TOP-DOWN SYSTEMS ANALYSIS AND MODELING

by

F. RECHENMANN

Ecole Nationale Supérieure d'Informatique
et de Mathématiques Appliquées (ENS-IMAG)
BP 53 - 38041 GRENOBLE-Cedex FRANCE -

According to an implicit "start simple" principle widely accepted by system dynamics practioners, model's complexity must be progressively increased during the modeling process. How this increase in complexity should come about has yet to be explained.

In this paper, two strategies are discussed and evaluated. Since a top-down strategy starts with a high level of aggregation but includes in the model all the main variables since the first formulation, it is to be preferred to a bottom-up scheme. Moreover, the top-down strategy ensures the global coherence of the model at any stage of its conception and appears to be much more consistent with the system dynamics philosophy.

This paper emphasizes the need for an adequate computer modeling language and briefly describes a first attempt. The main property of such a language is to allow a hierarchical description of models, where any composing unit can be altered without the need for a complete recompiling of the whole.

TABLE OF CONTENTS

I - THE "START SIMPLE" PRINCIPLE

The systems analysis and modeling process is, in its very nature, progressive and iterative. Once the goals of the study - the questions to be answered by the model - have been stated, the analyst defines a first simple model which will be expanded when necessary. Every (?) systems dynamics practioner will agree on this start simple principle, but no precision has ever been given to the method of expanding the model. Although it is certainly impossible to settle precise rules, some general guidelines can be provided to assist the system analyst.

Relationships and variables are added to a model either because a class of system phenomena have been neglected in the past, or because the level of aggregation appears too broad to satisfy the objectives. On the other hand, relationships are removed when they link variables which appear to have no influence on the dynamics of the whole or when they embody an unnecessary fineness in the level of aggregation. As a direct consequence, the question of gradual model's expansion is directly related to the problems of choice of variables and of the level of aggregation.

The aim of the guidelines presented here is to reduce as far as possible the number of removals or replacement of relationships. These alterations are indeed very costly, since they generaly force the modeler to recompute the corresponding data (parameters and initial values) and always necessitate structural modifications of the model. All these manipulations consume computer and analyst time without bringing further understanding.

The guidelines take the form of a building strategy which explains how to increase the complexity of a model. Two main options are available, both of which make great use of the notions of sub-systems and sub-models. "Sub" is the name given to any part (= set of variables and relations) of the system and of the model under study. We shall formally represent such a part as a base supplied with inputs and outputs, as indicated in Figure 1.

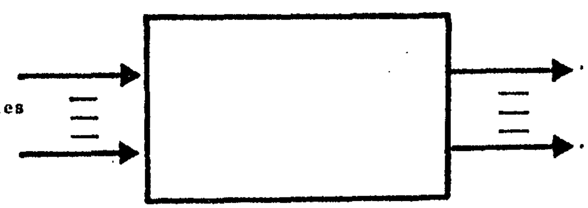


Figure 1. Symbolic representation of sub-model or sub-system

I - BOTTOM-UP VERSUS TOP-DOWN

While following a bottom-up strategy, the modeler first concentrates on a well-know or easy-to-model subsystem. He builds and tests the corresponding submodel by feeding its inputs - the variables not defined by the submodel but which intervene in its dynamics - with exogenous time series or with information supplied by an over-simple environment model. In the same way, he builds the other sub-models and, by making them interact, obtains a global model which constitutes the upper level of a beginning hierarchical structure.

On Figure 2, which visualizes such a process, all the interconnections are direct, that is, an output from a box is a direct input to another box. Such is rarely the case in reality. An input to a box is generally obtained as a functional combination of other box outputs. These linkage equations constitute the dynamics of the new level.

The model obtained can itself be considered a submodel whose inputs are all the variables which have not been internally defined and whose outputs are all the variables supposed to feed into the other submodels now to be connected. Each time a new level is constituted, the limits of the system are widened. The process stops when, regarding the questions of interest, all the phenomena have been included. Clearly, however, this convergence is not generally ensured.

