Homeostasis: From Living Creatures to Living Machines

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The Problem: While many robots in industry and research have proven capable of operating in complex environments, most robots still fall well short of living creatures in their ability to deal with extreme variations in their environment. Living creatures, by contrast, will typically cope in any environment to the extent that their physical bodies allow. Living creatures never give up trying to survive. Robots typically lack this **homeostatic** quality that allows living creatures to survive in the maximum range of environments. Until they are able to fully utilize their bodies to maximize "survival" in the same way, robots will not truly function as productive, independent creatures.

Motivation: As machines attempt to deal with tasks of increasing complexity (and, correspondingly, become more complex themselves), one typically finds that robotic improvements in a few areas: higher fidelity in sensing channels, greater reliability in actuation methods, and smarter or faster algorithms. Ultimately, the goal is to either extend the robot's capabilities in some critical way or to eliminate "mistakes" that the robot makes.

However, living creatures evolved differently and it seems clear that they currently operate using fundamentally different principles. Instead of constant improvements in the physical systems or the low-level control mechanisms, I believe that there is a different organizing principle that creates their near-failure-proof behavior. By examining some simple homeostatic creatures and building simple models, I hope to be able to both articulate some of these principles as well as demonstrate them, both in simulation and on real robots.

Approach: Polyclad flatworms (see Figure 1) provide an example of this kind of robust homeostasis. The polyclad flatworms have been studied by biologists and neuroscientists because of their primitive encephalization, meaning that their brains are probably among the most primitive. [3] However, these simple little creatures have been very suggestive as to the evolution of the very first brains.

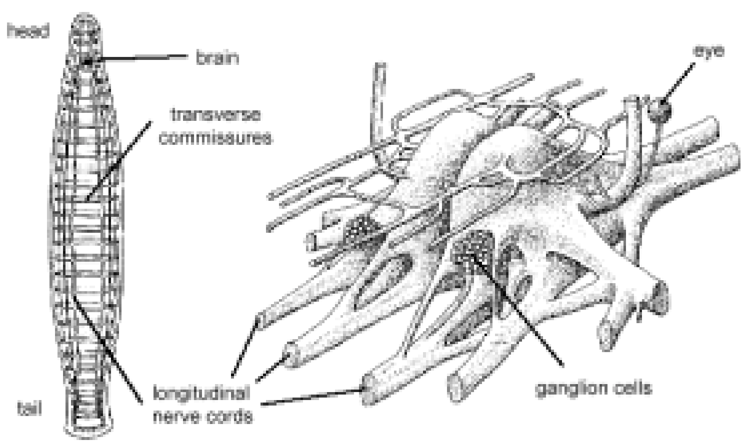

Figure 1: A simple drawing of a polyclad flatworm brain

Researchers have excised the brains of these worms to examine what regulatory role the brain plays in their behavior. [2] Decerebrate, the worms are far less effective (though, in most cases, still functional) when feeding, locomoting, flipping over, and avoiding noxious stimuli. Interestingly, the worms' ability to heal very quickly has also created a second avenue of exploration: replacing the brains in different configurations. Their healing ability is so strong, in fact, that brains which are transplanted upside down are still capable of healing and allowing the worm to regain some (and, in many cases, most) function. A closer look at the neuroanatomy of these transplants shows that, in many cases, the nerve plexus has actually healed to new brain sites, suggesting that the brains can work effectively while connected backwards.

The robustness of the behavior of these creatures, especially in light of trauma that is far beyond what one of these creatures would encounter in their natural habitat, serves as an inspiration for the study of homeostasis. In order to examine these issues, a platform for investigation is being developed both in simulation and in the form of a real robot. Parts of the neuroanatomy are being evolved and simulated, with special attention being paid to non-traditional neural modeling [1] and appropriate measures of complexity. [4]. The focus of this work is to shed light onto what organizational, systemic, or high-level control principles lead to this extraordinary robustness.

Impact: While it is difficult to predict what form these homoestatic principles will take, our hope is that they will allow robots to inspire a sense of life in a naive observer. Instead of failing in the face of environmental adversity, they should be able to utilize whatever physical systems they have at their disposal. Ultimately, these robots should give the same impression that living creatures give, namely, that they are doing everything within their power to survive.

References:

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[4] Steven R. Quartz and Terrence J. Sejnowski. The neural basis of cognitive development: A constructivist manifesto. *The Behavioral and Brain Sciences*, 20:537–596, 1997.