AGENT- BASED MODELLING OF HUMAN ACTING, DECIDING AND BEHAVIOUR - THE REFERENCE MODEL PECS

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ABSTRACT

Agent- based modelling and simulation is a powerful tool in studying complex systems. For the purpose of designing related simulation models, it is helpful to utilize already existing problem- related design patterns: reference models.

The PECS reference model provides capabilities for object- oriented model specification Its application area is settled in the field of agent- based simulation, especially for models deriving from studies in sociology, economy and psychology. Major aspect is the modelling of human acting and deciding, interaction of human beings with each other and with their environment, where a human being is considered a psychosomatic unit with cognitive capacities embedded in a social environment. Accordingly, the PECS architecture takes into account physical conditions, emotional states, cognitive capabilities and social status that are represented each by specialised components: Physis, Emotion, Cognition and Social Status from which the name of the PECS reference model derive.

The presented case study is supposed to explain the interplay between the PECS components in order to control and to coordinate the available reactive, deliberative and reflective behavioural patterns that enable a PECS agent to show the most complex form of human behaviour: emotional intelligent behaviour.

INTRODUCTION

Agent- based methods are suitable for constructing simulation models in which human behaviour is of importance. Human behaviour must not be reduced only to cognitive capabilities. More complex theories, among them the ψ- Theory by Dörner (Dörner 1999), additionally take into consideration physical and emotional circumstances as well as human interplay with a social background. In order to follow that approach, it gets necessary to model all known modes for the control of behaviour: reactive, deliberative and reflective behaviour. A description of these behavioural patterns is provided in (Schmidt 2000).

The PECS reference model described in (Urban 2000) and (Urban 2004) provides capabilities to model these forms of human behaviour. Taking into account a close interrelation between the components Emotion and Cognition, it is possible to model furthermore the most complex form of human behaviour called emotional intelligent behaviour, specified in (Mayer & Salovey 1997).

As a domain independent methodology-founded scheme of construction as proposed in (Klinger 1999), the PECS reference model acts as a pattern for the agent Adam. The agent itself is implemented as a Simplex3-simulation model. A detailed description of the model Adam can be found in (Schmidt 2000). Its implementation realises the ideas and principles introduced in this article and enables the agent to show emotional intelligent behaviour.

1 REFERENCE MODELS AND ARCHITECTURAL PATTERNS

A reference model describes a standard solution for an entire class of problems and serves as a blueprint for a class of real systems having a common deep structure and that do differ only in superficial qualities. Major aim in using reference models is to reduce the complexity of design tasks and thereby reducing the effort in time and work concerning the simulation model development. A reference models capacity depends on the size of its set of solvable problems.

With the PECS reference model, an architecture is proposed that applies to a wide range of systems where human behaviour plays a part. The principal architecture proposed here claims to be applicable for more than just special ad hoc cases. Adopting the general reference model to individual peculiarities of a real system is possible by filling in the empty spaces provided by the architecture. This means, for example, that the number and the type of state variables, the

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dependent variables as well as the structure of the transfer function F, the algebraic function H and the output function G can be modified without difficulty. Similarly, the agent can be endowed with a diverse repertoire of actions that india cate the internal and external actions that the agent is capable of. As a result, very diverse agents and communities of agents can be described with the same reference model.

1.1 Agents As Representatives For Humans

The application area for human-like agents is very wide. It comprises among others:

- figures in games,
- actors in movies,
- robots who interact with humans,
- software assistants meant to help users,
- tutors in teaching and learning systems,
- software agents meant to provide information to their clients,
- delegates for customers in e-commerce,
- humans in simulation models including human factors such as workers,
- human beings in social psychological theories.

In order to answer the question of whether human beings can really be modelled and whether human like agents can be designed at all, it must be pointed out that a model is never a direct replica of real facts. A model is always an abridged, reduced version of its original.

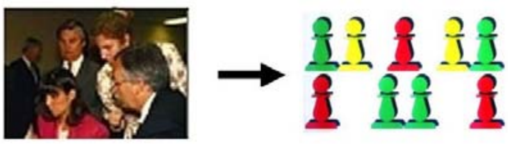

Figure 1: Real human beings and agents as their models

Agents as model-representatives for humans are constructed using the methodology of abstraction and idealisation. This filtering process of idealisation and abstraction reduces real human beings to agents. Figure 1 shows that the rich and colourful real situation is modelled by agents that look very simple. The model does not contain all the qualities that distinguish human beings as human beings. Nevertheless, agents can still have a purpose in science, technology and theory

1.2 System-Theoretical Principles

The basic methodology of the PECS architecture is based on system theory.

