Title
Countplan: A Model for Planning Counting Procedures Based on Utilization Knowledge, and Procedural and Conceptual Competence

Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 5(0)

Authors
Smith, Donald A.
Greeno, James G.

Publication Date
1983

Peer reviewed

COUNTPLAN: A Model for Planning Counting Procedures based on Utilization Knowledge, and Procedural and Conceptual Competence

Donald A. Smith and James G. Greeno
University of Pittsburgh

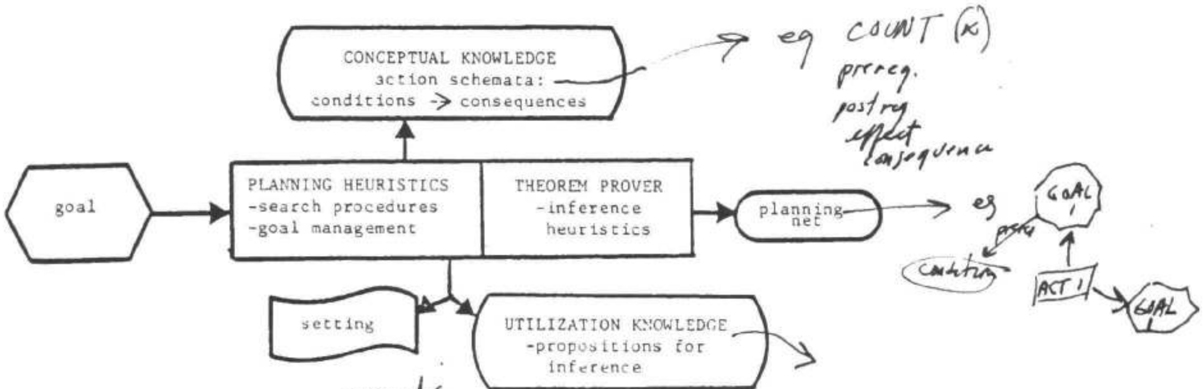
We are attempting to reach a clearer understanding of the distinction between competence and performance. By "competence" we mean the general knowledge that enables specific occurrences of successful performance. Competence includes understanding of general concepts and principles of a task domain; we refer to this as conceptual competence. For example, performance of young children in counting tasks provides evidence that they understand principles of number such as cardinality and one-to-one correspondence (Gelman & Gallistel, 1978). Judgments about a person's conceptual competence are problematic; the person may understand a principle adequately for a task, but lack skills or situational resources needed to apply the principle.

We report an analysis of knowledge needed to apply conceptual principles of number to perform correctly in counting tasks. Knowledge for application includes understanding of significant general principles, which we call procedural competence, as well as knowledge that applies to features of the specific task setting, which we call utilization knowledge. Procedural competence is understanding of general principles involving relations among goals, actions, and conditions for performance. Utilization knowledge enables features of the task setting to be used in satisfying required conditions and goals.

Our analysis uses a formulation of conceptual competence for counting given by Greeno, Riley, and Gelman (in press). Principles of number are represented as a set of schemata that specify requisite conditions and consequences of actions at several levels of generality (cf. Sacerdoti, 1977). The relation of the principles to performance in different situations is represented by planning nets that provide structural descriptions of procedures for counting (cf. VanLehn & Brown, 1980). The principles, expressed as action schemata, are used as premises of the derivations in a way that is analogous to the rewrite rules used to derive sentences in generative grammars.

In the present analysis, procedural competence and utilization knowledge are cognitive components needed to construct the derivations of planning nets for counting procedures. Figure 1 shows the main components of a production system, COUNTPLAN, that we have implemented. There is a planner that receives goals and constructs planning nets, using two sources of knowledge. One source contains the system's conceptual competence: principles of number in the form of action schemata. The other source is a representation of the task setting, coupled with utilization knowledge that enables inferences that link features of the setting with conditions that are required according to the action schemata. Procedural competence is represented by the heuristics of planning, including a standard means-ends method, procedures for managing goals during top-down planning, and knowledge for co-ordinating goals and actions relating to sets and individual objects. Procedural competence also includes heuristics that can prove theorems about goals and conditions based on features of the setting and propositions included in the utilization knowledge.

FIGURE 1: Components of COUNTPLAN



Planning begins with specification of the goal to find the number of objects in a set, and proceeds by top-down refinement. The planner searches among the action schemata in its conceptual knowledge for one whose consequence matches the current goal. When one is found, the schema is instantiated and its requisite conditions are formulated as planning goals that can be satisfied either by utilization of the setting or by other actions. Goals set by the planner are of three kinds: goals to enable actions, goals to achieve states corresponding to requisite conditions, and logic goals that arise from quantifiers (e.g., FOR-ALL) and from connectives (e.g., IFF). Planning continues until all goals can be satisfied by a verified plan. Principles of number are reflected in the requisite conditions of the schemata in the conceptual knowledge base, so that satisfaction of those conditions ensures that derived procedures conform to the principles.

