How to give Agents a Personality

Bernd Schmidt
University of Passau, Germany

Summary

The PECS reference model offers an integrated methodology for the behaviour of agents. It takes into account

* Physical conditions
* Emotional states
* Cognitive capabilities
* Social status

Within the framework of the PECS architecture, a system-theoretical methodology is used for specifying agents' personality traits.
The basic assumption of this methodology is that the personality of an agent determines two facts:

* The rate and the manner in which the internal state variables of an agent change.
* The way in which these changes in the internal state variables of an agent are reflected as actions or behaviour.

Changes in the internal state variables, and the determination of an agent's actions, are described by two functions F and H.
Both the functions F and H contain constants. These constants are related to personality traits. This means that an agent's personality traits can be modified by adjusting constants, without being forced to do any reprogramming.

1 System-theoretical Methodology

Agents are representatives for their respective human counterparts. Their tasks are manifold. For example, they may act as substitute tutors in educational software systems, work as commissioners in the internet, carry out difficult and dangerous tasks as robots, play roles in computer games in the entertainment business, or facilitate user communications with technical systems via a human-computer interface. In some cases they can even be used in scientific

research to validate psychological or social theories.
In all these circumstances agents are required to be as similar to human beings as possible. Therefore, it is essential that agents are able to show most of the behaviours that human beings are capable of.

Human behaviour is characterised by a very intricate interaction of physical, emotional, cognitive and social aspects. In most cases, reducing human beings to rational decision makers is an unjustified simplification.
Agents intended to model human beings should have an architecture capable of giving them all the required characteristics and behaviours. Agents should be provided with physical, emotional, cognitive and social characteristics. In addition they should have a number of personal traits and peculiarities in their make-up, which makes them unique and turns them into individuals.
The PECS reference model has an underlying architecture that incorporates all these requirements. PECS stands for
P Physical conditions
E Emotional states
C Cognitive capabilities
S Social status
A PECS agent has three basically distinct modes of behaviour at his disposal:
* Reactive behaviour
* Deliberative behaviour
* Reflective behaviour
All three modes of behaviour are influenced by the agent's personality.

The behaviour of an agent can be described using the terminology of systems theory.
The transfer function F indicates the way in which the current state $z(t_n)$ at time t_n is transformed into the subsequent state $z(t_{n+1})$ as a result of the input $x(t_n)$. Therefore, we have:

$$z(t_{n+1}) = F(t_n , z(t_n), x(t_n)) \qquad \text{(Eqn. 1)}$$

Usually, the state variables z are not directly related to observable behaviour. Other variables, known as dependent variables because they depend on the state variables, are ultimately responsible for an agent's behaviour. The relationship between a state variable and a dependent variable w can be described by an algebraic function H. Therefore, we have:

$$w(t_{n+1}) = H(z(t_{n+1})) \qquad \text{(Eqn. 2)}$$

The output function G determines the manner in which the new internal state of the agent, described by the state variables $z(t_{n+1})$ and the dependent variables $w(t_{n+1})$, is transformed into an externally observable output $y(t_{n+1})$.

$$y(t_{n+1}) = G(t_{n+1}, z(t_{n+1}), w(t_{n+1}), x(t_{n+1})) \qquad \text{(Eqn. 3)}$$

The basic assumption of PECS is that an agent’s personality depends on the form of the two functions F and H.
The transfer function F changes the internal state variables of an agent, either as a result of experiencing an input from the outside world, or of its own accord. The state variable z could be Anger, for instance. This state variable might be changed by an external input x, when the agent experiences a personal failure.

$$\text{Anger}(t_{n+1}) = F(\text{Anger}(t_n), \text{Experienced\_failure}(t_n)) \qquad \text{(Eqn. 1a)}$$

The strength of emotional anger that an agent feels, and the time it takes until this emotional irritation has vanished, are characteristic features of this agent. These determine whether he has a quick-tempered or a calm personality.

Another example of change in a state variable would be Energy demand. This state variable increases either continuously of its own accord, or changes according to the kind of action the agent performs.

$$\text{Energy}(t_{n+1}) = F(\text{Energy}(t_n), \text{Action\_performed}(t_n)) \qquad \text{(Eqn. 1b)}$$

Moreover, the state variable Energy does not directly influence the agent’s behaviour. The function H, which relates Energy to the drive Hunger, acts as a motive. This means, that the state variable Energy is converted into the dependent variable Hunger.

$$\text{Hunger}(t_{n+1}) = H(\text{Energy}(t_{n+1})) \qquad \text{(Eqn. 2a)}$$

The rate at which the Energy demand grows, together with the magnitude of the Energy demand and the urgency with which this demand is felt as Hunger, all determine whether the agent is a glutton or an ascetic.

In both examples the agent’s behaviour depends on the form of the two functions F and H, and in particular on the constants contained within these functions. This means that personality traits can be related to constants in the transfer function F and the function H.

