Human Factors in Complex Systems
The Modelling of Human Behaviour

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SUMMARY

Human beings are most often an integrated part of complex systems. In order to describe such a system with appropriate accuracy it is necessary to model the human components with the same accuracy as the technical components. Human factors must be included and modelled with the same degree of precision as the system's mechanical parts.
A human being is perceived as a psychosomatic unit with cognitive capacities embedded in a social environment. Human behaviour is structurally highly complex. As human behaviour is influenced by physical, emotional, cognitive and social factors, it is highly intricate. Consequently, a human being is perceived as a psychosomatic unit with cognitive capacities embedded in a social environment.

The PECS reference model makes it possible to specify and model these factors and their interactions.
PECS stands for:
Physical conditions
Emotional state
Cognitive capabilities
Social status
The PECS reference model aims to replace the so-called BDI (Belief, Desire, Intention) architecture. [Rao 1995]. Architectures, such as BDI, which conceive of human beings as rational decision makers, are sensible and useful to a very limited degree only. Restriction to the factors of belief, desire and intention is simply not appropriate for sophisticated models of real systems where human factors play an important role.
A detailed description of the PECS reference model and its underlying methodology including some basic examples can be found in [Schmidt 2000] and [Schmidt 2005].
The actual importance of models that include human factors will be shown in a case study which is intended for use in real decision-making processes.

- PAX
  PAX is a model, which is used to describe peaceful military operations in the distribution of food care parcels in an occupied war zone. The aim of the model is to investigate strategies for the soldiers under varying circumstances. It is obvious that in a situation like this, aside from rational and cognitive considerations, emotional and social (especially psychosocial), aspects have to be taken into account.

Further examples are:
- MedSim
  As prevention and screening become more important in health care, it would seem obvious to investigate the intended measures for screening by means of a simulation model before the actual implementation of the measures. Models to evaluate screening programs for the early detection of diseases must include factors related to the patients' compliance. Compliance is determined by physical, emotional, cognitive and social influences. Therefore, the PECS reference model offers an adequate framework for these investigations.
  A detailed description can be found in [Brailsford 2002]

- Adam
  Recently the importance of emotional intelligence has been realised. It is obvious that emotional control and social competence are more decisive than pure intelligence in determining success in coping with difficult problems, which embrace human beings in various settings. The Adam model describes the process of emotional control, its dependencies on other factors and its consequences on behaviour and decision-making.
  A detailed description can be found in [Schmidt 2000]

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

1 THE MODELLING OF HUMAN BEHAVIOUR

The first question, in modelling human behaviour, is whether the attempt to investigate human beings scientifically and capture their nature in a model is at all possible or whether it is simply an example of hubris.

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1.1. The Unfaithful Nature of Human Beings

Human behaviour is determined by a wide variety of influencing factors, which interact in complex ways. The following examples chosen at random serve to illustrate this:

- Personal Experience
  The behaviour of human beings is influenced by their life history and by the experiences they have had. These include early childhood experiences as well as consciously learned experiences through interactions with their environment.
- Social Norms and Role Expectations
  Every human being, to a certain extent, conforms to the norms and role expectations which society imposes on them. These demands often conflict with their individual wishes, plans and ambitions.
- The Unconscious
  Human beings are very often not conscious of their own actions. Again and again they act or react in ways which surprise them or which they did not expect of themselves. Is St Paul not right when he says: "I do not do the good that I want to do, but I do the evil that I do not want to do “ (Rom. 7, 19)?
- Conflicting Motives
  In conflict situations human beings are torn between different motives that vary and are often in conflict with each other. Should they in the Kantian sense, for example, do their duty or should they rather follow their inclinations?
- Human Freedom
  One also has to take into account free will, which enables human beings to decide what to do, who to trust, what roles to play and what norms to follow. These decisions take place independent of external influences and stimuli and are based solely on the individual's personality and free choices.
- The Experience and Response to Art
  In the arts, human beings have access to a world of experience, which eludes logical assessment. Beethoven noted in his diary: "Music is a higher revelation than all wisdom and philosophy.“

