# PROGRESS in MODELLING & SIMULATION

edited by
## F. E. CELLIER

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## François E. Cellier

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Progress in Modelling and Simulation

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# PREFACE

In June 1980, the third IASTED Conference out of a series of Conferences. on simulation techniques took place at Interlaken, Switzerland. This Conference, called SIMULATION '80, consisted of a two day's *Course* covering advanced topics in modelling and simulation methodology presented by the most eminent specialists in their respective fields, followed by a three day's *Symposium*, in which roughly 120 contributed papers concerning all aspects of Simulation were presented.

In recent years, quite a large number of conferences on simulation techniques have taken place responding to an ever-growing demand for simulation technology from a large variety of diverse disciplines reaching from the many areas of engineering divisions to biology, medical research, and even social sciences. As the growing simulation community originally suffered from tremendous communication problems (each discipline used a separate terminology not understood by any "outsider"), it was not easy for them to exchange information among themselves before a common terminology, founded on the grounds of a general system theory, was developed. For this task, a framework had to be derived which we nowadays call *modelling and simulation methodology*. This methodology presents a common usable language which unifies the concepts developed for the different application fields.

It was the major intention of the *Course* portion of SIMULATION '80 to summarize recent research efforts in the field of modelling and simulation methodology. Although many conferences on simulation techniques have been held in the past, the set-up at Interlaken, in particular the Course portion of it, was quite unique in that the Course consisted of only invited lectures presented by well-known specialists. These specialists had been personally asked to present the results of their recent research efforts to a community of simulation experts and the aims and intentions of the event had been thoroughly discussed with them. In this way, the different survey lectures were not independent of each other (as is usually the case), but rather were well harmonized from their beginning.

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A preliminary version of the presented material was distributed out to the attendants during the Course itself. In the mean time, all papers underwent careful reviewing and copy-editing. As a result, a number of them have been re-written, or at least partially modified, in order to create a well-rounded and uniform overall presentation of the subject. This revised version of the invited lectures presented during the Course of SIMULATION '80 is collected in the present volume.

This volume is certainly not intended to cover introductory aspects of modelling and simulation. The reader is expected to have acquired some back-ground knowledge (e.g. by having attended an introductory course on simu-lation techniques at university level, or by having read a more introductory book on simulation) prior to this reading. After such preparation, however, he should be able to read and understand all contributions contained in this volume as they are presented without requirement for further reading of the numerous cited references.
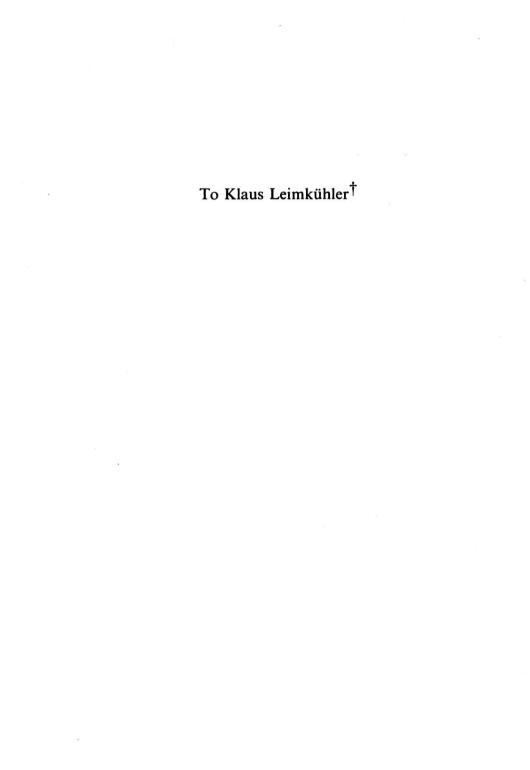
We are convinced that this volume will help the reader to

(a) consolidate previously acquired knowledge on modelling and simulation by placing it in a unified framework, and

(b) open new perspectives for him of techniques and applications of simulation.

This book is, thus, a book for *teachers* of simulation techniques as well as for *practitioners* of simulation who believe that they may find simpler and more elegant solutions to their specfic simulation problems by broadening their view-points. We are, furthermore, fully convinced that this book, being much more than just a normal set of Conference Proceedings, will play a significant role in the development and progress of modelling and simulation.

Zürich, 1982.                                                            François E. Cellier

To Klaus Leimkühler[†]

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# PRELIMINARIES

François E. Cellier

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In recent years, simulation techniques have become more and more accepted as an invaluable tool for system analysis in a wide variety of different disciplines. Nowadays, hardly any scientific discipline could be mentioned which does not make use of simulation in one way or another. It would, however, be incorrect to conclude from this fact that the demands, as asked for by different disciplines, are necessarily the same throughout the wide spectrum of applications. It was, perhaps, one of the most tragic failures in simulation that in the early days of computerized simulation, a (well justified) enthusiasm concerning simulation results in engineering applications (so-called "hard" sciences) had led to the assumption that the previously so successful methodology could be used without modification to deal with biological or social systems (so-called "soft" sciences) as well. In fact, the demands are quite different as shall be shown with a very simple example.

