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Calibrating, Counting, Grounding, Grouping

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Abstract

Even an "elementary" intelligence for control of the physical world will require very many kinds of knowledge and ability. Among these are ones related to perception, action, and reasoning about "near space": that region comprising one's body and the portion of space within reach of one's effectors; chief among these are individuation and categorization of objects. These in turn are made useful in part by the additional capacities to estimate category size, change one's beliefs about categories, and form new categories or revise old categories.

In this position paper we point out some issues in knowledge representation that can arise with respect to the above capacities, and suggest that the framework of "active logics" (see below) may be marshaled toward solutions. We will conduct our discussion in terms of *learning to understand in a semantically explicit way one's own sensori-motor system and its interactions with near-space objects.*

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1 Introduction

Even an "elementary" intelligence for control of the physical world will require very many kinds of knowledge and ability. Among these are ones related to perception, action, and reasoning about "near space": that region comprising one's body and the portion of space within reach of one's effectors; chief among these are individuation and categorization of objects. These in turn are made useful in part by the additional capacities to estimate category size, change one's beliefs about categories, and form new categories or revise old categories.

In this position paper we point out some issues in knowledge representation that can arise with respect to the above capacities, and suggest that the framework of "active logics" (see below) may be marshaled toward solutions. We will conduct our discussion in terms of *learning to understand in a semantically explicit way one's own sensori-motor system and its interactions with near-space objects.*

Implicit in successful grouping (categorizing) of near-space objects are individuating (grounding, numbering, and binding) them and also calibrating one's sensori-motor system. A glossary below offers brief descriptions of some of these terms.

2 Motivational examples

Some instructive settings to keep in mind are:

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1. An infant whose near space is its crib: as its sensory-motor system develops, internal maps must be recalibrated again and again, so that "hand-eye" coordination can continue to develop as well.
2. An adult fitted with a new glasses prescription: the ground looks nearer or farther than before, and allowance must be made for this, until internal maps reorganize.
3. A robot whose arm has been replaced by a longer one, or whose lenses have become clouded or displaced: the same issues as above.
4. A mobile robot accustomed to horizontal ground, but now on sloped ground: more or less motor activity is required now, depending on direction of motion.

These settings all involve learning (or relearning) appropriate relations between sensory and motor modalities, where "appropriateness" is judged by results in terms of successful negotiation with objects in near space. Such negotiation includes individuating objects as objects (and distinguishing one object from another), binding object-identification over time as an object is seen in different contexts, manipulating or tracking objects (esp. with regard to sensory-motor miscalibration), semantically grounding internal syntactic expressions in terms of perceptual acts, categorizing objects into natural groups (by type, position, etc.) and noting multiple instances of objects of the same type (counting).

Our long-range goal is the design and implementation of a robotic agent has *explicit semantic access* to these evolving changes in its beliefs, so that it can communicate with others, and in particular can explain mistakes it made based on poor alignment of internal model. This will be important both to help it avoid future mistakes (or recalibrate more quickly) and to warn others to watch for similar problems.

Specific capabilities we wish to build into an artificial agent in the next few years are:

1. calibrate its internal self-model as needed to allow appropriate interaction with near space, and recalibrate in the face of changes in its perceptual or motor systems
2. perceptually pick out objects in its near space
3. properly individuate, count, and keep track of those objects in an internal language
4. classify those objects into appropriate categories
5. reason about those categories, e.g., count or estimate sizes, form and apply defaults, etc.
6. revise categories and category membership as needed

3 Discussion

Some of our previous work [3, 2, 6, 10, 8, 14, 11] treated rather disjointed aspects of this long-range problem. In this position paper we simply single out four key aspects of the more integrative long-range task: calibration, counting, grounding, and grouping.

Some aspects of the larger task are *not* ones we intend to address, especially those bearing most directly on basic perceptual or motor skills (vision and robotics). We also are not explicitly concerned with qualitative physics in the usual sense [16], but rather principally with an agent's self-models as they incorporate information about dealing with near space. Self-models and near space are what we are now beginning to focus on in some of our current research.

We have selected reasoning about near space because we think categorizing is both easier and more important there than in far space. Certainly infants and simple organisms deal primarily with near space; and imminent threats to survival tend to be in near space even for complex agents. It is plausible that most of our mental machinery has evolved in ways that are facilitative of near-space reasoning.

Calibration and grounding are inherently agent-oriented, whereas counting and grouping are less obviously so. Calibration and grounding refer to the agent's ability to coordinate perception and motion and (in our view) explicit beliefs about the agent's body in relation to near space. Some related work by others on calibration, grounding, and self-models includes [1, 9, 15, 5, 7]. Confusion and contradiction can easily arise in near-space (due to noisy or conflicting data from multiple modalities, or from defaults gone wrong), and the recognizing of such is a crucial step in setting one's world view right again; this is where symbolically explicit calibration can enter importantly.