A system in terms of system theory is characterrised by a set of state variables. These state variables can change their value on the basis of their own dynamics or on the basis of an external input. In addition to the state variables, there can be so called dependent variables, which can be calculated by means of the state variables. The modified internal system state consisting of the new state variables and the new dependent variables will then lead to an output that can, in some cases, take on the form of an action.

The transfer function F describes how the system state variable $z(t_n)$ turns into the subsequent state $z(t_{n+1})$,

in the time-discrete case:

$$z(t_{n+1}) = F(t_n, z(t_n), w(t_n), x(t) \quad (1)$$

in the time-continuous case:

$$z'(t) = F(t, z(t), w(t), x(t)) \quad (2)$$

The algebraic function H describes the relation between the state variable $z(t_{n+1})$ and the dependent variable $w(t_{n+1})$:

$$w(t_{n+1}) = H(t_{n+1}, z(t_{n+1})) \quad (3)$$

The output function G determines the manner in which the new internal state, which came about as a result of the input, shows itself as output $y(t_{n+1})$ to the outside:

$$y(t_{n+1}) = G(t_{n+1}, z(t_{n+1}), w(t_{n+1}), x(t_{n+1})) \quad (4)$$

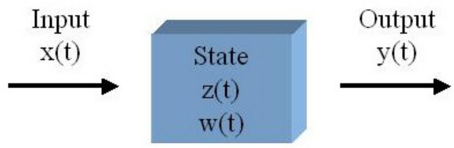

Figure 2: System-theoretical basis for the PECS architecture

An example could be the state variable Fear. It can change by itself or through input from the outside. Figure 6 shows how Fear decreases when nothing happens. A sudden frightening experience as input leads to a sudden increase. It is the function F that describes both these changes in time.

The dependent variable FearM is closely correlated to the state variable Fear. FearM is the corresponding strength of the motive to reduce that fear. The stronger the fear, the higher the value for the motive strength FearM. The algebraic function H determines the dependency of FearM on Fear. (See Figure 7)

2 THE PECS AGENT

The internal structure of a PECS agent is based on a system-theoretic approach and on the usual architecture in robotics. Accordingly, the structure can be divided into

- an input layer consisting of the components Sensor and Perception,
- an internal layer describing the state of the agent and including the components Physis, Emotion, Cognition and Social Status,
- an output layer comprising the components Be-haviour and Actor.

Figure 3 illustrates the overall structure of a PECS agent.

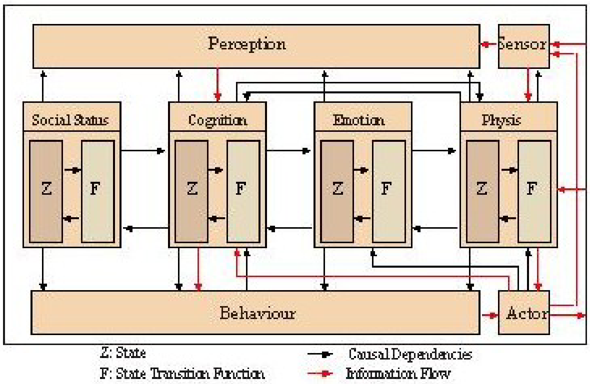

Figure 3: The internal structure of a Pecs Agent

2.1 Structure Of A PECS-Agent

The component Sensor is responsible for the reception of sensory input data from the environment of the agent. This sensory information is pre-processed in the component Perception, where information-filtering mechanisms or perceptional processes may be realised.

The components Social Status, Cognition, Emo-tion and Physis describe the internal state of the agent and contain the state variables of the agent and the associated state transition functions. The component Cognition, in particular, provides space to model the knowledge base as well as the deliberative and reflective behaviour of the agent.

