BioSensing & BioActuaction: Interface of Living & Engineering Systems

S.C Liu, B. Hamilton, B. Kramer, F. Heineken, L. Esterowitz, E. Misawa, C. Cooper, K. Baheti, R. Khosla, S. Midkiff, P. Fulay, E. Johnson, M.P Singh, R. Wellek, P. Phelan, S. Jayasuriya, J. Regalbuto, J. Vance, Y. Gianchandani,

D. Brent,. Z. Rosenzweig, M-A Horn, G. Yang L. Taylor, D. Du, J. Wu, H. Gill, K. Whang, P. Mazumder, T. Suda

(All PDs of ENG, MPS, BIO and CISE)

Development Background

1. Extramural (community) Blue Ribbon Panel study '06-'07

2. Internal (NSF) development of interdisciplinary research frontier at the interface of 4 Directorates ENG, MPS, BIO and CISE in "Biosensing and Bioactuation" since February '07

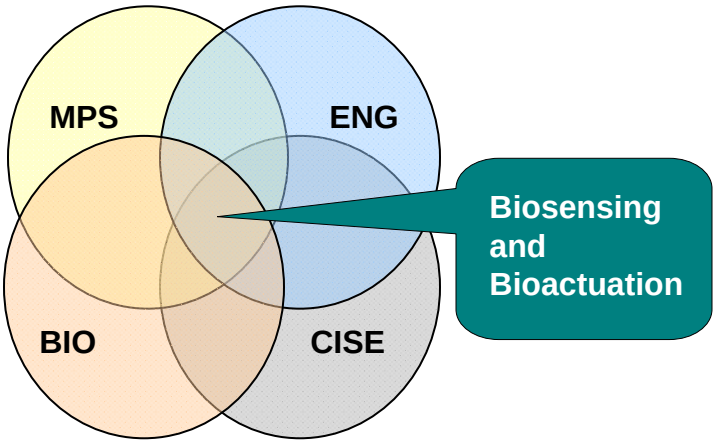
---NSF Internal Symposium: 07/31/07 (Report to ADs: 10/05/07)

3. Integration of internal & external developments

---Extramural BioS & BioA Workshop, 11/27 & 28/07 (Report to ADs 01/07/08)

This EFRI represents the consolidated context of the quadrilateral frontier research on BioS & BioA

Interface of Cross-Directorate Research Interest



Bio-inspired Autonomous Engineered Systems

Purpose: **Develop new integrated knowledge for creation of engineering systems and devices with embedded human-centric and bio-inspired intelligence and autonomy**

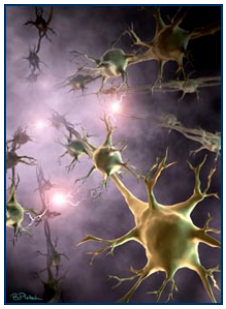
Application: **Better life quality, health, safety and security**

Biological Intelligence

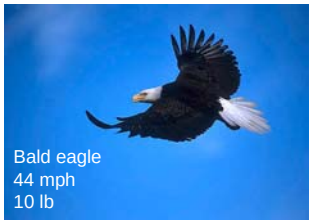
Sense

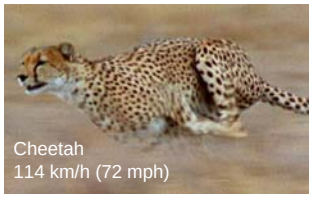
Compute/Control

Action



Machine vs. Biology



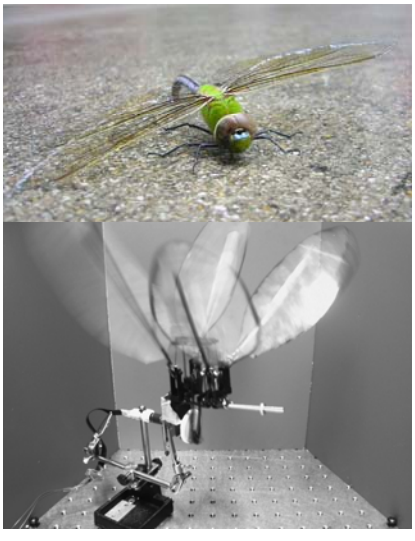


Biological Systems and Man-made Systems
(Real Time Decision Making/Actuation)