On the other hand, a top-down strategy tends to include in the model all the relevant relations and variables as early as the first formulation. In order to keep with the "start-simple" principle, a very high initial level of aggregation is then required. Indeed, some of the phenomena will not be completely described. They will appear as black boxes whose outputs are in fact inputs for the present model level and participate in its dynamics.

In order to test the model, such outputs have to be fed with time-series or with simple equations, which will be replaced by more complete and detailed submodels when the current level of aggregation will appear to be insufficient. At their turn, these submodels will be composed of equations which link black boxes. Each time a lower level is developed, the level of aggregation is reduced, and the process continues until a satisfactory level of aggregation is reached.

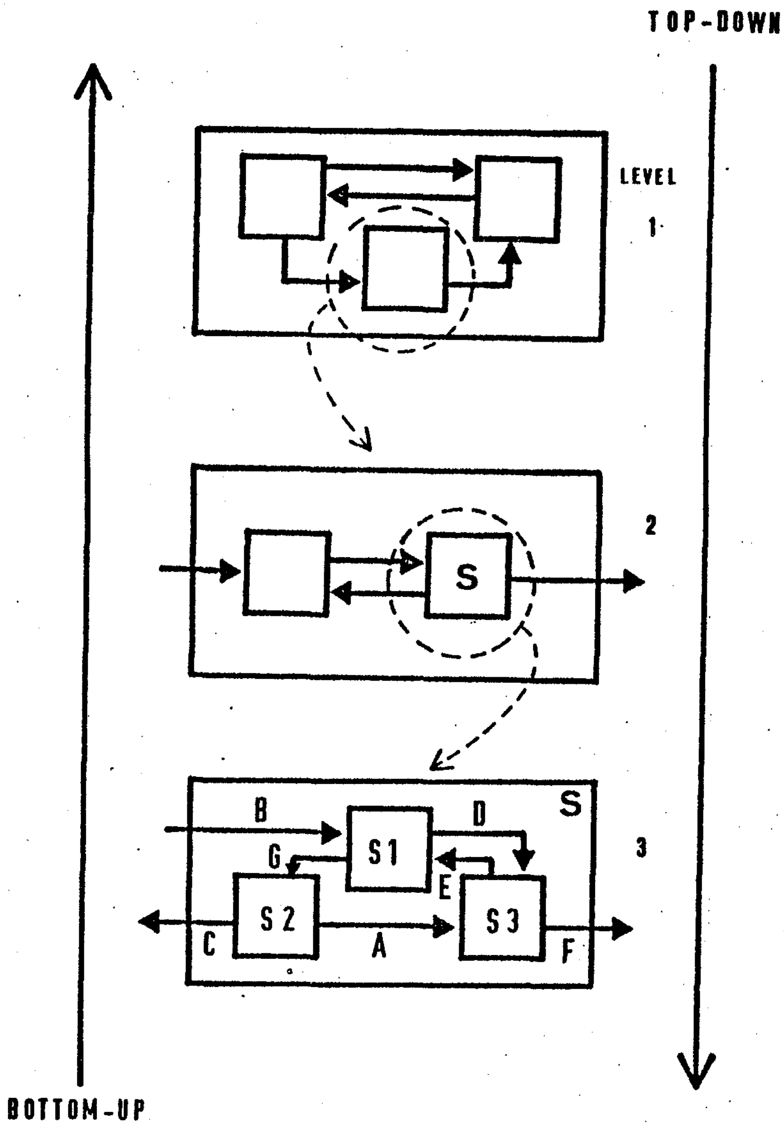


Fig.2

Bottom-up vs top-down

The top-down conception does not inevitably imply modular design as we assumed up to now. In practice, due more specifically to the lack of an adequate computer modeling language, a new model will be reformulated each time a black box is opened. A hierarchy of models is then obtained, instead of a hierarchically structured unique model. Anyhow, the basic principles are identical in both cases, although a modular design presents self evident advantages concerning the reduction of the apparent complexity of the model.