The component Behaviour determines the order in which actions are executed. It contains a set of condition-action rules on the basis of which an exe-cution order is issued. This set of rules is used to model the reactive behaviour of the agent and to co-ordinate the interaction of reactive, deliberative and reflective behaviour. The execution orders are passed on to the Actor, which is responsible for their execution.

The Actor contains the repertoire of actions that the agent is capable of. These actions can be divided into external and internal actions. External actions have an impact on the environment. Internal actions have an effect on an internal component of the agent itself.

2.2 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 the following five components:

- Self Model
- Environment Model
- Protocol Memory
- Planning
- Reflection

Each of these sub-components contains its own state variables and its own state transition function. Of particular interest is the component Reflection, which acts as a supervisor or manager within cognition. It is necessary if the agent should possess reflective capablities.

The component Self Model contains the agent's knowledge about its own internal state and related operations.

The component Environment Model stores a mental representation of the agent's environment and the processes designed to manipulate and extend this representation such as learning or reasoning.

The idea for a component Protocol Memory was inspired by the approach taken by 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 intended goal, whereas a plan is a sequence of actions to be performed one after the other. To construct a plan, the component Planning can retrieve information from the components Self Model, Environment Model and Protocol Memory. In PECS planning, algorithms known from Artificial Intelligence are used, such as A* search.

The basic idea of having a component Reflection was taken from 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.

A complete description of the PECS reference model is provided in (Urban 2004).

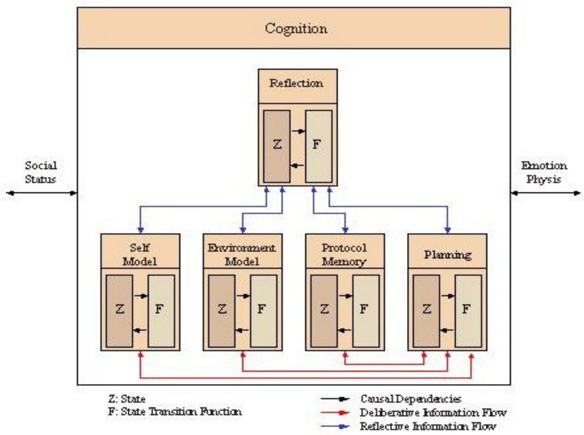

Figure 4: The interior of component cognition

3 MOTIVES AND MOTIVE SELECTION

An important part of the PECS agents is the mechanism of motives and motive-selection.

Motive is defined as a psychological force that drives the organism to execute an action. Motives can be

- Drives
- Emotions
- Acts of will

What all motives have in common is that they appear with a certain intensity and that they may also be in competition with each other. The motive with the highest motive-intensity will determine action.

Since drives, emotions and acts of will together are regarded as motives and as each of these motives has a corresponding intensity, these motives are comparable. It is possible to establish which motive is strongest at a given time and so determine the action to be executed. It is conceivable that an agent experiences hunger and fear simultaneously while also following the goal of deliberately tidying the house.

The three different selection criteria that determine action, namely drive intensity, emotional intensity and intensity of will, are not constant but change with time. This means that different motives may be action-determining at different times. Thus it is possible that at first the act of will *tidy the house* displays the highest intensity of motive. However, after a while, hunger becomes stronger and stronger. It will then overtake the intensity of will that led to the action of tidying. The action of tidying is interrupted. A new motive takes over control. The agent will go to the fridge.

For the modelling of human behaviour there will have to be a motive selector that monitors the development of various motive intensities and ensures that it is always the strongest motive that determines action. A particular example is shown in Figure 5.

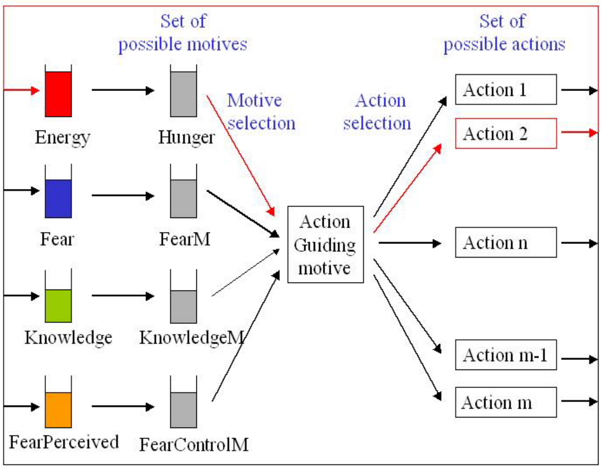

Figure 5: Motives and motive selection

On the left side are internal states that could be the causes of motives.

