Building Agents with Crow-Level Tool-Use Abilities: Challenges and Prospects

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Abstract

The tool-use ability has long been regarded by anthropologists as the indicator which separates humans from animals. However, numerous types of animals have also demonstrated amazing capability of making tools for their own purpose. How to build intelligent agents with this level of tool-use abilities, especially in practical and complex environments, is well worth attention. In this essay, we try to dive into current techniques of robotic tool use and analyze the prospects and challenges in achieving crow-level intelligence.

1 Introduction

The capability to craft and utilize tools has long been believed as the key distinction which sets humans apart from other animals. Although it has then been observed that many other species can also make practical tools under various circumstances, we may as well still treat tool-use ability as an indicator of certain level of intelligence.

It could be quite astonishing when it comes to how far can animals go in tool-making and using. Take Jane Goodall's groundbreaking work with chimpanzees as an example. Her observations of tool use in chimpanzees for termite fishing, leaf sponges, and nut cracking revealed instrumental intelligence of primates [4]. While the gap between chimpanzees and humans may seem narrow, it is definitely eye-opening to see how flexible and smart crows can be to make tools for water drinking and food lifting. In the popular YouTube video [13], scientists recorded how the crows crave a hook at the end of a twig to better reach their prey.

As artificial intelligence is rocketing towards the sky nowadays, it is natural to ask: can we build intelligent agents with tool-use abilities in complex scenarios like crows? Can we achieve this by synthesizing the current techniques into a super system, or does there exist any fundamental barriers which need to be conquered?

In this article, we first examine the different aspects of abilities required for a crow to craft tools. Then we inspect current technologies in AI, especially robotics, for the corresponding behaviors. In the end, we conclude the analysis with potential challenges and future directions for a comprehensive intelligent system with crow-like tool-use capabilities.

2 Tiny crow, huge intelligence

In the video, the crow exhibits remarkable problem-solving skills. The food is hidden in the tube with only access from a tiny hole. With no possibility to reach the food with its beak, the crow turns to tool-making for securing this reward.

First, the crow needs precise observation and reasoning abilities to make the plan and execute a sequence of actions. Recognizing that the twig alone is insufficient to reach its goal, the crow devises a plan to enhance the tool's utility by crafting a hook. This process suggests that the crow has a level

Figure 1: Examples of crows' ability to carve hooks and lift food.

of abstract thinking, since it can envision the transformation required to achieve the desired effect. It also demonstrates an innate competence of foresight and strategic thinking.

Second, the crow should take specific actions to modify the twig. Since it has no hands like humans, it can only utilize its beak and claws to twist the twig and derive a hook at the end. Moreover, since the hole is tiny and narrow, it requires delicate manipulations of the hook to lift the food out. All these are done through a series of deliberate and strategic movements, showcasing the precise control ability of the crow.

What truly sets the crow apart is its adaptability and innovation. As more experiments shows, the crow possesses the creative insight to modify the tools for different new purposes. It demonstrates a flexibility to adapt to new challenges and improvise under different scenarios. In addition, in most cases the crow is able to maximize the effectiveness of its tool and achieve its goal with minimal effort, exhibiting an understanding of resource optimization and efficiency.

3 A survey on AI tool use

In a survey on robotic tool use by researchers from Yale [9], they give definition of robot tool use adapted from animal tool use [11]. In alignment with the analysis in the former section, we can separate the skills required for robotic tool use into three categories: perception, manipulation and high-level cognition skills. This coincides with an affordance model with a three-way relation between actions, objects, and effects [7]. Based on the taxonomy of animal tool use [1, 2, 14], the researchers proposed a taxonomy for robot tool use as shown in Figure 2.

We can find corresponding literature of robotic tool use for each sub-category in the taxonomy. For example, in non-causal tool use which imitates the stereotyped tool use of animals, the robot does not need to understand the cause-and-effect relationship between actions and goals. Therefore this relates to abundant studies where robots use learned tools to solve learned tasks [8, 6]. This may involve tool use tasks learning as general manipulation tasks which produces better generalization across tasks. Typical methods include dynamic movement primitives (DMP) [5], segmenting continuous actions into action primitives [10], and so on.

Causal tool use involving single or multiple manipulation is closer to our crow-like tool use behaviour. The crow exhibits remarkable ability to adapt to different complex situations and improvise according to the dynamic environment. This calls for transferable and improvisatory tool use skills of robots to generalize trained objects to new scenarios. There are some primitive attempts and achievements, such as human-guided adaptation [3], point cloud matching of unseen tools [12], and more.

