Meso: A Biochemical Subsystem for a Humanoid Robot

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The Problem: While humanoid robotics often focuses on building behaviors around vision and occasionally hearing or touch, a great deal of the information governing the organization and execution of limb movement comes from the energy metabolism that supplies muscles with energy. However, a robot has an infinte supply of energy, and as such lacks these senses (or even a reasonable mechanical analog to use as a sensor). A robot must have some notion of energy consumption to successfully create humanoid movement.

Motivation: As we try to build robots that can effectively operate in a human environment, biological models have inspired many of our efforts. Theories of human attention inspired visual subsystems, neurological structures inspired arm control modules, and speech pattern recognition in infants inspired an auditory sense. By creating behaviors that respond to environmental stimulus, the robot not only acts more human, but also has a better context to decipher and imitate the behavior of other humans.

However, these subsystems need not be tied to any of the "typical" five senses. The meso model provides the robot with a sense of how muscle exertion translates into both muscle-based and whole-body senses of fatigue. This sense can affect not only how we form our gestures, but also how we select behaviors and change moods as well.

Previous Work: Cog's arms have been driven using a series of increasingly sophisiticated control models. For a simple reaching task, a linear combination of postural primitives was sufficient to allow the robot to behave in a roughly human fashion [1]. As the task complexity was widened to include rhythmic behavior, neural oscillators allowed the robot to perform a wide variety of tasks such as crank turning, pendulum swinging, and sawing wood using a single simple model [2]. While each of these systems has created functional humanoid behaviors, they have failed to create a generalized structure for generating both rhythmic and ballistic gestures.

Approach: The metabolism of energy in the human body is a complex chain of reactions that work in concert to keep fuel levels within a range of acceptable values despite bursty supply patterns [3]. The problem is complicated by many different energy sources and the conditions under which each can be used.

This implementation creates four virtual "organs" that communicate through messengers and fuel sources dumped into the blood. A pancreas/adrenal gland module creates the signals that tell the other organs whether or not there is energy available in the bloodstream. Adipose tissue, or fat, serves primarily as long-term storage for energy. The liver serves as the energy warehouse, drawing energy both from nutrients as well as recycling energy from the bloodstream. Each of these organs works together to provide the right levels of fuel for the muscle tissue that drives the robot's arms. As the robot's arms exert force, chemical messengers are "released" into the blood and cause the other organs to spring into action.

Ultimately, the meso system has two effects on the behavior of the robot. First, the muscles include a trigger for overexertion. When the abundance of waste products in the muscle changes the ph of the tissue enough, the muscle loses its ability to contract, and consequently, the robot's motor power is reduced, simulating the muscle "giving out." This effect heightens the safety of interaction with the robot in addition to creating human-like reaction to the environment.

The second effect of the meso system is more abstract, but will help direct future development on the robot. By creating a realistic simulation of the the biochemistry involved in muscle movement, the robot is more able to accurately judge the state of its arm in the context of how a human arm would feel. If the robot is going to make a short, simple gesture, that may require a different type of control from a strong exertion, which may be different again from an extended low-level exertion. With the meso system in place, not only can these gestures be differentiated, but the magnitude of each can be measured by the type and quantity of energy used.

Difficulty: Any implementation of the metabolic system must deal with the issue of complexity. While the metabolic system is well understood at the chemical-reaction level, the interplay between each of the reactions creates a system that can quickly outstrip even the most powerful of computers. For our application, the requirements are even more stringent: the model must operate on a robot in real-time, hence the computation available must allow the model to create the proper feedback on the proper timescale.

Impact: This work has laid the foundation for a new type of arm control By creating a system of "virtual sensors" that provide information about the arms both as a series of joints and as parts of an overall body.

Future Work: The biochemical systems that govern energy consumption in muscles also impact the performance of other tissues in the body as well. Taken collectively, these processes and their relative levels of performance make up a basic "feeling" that can serve as a basis for an emotional model on a robot. By continuing to develop and refine the model of the biochemical processes, our humanoid robot can mix neurologically-based emotions such as loneliness and fear with biochemical emotions such as hungriness, fatigue, and excitement.

Figure 1: The humanoid robot Cog

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