Design Multi-Level and Multi-Length Scale Hierarchical Systems Inspired by Biology

Objectives

- Synthesize new fabrication methods suitable for creating multi-level hierarchical systems that possess desirable material properties and functionalities at specified length scales
- Reverse engineer biological systems and develop new tools/approaches for identifying their fundamental operating principles and design
- Integrate sensing/actuation for synergistically performing specific engineering functionalities

Multi-hierarchical design in gecko feet

Integrated sensing and actuation in the wings of fruit flies

Technological Challenges

- Integration and scalability of top-town and bottom-up fabrication methodologies
- Multi-dimensional fabrication principles that encode desirable properties at drastically different length scales
- Self-assembly methods for attaining precise spatial structures, arrangements, and functionalities
- Comprehensive and realistic mathematical models and representations of biological systems and functionalities
- Fusion of multiple sensing modalities, linear versus logarithmic processing, and digital versus analog data

Broader Impacts

- New self-assembly and fabrication methods
- New sensing/actuation functionalities
- Efficient structural systems
- Military applications of new technologies
- Medical breakthroughs in diagnostics, monitoring, therapeutics, and prosthetics
- Understanding the central nervous system and immune system (and biological systems)

Grand Challenge Summary

Design of Multi-Level and Multi-Length Scale Hierarchical Systems Inspired by Biology

Summary: Biological systems employ hierarchical structures to achieve multifunctional system performance that far exceed the performance of current engineered systems. The grand challenge is to synthesize new fabrication methods that utilize and achieve hierarchical systems, utilize reverse engineer techniques to develop new tools, and integrate sensing and actuation technologies. The research challenges include integration and scalability of top-town and bottom-up fabrication methodologies, multi-dimensional fabrication principles that encode desirable properties at drastically different length scales, self-assembly methods for attaining precise spatial structures, arrangements, and functionalities, and comprehensive and realistic mathematical models and representations of biological systems and functionalities. Accomplishing this grand challenge will yield a new generation of leaders adept in bio-inspired sensing and actuation systems.

Teaching Biologically-Inspired Design

Objectives

- Support intensive courses for graduate and postdoctoral students in bio-inspired design.
- Courses must include participation of both students and instructors from biology and engineering.
- Organizers are encouraged to combine practical training and independent research project as components of the course.

Technological Challenges

- There are no technological hurdles to be overcome by such a course. However, course organizers will face a number of logistical challenges. These include recruiting top instructors and guest lecturer from both disciplines, the setup of laboratory equipment for use in student projects and attracting promising students.

Broader Impacts

- This program will foster a cross-disciplinary exchange that generally does not currently exist in the training of either engineers or biologists.
- Engineering students will be exposed to biological concepts that could lead to the development of revolutionary devices or engineering approaches.
- Biology students will be exposed to cutting-edge techniques and rigorous analytical approaches to greatly enhance biological research.

Grand Challenge Summary

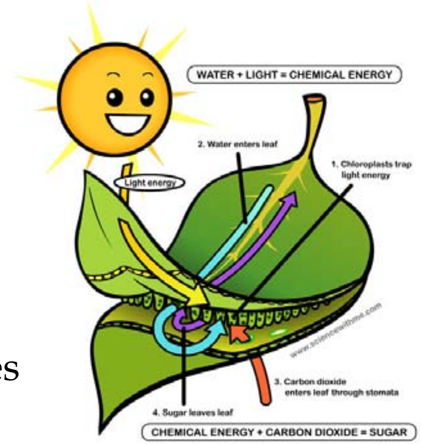
Teaching Biologically-Inspired Design

Summary: While there are numerous examples of revolutionary advances in engineering that have been inspired from biology, the education of engineers in the US and Japan generally does not expose students to biological concepts. The training of biologists in these countries similarly does not generally include education on the state-of-the art techniques and quantitative approaches offered by engineering. We propose that program that supports intensive training in biological-inspired engineering for graduate and postdoctoral students of engineering and biology. These courses are intended of offer a multidisciplinary training in techniques as well as an exposure to research in both engineering and biology.