As a reference model, PECS offers a pattern or framework containing empty spaces which have to be filled in order to adapt the general reference model to a specific, real task or an actual problem. The specific state variables and the functions F, H and G are freely definable. By assigning values to the constants in the functions F and H, agents can be given individual personalities, which determine how their inner states change. The output function G depends on these internal state variables and describes how the agents behave.

It is important to emphasise that PECS is almost entirely theory-independent. It is the task of a theory to determine the mathematical form of the functions F and H, and which variables should appear in them as arguments. All possible functions F or H proposed by a particular theory can be used in PECS and their consequences investigated.

As a reference model, PECS provides a conceptual framework that can be implemented in arbitrary agents in any simulation language whatsoever.

2 PECS Agents as a Reference Model

A reference model can serve as a blueprint for a class of real-life systems. It provides a model structure for all real-world systems sharing the same deep structure and differing only in superficial aspects.
In this sense, PECS models are a reference model for modelling agents and their individual personalities. The architecture proposed here claims to be universally applicable. The architecture is adapted to individual conditions by filling in the empty spaces within it. This means, for example, that the number and type of the state variables, the structure of the transfer function F, the function H and the output function G can be easily modified. The exact definitions of the functions F, H and G determine the agents’ individual personalities. Similarly, an agent can be endowed with a varied repertoire of actions, stating what external actions the agent is to be capable of. As a result very diverse agents and agent communities can be developed, but they all have the same deep

structure and therefore they can all be described by one and the same reference model.
The description of the PECS architecture is largely based on [Urban 1999], where a more detailed and wide-ranging account is given.

2.1 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

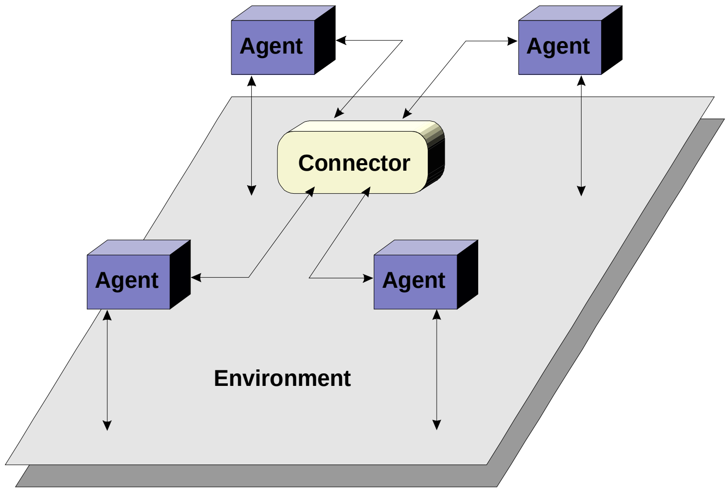

Figure 1 The Structure of the PECS Agent World

Figure 1 shows the basic structure.
These conceptual sections are reflected in the simulation model, and can be identified there as independent components.

2.2 The Environment

The Environment component is used to model external events and influences which are important for the behaviour and actions of agents. It may also include other agents.
The environment is also reflected in the agents' knowledge. An agent's knowledge of his environment will affect his view of that environment, which may be incomplete, uncertain and even erroneous.
As the environment will vary considerably between applications it is impossible to provide a universally applicable structure, and so the PECS reference

model is not proscriptive in this respect. It merely provides a framework within which the agents can move. The individual design of the environment component is a matter for the user alone.

2.3 The Connector

Communication is an essential aspect of multi-agent systems. The basic principle is that all agents must have the capability of communicating with all other agents. This is the purpose of the Connector component, which serves as a central switchboard to organise the exchange of information between agents. Again, its individual design is left to the user.

2.4 The Structure of PECS Agents

Figure 2 shows the structure and the internal organisation of a PECS agent. The basic structure can be clearly discerned. Based on systems theory, it consists of input, internal states 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 four components, i.e. Status, Cognition, Emotion and Physis, contain the agent's state variables and their changes of state. The state transition function F describes which states change, how they change, and which dependent variables determine this change. Some examples of possible state variables are given in Section 3.

The two components at the bottom of the Figure, Behaviour and Actor, are responsible for the output. This is where we find the output function G.

The Behaviour component contains a set of rules which form the basis for issuing "execution orders". An execution order is an instruction to perform a specific behaviour.

Execution orders are passed on to the Actor, who is then responsible for carrying them out. The Actor component contains the full repertoire of actions of which the agent is capable. These actions can be subdivided into internal and external actions.

Internal actions affect only the agent himself. Examples of internal actions are:

* Reflecting on previous perceptions
* Reformulating a goal
* Focussing attention on a point in the environment

External actions impact on the environment, and also on other agents within the environment. Examples of external actions are:

* Moving to the next field
* Sending information to agent XYZ

The execution of an action by the Actor is modelled as a process which occupies a specified amount of time. This process can be interrupted by more important incoming execution orders.

The black arrows in Figure 2 represent causal dependencies. For example, Perception, which carries out the initial processing of the incoming input, depends on all four classes of internal state variables.

