Grand Challenges in Bio-sensing and Bio-actuation – actuators as sensors

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Every living creature acquires, processes, stores and disseminates information. One overarching challenge we face today is to understand how diverse organisms perform these crucial functions – at all imaginable spatial scales. Indeed, living systems do so in ways that fundamentally differ from synthetic systems that we have commonly designed. Thus the speed and accuracy with which we can process language or complex visual information well exceeds that for any computer-based system. At the same time, few (if any) can report the product of e and π in 12 nanoseconds. There are living model systems which would win the X-prize for the acuity at which sensory information is acquired, the speed and integration of massive sensory information flow, long range sensory communication, or even multimodal sensory information integration. Similarly, there are living systems that perform outstanding feats of actuation and maneuverability. Rapid ballistic movements of predatory systems, complex maneuvers of flying insects, and long distance migration with effective energy use are just a few samples.

Interestingly, in many instances in biology *the actuator serves as a sensor* (and vice versa). For example wings of insects are imbued with hundreds of strain sensors, all of which send information to the neural system, providing data about the Coriolis forces associated with body rotation, in addition to the dynamic bending state of the wing. Similarly, passive dynamic properties of muscles and, in certain instances, stretch activation, provides combined sensor-actuator system. Sensor-actuators include insect wings, muscles (at a protein level), sub-cellular processes (cilia and flagella) and much more. One grand challenge, therefore, is to define design rules for "sensor-actuators". How do living systems deploy these and how might we employ them?

In probing this problem, we face four key issues:

1: How neural muscular systems interact with highly non-linear mechanical systems is an open problem. In all instances, biomechanical processes are inextricably linked to protein, cellular, neural, and organism-level processes. Thus the design rules will require an understanding of this integration.

2: How the biomechanics of sensory and motor systems modulate information transformation is an open problem. Forces, motion, stresses, and strains are all part of the information flow into organisms (plants, animals, bacteria ...) and this information is conditioned by biomechanical factors and how it is used is a key characteristic of biological systems.

3: Biological systems integrate across all many size scales of organization*:* how the dynamics and kinetics of protein level processes affect organ and organism function is one example of open problems in integrating across scale. From protein motors to protein mechanics, organism function is keenly sensitive to their mechanics and dynamics.

4:Biological systems integrate across all many temporal scales of organization: the dynamics and responses biomaterials, biosensors, and biological networks occur over many time scales. How these evolve, how they function are key problems in biology.