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A Tutoring System For Air Traffic Control On the Basis of a Cognitive Model

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Abstract

In this paper we present a new computer based training environment for the domain of air traffic control. It is the application of an already existing implementation of a cognitive model for air traffic control (Niessen et al., 1998) that is based on the psychologically founded cognitive architecture ACT-R (Anderson & Lebiere, 1998).

The novelty of our new training system lies in its approach to use a cognitive model of an experienced operator. This simulated operator monitors the ongoing events in the environment and builds up an internal representation of the situation. The resulting structure is assumed to be analogous to the mental model the trainee is desired to have. The simulated mental model enables the training system to support the learner by presenting additional training related information.

In the next section we describe what air traffic control is. After that we show that in the air traffic control domain other computer based training approaches can not be sufficiently exploited. Thus we describe the ideas behind our training system. We close our report with a brief discussion of the possibilities to apply our approach to other domains.

Keywords: cognitive modelling, tutoring system, air traffic control

Air Traffic Control Task

First we introduce air traffic control (ATC) to show what distinguishes it from other control tasks in dynamic man-machine systems. After that we show why learner modelling in computer based training for air traffic control is harder than in other domains.

The goal of ATC is to assure safe and economical air traffic. To achieve this all flights are planned in advance and then watched by radar. Operators monitor the ongoing traffic using planning and radar information. A possible conflict would lead to a too close approximation between two aircraft. When a conflict is detected the controller is responsible to give one pilot order to alter his or her course.

In order to achieve this task the controller monitors his or her radar screen. He or she anticipates future movement of aircraft and detects possible conflicts on that basis. To solve conflicts a solution has to be generated and its impact on other flights must be mentally simulated. A major task for this is scheduling the multiple ongoing demands. Niessen et al. (1998) postulate that an explicit representation, a mental model, is necessarily needed to manage air traffic control. Building up and maintaining this *pictur*e, as air traffic controllers themselves call their mental model, is the central operation controllers have to perform.

Every controller is responsible for only a certain fixed area, the *secto*r. In the sub-domain of *en-route* traffic, that we focus on, the sector is of about a size which an aircraft needs ten to fifteen minutes to pass. About five to fifteen aircraft are at the same time in the sector. Conflicts are quite rare. Depending on the specific traffic situation the controller has to interfere at most once every five minutes.

That means that an observer cannot register many operations executed by the controller. Although many complex mental processes are executed the predominant activity is to watch the radar screen. In other domains of controlling dynamic man-machine systems like driving there are much more operations executed, and less deep mental operations are carried out.

Training Method

In the following section we concentrate on training for ATC. From general attempts we discuss different types of computer based training (CBT) systems. Our own approach to CBT for this domain is motivated.

Conventional CBT systems are organised in information screens. The learner navigates through an interconnected set of such screens. Often at the end of a lesson control questions test the advance of the student. According to the results of the test the learner is directed back to some screens of information to repeat parts of the lesson.

Self studying using CBT has some advantages over an education environment where a human teacher is needed: The student is able to choose the times and the places (tele-learning) he or she wants to be taught, and how often a lesson is repeated.

Thus a CBT environment has a better *macro-adaptation* to the learner than in a conventional teaching situation. Macro-adaptation describes the possibility to change the overall structure of a learning scenario between lessons, while *micro-adaptation* is the ability to change the kind of presentation or its speed within a lesson to meet the learner's needs.

The description of the possibilities of conventional CBT systems based on screen presentation shows that they are poor in micro-adaptation compared to a human teacher. A human teacher is always able to go into details for a learner. A teacher can do this because he or she has good knowledge about the misconceptions of the learner.

Later in this text we will use the concept of micro-adaptation. But first we will look closer on training in ATC and the kinds of CBT tools that are used there.

Current Training Situation in ATC

ATC puts high demands to the capabilities of the operators. Therefore an expendable procedure is carried out, which ensures that suitable trainees are selected. The training itself is costly and lasts about three years. During the training theoretical knowledge is taught as well as practical exercises are carried out.

There exists CBT software for theoretical education that is intended for self learning. The kind of knowledge that is covered includes types of aircraft, capabilities of the radar-display, and weather conditions.

To teach practical knowledge about control of dynamic man-machine systems it is essential to instantly demonstrate the results of an action to enable the learner to develop a mental model of the task. Thus computer aided training of practical skills in ATC is done using large simulation environments. These realistic but expensive training environments are not intended for self studying. A coach watches the performance of the trainee and helps him or her directing the attention focus on specific traffic constellations.

