# Neuro-bionic Architecture of Automation Systems – Obstacles and Challenges

E.Brainin, D. Dietrich, W. Kastner, P. Palensky, C. Roesener

***Abstract*— For a long time, engineering technologies tried to learn lessons from biology and took the line of bionic approaches. Well known examples of bionic methods can be found in robotics or in the aerospace industry. Without question, the human brain is the most important example of successfully controlling a complex system – our body. When building up complex automation systems with massive numbers of information, implications and relations, a next step could be to include neurobiology, psychology and psychoanalysis aspects. In this context, we present a new model and show obstacles and demands when putting the model into practice.**

***Index Terms*—Control systems, Cognitive science, Modeling, Biological control systems**

## I. MOTIVATION AND INTRODUTION

IN presence, ubiquitous and pervasive computing is the major catchphrase in information technology. To realize aspects out of these computational trends for automation systems, the number of sensors and actuators has to increase. Unfortunately, today's automation systems are not ready to handle massive amounts of data. In the past, monolithic design with closed architectures and communicating facilities allowed only a limited number of devices to interact. Next generation systems have to cope with huge data amounts where, for instance, data have to be processed originating from ad-hoc sensor networks (cf. "smart dust" systems as described in [1]). Obviously, present data acquisition and management systems are not able to handle the expected data stream. To act effectively, for modern automation systems a transformation from simple data to meaningful information is a must. However, information can only be transformed if the underlying communication systems provide a high degree of interoperability [2]. Otherwise, complex situations can never be perceived and recognized. It is now high time to reason about new models for communication systems able to cope with interoperability problems. In our opinion, neuro-biological science provides useful means when developing such a new model. Thus, this article starts with a general introduction to the neuro-biological principles. Next, our model is presented. Since we plan to put the model into practice, we show the architectural gap we have to face. As a consequence we express demands for new suitable architectures.

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## II. RELATED WORK AND THEORY

The human nervous system is the most complex communication network ever existing. A closer look at computer systems allows locating some analogies between

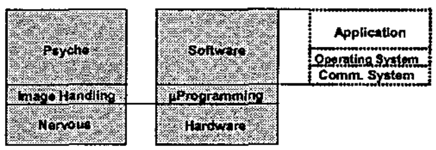


Fig. 1. Relating technical systems to the human archetype

hardware and software and the human archetype (Figure 1)

The nervous system represents the biological hardware and can be compared with sensors embedded in a technical process. The consciousness is the biological software, which can be conferred with classical software including mechanisms for communication, the operating system and actual application. In between, on the one hand methods for image handling, and on the other hand, interfacing hardware by means of microprogramming can be identified.

Traditional understanding of the brain is based on a geographical modular model where different tasks are assigned to single modules. However, this old-fashioned view cannot describe the dynamic facilities of the human nervous system that in fact is a highly redundant dynamic network changing its topology depending on demand [3]. Now, it could be argued, that ideas out of the area of artificial intelligence are a good basis for a new model. They rely on the hypothesis that machines can learn "intelligent behavior". This means, that symbols might be realized in physical structures [4]. Thus, artificial neuronal networks (ANN) try to rebuild brain functionalities by forming neurons, the smallest processing unit of the virtual nervous system. However, neither its architecture, which is limited in the number of nodes, nor its functionality can describe the genuine functionalities of the human brain in its high complexity.

In [5] a leading thesis about the understanding of the nervous system (containing the central, peripheral, nervous system and the brain) was created. Eccles unsuccessfully tried to close the gap between technical terminology and the

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biological archetype - the interface to perception [6] – an idea that met no response. Mark Solms formed a graphical model representing the mental apparatus and pointed out the

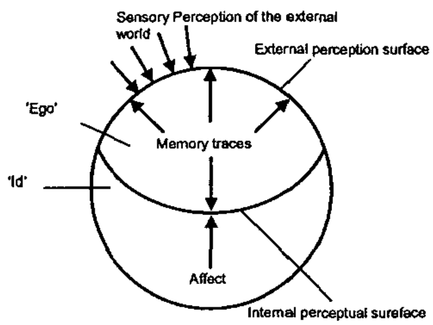


Fig. 2. Mental apparatus according to [9]

interoperation of perception modules (Fig. 2) [7], [8].

