The Faustian Bargain of Learned Motor Behavior

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The vast majority of animals have highly constrained repertoires of essentially innate motor behaviors. The evolutionary success of such animals depends on combinations of speed, accuracy, strength, efficiency and robustness that are achieved by sophisticated processes for adaptation and fine-tuning. Such processes are handled by phylogenetically old parts of the central nervous system, including spinal cord, brainstem, midbrain tectum, reticular formation, cerebellum and basal ganglia. Learning completely new behaviors is a very different process that requires the initiatives of the older nervous subsystems to be suppressed and their highly capable circuitry to be made subservient to the new brain, the cerebral neocortex.

Innate behaviors fall generally into two classes: patterned and targeted. **Repetitive activities** pursued for their own value include locomotion, chewing and breathing. In most animals, these are driven by central pattern generators that are preprogrammed into neural circuitry in the spinal cord and brainstem. This is why a newborn colt can be up and running with its mother within minutes of its birth. **Targeted activities** include acquisition or evasion of external objects such as capturing food with mouth or paws or avoiding danger by running away from it. In most animals, these behaviors are driven by hardwired representations of the external world in the midbrain tectum (superior and inferior colliculi in mammals).

The cerebral cortex is a huge elaboration of neural circuitry that originally subserved the simple function of remembering previous events and recalling them when similar situations arose again. This allows an animal to anticipate the likely effects of different courses of action based on previous experience. Such anticipation is only useful if the faster, innate behaviors of the older nervous subsystems can be suppressed until more promising actions can be selected. The output circuitry of the cerebral cortex must initially inhibit these older subsystems and then selectively activate those parts that will produce the desired behavior:

- Consider the task of navigation in a complex world. The oldest structure corresponding computationally to cerebral cortex is the hippocampus, which is known to learn and control such navigation. Navigation is essentially a learned sequence of starts, stops and steering commands to the subcortical locomotor apparatus, which otherwise functions autonomously to create sophisticated but directionless patterns of musculoskeletal coordination.
- Consider the task of selecting and acquiring prey. The subcortical tectal system can localize objects in extrapersonal space and issue commands that lead to movements of eyes, head and limbs to acquire them visually and physically, but it cannot recognize and prioritize those objects based on previous experience. The visual cortex can use contextual information and compare the visual input to memory to select more promising targets and enable the tectal system to proceed with their acquisition.

At some fairly recent point in evolution, this supervisory role of the neocortex morphed into the qualitatively different capability to learn the entirely new motor behaviors required for functions like dexterous manipulation of tools and articulate vocalizations of speech. This required rapid evolution of the musculoskeletal structures of the primate hand and larynx for which there were no subcortical control systems. The only way in which these musculoskeletal mutations could be used effectively by the individuals in which they occurred would be for the neocortex to take over detailed control, as opposed to simply suppressing, directing and enabling subcortical controllers.

The neocortex is good at remembering and recalling experiences or motor outputs that were useful, but it uses reinforcement neural networks that require many presentations of data to form such associative memories. The sensorimotor experiences required to learn dexterous manipulation and articulate speech involve thousands, even millions of practice trials. This is the "motor babbling" and "motor play" that consumes most waking hours of infants for the first few years of their lives. This is the Faustian bargain of learned motor behavior: Human infants are virtually helpless for a period of time that corresponds to a newborn colt becoming a Kentucky Derby winner. But the human will eventually learn to play soccer and the horse never will.

Once a species develops the social support systems required to get infants through this extended learning phase, it becomes advantageous to suppress more and more of the innate subcortical behaviors. The infant then must and can learn detailed patterns of coordination for all of its musculoskeletal apparatus, thereby eventually achieving higher levels of performance. The adult may still employ much of the old subcortical circuitry in the same way and for the same purpose as the central processor of a computer might be programmed to use a dedicated arithmetic coprocessor to improve the speed and accuracy of frequently needed functions. But the internal function and the observable behaviors become qualitatively different from more primitive animals that have what appear to be only quantitative differences in the relative sizes of all of the same anatomical structures.