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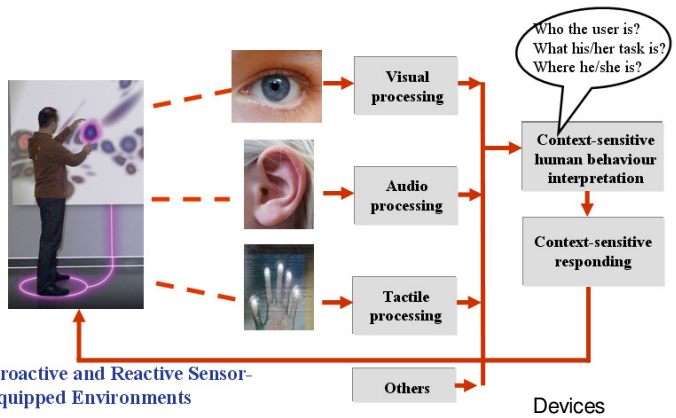
LISTEN TO YOUR BRAIN

ANTON NIJHOLT

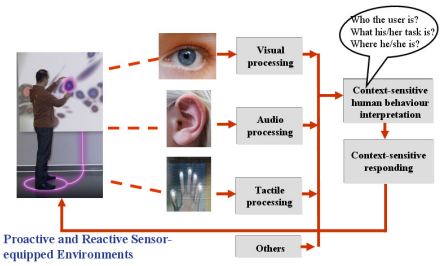
RESEARCH CONTEXT
MULTIMODAL INTERACTION



Proactive and Reactive Sensor-equipped Environments

Devices
Sensors/Wearables
Multi-party

PHYSIOLOGICAL INFORMATION
MULTIMODAL INTERACTION



OTHERS?

Physiological: skin conductivity, heart rate (variability), blood pressure, …

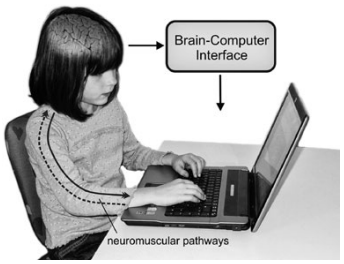
Brain Imaging: regions, functions, methods (EEG, fNIRS, …)

INFORMATION FROM THE BRAIN
WHERE DOES IT COME FROM?

Vision/Audio/Tactile/Physiological/ Position/Proximity/… Sensors => **Brain Sensors**

INFORMATION FROM THE BRAIN
TRADITIONAL VIEW

- Brain-Computer Interfaces



A BCI bypasses the normal neuromuscular output channels

- A BCI enables communication without movement
- Some patients (disabled) cannot use any interface requiring movement
- BCIs can be interesting for 'abled' users too!
  - add BCI information to other (multimodal) information that can be obtained from the user
  - applications that are designed for BCI

BRAIN-COMPUTER INTERFACES
PASSIVE AND ACTIVE

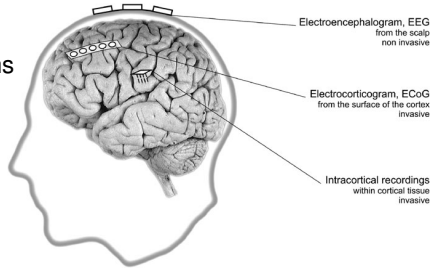
- . . . to get informed about the user's affective state (and adapt the interface)
- . . . to transform brain activity to commands to a computer, a robot, or a prosthetic device

INFORMATION FROM THE BRAIN
ACQUISITION TECHNOLOGY

- Measurement of voltage fluctuations of large populations of neurons
  - Invasive (requires surgical intervention)
    - Implant microelectrodes in the brain
  - Non-invasive
    - NIRS, MRI, MEG
    - EEG (Electroencephalography)

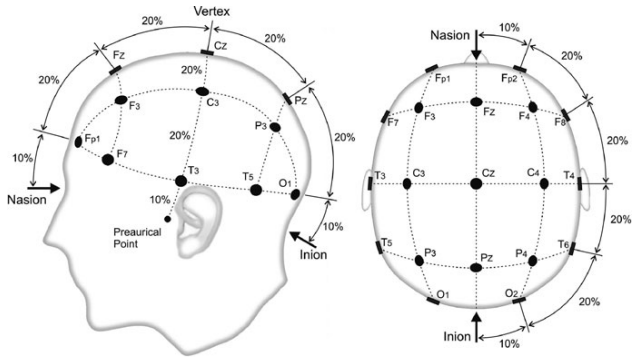
INFORMATION FROM THE BRAIN
ACQUISITION: INVASIVE AND NON-INVASIVE

- Measurement of voltage fluctuations of large populations of neurons
  - Invasive (requires surgical intervention)
    - Implant microelectrodes
  - Non-invasive
    - NIRS, MRI, MEG
    - EEG (Electroencephalography)



INFORMATION FROM THE BRAIN

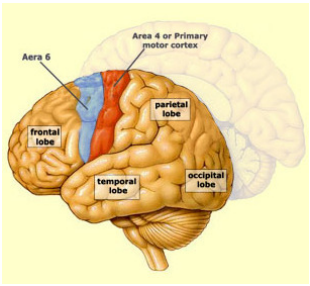
EEG: ELECTRODE POSITIONS



The International 10-20 System

BRAIN REGIONS

- Different parts of the brain are used for different functions
  - Visual cortex: processing visual information
  - Temporal lobe: memory
  - Motor cortex: planning and performing movements



Frequency + Location + Fluctuations

BRAIN ACTIVITY FREQUENCIES

- delta (< 4 Hz), sleep
- theta (4-8 Hz), drowsiness, light sleep
- alpha (8-12 Hz), relaxed state; mu is a subclass of alpha, it can be seen over the motor cortex, associated with actual or imagined movements
- beta (> 12 Hz) concentration, active thinking
- gamma (26-100 Hz) 'higher mental activity'

SOME HISTORY

- Hans Berger (1924-1931)
  - "electroencephalogram" (EEG): "brain electricity writing" (1929)
  - Alpha waves, beta waves, ….
- William Grey Walter (1936)
  - Delta waves, theta waves, …
- Herbert Jasper & Howard Andrews (1938)
  - Gamma waves, …
- Joe Kamiya (1962-1968)
  - People can recognize and manipulate (increase/decrease) their alpha waves (reward system/biofeedback)

SOME HISTORY
1968

Kamiya, J.

