MODELING, SIMULATION
AND INTERDISCIPLINARY RESEARCH

By

R. Vichnevetsky

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Rutgers University
The State University of N. J.
Department of Computer Science
New Brunswick, New Jersey 08903

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That modeling and computer simulation have become a major component in most segments of applied science may be recognized by even a casual observation of our community. Interesting aspects of this phenomenon upon which I wish to delve somewhat into are:

a) that modeling and simulation have come to play an interdisciplinary role somewhat akin to that traditionally played by the applied mathematics;

b) that the overwhelming power which has resulted from the introduction of computers in the process of scientific research has expanded the application of the mathematical method, through modeling and simulation to disciplines which have been by tradition impervious to the kind of scrutiny characteristic of the exact sciences. Whether this expansion to those new disciplines (sometimes referred to as "soft") has been even moderately successful is a question which is much debated, and far from being resolved [5].

A characteristic feature of older classical texts about simulation in the hard sciences is that they contained many examples, in fact more examples than general theories: everyone knew well then what the problems were, and the new techniques of simulation could be explained by examples better than by theory. The mass-and-spring, level feedback control and, more recently, predator-prey systems have been used profusely to illustrate dynamic systems computer simulation.

By contrast, a characteristic feature of many (although not all) texts about "soft" systems simulation is that they contain generalities, sometimes a great deal of abstract and somewhat philosophical theories, and few examples. This, of course, is mostly the case in the social sciences. Whilst many workers in this field have general ideas of what computer simulation is all about, mostly acquired by looking over the fence to see what the exact or hard scientists were up to, the "how to go about doing it" is yet often unclear in their mind. There are also many texts to be found about case-studies involving modeling and computer simulation of specific systems in these areas: but what can eventually be expected in terms of significance of results of these mathematical modelings and computer simulations is somewhat fuzzy. The resistance to and displeasure about Forrester's and followers work which one finds in certain social science circles are just one example of the present state of affairs.

What is little realized in all this is that the natural sciences, and in particular those which rely heavily on applied mathematics, find themselves in the middle of a transition between two eras. The past era is that which started toward the 16th and 17th century with the works of Galileo, Bacon, Descartes and Newton, in which it came to be recognized that phenomena of nature may be described by laws, that these laws may be expressed by a very specific brand of mathematical equations (those of algebra and calculus) and that solving these equations results in not only explaining, but also in predicting the behavior of natural systems. The development of the mathematical tool went hand in hand with the search for the understanding of nature, and the names of savants of the past centuries are often associated with both mathematics and physics. Well known examples are those of Newton, calculus and astronomy, of d'Alembert, partial differential equations and the vibrating string, of Fourier, mathematical series and the theory of heat, of Hamilton, variational calculus and rational mechanics and of Rayleigh, eigenvalue problems and the theory of sound, to name a few.

It was the case then that only those problems which could be solved analytically with a certain degree of ease (or approximated numerically with a certain degree of ease) were those which were holding the attention of sufficient *numbers of scientists to become the classical background against which applied scientific investigations were being conducted.*

Much has been changed with the advent of the computer age. With the dramatic increase of automatic means for computation becoming available, more and more of the problems which could not be solved analytically, or manually by simple enough numerical methods, are now solved by machines on a routine basis.

Past decades have been extremely productive in the development of hardware, the adaptation of pencil and paper mathematics to the use of computers and, to a lesser extent, in the invention of new mathematics about computer methods for the solution of scientific problems.

In practically each such case, the relation to the physical problem that was intended to be solved was clear, explicit. The first differential analyzer was conceived in the 1870's by Lord Kelvin who was concerned with obtaining solutions to the differential equations of physics. The development of ENIAC was motivated by the need to solve war-time problems of ballistics. The first electronic analog computers were applied to airplane autopilot design, and John von Neumann's conceptual description of the stored program electronic computer contains ample reference to problems in fluid dynamics [12].

The adaptation of the theories of numerical approximation of past centuries to modern day tools has flourished over the past twenty years or so, again in most cases motivated by specific problems which have their roots in the physical sciences.

One visible result of this is in the recent appearance of a number of new professional journals devoted entirely or almost entirely to computer methods in physics, structural analysis, applied mechanics, water resources, fluid mechanics and the like.

But whereas the mathematics of computation and approximation were for a time at the forefront of the problem solving scene, one may easily identify today many segments of this field which have been overkilled, so to speak, and where further theoretical developments are more pleasong to their originators than useful in real applications. In effect, they have moved from the "applied" to the "pure", if we are to accept the definition of pure as that which is not to be foreseeably applied.

Solving well-posed problems has gradually shifted from a creative, somewhat spectacular activity to the more routine one of writing programs of various degrees of size and complexity. A new era is emerging for many if not most disciplines, in which the creative work has shifted away from problem solution toward formulation. Or, in terms of modeling and simulation, away from simulation toward modeling. To be able to function properly in this new environment, scientists must have both the mathematical and the disciplinary trainings and inclinations. He who is trained only in the mathematics or computation cannot convey to the disciplinary scientist the information needed by the latter to conceive of mathematical models which can lead to needed simulations. Nor can the disciplinary scientists conceive of these models if he does not have an intimate knowledge not only of mathematics, but also of the subtle ways in which they blend with the information processing capabilities of computers. Nor, without that knowledge can he even make an intelligent interpretation of the scope and limitations of computer simulations of systems which are in his province, if they are to be described by abstract mathematical models whose limitations he cannot grasp.

What this points to is a need to revise our views of the division of science in compartmentalized disciplines. Without going as far as advocating a return to the universal kind of higher education which prevailed during the Renaissance, it seems to us that a clear need exists for scientists who are trained in the tradition of exact investigations as well as in at least one of the softer disciplines such as the social and life sciences. It is also clear that research in modeling and simulation of the large and soft systems which are today mankind's concern will foster the growth of interdisciplinary schools, in which scientists of different training will learn to work together and, maybe more importantly, will learn to respect the opinion and kind of knowledge of those on the other side of the proverbial fence between the exact and, by inference, the not so exact sciences.

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