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SYSTEM-THEORETIC UNDERSTANDING OF MMI - PART I: FORMALIZATION MMI

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Abstract: In this part of the contribution a specified SOM-approach is introduced and used to discretize the Real World (RW), defining suitable and corresponding relations in the human operators imagination of RW as mental models. To illustrate the modeling approach a graphical code is developed showing the connections between the SOM-metamodeling approach and the dynamics of the HMI. Here changes of the RW are understood as a sequence of scenes and actions. Depending on the principal sensorial inputs, perceptions, and on the perception-defined knowledge base, it is assumed that humans adept and learn only parts of the RW. These parts are modeled using a special situation and operator calculus.

Keywords: System-theory, Human-machine Interface, Human-error, Modeling, Supervisory Control, Man/machine Systems

1. INTRODUCTION

In the first part of the paper the results from previous papers (Söffker, 2001; Söffker, 2003) are summarized and focused with respect to the goal of the second part.

Whereas classic control schemes typically address issues relating to speed, accuracy and other (low-level) problems typically to physical oriented technical tasks, more complete theoretical models of system control or interaction behavior often are quite complex and unwieldy in unknown environments or situations.

In the sixties and seventies the human-control behavior was examined for stimulus-response tasks, e.f. describing the time behavior of human driving etc., e.g. (Schweitzer, 1970). In the nineties the Human-Machine-Interaction itself has been focused more intensively. An actual overview to the developed approaches is given by Cacciabue (Cacciabue, 1998). Different research directions have been established, which are oriented between Artificial Intelligence (AI) approaches and phenomenological macro cognition oriented engineering approaches (Cacciabue, 1998). In the nineties the focus of AI-approaches also changes from logic-based approaches allowing the realization of rational functions to cognitive-oriented approaches with the goal to 'imitate' human thinking and acting. The resulting paradigm-change mainly assumes, that the absolute approach describing the reality is not based on the certainly about the identity between modeled reality and reality. The introduced approach here assumes that reality of the considered human is a subset of the reality, may be also a wrong or incomplete one.

In (Söffker, 1999) this modeling approach of human interaction with formalizable technical environments is firstly presented. Core of the work is a specified Situation-Operator model (SOM). In contrast to similar and known procedures (Görz, 1995; Müller, 1993; Sandewall, 1994) the developed approach is neither based on exact temporal logic (as a calculus behind) nor assumes a mathematical based perfect understanding of context structures, assuming that the reality can be described by mathematical approaches, and, much more premising, by humans. Gigerenzer and Goldstein (Gigerenzer, Goldstein, 1996) show that unsatisfying classical norms of rational inference fast and frugal algorithms can lead to effective rationality. This includes the possibility working with non-perfect algorithms to imitate aspects of human learning. This also includes that the assumed knowledge about facts, structure and details of the RW) must not necessary perfect for successful interaction. This ideas represent what we already know: working with incomplete and/or wrong knowledge (or subjective) knowledge can also lead to stable and successful interaction (depending on the robustness properties of the complete scene, and on the learning capabilities of the human).

The introduced approach can be used in several ways:

- to bridge system theory (from the technical control theoretic view) and information science (Söffker, 2003b),
- to build autonomous systems based on the (modeled) human learning capabilities (Söffker, 2001),
- to describe and analyze HMI (Söffker, 2003),
- to formalize parts of RW, where usual (detailed) modeling approaches fails due to the complex structural dependencies or to
- supervise the HMI, whereby this idea is introduced here firstly and conceptional introduced within the second part of the paper.

The core idea is that the assumed structure of RW can be modeled. If so, it is assumed that facts of RW can be abstracted (by understanding the interaction) given to machines (here called Intelligent Systems IS). Humans also learn these facts from the interaction and by the way build up their (individual) mental models. In the best case the given structure of RW is copied by two representations, one in the human brain (called mental model) the other by IS. The introduced modeling scheme deals with these assumptions and details some inner aspects of the three dependencies.