Conscious control of brain waves.

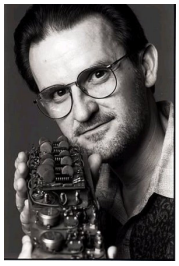
Psychology Today, 1968, 1(11) 56-60.

Indicates the possibility of teaching "man to perceive and control some of his brain functions." After Ss had learned to distinguish between alpha and nonalpha states, they were able to consciously produce the alpha state. Control of alpha rhythms was monitored by EEGs. Experienced Zen mediators "learned control of their alpha waves far more rapidly than did the average person...The possible value in studies of alpha wave control during the LSD experience" is indicated. The lack of connection between alpha waves and extrasensory perception is stressed. "No evidence of electromagnetic radiation to the outside world by brain activity..." was found. Studies with groups other than college educated Ss are suggested.

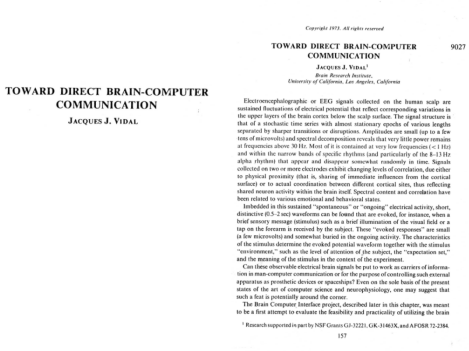
Psychology Today
J. Kamiya, based on earlier work (1962), submitted in 1966

INFORMATION FROM THE BRAIN
EARLY BCI

Mike Douglas Show, 1972



JACQUES VIDAL
1973



TOWARD DIRECT BRAIN-COMPUTER COMMUNICATION
JACQUES J. VIDAL

TOWARD DIRECT BRAIN-COMPUTER COMMUNICATION 9027
JACQUES J. VIDAL[1]
Brain Research Institute, University of California, Los Angeles, California

Electroencephalographic or EEG signals collected on the human scalp are sustained fluctuations of electrical potential that reflect corresponding variations in the upper layers of the brain cortex below the scalp surface. The signal structure is that of a stochastic time series with almost stationary epochs of various lengths separated by sharper transitions or disruptions. Amplitudes are small (up to a few tens of microvolts) and spectral decomposition reveals that very little power remains at frequencies above 30 Hz. Most of it is contained at very low frequencies (< 1 Hz) and within the narrow bands of specific rhythms (and particularly of the 8–13 Hz alpha rhythm) that appear and disappear somewhat randomly in time. Signals collected on two or more electrodes exhibit changing levels of correlation, due either to physical proximity (that is, sharing of immediate influences from the cortical surface) or to actual coordination between different cortical sites, thus reflecting shared neuron activity within the brain itself. Spectral content and correlation have been related to various emotional and behavioral states.

Imbedded in this sustained "spontaneous" or "ongoing" electrical activity, short, distinctive (0.5–2 sec) waveforms can be found that are evoked, for instance, when a brief sensory message (stimulus) such as a brief illumination of the visual field or a tap on the forearm is received by the subject. These "evoked responses" are small (a few microvolts) and somewhat buried in the ongoing activity. The characteristics of the stimulus determine the evoked potential waveform together with the stimulus "environment," such as the level of attention of the subject, the "expectation set," and the meaning of the stimulus in the context of the experiment.

Can these observable electrical brain signals be put to work as carriers of information in man-computer communication or for the purpose of controlling such external apparatus as prosthetic devices or spaceships? Even on the sole basis of the present states of the art of computer science and neurophysiology, one may suggest that such a feat is potentially around the corner.

The Brain Computer Interface project, described later in this chapter, was meant to be a first attempt to evaluate the feasibility and practicality of utilizing the brain

[1] Research supported in part by NSF Grants GJ-32221, GK-31463X, and AFOSR 72-2284.

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J. Vidal. "Toward Direct Brain-Computer Communication", in Annual Review of Biophysics and Bioengineering, L.J. Mullins, Ed., Annual Reviews, Inc., Palo Alto, Vol. 2, 1973, pp. 157-180.

Control External Devices

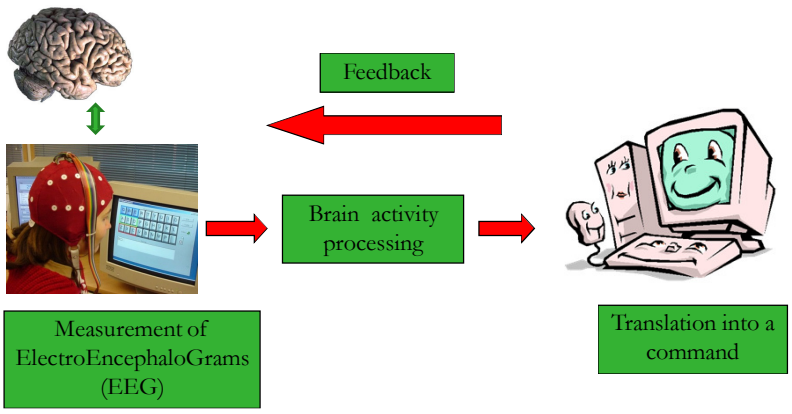
"Can these observable electrical brain signals be put to work as carriers of information in man-machine communication or for the purpose of controlling such external apparatus as prosthetic devices or spaceships?"

