***1***, and Paul Carus 193***2***.

The Binary Electronic Homology System: our substrate for digital semiotic subsystems

Homology is more precise: "one-to-one" correspondence.

As a standard textbook on digital design explains:

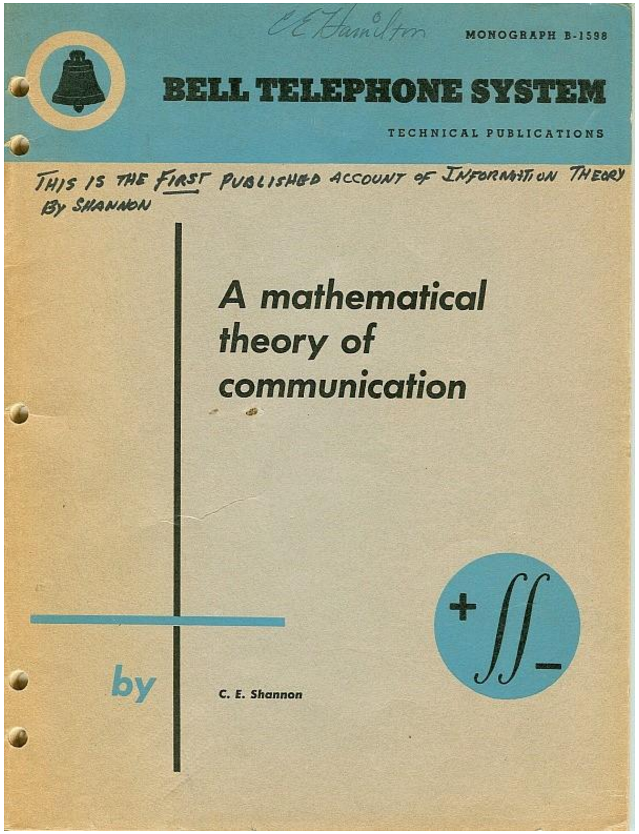
Digital systems use signals that have two distinct values and circuit elements that have two stable states. There is a direct analogy among binary signals, binary circuit elements, and binary digits. A binary number of *n* digits, for example, may be represented by *n* binary circuit elements, each having an output signal equivalent to 0 or 1.

Digital systems represent and manipulate not only binary numbers, but also many other discrete elements of information. Any discrete element of information that is distinct among a group of quantities can be represented with a binary code (i.e., a pattern of 0s and 1s). The codes must be in binary because, in today's technology, only circuits that represent and manipulate patterns of 0s and 1s can be manufactured economically for use in computers. However, it must be realized that binary codes merely change the symbols, not the meaning of the elements of information that they represent.

If we inspect the bits of a computer at random, we will find that most of the time they represent some type of coded information rather than binary numbers.

M. Morris Mano and Michael D. Ciletti, *Digital Design*, 5th edition. Upper Saddle River, NJ: Prentice Hall, 2012: 18.

Next step:
From Peirce to Shannon and Information Theory as Covert Semiotics



From: *A Mathematical Theory of Communication*, 1948

"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."

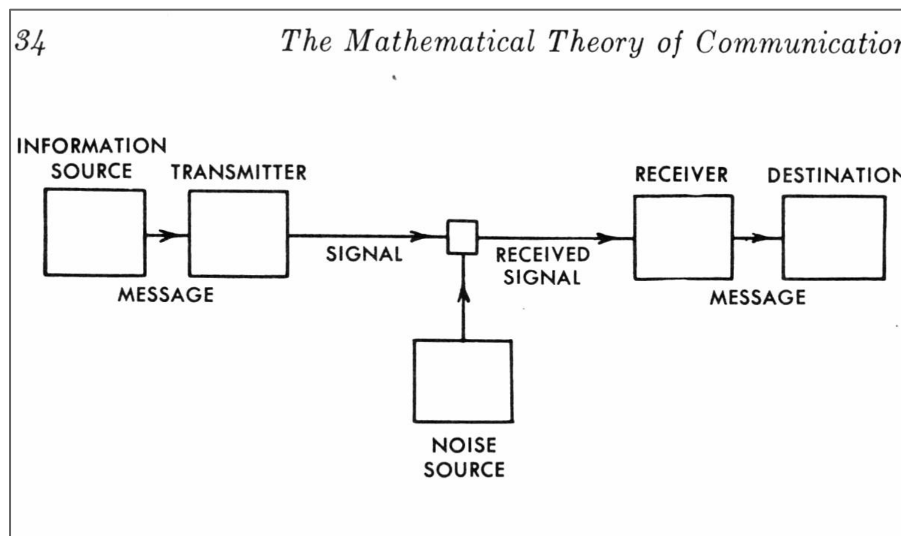


Fig. 1. — Schematic diagram of a general communication system.

