Modelling of Human Behaviour
The PECS Reference Model

Prof. Dr. Bernd Schmidt
Lehrstuhl für OR und Systemtheorie
Universität Passau
Innstrasse 33, 94032 Passau
E-Mail: bschmidt@fmi.uni-passau.de

KEYWORDS

Human Behaviour, Emotion and Cognition, Emotional Intelligence, PECS - Architecture

ABSTRACT

PECS is a multi-purpose reference model for the simulation of human behaviour in a social environment. Particular emphasis is placed on emergent behaviour which is typical of the formation of groups and societies in social systems.
Human behaviour is highly complex in its structure. It is influenced by physical, emotional, cognitive and social factors. The human being is consequently perceived as a psychosomatic unit with cognitive capacities who is embedded in a social environment.

1 THE PECS REFERENCE MODEL

PECS is a reference model which makes it possible to specify and to model these factors and their interactions. A detailed description of the PECS reference model and its underlying methodology including some basic examples can be found in [Schmidt 2000 & 2002].

PECS stands for:
Physical conditions
Emotional state
Cognitive Capabilities
Social Status

The PECS reference model aims to replace the so-called BDI (Belief, Desire, Intention) architecture [Rao 1995]. Architectures which conceive of human beings as rational decision-makers are only to a very limited degree sensible and useful. Restriction to the factors of belief, desire and intention is simply not appropriate for sophisticated models aiming to model real social systems.
The basic approach adopted for the modelling of human behaviour is explained using the *Adam* model. This model shows the interplay of physical, emotional and cognitive components in an individual. The complete model is described in detail in [Schmidt 2000 & 2002].

The PECS reference model opens up new challenging possibilities for the modelling of systems which include human factors as important and decisive subcomponents. PECS is especially useful when complex human behaviour has to be taken into account which includes physical conditions, emotional states. cognitive capabilities and the social status along with their mutual interactions.

A reference model can serve as a blueprint for a class of real systems. It shows the structure of a model for all real systems that have a common deep structure and that differ only in superficial qualities.
PECS models in this sense are a reference model for the modelling of human behaviour. The architecture proposed here claims to be universally applicable. Adaptation to individual conditions occurs by means of filling in the empty spaces provided by the architecture. This means for example that the number and the type of state variables, the structure of the transfer function F and the development of the output function g can be modified without difficulty. Similarly the agent can be endowed with a varied repertoire of actions that state what external actions the agent is to be capable of. As a result very diverse agents and agent communities develop but they all have the same deep structure and therefore they can all be described by one and the same reference model.
The following sections describe the PECS reference model. They are for the most part based on [Urban 2000a], where a more detailed and wide-ranging description is given.

1.1 The Structure of the Agent World

The agent world of the reference model PECS consists of the following fundamental components:

- the environment component
- the connector component
- the agents

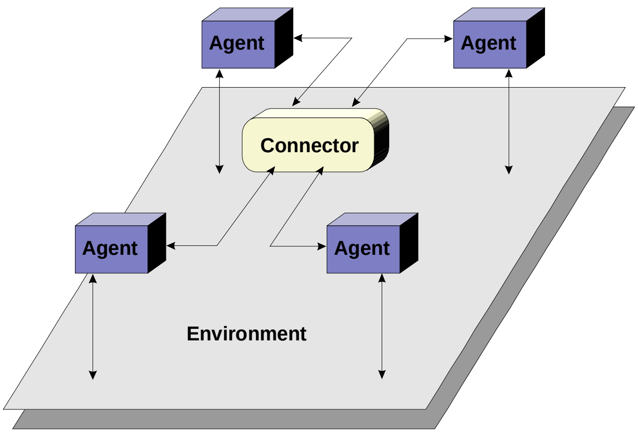

Diagram 1.1 The Structure of the Agent World

Diagram 1.1 shows the basic structure.