But generally prominent barriers and obstacles remain in the way to truly intelligent robotic tool use like crows. We try to enumerate some of the challenges as follows:

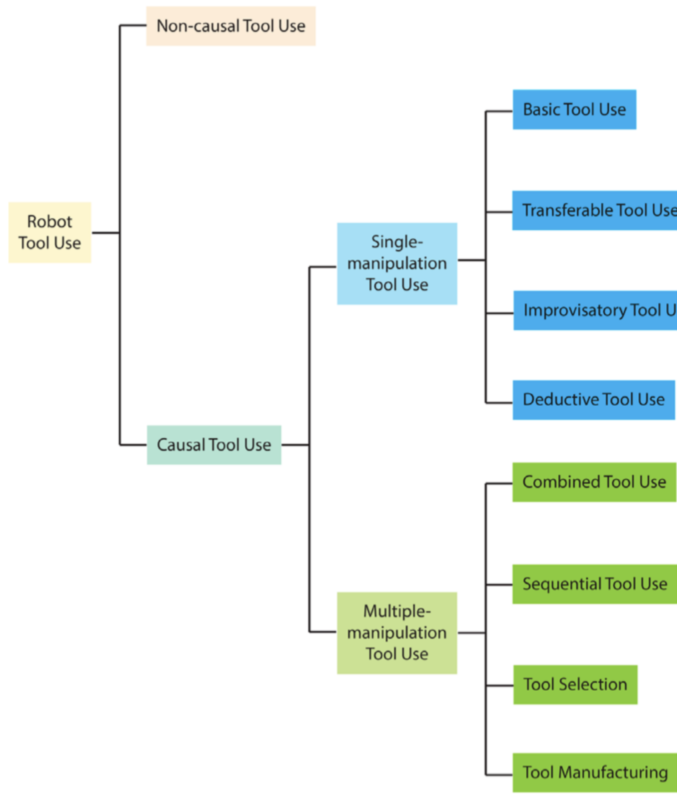

Figure 2: Proposed taxonomy of robotic tool use inspired by animal tool use.

- Sensory Perception: Crows rely on their visual, auditory, and tactile senses to evaluate the environment and manipulate tools. However AI agents are more often only equipped with “eye-sight" regarding sensory. It is very likely that a robot cannot even identify the food hidden in the tube in the YouTube video mentioned before. Hence more advanced perception systems are needed to mimic the capabilities of crows effectively.

- Cognitive Complexity: In the videos, crows exhibit a deep understanding of the physical properties of objects, the affordances they offer, and how to combine them to achieve their goals. But currently it is hard to develop effective cognitive models which encompass these aspects well. Moreover, crows can operate in a wide range of environments, each presenting unique challenges. Understanding and improvising with these complex environmental interactions is also a key barrier.

- Learning and Adaptation: It is easy for crows to learn from experiences and adapt their tool use strategies. However transfer ability has long been a significant difficulty for any AI system. Replicating this learning capability in robots is key to handle dynamic and complex tool-use scenarios.

To overcome these challenges and barriers, we can explore several research directions in the future. For start, high precision of perception ability is necessary to lay the foundation of tool-use. Combination of sense of smell and hearing may be of help when “seeing" falls short. Secondly, it is compelling to create cognitive models which can understand the physical properties of objects and plan complex tool-use actions. The model also needs to learn and adapt in dynamic unstructured environments just like crows. In the end, flexible and robust manipulation of tools is deterministic for successfully leveraging the tool to achieve the goal. Researchers may try to develop more advanced reinforcement learning algorithms which can handle complex tool-use tasks. Considering that tool use often requires the collaboration of multi-components, this may call for hierarchical and multi-agent reinforcement learning algorithms.

4 Conclusion

In conclusion, replicating crow-like tool use in AI agents is a fascinating but complex endeavor. I think the current technologies have achieved extraordinary performances in certain aspects required for tool-using. But still many obstacles remain to be conquered in order to achieve crow-level tool use abilities. Overcoming these challenges will require a concerted effort from researchers in AI, robotics, cognitive science, and related fields. I believe ultimately we can design AI systems which can learn, adapt, and effectively use tools in practical and complex environments.

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