INTERNATIONAL DESIGN CONFERENCE - DESIGN 2008
Dubrovnik - Croatia, May 19 - 22, 2008.

TO THE DEVELOPMENT OF A SYSTEM ARCHITECTURE OF COGNITIVE TECHNICAL SYSTEMS

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Keywords: multidisciplinary products, cognitive abilities, product development

1. Introduction

Today increasingly intelligence is expected by technical systems with which technical systems should be enable to operate autonomously. Therewith technical systems are to be put in the position to react flexible in terms of system purpose to various environmental conditions. To implement this abilities in a technical system it is necessary to open rigid stimulus-reaction mechanisms. Only with such a modifiability one's accomplish finally the desired flexibility. Such an interpretation between absorption of stimuli and the resulting behaviour in biological systems will be assured by cognitive abilities. By implementing cognitive abilities in technical systems the possibility to equip this with an appropriate intelligence will be established in order to master the complexity of the environment and the task, which has to be solved therein.
Contrary to classical mechatronical systems a pool of alternatives for acting is no longer provided to the technical system to accomplish the system purpose in a pre-configured and pre-structured environment, but at the same time the possibility of being able to react to changes in the environment in terms of goals of the technical system. The integration of cognitive abilities proves however a not simple setting of tasks. Indeed these can be acquired and described and/or interpreted from technical point of view, whose development and finally their use implicates a multiplicity of problems. The greatest challenge is to be seen in it, that cognitive abilities can not implemented into a system only by the configuration of the information processing. Rather a system structure is to be realized, from that out the cognitive abilities will be developed. For this aspects solutions are to be deduced and discussed in the contribution.

2. Basics for the Development of Cognitive Technical Systems

The term cognition derives from the Latin term *cognoscere* and means something like to recognize, to perceive, or to know (Figure 1) [Strube, 98]. Strube characterizes those cognition as the intervention between absorption of stimuli and behavior. By cognitive abilities a technical system is accordingly able to adapt the system behavior to variable environmental conditions. This occurs depending on external and internal states which will be perceived subjectively by the system. The process of intervention between the stimuli and actuatory reaction comprehends the partial functions perceiving and recognizing, encoding, memorizing and remembering, thinking and problem solving, a motoric function control and using of language as a form of communication. Cognitive abilities will be only generated, if all of the mentioned characteristics are fulfilled by the system. The degree of their development decides again on the degree of the cognitive abilities.

In order to place cognitive abilities surely as system property, the question must therefore be answered, how does the corresponding system architecture has to looks like to enable the technical system to react autonomously and goal oriented in a specific situation. At first view three components prove for the integration of cognitive abilities as essential, which are described in the following briefly.

Information processing: Cognitive processes are considered as computation processes [Strube, 98]. In the fields of cognitive sciences and artificial intelligence therefore special cognitive architectures were developed to in order to accomplish the complex data processing on basis of elementary mechanisms. For this exists a number of different approaches, the chapter 4 will be going into greater detail with ACT architecture and PSI architecture. The data processing is incumbent on the task, to interact with the environment in real time, To construct memory contents and to allocate it to a representation and to allow an assortment of alternative actions in decision points [Newell, 90].

Embodiment: Among them one understands the technical basic equipment by which is made the actual physical acting of the system. On the one hand these technical equipment must be designed for the systems purpose in consideration of constraints. Otherwise the degree of freedom of the technical system will be limited by the selection of the used physical effects. With it the embodiment supplies those over the time constant conditions for the cognitive abilities of the system, which manifest themselves in an appropriate behaviour. Elementary mechanisms for the ability to act serve as basis for the information-processing processes according to the definition to establish physical boundary values. It is crucial that only by a real basic system a reference to the environment and the technical system is developed, whereby this is enable to perceive data and to convert into information. Thereby the environmental information and the performed actions will gain in importance [Haselager et al., 06]. The importance of the embodiment becomes clear with the analysis of mechatronischer systems, which will designed today: already with a comparatively simple purely reactive information-processing we are able to master complex environments (e.g. autonomous vehicles). However for this purpose today the environment will be exactly predefined and with it determinate. This may be one of the reasons, why the autonomous vehicle in the mars mission has failed, because all environmental conditions could not be ahead-thought here.

