PECS

A Reference Model for Human-Like Agents

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Abstract: In recent years autonomous agents have significantly gained in importance for the modelling of human behaviour. With this development a need for adequate design methodologies for complex agents emerges which are capable of modelling essential characteristics of human beings in connection with their decision making and behaviour control. In this article the *PECS* reference model for the construction of human-like agents is introduced which enables an integrative modelling of physical, emotional, cognitive and social influences within a component-oriented agent architecture. Furthermore the case study *Adam* is introduced which demonstrates the practical application of the design methodology. Also a perspective should be drawn on how the reference model could be used for the control of virtual humans.

1. INTRODUCTION

In recent years agents play a vital role for modelling and simulation in empirical sciences. Parts of real systems or systems as a whole are modelled on the basis of autonomous agents. Agents are especially useful as a modelling paradigm when creatures or even human beings are part of the system to be examined. Agents act as virtual representatives of real world entities here. A very prominent example in which agents are used to construct an artificial social system is given by the *Sugarscape* experiments conducted by Epstein and Axtell (1996). Further examples for the

application of agent technology in the social sciences, psychology, economics, ecology or other related areas can easily and numerously be found in literature (see e.g. Sichman, Conte & Gilbert, 1998; Urban, 2000a; Suleiman, Troitzsch & Gilbert, 2000).

In contrast to the application of agent technology to technical domains the structure, the properties and the behaviour of agents must not be selected freely when they are used in the context of modelling. In fact it is a basic requirement for good models to display structural and behavioural similarity with the original system. For the design of agents this means, that they have to be constructed in a way, which makes them quite similar to their real counterparts with respect to their structure and behaviour. When an agent is used for modelling a human being for example, the agent has to be equipped with all properties and behavioural patterns of the real human which are of relevance in the given scenario.

Looking at agent-based models of social systems in the literature one can find that human behaviour is often reduced to cognitive abilities and cognitively controlled actions. Human beings are often seen as pure rational decision makers. But recently these “classical” approaches which are often based on BDI architectures (Rao & Georgeff, 1995) are criticised more and more. The view of human beings as rational decision makers who are perfectly informed and maximise an exogenously given utility function seems to be too restrictive. At the same time in psychology more complex theories about human behaviour come into the foreground. Such theories, as e. g. introduced by Dörner (1999), are not restricted to cognitive aspects, but also take physical or emotional influences as well as interactions with the social environment into account.

With the increasing complexity of models for human beings the demands made on the design methodology for agent-based simulation models rise, too. There is a need for agents which are capable of modelling quite complex internal states as well as interactions between physical and psychical processes. The *PECS* (Physis, Emotion, Cognition, Social Status) reference model which will be introduced in the following chapters provides concepts for the construction of such human-like agents. In the second part of this paper a case study is described which shows the practical application of the reference model in the context of a psychological problem.

2. THE *PECS* REFERENCE MODEL

The *PECS* reference model is intended to support the design process of agent-based simulation models in which individual human behaviour and decision making, interactions between individuals as well as interactions of

individuals with their environment are in the centre of interest. Therefore the reference model provides a concept for the construction of agents, a communication infrastructure and an environment component. The reference model provides a domain independent model architecture. It proposes a general, methodologically founded construction scheme which can be applied to various application areas and therefore must be filled with specific attributes and dynamic behaviour.

In the following sections the basic ideas of the reference model and the agent architecture will be discussed in further detail.

2.1 Basic Ideas of the *PECS* Reference Model

In order to reach a high degree of comfort in model description and a clear structure of resulting models, *PECS* is designed according to two major design principles.

The first principle relates to the structuring of models and is called *component-oriented, hierarchical modelling* (Urban, 2000b). According to this principle it is possible to functionally decompose complex models into a set of smaller model components. Each model component is responsible for modelling a special part of the required functionality and may be connected to other model components. By connecting components to each other it is possible to generate more complex components on a higher level of abstraction. Following this principle leads to clearly structured and well understandable models.