"Information Theory" as Digital (Binary) Data Design in the Shannon model is an *engineering solution to a semiotic problem*:

The semiotic design problem solved in information theory is:

How to use selected slices in the energy continuum of the electromagnetic spectrum as a *substrate* for designing *structure-preserving structures* for reliable *tokenization* and *re-tokenization* of the distinguishable, interpretable *patterns* of the symbolic systems encoded.

Modeling representations in binary bit sequences enabled the convergence of telecommunications and computing: any sign system could be digitized and distinguished in data types (sound waves, text characters, mathematical symbols, and matrix of light values for images).

Shannon and Bell Labs-MIT standardization on the bit (binary digit) is a perfect mapping (design homology) of mathematical structure and values ({1,0}, base-2 number system) and logical values (true/false, yes/no, 1/0) to electronic structures (open/closed circuits, on/off, presence/absence of current, +/- voltage charge).

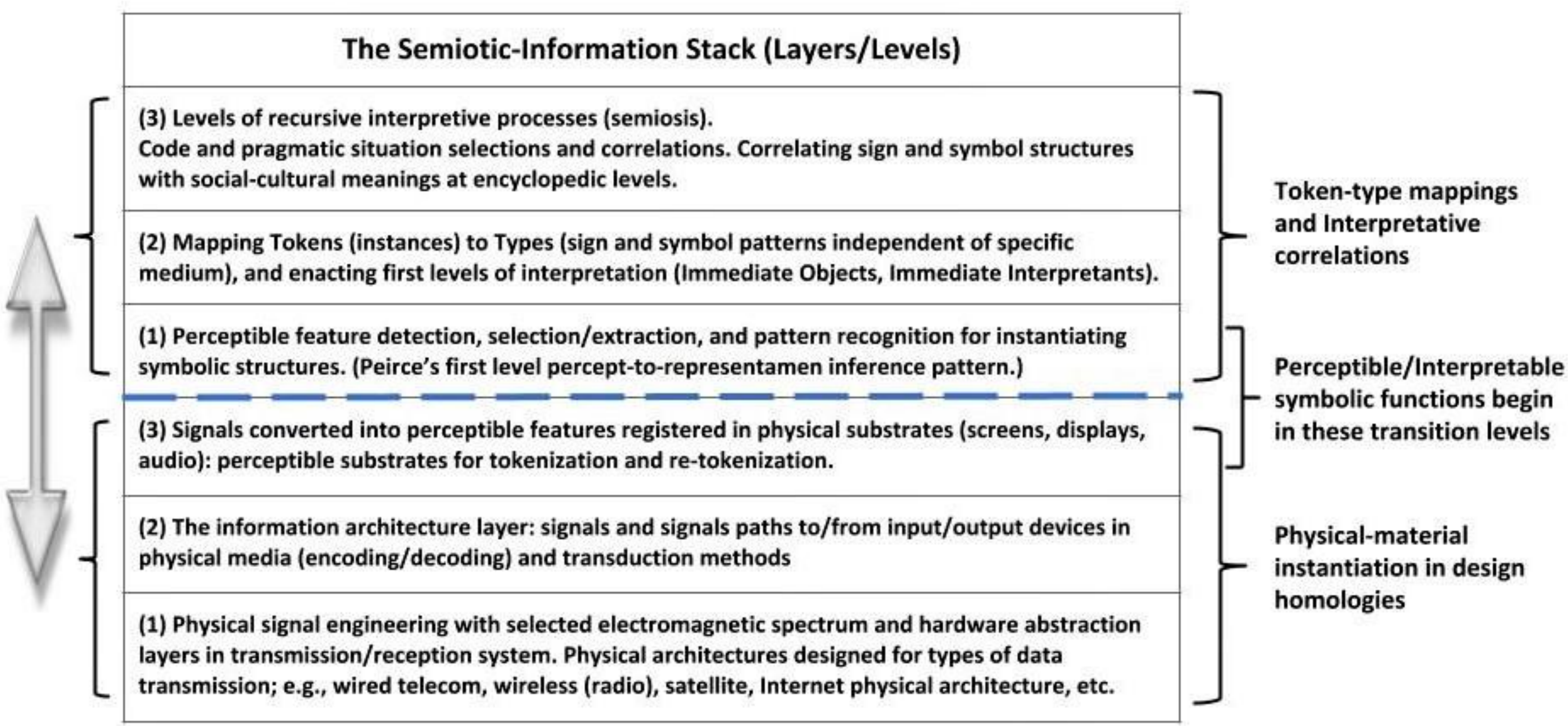
Extending Morse, the symbolic values (types) of sequences of {1,0} mapped to electronic states are reciprocally convertible to token representations of whatever sign system is encoded.

