Go Back

Towards a Platform-Strategy for System Dynamics Modelling:

Using Generic Structures Hierarchically

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Abstract

The question of aggregation and of system boundaries is a primary concern for all modelling efforts: How deep is the level of detail? How expansive are the boundaries? In System Dynamics we have the powerful concept of generic structures. In the following it is suggested that generic structures offer the possibility to switch between different levels of aggregation and to broaden the boundaries with first pass models. In a first step new subconcepts of generic structures are identified and put into a dependent relationship. Secondly the different concepts are organized in a hierarchical order. And finally an outlook is given how to use them for formal model building.

The aim is to operationalize generic structures for practical use – especially for model construction. Recent work on generic structures has significantly advanced the scientific discussion in this field, redefining and identifying three distinct concepts. The article takes these insights as a starting point. The steps towards an operationalization of generic structures will be illustrated. The paper focuses on methodological considerations.

Key words: generic structures, model components, model aggregation, system boundaries, platform-strategy

Introduction

> "*I believe the system dynamics community places far too little emphasis on developing generic models that each treat a kind of dynamic situation that is to be found in many places*."
> (Forrester, J. W. System-Dynamics-Newsgroup, News No. 2671, March 2000)

Generic Structures belong to the most fundamental and important concepts in System Dynamics. From a theoretical as well as practical point of view their characteristics correspond to central goals of the field of system modelling. Generic structures are generalizations of behavioral insights in complex systems, and can be seen as building blocks of an integrative behavioral theory of social systems. They enable transfer of structure and knowledge about the dynamic behavior of systems. As such they can be of practical use in different situations.

The development of generic structures can be persued all the way through the history of System Dynamics. In qualitative as well as in quantitative modelling they have been used in a large variety of ways, under different definitions, notations and names. This diversity can be seen as a result of their flexibility and as an indicator for their frequent use in modelling and systems thinking. A common taxonomy and understanding are the prerequisites for an operationalization and a more standardized use of generic structures. The latter could yield high internal and external impact for the System Dynamics community, e.g. strengthen the links with other disciplines.

The three main concepts of generic structures

> "*If meaningful generic structures could be isolated and understood, they would form a body of system theory that could be transferred from situation to situation. The property of transferability would lead to enormous gains in intellectual efficiency. The same concepts could be applied over and over again within a discipline and possibly even across disciplines*"
> (Paich, M. 1985)

In recent work, a redefiniton of the concepts of generic structures has been proposed and their application domains as well as validity have been discussed (Lane and Smart 1996; Lane 1998). This research has significantly advanced conceptual clearness and theoretical underpinnings in this area. The resulting definitions serve as a starting point for an operationalization of generic structures for fomal model building and are extended in this paper.

Three main concpets of generic structures can be identified: counter-intuitive system archetypes, abstracted micro-structures and canonical situation models (Figure 1) (Lane and Smart 1996).[1]

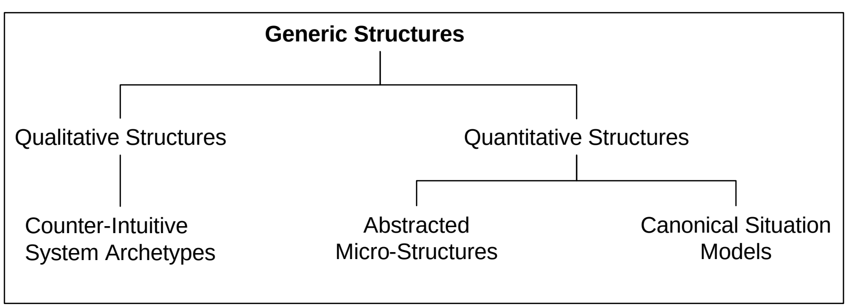

Figure 1: The three main concepts of generic structures

Counter-intuitive system archetypes emerged in the context of qualitative modelling, and were firstly developed by Meadows who described them as "systemic malfunctions" (Meadows 1982). They characterize unexpected, policy-resistant behaviors of complex systems that "recur again and again" (Senge 1990). Counter-intuitive system archetypes are visualized in qualitative maps–causal loop diagrams–and are combined with a systemic story (Andersen and Kim 1998) plus a management principle which encourages the development of systemic thinking.

Canonical situation models and abstracted micro-structures are embedded in the context of quantitative modelling. Canonical situation models–in this paper refered to as "*general models*"–are "case studies reduced to their essentials in order to make more explicit the causal explanations (or theory) of the dynamic behaviours that the structure generates" (Lane 1998). General models are validated and fully specified simulation models that produce different modes of behavior, depending on the parameter settings.

A*bstracted micro-structures* are combinations of stocks, rates and auxiliary variables that are building blocks of larger models; each micro-structure generates a particular mode of behavior (Lane 1998). They comprise structural expressions ranging from elementary structures (Andersen and Richardson 1980, see below) to infrastructures (Richmond et al. 1990, see below). Abstracted micro-structures are considered as theories of dynamic behavior of classes of systems.

Towards an Operationalization: Identifcation of Generic Subconcepts

„*The continuity in transition is the dilemma*
that forbids a clear delimitation"
(Foley, R. 2000–translated by the author)

General models and abstracted micro-structures differ from system archetypes in their definition of structure and thus in their applicability. While the former precisely define the elements of a system and their relations, the latter merely describe chains of causes and effects. System archetypes are restricted to verbal and graphical descriptions of dynamic behavior, infering it from causal loop diagrams. However infering dynamic behavior from caual loop diagrams and loop polarity is a dangerous process (Richmond 1994). Transforming system archetypes in stock-flow diagrams and simulation models in order to deduce their behavoir proves to be problematic too: the resulting model structure is not unequivocal (Dowling et al. 1995). For one system archetype several simulation models with different structures are in principle conceivable. This means that the criteria of homomorphism between model and reality cannot be met. Full validation is thus not possible.