Figure 3 sums up the presentation of the two strategies by showing the trajectories followed by an analyst in an hypothetical two dimensions space in either case. It is a highly simplified diagram since, in fact, the level of aggregation and the limit of the system are not each other independant.

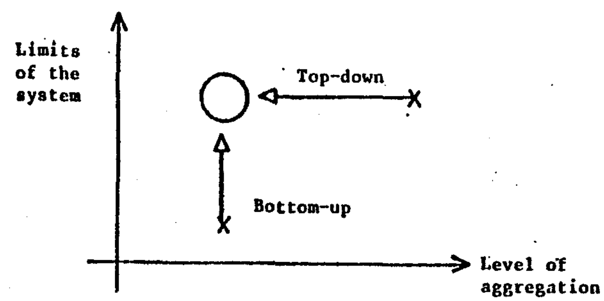


Figure 3.

"Top-down and bottom-up strategies as trajectories in an hypothetical conception space".

Because of its apparent facility, most model makers have decided for a bottom-up strategy, although their procedures are certainly not so schematic it would appear from our description. However, a top-down analysis is much more consistant with the systems approach, since at any level the emphasis is on the interconnections rather than the very details of the phenomena involved. Moreover, the global point of view has a central role from the beginning. On the other hand, the use of a bottom-up strategy supposes that a modeler can study a part without knowledge of its environment. Such an accomplishment is not possible however without the trials and errors which every modeler wants to reduce.

III - EVALUATION OF THE TWO STRATEGIES

This evaluation will be conducted while detailing the various stages of each strategy displayed in Figures 4 and 5.

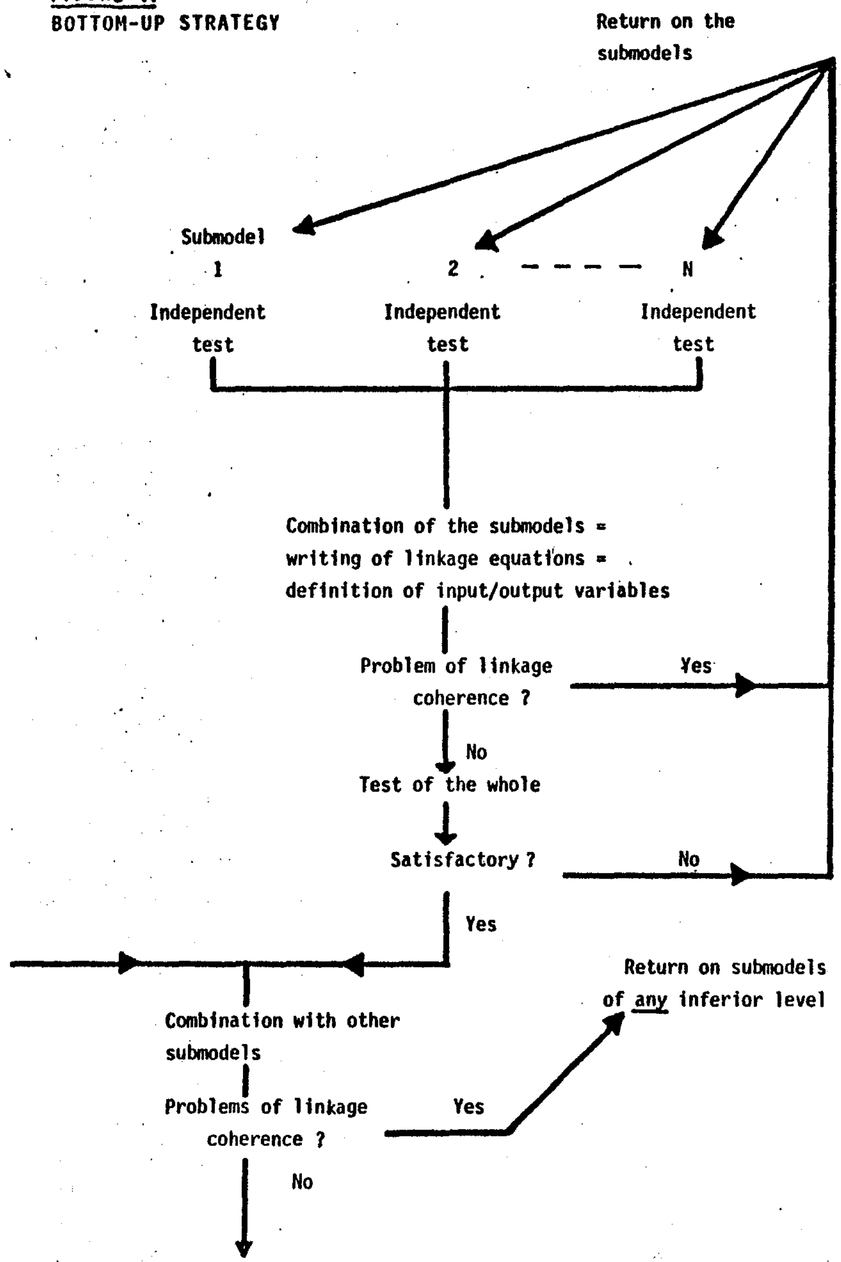
When using a bottom-up scheme, the initial problem is to fix a-priori level of aggregation for each subsystem of the lowest level. This choice may have several motivations. The analyst could want to disaggregate at a given level because, for him, complexity and size of model are synonymous with validity and seriousness. In the case of a demographic submodel for instance, he may decide to take into account eighty age levels and thereby hopes to increase his chances for a realistic model. Another motivation in the choice of level of aggregation may be the availability of corresponding data. The modeler rarely has at his disposal the necessary data without transformation and he could be tempted to fit the structure of his model to the available statistics.

