Modelling the process of complex system control

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1. INTRODUCTION: EMPIRICAL RESEARCH

The research reported here is concerned with the determinants of complex system control. It is part of a rather comprehensive project where subjects are studied when acting in an unfamiliar, dynamic task environment. In the following the research approach as well as some of the empirical results will be reported only briefly. The focus is on the description of a computer programme and its role in the research strategy.

In order to provide subjects in the laboratory with a complex task a system is applied which is implemented on a computer. Essentially two criteria guided the selection of the task: **(a)** it should have essential characteristics of systems in reality; **(b)** it had to be mathematically well defined. In the empirical studies a system has been used, named SIM006, which is described as a time invariant, time discrete system. It allows the implementation of specific system characteristics by constructing decoupled subsystems that differ with regard to characteristics like connectivity and dynamics. The control task in the laboratory required the subjects to operate the system in a manner that the system state is approximated as close as possible to reference values provided for each of the 15 system variables.

There are two types of inputs in order to operate the system: **(a) monitoring inputs:** it is not possible to see the states of all system variables at one point of time on the screen. That is, in each trial it has to be decided which system variables should be monitored, i.e. should be selected for being shown on the display. There are 15 system variables; a maximum of 8 variables can be selected for control. This condition has been implemented in order to acquire some insights with regard to the subjects' information search. **(b) Control inputs:** the modification of system states in order to approximate them to the reference values is achieved by inputs that increase or decrease the values of system variables. Of course, the subject can also decide not to perform changes on a system state. It is important to note, that in each trial the subject is allowed to perform changes on all of the 15 variables, i.e. also on those variables that have *not* been selected for monitoring.

The empirical research in the project is concerned with extensive single case studies. The criterion for determining control performance is given with the average deviation of control inputs from the ideal input that would be necessary, in order to reach the reference values of the system. All subjects under study improved their control performance considerably during a learning period of 200 trials; however, there are remarkable individual differences. In addition, subjects increased the number of monitoring and control inputs, thus successively larger segments of the system were examined and changed. Highly connected and dynamic subsystems are difficult to control; control performance is decreased here, and the learning process is delayed (Kluwe et al. 1986; in press).

A more finegrained analysis of the individual behavioral data lead to a preliminary description of the learning process in terms of three stages. They can be distinguished on the basis of different control and monitoring pattern: (a) Initial Orientation where the major goal is to identify the components of the systems; (b) Initial Exploration where the goal is to identify the features of the system's behavior. Both stages are essentially directed at information search which is performed at the cost of system control. The approximation of the system state to the reference values decreases during these stages. The monitoring and control behavior in these periods can be described briefly as follows: the goal is to acquire information about the system in small portions; also, it is avoided to generate too much information by control inputs at the beginning. (c) Operating the system where the goal is to improve the control inputs (the "dosage"), in order to reach an optimal approximation of the system state (Kluwe et al. in press; for a related description of stages in the learning process see Shrager & Klahr 1986).

2. DEVELOPMENT OF THE COMPUTER PROGRAMME

One of the goals of this research project on complex system control is the development of a computer programme that operates the system SIM006, and that engenders performance data similar to those of human subjects.

Carlo Misiak, who is a member of the research group elaborated a programme that is based (a) on the analysis of the behavioral and verbal data obtained from single case studies, and (b) on theoretical assumptions, e.g. with respect to the formal characteristics of the system. The existing programme SIMSHELL.001 can be conceived of as a protoype that allows for the representation of many intra- and interindividual variants. Its components are elaborated in the framework of KEE which is based on COMMON-LISP. Central for the SIMSHELL is the construction of heritance-networks from units which are based on frames in the sense of Minsky.

2.1 COMPONENTS OF SIMSHELL.001

The four central components of SIMSHELL.001 are the following:

(1) Knowledge base NEW.SYSTEM

These are technical components: (a) the task component: it is given with the mathematical formulation of system SIM006; this is the same system that had to be operated by the subjects in the single case studies; (b) the book-keeping component: it performs the control and administration of superordinate parameters selected a priori that determine the conditions for running the program.

