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THE COMPUTER AIDED SIMULATION MODELING ENVIRONMENT: AN OVERVIEW

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ABSTRACT

The Computer Aided Simulation Modelling project at the London School of Economics started in 1982. Since that time a number of software developments have taken place which have been reported in the literature. These developments reflect the research group's views on one of the ways in which simulation modelling could be conducted in practice. This paper examines these views with respect to the underlying methodology of simulation modelling; discusses the latest version of the simulation software developed by members of the CASM team; and mentions the method of organisation of the CASM research team. Some comments on the success or otherwise of these endeavours are made and on the future anticipated research endeavours of the group.

1 INTRODUCTION

The Computer Aided Simulation Modelling project (CASM) at the London School of Economics (LSE) was initiated in 1982, and its fundamental approach to simulation annunciated by Balmer and Paul (1986). The research is now being conducted at Brunel University as well as the LSE. The research group's objectives were based on the teaching and consultancy experience of the project's directors. Research work is undertaken by a continuous stream of bright would-be Ph.D students, who undertake specific parts of the research programme. Seven students have already succeeded in obtaining their Ph.Ds (Doukidis 1985, Chew 1986, El Sheikh 1987, Knox 1988, Mashhour 1989, Au 1990 and Domingo 1991) and three students are likely to complete in 1992. There are six research students currently working on the project. Many papers have been published in the research literature and these and prospective papers are listed in a fairly complete listing of all the CASM papers and theses.

The CASM research group concentrates on the problems related to discrete event computer-based simulation modelling. This area of modelling is particularly popular amongst the operational research and information systems fraternities. Whilst continuous modelling, differential equations, systems/industrial dynamics and other temporal modelling systems are undoubtedly of interest, and are related to discrete event modelling, at the current time CASM is restricting its research interests in order to make progress in one of these dimensions.

In the next section, the process of simulation modelling is examined and the problems associated with simulation modelling as seen by the author are outlined. Following this, the objectives and underlying methodology of the CASM research group are described. Some of the modelling environments that have been developed are described in the following section. Application areas are covered next. The paper concludes with the experiences and future anticipated research of members of the research group.

2 SIMULATION MODELLING

In many text books on operational research and in some text books on simulation modelling, the simulation process is described as follows. There is a real world problem. This problem is formulated as a logical model. Logical models can be activity cycle diagrams, flow charts, block diagrams etc. There are a variety of ways to represent the logic of a formulated problem. The next step is to convert the logical model into a computer model; sometimes it is a computer program, sometimes it is a data driven generic simulation system. This computer model is verified, tested to see if it is doing what the analyst wants it to do. The model is used as an operational model to produce some results, or some conclusions, or for implementation after the operational model has been validated against the real world. An implicit assumption is that the product of the modelling process is a set of results, usually numerical, which lead decision makers and/or analysts to some conclusions, from which some decisions are implemented. Many text book expositions point out that the process is not quite as linear as has just been described. There are many iterations or feedbacks in the process as understanding of the real world problem changes.

In many real world situations, however, the above description of the simulation process is inadequate. Real world problems are owned by interest groups. The definition of the problem is influenced by the owners of the problem, especially for complex strategic decision making. Such problems are usually owned by many interest groups, some of whom may be in conflict. Because the problem is complex, formulation is a very difficult task. The construction of a logical model representing the formulation of the problem is, in many instances, the most difficult aspect of the problem. In fact, understanding what the problem is may be the object of the whole exercise. The analyst should be prepared to constantly undertake problem reformulation to obtain a common understanding of the problem as part of the modelling process.

A dynamic (changing) logical model needs to be turned into a computer model with relative ease. Otherwise, if this part of the process takes a long time, contact with the real world problem starts to diminish. If the analyst discusses the computer model with the decision makers infrequently, then the chance that the computer model represents the real world problem is small. In many instances, the function that the computer model serves, is to perform a medium of communication for the structuring of the problem for all participants in the decision making process.

It is obviously necessary to verify that the computer model does what one thinks it should. But it is questionable as to how much emphasise should be placed on producing the operational model which is going to be used for experimentation purposes. In many cases, the production of a computer model which secures problem definition agreement among the decision makers may be sufficient to satisfy all participants. It may not be necessary to actually pursue the modelling process to the point of getting statistically valid results. In the event that the latter should be required, it is usually a minor part of the whole modelling process. It is curious that so many text books concentrate on the theoretical aspects of this part of the modelling process.