To operationalize generic structures for formal model building we will focus on the concepts of general models and abstracted micro-structures. [2] However the transition between the two concepts seems too rough and unprecise to be of practical use. The gap in the structural size between general models and abstracted micro-structures can be very large: Compare e.g. the structure of the model for urban development classified as a general model (Lane and Smart 1996). It contains 118 equations (constants and initials not included, Forrester 1969). Whereas the structure of the draining process belonging to abstracted microsructures contains only two equations (Richmond et al. 1997). The existence of this gap indicates a missing graduation between the two concepts.

This leap occurs because the notion of abstracted micro-structures contains structural expressions that differ largely in transferability, aggregation, and thus in their dynamic statements. Following its definition, all "simple" structures can be interpreted as abstracted micro-structures, because they are building blocks of complex systems. Therefore

- on one hand abstracted micro-structures include structural types that have an ubiquitous character; compare the example of the draining process. These kinds of structure can be used to describe the vast majority of (organizational) activities “90%–95% of them in our experience” (Richmond 1997).
- on the other hand they contain structures that are domain specific, more disaggregated, and therefore less transferable. Examples are the different types of oscillators (Andersen and Richardson 1980) or structures for business applications, like the process improvement modules from Richmond (1997b).

For practical use however this leap is too big. For a systematization which is the prerequisite of an operationalization more specification is needed.

In the following the concept of abstracted micro-structures is thus further specified.[3] The specification is based on a review of the relevant System Dynamics literature. Studies of general nature in this area are considered, as well as specific collections and catalogs of abstracted micro-structures. The result of the analysis is a division into the following three subconcepts:

1) universal applicable structures
2) multiple applicable structures, and
3) domain specific structures.

The chosen names of the subconcepts reflect the degree of their transferability. In the context of formal model construction generic structures can have two functions: They can be used either as *closed systems*–to display a behavior mode at different levels of aggregation, or as *building blocks*–for constructing models with predefined structures of different size. Building blocks need not necesserily to be closed systems (see Vensim Molecules below). In the following a definition is proposed for each subconcept and examples are given. Figure 2 shows the three subconcepts of abstracted micro-structures.

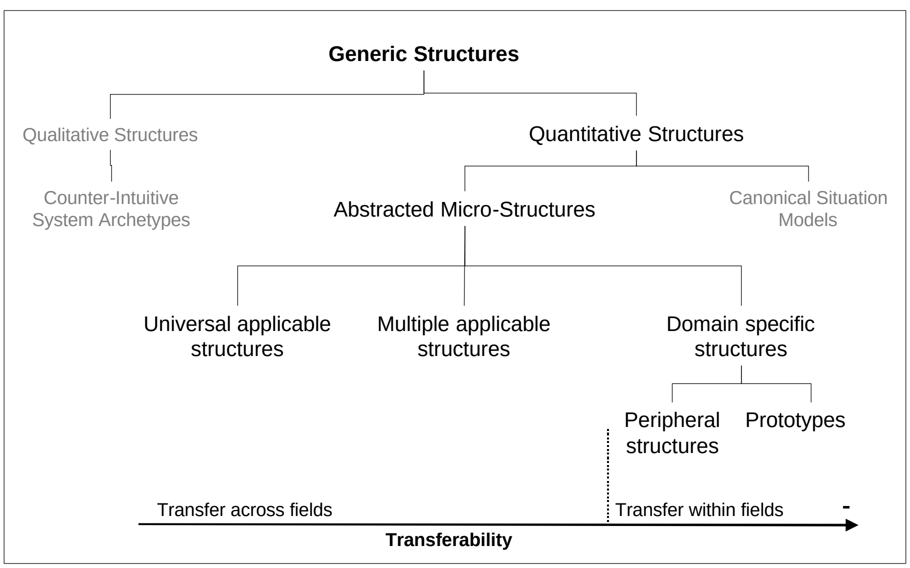

Figure 2: The subconcepts of abstracted micro-structures

Note that a subdivision of generic structures is a function of its purpose. The distinction between the three main concepts–general models, abstracted micro-structures and system archetypes–results from an attempt to understand their evolution and to establish a taxonomy. For this purpose it is adequate and sufficient. In this paper the purpose is formal model building. The criteria for systematization is now transferability, and thus the degree of aggregation. It is important to note that the limits between the concepts–especially between multiple applicable and domain specific structures–is floating.

Universal applicable structures

The first subconcept of abstracted micro-structures is called *universal applicable structures*. This subtype is the simplest form of system structure: 1st order systems as they have firstly been described by Forrester (Forrester 1971; in more detail and with examples Goodman 1974). As building blocks they can be found in all models of social systems. Universal applicable structures represent positiv or negativ feedback loops and generate always one specific behavior mode. They are differentiated in linear and nonlinear 1st order systems (Roberts et al. 1983). The number of principal behavior modes linear 1st order systems can generate is restricted to seven (Milling 1972). Nonlinear single level structures exhibit sigmoid growth, a shift in loop polarity from positiv to negativ (Goodman 1974).

Universal applicable structures can either be used as very highly aggregated system models, or as single chain-links in disaggregated processes. Their ubiquitious character allows e.g. Goodman to focus on 1st order systems in his pedagogical approach to System Dynamcis modelling (Goodman 1974). The concept is universal applicable in the sense that it describes the structure and behavior of the principal activities in systems: producing and draining, resp. growth and decline. Therefore Richmond calls these structures "general flow templates" (Richmond et al. 1997). Their names mark the behavior mode they generate. Despite their very simple character there are some stand-alone applications for this subconcept to be found in the literature (La Roche and Simon 2000).

