An Integrative Agent Model for Adaptive Human-Aware Presentation of Information During Demanding Tasks

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Abstract. This paper presents an integrative agent model for adaptive human-aware information presentation. Within the agent model, meant to support humans in demanding tasks, a domain model is integrated which consists of a dynamical model for human functioning, and a model determining the effects of information presentation. The integrative agent model applies model-based reasoning methods to the domain model to analyse the state of the human and to determine how to adapt the presentation of information to this state.

1 Introduction

When a human is performing a demanding task, often support can be offered by presenting information that is relevant for the task. For example, a naval officer or air traffic controller may be offered visualised information on location and speed of several objects in the environment, and of the characteristics of such objects. Other cases are when information is presented on the workflow that is being followed, and on the status of the different tasks in a workflow, or relevant task information such as manuals for systems used. In all of such cases the human may take the initiative, for example, by activating certain options using menu structures. However, especially when tasks require a high level of attention and concentration, it is more beneficial when the human does not need to bother about such presentation aspects, by giving the system itself an active role in offering information of appropriate types and forms.

Adaptive information presentation can provide a useful type of support in a number of application contexts, varying from tourists in a museum (e.g., Oppermann and Specht, 2000; Stock, Zancanaro, Busetta, Callaway, Krüger, Kruppa, Kuflik, Not, and Rocchi, 2007) and users in hypermedia and Web contexts (e.g., Tarpin-Bernard and Habieb-Mammar, 2005), to students using educational systems (e.g., Kashihara, Kinshuk, Oppermann, Rashev, and Simm, 2000) and humans in demanding tasks (e.g., Hudlicka and McNeese, 2002; Fricke, 2007). A main requirement for an adaptive information presentation system is that it presents information in types and forms that are strongly depending on these circumstances. Here circumstances may involve a number of aspects, for example (see also, e.g., De Carolis, Di Maggio, and Pizzutilo, 2001; Sarter, 2007): (1) the characteristics of the task, (2) the characteristics of the human involved, such as expertise level with respect to the task, (3) the state of the environmental context (4) task status and task progress, and (5) the cognitive, affective or functional state of the human. Here (1) and (2) may be considered static over longer time periods, but (3), (4) and (5) usually have a highly dynamic nature. To take such aspects into account an adequate presentation system has to be highly adaptive and has to be constantly aware of them.

Awareness of the state of the human, the task and the environment can in part be based on observation and sensoring information acquired. However, often awareness is required on aspects for which information cannot be acquired in a direct manner, for example, the level of anxiety, stress and exhaustion of the human, or the progress on the task. In such cases dynamical process models can be used to relate information that is directly acquired to information about aspects that are not directly accessible. In this paper an integrative agent model for an adaptive human-aware presentation system for humans in demanding tasks is presented that makes use of a dynamical model of human functioning, in particular to monitor the human's functional state (covering aspects such as exhaustion and experienced work pressure), combined with a model to determine the effects of information presentation. In Section 2 first the context is described in some more detail. A computational domain model is introduced in Section 3. Section 4 introduces the overall architecture of the integrative agent model, whereas in Section 5 more details of the model are discussed. Section 6 presents simulation results based on two example scenarios. Finally, Section 7 is a discussion.

2 On Adaptivity in Information Presentation

The context of the research reported in this paper is the domain of naval warfare or, since its character has changed over time, naval operations. These operations are carried out by naval ships, organisationally grouped together into a navy escadre. Aboard such naval ships, a team of operators cooperates with an automated Combat Management System (CMS) to perform their task as part of the overall operation. An important factor of influence on the success of an operation, is the environment in which naval ships have to operate. When the environment is complex and dynamic, high volumes of frequently changing data will be detected by sensoring equipment of a naval ship, resulting in highly strenuous situations for the CMS as well as the operator. When the heat is on, each operator has to build up and maintain *situation awareness* when interacting with the CMS, decide on and perform actions within limited time. The results of these actions can be critical for the result of the entire operation and can even be critical for self preservation, so besides timeliness, quality of human task performance is also essential.

Given this context and the inherent fallibility of human task performance, automated support for operators in strenuous situations is an interesting topic of research that is likely to be beneficial. This kind of support cannot only be provided at the team level, but also on an individual level. An example of support at team level is *dynamic task allocation*, in which tasks are reallocated from one operator to another in case an operator gets overloaded. An example of support at the individual level is *adaptive information presentation*, in which information presented to an operator is personalized and adapted to his specific circumstances. This last kind of support is explored in this paper.

The main principles of design of information presentation in displays are extensively described in literature on Human Information Processing and Human Factors; e.g., see Johnson and Proctor, 2004; Wickens and Gordon-Becker, 2004. It is well established in this literature that a good display design can enhance information processing and improve human performance. However, this conventional display design is based on the general characteristics of human information processing and aims to serve an average person performing a particular type of a task. It usually does not consider personal characteristics and dynamic, constantly changing environments and human functional states. The goal of the research reported here is to incorporate principles of information presentation in a dynamic model along with such factors as operator's functional states, environmental and task characteristics. The integrative model presented in this article will represent the relations between these factors and human functioning while performing a task.

