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FOUNDATIONS FOR AN INFORMATION TECHNOLOGY

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ABSTRACT

An information technology to manage complex problems would benefit from a synergy of simulation, software engineering, artificial intelligence, and general system theories. A perception of the needs, the importance of problematique (i.e., systems of ill-structured, ill-defined, or ill-delimited problems), different approaches to problems, and the uprise of systemic thinking are outlined. Model-based activities are defined to encompass simulation. Possibilities for synergies of simulation, software engineering, artificial intelligence, and general system theories are explored.

1. A PERCEPTION OF THE NEED

The epilogue of another study written in 1976 may serve as the prologue of this presentation. I quote from the beginning of it:

> "To be able to grasp the situation which requires the development and application of new methodologies, the contradistinction of two terms, i.e., 'problem' and 'problematique' is in order.
>
> Fontela and Gabus (1976) define a 'problem' as a known unacceptable situation which can be improved by various possible actions.
>
> Ozbekhan uses in English the French noun 'problematique' to mean sets of ill-structured, or ill-defined, or ill-delimited problems and justifies the need for such a new term by: 'How, then, can we more realistically 'see' reality? If we accept the interlinkage, interaction and dynamics of the problems that are proliferating in our situation it seems that we might approach a clearer view of that situation were we to conceive of these problems as a generalized meta-problem or meta-system of problems - a system which I shall henceforth call, the problematique" (Özbekhan 1976, p. 16)." (Ören 1978c).
>
> An important reference, The Yearbook of World Problems and Human Potential 1976, realized by the cooperation of 3300 international associations, gives a list of over 2600 world problems the majority of which are of the problematique which require immediate solutions (UIA 1976)" (Ören 1978b, p. 181).

The "Yearbook of World Problems and Human Potential 1976" contains an interesting classification of problems into four categories, i.e., 1) docile, isolated problems, 2) docile problem group, 3) dynamic interactive problems, and 4) aggressive interactive problems (UIA 1976, p. 1132).

A comprehensive list given by Berkeley (1973) comprises thirty principles for problem solving. The list starts with "the principle of ignorance" ("that you don't know won't hurt you") and ends with "the principles of science and scientific method", "the principle of systems analysis and synthesis", and "the principal of careful, systematic verification". This list is worth perusing.

What is needed is a "macroscope" to see the macro-system, as Rosnay (1975) promotes it very appropriately.

Simulation techniques are applied to a multitude of areas as can be easily checked with the available literature (over 100 bibliographies, about 500 books on modelling and simulation, well over 100 conference proceedings, about 1500 doctoral dissertations) not to mention the activities of about 30 associations or groups specialized in simulation.

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Even the richness of the terminology associated with different aspects of modelling and simulation may show how multi-faceted, simulation and modelling are. Ören (1977d) provides a list of simulation terms and Pritsker (1979) compiled a list of definitions of simulation. As Buschovitch (1977) reports, Uyemov compiled, as of 1971, a list of thirty-seven definitions of the term "model". Ören (1979) provided a categorization and definitions of about eighty types of models.

These and similar variety and richness of the concepts and the possibilities for modelling and simulation are also part of the reasons of the pariochialism the field suffered for a long time. Due to the pressure for specialization, the field of simulation has been fragmented to a multitude of sub-areas according to different criteria such as goal of the experimentation, type of appliation area, type of system, nature of the model, nature of the relationships, time set of the model, ratio of simulated to real time, the way state of the model is updated, device used to do the computations, way of accessing the computer in computerized simulation, and time structure of the simulation (Ören 1977a, p. 183).

Some of the applications task in an unprecedented way the predictive power of simulation techniques. For example in nuclear fuel waste management studies, simulation is used to assess the integrity and reliability of the underground containers to maintain nuclear waste for thousands of years. At least in Canada, it is recommended that tools and techniques of assuring softaware reliability should be used in the project and it is noted that application of state-of-the-art knowledge of advanced computer-aided systems may enhance comprehensibility, modifiability, and reliability of models (Shemilt et al. 1981).

2. DEVELOPMENTS IN SIMULATION

In the 1970s, there has been studies to consolidate and advance the field of Simulation. For example, Karplus, as early as 1973, provided a spectrum of mathematical modelling and systems simulation where different types of simulation application areas and objectives for such studies are matched in a framework.