Formation flight

Vehicle platoon (Automated Highway Systems by Calif PATH)

Bio-inspired Robots:
Dragonfly Robot and Boxfish Robot



Concept and Motivation

- Bio-systems (such as animals) have vastly superior sensors and actuactors than the best engineered systems
- It is meaningful to bridge the gap between sensing & actuaction in the biological world and engineering world
- The proposed EFRI will leverage on NNI on new materials and CDI on bio/hybrid computing and cyber tools for data management (diagnosis, prognosis & optimal decision)

What is Encompassed?

The proposed EFRI program will:

--address fundamental biological questions pertaining to sensors & actuators, new functional materials, and novel fabrication and manufacturing technology;

--develop smart intelligent engineering systems such as: autonomous robotics systems, interactive electronics, and intelligent civil & aerospace structures;

--plot a roadmap beyond today's chip electronics integration; and

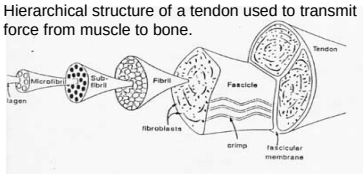
-- deepen understanding of biological systems at generic, molecular, cellular and tissue levels with new engineering motivations & tools.

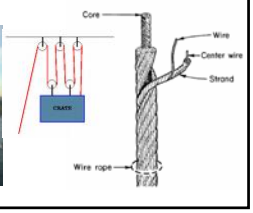
Research Thrust Areas

1. Hierarchical Organization of Biological Systems

--determine the subtleties underlying the growth of hierarchical bio-systems, and their use in sensing and actuation; apply to new multi-scale and multi-functional engineered systems

Hierarchical structure of a tendon used to transmit force from muscle to bone.

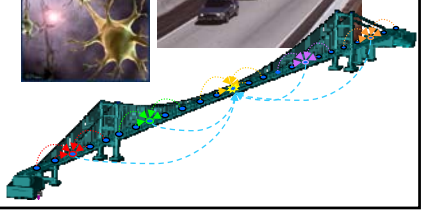




Research Thrust Areas

2. Sensor Informatics Guided by Life

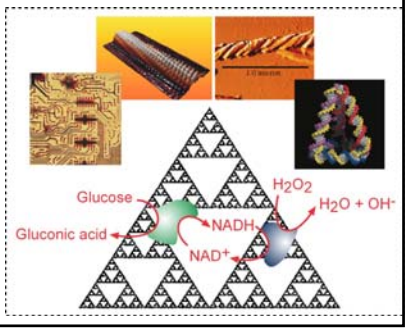
--Understand and emulate data mining and prioritization, as well as decision-making processes, in living organisms to facilitate monitoring, assessment, and control of complex engineered systems in sensor rich environments



Research Thrust Areas

3. Multi-functional Materials and Devices for Distributed Actuation and Sensing

--Through understanding of biological systems, their ability to exhibit fault-tolerant actuation under control with a wide dynamic range, develop new composite material systems & devices that can retain some of nature's behavioral characteristics



Research Thrust Areas

4. Forward Engineering & Design of Biological Components & Systems

Programmed tissue generation / repair

-- Synthesize hybrid *mechanical/electronic/living* systems through system-level integration of biological and engineering components that sense, actuate, compute, regenerate, and efficiently reallocate resources to achieve desired responses and functions

Sustainable / green construction materials
http://www.inhabitat.com/2005/09/18/fab-tree-hab/

Integration of Engineering and Biosciences- Examples

- Using microfluidic incubator arrays to study environmental pressure on bacterial, viral, etc. evolution/selection
- Understanding interaction between fluid dynamics, cell orientation, raft formation, and cholesterol absorption issues resulting in plaque formation in the arterial passages.
- Solid-fluid interaction computational modeling of lung behavior, so that effects of scar tissue, resections, and other abnormities can be observed on compliance, particle deposition etc.
- Novel design of bioreactors (magnetic) to grow larger tissues for different studies i.e., long arterial

