

# Brain Computer Interface

# BCI Outline

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- ▶ **BCI Concept:** *rebuilding instead of repairing*
- ▶ **BCI overview:** *actions from thoughts*
- ▶ **BCI Story:** *from fiction to reality*
- ▶ **BCI apps:** *Silent Talk*



# BCI Concept:

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- ▶ direct communication pathway between a brain and an external device.
- ▶ Often aimed at assisting, augmenting or repairing human cognitive or sensory-motor functions.



# BCI motivation:

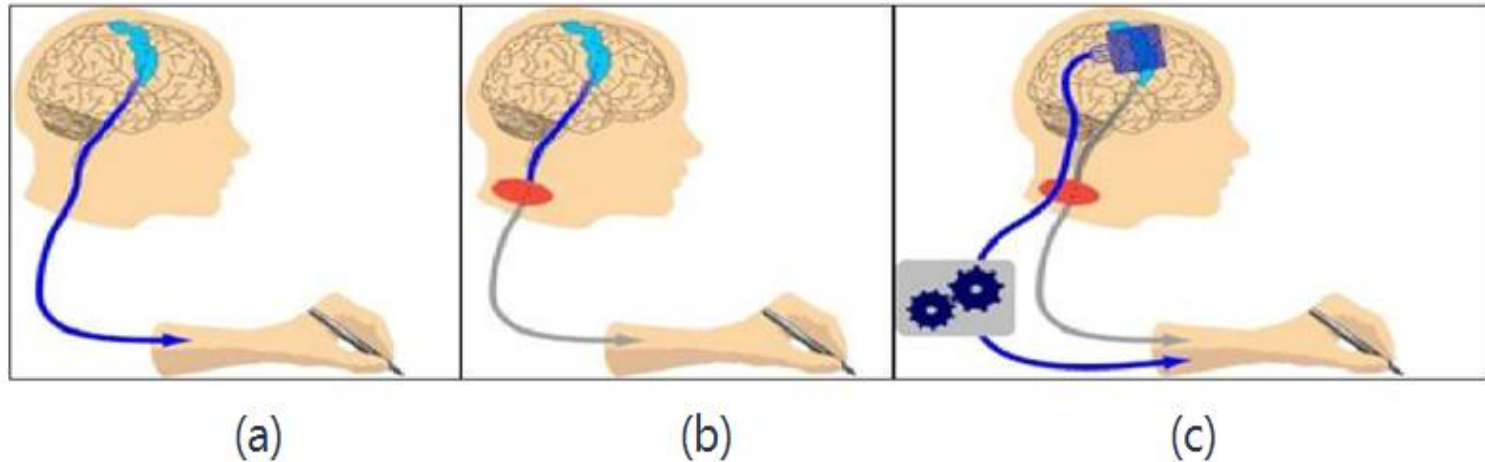
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- ▶ In USA, more than 200,000 patients live with the motor sequelae (consequences) of serious injury. There are two ways to help them restore some motor function:
  - Repair the damaged nerve axons
  - **Build neuroprosthetic device**



# BCI Principle:

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- (a) In healthy subjects, primary motor area sends movement commands to muscles via spinal cord.
  - (b) But in paralyzed people this pathway is interrupted.
  - (c) A Computer based decoder is used, which translates this activity into commands for muscle control.
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# BCI versus neuroprosthetics:

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## ▶ Neuroprosthetics:

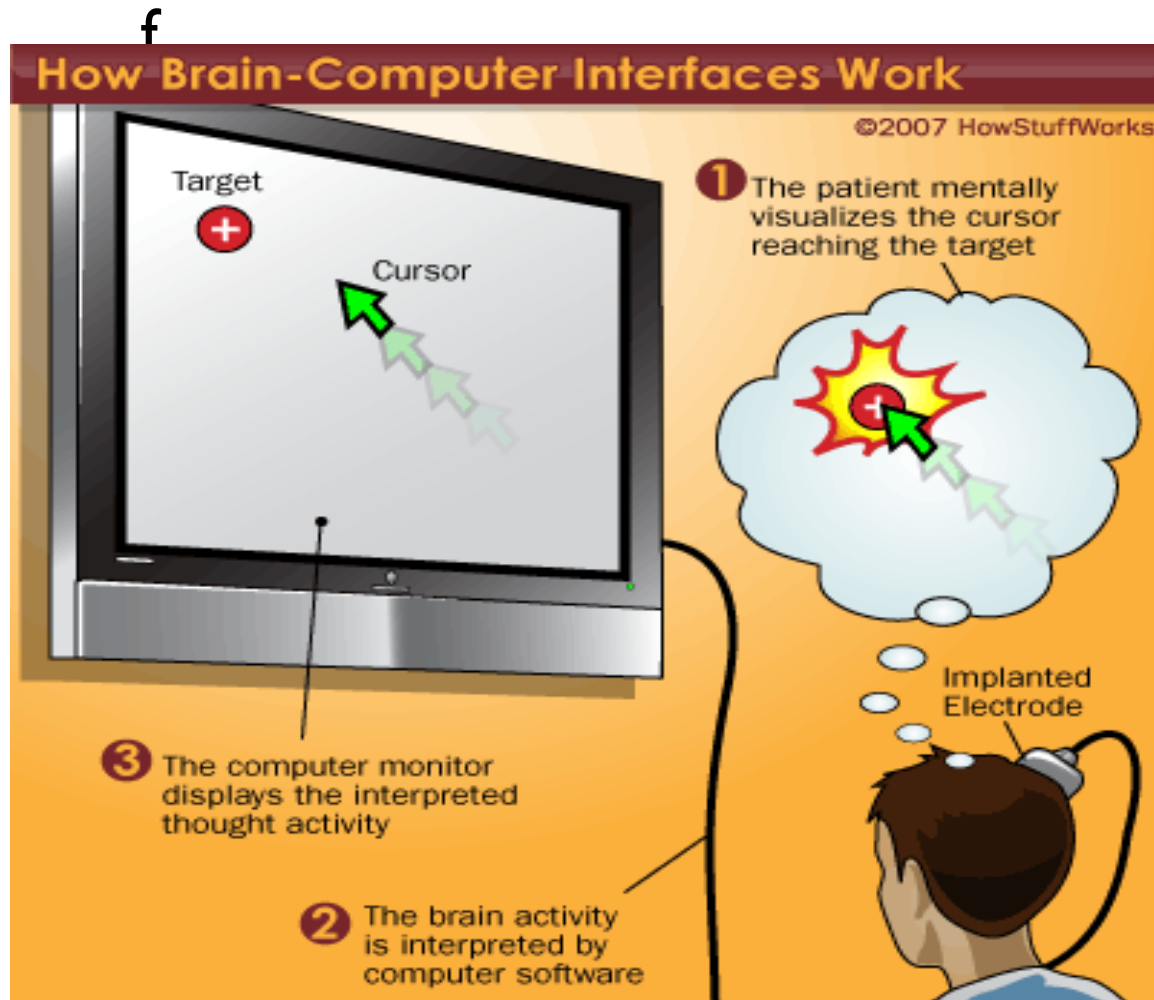
- ▶ uses artificial devices to replace the function of impaired nervous systems or sensory organs.
- ▶ connect the nervous system to a device
- ▶ E.g. cochlear implants, retinal implants.

## ▶ BCI:

- ▶ connect the brain (or central nervous system) with a computer system.
- ▶ E.g. EEG,



# BCI Input and Output:



# Brain “Features”

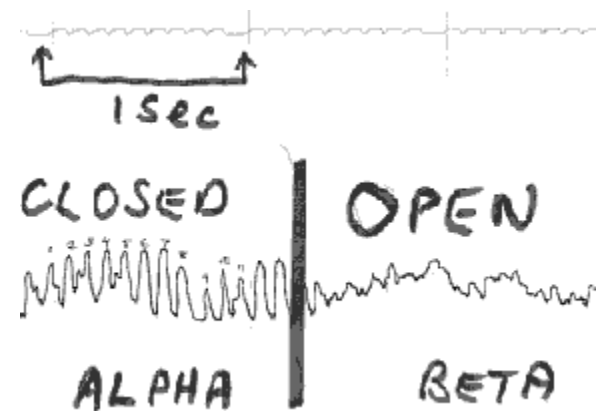
- ▶ **User must be able to control the output:**
  - ▶ use a feature of the continuous EEG output that the user can reliably modify (waves), or
  - ▶ evoke an EEG response with an external stimulus (evoked potential)
- ▶ **Brain waves transformations**
  - ▶ wave-form averaging over several trials
  - ▶ auto-adjustment with a known signal
  - ▶ Fourier transforms to detect relative amplitude at different frequencies





