Brain-Computer Interface

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SO FAR...
SO FAR...

Neuroimaging techniques to read it?
SO FAR...
SO FAR...

What are the types of data we get?
SO FAR...
What can we do with this data?
• Try to understand the neural code
• Diagnose diseases
• Psychological studies
• Distinguish different brain states
• …
Try to understand the neural code
Diagnose diseases
Psychological studies
Distinguish different brain states
Brain-Computer Interface
Brain-Computer Interface happens
Brain-Computer Interface happens

Controlling An Avatar By Thought Using Real-Time fMRI
How it happens?
Based on evoked potential
Based on **evoked** potential

Based on **indirect** mental intention
Based on evoked potential

Based on indirect mental intention

Based on direct mental intention
Step 1
Get the Data

Step 2
Process the Data

Step 3
Learn from Data
Step 1: Get the Data
Invasive

- Microelectrodes
- ECoG

Non-invasive

- EEG
- fNIRS
- fMRI
- MEG

How it works?
- Temporal resolution
- Spatial resolution
- Advantages
- Disadvantages
- Portable?
- Cost
Invasive

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- ECoG

Non-invasive

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How it works?
Temporal resolution
Spatial resolution
Advantages
Disadvantages
Portable?
Cost
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What happens to a magnet if you put it in a magnetic field?
IN A MAGNETIC FIELD

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\[ \Delta E = E_{-1/2} - E_{+1/2} \]

\[ m_S = -\frac{1}{2} \]

\[ m_S = +\frac{1}{2} \]

\[ B_0 = 0 \quad B_0 \neq 0 \]

Magnetic Field
IN A MAGNETIC FIELD

Stronger field — larger energy gap

\[ \Delta E = E_{-1/2} - E_{+1/2} \]

- \( m_s = -1/2 \)
- \( m_s = +1/2 \)

\( B_0 = 0 \)
\( B_0 \neq 0 \)
Radio Frequency Pulse

We can give energy to a particle and move it to a higher energy level.

\[ \Delta E = E_{-1/2} - E_{+1/2} \]

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\[ m_s = +1/2 \]

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Magnetic Field
Radio Frequency Pulse

We can give energy to a particle and move it to a higher energy level.

To do that we send an electromagnetic wave.
We can give energy to a particle and move it to a higher energy level. To do that we send an electromagnetic wave. Nucleus will absorb energy only if frequency of the wave is correct for:

- the nucleus we work with
- strength of the magnetic field

\[
\Delta E = E_{-\frac{1}{2}} - E_{+\frac{1}{2}}
\]
RELAXATION

Now we stop the pulse
Now we stop the pulse
RELAXATION

Now we stop the pulse

Nucleus will give out same amount of energy in the form of electromagnetic radiation.
Nuclear Magnetic Resonance
Nuclear Magnetic Resonance Imaging
HYDROGEN

Human Body
72% Water
HYDROGEN

Possible spin states
+1/2 or -1/2
HYDROGEN IN A MAGNETIC FIELD
HYDROGEN IN A MAGNETIC FIELD

http://www.howequipmentworks.com/physics/medical_imaging/mri/magnetic_resonance_imaging.html
RF Pulse
RF Pulse

What will happen?
RF Pulse
RELAXATION
RELAXATION
For different tissues the time of relaxation is different
NUCLEI SEND SIGNALS

One large piece is still missing…
Gradient Coils

The Inner Workings

Radio Frequency Transmitter & Receiver
Sends and receives radio signals

Main Magnetic Coil
Creates a uniform magnetic field

X Magnetic Coils
Create a varying magnetic field from left to right

Y Magnetic Coils
Create a varying magnetic field from top to bottom

Z Magnetic Coils
Create a varying magnetic field from head to toe

GRADIENT COILS

http://www.howequipmentworks.com/physics/medical_imaging/mri/magnetic_resonance_imaging.html
GRADIENT COILS

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BOLD
BLOOD-OXYGEN-LEVEL DEPENDENT

I need oxygen and glucose!

I need nothing…

Active neuron

Passive neuron

Oxygenated

Deoxygenated
FMRI

Have different magnetic resonance

Distinguishable by MRI
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SQUID* sensor array aligned to cortical surface of the brain

Axons in the cortical surface of the brain

Direction of electric current in active axon

SQUID sensor detects magnetic field of current

* Superconducting Quantum Interface Device
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Electrocorticography (ECoG)

- Higher temporal (3 ms) and spatial (1 mm) resolutions
- Higher amplitudes
- Lower vulnerability to artifacts (eye blinks, etc.)
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http://wiki.neurotycho.org/ECoG_for_primates
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STEP 2: PROCESS THE DATA
Step 2: Process the data you know?
As an example

EEG

Potential A

Potential B

A - B
EEG

CHANNELS

TIME
EEG

TIME

CHANNELS

?  

