Rules and Instances in the Control of a Static System - Modelling the Influence of Causal Interpretation

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Abstract. This paper reports an experiment that investigated the influence of causal interpretation on acquisition and use of two knowledge types about a static system: specific I-O-knowledge (instances) and general knowledge about effects (rules, structural knowledge). One group of subjects saw 40 system states without being informed about the causal nature of the material. Another group saw the same states as switches and lamps. It is assumed that the group without causal interpretation cannot acquire knowledge about effects but only I-O-knowledge. If that type of knowledge really is the predominant type learned when dealing with small systems, then there should be no group differences in a speeded recognition task. Actually, the group with causal interpretation discriminates much better between old and new system states, but with longer RTs. This could be interpreted in terms of knowledge about effects acquired by the group with causal interpretation which was used to reconstruct system states in cases of doubt. Results of a speeded judgement task where subjects had to judge single causal relations support that interpretation, but also indicate that the knowledge about effects is probably not represented in a symolic form. An ACT-R model that uses associations between events as a subsymbolic form of knowledge about effects reproduces the data very well. Thus, data and model support the significance of I-O-knowledge but also shed some light on the role and the development of general knowledge about effects.

1 Introduction

One central question in the psychological research on complex dynamic systems refers to the knowledge used for controlling a system. Two main types of knowledge are discussed in the literature: structural knowledge, defined as general knowledge about the variables of a system and their causal relations, and input-output knowledge, which represents instances of input values and the corresponding output values.

There is evidence for the influence of both types, but currently many authors emphasize results indicating that I-O-knowledge is the predominant type used, particularly when dealing with small systems like the "Sugar Factory" (Berry & Broadbent, 1988). Models developed on the basis of Logan's Instance Theory (Dienes & Fahey, 1995) or ACT-R (Lebiere, Wallach & Taatgen, 1998) demonstrate the sufficiency of I-O-knowledge for the control of the "Sugar Factory".

In the Experiment reported here, the significance of the two knowledge types was studied with a static system consisting of four lamps operated by four switches. Fig. 1

shows a screenshot with the effects of the switches mapped (invisible for the subjects).

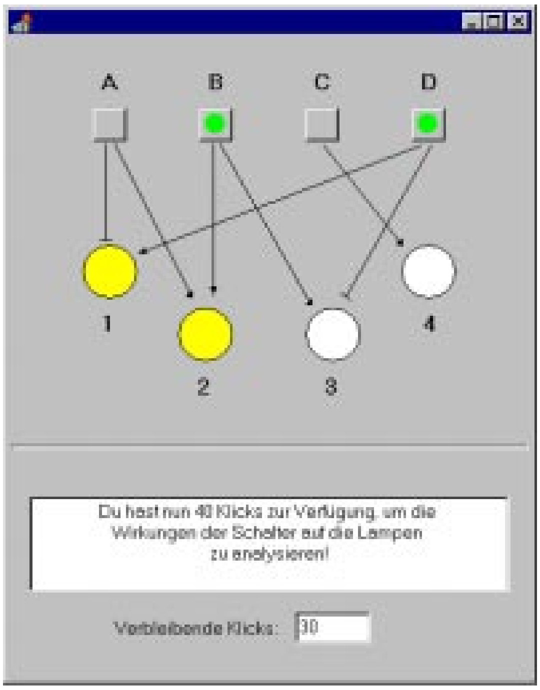

Fig. 1. The system used in the experiment

Two tasks were used, each more sensitive to an other type of knowledge. A recognition task should be easiest to be done with I-O-knowledge, and a causal judgement task, easiest to be done with structural knowledge.

The rationale of the experiment is that learning of instances does not depend on the causal interpretation of stimuli. Consequently, if knowledge about instances is the main knowledge type learned in the control of small systems, there should be no effect of causal interpretation on recognition of system states. On the other hand, if structural knowledge is learned additionally, then causal interpretation should have positive effects on causal judgements.

