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Closing loops: a unified view from control to information science

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Abstract. The paper introduces into a new and systematic view to control loops. The developed Situation-Operator-Meta Modeling approach is used to demonstrate the connections between control loops and algorithms. The paper also details some new distinction criteria.

1. Behind control: the historic view

The application of feedback mechanism to technical systems is one the most important steps improving the dynamics of technical systems and also to realize new technical solutions. The dynamical behavior of technical systems is considered without and with control, conditions are calculated improving vibrational behaviour first of SISO, since the sixties also of MIMO systems. New mathematical approaches are used to examine the structural inner connections between the system itself and also from the input and to the output. In all of these cases physical values on the input and output side are considered as signals equal to functions of time. Mathematical equations (like ODE/PDE or DAE) are ususally used to describe the I/O behaviour. With the same roots, information scientific approaches are developed in the last 60 years. The objects of information science approaches are data in various pure and combined variations, but mainly numbers. The common root is founded by Wiener (6) and others. Inspired by the success of computing machines, Wiener regrets the feedback mechanism and combines this with algorithms realized on computing machines and thoughts about self-organizing and -optimizing systems (like closed-loop systems are self-optimizing systems with respect to the dynamic behaviour of the output). This gives the new scientific community the name used for over 20-30 years: cybernetics. The mathematical core of this new science focused to technical applications based on mathematics: control and control theory. Up to the eighties this area is growing and several new applications demonstrate daily the success of this ideas. The development of computers, the increasing memory capabilities, the processing speed but especially the success in software technologies decouples the development of applied information science from those of control techniques.

2. Behind dynamics and control: the structural view

Control in the sense of classical closed loop control implies the realization of a feedback system, which means the implementation of a fixed connection (with some kind of filters in between) from the output to the input, from a more abstract view, the application of feedback laws (in a mathematical sense) to improve the system dynamics, to ensure system robustness etc.
Looking to systems where the I/O-behaviour is realized by physical, measurable values, the O/I-connection can be realized by filtering the signal (control) in both cases: the SISO and the MIMO case. The graphical illustration of open loop and closed loop systems are well known.

3. Behind algorithms: the structural view

Instead of physical values understand as signals, algorithms are dealing with data, pure numbers or structured sets of data. Algorithms are changing the actual state of present data from the beginning state to the goal state, in practice strongly connected to the process clock or something similar. The algorithm itself realizes the solution of dataprocessing problems, changing data representing information. Therefore classical sequential algorithms are dealing with sequences, selections, and loops. The common aspect is the goal oriented change of data, especially loops (repeat-until or while-do) are strongly connected to control loops, due to the fact, that also a loop is realized, controled by a condition. In contrast to automatic control the continuous changing of data during the acting loop is not usual.

4. The Situation-Operator Meta Modeling (SOM) Technique

Both engineering approaches are dealing with signals, but different ones. Both approaches realize a goal oriented change of these signals by the inner construction, but the goal is implemented by the construction of the approach itself. In the view of the introduced SOM-modeling technique, the classical control approach appears as a subset of algorithms, the algorithms as the extension of control approaches.

Core of the approach is the assumption that changes inside the considered part of the real world (RW) (¿ system) are understand as a sequence of scenes and actions. The idea of the separation of hold and change is not new, it is part of the algorithm calculus of Leibniz and actually used in artificial intelligence (1,2).

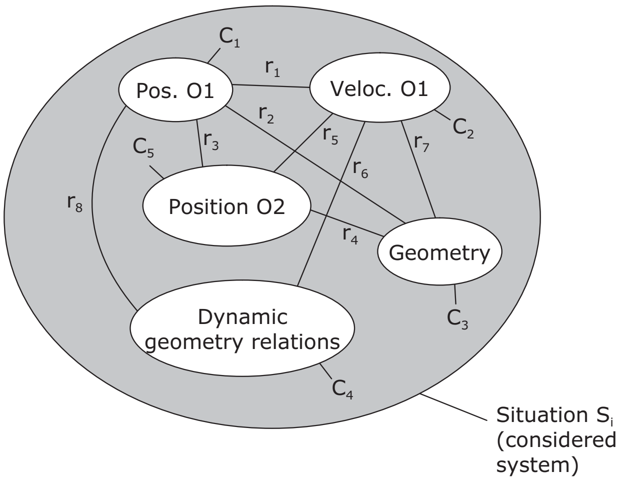

Figure 1: Structure of the proposed item situation S (example)

