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Total and Partial-Order Planning: Application of Results from Artificial Intelligence to Children and Lesioned Adults

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Introduction

This paper examines human planning abilities, using as its inspiration planning techniques developed in artificial intelligence. AI research has shown that in certain problems, which we call 'partial-order/total-order discriminators (or POTODs), *partial-order planners*, which manipulate partial plans while not committing to a particular ordering of subplans, are more efficient than *total-order planners*, which represent all partial plans as totally ordered. This research asks whether total-order planning and/or partial-order planning are accurate descriptions of human planning, and if different populations use different planning techniques.

We examined partial-order and total-order planning in three different populations: children, adults, and adults with damage to the prefrontal cortex. Previous work suggests that young children have difficulty forming flexible plans (Pea & Hawkins, 1987) and will use linear, total-order plans, while adults, capable of using *opportunistic* planning (Hayes-Roth and Hayes-Roth, 1979) will use flexible partial-order plans. Research showing that adults with damage to the prefrontal cortex have planning deficits (Grafman, 1989) suggests that they will exhibit total-order planning.

The Chores Experiments

We presented 17 normal adults, eight 7- to 9-year-old children, eight 10- to 12-year-old children, and five adults with damage to the prefrontal cortex with tasks that could be completed using either total-order or partial-order planning and noted the overall time needed to complete the task. As in AI planning systems, linear growth rates in human performance times in POTODS are suggestive of partial-order planning, while exponential growth rates are suggestive of total-order planning. Using the Chores software (Spector and Grafman, 1994) a Macintosh computer displayed a map of a city with icons representing items to acquire and items already possessed. The task was to perform a series of chores in this city. The relationship between each chore and the items to be acquired was listed on an "Item Info" screen. Because the completion of one chore deleted the item required by the previous chore there was only one correct ordering possible. In the present experiment we varied the number of chores from two to five.

Linear trend analysis revealed that the adults and older children exhibited linear increases in total time as the number of chores increased, while the young children and the adults with damage to the prefrontal cortex exhibited exponential increases. The subjects were also categorized based on their response to ordering violations, with total-order planners completely backtracking and reordering their plan, and partial-order planners backtracking only to the violation, revising and then continuing. Not all of our subjects backtracked, but of those who did all of the younger children (6) and the majority of the adults with damage to the prefrontal cortex (2 out of 3) completely backtracked, while all of the adults (3) and the majority of the older children (4 out of 6) revised and continued their plans.

Conclusions

We have found that the results of analytical work in AI planning can be used to investigate human planning. Specifically, we have evidence that normal human planners use partial-order representations for partial plans, as do most modern AI planning systems. Further evidence suggests that damaged human planning systems use methods akin to those used in less efficient AI systems; specifically, that children with developing frontal lobes and adults with frontal lobe lesions use planning methods similar to those of total-order planners. We believe that the parallels between the human and machine cases are instructive, and that they may lead to further developments in both human and machine studies.

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