2016 ICB SABRE Project List and Descriptions

ICB Systems and Synthetic Biology Projects

(1) Stochastic Biological Oscillators, Circadian Rhythms, and Cognition

Linda R. Petzold

Spatial Organization of Circadian Rhythms in the SCNCircadian rhythms exert control over many biological processes including sleep, metabolism, body temperature, and blood pressure. This biological clock is coordinated across temporal and physical scales in the body by a network of approximately 20,000 neurons called the suprachiasmatic nucleus (SCN), located in the hypothalamus of the brain. When fully synchronized, these rhythms display an organizational hierarchy: oscillators located in the "core" of the SCN entrain oscillators in the SCN "shell." There is also a phase delay between core and shell regions. This summer project will use both physical and phase-only (Kuramoto) models of the circadian oscillator to model this spatial organization, and investigate the causes of the observed phase relationships.

(2) Engineering Synthetic Cellulose-degrading Complexes from Gut Fungi in *S. cerevisiae*

Michelle A. O'Malley

Renewable biofuels derived from plant biomass are an attractive alternative to petroleum-based fuels. However, problems associated with substrate recalcitrance in the depolymerization of lignocellulose have prohibited biofuel development. To address this issue, much may be learned by studying nature, particularly microbiomes where high efficiency biomass breakdown regularly occurs. For example, anaerobic gut fungi found in the digestive tract of large herbivores are among the most efficient degraders of lignocellulose on earth. This project aims to discover novel cellulose-degrading enzymes from anaerobic gut fungi and to engineer synthetic multi-protein enzyme complexes (cellulosomes) for the conversion of plant biomass into biofuels.

(3) Macromolecular Design from Sequence-Activity Analysis

Irene A. Chen

Synthetic biology aims to create tailor-made microorganisms and artificial cells to perform specific tasks, such as detection and cleanup of environmental contaminants or dangerous chemicals. RNA can be used to detect specific metabolites and turn a specific genetic program on or off in response to the metabolite. However, macromolecular biophysics inside cells differs in important ways from that in bulk solution. A summer intern will participate in experiments to encapsulate functional RNA inside artificial cells and probe how the encapsulated environment affects RNA activity.

ICB Control and Dynamical Systems Projects

(4) Neuro-inspired Architectures for Inference and Control in Massively Scalable Multi-Agent Systems

Joao P. Hespanha and Upamanyu Madhow

As in the past years, we are running a Summer School program with the Dos Pueblos High School. The six-week course gives students experiences beyond the classroom in the form of applied challenges in the area of Robotics.

(5) Design Principles and Strategies for Biomimetic, Gecko-like Ambulation

Jacob N. Israelachvili, Kimberly L. Turner and Katie Byl

Gecko-inspired adhesive development for industrial, commercial, and robotic applications requires scaling up the adhesive patch sizes and the ability to retain forces when misalignment between surfaces is present. Current test areas are 0.1–12 mm^2 depending on the testing apparatus used and require careful alignment before testing. The intern could work in the following areas: (1) creating an adhesion and friction test apparatus with the ability to test areas greater than 10 cm2 and using the apparatus to characterize large adhesive patches, and/or (2) creating a self-alignment mechanism for even loading of the synthetic adhesives during adhesive placement

ICB Photonic and Electronic Materials Projects

(6) Bio-inspired, Lightweight, Polymer-based, Flexible Optoelectronics

Daniel E. Morse

Pursuing our discovery that tropical Giant Clams use their nanostructured reflective cells to increase the efficiency of solar energy capture and conversion by photosynthetic algae that live symbiotically within the clam tissue, we now are conducting research to “translate” these biophotonic mechanisms to make higher efficiency, lightweight, flexible solar cells. The SABRE Intern working with us in this effort will explore means to increase the efficiency of solar cells by optimizing the addition of light-scattering nanoparticles to their top-most layers. Research will involve the close integration of experimental and quantitative studies.

(7) Understanding the Mechanism of Transmembrane Electron Transfer and its Influence on Intercellular Communication and Biofilm Diversification

Guillermo C. Bazan

A useful undergraduate research project concerns the synthesis of new COEs using the modular approach already reported by our group. These syntheses are relatively straightforward and would enable education of organic chemistry techniques. Once in hand, the new COEs can be used to modify microorganisms, of which various yeasts are simplest by virtue of their larger size. Intercalation within membranes can be confirmed by using confocal fluorescence microscopy. If time permits, the preparation of microbial fuel cells and the impact of modification by the presence of COEs can also be carried out.