(2) Knowledge base PERSON

It includes static and dynamical, nonprocedural knowledge components: (a) time-invariant knowledge about facts: a priori available knowledge about the existence of system variables and those features that do not change; (b) evaluation parameter: "thresholds" for the evaluation of the dynamic behavior of a variable; dependent on the level of a threshold the deviation of a variable from the reference value leads to the categorization of a variable in "corrective class high, medium, low". This again affects the probability of a variable for being monitored or controlled; (c) information search: this component refers to the maximum number of variables selected for monitoring of the system state ("maxchoice"); (d) rules for the control of the selection of variables: the selection of system variables for monitoring the system state is determined by groups of rules ("choice rules") that are related to the three categories of "corrective class" (high, medium, low). There are three groups of rules: difficult, medium and easy choice rules. The conditions of these rules refer to the fact whether a variable has been selected or not, and to the actual probability of a variable for being selected. (e) rules for the adaptation of probabilities for the selection of system variables: the "chancerules" are central for the entire selection procedure and therefore for the monitoring behavior of the programme when operating the system. The condition part refers to the actual "chance" (high, medium, low), to the actual "corrective class", and finally to the selection status (if the variable has been selected before or not). It is important to note, that these rules ensure that also variables with low deviations from reference values as well as variables that have been selected for monitoring are not neglected in the monitoring process, but instead reach a status where there is again a chance for selecting such variables. (f) rules for the control of "corrective values": these are rules that determine the final input value which is directed at the reduction of the difference between the actual value of a system variable and its reference value.

The dynamic components of knowledgebase PERSON refer to all facts that emerge during the programmes performance: e.g., knowledge about the actual state of a selected variable, about the actual features or about appropriate control inputs.

(3) Procedural knowledge components

(a) procedural demons (active values) for the adaptation of values that have been changed during a trial; e.g. the adaptation of corrective class to the actual deviations of the system variables from the reference values. (b) the inference machine provided by KEE for the organization of of rule application.

(4) Metacomponents: the essential component is here the KEE-world feature which allows the description and control of the information available to the program for each trial, i.e. there are facts stored about the system's state. Since this knowledge increases dramatically during the course of system control there is an extinction mechanism that extinguishes information that is no longer needed.

2.2 CONTROL PERFORMANCE OF SIMSHELL.001

2.2.1 MONITORING BEHAVIOR

The actual selection of a variable for the evaluation of its present state is dependent on 3 KEE-rules ("choicerule difficult - medium - easy) that take into account: (a) chance: i.e. the actual probability for the selection of this variable; (b) corrective class: i.e. the categorization of a variable dependent on its deviation from the reference value and dependent on the threshold as "corrective class high, medium, low"; (c) rank on the random list. When the program starts to operate the system all variables are assigned the same parameter values: chance and corrective class is medium, the actual value is 3.

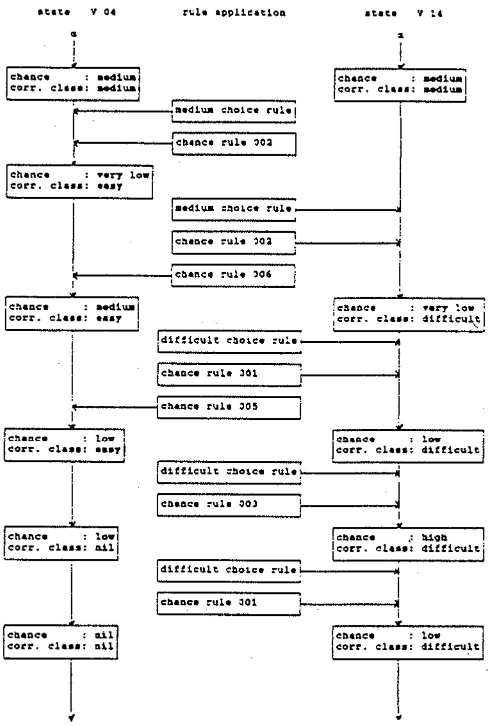

Fig.1 Monitoring behavior of SIMSHELL.001 for two system variables V04 and V14 over 5 trials.

Fig. 1 shows the monitoring behavior of SIMSHELL.001 for two variables V04 and V14. The states of these variables change with respect to chance and corrective class by application of these rules. V04 is a system variable with low dynamics and minor deviations from the reference value. V04 is classified by SIMSHELL.001 as easy and it is no longer monitored after some trials by the programme. This is also in accord with the observable behavior of subjects.

V14 on the contrary, is a highly dynamic and oscillating variable. It has a tendency for high deviations and is classified by the programme as difficult, that is as a variable that needs to be monitored and controlled intensively. This leads to the fact that V14 is monitored in 4 of the 5 trials shown in figure 1.

