Functional and Structural Requirements for Goal-orientated Systems

By

Helmut Nechansky

Nechansky, H. (2008c), Functional and Structural Requirements for Goal-orientated Systems, in Trappl, R. (Ed.), *Cybernetics and Systems 2008*, Proceedings of the 19th EMCSR, Austrian Society for Cybernetic Studies, Vienna, pp 185 - 190, © Dr. Helmut Nechansky

Dr. Helmut Nechansky
Consultant on Systems Engineering
Rotenmuehlgasse 14 / 16
A - 1120 Vienna / Austria
Tel. + 43 / 1 / 817 5863
Email: hn@nechansky.co.at

Functional and Structural Requirements for Goal-orientated Systems

By **Helmut Nechansky**
nechansky - ENGINEERING EFFICIENCY
Rotenmuehlgasse 14 / 16
A-1120 Vienna
Austria
hn@nechansky.co.at

Abstract

The paper starts analyzing the structure of simple feedback systems following in principle the approach of Miller's Living System theory. It is shown how this structure enables making elementary decisions by fulfilling a set of basic physical functional and structural requirements. Then it is illustrated that these requirements are necessary, too, but not sufficient, for the structure of more complex controller systems able to make more complex decisions. Based on that it is proposed that there is a set of basic design rules for the structure of all goal-orientated system that can be revealed by gradually expanding feedback systems.

1. Introduction

In a previous paper we have analyzed in detail the content of elementary decisions made by simple feedback systems [Nechansky, 2006]. Then we applied this approach on a macro level to systematically analyze the possible interactions of two or more goal-orientated systems [Nechansky, 2007], which allowed us to derive insights in the behavioral and developmental options even of social systems [Nechansky, 2008a, 2008b].

Here we want to expand our analysis of decision-making in another direction, i.e. on a micro level, turning to the inside of feedback systems:

(1) We will analyze the structure of a feedback system, following in principle Miller`s idea of subsystems necessary for the functioning of living systems.

(2) We will show the close interrelation between that structure and the ability to make elementary decisions.

(3) From that we will derive some basic physical and structural design rules that enable this elementary decision-making.

Based on that we will briefly show that these design rules apply, too, when we want to make an expansion of a simple feedback system to give a more complex goal-orientated system able to make more complex decisions.

2. Functional Elements for Processing Certain Physical States

For the analysis of the cybernetic structure of goal-orientated systems and their ability for decision-making we define *functional elements* as smallest units of our investigation.

We distinguish functional elements by their input - output relations for processing certain physical states. By *processing* we mean the ability of a functional element to transform certain physical input-side states into certain physical output-side states. This notion we see as equivalent to the notion of data processing.

Here we follow *in principle* Miller's seminal work on living systems. Miller [1978] distinguished 20 subsystems for processing matter, energy and information that are necessary for the functioning of living systems. In this paper we will just deal with Miller's idea of subsystems for processing information. Introducing the notion of *functional elements* for *data* processing we deviate from Miller's notion of subsystems for processing information. Main reasons for that are:

(1) Using our definition of processing we intend to move Miller's [1978] idea of subsystems of living systems closer to the realm of physics.

(2) Because of our more narrow but more precise definition of processing we have to distinguish a larger number of functional elements than Miller's number of subsystems.

(3) For his subsystems processing information Miller [1978, 62] defines processes as dealing with "markers bearing information". Here Miller uses the term information differently from our definition [Nechansky, 2006] which sees information as a *result* of various functions of data processing. And in our understanding the processes of our functional elements, i.e. the input side state changes causing output state changes, just occur

due to their structure. The states involved bear nothing. If there is anything happening because of these changes of states depends on the overall structure of the system and its environment.

So even if our approach is inspired by and closely related to Miller [1978] we decided to use different naming to avoid confusion as far as possible. Yet we propose that our functions and functional elements either correspond to Miller's processes and subsystems or are a lower level detailing and such fit in his overarching approach. We can here just suggest, without detailing it, that our approach will allow to analyze what is going on in such a complex subsystem as Miller's "assoziator".