In summary then, the problems associated with using simulation modelling as a decision aiding technique are as follows. First of all, most problems to which one applies simulation are poorly defined. In fact one might go further, and claim that if the problem is not poorly defined, there are probably better and more reliable methods of solving the problem than the rather crude technique of simulation modelling. Secondly, any problem of any complexity which is important will probably involve conflicting interests and understanding. One must anticipate that if the modelling process is going to lead to change in the organisation, then it is unlikely that all decision makers will see these changes as favourable to them. The analyst must anticipate negative attitudes and spoiling tactics. As much as possible, the modelling process is used in a neutral way to help the participants in the decision making process understand their problem, and come to a resolution amongst themselves. The third problem associated with simulation modelling is that there never exists a static specification of the problem, it is always dynamic. Even if one succeeds in satisfying the conflicting views of the decision makers, it is probable that for complex problems the specification still undergoes change. The real world is dynamic and therefore the perceived problem will be dynamic as well. The fourth problem with simulation modelling is the question of 'model confidence', which is better terminology than the commonly used description of verification and validation. No computer program of any size can possibly be verified. No model of any size can possibly be validated against the real world, especially given that the real world is not static. The model cannot be proved to be correct. The aim should be to use methods that demonstrate confidence in what the model is doing and the way it is doing it.

The last feature associated with simulation modelling, which is a desirable characteristic, is that it involves decision aiding. Discrete event simulation modelling is a quantitative technique. The outputs are numerical, and numerical values tend to indicate that one course of action might be better than another. However, such a numerical technique cannot represent all possible factors in the problem scenario. It can crudely represent most or some of them in a quantitative way, but it cannot represent subjective factors. It must be remembered that the simulation modelling process is not designed to find the answer or answers. It is there to help decision makers take decisions, or to help decision makers gain an understanding of their problem. The numerical output of the simulation model in itself may often be of no particular intrinsic value. Learning about the processes of the interactions that go on within a complex environment, the relationships between the variables, is probably the dominating characteristic of interest in simulation modelling.