2. FROM SCENES AND ACTIONS TO SITUATIONS AND OPERATORS

Core of the approach is the assumption that changes of the considered parts of the real world (RW) are understood as a sequence of effects described by the items scenes and actions (of RW). In the proposed approach the definition of the items scenes and actions are coordinated in a double win. They are related to each other and they relate the assumed structure of the RW to the structure of the database - called mental model - of IS.

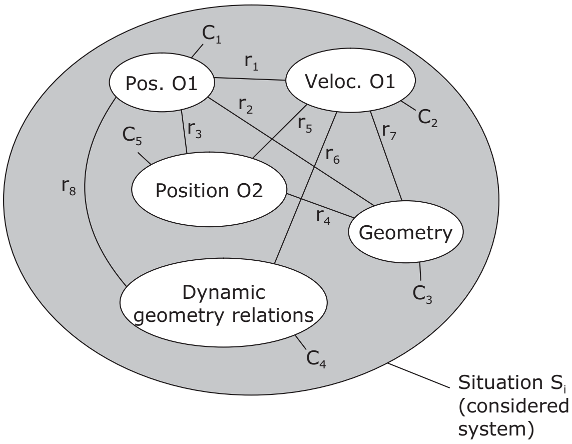
ISs and humans (human operators HOs) are included in the real world (RW). Depending on their principal sensor inputs, their natural (HO) or technical (IS) perceptions, and on the related knowledge base, the ISs and HOs adapt and learn only parts or aspects of the RW. These parts are modeled using the developed situation and operator calculus. The describable part of RW is called a system.

The item situation, which is (in contrast to (McCarthy, Hayes, 1969)) a time-fixed, system-, and problem equivalent one, is used describing the internal system structure (as a part of the RW). Here only the logical structure of the 3D-space, time and functional-oriented connections are of interest. The item operator is used to model effects / actions changing scenes (modeled as situations) in time. The situation S consists of characteristics C and a set of relations R. The characteristics are linguistic terms describing the nodes of facts (as perceptible qualities). This will include physical, informational, functional, and logical connections. To describe the relations r_i known problem related modeling techniques, like ODEs, DAEs, algorithms or more general, even graphical illustrations (e.g. Petri-nets) can be used.

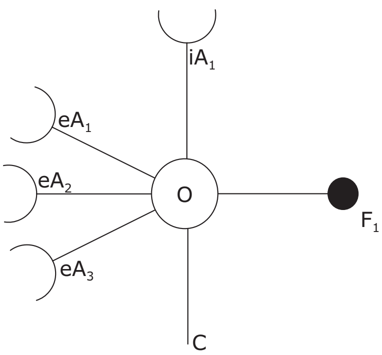
The SOM-approach only gives the frame to model the structure of changeable scenes, and therefore maps the 'reality' of RW using the proposed structural framework to a formalizable representation. This is useful describing problems, where the system structure is complex (and can not be described with available (single) approaches) and can not be modeled using single approaches. This is also useful to describe interactions between HOs and its environment.

The introduced item characteristic (C) also includes the possibility of representing time-dependent parameters P as example. The complete set of relations R (of Cs) fixes the structure of the considered scene of RW modeled as situation S. The introduced situation concept consequently allows the integration of different types of engineering-like descriptions.

As an example in (Söffker, 2001) the complex physical situation of the rail-wheel physics and the dynamics of the interaction and the structure of the related modeling is given. There the illustration shows the dependencies of the considered mapping from the real world problem to the engineering oriented modeling using ODEs and case-depending algorithms into a qualitatively modeled and graphical illustrated network.



(a) Structure of the proposed item Situation



(b) Structure of the proposed item operator O

Fig. 1. Introduced Terms Sitation / Operator (here: graphically illustrated

The illustrated item operator is used for the modeling of a) internal (passive) connections of situations and b) changes between situations, cf. Fig. 2.