Cognitive performance is affected by the human's activation state, or alertness (Lehrl et al., 2007). Alertness is a physiological state that affects the attentional system and varies depending on internal and external factors (Thiffault and Bergeron, 2002). Besides alertness, cognitive performance is also influenced by human information processing aspects, such as perception and working memory (Wickens and Gordon-Becker, 2004). It is well-established that bright light rapidly increases alertness (Penn and Bootzin, 1990). Therefore one of the assumptions underlying the work reported here is that the level of brightness, or *luminance*, may have an effect on alertness of an operator. Another characteristic of a display that may affect alertness is the *background colour*. It has been shown that performance on monotonous tasks is better if the information is presented in a red background (Stone and English,1998). It can be related to the fact that the red colour has a stimulating effect and helps to increase alertness. Other findings support the idea that blue light improves performance (Lehrl et al., 2007). These findings are more convincing and report a more substantial effect on cognitive performance than the findings about the effect of red colour. The *time of the day* is an environmental aspect that can also influence alertness according to numerous findings that relate alertness and performance to circadian rhythms. It is found that the activation of central nervous system passes through different stadia during the day according to the inner clock in a brain. The highest level of activation is observed from 12:00 to 18:00 in the afternoon. The lowest level of activation is from 00:00 to 4:00 in the morning (Wickens and Gordon-Becker, 2004). Fatigue, the physiological and psychological state of tiredness and dislike of present activity, is one of the aspects that influence a person's functioning (Thiffault and Bergeron, 2003). Fatigue, on the other hand, is a general term which relates to both physiological and psychological processes. It can be defined as 'an experience of tiredness, dislike of present activity and unwillingness to continue' (Bartley, 1970). It may be assumed that *exhaustion* has also negative influence on the alertness level as exhaustion is placed on a higher level of tiredness-fatigue-exhaustion continuum. Exhaustion as a factor that affects a person's functioning while performing a critical task is also mentioned in the functional state model presented in (Bosse et al, 2008). It is found that motivation and alertness are correlated (Hull and Czeisler, 2003): the higher the level of motivation, the higher *alertness* is.

The findings below describe the relations between different factors of information presentation and processing demands. Display *luminance* affects visual search performance with monitor displays without affecting detection performance significantly (Krupinski, Roehrig and Furukawa, 1999). It was found that higher-luminance displays yielded more efficient search performance. The higher the *luminance*, the faster is visual search. According to Badderley's theory about the working memory, if the visuo-spatial sketchpad buffer of working memory is totally occupied by the processing of visuo-spatial information during the execution of a task, no more visual information can be perceived and processed (Baddeley, 1996). In this case presenting information in another modality, auditory for instance, will lead to less processing demand if a task being performed requires predominately visuo-spatial resources, but will lead to more processing demand if a task is predominantly auditory. This principle is applied in the PACE (Performance Augmentation through Cognitive Enhancement) system architecture presented in (Morizio, Thomas en Tremoulet, 2005). The PACE system was successfully applied to different domains and applications and yielded significant improvements in human performance in the conditions of high stress and workload.

The *grouping* of numerous objects imposes less processing demand because attention resources are applied on the groups of objects at certain locations rather than on the whole field of a display with the isolated objects (Wickens and Gordon-Becker, 2004). The grouping principle of information presentation in a display may be of importance under high work pressure and processing demands in order to provide appropriate allocation of attentional resources. The larger the symbols are, the easier it is to process them, but after a certain threshold there is no gain in processing anymore (Chung, Mansfield and Legge, 1998). It may be hypothesized that the processing of objects is performed in the same way: the larger the objects, the easier it is to process them. On the other hand, it is obvious that the more objects occur in a display and the larger they are, the more processing demand may be imposed because the objects become less distinct and more difficult to perceive.

3 A Domain Model for Functional State and Information Presentation

In this section the domain model used is presented, which consists of two interacting dynamical models, one to determine the human's functional state and one to determine the effects of the chosen type and form of information presentation. The approach used to specify the domain model is based on the hybrid dynamical modeling language LEADSTO (Bosse, Jonker, Meij, and Treur, 2007). In this language, direct temporal dependencies between two state properties in successive states are modeled by *executable dynamic properties*. The a bit simplified LEADSTO format used here is defined as follows. Let α and β be state properties. In the LEADSTO language the notation $\alpha \twoheadrightarrow_D \beta$, means:

If state property α *holds at some time t, then state property* β *will hold at time t+D*

Here, state properties can have a qualitative, logical format, or a quantitative, numerical format, and may consist of conjunctions of atomic state properties.

The dynamic model for the functional state used was adopted from (Bosse, Both, Lambalgen, and Treur, 2008); for a global picture, see Figure 1. Here the functional state is defined as the combination of exhaustion (fatigue), motivation, experienced pressure, and effort. These are determined by external factors such as task demands and the state of the environment, and by personal factors such as experience, cognitive abilities and personality profile. Originally the model was implemented in MathLab. For the work reported here it was remodeled in LEADSTO and integrated within the agent model, as discussed in Section 4. On the one hand this model is based on the (informal) cognitive energetic framework (Hockey, 1997), that relates effort regulation to human resources in dynamic conditions. On the other hand, the model is based on literature on fatigue in exercise and sports (Hill, 1993) as formalised by a computational model in (Treur, 2009), in particular on the concepts *generated power* and *critical power*. Critical power is the maximal effort level a person can (constantly) maintain over a longer time period without becoming (fully) exhausted.