# Alpha and Beta Waves

- ▶ Studied since 1920s
- ▶ Found in Parietal and Frontal Cortex
- ▶ Relaxed - Alpha has high amplitude
- ▶ Excited - Beta has high amplitude
- ▶ So, Relaxed -> Excited  
means Alpha -> Beta

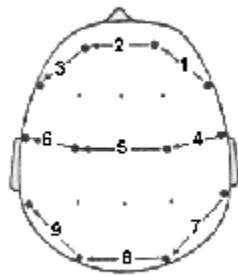


# Mu Waves

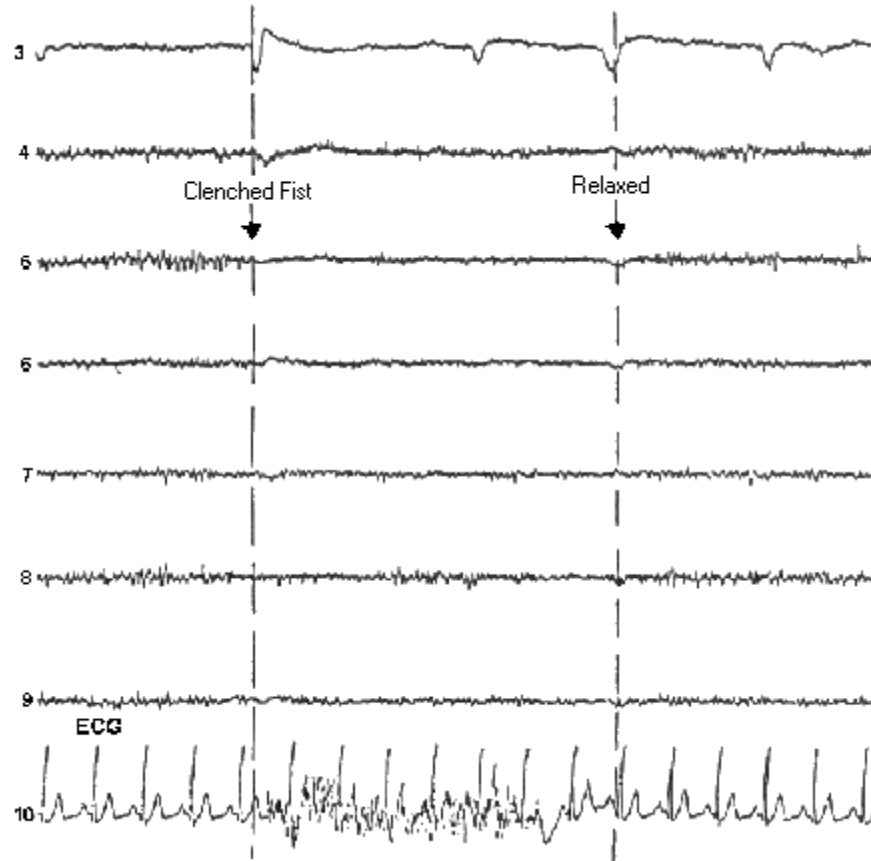
- ▶ Studied since 1930s
- ▶ Found in Motor Cortex
- ▶ Amplitude suppressed by Physical Movements, or *intent to move physically*
- ▶ (Wolpaw, et al 1991) trained subjects to control the mu rhythm by visualizing motor tasks to move a cursor up and down (ID)



# Mu Waves



50 $\mu$ V  
1second



# Mu and Beta Waves

- ▶ (Wolpaw and McFarland 2004) used a linear combination of Mu and Beta waves to control a 2D cursor.
- ▶ Weights were learned from the users in real time.
- ▶ Cursor moved every 50ms (20 Hz)
- ▶ 92% “hit rate” in average 1.9 sec



# P300 (Evoked Potentials)

- ▶ occurs in response to a significant but low-probability event
- ▶ 300 milliseconds after the onset of the target stimulus
- ▶ found in 1965 by (Sutton et al., 1965;Walter, 1965)
- ▶ focus specific

