The Philosophy of Models

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Much has been written on the applicability and the potentialities in general of physical models. It is hardly possible to give a comprehensive exposition of such techniques except in a long treatise, although the author would not find it difficult to articulate his enthusiasms for this extremely broad branch of technical theory and practice.

The methods of electronic models, or simulators, have become of considerable importance. However it should not be forgotten that model building and model manipulation range over almost all physical media. Most mathematical machinery may be considered a class of electronic models, since there must be embodied therein a physical system obedient to the same laws which apply in the case of whatever systems the machinery is employed to study. Computers may therefore be thought of as general-purpose flexible models or *synthesizers*, as well as *analyzers*. The question of names is a controversial issue, involving definitions rather than anything more fundamental, and is most happily resolved by recognition that the equipment under discussion is really a bridge between analysis and synthesis, bringing these two essential modes of study into closer collaboration.

Specific models are more prevalent, wherein problems of a particular category only may be studied. These may be simple replicas of other physical systems, retaining even the geometry and the appearance thereof. However by a transformation of one or more of the coordinates, of space, time, energy and so on, these replicas yield a means for experimentation in which certain limitations are removed in comparison with the original systems. The well known principles of similitude and dimensional analysis are guides for the construction, operation, and interpretation of models of this sort. The so-called *pi theorem* of dimensional anaylsis has even been taken to mean that the construction of a representative model is always possible. However it is generally held that the strictly mathematical form of the theorem is to be preferred in any venture short of philosophical reflection.

With models of the dynamic variety, time is involved as a principal variable. The transient state is often of greater interest than either the steady or the static states although these conditions of equilibrium are attainable in, and may be studied by, general transient-bearing systems. Quite commonly time in an original physical system is reflected as time in the model, albeit with a scale factor which may stretch or shrink it beyond recognition. The interchange of some other dimension for time, or of time for some other dimension, may also be arranged for. Time may even be eliminated altogether in a model, or employed in cases where it did not occur as an important factor at all in the original.

The most impressive models or synthetic representative structures are those in which one physical medium acts in place of another. Operation is by virtue of one or more of the many analogies which are demonstrable among components involving the known physical media. Of such analogies the better understood are those among mechanical, fluid, electrical, and thermal processes.

All such processes are self-analogous under the duality transformation, with the interchange of potential and kinetic energy. With regard to energy the thermal case is exceptional in that the usual analogy which is established makes electromotive force, for example, correspond to temperature, both quantities acting as *potentials*. This analogy leads logically to the identification of quantity-of-heat with quantity-of-charge, of which only one is truly energy. The preservation of energy, however, in such postulation of analogous correspondences in model techniques, is by no means essential. It even forms a restriction in scope. When several media combine, however, in a model or in any useful system to be studied, then it is of the greatest convenience to employ analogies which preserve energy.

A distinction must be clearly emphasized between two classes of model structures, synthetic and simulative devices, and physical representations. Members of one class are constructed and

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employed in the laboratory as tools of research and development. The others are intended for applications wherein an operator deals with the simulative equipment as a substitute for another apparatus represented thereby, and by such dealings familiarizes himself with the workings of the original apparatus under conditions which are relatively easier, cheaper, or safer.

The employment of synthetic training equipment for system operators is a good example of the latter category, and is useful whenever the effectiveness of a given man-machine interaction is important in the operation of a system. Generally even an approximate simulation of the dynamical relations, with which the operator must associate himself in such circumstances, is sufficient for his indoctrination or for the perpetuation of his skill through practice.

It is a common experience, however, for a simulator which has been developed for purely laboratory purposes, that is, in the exploration of new or proposed physical arrangements, to find incidental or ultimate application as a training device. In some such cases there has been confusion over which end was being served by a particular equipment. Not infrequently a trainer, in which certain approximations have been allowed as inconsequential to the needs of that function, has been misconstrued as presuming to embody the detailed characteristics of a system. The possibility of such misinterpretation, which might appear trivial from a larger viewpoint, has been of very real importance in several developmental endeavors.

An intermediate category must now be mentioned, at the risk of diffusing the dividing boundary already indicated. Simulators may be constructed, in a form more permanent than is the case for the study phase in research, for the express purpose of teaching what is already known of the dynamics of a given physical system. These are not trainers, although they may certainly impart to the user a facility in carrying out such operations as the adjustment of parameters in an automatic apparatus to give maximum performance and stability. A simulator of this type might be called an *educational simulator*. In typical circumstance it may also stem out of the availability of a *developmental simulator*, as in the case of the *training simulators* already discussed.

Finally, no general discussion of models, of which simulators are only a special case, can conclude without citing the purest model of all, namely the medium of the mathematician. The symbolism of variables, functions, operations, and equations, taken in company with the rules which they follow, form what is almost the ultimate in flexible models. Thus the symbol for a variable is truly the analog of its physical embodiment, an equation of some truth which is stated or proposed.

The manipulation of the physical model is directly reflected in the manipulation of the mathematical model, or of the symbols belonging thereto. Thus it is not surprising that an underlying standard for the sufficiency of a model is aptly provided by comparing the equations of model and prototype.

To go a step further, the wave function of the mathematical physicist is a model without tangible physical counterpart. However the wave function describes in some detail a complex relationship having properties which agree with ascertainable data on the *unknown* physical entity. Why ask for more? Prediction is all that counts, ideally. But this is already too far afield. We should soon be discussing words and language as models, which of course they are.

George A. Philbrick has been one of the most far-sighted engineers of our time. His work with operational amplifiers and other functional signal-processing devices during the 1940s and 1950s contains the foundations of much modern electronic simulation and control.

Like many others, Mr. Philbrick worked for the government during the Second World War. His report at the end of that period was embodied as Part I of Volume III, of the Summary Technical Report of Division 7 of the National Defense Research Committee (NDRC), of the Office of Scientific Research and Development (OSRD). The report was issued in 1946 and has since been declassified. In a recent conversation with ICS editor Alan Krigman, Mr. Philbrick commented that the report contained discussions of feedback and modeling, which he considered to be the basis of his engineering philosophy.

INSTRUMENTS AND CONTROL SYSTEMS is pleased to be able to present excerpts from this previously unpublished work. **Feedback** was presented last month, and the **Philosophy of Models** appears here.