Digital (discrete quantized) information is designed to be a structure-preserving structure, a trick we can do to simulate invariance with variable energy substrates.

The mathematics for quantized units gives us bits: regardless of variations in voltage or time for registering or draining a charge, a system can be designed so that every physical unit evaluates to presence/absence, yes/no, +/-, 1/0.

"[E]lectrical circuit phenomena… are characterized by an invariance with respect to a shift of origin in time."

Norbert Wiener, *Cybernetics, or the Control and Communication in the Animal and the Machine*. 2nd edition. Cambridge, MA: The MIT Press, 1961; first published 1948, p. ix.



Martin Irvine, 2018

The information-theoretic models are electrical engineering solution designs for a semiotic problem: creating *semiotic subsystems* in *structure-preserving structures* of electronic units as substrates for tokenizing and re-tokenizing perceptible-interpretable sign/symbol structures.

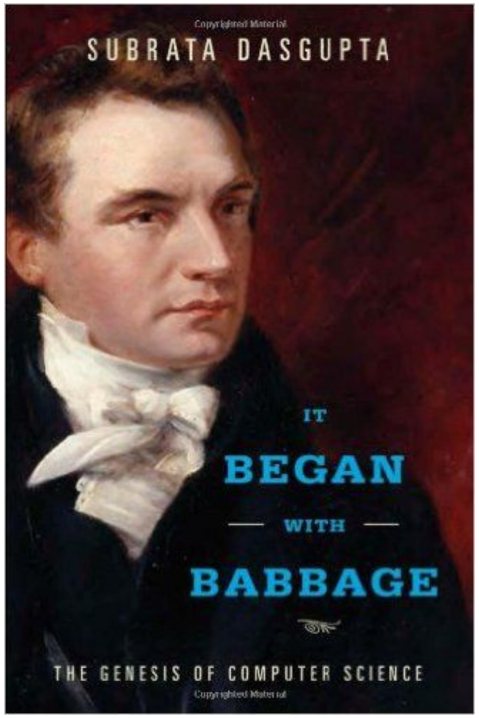
Meaning isn't *in* the communications system substrates; it *is* the whole semiotic system.

Homology of Form and Possibility of "Interactive" Programming, c. 1911. Possibility of designing a "logic machine" as a semiotic artefact.

From MS S 51:7-8 (1910-11), unpublished.

[p. begins broken off; introduction to the question of representation in reasoning machines:]

facts represented. Even this is not enough. It would be necessary to feed into the machine the fact of the degree of reasonableness of certain ideas, -- that is to say, the fact that they, in a certain measure, accord with what has been before ascertained about the ways of truth. It is far, far beyond what we could as yet explicitly represent. But there is nothing inconceivable in it. When all this was at last fed into the machine, it is not to be supposed that the handle could be turned and the conclusion from these premisses be ground out. *The* conclusion! There is no such thing. From the simplest premiss, the conclusions are innumerable. Look at all the propositions of geometry that are yearly added to the stock of conclusions from a few axioms and postulates! No, it will be necessary that the machine should receive a certain direction which should confine its results to a certain class of consequences and to a certain order of complexity within that class. Otherwise there would be a multitude of conclusions that no one infinite series could compass. It is, however, quite conceivable that that, too, should be done, and that the conclusion should be worked out by machinery, and should be there to be interpreted by human thought if desired, having up to that time not entered into any human mind. That would be a proposition, -- a *pensandum*, a *cogitandum*, not yet *pensatum* or *cogitatum*; and such pensandum would be what is meant by a *proposition*….