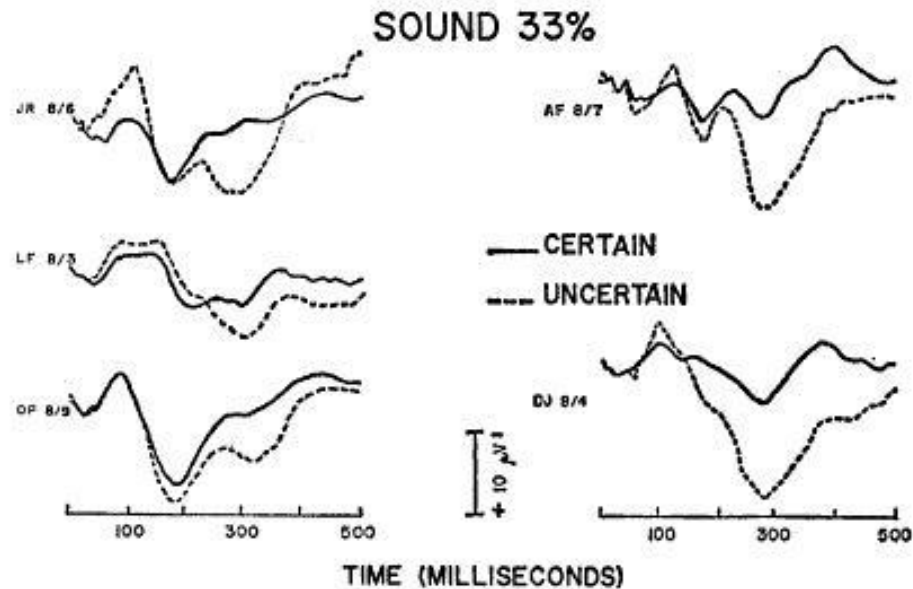
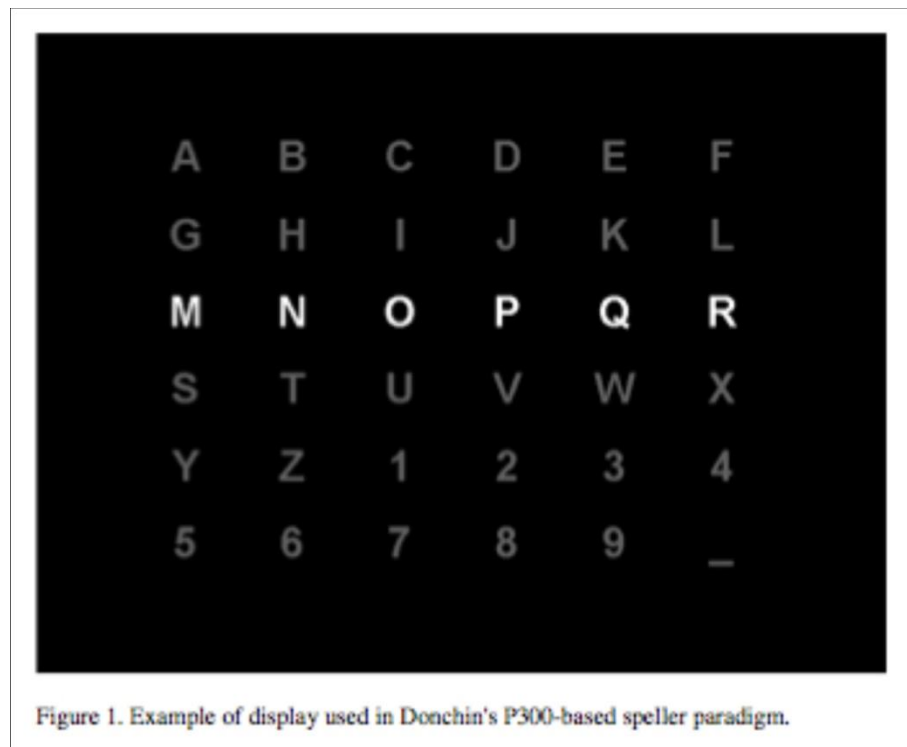


Fig. 1. Average waveforms for certain and uncertain ( $P = .33$ ) sounds for five subjects.

