Physiological Measurement Tutorial Overview

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Abstract

This document is a tutorial for using physiological measurement and biosignal acquisition techniques in the areas of human-computer interaction and neural engineering. The content is presented in extended outline form, and is intended for instruction and quick reference. Several references are made to Biopac and AcqKnowledge products, although the techniques can be applied to other systems. Background on physiological phenomena and analytical techniques are also provided.

Why would you want to use these methods?

1. For control: record signals, decode them using statistical learning and signal processing methods, and map to control states.

Examples: record muscle activity, decompose signal, map to the buttons on a cell phone.

2. For experimentation: free-viewing, continuous stimulus, decode signals using statistical and signal processing methods, find differences between stimulus epochs or control vs. treatment conditions.

Examples: view a movie, decompose signal, analyze results (time-series sensitive statistics).

Basic characteristics: electrophysiological methods = electrical activity in the central and peripheral nervous systems.

> Electrical activity generated by action potentials (ECG, EEG), muscle contraction as a result of action potentials (EMG), and membrane potentials across the skin (EDA).
>
> Contrast with methods that utilize hemodynamic activity (MRI, NIRS), glucose metabolism (PET), or radiation (X-rays).

Electrical signals can be recorded at the skin surface. Signal must be captured, channeled, denoised, and amplified.

> **Electrode:** use gel to decrease impedance, increase capacitance of signal (check using impedance meter.
>
> **Lead and amplifier:** signal gets amplified, and systematic noise (e.g. 60 Hz electrical noise) removed.

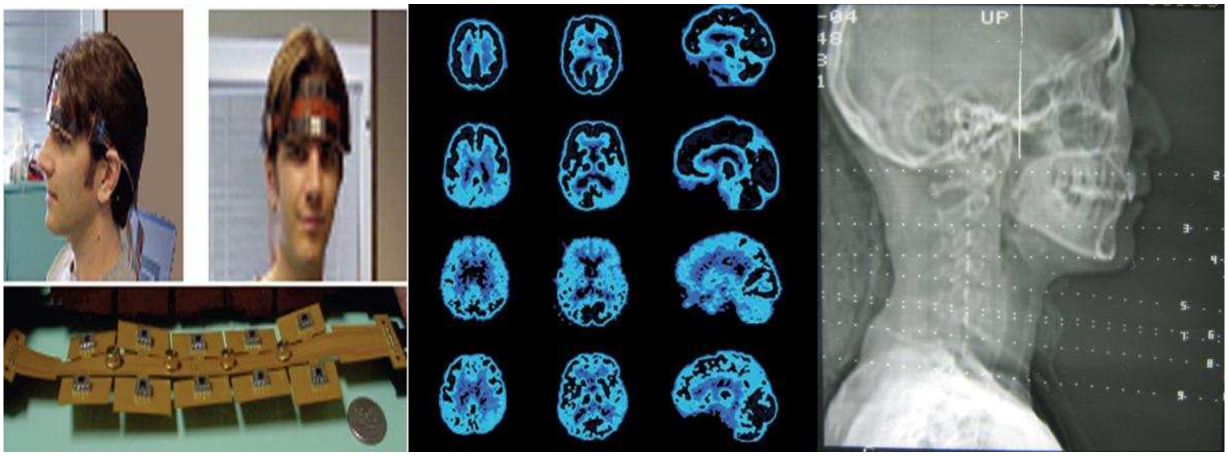

Figure 1. Other, non-electrophysiological measurement techniques (from L to R: NIRS (near-infrared imaging -- fNIR system shown), PET (positron emission tomography), and x-ray technology.

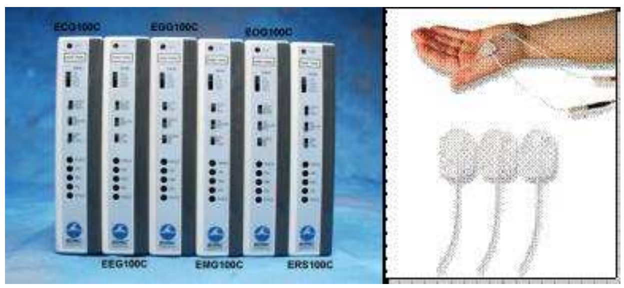

Figure 2. Left: a series of Biopac amplifiers connected in parallel. Right: a series of surface electrodes with one affixed to the skin.

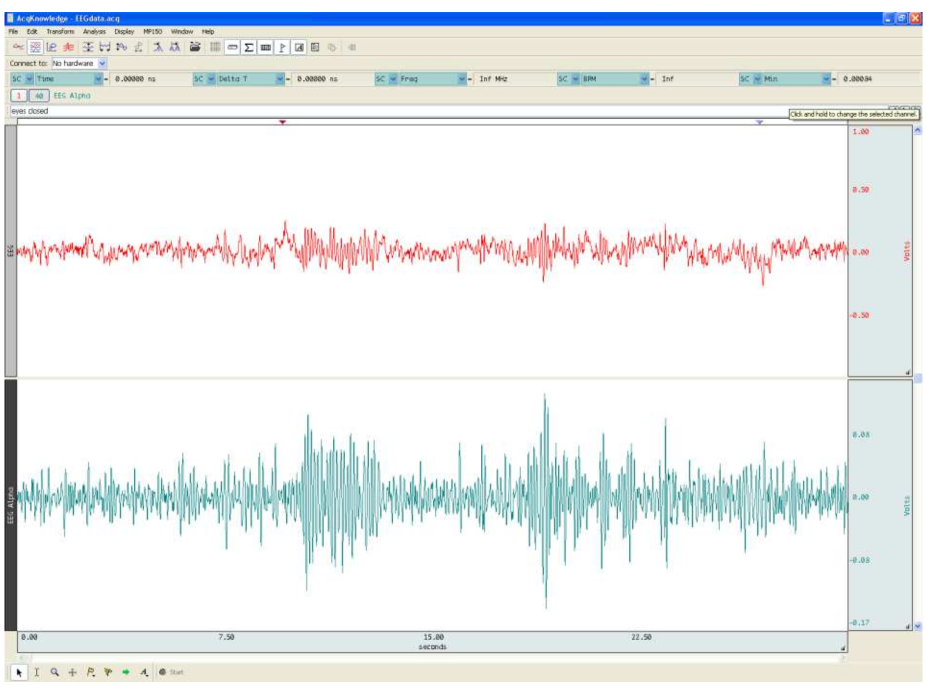

Figure 3. A sample template for EEG set up in AcqKnowledge. Top channel is signal acquisition, Bottom channel is calculation channel (an on-line spectral analysis)

AcqKnowledge software interface: GUI that organizes, analyzes, and refines signal (a specific output channel for each signal).

Raw channel (needed for each amplifier used).

Processing channel (used for calculating heart rate, integrated signal, rectification, and smoothing).

For more information, please see: Reference [1], Chapter 1 (introduction), 3, 4, and 5 (equipment, recording, and principles), and 15 (applications)

EEG: Electroencephalography. In this method, electrodes are used to capture local field potential[1] activity in brain. Electrodes can be brought close to surface of scalp via a nylon cap.

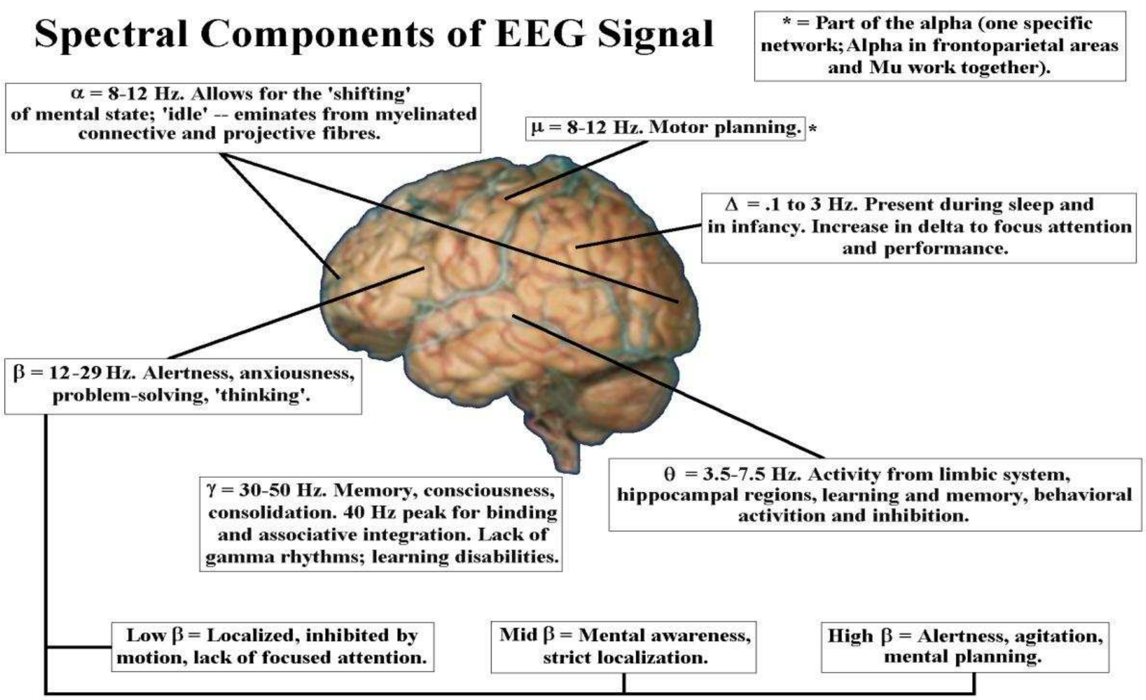

Figure 3. Map of spectral components found in brain wave activity.

EEG (at the surface) is most effective for cortical structures (those that involve "cognitive"-related functions). However, EEG also understood for internal structures[2].

Hemispheric EEG: two electrodes (one per amplifier) used to detect activity (gross spatial resolution, fine temporal resolution).

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[1] electrical (neuronal) activity in cell populations. Field potentials produced by cells that modulate each other.

[2] hippocampal θ associated with spatial navigation in clinical populations with implanted electrodes.