We will not ask how the abilities of functional elements come about and we will not investigate the necessary internal structure of such functional elements, for these elements have to have different structures depending on the nature of the physical states they process. We will only give some examples for such elements.

3. The Structure of a Feedback System

Now let us analyze the functions and the structure of a simple feedback systems. Control system engineering tells us that we need exactly one of the functional elements listed below but some channels, to give the structure shown in Fig. 1. Let us discuss these functional elements from input to output:

(1) A *sensor* observes actual states of a certain physical nature outside the system and transforms them into certain internal states of *another* physical nature, i.e. into sensor data, as we will call them. (E.g. a sensor may turn temperature into Volt.)

(2) A *decoder* transforms the data delivered from a sensor into states of the *same* physical nature, but of *another* particular form or intensity, i.e. *another* certain data format. (E.g. a decoder may turn Volt into mV).

Decoders bring internal data from different sources into a uniform format, which is necessary to process them mutually.

(3) *Memory* is a functional element for transforming the internal physical states used for data processing into *other* internal physical states with a higher permanence for storage.

For storing and recalling data a memory needs some input and output devices, we do not further specify and consider as a part of the memory structure. The output device has to deliver stored data in the same format as delivered by the decoder, to enable mutual data processing.

In a feedback system the memory has to contain goal-values for a comparison with the incoming sensor data. And furthermore it must contain decision-rules; we will discuss that in point 5 below.

(4) *Comparators* are functional elements with 2 inputs for 2 states or data A and B, making a comparison between these data, determining relationships of order between these data. The result of this comparison is a statement of the general form:

(datum A) relation (datum B).

The possible relations in this statement are elementary relations of order (like $<, \leq, =, \geq, >; \neq; \approx$).

As an output a comparator delivers a certain state or datum representing the result of this comparison.

(5) A *decider* assigns to the results of some data processing (e.g. the results of a data comparison in a comparator) a trigger for an action of an effector (see point 7 below). This assignment can be seen as a switching function. It is made by decision-rules which have in feedback systems the general form:

if {(data) (relation) (goal-value)},
then {trigger for a goal-orientated action}.

For making such decisions these decisions-rules have to be permanently available for the decider. Therefore they have to be *stored* in the system.

(6) A *coder* carries out the reverse function of a decoder at the output side of the system. It has to transform the trigger for an action, as received from the decider, into an unequivocal switching signal to trigger off an action of an effector. As output it delivers a state of the *same* physical nature but of an *another* particular form or intensity.

(7) An *effector* carries out the reverse function of a sensor. It transforms *internal* data into certain *external* states of *another* physical nature.

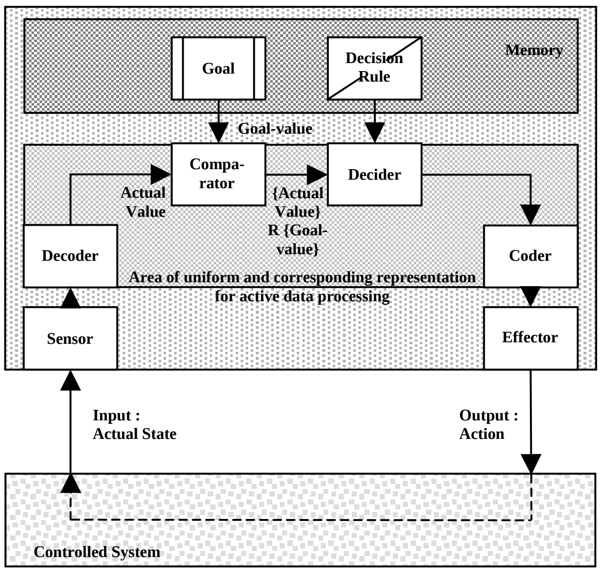

Figure 1: Functional Elements and Structure of a Simple Feedback System (see text for details)

The effector carries out the selected actions. Thus it determines the external behavior of a system. These actions have to change the state of the controlled system towards the goal-value. The sensor of the system has to be able to observe these changes of state, to get new actual data for starting a feedback loop.

