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Structure as Behavior:

Exploring Elements of the System Dynamics Modeling Process*

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Abstract: This paper explores the implications of considering the structure of the system as changing over time. Following the tradition of system dynamics and deeply believing that "the structure conditions the behavior," this paper makes the case for the analysis of the dynamics of the structure and its implications. In addition, the questions of what structure is and what behavior is, in system dynamics, are explored.

Keywords: Structure, Behavior, Supra-Structure, and System Dynamics Methodology

* I thank Rogelio Oliva, Mohammad Mojtahedzadeh, Aldo Zagonel, Luis Luna, Vedat Dikert, and my colleagues at the University at Albany for comments and assistance. All opinions and, especially, all errors are mine.

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Base Motivation

The motivation to write this paper was twofold. First, I felt that my understanding of how the structure conditions the behavior of a system was weak and that I needed to strengthen it. By doing so, I started to realize that many of the mechanisms that we use in system dynamics to understand how the structure conditions the behavior are not suited to think about the dynamic nature of the structure itself. Second, I realized that a deeper understanding of the structure of a model did not, necessarily, informed me about the structure and nature of the problem in the system under study. Thus, I began to question how I could learn about problematic situations in complex systems in such a way that I could gain better understandings of them. Not only about the deepness of the structure of a model, but also about alternative 'more realistic' models to represent the reality that I wanted to understand in order to be able to intervene and modify a certain problematic occurrence.

Following the tradition of system dynamics, and deeply believing that "the behavior of a system arises from its structure," (Sterman, 2000, p. 107) this paper makes a case for the analysis of the dynamics of the structure. In addition, the paper is geared towards understanding how to influence conceptual jumps from a '*model 1,'* representing reality, to a '*model 2'* being a better representation of that same reality.

In this paper I develop two major themes. First I explore the rationale of model's change and system's change. Next, I briefly describe what system dynamics is and some of its assumptions to clarify the specific area under study and to be able to put forward some questions. Then, I explore the concepts of structure and behavior in system dynamics as well as the implications that arise when considering the dynamics of the structure. As a final point, the paper ends with a concluding section and ideas about possible future research in this area.

Basic Rationale[2]

Let us suppose that we can represent the structure of the real world and the structure of the model of the real world with two circles “M” and “R”. Let us assume that these representations are accurate and complete. If these two representations adequately represent the structures of both the model and the real system under study, then we can think about some implications.

If we create a model that replicates completely the structure of reality and superimpose the two circles we would see only one because M = R. Therefore, any type of understanding that we could draw from the model we could say applies to the real world. However, a model that has the exact same detail as reality is as complex as reality is, therefore is very difficult to use efficiently (Sterman, 2000, p. 89). Furthermore, we know that there is no model that can replicate the real world exactly, because by definition, all models are simplifications of reality, and all models are wrong (Sterman, 2002, p. 525).

When using the system dynamics method, part of the process of generating understanding about the model, the problem, and the system, is to meticulously test and explore the model to gain as much understanding as possible (Richardson and Pugh, 1981; Sterman, 2000, Ch 3). The model is key to the process and must be subject to many tests, trials, and experiments in order to gain understanding and confidence on the understanding. By focusing on a model, we generate a tacit implication that the structure under study is fixed. Sterman (2002), speaks to the need to focus on the modeling process instead of on the model by saying that “focusing on the process of modeling rather than on the results of any particular model speeds learning and leads to better models.” (p. 521) Additionally, it has been proposed that the boundary of the system—in terms of time horizon—helps identify the relevant structure under study, specifically, the structure that does not change over the time period of enquiry. The underlying assumption used is that the modeler can identify the structure that does not change during the time frame of the modeling process. Unfortunately, perception of the modeler and access to information to evaluate if the structure is not changing is sometimes limited to the modeler. Furthermore, defining the

[2] I would like to acknowledge the invaluable help that I received from Mohammad Mojtahedzadeh in shaping and clarifying the rationale presented here.

system boundary and the degree of aggregation of the model has been identified as two of *the most difficult*[3] steps in successful modeling practice (Sterman, 2000, p. 100).

It seems that, even highly skilled modelers are subject to mistakes in the crucial definition of model boundary. Due to the fact that the models we build are static and have a fixed structure, we might think that the real world we are studying behaves in the same way. However, it might not be the case in every situation.

As said before, it has been argued that it is crucial to focus on the process of modeling instead of on the model itself (Forrester, 1985). In this paper, following and expanding on Forresters's (1985) argument, I argue that modelers, if they can focus on the processes instead of on the model AND if they can acknowledge the dynamic nature of the structure of the real system, will be able to expand the insights generated by system dynamics interventions.