Selective perception may serve as an illustration:

* The information which Perception filters out from the input signals received from the Sensor, and the way in which all or part of this information is processed further, may depend on the agent's physical state, current emotions, available knowledge of the world and social status.

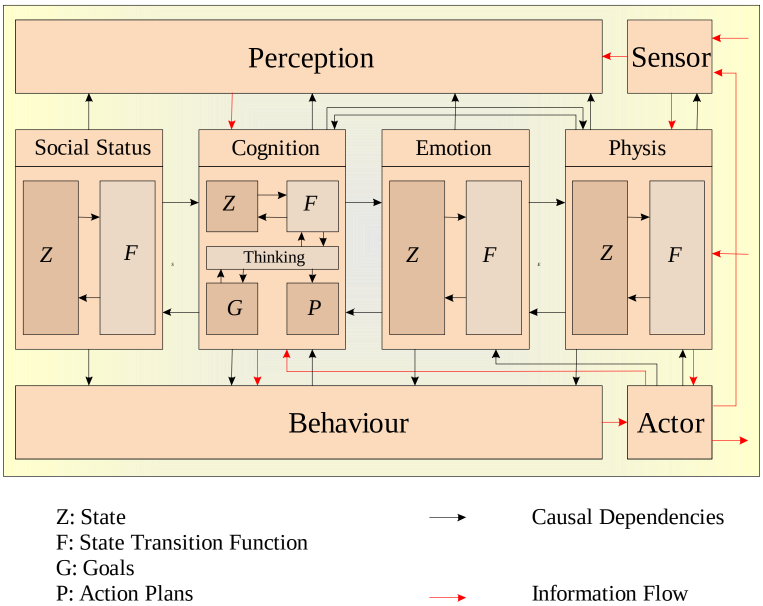

Figure 2 The Structure of a PECS Agent

The red arrows in Figure 2 represent the flow of information. These arrows may be thought of as paths for messages. For example, there is a path leading from 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.

3 The Agent, his Internal States z(t) and his Personality Traits

An agent's state is determined by the four types of state variable shown in Figure 2.
Changes in the state variables z are described by the transfer function F. Moreover, the state variables z can be converted into dependent variables w by means of the function H.
The functions F and H contain constants. These constants represent personality traits.
The agent's behaviour is determined by the values of the state variables z and the dependent variables w. This behaviour is described by the output function G.

3.1 State Variables and Dependent Variables, and their Changes
The following examples show how an agent's state can be described by his state variables z and the corresponding dependent variables w.

* Physical condition
  We could define a state variable Energy, which could take on various values. A corresponding dependent variable might then be Hunger.
* Emotion
  The agent could be capable of experiencing anger. According to the value of this state variable Anger, the agent is in an excited or a peaceful mood.
* Cognition
  The "world model" of an agent is his internal representation of the outside world. In PECS, this representation is an explicit one, described by means of state variables. These state variables capture the agent's knowledge about the environment in which he lives. Depending on the values of these state variables, the agent might wish to know more about his environment, and thus he might develop a strong will to explore and to investigate. Therefore, the intensity of the will to explore is a dependent variable, the value of which is determined by the agent's knowledge about his environment.
* Social status
  The state variables for social status indicate the agent's position within the

community or society to which he belongs. An example of a social status variable would be the number of friends an agent has. Consequently the current number of friends influences the dependent variable SocialNeed, which describes an agent's need or desire for social contact and company.

The important point to note here is the fact that these state variables are not constant, but are subject to changes. These changes can be described by the state transfer function F. This function F determines how the state variables change in accordance with the input and with the values of other state variables. In the case of continuous changes, the function F is a differential equation.
Let z(t) be the state vector, let w(t) be the corresponding dependent variables and let x(t) be the input. Then the function F has the following form:

$$z'(t) = F(t, z(t), w(t), x(t)) \qquad \text{(Eqn. 4)}$$

In case of a discrete-time change, F has the following form:

$$z(t_{n+1}) = F(t_n, z(t_n), w(t_n), x(t_n)) \qquad \text{(Eqn. 5)}$$

The state vector z contains all the state variables, irrespective of their class. That means that changes in any state variable can depend on the value of state variables in any other class.

Usually, the state variables z are not directly related to the observable behaviour. Other variables, known as dependent variables because they depend on the state variables, are ultimately responsible for an agent's behaviour. The relationship between a state variable and a dependent variable w can be described by an algebraic function H. Therefore we have

$$w(t_{n+1}) = H(z(t_{n+1})) \qquad \text{(Eqn. 6)}$$

3.2 Changes in State Variables, Dependent Variables and Personality Traits
The way in which state variables and dependent variables change is determined by the form of the state transfer function F and the function H. The functions F and H contain constants, which can be associated with traits or characteristics. Together, they make up an agent's personality.
The following simple examples help to explain the procedure.