(8) *Channels* connect other functional elements. They transport certain physical states, ideally totally unchanged, from input to output. In simple feedback systems their connections have to lead to a structure as shown in figure 1.

These functional elements are sufficient to get to the structure of simple feedback system. We will introduce more functional elements below. And we just want to mention that there may be still others, e.g. like timers.

And we just can mention here, too, that these functional elements will have very different internal structures depending on the nature of physical states they process.

4. Structural Requirements for the Comparison of Data

We have shown elsewhere [Nechansky, 2006] that there are some requirements that have to be maintained by the structure of a regulator so that a comparison of data and goal-values becomes possible and delivers results that can be used for feedback control. We have called them *uniform and corresponding representation*. Here we just want to briefly summarize what we mean by these terms. The requirements of *uniform* representation are:

(1) Sensor data and goal must be available as physical states of the same physical nature, so that they can be processed together and be compared physically.

(2) Sensor data and goal must be available as same physical states mapped in the same way in the same range of magnitude, i.e. in the *same data format*, so that a comparison delivers undistorted results.

There is one requirement for *corresponding* representation for simple feedback systems (The requirements for corresponding representation have to be expanded for more complex systems.):

(3) Sensor data and goal must be a *representation of the same external state* of a controlled system, so that the result of the comparison has a relation to the external world.

Only if these requirements are maintained by a system (1) a comparison of sensor data and goal is physically possible, (2) such comparison will be undistorted and (3) the result of such comparison will have a meaningful relationship with an external controlled system. And only if these requirements are fulfilled the result of a comparison of data will enable a feedback system to decide for goal-orientated actions. Due to this importance of the comparison of appropriate data we even proposed a definition of information [Nechansky, 2006] based on terms of the general form {(data) (relation) (data)}. But all we analyze here is completely independent of such questions of naming.

In Fig. 1 we show the area within a feedback system, where we see uniform and corresponding representation as a necessity for active data processing.

We propose that these requirements of *uniform and corresponding representation* are the general *minimal* requirements that two sets of data are comparable. We will show below that these requirements apply, too, when we expand a feedback system to get to more complex controllers able to make more complex decisions. We will show in forthcoming papers that a few more criteria have to be added to the demand of corresponding representation when dealing with complex systems. We suppose that there is just a small number of requirements for making data comparable and that these are necessary prerequisites for all data processing systems, from simple feedback systems to computers and from the first forms of life to human brains.

5. Minimal Content and Minimal Structure for Decision-making

We found that the content of an elementary decision has the general form [Nechansky, 2006]

if {(data) (relation) (goal-value)},
then {trigger for a goal-orientated action}

Now let us consider this content together with the structure and the functions analyzed above which enable this decisions. Then we find that neither the structure, nor the decisions themselves, can be reduced:

The decisions of a simple feedback system are the result of a processing of certain physical states, i.e. data, which is made possible by its functions and a certain structure. A decision becomes impossible when any part of its content is removed; and it becomes impossible, when a functional element of the structure is removed. To emphasis this point of the total interdependence of content, functions and structure for the ability of decision-making let us discuss briefly, what happens, when we remove a functional element from a feedback system:

(1) If we take away the sensor, the system does not “know” in any form what’s going on outside; it may cause somehow the effector to act, but such acts will not be situation-specific and will only occasionally have a goal-orientated effect.

(2) If there is no appropriate decoding of the sensor data, a comparison of sensor data with the goal will be distorted.

(3) If there are no goals the sensor data cannot be evaluated - then they have neither value nor importance

for the system and are all indistinguishable. Then the system could just react on every input like channel.