Left vs. right hemisphere or anterior vs. posterior (depending upon hypothesis).

Multichannel EEG: 2n electrodes, up to 256. This has better spatial resolution than hemispheric EEG, fine temporal resolution.

Dipole modeling: general localization of signal in brain using array signal processing methods (the more electrodes, the better).

Event-related potential: series of trials, stimulus triggers a change in signal. P300 and N50 = positive-going waveform 300ms post-stimulus and negative-going waveform 50ms post-stimulus, respectively.
Signal components: α, β, γ are extracted from single or multiple channels (depending on hypothesis) using a spectral analysis.

α is activity in the 7-13Hz band. Power (voltz/Hz) determines how much of this signal represents brain activity.

α = resting state, early stages of sleep, β = wakeful consciousness, γ = REM sleep, wakeful consciousness. Usually all are present in brain wave activity recorded at any single point in time.

Muscle, eyeblink artifact: remove using AcqK software, EOG,and EMG.

For more information, please see: Reference [1], Chapter 2 (neurons) and 7 (brain).

EMG: Electromyography. In this method surface electrodes are used to capture signals from skeletal muscle bodies. Electrodes placed on opposite ends of muscle length (electrical dipole).

Multiple channel systems used for operating prosthetics in rehabilitation settings.

Model: motorneurons (fire action potentials), synapse on skeletal muscle in face, limbs. Brain makes a demand of the muscle via motorneurons, muscles respond by contracting. Muscle fibres (slow, fast, and fast fatigue) work in different proportions in various muscles to produce a movement output (e.g. muscle contraction).

Evolutionarily, this has been varied within and between species. In toadfish, the swim bladder is powered by slow fibres (swimming) and superfast fibres (mating calls). These fibres are activated in a mutually exclusive fashion, which is not true of muscle fibres in human skeletal muscle. Across humans, variation is found in the number of fibre types found in each muscle. This results in individual differences for different types of physical activities. For example, some people are optimized for sprint running, while others are optimized for endurance running.

As the firing rate of muscle increases, the spectral signature of the signal has more power at higher frequencies.

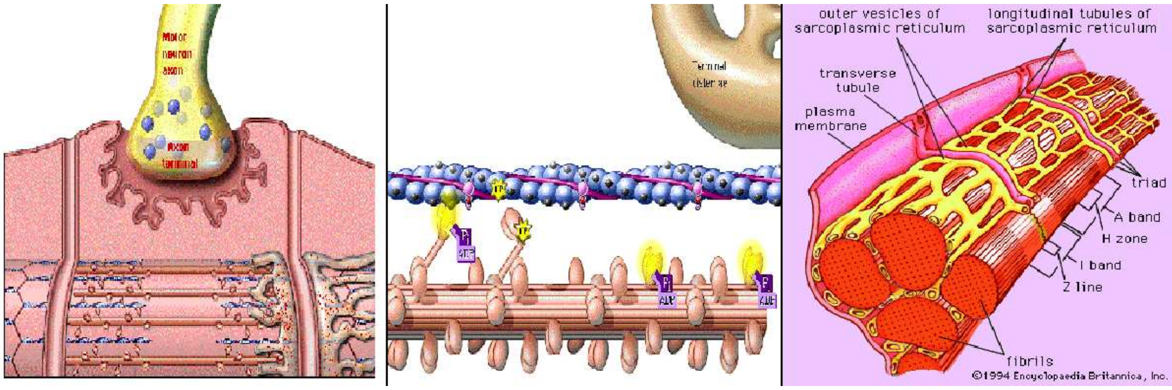

Figure 4. Left: motorneuron synapsing on muscle (neuro-muscular junction), center: muscle at the molecular scale as it is contracting and using ATP, right: a cross-section of a muscle fiber (center and right demonstrate sliding filament theory, an idea central to how muscles function).

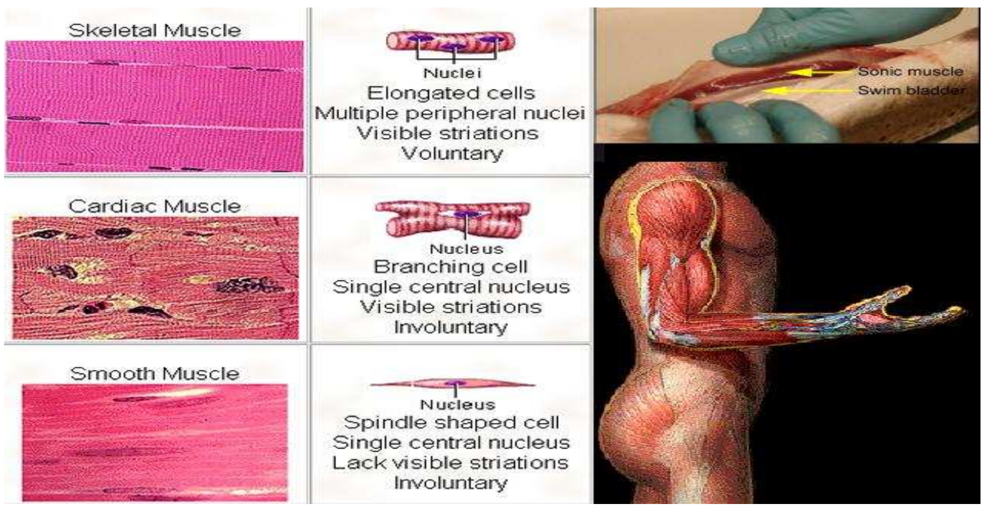

Figure 5. Left: different type of muscle in the human body. Upper right: two muscles made of different fiber types in toadfish, Lower right: cross section of muscles (showing muscle bodies) in human arm.

Peaks in the raw signal represent a single incident of muscle contraction. This can be correlated with the onset of a stimulus (autonomic response) or with force output/kinematics (muscle power).

Use IIR (infinite-impulse response) filter (analysis function) or integrated filter (calculation channel) to remove ECG artifact.

Cognitive-related measurement example: eyeblink conditioning. Blinking of the eye can be associated with a conditioned stimulus (a loud distractor noise). In rabbits, this is referred to the nictating membrane response, and involves cerebellar-based motor learning mechanisms.

EMG can be measured by placing electrodes immediately above and below the eye socket (on the muscle bodies).

A visual scene can be used as an unconditioned stimulus (primary stimulus), and a loud distractor tone can be used as a conditioned stimulus (presented randomly over the course of the primary stimulus activity).

EMG activity corresponds with an eyeblink event. Delivery of tone in time should be correlated with eyeblinks once association is learned. Two predictions can be made:

Distractor tone will affect performance on primary activity. Eyeblink (measured through EMG signal) should predict decrements in performance.

Operant conditioning predicts that association of eyeblinks with auditory cue will persist even in absence of primary stimulus (a "muscle memory").

For more information, please see: Reference [1], Chapter 8 (muscles).

ECG: Electrocardiogram. In this method, a set of electrodes are used to capture electrical activity from circulatory system. This can be measure by placing electrode over an artery or vein.

Organization in evolution: humans have single, four chambered hearts, while fishes have single, two-chambered hearts, and hagfishes have multiple hearts in decentralized anatomical locations. Why is this?

Heart is made of cardiac muscle that is driven by pacemaker neurons. Contraction in the heart is a function of circulatory complexity. In humans, the QRS complex is produced (complex, multicomponent waveform).

This QRS complex can be decomposed to yield heart rate, inter-beat interval, and other information.

Demands of circulatory needs: brain does more work, muscles and brain need more energy (ATP production produces heat energy, oxygen needed to fuel metabolism, thermoregulation delivered).

Regulation also based on autonomic function (sympathetic and parasympathetic nervous systems). Emotional stimuli can increase rate at which blood is pumped through the body (reoxygenated), and increases heart rate.

Match to stimuli: external stimulus can drive increases or decreases in heart rate, inter-beat interval.

For more information, please see: Reference [1], Chapter 12 (cardiovascular).

EOG: Electrooculogram. In this method, retinal potentials related to eyeball movement are measured. Specifically, they are related to contraction of extraocular muscles.

Measures eye movement to remove eyeblink artifact from EEG (AcqK does this automatically).

Can also use EOG as an eyetracking indicator, and can be done with a bit of tinkering.

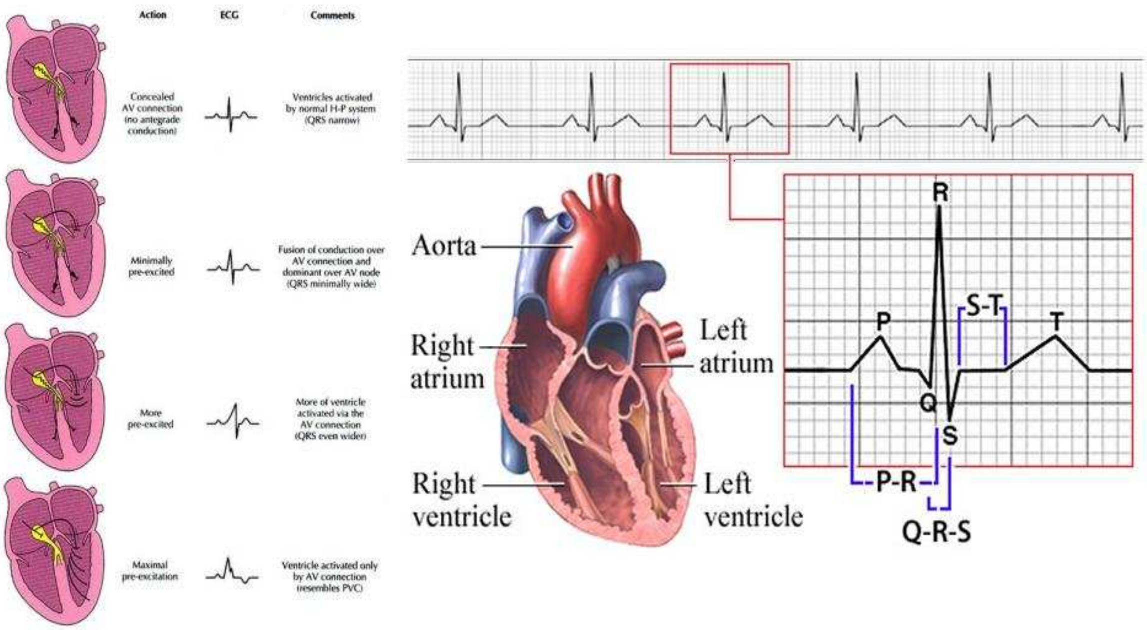

Figure 6. Human four-chambered heart functional anatomy in relation to the QRS complex. Heart rate (HR) and IBI (inter-beat interval) calculated from the different components.

