The Complexity, Simplicity, and Unity of Living Systems

Geoffrey B. West
Elementary Particles and Field Theory Group

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Life is surely the most complex physical system in the Universe. Understanding the enormous complexity of even the simplest organism is beyond the reach of present-day science. The origins, structures, dynamics and organisation of life ranging from molecules to ecosystems will remain a major ongoing challenge throughout this century requiring close collaboration across all sciences. Though based on the same fundamental physics and chemistry, Life manifests an extraordinary diversity of forms, functions and behaviours ranging over an enormous scale: the largest animals (whales) and plants (sequoias) weigh a remarkable billion trillion times more than the smallest microbes (mycoplasma). In spite of all of this, many of life's most fundamental and seemingly most complex phenomena scale with size in a surprisingly simple fashion. For example, metabolic rate (the power needed to sustain life - the approximately 2000 food calories you require per day), lifespan (your allotted "three score and ten years"), and growth rates (the 20 years you took to reach adulthood) all change in a remarkably simple fashion over this immense spectrum of biological size. Furthermore, these scaling laws exhibit a universal mathematical behaviour reflecting fundamental unifying principles that have crafted and constrained the way life functions and is organised from Molecules and Cells to Whales and Ecosystems. The basic idea to be explored in this lecture is that, driven by natural selection, life at all scales is sustained by hierarchical fractal-like branching network systems whose universal characteristics determine many of the generic properties of living organisms. Functionally, biological systems are ultimately limited by the rates at which energy, materials and information can be supplied through these networks. Examples include the macroscopic cardiovascular, respiratory and neural systems of mammals, the interconnectedness of an ecosystem, trees and plants, and the microscopic pathways within intra-cellular mitochondria. This paradigm will be explored and developed as a way of viewing many phenomena where hierarchical structures have evolved. Examples will include speculations concerning Growth, Aging and Mortality, Sleep, Genome Size, and Cities and Corporate Structures.