While at the beginning the application of choice rules is determined by the rank of a variable on a random list, the subsequent selection is determined by "chance", "corrective class" and "priority". If there are two "chance rules" activated, then the preferences according to the priority list determine the decision (e.g. selecting the difficult variable first). This can also be seen in fig.1 (trial 4).

2.2.2 PARAMETER VARIATION

The programme allows the examination of effects of parameter variations. At the time there are four groups of parameters which can be varied seperately: (a) "corrective values" which determine the input value; (b) the "threshold" to categorize the variables according to their dynamic behavior; (c) "maxchoice", the maximum number of system variables that can be selected for monitoring; (d) the "priority list" to determine the hierarchy for the selection of variables.

(1) **The effect of different priority lists** on the programme's control performance proved itself to be weak. It had been assumed that a good strategy for operating the system is to monitor and to control with priority especially the states of those variables that are classified as difficult, that is those variables that are highly dynamic with a strong tendency for deviations ("choice rule difficult-medium-easy"). Contrary to that assumption a systematic variation of the hierarchy of choice rules in 6 runs with 20 trials each did not engender performance differences, though the control and monitoring behavior of the programme clearly corresponded to the priorities implemented a priori. It may well be that the differences between both conditions would be more striking if the number of variables that can be selected and changed is increased (the number of system variables selected for monitoring and control could vary between 4 and 7 only). It would be necessary to examine this issue also with empirical subjects, provided with corresponding instructions (e.g. to give priority to difficult system variables when operating the system).

(2) Effect of the number of monitoring inputs ("maxchoice")

The question is here, how a different number of variables subject to monitoring and control affects the control performance. There is evidence from single case studies that this is an important factor. Improvements of system control go together with increases in the number of variables monitored and controlled by the individual. 4 runs have been analysed that differed with regard to the number of variables that can be selected for monitoring: "maxchoice" (a) 8; (b) 5 (variation between 4 - 5); (c) 7 (variation between 4 and 7); (d) 7 (variation between 6 and 7). The priority list for all conditions had been set to "choice rule difficult - choice rule medium - choice rule easy"; thresholds were 7.0 (for classification as corrective class high) and 3.0 (for classification as corrective class low). The resulting control behavior in the 4 runs corresponds to the parameter variation (average values for monitoring inputs are 7.9, 4.6, 4.6, and 6.5).

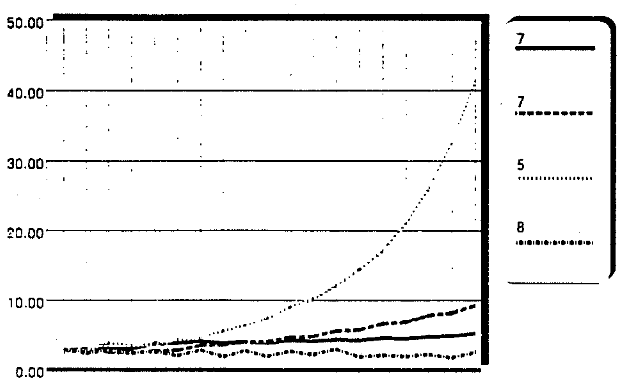

Fig.2 Control performance of SIMSHELL.001 under different conditions for "maxchoice", the maximum number of variables that can be selected for monitoring the system state.

Fig. 2 shows that there result marked differences between the 4 conditions: the control performance of the programme is better when monitoring and control is extended over broad system segments. Thus the effects of this parameter variation correspond well with the conclusions derived from single case studies with regard to the importance of the breadth of system segments selected for monitoring and control.

2.2.3 COMPARISON WITH EMPIRICAL DATA

The parameter variation described above is one possibility to examine more systematically the impact of different components on control performance. Another possibility is given with the goal to reproduce empirical data. In this case the parameter of the programme are selected according to empirical data. This would allow the examination of the control strategy implemented in the programme as well as the analysis of individual system control behavior. (1) In the following the control performance of one subject HH in an earlier phase of the learning period, namely session 2 (trial 21-40) is shown. In this period control performance is poor, not all variables are monitored (average x = 6.8) and only few are controlled (x = 1.5). For the simulation "maxchoice" was set to 7 (variation of monitoring inputs between 6 and 7). The number of control inputs could vary between 0 and 4. The other parameters of the programme have been determined as follows: (a) priority list choice rule difficult - medium - easy; (b) thresholds: difficult variables if deviation larger than 8.1; easy variables if deviation below 2.9.