> "Simulation can be applied to all three types of system problems, i.e., analysis, synthesis (design), and control (instrumentation) (Karplus 77). As a decision-making tool, simulation can be used in all five types of decisions, i.e., the descriptive, explanative, predictive, evaluative, and prescriptive decisions (O'Shaugnessy 1972). Simulation can be used to satisfy different goals such as product design, performance prediction, action prediction, experimentation with control strategies, testing theories, gaining insight, and arousing public interest (Elzas 1978). Owing to this versatility, different criteria have to be considered in assessing the acceptability of different types of simulation studies." (Ören 1981a, p. 180).

Especially, Karplus' spectrum should be kept in mind in assessing the degree of success of application of simultaion to a given type of problem.

An important milestone in the 1970s was the availability of the first book on the theory of modelling and simulation by Zeigler (1976).

In 1977, Ören developed a framework to categorize modelling, model manipulation, and programming concepts in simulation programming. Twenty-four groups of concepts are identified. The framework was originally published in Oren 1978d and was elaborated on in Ören 1978b.

In the 1970s efforts have been concentrated in developing methodology and software for combined discrete/continuous simulation studies (Ören 1977b,c). At an early stage of this development some simulation experts could even not realize the need for such developments. For example, Strauss wrote in 1969:

> "It is the considered opinion of the author that at present there is relatively little need for a combined discrete event, simulation language/continuous-system simulation language facility."

> "The reasons given to support this assertion were that discrete-event and continuous-system simulation studies had different objectives, different logic, and different levels of simulation activities." (Ören 1978b, p. 41).

The field of combined simulation has now over thirty five languages, packages, or procedures and is still maturing.

In the 1970s, in addition to Zeigler's book published in 1976, there were other studies initiating a very important trend in simulation, i.e., the use of general system theoretic concepts as bases of simulation studies. Ören wrote the first simulation language based on a mathematical system theory (Ören 1971). The language, called GEST (General System Theory implementor), is based on Wymore's system theory (Wymore 1967). The second language based on the same theory was DIGEST (DIscrete GEST) develop by Mullens (1973).

Some other studies promoting the synergism of modelling, simulation and general system theories were Elzas 1979, Klir and Uyttenhove 1976, Ören 1974, 1978a,b,c, 1981c, 1982, Ören and Zeigler 1979, Uyttenhove 1978, and Zeigler 1976, 1978, 1979, 1980. A brief note summarized the highlights of the simulation software activities of 1979 (Ören 1980).

An interesting simulation system published in 1980 is SONCHES (Simulation Of Nonlinear Complex Hierarchical Ecological Systems) which relies on a formal representation of mathematical model used in a ecological system simulation study (Wenzel et al. 1980).

To place the developments in simulation in the right perspective, one should consider different phases of societies as well as their respective strategic resources and methodologies.

" As Bell points out, a number of countries in the West are now passing into a post-industrial phase of society where the strategic resource is knowledge as opposed to raw materials or financial capital which were the strategic resources in pre-industrial and industrial societies respectively. The methodologies in pre-industrial societies are common sense, trial and error, and experience; and in industrial societies, empiricism and experimentation. Whereas in post-industrial societies the methodologies are abstract theory: models, simulations, decision theory, and systems anlysis" (Bell 1976).

Simulation is experimentation with models. Therefore the emphasis can be either on "experimentation" or on "models". For the specialists who are still under the influence of industrial revolution, the emphasis is obviously on "experimentation." Even from this point of view, simulation is an invaluable decision support tool.

For those who realize the impact of Tofflerian third wave (Toffler 1980), i.e., those who are part of post-industrial phase of society, the strategic resource is "knowledge." Therefore for them the emphasis is on "models" without ignoring the value of experimentation. Models, to paraphrase Zeigler (1981), should be regarded as knowledge that can be transmittable, reusable, testable, and correctable. It is from this point of view that some authors are interested in methodological foundations of development of computerized model bases which would in turn be part of computer-assisted modelling and model manipulation systems (Ören 1978b,c,d, 1979, 1981c, 1982, Ören and Collie 1980, Oren and Zeigler 1979, Zeigler 1979, 1980, 1981).