(8) Tailoring Cooperative Electroactive Microbial Systems for Energy Generation

Frederick W. Dahlquist

Certain conjugated oligoelectrolytes (COEs) enhance the interaction of microorganisms with electrodes. We will test if COEs are playing a direct role in catalyzing electron transfer between the cells redox proteins and the electrode surface. The experiments will employ kinetic methods to monitor the rates of electron transfer between these redox proteins and the normal physiological electron acceptors. These experiments will use both optical and nuclear magnetic resonance techniques to follow the reactions.

(9) Bio-inspired Photonic Control of Surfaces for Broadband IR Detectors, TPVs, and LEDs

Michael J. Gordon and Daniel E. Morse

In this summer project, the intern will assist researchers in the development and characterization of anti-reflective surface coatings that mimic the graded refractive index behavior of the moth eye. The goal of the project is to develop an easy, scalable, and defect-tolerant surface coating method to manipulate the optical behavior of surfaces in the infrared spectral range. In addition, we seek to understand how structuring surfaces with sub-wavelength features can be used to control reflection and transmission of infrared light at material interfaces for applications in optics, photo-detection, and solar energy harvesting.

(10) Functional Hierarchically Structured Polymer Colloids: Combining Bio-Inspired Self-Assembly with Chemical Functionalization

Craig J. Hawker

The basis of this project is to develop new multi-functional polymer particles that exploit bio-inspired, self-assembly strategies for structural control. Of special interest is the development of new sorting methods that allow for unprecedented influence over size and shape distribution. Together with the selective introduction of chemical functionalities, the assembly of such well-defined particles into ordered super structures will ultimately lead to the development of particle-based photonic materials that mimic the natural camouflage behavior of marine organisms such as octopi and squid.

ICB Cellular Structural Materials Projects

(11) Topology and Shape Optimization of Energy-Dispersive Cellular Structures

Frank W. Zok

Protection of Army personnel against blasts in combat environments requires use of lightweight compressible materials that both dissipate energy during crushing and reduce the pressure level of blast waves to non-lethal levels. In this ICB project, we are pursuing new paradigms in structures and topological designs that offer potential for high-energy absorption and effective pressure attenuation. The work combines fabrication, testing and analytical and numerical modeling.

(12) Bottom-up Synthesis of Bio-Inspired Hierarchical Materials via Three-Dimensional Ink-Jet Printing

Matthew R. Begley

The proposed program will develop printing strategies for two-phase materials (composites) that integrate the distribution of microstructural reinforcements with component geometry. For example, the program will develop carbon whisker (or silicon carbon whisker) epoxy composites that can be printed with fiber alignments in the direction of component stresses. The ultimate goal is to print ultra-high strength and stiffness components with tailored, spatially varying composites, analogous to wood, marine exoskeletons, etc. Researchers are identifying the combination of inks (e.g. epoxy chemistry), whisker properties, acoustic excitation parameters, and nozzle geometries that enable high performance components.

(13) Theoretical and Experimental Investigations of Energy-Dispersive Cellular Nanostructured Polymeric Materials

Glenn H. Fredrickson

This project aims to develop a new type of bio-inspired elastic polymer expected to have unusual morphology and mechanical properties that could be transformative in soldier protection systems. Specifically, we seek to identify new types of nonlinear block copolymers (“mikto-polymers”) that when blended with other polymers will exhibit an equilibrium nanoscale morphology resembling cells of a foam, but with a hard material inside the cells and a soft material comprising the walls. The intern will assist a graduate student researcher in performing computer simulations to explore the relationship between the molecular parameters of a mikto-polymer blend (compositions, architectures, molecular weights) and its equilibrium morphology. The project will provide experience with state-of-the-art computational methods in polymer science and serve to develop reporting and presentation skills.

ICB Biotechnology Tools Projects

(14) Instructive Biomaterials for Stem Cell Differentiation

Dennis O. Clegg, Craig J. Hawker and Lincoln V. Johnson

Regeneration of damaged tissues using stem cell derived cellular therapies will have broad applications for the treatment of trauma and disease. Our objective is to use an interdisciplinary approach to develop scaffolds of synthetic biomaterials that can be used to support stem cell-derived cell survival and differentiation. Efforts include use of adipose stem cells for soft tissue regeneration and human embryonic stem cell derived ocular cells for ocular trauma and disease. Summer interns will work closely with researchers in the Clegg Lab to develop both encapsulating gels and planar scaffolds that mimic normal substrates and support stem cell derived cells.