The second principle concerns the description of attributes and model behaviour. *PECS* follows a *system-theoretic approach* (Urban, 2000b) here. Every component is characterised by an internal state Z which is defined by the current values for the given set of model quantities at each calculated point in time. This internal state may be influenced by a time-dependent input and also an output may be produced according to the given dynamic behaviour. For the dynamic behaviour of a model component time-continuous as well as time-discrete state transitions may be specified. This system-theoretic approach leads to a comfortable handling of complex internal states and state transitions and is therefore especially useful for the description of agents which are strongly influenced by complex internal processes.

2.2 The *PECS* Agent Architecture

The *PECS* agent architecture grounds on the opinion that an agent must be capable of integrating physical, emotional, cognitive and social attributes and processes in order to provide an adequate means for modelling human

behaviour. For that reason the *PECS* agent architecture is structured as shown in Fig. 1.

Figure 1: Basic Architecture of *PECS* Agents

The architecture may be divided up into three different horizontal layers. The input layer consists of the components *Sensor* and *Perception* and is responsible for the processing of input data coming from the environment of the agent. The internal layer is composed by the components *Physis*, *Emotion*, *Cognition* and *Social Status*. This group of components models the internal state of the agent. And finally in the output layer, covering the components *Behaviour* and *Actor*, the behaviour of the agent is calculated and the actions are executed.

The *Sensor* component receives sensory input from the environment of the agent. The incoming information may be divided into visual information and audible information. The visual information is about current processes going on in the environment of the agent and the audible information packets cover messages produced by other agents or also by the environment.

The sensory input received in the *Sensor* component is forwarded to the *Perception* component for further processing. In the *Perception* component for example information filtering mechanisms or other perceptual processes may be realised. In general percepts are generated in this component which contain information about the external world of the agent. In subsequent stages of information processing these percepts may be used

for updating the mental model of the agent about its environment or for learning purposes.

The internal state of the agent may in general be composed of physical, emotional, cognitive and social attributes and processes. In order to achieve a clear structure of the agent architecture, these different attributes and processes are distributed to the four components *Physis*, *Emotion*, *Cognition* and *Social Status*. Nevertheless there could be various kinds of interactions between these components which can be modelled by causal dependencies.

The *Physis* component is responsible for modelling physical or material properties of agents. These properties could be influenced either by vegetative processes like ageing or by actions performed by the agent itself or even by the actions of other agents.

As emotions are considered as strongly relevant for the behaviour of human beings the *PECS* agent architecture provides a component *Emotion* which is able to model emotional states and processes of agents. Concerning the triggering of emotions we currently prefer cognitively oriented emotion theories (see e.g. Plutchik, 1993) which assume that emotions emerge as a consequence of information processing and cognitive appraisal. The consequences of emotions may be observed via the behaviour of an agent. Emotions can on the one hand modulate the behaviour of an agent and on the other hand even determine its behaviour.

The *Cognition* component models the knowledge base of the agent and related operations. In the centre of this component is a kind of memory which stores a mental representation of the agent's environment and of its own state. By incoming percepts this model may be extended and updated. Furthermore the mental representation provides information for the agent's decision making and planning. Deliberative agents are for example able to construct plans for their future behaviour based on their knowledge. Also learning processes may be modelled within this component which enable the agent to improve or adapt its behaviour in different situations. But not only the extension and elaboration of the knowledge base can be taken into consideration here. Also existing deficiencies like loss of information by forgetting may be modelled in the *Cognition* component.

An agent is in many cases embedded in a society and therefore a social entity. For that reason agents often have to be equipped with a set of attributes which describe their social properties. Such properties can for example be a social role of an agent in a given situation, the social status of an agent within a group or even social needs which direct the agent's behaviour. All these attributes and phenomena can be modelled within the *Social Status* component.

The repertoire of possible actions and the action selection processes are modelled in the components *Behaviour* and *Actor*. *PECS*-agents are able to

display simple reactive behaviour which can be described by condition-state-action rules. But agents can also be equipped with more complex deliberative behaviour which includes planning processes and is based on goals the agent has in mind. Depending on a given goal which can be described by a certain state to be reached, a planning process is triggered. As a result of the planning process a plan is generated. Such a plan determines in an abstract way which activities have to be undertaken in order to reach the given goal. The *Behaviour* component selects the individual actions or even sequences of actions that are connected with the currently triggered activity. An action instruction is generated by the *Behaviour* component and handed over to the *Actor* component where finally the execution of the action is triggered. The *Actor* component accordingly stores the set of actions the agent is able to perform and realises the output interface of the agent.