EDA: Electrodermal response. This method is also called skin conductance, and measures potentials at surface of skin. As part of generalized stress response, autonomic responses to emotional stimuli dilates pores in skin, electrical capacitance across skin surface increases.

Galvani: a historical figure who did experiments with bioelectricity. He is often considered to be a pioneer in understanding EMG and EDA (this is why EDA is sometimes called Galvanic Skin Response - GSR).

Gradual response (measured in microsiemans). Used primarily as an indicator of emotional state.

Used in lie detection (what people usually mean when they refer to a lie detector test). This is just one indicator of measuring "lying" vs. "truthfulness". Like ECG, EDA relies upon sympathetic and parasympathetic systems-level regulation. Also means that you cannot simply use a single indicator to arrive at a conclusive result.

Mythbusters problem-solving example: In the "Mind Reading" episode of "Mythbusters", the team built an EDA amplifier and hooked it up to a houseplant. They then smacked the plant's vascular tissue and hurled insults at it. There was electrical activity on the oscilloscope, but the question is whether or not a meaningful pattern existed in their results.

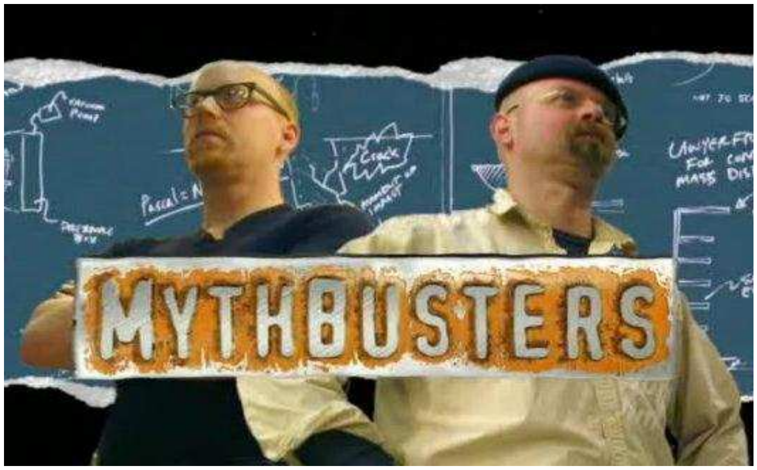

Figure 7. The Mythbusters logo.

Why or Why not?
* plant vascular tissue has a network of pores and ion channels similar to human skin (electrical activity).

But
* plant does not have a unified nervous system (no unified response, significant pattern).

In addition
* ambient electrical signals (from lights, other devices) and motion artifact can produce stochastic signal (random process, but can be filtered out).

For more information, please see: Reference [1], Chapter 13 (skin).

Analytical techniques:

Signal is continuous and NOT independently distributed in time domain (e.g. direct application of descriptive, analysis of variance statistics is limited.

Helpful hint #1: MATLAB (Matrix Laboratory) can handle large dataset such as those you will get from AcqK. Export data channels from AcqK as .txt files and import into MATLAB workspace. You can then perform a range of analyses, from simple to complex, on these data. They can then be exported in SPSS .sav format for further analysis.

Helpful Hint #2: you can use techniques such as ANOVA or a t-test in SPSS after signal has been partitioned.

Decomposition of signal needed; for example, spectral analysis (FFT, wavelets) – can be done in AcqK.

Windowing, binning, smoothing, and other techniques to group datapoints also helpful.

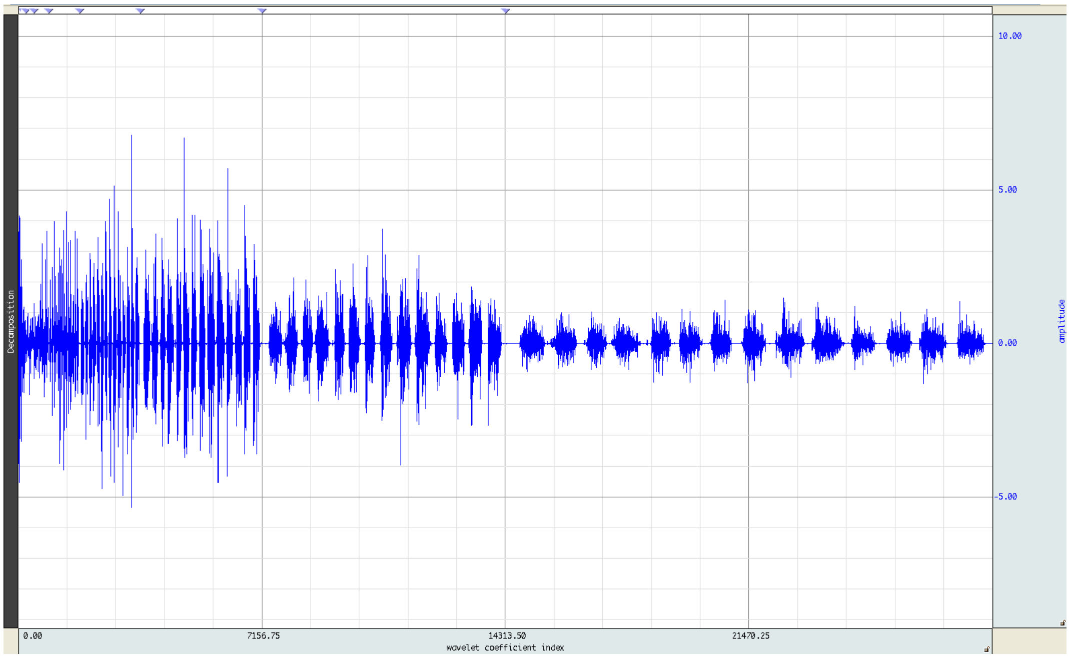

Figure 8. A wavelet-based (signal processing technique that can be done in AcqK 4.0) decomposition of EMG data.

For more information, please see: Reference [1], Chapter 14 (signal processing).

References

[1] Cacioppo, J.T., Tassinary, L.G., and Berntson, G.G. (2000). Handbook of Psychophysiology. Cambridge University Press, Cambridge, UK.

Introduction to Hybrid Bionic Systems

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Rationale

What is neurotechnology?

* a “short-cut” between the central and peripheral nervous system, technological interface, or the environment.

* the integration of neural and biological science with information technology.

* the ability to manipulate or augment the brain and behavior of an individual or group of individuals.

* a way to understand and implement “real-time” ergonomic and human factors principles to a system (adaptive fitting of the task to the user).

Background Reading

Where can we go to get a sense of the "state of the art"?

Unfortunately, not too many places (yet!). Here is a sampling:

Wikipedia site: http://en.wikipedia.org/wiki/Neurotechnology

Cyberkinetics Inc.: http://www.cyberkineticsinc.com/content/index.jsp

Neurotechnology and Neuromedia, MIT: http://neuro.media.mit.edu/

Biomechatronics, Howstuffworks:
http://health.howstuffworks.com/biomechatronics.htm/

Central Introductory Concept #1: Neurotechnology Interfaces

There are many operational examples of neurotechnological interface. These include (clockwise from upper left):

1) sensory substitution interfaces, 2) prosthetics (hybrid bionic systems), 3) cochlear implants, 4) artificial vision systems, 5) hybrots/ex-vivo neurons, 6) brain-machine interfaces, 7) .....and many other associated technologies.

Central Introductory Concept #2: learning and neuroplasticity

Many of these technologies work (and sometimes don't work!) because of a phenomenon called Neuroplasticity:

* changes in the nervous system due to training (learning) or recovery from injury. Three types: neuronal (electrical cells), synaptic (number of connections between neurons), and other cells.

* training can improve or recover function (vibrations delivered to proprioceptors at feet can improve balance, practicing tasks such as games can improve cognitive function – may induce neuronal and synaptic plasticity).

* growth of supporting tissues around implants can disrupt their function.

Central Introductory Concept #2: learning and neuroplasticity (con't)

In mammals, neurons in premotor and motor cortex contribute to the basic planning and directionality of movement (activity onset is 1-2 seconds before actual behavior):

* a "population code" (collective encoding of single behavioral events by neuronal populations) has been found to exist here:

* movement vector: Georgeopoulos et al (1987) discovered that single cell activity in the premotor and motor cortex can predict direction of movement, mental rotation, force and velocity parameters.