- Spontaneous EEG
- Evoked responses by sensory stimulation

Real-Time

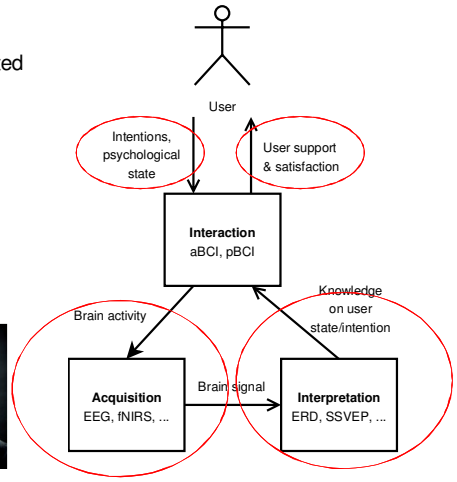
"All these methods are geared to a type of computer procedure known as batch processing, where data sets are created during an experiment and analyzed later. None of them is readily amenable to the interactive, on-line, real-time feature extraction that the present project demands."

BRAIN-COMPUTER INTERFACE CYCLE
TRADITIONAL VIEW



INFORMATION FROM THE BRAIN
BCI MARKERS

- Event Related Potentials
- Evoked Potentials
- Imagery
- Relaxation
- Focus
- Emotion
- …..



INFORMATION FROM THE BRAIN
WHERE DOES IT COME FROM?

Voluntary/Involuntary

- Active BCI
  - The user intends to interact, initiates brain activity voluntarily
- Reactive BCI
  - The user intends to interact, brain activity is generated involuntarily, in reaction to exogenous stimulation
- Passive BCI
  - The user does not intend to interact, system monitors the user (e.g. attention level, cognitive load) and adapts task or environment

EXAMPLE BCI MARKER
ERP

- ERP (Event Related Potential)
- Anticipate an auditory, visual or somatosensory stimulus. About 300 ms after appearance of the stimulus a positive peak occurs over the parietal cortex
- 'Oddball' paradigm (high-probability vs low-probability events)
- E.g., faces vs non-faces

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EXAMPLE: P300 BRAIN TYPING
EVENT RELATED POTENTIAL

- Anticipate an auditory, visual or somatosensory stimulus. About 300 ms after appearance of the stimulus a positive peak occurs over the parietal cortex

These 2 flashes illuminate the target letter K.
The user counts these flashes.

These 2 flashes do not illuminate the target letter K.
The user ignores these flashes.

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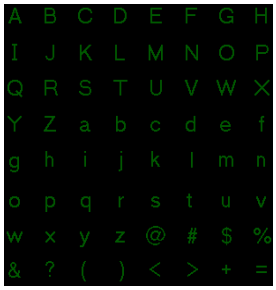
Example: P300 Brain Typing

Your brain produced different EEGs in response to ignored vs. counted flashes

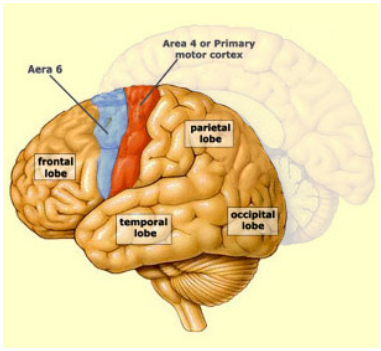


EXTERNALLY EVOKED POTENTIALS

- **VEP** Visual Evoked Potentials (visual stimuli)
  - Depends on oculo-motor control
  - Visual cortex
- **AEP** Auditory Evoked Potentials (auditory stimuli)
  - Auditory cortex
- **SEP** Somatory Evoked Potentials (tactile stimuli)
  - Somatosensory cortex

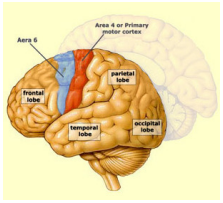
IMAGERY MOVEMENT
MOTOR IMAGERY

- The motor cortex is the brain area most involved in movements
- The motor cortex receives information from the various lobes of the brain: information about the body's position in space; about the goal to be attained and an appropriate strategy for attaining it; about memories of past strategies; and so on



MOTOR CORTEX ACTIVITY
MOVEMENTS

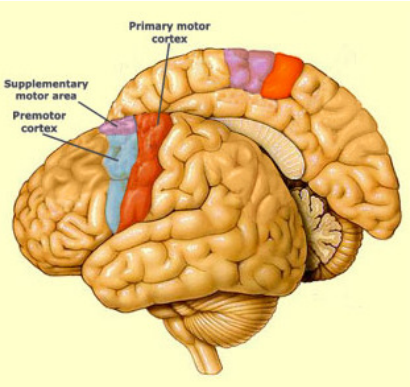
- Movements
  - intending to move
  - imagine to move
  - perform a move,
  - observe a move

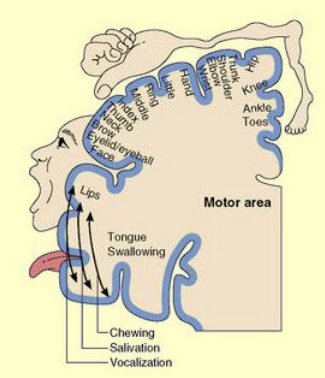


- Imagining evokes similar brain activity in the motor cortex as intending, performing and observing the actual movement
- Motor Imagery: imagine the performance of a movement