Knowledge management: To describe the system-architecture as generally as possible it seems to be meaningful, to consider the actual knowledge storage and the knowledge preparation not as a part of the cognitive architecture. The knowledge management is to be regarded separately. Cognitive architectures concretize in the long run only their abstract specification [Langley et al, 06]. The knowledge of a system will be subdivided ultimatly itself into so-called factual knowledge (with Anderson Chunks [Anderson, 96]) and production rules [Anderson, 96] or action scheme's [Dörner, 01]. To the factual knowledge above all are to account the limit values from the Embodiment, from those are to derive the necessary reference values for the application in the production rules. Production rules or actions scheme's against describe the rules, which are to be kept with the occurrence of a certain situation. An example: an autonomous vehicle is able to brake friction-poor electrically by changing from the motor-driven operation into the generator operation. With a critical speed as a function of the engine characteristic this is ineffective, that's why for the deceleration into the stop mechanical brakes are necessary. From this technical situation two production rules result:

if $v_{worstz} > v$, *then „brake electrical“, if* $v_{worst} < v$, *then „brake mechanical“*

While the fact knowledge must be deposited in appropriate form as information the system, production rules are implemented over the organization of the automatic control loops into the system. More complex connections, which must pay attention to several physical limit values, can be illustrated e.g. over cascade nestings of control loop architectures. In the knowledge preparation thereby are also on basis of the embodiment of the technical system substantial decision criterias deposited for the action selection. These are comparison parameters regarding physical boundary values and statements about the ability to respond and thus the real time ability of the system.

3. Methodical Conditions for the development of cognitive technical systems

For product development today a multiplicity of methods are available, which facilitate it for the engineer to design products for a system purpose according to the requirements. The basic consideration is thereby always to extract from an ahead-thought environment the boundary conditions for the development and to ahead-think and structure the later employment environment. The more parameter and factors of influence thereby to be considered, the more complex the developed technical systems becomes generally. As notedly problematic it proves thereby again and again if environmental conditions unexpectedly arise and/or were not considered. Such events breeds then to system failures with more or less serious consequences.

With the implementation of cognitive abilities in technical systems one works against by breaking up rigid couplings between sensors and actuators and to arranging modifiable. These modifications occur situation-suitably, that means as a function of a current environmental description and the internal states of the technical system. By a description of situation thus will be understood the sum of all sensor data (external and internal) at a defined time. Basis for this forms the three-layer architecture, according to which production rules in the technical system will be subdivided and are embodied in the data processing [Strube, 98]. While the lowest reactive level is specified by rigid connections between sensors and actuators, must the associative and the cognitive level ensure the modifiability of the sensor actuator chains. Thereby autonomously acting systems will be generated, which are able to orient in any environment. However questions of the reliability of the system, the user security and environment security have to be analyzed, previous approaches for the handling of these problems are only conditionally transferable.

As the large challenge for the product development proves not only the complexity of the products themselves but rather the complexity of the environment, which has to accomplished by the technical system autonomously. The environment is to be described as far as aspects are not abstracted and simplified, which not influence the purpose fulfilment, the user security and the system existence.

the fact that of aspects, those the, which do not affect abstracted and is simplified. The structuring of the environment should occur only so far that the existence and the reliability of the system are guaranteed. The robustness in relation to environmental variants results from the cognitive abilities. The cognitive abilities provide a pool of resources and behaviour, which it makes possible to accomplish the complexity of the environment and the therein to solving tasks [Müller, 98]. From these considerations result four problems, which have to be solved, if cognitive abilities are to be implemented into technical systems [according to Riegeler, 06]:

- mechatronical systems are aligned to optimize and/or to hold certain parameters without to analyze that parameters are within an optimal range or to understand why the system is using this range; that means, the system does not know the meaning of subjects and their relevance for the self-preservation; this is given maximally by the designer;
- the technical systems need an internal model of oneself and of the environment, in order to ahead-think and to test actions; Otherwise exists the danger that the technical system does not emerge from the pure reaction (behaviouristic model in form of the well-known black box);
- the definition of production rules, means the structure the functionality of the control loops and with it the classification and recognition of situations today often take place binary (target/actual comparision); the real world is characterised by a certain degree at fuzziness; somehow it applies to consider.
- Information processes, which secure the knowledge- and data processing and which may based on methods like neuronal nets, are with rising complexity no longer explainable and by the learning mechanisms no longer comprehensible.

These four problems lead to boundary conditions for cognitive technical systems [according to Riegler, 06], for which suitable methods have to be found, in order to give an engineer action guidelines for the designing of cognitive technical systems:

- Cognition describes the ability of a system to master its environment by organization and evolution of complex behaviour structures and to received itself in this;
- The development of cognition in technical systems is an incremental Bottom-up process, which begins at the designing of the reactive level. Each more highly developed level build up on their previous level, so that the cognitive structures are strictly hierarchically formed, whereby higher cognitive functions are developed on lower. However this hierarchical

structure leads not to separated working modules, but is for cognitive technical systems a condition for the developmental robustness and the evolutionary speed.