Proceedings 14th European Simulation Symposium
A. Verbraeck, W. Krug, eds. (c) SCS Europe BVBA, 2002

1.2 The Environment

The Environment component is used to model external events and influences which are important for the behaviour and the actions of agents. It may also include other agents.
This environment is also reflected in the agents‘ knowledge. The environmental knowledge that an agent has and that is represented in the model it has made of the environment may be incomplete, uncertain and even erroneous.
As the environment is generally very diverse and difficult to squeeze into a uniform schema, the PECS reference model provides little assistance in this respect. It merely provides a frame within which the agents can move. The individual design of the environment component is a matter for the user alone.

1.3 The Connector

Communication is an essential aspect of multi-agent systems. The basic principle is that all agents must have the possibility of communicating with all other agents. For this purpose the Connector component is introduced, which serves as a central switchboard that organises the exchange of information between agents. Again, its individual design is a matter for the user.

1.4 The Structure of PECS Agents

Diagram 1.2 shows the structure and the internal organisation of a PECS agent. The basic structure is clearly recognisable: Based on system theory, it consists of input, internal state and output.
The upper level with the components Sensor and Perception corresponds to the input. These components are responsible for the reception and initial processing of information from the environment.
The middle 4 components, i.e. Status, Cognition, Emotion and Physis contain the state variables of the agent and their changes of state. The state transition function F states in F, which states in what way and on the basis of which dependencies the state variables of the relevant class may change.
The components at the bottom of the diagram, i.e. Behaviour and Actor, are responsible for output. Here we find the output function g.
The Behaviour component determines the execution order. It contains the set of rules on the basis of which an execution order is issued as it were automatically.
The execution orders are passed on to the Actor, who is responsible for their execution. The Actor contains the full repertoire of actions of which the agent is capable. These actions can be subdivided into internal and external actions.
Internal actions relate to agents themselves. They include for example *Reflection* or *Reformulate Goal* or *Focus Attention on a Point in the Environment*. External actions impact on the environment as well as on the other agents that belong to the environment. External actions for example are *Move to the Next Field* or *Send Information to Agents XYZ.*

The execution of an action in the Actor is modelled as a time-consuming process that can be interrupted by more important incoming execution orders.
The black arrows in Diagram 1.2 represent causal dependencies. Perception for example, which carries out an initial processing of the incoming input depends on all 4 classes of the internal state variables.
Selective perception may serve as an illustration:

- What perception filters out from the input signals received from Sensor and what it processes further and in what manner may depend on the physical state, on current emotions, on available knowledge of the world and on social status.

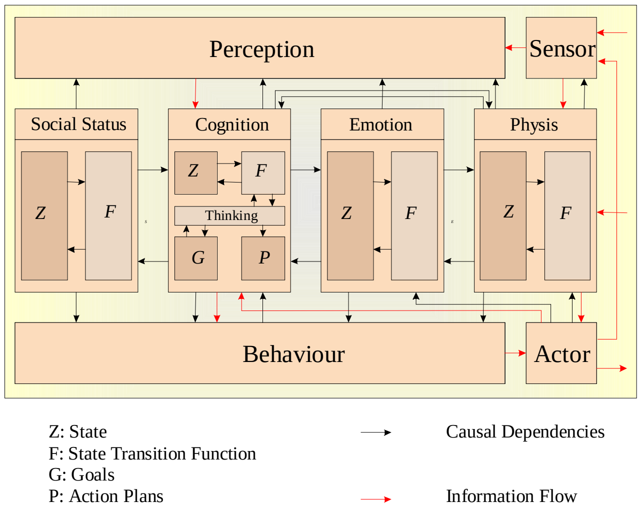

Diagram 1.2 The Structure of a PECS Agent

The red arrows in Diagram 1.2 represent the flow of information. These arrows may be thought of as paths for messages. There is for example a path leading form sensor to perception. Here the raw input data flow into the perception component, where they are further processed and then passed on to the cognition component. Similarly there is an arrow leading from the behaviour component to the actor component. Here the execution orders originating in the behaviour component are passed on to the actor, where they await processing.