The arrows in Figure 1 denote causal dependencies; note that cycles occur. For example, generated effort is affected by the person's motivation level (*effort motivation*), the amount of effort the task requires (*task level*) and the effort the human is able to contribute (*critical point* and *maximal effort*). When generated effort is above the critical point, the exhaustion is increased. When generated effort is below the critical point, some recovery takes place (*recovery effort*), thus decreasing *exhaustion*. Effort contributed to cope with noise in the environment (*noise effort*) is extracted from the generated effort, so that the effort that can effectively be contributed to the task (provided effort) is less. The motivation is taken proportional to the task level, but also depends on the *experienced pressure*. An *optimal experienced pressure* is assumed which depends on the *personality profile*. The dynamical model has been formalised as a system of differential equations. For more details of this model, see (Bosse, Both, Lambalgen, and Treur, 2008).

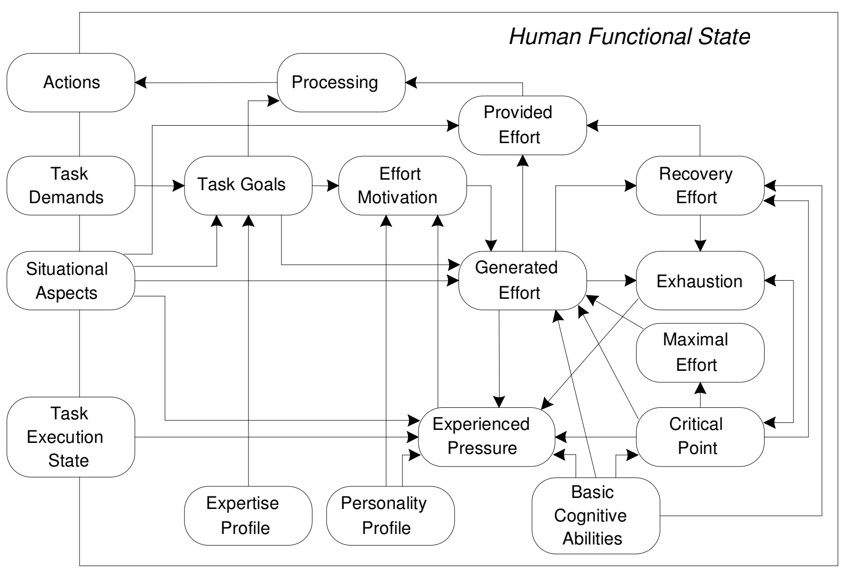

Figure 1: Functional state domain model

The interaction from the model for information presentation to the model for functional state takes place by affecting the task demands. Conversely, a number of aspects of the functional state are used as input by the information presentation model: effort motivation, exhaustion, experienced pressure and provided effort. Figure 2 shows an overview of the information presentation model.

The general paradigm of the relations within the presentation model is partially based on the existing models on workload that consider the fit between individual factors, such as coping capacity, effort, motivation, on one side and work demands on the other side. One example of such a model can be found in (Macdonald, 2003). This paradigm has been applied to the fit between the effort that a human is willing to invest while performing a task and demand. Effort is determined by internal and external factors while demand is imposed externally.