3 CASM OBJECTIVES

CASM is researching into simulation modelling, with

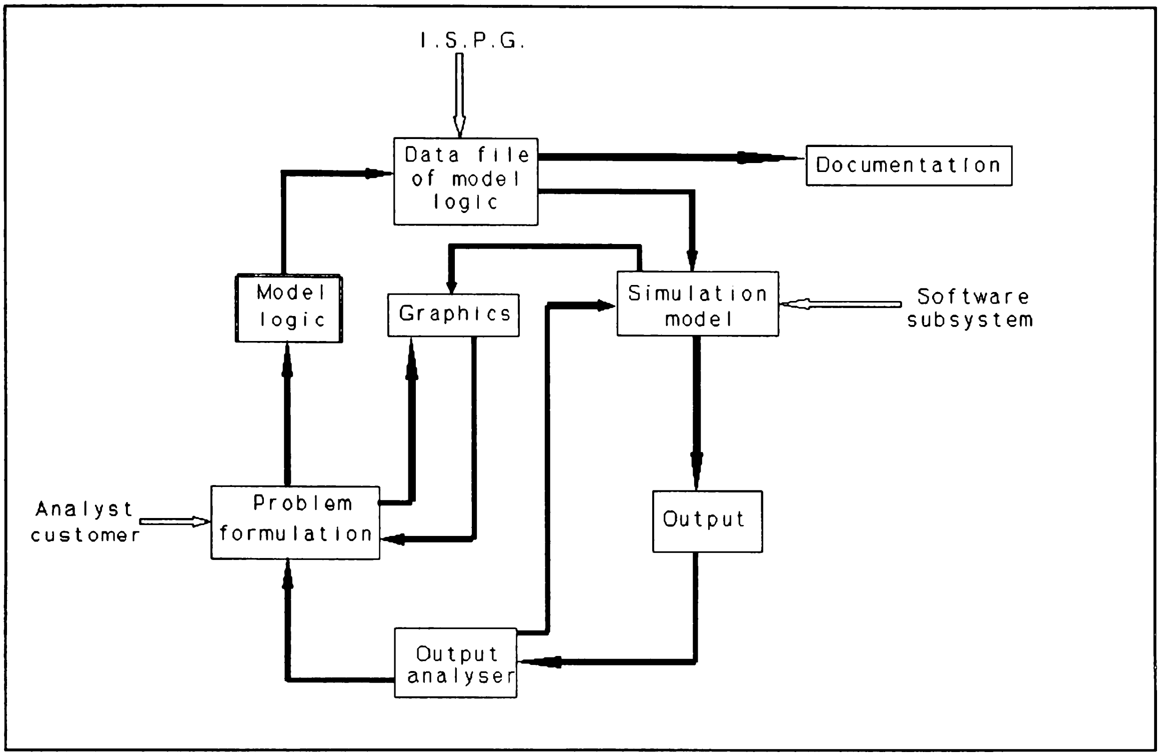

Figure 1: CASM Modelling Environments

a view to producing computer systems that automate as much as possible, the simulation modelling process. The aim is to make simulation efficient as a modelling tool for helping decision makers understand their problems. It is impossible to produce an all purpose simulation modelling system that can handle any problem that one might wish to model. The analyst is restricted to what a simulation system can handle, or the simulation system must provide programming code that can be modified to do the task that has been set. In this latter context, CASM are dedicated to the production of transparent models (i.e. program code that can be read by somebody else). Gifted amateurs not only produce program code that cannot be read by other programmers, but after a short lapse of time, cannot even be read by themselves! It is therefore quite apparent that a highly stylised, highly structured method of writing computer simulation models is required, so that anyone familiar with this structuring and style is able to read and understand it.

CASM is a research group operating within a university environment, so the computer systems that are researched into must also help in the teaching of simulation modelling, as well as assisting in further research into simulation modelling. Other apparently relatively insignificant factors need to be taken into account. A variety of career paths for the research participants must be satisfied. If this were not so, then individuals would feel free to go in any direction that appeared to satisfy their goals. Lastly, but not least, in a research environment it is important that the individuals concerned enjoy what they are doing. If the researchers do not enjoy their work, a variety of reasons will be found for why things are not working, not being done, or not happening.

4 THE CASM APPROACH TO ENVIRONMENTS

Figure 1 illustrates the sort of simulation environment that CASM envisages would assist the analyst assist the decision maker. This environment is more extensively described by Balmer and Paul (1986). The analyst and customer, or decision maker, would use a system that assisted in problem formulation. This problem formulation system would essentially capture the model logic of the problem to which could be applied an interactive simulation program generator (ISPG). The ISPG would produce a simulation model which called on a library of software subsystems to actually run the simulation itself. Simulation model output would be analysed by an output analyser which would, again under analyst control, help determine experimental design for running and controlling the simulation model. It is anticipated that the problem formulator and output analyser would close the loop, so that the analyst and decision maker could collectively use the complete system.

Attempts have been made by CASM to develop a problem formulator. These attempts are described by Doukidis (1985,1987), Doukidis and Paul (1985,1986,1987b), Paul & Doukidis (1986), and Paul (1987). The final system, which works, is a natural language understanding system. Using an activity cycle diagram paradigm, the natural language understanding system asks questions of the analyst at a computer terminal. These questions concern the dynamics of the problem being formulated. The analyst replies with textual responses, specifying what the various actions and objects in the problem are. The input sentences are in a prestructured form, which determine the flow of control of the objects in the system. This system has been demonstrated to work, in that the model logic for a problem can be determined in this way. Curiously enough, however, the system is not used in practice. The reason is that the purpose of the system, to help the analyst formulate a problem in conjunction with the decision makers, is not practically feasible in this way. One cannot expect a decision maker, or decision makers, to sit in front of a screen, talking sideways to an analyst, who is being controlled, in a textual sense, by the computer. This is a completely unnatural way for humans to hold a discourse. The terminology that the natural language understanding system uses is also unnatural for the decision maker, albeit well understood by the analyst.

