Biosciences in the 21st century

Lecture 2: Innovations and Challenges

Dr. Michael Burger
Outline:

Review of last time

Organization of the nervous system (in brief)

The mapping concept

Bionic implants and our cyborg future

Auditory function and cochlear implants

Restoring paralysis: promising technology
Nervous system is segmented in invertebrates

Each segment is controlled by its “own” bit of brain
and in vertebrates....... 

Each segment has repeatable structures

http://embryology.med.unsw.edu.au/wwwhuman/Stages/Stage10L.htm
Each segment has its own inputs and outputs

![Diagram of a spinal segment with labeled afferents and efferents](image)

**Afferents (inputs; i.e. sensory neurons)**

**Efferents (outputs; i.e. motor neurons)**
Let’s consider the somatosensory system....
each vertebral segment is connected to a particular patch of skin

The area of skin innervated by one segment is called a “dermatome”

You will see that this organization is preserved at every level of processing
The brain (*also segmented*) has its own afferent and efferent nerves.
The neocortex is an elaboration of the foremost segment, and it has a highly organized structure.
The cortex has functionally distinct regions...

a closer look at the somatosensory cortex...
The somatosensory and motor cortex contain orderly maps of the body surface.

The representation is distorted because more brain tissue is devoted to the most sensitive areas.
This distorted representation gave rise to the concept of the homunculus or “little man in the brain”

The point is: the brain is organized into maps of important features and functions
The point is: the brain contains maps of features and functions

we learned this in the 1950’s!

The more that we understand about the structure and function of each region of the nervous system, the more likely we are to be able to develop an intervention when things go wrong.....
Neurological Medicine:

**Today:** mainly concerned with limiting damage as it happens, or slowing degenerative processes.

Sometimes medication can correct deficiencies in neurotransmitter systems etc.

**Long term:** stem cells, tissue engineering, gene therapies will correct the *mechanisms* of disease, not just the symptoms

**The intermediate term:** current research in nanoscale engineering, computer science, and neuroscience will lead to technological interventions that provide solutions to neurological disease
The dawn of the brain machine interface...

welcome to your cyborg future....
The most successful machine/neuron interface thus far is the cochlear implant.
Sound is defined by frequency
Outer ear  Middle ear  inner ear (neural)

The cochlea
Organ of Corti
- hair cells
- support cells
- basilar membrane
- Primary Auditory Afferents!!
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The inner ear translates stimulus frequency to a topographic place.

This “tonotopic” organization is the primary mapping feature in the auditory brain.
The most common cause of hearing loss is hair cell damage and death; in mammals they do not regenerate.
The cochlear implant is an electrode array positioned to stimulate the auditory afferents directly, in the absence of hair cell function.
Cochlear Implant

- Two elements
  - External
  - Internal

- A microphone
- A speech processor
- A transmitter and receiver/stimulator
- An electrode array

- Bypasses damaged part of the ear
- Directly stimulates auditory nerve
Age Matters
Vocabulary

The point here: deaf children can recover near normal language ability if they are implanted early enough (Connor et al. 2006)
The limit of implantation, is frequency resolution because today's best electrode has a max of 23 inputs to the ear.
The limit of implantation, is frequency resolution

6 channel hearing
The limit of implantation, is frequency resolution

4 channel hearing
Cochlear implants compress sound into bandpass filter channels, but only a few are needed to make sense of the world....
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![Diagram showing frequency bands and time]
Cochlear implants compress sound into bandpass filter channels, but only a few are needed to make sense of the world....
New technology is allowing researchers and their patients to control machines with only the power of thought, and the help of computers.
The cortex has functionally distinct regions

a closer look at the Motor cortex...

1. Motor neurons fire predictable patterns before movement
The cortex has functionally distinct regions

2. Computer programmers are getting sophisticated enough to have algorithms that interpret the output of 100's of neurons.

http://www.emc.maricopa.edu/faculty/farabee/BIOBK/cerebrum_1.gif
The cortex has functionally distinct regions.

3. computers can then send complex commands to robots.
Recently developed tiny electrode arrays can sample the activity of many neurons at once, and cause minimal tissue damage.
In 1999, researchers succeeded in demonstrating that a rat could control a single arm robot with signals from motor cortex neurons.
By 2002, researchers demonstrated that monkeys could control robot arms in 3D and computer cursors on a monitor with brain activity alone.
Movies....
From the following article:

Cortical control of a prosthetic arm for self-feeding
Meel Velliste, Sagi Perel, M. Chance Spalding, Andrew S. Whitford & Andrew B. Schwartz
Nature 453, 1098-1101(19 June 2008)
doi:10.1038/nature06996
Human brain implants are here with some devices already in use... but the technology is not yet mature.
Summary:

The brain is highly organized into functional maps (somatotopic, tonotopic, etc.) where neighboring neurons process similar information.

One function of the ear is to transmit sound frequency information to the brain.

Auditory transduction is achieved by hair cells that translate mechanical energy into electrical energy.

Cochlear implants bypass hair cells by stimulating auditory nerve fibers directly.
Summary:

Small electrode arrays and computers can bypass motor systems to operate prosthetic devices etc. This strategy is highly likely to help patients with neurological disease.
Good Luck, work hard, and earn success!