Alpha  
7-14 Hz

Beta  
15-30 Hz

Gamma  
30-100 Hz
FOURIER TRANSFORM
FOURIER TRANSFORM*
FOURIER TRANSFORM

2 Hz + 6 Hz + 9 Hz = Sum

*discrete
\[ X_k = \sum_{t=0}^{N-1} x_t e^{-i2\pi k \frac{t}{N}} \]

\( x_t \): signal at time \( t \)

\( k \): frequency

\( X_k \): complex number

*discrete*
**Fourier Transform***

\[ X_k = \sum_{t=0}^{N-1} x_t e^{-i2\pi k \frac{t}{N}} \]

- \( x_t \): signal at time \( t \)
- \( k \): frequency
- \( X_k \): complex number

\[ \sqrt{Re(X_k)^2 + Im(X_k)^2} \]

Amplitude of the component with frequency \( k \)

*discrete*
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STEP 3: LEARN FROM THE DATA
Based on evoked potential

P300
Based on evoked potential

P300

- Test subject is instructed to wait for specific stimulus
- All targets flash in random order
- ~300ms after the expected stimulus is presented, test subject generates positive peak in central and parietal cortex
Based on evoked potential

**P300**

- Test subject is instructed to wait for **specific stimulus**
- All targets flash in random order
- ~300ms after the expected stimulus is presented, test subject generates positive peak in central and parietal cortex

How to type letters with that?
Based on evoked potential

VEP

1. Each target (square) flashes in a unique way
2. Brain reacts on each flashing pattern in a unique* way
3. User stares at the target he is interested in (letter “N”)
4. We look how his brain reacts
5. From that we know what was the target he was looking at
Based on evoked potential

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* t-VEP (time modulated)
Only one target is ON at a time
Based on evoked potential VEP

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**t-VEP** (time modulated)
Only one target is ON at a time

**f-VEP** (frequency modulated)
Each target is flashing with its own frequency
Based on mental intention
Based on mental intention
Which machine learning algorithms you’ve heard of?
Based on mental intention
Based on mental intention.
Based on mental intention
Step 1
Get the Data

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Process the Data

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Learn from Data
Mind-controlled drones promise a future of hands-free flying

There have been tentative steps into thought-controlled drones in the past, but Tekever and a team of European researchers just kicked things up a notch. They've successfully tested Brainflight, a project that uses your mental activity (detected through a cap) to pilot an unmanned aircraft. You have to learn how to fly on your own, but it doesn't take long before you're merely thinking about where you want to go. And don't worry about crashing.
Mind-controlled drones promise a future of hands-free flying.

The first human brain-to-brain interface has been created. In the future, will we all be linked telepathically?

By Sebastian Anthony on September 3, 2014 at 2:27 pm | 49 Comments

There have been tentative steps into testing Brainflight, a project that uses your mind to control an unmanned aircraft. You have to learn how to think before you're merely thinking about where you want the drone to go.

International researchers are reporting that they have built the first human-to-human brain-to-brain interface, allowing two humans — separated by the internet — to consciously communicate with each other, with no additional sensory cues. One researcher, attached to a brain-computer interface (BCI) in India, successfully sent words into the brain of another researcher in France, who was wearing a computer-to-brain interface (CBI). In short, the researchers have created a device that enables telepathy. In the future, rather than vocalizing speech — or vainly attempting to vocalize your emotions — you can just think them. After all, robots can hear your thoughts, so why can't you hear their thoughts?
Mind-controlled drones: a step towards hands-free flying

There have been tentative steps into this technology and a team of European researchers just tested Brainflight, a project that uses your brain to control an unmanned aircraft. You have to learn how to consciously communicate with a researcher, attached to a device that interface in the brain of another robot.

BE CAREFUL

Mind-controlled exoskeleton prepares to kick off the 2014 World Cup

It’s showtime for the 2014 World Cup. On Thursday, one of the eight partially paralyzed men who have been training with Miguel Nicolelis’ robotic, mind-controlled exoskeletons will stand up from their wheelchair and make the opening kickoff. The technology used to do this springs from a close collaboration between Nicolelis the neuroscientist, and electrical engineer Gordon Cheng. Together they lead the Walk Project which now promises to make history.
## Summary of Neuroimaging / BCI Techniques

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<thead>
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<th>Technology</th>
<th>Electrical</th>
<th>Magnetic</th>
<th>Optical</th>
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<tbody>
<tr>
<td>Name</td>
<td>EEG</td>
<td>ECoG</td>
<td>Intracortical</td>
</tr>
<tr>
<td>Invasive</td>
<td>☑️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Portable</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
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<tr>
<td>Cost</td>
<td>From $100 to $30,000+</td>
<td>$1000 grid</td>
<td>$2000 per array</td>
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<tr>
<td>Temporal resolution</td>
<td>50 ms</td>
<td>3 ms</td>
<td>3 ms</td>
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<tr>
<td>Spatial resolution</td>
<td>1+ cm</td>
<td>1 mm</td>
<td>0.5 mm - 0.05 mm</td>
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<tr>
<td>Pattern classification</td>
<td>VEP</td>
<td>ERD/ERS</td>
<td>P300</td>
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<tr>
<td>Performance</td>
<td>2 class 90%</td>
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