NeuroEngineering IGERT @ Illinois
A Unified Educational Program for Systems Engineering and Neuroscience
Motivation

• Many of the most important and challenging problems in both engineering and neuroscience lie at the interface of these disciplines

• Major progress now requires deep collaboration across these now-separate fields
Our Educational Premise

- Research at engineering/neuroscience interface requires deep *collaboration*
  - Too much for one person to fully master it all
  - Too big to do it all by oneself, anyway

- Major progress will emerge from effective interdisciplinary teams of researchers
The Bottom Line

Major progress will emerge from effective interdisciplinary teams of researchers
A Few Grand Challenges

• High-resolution imaging of brain function
  – Human brain has 100 billion neurons
    • 256 x 256 x 256 images not adequate!
  – We need better imaging
  – We need *functional* imaging
    • Show the neural activity, not just anatomy
    • Need new types of imaging especially for brain activity
  – Engineers will build it, but neuroscientists must help figure out what to build
A Few Grand Challenges

• Brain and cognitive models
  – How does the brain work?
  – What is it doing at a high level?
  – What is the functional purpose?
  – Can we engineer systems (such as robots) to do some things as well?
    • Image understanding doesn't really work
    • Robots can't even walk properly
    • Machines, robots aren't safe to be around
A Few Grand Challenges

- Image recognition and understanding
  - Image understanding doesn't really work
  - Face recognition even has a hard time finding the faces, let alone recognizing someone!
  - Software can't reliably find, count, classify neurons in an image
    - Neuroscience is held back by intensive labor to do “trivial” but tedious tasks
A Few Grand Challenges

• Speech recognition
  – If only we could talk to our computers and electronics, the world would be different (and better)!
  – Current engineered methods are bad!
    • Not improving much, either!
  – Understanding how the brain does speech recognition is essential to real progress
A Few Grand Challenges

• Intelligent machines and robots
  – Robots are stupid, dangerous
    • Unaware of their surroundings
    • Can't recognize humans or fragile things
    • Can't really learn
  – Understanding how neural systems work is key to better robotics
A Few Grand Challenges

- Brain implants
  - In vivo multichannel neural recordings could revolutionize neuroscience
  - brain-machine interfaces for paralyzed people
    - Restore hearing, sight, muscular control
  - Must interface with brain and neural tissue, not harm it
  - Requires both neuroscience and engineering to progress
Neuro-engineering IGERT

• Senior Investigators
  – Large group of faculty spanning engineering and neuroscience disciplines
Neuro-engineering IGERT

• Senior Investigators
  – Large group of faculty spanning engineering and neuroscience disciplines
    – Neuroscience
    – Engineering
  – Assessment
    – M. Loui, Jennifer Greene
Thrust I: Audition

• Speech: fundamental to humans; much of human brain function is uniquely centered around speech and language.

• UIUC has unique strengths in several departments in all aspects of audition:
  • Molecular & Integrative Physiology, Psychology and Speech & Hearing faculty use neurophysiology, fMRI, and molecular approaches to understand the auditory system’s neural pathways
  • ECE faculty study the computational and information-processing aspects of the auditory system, as well as computational language models and speech recognition methodologies.

  • Probabilistic models of transforming sound to neural signals
  • Signal processing for hearing aids
  • Biomolecular cochlear prosthetics
  • Mechanisms of chemically induced hearing loss
  • Cortical auditory processing and plasticity
  • Speech perception and speech recognition
Thrust II: Neuro-Imaging

Brain imaging is a core strength at the University of Illinois:

- P. Lauterbur won Nobel Prize in 2003 for inventing fMRI
- “Real-time” fMRI pioneered by Hwu et al
- Event-related optical signal (EROS) was pioneered by Fabiani and Gratton here at UIUC
- Quantitative phase imaging (QPI) of single neurons pioneered by Popescu and Gillette
- Characterization of unknown neuropeptides across single neuronal processes pioneered by Sweedler

- Multi-modal functional brain imaging
- Real-time functional brain imaging
- Real-time neuronal imaging
- Chemical-imaging of neuropeptides
- Dynamic optical brain imaging
Thrust III: Brain Machine Interfaces

- UIUC faculty are developing general-purpose methodologies to design novel brain-machine interfaces.
- Techniques combine:
  - *experimental* and *cognitive neurobiological principles*,
  - *bioengineering* and *materials science* engineering for novel interface designs,
  - Mathematical formalisms of *feedback information theory* and *stochastic control*.
- The result is a first-principles paradigm change for developing BMIs, from the *neural interface to actuation*.
- *Non-invasive brain-controlled devices and neuro-robotics*
- *Human-computer interaction interface design*
- *Cognitive Models of User Interactions with Environment*
- *Neuron/chip interfaces*
- *Recursive estimation algorithms for real-time neural control*
IGERT Fellowship Support

• Fellows supported by IGERT for two years during coursework part of program

• Fellows transition to Research Assistantships with chosen advisors within neuro-engineering faculty

• Free to select research advisor, topic
  – But we anticipate they'll put their unique interdisciplinary knowledge to good use!
Neuro-engineering Curriculum

- A graduate-level neuro-engineering concentration is being created to give students the needed knowledge and understanding.
Neuro-engineering Concentration: for Engineers

- Fundamentals of Systems Neuroscience
- Select at least one course from a variety of existing neuroscience courses
- Cross-disciplinary Neuro-engineering Research Projects course
Neuro-engineering Concentration: for Neuroscientists

• ECE 5xx: Principles of Signal Analysis
• Select at least one of
  – ECE 537: Speech Production, Coding, and Recognition
  – Fundamentals of Computed Imaging
  – Stochastic Modeling of Neural Processes
• Cross-disciplinary Neuro-engineering Research Projects course
Other Training Program Components

- Neuro-engineering faculty mentor
- Neuro-engineering seminar program
- Neuro-engineering ethics training
- Leadership certificate program
- Co-advisor from other discipline
- Optional participation in Teaching Certificate and/or Certificate in Entrepreneurship and Management for Life Scientists programs
NeuroEngineering IGERT Fellows

- 2 BioEngineering
- 7 Electrical & Computer Engineering
- 6 Neuroscience
- 2 Psychology

Current Faculty Advisors

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<tr>
<th>Name</th>
<th>Department</th>
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<td>Jont Allen</td>
<td>ECE</td>
<td>Doug Jones</td>
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<td>Tim Bretl</td>
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<td>Deborah Leckband</td>
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<td>Kara Federmeier</td>
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<td>Martha Gillette</td>
<td>Cell &amp; Dev Biology</td>
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<td>Fatima Husain</td>
<td>Speech &amp; Hearing</td>
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<td>Wen-Mei Hwu</td>
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### NeuroEngineering IGERT Fellows

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<tr>
<th>Cohort</th>
<th>Student</th>
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<td>1</td>
<td>Li-Wen</td>
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<td>Amy</td>
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<td>Jonathan Sweedler</td>
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Student Progress So Far

- Chris Quinn:
  - DOE Computational Science Fellowship

- Johana Vega: NSF Graduate Fellowship

- Li-wen Chen: 2010 Virtual School of Computational Science and Engineering (VSCSE)


- Steines, Bretl, Maclin, Coleman, “Application of feedback-related Negativity to Brain-Computer Interface”, *SFN* 2010

- Pauline Baniqued: 2010 NIH fMRI Summer School Scholarship