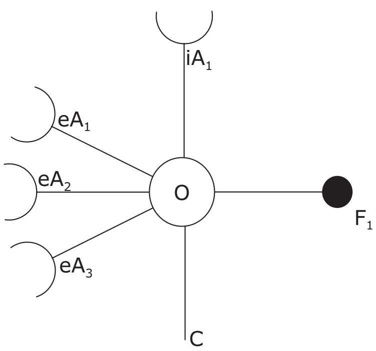

Figure 2: Structure of the proposed item operator O

In (5) a modified model is introduced, which the modeling of human knowledge-based interaction behavior to observable changes within the Human-Machine-Interaction. The term situation is used for modeling the describable part of the scenes. In this way, the term situation, is used to describe the inner relations (the structure) of a system or problem. The term operator is used for modeling actions changing scenes modeled by situations.

The situation S consists of characteristics C and relations R. The characteristics are linguistic terms describing important facts (as qualities). This includes physical and informational values. The introduced item characteristic (C) includes the possibility of time-dependent parameters P. The relation R (of Cs) fixes the structure of the considered scene of the world modeled as situation S. The introduced situation concept allows the integration of different types of engineering-like descriptions. Therefore the inner relation R has to be detailed by quantitative modeling approaches.

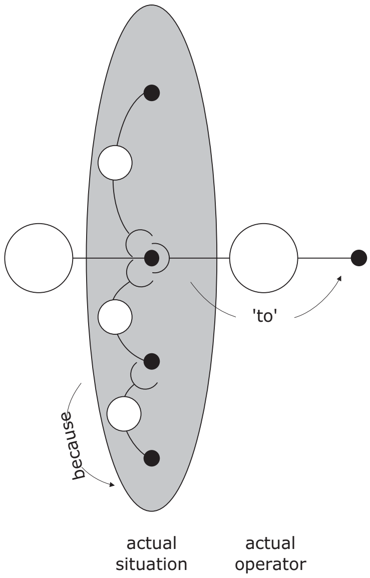

Figure 3: Connection between situation and operator

A graphical illustration of the structure of a situation is given with figure 1. The operator O (cf. figure 2) is understand and modeled from a functional point of view: the operator is an information-theoretic construct which is defined by his function F (as the output) and assumptions. Here explicit and implicit assumptions eA, iA are distinguished. F can only be realized if the explicit assumptions eA are fulfilled. The iA includes the constraints between the eA and F of the operator. The eA are of the same quality as the characteristics C of S. For the internal structure of the operator other descriptions like textual, logical, mathematical or other problem-related descriptions are possible.
Operators are used to model the change from situation to situation as discrete events (called action-discrete). Operators and situations are strongly connected due to the identity of the characteristics of the situations and the explicit assumptions of the operators. This includes that the situation also consists of 'passive' operators (internal causal relation: 'because'), whereby the change is modeled by 'active' operators (external causal relation: 'to'), illustrated with figure. 3. The change of the world results as a sequence of single actions modeled by operators, illustrated in figure 4.
Please note that the operators correspond to situations. Both are not only used for structural organization of the (outerside) world of the system, but also for internal representation and storage in the related area of HMI-modeling (5). In this contribution the SOM-model is used in a more general way.

5. Classical closed-loop control and algorithms from the SOM-view

In (5) a system-theoretic hierarchy of different feedback mechanism is introduced, repeated briefly and detailed in (4). Here the results are very briefly repeated. Feedback control is understand 'as the operation that, in the presence of disturbances, tends to reduce the difference between the output of the system and some reference input and that does so on the basis of this difference' (3). The influence / effect of the values to be controlled to the input values is realized by the controller. So the main characteristics of automatic control are

- the closed loop by feeding back values to be controlled to the input and
- the automatic response realizing a loop.