C. S. Peirce wrote the obituary for Charles Babbage for the *The Nation*, 9 November 1871. Peirce discusses Babbage's two "engines," and the Scheutz difference engine being used in the Albany Observatory (purchased on the advice of a scientific committee in which his father, Benjamin Peirce, was a member). Peirce cites Babbage many times in his writings.

A symbolic and semiotic view of computing can be found in many contexts in computer science:

"We have come a long way from this association [of computing as calculating with numbers]. We will see that **the domain of computation actually comprises *symbols***—by which I mean things that represent other things (for example, a string of alphabetic characters—a word—that represent some object in the world, or a graphical road sign that represents a warning to motorists).

The act of computation is, then, *symbol processing*: the manipulation and transformation of symbols. Numbers are just one kind of symbol; calculating is just one kind of symbol processing. And so, the focus of automatic computation, Babbage's original dream, is whether or how this human mental activity of symbol processing can be performed by (outsourced to) machines with minimal human intervention. Computer science as the science of automatic computation is also **the science of automatic symbol processing**."

Subrata Dasgupta, *It Began with Babbage: The Genesis of Computer Science* (Oxford: Oxford University Press, 2014)

Fast Forward to 1960-1962, new capabilities emerge after WW2:

Doug Engelbart at SRI begins designing the prototype, proof-of-concept "symbolic interface system" for our current GUI interactive systems.

Astonishingly, he successfully pitches his project to the Air Force Office of Scientific Research for funding what he calls the "Augmenting Human Intellect Program."

Engelbart took a very philosophical and intuitively semiotic approach to his engineering problem:

How to design all the levels and layers of a digital system [to be extended and re-conceived] with interface inputs [to be re-conceived] and interface outputs to a screen (CRT tube) [to be re-conceived] so that the internal system *subsystems* serve core human symbolic thinking needs (presenting all symbol systems in an active substrate that an interpretive agent can organize, transform, and *think with*.

From drafts and the main proposal for "Augmenting Human Intellect: A Conceptual Framework," October 1962.

Douglas C. Engelbart, "Augmenting Human Intellect: A Conceptual Framework. SRI Project No. 3578". Menlo Park, CA: SRI, Stanford Research Institute, Computer Techniques Laboratory, October 1962.

Engelbart's early description in 1961 reads like Peirce describing Existential Graphs as "moving pictures of thought":

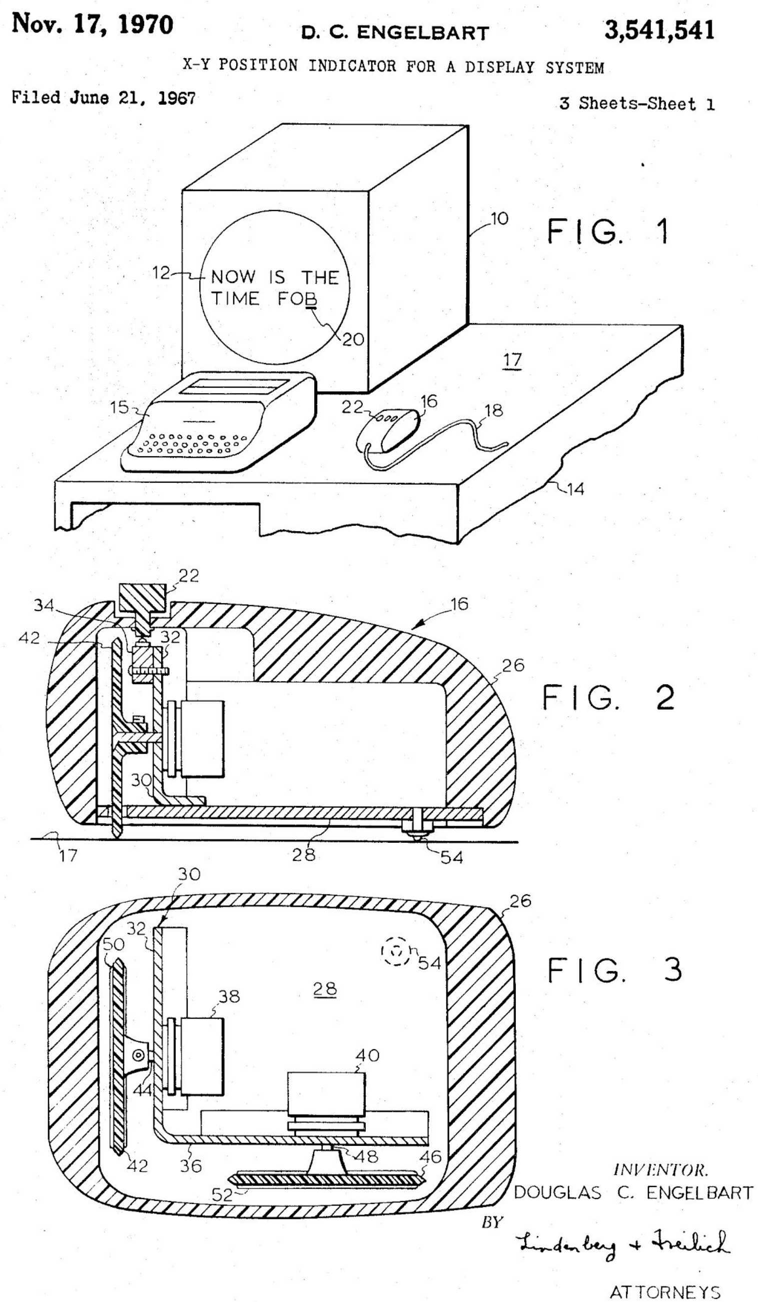
For other than intuitional or reflexive actions, an individual thinks and works his way through his problems by manipulating concepts before his mind's eye. His powers of memory and visualization are too limited to let him solve very many of his problems by doing this entirely in his mind. For most real-life problems, an individual needs to represent these concepts with numbers, letters, words, graphs, drawings, etc. (i.e., with symbols) that can be assembled and rearranged before his eyes in patterns that portray the conceptual relationships to be considered. We conventionally use marks on paper for thus augmenting our visualization and memory capabilities.

