Can I Use a Sandal Instead of a Hammer?: A Cognitive Approach to a Tool Substitution Extended Abstract

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I. INTRODUCTION

When a robot is operating in a dynamic environment, it can not be assumed that a tool required to solve a given task will always be available. For instance, a service robot is asked to serve drinks on a tray, but the tray is broken; such mishaps in day-to-day activities are common. In situations like these, an effective way for a robot would be to adapt like humans, for example, by using a substitute, like an eating plate for serving. This skill is significant because it will allow the robots to adapt to the unforeseen situations when performing the tasks. Moreover, when tool is found to be unavailable during the task execution, finding a substitute in a reasonable amount of time will be necessary to ensure the successful completion of the task in a timely manner. However, it would be time consuming if a robot interacts with an every similar looking object in the environment to determine a suitability of a substitute. The question is how to enable a robot to find a substitute without interacting with the objects.

In my doctoral research, I would like to address this problem using the techniques from the area of knowledge representation and reasoning in the context of a service robot. The primary goal of the research is to propose a representation formalism to express the knowledge about objects and develop a reasoner based on the proposed representation to determine a possible substitute.

II. RESEARCH QUESTIONS

One may wonder what is perceived as a tool. There are multiple definitions of a tool in the literature. For the proposed research, the definition offered by Parkar and Gibson [1] is adopted:

[Goal directed] manipulation of one detached object relative to another (and in some cases through a force field) involving subsequent change of state of one or both of the objects.

The definition offers a simplified account of what is considered as a tool in general. Consider, for example a heel of a shoe. Though its primary function is to increase the height of a person, it can also be used for hammering a nail. This raises a question, how does one know that a heel can be used as a hammer. The answer lies in the properties and functionalities of a tool, and the cognitive processes involved in the decision making [2]. Both of these factors leads to the following research questions.

A. How to acquire and represent knowledge

There is a consensus in the cognitive science literature that the properties of objects play a crucial role when a tool selection is involved. The challenge posed by this theory in the context of knowledge acquisition is twofold. The first challenge is how a robot can acquire the required knowledge about the objects and its properties. The properties such as shape, texture, sound can be learned using visual, auditory, tactile etc. perception systems. On the other hand, more abstract properties such as rigidity, heaviness can be learned by performing experiments on the objects. The viability of these perception systems relies on the complexity of a required knowledge which unfolds the next problem. It is clear that a sufficient knowledge is required to describe an object in terms of its properties and functionalities. The question is, what is the desired granularity of the knowledge to be acquired. In other words, whether knowledge should describe an object down to the smallest details. For example, if a rock is to be used in place of a hammer, the properties such as rigidity, solid mass, palm size may be sufficient to determine its suitability. However, if a heel of a shoe is to be used then in addition to rigidity, mass and palm size, properties such as a heel on the back side, higher mass on a heel side etc are required to determine its suitability. The granularity can also be seen in terms of the relevant and irrelevant properties of an object with respect to the required function. For example, the color of a shoe is relevant to the choice of the clothes one wants to wear, but irrelevant if one wants to use a shoe for hammering. The details may also include information about an object's geometrical properties such as shape, size; surface topology such as roughness, waviness; elasticity such as flexible, rigid; material such as wood, metal etc.

The research question, what is an appropriate representation for object properties, explores the ontological approaches to formally represent the object related knowledge acquired by the different perception system. The idea is to create a knowledge base of house-hold objects, their properties and their functionalities such that each property can be grounded in the sensor data or experimental data. The common components of ontologies such as *individuals, classes, properties, relations* allows the knowledge to be represented systematically and makes it easily accessible for reasoning purposes. Also, as the object related knowledge is acquired from multiple perception systems, ontologies offers a uniform representation without having to worry about the underlying structure of the corresponding perception data.

B. How to determine a reasonable substitute?

There is an evidence that in case of a tool-selection, possible substitutes can be short-listed based on their similar physical appearances, for example, there is some similarity in the appearance of a hammer and a shoe with a heel [3]. However this manner of tool-selection is based on the visual perception which may not be an adequate choice. For instance, a rock can also be used to hammer a nail, but its physical appearance is not similar to a hammer. The selection of a rock is more driven by the properties of a head of a hammer which are similar to that of the rock. It is also important to note that an appearance alone may not be a sufficient factor to select a substitute, for example, tobacco pipe has a similar appearance but it can not be used for hammering because there is a hole on a head of a pipe which can obstruct the hammering. Recall that not all properties of a substitute are relevant with respect to the required function.

The question is how to select a substitute which is somewhat similar in appearance to the original tool and also has other relevant properties with respect to the function. The challenge here is identifying the relevant and irrelevant properties from the set of all properties of a tool. It is essential because, if the relevant properties are present in an object, the object can be used as a substitute. The problem of how the certain properties of a tool enable a certain function in a tool is being pursued in the area of functional ontology [4] and functional affordances [5] which may provide cues in identifying the relevant features computationally. The primary focus of this research is on developing a system which can compute one or more possible substitutes without interacting with the existing objects. The computational techniques in the area of machine learning and formal reasoning such as analogy reasoning will primarily be explored.

III. RELATED WORK

The area of a tool substitution has not received enough attention in the robotic research, although there have been attempts in the area of affordances where the focus is to learn the object affordances by performing a given set of actions on an object and learning from its effect on the environment. By contrast, the proposed approach does not require a robot to learn to maneuver a tool, instead it relies on the assumption that a substitute can be used in a similar manner to the original tool which a robot already knows. In this section, work which explicitly addresses the problem of determining a substitute for an original tool is discussed.

In the approach proposed in [6], a substitute is determined by comparing the functional affordances and a conceptual similarity of the original tool with a possible substitute. The functional affordances of an object are affordances that *help or aid to the user in doing something to achieve a goal* [5]. The required object related knowledge such as properties and functional affordances are modeled after dictionary definitions of the objects and expressed as OWL-DL ontologies while the lower-level representation of an object is represented using conceptual spaces [7] in a sub-symbolic manner. How the objects are represented in conceptual spaces and how the conceptual similarity between objects is learned in the conceptual spaces are not explained in the paper, as according to the author it is still being investigated.

IV. CONCLUSION

This is a work-in-progress report. The primary focus of this research is to propose a representation formalism to express the knowledge such as properties and functionalities about objects; create a knowledge base of such object related knowledge; and develop a reasoner based on the proposed representation to determine a possible substitute. The reasoner is intended to be a stand-alone system which can aid a robot during, for example, planning or affordance learning. The reasoner will be evaluated initially in a simulated environment to examine its performance and later will be tested on a robotic system to analyze its applicability in a real-world environment.

The current work focuses on the development of a knowledge base consisting of house-hold object related knowledge represented as an ontology. The ongoing literature research involves the literature on tool use in animals and humans such as [8], [9].

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