As it is already elaborated on in the literature (Ören 1982), Simulation is one of the several possible ways of manipulating models, i.e., for the purpose of behaviour generation under controlled conditions. So far as behaviour generation is concerned there are other types of behaviour, such as point behaviour as it is the case in numerical computations or optimizations or query systems, and structural behaviour. In the case of simulation, the interest is on trajectory behaviour. However, at the end of the simulation study a scalar or a vector-valued figure of merit may be used to characterize the trajectory behaviour generated during the simulation. Model-base activities provide a much richer paradigm for decision support systems then mere simulation studies.

3. UPRISE OF SYSTEMIC THINKING

Several terms exist to denote different aspects of systemic thinking. Some of them are:

system analysis
system control
system design
system design, tricotyledon theory of
system instrumentation
system optimization
system synthesis
system theory
system theory, axiomatic
system theory, deductive
system theory, fuzzy
system theory, general
system theory, hierarchical
system theory, inductive
system theory, living-
system theory, mathematical
system theory, scattered-
systems approach
systems engineering
systems research
systems research, general
system, adaptive
system, allopoietic
system, allotelic
system, anticipatory
system, autopoietic
system, autotelic
system, coupled
system, evolutionary
system, fuzzy
system, goal-determined (teleonomic)
system, goal-generating (teleogenic)
system, goal-seeking (teleological)
system, goal-selecting (teleozetic)
system, hierarchical
system, learning
system, loosely-coupled
system, scattared
system, self-learning
system, self-monitoring
system, self-organizing
system, self-referencing
system, self-regulating
system, self-reproducing
system, self-stabilizing
system, variable-structure.

The definitions of some of the terms, especially pertaining to different types of systems or models are given in Ören (1979).

An excellent report prepared by Cavallo (1979a) summarizes characteristics, accomplishments, and developments of the contemporary systems research. A bibliography of basic of basic and applied general systems research contains 1409 entries, 1182 entries being associated with the various areas of general systems research (Klir and Rogers 1977). The bibliography also contains interesting statistical analysis. for example, for the period 1945 to 1976 the literature has been doubled approximately every four years. A draft of a glossory of systemic terms appeared in 1980 (Umpleby).

Some important references on systemic thinking are:

Ashby 1956, 1970, Broekstra 1977, Churchman 1968, Drenick 1981, Francois 1980, Haddad 1981, Ho and Mitter 1976, Hogeweg and Hesper 1979, 1981, Klir 1969, 1972, 1978, 1979, Klir and Uyttenhove 1976, Kramer 1974, Mesarovic et al. 1970. Moulin et al. 1980, Ören 1971, 1974, 1978a,b,c, 1981b, Ören and Collie 1980, Ören and Zeigler 1979, Rosnay 1975, Sage and Thissen 1980, Subrahmanian and Connon 1981, Thom 1978, Uyttenhove 1978, Vallet et al. 1980, Van Gigch 1974, Varela 1979, Weinberg 1975, Wiener 1948, Winkowski 1976, Wymore 1967, 1976, Zeigler 1976, 1978, 1979, 1980, 1981.

Some general system theories are basically for quantitative representations like general systems approach of Klir (1969), mathematical system theory of Wymore (1967, 1976), hierarchical system theory of Mesarovic (1970), the arithmetical relators of SYSTEMA group (Moulin et al. 1980, Vallet et al. 1980) and Greenspan's arithmetic approach (Greenspan 1980a,b). A particular merit of Greenspan's approach is to represent, by discrete models, physical phenomena which were traditionnally represented as continuous models. His approach which is basically replacing calculus by arithmetics has only be made possible with the advent of digital computers.

Some other theories allow qualitative as well as quantitative representations like automata theory, Markov processes, catastrophe theory of Thom (1978), general system theory of Goguen (Ginali and Goguen 1978), fuzzy systems theory of Zadeh (1979), and theory of fuzzy measures which includes theory of credibility and calculus of plausibility.

Another important development in system theories is the development of a comprehensive framework and algorithms for computerized investigation of the relation between parts and wholes. Cavallo and Klir (1979, 1981, 1982) provide a framework and further references.

4. PROBLEM SOLVING

Ackoff (1977) stresses on fundamental points in problem solving. Some quotations follow:

> "The optimal solution of a model is not an optimal solution of a problem unless the model is a perfect representation of the problem".