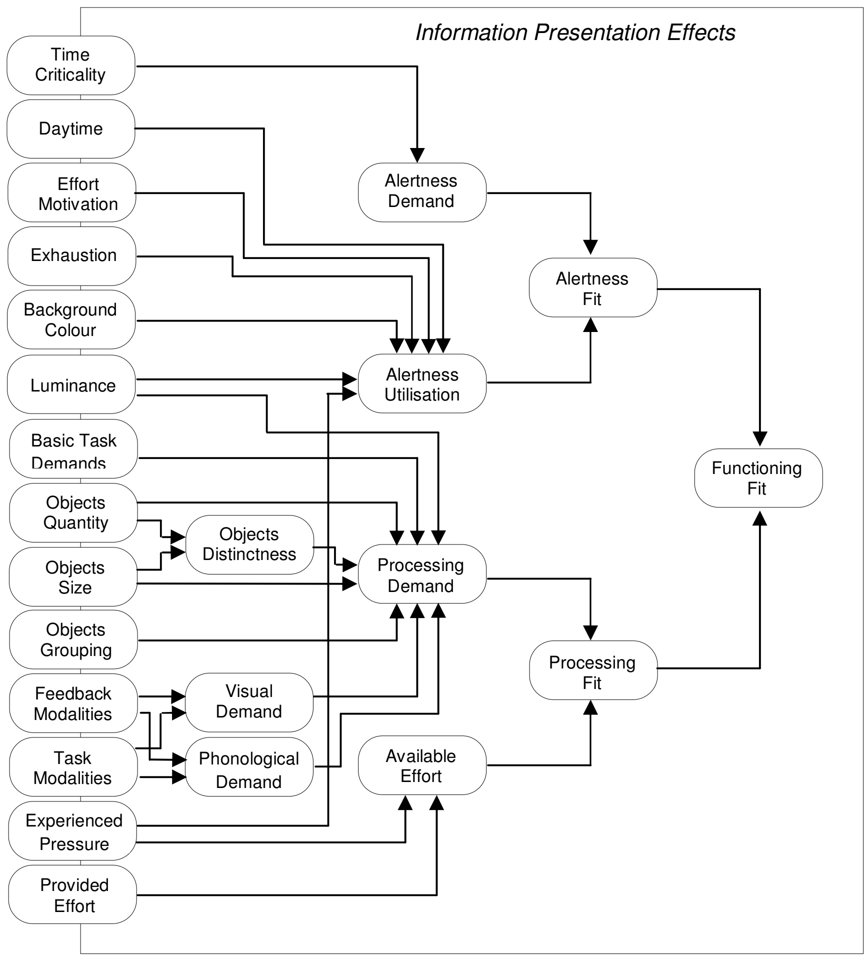

Figure 2: Information presentation effect domain model

Presentation format aspects can be seen as a part of task demands that are imposed on a person because a form of a presentation may change processing demands. On the other hand, some presentation aspects, for example, background colour and luminance, can be seen as available resources that help a person to perform a task. Luminance is regarded both as a part of demands and as a part of resources in this model. All types of aspects are converged into two more global internal factors that influence the task performance: physiological state of *alertness* and mental *information processing* state of an operator. Among these concepts a distinction is made between the states of available and used recourses of alertness and information processing, *alertness* *utilization* and *provided effort* respectively, and the states of demand for alertness and information processing, *alertness demand* and *processing demand*. The fit between the usage of these capacities and the demands determines the functioning of a human while performing a task, the *functioning fit*. Two specific types of fit are considered: *alertness fit* and *processing fit*.

If the usage of capacities and demands are at the same level, the fits will be high. If the levels of capacities and demands differ much, then the fits will be low. If both *alertness fit* and *processing fit* are high, then the *functioning fit* will be high.

All inputs for the model are represented by numbers between *0* and *1*. The same holds for the concepts *objects distinctness*, *visual demand*, *phonological demand*, *alertness demand*, *alertness utilisation*, *processing demand*, and *available effort*. The concept *alertness fit* indicates the difference between alertness demand and alertness utilisation and is represented by a number between *-1* and *1*. The same holds for *processing fit* which is the difference between available effort and processing demand. This was expressed in LEADSTO as follows.

If alertness utilisation has value V_1 and alertness demand value V_2,
then alertness fit has value V_1-V_2
has_value(alertness_utilization, V_1) & has_value(alertness_demand, V_2) $\rightarrow$ has_value(alertness_fit, V_1-V_2)

If available effort has value V_1 and processing demand value V_2,
then processing fit has value V_1-V_2
has_value(available_effort, V_1) & has_value(processing_demand, V_2) $\rightarrow$ has_value(processing_fit, V_1-V_2)

Furthermore, *functioning fit* is the sum of the absolute values of alertness fit and processing fit and is represented by a number between *0* and *2*.

If alertness fit has value V_1 and processing fit has value V_2,
then functioning fit has value $|V_1|+|V_2|$
has_value(alertness_fit, V_1) & has_value(processing_fit, V_2) $\rightarrow$ has_value(functioning_fit, $|V_1|+|V_2|$)

Processing demand is termined as a combination of a number of aspects, each with a weight factor, as follows.

If the basic task demand has value V_4, luminance V_6, visual demand V_1, phonological demand V_2, objects grouping V_8, objects size V_9, objects quantity V_{12} and object distinctness value V_3,
then processing demand has value
$\alpha_9*V_4+\alpha_{10}*(1-V_6)+\alpha_{17}*V_1+\alpha_{18}*V_2+\alpha_{12}*(1-V_8)+\alpha_{13}*(1-V_9)+\alpha_{14}*V_{12}+\alpha_{16}*(1-V_3))$
has_value(basic_task_demand, V_4) & has_value(luminance, V_6) &
has_value(visual_demand, V_1) & has_value(phonological_demand, V_2) & has_value(objects_grouping, V_8) &
has_value(objects_size, V_9) &
has_value(objects_quantity, V_{12}) & has_value(objects_distinctness, V_3)
$\rightarrow$ has_value(processing_demand, $\alpha_9*V_4+\alpha_{10}(1-V_6)+\alpha_{17}*V_1+\alpha_{18}*V_2+\alpha_{12}*(1-V_8)+\alpha_{13}*(1-V_9)+\alpha_{14}*V_{12}+\alpha_{16}*(1-V_3)$)

Available effort depends on provided effort and experienced pressure, specified as follows.

If provided effort has value V_{15} and experienced pressure value V_3,
then available effort has value $\alpha_1*V_1+\alpha_2*(1-V_2)+\alpha_{19}*V_3+\alpha_3*V_5+\alpha_4*V_6+\alpha_5*V_{10}$
has_value(provided_effort, V_{15}) & has_value(experienced_pressure, V_3)
$\rightarrow$ has_value(available_effort, $\alpha_{20}*V_{15}+\alpha_{21}*(1-V_3)$)

Alertness utilisation depends on a number of functional state and information presentation aspects as follows.