The drawback is that a human teacher, the coach, is needed. Thus the ability for macro-adaptation in such a scenario is not so good. In the next subsection we show how both micro and macro-adaptation can be good in a simulation system for CBT of practical knowledge in ATC.

Intelligent Tutoring Approach

To achieve micro-adaptation a CBT system needs a model of the learner. If it has one and is able to use it to change the way information is presented a human teacher is not needed for many parts of the training.

This approach is taken by *intelligent tutoring systems* (ITS). They contain a component that diagnoses the behaviour of the learner and represents knowledge about him or her internally. Common methods for diagnosis are looking for errors the learner makes, or building a plan of steps in problem solving and detecting derivations from it.

All these methods rely on the input from the learner while using the ITS. But an ATC trainee has seldom interaction to the traffic simulation. Thus the content of the trainee's *pictur*e, which had to be the primary source for the learner model, cannot be deduced.

Instead several tutoring systems for training of control in dynamic man-machine systems monitor the state of the simulation environment (s. e.g. Bass, 1998). Certain derivations from predefined states or state transitions are detected and trigger teaching functionality. Thus they do not really build up and maintain a model of the learner but of the system. So their micro-adaptation is oriented to the simulation system, not to the learner.

A Tutoring System for Air Traffic Control

To get a more human oriented model of the learner we use the simulation of the cognitive model that builds up and maintains its picture according to the perceived simulation environment. It performs further processing like anticipation and conflict detection and changes the internal representation of the current situation on the basis of these processes. Thus we can observe the mental state of this "parallel simulated learner". Using this model we can access the simulated current mental model of an experienced controller.

Guiding the trainees' attention

Using the state of that simulated picture we can *guide the attention* of the ATC trainee to certain traffic constellations. We achieve this by presenting the trainee not only a radar picture of the current situation. We also present constellations and anticipated problems that the simulation detects. Thus mental processes and the attention concept of the cognitive model is mediated to the learner.

There is evidence that directing a learner's attention to certain important constellations in a simulation of man-machine systems during training can increase the performance during practice. A study of Gopher (1993) with military pilot cadets used a simple computer-game where the players' attention had to be divided between different aspects of the game situation. Some subjects were trained in advance to change their focus on currently relevant aspects by changing the emphasis of their presentation in the game. Their performance has been better in the game than that of subjects that trained the computer-game without emphasised aspects. But the "emphasis-change" computer-game trained subjects were also significantly better in handling "real-life" flight-training situations. Their performance increased especially in high-load manoeuvres that required an integration of several elements.

Thus we assume that showing the mental state of an experienced operator i.e. of the simulated model enables the learner to move his or her attention to important traffic events and that he or she learns doing it autonomously by repeating the experts' attention distributions. It can be seen in analogy to the current training situation where a human coach helps the trainee to understand the situation in a specific traffic simulation, but without the need for a human coach.

Realisation

We have developed a simple traffic simulation system, a radar-like display and incorporated a training unit according to our approach. The training unit consists of a modified version of the cognitive model described by Niessen et al. (1998) and a module that detects changes of the model's *picture* and triggers attention guiding commands to the radar display.

The current realisation of this training concept uses only one technique to guide the trainee's attention. It uses information on aircraft in the task environment that is stored as objects in the *picture*. Every aircraft object in the *picture* has an additional property that reflects its importance according to the cognitive processes that are realised. This attribute classifies the current relevance of every aircraft in five different classes:

- not yet under control
- focal (needs high attention)
- constellation to monitor (needs long-range attention)
- extra-focal (needs less attention)
- not under control anymore

Figure 1 illustrates how these classes are displayed as different colours in the radar-like display to guide the trainee's attention.

