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Metamodeling Aspects of Model Conceptualization

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This paper suggests a technique for improving the conceptual-ization of models. The key aspect of this technique is to set aside the main model for a period of time during the model conceptualization process and focus on building a "watchdog" submodel. The primary purpose of the watchdog submodel is to assure that the main model remains internally consistent during its operation. In the experience of this author, such a submodel can help to identify model conceptualization errors and to determine if a model is sufficiently "robust" to adequately replicate the behavior of the system being modeled.

This is not a research paper. Rather, it is a discussion paper intended to stimulate thought and to encourage dialogue among modelers regarding the challenging task of model conceptualization. The ideas presented herein have not been fully tested by this author through appropriate research; they are merely concepts that appear to have potential within the modeling field.

As a model is being developed, its structure (equations and logic) is constantly being modified by the modeler. However, at any given point during the creation of the model, the structure of the model is essentially fixed or constant. That is, whenever the model is "run" or "iterated" or "solved," the underlying structure does not change.

Typically, after the model is run, the modeler studies the performance of the model and makes changes to the model structure, such as adding equations to define parameters that were previously constant, changing formulas, etc. The model is then rerun with this modified structure. As before, the structure itself remains fixed during the run. This process repeats until the performance of the model is deemed satisfactory.

Some models are considered adaptive1 in the sense that the parameters change during the run according to predetermined rules. These rules, however, are part of the fixed structure of the model and do not change during the run.

Models may also contain logic that substitutes an entirely different equation for a variable depending on what happens during the run. But, again, this logic is predetermined.

The point of this discussion is that, regardless of the complexity of the structure of a model, at some "meta" level, the structure is always fixed during any given run of a model.

One might consider the structure of a model to "evolve" during the model conceptualization process. A metamodeling perspective can help to assure that this evolution proceeds far enough to assure that the structure of a model is able to replicate the dynamic behavior of system being studied. Thus, one use of metamodeling is to help determine when to stop the model conceptualization process.

Creating a model that is able to accurately replicate the observed behavior of a complex system is a significant challenge. What is even more difficult is to conceptualize a model that is sufficiently robust to anticipate the twists and turns of reality without the benefit of hindsight.

One barrier to developing such models may be that modelers operate within specific paradigms when building models. The paradigm may consist of the modeler's specific field or discipline. Is it is possible for the modeler to somehow transcend his/her paradigm? One obvious solution is to use interdisciplinary teams when building models. However, this approach is not always feasible.

Another possible solution is for the modeler to develop a special submodel to serve as a "watchdog" over the main model. This submodel should contain variables functioning as indicators of internal consistency. These variables will be printed when the model is run. In the event of inconsistencies, the modeler will be "flagged" to reexamine the structure of the model. Thus, an important use of metamodeling is to help assure internal consistency of models.

This author has experimented with the use of a watchdog submodel when modeling technological change (Wakeland, 1976). In this case, the main model was developed first. The submodel was then developed, based on an anthropological theory that provided a way to measure both the sociocultural complexity and the technological complexity of a society (Fried, 1976). The theory hypothesizes that unless these two domains have the same degree of complexity, the system will be unstable. This author (who is not trained in anthropology) used his interpretation of the theory to create specific indicator variables that were included in the simulation model and were graphed in addition to the main variables. When the modeler examined the output, the indicator variables were convergent during the first part of the run (indicating internal consistency), but then diverged at a particular point in time. The modeler examined the structure of the main model at that particular point in time and found an error in the equations of the main model. When this error was corrected, the indicator variables no longer diverged. Would the modeler have discovered the error without the use of the indicator variables? Perhaps, but there is no guarantee.

Also, how important is it for a watchdog submodel to be built using theoretical concepts from another discipline? Frequently the modeler may not be aware of appropriate theories from other disciplines on which to base a watchdog submodel. In these cases, would it still be beneficial for the modeler to set aside the main model and focus on the construction of a watchdog submodel, even if no attempt is made to transcend the modeler's paradigm bias during this process?