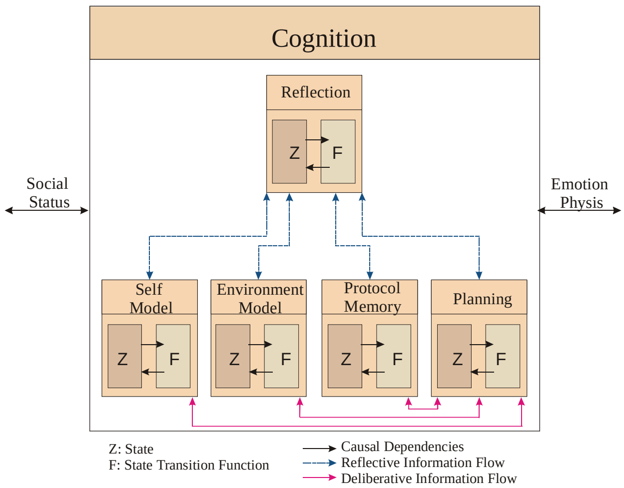

Diagram 1.3 : The interior of the component *Cognition*

1.5 The component Cognition

The *PECS* reference model is based on the *component-oriented, hierarchical modelling principle*. Accordingly, complex components can be functionally decomposed into a set of specialised, interconnected sub-components. Following this maxim, the component *Cognition* of the *PECS* reference model will be subdivided into five components: the component *Self Model*, the component *Environment Model*, the component *Protocol Memory*, the component *Planning* and the component *Reflection*. Each of these sub-components contains its own state variables and its own state transition function. Of particular interest for the modelling of human cognition are the causal dependencies that may exist between each sub-component and the components *Social Status*, *Emotion* and *Physis*. Diagram 1.3 shows the interior of the component *Cognition*.

The component *Self Model* contains the agent's knowledge about its internal state and related operations. The component *Environment Model* stores a mental representation of the agent's environment and processes designed to manipulate and extend this representation. The idea for a component *Protocol Memory* was inspired by the approach taken by the Dörner [Dörner 1999]. The component *Protocol Memory* gathers information about executed action sequences, formerly pursued plans and methods used to analyse them. Within the component *Planning*, planning knowledge and the planning process are modelled. The planning process is responsible for the generation of a plan to reach the agent's current goal. To do this, it can retrieve information from the components *Self Model*, *Environment Model* and *Protocol Memory*. The basic idea of having a component *Reflection* was taken from A. Sloman, who proposed a three-layered architecture for human-like agents including a Meta-Management-Layer [Sloman 2000]. The function of the component *Reflection* is to monitor, evaluate and improve internal processes. In order to perform this task, reflective processes can exchange information with the components *Self Model*, *Environment Model*, *Protocol Memory* and *Planning*.

The idea is to adapt the structure of the component *Cognition* to the requirements of the current problem. For example, a human-like agent with simple planning capabilities may be needed. In this case, it may be sufficient to fill the components *Environment Model* and *Planning*. In a different scenario, an agent must be enabled to reformulate its goals and to improve its planning strategies. Under these circumstances, the component *Reflection* provides the scope needed to model the required reflective processes.

2 DESIRES, MOTIVES AND ACTIONS

In some simple cases, the state variables directly determine the behaviour of an agent. This is particularly the case with reactive behaviour.

In general the situation is more complex. Behaviour is usually dependent on drives, needs or desires which can be regarded as motives. The strength or intensity of these motives is a function of the state variables. Thus in this case the state variables do not determine behaviour directly, but rather indirectly, via the motives belonging to them. This basic idea was adopted from [Dörner 1999] and generalised to include all four possible classes of motives.

Drives, needs and desires can be very diverse. The PECS reference model provides no directions about which ones should be included. PECS simply contains empty spaces into which the user can insert the drives, needs or desires he considers to be relevant.

It is possible to arrange the desires in a hierarchical order, as in the humanistic approach of Maslow [Maslow 1954]. It is equally possible to adopt a position where all the desires compete with one another on the same level, as in the approach of Reiss. Reiss assumes 16 different basic desires that motivate our behaviour and define our personality. [Reiss 2000].

Drives, emotional intensity, will and social desire are all called motives. Thus "motive" is a collective concept comprising four different constructs.