Transformative Ideas & Research

- New generation bio-inspired sensors and actuators mimicking human senses & control
- Autonomous systems with cognitive capabilities mimicking self awareness and learning
- New paradigms of sensor fusion and on-line informatics
- Human-like cognitive robotic systems
- Multi-functional materials & morphic systems: design & control

Management Plan and Budget

- **Management Team: one member from each participating ENG division plus one each from MPS, BIO and CISE, with balanced device and systems expertise**
- **Estimated budget requirement: $10-15M total**
- **Multi-disciplinary team (minimum 3 PIs/coPIs) proposals only, with PI from an Engineering Department**
- **Standard grants for 4 years duration at max $500K/yr**
- **Estimated number of proposals: 100 (PIs/co-PIs must be from different disciplines [3 minimum])**
- **Estimated number of awards: 5-7**

Future Path of the Community

- **Fundamental EFRI research on this topic will create:**
  - **New paradigms for Biosensing & Bioactuation R&D**
  - **New technologies and tools for health care, search and rescue, infrastructure safety, living environment quality control, energy consumption efficiency, etc.**
  - **Technology-driven wealth and employment, and enhanced national security**
- **A new interdisciplinary research community will be created to provide intellectual leadership in Bio-inspired Autonomous Engineered Systems**
- **Talented graduate students will go on to become:**
  - **Interdisciplinary academic leaders**
  - **Entrepreneurs leading start-up companies**
  - **Bridges to the global community**

Samples of Proposal Titles

Sensors & Informatics

- Nano-engineered artificial neuron circuitry for multimodal signal processing and control
- Soft polymer micro-systems with integrated sensing, control and energy harvesting capability

Samples of Proposal Titles

Bio-inspired Active Materials & Devices:

- Active material-based actuators for flying "insect" robots (*ref: IEEE Spectrum, March 2008*)
- Flipper-driven bio-autonomous vehicles for underwater monitoring and exploration
- Self-controlled knee implants with energy harvesting mechanism
- Toxic-free biomaterials for nano-robot detection, diagnostic & surgery systems

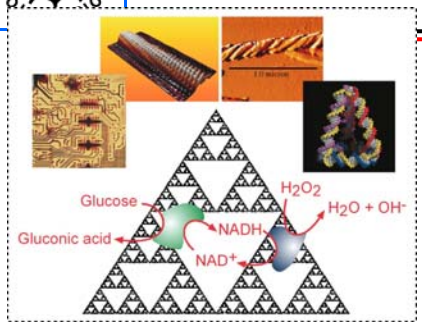
Samples of Proposal Titles

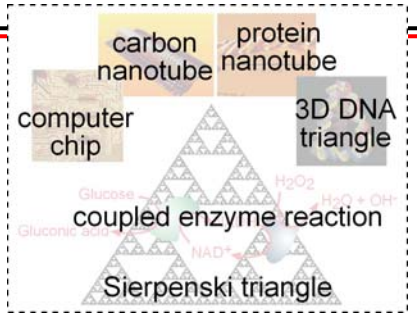
Civil Infrastructures & Other Systems

- Smart skins for civil structures
- Self-regenerated, self-healing engineered systems
- Bio-mechatronic micro/nano robots for search & surveillance
- Bio-reactive materials and structures for impact mitigation

Backup Slides to follow

Explanation of the figure





Sources of the 5 pictures:

Goodman et al. 2005 Science 310 1661-5

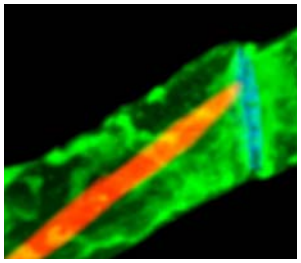
http://alglobus.net/NASAwork/papers/NanoSpace1999/paper.html

http://www.utsa.edu/today/2005/04/apple.cfm

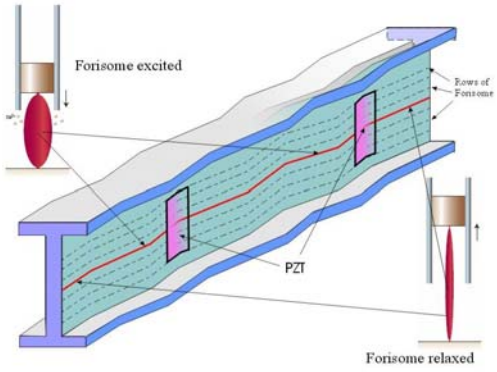
http://www.pha.jhu.edu/~ldb/seminar/fractals.html

Self–Powered Hybrid Forisome Nerve System

Objective: produce a sensory nerve system for civil structures by using forisomes as the mechanoreceptors, nerve fibers, and spinocervical tract to the nodal and central processing units.