Can all this be modelled?
Can we really fully understand human beings? Will we really be able to reproduce their behaviour in a computer model?
Do these examples indicate that human beings are far too complex, far too contradictory and far too unfathomable to be made comprehensible and in turn predictable by means of a model? Would such an attempt be bound to remain superficial and shallow and thus fail to capture precisely what constitutes being human?
Should we agree with Pascal, who wrote in the Pensées:

What a chimera the human being is! Wonder, confusion, contradiction! Judge of all things, powerless earthworm, dark room of uncertainty, the glory and the shame of the universe. When he praises himself, I will humble him; when he humbles himself, I will praise him; and I will go on contradicting him until he comprehends that he is incomprehensible.

Is the human being truly incomprehensible?
Of course it can be assumed that human behaviour is very complex and many-layered. The PECS research project however, is based on the conviction that it is possible to reduce this complexity by means of conscientious functional decomposition and to dissolve this multi-layered quality by carefully isolating the individual layers. These layers are first studied in isolation and then their interaction and their interplay are investigated. To these ends, it is hoped we can approximate a deeper understanding and comprehension of human behaviour.

1.2 The Difference between Model and Replica

In order to answer the question, "can human behaviour be modelled?", we must distinguish between developing a *model* of human behaviour and producing a *replica*.
A replica is an identical copy of an original. It is completely indistinguishable from the original. It appears to be impossible, at least for the foreseeable future, to produce an artificial replica of a human being.
A model, on the other hand, is an abbreviated depiction of an excerpt of reality based on abstraction and idealisation. It does not have to conform to reality in every aspect and all respects. An example of such a model is that of the model aeroplane used in wind tunnel experimentation. Such insights are valid in the human sciences too. For example, literary and historical scholarship have developed a picture and hence a model of Goethe. This picture is of course not identical to the real Goethe. It does not claim to be a replica. Nonetheless it does provide useful and useable insights. The more precise and the more detailed our image and thus our model of Goethe is, the better he can be understood and the more accurately his behaviour in a certain situation can be predicted. Not exactly of course, but in terms of a general tendency. If we had a good model of Goethe, we would know something about his physical condition, his emotional state, the state of his knowledge of the world and his social position. It would then be conceivable we could understand, for example, why at an advanced age he falls in love with a young woman. We would even perhaps be in a position to forecast something of the kind. We would not be able to state exactly where and when this would take place. But we could assume that it might happen.
A robust and useful model, capable of providing valuable insights, does not necessarily have to be insurmountably complex and difficult. It could turn out in fact to be quite simple, so simple that modelling could be successful. This means a model of a human being does not necessarily have to contain all the quailties that distinguish the individual as a human being. One can try to begin in a simple way and concentrate on the dominant facts in the problem under investigation.

Applying this to the PAX model of peaceful military operations, this insight leads us to hope that such a project is not impossible from the outset.
In order to understand the behaviour of soldiers and civilians and make it predictable within limits, it is not necessary to model the participants in all their complexity. There is no need for a replica. Many qualities and modes of behaviour that normally typify an affected person can be sacrificed to the filtering abstraction and idealisation process without rendering the modelling process completely futile.

1.3 Models of Human Behaviour in the Empirical Sciences

When considering the modelling of human behaviour, it should be kept in mind that excellent models of human beings and their behaviour already exist in certain disciplines.
Physiology has developed very detailed and expressive models of the human body and its behaviour in changing circumstances. It is possible to model, understand and predict physical and chemical processes in the human body.
In a similar manner, psychology attempts to develop models of human psychological life which deepen our understanding of internal processes. This category includes cognitive aspects such as intelligence, learning, memory and powers of imagination. In addition, considerable work is being done to improve our understanding of emotion in its healthy as well as pathological forms.
Sociology also works with models and attempts to understand human behaviour in its non-individual form, i.e. in relation to society. Sociological models investigate, for example, the development, the passing on and the implementation and development of norms. In both cases, sociology attempts to identify human behaviour in social groupings.
If one were to question the explanatory value and prognostic capacity of these models, then physiology, psychology and sociology would cease to exist as no one would wish to adopt such a stance.
Everyday experience provides a further example. The better one knows a person, the better one is generally able to understand this person and in some circumstances even to predict their behaviour.
These arguments have shown that it should be possible, at least in certain areas, to model and understand human behaviour and make it reasonably predictable. However, the important proviso remains. Many people themselves consider a model to be an abbreviated and crude version of the original, never being identical. A model of an individual is fundamentally different from the individual themself. Nevertheless a model can be useful and meaningful.
Many critics who doubt the possibility of modelling a human being are not aware of this point. They confuse a model with a replica and because of this become engaged in incomprehensible polemics.