The interactive simulation program generator (ISPG) part of the environment has been researched into throughout the duration of the CASM research project. First attempts emulated the work of Clementson's CAPS/ECSL package (1982). The second version, called AUTOSIM, made some minor improvements (Paul & Chew 1987). A later version, VS6, is described by Knox (1988). All these interactive simulation program generators generate program code in a high level programming language, in this case Pascal. A high level programming language was deliberately selected because of the availability of expertise and assistance on a broad level. Many simulation systems develop simulation code in their own purpose built language. These languages have undoubtedly been developed to a high degree of sophistication suitable for simulation modelling purposes. However, they require participants in the modelling process to learn the language in order to use it. CASM has concentrated on using a high level programming language to avoid the problem of scarcity of experts.

In order to handle the problem of simulation specific code, CASM have produced well written modifiable libraries of simulation routines. These routines enable the commonplace parts of any simulation model to be easily accessed. The generated program code for any particular problem is written in a three phase structure, as described by Crooks et al (1986) and Paul and Balmer (1992). This structure has the virtue of describing the control of flow in any model accurately and is easy to modify. Bearing in mind the earlier points made about the need for dynamic model development, it is clear that this ease of modification is an essential characteristic of any generated simulation program. Apart from the virtue of writing simulation models in a highly stylised structured way, an interactive simulation program generator also has the advantage that it produces models in which one may have a high degree of confidence. As the ISPG is applied to more and more problems, the errors in the system itself are slowly removed, so that the generated code is more likely to be correct. Another virtue of using an ISPG is the ability to undertake rapid prototyping. This means that if the specification of the problem changes, as it almost invariably does, then the ISPG can be reapplied to write a new program each time.

In theory, if the description of the model logic is adequate enough for an ISPG to produce the simulation code, then it must be adequate enough for documentation of the simulation model to also be automatically produced. Whilst this is almost self evident, it seems that the task of producing a system that automatically documents programs is not quite as exciting for prospective researchers as many of the other tasks available within the research project!

Figure 1 includes graphics in CASM's view of simulation modelling. Most simulation systems develop a simulation model to which a picture is added. This picture represents the computer model, which represents the logical model, which represents the real world problem. This is curious since, if the graphics, through these several steps, represents the real world problem, why is the real world problem not expressed in graphical form first? This graphical description of the problem could then be used to generate the rest of the system. This is an aspect of the simulation modelling environment that CASM are actively researching into.

The last part of the diagram, the output analyser, presupposes that the large body of published statistical knowledge describing how to analyse output from simulation models can be encoded into some sort of intelligent system. Regrettably, however, it turns out that the statistical knowledge available, largely tested on simple simulation models, does not appear to work so readily on the complex sort of models that one generally applies simulation to. Therefore, research in this area is into simple ways of analysing the output from simulation models. Some early results that reinforce this approach are emerging in work being undertaken by Mejia (1992).

A last feature of the underlying methodology of the CASM project is that the software systems used to automate the simulation modelling process should not be expensive. Therefore, CASM research has been predominantly based on commercially available microcomputers, since these are the most widely available and popular computer. CASM systems have been devised to be used without the need for extra hardware being added to the microcomputers. The overall aim is that CASM systems will assist in producing software that makes the simulation modelling process easier to use and less expensive.

5 MODELLING ENVIRONMENTS

5.1 Specification Methods

Surprisingly, given the relative length of time that simulation modelling has been undertaken on computers, there is no fixed method for specifying simulation problems. There are a large number of diagrammatic techniques such as activity cycle diagrams and Petri nets, and semi formal methods as exemplified by Zeigler's work (1984). The basic problem in specification appears to be as follows. If specification is going to be used as a vehicle for communication, it must have a simple structure. However, many simulation models inherently model complex situations, and the combination of objects or entities in an activity requires some complex conditions to be stated. If these conditions are described explicitly in the specification method, then the specification becomes very difficult to follow.

At one extreme are diagramming methods, which give a very simple representation of the basic simulation model structure. At the other extreme are formal methods or mathematical approaches, which make everything explicit but suffer from a heavy use of mathematics, and which is therefore not understandable by very many people. Ceric and Paul (1989) describe a brief survey of available diagrammatic methods that are commonly used in simulation modelling. In a later paper by Paul and Ceric (1992), the principle of Comprehensive Harmony is expounded for the requirements of a specification method. This principle quite simply requires that the specification method must be reasonably comprehensive. However, this comprehensiveness must be balanced by a harmony in the method of specification that makes it intelligible to the active participants in the simulation modelling process. It is anticipated that such comprehensive harmony might be provided by a mixture of diagrammatic methods with a hierarchy of descriptions leading to formal methods at the lowest level.