(4) No comparator - and the relation between actual situation and goal cannot be determined.

(5) No decider - and no action can be chosen.

(6) No coder - and no appropriate action can be caused.

(7) No effector - and the system cannot act.

Thus a simple feedback system contains the minimal number of functional elements and the minimal structure for decision-making. All these functions and structures have to be available for any decision. And every decision must at least contain the content of an elementary decision-rule of a simple feedback system. These are the requirements that a system can make an elementary situation-specific and goal-orientated decision *by itself*. So the minimal structure of a simple feedback system gets an importance reaching far beyond control theory. So we can say: *To control means to decide*.

Based on that we propose that the minimal structure of a simple feedback system has to be contained as a core in every observing, goal-orientated system that can make situation-specific decisions for goal-orientated actions.

And that means furthermore, wherever a decision is necessary, i.e. wherever a system should be able to cause some particular change of state, we can use a simple feedback system and an elementary decision-rule as the first approximation for the structure and the process able to achieve that. We showed already the applicability and explanative power of this approach for social systems [Nechansky, 2008a, 2008b]. Here we delivered the detailed cybernetic explanation.

6. A Set of Basic Design Rules For Goal-orientated Systems

Our considerations of the structure of a feedback system showed that this is the minimal structure for making an elementary decision. In analyzing this structure we found some necessary functional and structural requirements along a basic logic of data flow from input to output:

(1) Making available observed external states as internal sensor data.

(2) Combinations of functional elements providing all internal data (sensor data, data retrieved from memory like goal-values) as states of the same physical nature in the same data format to make them comparable ("Uniform representation").

(3) Combinations of functional elements making sure that only appropriate data (i.e. representing the same external states) are compared ("Corresponding representation").

(4) Deciding for an action on base of the result of a comparison of data ("Information" as we proposed to define it in Nechansky, [2006]).

(5) Using a decision-rule to trigger an action effecting the observable external state.

We propose that these necessary functional and structural requirements apply for all goal-orientated systems.

This would mean, that a feedback system is not only the minimal structure for making elementary decisions. It is, too, a fundamental structure that allows to derive a basic set of design rules that apply for more complex systems that enable more complex decisions. Furthermore we propose, that this set of design rules will have to be expanded for complex systems, but cannot be reduced.

From this base we can start to investigate the path towards complexity: Since we found the feedback system to contain the minimal structure, more complex decision will obviously require structures with more functional elements. Exploring systematically how adding certain functional elements increases the ability to make more complex decisions will lead ultimately to a complete set of general design rules for goal-orientated systems.

In the following we can just start to show with one example this process of constructing a more complex goal-orientating system. And thereby we will have to apply and expand the set of design rules, i.e. the necessary functional and structural requirements

7. A Step towards Complexity: The Recognition of Change in Time

Let us consider an expanded feedback system, that cannot only just observe a certain external state and react on it, but can recognize, too, recent change in that state and can use that for decisions for actions.

To achieve that we have just to add a few functional elements to a feedback system. Figure 2 shows the resulting structure of a controller system that has additional functional elements to store sensor data $\{S_{t0}\}$ at a time t0 and can compare them with the next incoming data $\{S_{t1}\}$ at the next point in time t1.

The structure follows the structural requirements of uniform and corresponding representation: Both data are available as states of the same physical nature in the same data format and represent the same external state observed by the sensor. So the result of this comparison [(sensor data S_{t1}) (relation) (sensor data S_{t0})] delivers information [Nechansky, 2006] about constancy or change of the sensor data in time. So far we could follow our basic design rules.

When we want to include this information into a decision of the system we face the question how to include it. Here we come to the point of defining complex decisions using more information, i.e. more terms (data) (relation) (data).

