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The Logic of Ingenuity

Part 2: Engineering Analysis

By Jon A. Schmidt, P.E., SECB

> *The Logic of Ingenuity*
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> The process of (abductively) creating a diagrammatic representation of a problem and its proposed solution, and then (deductively) working out the necessary consequences, such that this serves as an adequate substitute for (inductively) evaluating the actual situation.

Charles Sanders Peirce wrote many thousands of pages during his lifetime on a wide variety of topics, but evidently had little to say about engineering. One place where he did address it was in an 1898 article, "The Logic of Mathematics in Relation to Education." It appeared initially in a journal called *Educational Review*, and subsequently as CP 3.553-562 and PMSW 15-21.

Peirce briefly discussed and rejected several characterizations of mathematics throughout history; most notably, the still-common misunderstanding of it as merely "the science of quantity." He then favorably quoted the definition advocated by his father Benjamin, one of the foremost 19th century practitioners in that field: "the science which draws necessary conclusions." He also cited the ninth edition of the *Encyclopaedia Brittanica* to support his contention that "it is only about hypotheses that necessary reasoning has any application," where a hypothesis is "a proposition imagined to be strictly true of an ideal state of things."

Next came the key passage (CP 3.559), which I will quote throughout the rest of this article. Peirce sought to describe what a mathematician *does*, rather than what mathematics *is* or what sort of objects it studies:

> *A simple way of arriving at a true conception of the mathematician's business is to consider what service it is which he is called in to render in the course of any scientific or other inquiry. Mathematics has always been more or less a trade. An engineer … finds it suits his purpose to ascertain what the necessary consequences of possible facts would be; but the facts are so complicated that he cannot deal with them in his usual way. He calls upon a mathematician and states the question.*

In Peirce's day, this is what literally occurred on many occasions – engineers would retain mathematicians to perform a lot of their calculations. It is worth noting that Peirce's rare mention of engineering here may not be coincidental. At about the same time, he was providing precisely this type of assistance to George S. Morison in support of the latter's preliminary design for a span over the Hudson River, near the eventual site of Othmar Amman's George Washington Bridge. Portions of the resulting report survive in Peirce's manuscripts that Richard S. Robin numbered 1357-1360 in his 1967 catalog.

> *Now the mathematician does not conceive it to be any part of his duty to verify the facts stated. He accepts them absolutely without question. He does not in the least care whether they are correct or not.*

Today the engineer normally serves as the mathematician, as well – typically aided by a computer, which likewise "does not in the least care whether [the facts] are correct or not." A machine is perfectly capable of drawing necessary conclusions by executing a deterministic algorithm, but it is up to the engineer to formulate the initial hypothesis – i.e., the *model* – in a way that adequately *represents* the circumstances of interest.

> *He finds, however, in almost every case that the statement has one inconvenience, and in many cases that it has a second. The first inconvenience is that, though the statement may not at first sound very complicated, yet, when it is accurately analyzed, it is found to imply so intricate a condition of things that it far surpasses the power of the mathematician to say with exactitude what its consequences would be. At the same time, it frequently happens that the facts, as stated, are insufficient to answer the question that is put.*

In other words, it is rarely feasible to incorporate *all* aspects of the "condition of things" into an engineering model; and a *complex* system is one for which it is not even feasible to incorporate all of the *relevant* aspects. Also, there are inevitable uncertainties that require the engineer to make various assumptions. The upshot is that, despite being the creator of the model and presumably familiar with it in all of its details, the engineer will probably not be able to anticipate all of its results in advance.

> *Accordingly, the first business of the mathematician, often a most difficult task, is to frame another simpler but quite fictitious problem (supplemented, perhaps, by some supposition), which shall be within his powers, while at the same time it is sufficiently like the problem set before him to answer, well or ill, as a substitute for it.*

Here Peirce calls attention to something that engineers would do well to keep in mind: We routinely develop a viable solution to a real problem by solving a "quite fictitious" one in its place. Indeed, even the most fundamental phenomena of engineering science – for structural engineers, concepts like force, moment, shear, and stress – do not strictly *exist*, except as convenient tools for mental and mathematical manipulation of idealized scenarios.

> *This substituted problem differs also from that which was first set before the mathematician in another respect: namely, that it is highly abstract. All features that have no bearing upon the relations of the premises to the conclusion are effaced and obliterated. The skeletonization or diagrammatization of the problem serves more purposes than one; but its principal purpose is to strip the significant relations of all disguise. Only one kind of concrete clothing is permitted – namely, such as, whether from habit or from the constitution of the mind, has become so familiar that it decidedly aids in tracing the consequences of the hypothesis.*

This is where judgment comes into play. When translating an artifact into an abstract representation thereof, it is up to the engineer to ascertain which features "have no bearing" and which relations are "significant" enough to warrant making them explicit. The only people who can do this successfully are those who have cultivated the appropriate instincts and sentiments – habits of feeling, action, and thought – by virtue of gaining the requisite experience.

> *Thus, the mathematician does two very different things: namely, he first frames a pure hypothesis stripped of all features which do not concern the drawing of consequences from it, and this he does without inquiring or caring whether it agrees with the actual facts or not; and, secondly, he proceeds to draw necessary consequences from that hypothesis.*

This is engineering analysis in a nutshell; and in my next installment, I will further explore the nature of the reasoning that is involved.▪

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References

In accordance with standard scholarly conventions, Peirce's works are cited as follows. CP with volume and paragraph number(s) is *The Collected Papers of Charles Sanders Peirce*, edited by Charles Hartshorne, Paul Weiss, and Arthur W. Burks, published by Harvard University Press in 1931-1935 and 1958. PMSW with page numbers is *Philosophy of Mathematics: Selected Writings*, edited by Matthew E. Moore, published by Indiana University Press in 2010.