Many other reasons can be involved in aggregation decisions, such as personal knowledge and the available litterature. The only valid rationale of course is really wether or not the level selected will allow to answer the questions raised at the beginning of the study. But it cannot be denied that all the reasons listed above intervene in practice. This intervention is quite unavoidable when the choice must be made without knowledge of the other parts of the model.

Suppose that all the submodels associated to a part of the system under study have been built. This part of the system may have been defined in various way. It may have been delimited according to a well defined discipline : ecology, financial economics, demography and so on. In the case of a big project involving several subgroups, it can be simply the product of overall planning. Then, the following step consists in linking the submodels to get a model of the superior level. The linkage equations define the necessary outputs of each submodel and the inputs to the present global model. Problems of linkage coherence may (and probably will) then appear.

The modeler may recognize that one or more submodel is unable to provide the information some other submodel needs. These findings necessitate a reconsideration of submodels involved and the transformations of structure thus implied can be very important : they can affect both the level of aggregation and the limits of the subsystems. The level of aggregation at

FIGURE 4.
BOTTOM-UP STRATEGY



a given level is indeed heavily dependent on the precedent choices, even after several iterations, unless the modeler decides upon a complete reformulation, as happens quite frequently while using the bottom-up strategy.

In the other hand, the complexity of one or more of submodel may appear useless for the amount of information needed by the other submodels of this level. Although useless complexity does not by itself necessarily requires reformulations and alterations, it can lead to a much bigger model than necessary, with all the well-known consequences for subsequent understandings and applications.

Moreover, errors of formulation may appear much later in the study where they will have much more severe consequences when, for instance, work of several groups has to be joined. To avoid trouble requires a level of intercommunication which in practice is very difficult, if not impossible, to satisfy.

In short, the confrontation between the emerging model and the goals of the project generally occurs too late : many irrevocable choices have been already made. The result will be often a partial failure even if the final report tries to say otherwise.