The operator O (cf. Fig. 1b) is understood and modeled from a functional point of view: the operator is an information-theoretic term which is defined by his function F (as the output) and the related necessary assumptions. Here explicit and implicit assumptions eA, iA are distinguished. The function F will only be realized, if the explicit assumptions eA are fulfilled. The iA includes the constraints between 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 problem-related descriptions are allowed. The double use of the term operator O is graphicly illustrated with Fig. 2. The description of complex systems using a Situation-Operator model allows

- the mixture of different types of (variable) quantities (the relations R can be different ones within the situation S,
- the integration of logical and numerical quantities (by different characteristics C), and

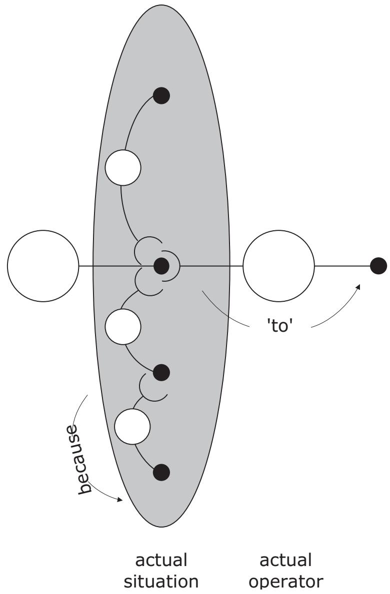


Fig. 2. Connections between Situation and Operator

- the description of real-world problems using a mixture of a complex set of descriptions (variables).

In the following also a hidden structure of R is used as graphically illustrated in Fig. 3.

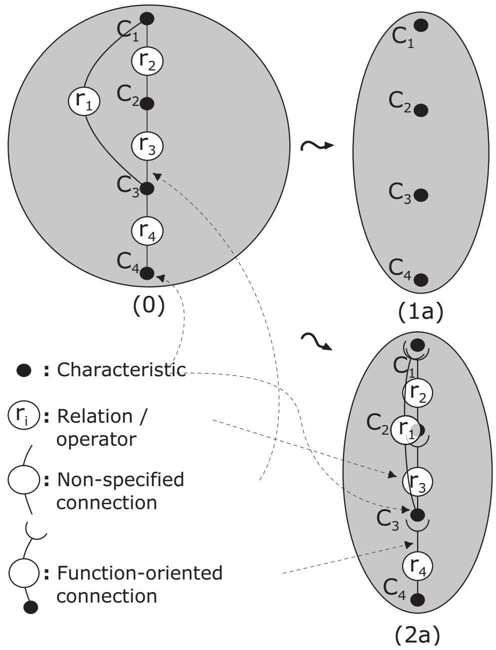


Fig. 3. Graphic notation of S

Operators are used to model the system changes (changes of situations). This defines the discrete events of the change of the considered part of RW, the system. Operators and situations are strongly connected due to the identity (partly or complete) of the characteristics of the situations and the explicit assumptions of the operators. This includes that the situation consists of 'passive' operators (internal causal relation: 'because'), whereby the change is done by 'active' operators (external causal relation: 'to'), shown in figure 2. The change of the considered world results as a sequence of actions modeled by operators as illustrated in figure 4.

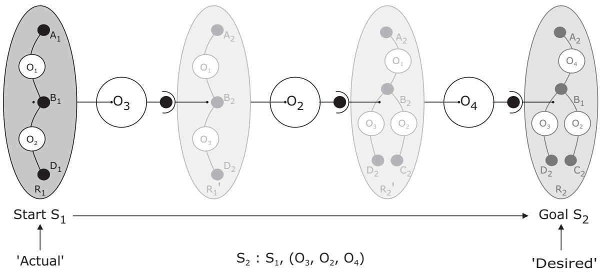


Fig. 4. Sequence of operators changing the situations (arbitrary example)

It should be noted that operators correspond to situations. Both are not only used for structural representation of the organization of the system, but also for internal representation and storage of of HOs and ISs. They are the core/background of all higher organized internal (cognitive) operations and functions of the IS like learning, planning etc. (Söffker, 2003) and also of the proposed supervision concept.

3. LEARNING

The following assumptions have been made:
• The problem-dependent structures of the real world scenes can be clearly identified as situation dependent R's and C's.
• The resulting identified S describes the RW in the way, that the relevant structure of the scenes and those of the identified S is equal.
• Operators are (without loss of generality) defined as time-independent.