MOTOR CORTEX ACTIVITY

MOTOR MAP





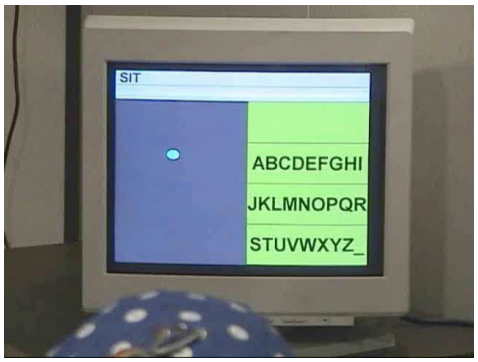
Every part of the body has a particular region of the primary motor cortex that controls its movement

EXAMPLE: MENTAL TASK BCI

MARVIN MINSKY & EMOTIV

SOME EXAMPLES

- Motor imagery
- P300
- Motor imagery



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BCI AND GAMES

WHY GAMES?
GREAT TEST GROUND

- Lots of Movements
  - Navigate, control objects (swords), avoid obstacles, …
  - Designed motor imagery tasks can play a natural role in games
- Lots of Expectations, Anticipations, Recognition, and Decision Making
  - Designed evoked and event related potentials can be used by the gamer to make decisions, show preferences
  - Designed event related potentials can play a natural role in games
- Robustness is not necessarily an issue
  - Turn shortcomings into challenges
- Lots of Possibilities to Adapt to the Gamer
  - Environments and offered capabilities can be adapted to the mental state of the gamer
- Gamers are Early Adopters, Looking for New Challenges, Extremely Large Number of Gamers, Economic Value, …

ENTERTAINMENT VS SERIOUS GAMES?

- Entertainment games
  - Play, challenges, cooperation, competition, communication, decision-making, skills, learning, …
- Edutainment games
  - Explicit learning goals
- Serious games
  - Game designed for a primary purpose other than pure entertainment
  - Simulations of realistic situations, training, safe failures

MEDICAL EEG-BASED SERIOUS GAMES

- Neurofeedback games
  - enhancement of attention and cognitive skills
  - therapies for psychological disorders: ADHD, ASD, GAD, SUD, ….
- BCI games for rehabilitation exercises
  - retain motor control
  - Brain-Kinect interface

Thirty Minutes Of Gaming A Day Makes Your Brain Bigger: Science

Could 30 minutes a day keep the neurologist away? posted on October 31, 2013

Joseph Bernstein BuzzFeed StaffFor years, proponents of video games as more than idle time-wasters have argued that the act of playing games can in and of itself boost brain function. A study published yesterday by researchers from the Max Planck Institute for Human Development, in the prestigious journal *Nature*, may be the best proof yet that regularly playing video games can actually make your brain more powerful.

It's certainly the most visceral. The study, titled "Playing Super Mario induces structural brain plasticity: gray matter changes resulting from training with a commercial video game," found that people who played at least 30 minutes of *Mario 64* every day for two months actually grew significant amounts of new gray matter in three areas of the brain correlated with spatial navigation, strategic planning, working memory, and motor performance.

BCI FOR GAMES: 'ONE TRICK' GAME
PIN BALL

BCI FOR GAMES: 'ONE TRICK' GAME
BRAIN PONG

Noisy environments
No training

BCI EMBEDDED IN GAMES
WORLD OF WARCRAFT

Blizzard Entertainment

MMORPG

2006: about 11 million players
2013: 7,7 million subscriptions

BCI EMBEDDED IN GAMES
WORLD OF WARCRAFT

- alphaWoW: Multimodal (keyboard/mouse + BCI)
  - Becoming angry/acting angry
  - Becoming relaxed/acting relaxed

BCI EMBEDDED IN GAMES
WORLD OF WARCRAFT

BCI EMBEDDED IN GAMES
WORLD OF WARCRAFT

20 July 2009:
Visit to Blizzard Entertainment HQ, Irvine, CA

BCI: INTEGRATING BRAINS
MULTIPLE BRAINS: BRAINBALL

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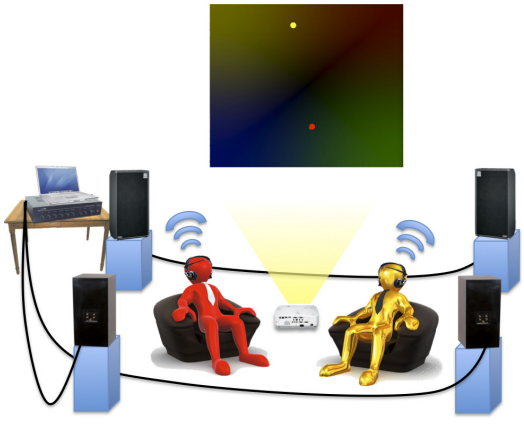
BCI: INTEGRATING BRAINS
MULTIPLE BRAINS: MOOD MIXER



MoodMixer

- Sonification
- Visualization
- Relaxation/Focus
- Multibrain

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BCI: MULTIMODAL GAME
MIND THE SHEEP!

- Multimodal
  - Mouse/Wii
  - BCI (SSVEP, P300)
- Multiplayer
- Preference of paradigms/modalities
- Social interaction wrt modalities

BCI: MULTIMODAL MULTI-PARTY GAME
MIND THE SHEEP!