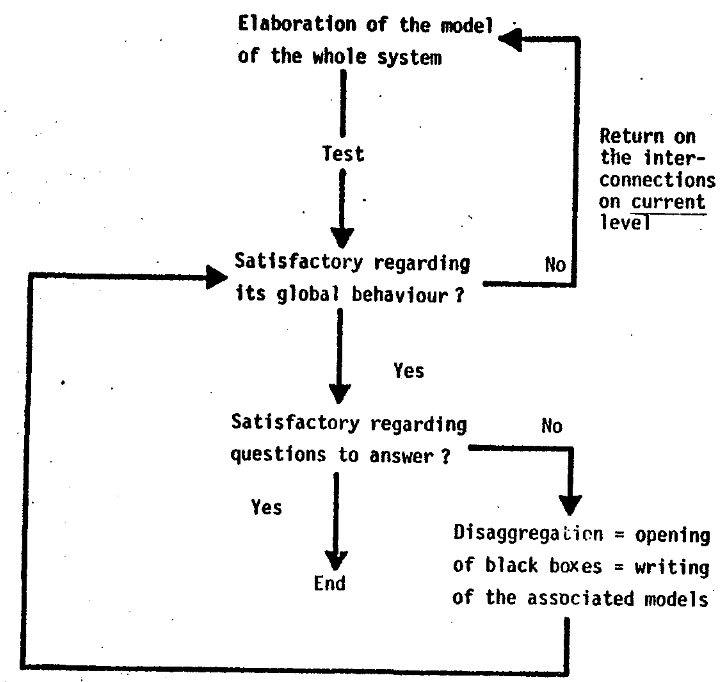
With a top-down strategy, the initial problem is quite the same as with a bottom-up approach. The analyst has to define a level of aggregation, but this time the choice is easier and less decisive. As previously explained, some subsystems are enclosed in black-boxes for which the level of aggregation will be established later. The present choice implies only the interconnections. Since the whole system is under consideration from the beginning, it is much easier to conciliate the level of aggregation with the objectives of the study.

The model can be tested by using time-series to feed the outputs of the submodels, which then are inputs for the present level. However, it is much more efficient to use simple over-aggregated submodels instead, since then feedbacks exist between the inputs and outputs of the boxes, making the test more useful and realistic. °

The black boxes are opened -that is, their associated models are disaggregated- when the dynamics of the whole apparently cannot be correctly represented or the present model does not provide the variables which could answer the questions. In any case, this disaggregation is greatly assisted

FIGURES

TOP-DOWN STRATEGY



by the previous definition of the interconnections, which include the inputs and outputs of each submodel. The analyst has two guidelines at his disposal : the variables which must be used by the submodel, and the variables which must be generated. The minimum level of aggregation is determined in this way, and coherence with already defined parts of the whole model is ensured. The same argument helds when the analyst wishes to take advantage of existing generic submodels or dynamic structures. Strictly speaking, such a practice is a violation of top-down principles. But we are interested in developing guidelines, not rules; so variations have to be accepted. The obvious danger in using generic structures lies in the temptation to force the analysis and the model to fit the features of the structure which, in fact, may have been defined in a totally different context. Such a danger is considerably reduced in a top-down analysis since the context of use of any submodel is defined before the submodel itself.

The process will go down until disaggregation looses further merit. Returns on previous levels will of course take place from time to time when the constraints imposed by a superior level cannot be satisfied. In any cases, they will be very limited in extension and number, because, in opposition to the bottom-up scheme, the analyst does not have to make a priori choices and coherence of the whole is insured at <u>any stage</u> of conception.

Moreover, the complexity thereby obtained is certainly minimal. If the modeler has disaggregated one submodel too far, he goes back too an earlier less disaggregated version.