- *Energy*
  Every organism needs energy. An energy deficit will result in hunger as a drive.
- *Fear*
  The encounter with a dangerous situation may induce the emotion fear. This fear is correlated to a motive with the motive strength FearM.
- *Knowledge*
  An act of will is presupposed that has consciously set itself the goal of acquiring knowledge about an unknown environment. The intensity of will that operates as a motive will be determined, e.g. by the amount of knowledge an agent already has and the amount he still wants to acquire.
- *Fear Perceived*
  The state variable is FearPerceived coming from the self-model. Dependent on this consciously known emotion, the strength of will, FearControlM, can be activated, with which the agent is motivated to control his fear.

The motive intensities of hunger as a drive, fear as an emotion-motive and knowledge acquisition as acts of will are in competition with each other. The motive with the highest motive intensity is chosen as the action-guiding motive via motive intensity. From the set of possible actions it determines the action or action sequence that is actually carried out.

In Figure 5, hunger has the highest motive intensity. It will determine the action to be executed. This could, for example, be food search and food intake. These actions will improve the energy level and thus reduce hunger. It follows from this that instead of hunger, an act of will, for example knowledge acquisition, will become the strongest and thus the action-guiding motive. The action of exploration of the environment could then come into play.

The central idea of motive intensity and of the motive selector has been taken from (Dörner 1999), and developed and adapted to the basic concepts of the PECS reference model.

4 MODELLING OF EMOTIONAL INTELLIGENCE

The following investigation is intended to present the methodology that the PECS-reference model follows to specify and model the reflective control of emotion and cognition. It shows that the PECS reference model can even deal with very complicated and difficult processes in a well structured and clear manner.

4.1 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 (Mayer, Salovey 1997). This concept was then popularised by D. Goleman, author of the bestseller *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.

The following is a short example of the procedure:

An agent encounters a dangerous situation that causes a strong emotion of fear. Emotional intelligence would take into account the following procedure:

- Emotions and their dynamics
  The agent becomes afraid and feels fear. Under normal circumstances, the increase in A's emotion of Fear would lead to an increase in the corresponding motive FearM, that as a consequence would cause the action of fleeing headlong and without consideration.
- The capacity to observe and to monitor the actual emotions
  If the agent has a high degree of emotional intelligence he will be able to avoid being overwhelmed by his emotions. He is able to observe what is going on inside. He notices that he has become afraid.
- The cognitive capability to recognise and to categorise the emotions
  The agent realises that it is the increased fear that troubles him and that motivates him to flee.
- The act of will to influence the emotions and to replace the emotion-induced actions by others more sensible ones.
  If the agent's emotions stay within manageable limits and the agent's will is strong enough, he can consciously decide not to yield to his emotions but to control them and replace the original action of fleeing by a more sensible one.

The presented concepts are in accordance with (Canamero 1997), (Damasio 1994), (Moffat et al. 1995), (Ortony et al. 1988) and (Velásquez 1997).

4.2 The State Variable Fear And The Dependent Variable FearM For The Motive Strength

Fear is considered a state variable.

Without an input, that means that without a triggering event from outside, the state variable Fear decreases continuously over time. This process can be modelled by the following equation:

$$\text{Fear} := \text{FearMax} * e^{\text{FearDecrease} \;*\; \text{Fear}} \qquad (5)$$

An event from outside leads to a sudden, discrete increase of Fear. Figure 6 shows this discrete increase and the continuous decay of the state variable Fear.

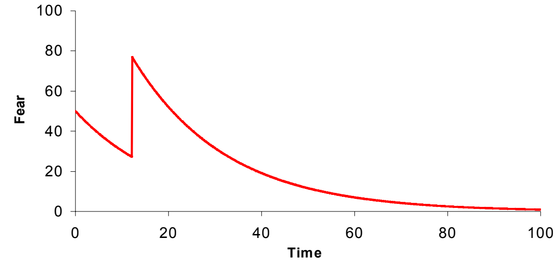

Figure 6: Dynamics of the state variable Fear

The emotional states connection to the corresponding motive FearM is determined by the adoption, that motives can be modelled by following the regularities of a generalized logistic curve of expansion.

$$\text{FearM} := \frac{\text{FearMMax}}{(1 + e^{-\text{FearMIncrease} * (\text{Fear} - \text{FearMTurn})})} \qquad (6)$$

Figure 7 shows the dependency of motive FearM on the state Fear.