3.2.1 The personality trait anxiety
Suppose that an agent experiences an input x via cognition by realising that the

space in front of him contains a dangerous beast. This then causes a change in the state variable Fear:

$$Fear(t_{n+1}) = F(t, Fear(t_n), Knowledge(t_n)) \qquad \text{(Eqn. 7)}$$

If (Fear > FearMax)
Then
Fear = FearMax

Thus the new value of the state variable Fear depends on the old value of Fear and on the state variable Knowledge, which belongs to the class of cognitive state variables and which contains the information that there is a dangerous beast nearby.
Usually, Anxiety decreases slowly with time. This decrease can be described by the following differential equation:

$$Fear' = - FearDecrease * Fear \qquad \text{(Eqn. 8)}$$

where FearDecrease is a constant. This means that Anxiety fades away exponentially.
Figure 3 shows the sudden increase of the dependent variable Fear as a result of the change in the state variable Knowledge, and its subsequent steady decrease.

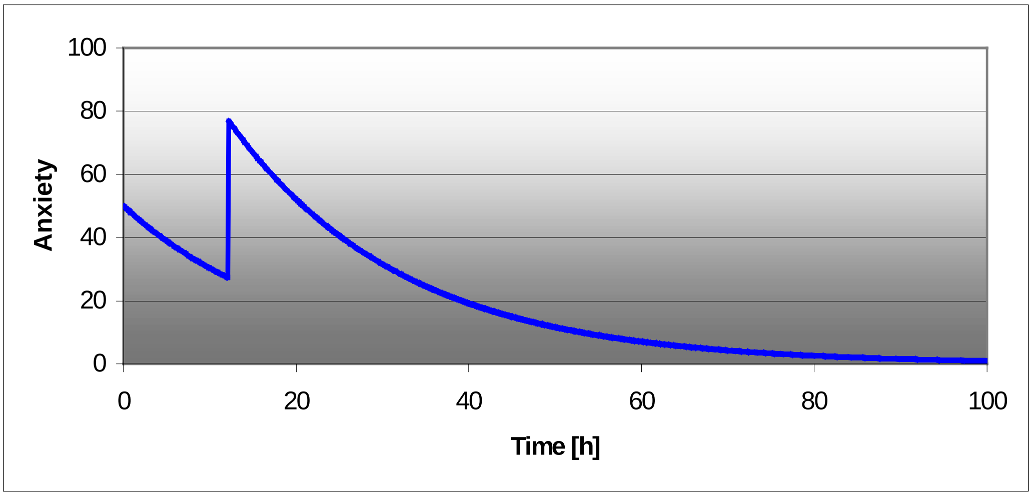

Figure 3 The increase and the steady decrease of the state variable Fear

The exact form of the graph depends on the constants FearMax and FearDecrease. These two constants indicate how sensitive the agent is with respect to

fear. Depending on the values of these constants, an agent can be made to be very anxious, or not so anxious. These two constants determine the personality trait Anxiety. By fixing these two constants, PECS-agents can be given an individual personality.
A more elaborate description of the way this single personality trait is embedded in the complete inner life of an agent can be found in [Schmidt 2000, Section 7 The Adam Model] or in [Urban 2001].

The form of the functions F and H is not fixed within PECS. The form of these functions can be adapted to the task the agent is designed for. In particular, there are no theoretical assumptions involved in PECS. In the above extremely simple example, the intensity of the emotion is dependent on a cognitive state variable. That does not mean that PECS subscribes to a theory of emotions based on cognitive appraisal theory. If other state variables are included in the function F, other theories can be implemented. Two other possibilities for the form of F are given in [Picard 1997] or in [Velasquez 1997].
The use of differential equations is recommended for continuous state changes like the decrease of emotions. This seems to be the most natural approach. However, it presupposes familiarity with the use of differential equations and their numerical solution.

3.2.2 The personality trait intelligence

Consider an agent representing a student preparing for an examination. The rate at which the student acquires new knowledge depends on his intelligence.
KnowAct is a state variable describing the current level of knowledge the student has already absorbed. The knowledge increase in time is described by means of the transfer function F, which has the form of a differential equation:

$$\text{KnowAct}' = a * \text{KnowCap} * \text{KnowNormal} * \text{Intelligence} * \text{KnowAct} \quad \text{(Eqn. 9)}$$

KnowCap is a variable which reflects the way that knowledge acquisition begins with a less efficient warm-up phase, then leads to high performance and decreases again towards the end. The equation for KnowCap has the following form:

$$\text{KnowCap} = (\text{KnowActMax} - \text{KnowAct}) / \text{KnowActMax} \qquad \text{(Eqn. 10)}$$

KnowActMax is the maximum amount of knowledge an agent is able to absorb.
The increase in acquired knowledge in a learning phase is shown in Figure 4.