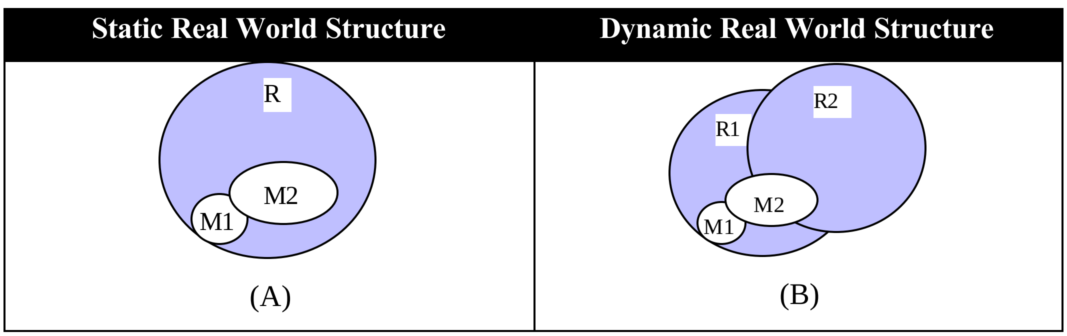

Figure 1—Static versus Dynamic Real World Structure

We have come to know that the iterative nature of the modeling process (Sterman, 2000, pp. 87-88) creates the possibility for different models to arise as products of the process. Figure 1 (A) depicts the possibility of having two models (M1 and M2) that are related to the real world structure (R). Model 2 in this figure; represents a *better* and *expanded* way of looking at the real world structure (R) under study. So far, the process through which a modeler creates the evolutionary change from M1 to M2 is not well understood and/or documented. This process tends to rely mainly in the creativity of the modeler. To date, many of the mechanisms devised to understand the structure of the model better, like eigenvalue analysis

[3] Italics added.

or automated ways like DIGEST (Mojtahedzadeh, 2001), would not take the modeler from M1 to M2. Instead, these mechanisms help the modeler go one layer deeper into the original model or theory about the world. The more sophisticated we become at analyzing a determined structure, the deeper we will be able to go into the same view of the world.

If the real world is changing in its structure over time as depicted in Figure 1(B)—represented by R1 and R2, then gaining deeper understanding of the same theory or worldview might be counter productive and even misleading. As shown in Figure 1(B), a first model (M1) was related to the real world observed at time 1. Then the model evolved to (M2) in an attempt to gain a better and further understanding of the real world in order to intervene and try to change the problematic situation but at the same time the real world structure changed from R1 to R2. Nevertheless, thanks to the evolution of the model from M1 to M2, the model—M2 in this case—still has some relation to the real world. If the modeler had decided to gain a deeper understanding of M1 only, instead of allowing the model to evolve to M2, the model's relation to the real world at R2 would have been lost.

System Dynamics: Some Assumptions, The Modeling Process, and Terminology

System Dynamics was developed in the late 1950's and early 1960's at the Massachusetts Institute of Technology's Sloan School of Management by Jay W. Forrester as he consciously applied control principles to management and economics (Lane and Oliva, 1994, p. 219). System dynamics is a computer-aided approach to policy analysis and design (Richardson, 1996, p. 656). This approach can be applied to dynamic problems arising in complex social, managerial, economic, or ecological systems. In general, any dynamic system characterized by interdependence, mutual interaction, information feedback, and circular causality can be examined using system dynamics (Richardson, 1996). System dynamics concentrates on the circular causality and feedback nature of systems in order to understand their behavior throughout time. The main purpose of system dynamics is to try to discover the 'structure' that conditions the observed behavior of the system over time. System dynamicists try to pose 'dynamic' hypotheses that *endogenously* describe the observed behavior of systems. The 'endogenous' view is critical to system dynamics modeling allowing the existence of feedback rich explanations for certain types of phenomenon. System dynamics is fundamentally interdisciplinary and is grounded in the theory of nonlinear dynamics and feedback control developed in mathematics, physics, and engineering (Sterman, 2000, pp. 4-5).

Since its creation, many people in system dynamics including Jay Forrester (1979, p. 14) have said that "the most important and difficult step in system dynamics is perception of a model structure appropriate to the chosen purpose." One of the questions constantly asked is: how is a model structure determined? Many answers revolve around words such as, art, craft, intuition, expertise, process, style, and science. However, the word 'reality' is hardly heard. According to Forrester (1979, p. 15), "perceiving model structure is akin to the process of invention," and "[perception of model structure] is not easy." Forrester goes on by saying that (p. 15), to him, "it is a trial and error process" where models are formulated, tested, evaluated, discarded, and replaced over time in "a gradual shaping of a unity between the structure of the *real system*[4], the behavior of the real system, the [structure of the] model, the behavior of the model, and the model builder's purpose."

If the modeling process that Forrester describes takes a considerable length of time, then many changes—to the model and to the real world—can occur during the process. The structure of the real system can change, the behavior of the real system can change, the model builder's purpose can change, and the model can be changing. These series of changes can be highly interrelated in the context of a system dynamics intervention. Probably, the changes in the model development will influence understanding that will trigger action that, in turn, will change the structure of the real world before the whole exercise is over (a representation of this idea can be seen in Figure5). The structure of the real system then becomes a moving target that the modeler is trying to capture. Nevertheless, in the system dynamics literature, mentions of the dynamics of the structure are virtually nonexistent. The focus of the modeling process is on understanding the dynamics of the behavior assuming that the structure is fixed (Richardson and Pugh, 1981; Sterman, 2000).

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[4] Italics added

According to Forrester (1979), “a system dynamics model contains policies that generate certain behavioral responses; these policies are constant for the duration of the model simulation” (p. 16). This static view of the structure makes things easier for the modeler, but what about the behavior of the structure of the real world, is that static?