If the effort motivation has value V_1, exhaustion V_2, experienced pressure V_3, background colour V_5, luminance V_6, and daytime value V_{10},
then alertness utilisation has value $\alpha_1*V_1+\alpha_2*(1-V_2)+\alpha_{19}*V_3+\alpha_3*V_5+\alpha_4*V_6+\alpha_5*V_{10}$
has_value(effort_motivation, V_1) & has_value(exhaustion, V_2) &
has_value(experienced_pressure, V_3) & has_value(background_colour, V_5) &
has_value(luminance, V_6) & has_value(daytime, V_{10})
$\rightarrow$ has_value(alertness_utilization, $\alpha_1*V_1+\alpha_2*(1-V_2)+\alpha_{19}*V_3+\alpha_3*V_5+\alpha_4*V_6+\alpha_5*V_{10}$)

Finally, for alertness demand time criticality has been taken:

If time criticality has value *V*,
then alertness demand has value *V*
has_value(time_criticality, V) $\rightarrow$ has_value(alertness_demand, V)

4 The Overall Architecture of the Information Presentation System

For the overall architecture of the integrative agent model, principles of component-based agent design have been followed, as, for example, used within the agent design method DESIRE; cf (Brazier et al., 2002). Within the agent model two main components have been distinguished: the analysis component and the support component (see Figure 3). Accordingly, two different ways to integrate the domain models within the agent model have been used; see Figure 3.

- *analysis component* To perform analysis of the human's states and processes by (model-based) reasoning based on observations and the domain model.
- *support component* To generate support actions for the human by (model-based) reasoning based on observations and the domain model.

Within these components of the agent model, the domain model has been integrated which by itself consists of two (dynamical) models, as described in Section 3: a model for the functional state of the human and a model for the effects of information presentation. By incorporating such domain models within an agent model, an integrative agent model is obtained that has an understanding of the processes of its surrounding environment, which is a solid basis for knowledgeable intelligent behaviour. Note that here the domain model that is integrated refers to one agent (the human considered), whereas the agent model in which it is integrated refers to a different agent (the ambient software agent).

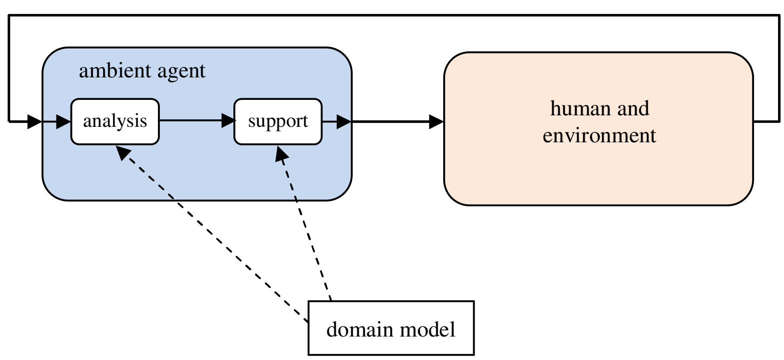

Figure 3: Overall design of the ambient agent and the integration of the domain model. Here solid arrows indicate information exchange (data flow) and dotted arrows the integration of the domain model within the agent model.

Analysis Component
Within the analysis component, by model-based reasoning forward in time based on the domain model, predictions are made about future states of the human and the environment. The integration of the domain model relationships within such an analysis model for model-based reasoning forward in time is done in a systematic manner by replacing the atoms in a domain model relationship, for example

$$\text{has\_value}(a, V_1)\ \&\ \text{has\_value}(b, V_2)\ \rightarrow_D\ \text{has\_value}(c, f(V_1, V_2))$$

with $f(V_1, V_2)$ a function of V_1 and V_2 by predictions of the ambient agent about them:

$$\text{predicted\_value\_for}(a, V_1, t)\ \&\ \text{predicted\_value\_for}(b, V_2, t)\ \rightarrow\ \text{predicted\_value\_for}(c, f(V_1, V_2), t+D)$$

An example is a weighted sum function with weights w_1 and w_2: $f(V_1, V_2) = w_1{*}V_1 + w_2{*}V_2$.