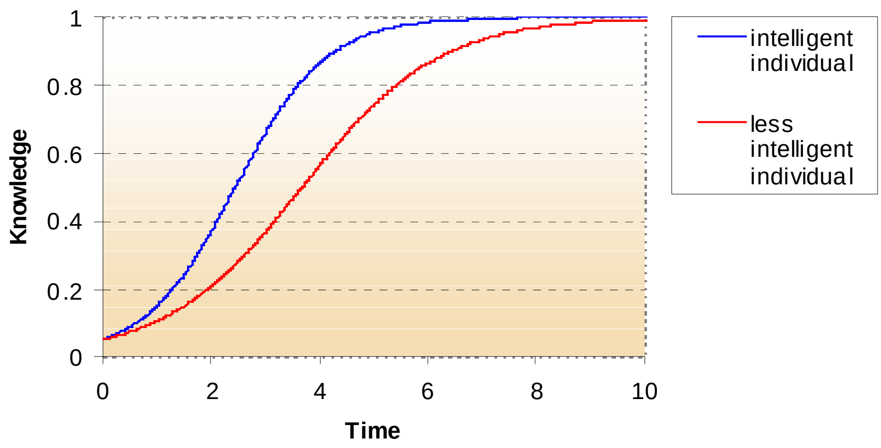

Figure 4 The acquisition of knowledge as a learning curve, depending on intelligence

The exact form of the “learning curve” depends on the two constants KnowActMax and Intelligence. These two constants indicate how easy or how difficult it is for a student to learn. These values of these constants specify whether an individual agent is smart, or a slow learner. These two constants determine the personality trait intelligence. By fixing these two constants, PECS agents can be given an individual personality.

3.2.3 The personality trait sociability

The state variable SocAct measures an agent’s current social satisfaction. SocAct increases when the agent is in the company of other agents, and decreases when he is by himself.
The increase and decrease of SocAct is described by two transfer functions F.
For decreasing SocAct we have the following differential equation:

$$SocAct' = - b * SocCap * SocNormal * SocProperty * SocAct \qquad \text{(Eqn. 11)}$$

where

$$SocCap = (SocActMax – SocAct) / SocActMax \qquad \text{(Eqn.12)}$$

For increasing social satisfaction we have a corresponding differential equation.

The course of the state variable SocAct for the case when an agent is by himself is described in Figure 5.

The exact form of the graph of the social satisfaction SocAct depends on the constants SocActMax and SocProperty. These two constants indicate how easy or how difficult it is for an agent to find social satisfaction and contentment. According to the values of these constants, an agent can be made sociable or unsociable. Therefore, these two constants determine the personality trait sociability. By fixing these two constants, PECS-agents can be given an individual personality.

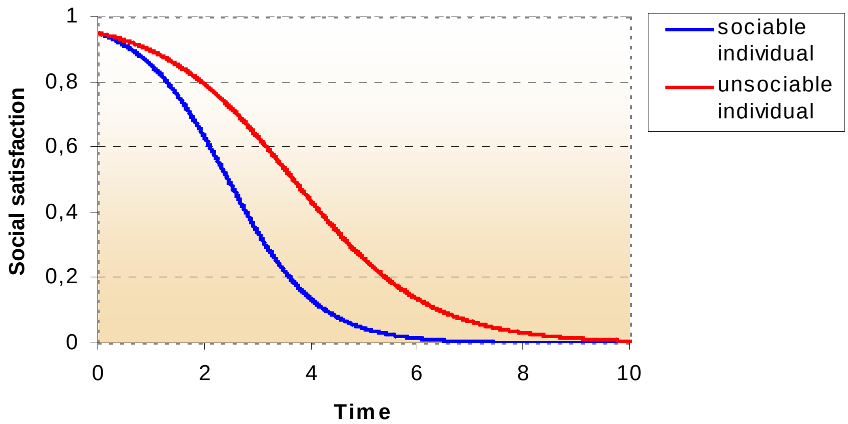

Figure 5 The decrease in social satisfaction for an agent on his own

A more elaborate description of the way this single personality trait is embedded in the complete inner life of an agent can be found in [Schmidt 2000, Section 8 The Learning Group Model].

4 Motives and Motive Selection

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 generalized to include all four possible classes of motives.

Example:
The state variable Energy was introduced in section 1. This variable did not influence behaviour directly. The function H was used to define the drive Hunger. It is the intensity of this drive which determines whether the agent goes to the refrigerator or whether he does something else.
Similarly to the state transition function F, the function H contains constants which give an agent his characteristic and individual nature.
A PECS agent can be endowed with various drives, needs or desires. The agent experiences these drives, needs or desires as internal forces that motivate him to perform corresponding actions.
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].
Unfortunately, psychology does not offer a clear-cut definition of the concepts of drive, need, urge, desire or motive. In order to explain the following procedure more clearly, these concepts are defined arbitrarily. These definitions are not claimed to be generally valid: they apply to this case only.

4.1 Intensity of Drives

Drives are related to physical state variables like blood pressure, body temperature or energy. They denote the urge a person experiences or feels in order to satisfy a particular physical need. Drives usually serve to maintain the homeostatic equilibrium of an agent's body in order to support his physiological functioning.
Once again, the above-mentioned state variable Energy and the drive Hunger serve as examples.
The body strives to maintain a fixed level of energy. If this level is not achieved, for example if it is too low, the body tries to regain the desired state by urging the agent to look for food.