Perceiving the structure of the model may be the most important and difficult step in system dynamics modeling. Thus, it makes sense to try to purposefully learn from the structure and emphasize the differences between learning from the structure and learning from the behavior as separate sources of system understanding and insight. Also, if the structure is so important—among other things is the one that conditions the behavior—it makes sense to try to understand the dynamic nature of the structure once it is perceived. It can be hypothesized that most system dynamics interventions will take place more rapidly than changes in the structure of the system. However, even when that is the case, acknowledging the dynamic nature of the structure can provide additional insights.

Mathematically, the basic structure of a system dynamics model (Richardson, 1996, p. 657) is a system of coupled, nonlinear, first-order differential (or integral) equations that can be written in the form:

$$(1)\quad \frac{dx}{dt} = \dot{x}(t) = f[x(t), u(t)] \text{ ; Given } x(t_0)$$

Where:

$x(t) = n^{th}$ Order vector of system states (or levels)

$u(t) =$ Vector of exogenous inputs

$x(t_0) =$ Initial value for state vector at $t = t_0$

$f(\ ) =$ Nonlinear vector function

$\frac{dx}{dt} = \dot{x}(t) =$ Time derivative of the state vector

The set of equations representing a system dynamics model can always be manipulated into the form shown in equation (1). This can be identified as *the structure of the model*. However, is this what system dynamics is all about? Is system dynamics modeling more than just mathematics?

Understanding the Structure

Structure and Behavior

I had always thought that when we said 'structure' within the system dynamics field, we all thought about the same thing. However, that might not always be the case. To clarify what structure is, what behavior is, and the relationship between the two might be a challenge. Forrester (1968b, p. 406), in his discussion about the nature of system dynamics as a theory of structure, argues that "it may be helpful to distinguish two aspects of a system investigation—that relating to structure, and that relating to dynamic behavior." Then he goes on to say, "The two [structure and behavior] are intimately interwoven because it is the structure which produces the behavior". Following Forrester (1968a; 1968b; 1968c; 1969), I think that if we can understand how to learn from behavior and how to learn from structure we could move ahead in our understanding of how to influence change in complex systems. Possibly a theory of structural evolution will allow us to learn from structures the way that we historically seem to be learning from the evolution of behavior. In a way, when we build a system dynamics model, we create a structure that supports a theory of behavioral evolution. After we create that structure—which is a mental construct—we try to learn the way in which that specific, static and fixed, structure creates the evolution of behavior of the systems that concerns us.

When system dynamicists are trying to claim something about the real world by means of mental constructs, which we adjust to fit our views of the world using our own mental models, are generating behavior conditioned by a predefined structure. This type of behavior is in itself the product of a structure that conditions what we do when we create a simulation model. This behavior is the result of a set of rules—written and unwritten—that shape our actions and understandings about system dynamics modeling and what it is that it can do for us and for the world.

Definitions of Structure

Forrester (1979) argues that an important focus of system dynamics is in the policy domain. He says (p. 2) that "system dynamics focuses on policy and how policy determines behavior." Policy, to Forrester, is the criteria for decision-making: the rules. He says that policy "is the rationale that determines how a stream of decisions will be modulated in response to changing inputs of information." He argues that system dynamics deal with policy and structure and the resulting behavior. Forrester is very clear about the focus on policy because, essentially, the interconnectedness of policy *is* the structure that produces the observed behavior. According to Richardson (2002a), in the system dynamics world, 'structure is an interconnected set of stocks and flows and feedback loops.' System dynamicists like to focus on, and think in terms of, accumulations, causal connections, flows of change in accumulations, and parameters. According to Senge (1990, p. 44), structure, or better said 'systemic structure' is "concerned with the key interrelationships that influence behavior over time, […], interrelationships not between people but among key variables" of the system under study. According to Sterman (2000, p. 107), "the behavior of a system arises from its structure" and "the structure consists of the feedback loops, stocks and flows, and nonlinearities created by the interaction of the physical and institutional structure of the system with the decision-making processes of the agents acting within it." However, we need to be very conscious that other disciplines have specific definitions of 'structure' too. Organizational theorists, and sociologists, among others, also talk about structure.

It is complicated to talk about structure and behavior because these two words can mean different things to different individuals even within the same community. As Richards (1936, p. 27) points out, "words are arbitrary symbols and they have no inherent meaning," they take on the meaning of the context in which a person encounters them. Additionally, the specifics of the context itself are the product of a process of personal or individual interpretation. Context is the key to meaning because words, as they pass from context to context, change meanings. The meaning is not in the words themselves but in people's heads.

When we are using system dynamics to try to understand the world and do something about it, are we changing the structure of the real world? Are we changing the behavior of the real world? Can we change the behavior of the real world without changing the structure of it? If we consider stocks, flows, and parameters as part of the structure, then any change to one would have to be considered a structural change.