Multimodal & multi-player

Collaboration & social interaction

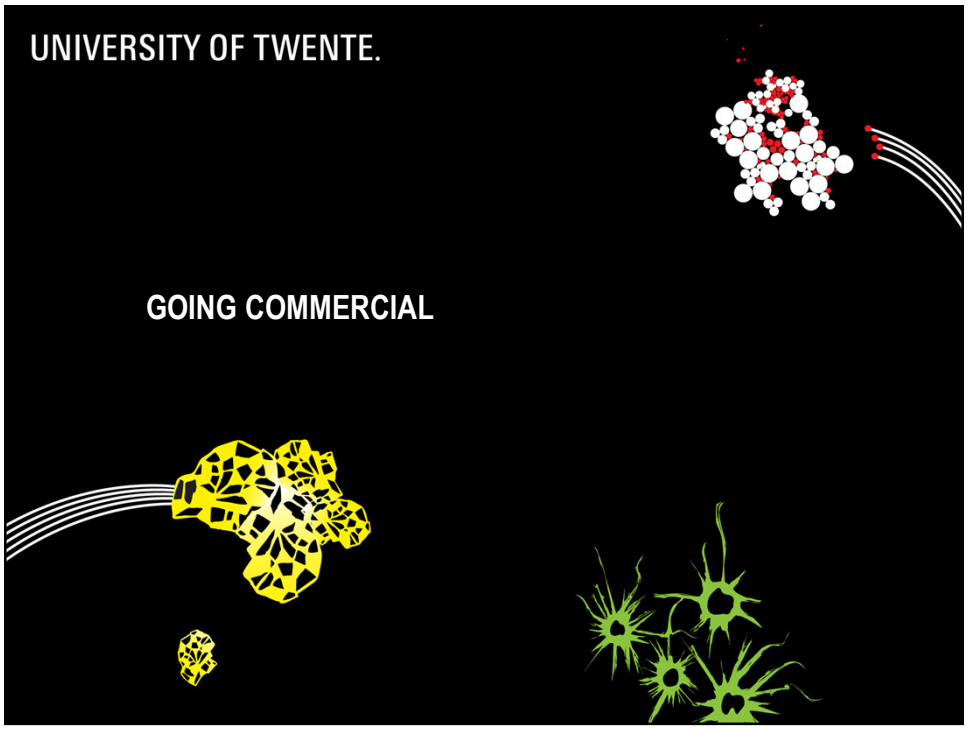
EXAMPLE: BCI MULTI-PARTY GAME

PHYSICAL AND PHYSIOLOGICAL PERFORMANCE

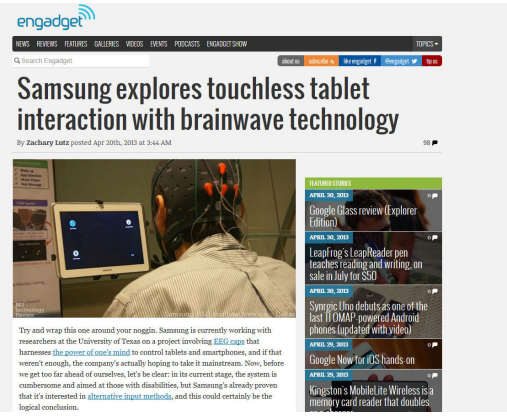
Multimodal, Multiplayer, but ….

- Physiologically Modulated Videogame (FPS)
- Controller: Wii Zapper
- Competition/Collaboration

NASA: interpersonal interactions may be mixes of competition and cooperation for simulation training

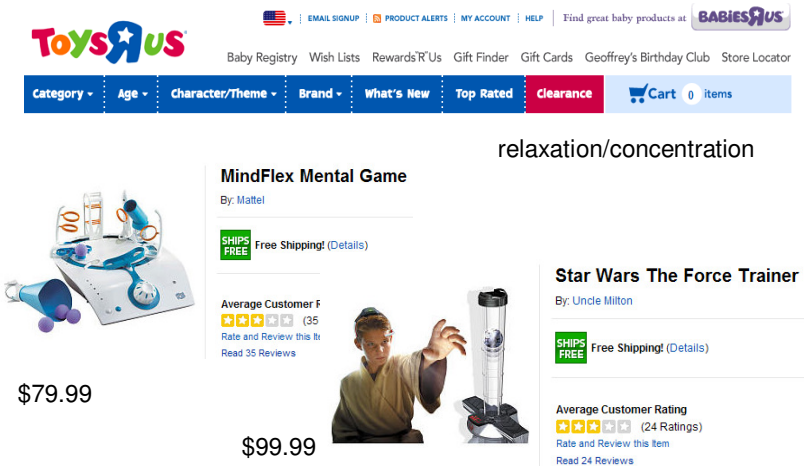


GOING COMMERCIAL
SAMSUNG BCI TABLET



Microsoft
Sony
Samsung

GOING COMMERCIAL
BCI GADGETS



relaxation/concentration

$79.99

$99.99

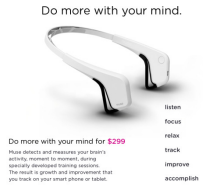
GOING COMMERCIAL
BCI GADGETS

Shippo

GOING COMMERCIAL
STYLISH DEVICES

Interaxon Muse

Emotiv Epoc

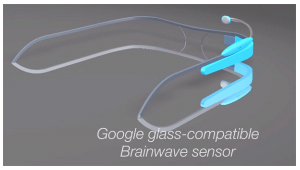


Emotiv Insight

GOING COMMERCIAL
INTEGRATION

Google Glasses

Ocular Rift



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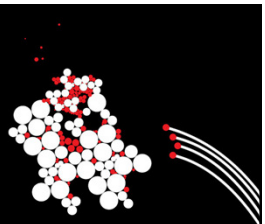
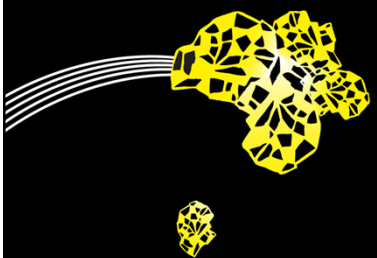