# P300 Experiments

- ▶ (Farwell and Donchin 1988)
- ▶ 95% accuracy at 1 character per 26s



# BCI System: Non-Invasive BCI

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- ▶ **Non-Invasive BCIs:**
  - ▶ easy to wear
  - ▶ produce poor signal resolution because the skull dampens signals
  - ▶ Signals recorded in this way have been used to power muscle implants and restore partial movement
  - ▶ E.g. EEG.



- ▶ [http://www.youtube.com/watch?v=G0cz-qIlg6go&feature=player\\_embedded](http://www.youtube.com/watch?v=G0cz-qIlg6go&feature=player_embedded)



# Model Generalization (time)

- ▶ EEG models so far haven't adjusted to fit the changing nature of the user.
- ▶ (Curran et al 2004) have proposed using Adaptive Filtering algorithms to deal with this.





# Model Generalization (users)

- ▶ Many manual adjustments still must be made for each person (such as EEG placement)
- ▶ Currently, users have to adapt to the system rather than the system adapting to the users.
- ▶ Current techniques learn a separate model for each user.



# Model Generalization (users)

- ▶ (Müller 2004) applied typical machine learning techniques to reduce the need for training data.
- ▶ Support Vector Machines (SVM) and Regularized Linear Discriminant Analysis (RLDA)
- ▶ This is only the beginning of applying machine learning to BCIs!



# BCI System: Partially-Invasive BCI

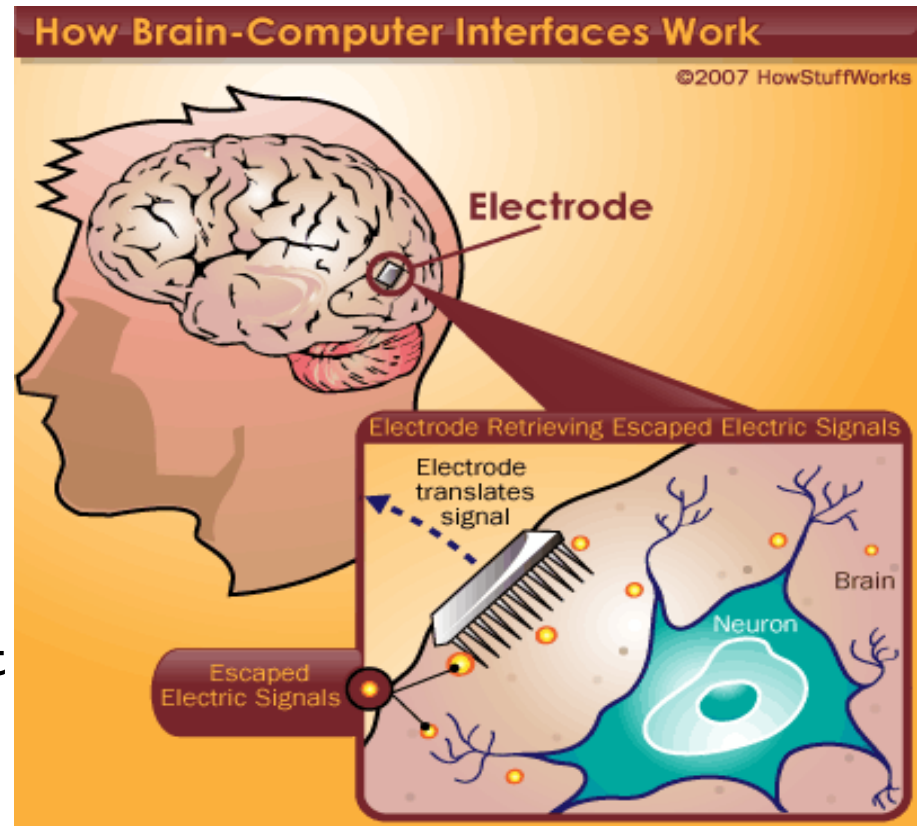
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- ▶ *Electrocorticography* (ECoG) with a sensor tapping directly into the brain's cortex is a very promising intermediate BCI modality.
  - ▶ higher spatial resolution,
  - ▶ better signal-to-noise ratio,
  - ▶ wider frequency range
- ▶ first trialed on humans in 2004 on a teenage boy suffering from epilepsy to play *Space Invaders*.
- ▶ The units of speech known (phonemes) allow signals of a particular "discrete" nature: e.g. phonemes - "oo", "ah", "ee" and "eh" produce signals that reliably move a cursor on a computer screen.
- ▶ <http://www.braingate2.org/systemOverview.html>



