# PECS – Agent-Based Modelling of Human Behaviour

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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 *Learning Group* is introduced which demonstrates the practical application of the design methodology and is intended to model basic social psychological mechanisms in the context of group formation and disbandment.

## 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 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 modelled as purely rational decision makers. But recently these “classical” approaches which are very often based on the BDI approach (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 turns out 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. Additionally an increasing number of AI projects can be found which deal with design questions for emotional agents (see e.g. Sloman, 1996; Bates, Loyall & Reilly, 1991; Moffat & Frijda, 1995; Velásquez, 1997; Cañamero, 1997).

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 social psychological scenario.

## 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.

## 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.

## 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 Figure. 1.

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 *Behavior* 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 perceptional processes my 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.

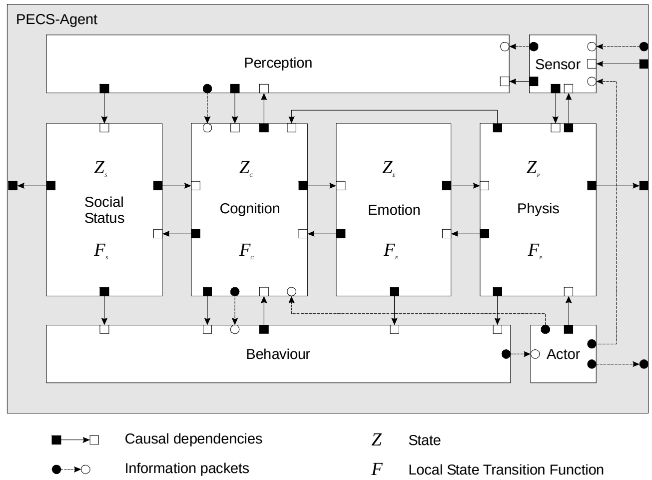


**Figure 1: Basic Architecture of *PECS*-Agents**

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, 1994) 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 are instances of various kinds of memories which store mental representations of the agent's environment and its own state. By incoming percepts and internal processes these representations 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 *Behavior* 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 *Behavior* 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 *Behavior* 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. The architecture is not based on a certain kind of social or psychological theory. It is intentionally designed and described in a way which enables the integration of a variety of theories at various levels of complexity.

In order to demonstrate how the components of the architecture may interact for realizing a certain kind of behaviour, we introduce a very simple example that deals with the generation and decay of the primary emotion of fear. Let us start with a scenario in which an agent gets into a dangerous situation within its environment. The agent realizes the threat by evaluating the received information about the given external situation within its *Cognition* component. The result of the evaluation will be stored in the cognitive state variable *InDanger*, which is assigned the value *true* when the agent recognizes a dangerous situation. The agent's *Emotion* component is able to read the current value of the variable *InDanger*. As soon as the agent becomes aware of the danger he gets fearful. This correlation can be modelled by a sudden increase of a state variable *Fear* which is stored in the *Emotion* component. In order to prevent the agent from being fearful for the rest of his virtual life, the value for the state variable *Fear* decays over time which can be modelled by a simple differential equation describing a negative exponential function in time.

This description leads to a progression of the state variable *Fear* which is shown in Figure 2.

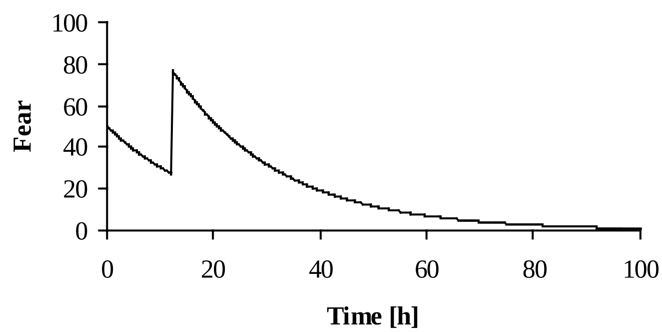


**Figure 2: Progression of the State Variable *Fear***

## The *Learning Group* Model

The *Learning Group* model shows in principle how agents form groups, how they work together in groups and how they leave groups. It includes the process of group formation when new groups are formed and the process of group dissolution when a group ceases to exist.

