Philodemus was written under Peirce's supervision and was the only doctoral dissertation ever completed under Peirce's direction. *Studies in Logic by Members of the Johns Hopkins University*, which appeared in 1883 under Peirce's editorship, included the introduction to Marquand's dissertation, entitled "The Logic of the Epicureans," as the first part. In 1881 Marquand joined the faculty at Princeton as Tutor in Latin and lecturer in Logic. In 1883, probably as a result of a dispute with the university president, Marquand changed his position at Princeton by becoming professor of art and archaeology, a position he held until his death.

While still a student at Hopkins, Marquand had been directed, by Peirce, to the task of developing an improved version of William Stanley Jevons's mechanical instrument for performing syllogistic reasoning, his "Logical Piano," so called because, to use an analogy with modern computers, its "keyboard" resembled a section of a piano keyboard. Marquand contributed heavily to the first issue of *Studies in Logic*, including an essay entitled "A Machine for Producing Syllogistic Variations" and the following "Note on an Eight Term Logical Machine." From these contributions it is clear that Marquand had already devised three types of aids for logical computation. The first such device consisted of logical diagrams or graphs; the second was a mechanically crank-operated realization of these diagrams; and the third improved the Jevons machine, providing operation by depression of keys. Peirce was completely familiar with these developments and certainly had the upgraded Jevons device in mind when writing the "logical machine" entry for Whitney's *Dictionary and Cyclopedia*.

> Logical machine, a machine which, being fed with premises, produces the necessary conclusions from them. The earliest instrument of this kind was the demonstrator of Charles, third Earl Stanhope: the most perfect is that of Professor Allan Marquand, which gives all inferences turning upon the logical relations of classes. The value of logical machines seems to lie in their showing how far reasoning is a mechanical process, and how far it calls for acts of observation. Calculating machines are specialized logical machines. (Peirce 1889: 3560)

But what, exactly, was Peirce referring to when noting Marquand's "most perfect" machine? James Mark Baldwin reported the important third development by Marquand, the improved or upgraded version of Jevons's Logical Piano, in his *Dictionary of Philosophy and Psychology* under the entry "Logical Machine." He also mentioned a crucial fourth development, one that, by involving electricity, departed quite radically from its predecessors.

> In 1882 Marquand constructed from an ordinary hotel annunciator another machine in which all the combinations are visible at the outset, and the inconsistent combinations are concealed from view as the premises are impressed upon the keys. He also had designs made by means of which the same operations could be accomplished by means of electro-magnets. (Baldwin 1902/II: 2930)

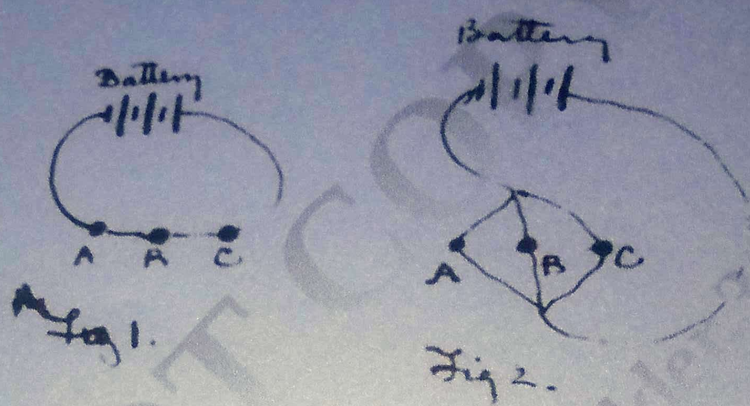
Did Peirce have, in addition to his thorough acquaintance with the improved Logical Piano, knowledge of such designs involving electromagnets when reporting in the *Century Dictionary and Cyclopedia* on Marquand's "most perfect" logical machine?