Motives are not static but change continuously over time. Moreover, they compete with one another. The strongest one becomes the action-guiding motive and determines the action the agent performs.

Since drives, emotional intensity, strength of will and social desire are all regarded as motives, and since each of these motives has a corresponding intensity, motives can be compared with each other. It is thus possible to establish which motive is the strongest at a given time and hence determine the action to be executed.

For example, it is possible for an agent to experience hunger at the same time as following the goal of tidying the house. In addition, he feels lonely and wants to go out to see friends.

We then have the following scenario:

1.) Intensity of the drive hunger
    Drive-controlled behaviour: Go to the fridge
2.) Intensity of will
    Will-controlled behaviour: Tidy the room
3.) Intensity of social desire
    Socially controlled behaviour: Go to a party

At the beginning, the agent's will may have the highest intensity. That means the agent will start to tidy the house. However, as time goes by hunger may become stronger and stronger. At some point the intensity of hunger will overtake the intensity of will that led to the action of tidying the house. The action of tidying stops and is replaced by going to the fridge.

The three motives are not constant, but change over time. Therefore different motives may be action-determining at different times. Thus for example, it is possible that initially the intensity of will has the highest value, and so the agent is interrupted. A new motive takes control. The agent goes to the fridge.

The proposed methodology makes it possible to combine motives as diverse as intensity of drives, emotional intensity, strength of will and intensity of social desire. Furthermore, the rich and vivid dynamics which exist within the mind of an agent can be modelled in a clear and manageable way.

Diagram 2.1 shows this competition between the four different kinds of motives.

Under the proposed methodology, the following steps are carried out before an agent undertakes an action:

1.) Determine the new values of the internal state variables using the state transfer function F.
2.) Calculate the corresponding intensity of each motive using the function H.
3.) Compare the various competing motives and select the one with the highest intensity as the action-guiding one.
4.) Perform the action which is demanded by the action-guided motive.

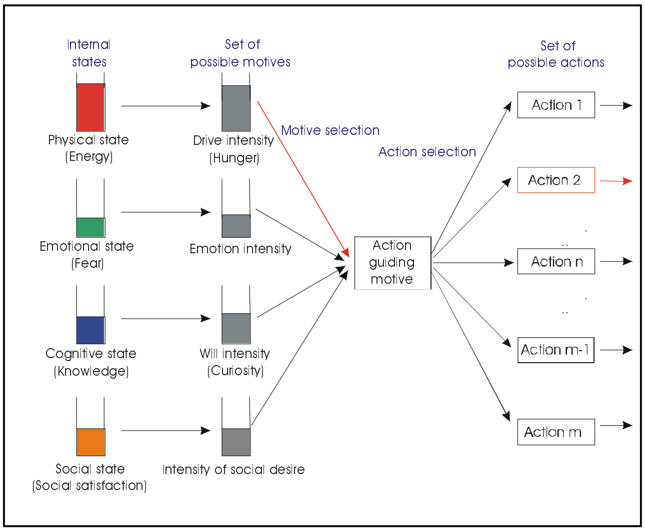

Diagram 2.1 Motives and motive selection

3 EMOTIONAL INTELLIGENCE AND THE ADAM MODEL

The reference model PECS provides a general framework for specifying physical, emotional, cognitive and social factors and their interactions. Especially interesting are the interactions and the mutual dependencies. As an example the process of emotional intelligence will be investigated. In this case, there is a close interrelation between cognition and emotion. Both influence on another in a very intricate way.
The investigation is conducted within the Adam model. Originally, this model has a much wider range. Emotional intelligence is only one aspect of it. The complete model is described in detail in [Schmidt 2000 & 2002].
Further concepts can be found at [Cañamero 1997], [Damasio 1994], [Ortony 1988], [Picard 1997] and [Velásquez 1997.]