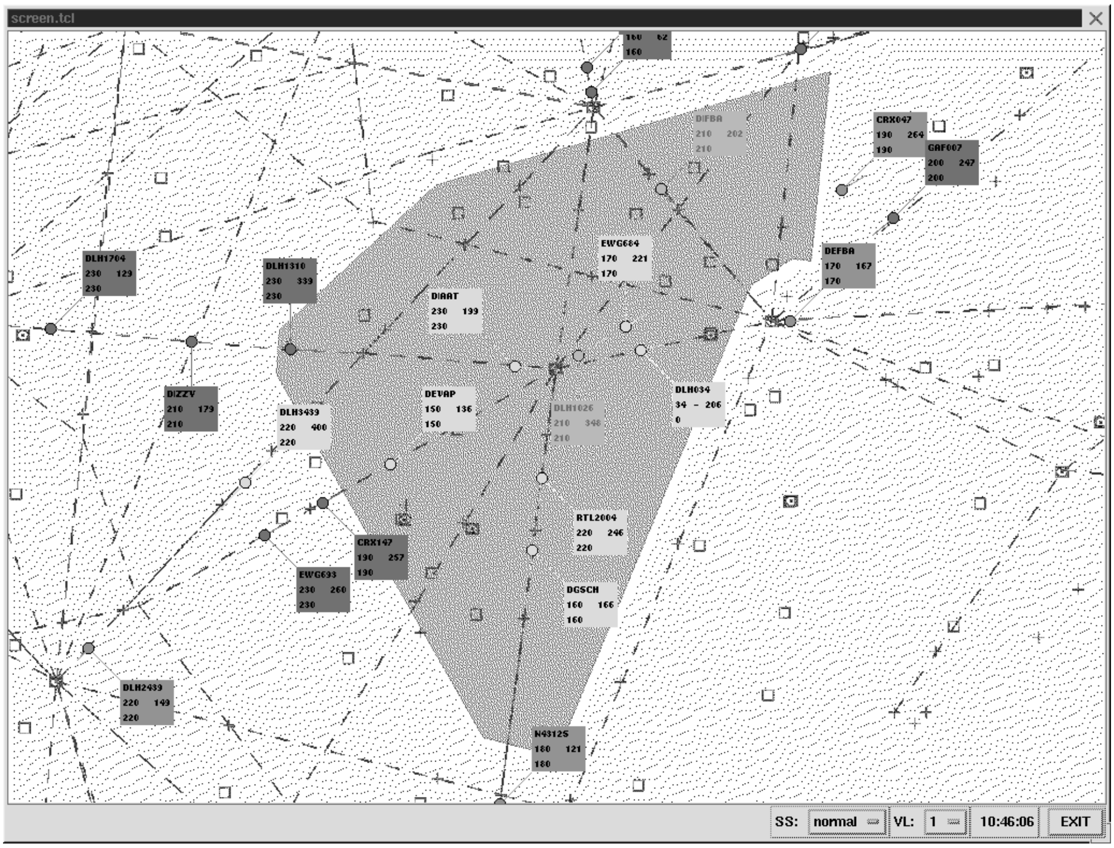

Figure 1 Realised radar-like display for the trainee (different colours of items rendered in greyscale for this illustration).

To realise a complete training system we had to implement other components besides the training unit and the radar display (see figure 2). A simple air traffic simulation computes the movement of aircraft and generates paper "flight strips", an additional planning aid for the controller. Radar display and cognitive model monitor the state of the traffic situation. The cognitive model sends commands to the radar screen to modify the displayed colours. If the trainee wants an aircraft to alter its course he or she has to be able to send a command to the traffic simulation. Thus we implemented an additional component, the "ghost pilot", that can be used by the trainee directly or by a person that is connected to him or her by a (possibly simulated) radio line.

All components are implemented as independent processes. They communicate using the internet protocol. For easy integration of additional components they are not connected directly but an additional component, the broker, receives and dispatches all communication between them.

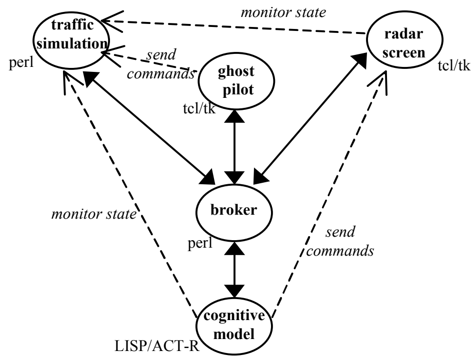

Figure 2 Architecture of the training system

The design of the whole training system allows the distribution of all connected components across a computer network. It emphasises the incorporation of heterogeneous software modules. It is implemented mostly in scripting languages like Perl and Tcl/Tk while the cognitive model is implemented in the cognitive architecture ACT-R (Anderson & Lebiere, 1998) on the top of CommonLISP. The use of interpreted languages enables the application of meta-programming techniques for dynamic reconfiguration and communication between the components via the broker component.

The whole system runs on standard hardware. Thus the learner is able to exploit the advantages of macro-adaptation in CBT systems described above. By our learner modelling approach and human oriented attention guiding technique our system shows also quite a good micro-adaptation.

Conclusion

For the programmer of an ITS the hardest task is the diagnosis of the learner. This applies especially to dynamic man-machine systems because of the multitude of possible actions at any one time. Using indirect learner modelling with a "parallel simulated learner" as in our system offers an easier approach. But an appropriate cognitive model has already to exist. Nevertheless it shows that for certain domains it might be the only way to build any model of the user.

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