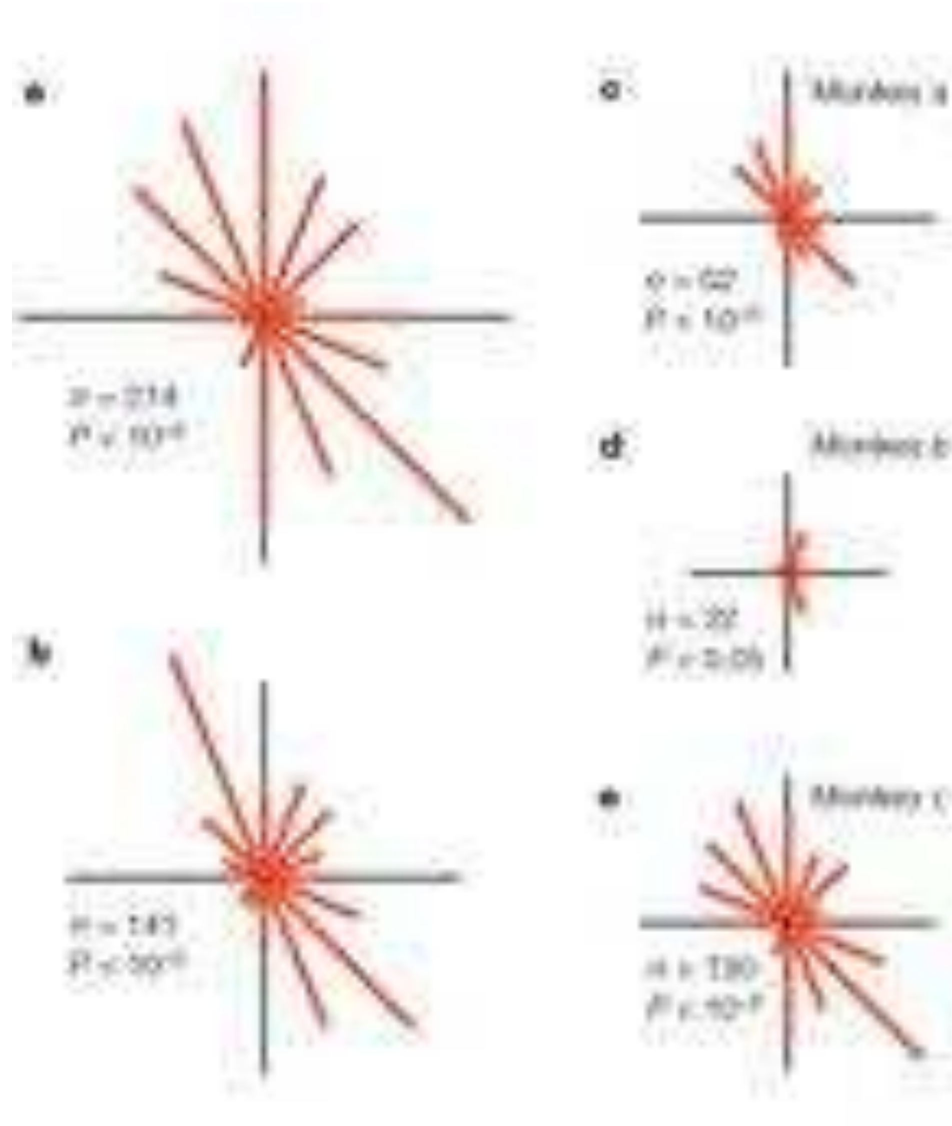
* brain-machine interfaces have used this signal as a means to drive prosthetic devices (see Carmena et al, 2003; Hochberg et al, 2006).

Central Introductory Concept #2: learning and neuroplasticity (con’t)

The collective activity of cells results in the encoding of desired behavioral states.

* average activity of a population is greatest in a certain direction (e.g. 45, 90, 155 degrees from straight ahead).

* population coding also An issue for other functions (memory encoding, etc)



Central Introductory Concept #3: real-time behavior and physiology

Many of these technologies also work (or don't work!) based on real-time assessments of behavior and physiology:

* many behavioral experiments are single-trial assessments of a response to a simple stimulus.

* many physiological experiments are done in real-time, but have no “naturalistic” component.

* real-time assessments are very hard to do. Especially when the user is interfacing with the technology for the first time (like breaking in a pair of shoes, except that technology must learn multiple aspects of user).

Central Introductory Concept #3: real-time behavior and physiology

Many of these technologies also work (or don't work!) because the signal captured from the nervous system needs to be processed in a special way:

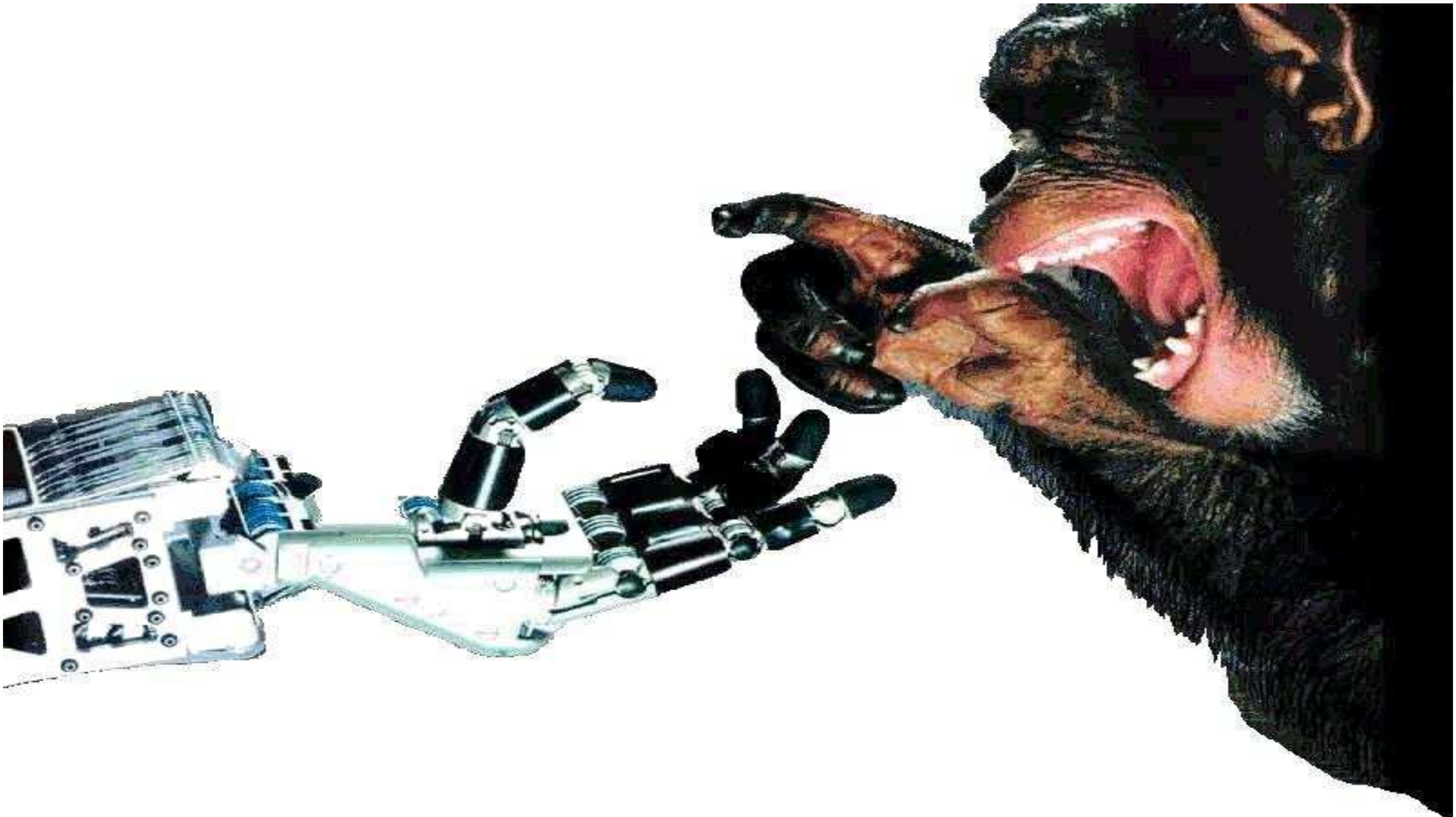
* signal processing techniques are used to find components with high degrees of information content to drive the system (regularities in real-time data).

* Donaghue group (Cyberkinetics) uses a Kalman filter: http://en.wikipedia.org/wiki/Kalman_filter

* CNEL group (U. Florida) use several nonlinear adaptive methods: http://www.cnel.ufl.edu/

* NSEL group (Michigan State) uses wavelet-based methods: http://en.wikipedia.org/wiki/Wavelet

General Neurotechnology Interfaces



Brain-Machine Systems: major components - feedback

Feedback involves adapting to current conditions. Usually involves a signal from the interface.

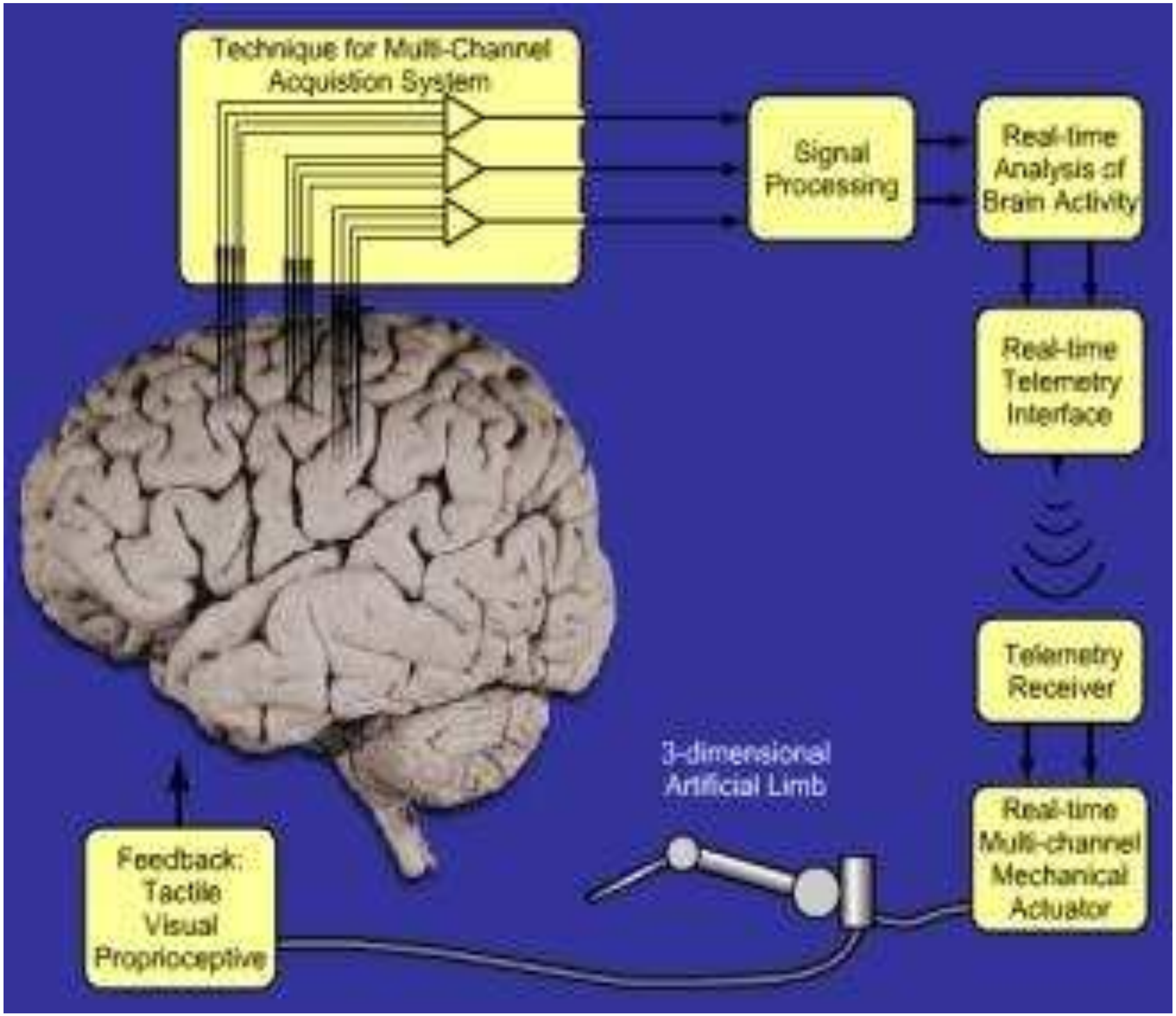
1) closed-loop systems (BMIc) rely on operant conditioning and feedback.

