latter requires the kind of parallel logic described in the last section with interconnections and thresholds so selected that the failure or erratic behavior of one or more elements will not affect the output.

APPENDIX

DEFINITION OF SIMULATION

The word “simulation” is used in this paper in its modern technical sense:

... to assume the appearance of, ... without any intention to deceive. I refer to its use in the field of mechanical-electronic computation. Here the procedure is to simulate physical or mental processes in setting up a problem which is then given to a computer to solve.98

The Industrial Dynamics Research program at M.I.T. uses the words “make a model of” in the place of “simulate.” The model in this case is a set of equations. These M.I.T. people save the word simulate to describe the evaluation of these equations, one at a time, for a given set of input conditions. They solve the equations at time intervals which are short compared to the shortest delay intervals of the system being modeled. They are thus simulating simultaneous solution.

In this paper “simulate” is given the meaning of the first paragraph above. Simulation here is intended to achieve a “quality” equal to or excelling the performance of the human being to be simulated, for the periods when it is given his responsibility. The “quality” of performance is a composite of breadth of facts which lead to a decision, reliability of the logic and computation used in processing these facts, speed, and human considerations. A simulator might attain acceptable quality by excelling in some of these considerations while falling short in others.

Can Computers Help Solve Society’s Problems?

JEROME ROTHSTEIN†

INTRODUCTION

THE advent of large-scale computers gave new impetus to mechanizing the handling of tremendous quantities of data. It also indicated the possibility of carrying out many ventures of social significance which are now completely impractical. It is hard to see an important social revolution in the first, per se. Automatic billing of telephone subscribers or mechanization of clerical activities, for example, is only substitution of machine for manual activities. This has been going on continuously since the beginning of the industrial revolution. Exciting prospects emerge when one considers fields characterized by enormous amounts of data together with complicated intertwining causal relationships buried under statistical blur.

The present paper considers a few of very many possibilities. They were chosen mainly because one might expect them some day to have enormous impact, both on the individual and on society. The first group bears on the weather and on economic planning and policy, the second on various questions of public health, and the third on "the proper study of mankind," man himself. They are tentative groupings with no pretense to completeness or profundity. It is believed, however, that they make some general statements plausible. These are that modern computer and data handling techniques may

1) lead to making our economic system more productive, and to smoothing cycles of inflation and deflation, or employment, and of farm income;

2) revolutionize our ideas of public health, and make the world a more wholesome dwelling place;

3) revolutionize our knowledge of ourselves, our abilities, susceptibilities, mental, physical and genetic constitution, as well as diagnostic and preventive medicine.

We believe it is the responsibility of the computer engineer and scientist to point out such potentialities, to acquaint specialists in many fields with what computers can do, to collaborate with them in applying computer techniques to those fields, to keep research foundations and government agencies aware of areas worthy of support, to keep administrators, policy makers, and legislators informed and advised, and thereby to assist in the formulation of sound public policies.

In the discussion below, military, industrial, and scientific applications are very largely neglected. This is

not because these fields are unimportant, but rather because their importance has been so well recognized that a paper of this length could now contribute little to them.

**Weather, Computers, and Economic Policy**

The historic role of weather and climate in human and economic terms needs no belaboring. Famine, drought, floods, plenty, epidemics, mass migrations, the rise and fall of civilizations, wars and their outcome have often been engendered or decided by long- and short-range weather and climatic variations. With foreknowledge, as in the biblical story of Joseph and Pharaoh, countermeasures become possible, with tremendous gain in economic and human terms. Modern data processing is making it possible to use the tremendous mass of accumulated and current meteorological, astronomical, and climatic data to make long- and short-range weather predictions more accurate. When continuous global cloud surveys by satellite are available, accuracy will advance even more, and even weather control will doubtless be more effective. The average citizen will know when to carry an umbrella or plan a vacation, retail establishments will plan inventories more intelligently, and farming will be less of a gamble. If one knows a drought is going to occur, for example, it is silly to plant extensively where there is no artificial irrigation. If it is known that a good crop is imminent and that the following year will be one of drought, the government might well consider making provisions for crop storage. Knowledge of this sort on a global scale can go a long way toward eliminating famine in one place and glut in another. The effect of this on international relations and on the likelihood of revolutions and wars may well be stupendous. More locally, public works programs in agricultural areas could be planned to dovetail with an expected decline in demand for farm labor, with lowered shock or recession of the whole economy. Production based on agricultural raw materials can be more intelligently programmed when yields are forecast even approximately. Inventory policy and servicing depots for farm machinery could be set up more efficiently. Railroad rolling stock, truck fleets, and the like can be administered more efficiently when demand is predicted more accurately. Clearly, the techniques of operational research, which could make extensive use of data-handling systems, would become much more readily applicable to tremendous areas of planning, allocation, production, servicing, inventory, and other policy problems. Expert consulting services for small enterprises, unable to support operational research on their own, would become economically justified, and might well lower failure rates for small business. Fuel, electric power generation, and hydropower policies are also weather dependent, and the economic value of long-range weather information in these fields is clearly tremendous. It hardly seems an exaggeration to say that little of the national and world economy is un-