Marquand published on the subject of his advancement of the Logical Piano in the *Proceedings of the American Academy of Arts and Sciences for 1885–1886*, naming the essay "A New Logical Machine." He had presented this paper before the AAAS on 11 November 1885, apparently being disappointed with its reception. In a letter dated 30 December 1886, Peirce encouraged Marquand's will to learn and urged him to continue improving his logic machine. In his letter, Peirce suggested the introduction of a new component in the design of logic machines, a component that would quickly lead to a design, as reported by Baldwin, involving electromagnets. The component was electricity:

> I think you ought to return to 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.

Diagram 4.6

Peirce's hand-drawn circuits



(Papers of Allan Marquand, Manuscript Division, Department of Rare Books and Special Collections. Courtesy Princeton University Libraries)

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 1886, using his hand-drawn figures)

These diagrams of series and parallel electrical circuits make possible and indeed illustrate the inevitability of properly performed logical multiplication and addition: the conjunction "A · B"; the disjunction "A v B" (see diagram 4.1). Either or both relations may represent for us propositions, beliefs, and knowledge items, and either or both relations may clearly be instantiated in electrical circuitry and computing machines, as in Shannon's analogs of fifty years later (see Shannon 1938). So, clearly, some parts of our knowledge that are deductive in character can be instantiated in machines. But this is quite different from concluding that because *some parts* of our knowledge are machine computable, *all parts* must be.

Peirce's remarkable letter lay in the Allan Marquand Papers at Princeton University Library, apparently unnoticed, until its discovery around 1970 by Professor Preston Tuttle. In addition to this unique letter there is another, even more fascinating piece of evidence on the subject of Peirce, Marquand, and logic machines in the Marquand Papers at Princeton. This is a design of the type using electromagnets that, according to Baldwin, Marquand "had made." This electromagnetic design was first noticed at Princeton by Professor Alonzo Church, about 1950. Historical evidence surrounding this diagram indicates that it was drawn up about 1887 and that its author was Peirce (see diagram 4.7).

This diagram represents a proposed electromechanical machine that performs, by purely algorithmic means, deductions in the logical relation of classes involving up to four terms. It exhibits four basic types of components: electromagnets, circuit keys for the introduction of premises, an operations switch, and a power supply consisting of two batteries. Consistent with Baldwin's remarks and with the instructions for operation found on the original drawing, we would begin logical operations with this machine with "all the [logical] combinations [being] visible" (Baldwin 1902/II: 29). These logical combinations, each four letters in length, would be matched to the electromagnets according to the grid of exhaustive possibilities implicit in the lettering on the diagram, where uppercase and lowercase letters represent the truth and falsity, respectively, of each of the four terms. The "visible combinations," to begin, would look like this.

