Math Is Key to Identifying Source of 'Strange Foot-Print'

The discussion about the relation between mathematics and physics is an old and an interesting one. It is also an ongoing one, as reflected in the pages of PHYSICS TODAY—see, for example Roman Jackiw's article in February 1996 (page 28) and Paul Roman's subsequent letter to the editor in June 1996 (page 11). Here, I argue that physical reality is, to some extent, a construct of our own; mathematics is innate to this constructive process; and we construct physical reality so that it complies with mathematics. Many physical objects such as fundamental particles, black holes and dark matter are not directly perceived by our senses, and their existence is revealed to us only through indirect evidence. We ask ourselves if they really exist. Such questions, of course, are not new, as similar ones have preoccupied philosophers since antiquity.

The subject is far from closed, and contemporary physicists actively participate in the controversy, as evidenced by the debate concerning the existence of the neutrino. Carl Adler took this particular case, and argued that the neutrino can exist only in a certain context; a context consists of a specific theoretical structure and specific experimental arrangements.[1] He examined Frederick Reines and Clyde Cowan Jr's experiment that led to their detection of the neutrino and said, "I believe there is little reason to be convinced by this experiment that the neutrino exists apart from the theory and experiments that define it."[1]

Elementary particles exist in a context; if the context were to break, their existence would be seriously questioned. This can be seen, for example, in the fact that special relativity belongs to the context in which modern elementary particles exist.

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In fact, special relativity plays a crucial role in the theories and experiments concerning elementary particles. On the one hand, the theoretical structure of the physics of interactions is quantum field theory, which is manifestly covariant under the transformations of the Lorentz group; on the other hand, the data of the experiments are usually analyzed by the reconstruction of events, and in this reconstruction, relativistic dynamics is used. We thus see that special relativity belongs to the context (both theoretically and experimentally) in which fundamental particles exist. If the theory of special relativity were to turn out to be false, or of limited validity, the existence of our elementary particles would be challenged.

Mathematics is systematically used in the construction of contexts for physical problems. Take, for example, the case of the top quark. According to Michelangelo Mangano and Thomas Trippe: "The existence of the sixth quark . . . has become an absolute theoretical necessity within the Standard Model (SM)."[2] But the Standard Model is strongly rooted in the $SU(2) \otimes U_1$ group: The mathematical implications of this group are some of the reasons that make the existence of the top quark an absolute theoretical necessity. In this manner, we see that mathematics is essential to the very existence of many elementary particles and, in general, is an indispensable condition of physical reality.

Contexts contain theories. But, according to Einstein, the axiomatic basis of all theories is constructed by us—he declared that it "cannot be extracted from experience but must be freely invented."[3] We thus see that the context in which elementary particles exist is, to some extent, constructed by us, and so are the existence of those particles and physical reality. As evident in the example of the top quark, mathematics plays an inherent role in this process of construction of physical reality. It is clear that we systematically construct physical reality with certain preconceived mathematical structures; we adjust physical reality so that it agrees with mathematics.

We use mathematics to build up

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physical reality and consequently we find that reality is mathematical in nature. Arthur Eddington stated that "the mind has but regained from nature that which the mind has put into nature."[4] And also: "We have found a strange foot-print on the shores of the unknown. We have devised profound theories, one after another to account for its origin. At last we have succeeded in reconstructing the creature that made the foot-print. And Lo! it is our own."

Pythagoras understood the importance of a string's length, Archimedes formed in his mind the idea of the weight of a displaced liquid and Newton activated the concept of the amount of matter of bodies. In these cases, and in many others in the history of science, physicists have looked for measurable quantities as a basis to support natural laws. The use of quantities in theoretical explanations and predictions, and in the analysis of experimental data, is innately connected to mathematics. Physics characteristically looks for natural laws that have a mathematical structure. This search is essential to physics and is one of the marks that distinguish it from other natural sciences.

In conclusion, mathematics is inherent in the construction of both physical reality and physics. We cannot imagine either a physical reality or a physics that is deprived of mathematics.

References

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2. M. Mangano, T. Trippe, Phys. Rev. D **54**, 309 (1996).
3. A . Einstein, *Ideas and Opinions, On the Methods of Theoretical Physics*, Dell, New York (1978) (reprint of 1954 ed. published by Crown), p. 267.
4. A. Eddington, *Space, Time and Gravitation*, Harper & Row, New York (1959) (reprint of 1920 ed. published by Cambridge University Press), p. 201.

