THOMAS WENGEREK* and HELGE RITTER**

COMBINING ELEMENTARY FUNCTIONS: LEARNING APPROACHES

1. INTRODUCTION

Complex behavior can emerge from elementary functions or simple building blocks as many examples from biology show. This might constitute an attractive paradigm of programming robots to overcome the strong limitations of present day robot applications. The required coordination of such elementary functions should be acquired by learning, but in many cases the evaluation of actual performance can only be given by high-level feedback. Therefore we have focused on recent reinforcement learning techniques. As a testing scenario for these conceptual ideas we consider the domain of robot grasping. We report encouraging results aiming at the coordination of simple gradient motion pattern as elementary skills. To elucidate some main aspects we investigated the approach within very different environments ranging from abstract simulations up to an implementation for a real robot.

Building intelligent robots is one of the greatest technological challenges in our time. Robotic research of the past decades has shown that most of the seemingly simple-looking tasks like grasping and manipulating objects in real-world environments are too demanding for present day robots. Requirements on robustness and adaptivity while interacting flexibly with the environment make such problems much too complex to be solved by a detailed analysis of the entire problem. Brooks (1989) gives a very convincing discussion of that aspect. Needed are design strategies that allow to build complex robot capabilities from simpler “building blocks” that themselves represent more or less complete and independent skills or elementary functions to bound the combinatorics of the entire task. Consequently, learning methods could provide an important, perhaps even the decisive contribution for coordination of such basic skills to exploit the full capacity contained in them and to make hidden properties accessible and emergent.

This approach has motivated us to look for solutions and examples from biology. Particularly the experiments of Bizzi et al. (1991) are inspiring in this context. They showed that limb movements of frogs are elicited by superpositions of a set of what they call convergent force fields (CFF), see Figure 1. Each CFF can be activated by local stimulation of a neuron pool.
and tries to move the limb into a particular equilibrium position. Moreover, there is evidence that each CFF may be generated from simpler force fields that can be activated by stimulating neurons on a lower level of the motor hierarchy. These findings suggest some kind of hierarchical order of motor behaviours with increasing complexity. On each level there are only a limited number of basic movements which are able to cover the needed repertoire by superposition or more generally by cooperation of their members. This approach is intuitively appealing and leads to the speculation that such procedure might be related to the use of basic reflexes and their combination into more sophisticated sequences of movements in the case of movement learning in organisms and should be useful also in robots. Mussa-Ivaldi et al. (1992, 1992a) have explored how such force fields can be constructed by interpolation from sparse data.

Crucial for the success of this approach is the proper choice of basis skills and possible learning techniques for their coupling. However, this style of robot "programming" is very different from the traditional approach, since it exploits the emergent properties that result from complex interaction among the basis behaviors. For this purpose we are especially interested in reinforcement learning (RL) schemes because of their ability to build control strategies by trial and error, which represents in a lot of situations the only