In a speeded recognition task subjects saw ten possible and ten impossible system states two times each, and had to decide if they had seen the state in the learning phase or not. The items of a speeded judgement task were pictures of the switches and lamps with one switch and one lamp highlighted. Subjects had to decide if there was a causal relation between the highlighted elements. The 16 possible combinations were shown twice.

2 Experiment

Two factors varied between subjects: (1) the possibility to interprete the pictures of system states shown in the learning phase as causal, and (2) the subject's activity, i.e. if the system states were only observed, or produced by operating the switches. I will focus on the effects of the first factor (that were the strongest ones, anyway). So now I report the data of the two groups who observed the system states in the learning phase, either with causal interpretation (obs/c), or without (obs/0). Each of the groups consisted of 12 subjects.

Other factors were varied within subjects: (1) the number of presentations of each state in the learning phase, and (2) the number of switches that were "on" in each system state of the recognition task.

The experiment started with a learning phase where subjects saw 40 system states in intervals of four seconds. The group without causal interpretation (obs/0) was told that they would see spatial patterns which they should memorize. The group with causal interpretation (obs/c) was informed that the patterns were states of a system of switches and lamps.

Three minutes after completion of the learning phase the recognition task was administered, followed by another 25 system states. After that, subjects worked on a kind of cued recall task where they had to complete fragmentary system states. Then the subjects of the group without causal interpretation were debriefed about the causal nature of the stimulus material. After that the judgement task was provided, followed by two other tasks that are not reported here.

Given the assumption that knowledge about the system is primarily stored as specific instances, the factor "causal interpretation" should have no effects on performance in the recognition task. If, however, subjects acquire structural knowledge - which is expected only in the group with causal interpretation - that group should outperform the obs/0-group, particularly in the judgement task.

As a measure of performance in the recognition and judgement tasks discrimination indices P_r were calculated according to the Two-High-Treshold-Model (Snodgrass & Corvin, 1988).

	obs/c	obs/0
recognition	M=0.48 s=0.23	M=0.30 s=0.22
causal judgement	M=0.55 s=0.18	M=0.17 s=0.23

Table 1. Discrimination indices for two tasks

Table 1 shows means and standard deviations of these indices. In both tasks the group with causal interpretation is significantly better, but there is an interaction between task and group. The obs/0-group is better at recognition than at judging causal relations; for the obs/c-group the reverse is true. Latencies for hits are longer in the group with causal interpretation (obs/c: 2250 ms, obs/0: 1493 ms). The fact that the variance is also significantly higher points to the use of different strategies: If a system state could not be retrieved in the recognition task, subjects of the obs/c group might have tried to reconstruct the state using knowledge about the effects of the switches. That would mean that subjects used both types of knowledge: I-O-knowledge and general knowledge about effects.

This interpretation is also supported by the effects of the within-subjects factors on recognition performance (fig. 2, left panel). If the reconstruction hypothesis is true, then there should be an effect of the number of switches "on" in the obs/c group, because the reconstruction process takes longer the more switches have to be considered. Actually, a significant interaction between group and number of switches "on" was found in the data. States with three or four switches in "on"- position are particularly badly recognized by the subjects of the obs/c group. However, in the group without causal interpretation the influence of the number of presentations is higher than in the other group (interaction marginally significant).

All that supports the assumption that the group with causal interpretation used knowledge about effects even in the recognition task. But why does it take them so long to use that type of knowledge in the causal judgement task? As in a previous experiment (Schoppek, 1998), the mean latency for hits in that task was 2234 ms. One possible explanation would be that most subjects primarily try to use I-O-knowledge and use knowledge about effects only after retrieval of relevant I-O-knowledge fails. In the next section I propose that initially, knowledge about causal relations is not represented symbolically, but rather exerts its influence in form of associations between events. This could be the reason, why subjects do not try to retrieve that type of knowledge.

3 ACT-R-Model

In order to test how the above interpretation can reproduce the data, I developed an ACT-R model simulating the learning phase, the recognition task, and the judgement task. There are two versions of the model. The difference between these versions is that one entails additional production rules modelling causal interpretation. Those rules reconstruct a system state when no relevant state-chunk can be retrieved.