As can be seen from the previous paragraphs, with the *PECS* reference model we intend to provide a model architecture which enables an integrative modelling of the various aspects and processes that essentially influence human decision making and behaviour.

3. THE CASE STUDY *ADAM*

In the following chapter the model *Adam* (see also Schmidt, 2000) will be introduced. This model is strongly influenced by Dörner's ? (1999). But in contrast to Dörner's approach which is intended to model psychological reality, the major goal of *Adam* is to demonstrate as simply as possible, how various control mechanisms for human behaviour can be integrated within the *PECS* architecture.

The chosen scenario is quite simple. We start with only one agent called *Adam*. Adam may be thought of as a prehistoric man at a very early stage of development – perhaps a member of the early *homo habilis* species which inhabited the savannah.

3.1 Adam's World

Adam lives and moves in a world consisting of a matrix with 12×12 fields. There are danger points, food sources and other fields with no special meaning in this world. Fig. 2 shows one possible configuration for Adam's world as an example.

A danger point is marked by a dark square. When Adam steps onto such a field, he gets into danger, loses a lot of energy and time, and becomes fearful for a certain period of time.

Adam's world also contains bright squares which provide the food that he needs to satisfy his energy requirements. As soon as Adam is hungry and reaches a food source, he will eat the food he finds there. Fortunately for Adam, the food grows again. The food regeneration is modelled by a logistical growth curve.

Figure 2: Adam's World

3.2 Adam's Internal State

Adam's internal state spans over physical, emotional and cognitive variables. Social attributes are not necessary as Adam lives alone in his world.

Adam's physical state is determined by his energy level. The state variable *energy* indicates how much energy Adam possesses and therefore how vital he still is. When Adam's energy has been used up, his life ends. Every action that Adam performs consumes a certain amount of energy. In order to replace lost energy, Adam must keep visiting food sources and intake food provided there.

The range of emotions accessible to Adam is for simplicity reasons very limited. His emotional state is described solely by the state variable *fear*. It will suddenly and abruptly reach a high level when Adam comes across a danger point. When Adam is in a fearful state, he will examine every new field for danger points before entering it.

The knowledge that Adam possesses of his environment and of himself is represented in the cognition component. For the description of this mental representation, state variables are used. There are two basic processes that influence the mental model essentially: *learning* and *forgetting*. By a learning process Adam gets more detailed knowledge about the growing behaviour of food sources. Forgetting reduces the knowledge of Adam, i. e.

he forgets information about fields he has not visited for a long period of time.

Independently of the mental representation two further variables *competence* and *level_of_knowledge* exist. *Level_of_knowledge* denotes the number of fields that Adam knows as opposed to the total number of fields in the environment. The *level_of_knowledge* variable triggers a knowledge acquisition motive. The state variable *competence* is intended to describe in the simplest possible form an element of self-awareness. In the present model, when Adam displays high competence he will choose riskier strategies in cases of uncertainty.

3.3 Adam's Repertoire of Actions

Adam is able to perform internal and external actions. Internal actions trigger processes that modify attributes and structures within the agent itself. They are delegated from the *Actor* component to another internal component of the *PECS* agent architecture. External actions are actions which are directed at the external world of the agent and produce changes in the environment.

The set of internal actions consists of the actions *planning*, *examination* and *exploration*.

Planning is an action that is delegated from the *Actor* component to the *Cognition* component. As the consequence of a *planning* action Adam devises a plan according to a given goal. The plan consists of partial goals which must be achieved one after another in order to achieve the final goal.

Examination is an action which activates the *Sensor* component and is related to a field that is part of Adam's environment but where Adam is not at present located. By means of examination Adam wishes to find out whether an adjacent field is a danger point to be avoided or whether he can enter it unimpeded. Adam examines only if he is in a state of fear.

The *Exploration* action also activates the *Sensor* component. Via this action Adam examines the field on which he is currently located.