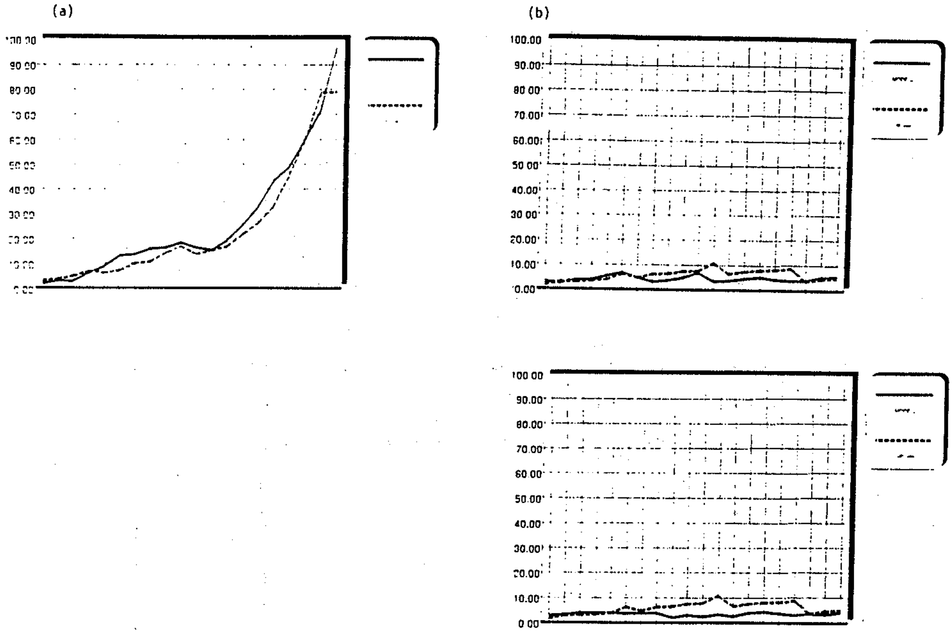

Fig. 3 Comparison of control performance between SIMSHELL.001 and subject HH (a) for session 2 (trials 21-40); (b) for session 7 (trials 131-140).

The control behavior of the programme after 20 trials is similar to that of subject HH. The average values for monitoring inputs and for control inputs are x=6.2, and x=1.2 respectively. Fig.3 a shows the remarkable correspondence betweeen the performances of programme and subject. However, one has to state critically that the distribution of monitoring and control inputs on the 15 system variables is not the same in both cases.

(2) The second example is a comparison of the subject's data with the performance of the programme at the end of the learning period, that is in session 7 (trial 131 - 140). In this stage system control is rather successful. Again, a simulation with the same parameters as outlined above has been implemented. The resulting average values for monitoring and control inputs of the programme are x=8, and x=4.0 respectively; they are nearly identical to those of subject HH (x=8 and x=4.1). The correspondence between both performance curves is very high (fig.3 b). This is also true for a second run of the programme with the same parameters.

3. CONCLUSION

The goal of developing the programme SIMSHELL.001 is a more detailed analysis of those factors that determine performance control when operating a complex system. The results reported above can be conceived of as first examples for the research strategy.

First we derived assumptions from the data with regard to variables that influence control performance. Together with theoretically based considerations they guided the development of the programme. Thus the impact of specific variables on system control can be studied. In addition, it is possible to predict the performance of the programme on the basis of a priori determined parameter. If this is successful than one can examine if it is possible to predict empirical data on the basis of parameters of the programme. Deviations from predictions can be the basis for improving the programme succesively. Thus it is possible to examine the determinants of control performance implemented in the programme with regard to their empirical usefulness. An important issue in this context is the decision about the quality of the programme's performance.

Finally we assume that programmes of this type are useful to analyse individual probelm spaces with respect to complex tasks. It is possible to implement on the basis of hypotheses specific problem spaces and to predict the control performance. This would allow statements about the effects of different subjective problem spaces on system control. Note for example, that SIMSHELL.001 has no declarative knowledge with regard to the interrelations betwen the system variables. This is not in accord with a wide spread assumption according to which successful system control would require structural knowledge, i.e. knowledge about the components of a system and its interrelations (Ringelband et al., in press).

SIMSHELL.001 is not yet conceived of as a simulation model, but instead as a research tool for exploring the domain of complex system control. The application and development of the programme may improve our understanding of the control task, of interindividual differences and of learning. Also new hypotheses can be derived for further empirical investigation, as for example for the effects of priorities in system control mentioned above see also Neches 1982; Ohlsson 1988 for this issue).

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