The design and application of classical controllers gives

- fix strategies / rules /relations / or just a set of gains as control coefficients, which connect the output of the system with the input of the system and
- an system extension to optimize the system behavior.

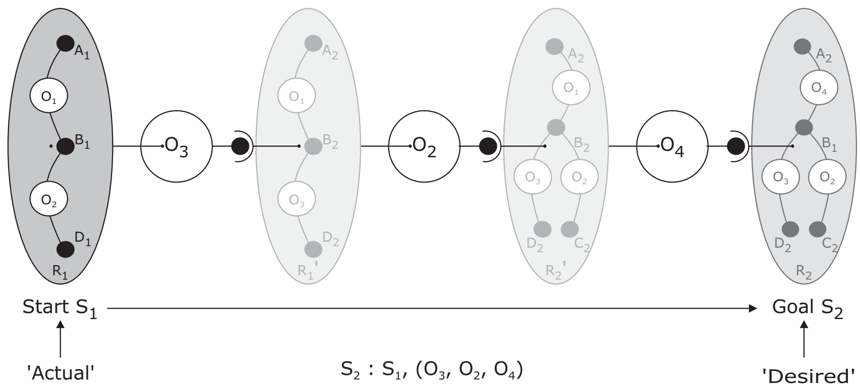

Figure 4: Sequence of operators changing the situations from the actual situation to the desired goal

Based on the SOM-structured view, a new and more general view of automatic control is firstly introduced in (5).

SOM-based definition:
Automatic control defines an autonomous change from actual to desired situations, whereby the inner structure or the modification of the inner structure of the considered and through the situation-space described system can be used (5).
The proposed definition includes the old one of classical control, solves the problem of integrating algorithms / soft-computing algorithms, includes the interaction of Intelligent Systems (4), and - much more important - gives the view to new applications due to the introduced homogeneous and uniform approach.
Please note that the definition is independent from any kind of realizations or implementation details. It uses only the structural connections introduced with the terms system, situation and operator.

Example: SOM-view to classical control
A controlled continuous system, where the input (B) - output (A) behavior can be described using an ordinary differential equation, appears in the SOM-structured context as a fix situation. The connections are as follows:

Characteristic C_i:	A:	(Scalar) system output with time variant values
	B:	(Scalar) system input with time variant values
	C:	(Scalar) reference value
Relation R_i:	r_1: ODE (B input, A output)	
	r_2: Controller rule (A, C) inputs, B output)	
Operator:	No operator exists, due to the fixed control law structure, this includes that nothing more will be changed by the controller	

The characteristics (here physical values) are modeled with scalar parametes, represented by numbers, the parameters of A, B, C are time variant, the inner relations r_i are fixed, the implementation of control connects two situations (without and with control), after the implementation of the control structure there is - from a SOM-theoretic point of view - only the fixed situation including the closed loop (as a closed chain of relations). This includes a fixed situation space, only depending on the dynamic behavior determined by the system behavior (described by r_i) and the input, which can not be changed by this type of control.

Example: SOM-view to algorithms
An algorithm appears as a fixed sequence of situations, which may depend on external values. The algorithm steps directly correspond to operators. The complete algorithm is fixed before his execution.

Characteristic C_i:	Data of the algorithm
Relation R_i:	Internal connections between C_i, given by the problem modeling implemented in data-objects
Operator O_i:	Execution procedures change the objects of the algorithm: the data; the sequence of operators is defined before the operation itself, the situation space is previously defined.

