Solving meta-tool problem like a crow

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Abstract

In 1972, Alcock proposed a dichotomy of tool use in animals, distinguishing between "stereotyped tool use" in invertebrates and fish and "flexible tool use" in birds and mammals. This dichotomy spurred a deeper exploration of causal tool use in non-human animals. Meta-tool use, exemplifying the use of tools to create or obtain more complex tools, has been a key driver of technological evolution in both humans and crows. This essay delves into the challenges crows face when completing meta-tool use tasks, which include analogical reasoning, inhibiting direct responses, and hierarchically organized behavior. Moreover, it explores the transition from crows to intelligent agents, specifically in the context of task and motion planning (TAMP) in robotics. The essay concludes by highlighting the efficiency of TAMP in addressing meta-tool use tasks while acknowledging ongoing challenges, such as tool selection complexities and system integration risks. This pursuit of understanding and improving meta-tool use tasks remains an essential and valuable endeavor.

1 Introduction

In 1972, Alcock proposed a dichotomy of tool use in animals[1]: *stereotyped tool use* is seen mostly in invertebrates and fish and *flexible tool use* is typically seen in birds and mammals. Stereotyped tool use is inherited and animals only utilize tools in default ways in particular contexts. In contrast, flexible tool use, which is also referred to as creative tool use, is learning-based, and animals explicitly reason about the usages based on the context. This dichotomy drives us to think about more details on causal tools used by non-human animals.

Meta-tool use is a tool use task that refers to using "the tool of the tool", that is, using simple tools to make more complex tools or getting other tools that are much more proper for the task, which is a representative example of causal tool use tasks.

In this essay, we will take crows completing meta-tool use tasks and discuss how can intelligent agents complete such tasks.

2 Meta-tool problem

Metatool use was one of the major innovations in human evolution which refers to the use of simple tools to make more complex tools and has even been considering as the "cognitive leap" that initiated technological evolution in hominins. In addition to humans, crows also have an impressive performance at this task. Studies on corvids have shown that New Caledonian crows can solve both two- and three-stage meta-tool problems(Figure 1).

What are the challenges for crows to complete meta-tool tasks? Meta-tool use has three distinct cognitive challenges[5]. First, an individual must recognize that tools can be used on nonfood objects. This recognition may require analogical reasoning abilities. Second, an individual must initially inhibit a direct response toward the main goal of obtaining food, a reaction that both children and primates find difficult to suppress. Third, an individual must be capable of hierarchically organized behavior[3]. That is, they must be able to integrate newly innovated behavior (tool→tool) with established behaviors as a sub-goal in achieving a main goal (tool→tool→food).

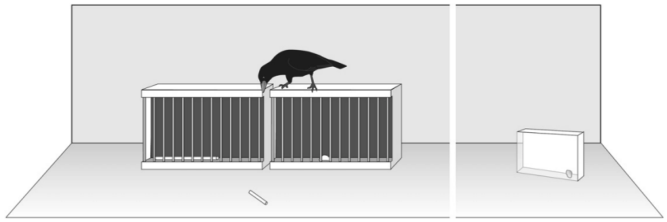

Figure 1: The Meta-tool Use Task Experiment Of Cows: The experimental apparatus consists of a long, functional tool in one toolbox, a stone in the second toolbox, a short, nonfunctional tool in front of both toolboxes, and a 15 cm deep horizontal hole in which meat was placed.

Alongside the observation above, let's consider what should intelligent agents do if they want to complete meta-tool use tasks.

3 From crows to intelligent agents

We've mentioned Alcock's dichotomy in section 1. For more details, in contrast to the above taxonomies, Wimpenny et al. categorized tool use based on the number of tools involved in a problem but overlooked the complexity of the decision process[7]. Boesch categorized tool use based on four levels of increasing complexity though in some sense reminiscent of Wimpenny et al.'s approach[2]:

- Simple tool use
- Combined tool use
- Sequential tool use
- Composite tool use

The meta-tool use task which we mentioned above, in Boesch's taxonomy, is a sequential tool use task. That is, involves completing multiple tool-use tasks in order. This requirement falls under the topic of task and motion planning(TAMP). As its name suggests, it integrates low-level motion planning which includes classic robotic manipulation techniques and high-level task planning which belongs to classic AI planning.

TAMP currently has two main approaches to find action parameters: the sampling-based approach and the optimization-based approach. The sampling-based approach, which is used in the majority of TAMP studies, samples action parameters and tests the feasibility of the sampled combinations. Therefore, this approach may have difficulty when the solution space is relatively small since the probability of being able to sample the correct solution is small. In contrast, the optimization-based approach used optimization techniques such as logic-geometric programming[6] or sequential quadratic programming[4]. It is able to handle problems with a small solution space more efficiently if the local optima can be handled properly.

4 Conclusion

TAMP is probably an efficient approach toward completing meta-tool use tasks for robots. However, there are still plenty of challenges.

The first challenge is on tool selection problem. We only considered the simplest situation of meta-tool use tasks in section 2. What if, there are multiple orders that work for the task? What if a combination of tools is necessary for the task? We have no idea about that challenge.

Developing a super system that adopts and integrates existing work seems like a possible way. For example, such a system should decide whether local or global features should be considered, or choose features beyond geometric ones. But this inevitably leads to the suspicion of using exaggerated words to cover up the complex reality. The larger our system, the greater its risk.

Meta-tool usage represents a straightforward yet illustrative instance of tool using. It provides an opportunity to experiment with and refine causal tool-using models. While pinpointing the ultimate best approach remains elusive, the pursuit of delving further into this challenge is undeniably worthwhile.

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