Co-Evolution of Man and Machine: Neuroprosthetics in the 21st Century

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Neuroprosthetics Research Group (NRG)
Promise of Neuroprosthesis

- Develop communications pathways between the brain and external devices to restore lost sensory, motor, or other internal neural function.
- Use the device to bypass injury or aid in rehabilitation
- Direct contact with body’s command and control systems
- Seamless, intertwining of electronics, mechanics and materials.
- Biomimicry: Closely replicates physiological function.

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21st Century Bionic Human

Lebedev et al.

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A Little History of Human-Tool Interaction...
Traditionally, Tools Have Passively Impacted our Lives

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Although passive, they can extend one’s body schema and impact on the world.

Iriki, et al.
Evolving Impact of Tools

Transformation - The beginning of goal-seeking machine behavior (1941)

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After the War...

- Scientists/Engineers apply wartime techniques to broader problems
- Ideas from:
  - Living organisms
  - Control and communication devices
  - Human society
- Focus on:
  - Information, feedback, control
Josiah Macy Jr. Foundation Meetings (1946)

Participants:

Shannon
Weiner
Meade
Von Neumann
McCulloch
Pitts

Biologic phenomena, engineering, mathematics, computing
Cybernetics (1948)

Improve tool performance with control systems that have humans in the loop.

- Systems that have goals
  - Using circular “feedback” loops of
    - sensing ➔ comparing with goals ➔ action ➔ sensing ...
  - Communication systems, control theory
  - Understand human interaction to design computer interaction

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J. R. Licklider

- 1960 - Postulated “man-computer symbiosis”
- Couple human brains and computing machines tightly to revolutionize information handling
- Concept of a “dialogue” and “partnership”

Licklider, J. C. R., Man-computer symbiosis, *IRE Transactions on Human Factors in Electronics, HFE-1*, 1960, 4-11.

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Meanwhile, Others were Interested in Translating Thoughts into Action: The Neural Code

Stimulus → Neural System → Neural Response

Coding

Stimulus: Given

Decoding

Neural Response: To determine

Given: To determine
Information Technology begins in the neuron doctrine:

Santiago Ramon y Cajal 1852-1934

Superior temporal gyrus

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Theory of neural information processing was led by Cajal’s last graduate student, Lorente de Nó.

The Entorhinal Cortex, 1934
McCulloch & Pitts, 1945
Digital Computers, AI
Donald Hebb, 1949
Neuropsychology
Frank Rosenblatt, 1956
Neural Networks
Hubel and Wiesel, 1959
Neurobiology visual system

Rafael Lorente de Nó 1901-1982

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Culmination of this Work Forms the Cornerstones of Neuroprosthesis Design

Neural Information Processing

Adaptive Signal Processing

Feedback Control

Leuthardt

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Uncover the *principles and mechanisms* that guide the development, *organization, information processing*, and *mental abilities* of the nervous system.

- **Representation** – stimulus activated elements
- **Computation** – how the elements optimally use the stimulus
- **Dynamics** – how the elements change in time.
Neuroprosthetic Decoding Theory has been Driven by Adaptive Signal Processing

- Supervised and Unsupervised learning have been the key players in BMI design.
BMI lessons learned (Ironic)

Relationship between user and BMI is inherently still lopsided. Users are intelligent and can use dynamic brain organization and specialization while BMIs are passive devices that enact commands. I/O models have difficulty contending with new environments without retraining.
Vision for Next Generation Brain-Machine *Interaction*

- Intelligent behavior arises from the actions of an individual seeking to maximize received reward in a complex and changing world.
- Perception-Action Cycle: Adaptive, continuous process of using sensory information to guide a series of goal-directed actions.
A New Framework: Co-Adaptive Interfaces
Co-Adaptive BMI involves TWO intelligent agents involved in a continuous dialogue!!!
# Prerequisites for Symbiosis (dialogue)

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Challenges for the Future

- IEEE
  - Multidisciplinary culture focused on innovating “grand challenges”
- Human-Tool Interfaces
  - Sharing of goals / neural assistants
- Technology
  - Implantable medical devices – amplifiers, wireless, DSP, etc.
  - Power and bandwidth constraints