Domingo (1991) describe a range of simulation specification methods leading up to possible ways of using formal methods as the specification approach. Some research is going on into visual formulation methods which include diagrammatic methods such as activity cycle diagrams and Petri nets and simulation graphs. More particularly, specification languages and the systems theoretic approach by Zeigler are being examined. Some of this research encompasses an examination of formal languages such as Z and VDM. Whilst these languages have not been designed for simulation specification, and in particular are not very adept at handling temporal issues, it is felt that an attempt to use such methods for simulation specification will assist in the derivation of a language in its own right. The main advantage of using formal methods is that the specification is provable in some sense. In other words, the model logic is at least consistent, albeit it can never be known if it is exactly what is required.

5.2 Graphics Driven Environments

Since the inception of CASM, the creation of a simulation environment has been one of the main objectives of the research group. Chew (1986) produced the first of CASM's interactive simulation program generators (ISPGs) which form the basis for a three phase simulation system written in Pascal. Later work on graphics, adding a picture to the simulation modelling process, is described by Knox (1988).

The latest development in these environments is described by Au (1990) and Au and Paul (1990b). This graphics driven environment allows the users, the analyst and the customer, to specify the problem using iconic representations for the objects in the system. The icons are laid out on the screen in a logical fashion, intelligible to the user as well as to the analyst. No particular formulism is used for this, in terms of diagrams or methods, although underpinning the method is the activity cycle diagram concept. This system was developed on the Macintosh microcomputer, which is an ideal environment for mixing graphics display with text. The system provides the user with assistance in the construction of the logic of the problem, and in the addition of quantitative and conditional information to the model logic.

A feature of this system, which is called MacGRaSE, is that different levels of detail concerning the problem are constructed in parallel by a mixture of diagramming methods and tabular information. So for example, if the users specify an object such as a person in the system, then this person can be represented by an easily identifiable icon. At the same time, a description of what type of object or entity a person is can be input to a table. The MacGRaSE system allows the user to draw the equivalent activity cycle diagram for the problem. The problem can be run in interpretive mode so that the dynamics of the system can be visually seen on the screen, checked and verified as much as any such visual representation can verify anything. Some complex simulations might be difficult if not impossible to describe completely using such a graphics driven specification environment. MacGRaSE allows a more basic model to be input and generated as a Pascal program, so that the particular idiosyncratic difficulties can be edited in to the program code. Such complexities usually revolve around the conditions for an activity to start, and often involve several levels of conditional statement, which is difficult to encompass entirely within a graphics driven environment.

Future work in this area is intended to remedy some of the possible deficiencies in complexity of problem that can be handled by this system. This might be achieved using a mixture of graphics and artificial intelligence techniques. Further enhancements might in any case be provided by producing a richer mixture of interrelated screens for the analyst to specify the problem with, plus some better help facilities for reminding the user of what is required for a complete specification. Hopefully, in the not too distant future, one might build such an environment and incorporate the benefits of the research in formal methods described above.

Another research direction, which incorporates many aspects of artificial intelligence, is a simulation system which is very different to the ones described above. This simulation system is based on a spreadsheet approach to simulation software. This approach was adopted since it was felt that many potential users of simulation modelling are already familiar with spreadsheet packages such as Lotus 1-2-3. So the interface to this package is basically similar to Lotus 1-2-3 itself. A description of the simulation problem can be written in natural language form, and then the simulation system will interpret this natural language using some artificial intelligence approaches such as semantic networks. So one spreadsheet level in the simulation package, as described by Barakat (1992), is a semantic network connecting the objects in the system to their definition, such as entities, activities and so on. A second equivalent level to this, in spreadsheet terms, provides an activity cycle diagram for the problem. A third equivalent level in the spreadsheet system provides the numerical data required to actually run the simulation model. It is also possible to add to the system an iconic visual representation which can be run dynamically.

6 APPLICATION AREAS

The CASM research group are constantly aware that their research endeavour into simulation modelling needs to be related to the real world if the research is not to become esoteric. There are a number of application areas that we are looking at.

