# A Robotics Perspective on Motor Programs and Path Planning

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February 9, 1993

The Alexander, DeLong and Crutcher article is relevant, not only to theories of biological motor systems, but to robotics research as well. If we roboticists are to construct versatile robot systems, then we need to concentrate on engineering solutions which provide robot systems with the ability to react quickly and appropriately to environmental changes – just as their biological counterparts do. Indeed, biological motor systems are the only existence proofs for this sort of flexibility. Therefore, I think it is appropriate for roboticists to maintain at least some familiarity with those aspects of neural science which are relevant to their objectives. In light of this opinion, I would like to tie the article's criticisms to some current robotics literature.

The notion of a "motor program" is prevalent in the robotics path planning literature. This is most apparent in techniques which rely on methods from computational geometry or algebra (see, for example Canny 1987; Hopcroft et al. 1985; Kapur and Mundy 1989; Lozano-Perez 1981). In these methods, the emphasis is on constructing complete paths from one point to another. Some of these algorithms are of great value to theoretical computer science, but in a practical sense, they succumb to the same criticisms that

* *Behav. Brain Sciences* 15(4):728-729

Alexander, DeLong and Crutcher level at theories of biological motor systems. Most "motor program" algorithms in robotics are not naturally suited to a massively parallel computing archi- tecture. Moreover, with these techniques, any change in the robot's environment requires a "substantive planning phase". With current computer technology, such replanning is a time consuming step and of necessity results in a certain inflexibility in the robot system.

Over the past ten or so years, a class of "potential field" planning methods has arisen in robotics (see, for example Arkin 1987; Barraquand & Latombe 1991; Khatib 1985; Krogh 1984; and Newman & Hogan 1986). Such methods rely on the gradient descent of a potential function constructed in some state space to drive the robot system away from obstacles and toward goal positions. These algorithms typically use a geometric model of the environment to set up a repulsive vector field around every obstacle, and an attractive field around the goal (this is also reminiscent of Arbib's control surfaces Arbib 1981, and the path-planning model of Arbib and House, Arbib 1987). The robot system then follows the vector field which results from the sum of the repulsive and attractive fields. These techniques are sometimes regarded as being local in nature; it has been assumed that they cannot by themselves be used for generating whole paths from start to goal. The reason for this is that in the case of arbitrary vector fields, spurious local minima can arise. These are points where the individual vector fields cancel, the result being zero. No movement can occur at these points, and once there, the robot is stuck short of the goal. Recently, however, progress has been made in devising techniques which do not exhibit the "local minimum" problem (see Connolly et al. 1990; Koditschek 1987). Moreover, the technique described in Connolly et al. (1990) admits of a very simple and fast hardware implementation (Tarassenko & Blake 1991) that has some connectionist qualities. It consists simply of a programmable resistive network. Voltage levels within the network provide the function to be descended.

Although not strictly connectionist by some definitions, potential field methods can also serve as candidates for partial models of the motor system (Mussa-Ivaldi et al. 1991a). The implementation described by Tarassenko and Blake is indeed "unsupervised, with changes in synaptic weights (connection strengths) being based entirely on local synaptic conditions". In this case, the "weights" correspond to voltages within the grid. Obviously, such a model is a simplification which ignores the plasticity of the motor system.

On the other hand, the medium spiny neurons of the neostriatum receive massive cortical afferents, yet are the primary output neurons for the neostriatum. The monosynaptic nature of the cortico-striato-pallidal pathway does not suggest the presence of "hidden units" which would support a more traditional connectionist model. These same cells are also relatively quiet (Kandel et al. 1991; Shepherd 1990). Is it possible that these cell properties really reflect some sort of local, passive computation, such as that seen in a resistive grid?

The somatotopic divisions of the putamen are consistent with a state-space, especially in light of the results of Crutcher and DeLong (Crutcher & DeLong 1984a; 1984b) and Kimura (1990). The massive striato-pallidal convergence presumably gives the globus pallidus access to information from any point within the neostriatum. Could this somatotopy and convergence reflect some sort of computation of potential functions within different state spaces (corresponding to positions of limbs, face, etc.), which are then sampled by the globus pallidus in order to drive state changes within the system?

Alexander, et al. suggest that the transformations required by "a sequential/analytic approach to control movement" (sect. 3, para. 4) would be reflected in specialization within the motor system. I would like to note that in some discrete spatial representations used in robotics, forward and inverse kinematics computations can be performed in a massively parallel manner by simply permuting and combining the inputs using a boolean "or" function to go from one representation to another. Is it possible for this to be accomplished within the motor system by permutation and arborization of afferent fibers?

In conclusion, I think the article offers insights and criticisms that are applicable to the field of robotics. Moreover, increased knowledge of biological motor systems should lead to improvements in our own ability to build successful, versatile robot systems. I especially agree with the authors insofar as the only real successes in robotics will come through the use of distributed, massively parallel com- puting, similar to that found in biological systems.

I would like to thank Brian Burns for some very crucial discussions during the preparation of this commentary. I would also like to thank Mary Andrianopoulos and Rod Grupen for their insights.

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