Support Component
Within the support component model-based reasoning based on the domain model takes place in a goal-directed manner, backward in time starting from desired (adjusted) future states. Within the

support component this model-based reasoning can be done in a qualitative manner or in a quantitative manner. The former case is shown in Section 5, where based on the causal graph as depicted in Figure 2, desires to increase or decrease values are derived (from right to left, against the direction of the arrows), ina heuristic manner without specifying numerically how much the increases or decreases should be. Below it is shown how a quantitative approach can be used, based on the more precise numerical relations of the information presentation model. In this case the integration of a domain model relationship within a support model for model-based reasoning backward in time can be done in a systematic manner by embedding some atoms in a domain model relationship in adjustment desires and some in beliefs and reversing the order, for example,

has_value(a, V_1) & has_value(b, V_2) $\rightarrow_D$ has_value(c, f(V_1, V_2))

for the case that the attribute b is kept fixed (not adjusted) is transformed into:

desire_for(c, V_3, t+D) & belief_for(b, V_2, t) $\rightarrow$ desire_for(a, g(V_2, V_3), t)

where g(V_2, V_3) is a function of V_2 and V_3 that inverts the function f(V_1, V_2) with respect to its first argument: f(g(V_2, V_3), V_2) = V_3 and g(V_2, f(V_1, V_2)) = V_1. For the example of a function f(V_1, V_2) as a weighted sum with weights w_1 and w_2 the inverse function is found as follows: $f(V_1, V_2) = w_1{*}V_1 + w_2{*}V_2 \Leftrightarrow V_3 = w_1{*}V_1 + w_2{*}V_2 \Leftrightarrow w_1{*}V_1 = V_3 - w_2{*}V_2 \Leftrightarrow V_1 = (V_3 - w_2{*}V_2)/\, w_1 \Leftrightarrow g(V_2, V_3) = (V_3 - w_2{*}V_2)/\, w_1$.

It is also possible to distribute a desire for adjustment over adjustment desires for multiple attributes. Suppose as a point of departure an adjustment Δv_1 is desired, and that v_1 depends on two variables v_{11} and v_{12} that are adjustable (the non-adjustable variables can be left out of consideration). Then by elementary calculus the following linear approximation can be obtained:

$$\Delta v_1 = \frac{\partial v1}{\partial v11}\,\Delta v_{11} + \frac{\partial v1}{\partial v12}\,\Delta v_{12}$$

This is used to determine the desired adjustments Δv_{11} and Δv_{12} from Δv_1, where by weight factors μ_{11} and μ_{12} the proportion can be indicated in which the variables should contribute to the adjustment: $\Delta v_{11}/\Delta v_{12} = \mu_{11}/\mu_{12}$. Since

$$\Delta v_1 = \frac{\partial v1}{\partial v11}\Delta v_{12}\,\mu_{11}/\mu_{12} + \frac{\partial v1}{\partial v12}\Delta v_{12} = \left(\frac{\partial v1}{\partial v11}\,\mu_{11}/\mu_{12} + \frac{\partial v1}{\partial v12}\right)\Delta v_{12}$$

then the adjustments can be made as follows:

$$\Delta v_{12} = \frac{\Delta v1}{\frac{\partial v1}{\partial v11}\,\mu 11/\mu 12 + \frac{\partial v1}{\partial v12}} \qquad \Delta v_{11} = \frac{\Delta v1}{\frac{\partial v1}{\partial v11} + \frac{\partial v1}{\partial v12}\,\mu 12/\mu 11}$$

Special cases are $\mu_{11} = \mu_{12} = 1$ (*absolute equal contribution*) or $\mu_{11} = v_{11}$ and $\mu_{12} = v_{12}$ (*relative equal contribution*: in proportion with their absolute values). As an example, consider again a variable that is the weighted sum of two other variables: $v_1 = w_{11}v_{11} + w_{12}v_{12}$. For this case, the partial derivatives are w_{11} respectively w_{12}; therefore

$$\Delta v_{11} = \frac{\Delta v1}{\text{w11} + \text{w12}\,\mu 12/\mu 11} \qquad \Delta v_{12} = \frac{\Delta v1}{\text{w11}\,\mu 11/\mu 12 + \text{w12}}$$

When $\mu_{11} = \mu_{12} = 1$ this results in $\Delta v_{11} = \Delta v_{12} = \Delta v_1/(w_{11} + w_{12})$, and when in addition the weights are assumed normalised, i.e., $w_{11} + w_{12} = 1$, then it holds $\Delta v_{11} = \Delta v_{12} = \Delta v_1$. Another setting is to take $\mu_{11} = v_{11}$ and $\mu_{12} = v_{12}$. In this case the adjustments are assigned proportionally; for example, when v_1 has to be adjusted by *5%*, also the other two variables on which it depends need to contribute an adjustment of *5%*. Thus the relative adjustment remains the same through the backward desire propagations:

$$\frac{\Delta v11}{v11} = \frac{\Delta v1}{\text{w11} + \text{w12}\,v12/v11} / v_{11} = \frac{\Delta v1}{v1}$$

This shows a general approach on how desired adjustments can be propagated in a backward manner using a domain model.

5 Detailed Description of the Information Presentation System

In this section the detailed design of the agent architecture is presented. The approach used for the detailed design is based on the hybrid dynamical modeling language LEADSTO.

Analysis Component

Within the analysis component, as explained in Section 4 the integrated domain model is used to make predictions for the alertness and processing demand and utilisation, by reasoning forward in time with input on task demand and the chosen information presentation. Given these predictions assessments for alertness and processing fit values are made in the following manner.