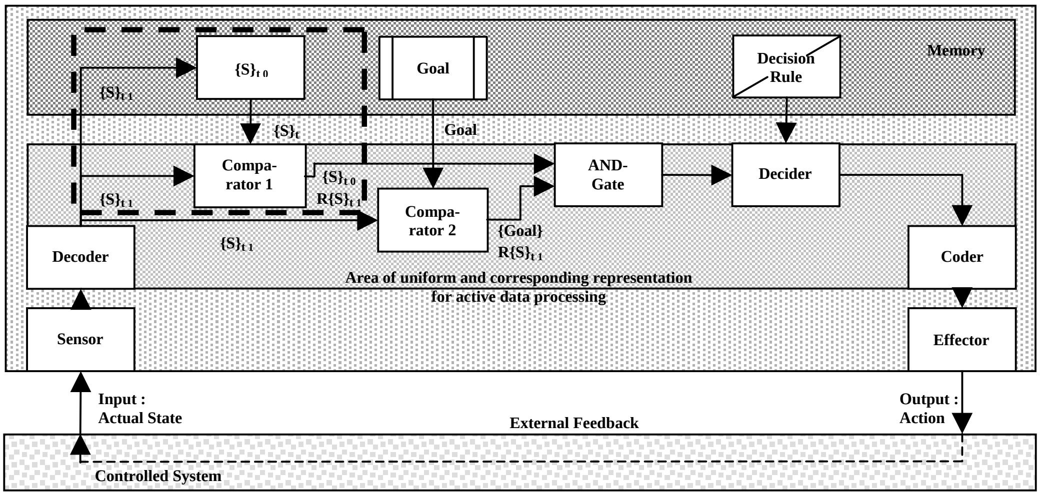

Figure 2: Functional Elements and Structure of a Controller System
with the Ability to Recognize Constancy and Change in Time (see text for details)

To deal with that question we have to introduce new functional elements for logical operations:

These functional elements are usually called *logic gates*.

There are five elements for combining two inputs to deliver one output signal. They differ in the logical operation they carry out, i.e. the operations AND, OR, NAND, NOR respectively XOR And there is one logic gate for inverting the input signal, i.e. the NOT gate. The input - output relations determining their functions can be found in any text on computer engineering [see e.g. Ralston *et al.*, 2000], so we do not repeat them here.

Logic gates have to be added to a structure wherever data shall be combined.

Adding an AND-gate we can get to the structure shown in figure 2 which is probably the most simple structure that can recognize and act on constancy respectively change in time. This structure can e.g. enable decisions of the form:

if {[(sensor data S_{t1}) > (goal-value)]
AND [(sensor data S_{t1}) > (sensor data S_{t0})]},
then {trigger for a goal-orientated action}

So the system can cause an action, if sensor data start changing in the direction off the goal-value. Of course, many other examples for useful decision-rules become possible by this structure.

With that example we illustrated our point, that the basic structural requirements found in feedback systems apply to more complex goal-orientated systems, too. Specifically we had again to provide comparable data ("uniform and corresponding representation") and the results of comparisons ("information") to enable a complex decision.

In the example we found furthermore, even if the design-rules derived from simple feedback are necessary, they are not sufficient for more complex controller systems and complex decision-making.

8. Discussion

With the approach briefly outlined in this paper we followed *in principle* Miller's [1978] seminal work on living systems. But, focussing just on data processing structures, we proposed some steps to modify and expand Miller's approach:

(1) We proposed to start with functional elements as smallest units of our investigation characterized by their input - output relations for processing certain physical states.

(2) We proposed a physical definition of *processing*, meaning the ability to transform certain physical input-side states into certain physical output-side states. This notion we see as equivalent to the notion of data processing.

With that physical definition of processing we intended to move Miller's [1978] idea of different subsystems carrying out different processes closer towards control systems engineering and ground it in physics, giving our functional elements notions directly derivable from natural science.

(3) In addition to Miller's [1978] idea that a living system has to contain one of his subsystems, we started to analyze something Miller has to the best of our knowledge neither explicitly considered nor denied, i.e. that living systems may contain more then one. So we started to investigate *how* more functional elements for data processing may be added to a feedback system.