<u>Example:</u> An example for a universal applicable structure is the "compounding process" (taken from Richmond 1997a), shown in Figure 3. It describes a self-reinforcing process with exponential growth.

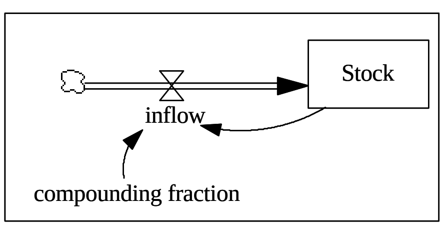

Figure 3: A linear 1st order system: the compounding process

Multiple applicable structures

While 1st order systems and their behavior are intuitive and easy to understand, the second subconcept contains more complicatd expressions of greater complexity. They are called *multiple applicable* because they comprise structures that recur in divers settings and numerous kinds of systems.

Multiple applicable structures result from the process of iterative aggregation and generalization of validated System Dynamics models or model sectors. Deducing generic structures by continuingly simplifying and aggregating complex models has often been advocated in the field: “The inventory-employment interactions in that model [Production-Distribution] are at the core of economic business cycles behavior. The model could be simplified and its generality extended” (Forrester 1980). Andersen and Richardson describe how the process of generalization can be of practical use in education (Andersen and Richardson 1980). The process of identification of these structures works not only formally–via aggregation–but also results from experience, i.e. modelling practice.

Multiple applicable structures are 2nd and higher order systems which normaly generate one typical type of behavior. In contrast to 1st order systems the list of existing multiple applicable structures can never be complete. Well known examples of this subconcept are among others: the co-flow structure, the aging chain, the epidemic structure, structures for different oscillations, the diffusion structure, and the simple inventory control structure. The names of multiple applicable structures are abstract expressions for the systems they represent or (more rarely) behavior modes they generate.

<u>Examples:</u> A simple inventory control structure is depicted in Figure 4 (Pugh and Richardson 1996). It can be found in various micro and macro economic contexts (Compare e.g. Rasmussen 1985 with Sterman 1989).

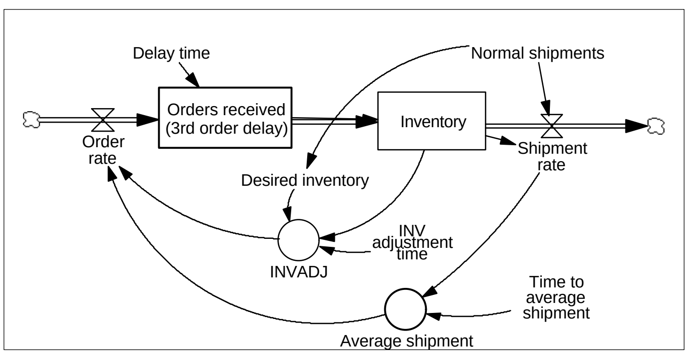

Figure 4: The simple inventory control systems as a multiple applicable structure

Universal and multiple applicable structures differ from the third subconcept of abstracted micro-structures in an important point: their transferability. Following the typologie of Paich they belong to the categorie of structure that enables transfer “across fields” (Paich 1985). Hence these structures can be seen as building blocks of a general behavioral theory of social systems. In this way they contribute to one of the fundamental goals in the field of System Dynamics: generalization of insights from specific cases for use in other systems (Forrester 1958).

Domain specific structures

The third subconcept of abstracted micro-structures can be described as *domain specific*. The structures are typical representations for well-defined domains with a general character. System Dynamics models generally contain one or more of these structures

(Myrtveit 2000), which usually correspond to their sectors. Model descriptions often follow the domain specific structures that are embedded in a particular model, their boundaries being defined by the modeller. The structures can be used as *prototypes* for problem or application domains (e.g the model for innovation and diffusion from Milling and Maier 1996), or as *peripheral* structures in order to add sectors to a model that need not be considered in detail (e.g. some of Richmond`s support infrastructures, see below).

Domain specific structures belong to the categorie of structures that are transferable “within a particular field” (Paich 1985, p. 126). Next to general models they can be interpreted as one possible realization of Forrester`s “models of typical and important social systems” (Forrester 1968). In contrast to universal and multiple applicable structures they are theories for the specific domain and system they represent: “particular applications of industrial dynamics could become theories of behavior of particular systems” (Forrester 1968).

<u>Example:</u> Milling’s model for technological progress in industrial corporations contains five system specific structures: capital sector, production process, workforce sector, market sector, and technological position (Milling 1974). Another example is Lyneis’ model for corporate planning and policy design, which contains several domain specific structures, e.g. an inventory system model for industrial corporations (Lyneis 1980)

Figure 6 shows catalogs of abstracted micro-structures identified in the System Dynamics literature and their integration in the subconcepts defined above.