To attempt to answer this question, consider the following example from the business management field. Most companies have planning models that project monthly sales, profits, cash flow, space, personnel, etc. These models tend to be very detailed and are designed to provide credible numbers for the operating plan for the upcoming fiscal year. It is not unusual, however, for a firm to deploy these same models for strategic planning. In this case, the models may be run five or more years into the future. Since the models were designed for a shorter horizon, the likelihood that internal inconsistencies in the models will manifest incorrect behavior is much greater when such models are run over a longer time frame.

As a simplified example of applying the watchdog submodel concept to the above business model, one might proceed as follows. An indicator of internal consistency within a company might be the ratio of sales to the number of employees. This is a commonly reported statistic and tends to be within a certain range for companies in a particular industry. While this ratio is likely to be implicit within the existing planning models, it probably is not integral to the structure of these models, nor is it likely that it is computed and printed out with the rest of the results.

By printing out sales per employee, the modeler is likely to discover that the results for the first two or three years are fairly reasonable. However, the sales per employee will probably be unreasonable in years four and five. The reason is that the structure of the models typically includes logic to increase direct labor employees (workers) in proportion to projected sales. However, projected indirect employees (support staff) is typically entered into the models via table functions. By monitoring sales per employee, the modeler would be more likely to spot possible discrepancies and make corrections that may have otherwise been overlooked.

As this example illustrates, it is this author's opinion that the creation of a watchdog submodel is a useful process even when the modeler operates within a specific discipline.

Taking the submodel concept a step further, it is possible to make the structure of the main model dependent upon the variables in the watchdog submodel. Essentially, the model would become adaptive in the sense that the structure "monitors itself" and makes corrections in order to bring the system back to a condition of internal consistency. An interesting question is whether these "self-corrections" should be considered structural changes. The corrections occur within the fixed overall structure but not within the structure of the main model. Perhaps the question is strictly academic or merely a matter of semantics.

In many cases, it may be possible to deduce the corrective mechanism(s) from the past behavior of the system. That is, the corrective mechanism has already been observed (perhaps in retrospect) to be used by the system as part of its normal control structure. The corrective mechanism "should" have been designed into the model in the first place. In this case, the watchdog submodel is helping to correct and refine the structure of the main model.

If the system being modeled has not yet experienced a state wherein the corrective mechanism becomes apparent, it may be possible to design the corrective mechanism by analogy to other systems which do manifest such a mechanism. In this case, the watchdog submodel is actually helping to "create" the structure of the model.

If suitable analogies are not apparent, it may be necessary and useful for the modeler to resort to speculation. This could occur if the watchdog submodel predicts an inconsistency in the state of the system at some future point in time. Since the real system has never been in that particular state, nor has any analogous system (at least within the experience of the modeler), the mechanism by which the system would respond to the inconsistency is not known. In this case, the watchdog submodel is forcing the user to speculate and create structure that, in a sense, does not yet exist in the system being modeled.

Perhaps, at some point in the future, if the real system does in fact enter the predicted state of inconsistency, the corrective mechanism may be quite different from that speculated by the modeler. However, assuming the watchdog submodel is properly conceived, the behavioral implications should be the same--to bring the system back into a state of internal consistency.

In conclusion, this paper suggests that during the model conceptualization process, modelers may want to consider setting aside the main model and develop a watchdog submodel to help assure the internal consistency of the model. It is desirable, but not necessary, for the logic of submodel to be based on theoretical concepts from another discipline. In some cases, it may be useful for the submodel to interact with the main model; in other cases, the submodel will merely provide indicator variables for the modeler to observe.

Some of the possible benefits of using a watchdog submodel are: 1) It may help to identify modeling errors, 2) It may assist with the creative process of model conceptualization, and 3)

It may actually force the user to speculate regarding model structure in situations where suitable modeling analogies do not exist.

Although it has not been explored in this paper, another possible contribution of a properly constructed watchdog submodel is in the area of model validation. In addition to being an explicit indicator of validity, a watchdog submodel may also help to significantly increase confidence in the model--both for the modeler and for potential users.

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1The literature on adaptive models deals almost exclusively with adaptive control and optimization (c.f. Chalam, 1987 or Eveleigh, 1967). In adaptive control, the control structure adjusts its control parameters as it receives feedback regarding how the system under control is responding to control signals. In adaptive optimization, the optimization algorithm adjusts its search parameters as it obtains feedback on how well its search strategy is performing. ??

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