Current simulation software provides for a very powerful behaviour generation, that is, given a model together with values specified for all parameters of the model, and given a particular experiment to be performed on that model, time histories (trajectories) of all state variables in the model are computed with good confidence and are displayed with high precision. This is certainly what is needed for most engineering applications (e.g. electrical network analysis). The models themselves have a high quality and, thus, the results from simulation studies performed on such models can be expected to be trustworthy. However, the same behaviour generation mechanism is entirely inacceptable for most soft science studies. The models obtainable there are of low credibility, the parameters are known at the best to some percent, and even the structure of the model is often more than questionable. Under such circumstances, it makes no sense at all to display results with 14 digits if we know that most probably not a single one of those is significant. However, the (in most cases rather credulous)

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user is inclined to validate the obtained results by the fact that 14 digits are displayed to him out of which not a single one is zero. In fact, one of the major reasons for the somewhat limited credibility which is assigned to simulation results in many domains lies in the credulity of their end users. As it is, in general, easier to change the software than to change its users, we should provide for means of adjusting the format of the displayed results to the application the software is used for. For instance, if the user would be asked to specify on input tolerances for all parameters of his model (which, in most cases, would not be too difficult to do), the software could perform an automated sensitivity analysis, and select dynamically an acceptable format for all output displayed. Even if no significant digits remain, it still makes sense to present results; however, rather than displaying a single curve, the simulation software should display a bandwidth (confidence interval) in which the results are expected to be found. Such a display could tell the user much more than a rather incidentally selected single curve. The so-called ill-definition of models from soft sciences, therefore, calls for a quite drastic modification of the modelling and simulation methodology. Obviously, the here mentioned example is just one among many aspects in this field.

Concerning biological systems in particular, some steps have meanwhile been taken towards a unifying methodology, and the chapter presented by *G. C. Vansteenkiste* discusses this issue in detail. To appreciate how deeply simulation techniques have influenced biological research already, the chapter presented by *J. R. Barrett and R. M. Peart* presents an impressive bibliography on just one among many biological topics, namely agriculture.

In biological sciences, the ill-definition of models results from among other things problems with taking appropriate measurements. As human beings (that is, the investigators) are to be considered as biological systems themselves, it is further not astonishing to notice that the time constants dominating the systems under study are frequently of the same order of magnitude in the investigator (that is a life-time). This fact certainly acts as a tremendous obstacle against the provision for reasonably accurate and validated models, in particular, if one considers that modelling (as we understand the term today) is an art which does not date back an entire life-span yet. However, I am fully convinced that reasonably accurate models for these types of systems would in theory exist even if neither we nor our direct descendants were able to determine them.

In the social sciences, the situation is complicated by some additional troubles. When human beings play an important role in the system under study, the systems often change their behaviour as they notice that they are modelled. I call this the keep-smiling effect (people tend to change their behaviour if they notice that a photographer is sneaking around trying to take their picture). This is certainly nothing new. At least since the days of Heisenberg, we know that it is impossible to observe a system without disturbing it. However, the disturbance may be somewhere in the twentieth decimal, and then we may easily

neglect this disturbance, or it may be a significant change of the system behaviour as a whole. Unfortunately, in social sciences, the latter is usually the case, that is, the keep-smiling effect often is the dominating factor in the system behaviour. For this reason, I am rather doubtful that for all imaginable systems from social sciences, acceptable models would even in theory exist, independent of the question of whether we can determine them or not. For this reason, one must even be more cautious with models in the social sciences, and it is quite seductive to draw illegitimate conclusions from results of social system studies based on dubious models which have not been cautiously validated for their task. The contribution by *K. Leimühler* discusses these aspects in detail, and opens new perspectives as concerning possible means to overcome these difficulties. Certainly, it is one of the most challenging tasks in modelling today to investigate the problems resulting from ill-definition and to find new methodologies to overcome these problems. For this reason, an entire section of this book deals with the subject matter.

In addition to ill-definition, however, there exists a second problem in many soft science studies which is often not even easily separable from the previous. When modelling an electric resistor, for instance, it is very easy to postulate a model which is acceptable for a wide variety of experiments. Nevertheless, it is still just a model which should not be mixed up with the real system itself. If, for example, the experiment would include a variation of the surrounding temperature in a large range or would include very high frequences, the same model would no longer be acceptable. Fortunately enough, such experiments are seldom, and, for most applications, the simple model $U=R*I$ will do. In the soft sciences, however, it is for the most part much more difficult to separate out the importance of different potential input variables both in the time scale as well as in the space dimensions. This aspect is also discussed carefully in the chapter by *G. C. Vansteenkiste*. If one models the growing speed of a flower in spring, this shall depend on many influencing factors like temperature, photoperiod, air and soil humidity, nutrients in the soil, solar radiation, wind velocity, rain, microbial activities of the soil, and so on. Unfortunately, all those factors have effects of the same order of magnitude. For almost any kind of experiment, we should take them all into account. This calls for rather complex models with many input variables which are often only to a small extent observable and to an even smaller extent controllable. We call these models large-scale models. Quite obviously, such large-scale models are again more difficult to identify, making them even more ill-defined.