(15) Biomolecular Analysis and Characterization in Nanofluidic Channels

Sumita Pennathur and Carl D. Meinhart

Nanofluidic technology has the potential to revolutionize bioanalysis systems. In this summer internship project, a student will be exposed to the potential of nanofluidics and perform fundamental experiments characterizing not only nanofluidic channels but also organic dyes and biological substances within these nanofluidic channels using a combination of experimental techniques. These techniques include epifluorescent microscopy, image analysis, current monitoring, electrokinetic injections, and data analysis. The summer intern will not only be trained on equipment and techniques, but also use them to produce useful data towards efficient protein separations.

(16) Exploring Key Design Parameters Exploited by Naturally Occurring Chemoperception Systems

Kevin W. Plaxco, H. Tom Soh and Tod E. Kippin

A key component of the proposed research program is the development of surfaces that mimic the highly inert surface of the cell membrane. This involves the fabrication of self-assembled monolayers comprised of long chain alkane-thiols, which spontaneously form on gold. By using mixtures of thiols terminated with various membrane-head-group-mimicking terminal groups (e.g., phosphoserine) we hope to fabricate sensor surfaces that are highly resistant to the adsorption of contaminating proteins.

2016 ICB SABRE Project List and Descriptions

ICB Cognitive Neuroscience Projects

(17) Action Selection Under Time-Pressure

Scott T. Grafton

The Action Lab of Dr. Grafton hosts undergraduate students interested in learning to map human brain function using both magnetic resonance imaging and electroencephalography. The student will learn how to operate the MRI scanner and perform EEGs in healthy normal volunteers. They will learn basic data analysis and the identification of brain activity that is task specific. They will be matched with a laboratory member to work on an ongoing project in action recognition, planning or decision-making. This is a great opportunity to work with human subjects, learn state of the art brain mapping methods and advanced image analysis.

(18) Neural Indicators of Optimal and Adaptable Decision-Makers

Michael B. Miller

We explore ways in which neuroscience can improve decision-making. Decisions to take action on the battlefield must often be made quickly, in rapidly changing environments, and on the basis of uncertain evidence. Under such circumstances, it is crucial that decision-makers adapt their criterion for taking action to the current situation (e.g., being cautious about pulling the trigger when civilians are present). We use neuroimaging techniques to identify and predict individual differences in decision-making. We also are developing neuroscientific tools to monitor effective criterion placement in real-time and to directly intervene with prefrontal cortex functioning in order to optimize decision performance.

(19) Cognitive Neuroscience Embedded in Large-Scale Models of Systems Dynamics

Jean M. Carlson

Potential summer interns would investigate the application of complex systems analysis to the study of anatomical and functional brain architecture. The proposed study would expose the intern to techniques drawn from control and systems engineering, complex network analysis, and statistical analysis for the theoretical and computational modeling of complex biological systems. Critical research investigations will address the relationships between brain anatomy and dynamic activity, measured via DTI and fMRI neuroimaging techniques, and the constraints imposed by this structural and functional brain architecture on behavioral and external variables such as cognitive flexibility, reaction time, and performance in high-pressure situations.

(20) Perceptual Decisions from Human Brain Activity

Miguel P. Eckstein

Finding your toothbrush, recognizing a face or identifying an object all might seem effortless but behind the scenes the brain devotes over one quarter of its neural machinery to make these complex tasks seem easy. How does the brain do it? We use a wide variety of tools including behavioral psychophysics, eye tracking, electro-encephalography (EEG), functional magnetic resonance imaging (fMRI) and computational modeling to understand how the brain successfully achieves these everyday perceptual tasks. We utilize knowledge gained to collaborate with engineers and develop bio-inspired computer vision systems and improve the interactions between robots/computer systems and humans.

2016 ICB SABRE Project List and Descriptions

(21) Identifying the Neural Biomarkers of Adaptive Cognition Under Fatigue and Stress

Barry Giesbrecht

Successful, goal-directed behavior requires a cognitive system that is both highly flexible to one's ever-changing internal goals and adaptive to external physical and psychological stressors. The primary objective of this project is to use cutting-edge methods from cognitive neuroscience to identify the neural mechanisms of adaptive and maladaptive cognitive states under conditions of changing task demands, physical fatigue, and mental stress. ICB SABRE Students will be exposed to how to perform research using multiple methods (EEG, fMRI, and behavior) in a variety of experimental contexts.