3.1 Emotion and Cognition

The case study is based on aspects of the psychological concept introduced in 1990 by J. D. Mayer & P. Salovey in Emotional Intelligence [Mayer & Salovey 1990] and popularised by D. Goleman, author of the best-seller "Emotional Intelligence. Why it can matter more than IQ" [Goleman 1995]. Mayer & Salovey defined emotional intelligence as "the ability to monitor one's own and others' feelings and emotions, to discriminate among them, and to use this information to guide one's thinking and action".
This short definition makes clear that the following aspects are part of the process:

* The emotions and their dynamics
* The capability to observe and to monitor the actual emotions
* The cognitive capability to recognise and to categorise the emotions
* The act of will to influence the emotions and to replace the emotion-induced actions by others more sensible ones.

A short example exemplifies the procedure:
An agent A is working as a project manager. He is in charge of a task force comprising several agents. A receives from agent B a message containing a status report on a task which A has to keep track of. A evaluates the job B has done up to this point and realises that B has made a serious mistake leading to a significant time delay.

* Emotions and their dynamics
  A gets angry and feels a strong desire to reproach B in front of the group. Under normal circumstances, that increase in A's emotion of anger would lead to an increase in the corresponding motive AngerM, that as a consequence would cause to the action of reproaching the co-worker.

* The capability to observe and to monitor the actual emotions
  If A has a high degree of emotional intelligence he will be able to avoid being carried away by his emotions. He is able to observe what is going on inside of him. He notices that he became upset.

* The cognitive capability to recognise and to categorise the emotions
  He realises that it is the increased anger that troubles him and that motivates him to reproach B.

* The act of will to influence the emotions and to replace the emotion-induced actions by others more sensible ones.
  If the emotion stays within manageable limits and if A's will is strong enough A consciously decides not to yield to his emotions but to control them and to discuss the problem with B in a calm and deliberate way.

3.2 The emotion Anger and the Motive AngerM

The emotion anger is modelled in the usual way. Anger is made a state variable.
Without an input, that means without a triggering event from outside, the state variable Anger decreases continuously over time. This process can be modelled by the following equation:

$$Anger := AngerMax * e^{AngerDecrease * Anger} \qquad \text{(Equ. 3.1)}$$

An event from outside leads to a sudden, discrete increase of Anger.

Diagram 3.1 shows this discrete increase and the continuous decay of the state variable Anger.

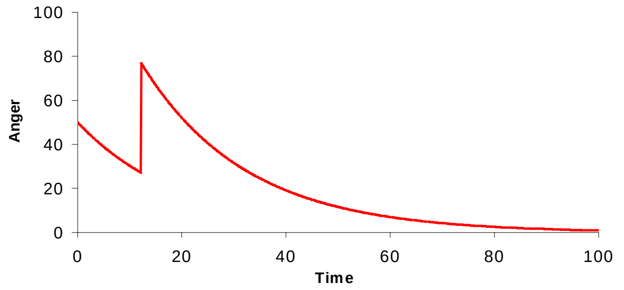

Diagram 3.1 The dynamics of the state variable Anger

The emotional state is connected to the corresponding motive AngerM.

$$AngerM := \frac{AngerMMax}{(1+e^{-AngerMIncrease*(Anger-AngerMTurn)})} \qquad \text{(Equ. 3.2)}$$

Diagram 3.2 shows the dependency of motive AngerM from the state Anger.

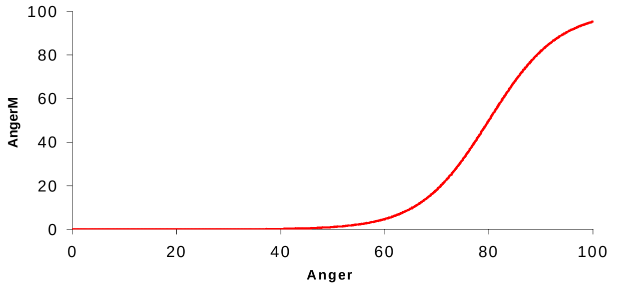

Diagram 3.2 The intensity of the motive AngerM in dependence of the state variable Anger

Two points should be kept in mind:

* It is not the state variable Anger but the motive AngerM that leads to an action in the end.
* The motive AngerM does not lead to an action at any rate. AngerM has to compete with other motives. Only if AngerM is the strongest motive and dominates all the others, AngerM determines, what the agent does. (See diagram 3.1)