Thus, a large part of an individual's meaningful intellectual activity involves the purposeful manipulation of concepts; and of this concept-manipulation activity, a very important part is accomplished by the external manipulation of symbols. A fundamental hypothesis of the proposed approach is that the ability of a given human to control the real-time external manipulation of symbols, in response to the minute-by-minute needs of his thought processes, has a profound effect upon the whole structure of concepts and methods utilized in his intellectual activity. The approach can be succinctly described by saying that our aim is to use the best that technology can offer in providing increased symbol-manipulation power to the human….

For this application, the stereotyped image of the computer as only a mathematical instrument is too limiting -- essentially, a computer can manipulate any symbol in any describable way. It is not just mathematical or other formal methods that are being considered. Our aim is to give help in manipulating any of the concepts that the individual usefully symbolizes in his work, of which those of mathematical nature comprise but a limited portion in most real-life instances. (SRI Memo, 1961)

Engelbart's 140-page report is description of the symbolic-interpretive needs of "problem solvers" with the requirements for the design homologies that must be implemented in the levels of computing system architecture and the emerging possibilities for screen interaction, file and data type integration, and collaborative work in network systems.

The important point is that all our contemporary systems are based on design homologies, abstracted out of view, but everywhere operational.



Engelbart's first patent for a "X-Y Position Indicator for a Display System" (aka "Mouse")

The rest is our history...

What are the consequences of a Peircean semiotic redescription of computing systems and digital design?

Computation and digital media structures are *artefacts of human symbolic cognition*.

Digital electronic computing systems are based on *homologous designs* of “logic as semiotic” implemented in physical electronic and material substrates for (1) instantiating token structures of symbolic types, (2) enacting logical patterns of recursive interpretation (automatable semiosis), and (3) returning interpretable representations for further interpretations.

Everything designed in/for computing systems is in the service of one or more human sign/symbol system, and the very design of computing and digital information is based on implementing formal symbolic homologies in computational and data substrates.

As a designed artefact of the human symbolic faculty -- implemented by means of “logic as semeiotic” -- all digital computing and information is implemented at different levels in the architecture for homologies of representation and operations by means of physical structured substrates.

And in every age, it can only be the philosophy of that age, such as it may be, which can animate the special sciences to any work that shall really carry forward the human mind to some new and valuable truth. Because **the valuable truth is not the detached one, but the one that goes toward enlarging the system of what is already known**.

Peirce, *The First Rule of Logic*, MSS 442, 825 (Cambridge Conference Lecture IV, 1898)

Comments and suggestions welcome!

Contact info:

Martin Irvine

Founding Director and Associate Professor

Communication, Culture & Technology Program

Georgetown University

Washington, DC USA

web: irvine.georgetown.domains

email: irvinem@georgetown.edu