BEER TAP THOUGHT CONTROL
INTERMEZZO

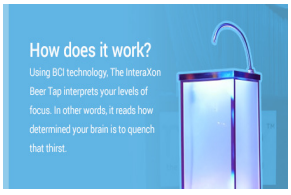


BEER TAP THOUGHT CONTROL
EXERCISE

Real Life Situation

Research Simplification

BEAR TAP THOUGHT CONTROL
EXERCISE



- Imagine a nice cold mug of beer. Now imagine how you could actually pour one for yourself simply by using the power of your brain.

- Wearing a Muse headband, you stand in front of the Beer Tap and concentrate as your brainwaves are transmitted to a computer and interpreted as ‘relaxed’ or ‘focused’. When these signals exceed a certain threshold, the beer spout opens. The result? Your thoughts are turned into a frosty serving of beer right before your eyes.

… AND HOW TO CHOOSE BETWEEN BEER TAPS?

OTHER BCI PARADIGMS

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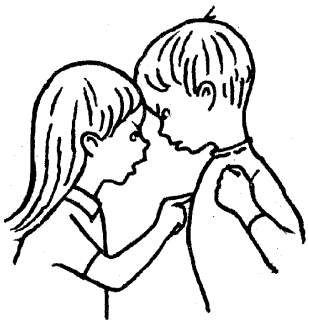
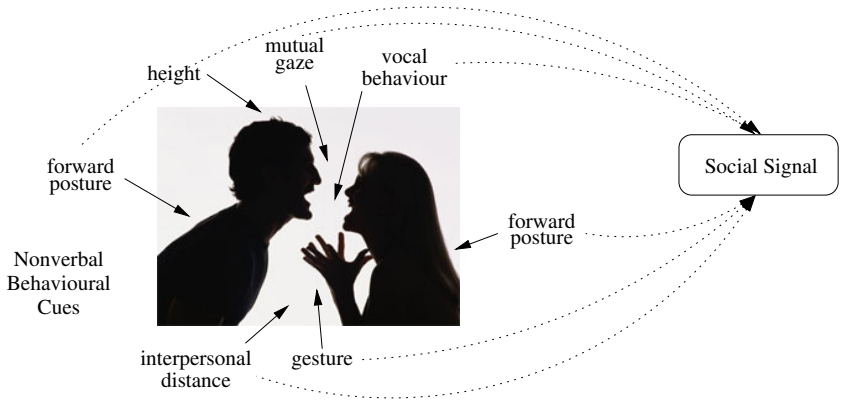
SOCIAL SIGNAL PROCESSING AND BCI