1.4 The Human Being as a Psychosomatic Unit with Cognitive Abilities in a Social Environment

The sciences have so far concentrated on investigating partial aspects of human behaviour under laboratory conditions appropriate for each field of research. As a result there has been a tendency to lose sight of the interactions between the emotional, the cognitive and the social areas. It is a fundamental conviction of the PECS research program that an understanding of human behaviour can be achieved only if all 4 aspects and their interaction are taken into account. According to this interpretation, a human being is a psychosomatic unit with cognitive capacities who is capable of surviving only in society. Their behaviour will always be determined and shaped by the interaction between their physical situation, emotional state, cognitive capacities and social position.
As soon as one attempts to model real human behaviour, it is essential to have a reference model that permits the possibility of this interaction and this interplay. Engineering sciences with their architectural models and theory with its virtual realities do not need to take this possibility into account.

1.5 Behaviour Control

Generally speaking we can start by assuming that every organism has certain needs, which it wishes to satisfy. In the course of time, evolution has constantly developed and improved more powerful forms of behaviour control in order to guarantee the satisfaction of these needs. For reasons of clarity it is useful to distinguish the following forms of behaviour control:

- Reactive behaviour
- Deliberative behaviour
- Reflective behaviour

We can assume that a human being, as a product of evolution, has all these modes of behaviour control at their disposal. They are capable of the highest form of reflective behaviour without having completely liberated themselves from elementary forms of instincttive behaviour. The human being is a citizen of several worlds.
A reference model that presumes to model human beings as a whole must provide an architecture that makes it possible, in principle, to model all forms of behaviour control.

2 THE HUMAN BEING IN THE MODEL

If human beings with their diverse modes of behaviour are to be represented in the model, a fundamental concept is at first required. The present study assumes that the model of a human being should have the structure of a system.

2.1 System-Theoretical Principles

A system in terms of system theory is first charac-

terised by unequivocally defined state variables. These state variables can change their value on the basis of their own dynamism or an external input. The modified internal system state will then lead to an output, which one can regard as an action.
This can be shown in the simplified diagram 2.1.

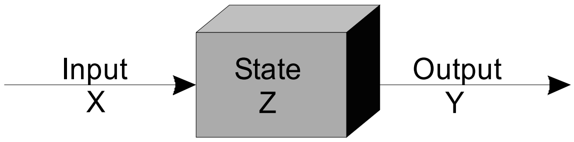

Diagram 2.1. A System with Input and Output

A number of simple examples will illustrate how the fundamental concept of a system in the case of a human being could look:

- Let the internal state variable be body temperature. By taking a medicine as an input the body temperature is increased. This leads to observable behaviour that causes the person concerned to take a towel and wipe away the sweat.
- Let a possible internal emotional state of a person be joy. Let it at first have a low value. A positive piece of news from outside leads to an increase in the value of the joy state variable. The person might then respond by jumping in the air or by yodelling.
- The state of a person's knowledge may also be described with the aid of state variables. A person's knowledge level may be increased by the acquisition of information. As a result the person is now able to visit a restaurant, the location of which he has just found out. He knows the place coordinates.
- A person's social status may be increased by a promotion as input. He may be promoted from the position of subject teacher to that of head of department. This new state as head of department leads him to take new actions that have now become possible. He could for example rent a new and better flat.