A program organizes the changing of objects of the algorithm: the data. The integrated feedback mechanism is not necessarily numerically defined, furthermore also logical comparisons are possible (repeat-until, while-do, for-do - algorithms). Especially the dynamic sequences represent a higher quality of feedback, not only restricted to the comparison of (mostly scalar) numerical values and variables as classical control.
Without external effects (like inputs) no really feedback behavior appears. With external effects (external given parameters, decisions etc.) algorithms also control the change and the flow of data, goal-oriented depending on different inputs. The reachable situation space is defined in advance, which includes that algorithms are not completely autonomously working in general sense.
In (4) some criteria to distinguish different control and interaction mechanisms are declared, which will be very briefly repeated here:

- Quality of the closing feedback and reference
- Connection between control criteria and control goal
- Time behavior during control
- Variability of control (law)
- Anticipation of the situation trajectory

The connection between the classical control approach and the SOM view to system interactions is graphical given in figure 5.

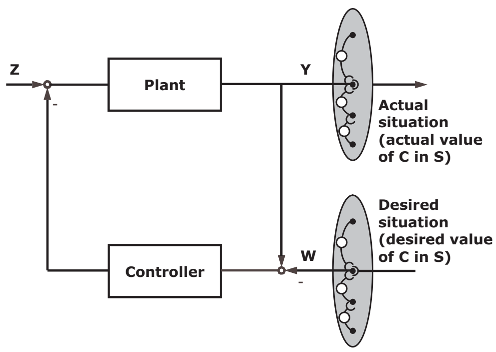

Figure 5: Structure of closed loop and SOM-description of situation

In this case the situation description S is not modified by the controllers work, only the numerical value of the describing characteristic C is changed due to interaction between plant and controller. So classical control appears as a reduced subset of a general interaction mechanism for the case of

- situation describing characteristics as physical scalar values,
- situation describing inner relations are fixed (the controller does not change the problem, it just change the time behavior of characteristics)

6. Detailing the hierarchy of control or interaction mechanism

The new idea behind the unified view to control and interaction is mainly based on the ideas:

- The values to be controlled/changed can also be data or sets of data in general including the scalar case with numerical values.
- The rule used for feedback can be changed. In the case of classical control fixed rules are used, modern control uses time-variant control laws or nonlinear control approaches using highly complex models of the system to be controled. Here the feedback law can be changed during the interaction, the change depends not only on a mathematical model of the system but on the situation resp. the possible varying desired goal situation.

Such kind of understanding of interaction gives a unified view of interaction including different kind of control and formalized interaction approaches. From this unifying SOM-metamodeling view all design degrees for interaction are available. Known approaches can be easily integrated by cutting properties.

	Character of the control design	Character of the control law
Open loop	reactive	reactive
Classical control law	simple, fixed realisation (not goal designed)	fixed rule
Adaptive controller	goal oriented with fixed behaviour	adaptive rules (variabel)
Optimal control	principal oriented with fixed behaviour	fixed or variabel rules
Algorithm	principal oriented with variable behaviour using a fixed setting	variable rules depending on parameters within a fixed setting
Human behavior	principal oriented with with variable behaviour with variable settings	variable rules with fixed setting - variable Rrules with variable setting

Figure. 6: Control design principle and rules in the hierarchy of interaction

Figure 6 gives several interaction scheme and denotes the difference between the character of the control design and the character of the control law. Figure 7 details the same aspects from another view, it connects control rules of the interaction on the one hand side with the goal-oriented character of systems design.

