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GLOBAL MODELS: ROBOT SENSING, CONTROL, AND SENSORY-MOTOR SKILLS

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ABSTRACT *

Robotics research has begun to address the modeling and implementation of a wide variety of "unstructured" tasks. Examples include automated navigation, platform servicing, custom fabrication and repair, deployment and recovery, and science exploration. Such tasks are poorly described at onset; the workspace layout is partially unfamiliar, and the task control sequence is only qualitatively characterized. The robot must model the workspace, plan detailed physical actions from qualitative goals, and adapt its instantaneous control regimes to unpredicted events. Developing robust representations and computational approaches for these sensing, planning, and control functions is a major challenge. The underlying domain constraints are very general, and seem to offer little guidance for well-bounded approximation of object shape and motion, manipulation postures and trajectories, and the like. In this paper we discuss this generalized modeling problem, with an emphasis on the role of sensing. We argue that "unstructured" tasks often have, in fact, a high degree of underlying physical symmetry, and such implicit knowledge should be drawn on to model task performance strategies in a methodological fashion. We propose a group-theoretic decomposition of the workspace organization, task goals, and their admissible interactions. This group-mechanical approach to task representation helps to clarify the functional interplay of perception and control, in essence, describing what perception is specifically for, versus how it is generically modeled. One also gains insight how perception might logically evolve in response to needs of more complex motor skills. We discuss why, of the many solutions that are often mathematically admissible to a given sensory motor-coordination problem, one may be preferred over others.

* Due to the length of this manuscript, only its abstract and a brief introduction are included within the proceedings. Those wishing a copy of the full paper should request it directly from Dr. Schenker at the above address.

I. INTRODUCTION

Traditionally, robotics applications have been in structured settings. Factory floor robotic assembly is an example -- it is known in advance where objects are located, how they are shaped, a desired sequence for their mating, and desired physical trajectories and forces for their grasp and manipulation. Recent robotics research has taken automation into semi-structured settings, where the robot itself can derive portions of this information during task execution. More flexible and diverse applications can be achieved, with reduced time for task set-up and programming. Supporting developments include CAD/graphical modeling, machine object location and recognition, geometric reasoning, proximity sensing applied to kinematic trajectory correction, contact sensing applied to force-position control adaptation, redundant kinematic design, and grasp dexterity.

Beyond such structured and semi-structured settings, there is a vast range of unstructured robotic tasks. Applications currently under investigation include reconnaissance, navigation, inspection, servicing, repair, recovery, and science exploration, for both terrestrial and space applications [1-2]. Aid-to-the-medically-impaired is another area of great opportunity. Tasks performed in these scenarios are characterized by the uncertain and the unknown. Objects, object motion, and workspace layout may be a priori unspecified; task goals are usually qualitative in nature; kinematic and dynamical control will encounter unmodeled environmental constraints. Thus, successful task performance depends heavily on the robot's ability to organize a physical understanding of its environment, dynamically plan an appropriate sequence of actions, and adapt its sensing and control regimes to the current environmental state [3-6]. Engineered constraints of structured task design expand to natural constraints of the unstructured task environment; requirements for human and machine task performance often begin to look similar [7].

Unstructured tasks present to roboticists, as well as cognitive scientists, a major challenge: identifying and modeling the constraints around which the task will be computationally organized. The following sorts of questions must be answered: what "object" constructs should perception derive and maintain? -- how are they made specific and unique to requirements of a particular task? -- how are they made explicit in a particular set of sensing modalities and configurations? -- how are they accessed and used, in concert with motor control and task constraints, to compute a specific set of motor actions? -- overall, is there hope for a modeling approach in which models for perceiving, planning, and acting can be viewed as a common information structure? Roboticists need answers to these questions, not just from a computational viewpoint, but also from the human performance perspective, e.g.: interactive task planning tools will benefit; telerobotic design will reflect better approaches to shared and traded functional control.

In this paper, I suggest that representations of unstructured perceiving, planning, and acting can be made explicit from a group-theoretic decomposition of a task goal. The basic idea is this: transformation groups and their invariants are defined with respect to underlying symmetries of the workspace, observation space, and kinematic and dynamical constraints of robot-workspace interactions. The admissible group operations define solutions to perception, planning, and control; the associated group invariants, and their underlying metrics, categorically structure the solution space. Of the mathematically admissible solutions, some are rooted in more basic physical symmetries than others, and should be inferred as the more projectively/dynamically stable, globally probable instantiation of the task. The suggested approach, while currently conceptual, offers potentially practical, important insights for robotics, visual psychology, motor performance, and underlying implementations. As one example, it attempts to formally characterize what perception is for, and how this is manifested in a given task, prior to describing how the individual elements of perception are to be generically modeled, computed, and implemented.

Our paper is non-mathematical and self-contained; here, I concentrate on explaining the group representation concept and its motivation, versus its formal development. In Section 2, I provide an epistemological background and motivation for my approach. In Section 3, I outline the approach, and some past related work. In Section 4, I summarize the main points of my idea and discuss some of its possible implications for further work in robotics and cognitive science.

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