The intensity of this drive is a function of the state variable Energy and can be calculated by means of the function H. In general, the lower the available energy is the more intense will the drive hunger be.

$$\text{Hunger}(t_{n+1}) = \text{H}(\text{Energy}(t_{n+1})) \qquad \text{(Eqn. 13)}$$

In the special case of energy and hunger, the function H could have the following form:

$$\text{Hunger}(t_{n+1}) = \text{MaxHunger} * (1 - f(\text{Energy}(t_{n+1}))) \qquad \text{(Eqn. 13a)}$$

$$f(\text{Energy}(t_{n+1})) = [1 + \exp(-\text{HungerIncrease} * (\text{Energy}(t_{n+1}) - \text{HungerMean}))]^{-1}$$

$\text{If}\,(\text{Energy}(t_{n+1}) > \text{EnergyLimit})$

Then

Hunger = 0

The function $f(\text{Energy})$ is the so-called Richard's curve, which is frequently used to describe dependencies of this form. [Horgan 2001]

Figure 6 shows the course of the intensity of the drive hunger depending on the available energy, according to equation (13a). As the available energy decreases, we see an increase in the hunger felt.

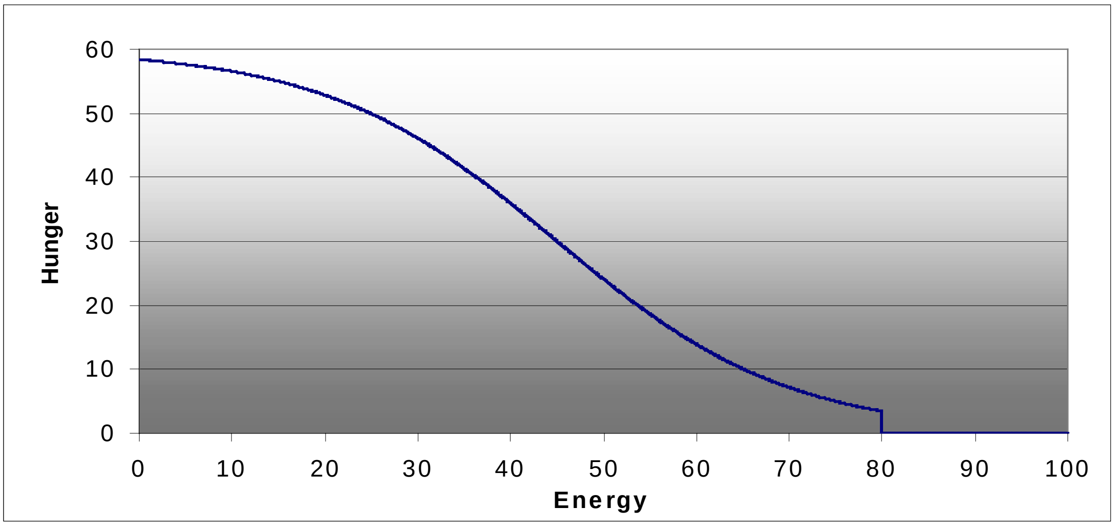

Figure 6 The intensity of the drive hunger, depending on the available energy

Clearly there is a distinct difference between the physical state energy and the felt drive hunger. In particular, even if the energy is high, the agent does not experience any drive as long as the energy stays over the threshold value of EnergyLimit.

Another possibility for the intensity of the drive hunger could be:

$$\text{Hunger}(t_{n+1}) = \text{HungerIncrease} * (\log(\text{EnergyDeficit}(t_{n+1}) + 1) \qquad \text{(Eqn.13b)}$$

$\text{If}\,(\text{EnergyDeficit}(t_{n+1}) < \text{EnergyMin})$
Then
Hunger = 0
The equation (13b) was taken over from [Dörner 1999].

The exact form of the drive Hunger is determined by the three constants MaxHunger, HungerIncrease and HungerMean in equation (13a).

The equations (13a) or (13b) with their two constants MaxHunger and Hunger-Increase, determine, how intensively the agent really feels or experiences the objective current internal state Energy. It is essential that it is not the real internal state energy itself, but only the experienced intensity of the corresponding drive Hunger, which is responsible for the actual form of an agent's action.
It follows that the two constants MaxHunger and HungerIncrease, together with the constants that determine the value of the state variable Energy in equation (13b), are the values that make up the personality trait in respect to the Energy state and the drive Hunger. (See section 1 *System-theoretical Methodology*).
The greater the Energy deficit, and the more strongly the drive Hunger is felt, the more vehemently the agent will act. An agent with a personality which is very sensitive to possible Energy deficit and to the drive Hunger will attach great importance to the fulfilment of this particular desire.