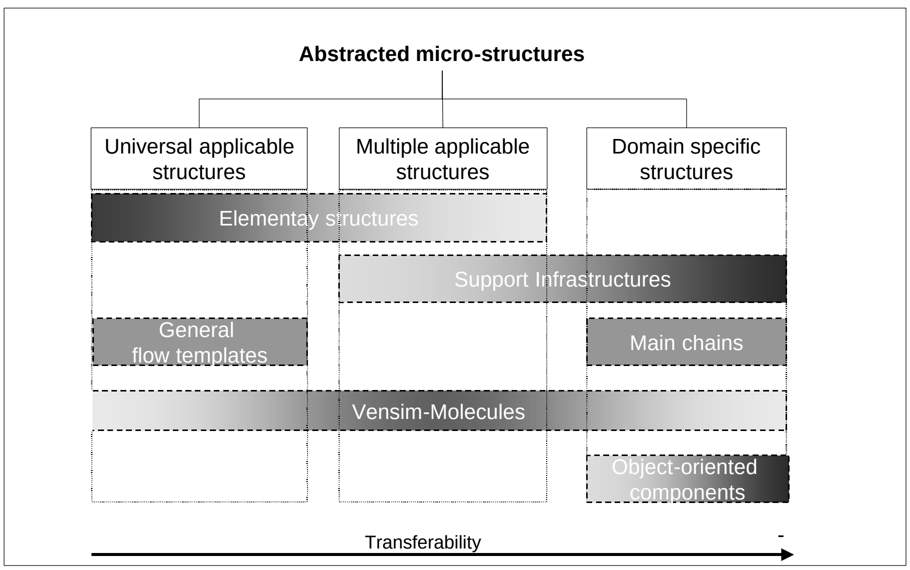

Figure 6: Integration of catalogs of abstracted micro-structures in the subconcepts

The shown catalogs follow different goals and are designed for different applications. Their prior concern lies not in systematization and therefore they are not precisely delimited. The focus of each concept is shaded dark in Figure 6. It seems interesting to note that five of six catalogs originate from simulation software producers (iThink, Vensim, Powersim) and represent relatively recent developments in modelling (1990-2000, except elementary structures).

Elementary structures:

The catalog of elementary structures presented by Andersen and Richardson (1980) ranges from 1st order systems to different oscillators, containing a general model. Elementary structures are part of a pedagogical approach to System Dynamics and conceived as an aid for students to get familiar with basic structures and system behavior: "It may be said, in fact, that the most important single reason for teaching System Dynamics is to communicate reliable intuitions about relationships between feedback structures and dynamic behavior."(Andersen and Richardson 1980).

The catalog is open and can be extended to more complex models that build on existing structures. These are developed step by step beginning with first order positiv and negative fundamental loops. The goal is the creation of personalized catalogs.

General flow templates and Infrastructures:

Richmond distinguishes between general flow templates and infrastructures. All of his structures have an organizational meaning or reference. As described above general flow templates belong to universal applicable structures.[4] They are simple structural statements that represent organizational actions. Richmond differentiates between five templates: compounding process, draining template, producing process, stock adjusting process and co-flowing process.

Infrastructures are higher order systems–up to 10th order (Richmond et al. 1997a). They are organized in function of corporate units. Two categories of higher level infrastructures can be differentiated: Main chain infrastructures and support infrastructures:

- Main chains are representation of processes and considered as nuclei of models. Examples are the Human Resource Main Chain or the Customer Main Chain. The structures have a sequential character and only a few feedback loops. Hence, each one exhibits only one or a limited number of dynamic behavior modes. Their application domain is restricted to process-like structures; therefore their generic character is rather limited.
- Support infrastructures represent activities, soft variables, subsectors, and whole systems. Examples are the Attribute Tracking Infrastructure or the Resource Allocation Infrastructure. They vary in size and transferability. They can perhaps best be interpreted and used as structures to complete a model's peripheral sectors that are not of primary interest.

Molecules:

Molecules are defined as elements of substructure that serve particular purposes. They are commonly used elements of model structure. Being "building blocks from which structure is created" (Hines et al. 1999) they are clearly differentiated from system archetypes which are described as "dynamic lessons". Following the developers of molecules, in System Dynamics most teaching is by example "with no usable taxonomy presented for further learning.” (Hines et al. 1999) Molecules aim providing such a taxonomy. The benefit of using them are among others time and cost savings.

The spectrum of molecules (Version 1.1, Hines 1996) starts with a single level equation and ends with more specialized structures, such as “Aging Chain with PDY” (PDY stands for productivity). It also contains particular mathematical functions, like the “Trend Molecule”. Complex molecules are constructed step by step and contain to some extent parts of other molecules. Not all of them seem to fit in the definition of generic structures. E.g. levels are types of variables, but cannot be classified as generic; the same can be said for most mathematical functions. They are useful components for model construction, but they are not generic in nature.

The majority of the molecules belong to multiple applicable structures. Their denommination and size however render systematization difficult. The names of the molecules describe either the represented structure or function, or the generated behavior.

Object-oriented components:
The creation and use of object-oriented components is a relatively new current in System Dynamics modelling (Myrtveit 2000, Tignor and Myrtveit 2000). It builds on methodological commonalities between System Dynamics and Object-Oriented Modelling. The idea is to combine principles of the object-oriented paradigme with principles of System Dynamics. The result is the modelling of real world objects that can contain other objects (in form of submodels), while preserving the traditional level-rate notation of System Dynamics. Structural components correspond to classes in the object-oriented methodology that can generate multiple instances.

As object-oriented components are a relatively new current in System Dynamics there are no comprehensive catalogs to be found in literature. An explicit goal in this field is the development of catalogs of domain specific structures for particular application domains.

Generic structures as building blocks of complex models

In the following it will be shown how generic structures can be used as building blocks and how they can be organized in a hierarchical order. Hierarchie is a central characteristic of complex systems and a prerequisite for their perception by individuals (Simon 1969). Hierarchical representations enhance interpersonal communication and reusability of models and their components. The conclusions that can be drawn for the modelling of social systems will be discussed.

As building blocks, generic structures help structuring complex systems and constructing the corresponding models. Depending on their level of aggregation system dynamics models are decomposable into the generic components defined above. These are the building blocks of the models and they differ in size, transferability and dynamic behavior. In Figure 7 they are organized hierarchically.