**Computers and Public Health**

In many fields of public health, detailed cause-and-effect relationships are submerged by multitudinous accidental factors. Masses of data gathered over long periods of time must often be digested and tested by sophisticated statistical techniques before valid statements can be made about them. All statements, on which action is to be taken, should be treated as testable statistical hypotheses, with action justified when the hypothesis has reached some preassigned confidence level. The examples below were chosen at random, and represent but a small sample of the total one could cite. Fluoridation of drinking water is a measure backed by much competent medical opinion and bitterly fought by a number of lay groups. Proponents of fluoridation claim that tremendous reductions can be made in dental carries with no ill effects. Its opponents make dire predictions about the effect of fluoride on the kidneys, the nervous system and almost every other organ in the body. There are millions of people at the present time who consume fluoridated drinking water. It therefore seems entirely feasible to amass completely convincing and compelling data on the correlation between fluoridation of drinking water and every ill to which the flesh is heir. Of course, even in the face of compelling evidence one often finds crackpots who refuse to be convinced. If one has faith in democracy, however, one must believe that in the long run the majority will recognize and accept the truth. If statistically valid evidence of this sort is gathered—and computers can certainly play a vital role in doing this—and it turns out that almost all tooth decay can be safely and permanently eliminated from the population, the gain would be incalculable. A similar situation appears to be involved in estimating the effect of radioactive background and cosmic rays on stillbirths, cancer, and genetic impairment of large populations. It has been supposed by some that
there is a certain threshold of danger. Others maintain that any increment in the radiation background, no matter how small, will produce additional cases of defective births, mutations, and of cancer. One clearly cannot make controlled human experiments, but the city of Denver is a mile higher than New York. The inhabitants of Denver are thus exposed to a higher cosmic-ray background than the people of New York. In addition, uranium ores in Colorado and a number of other western states must subject the people in those regions to radioactive background, to uranium materials in their foods and the like which are absent in many coastal areas. Some parts of the world, such as Travancore, India, have high natural backgrounds due to the presence of monazite sands or other radioactive materials. It thus seems entirely feasible to get statistically convincing data on the incidence of conditions of all sorts in existing populations living under a variety of radiation backgrounds. With extensive, computer-processed data one can make a more realistic assessment of the dangers of atomic testing, for example. One can perhaps find whether a threshold for radiation damage exists, or even if there are beneficial effects of radiation in very small amounts. There is some evidence that normal individuals have some immunity to cancer. It therefore does not seem entirely impossible that fall-out in very small amounts might have no effect on normal individuals but could shorten the life expectancy of individuals fated to succumb to cancer by a small amount. Similarly, data on abnormal births and congenital defects might lead to a better understanding of the genetic hazards.

A third field is that of poisons, taken in a broad sense. Coal or oil smoke from the heating plants of private dwellings, and exhaust fumes from automobiles could conceivably have subclinical toxic effects. It is known that carcinogenic substances are produced in oil refineries. Such substances can also be produced by combustion of tobacco and many organic or carbonaceous materials. Some studies indicate a connection between smoking and the incidence of lung cancer and cardiovascular diseases. It seems possible that “chemical fall-out” from daily industrial, heating, smoking, and automobile-riding activities could be a hazard greater than radioactive fall-out. Chemical agents can also produce mutations. Among these are colchicine and other complex compounds related to coal tar derivatives and other substances with great biological activity. A large-scale statistical survey of the quantities and identities of atmospheric and other contaminants of all sorts, and their correlations with the incidence of various diseases, appears eminently desirable. If one found, for example, that small communities in the Rocky Mountains have far lower incidence of cardiovascular disease than smoggy industrial areas, with suburban residential areas intermediate, then laws requiring the chemical clearance of smog and precipitation of dust particles might ultimately be in order. Many industrial poisons are known and in many places measures have been taken to prevent atmospheric contamination, but by and large a serious and obvious outbreak of some condition seems to be required before public opinion is aroused enough to take action. It is therefore quite possible that many cases of this sort are unnoticed because cause-and-effect relations are buried in a sea of accidental factors. The possibility that we can live under healthier conditions seems too real for us to overlook these potential applications of computer processing and analysis of the tremendous amounts of data required.