* operant conditioning involves associating a stimulus with a specific event (feel vibration, expect to hear tone).

2) open-loop systems involve the one-way transmission of information.

* from environment to brain, or from brain to environment.

Brain-Machine Systems: major components – feedback system



A: signal acquisition (determines bandwidth)

B: signal processing

C: telemetry system (remote control)

D: actuator/mapping to interface

E: feedback channel (closed-loop control)

Brain-Machine Systems: major components – bandwidth problem

Bandwidth Problem:

Q: using a set of electrodes (sensors) and a series of transponders, what is the maximum amount of information that can be passed out of the nervous system?

* in some systems (particularly implantable technologies), telemetry systems must be used.

A: this is an ongoing problem. In some cases, data is compressed before it leaves the body. In other cases, some sort of informatics solution is needed.

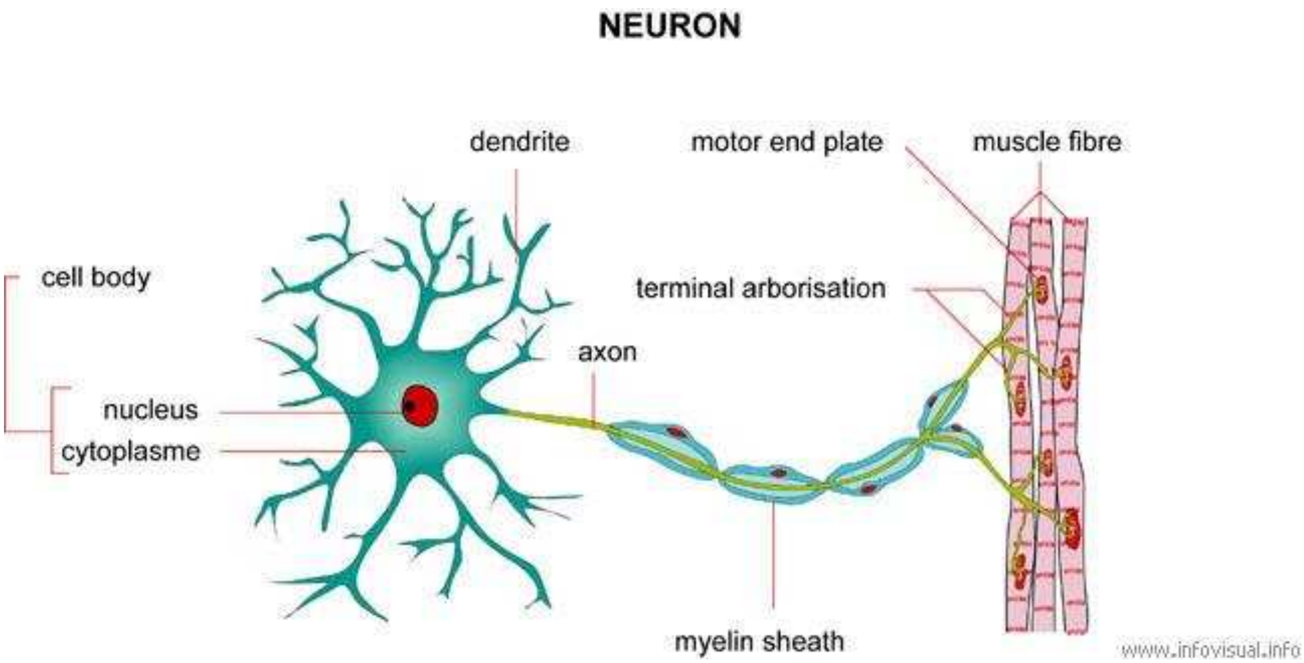
Brain-Machine Systems: major components – information transduction

The nervous system is an electrical transduction system:

* “excitable” cells – an exchange of ions across the surface membrane of a neuron.

* creates an electrical potential called a depolarization.

* usually pulses of 60-70 μv; collective action of many neurons results in a local field potential.



Brain-Machine Systems: major components -information transduction

Other sensors have been devised to measure hemodynamic potential (relative oxygenation of blood in the context of metabolism):

* this can be done for brain or muscle tissues (fMRI is a high-end technology – immobile, fNIR is a low-end technology – highly mobile).

* in this case, the amount of information retrieved from the nervous system limited (only an indirect measure of nervous system activity, not even a direct measure of metabolism).

* increase in the number of sensors recording from different parts of nervous system helps increase information content (signal); also increases the amount of noise.

Brain-Machine Systems: major components – signal mapping

Signal Mapping Problem:

How do you translate a raw signal or other information gathered from the nervous system into something that can be used to control a machine or interface?

* a "hard" problem (many possible ways to do this, represents the "logical layer" of this technology).

* signal processing, artificial intelligence, and other statistical tools are used currently.

* possibly the most important topical area (vital to the continued development of Neurotechnology).

Brain-Machine Systems: major components – signal mapping

One major goal of neurotechnology research is to convert all of this activity into a series of control signals:

* create a “map” of activity in space; where are the signals coming from?

* what does this mean in terms of predicting function (brain activity, limb movement, etc)?

* create a “map” of activity in terms of signal power.

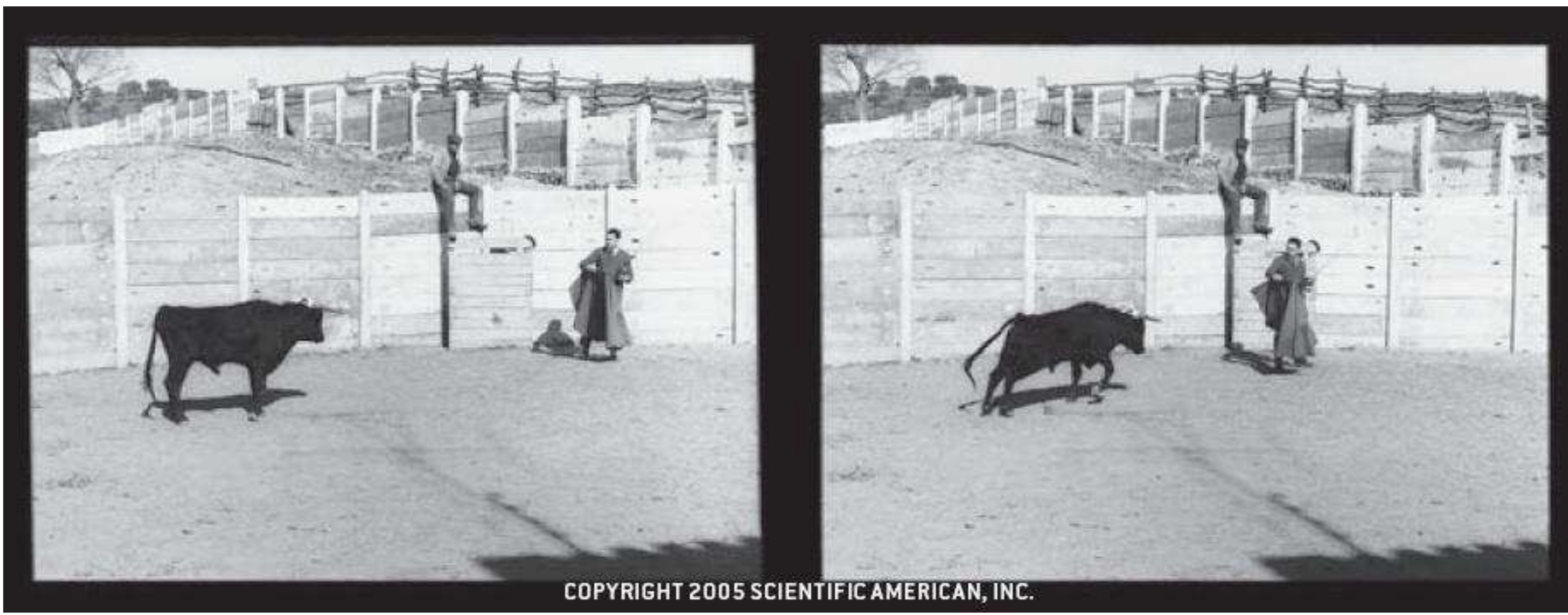
* what does it mean when a signal increases or decreases in activity?