4.2 Emotional Intensity

In PECS, emotions like anger, fear, surprise or envy are treated as basic state variables. Their change can be described by the state transition function F. An example is given in section 3.2.1 *The personality trait anxiety.*
Similarly to the relationship between the internal state Energy and the drive Hunger, there is a relationship between an emotion and the experienced or felt intensity of this emotion. The function H connects the emotion state variable, for example Fear, with the intensity UrgeFear. (UrgeFear is an artificial construct, since colloquial English does not possess a separate word for the intensity of an emotion in comparison with the emotion itself.)
For the intensity with which the emotion Fear is felt, we may use the following

equation:

$$UrgeFear(t_{n+1}) = H(Fear(t_{n+1})) \qquad (Eqn.\ 14)$$

4.3 Strength of Will

Deliberative behaviour is focussed on a goal. A goal is a situation which can be described in terms of cognitive state variables. An agent pursues a goal strongly or less strongly, according to his strength of will. As before, strength of will can be calculated using the function H, using the cognitive state variables of the goal as arguments for H.

The state variable KnowAct was introduced in section 3.2.2 *The personality trait intelligence*. This variable describes the quantity of knowledge an agent possesses at a particular point in time. One of the agent's goals might be to increase that quantity.

The agent pursues the goal with the strength WillKnowledge. The dependent variable WillKnowledge will usually increase as the value of the corresponding state variable KnowAct gets smaller. The function H will be of the following form:

$$WillKnowledge(t_{n+1}) = H(KnowAct(t_{n+1})) \qquad (Eqn.\ 15)$$

In its most simple form, equation 15 might look as follows:

$$WillKnowledge(t_{n+1}) = - WillIncrease * 1/KnowAct(t_{n+1}) \qquad (Eqn.15a)$$

Another possibility could be:

$$WillKnowledge(t_{n+1}) = \exp(-WillIncrease * 1/KnowAct(t_{n+1})) \qquad (Eqn.15b)$$

The constant WillIncrease, and the two constants Intelligence and KnowActMax from Equations 9 and 10, together determine the agent's personal characteristics relating to his capability of pursuing the set goal.

The less the agent knows, and the stronger the will to change that situation is felt, the more vehemently the agent will act. He has a personality with a very strong will as far as the acquisition of knowledge is concerned.

4.4 Intensity of Social Desire

Social state variables describe facts about the agent in relation to other agents. The state variable SocAct was introduced in section 3.2.3 *The personality trait*

sociability. This variable measures an agent’s current social satisfaction.
SocAct increases if the agent is in the company of others and decreases if he is by himself.
An agent’s current social satisfaction shows itself through a corresponding desire for company. The intensity of this desire can be calculated using the function H.

$$\text{DesireCompany}(t_{n+1}) = H(\text{SocAct}(t_{n+1})) \qquad \text{(Eqn. 16)}$$

The exact form of the function H in equation (16) will depend on the nature of the problem. For example, it could have a similar form to equations (13a) or (13b).
The constants which appear in equations (11) and (12), along with the constants in equation (16), determine how rapidly an agent feels lonely and how strongly the agent desires to do something about it. Therefore, these constants describe the personality trait sociability.

4.5 Motives and the general procedure
In all the above cases, initially changes in the state variables are calculated using the transition function F. The transformed internal state may then result in the agent feeling or experiencing an internal urge, which may drive him to perform a particular action.
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

These 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 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 is interrupted. A new motive takes control. The agent goes to the fridge.

