Towards affordance-based solving of object insight problems

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Abstract—**Humans can use knowledge about object affordances creatively to solve problems. Cognitively-inspired affordance inference mechanisms can make artificial systems more robust, flexible and independent when dealing with real-world environments from an incomplete knowledge perspective. Three levels of creative substitution of objects in problem-solving are described. The application of a theoretical framework for re-representation to such object problems is proposed. The use of affordance inference in the solving of creative object problems is explored.**

I. Introduction

Efforts towards creative computation [6, 1] and knowledge about creative cognition [3] can inspire frameworks [8] for creative problem solving for artificial systems. These can be used for solving practical object-based problems which involve affordances [5] and spatial reasoning [4]. An object-based insight problem - the two-string problem - is presented in Section II. A cognitively inspired theoretical framework which makes use of affordances and knowledge organization principles to find creative inferences is summarized in Section III. Three levels of difficulty for creative problem-solving with objects are proposed and described in Section IV, together with the mechanisms they require to be solved. Finally, the two-string problem is described in terms of such a framework in order to differentiate between the problem-restructuring and object-restructuring step in Section V.

II. The two-string problem

An example of an empirically studied and affordance-related insight problem is the two-string problem [7]. A participant is put in a room with two strings hanging from the ceiling (Figure: 1). The task given is to tie the two strings together. However it is impossible to reach one string while holding the other. Various objects are scattered on the floor. The accepted solution to this problem is to take one of the heavy objects (like the pliers) and tie it to one of the strings, and then set that string in motion, catching it while it is close enough to tie to the other one. The insight is seeing the capacity of the string to act as a pendulum, and a secondary challenge is to create such a pendulum. When human participants have difficulties reaching the solution to such a problem, the experimenter brushes past the string, setting it in motion. This is sometimes enough to trigger the pendular motion affordance of the string
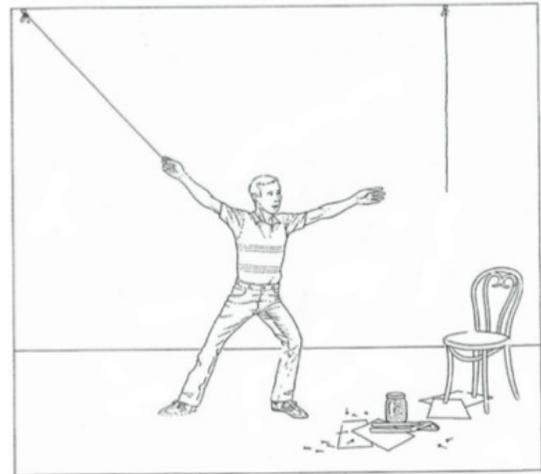

Fig. 1. A depiction of the two-string problem

in the mind of the participants, which find it much easier to then come up with a solution.

III. Framework

An essential quality in insight problem solving is an ability for re-representation. A previously proposed cognitively-inspired theoretical framework [8] focuses on types of knowledge organization adapted for the ease of processing of such problems. The framework (Figure: 2) contains three levels:

- A subsymbolic level, which encodes the various features of objects (shape, color, motion trajectory, etc.) in similarity based maps;
- A concept level, at which each object known is encoded symbolically (while being anchored in activation of certain points of the subsymbolic level);
- A structured representation level, which encodes problem interpretations and problem templates (and in this case as described later known complex objects) in the basic concepts they contain, their known relations and affordances (or solutions at the problem template level).

The subsymbolic level is used for grounding and for the search of objects with similar features as the ones given, on
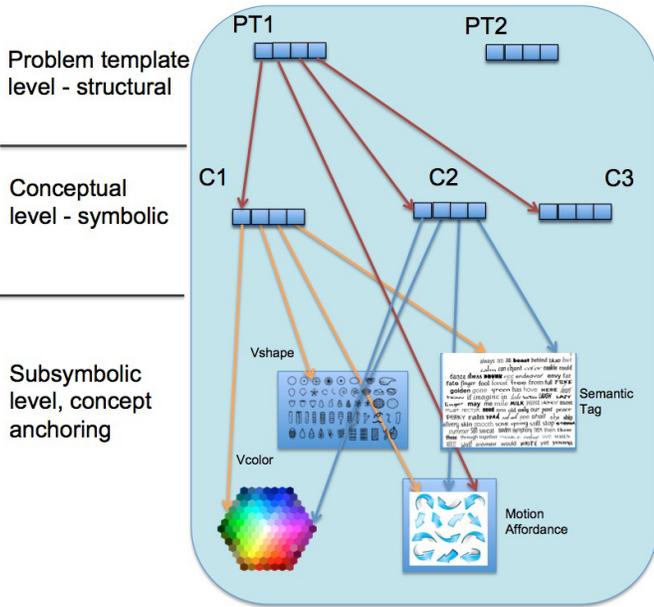
Fig. 2. A depiction of the framework for creative problem-solving and re-representation

Fig. 3. Creative object replacement - from [8]

various dimensions. The structured representation provides the ability to switch between the various objects used to solve the problem (in previous experience), or navigate between different possible interpretations of the problem.