If agent A predicts that at *T* the alertness utilisation has value V_1
and agent A predicts that at *T* the alertness demand has value V_2
then agent A will assess that at *T* the alertness fit has value V_1-V_2

prediction(agentA, has_value_for(alertness_utilization, V_1, T) &
prediction(agentA, has_value_for(alertness_demand, V_2, T)
→ assessment(agentA, fit_value_for(alertness, V_1-V_2, T))

If agent A predicts that at *T* the available effort has value V_1
and agent A predicts that at *T* the processing demand has value V_2
then agent A will assess that at *T* the processing fit has value V_1-V_2

prediction(agentA, has_value_for(available_effort, V_1, T) &
prediction(agentA, has_value_for(processing_demand, V_2, T)
→ assessment(agentA, fit_value_for(processing, V_1-V_2, T))

For overall functioning fit the sum of the absolute values of alertness and processing fit is taken.

If agent A assesses that at *T* the alertness fit has value V_1
and agent A assesses that at *T* the processing fit has value V_2
then agent A will assess that at *T* the functioning fit has value $|V_1|$-$|V_2|$

assessment(agentA, fit_value_for(alertness_fit, V_1, T)) &
assessment(agentA, fit_value_for(processing_fit, V_2, T))
→ assessment(agentA, fit_value_for(functioning, $|V_1|+|V_2|$, T)

Given the fit values, more abstract assessments are made as a form of classification in terms of 'perfect', 'good', 'effort dominance', demand dominance', and 'poor'.

If agent A assesses that at *T* the fit for *F* has value *0*
then agent A will assess the fit for *F* at *T* as perfect

assessment(agentA, fit_value_for(F, 0, T)) → assessment(agentA, fit_for(F, T, perfect))

If agent A assesses that at *T* the fit for *F* has value *V*
and $0<V$ and $V\leq 0.1$
then agent A will assess the fit for *F* at *T* as good

assessment(agentA, fit_value_for(F, V, T)) & $0< V$ & $V\leq 0.1$ → assessment(agentA, fit_for(F, T, good))

If agent A assesses that at *T* the fit for *F* has value *V*
and $-0.1\leq V$ and $V<0$
then agent A will assess the fit for *F* at *T* as good

assessment(agentA, fit_value_for(F, V, T)) & $-0.1\leq V$ & $V<0$ → assessment(agentA, fit_for(F, T, good))

If agent A assesses that at *T* the fit for *F* has value *V*
and $-1\leq V$ and $V<-0.1$
then agent A will assess the fit for *F* at *T* as demand dominance

assessment(agentA, fit_value_for(F, V, T)) & $-1\leq V$ & $V<-0.1$
→ assessment(agentA, fit_for(F, T, demand_dominance))

If agent A assesses that at *T* the fit for *F* has value *V*
and $0.1<V$ and $V\leq 1$
then agent A will assess the fit for *F* at *T* as effort dominance

assessment(agentA, fit_value_for(F, V, T)) & $0.1< V$ & $V\leq 1$ → assessment(agentA, fit_for(F, T, effort_dominance))

If agent A assesses the fit for *F* at *T* as demand dominance
then agent A will assess the functioning fit at T as poor

assessment(agentA, fit_for(F, T, demand_dominance)) → assessment_of(agentA, fit_for(functioning, T, poor))

If agent A assesses the fit for *F* at *T* as effort dominance
then agent A will assess the functioning fit at T as poor

assessment(agentA, fit_for(F, T, effort_dominance)) → assessment_of(agentA, fit_for(functioning, T, poor))

Support Component

Within the Support component, based on the assessments received and a general desire to obtain an adequate functioning fit more specific desires are generated to change unsatisfactory fits.

If agent A desires that functioning has an adequate fit
and agent A assesses the functioning fit at *T* as poor
and agent A assesses the alertness fit at *T* as demand dominance
then agent A will desire an increased alertness fit

desire (agentA, adequate_functioning_fit) & assessment(agentA, fit_for(functioning, T poor)) & assessment(agentA, fit_for(alertness, T, demand_dominance)) $\twoheadrightarrow$ desire(agentA, increased(alertness_fit))

If agent A desires that functioning has an adequate fit
and agent A assesses the functioning fit at *T* as poor
and agent A assesses the alertness fit at *T* as effort dominance
then agent A will desire a decreased alertness fit

desire (agentA, adequate_functioning_fit) & assessment(agentA, fit_for(functioning, T poor)) & assessment(agentA, fit_for(alertness_fit, T, effort_dominance)) $\twoheadrightarrow$ desire(agentA decreased(alertness_fit))

If agent A desires that functioning has an adequate fit
and agent A assesses the functioning fit at *T* as poor
and agent A assesses the processing fit at *T* as demand dominance
then agent A will desire an increased processing fit

desire(agentA, adequate_functioning_fit) & assessment(agentA, fit_for(functioning, T, poor)) & assessment(agentA, fit_for(processing, T, demand_dominance)) $\twoheadrightarrow$ desire(agentA, increased(processing_fit))

If agent A desires that functioning has an adequate fit
and agent A assesses the functioning fit at *T* as poor
and agent A assesses the processing fit at *T* as effort dominance
then agent A will desire an decreased processing fit

desire(agentA, adequate_functioning_fit) & assessment(agentA, fit_for(functioning, T, poor)) & assessment(agentA, fit_for(processing, T, effort_dominance)) $\twoheadrightarrow$ desire(agentA, decreased(processing_fit))

Given these desires, as discussed in Section 4, the integrated domain model is used to reason backward in time to determine more specific desires. The first steps of this backward reasoning process are based on the dynamic properties shown below.