# Working of BCI:

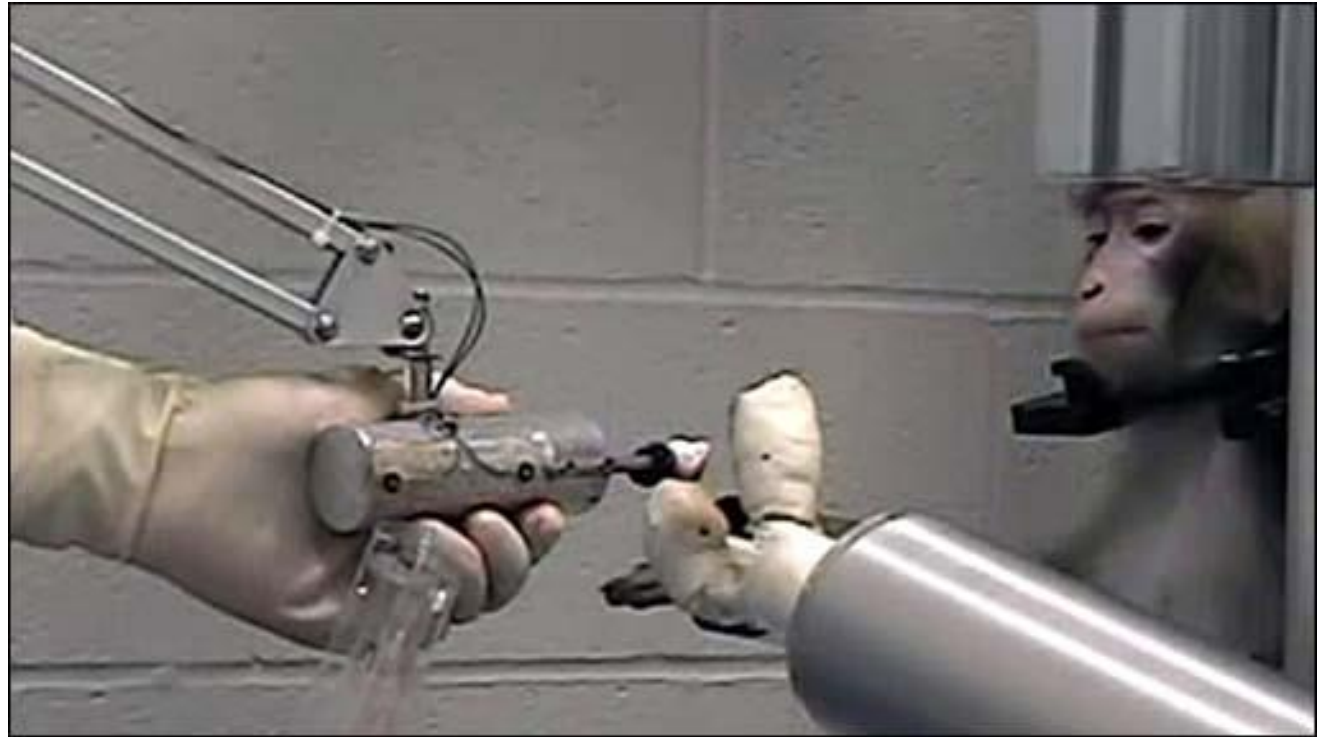
- ▶ Every time we think, move, feel or remember something, our neurons are at work. That work is carried out by small electric signals that zip from neuron to neuron as fast as 250 mph
- ▶ some of the electric signal escapes, which can be detected, interpret and use them to direct a device of some kind.



