Seeing Your Way to New Insights in Biology☆

From the first hand sketches of objects viewed under a microscope by Robert Hooke to the diagrammatic representations of atomic structures proposed by Ernest Rutherford, visualization has been used to communicate abstract concepts associated with discovery in all fields of science. This special issue on *Biovisualization* highlights how computation and new software technologies can advance visualization of living systems by leveraging the massive amounts of data now being produced by scientific instrumentation and experimentation. Many of the articles contained within this issue show how well-established scientific models can now be described using experimental data directly to generate complex renders with exquisite resolution and engaging narrative [1–3].

While visualization is widely accepted as being an integral part of scientific communications, its contribution to other stages of the discovery process has been somewhat under appreciated. In fact, visualization has always played a role in facilitating scientific discovery in the field of structural molecular biology [4]. For example, advances in both computational hardware and software used for visualization of three-dimensional (3D) molecular structures have been continually leveraged to understand experimental data and refine conceptual molecular models of macromolecular structure and dynamics, as highlighted by multiple articles in this issue [4–6]. Visualization advances in confocal microscopy have had an even broader positive impact on molecular cell biology, including advancing understanding of the organization and dynamics of cellular membranes as well as many intracellular organelles and structures [7]. An additional key challenge for visualization in all of these areas is the modeling of integrated multiscale systems, which is also discussed in some of the articles [2,5]. But while many areas of molecular cell biology research produce data that have inherent structure, lending itself to visualization, other disciplines produce high dimensional data set; yet, they can still benefit from visualization. Various strategies associated with these kinds of bioinformatic data are discussed, including visualizing the dynamics of post-translational modifications [8].

As is evidenced by the articles in this issue, visualization is a powerful scientific tool in biology that will become of even greater importance as we seek to more accurately describe biological phenomenon in the living 3D physical context of living cells and tissues based on the assembly of many different kinds of data. Using hierarchical 3D models of complex dynamic systems, for example, it should be possible to generate hypotheses in both a top-down and bottom-up fashion, which is difficult to do using conventional reductionist approaches.

One intriguing possibility is that visualization will begin to be used in science more like it is in the field of design. In a design setting, visualization can be used to represent mental images or concepts, and to develop and optimize solutions in an iterative manner. This approach helps to better understand the design problem and rapidly evaluate how well various potential design solutions address the problem. In science, we might be able to leverage advanced visualization tools to pursue a similar approach to scientific hypothesis design, where we iterate through models of biological systems and evaluate how well each faithfully integrates new and existing data, as well as how well it can predict structure and function in living systems.

In our own research, we utilize various visualization technologies to repurpose existing data through integrative modeling strategies, utilizing visualization to aid the integration of animation, simulation, informatics, and machine learning strategies. With these strategies, we are able to design hypotheses and models in an iterative manner, which lead to execution of high value experiments that are able feed back into our models. Using this visualization approach, we have been able to generate multi-scale models of a living sperm cell that faithfully recapitulates biological structures and functions from the atomic to whole cell levels [9,10].

Importantly, while this special issue highlights visualization using many advanced computational techniques, biovisualization should not be limited to computational experts or talented artists. We should encourage all scientists to include visualization in the various stages of their research and not just at the end communication stage. By taking a design approach to hypothesis generation that utilizes visualization, scientists can further refine their mental image of this biological system they study, test their hypothesis, and iterate this process until they identify the best

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solution or develop new hypotheses that can be pursued by leveraging existing as well as new data. It is likely that through the mere process of attempting to do this, that new hypothesis emerges and paradigms can be shifted. Even starting with the most modest sketches of results made with pen and paper, it should be possible to develop new hypotheses and even shift current paradigms. After all, this is how biology was birthed in the beginning.

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