Brain Chips: the early years (1950s)

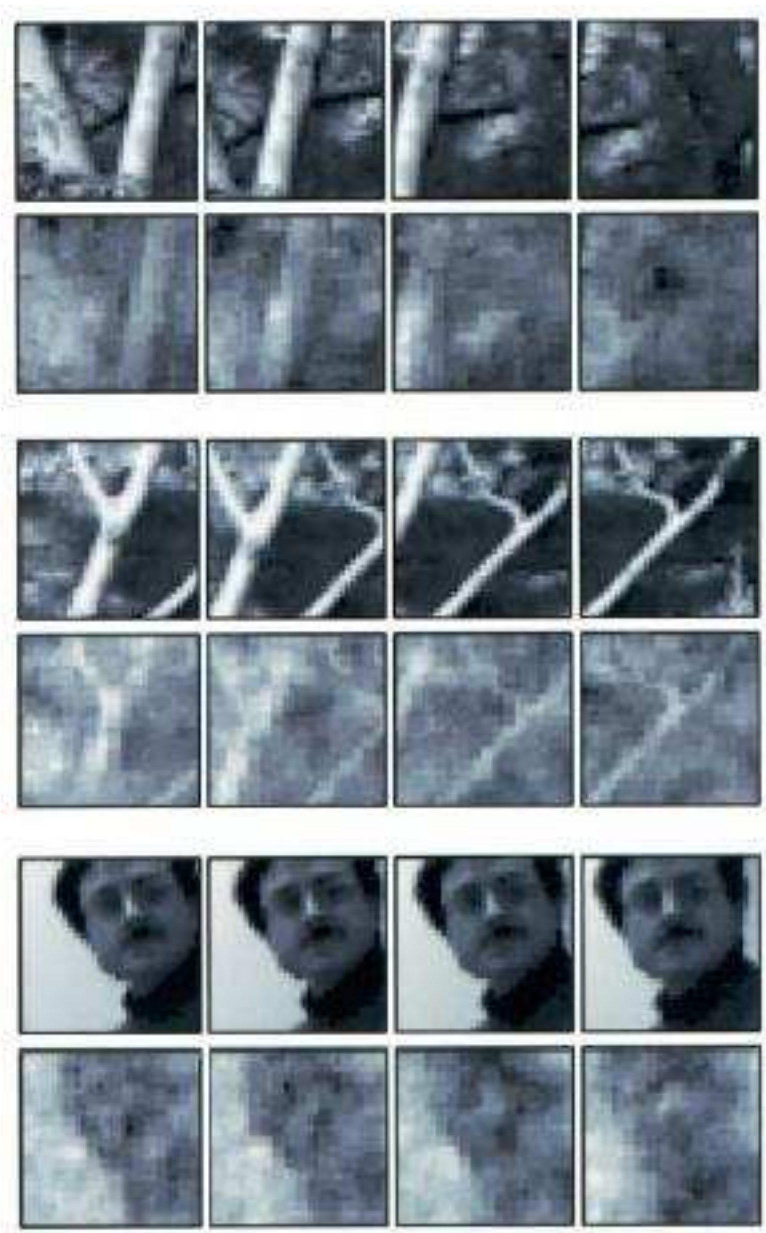
Jose Delgado is the "father" of the brain implant.

* implant in the amygdala (an emotional center) of a bull.

* implant inactive, bull charges the matador. Implant inactive, bull stops charging.



Movies reconstructed from Cat vision: 1999

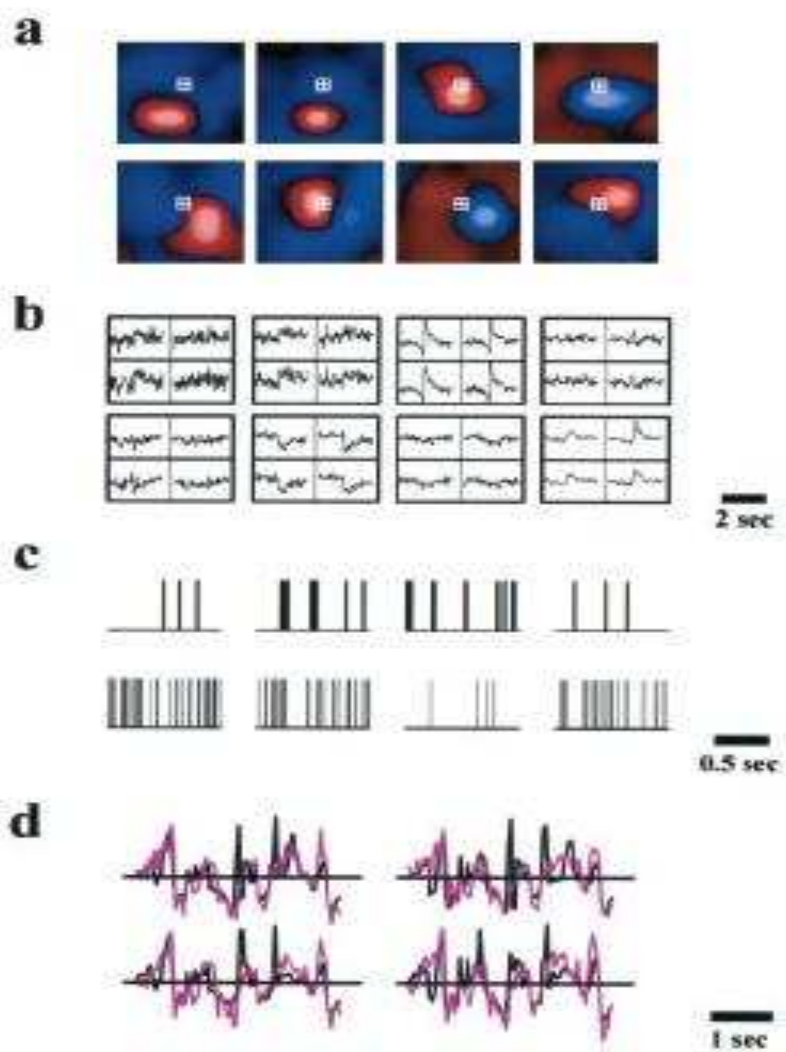


Garrett Stanley decoded neural firing from 177 neurons in the lateral geniculate nucleus (part of the visual pathway).

Generated a series of movies; a cat (Felis catus) viewed the movies, signal recorded from brain, images reconstructed.

For each set of rows, top images are actual movies, bottom images are reconstructed movies.

Movies reconstructed from Cat vision: 1999



Each neuron has a receptive field (A): red = on response, blue = off response, brightest = strongest response.

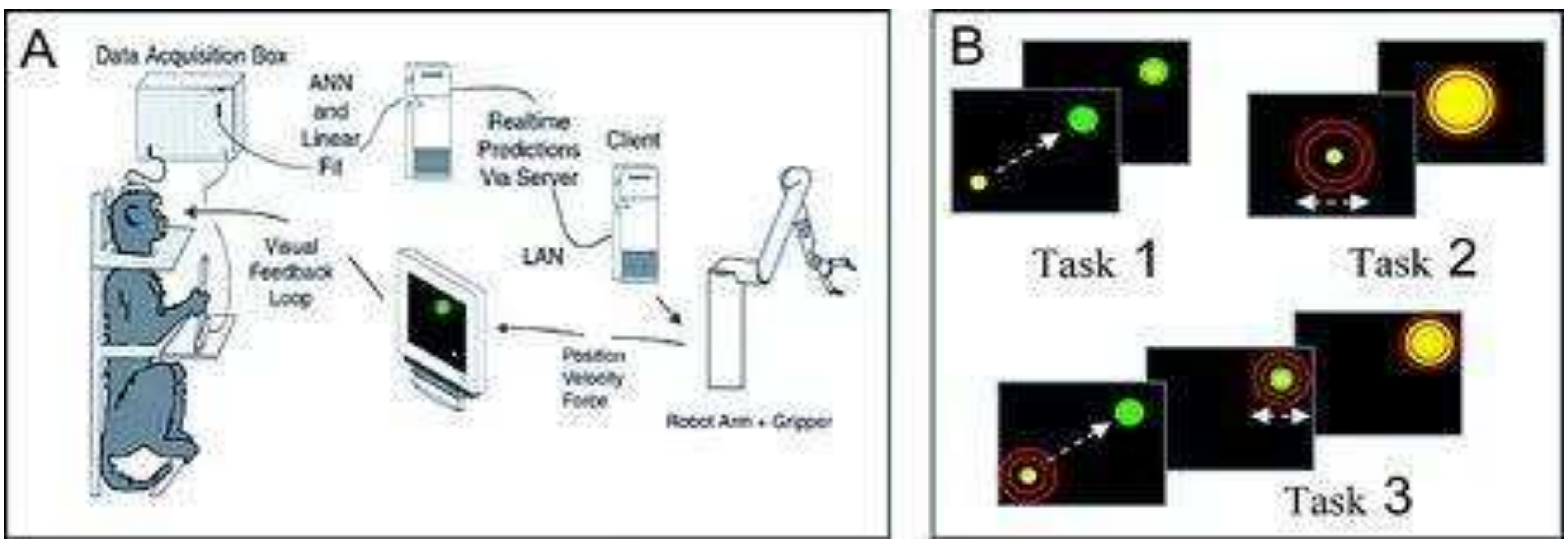
Response of one neuron mapped to a single pixel (B).

After linear filtering, reconstructed movie signal per pixel compared with actual signal (D).

Durham-Boston: 2002

The Nicolellis Lab at Duke: http://www.nicolelislab.net

In 2002, an elegant set of experiments were performed with a monkey located at Duke University and a high-bandwidth connection with a lab in Boston.



Durham-Boston: 2002

Experiment #1: juice box retrieval.

* monkey was trained to retrieve a juice box manually. The arm was then restrained; using direct interface, monkey was able to retrieve juice box with robotic arm.

Experiment #2: targeting task.

* monkey was trained to move a virtual ball to a target. Using the direct interface, monkey was able to improve performance.

Experiment #3: remote control.

* the monkey was able to manipulate a robotic arm located in Boston using the direct interface (brain activity + telemetry).