3.3 The Emotional Intelligence Quotient EQ

The state variable EQ is introduced as a measure of the degree of an agent's emotional intelligence. We assume that the agent has an innate EQ that can increase throughout its life span. The agent may gain emotional experience and enhance its capabilities of emotional intelligence [Mayer & Salovey 1997]. To simplify things, it is assumed that the process of learning depends on the time taken by the agent to reflect upon its emotional state and that this can be described by the following differential equation:

$$EQ' = EQIncrease * \frac{EQMax - EQ}{EQMax} * EQ \qquad \text{(Equ. 3.3)}$$

The EQ has an influence on the agent's ability to perceive, monitor and regulate its emotional state.

3.4 The self-perception

The self-perception enables an agent to observe and to monitor his own state. The information the self-perception provides is stored in the component self-model. (See diagram 3.3)
All reflective considerations are based on the state of the self-model. That means that an agent does not have access to his original state variables but only to the state variables he observed and which entered in his self-model. This accounts for the obvious fact, that the motives and the actions of an agent are not determined by what is the case but by what the agent thinks or beliefs is the case.

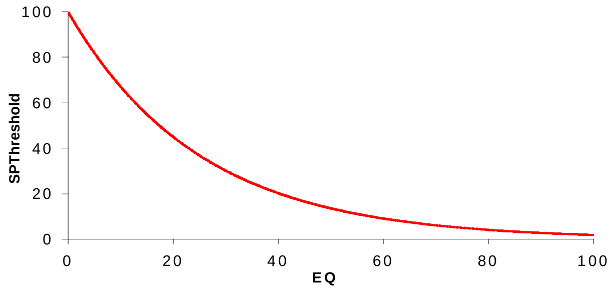

Diagram 3.3 The dependency between the self-perception threshold and the EQ

Before an emotion is observed and before the value is transferred to the self-model, the emotion must have a definite strength. This self-perception threshold SPThreshold from which onwards an emotion is observed depends on the EQ. Equation 3.4 describes this matter of fact.

$$SPThreshold := SPThresholdMax * e^{SPThresholdDecrease * EQ} \qquad \text{(Equ. 3.4)}$$

The diagram 3.3 shows that an agent with a high EQ is able to observe and monitor already small emotions whereas an agent with a low EQ needs very strong emotions before he is able to realise them and to incorporate them in his self-model.

3.5 The Competition between AngerM and AngerControlM

The motive AngerControlM is a motive that indicates the willpower. (See Diagram 3.4) The value of AngerControlM depends on the EQ and on the observed value of the emotion AngerPerceived.

$$AngerControlM := \frac{AngerControlMMax * b * EQ}{(1+e^{-AngerControlMIncrease*(PerceivedAnger-AngerControlMTurn)})} \qquad \text{(Equ 3.5)}$$

Diagram 3.4 shows the dependency of AngerControlM on the EQ. One sees, that the strength of the motive increases if the EQ increases as well. That means, that with the same observed value for AngerPerceived the will to do something against that anger is the higher the higher the EQ is.

Furthermore, the diagram 3.4 shows again the values for AngerM, which are taken over from diagram 3.2.
Let us assume that the real anger and the perceived anger both have the value 80. For an agent with an EQ of 25 the value for the motive AngerControlM is approximately 20. The value for the motive AngerM is EQ-independent and has the value of approximately 60. That means that that AngerM has a higher value than AngerControlM and therefore becomes action-leading. The emotion anger dictates the behaviour. The deliberative motive to control the emotion is too weak. However, for an agent with a higher EQ e.g. 75 the situation is different. Because of his high EQ his motive AngerControlM is higher than his motive AngerM and therefore, he is able to determine the course of his actions deliberately.