Reconstruction of a sieve element of the Vicia faba with a forisome (red) located close to a sieve plate (blue); other membrane structures in green. The forisome shown is 30 µm long. Forisome can swell/deswell in response to stimuli.



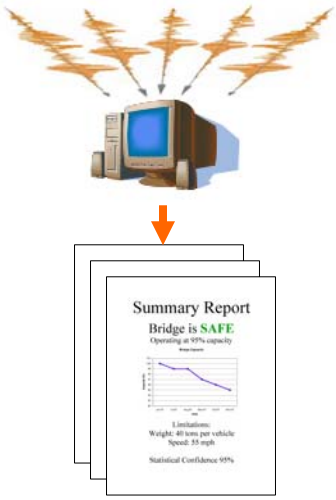
Online Informatics

Optimal use of information for effective real-time decision making and system control for infrastructure and the environment

Current Challenge: The continuous growth in our ability to collect and disseminate data and information results in the likelihood of data inundation

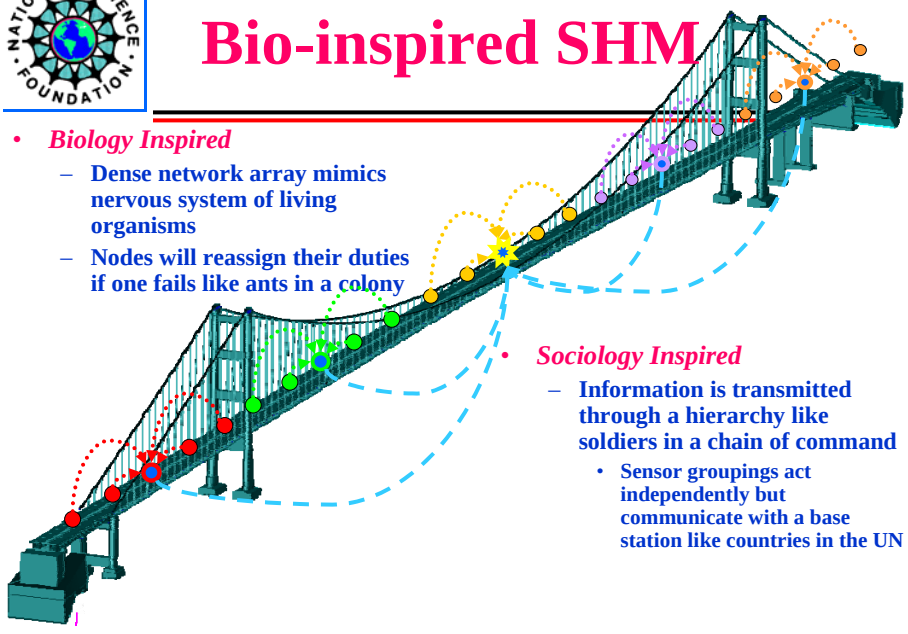
Research Thrusts

- Multiple strategies to acquire, store, transmit, aggregate , mine, validate, analyze, and visualize data
- Inference mechanisms for *information trustworthiness* and *risk uncertainty*.
- Cyber tools for diagnosis and prognosis for fast and robust extraction of essential features from the data and identify anomalies in highly uncertain and evolving environments.
- Ways of evaluating related social sciences, public policy, and human behavior



Bio-inspired SHM

- *Biology Inspired*
  - Dense network array mimics nervous system of living organisms
  - Nodes will reassign their duties if one fails like ants in a colony



- *Sociology Inspired*
  - Information is transmitted through a hierarchy like soldiers in a chain of command
    - Sensor groupings act independently but communicate with a base station like countries in the UN