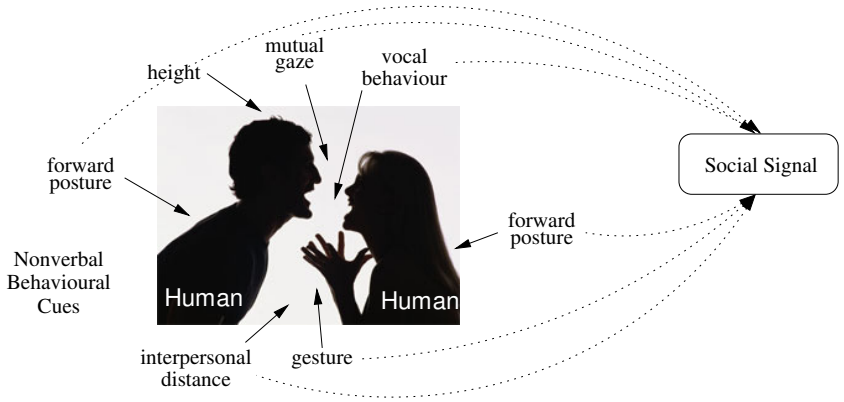
RESEARCH CONTEXT
INTERACTION BEHAVIOR



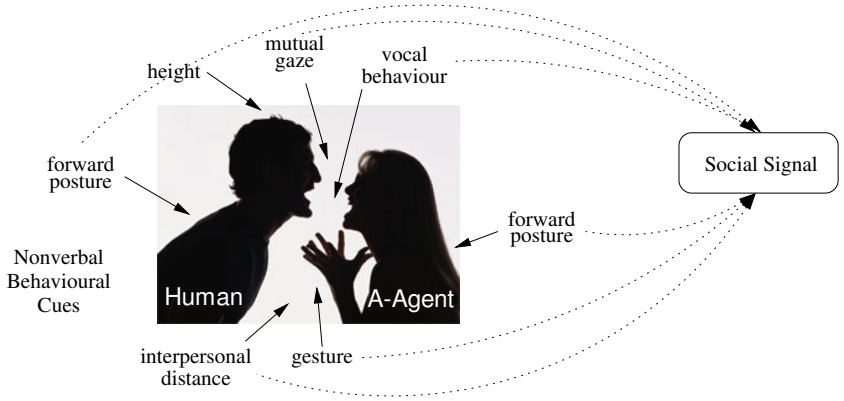
INFORMATION FROM INTERACTION BEHAVIOR
SOCIAL SIGNALS



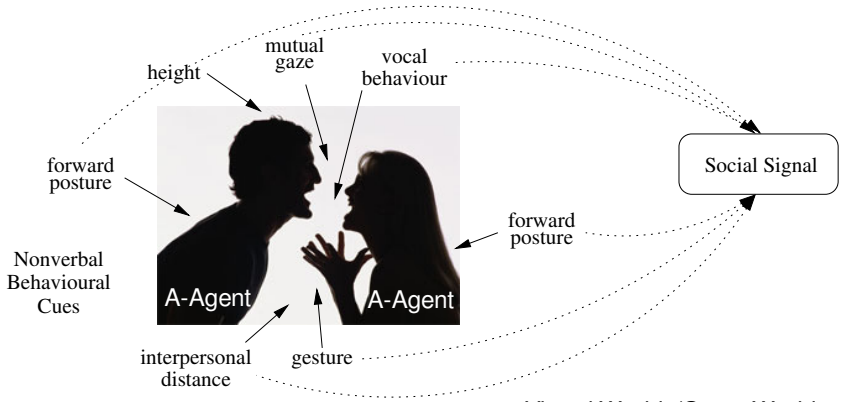
INFORMATION FROM INTERACTION BEHAVIOR
SOCIAL SIGNALS



INFORMATION FROM INTERACTION BEHAVIOR
SOCIAL SIGNALS



INFORMATION FROM INTERACTION BEHAVIOR
SOCIAL SIGNALS



Virtual Worlds/Game Worlds

AUGMENTING INTERACTION BEHAVIOR
SOCIAL SIGNALS

Human	Human
Human	Agent
Augm Human	Human
Augm Human	Agent
Augm Human	Augm Human

Social Signals Generated

Social Signals Perceived

Social Signal Tools
Wearables that detect, strengthen, visualize social signals:
BCI (Epoc/EmotivInsight/Neurosky), Shippo, Oculus Rift, Google glasses, Brain Stimulation (Foc.us), Vesty, …

Voluntarily/Involuntarily

AUGMENTING INTERACTION BEHAVIOR
VESTY

NEUROTIQ
EXTERNALIZING INTIMACY

NEUROTiQ is a wearable fashion accessory that combines knitted and 3d printed elements with Emotiv's 14 sensors brain-computer interface technology.

NEUROTiQ turns brain activity into colorful lights that correspond to specific brain states.

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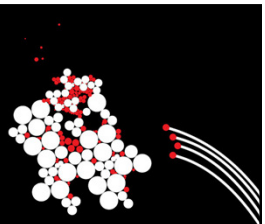
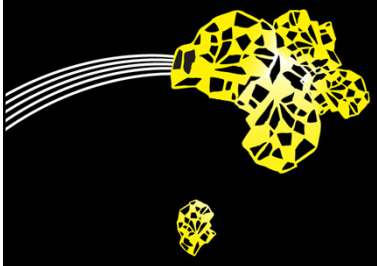
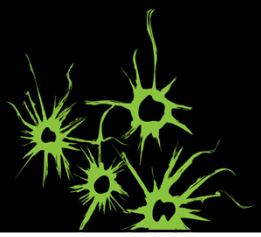
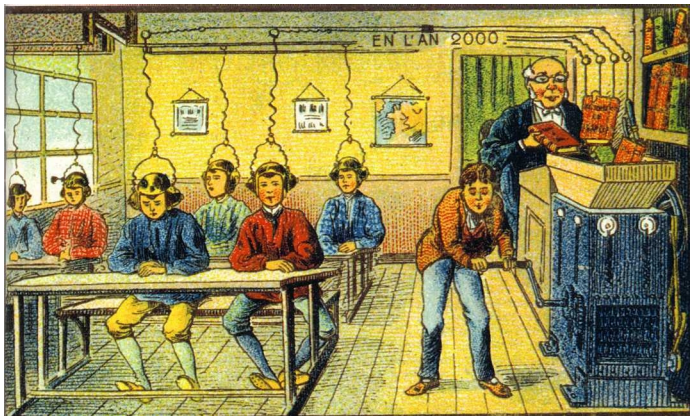


BRAIN STIMULATION
& MONITORING & GAMING





NOT BCI?
BRAIN STIMULATION



GOING COMMERCIAL
BRAIN STIMULATION GADGETS

This Gaming Headset Shoots Electricity Into Your Brain. Seriously

GOING COMMERCIAL
BRAIN STIMULATION GADGETS

- Overclock your brain using transcranial Direct Current Stimulation (tDCS) to increase the plasticity of your brain. Make your synapses fire faster.
- Excite your prefrontal cortex and get the edge in online gaming
- Anodal or cathodal stimulation of the prefrontal cortex using 2 x 2 focused electrode array.

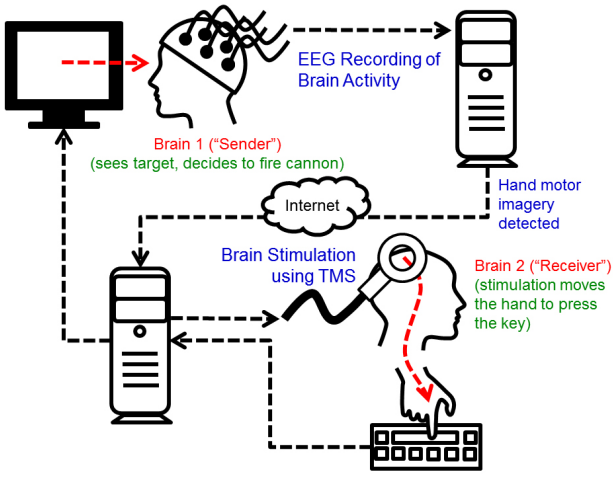
BRAIN STIMULATION
MORE SERIOUS MONITORING AND STIMULATION

- High resolution tCS with simultaneous EEG monitoring

tCS?