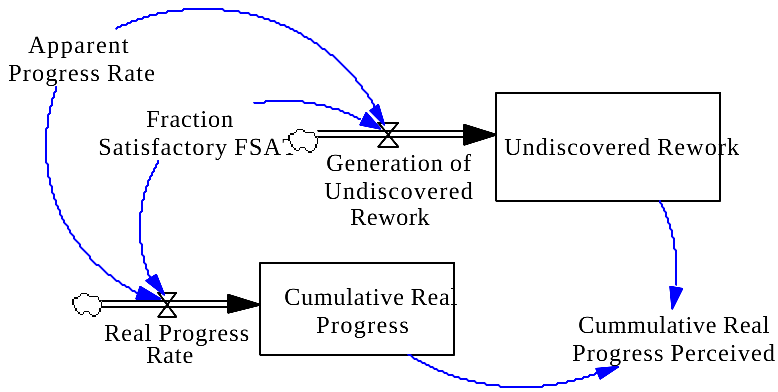


Figure 2—Part of Project Model (adapted from Richardson and Pugh, 1981, p. 199 Figure 4.28)

For example, in the case of a standard project model (Richardson and Pugh, 1981, p. 199), a parameter like *fraction satisfactory FSAT* has an influence both on the level of *cumulative real progress* and *undiscovered rework* (see Figure 2 above). Having a value of 0.5 means something about the accumulation of work and rework. However, fraction satisfactory having a value of one would mean that the whole structure of the model related to undiscovered rework is inactive and turned off. Therefore, changing fraction satisfactory from 0.5 to almost anything but one will not change the structure of the model, while changing it to one will wipe out a whole portion of it. Again, some parametric changes do change the structure yet most do not change it.

Structure and Understanding

Quite commonly, a picture of an iceberg is used to depict the power of systems thinking and system dynamics interventions—see the upper part of Figure 3 that includes events, tendencies, and structure—as described in prose by Senge (1990, p. 52). The lower part of the figure (the additional fuzzy iceberg-like figure below the upper iceberg) is an addition offered by the author. The picture in Figure 3 conveys the idea that event-based explanations to phenomena are very superficial—above the waterline and therefore easily visible—and doom their holders to a reactive stand in the world. Tendencies-based explanations are better in the sense that these are responsive and focused on long-term implications of the phenomena. Structure-based explanations are the most powerful and least common because of the difficulties inherent to this type of explanations.

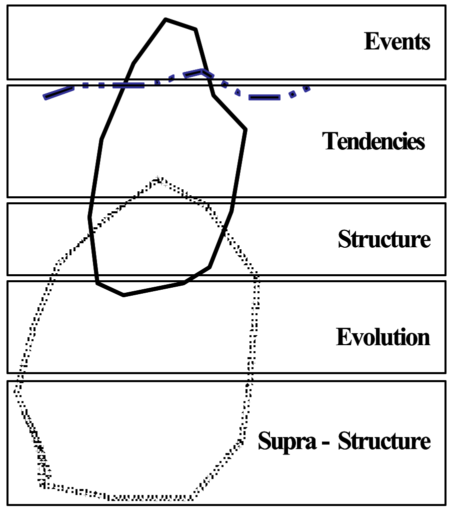


Figure 3—Supra-structure to Events

The structure is hidden and difficult to see making it virtually impossible for laypersons to 'uncover' it. The structure, in order to create generative explanations of the phenomena, needs to be uncovered (Senge, 1990). As Senge (1990) argues, "[though rare] , structural explanations, when they are clear and widely understood, have a considerable impact." (p. 53) The overall idea is that the leverage points for change lie in the structural layer of understanding. Now, let us go deeper into this way of looking at explanatory power. What if the structure is in itself just the tip of another deeper, more burdensome iceberg that has elements that conditions its behavior. Is this behavior what we *perceive* as *structure*? This would be like uncovering a deeper layer of understanding to clarify what it is that conditions the structure, which is conditioning the behavior that we are interested in. Possibly, the structure that we are able to perceive is just a 'snap shot' of the dynamic structure. Just like an event is nothing but a 'snap shot' of the dynamic behavior. The point is, that when we use systems thinking or system dynamics in interventions in the real world, looking at a snap shot of the behavior is not enough. Having a static view of the behavior of the real world is what has kept the solutions for problematic situations in low-leverage mode in the real system. System thinkers and system dynamicists argue that we should try to see the overall picture of the behavior. We should try to have a dynamic view of the behavior in order to have a better opportunity to learn key insights that will help change the world. Even further, we say that we should go beyond dynamic behavior focusing on structural explanations to uncover the causal relationships that are conditioning the observed dynamic behavior. We say that the *true* source of deep learning and change lies in the structure. Only if we are capable to see the structure and learn from it, will we be able to find high leverage points for change and be able to change the world in an efficient, effective, and long-lasting way.

Subsequently, what about if we took the same approach towards the structure itself? What if we try to grasp the deep conditioner of the structure—herein called the supra-structure—and try to learn both the dynamics of the structure and the supra-structure that is conditioning the way the structure appears today? The change in paradigm would be to focus on the structure as the behavior of a deeper structure that is operating in the real world. I know that some fraction of the readers will be thinking that this recursive approach has an infinite number of possible layers to it. That if the structure has a supra-structure that conditions its behavior, then the supra-structure by extension should have a *supra*-supra-structure conditioning its behavior as well. This story could go on and on, down or up, the chain forever. This would be similar to the paradox of Wigner's Friend of quantum physics related to consciousness and parallel universes (for an explanation of the paradox go to Wolf, 1989, pp. 215-225).

It seems to be that, in the system dynamics literature, there are no clear indications that lead us into the clarification of the dynamics of the structure, only the dynamics of the behavior. In discussing impediments to learning and the iterative nature of system dynamics modeling, Sterman (2000, pp. 20, 87-89), depicts the role of a higher-order structure in the process of modeling and learning that can be very well related to the ideas of a dynamic structure.