The fundament of the pyramide in Figure 7 is built of levels and rates, the two variable types that are in system dynamics necessary and sufficient to describe social systems (Forrester 1971). They can be seen as the most basic form of building blocks (not belonging to the concepts of generic structures, though): without levels there is no dynamic in a system, rates are the source for change (Richardson and Pugh 1996).

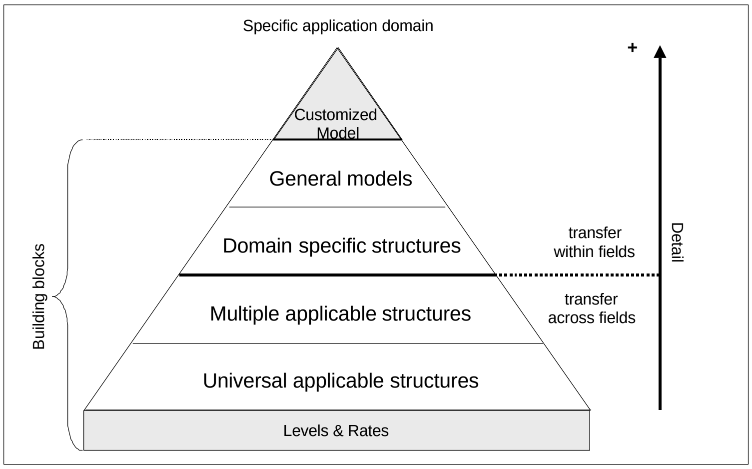

Figure 7: The building blocks of System Dynamics models in a hierarchical

At the lowest level are universal applicable structures followed by multiple applicable and domain specific structures. At the upmost level of generic concepts are general models. They represent the essential structural characteristics of customized models for a specific problem domain. As such they are generalizations of special cases and therefore closest to customized models in the hierarchical perspective. Universal applicable structures have the highest degree of transferability. Figure 7 relates transfer across fields and transfer within fields to the subconcepts. Note again that the boundary between the two as well as between the subconcepts is floating. Transferability decreases from general models to universal applicable structures and is negatively correlated with the structural size of the building blocks.

On top of the pyramide, customized models–the “counterpart” of levels and rates–contain elements, relations and processes of particular situations in specific systems. Adapted to a specific problem they are highly disaggregated and not transferable to other situations or systems. Nevertheless, despite their specification and detail, customized models are built on generic structures being their core components.

This decomposition of models is also applicable to the real-world systems. Depending on the chosen perspective, the generic building blocks from Figure 7 can be identified in real systems. This is no surprise, as models are simplified representations of reality. 1st order systems can be identified in every complex system describing its fundamental activites. They correspond to positiv and negative feedbackloops with one integration that captures the effects of activities over time. Multiple applicable structures also have an ubiquitious character in real-world systems: they appear in various places, under various circumstances. Their chains of cause and effect producing a particular dynamic phenomenon can be found in a large number of systems too, provided that the degree of abstraction is adequately chosen. Concerning the domain specific structures, it seems evident that every complex real-world system contains structures that are characterized by typical and basic elements and structural relations. They are representative for the considered domain, and can be applied in it under different contexts and in different situations.

As already mentioned above, the question which ones of the concepts can be identified in a given model depends on its level of aggregation. In the following we will look at a general model–the model for commodity production cycles from Meadows (Meadows 1970)–that serves as example to illustrate the building block function.

Figure 8 depicts the model for commodity production cycles. Note that the displayed structure is already a general model. Specific cases for particular markets–cattle, hog or chicken markets–are not displayed. Their corresponding customized models build on the shown general model and are slight structural extensions of it (Meadows 1970).

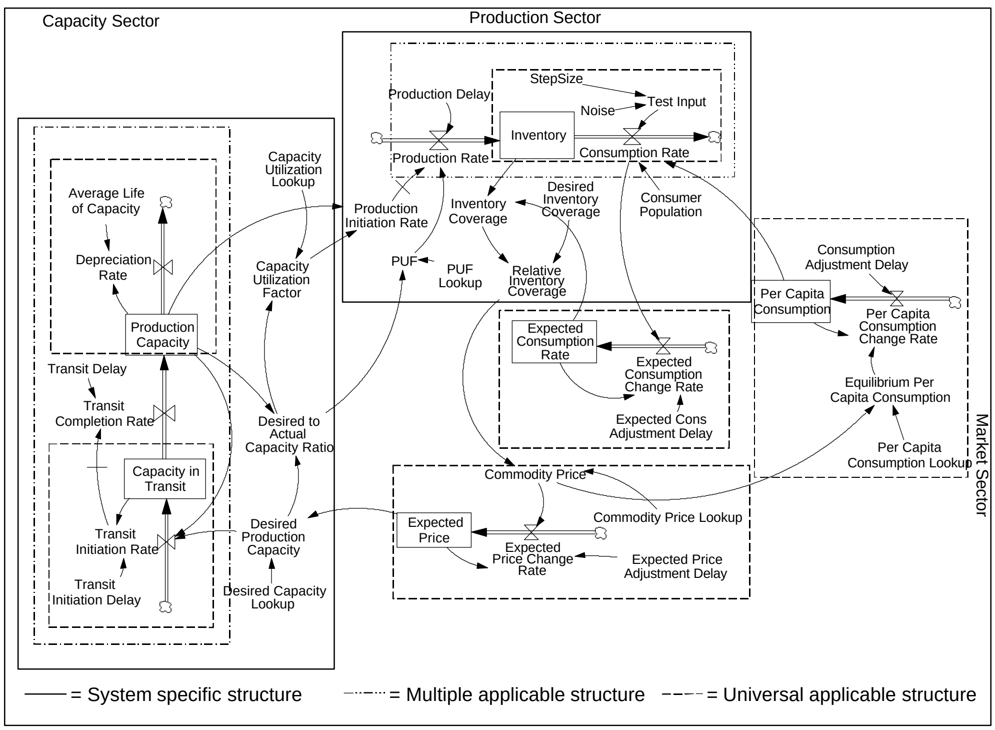

Figure 8: Generic concepts as building blocks of the general model for commodity production cycles[5]