This framework can of course be adapted to object composition problems, if composed objects are to be understood as structures similar to the representation structures used at the problem template level.

Creating new objects out of known objects can happen in this framework as follows. A complex object is encoded as a collection of other objects - i.e. a fishing rod can be encoded as being composed of some essential parts - a rod, a string and a hook - and a few other parts (floater, thrower). The affordance of such an object is also encoded in its representation (catching fish), together with the motion required to use the rod. When in need of such an object, the system should be able to decompose it in its primitive object parts, and search for the affordances (properties) of these objects. Objects similar in affordance or other functional properties (shape, size, weight, etc.) with each of the primitive parts can then be recruited from the environment, and re-assembled into a creative, custom-made fishing rod.

IV. THREE LEVELS OF DIFFICULTY FOR CREATIVE PROBLEM-SOLVING WITH OBJECTS

Three levels of difficulty in creative problems involving objects and object composition are proposed. These are (i) simple object replacement creative problems, (ii) object composition creative problems and (iii) object composition insight problems.
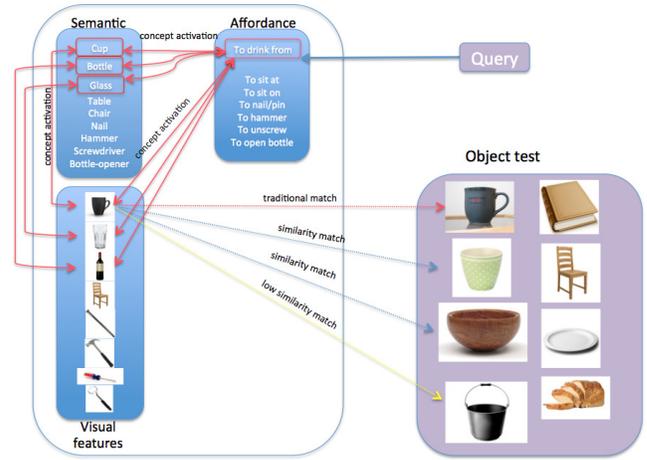
A. Simple object replacement creative problems

These are problems of the following form: a cognitive agent requires a certain object (e.g. a cup - Figure: 3), and this is not to be found in the environment. Thus a creative agent will look for another object which has functional properties relevant for the affordance it was initially searching the object for (in the case of the cup, another object which affords liquid containment can be found). Similarly, when needing a hammer, the agent can look for an object of similar weight (affords hammering) and size (affords grabbing).

The mechanism to solve such problems in the aforementioned framework is based on anchoring objects in property and affordance maps which are organized by similarity. In some cases, visual properties of objects can be directly correlated with functional properties, and inferences about affordances can be made based on visual properties (this is one explanatory account for the existence of shape bias in humans). A search for objects with similar functional properties can then be performed when the initial sought-for object is missing, as to obtain a "creative" solution to a practical object problem.

B. Object composition problems

Object composition problems involve again the need for a certain object, when the object is not to be found in the environment. However, in this case, no object in the environment can be used as a direct replacement. A complex object needs to be formed from simpler parts in order to provide the solution. Thus, objects like a fishing rod, an umbrella, or a lever need to be improvised out of parts that can be found in the environment.

The mechanism for solving such problems can make use of the encoding of the initial composed objects which need to be replicated (fishing rod, umbrella, lever) as part-based objects. In the aforementioned framework, this would mean encoding the object at the problem-template level as a complex object, grounded in its constituent object parts (concepts), which are further grounded in their properties. A mapping of the object parts to replacements objects (objects with similar relevant

affordances) can then ensue, in the attempt to fit the various given objects in the environment to the representation of the composed object. Then various hypotheses of creatively using subsets of the given objects to compose the complex required object can be made.