It might be that not only we have problems understanding complex systems because they are rich in feedback (Sterman, 1994), but we also have problems understanding complex systems because these complex systems are changing their structure while we are trying to understand them using a fixed structure approach.

Misperception of Structure

One interesting consideration with respect to identifying the structure of a system is whether or not we could *get it* wrong. Could we be learning the wrong structure? Could this be what Forrester calls dangerous models? According to Forrester (2001) there are a few very useful models, a lot of unimportant—those that neither help nor cause problems—models, and some dangerous models—those that cause problems when they are used. Forrester says that the world would be better off without these *'wrong'* models. Furthermore, if we get it wrong, what is the effect on behavior? What are the problems that are created by our inability to perceive the correct structure? Is this a problem of perception or capacity? If this is a problem of perception, then we could address it by working on better structure-perceiving mechanisms. However, if this is a problem of fundamental capacity, we would be facing a much more complicated issue. Part of the problem lies in the way you can build capacity in an organization or a field of study. One way to build capacity in the field would be by clarifying the rules of engagement in intervention projects using system dynamics. Clearly, this could create unintended consequences that might be worth exploring in advance. Oliva's (Forthcoming) work on calibration addresses the problem of misperception of structure by treating the 'wrong' structures as alternative hypotheses that we should be able to discard using scientific procedures. Oliva (Forthcoming, p. 2-3) argues that "in testing a DH [dynamic hypothesis] is not enough for the model to match the observed behavior, the behavior generated by the model has to be right for the right reasons."

Understanding Changes in Structure

Structural Evolution

Structural evolution has to do with how structure changes over time. It is related to the different characteristics of the structure of a system at different points in time. The question now is how do you measure changes in structure? What it is that we would be graphing over time? The number of equations? The number of variables (stocks and flows)? The [number of, or characteristics of] dominant loops? Certain indicators of the dominant loops could be used. For example, overall contributions to the behavior using eigenvalue elasticity indexes or the pathway participation metrics developed by Mojtahedzadeh (1996) might be used.

A theory of structural evolution might be geared towards generating insightful system stories (Mojtahedzadeh, 2001) about the way the structure changes. The research interest moves from understanding the behavior derived from a particular structure to changes in this structure over time.

If it is true that structure *is* changing we should be really careful about clarifying which structure is changing. Is the model structure the one that is changing or is the real world structure the one that is changing? Fey (2002), in a recent work related to organizational change, presents the idea of 'pattern feedback control' (PFC). PFC relates desired changes in behavior with changes in structure. He argues that (p. 1) "system dynamics (SD) is intended to solve dynamic problems in existing living systems by achieving improved future time patterns for problematic system variables" and "since the general time patterns of a system's variables are created by the system's feedback control structure operating through time, improved patterns can only be obtained by changing the system's feedback structure in ways that will produce improved future patterns."

> Here the "variable" of interest is not a single time value for a clearly defined entity, but the analyst's perception of the *nonplanar* map of the system's dominant loop geometry that existed during the period when the patterns in the time histories were created. [...] *These unusual feedback entities are necessary because the patterns cause the problems and the loop geometry causes the patterns, so the dynamic problem has to be solved by understanding and then changing the loop geometry.*

The question is: How can you 'optimize' the structure in order to 'optimize' the desired behavior? Traditional optimization algorithms will try to 'optimize' the behavior by finding values of parameters that, within a fixed structure and according to a certain objective function, will generate the closest fit in behavioral patterns (Oliva, Forthcoming). However, these changes are parametric changes and not necessarily structural changes. What could one feed back as *trend* of dominant structure? A numerical profile of the dominant structure perhaps?

The behavior of interest switches from behavior over time to structure over time. Instead of concentrating on calibrating the parameters of the structure to *'optimize'* the generated behavior, now the focus of the effort would be on calibrating the *new* structural behavior to optimize the *final* structure. Possibly, how this works is that you click <*run*> and generate a certain behavior over time for the full time horizon of inquiry, lets say 120 months. Then an automated piece of software identifies the prominent structure for all the variables in the model and creates a pattern for you. However, because we know that the existence of a dominant structure does not imply that other loops are not active, the indicator to be chosen must be treated with caution. Additionally, we have to be aware that changes in parameter values will change the pattern in dominant structure. In order to understand the stability of the pattern we could apply parametric sensitivity analysis to the dominant structure pattern generation. If the dominant structure pattern is sensitive to parameter changes then we could conclude that the dominance is weak or unstable. If the pattern turns out to be not sensitive to parametric changes then the dominance is strong or more stable. Consider the example of the simple system presented in Figure 4. In this simple model there are 8 variables in total—see the equation list in Appendix 1. Out of the eight variables used, four are variables and four are constants (sounds contradictory, right?). The four constants do not vary over time and therefore are not considered for the dominant structure pattern definition.