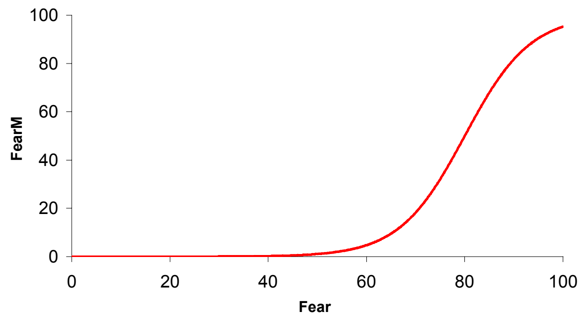

Figure 7: The intensity of the motive FearM as dependent on the state variable Fear

Two points should be kept in mind:

- It is not the state variable Fear but the motive FearM that leads to an action.
- The motive FearM does not always cause an action. FearM has to compete with other motives. If FearM is the strongest motive and dominates all others, only then does FearM determine what the agent does (see Figure 5).

4.3 The Emotional Intelligence Quotient EQ

The state variable EQ is introduced as a measure of the degree of an agent's emotional intelligence. It is assumed 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, 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:

$$EQ' = EQIncrease * \frac{EQMax - EQ}{EQMax} * EQ \qquad (7)$$

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

4.4 Self-Perception

Self-perception enables an agent to observe and to monitor its own state. The information self-perception provides, is stored in the component self-model.

All reflective considerations are based on the state of the self-model. This means that an agent does not have access to its original state variables but only to the state variables it observes and which entered into its self-model. This accounts for the obvious fact that the motives and the actions of an agent are not determined by the reality of the case, but by what the agent thinks or believes is the reality of the case.

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 describes this matter of fact.

SPThreshold :=

$$SPThresholdMax * e^{SPThresholdDecrease * EQ} \qquad (8)$$

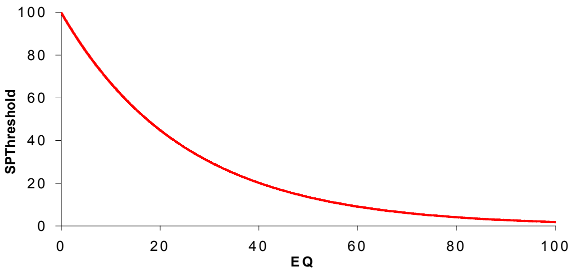

Figure 8: The mutual dependency of the self-perception threshold and the EQ

Figure 5 shows that an agent with a high EQ is already able to observe and monitor slight emotions whereas an agent with a low EQ needs very strong emotions before it is able to perceive them and incorporate them in its self-mode

4.5 The Motive FearControlM

The motive FearControlM is a motive that indicates willpower (see Figure 9). The value of FearControlM depends on the EQ and on the observed value of the emotion FearPerceived.

FearControlM :=

$$\frac{FearControlMMax * b * EQ}{(1 + e^{- FearControlMIncrease * (FearPerceived - FearControlMTurn)})} \qquad (9)$$

Figure 9 shows the dependency of FearControlM on the EQ. One sees that the strength of the motive increases as the EQ increases. This means that with the same observed value for FearPerceived, the higher the EQ the higher the will power to do something against that fear.

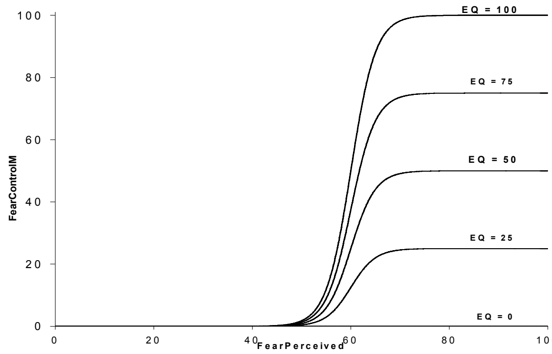

Figure 9: Intensity of the motive FearControlM dependent on the state variable FearPerceived

5 ADAMS MENTAL DYNAMICS

The investigation is conducted within the simulation model Adam. This model Adam is supposed to show and explain the intricate interplay between the various PECS-components.