Based on the introduced assumptions, learning appears as the definition / redefinition of operators, driven by the interaction between HOs / ISs and the considered system, whereby the interaction can be intended or not, useful or not, and planned or not. This includes different cases, where S_i denotes the i-th situation, R_i denotes the i-th set of relations and A_i, B_i, D_i denote a set of characteristics C_i describing the system structure of the i-th situation.

A straight forward learning strategy includes the definition of O_1 by the induced (: active learning) or observed (: passive learning) situation changes,

- learning where only the characteristics are changing

$$O_i : S_i(R_i(C_i)) \rightarrow S_{i+1}(R_i(C_{i+1})) \quad R_i = R_{i+1},\, C_i \neq C_{i+1} \quad (1)$$

- learning of changing internal relations

$$O_i : S_i(R_i(C_i)) \rightarrow S_{i+1}(R_{i+1}(C_i)) \quad R_i \neq R_{i+1},\, C_i = C_{i+1} \quad (2)$$

- learning of complete changing situations

$$O_i : S_i(R_i(C_i)) \rightarrow S_{i+1}(R_{i+1}(C_{i+1})) \quad R_i \neq R_{i+1},\, C_i \neq C_{i+1} \quad (3)$$

which includes possible changes of situation structures $R_i \rightarrow R_{i+1}$, characteristics $C_i \rightarrow C_{i+1}$ or both.

Please note that learning necessary assumes awareness of HOs and ISs related to the starting situation (this includes, that S_i and R_i must be known and be aware and additionally the resulting situation S_{i+1} also must be understandable. This necessary connects the situation awareness to the mental model of HOs and ISs. This assumption also can be used to understand human error from a logical point of view (Söffker, 2003), whereby logic means understanding of scenes / situations assuming restricted physiological possibilities or restricted / incomplete knowledge, and/or restricted mental capabilities.

This forward learning and definition procedure of operators O_i is the main mechanism to map the outer world of the considered environment (system) to the inner (mental) model/world of HO/IS and to add new experiences into the memory/'database' of of HO/IS.

As mentioned above this assumes that HO/IS are able to identify R_i, C_i from the available sensory inputs in combination with the actual knowledge. This can not be assumed in general. One path to overcome the included problem of learning coincidental coherencies and learning non-concrete coherencies due to insufficient memory - mental model (MM) - capabilities, is to include backward oriented learning abilities: this includes the ability to distinguish Cs necessarily connected to R to those of coincidental presence and not directly connected to the problem structure.
Example 1:
The reality consists of $S_i(R_i(A_i, B_i), D_i)$ (R_i connects A_i and B_i, D_i is unconnected present) and the learning mechanism of IS assumes / identifies S_i as $S_i(R_i(A_i, B_i, D_i))$. After application of the O_1-related action the system appears as $S_2(R_1(A_2, B_2, D_1))$, so O_1 can be defined by IS as

$$O1 : S_1(R_1(A_1, B_1, D_1)) \rightarrow S_2(R_1(A_2, B_2, D_1)). (4)$$

Due to the contingencies of the reality it may happen that

$$S_1(R_1(A_1, B_1)), O_1 \rightarrow S_2(R_1(A_2, B_2)) \quad (5)$$

can be observed, which is in opposition to (4). So HO/IS gets the chance to rebuild the O_1 definition by 'replaying' to find the true $S_1, O_1 \rightarrow S_2$ sequence redefining the operator O_1. In the example this gives the opportunity to reject the coupling of D_1 to O_1.

In this way learning appears as a strictly nonlinear procedure due to the strong connection of the definition process of operators to the actual context, which includes the individual initial conditions of HO/IS (the actual S and MM).

Example 2:
The task of IS should be the realization

$$S_1(R_1(A_1, B_1, D_1)) \rightarrow S_2(R_1(A_2, B_2, D_1)). \quad (6)$$

IS will take O_1, as learned (eq. 4). Different results are possible:

- D_1 appears as learned, so O_1 seems to be confirmed.
- D_1 changes unexpectedly to D_2 or disappears.