The set of external actions consists of the actions *walking*, *food_intake* and *escaping*. All external actions are passed on by the *Actor* component to the *Environment* component where the resulting state transitions are executed.

The action *walking* enables Adam to move from one field to a neighbouring field in the environment. Using the action *food_intake* Adam is able to eat the food he finds on a food source in his environment. After Adam entered a danger point in his environment as a consequence of incautious behaviour he can use the action *escaping* for climbing out of the trap and freeing himself.

3.4 From States to Actions – Basic Principles of Adam’s Behaviour Control

Looking at a scenario in which our agent Adam gets hungry and therefore has to seek for food, the basic elements of the behaviour control used in this case study should be illustrated in this section.

The entire behaviour of Adam is guided by *motives*. In general motives are activated in connection with certain *needs* and needs are immediately connected to *state variables*.

In our example the whole process starts with the internal state variable *energy* which is calculated in the *Physis* component. Depending on the actions Adam performs, his energy level goes up and down over time. The energy level is directly connected with a variable describing Adam’s *need for food*. From his need for food a motive called *hunger* results. The intensity of the motive depends on the strength of the need. For modelling this relation, a logarithmic function as shown in Fig. 3 is assumed.

Figure 3: Intensity of the Motive *Hunger* in Relation to the *Need for Food*

On the next stage of behaviour control all existing motives struggle for the right to determine the actions of the agent and become so-called *action-guiding motives*. In our example besides the motive *hunger* there is a second motive called *knowledge acquisition*. It is derived from the wish and the conscious effort to discover more about the environment. For choosing an action-guiding motive the motive intensities are decisive. The motive with the highest intensity will be action-guiding. Fig. 4 shows the intensities of both given motives over time. One can see that Adam’s behaviour will alternately be dominated by his need for food and by his thirst for knowledge.

For continuing this example let us assume that the motive *hunger* has been selected as the action-guiding one. In order to satisfy his need for food, Adam has to start a food search now. Let us further assume that Adam has

information about the location of food sources stored in his mental representation (in any other case there is no other chance for Adam than starting a trial and error search in his environment). Then Adam locates the place on his mental map which is closest to his current position and provides some food. This place is declared as the goal of a sequence of actions that is to be planned now.

Figure 4: Temporal Sequence of Motive Intensities

An action plan is strategic in nature and consists of partial goals which have to be reached one after another in order to reach the superordinated goal. In the case of our example within the planning process a sequence of fields is calculated which leads our agent from his current position to the intended food location.

As soon as the action plan has been finished the first partial goal is released for execution. Therefore first of all the *Behaviour* component is activated. Within the *Behaviour* component a sequence of elemental actions is determined which depends on the overall internal state of the agent and which should lead to the fulfilment of the given partial goal. In case of a situation where Adam is very fearful such an action sequence could have the form (*examination – walking – exploration*). In another case Adam may leave out the *examination* action and simply decide for *walking* and *exploration*.

As soon as the action sequence is fixed the first action is handed over to the *Actor* component which immediately starts with its execution. When the execution of this action is finished the subsequent action will be performed etc. In this way all actions of an action sequence must be executed successfully before the next partial goal of the action plan can be activated. This cyclic process ends when the last partial goal which equals the superordinated goal of the action plan has been reached. In this case a new plan must be conducted or a new motive may be selected as the guiding one and thus the whole process starts over again.

4. SUMMARY AND OUTLOOK

The *PECS* reference model provides an architectural pattern which can be used to construct agent-based simulation models in which human behaviour is of particular interest. Up to now, the reference model was exclusively used for modelling purposes. But looking at virtual human-like agents or avatars and new approaches in the context of human-computer interaction it seems to be worth spending some effort on the question if *PECS* could also be used as a basic architecture for designing control systems for virtual human-like agents.

One of many examples one could think of here could be found in the context of distance learning systems. Approaches in this area introduce so-called tutor agents for example which take over the role of human teachers. In order to make these agents more believable to the human user it could be useful to equip them with a control system that enables such agents to display human-like behaviour.

In this context the *PECS* agent architecture seems to provide a useful starting point for designing control systems of autonomous human-like agents and avatars. This question has to be discussed in further detail in the near future.

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