This schematic presentation of mental processes defines that impulses can have three sources: the external world, the "Ego" (based on past conscious experience), the "Id" (based on past unconscious experience). This presentation is the

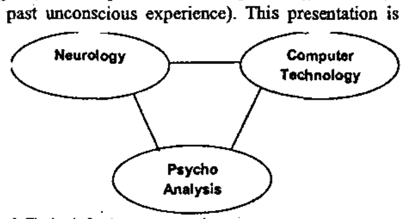


Fig. 3. The basis for the new approach

archetype for our new model.

It is the goal to combine the lessons learned from neurology, computer technology and psycho analysis (Fig. 3) in order to get a new understanding of the human mind and in order to use this understanding for new computer systems that can solve complex problems.

## III. THE NEW APPROACH

To allow different devices to interact properly, they have to provide and use common standardized interfaces. The more components implement a specific interface, the wider becomes the choice for mixing and matching them. Thus, such interfaces should cover a broad range of applications in order to make them suitable for implementation by as many components as reasonably possible. A popular approach towards such an interface suitable for the representation of arbitrary devices functionality is to break the latter down to the data point level based upon the definition of profiles.

With reference to the biological concept, the Intra-Industry, the Inter-Industry and the Inter-System Layer functionality of our model accords to data adaptation of data points (cf. Sensory Perception in Fig. 2) [10]. This comprises the abstraction of the quantitative measurement data to more qualitative information and also the transformation from cyclically performed observation of the environmental data toward attention attracting symbol state changes (events). Though the functionality of these 3 layers is quite the same, they allow the combination of different information. So far, only the first one was realized by using

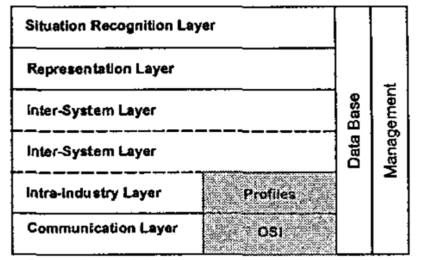


Fig. 4. Layers of the model

profiles (Fig. 4).

The *Intra-Industry Layer* is responsible for functions within a single industry – for example, a distance and an occupancy sensor for controlling a light scene which use the same bus system. Devices out of different industries are combined in the *Inter-Industry layer* – they still use the same communication technology, but they have been designed for different industry areas. In case of different systems or technologies respectively, the combination is done in the *Inter-System Layer*.

According to the human senses, the data adaptation results in merging and processing of the data collected (cf. *Memory Traces* in Fig. 2). Due to this, the layers allow the definition of symbol stocks for the common information base in order to achieve an unrestricted data exchange, a description of the common language. This symbol stock has to ensure the correct transformation of the information (syntax) and it has to represent the correct meaning of the data (semantic). Moreover, it has to satisfy the requirements by the different technologies used for the bottom layer. It must be possible to map various information types from the sensors (strings, numbers, binary values, data structures, etc.) to symbolic representations.

The combination of diversified information leads to a very promising discipline: sensor fusion. Take, as an example, pressure sensors that work much better (more accurate) when they are "supported" by a temperature sensor. Accuracy is, however, not the only thing that we can gain from sensor fusion. Sometimes it is possible to come to an entirely other (higher) level of information: Two cameras combined can not only deliver a more accurate 2D image than one camera. They can rather provide a 3D image with distance information. This is exactly what happens in the human brain when information from various and divers sensors is merged to symbols.

The result of the sensor fusion is passed to the *Representation Layer* where a detection that a potential dangerous situation occurs can be started and passed to the *Situation Recognition Layer*. Based on the symbols and memory traces a proper reaction can follow (cf. *Affect* in Fig. 2).

Fig. 5 shows by example how symbols can be defined and a situation can be detected. For better understanding, we selected a common situation that takes place in a kitchen.

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Our symbols hold information pertaining to the persons affected (e.g. child), the location of effect (e.g. far away, in range, close, near) and the purpose of data points (e.g. stove).