BCIc technology: mid-2000's

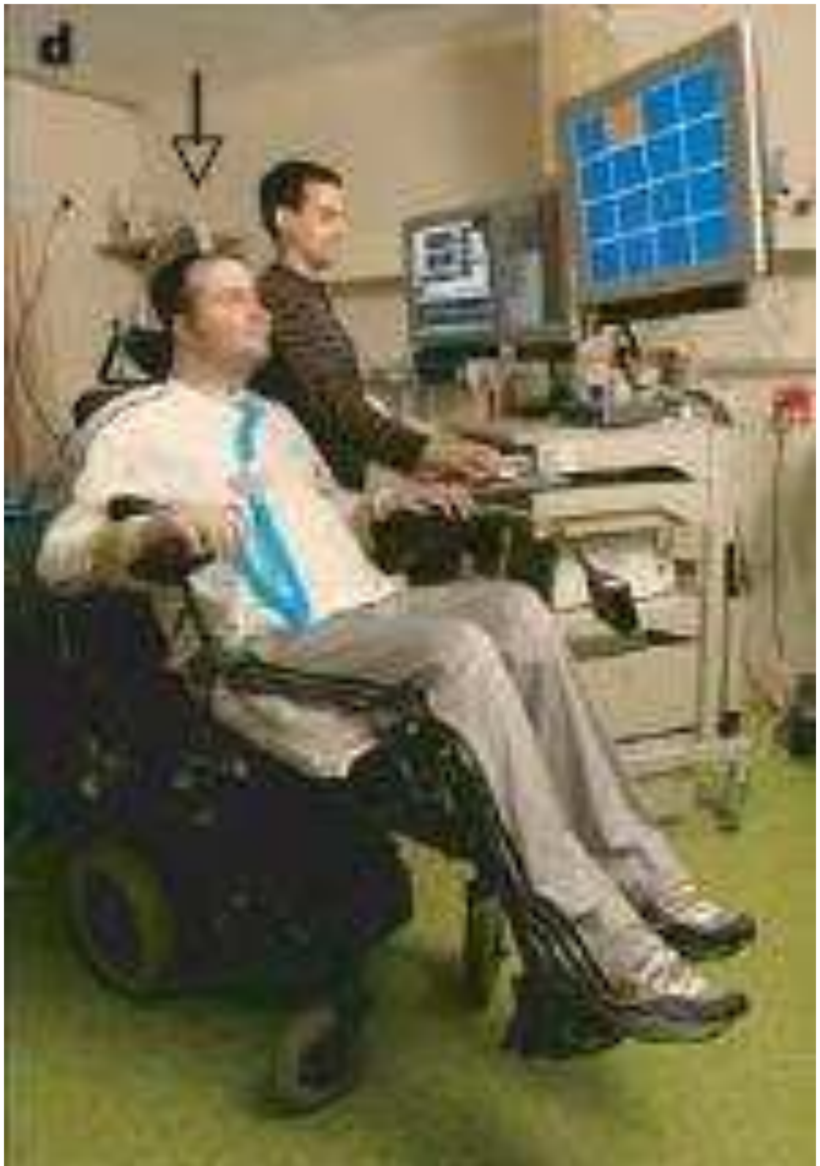
Closed-loop Brain-Computer Interfaces are becoming a hotbed of research (and close to becoming commercial!):

* Jonathon Wolpaw's group: have developed interfaces that use electrical signals from the brain to move a cursor in one of eight directions.

* Trejo (2006): used signals from the arm muscles to type the numbers 1 through 9 out on a computer screen.

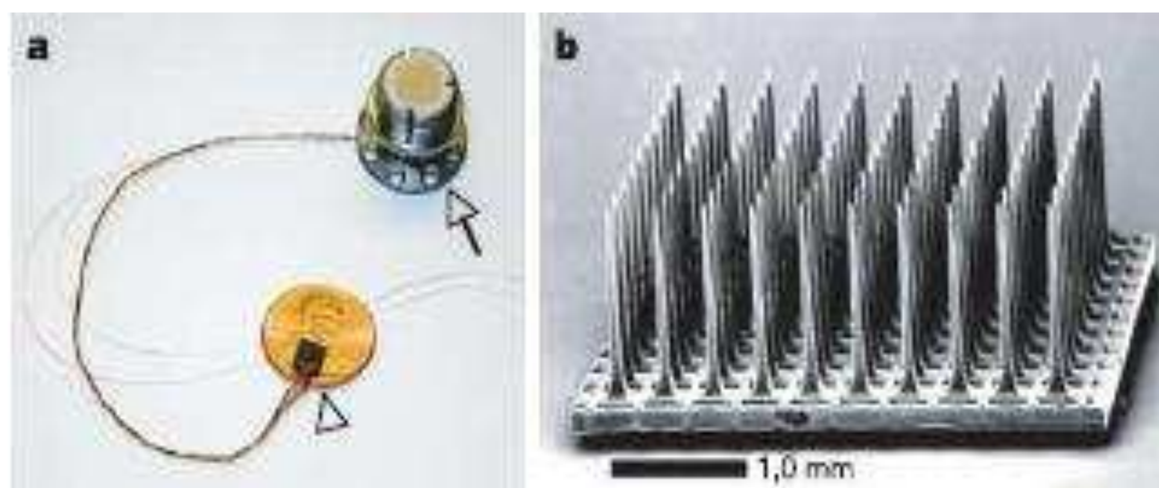
* Graz BCI: have developed a simple MATLAB-driven interface that creates a closed-loop system from a set of sensors and mappings.

Cyberkinetics: towards the future



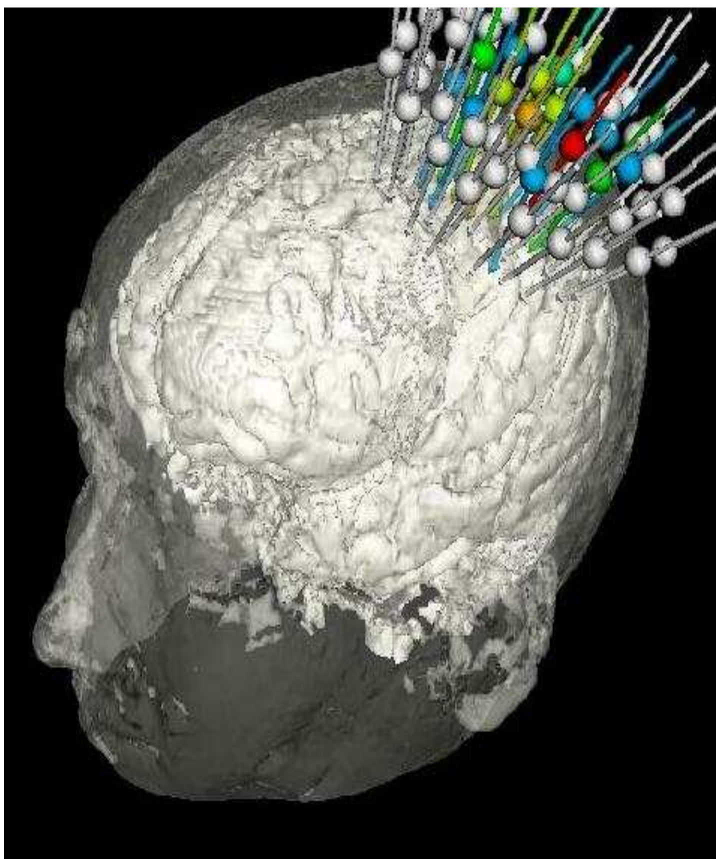
Cyberkinetics is moving towards a commercially-viable product.

The “Braingate” has recently undergone clinical trials. The quadriplegic pictured at the left uses the interface for cursor control and wheelchair control.



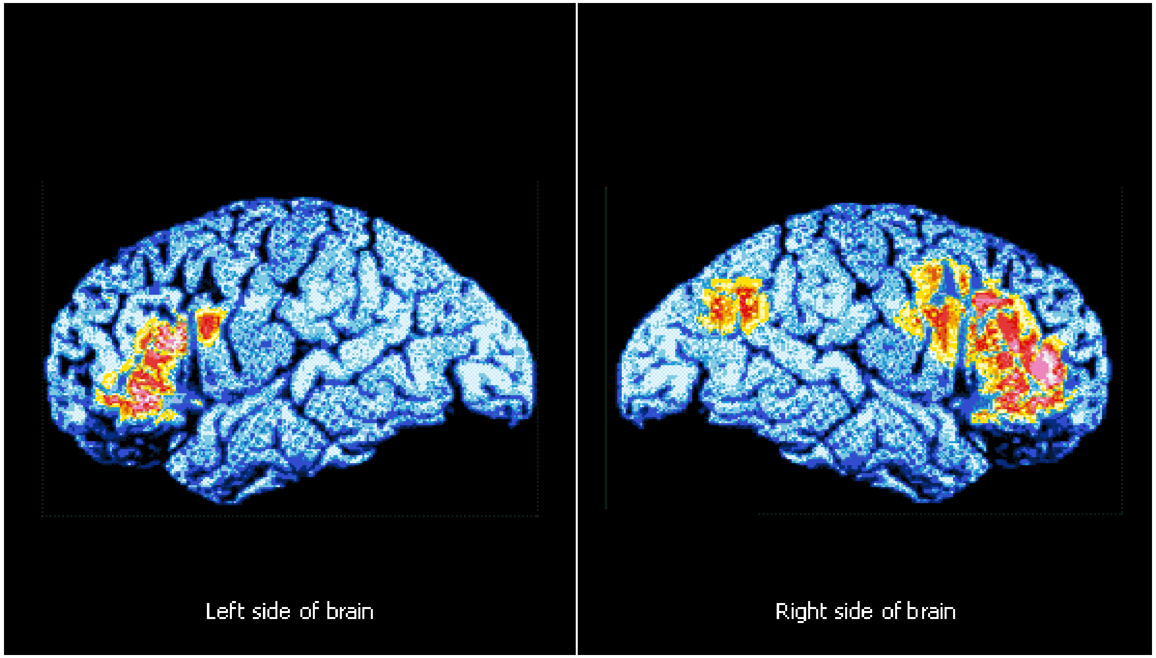
TMS: freezing time, towards the future

Ed Boyden (MIT Media Lab) uses TMS (transcranial magnetic stimulation) to modify behavior by "shutting off" and "turning on" sections of the brain (plays a role in "augmenting cognition").