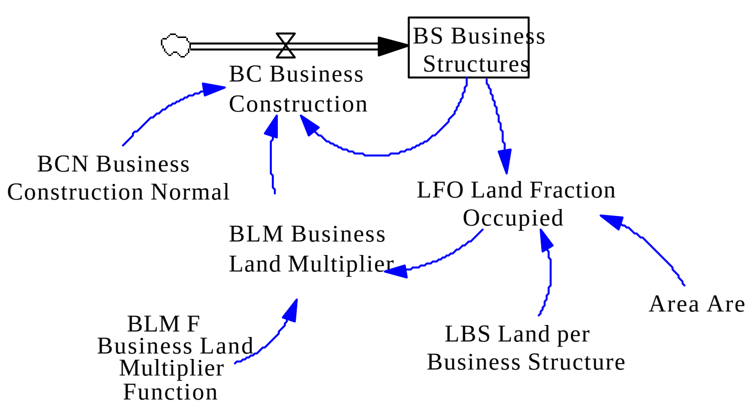
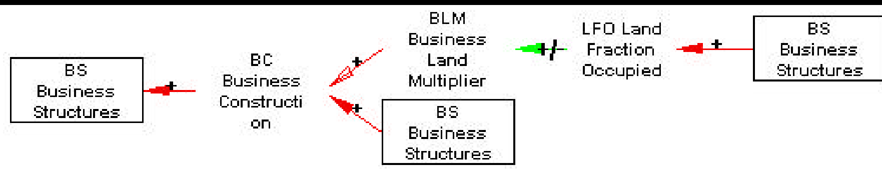


Figure 4—A Simple Model

The prominent-structure analysis of this simple model would include four variables—BC Business Construction, BS Business Structures, LFO Land Fraction Occupied, and BLM Business Land Multiplier. The prominent structure for each variable would be identified over time and recorded—see possible arrangement in Table 2—first with the original set of parameters (U), then with different sets of parameters (U') for the sensitivity analysis.

<table>
<tr><th>Param</th><th>Var</th><th colspan="2">Causal Route / Prominent Structures</th></tr>
<tr><td rowspan="6">Original Set (U)</td><td rowspan="2">Stock BS Business Structures</td><td colspan="2">
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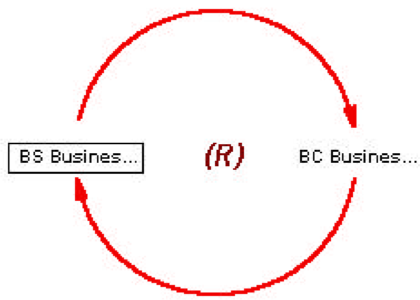
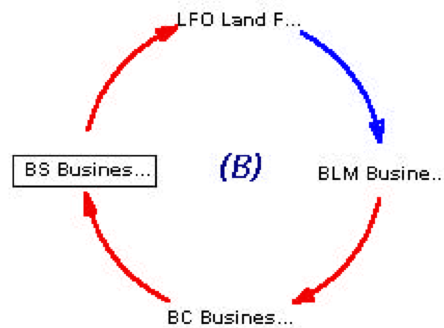
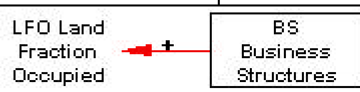
<tr><td>

From t=0.00 to t=10.63</td><td>

From t=10.75 to t=24.00</td></tr>
<tr><td rowspan="2">Aux LFO Land Fraction Occupied</td><td colspan="2">
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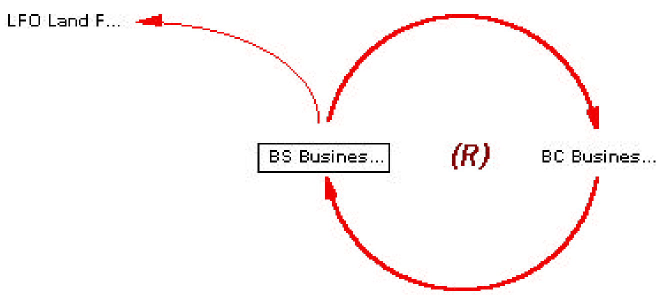
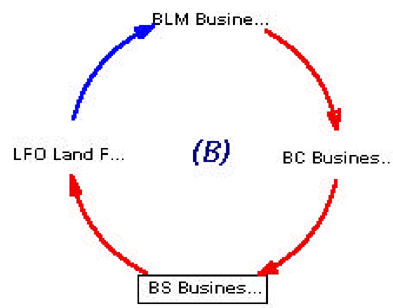
<tr><td>

From t=0.00 to t=10.63</td><td>

From t=10.75 to t=24.00</td></tr>
<tr><td>X</td><td colspan="2">Elements corresponding to Flow BC Business Construction</td></tr>
<tr><td>Y</td><td colspan="2">Elements corresponding to Aux BLM Business Land Multiplier</td></tr>
<tr><td>Alternate Set (U')</td><td></td><td colspan="2"></td></tr>
</table>

Table 2—Prominent Structure Pattern

Then this pattern of dominance is somehow 'feed back' to change the structure in the way that makes more sense to what I want. I do it, or the software does it, and then I have finished iteration 1 of the process. Then one does it again for as many iterations as one wants.

Forrester (1979, p. 16) says that "a system dynamics model contains policies that are constant for the duration of a model simulation" and that "the policies are laws of human behavior, for the circumstances within the system" excluding any possibility of change during the simulation process. Subsequently, being conscious that when you hit the *run* button you have a fixed structure generating the behavior—a snap-shop of the structure. And being conscious that the main concern of the process many times is with hitting run and being able to get a behaviorally deductive artifact to analyze. Maybe, we could try to change the concern from *the run button* to something else. Possibly, the focus of attention of the overall process should be on the mental and social processes that are triggered before and after we hit the *run* button. Actually, hitting the *run* button is just an excuse to activate a learning process about the system, and the model, that allow us to create an intervention that can lead to changes in the real world (see Figure 5).