These examples may appear somewhat artificial and even silly in their simplicity as they certainly do not do justice to the complexity of human behaviour. However their function here is simply and solely to illustrate the basic underlying principle.
A further objection to the concept of producing a model of the human being on a system-theoretical basis has been raised by representatives of the human sciences. They consider a terminology which talks of internal state variables being modified by external inputs which lead to actions as output as mechanistic, technocratic and therefore inappropriate. Such terms, they argue, may be appropriate for machines, robots and even for trained rats but not for human beings.
It should be made clear at this point that the present research program does not accept this objection. Thanks to evolution human beings have developed ever newer, more complex and more efficient forms of behaviour regulation. It is not immediately clear why a descriptive procedure appropriate for the rest of the natural world should not apply to the human being. There are no insurmountable barriers between human beings and the rest of the natural world, from which the human being originated and as a part of which he may be seen. The present research program is based on naturalistic principles.

Formally a system can be described in terms of eleven elements
(T, X, Y, Z, W, **X**, **Y**, **Z**, F, H, g)

- T Set of time values
- X Set of inputs
- Y Set of outputs
- Z Set of internal state variables
- W Set of dependent variables
- **X** Set of time-dependent input functions $X \subset X^T$
- Y Set of time-dependent output functions $Y \subset Y^T$
- **Z** Global state transfer functions **Z**: $T \rightarrow Z$
- F Local state transfer function, F: $(T \times Z \times X) \rightarrow Z$
- H Algebraic function, H: $(T \times Z \times X) \rightarrow W$
- G Output function, G: $(T \times Z \times W \times X) \rightarrow Z$

The behaviour of an agent can be described using the terminology of system 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:

$$z(t_{n+1}) = F(t_n, z(t_n), x(t_n)) \qquad \text{(eq. 2.1)}$$

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 z and a dependent variable w can be described by an algebraic function H. Therefore, we have:

$$w(t_{n+1}) = H(z(t_{n+1})) \qquad \text{(eq. 2.2)}$$

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 $y(t_{n+1})$.

$$y(t_{n+1}) = G(t_{n+1}, z(t_{n+1}), w(t_{n+1}), x(t_{n+1})) \qquad \text{(eq. 2.3)}$$

The basic assumption made in PECS is that an agent's personality depends on the form of the 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.

$$Anger(t_{n+1}) = F(Anger(t_n), Experienced\_failure(t_n)) \quad \text{(eq. 2.1a)}$$

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.

$$Energy(t_{n+1}) = F(Energy(t_n), Action\_performed(t_n)) \quad \text{(eq. 2.1b)}$$

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.

$$Hunger(t_{n+1}) = H(Energy(t_{n+1})) \quad \text{(eq. 2.2a)}$$

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.

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 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.

3. DESIRES, MOTIVES AND ACTIONS

In some simple cases, the state variables directly determine the behaviour of an agent. This is particularly the case with reactive behaviour as situations that cause reactive behaviours are in general 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. In this case the state variables do not determine behaviour directly, but rather indirectly, via the motives belonging to them. This basic idea was adopted from [Dörner 1999] and generalised to include all four possible classes of motives.

For example, lets examine the state variable Energy. This variable was introduced in section 2 (see eq. 2.1b) and 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 it 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 being 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 processes more clearly, these concepts are defined arbitrarily. These definitions are not claimed to be generally valid: they apply to this presentation only.

3.1 Intensity of Drives

Drives are related to physical state variables like blood pressure, body temperature and 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 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 the more intense the Hunger drive will be.

$$Hunger(t_{n+1}) = H(Energy(t_{n+1})) \quad \text{(eq. 3.1)}$$

In the special case of Energy and Hunger, the function H could have the following form:

$$Hunger(t_{n+1}) = MaxHunger * (1 - f(Energy(t_{n+1}))) \quad \text{(eq. 3.1a)}$$

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

If $(Energy(t_{n+1}) > EnergyLimit)$
Then
Hunger = 0

The function f(Energy) is the so-called Richard's curve, which is frequently used to describe dependencies of this form. [Horgan 2001]
Diagram 3.1 shows the course of the intensity of the Hunger drive depending on the available Energy, according to equation (3.1a). As the available Energy decreases, we see an increase in the Hunger perceived.