The different generic subconcepts are drawn in Figure 8. Look e.g. at the capacity sector. It contains substructures from universal applicable to domain specific. Universal applicable structures have a hybrid character. They are either highly aggregated representations of systems or small sections of detailed, disaggregated processes. In the capacity sector they are the latter, while in the market sector they are the former. The 1st order systems that are incorporated in the capacity sector are the draining process (production capacity) and the producing process (capacity in transit). The multiple applicable structure in the sector is a simple inventory control system, with a 3rd order delay (transit completion). The domain specific structure displays the elements of the production capacity sector.

The general model contains another domain specific structure. It displays the core structure for the production of commodities. This in turn contains other substructures, analogous to the first domain specific structure. The general model encloses furthermore three 1st order systems that represent consumption per capita, expected consumption, and expected prices respectively.

The example elucidates that the generic components defined above can be identifed in the model and organized into a hierarchy of subordinate and major structures. The subordination is however not strictly similarly directed: 1st order systems can be part of the general model without being part of domain specific or multiple applicable structures–compare e.g. consumption per capita. Figure 9 shows the relations between the generic components.

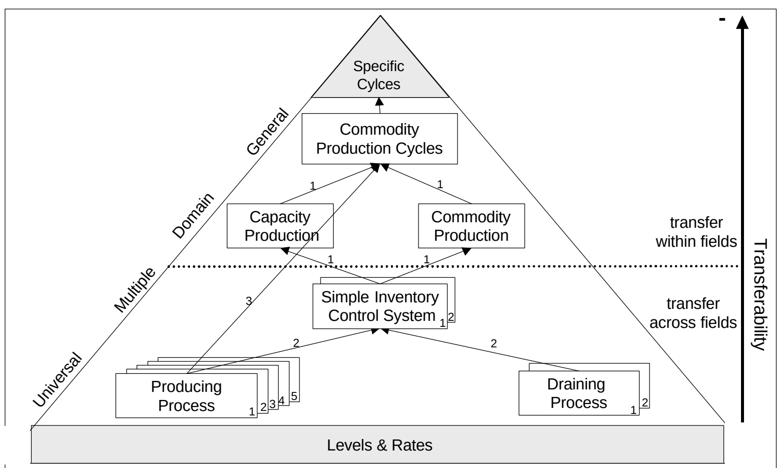

Figure 9: Generic components in the general model for commodity procduction cycles

Hierarchical representation of complex systems

Having looked at generic structures as building blocks we will now use them as closed systems. As such they have to meet the four criteria of structure, which describe the architecture of complex systems: closed boundary, feedback loop, level and rate substructure, and goal-observation-discrepancy-action substructure (Forrester 1971),[6] as depicted in Figure 10.

Generic structures generate their behavior endogenously, enclosing all relevant elements and relations. Their implicit and explicit policies are embedded in feedback loops, the central structural characteristic of systems. Generic structures always enclose level and rate variables: the simplest subconcept (universal applicable structures) being a 1st order system, contains *ex definitione* one integration (level and rate). The decisions are based on the same components as those of complex systems: an observed discrepancy between desired and actual system state leads to an action that alters the system state

(Milling 1984). Hence, generic structures can be treated as autonomous systems. They can be simulated as stand-alone applications.

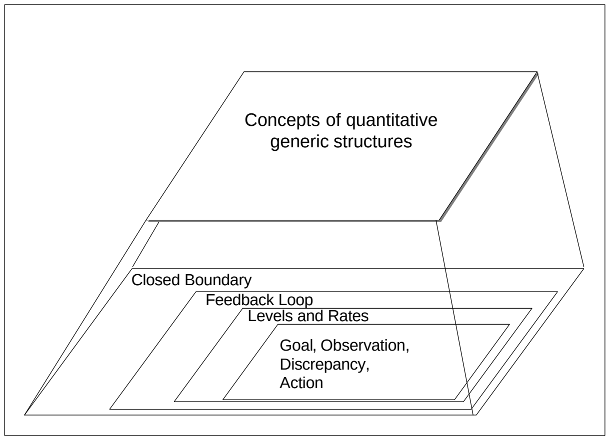

Figure 10: Generic concepts as closed systems

The main benefit of using generic structures as closed systems lies in the dominant loop principle. Not only customized models show the reference mode of interest. Also generic models–that have a much smaller structural size–are able to generate it. The difference is that customized models add detail to the structure and behavior, while generic structures help to see the general nature of the phenomenon under study. Compare e.g. Lyneis who presents a very complex model for the airline industrie. Despite its complexity he states that the heart beat of the model is controlled by a much smaller, basic feedback structure: ”Detail was added to the model...: demand was disaggregated into domestic and international components (different size and operating characteristics of the aircraft) and into major regions (because of significantly different growth potential). Airlines were similarly disaggregated by region... However, the same basic feedback structure underlies the detail.” (Lyneis 2000).[7] A model’s purpose is the determinant for the choice of aggregation. In the case of Lyneis the purpose is forecasting and customer orientation.