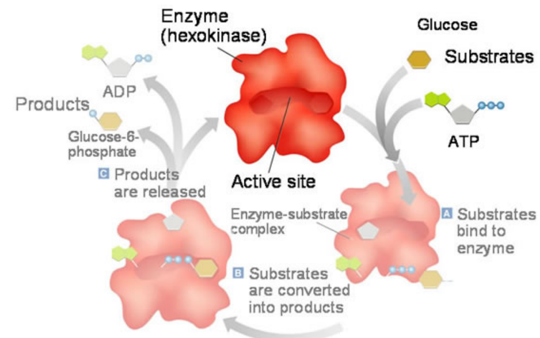
Bio-inspired Biochemical Engineering of Systems for Energy, Water, Food, Communications, and Medical Applications

OBJECTIVES

- Design robust, durable, self-regulating, and homeostasis engineered systems with inherent failure tolerance, monitoring, and self-repair
- Control energy, material, and information interaction among networked nodes using homeostasis, metabolic, and enzymatic processes
- Enable self-diagnosing sensors/actuators that self-regulate and self-control while reducing system complexity with improved performance



Plant photosynthesis



Enzyme reaction process

TECHNOLOGICAL CHALLENGES

- Incorporate a heterogeneous network of evolving, adjustable, and adaptable multifunctional nodes
- Cradle-to-grave sustainable design approaches
- Artificial enzymatic systems for material generation, operation, and digestion/decomposition
- Direct energy transduction, storage, and utilization
- Achieve efficient energy use and production that's complimentary to environmental resources
- Active and responsive nanomaterials for medical diagnostics and therapeutics

BROADER IMPACTS

- Intelligent and self-diagnosing infrastructures and artificial/engineered systems
- New media for energy, materials, and information exchange and broadcasting
- Biocompatible and implantable active devices
- Fault-tolerant, self-corrective devices/networks
- Early warning systems and disaster prevention
- Sustainable food, energy, and water supply

Grand Challenge Summary

Bio-inspired Biochemical Engineering of Systems for Energy, Water, Food, Communications, and Medical Applications

Summary: Biological systems thrive by inherent biochemical processes capable of controlling energy, material, and information interactions between components in the system. The grand challenge is to design robust, durable, self-regulating, and self-healing engineered systems with built-in artificial homeostasis, metabolic and enzymatic mechanisms. The research challenges include the incorporation of a heterogeneous network of evolving, adjustable, and adaptive multifunctional nodes capable of direct energy transduction, storage, and utilization. Accomplishing this grand challenge will result in sustainable food, energy, and water supply.

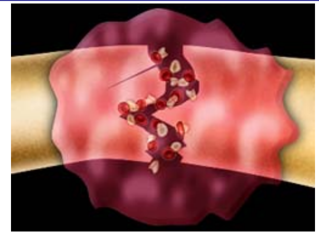
Biologically Inspired Robustness: Self-sustaining sensors and actuators

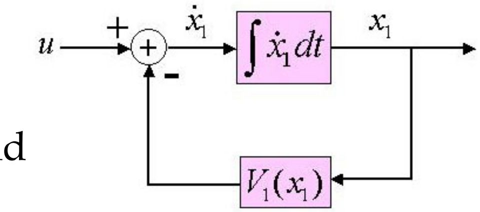
Objectives

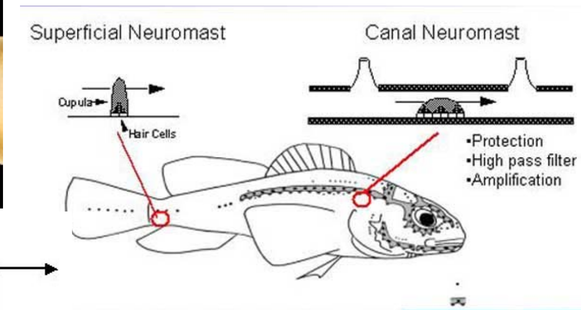
- To understand the mechanisms for self renewal and self repair in biological systems
- Identify physical, chemical, and mechanical principles that perform similar functions
- Design and build new generation of sensors and actuators that incorporate self-renewal and self-sustaining characteristics
- Maintain performance in uncontrolled and harsh environments

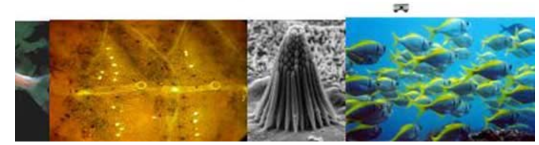
Technological Challenges

- Develop sensors for recognizing damage in sensor and actuation systems
- Develop sensors and actuators that have ability to be repaired and renewed
- Incorporate redundancy in sensor and actuator design.
- Developing new functional materials with feedback for diagnostics and prognostics
- Sensors and actuators with energy sustainability