- The complete cognitive layer with its cumulative data processing should be realized as a closed circuit, because the system cannot distinguish between internal and external states. Such an organized seclusiveness of the cognitive module presupposes, that its processes are not defined in semantic representation and dependence of the environment like in classical physical systems. A clear delimitation of the cognitive structure must be existing.
- Because cognitive processes must be explainable and examinable on an abstract and functional level, connectionistic approaches, like the method of the neural nets, are not available. However cognitive, hierarchically organized approaches can be decoupled in layers due to its linear decomposability and analyzed.

For the development of cognitive technical systems thus are basic considerations for the configuration of the information processes and for the designing of the essential structure necessary, which have to be coupled to a holistic approach. For this Strohner [Strohner, 95] submits a tripartition for the development, which reflect the boundary conditions: (a) defining the system tectonics; (b) defining the system dynamics; (c) by evolution to the cognitive technical system. In the following two relevant cognitive architectures will be described briefly. Afterwards it is to be dealt with questions to system tectonics and dynamics, in order to specify solutions for cognitive technical systems.

4. Comparison of Cognitive Architectures

In cognitive science research several frameworks for simulating cognitive processes were proposed (see [Gray, 07] for a recent overview). Such frameworks, or cognitive architectures, provide theories about how human cognition works. They are based on a small set of assumptions about basic processes of information processing, often derived from psychological experiments, which are inherent in the architecture. For concrete tasks or problems, simulation models can be formulated in the language provided by the architecture and tested against human performance.

One of the most popular frameworks is ACT-R (adaptive control of though-rational , [see Anderson et al. 04]). In its core, ACT-R is a classical production system. That is, a system which manipulates the content of a working memory by executing conditioned rules (productions) based on match-select-apply cycles. In contrast to other production systems (as Soar, [Newell, 90]) ACT-R provides a long term memory of declarative knowledge. The memory is hierarchically organized and chunks of knowledge can be made accessible by activation spreading. ACT-R is the last in a sequence of predecessor systems which originally had a focus on classical topics of higher cognition as reasoning and problem solving. In its current version it is extended by perceptual-motor modules to allow embedding into an environment which provides tasks and constraints. Among current applications are models addressing usability and human-computer interaction.

The PSI system [Dörner, 01] is radically different from most other cognitive architectures. While systems as ACT-R started with an isolated look on higher cognitive processes and over the time added modules for additional aspects as perception or motivation, PSI from the beginning was intended as an integrated theory of mind [Bach, 07]. It addresses perception, memory, reasoning, problem solving, motivation, emotion, and social behaviour embedded in a dynamic environment. PSI is constructed on a hierarchy of neuro-symbolic representations which are grounded in the environment and by its hybrid nature can exploit neuronal mechanisms for spreading of activation and learning and symbolic information processing for reasoning and problem solving.

Due to the radically different frameworks of ACT-R and Psi, the systems differ on several crucial aspects of how to model information processing.

Embedding: In ACT-R embedding in the environment can be realized in a very abstract way -- by interacting over symbolic descriptions of the current state of the world -- or via some perception-motor modules allowing access to visual and auditory information and execution of manual actions. PSI, on the other hand, models a cognitive system as an agent which aims to maintain a homeostatic balance in

a dynamic environment. The best worked out environment for PSI is an island which offers different resources which are partially necessary for the agent to survive and partially endangering to the agent.
Action planning: Action planning in ACT-R is realized as goal-directed production system. That is, hierarchical structuring of problems is predefined in a set of production rules with goals as conditions and setting of subgoals or performance of basic actions as effects. In PSI, action selection is governed by demands which give rise to motives. Depending on the current strength of a demand, action sequences can be aborted to switch to fulfilling a more urgent demand. Emotions are always present and considered as modulators of behaviour and mental processes.
Knowledge management: Knowledge management in ACT-R is based on its hierarchically organized declarative memory. The basic memory units are so called chunks, similar to schemas with slots containing attributes which can be objects or other chunks. Hierarchical organization is realized via ``is-a'' slots, representing type-supertype relations. Links between chunks are associated with real values representing strenghtes of interrelation. In PSI, conceptual knowledge is represented as taxonomies in a similar way as in ACT-R. Own experiences are represented in episodic schemes and a protocol memory. Action schemes take the part of the production rules of ACT-R. The basic difference between ACT-R and Psi is that the latter explicitely addresses the problem of symbol gounding by relating symbolic representations with perceptual encodings gained from the interaction of the agent with the environment.