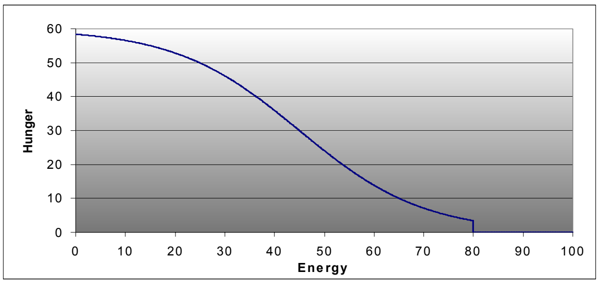

Diagram 3.1 The intensity of the drive Hunger, depending on the available Energy

Clearly there is a distinct difference between the physical state Energy and the perceived Hunger drive. In particular, if the Energy is high, the agent does not experience any drive as long as the Energy stays over the threshold value of the Energy limit.

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

$$Hunger(t_{n+1}) = HungerIncrease * (log(EnergyDeficit(t_{n+1}) + 1) \quad \text{(eq. 3.1b)}$$

If $(EnergyDeficit(t_{n+1}) < EnergyMin)$
Then
Hunger = 0

The equation (3.1b) was taken over from [Dörner 1999].

The exact form of the Hunger drive is determined by the three constants MaxHunger, HungerIncrease and HungerMean in equation (3.1a).
The equations (3.1a) and (3.1b) with their two constants MaxHunger and HungerIncrease determine how intensively the agent really perceives or experiences the internal state Energy. It is essential that it is not the real internal state Energy itself, but only the experienced intensity of the corresponding Hunger drive, 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 (3.1b), are the values that make up the personality trait with respect to the Energy state and the Hunger drive.
The greater the Energy deficit, and the stronger the Hunger drive is, the more vehemently the agent will act. An agent with a personality that is very sensitive to possible Energy deficit and the Hunger drive, will attach great importance to the fulfilment of this particular desire.

3.2 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.
Similar to the relationship that exists between the Energy state and the Hunger drive, there is a relationship between an emotion and the experienced intensity of this emotion. The function H connects the emotion state variable, for example Fear, with an intensity, such as 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 Fear is perceived, the following equation can be used:

$$UrgeFear(t_{n+1}) = H(Fear(t_{n+1})) \quad \text{(eq. 3.2)}$$

3.3 Willpower

Deliberate 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 more or less resolutely, according to his willpower. As before, willpower can be calculated using the function H. The cognitive state variables of the goal are used as arguments for H.
As an example, the state variable KnowAct might describe 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 Will Knowledge. 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:

$$WillKnowledge(t_{n+1}) = H(KnowAct(t_{n+1})) \quad \text{(eq. 3.3)}$$

In its most simple form, equation 3.3 might look as follows:

$$WillKnowledge(t_{n+1}) = - WillIncrease* 1/KnowAct(t_{n+1}) \quad \text{(eq. 3.3a)}$$

Another possibility could be:

$$WillKnowledge(t_{n+1}) = exp(-WillIncrease*1/KnowAct (t_{n+1})) \quad \text{(eq. 3.3b)}$$

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

3.4 Intensity of Social Desire

Social state variables describe facts about the agent in relation to other agents. For instance, the state variable SocAct measures an agent's current social satisfaction. SocAct increases if the agent is in the company of others and decreases if it is by itself. 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, thus:

$$\text{DesireCompany}(t_{n+1}) = H(\text{SocAct}(t_{n+1})) \qquad \text{(eq. 3.4)}$$

The exact form of the function H, in equation (3.4), will depend upon the nature of the problem. For example, it could have a similar form to equations (3.1a) or (3.1b). The function H determines 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.

3.5 Motives and the general procedure

Initially, in the above cases, 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 it to perform a particular action.
Drives, emotional intensity, will power 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 agent's behaviour.
Since drives, emotional intensity, will power 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 point in 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, it can feel 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 power
   Will-controlled behaviour: Tidy the room
3) Intensity of social desire
   Socially controlled behaviour: Go to a party

At the beginning, the agent's will power may have the highest intensity. That means the agent will start to tidy the house. However, over time Hunger may become stronger and stronger. At some point the intensity of Hunger will overtake the intensity of the will power. The action of tidying stops and is replaced by going to the fridge.
The three motives are not constant, but change over time. Therefore different motives may be action-determining at different times. Thus, for example, it is possible that initially the intensity of will has the highest value, and so the agent is interrupted. A new motive takes control and the agent goes to the fridge.

