Synthetic Biology: from Bacteria to Stem Cells

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With recent advances in our understanding of cellular processes and improvements in DNA synthesis methods, we can now regard cells as "programmable matter." Through genetic engineering, we are equipping cells with new sophisticated capabilities for gene regulation, information processing, and communication. These new capabilities serve as catalysts for Synthetic Biology, an emerging engineering discipline to program cell behaviors as easily as we program computers. Synthetic biology will improve our quantitative understanding of natural biological processes and will also have biotechnology applications in areas such as biosensing, synthesis of pharmaceutical products, molecular fabrication of biomaterials and nanostructures, and tissue engineering.

In this talk, we will describe the use of computer engineering principles of abstraction, composition, and interface specifications to program cells with sensors and actuators precisely controlled by analog and digital logic circuitry. Here we will present theoretical and experimental results from synthetic systems implemented in bacteria and higher order organisms. We will begin by describing how information flows through synthetic transcriptional cascades in single cells by examining noise propagation, ultrasensitivity, and impedance matching. Understanding these issues is critical for the analysis and *de novo* engineering of complex gene networks. We will then discuss several synthetic multicellular systems that have been programmed to exhibit unique coordinated cell behavior. These are the pulse generator, band detector, and Conway's Game of Life. These systems allow us to explore programmed pattern formation and observe how complex global behavior emerges from localized interactions between cells. We will also discuss the implementation of artificial cell-cell communication and quorum sensing behavior in higher level organisms such as yeast. Finally, we will discuss preliminary results in mouse embryonic stem cells of implementing synthetic gene networks that regulate gene expression, direct differentiation, and orchestrate artificial cell-cell communication with the ultimate goal of programmed tissue engineering.