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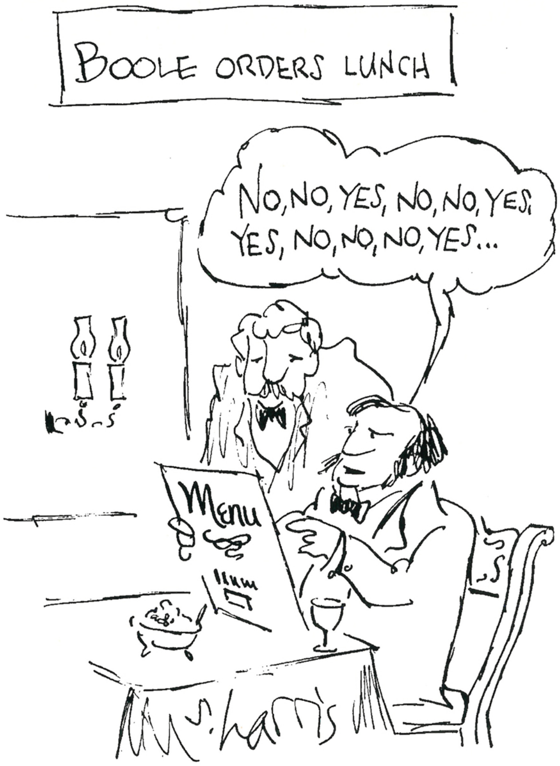
Pioneer Recalls How Computers Replaced Handwork at Oak Ridge

This letter is prompted by your October 1996 issue that featured 50 years of computers and physicists. Since I was involved with computing in the late 1940s and early 1950s, I may have something to add to the story.

In 1948, I started working with Gerald (Jerry) Goertzel on automatic computing. The idea was to introduce such computing to Oak Ridge National Laboratory, which was then doing a lot of hand computations. We considered a number of different problems, but finally narrowed our work to the computation of internal conversion coefficients of gamma rays, which had just been formulated by Maury Rose. Jerry took Maury's formulation, on which he had also worked, and he and I reduced it to a scheme for computing on a von Neumann machine. Then we verified that our formulation worked by simulating a von Neumann machine with pencil and paper—for a single energy and a single nuclear charge. That took us about a month.



Armed with those results, we proceeded to look for a machine to do the computations in bulk. IBM had a suitable machine for our purposes, the Selective Sequence Electronic Calculator (SSEC) in New York City, so Jerry and I went there to work with IBM programmers on the problem. Unfortunately, IBM decided to charge us a pretty penny to use the SSEC, and we were forced to look elsewhere. Eventually, we made contact with Howard Aiken's group at Harvard University, and we were quoted a reasonable price.

The Mark I machine on which we worked was a relay calculator and externally programmed with paper tape. In other respects, though, it functioned very much like a von Neumann machine, except that recursive calculations had to be performed using a circular tape, which continued until convergence was reached, at which point it signaled us to change the tape.

I was the principal middleman with the Harvard group and worked with John Harr and Peter Strong both on programming and running the problem. As I recall, it took about two days to run the whole set of calculations. Then I took the results back to Oak Ridge, where Maury very quickly found errors in the results. Back, then, to Harvard, where the program glitch was found and corrected, and from which I took back results that were acceptable to Maury. The work was announced in *Physical Review* (volume 76, page 1983, December 1949) and finally published in the same journal (volume 83, page 79, July 1951).

By that time, I had moved to Argonne National Laboratory, which began building an early von Neumann machine of its own soon after I arrived. I did some consulting on programming there, but soon became involved as a consultant to the Naval Reactors Group, which was designing the first nuclear submarine, *Nautilus*. I was then an acknowledged expert on nuclear reactor computations, and quite soon was tapped to be the reactor representative on the Atomic Energy Commission's Computer Use Committee, which was charged with dividing up the "use pie" for a UNIVAC that AEC had bought and installed at New York University. As it turned out, the committee was completely dominated by Edward Teller, and we did little until Teller's requests were settled. Then the rest of us split the rest of the pie pretty quickly. Ultimately, the committee was disbanded as other machines started to take more of the computing