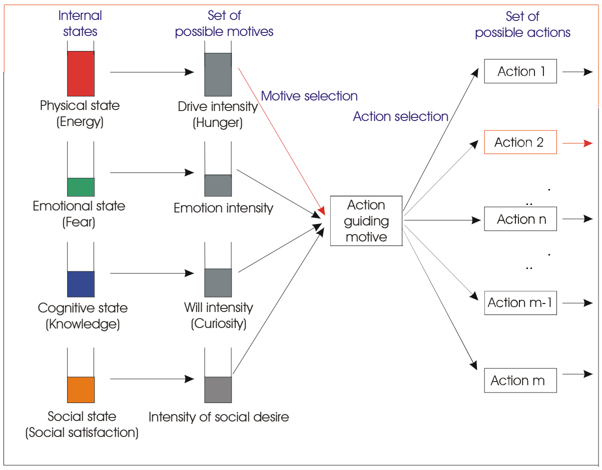

Diagram 3.2 Motives and motive selection

The proposed methodology makes it possible to combine motives as diverse as the intensities of drives, emotion, will power and social desire. Furthermore, the rich and vivid dynamics, which exist within the mind of an agent, can be modelled in a clear and manageable way.
Diagram 3.2 shows the 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.

4 THE PAX MODEL

PAX is a model that is used to describe the peaceful operations of the military for the distribution of food care parcels in an occupied war area. The aim is to investigate strategies for the soldiers in a variety of different circumstances. It is obvious that in such a situation, emotional, social, and especially psychosocial aspects have to be taken into account in addition to rational and cognitive considerations.

The model contains the soldiers who distribute the food parcels, the supply vehicle and the civilians. The setting of the scene is as village such as one found in Bosnia, Macedonia or Afghanistan. A general description of the project can be found in [Schwarz 2000].
Diagram 4.1 shows the real environment and its representation as a chessboard in the model. In the model the colours stand for the following:
Black areas: houses
Blue square: the supply vehicle
Blue circles: soldiers
Yellow circles: civilians

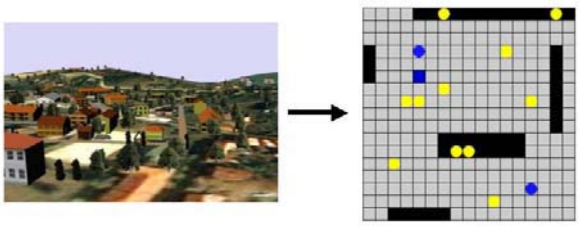

Diagram 4.1 The real system and its model

Each human being is represented by an agent. There agents are constructed internally using the PECS structure.
Via the Sensor component, the civilian-agent realises the actions of a soldier. According to his momentary internal state and his persistent personality the agent's actor component responds with an action.

4.1 Internal states, motives and actions

Each agent is characterised by the following three internal variables:

- Fear
- Anger
- Need for food

Each of these internal variables can change its value for the following three reasons:

- Self-dynamics
  This variable changes its value independently without any external influences.
  For instance, Fear or Anger decrease with time if nothing happens. Individual psychology provides information on how this happens.
- Actions of the soldiers
  The various actions the soldiers are capable of influence the internal state of an agent. For instance, if a soldier calms down a civilian, the civilian's Anger and Fear will decrease.
- Influence of the group
  The common state of the surrounding group affects the state variables of the agent. For instance, if a peaceful agent enters a hostile, aggressive environment the agent's Anger will increase. Social psychology provides descriptions of this type of situation

Diagram 4.2 shows the threefold way the internal state of an agent can change and as a consequence how actions are induced.

4.2 The change of the state variables

As previously mentioned, the internal state variables of an agent can change in a threefold way. The procedure will be described in more detail using the state variable Anger.