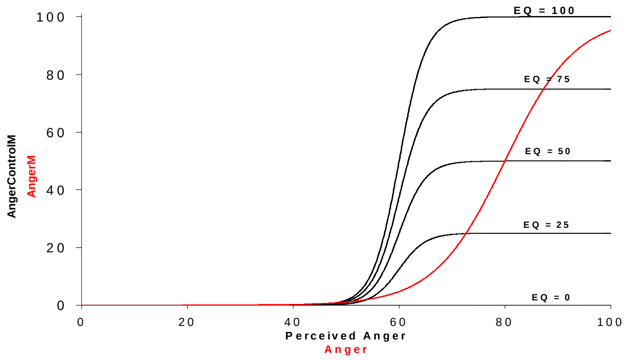

Diagram 3.4 The competition between the two motives AngerM and AngerControlM

4 CONCLUSIONS

Human behaviour is strongly influenced by physical, emotional, cognitive and social factors. All of them play a role and determine the inner life of a human being. It is certainly an unjustified oversimplification to consider only a few factors and declare them as basic.
Agents intended to represent human beings should be able to show individual behaviour, and should resemble their human counterparts in those respects which are relevant to the situation. Fortunately, it is not necessary for this purpose to model all human personality traits. The designer of an artificial agent can concentrate on those attributes which are relevant for a particular task. Therefore the internal structure of an agent is not generally and universally valid, but should be adapted to the task the agent has to fulfil.
The PECS reference model is an open architecture which provides a framework with spaces that can be filled in by the user, according to the problem to be dealt with. By giving an agent more internal state variables, it is possible to enrich his inner life.
The PECS architecture allows the rich and vivid dynamics within the mind of an agent to be modelled in a clear, understandable and manageable way, incorporating a wide variety of possible personality traits. Therefore, the PECS reference model opens up a new possibilities for modelling human behaviour in all its complexity.

Bibliography

Cañamero, D. (1997); Modeling Motivations and Emotions as a Basis for Intelligent Behaviour, in: Johnson, W. L. (ed.), Proceedings of the First International Symposium on Autonomous Agents (Agents ’97), The ACM Press, New York, 148-155

Damasio, A. R. (1994), Descartes’ Error, Emotion Reason and the Human Brain, Grosset/Putnam Books, New York

Dörner, D. (1999); Bauplan für eine Seele; Rowohlt Verlag, Reinbeck bei Hamburg

Goleman, D. (1995); Emotional Intelligence. Why it can matter more than IQ, Bantam Books, New York

Maslow, A. (1954); Motivation and Personality; Harper and Row, New York

Mayer, J.D., Salovey, P. (1990); Emotional Intelligence, in: Imagination, Cognition and Personality, 9, 185-211

Mayer, J.D., Salovey, P. (1997); What Is Emotional Intelligence ?, in: Emotional development and emotional intelligence, BasicBooks, New York, 3-32

Ortony, A., Clore, G. L., Collins, A. (1988); The Cognitive Structure of Emotions, Cambridge University Press, Cambridge, UK

Picard, R. (1997); Affective Computing; MIT Press, Cambridge

Rao,A.S., et al. (1995); BDI-Agents: Fron Theorie to Practice; in: Proceedings of the First International Conference on Multi-Agents-Systems

Reiss, S. (2000); Who am I? The 16 basic desires that motivate our behaviour and define our personality; Penguin Putman, New York

Schmidt, B. (2000); The Modelling of Human Behaviour, SCS-Europe BVBA, Ghent

Schmidt, B. (2002); http://www.or.uni-passau.de/english/2/Human_Factors.php3

Sloman, A. (2000); Architectural requirements for human-like agents both natural and artificial. (What sorts of machines can love?), in: Human Cognition and Social Agent Technology, Advances in Consciousness Research, John Benjamins, Amsterdam, 163-195.

Urban, C. (2000a); PECS – A Reference Model for the Simulation of Multi-Agent Systems, in: Suleiman, R., Troitzsch, K. G., Gilbert, G. N. (eds.), Tools and Techniques for Social Science Simulation, Physica Verlag, Heidelberg

Velásquez, J. (1997); Modeling Emotions and Other Motivations in Synthetic Agents, in: Proceedings of the National conference on Artificial Intelligence (AAAI-97), MIT/AAAI Press