Influencing the Structure

Figure 5 expands Saeed's (1992) view of the system dynamics modeling process (p. 252) and includes the effects of understanding the structure and the behavior—system conceptualization—on actions that actors make to change the real world. Saeed's (1992) main concern while discussing his view of the system dynamics modeling process is with model creation and the representation of reality, not with how enhanced understanding changes reality. Saeed (1992) stresses two types of processes present in a system dynamics modeling intervention: the structure-validating process and the behavior-validating process. These two processes, according to Saeed, are the mechanisms through which actors fine-tune the models that represent real systems in order to understand better the nature of the problematic behavior identified. The basic mechanism used is the comparison and reconciliation of the model with the perception of the real world. I argue that through those very same processes, actions are triggered that change the very same elements that are trying to be understood and identified. Three more elements are suggested: two actor-centered processes, and an autonomous process.

The *behavior-influencing-processes* loop identifies the way in which actors, as a result of perceiving behavioral cues of reality, generate actions that change behavior. These actions would be of the type that Richardson (2002b) calls parametric changes that do not change the structure. This loop can be related to what Argyris and Schön (1996) call "single-loop learning". Also, the *structure-influencing-processes* loop relates to exactly the same as the behavioral-influencing-processes loop but associated to structural cues of the system instead of behavioral ones. This way of learning about the system and changing the system would be a 'structural' one. This two different processes presented can help us identify two different "single-loop learning" processes: the behavioral single-loop learning and the structural single-loop learning. Even thou this two learning processes would be considered "single-loop" type, the main source of learning would be quite different: behavioral vs. structural.

The *changing-behavior-via-structure* loop, which identifies the path in which actors change the behavior of the system through changes in the structure, is related to what Argyris and Schön (1996) call "double-loop learning". In the representation presented in Figure 5, actors in the system judge perceptions of the behavior and of the structure of the system (against goals or standards) in order to generate actions that can modify the reality perceived. The action will be triggered when the existence of a difference or gap between the perception of the real system and the goal is larger than the tolerance that the actors have to the existence of this gap. The greater the tolerance, the larger the gap must be to actually trigger actions geared towards changing the real system. Theoretically, a 'super-tolerant' actor would never act in response to any gap because no gap would be large enough to be considered reason for action, and a completely 'intolerant' actor would generate a continuous stream of action in response to the smallest perceived difference. Additionally, these perceptions—behavioral and structural—can, and most probably will, be biased and/or mistaken (Levinthal and March, 1993).