In the case of problematique, i.e., complex and highly dynamic system of interacting problems, the sum of the optimal solutions to each component problem considered separately is not an overall optimal solution.

> "... there is an urgent need for OR (Operations Research) and MS (Management Science) to devote their efforts to the design of decision systems that learn and adapt quickly and effectively rather than to the production of optimal decisions that don't".

This last message which is very important, transcends even the abilities of currently available decision support systems. A definition of decision support systems is "interactive computer-based systems which help decision makers utilize data and models to solve unstructured problems." (Sprague 1980, p. 8). Not only simulation out also decision support systems can benefit from general system theories and artificial intelligence to be able to satisfy the norm expressed by Ackoff. Some other issues for the future of decision support systems have already been expressed by Dempster (1980).

Ackoff (1981) provides a lucid presentation of three approaches in problem management, i.e., clinical approach for problem resolving, research approach in problem solving, and design approach in problem dissolving.

Problem resolving is for satisficing (satisfies and suffices). It is the approach for most of the managers who are interested in survival. The approach in called clinical and is qualitatively oriented and uses subjective judgment.

Problem solving is for optimization. It is the approach for scientists or technologically oriented managers who are interested in growth. This research approach relies on mathematical models as well as on experimentation with real systems or models. It is quantitatively oriented and requires objectivity. "Researchers, more than managers, tend to resist the dilution of optimal solutions with qualitative considerations and often prefer an optimal solution of an incompletely formulated problem to a less-than-optimal solution of a completely formulated problem." (Ackoff 1981, p. 21.)

Problem dissolving is the design approach. The goal is to change the system involved or its environment in such a way that the resulving or solving the dissolved problem will produce a desirable solution which could not be obtained by resolving or solving the original problem. It is evident that this is also the approach for systems engineers who have general system theoretic backgrounds for system design.

5. THE PROMISING SYNERGY

To explore the synergy between simulation, software engineering, general system theories, we can consider the three interfaces of each of these fields with respect to the remaining fields. Furthermore, two aspects of simulation, i.e., modelling and experimentation can be considered separately.

Contribution of Simulation to:

Software engineering
- Simulation of Software

Artificial intelligence
- Cognitive simulation

General system theories
- "Basic tool of inquiry into complex systems" (Zeleny)

Contribution of Software Engineering to:

Simulation (modelling aspect)
- Computerized simulation
  (Ören 1978d, 1981c, 1982)

Simulation (experimentation aspect)
  (Ören 1978d)

Artificial intelligence
- Software for artificial intelligence applications

General system theories

"Artificial intelligence is the subfield of computer science which is concerned with the use of computers in tasks which are normally considered to require knowledge, perception, reasoning, learning, understanding, and similar cognitive abilities." (Duda et al. 1980, p. 729).

Contribution of Artificial intelligence (AI) to:

Simulation (modelling aspect)
- Simulation of "intelligent systems"
  (or Simulation with "intelligent models"
  (i.e., AI contribution in models)

Simulation (experimentation aspect)
- "Intelligent simulation" of systems
  (i.e., AI contribution in experimental frame)

Software engineering (Ören 1981d)
- "Intelligent software"
- AI in software life cycle

General system theories
- "Intelligent model"
  (i.e., models with cognitive abilities such as learning, adoptation)

Contribution of general system theories to:

Simulation (modelling aspect)
- Modelling formalisms (some of them very advanced)
  (Ören 1979)
- Bases for algorithmic model manipulation
  (Ören 1978a, 1979 Wymore 1967, Zeigler 1976)

Simulation (experimentation aspect)
- Basis for system design/analysis
  (Wymore 1967, 1976)

Software engineering
- Formalisms to design complex software systems

Artificial intelligence
- Advanced basis for knowledge representation for "expert systems", i.e., not only static structure of a model but also dynamics of the model.

6. CONCLUSION

As Berkeley (1973) indicates, all human problem solving activities are not necessarily based on rational principals. Furthermore, there are numerous problematique situations which require urgent solutions. Simulation, computerization, artificial intelligence as a subfield of computer science, and general systems theories provide concepts and tools to attack complex problems. However, an information technology to manage complex problems would benefit from a synergy of simulation, software engineering, artificial intelligence, and general system theories.

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