- transcranial Current Stimulation is a form of neuromodulation which uses low current delivered directly to the brain via small electrodes

EXAMPLE: FUTURE GAMES?
MONITORING AND STIMULATION



University of Washington

Rao, R.P.N., Stocco, A. (2013) Direct brain-to-brain communication in humans: A pilot study.

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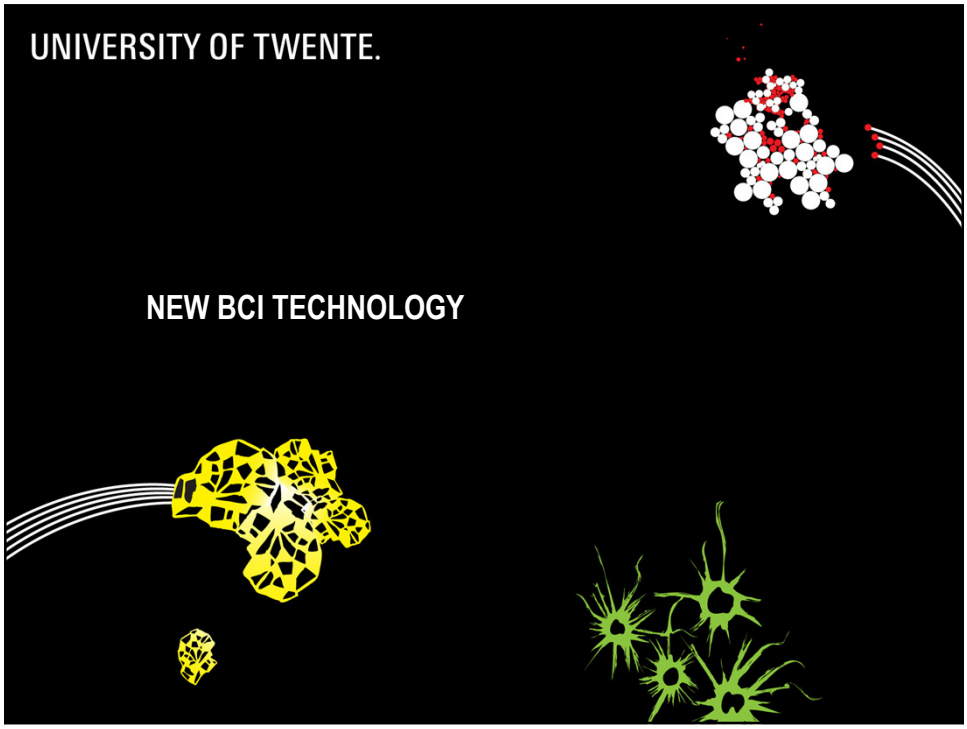
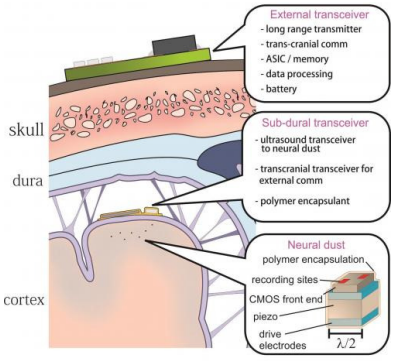


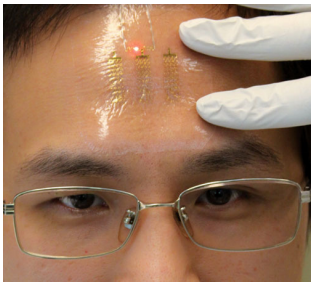
NEW BCI TECHNOLOGY

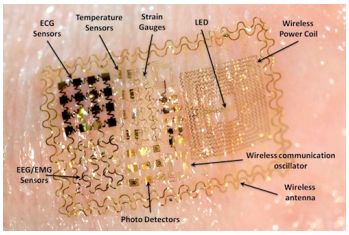
SCIENCE & TECHNOLOGY
NEURAL DUST



- Sprinkle electronic sensors the size of dust particles into the cortex and to interrogate them remotely using ultrasound. The ultrasound also powers this so-called neural dust.
- Each particle of neural dust consists of standard CMOS circuits and sensors that measure the electrical activity in neurons nearby

SCIENCE & TECHNOLOGY
BCI TATTOOS





(Temporary) Tattoos
- EMG
- EEG
  - P300 detection

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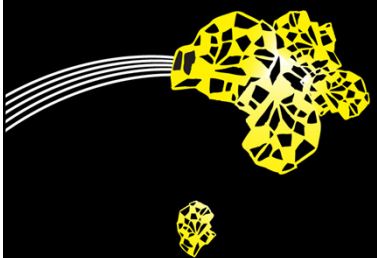
CONCLUSIONS



CONCLUSIONS
BCI APPLICATIONS

- Previously
  - Many 'applications' were one-trick only
  - Many applications assume disabled users
- Now and Future
  - Design interfaces that use input from various BCI markers
  - Embed BCI in Intelligent (AI) and Multimodal Interfaces
  - Develop Multi-Party and Multi-Brain applications
  - Develop BCI applications in 'natural' situations, including (face-to-face) Human-Human Interaction
  - Further development of BCI technology and commercial devices

THANKS TO
DUTCH AND EUROPEAN UNION PROJECT FUNDING

- Dutch National BrainGain project
- EU Future BNCI Road Mapping project (2010-2012)
- EU BNCI 2020 Road Mapping project (2013-2015)

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THANKS

MORE TO READ
BOOKS