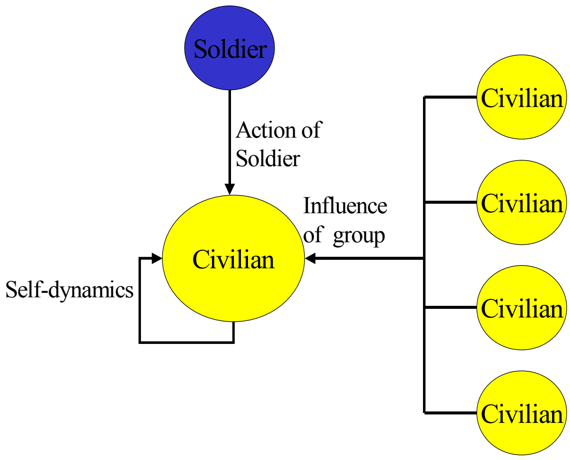

Diagram 4.2 The threefold way to change the internal state of an agent

The overall change of the state variable is specified by means of a differential equation and by means of a time-discrete event. The differential equation 4.1 accounts for the continuous change of the state variables. It has the following form:

$$\text{Anger}' = ((\text{AngerMax} - \text{Anger}) / \text{AngerMax}) * \text{AngerChange} * \text{Anger} \quad \text{(eq. 4.1)}$$

AngerChange describes the rate with which the Anger changes over time.
It has two parts:

$$\text{AngerChange} = \text{PersonalAnger} + \text{GroupAnger} \quad \text{(eq. 4.2)}$$

PersonalAnger is a variable that describes the self-dynamics with which the variable Anger decreases of its own accord. GroupAnger adds the amount of Anger that is induced by the surrounding group members.

Diagram 4.3 shows the natural decrease of Anger without external influences.

Eq. 4.3 describes the discrete change as a consequence of an action by a soldier, thus:

$$\text{If ActionSoldier} \quad \text{Anger} = \text{Anger} + \text{AngerActionSoldier} \quad \text{(eq. 4.3)}$$

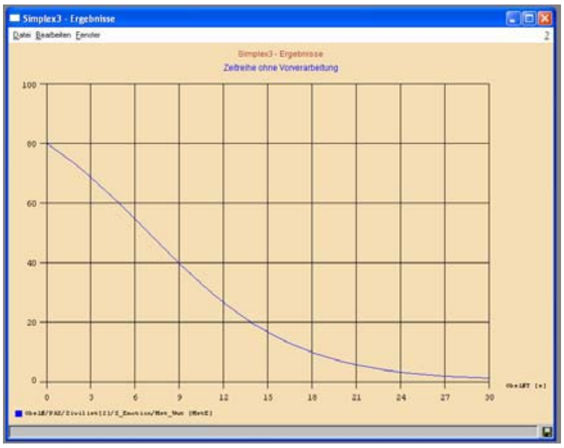

Diagram 4.3 The natural decrease of Anger without external influences

If a threat is present this action leads to a sudden increase in Anger by the amount of AngerAction Soldier, which is added to the already existing amount of Anger. Diagram 4.3 shows the course of the natural decrease in Anger if there are no group influences and no actions of the soldiers are experienced

Diagram 4.4 shows how the state variable Anger changes in a discrete way, when a soldier exerts an action such as a threat. The methodology is the same as the one described by diagram 1.

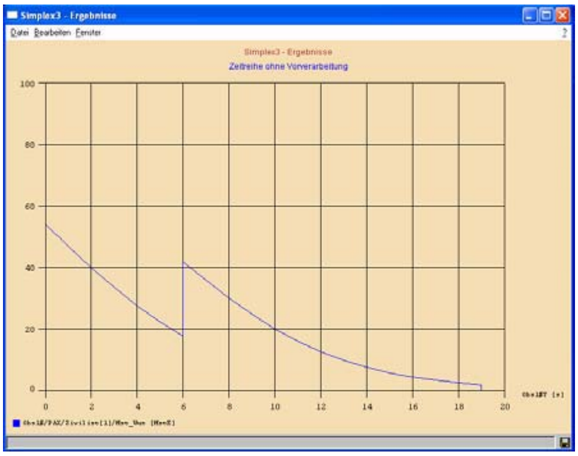

Diagram 4.4 The discrete increase of Anger as a consequence of an action

4.3 The repertoire of actions and behaviour

Each agent has a limited repertoire of actions at his disposal.