C. Object composition insight problems (wrapped problems)

Object composition insight problems (e.g. the two-string problem [7], the candle problem [2]) require both the ability for object composition (from the previous step), and an insight into what kind of object is needed to solve the problem.

The mechanisms required to solve such problems are the ability to re-represent not just the composed object in terms of different parts, but also the problem in a form that "affords" the solution. This is the reason for which such problems are called here wrapped problems: to reach the solution, an object composition problem must be solved, which is wrapped in the larger challenge of re-representing the problem in a manner which makes it solvable. Thus, in the two-string problem, creating a pendulum is the object composition part of the problem, while seeing one of the strings as a possible pendulum is a re-representation of the given problem.

V. A CASE STUDY - SOLVING THE TWO-STRING PROBLEM

In the proposed framework, each recognized object can be understood through the agent's knowledge and/or experience with it. If an object is already in the knowledge base of the system, various affordances and properties are pre-encoded with it. Thus affordances like "tying" can be correlated with other properties of the string, like "tensile strength".

The solver can start with a representation structure which involves the end state - tying the two objects together. However, means-end analysis yields the constraint that strings are too far apart or too short to be tied together, and focuses the system on a new goal - how to make one of the strings longer so they can reach each other. This new goal is a different representation structure which activates the "tying things to" affordance of the string as a way of making one or both of the strings longer. However making one of the strings longer with another object is not enough to solve this problem. The leap in reasoning is attained by understanding that one of the strings must move on its own.

Imagining (or perceptually simulating) a string fixed at one point (input from the environment) in motion (input from the problem solver's processing state in which it needs the string to move) could trigger in the similarity-based encoding of the solver (on the motion trajectory dimension) another known concept - a pendulum. The pendulum concept must then be decomposed in its basic parts and recreated out of objects with similar affordances from the environment, like in Figure 4 (i.e. a string and a heavy object).

In terms of arriving at the required insight, the system needs to search for the kind of motion that would help solve its problem. Thus it has to frame its problem as the search for an object that affords such motion. A knowledge base of such types of learned motion (and objects capable
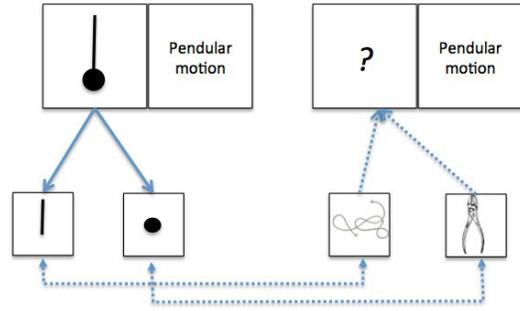

Fig. 4.   A pendulum template created out of other objects

of it) is assumed in humans and would be a requirement for a system implementing this theoretical framework. The requirement for this motion triggers the requirement for a certain object (not present), the representation of which has been pre-encoded in the system (indeed the challenge for humans is to find the objects which are relevant to the solving in their commonsense knowledge). Parts that could be matched to a traditional representation of this object are then searched for. A long object attached at one point (the string) and a heavy object (the pliers) are sufficient to re-create the triggered "pendulum" representation. This improvised object is then capable of pendular motion (and allows the solver to grab the other string and wait for the one set in motion to come close). However, such an object could have been created out of a variety of long+heavy objects tied together.

"Seeing" the possible combinations of the objects given in such an ill-structured problem via affordance inference and knowledge about how affordances combine in some composed objects is an ability which itself affords dealing with new environments in a productive and adaptable manner. The knowledge representation structures in the framework can be compared to the objects in the environment, even if some of these objects are unknown. The latter can be used in novel ways by being re-represented as similar in functional properties and therefore affordances to objects the solver knows already. Thus ill-structured problems can be represented and re-represented as a search over variations of known objects and previously solved problems. The combinatorial effects of both objects and problem templates can then be assessed, or the possible usefulness of such combinations can be hypothesized upon. Such framing brings different representational structures to help the attempt of interpreting and solving ill-structured problems.

VI. CONCLUSION

Creative problem-solving of object problems using affordance based inference can make artificial systems more adaptable and robust when dealing with unknown environments or ill-structured problems, and when only having incomplete knowledge.

A framework for problem re-representation has been described, together with the similarity between problem template

re-representation and re-representation of composed objects.

Three levels of difficulty for creative object problems have been proposed, together with necessary mechanisms for solving them. Affordance-based reasoning in the proposed framework can help solve creative object composition and practical insight problems.

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