Counting and grouping are more general tasks, but again in our view they can (and should) be seen as extensions of basic measurements the agent can carry out based on fundamental notions of its own bodily measurements, in an internal self-model. (This also bears on the so-called active-vision paradigm, which maintains that the intentions and actions of the seeing agent are critical to its visual computations.)

It is of interest that although categorization (grouping) has received a great deal of attention by psychologists [4], little study has been made on the human use of categories to advance default inferences. Thus much is known about how humans come to classify something as a bird (e.g., by comparison with a prototype feathered creature), but not much about how humans then draw further inferences about that object (e.g., that it can fly). On the other hand, in AI much attention has been given to the latter, but less to the former. We wish to bring these two areas closer together, using active logics as a formal tool in which change of belief over time can be modeled. We believe their combination to be fundamental to intelligent near-space behavior.

In each of our four key capabilities, learning must take place in order for appropriate behavior to be possible: the agent must learn a new relation between its body (sensors or effectors or both) and its near space, along with individuation of objects and their categories and quantities. While such learning is possible without explicit symbolic representation (indeed probably is most commonly so), there is added benefit to having some explicit knowledge and even meta-knowledge of the process of learning. We gave some benefits above. Another is that an agent who is aware of the discrepancy between its current sensory-motor behavior and its desired behavior (e.g., in reaching for objects but missing them) may take more care during the learning period, so as to make fewer (or less drastic) mistakes until automatization occurs.

The portion of the meta-reasoning that we have been working on to date includes representational tools for change in belief and for recovery from contradictory beliefs. Others to be worked on include change in category; magnitudes (cardinal and ordinal counting and measurement); sets [13, 12] (as convenient representations for both categories and counting); and rule-learning (automatization of explicit beliefs about actions).

Category discrimination in itself may be largely perceptual and is not the direct focus of our concern here. Rather, our topic is the *reasoning* about categories that one can discriminate. There are several issues in knowledge representation that arise here, that appear not to have been addressed in existing work. Chief among these is counting: simple arithmetical skills such as comparing relative sizes of two categories, or noting that a category has exactly three members, all of which share a salient property, are taken for granted in human behavior, and are extremely useful. Yet they are generally left out of computational models. Closely related to "numerosity" is change of belief, for the process of size-estimation leads to new information about categories, that may require revising of previous beliefs. Size-estimation in turn we will relate to bodily measurements, alluded to above; preliminary work on this is found in [14, 11].

4 Active Logics

Our perspective is that active logics may provide a useful (even crucial) tool for addressing the issues of calibrating, counting, grounding, and grouping of near-space objects and actions in a semantically explicit way. The principal reason for our view is that all four of these capacities are ones where error and belief-revision will be common occurrences. Active logics were developed largely to deal with just such matters, with special meta-inference rules to recognize and contain errors. This is one form of self-modeling, and is related in a general way to the above comments about measurement as well.

In 1986 we coined the term "step logics" for a new kind of time-situated reasoning, in which the passage of time *during* reasoning is itself encoded in the syntax of the logic, via special time-sensitive inference rules. These were used to provide time-situated solutions to a number of problems in commonsense reasoning, including default reasoning, reasoning about others' beliefs, planning with deadlines, and recognizing and correcting errors (including contradictory beliefs). More recently, we have adopted the term "active logics" as both more descriptive and also more general, to allow learning of new syntactic expressions (lexicon growth) and altering of semantic content of existing expressions (semantic shift), in addition to the features of step logics.

An active logic is both an abstract rule system and an inference engine that produces theorems (beliefs) using those rules. Their single most unusual feature is a special rule for the predicate $Now(t)$ whose intended meaning is "the time is now t". As the logic produces theorems over time, a sequence of wffs of the form $Now(t)$ become briefly believed and then replaced by the next in the sequence: $Now(0)$, $Now(1)$, $Now(2), \ldots$ so that the argument t to the currently-believed $Now(t)$ is a dynamic measure of the actual (changing) time as the logic draws inferences. In effect an active logic has a wristwatch that it checks to update its belief as to what time it is, in parallel with its other reasoning.

This "wristwatch" is the key to most of the special capacities of active logics, and we have used it extensively in addressing the problems listed two paragraphs above. In particular, it facilitates a powerful and computationally tractable kind of meta-inference. It is our hope that we will have equal success in finding semantically explicit solutions to the problems of calibrating, counting, grounding, and grouping, for all of these are ones where error and revision of beliefs will be frequent.

5 Glossary

Calibration: setting up appropriate internal maps to put sensory modalities in correspondence with one another and with motor systems, to allow coordinated sensori-motor behavior. Such maps need to be adjusted, during growth and other times of physical change.

Individuation: picking out aspects of perceptual space as being (or representing) real individual objects; thus two red balls are individuated as two objects, not one. Related to counting.

Grounding: tying internal symbols to the external entities they represent; that is, providing the means by which internal symbols can represent specific external entities. Related to counting: one object-symbol should not be grounded in two different objects.

Binding: Many percepts can "represent" the same external object (e.g., visual, auditory, tactile); these must somehow be tied together cross-modally as well as over time, to form a representation of a single external object.

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