The second section of this book deals primarily with different aspects of modelling large-scale systems. The contribution by *K. Frohberg* discusses the example of the difficulties of world food supply. Typical keywords are hierarchism and regionalization, keywords which are also central to the discussions by *N. Müller* and by *A. Sydow*. *N. Müller* discusses hierarchical concepts of social systems, whereas *A. Sydow's* chapter is a little more technically oriented

both in its presentation and selected applications.

Certainly, the best established methodology for large-scale system modelling is System Dynamics, a methodology we owe to J. Forrester. The presentation by *J. D. Lebel* discusses some aspects of System Dynamics models and, primarily important, contains an impressive bibliography with more than 700 entries on applications of this methodology.

As we have already seen, models must never be confused with reality. They just map some facets of reality (hopefully the ones we had in mind) into an abstract description. It is, therefore, of utmost importance to cautiously validate the obtained models for their respective tasks. This is usually a quite simple job when dealing with one or two differential equations and three or four parameters. It becomes, however, tedious and extremely difficult to perform when we deal with large-scale models. The chapter by *R. G. Sargent* surveys a large variety of aspects of validation and of means to achieve it. This chapter furthermore contains a discussion of the verification of simulation results: a topic which would be better included in the second part of this book; however, as the techniques used are very similar to those used in validation, it did not seem justified to split up the presentation of these topics into two separate chapters. Incidentally, the same holds true for the presentation by *A. Sydow* the first part of which deals more with large-scale system simulation rather than large-scale system modelling (and is somewhat related to the chapter by *E. Eitelberg*). However, in reality, it is often not so easy to clearly separate the different aspects out, and the contributions have therefore been placed where we felt that their major emphasis lay.

In many models, statistical aspects have an important role to play. As it was mentioned above for the case of models from soft science, results of simulation studies involving stochastic signals are not so easily interpretable. Again, one single curve doesn't tell very much. The question thus raises what possibilities exist to interpret the obtained simulation results correctly, and how the statistical experiments should be designed to allow (with minimum computation) an appropriate interpretation of the results. The chapter by *J. P. C. Kleijnen* surveys a variety of methods for this purpose.

Also previously postulated was the need for an automated sensitivity analysis. Obviously, this is just one among many potential fruitful extensions to the currently available simulation software. Current software always assumes that a model already exists, and restricts itself to pure behaviour generation. This ought no longer to be the case in the future. The computer should help the investigator both in the preparation of the model and in its validation. To distinguish from the currently available simulation software, we would rather want to call this "modelling software". The contribution by *T. I. Ören* lists a large variety of possibilities for such software. Obviously, not all of these possibilities shall be easily integratable into one system without making it so large, slow, and unmanageable that we had better forget about it all together. This is, however,

not the intention of this contribution, as the author expressed clearly during his presentation. This contribution aims at systematizing possibilities for such systems from a methodological point of view.

As the models which are investigated tend to become larger and larger, it is quite obvious that there exists an increased risk of modelling errors which remain undetected due to the fact that the models we deal with are no longer very transparent. One possible answer lies in the hierarchism discussed above; another answer may be found by changing the model description mechanisms, e.g. by using graphical techniques. Two possible solutions are discussed for continuous systems by *J. J. van Dixhoorn*, and for discrete systems by *C. D. Pegden and A. A. B. Pritsker*. These two contributions conclude the first part of this book which deals with a diversity of topics in modern modelling theory.

The second part of this book is devoted to simulation issues. The large-scale aspect does not only influence modelling but simulation as well. It is, for instance, a quite general statement that large-scale models of continuous systems are stiff. These models require, therefore, particular techniques for integration. Again, partitioning mechanisms may provide one possible answer. However, this can in many instances not be done in the same way as described under the heading "modelling" as the partitioning should be done here for the benefit of the numerical algorithm, and not for the user of the model. It would, for instance, be very fruitful to partition the problem into a fast and a slow part. However, in many applications, it is not so easy to determine which equation belongs to the fast and which to the slow part. Actually, the eigenvalues of the Jacobian may tell something, but it is no trivial task to relate those eigenvalues back to the differential equations from which they were generated. Moreover, in a nonlinear case, it may well happen that the eigenvalues move around, and one and the same mode may belong for a time to the fast and then again to the slow subsystem. It is, therefore, one of the "hottest" research problems in numerical mathematics to develop an algorithm which would allow an automated partitioning of the differential equations to be done. The chapter presented by *M. B. Carver* discusses this matter and presents a partial solution to it. The problem must still be considered unsolved as no algorithm could be found which would work equally well for all application problems. Furthermore, the algorithm presented by *M. B. Carver* leaves some parameters for tuning to the user and it is not entirely clear how they should be properly chosen. This is, however, not at all meant to be a criticism, as the problem seems to be extremely difficult to solve; I am personally very sceptical as to whether a completely automated algorithm can be developed which works under all circumstances satisfactorily. The contribution by *E. Eitelberg* is somewhat related to the previous one. In this contribution, the aim is not an automated partitioning. Here, the partitioning is left completely to the user. However, the algorithm presented by *E. Eitelberg* allows for a modular simulation of once partitioned