The model Adam has a broader application than is described here. Emotional intelligence is only one aspect of it. A detailed description of the complete model Adam can be found in (Schmidt 2000).

5.1 Initial Situation

At the beginning, Adam stands on field (3,3). His present state of the state variables and the corresponding motive-strengths indicate that the motive hunger has the highest value and is therefore action-guiding (Figure 10).

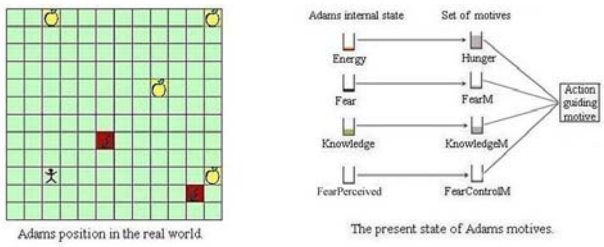

Figure 10: Present state of the agent Adam

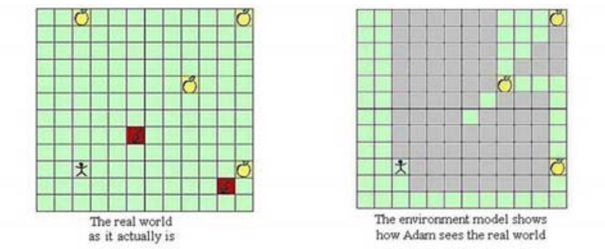

Figure 11: The real world and Adam's environment model

As a consequence, Adam will deliberatively develop a plan to reduce his hunger. For this purpose, Adam uses the information that he possesses and that he has integrated in his enviroment model. Figure 11 shows the environment as it really is on the left side and on the right side the model Adam has of it.
The environment model Adam has is the basis for his planning.

Adam realises that a food source exists on field (9,8). He develops a plan to get there. For his planning he uses the usual algorithms known in Artificial Intelligence. In the present case, an A* algorithm is applied. Figure 12 shows the intended path. One notices that Adam does not know that the field (6,5) is a danger point. Therefore, he cannot take this into account.

Now Adam follows his plan by executing one action after another. He slowly proceeds towards the food source. This goes on until he hits the danger point on field (6,5). At this point, Adam's original plan of action will be interrupted. A new situation arises.

In the following, the very complex and intricate procedures that will take place and that will help Adam to cope with the situation by controlling his emotion of fear will be thoroughly described. This leads to an increased chance of solving the problem.

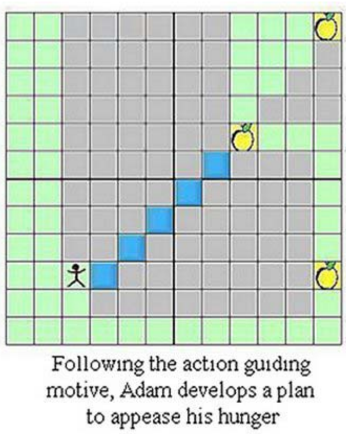

Figure 12: Intended path to the food source

5.2 Extension Of The Environment Model

In a step-by-step fashion, the various actions are explained that take place within the agent Adam:

(1) Adam encountered a new situation. He performs the action Explore. He notices that he has landed in a trap. This information is taken up by the Sensor.

(2) This information will be handed on to the component Perception. The component Perception transfers it, in this case unmodified, to the component Cognition.

(3) The information, that the field (6,5) is a danger point, will be incorporated into Adam's environment model. Adam has extended his knowledge about the real world.

Figure 13 shows these steps.