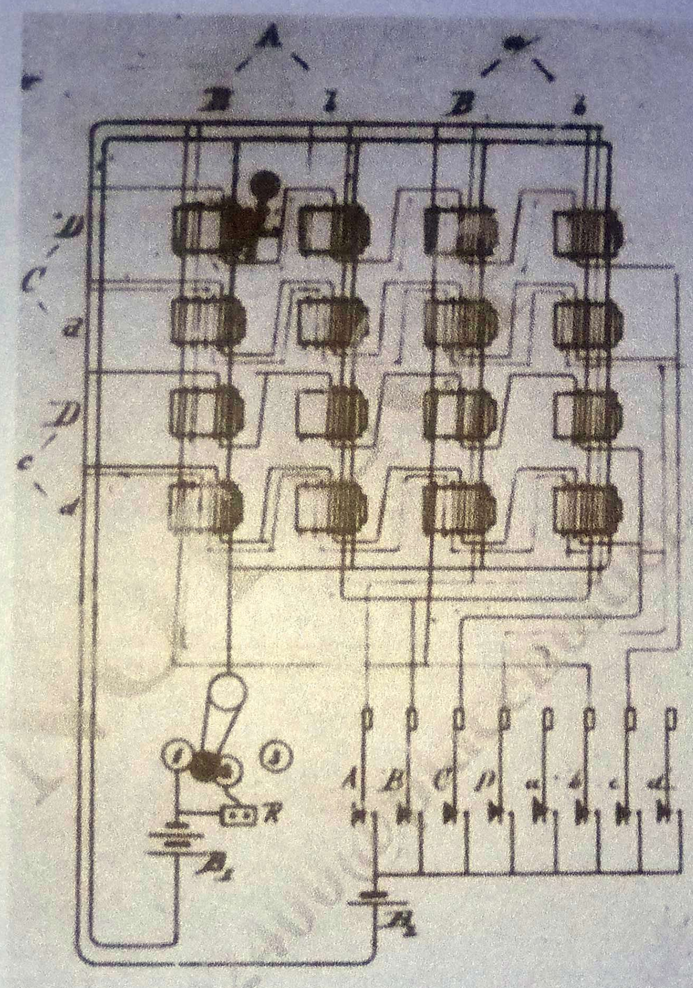
Diagram 4.7

ABCD	AbCD	aBCD	abCD
ABCd	AbCd	aBCd	abCd
ABcD	AbcD	aBcD	abcD
ABcd	Abcd	aBcd	abcd

The design with electromagnets looks like this:

Diagram 4.8

Circuit diagram for electromagnetic logical machine



(Papers of Allan Marquand, Manuscript Division, Department of Rare Books and Special Collections, Courtesy Princeton University Libraries)

Premises are introduced by means of the circuit keys, which are lettered, as in diagram 4.7, above, to handle these four terms and their negations. As premises are thus entered, the inconsistent logical combinations that result are, by actions of the electromagnets, removed from view. So, for example, successful entry of the premise "All A are B" would leave in view only those combinations with 'A' and 'B' in them. A second premise "All B are C" would retain in the machine's memory only those combinations containing 'B' and 'C'. Successive entries would rely on the same principles.

Let us now suppose that we wish to work a four-term categorical deduction of the type initiated earlier with the premise "All pianists are keyboardists." Here, however, we will use the four terms A, B, C, and D instead of our earlier abbreviations. Our three premises are, then:

Diagram 4.9

All A is B
All B is C
All C is D

Our aim is to discern what logical relation may obtain between classes represented by the terms A and D. These premises are entered in discrete steps, with each term or variable handled in turn. After all three premises have been entered and the attendant inconsistent logical combinations, which in this case means any combination containing at least one lowercase letter, concealed, the result of our mechanized working of a four-term categorical deduction is the valid conclusion "All A is D."

We see that by observing the conventions for entry of premises and thus setting into action the matrix of the proposed machine, the result is completely, precisely, and *repeatably* determined by finite, algorithmic means. The elements with which this deductive activity began were, of course, our premises for a four-term categorical deduction.

This is, then, an example from the collection or set of argument forms that the Peirce-Marquand machine *can* execute. Especially important is the procedure or method embodied in the actual physical arrangement of the machine with its entry keys, electromagnets, and such by which this activity is carried out. This method mechanically, deterministically, and repeatably proceeds from premises to conclusions by means of a recipe, or finite set of instructions. Such a set of instructions is termed an algorithm. And again, *some* parts of our knowledge may indeed be instantiated in machines driven by algorithms, but this does not soundly argue that *all* our knowledge may be reduced to algorithms. The machine driven by an algorithm is limited in ways that the active mind is not. Now the active mind may, of course, make mistakes that the computer would not, but the active mind's limits to truth or error will not be set by an algorithm, as they explicitly are in computing machines.

The fact that deductive logic is thus machine computable by algorithmic means illustrates yet again that this adjunct method of acquiring and developing human knowledge involves matters independent of our subjective views. Deductive validity is an *objective* state of things. It is *real* and, as Peirce put it, "therefore independent of the vagaries of me and you" (*CP* 5.311). In this same objective sense, both the formal and informal fallacies we shall see in chapter 5 are important cutting or filtering tools in pragmatic investigations.