The example chosen to illustrate this is that of students who wish to prepare for an examination and to revise. This learning may take place in peace and quiet at home. However in some circumstances working in a group will be more efficient. In this case a student can choose an already existing group and try to join it. If this does not work out, he or she may start a new group. There is also the possibility that a student will leave his group if group work no longer seems to offer any advantages. If no student wants to join a particular group, that group will disband. A detailed description of this model can be found in Schmidt (2000).

First of all the attributes of the agents operating in the *Learning Group* model will be described.

### The Personality of Agents

Each agent as the representative of a student will be endowed with an elementary personality that will influence its behaviour. The personality features are as follows:

- Intelligence
- Social make-up

Intelligence and social make-up can be combined in any number of ways. Basically four different types of personality patterns emerge. An agent may for example combine high intelligence with high social competence etc.

### The Repertoire of Possible Actions

Alongside the above-mentioned personality constants, the repertoire of actions available to an agent is a decisive factor in its behaviour. The number of actions is kept to the strict minimum for simplicity reasons. The following six actions are available to an agent:

- Learning
- Choosing a group
- Join the chosen group
- Start a group
- Leave the group
- Disband group

Learning is an internal action. Learning leads only to a change in the value of the internal state variables. As far as its internal life is concerned, the agent is constantly chopping and changing from learning in a group to learning alone.

The other actions relating to group membership depend on learning alone or learning in a group. These are external actions, observable from outside.

### The Agent's Needs

The agent in its simplicity has only two needs:

- Knowledge acquisition
  The agent wishes to increase its knowledge. It does this by learning alone or in a group.
- Social Satisfaction
  Every agent is sociable. It has the need to increase its social satisfaction. However it can only do this if it joins a group.

The agent will always arrange his behaviour so as to satisfy both needs as well as possible. However for this purpose he has access only to those actions which we mentioned in the previous section.

Depending on its internal state at a given point in time, the agent will either choose his study and private learning or group membership and group learning.

## Internal State Transitions of the Agent When Learning

The two main state variables that determine the internal behaviour of an agent are its current state of knowledge *KnowAct* and its present state of social satisfaction *SocAct*. These state variables develop differently depending on whether the agent is learning alone or is in a group.

Learning increases the knowledge level *KnowAct*. This increase in knowledge will be called *KnowAct´*. It is described by the state transition function *F*, which has the form of a differential equation:

```
KnowAct´ : = a * KnowCap * KnowNormal *
             Intelligence/100 *
             KnowAct
```
(Eq. 1)

*KnowCap* is a factor which takes into account that knowledge increase begins with a less efficient warm-up phase, then leads to higher performance and decreases again towards the end. The *KnowCap* factor has the following form:

```
KnowCap := (KnowActMax – Know Act) /
           KnowActMax
```
(Eq. 2)

It can also be seen that knowledge increase depends on intelligence. The higher its intelligence, the more quickly the agent will learn. This manifests itself in a faster increase in the knowledge to be acquired.

The knowledge *KnowAct* acquired in a learning phase is shown in Figure 3. The temporal sequence is based on equation 1 and depends on intelligence.

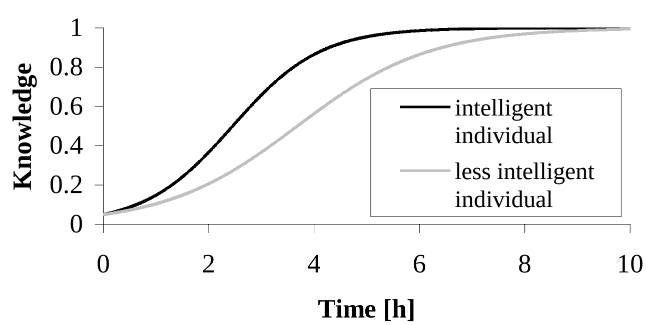


**Figure 3: Knowledge Increase When Learning Alone**

When the agent is learning alone, not only its knowledge level *KnowAct* will change but also its social satisfaction. This will decrease.