Data points are collected by several different sensors. Basically, the first three sensors, the occupancy and the distance sensor (working in an EIB network), and the feedback of a relays contact (working in a LON network) provide information that there is someone near the stove. The last sensor, i.e. a camera transmitting data via FireWire is used to determine who actually is present in the kitchen. Using the different interoperability layers, the different sensor information is merged ("fusioned"). The distance sensor and the occupancy sensor are out of same industry and thanks to specific interworking standards can be combined easily. It is the task of the Inter-Industry Layer to join the feedback of the relays contact and the EIB sensors. Since the camera is based on a completely different technology, the result of the first three sensors (someone near the stove) and the information from the camera (small person, possibly child) are merged in the Inter-system layer.

| | | | | |
|---|---|---|---|---|
| Representation Layer | Potential dangerous situation: Child near hot stove | | | |
| Inter-System Layer | Child near hot stove | | | |
| Inter-Industry Layer | Someone near hot stove | | | |
| Intra-Industry Layer | Someone present | Someone near stove | on | Small person possibly child |
| Communication Layer | Occupancy (EIB) | Distance (EIB) | Stove (LON) | Media (FireWire) |

Fig. 5. Example for sensor interaction

Evaluating the symbols means judging the situation. Up to now this evaluation is done statically: there is a rule base, some thresholds, maximum levels etc. to find out what the set of valid symbols actually mean for the current situation. We want to introduce another "feature" of the human mind which evolutionarily has proven its usefulness: feelings. We see feelings as the "weights" of our evaluation network. Depending on the current condition (angry, anxious, etc.) one and the same set of symbols can be evaluated differently. This condition, the current feeling, is, however, a result of previous symbols (sensory information, memory knowledge). Therefore we have introduced a feedback into our system (if you are already anxious, almost every sensed sound makes you even more anxious) that needs careful examination. This feelings transforms the static evaluation into a dynamic one.

## IV. The Architectural Gap

The parallel nature of bionic algorithms does simply not fit to traditional "von Neumann" machines. It makes a big difference to implement an ANN in software, hosted on a universal Neumann machine, or in software that is running on a machine specialized for ANNs. The difference between data structures of higher programming languages (e.g. objects or structures) and the real data structures on the machine (e.g. bit octets) is often referred to as the "semantic gap". The machine does not know about the object or the structure and can only treat octets. Therefore all operations on this structure must be composed of sequential octet operations: a universal but very inefficient way.

Our system might have even larger gaps. The model describes a flow of (massive) data and layers that process and condense this data. If this model is supposed to be implemented by using an ordinary general purpose Neumann machine, we might come to the situation where the simplest operations (simple for our model) lead to massive problems on the Neumann architecture. Especially the large amounts of data that we are facing in our model might not be processable with traditional hardware. Data flow or connectionist architectures stand in contrast to the control flow architecture and might be more appropriate. Very promising approaches for hosting bionic algorithms are done in nano-computing [11] and other parallel architectures [12].

The concepts discussed in this paper partly rely on layers of bionic software that can not be implemented efficiently on standard hardware. It will therefore be of eminent importance to find or develop suitable hardware that supports our model. This will have to happen by using dataflow models and parallel dedicated hardware computation [1].

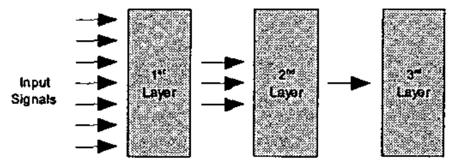


Fig. 6. Data flow through processing layers

Fig. 6 shows the principle of the intended data flow architecture.

Each layer has its own set of symbols and condenses the information that flows from left to right. Since the software model uses autonomous layers that work in parallel (on sequential data) it is just natural to reflect this structure in hardware, instead of implementing it in, for example, a multi-threaded software program, running on a general purpose "von Neumann" machine. The higher layers of our model might still be based on traditional databases and general purpose computers. The "lower" layers, those that are nearer to the sensor, however have to deal with an extreme amount of data and need specialized hardware that uses parallel processing and data flow methods.