**Computers, The Individual, and Society**

Every human being is a unique complex universe. As life insurance companies well know, this does not prevent the drawing of valid statistical inferences about human populations. The more homogeneous a statistical population, the more accurately can inferences be made about unobserved individuals on the basis of observations on a sample. In between the heterogeneity of *homo sapiens* as a whole, and the homogeneity of identical twins, one senses the possibility of a classification scheme which would divide mankind into groups of sufficient homogeneity to make it possible to draw medically or otherwise useful inferences about a group. The scheme would certainly be complex; and there is no *a priori* reason to assert, for example, that even a million categories would enable one to predict that a particular ten-year-old boy, let us say, will develop angina pectoris between the ages of forty-five and fifty-five, or that a healthy young woman will have a cervical cancer before she is sixty.

The existence of recognizable hereditary characteristics, the small number of clinically distinguishable blood types, the “tendencies” or “predispositions” known to practicing physicians, the experience of plant and animal breeders, the development of strains of laboratory mice like waltzing mice or those who invariably develop cancer, and research in heredity (e.g., on Drosophila or Neurospora), and other examples, all suggest that very useful classifications probably exist whose numbers of categories are not astronomically large. If a number of the order of ten thousand categories could adequately characterize an individual biologically, such a characterization would be of tremendous use in preventive medicine. Who knows the extent to which cancer and heart trouble could be anticipated, and perhaps prevented or corrected or ameliorated by proper control of diet, activity, or environment? The Rh factor which used to kill babies born to mothers of opposite Rh blood type is now understood well enough to predict the couples to whom this would happen. The tragedy is now avoidable. Who can say what anguish and burdens could be prevented if a similar understanding of congenital idiocy and other genetically based abnormalities or inferiorities could be achieved? Who knows but that the patterns of potential parents of future Einsteins might become recognizable?
Such knowledge, like all knowledge, would be a double-edged sword. Unattractive Orwellian prospects suggest themselves under totalitarian regimes. But under a form of government in which the sanctity of human personality is preserved, one sees the possibility of great good, of healthier individuals, and of a gradually improving human stock. The concept of eugenics is basically good, and if the individual is free to use eugenic information or not, if he is never coerced, and if the program is kept free of bias and fanaticism, only good can come of it.

Setting up such a program would ultimately require a tremendous amount of experimental data, data processing, analysis, and testing of statistical hypotheses. Years might pass before results with practical application could be obtained (though we doubt it), and automation of hundreds of complex laboratory procedures, many not now known, might be necessary before people could be adequately "typed." But if a program developed capable of coming anywhere near the goals described it would bring benefits even greater than those discussed. The old problems of nature vs nurture, or heredity vs environment as determinants of human capability and achievement might become better understood. Factors leading to more valuable and satisfying lives might stand out in bolder relief if the life patterns of a large number of biologically similar individuals were studied with the tools of psychology, sociology, and anthropology. A far deeper understanding of psychosomatic interactions would almost surely result. Cross-cultural studies, as part of the broad program, might give deeper insight into the interactions between individual psychology and the cultural milieu, perhaps to enable us to see how the values and goals of different cultures (which have much to do with the stresses and motivations of an individual) generate different statistics of stress syndromes, diseases, antisocial behavior, or mental conditions in biologically similar individuals. Could such knowledge be obtained, we could begin to develop a science of society which would permit conscious improvement of our customs, values, and motivations, provision of sanitifying influences, and tend to maximum development of individual talents and opinions. These utopian dreams, distant as they may now seem, need not be unattainable. With computer techniques, automation, and the devoted labors of inspired, determined, and creative people, such dreams will come ever closer to reality.

In these times of international tension, omnipresent powder kegs and atom bombs, one can seriously maintain that the world cannot afford to neglect these possibilities.

Conclusion

There is an old witticism about the difference between a scientist and a philosopher. The former applies increasingly refined techniques to an increasingly specialized and narrowing aspect of the world. As time goes on he knows more and more about less and less. The latter continually generalizes, going into increasingly abstruse abstractions. As time goes on he knows less and less about more and more. In the end, the story goes, the scientist knows everything about nothing, while the philosopher knows nothing about everything. While neither scientist nor philosopher would admit approaching the limits described, there is enough truth to the story to show that it might sometimes be good for the scientist to be a little more philosophical, and for the philosopher to be a little more scientific.