In the learning phase a goal is pushed for each system state. After processing the goal it represents a system state with its slots holding the arrays of switches and lamps. Also in each cycle a "change-picture" is created as a subgoal, representing the changes between the previous and the current system state. Most of the change-pictures are not strong enough to be retrieved later on, but during goal elaboration associative weights are learned between switch- and lamp-events. Afterwards these associations are used to reconstruct system states in the condition with causal interpretation.

In the recognition task both model versions try to retrieve an instance similar to the probe (with partial matching and a bias in favor of retrieving by input). If retrieval fails, the version without causal interpretation guesses, the other version starts the reconstruction process. Reconstruction is based on the lamp-events that are most strongly activated by the switch-events shown in the probe ("switch on"). The probability of false reconstructions rises with the number of switches that are "on" -

an effect which can explain the bad recognition performance under condition obs/c & 3-4 switches.

I simulated two samples with 24 cases each. Some results are shown in the right panel of fig. 2. In both versions recognition performance depends more on the number of presentations as compared to the real subjects. But the interaction between number of switches and causal interpretation is well reproduced by the model. In general recognition performance is overestimated by the model. This effect is mainly due to the excellent recognition of the frequently shown system states. Latencies for hits are very close to the data: 2314 ms in the simulated obs/c-group and 1541 ms in the simulated obs/0- group (note that the latency factor was fitted for the obs/0-group only).

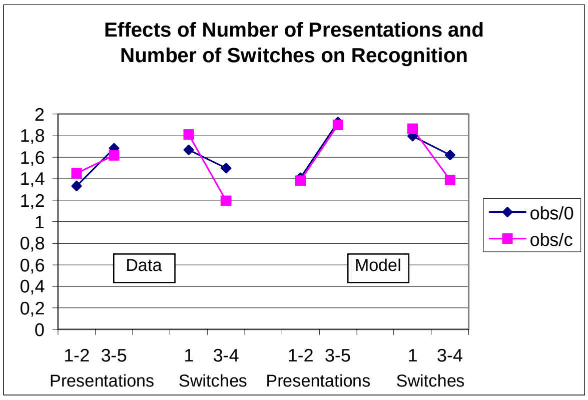

Fig. 2. Experimental (left) and model (right) results

After fitting parameters for the recognition task the model was extended with a few productions to solve the causal judgement task. In that task the model tries to retrieve a "diagnostic picture" appropriate to confirm the causal relation. If none can be retrieved, the model reconstructs a relevant system state the same way as in the recognition task. The model matches the subjects' data quite close without fitting any parameters! For example, mean latencies for hits were 2305 and 2234 ms in the model's and subjects' data, respectively.

To summarize, the model supports the view that I-O-knowledge is the primary but not the only type of knowledge used when dealing with a small system. Structural knowledge plays a role, too, but in a preliminary, subsymbolic form.

4 References

Anderson J.R., & Lebiere C. (1998). *The atomic components of thought.* Mahwah, NJ: Lawrence Erlbaum Associates.

Berry D.C., & Broadbent D.E. (1988). Interactive tasks and the implicit-explicit distinction. *British Journal of Psychology, 79,* 251-272.

Dienes Z., & Fahey R. (1995). Role of specific instances in controlling a dynamic system. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 848-862.

Lebiere C., Wallach D., & Taatgen N. (1998). Implicit and explicit learning in ACT-R. In F.E. Ritter & R. M. Young (Eds.), *Proceedings of the Second European Conference on Cognitive Modelling (ECCM-98)*, pp. 183-189. Nottingham: Nottingham University Press.

Marescaux P.-J., Luc F., & Karnas G. (1989). Modes d´apprentissage selectif et nonselectif et conaissances acquises au controle d´un processus: Evaluation d´un modele simule. *Cahiers de Psychologie Cognitive, 9,* 239-264.

Schoppek W. (1998). Modeling causal induction. *Paper presented at the Fifth Annual ACT-R Workshop 1998, Carnegie Mellon University, Pittsburgh, PA. (*http://act.psy.cmu.edu/ ACT/ftp/workshop/Workshop-98/Schoppek/quick_index.html)