Broader Impacts

- Lower cost in sensor and actuator replacement
- Environmentally sensitive engineering and manufacturing
- Increased safety in harsh environments and critical applications
- Self-sustaining sensors for implants in patients and synthetic organs
- Novel sensing and actuation
- Training of students in cross-disciplinary field.
- Self-healing mechanisms

Grand Challenge Summary

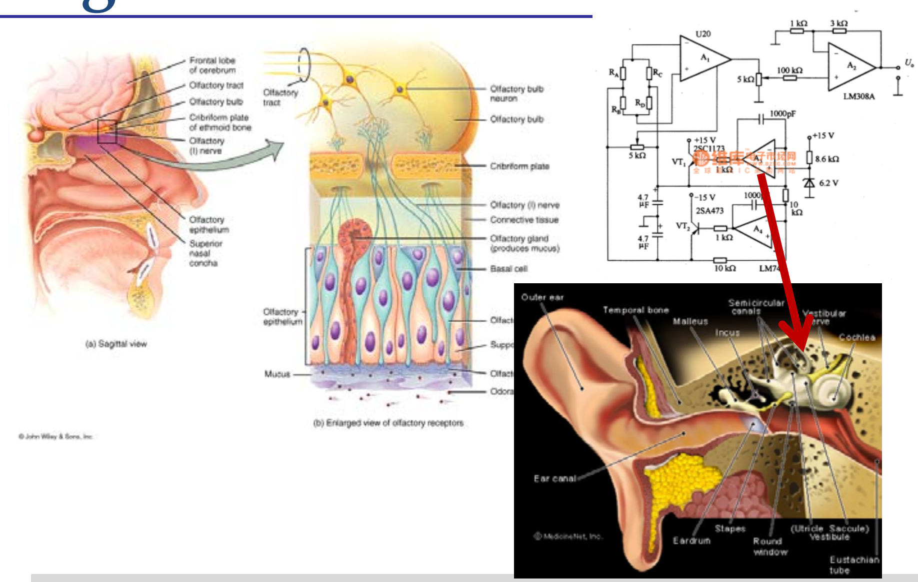
Biologically Inspired Robustness: Self-Sustaining Sensors and Actuators

- ***Summary:*** Biologically Inspired Robustness: Self-sustaining sensors and actuators. The grand challenge is to understand the mechanisms of self renewal and self repair in biological systems and to translate the knowledge towards designing a new generation of self-sustaining sensors and actuators. The vision is that the developed sensors will maintain its performance under uncontrolled and harsh environments. The research challenges include: developing techniques for recognizing damage in sensors and actuators that could then be used for self-repair and self-renewal; incorporating redundancy in the sensor and actuator design; developing new functional materials with feedback for diagnostics and prognostics; and developing sensors with energy sustainability.

BICEP: Biologically-Inspired Control, Enhancement and Processing

Objectives

- Understand biological mechanisms of amplification, sensitivity, and selectivity in sensing and actuation
- Identify local sensing and processing in biological actuation systems
- Translate biological principles for developing integrated sensory and actuation systems with local feedback control
- Development of paradigms in education integrating computer science, engineering, and biology



Technological Challenges

- Identification and distinguishing between local and global information under resource constraints (size, energy, speed, etc)
- Incorporate amplification and feedback in sensors and actuators using biomimetic processes, such as avalanche, cascade, etc.
- Understanding role of noise and nonlinearity in biological sensory systems
- New system design and control based upon above

Broader Impacts

- Computational reduction in central processing of complex systems
- Next generation of intelligent robotics
- Smart house/factory/office
- Smart grid
- Increased sensor sensitivity, selectivity, and signal to noise ratio
- Training next generation of students in multi-disciplinary research

Grand Challenge Summary

BICEP: Biologically-Inspired Control, Enhancement and Processing

- *Summary:* BICEP: Biologically Inspired control, enhancement and processing. The grand challenge is to understand biological mechanisms of amplification, sensitivity, and selectivity in sensing and actuation and to translate these principles into developing integrated sensory and actuation systems with local feedback control. The research challenges include: identification and distinguishing between local and global sensory information under resource constraints (size, energy, speed, etc); incorporation of amplification and feedback in sensors and actuators using biomimetic processes, such as avalanche, cascade, etc; understanding and exploiting the role of noise and nonlinearity in biological sensory systems; and design of novel systems based on these bio-inspired principles.