# Monkey thinks, Robot does!

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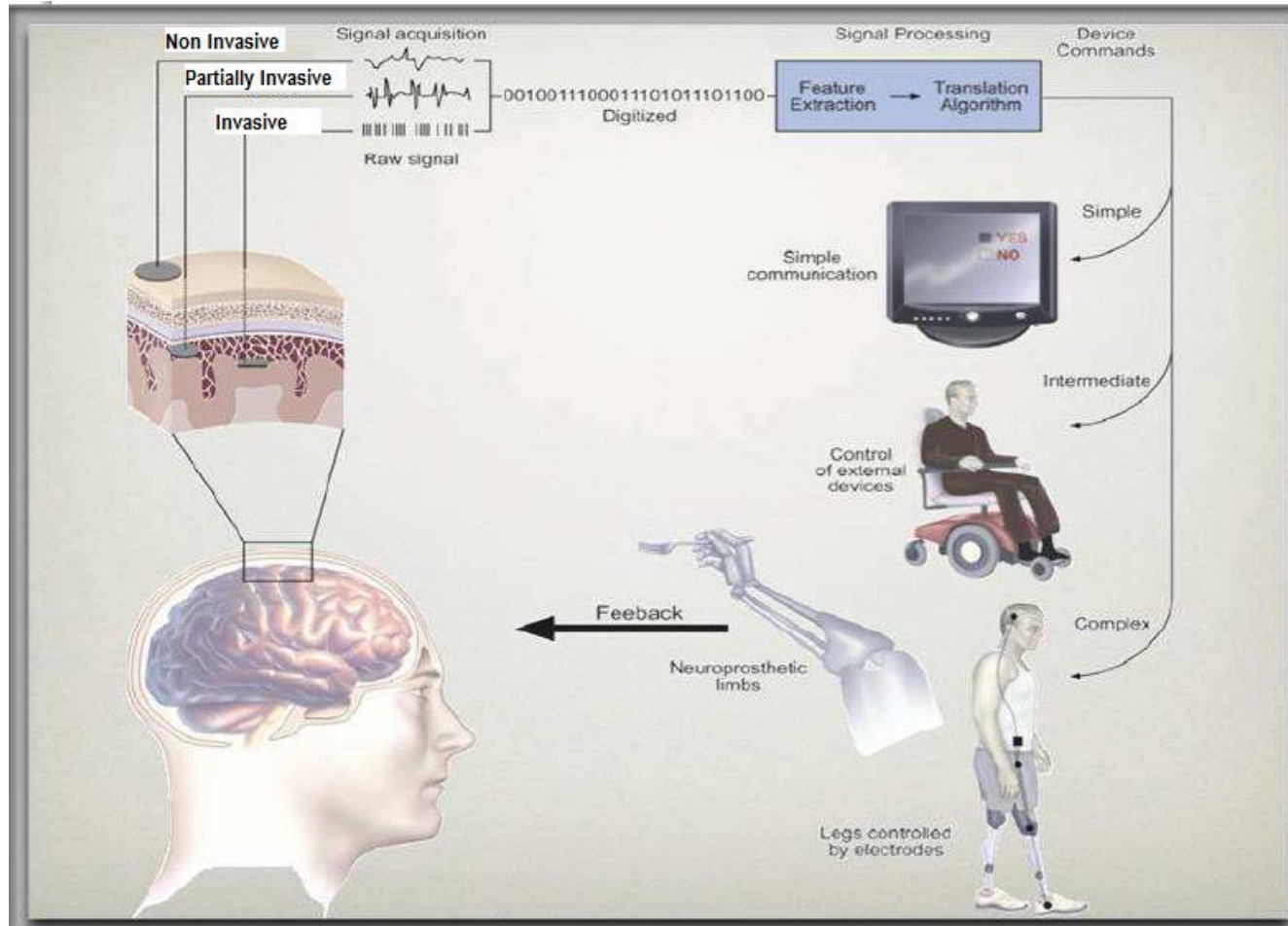
- ▶ *Experiments with monkey operating a robotic arm with its mind at the Pittsburgh University Medical Center*



- ▶ <http://www.makeahistory.com/index.php/your-details/222-the-worlds-first-commercial-brain-computer-interface->
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# BCI System:



# Cell-culture BCIs:

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## ▶ Aim of the experiment:

- ▶ to study how brain cells function as a network and to learn more about one of the most complex devices in the known universe: the human brain.
- ▶ to find out exactly how the neurons do what they do and extract those rules and apply them in software or hardware for novel types of computing
- ▶ By watching the brain cells interact, scientists hope to understand what causes neural disorders, such as epilepsy. The research may also help the researchers in their quest to build "living" computers that combine neural and silicon systems.
- ▶ Computers lack the flexibility and adaptability of the human brain and perform poorly at pattern recognition tasks.