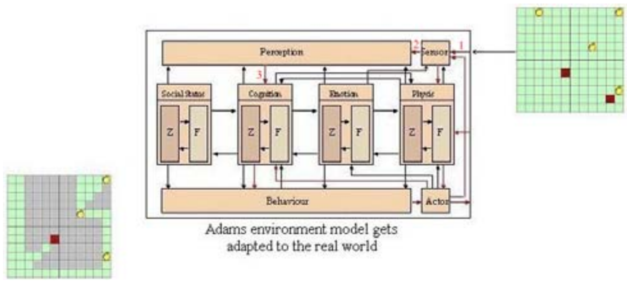

Figure 13: Extension of the environment model

5.3 Emergence Of The Emotion Fear

(4) The component Cognition evaluates the new facts. It realises that there is a dangerous, fear-inducing situation. This insight leads to a sudden increase in the value for the state variable fear in the component Emotion to a new value of 95 [FU]. This increase is based on the cognitive appraisal theory of emotions.

(5) With the state variable Fear there is a dependent variable which indicates the motive strength that belongs to the corresponding state variable (see Figure 6 and Figure 7). Figure 7 shows that the value of 95 for Fear leads to a motive strength of 94,2. That would mean that the motive FearM has the highest value and therefore would become action guiding.

Figure 14 shows these steps.

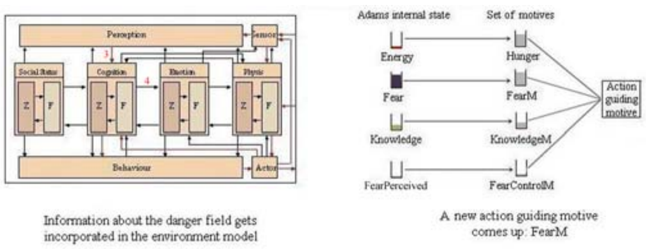

Figure 14: Emergence of the emotion fear

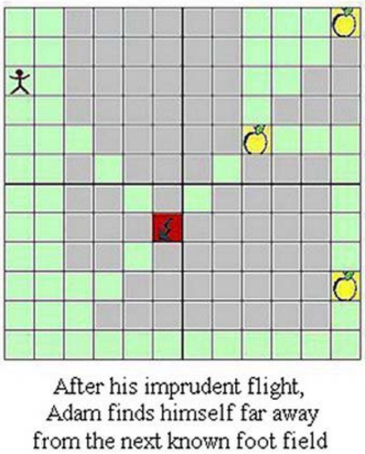

Figure 15: The action Flee without a reflective architecture

If Adam did not posess the capabilities for reflective behaviour, he would exert the action Flee (see Figure 15). However, if Adam has an architecture which makes reflective behaviour possible, Adam will be in a position to control his fear and to cope with the situation more effectively.

5.4 Realisation Of The Emotion Fear And Its Transfer Into The Self Model

(6) Because of the new situation, Adam with his reflective capabilities will call the action SelfObserve. This action is supposed to register Adam's own fear and transfer it to the self model

(7) The component Actor transfers the action SelfObserve to the component Sensor.

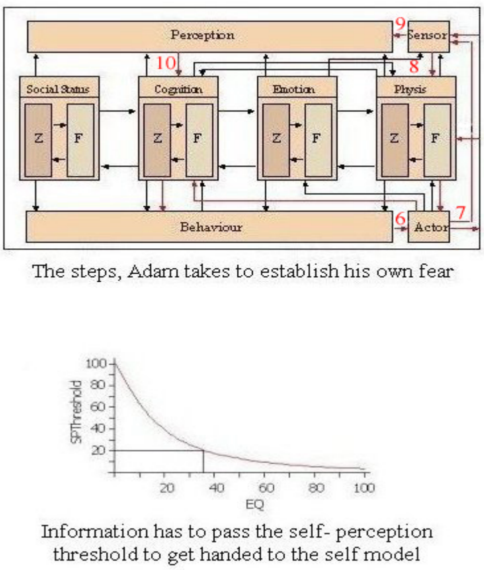

Figure 16: Realisation of the emotion fear and its movement into the self model

(8) The component Sensor establishes the value for the emotion Fear.

(9) This information is handed on to the component Perception in the usual way. At this point, the value of the EQ is introduced for the first time. To be able to establish his own fear, the Fear must have a fixed value. The value of Fear must lie over the so-called self-perception threshold. This threshold depends on the EQ in a way that is shown by Figure 8. The higher the EQ, the more Adam is able to observe his own emotion – in this case his fear. With a high value of 90 for EQ [EQU] the threshold is very low. It is only 2,7, meaning that Adam is aware of his fear.

