Active Mechanisms

William Bechtel
Department of Philosophy and Programs in
Science Studies and Cognitive Science
University of California, San Diego

Research in the life sciences, including neuroscience and cognitive science, are replete with the search for mechanisms to explain different phenomena of interest. A growing cadre of philosophers of science has tried to explicate the notion of mechanism and mechanistic explanation as emphasizing the decomposition of a system into its parts and operations and trying to understand the phenomenon of interest as resulting from the organized and coordinated operation of these parts. Commonly both most mechanisms proposed in the life sciences and philosophical accounts of mechanisms treat them as responsive systems that perform their operation only when appropriate conditions are presented to them. But, as vitalists in the 18^{th} and 19^{th} century were keen to point out, biological organisms are active systems. As Xavier Bichat emphasized, they work in opposition to the physical forces that would otherwise destroy them. The vitalists' contention was that this showed the inadequacy of the project of explaining phenomena associated with life mechanistically. But a different response, initiated by mechanists such as Bernard, Cannon, and Hopkins, is to focus on one of the key components of mechanistic explanation, the organization of the components, and to show how the particular modes of organization found in living systems can explain their distinctive, active character.

One of the first modes of organization to be explored was negative feedback. Although negative feedback has been employed as a solution to engineering problems repeatedly through history (introduced first by Ktsebios in his design for a water clock in the third century BCE), it only became a generally recognized principle of design for both engineered and biological systems with the cybernetics movement in the 1940s and 1950s. While negative feedback became useful for explaining the goal-directness of systems, it continued to construe such systems as responsive, not active. During this period positive feedback was largely rejected as a tool of organization, since it was viewed as leading to systems with run-away behavior. The initial discovery of self-organizing autocatalytic chemical systems by Boris Belousov in the 1950s was dismissed since such reactions were clearly impossible. Subsequently such reactions have not only been shown to be possible but have been subjected to detailed analysis. Such reactions occur in non-equilibrium conditions and theorists interested in how biological mechanisms can be active systems have increasingly focused their attention on non-equilibrium conditions.

Biological systems are not just active non-equilibrium systems, but develop and maintain themselves as such systems over sustained periods of time. Varela and Maturana and more recently Moreno and his collaborators have characterized such systems as *autonomous* systems. Identifying biological systems as autonomous focuses attention on the modes of organization that enable such systems to build themselves and then repair themselves as inevitably the organization breaks down in accord with the second law of thermodynamics. Robert Rosen has emphasized that such systems must rely on components internal to the system to execute repairs and hence that the system of repair must be closed to efficient causation (while being open to the flow of matter and energy). Although Rosen claims this is incompatible with a mechanistic perspective, his analysis suggests the mode of organization that is critical—cyclic systems in which the product of later reactions in a pathway support the maintenance of earlier reactions in that pathway or on which that reaction depends. Cyclic processes have been discovered in biological systems at many levels of organization. Typically cycles were proposed as solutions to obstacles theorists encountered in trying to fill out a mechanistic account involving linear organization of components, but their significance has often proved elusive. Tibor Gánti incorporates cycles as the core of his analysis of a chemoton, a minimal chemical system exhibiting the characteristics of living systems and his account provides clues to the significance of cycles.

In this paper I will develop these threads in biological thinking that provide a framework for understanding the modes of organization that enable mechanistic systems to realize the characteristics of active, living systems. What is particularly important for understanding active systems is placing metabolism at the center of any account since to maintain itself a system must have the means to recruit matter and energy and direct their deployment to the operations that build and repair themselves. Living systems do more than build and maintain themselves, but these requirements place constraints on any additional mechanisms the evolve to perform these activities in living systems. Moreover, the mechanisms of interest in biology above the level of individual cells are themselves built of cells that are active systems maintaining themselves as a result of their internal organization. Such mechanisms are both composed of active components and constituents of systems that maintain themselves in an active manner. As a result, the mechanisms involved in living systems have capacities that the vitalists could not begin to envisage.