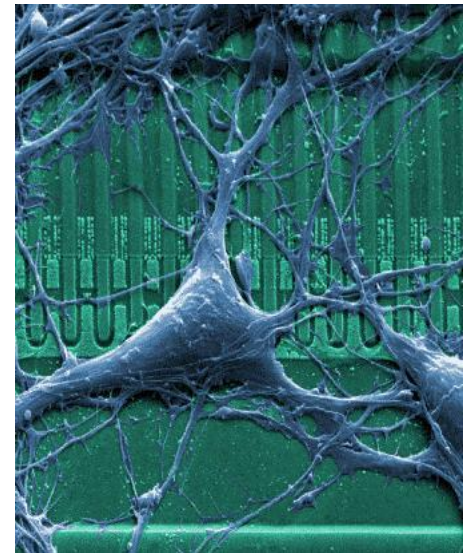


# Cell-culture BCIs:

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## ▶ Experiment at Univ. of Florida

- ▶ 25,000 neurons taken from the brain of a rat that are connected to a computer via 60 electrodes.
- ▶ rapidly began to reconnect themselves to form a living neural network.
- ▶ To put the experimental brain to the test, it is connected to a jet flight simulator via the electrode grid and a desktop computer.
- ▶ If you take these cells out of the cortex and you put them into one of these dishes, you remove all of the inputs—sensory systems like vision or hearing—that they would normally have. The only thing that's going on is the spontaneous activity of reconnecting.





# Cell-culture BCIs:

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- ▶ **Warwick et al.: Controlling a mobile robot with a biological brain (Jan 2010)**
  - ▶ Closed-loop adaptive feedback system with approximately  $10^5$  neurons receiving information about robot position from the computer about flight conditions
  - ▶ Information is sent back and forth creating a feedback system



# In Review...

- ▶ **Brain Computer Interfaces**
  - ▶ Allow those with poor muscle control to communicate and control physical devices
  - ▶ High Precision (can be used reliably)
  - ▶ Requires somewhat invasive sensors
  - ▶ Requires extensive training (poor generalization)
  - ▶ Low bandwidth (today 24 bits/minute, or at most 5 characters/minute)



# Future Work

- ▶ Improving physical methods for gathering EEGs
- ▶ Improving generalization
- ▶ Improving knowledge of how to interpret waves (not just the “new phrenology”)



# Commercialization and companies:

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- ▶ Ciberkinetics
- ▶ Honda
- ▶ Neural Signals
- ▶ Starlab
- ▶ NASA



# BCI video

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- ▶ In this short talk, Dr. Shenoy describes how his team of Stanford researchers has built a system that achieves typing at 15 words-per-minute, just by "thinking about it".
- ▶ [http://www.youtube.com/watch?v=l7lmje\\_EXEU&feature=related](http://www.youtube.com/watch?v=l7lmje_EXEU&feature=related)



# References:

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- ▶ <http://mlpr.wikidot.com/brain-computer-interface>
  - ▶ <http://www.makeahistory.com/index.php/your-details/222-the-worlds-first-commercial-brain-computer-interface->
  - ▶ <http://www.wireheading.com/>
  - ▶ [http://news.nationalgeographic.com/news/2004/11/1119\\_041119\\_brain\\_petri\\_dish\\_2.html](http://news.nationalgeographic.com/news/2004/11/1119_041119_brain_petri_dish_2.html)
  - ▶ <http://www.wired.com/dangerroom/2009/05/pentagon-preps-soldier-telepathy-push>
  - ▶ [http://en.wikipedia.org/wiki/Brain-computer\\_interface](http://en.wikipedia.org/wiki/Brain-computer_interface)
  - ▶ [http://www.wired.com/wired/archive/9.08/assist\\_pr.html](http://www.wired.com/wired/archive/9.08/assist_pr.html)
  - ▶ [http://www.youtube.com/watch?v=I7ImJe\\_EXEU&feature=related](http://www.youtube.com/watch?v=I7ImJe_EXEU&feature=related)
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