The speed at which social satisfaction diminishes will be called *SocAct´*. *SocAct´* is described by the differential equation (Eq. 3), which is as follows:

```
SocAct´ : = -b * SocCap * SocNormal *
            SocMakeUp/100 * SocAct
```
(Eq. 3)

here

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SocCap: = (SocActMax – SocAct) / SocActMax
```
(Eq. 4)

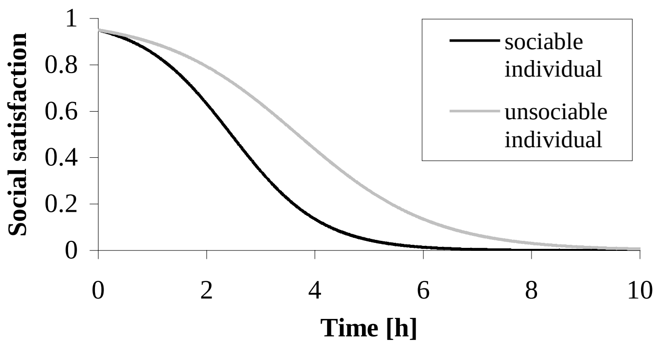


**Figure 4: The Decrease in Social Satisfaction When Learning Alone**

Learning in a group takes a different course from learning alone. The decisive difference results from the group quality *QualityG*. The variable *QualityG* here influences both knowledge increase *KnowAct´* and the increase of social satisfaction *SocAct´* of the individual agent.

The equations 1 and 3 can now be expanded in the following way:

```
KnowAct´ : = a * KnowCap * KnowNormal *
             Intelligence/100 * KnowAct *
             QualityG                        (Eq. 5)
SocAct´ := b * SocCap * SocNormal *
           SocMakeUp/100 *
           SocAct * QualityG                 (Eq. 6)
```

In each equation the *QualityG* factor has been added. It takes account of the fact that learning behaviour and social satisfaction develop differently in the group than in the case of learning alone.

## The Behaviour of an Agent

So far the temporal development of the two internal states *KnowAct* and *SocAct* have been described. The next task is to show how these internal states manifest themselves externally as behaviour. The output function *g* is responsible for describing external behaviour. Each agent's behavioural repertoire includes the following actions:

- Select group
- Join the selected group
- Found group
- Leave group
- Disband group

For every one of these actions it must be clearly stated under which conditions one of the actions is chosen, passed on to *Actor* and executed by *Actor*.

### Select Group or Find Group

An agent will want to end his solitude and look for another group when the following situations occur:

- Knowledge *KnowAct* has reached a certain level when the agent is studying alone. Not much more can be achieved by learning in private. The stimulation and encouragement that group work brings are required.
- Social need has exceeded a certain limit. The agent feels so lonely that it looks for sociability in a group.

Both reasons together can cause an individual to apply for membership of a group. The importance of the cognitive and social aspects can be established by means of weighting factors.

### Leave Group and Disband Group

An agent will not always remain in a group. It will leave the group when it sees no further advantage in staying in it. This will be the case when in a new learning phase it learns better on its own for a while and when its social satisfaction has reached such a high level that it no longer needs social contacts. This means:

- Knowledge *KnowAct* has reached a relatively high value in group learning. Not much more is possible through learning in the group. Concentration and individual reflection are necessary to familiarise oneself with new material.
- Social satisfaction has also reached a relatively high level. The agent no longer needs any further social contacts. It can manage for a while on its own.

These two reasons together can cause an individual to leave a group. The importance of the cognitive and socio-emotional aspects can be expressed by weighting factors. The same behaviour occurs that already regulated the decision to join the group.

## Model Experiments

A number of experiments can be carried out using the learning group model. Parameters can be varied at will and the resulting consequences can be studied.

The two following problems may be studied as an example:

- Group size for two selected groups over time
- The number of agents in the solitary learning phase and in the group learning phase

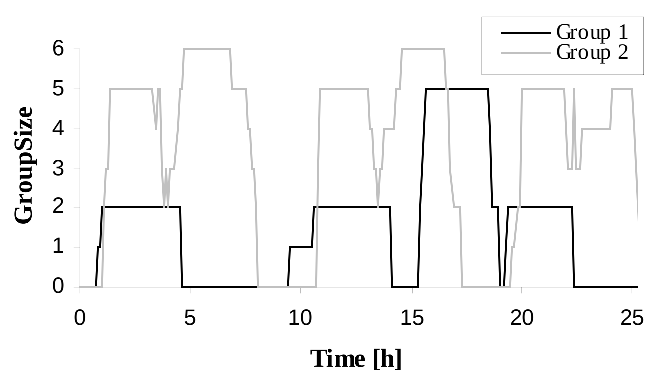


**Figure 5: The Number of Members in Three Selected Groups**

During a simulation run the learning group model will display a lively dynamic behaviour. Groups will form anew and will later on disband again. The agents will join these groups and will then leave them again according to their internal states and individual dynamic behaviour.

A possible experiment with the model might study the question of how many participants a certain group has in the course of time. Figure 5 shows the number of members in group 1 and 2 over time as an example.

It can be seen that group 2 quickly reaches its maximum number of 6 members. Many agents join existing groups at this point of time, because they are no longer able to acquire significantly more knowledge by learning alone and their social need forces them to meet other agents. After that the agents work together in their groups. Therefore their knowledge as well as their social satisfaction increase. But after a while the agents tend to leave their groups again following their internal driving forces. In the interval between 8 and 9 time units both of our observed groups have no more members as their agents have withdrawn into the solitary learning phase again.

A further example shows the number of agents in the solitary learning phase and in the group learning phase over a period of time. Figure 6 shows the sequence.

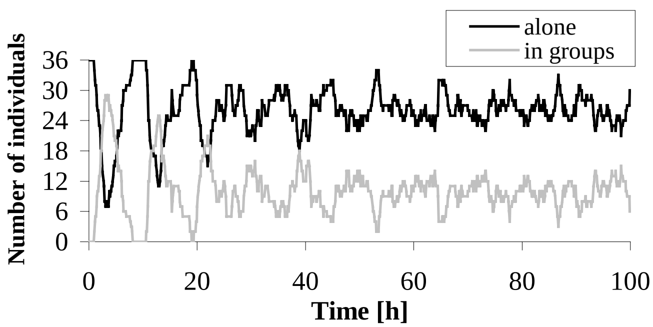


**Figure 6: The Number of Agents in the Solitary Learning and in the Group Learning Phase**

It can be seen that the black curve falls at the beginning. This curve represents the number of agents learning alone. At the same time the number of agents in the group learning phase increases correspondingly as the total number of agents is fixed in our model.

## Results

With the *PECS* reference model we developed an architectural pattern which can be used to construct agent-based simulation models in which human behaviour is of particular interest. By means of PECS it is possible to construct a wide range of models for agents whose dynamic behaviour is determined by physical, emotional, cognitive and social factors and who display behaviour containing reactive and deliberative elements.

The Learning Group model shows in exemplary and prototypical fashion the procedure to be followed in the modelling of complex human behaviour. In order to prove the domain independence of the reference model we built three additional case studies up to now stemming from the application domains artificial social systems, economics and psychology.

Current work in progress deals with the refinement of the components *Emotion* and *Cognition* of the *PECS* agent architecture. The major goal in this context consists of exploring the relations between cognitive and emotional processes within agents.

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