(4) So we want to add to Miller's idea of *necessary subsystems* the obvious idea that there must be *necessary structures*, too. These are determined by functional and structural requirements, that allow only certain combinations of functional elements which yield working goal-orientated systems - living or technical.

We showed that a basic set of such functional and structural requirements, i.e. design rules, can be derived from feedback systems. And we have illustrated, here just with one example, that these design rules prove to be necessary, but not sufficient for more complex goal-orientated systems.

With this approach we want to modify and expand Miller's [1978] living system theory, yet keep as close as possible to his theory so that it can work as an overarching approach.

Finally we want to outline where we are aiming at with our approach, even if we have to admit that we could present here just a few first steps:

(1) We want to show that feedback systems can have a variety of complicated structures that offer very different cognitive possibilities. So we want to overcome the shortcomings of many approaches to epistemology, that analyzed simple feedback systems and tried to draw conclusions on the working of the brain. Even Powers [1973], who considered 9 hierarchical levels of feedback systems to analyze the functions of the human brain, stuck to closely to this basic structure. So he could not recognize the cognitive abilities that are possible on just one level resulting from an expansion of a feedback system, as we started to illustrate in our example above.

(2) We want to show a way leading from Miller's [1978] living systems theory to the structures of Beer's [1979] viable systems theory, developed to investigate the complex controller structures to manage the production of a company. We suggest that we have collected here the first pieces of a puzzle that allow to derive Beer's controller structures by combining functional elements that are in accordance with Miller's subsystems for processing information.

(3) Finally we see our approach as a starting point and a very small first step towards a *cybernetic theory of the higher level material functional and structural necessities of goal-orientated systems* beyond lower level chemistry and physics.

In physics we find that only certain combinations of particles with certain properties can give stable larger units with new properties (e.g. certain combinations of protons, neutrons and electrons give stable atoms). On a higher level we find the same in chemistry (e.g. only combinations of certain atoms are feasible and give stable molecules).

Considering an even higher hierarchical level of material organization we showed above that we (1) need certain functional elements that must be able - independently of their physical or chemical realization - to carry out particular physical functions. Then we (2) had to combine these functional elements to larger structural units following certain design rules to get to working goal-orientated systems. Finally we showed that (3) to get even more complex goal-orientated systems with increased abilities for control we have to repeatedly apply these design rules and have occasionally to expand them.

We will show in future work that this approach can be carried on to very complex structures, yet needing surprisingly few design rules.

References

[Beer, 1979], Stafford Beer, *The Heart of the Enterprise*, Wiley, Chichster, 1979

[Nechansky, 2006] Helmut Nechansky, Special States in Goal-Orientated and Adaptive Systems: Base for Definition of Information, in Trappl R. (Ed.), *Cybernetics and Systems 2006*, Vienna, 2006, 97 - 102

[Nechansky, 2007] Helmut Nechansky, Elements of a Cybernetic Epistemology: The Four Modes of Coexistence of Goal-orientated Systems, *Kybernetes*, 2007, 36, (2), 157 - 174

[Nechansky, 2008a] Nechansky, Helmut, Elements of a Cybernetic Epistemology: Decisions, Control and Principles of Societal Organization, *Kybernetes*, 2008, 37, (1), 83 - 93

[Nechansky, 2008b] Nechansky, Helmut, The Cybernetics of Social Change - and History, *Kybernetes*, 2008, 37, (2), 265 - 281

[Miller, 1978] James G. Miller, *Living Systems*, McGraw Hill, New York, 1978

[Powers, 1973], W.T. Powers, *Behavior: The Control of Perception*, Aldine de Gruyter, New York, 1973

[Ralston *et al*., 2000], A. Ralston et. al (Ed.), *Encyclopedia of Computer Science*, Nature Publishing Group, London, 2000