The feedback of "feelings" as described before must be reflected in this hardware as well. If the system is for instance in the state "Alertness", the first layer of the optical sensors might be "rewired" in order to react on fast movements.

## V. Conclusion and Outlook

To achieve a high capacity of perception, additional technical requirements have to be faced. Large amounts of data have to be collected and stored form different resources of different technologies. Data processing will be executed on different levels simultaneously. Traditional control networks can provide basic communication. But not only communication between devices of the same technologies, but also devices based on different technologies is necessary for global perception.

Our model lays the foundation for future systems of control networks. Interoperability is fulfilled on three levels:

1. Within industries,
2. Between different industries, and
3. Between different systems.

The first level can be provided with existing profiles. Within the model two powerful levels can be added to achieve global interoperability. By using the storage of knowledge of the system and a complex system of data and process management two further capable mechanisms have been integrated.

Putting this theoretic model into practice is an interdisciplinary project that involves scientists from psycho analysis to computer science. We intend to verify as much of the model as possible in simulations. Implementing the system is the final challenge and subject to further publications. We are aware of the fact, that it will be hard to put the theoretical model into practice, when considering today's hardware. Therefore, we presented a first outlook on new ideas about possible hardware architectures applicable for our model.

## REFERENCES


[1] Warneke, B.; Last, M.; Liebowitz, B.; Pister, K.: Smart Dust: Communicating with a Cubic-Millimeter Computer; IEEE Computer, 2001, S. 2-9.

[2] Kabitzsch, K.; Dietrich, D.; Pratl, G.: LonWorks Gewerkeübergreifende Systeme. VDE Verlag Berlin Offenbach 2002, ISBN 3-8007-2669-6.

[3] Ramachandran V.s., Blackeslee S.: Phantoms in the Brain. Probing the Mysteries of the Human Mind, William Morrow and Company, Inc., New York, 1998.

[4] Borgelt C., Klawonn F., Kruse R. , Nauck D.: Neuro-Fuzzy-Systeme, Vieweg Verlag, Wiesbaden 2003.

[5] Eccles, J. C.: The Evolution of the Brain – Creation of the Self; Routledge, London, 1989.

[6] Eccles, J. C.: How the Self Controls its Brain; Springer Verlag Berlin, Heidelberg, 1994.

[7] Karen Kaplan-Solms, Mark Solms: Clinical Studies in Neuro-Psychoanalysis; International Universities Press, Inc., Madison, CT; 2000.

[8] Solms, M., Turnbull, O.: The Brain and the Inner World; Karnac/Other Press, Cathy Miller Foreign Rights Agency, London, England, 2002.

[9] Solms M.: What is consciousness?, Journal of the American Psychoanalytic Association, 1997.

[10] D. Dietrich, W. Kastner, T. Maly, Ch. Roesener, G. Russ, H. Schweinzer: Situation Modeling; Proceedings of the 5th IEEE International Workshop on Factory Communication Systems WFCS04, Vienna, 2004.

[11] L. Durbeck and N. Macias: The Cell Matrix: An Architecture for Nanocomputing, Nanotechnology 12 (September 2001) 217-230, the Institute of Physics.

[12] Oguri, K., Imlig, N., Ito, H., Nagami, K., Konishi, R., and Shiozawa, T.: General Purpose Computer Architecture Based on Fully Programmable Logic, Proc. of Inter. Conference on Evolvable Systems: From Biology to Hardware (ICES'98), Springer Verlag, LNCS 1478, pp. 324-334, 1998.

[13] R. A. Iannucci: Toward a dataflow/von Neumann hybrid architecture, Proceedings of the 15th Annual International Symposium on Computer architecture, Honolulu, Hawaii, United States, ISSN:0163-5964, pp. 131 – 140, 1988 [Moore1997] Ronald Moore, Bernd Klauer and Klaus Waldschmidt: What Computer Architecture can Learn from Computational Intelligence - and Vice Versa, EUROMICRO '97, Budapest, Hungary, Sept. 1997.



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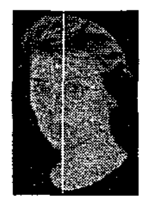

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