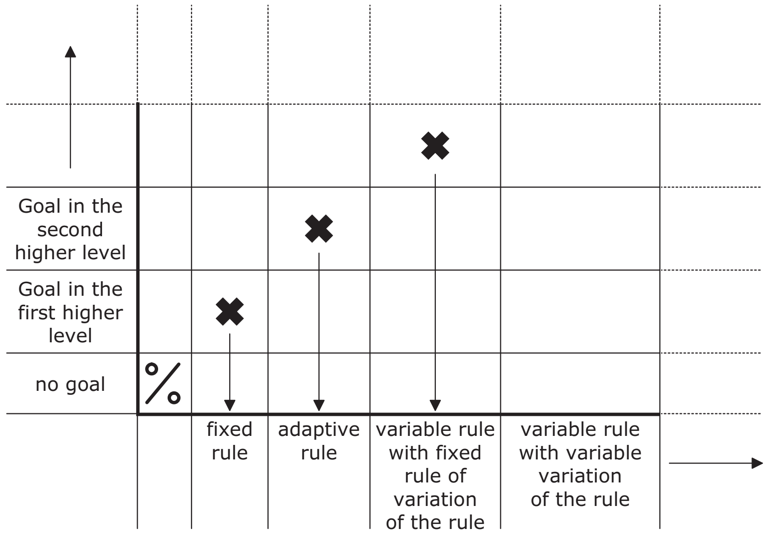

Figure 7: Connection between control design character
and the character of control law for different interaction schemes

	Character of the Character C defining the situation*	**Character of the inner structure R of the situation ***	**Inner connections (feedback) present ***	**Availability for system inherent goal generation**
Passive system, like mechanical structure	physical defined characteristic: continuous or discrete values	fixed	sometimes	no
Classical technical control	physical defined characteristic: continuous or discrete values	fixed	yes, > idea of technical feedback	no
Algorithm	general information science oriented characteristics	changeable, but on a closed set	yes	no
Computational Intelligence Control	general information science oriented characteristics	changeable with an open set, closed by construction principle	yes	yes, but limited
Goal oriented human interaction	arbitrary character of the characters C, also of linguistic nature, changeable by the human himself	unlimited changeable **	yes	yes **

Figure 8: Connection between rules (control laws) and design goals

Figure 8 gives different interacting schemes within the SOM-focus detailing the structure of R and C. It can be seen, that the SOM-view brings the schemes together and allow the distinction between different schemes.

7. Concluding remarks

The paper introduces a unified view of control and/or interaction using a Situation-Operator-Model (SOM)-modeling technique. The idea of this introduced unified view is to understand the additional degrees of design freedom for the control engineer. By replacing classic control techniques like PID-controllers with microcontrollers new design procedures are realizable. Beside analytical stability requirements there is no reason not to use the new degrees of freedom. The new idea of this Metamodeling approach directly leads to new scientific questions:

- Is the SOM-modeling technique also able to be the background of hybrid systems combining different modeling techniques?
- In which way stability criteria can also be applied to this modeling approach?

7. Summary

In a previous work (1,2) a system-theoretic modeling approach is introduced, dealing with a special situation-operator modeling kernel (calculus), called (SOM). This modeling approach combines classical ideas of the situation and event calculus, and leads to a uniform and homogenous modeling approach describing human learning, planning and acting.

Understanding the human interaction with an outerside world as the complex feedback of a 'human controller' with the 'world to be controled', differences to classical (technical) control approaches appear. Classical technical control approaches consist of fix input-output relations, called controller, uses (usually) continous scalar physical values. The control design is done in advance with the background of a known control goal. On the other side the human learning and interaction capabilities are extremely flexible, but not fast. Changing environments (and control goals) can be understand, new connections can be setted, also algorithm-like strategies. The 'input-output' relation can be changed immediately.

After a short introduction into the Situation-Operator Modeling technique as background, the contribution deals with the classification of the distinctions between algorithms (and human control) on one hands side and classical control on the other. The classification also shows that between both, a lot of other known realizations (or from the point of view of the flexible human 'control': restrictions) exists, whereby the well known classical technical approach appears as the simpliest one (or from the point of view of the flexible human 'control': the version with the most restrictions). The items of the classifications will be clearly defined and detailed illustrated in the contribution with the examples of PID-control, Optimal control, Algorithms, Human Interaction, and Intelligent Systems. All examples spans a wide area for new types of technical realizations.

The goal of the contribution is the unified view to control from classical control approaches to approaches from information-science like SOM-approach. This gives - beside the academic scheme - the view to the next steps of improving automatic control algorithms. Based on microcontrollers, databases and intelligent datapreprocessing some 'human control' qualities like learning and flexible response abilities and situation control can be imitated by technical realizations.

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