Finally, top-down analysis and modeling present some more practical advantages concerning documentation and reliability of the project. If a modular approach is conjointly used,the resulting model displays a hierarchical structure as shown in Figure 2. The documentation report can then also follow a top-down procedure while describing the model. The emphasis is put on the overall structure and assumptions of the model. The reader has not to bother with very details if he does not want to or has no time for. Obviously, this reduction of apparent complexity comes also into play during the modeling phase. Unfortunately, no computer modeling language allows for structural description in a suitable way. The software described in the Appendix is a tentative realization in that direction.

The increased reliability of a project is directly related to the way the model is developed. With a top-down strategy, a working model exists at any stage of the study. Communication between modeler and client -if any- is therefore improved. The same with the modeler' morale since the progress in the project is much more apparent. Finally, if accidentally the project budget is cut back or the deadlines cannot be respected, an operational and complete, although simplified, model is nevertheless available.

CONCLUSION

The dop-down strategy and its associated computer language have been applied during the actual development of a urban regional model (4). The project focuses on the dynamics of interurban migrations in response to local employment variations. Although the goals are far from being attained at the present time, a simple model already exists which allows the study of the interurban linkage equations. At that level, each city involved is modeled through elementary equations.

These models will be expanded only when a satisfactory formulation of the current level will be retained.

REFERENCES

1) KARPLUS W.J., NILSEN R.N., 1974 : "Continuous Simulation Languages : A State-of-the-art Survey", Annales de l'AICA, n° 1.

2) RECHENMANN F., 1974 : "A Continuous Simulation Language for Dynamic Space-distributed Models", UNESCO Second International Seminar on Trends in Mathematical Modelling, Jablona, Poland.

3) RECHENMANN F, Sept. 1975 : "Equations Sorting in Multilevel Structurel Models", AICA International Symposium on Simulation Languages for Dynamic Systems, London, England.

4) UVIETTA P., Sept. 1976 : "Migration Dynamics in Urban-Regional Systems : a Multi-level Model". VIIIe Congrès International de Cybernétique, Namur, Belgium.

APPENDIX

The need for an adequate computer language in the context of modular top-down modeling approach has been emphasized in this paper. Such a language* has been defined and implemented. As it has been thoroughly described elsewhere (2,3) and as its functional properties are similar to those of other "continuous simulation" languages, this Appendix will only present its structural properties.

The description of the two modeling strategies has made great use of the term submodel with the meaning of "part". In fact, two main types of submodels can be distinguished which differ due to their interpretation regarding the system.

The aim of geographical partitioning of a model into regions is to allow for spatial disparities. Each composing region is considered an open system in the sense that its frontiers are crossed by material flows, partly controlled by its internal dynamics. The dynamics are described by an associated model. Each region can in turn be divided into subregions so that the resulting structure is a hierarchy, the levels of which are called geographical levels. In the language, the same generic model can be assigned to several distinct regions, with different respective sets of coefficients.

Each model associated with a region consists of sectors. This division has the aim of reducing model complexity and permitting a progressive top-down construction. To each sector, a list of inputs/outputs indicating the logical connections with the other sectors is attached. Within a region, the inputs or outputs of a sector which are not connected to other sectors correspond to interregional relationships.

For example, the following text :

```
Sector S(B; C, F);
       S1(B, E; B, G);
       S2(G; C, I);
       S3(A, D; F, E);
End    S;
```

defines the structure displayed in the lower part of Figure 2. The description of such a sector as S1 may be provided anywhere in the text and can be used

* LADESH : LAngage de DEscription de Systèmes Hiérarchisés

several times as needed, with different sets of parameter and initial values. Each sector description can include declarations and relationships to other sectors. This inclusion facility defines a hierarchical structure which coexists with the geographical hierarchy.

The majority of present day simulation languages offer possibilities of definition and insertion of macros, generally in a recursive manner (1). Nevertheless, macros are not apt to encompass the type of structure described above. First, macro mechanisms are generally hard to handle because of their universality. For instance, parameters, initial values and tabulated functions are associated to different macro calls (expansions) in a particularly inflexible fashion.