In general the structural surplus on top of the fundamental relationships adds accuracy to the model and its behavior. In some cases detail is unrenouncable, e.g. for most consulting work or when a calibrated model is used for forecasting (Lyneis 2000). However the behavior of complex systems composed of a network of interwoven loops is generally based on a limited number of feedback processes over a certain period of time (Milling 1972). The underlying principle that explains this phenomenon is that of the dominant loop (Richardson 1995).

Summing up it may be said that

- generic structures can be classified in several sub types
- generic structures can be organized hierarchically
- generic structures are at the core of all social systems
- generic structures determine the behavior of social systems

As a consequence the structures relevant for the behavior in social systems can be organized hierachically, using the generic concepts. The practical implication of this is straight forward: <u>with the help of generic structures the behavior of a model can be examined at different levels of aggregation.</u>

Figure 11 illustrates this idea. It shows the path of a particular problem behavior along different levels of aggregation. Customized models produce specific behaviors that can be traced "down" to high levels of aggregation and generalization. As we follow the path of the problem behavior one generic structure can always be identified that generates the behavior adequately. This structure is necessary and it is sufficient at the particular level of aggregation. It can serve as a starting point for aggregation or disaggregation. The possibility to move in the two directions helps to encompass differing mental models and can be used e.g. in group model building.

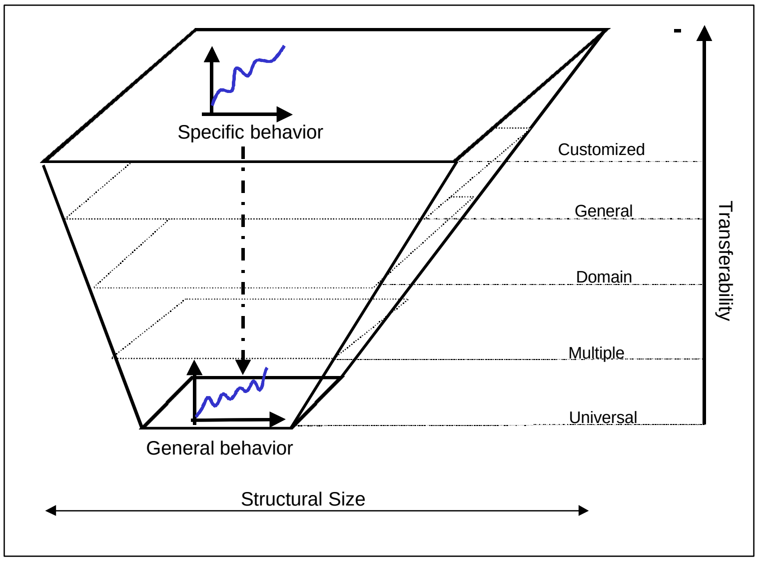

Figure 11: The path of a particular behavior along different levels of aggregation

To which type of generic structure we can "descend" to in Figure 11, in order to generate the problem behavior in its most basic form, depends on the particular case. The general model as nuclei of the customized model and the universal applicable structures are the two extreme points of a continuum in which the process of aggregation/ disaggregation takes place. The degree of abstraction can be succesively modified, variable by variable, going up or down.

A customized model is generally based on one underlying general model which displays all problem and domain relevant elements. On the other end lies the reduction of the customized model to a universal or multiple applicable structure. These represent the system's dominant loops in their most basic and simplified form. The resulting model structures is then transferable across fields.[8] Its behavior has a basic and stilized character.[9] At this level, the resulting model is a very abstract representation of the actual system. Its usefulness depends on the purpose of the model and/or the process of aggregation.[10]

Generic structures for formal model building

„In order to build a large model, I have replaced my computer screen with a larger one. When I drawed a large SD digram on a large screen, I realized that larger eyes and a bigger brain is also necessary. It was certain that something in my way of modelling was wrong, because I cannot update my small eyes and poor brain” (Kim and Jun 1995)

In this section the general framework for the use of generic structures in formal model building will be outlined. The different concepts of generic structure serve as predefined components.

In this paper the focus lies on model building and the applicability of generic structures. The process of identification of adequate components for a given problem, the customization of the resulting model and its validation are important steps in building models with predefined components. These issues are discussed elsewhere: the identification of an adequate component is structure-oriented or behavior-oriented (Liehr 2001), the technical aspects of customization are partly discussed by Myrtveit (2000), and the validation of generic structures is described by Lane (1998).

The question of aggregation and of system boundaries is a primary concern for all modelling efforts: How deep is the level of detail? How expansive are the boundaries? Figure 12 shows the relation between breadth and depth of a model (Milling 1981). The challenge is to capture the essence of the system which generates the behavior of interest. The aim is to provide a plausible explanation and a likely solution for a given problem. The determinant for the model’s intensive and extensive boundaries (Richmond 1997a) is its purpose which is to solve the problem (Sterman 1991). In system dynamics the latter is described by the reference mode.

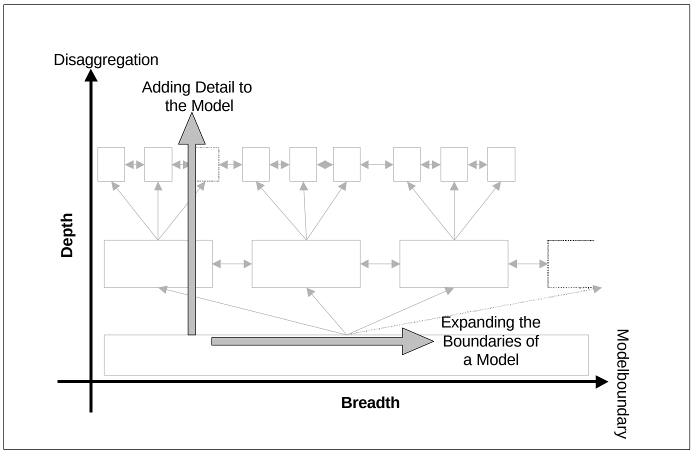

Figure 12: Depth and breadth of a model

Despite a clear purpose and a known reference mode, different individuals would chose different levels of depth and breadth for the same system. This complicates communication and hampers acceptance of the model. Simon discusses some of the reasons for this phenomenon (1969).