5. Methodical Considerations to System Tectonic and System Dynamic

For the design of the basic structure of cognitive systems one finds general in the literature an approach for a tripartition [Strohner, 95], which can be well transferred to technical systems. The first question, which is to be clarified, is the question about the system tectonics (components of a system in the sense of the system structure). Based on this the behaviour of the system has to configured, which processes in the system are to run off (system dynamics). Primary after this can be further-considered, how the cognitive abilities may be developed and and enhanced themselves. While the first two questions take up classical problem of the product development, the last question is to be clarified only in consideration of selected cognitive architecture.
It becomes fast clear that a view of the system structure cannot be regarded independently from the system dynamics. As starting point for the development of cognitive systems is the definition of the system purpose. From the system purpose the overall function is derived, which will be divided for further development into sub-functions. In the context of dividing the overall function into sub-functions usually the implementation of the principle behaviour stands in the focus. As recently as by the concrete choice of solution principles the designer begins to specify gradual structural components. Thereby the transition between the consideration of the behaviour and the predefinition of structure elements during the classical development process is continuous.

5.1 System Tectonics

The definition, which components and/or structural elements are actually used, depend on the sub-functions determined from task which has to accomplished. Thereby these sub-functions are not to be selected alone on the system purpose, but must also serve the accomplishment of the environment. Therefore the structural components include typically both: sensory elements and actuators.
90. From system-theoretical point of view the system tectonics then comprehends the integrated components of a system. The summary of the system components describes the system composition and represents clearly specified relations and allocations to system objects. Such a view of the structural components appears above all helpful, in order to support the action management. To act in the environment generally it will be necessary, that actions will be composed, which results from the cooperation of the behaviour of several actuators. The knowledge about several actuators and their efficiency helps to build up arbitrarily complex operational sequences based on a suitable hierarchical structuring [Dörner, 01]. From this hierarchical structure on the one hand actions can be arbitrary composed at, on the other hand it becomes apparend, which actuator components must being addressed in order to realize a desired action.

From the system tectonics the parameters for the performance of the selected components can be acquired, which will be deposited as boundary values and/or feasibility ranges in the knowledge data base in the sense of the factual knowledge.

5.2 System Dynamics

As previously mentioned, the development of technical systems starts with considerations to the system behaviour. By the decomposition of the overall function into sub-functions inner states of the system will already defined, what permits first conclusions on necessary changes in state. The coupling of sub-functions over its input/output relations establishes the physical relations between these. Therewith first conclusions of to behaviours in principle can be deduced; at first this results only from the choice of the solution principles and/or physical effects.

As described in chapter 3, production rules are deposited not only in the data processing but also manifested by the control loop architecture. Therefore the second step for the description of the system dynamics is the consideration, which parameter must be manipulable and in which way. At this it concerns to specify principle control mechanisms with which the technical system is able to act in the environment without endangering thereby its existence. The control mechanisms which can be specified have purely reactive nature. They corresponds thereby to the lowest level in the three-layer model according to capture 2. The challenge for the product development will be to specify which of the control mechanisms and therewith production rules in the sense of safety the existence must persist always unchanged (e.g. if the energy status is low, then the vehicle must drive in each case to the loading station). Within the description of the system dynamics in addition it is important that it does not only focus on the system purpose. Rather it must be attend to the operating conditions, this is comparably with the pre-structuring of the environment.

From the environment result a set of goals, which can be arise in work of the technical systems. For an autonomously working vehicle to vacuum cleaning would be such goals: receiving Energy status upright, updating maps from the area, evading furniture and large subjects, collecting small parts and bringing to central point, emptying dust storage.... Considering the example it becomes clear that these goals are not hierarchically structurable, depending on the situation several goals obtains a different meaning. It is the incumbent on the designer to specify and to weight priorities, so that in a decision situation the technical system can be supported regarding to the selection of the necessary actions. The technical system needs such a list of priorities, in the first step the designer has the task to define this list, in later steps the list will be modified by the cognitive abilities of the system.

The description and depositation of the system dynamics based on the system tectonics proves therefore as large challenge for the engineer, because in the long run the basic equipment decides on the existence of the system and furthermore whether the pre-defined pool of behaviour supply is actually sufficient to fulfil the system purpose in consideration with a multiple goal system. Therefore today no sufficient and efficient methods are available for the designer.

6. Conclusion and Outlook

Both descriptions of system tectonics and system dynamics are elementary preconditions to develop cognitive abilities in a technical system. It is crucial that cognitive abilities can not be implemented per se into the technical system, rather it must be ensured that these can develop themselves. In addition the major task again is incumbent on cognitive architecture.

With the help of the structural approach it could be shown that for the development of cognitive technical systems can be used in principle well-known procedures. However the complexity of the tasks requires sometimes an adjustment of the point of view, if results from well-known process steps and methods have to be analyzed. With the thought on the separation in system tectonics and system dynamics a novel approach is available to describe and to understand the system complexity better. Hereunto further work for the refinement of the approach is necessary, because the idea is in principle helpful for the development of interdisciplinary products.

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