(10) After the information passes the self-perception threshold, the perceived fear will be transferred to Cognition, which will hand it on to the self model. Adam now consciously "knows" how fearful he is. Using this knowledge he can now try to cope with his fear.

Figure 16 shows these steps.

5.5 The Motivation To Control The Emotion

(11) The action SelfObserve should cause the component Reflection to control the fear. This SelfControl is, however, not possible in all cases. It depends on Adam's level of general arousal. The higher the general arousal within Adam, the less he will be able to deliberatively control himself. Furthermore, the capability for self-control is influenced by the EQ. The higher the EQ, the more Adam will be able to control himself. The so-called arousal threshold is introduced in order to describe this fact. If the actual arousal lies below this threshold, the execution of the action SelfObserve is possible. Adam is not excited enough to be carried away by his emotions.

(12) The component Actor transfers the internal action SelfObserve to the component Cognition.

(13) Within the component Cognition, the component Reflection checks the self-model and reads the value of the perceived Fear. In the next step, the value for the motive FearControlM will be determined. The strength of this motive depends on the perceived Fear and on the EQ. The higher the Fear, the more Adam will attempt to reduce his fear. At the same time, Adam's capability to control his fear depends on the EQ. A high EQ value will lead to a high motivation to control the emotions. In the present case, the perceived Fear has the value 90 [FU] and the EQ has the value 90 [EQU]. This leads to a value for the motive FearControlM of nearly 100 (see Figure 9).

Figure 17 shows these steps in detail.

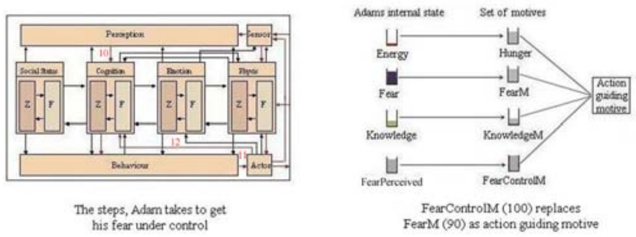

Figure 17: Motivation to control the emotion

5.6 Control Of The Emotion

(14) The strength of the motive FearControlM is transferred to the component Behaviour. In this component, the various motives and their strengths are compared and the motive with the highest value will be selected and made action guiding. Figure 17 shows the new situation. The motive with the highest value is the motive FearControlM. Therefore, the action Calming will be chosen.

(15) The action Calming is transferred to the Actor.

(16) The Actor instructs the Reflection in the component Cognition to execute the action Calming.

(17) The Reflection interferes with the component Emotion and changes the value for Fear from the value of 90 [FU] to the value of 30 [FU]. The agent succeeded in controlling his behaviour by reducing his emotion of fear.

5.7 The Continuation Of The Actions

Figure 18 shows the values of the motives after the action Calming. The strengths of the motives FearM as well as FearControlM are now noticeably reduced. The original motive Hunger again becomes action guiding. On the basis of his reflective capabilities, Adam was able to control his emotions. He can now deliberately devise a new plan with a sequence of actions that will lead him, like before, to the food source (see Figure 18).

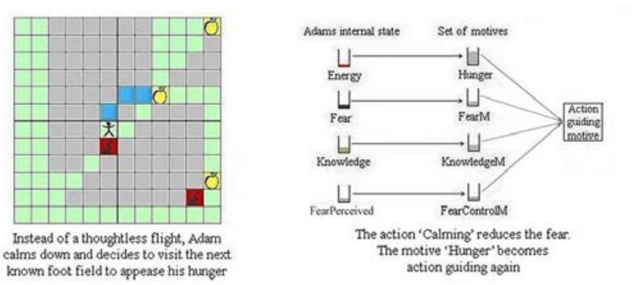

Figure 18: Deliberately devised new plan to the food source

6 CONCLUSIONS

The PECS reference model provides a structured framework for the design of agent systems with a special focus on modelling human-like agents. With PECS it is possible to construct a wide range of models for agents whose dynamics are determined by physical, emotional, cognitive and social factors and their interactions. Of particular value is the possibility to specify the following three modes of behaviour control:

- Reactive behaviour
- Deliberative behaviour
- Reflective behaviour.

The case study of emotional intelligence has shown in principle how the reflective layer of control can supervise and organise the complex interaction between cognitive and emotional processes.

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