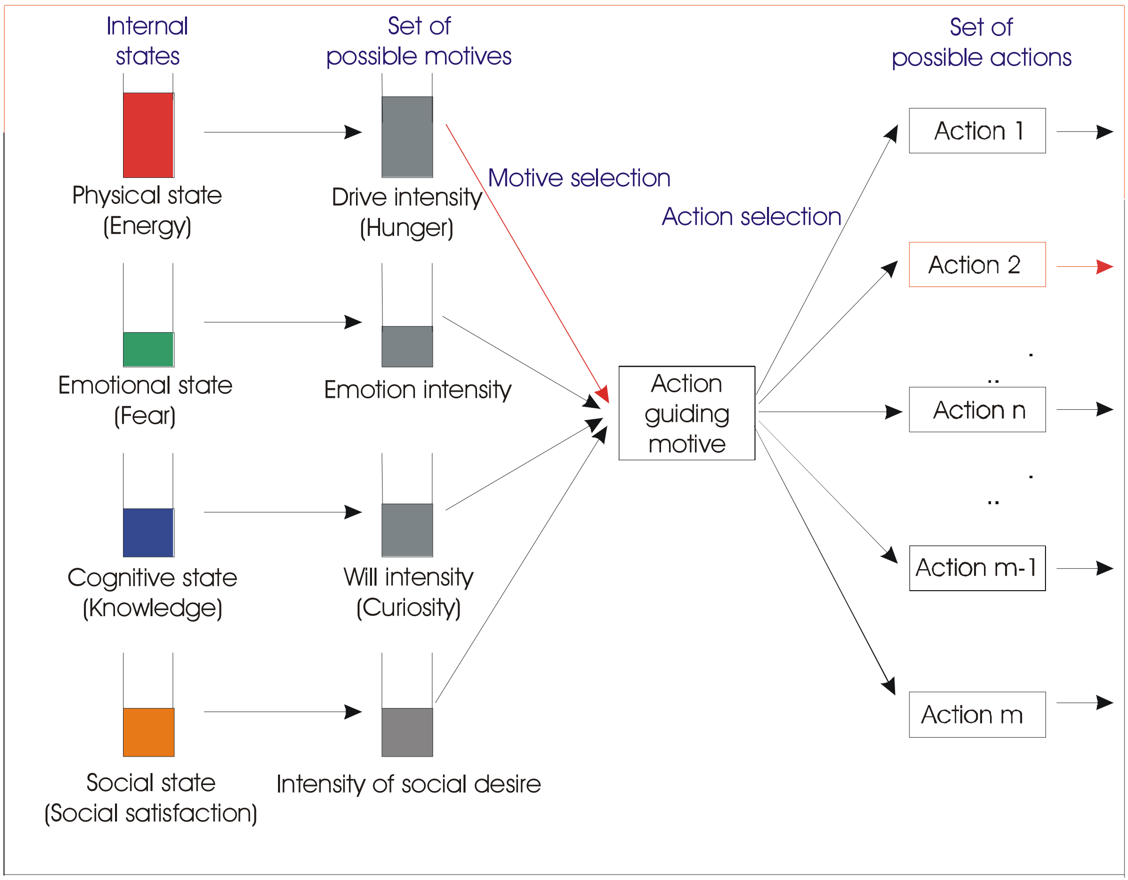

Figure 7 Motives and motive selection

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.

Figure 7 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.

Step 1 and step 2 are influenced by personality traits which can be modified by the constants in the two functions F and H.

5 Extension of the concept

Up to now the examples presented have been very simple. They only served to illustrate the principal methodology. For more realistic models, the procedure has to be extended.
First, the transfer function F may not just contain t_n, $z(t_n)$ and $x(t_n)$ as arguments. The argument list can be supplemented by further variables. Equation 1 then takes the following form:

$$z(t_{n+1}) = F(t_n), z(t_n), r_i(t_n), x(t_n)) \qquad \text{(Equ. 1a)}$$

$r_i(t_n)$ are further variables.

Example:
Suppose the transfer function for the state variable Fear contains an additional variable Knowledge. The emotion could be further influenced by:

K Knowledge about the input
I Importance of the input
A Assessment of the input
S Social situation of the affected agent

This means that the transfer function F could take the following form:

$$Fear(t_{n+1}) = F(tn, Fear(t_n), K(t_n), I(t_n), A(t_n), S(t_n), x(t_n)) \qquad \text{(Equ. 7a)}$$

PECS is not prescriptive about which variables determine the detailed development of a particular state variable. It is up to the modeller to decide what s/he considers relevant. In this respect PECS is characterised as a reference model offering a framework which has to be filled in appropriately.

In the same way, the function H in equation 6 can be expanded.

$$w(t_{n+1}) = H(z(t_{n+1}), r_i(t(_{n+1})) \qquad \text{(Equ. 6a)}$$

$r_i(t_n)$ are further variables.

Example:
Equation 13 specifies in which way the state variable Energy determines the strength of the motive Hunger. How strongly the drive hunger is really experienced may depend on the following circumstances:
C   Circumstances in the environment
Hunger will be felt more intensely if one sits in front of a delicious meal.
E   Emotions
If a strong emotion like fear prevails, an energy deficit exists but is not felt as hunger
I   Cognitive insight
Deliberative considerations can influence the strength of the drive hunger in a limited way.

This means that the function H could take the following form:

$$Hunger(t_{n+1}) = H(Energy(t_{n+1}), C(t_{n+1}), E(t_{n+1}), I(t_{n+1})) \qquad \text{(Equ. 13a)}$$

6 Conclusions

Human behaviour is strongly influenced by personality traits in a very individualistic manner. Many different physical, emotional, cognitive and social factors 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, for example like [Schaub 2001].

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.
The general methodology starts with variables describing the inner state of an agent, in the following four categories:

* Physical conditions
* Emotional states
* Cognitive capabilities
* Social status

By giving an agent more internal state variables, it is possible to enrich his inner life.
The internal state of the agent changes dynamically through the state transition function F, which describes how and why a state variable changes its value, and gives rise to a new internal state.
The new internal state results in a new value for the intensity of the various motives an agent is capable of experiencing. The intensity of the motives is calculated by the function H. The motive with the strongest intensity determines the action the agent performs.
Again, within the PECS architecture it is easily possible to change the functions F and H. This means that the user is free to create an agent that changes his internal state, and the corresponding intensity of his motives, exactly as the user requires.
Both the functions F and H contain constants. These constants are related to personality traits. This means that an agent's personality traits can be modified by adjusting constants without the user being required to do any reprogramming.
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.

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