The concepts of generic structure discussed above help to switch between different levels of aggregation and to broaden the boundaries with first pass models. This possibility to modify the intensive and extensive boundaries has several practical advantages. It creates a common understanding of the model, it facilitates the building of the model as well as “client” involvement, and improves the reuseablity of the model and its components.

Figure 13 illustrates the use of generic structures in formal model buidling. The basic idea is to work with a given number of predefined models for a specific application domain plus predefined model components based on the three subconcepts of abstracted micro-structures. Models and components can be combined with one another. The predefined models (grey triangle) display the system at various levels of aggregation, as discussed above. They can be simulated and analyzed independently from each other. The predefined models lose breadth with increasing depth. The components serve as building blocks, that allow to add more detail, if necessary (starting at the upper end of the triangle). And they permit a broadening of the boundaries at each level of aggregation of the predefined models.

The three subconcepts as defined above cover a range of structures that offers the possiblity to be more flexibile in formal model building.

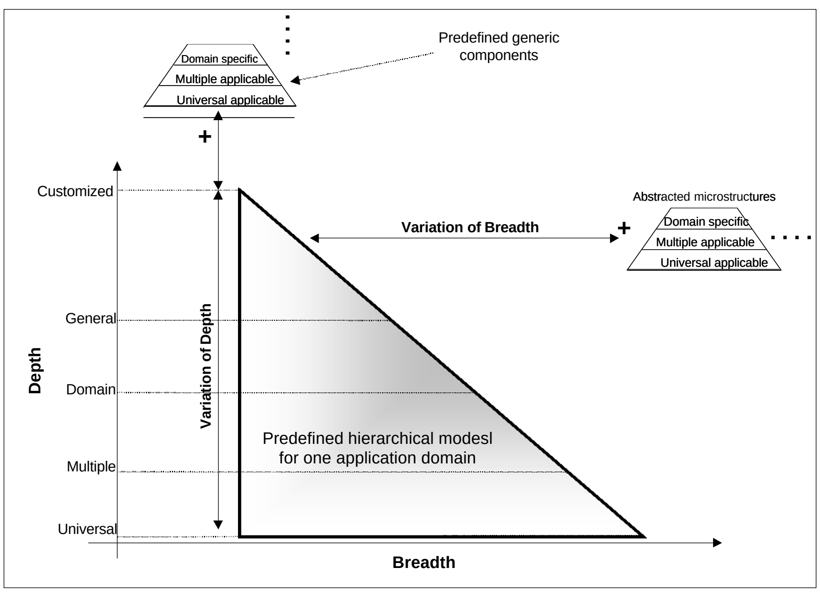

Figure 13: Generic structures as predefined components in formal model building

Conclusion and Outlook

Although far from being a brand new trend in System Dynamics generic structures are still a very fascinating research area that yields theoretical and practical insights and solutions. Generic structures are about transfering knowledge, componenent/model reusability and theory building. With each of these aspects they open the door to other disciplines and to an interdisciplinary perspective or perhaps exchange. In this context it seems particularly interesting to note that generic structures contain characteristics that emerged years later in new concepts of other disciplines (e.g. classes in object-oriented modelling).

In this paper the goal was to operationalize generic structures for formal model building. The subconcepts that have been identified–with the purpose being the criteria for the chosen systematization–, their use as building blocks and as closed systems in a hierarchical order are a step in this direction. The discussed methodological considerations are basic requirements for the development of a platform for System Dynamics models. The latter builds on the concepts of generic structures as defined above and offers a possibility to use standardized components for formal model building.

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Notes

[1] For a detailled description of the history of the concepts of generic structures see Lane and Smart (1996).

[2] One possibility to use system archetypes as simulation models in the phase of model conceptualization is shown by Corben. He develops simulatiom models of basic

archetypes–a meta concept of system archetypes (Corben and Wolstenholme 1993)–and uses them as predefined models (Corben 1994).

[3] General models are fully specified and validated models. Their transferability is restricted to the specific system they represent. A further subdivision in function of their transferability seems not necessary, and not to yield any practical value.

[4] An exception to this is the co-flow structure, that belongs to multiple applicable structures.

[5] Converted from Dynamo to Vensim.

[6] This general architecture of dynamic systems is typically displayed in hierarchical order, too (Größler, A 2000, p. 75.)

[7] Liehr et al. present a model for the same application domain. They show that the core structure can be further simplified to a multiple applicable structure (Liehr, M. et al. 1999).

[8] The reduction to a universal applicable structure is possible when the principle behavior mode of the customized model corresponds to one of the seven modes 1st order systems can generate.

[9] Small models encourage domain understanding and are typically used for theory building (Heij et al. 1997, p. xix). Herein lies an advantage of small over large scale models.

[10] A change in modelling practice in system dynamics towards an inclusion and documentation of different forms of generic structures incorporated in a model and different levels of model aggregation would yield several advantages. One important advantage would be the identification of common underlying structures in divers systems at different levels of aggregation. This would contribute to a strengthening of the field in a practical and a theoretical sense.