As a result the reality may be in contradiction to the MM, so occurring differences give good reasons to reflect and change the definitions (previous learning procedures). It depends on internal features of IS to rebuild the MM immediately, after additional experiences or after extensive hypothesis oriented tests of the definition of O_1 or not.

Please note that this definitions of learning are independent from external commendations, penalties or rewards. The learning capabilities are the key feature for successful acting in unknown situations. From a system-theoretic point of view the key feature is the model-updating capability of IS.

A problem is resulting from possible (unstable) learning-cycle behavior.

4. PLANNING AND ACTING

In this context planning can be assumed as the internal preparation of the action or the series of actions to change the actual S_{act} to desired ones $S_{des.}$, cf. figure 4. Modeling of planning based on the SOM-technique includes a MM as a set of previously learned definitions / operators and the ability to identify the given goal $S_{des.}$ and $S_{act.}$. The goal elaboration is not considered here. To elaborate goals (or part goals) detailed procedures (or algorithms) as cognitive procedures or functions have to be developed.

Planning includes the elaboration of a sequential ordered set of suitable O_i to solve the task $S_{act.} \rightarrow S_{des.}$. Due to the definition of S and O this can be done by comparison of C_i, eA, F applying a backward or forward inference strategy. The solvability strongly depends on the actual content of MM and the cognitive abilities. If this can not be solved exactly (different reasons possible), practical planning procedures are possible which use operators which do not exactly fulfill the requirements (full set of Cs), but requirements close to the desired perfect ones. This will lead to testing strategies, associative combinations (where internal similarities between the relation eA, F of the supposed unknown, but perfect O and the C of known O exist). In reality conflicts may exist between goals, part goals, necessary actions, reachable situations and unexpected effects of 'known' operators. This may be typical for human interactions but also will appear for IS. The collection of possible human errors and the related SOM-oriented representation shows that there exists a large variety of practical problems (Söffker, 2003). In general solvable conflicts can be solved using decision making strategies with given goals. Therefore the solving strategy is to transform the problem to a higher level, where a solution can be given using an algorithm etc.

This includes the development and evaluation of alternative paths (operator sequences), the choice of weighting factors etc. and also strongly depends on the MM. In the (lower level) case of scalar expressions (as characteristics and relations modeled by ODE) conflicts can be also expressed by mathematical expressions, which can be solved using some assumptions perfectly or can be optimized using weighting functions to find compromises related to given goal functions. In general this topics are discussed within game-theory, in detail also with the theory of optimal games or optimal control. In the assumed general case of considering HOs/ISs with formalizable and changing environments this problems are not considered up to now. Therefore game theory gives hints to the way the problem solution can be structured and solutions can be found. It should be mentioned that the HO in general has more degrees of freedom changing his 'algorithms'/planned operators sequences than any kind of known machines, in this way the human flexibility in interaction is unique.

The execution of the mentally prepared sequence of operators as actions realizes the interaction of IS with RW. The interaction itself gives a variety of learning sequences: the result of each action of IS can be compared with the predicted one to optimize the internal MM etc.

5. CONCLUSION

The new aspect of the contribution is the unique view to HMS especially to HMI by applying a modified and suitable adapted Situation-Operator-Modeling technique (SOM). Here the dynamic behavior of HMI and the related structural changes of the real World (RW) and the corresponding mental model of the operator are considered qualitatively and from a phenomenological engineering oriented point of view. The approach is based on classical situation operator calculus, but modified and detailed to fulfill modeling requirements and furthermore to understand to closed loop between human (operator (HO)), the environment (the machine) and the detailed interaction (from operator to machine and vice versa). Using the introduced approach it is possible to describe those parts of HMI which are charaterized by the knowledge-guided HMI. In part II of the contribution it will be shown how this approach can be used to model tpyical human errors (using the SOM-'language'), within the sequence of actions (modeled by operators and related situations) of HMI. The automation of this strategy will lead to a new concept for supervision of Human and Machine.

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