The possible actions for the soldiers are the following:

- Calm down
- Threat
- Attack

The possible actions for the civilians are:

- Retreat
- Wait
- Attack
- Queue for a food parcel in front of the food vehicle

The component Behaviour within the PECS architecture determines - according to a set of rules - which action is selected and finally performed. This selection depends on the strength of the motives and modifying factors.

4.4 Results

The goal of the PAX model is to investigate the best possible set of rules for the soldiers under various, diverse conditions. For this purpose the parameters of the model can display a wide range. Modifiable variables are among others:

- The personality traits of the soldiers
- The personality traits of the civilians
- The strategies for the soldiers
- The environment

One interesting investigation attempts to find a robust strategy for the soldiers. It should be applicable and successful in as many different circumstances as possible.

Diagram 4.5 shows the reaction of the civilians as a consequence of six different rule sets or strategies. One sees that strategy number 4 leads to a very low value for both the state variables Fear and Anger. This means that a behaviour of the soldiers that follows these instructions will lead to a peaceful and successful operation.

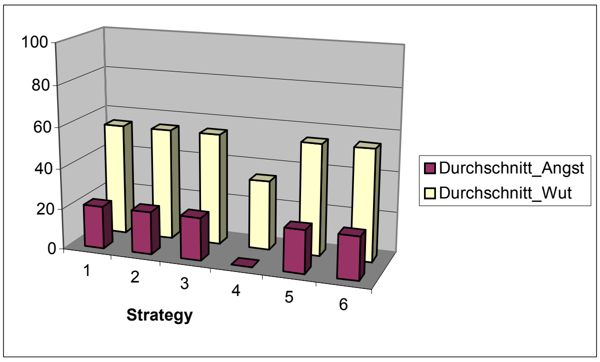

Diagram 4.5 Various strategies for the soldiers and their consequences for civilians

5 THE PECS REFERENCE MODEL

A reference model can serve as a blueprint for a class of real systems. It shows the structure of a model for all real systems that have a common deep structure and that differ only in superficial qualities.

A PECS model in this sense is a reference model for the modelling of human behaviour. The architecture proposed here claims to be universally applicable. Adaptation to individual conditions occurs by means of filling in the empty spaces provided by the architecture. This means for example that the number and the type of state variables, the structure of the transfer function F and the development of the output function G can be modified without difficulty. Similarly the agent can be endowed

with a varied repertoire of actions that state the external actions of which the agent is capable. As a result, very diverse agents and agent communities develop but they all have the same deep structure and therefore they can all be described by one and the same reference model.
The PECS reference model is based on [Urban 2000a], where a more detailed and wide-ranging description is given.

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

- the environment component
- the connector component
- the agents

Diagram 5.1 shows the basic structure.

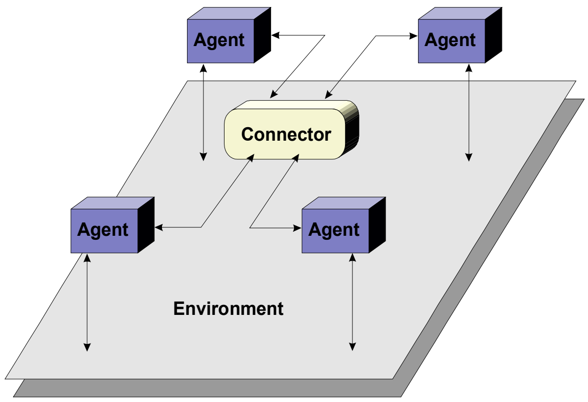

Diagram 5.1 The Structure of the PECS Reference Model

6. CONCLUSIONS

It is possible to construct a wide range of models for agents whose dynamics is determined by physical, emotional, cognitive and social factors and their interactions. Especially valuable is the possibility to specify the following three modes of behaviour control:

- Reactive behaviour
- Deliberative behaviour
- Reflective behaviour

It was shown in an exemplary and prototypical fashion the methodology to be followed in the modelling of human behaviour in general.

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