Kuljis et al (1990) are examining ad out-patients clinic model with respect to commercial application packages. This out-patients clinic is being built so that OR analysts in the health service can go to the administrators and doctors who operate, or who are responsible for, such clinics, to demonstrate the feasibility of different clinic practices. A common problem with clinics is the waiting time of the patients at various stages throughout the process, and it is hoped by showing a visual simulation representation of these clinics for different clinic operating practices, that the people concerned might be persuaded to operate practices that are more beneficial to the patients and at no loss to them.

El Sheik et al (1987) have described the application of early CASM simulation systems to a port problem. This particular application demonstrated that simulation was a powerful tool for handling a potentially difficult political situation. The results of the simulation were reasonably well known in any case. The simulation model's benefits derived from the discussion that took place around the results. Participants suggested that things would be different if parameters changes were made. The simulation model enabled such parameter changes to be rapidly tested, showing that some if not all of the suggestions made were in fact erroneous.

Paul (1989e) describes how simulation modelling has potential applications in the area of stock control. It is quite clear that in the world of increasingly complex and flexible methods of manufacturing, simulation modelling is an inexpensive method of testing such new approaches, without actually building a factory or a stock control system and then finding out too late that it doesn't do as required. Hlupic and Paul (1991, 1992a, 1992b, 1992c) describe work being carried out in the area of Flexible Manufacturing Systems, which includes an extensive case study with a manufacturing company.

Our early CASM systems, described by Crookes et al (1986), have been used in a number of military applications. These are described by Holder and Gittins (1989) and Williams et al (1989). The interesting characteristic of the use of the simulation systems by these groups is that they partially replaced previous systems quite successfully and very effectively. The models described in these two papers were eventually joined together in a reasonably short space of time. It is pleasing that the claimed flexibility and effectiveness of these systems has actually been demonstrated in a real application.

7 EXPERIENCES AND CONCLUSIONS

The CASM simulation systems have been tested on many groups of students at the London School of Economics over the last ten years. It is good experience for students who are going to work in Operational Research to use systems that are not fully tested. It teaches them to be more than a little wary of software! One of the features of the systems developed is the concentration on activity cycle diagrams. However, activity cycle diagrams are not all-embracing. It is very easy to construct examples of problems where the logic of the problem is not captured in the activity cycle diagram. For example, in the port problem described by El Sheikh et al (1987), the activity cycle diagram is very simple. It has two small cycles and only two activities, but the logic in the model is very complex. The rules for engagement of ships and berths require a matching between the ship cargo, the handling facilities of the berth, the priorities that various ships have on different berths, and so on. These priority rules cannot be visually displayed on an activity cycle diagram, but they are an essential component of this particular simulation problem.

A further problem with the CASM systems is that of modified code. An interactive simulation program generator will produce code that compiles and works. However, as mentioned above, some problems cannot be specified entirely through the specification system. It is impossible for an ISPG system to be all-embracing. Therefore, the generated code has to be edited to handle the extra sophistication. Invariably when an analyst changes the code, errors are introduced. Syntax errors are relatively easily removed, as with any high level programming language. The run time errors and logic errors are somewhat more difficult. Part of CASM research has been into systems that aid an analyst debug an incorrectly amended program. Doukidis and Paul (1988) describe an Expert System for debugging simulation programs.

In conclusion, CASM believe that their research approach will lead to a concentration on the more difficult tasks of simulation modelling. These are problem definition and understanding, improving model confidence, experimental design and 'implementation'. These are the intellectual tasks facing analysts in helping the decision maker. They are often not given the effort they require because of the time taken in the more mundane programming elements of the simulation model. If the analyst can concentrate, with the assistance of efficient low cost software support, on these more difficult intellectual tasks then the analyst will then be able to work more closely with the decision maker. There is no doubt that collaboration between analyst and decision makers in decision aiding is synonymous with success, however one defines success.

Future CASM research will be into the areas of graphical problem formulation to drive the software systems that automate the simulation process. Work is in hand to produce better output analysis from simulation output. The use of simulation modelling in conjunction with business databases is also an area of research for which some useful initial results have already been produced (El Sheikh 1987, Mashhour 1989). Some work has started on determining the relationships between discrete event simulation modelling and more general forms of modelling of systems over time, such as systems dynamics, control theory, differential equations and queueing theory.

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