It is hard, perhaps, for the computer scientist or engineer, wrestling with detailed problems of hardware, logical design, budgets, deadlines, maintenance, and operation, to take the philosophic approach very often. The viewpoint here espoused is that once in a while a broad philosophic look at things can be valuable. This paper has therefore studiously avoided technical minutiae and conventional computer applications in favor of bold (we hope not reckless) extrapolations and generalizations to broad problems. What we dream today we achieve tomorrow. It is our responsibility not only to develop day-to-day technology, but also to philosophize enough to find fields where technology will promote advances measured in broad human terms. Just as we have learned to dig better with steam shovels than with our fingers, so must we learn to tackle civilization's problems with the aid of computer techniques rather than with our bare brains.

We cannot wait until the perfect master plan is worked out. Not only would this never be done, but even if some plan were set up as near perfect, it would probably be obsolete before it could be implemented. The same kinds of piecemeal attack that characterize all research would have to be employed. There is much that can be done immediately and in parallel (some being done already), such as 1) mechanizing public health, hospital research, and individual physicians' case history data, 2) developing "common language" techniques to permit easy exchange and consolidation of information gathered by independent agencies, individuals, and countries, 3) making it possible to consolidate scattered data on individuals in order to amass birth-to-death histories, 4) creating techniques of integrated cooperation between individuals, institutions, local, state, federal, and international organizations, 5) encouraging cross-disciplinary research, 6) sponsoring programs designed to uncover areas to work on immediately, 7) perfecting routines for testing increasingly complex statistical hypotheses, 8) formulating special fields so that computer techniques can be used on them, and 9) doing this whenever it becomes feasible. We must press for the nine parts of action to support the one part of philosophy.
The Measurement of Social Change

RICHARD L. MEIER†

Is it possible to build a synoptic instrument, similar to a telescope or a radar network, for viewing one's own society? How may we interpret the myriads of social activities that are presently undertaken? Preliminary explorations suggest that we need sensing techniques, or transducers, that pick up changes going on inside the society. External indicators, like air photos, are too superficial. We are faced with a problem of discovering what operating characteristics a deep-probing instrument should have so that it may be as practical and useful as possible.

Economists judge change in society by modifications in the makeup of the gross national product and the level of expenditures, political scientists can analyze elections and polls, but sociologists and anthropologists have no cumulative sets of accounts or aggregate indexes. They have had hopes, however, similar to those expressed by Lazarsfeld [3]:

Our economic statistics are today quite well advanced. We know how much pig iron is produced and how much meat is exported every year. But we still have very little bookkeeping in cultural matters. The content of mass media of communication is an important and readily available source of social data, and it will not be surprising if this analysis becomes a regular part of our statistical services in the not too distant future.

These statistics have not yet come into being because the labor cost was high, the time lags were great, and the system description was incomplete, so it has been impossible to state how one set of measurements related to another.

Let us take a brief, searching look at the social system. Society is maintained and changed by the behavior of its members. Intuitively one feels that the basic unit of behavior is the act, but acts are not as easily counted and differentiated as particles, molecules, or organisms. Satisfactory data can only be obtained when actors are forced to confine their behavior within certain preset specifications or codes, which may be called languages, currencies, habits, or "standard operating procedures." This behavior must be observed in public spheres, since the objective, detached observer is missing in private affairs. The latter will require altogether different instruments and techniques for data accumulation, and will not be taken up here.

By far the most promising attack upon the problems of measurability is offered by lumping together small sets of acts into transactions. A social transaction involves, among other things, the emission of a message together with evidence of its receipt—apparent to an observer, but also, through one or another form of feedback, to the agency responsible for emission.

At any given moment, the population of the society can be divided into senders, receivers, and nonparticipants, much as the economist divides his population into producers and consumers, and each participant must play both roles. The message normally contains some information that is novel to the receiver, more that is redundant, and some symbols that are quite unintelligible. Some messages are not communicated directly to receivers, but are stored in libraries, files, and artifacts where they become a resource embedded in the social environment. Uncoded information may be gleaned from the environment through systematic observation. Scientists, weather observers, diagnosticians, and other professionals have been trained to reduce these phenomena to coded, communicable form (Fig. 1). The information flows should be sampled where the wavy lines occur.

Fig. 1—Communications flows in society.

The term "information" at this point has been used in its intuitive sense. At a later stage, it will be shown that the demand for information storage (used now in its technical sense) in our instrument corresponds crudely with the volume of these flows in society—about as well as national income figures represent the combined satisfactions of consumers. The greatest difficulty in the design of our instrument is the conversion of all of the codes for human communication, oral, written, graphic, gestural, musical, etc., into a single code