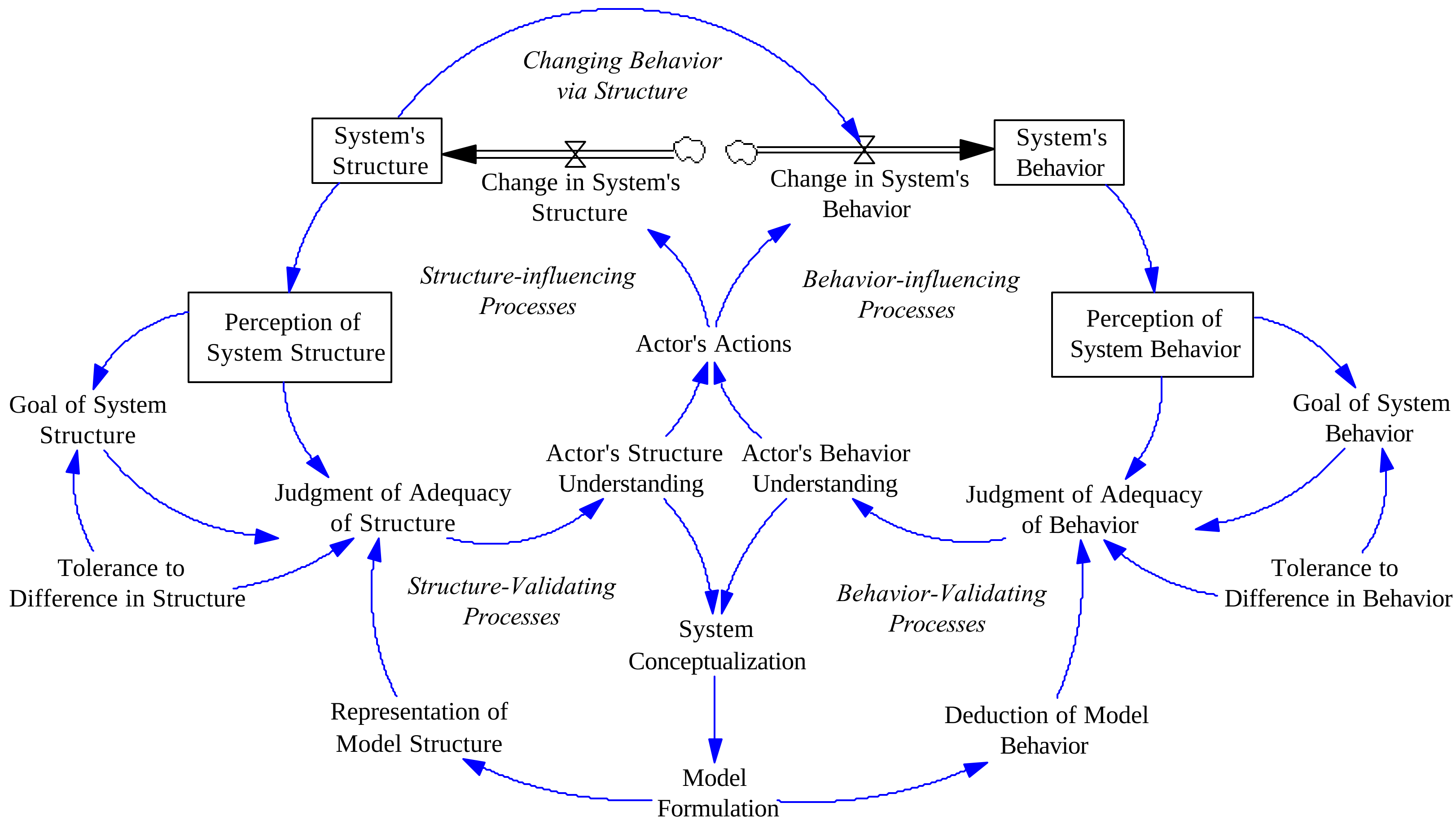


Figure 5—Structure-Behavior

The interpretation of the cues by means of the judgment functions—cognitive structures—of the actors of the system can have important conceptual problems as well (Mumpower, 1991). All of these possible misunderstandings can cause important differences for managers when acting in complex systems (Mumpower and Stewart, 1996) because, in a way, all of those elements are part of the supra-structure that is actively contributing to changes in the structure of interest associated to the problematic behavior under study.

Conclusion and Future Research

One of the basic assumptions of system dynamicists, is that when we hit the <run> button we have, in the model, an 'accurate' representation of the real world that can be considered a deductive mechanism for behavioral evolution analysis. An implicit assumption is that during the time horizon of the model run, or the simulation, the operating norms and physical constraints of the real world will remain constant. However, it could be that the technology would change and the norms would change altering the structure of the real world. If this were the case, the output of the model would not reflect the behavior of the real world unless we were to change the assumptions and relationships of the model for that point in time on.

The task of modelers trying to understand behavior based on the 'right' structure for the 'right' reasons as opposite to the 'wrong' structure or reasons have been identified in the system dynamics literature (see Oliva, Forthcoming, for a detailed explanation). If there are several different structures that can generate the behavior. How would you discriminate among them? As argued in other section of this paper, (Oliva, Forthcoming) addresses this problem by treating the alternative structures as alternative hypotheses that we should be able to discard using scientific procedures. Others, like Richardson (1985), suggests that it does not matter as long as the chosen structure resembles the real world. However, how about if the difference in representations is minor between the 'right' and the 'wrong' representation and, by not identifying it, you generate misleading recommendations? At the end of the day, are system dynamicists trying to understand systems or are they trying to solve problems? Isn't the former a prerequisite of the latter?

All the elements discussed in this paper have led me to think about the importance to find a way to understand them better, through an integrative framework or theory, how reality, perception, tolerance, gaps, goals, action, structure, and behavior, relate to each other in order to create the realities that we know. Richardson and others (1994) have thought really hard about the foundations of mental model research and how these might influence the way system dynamics interventions can change to change the world. This seems important because, as Sterman (2002, p. 527) says, “the real purpose of system dynamics [is]: To create the future we truly desire—not just in the here and now, but globally and for the long term.”

Further research can be done in trying to explore new sources of learning—individual and organizational—by exploring the differences that arise when individuals and organizations learn primarily from behavior or primarily from structure. In addition, it is needed to explore the research methods needed for the analysis of the dynamic nature of the structure: longitudinal studies and specialized mathematics might be needed. Lastly, and most importantly than anything else here presented, it is needed to explore the essential mechanisms to be able to change from M1 to M2—see Figure 1 at the beginning of the paper—both in a fixed world (R1) and a changing world (moving from R1 to R2) in an efficient and systematic way. This change in paradigm is needed to move forward the modeling practice and to be able to add a little more science to the craft of modeling.

Appendix 1—Equations for Simple Model

Number	Equation
1	Area Area=1000 Units: acres
2	BC Business Construction=BS Business Structures*BCN Business Construction Normal*BLM Business Land Multiplier Units: units/year
3	BCN Business Construction Normal=0.07 Units: fraction/year
4	BLM Business Land Multiplier=BLM F Business Land Multiplier Function (LFO Land Fraction Occupied) Units: Dmnl
5	BLM F Business Land Multiplier Function ([(0,0)-(1,1.5)],(0,1),(0.1,1.15),(0.2,1.3),(0.3,1.4),(0.4,1.42105),(0.5,1.36184),(0.6,1.19737),(0.7,0.907895),(0.8,0.539474),(0.9,0.25),(1,0)) Units: Dmnl
6	BS Business Structures= INTEG (BC Business Construction, 1000) Units: units
7	LBS Land per Business Structure=0.2 Units: acres/units
8	LFO Land Fraction Occupied=(BS Business Structures*LBS Land per Business Structure)/Area Area Units: fraction
Control	FINAL TIME = 24 Units: year INITIAL TIME = 0 Units: year SAVEPER = 1Units: year TIME STEP = 0.125Units: year

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