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Primitives as a basis for movement synthesis

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Abstract

Recent data from spinal frogs and mammals suggests that movements may be constructed from a standard set of primitives which represent postures and force patterns around postures. These postural primitives may be combined for movement synthesis and may also interact non-linearly. New data shows that the set of primitives may also contain of a collection of members which encapsulate aspects of movement control and dynamics. The linear interactions, non-linear interactions, and dynamic controls provide a means of bootstrapping motor learning. The non-linear interactions enable a basic pattern generator and a reflex functionality which can be parameterized and modified for elaboration of more complex behaviors.

Postural Primitives

Initial evidence for postural primitives has been obtained in frogs by microstimulation of spinal cord and examination of reflex spinal mechanisms (Bizzi et al. 1991, Giszter et al. 1993). A few types of force-fields were found represented in the frog spinal cord. More recently Tresch and Bizzi (1995) have extended this to the rat spinal cord. The conservation of these organizations through tetrapod phylogeny suggests an important role in the organization of movement. It seems clear that the postural primitives represent elements of reflexes. Microstimulation also showed that the different force-fields represented by primitives could be combined as vector sums. The important role of such a mechanism in movement synthesis was suggested by a theoretical analysis by Mussa-Ivaldi (1992), and simulations of Mussa-Ivaldi and Giszter (1992) which showed arbitrary force-fields could be synthesised by appropriate combination of conservative and circulating basis fields. This analysis suggested that the few primitives obtained in the frog spinal cord could form a substantial underpinning of a large and extensible repertoire of behaviors.

Convergent force-fields and Parallel force-fields

Convergent force-fields and parallel force-fields were observed in the set of primitives located in frog spinal cord but circulating basis fields were absent. It has been pointed out by Hogan, Colgate and others that non-conservative force-fields may cause instability when coupled to some environments. Their work suggests that conservative or parallel fields of the frog will guarantee limb stability in passive environments. The use of such fields for cyclic limit cycle limb motions as for example in swimming, crawling, or human locomotion or bicycling must entail sequencing and dynamic activation of these conservative fields and may use intrinsic dynamics of primitives.

Dynamic controls

We have examined the dynamics of interaction of the primitives with different environments and their control and timing in reflex behaviors. Results remain consistent with the idea of primitive as a basis for movement synthesis but extend the idea beyond static controls.

Reflex synthesis

The reflex behaviors utilize all aspects of primitives including non-linear interactions. In fact the non-linear roles may be essential for synthesis of reflexes. Dynamic pattern generating models based around the models of Maes (1991) for action synthesis and selection can be used to replicate several phenomena of reflex behaviors (Giszter, 1994). The primitives in reflexes and the sequence generating mechanisms utilizing them must be appropriately subsumed by any higher level controls and learning. The models using Maes nets demonstrate the importance of exclusion, and flexible dynamic chaining in flexible adapted reflex responses.

General movement

The scheme suggested by the neurophysiological data and analysis and simulation has ties to both robotic subsumption architectures and basis function approximation. In this scheme a layer of circuitry that represents primitives and encapsulates force-field structure, force-field dynamics and environmental interaction, is played upon both by pattern generator systems and descending controls. These two systems must cooperate through vector summation of primitives and arbitration of access to primitives in order to generate useful purposive movement. Motor learning is likely to involve cooperative learning and adaptation in primitives, generators and higher order controls. The organization of a system based around situated primitives guarantees an adapted initial functionality which may form an important bootstrap for motor learning. This initial functionality is likely to be extensible at each level of organization.

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