If agent A desires an increased alertness fit
then agent A will desire an increased alertness utilisation

desires(agentA, increased(alertness_fit)) $\twoheadrightarrow$ desires(agentA, increased(alertness_utilisation))

If agent A desires a decreased alertness fit
then agent A will desire a decreased alertness utilisation

desires(agentA, decreased(alertness_fit)) $\twoheadrightarrow$ desires(agentA, decreased(alertness_utilisation))

If agent A desires an increased processing fit
then agent A will desire a decreased processing demand

desires(agentA, increased(processing_fit)) $\twoheadrightarrow$ desires(agentA, decreased(processing_demand))

If agent A desires a decreased processing fit
then agent A will desire an increased processing demand

desires(agentA, decreased(processing_fit)) $\twoheadrightarrow$ desires(agentA, increased(processing_demand))

6 Simulation Results

In order to analyse the behaviour of the integrative agent model, a number of simulations have been performed using the LEADSTO software environment; cf. (Bosse et al., 2007). The model exhibits behaviour as expected. For example, in simulation (1) represented at the left hand side of Figure 4, it shows that after the manipulations of the ambient agent both alertness fit and processing fit have become better. Another interesting scenario is when alertness fit is assessed as ‘good’ while processing fit is assessed as ‘demand dominance’, shown in the simulation (2) depicted at the right hand side of Figure 4. Here the agent does not perform any manipulations of information presentation that affect alertness fit and therefore this fit does not change. The agent manipulates, however, the information presentation factors that affect processing fit and as a result the processing fit has been improved.

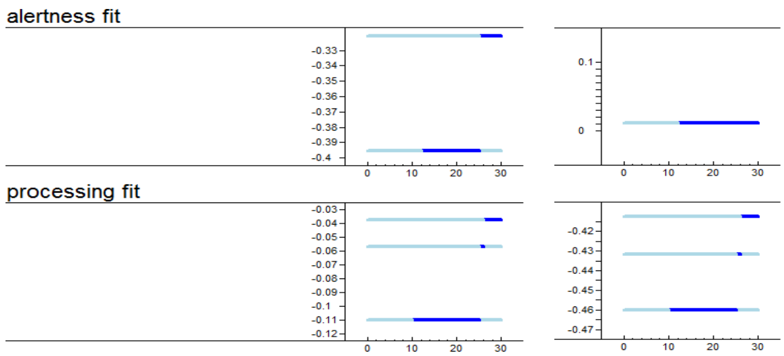

Figure 4: Two simulation traces: (1) alertness fit assessment 'demand dominance'; processing fit assessment 'demand dominance', (2) alertness fit assessment 'good'; processing fit assessment 'demand dominance'.

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7 Discussion

Adaptive information presentation involves presenting information in types and forms that are strongly depending on circumstances, which may comprise a number of aspects (e.g., De Carolis, Di Maggio, and Pizzutilo, 2001; Sarter, 2007). Some of these aspects are considered constant over longer time periods (e.g., personality characteristics or preferences), and often can be estimated in an accurate manner progressively over time, using some type of (machine) learning method. Other aspects may be more dynamic: they may change all the time. Such a moving target is not easy to estimate in an accurate manner at each point in time. One way that is sometimes exploited assumes that there are attributes (e.g., by sensors) observable at each point in time that directly relate (in a non-temporal manner) to the aspect to be estimated. For example, in (Hudlicka and McNeese, 2002) the human's anxiety state is determined in a non-temporal knowledge-based manner from monitor information. However, such attributes are not always available. A more general case is that there are relevant observable attributes, but they do not directly relate to the aspect to be estimated in a non-temporal manner, but instead, temporal, dynamic relations are available. This is the case addressed in the current paper. Model-based reasoning methods have been exploited by applying them to a dynamic model relating a human's functional state to information presentation aspects and task performance.

Other approaches to adaptive information presentation often address the human's characteristics and preferences; e.g., (Oppermann and Specht, 2000; Stock, Zancanaro, Busetta, Callaway, Krüger, Kruppa, Kuflik, Not, and Rocchi, 2007; Tarpin-Bernard and Habieb-Mammar, 2005). Such approaches usually do not address the human's cognitive, affective or functional state, which within one session may show much variation over time. For use within educational systems the learner's actions and progress can be monitored to get an estimation of the learner's cognitive load (e.g., Kashihara, Kinshuk, Oppermann, Rashev, and Simm, 2000). Especially for humans in demanding tasks monitoring the human's cognitive, affective or functional state, and adapting information presentation based on this monitoring information may be crucial. As already mentioned, in (Hudlicka and McNeese, 2002) the human's anxiety state is determined in a non-temporal knowledge-based manner from monitor information. In contrast to such approaches, the approach presented in the current paper makes use of causal or dynamical domain models for the human's functional state and the information presentation aspects, and generic model-based reasoning methods.

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