The propositions in COUNTPLAN's utilization knowledge are inference rules that transform specific information in the setting into a form that is compatible with the requisite conditions of the goals. In one of the settings that COUNTPLAN encounters the objects that comprise the set of things to count (TTC) are arranged in a straight line. This feature of the setting enables the inference that TTC is ordered. The fact that TTC is ordered allows the further inference that there is a first object and that each subsequent object is connected via a next relationship. Once generated, these properties of an ordered set allow the planner to verify the prerequisites of actions that operate on objects in ordered sets. Actions whose prerequisites cannot be verified in a given setting can be removed from the list of available actions. The process of applying these inference rules is a form of theorem proving in which the planning goals are linked with the inferences made about the problem setting. The requirement of linking goals about sets with actions performed on individual objects provided a problem in formulating planning knowledge that led to interesting insight about procedural competence. In general, the system establishes a global goal to count a set of objects regardless of their exact descriptions. This abstract representation of the object is propagated down the planning net. At a lower level this abstract representation is tagged with certain properties that provide a description of the specific object. This specification is passed to the lowest level of the plan where it is compared with the object that was retrieved. If the two specifications match, the retrieval process is accepted.

Procedural competence is represented in COUNTPLAN as a set of planning heuristics that handle the goals that cannot be satisfied through utilization knowledge. These heuristics represent general knowledge about relationships among actions, goals and constraints that enables the generation of a plan that is consistent with the principles governing the task. The planning heuristics provide procedures used in searching for the appropriate actions in conceptual knowledge, determining if goals are achieved, and making decisions about goal management. The model utilizes several types of planning rules to accomplish these tasks. One type of rule records significant changes in the state of the world and notes possible goal conflicts. For example, if two actions are included in a procedure and one action requires that a particular set be empty while the other action requires that the set is not empty, a goal conflict is noted. The information about this conflict can then be used to order the two actions appropriately. Another type of planning rule propagates constraints based on logical and requisite relations through the plan. For example, one of the logic goals (FOR-ALL) requires that a plan must assure that all the objects are counted. This constraint is propagated through the plan by linking each object related state and action to the FOR-ALL logical goal structure. These links prevent the system from accepting a plan that does not satisfy the global constraint imposed by the FOR-ALL goal. The links also provide a means of accessing these plan components if they cannot be adequately modified. An additional set of planning rules is responsible for verifying that state goals are true and testing that all the requisite conditions of actions goals have been verified. The final two types of planning heuristics involve monitoring the effects of actions and the constraints imposed by corequisites. One benefit of effects monitoring is that it allows the system to notice that the effect of one action corresponds to the prerequisite of the other action. Provided with this information, the system can adopt a least-commitment strategy and temporarily suspend the second action rather than making a stronger commitment to retract that action. One of the primary functions of corequisite monitoring is that it constrains the system to generate plans that are consistent with the counting principle of one-to-one correspondence between objects counted and numbers used. The constraints associated with this principle assume a special status within the system and the detection of a violation shifts the attention of all subsequent planning to restoration of a state of balance.

The generative capacity of the theory has been examined by analyzing several counting tasks that impose different constraints on the plan. These analyses demonstrate that the model is flexible in the sense that procedures are planned for various arrangements of objects, and robust in the sense that existing procedures can be modified to satisfy additional constraints. The analyses contribute toward development of a theory of implicit understanding by providing a mechanism to analyze the relationships between formal principles relevant to a task and cognitive procedures for performance in the task.

References

Gelman, R. & Gallistel, C.R. The child's understanding of number. Cambridge, Mass.: Harvard University Press, 1978.

Greeno, J.G., Riley, M.S. & Gelman, R. Young children's counting and understanding of principles, Cognitive Psychology, in press.

Sacerdoti, E.D. A structure for plans and behavior. North-Holland, Amsterdam: Elsevier, 1977.

VanLehn, K. & Brown, J.S. Planning nets: A representation for formalizing analogies and semantic models of procedural skills. In R.E. Snow, P.A. Frederico, & W.E. Montague (Eds.), Aptitude, learning, and instruction (Vol. 2): Cognitive process analysis of learning and problem solving. Hillsdale, N.J.: Lawrence Erlbaum, 1980.

FUNDAMENTAL PPLS

STABLE ORDER

CARDINALITY : last elt in name = set size

1-1 CORRESPONDANCE

INDIFFERENCE OF ORDER

INDEPENDENCE FROM THINGS COUNTED

CONCEPTUAL — COMPETANCE : PPLS

PROCEDURAL — " : ACTION SCHEMA

UTILIZATION — "

(2) robustness — modify procedures to fit new situations

flexibility: same ppls in different settings eg driving a different car (this is robustness)

generative: small set of ppls into large set of procedures

util < proced < comp

Do utilization pplets precede procedural