TMS: freezing time, towards the future

One example of how this works in comes from rTMS (repetitive TMS):

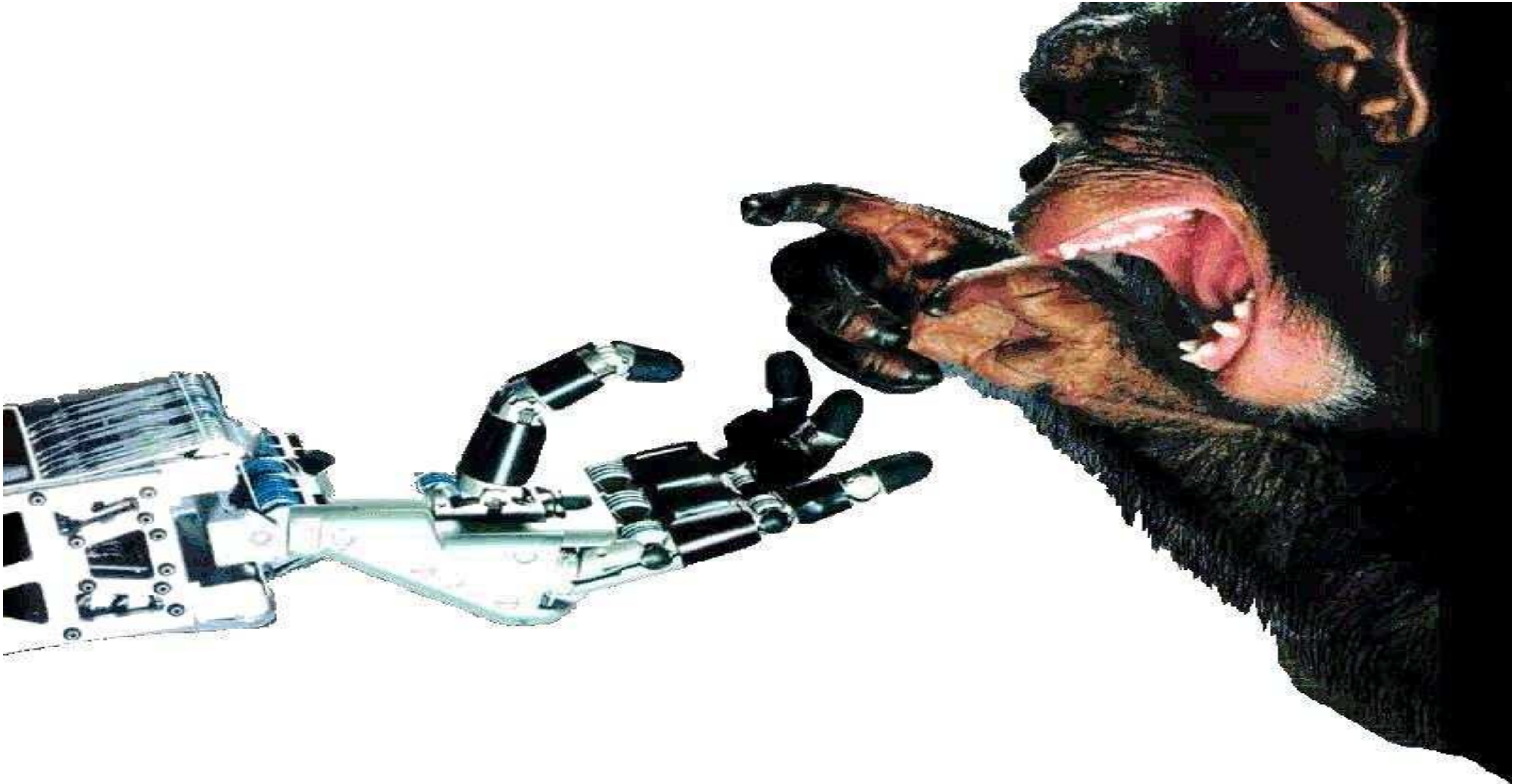


* apply weak electric current (electromagnetic induction) to rapidly change local field potentials in particular parts of brain non-invasively.

* trains of stimuli delivered at several Hz over a several second time interval.

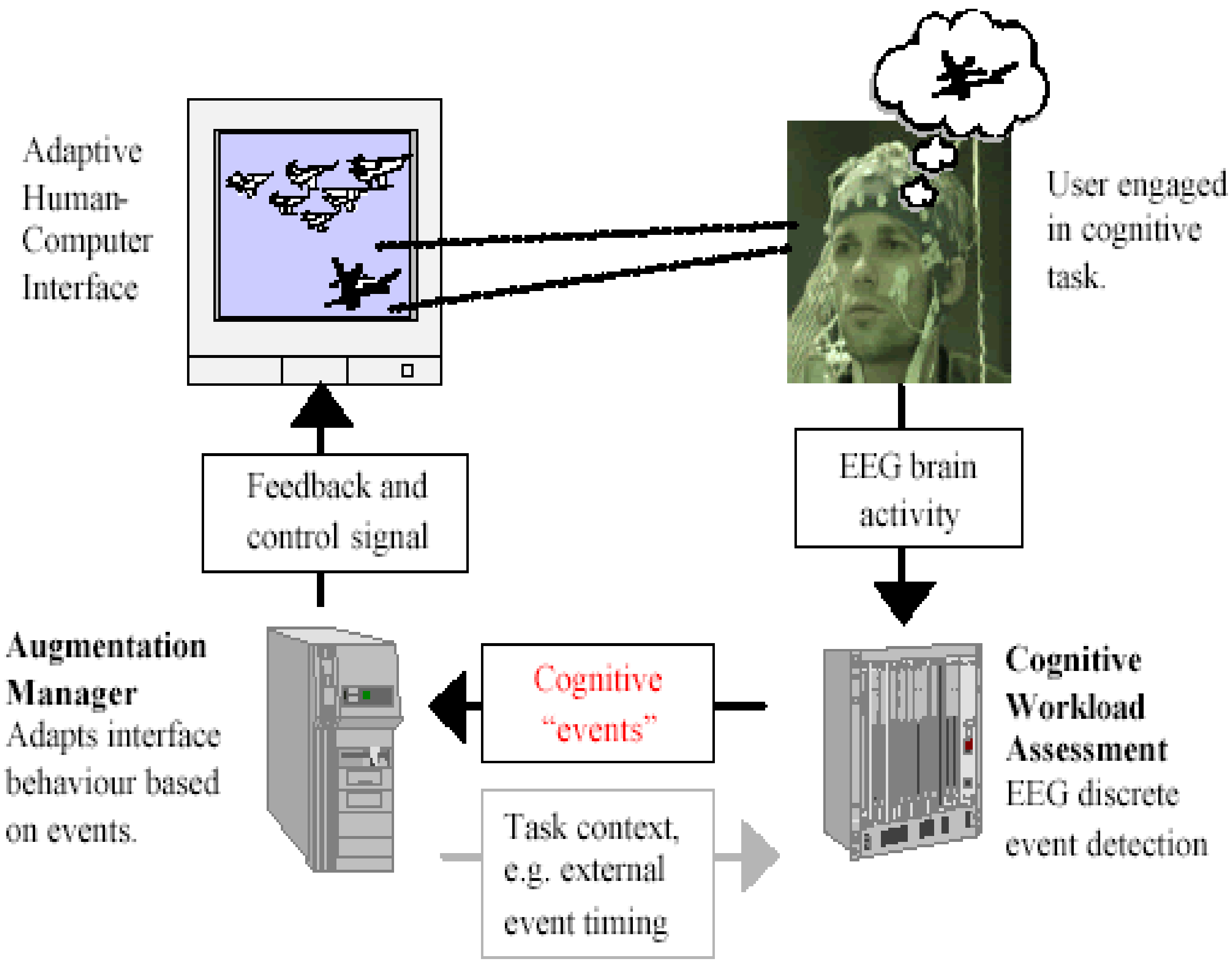
* produces an effect which can outlast the initial application (can either "turn on" or "turn off" a part of the brain for extended periods of time).

Augmenting Cognition: optimizing human performance



Augmented Cognition

DARPA's Augmented Cognition initiative:
http://www.augmentedcognition.org



Augmented cognition requires many of the same components as Neurotechnological interfaces :

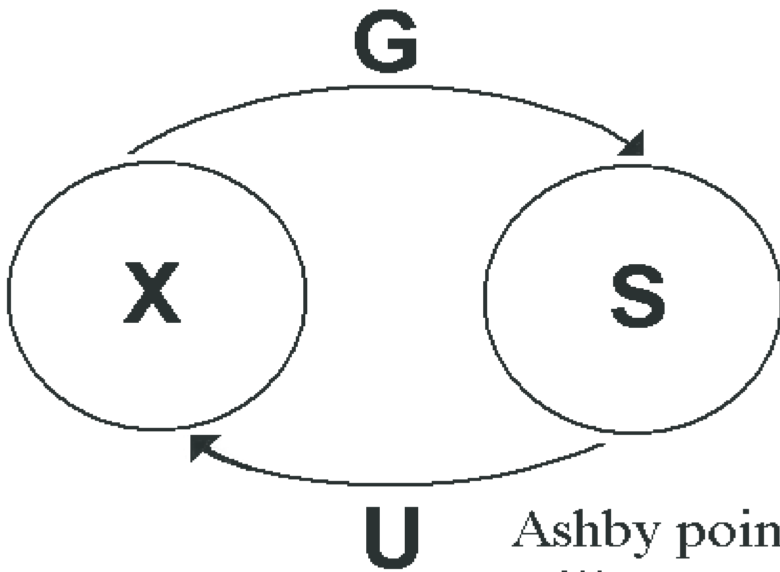
* neural recording device.

* assessment engine (suite of adaptive algorithms).

* adaptive interface.

Augmented Cognition: the early years

The idea of Augmented Cognition goes back to W. Ross Ashby, who proposed a design for an “intelligence amplifier”.



where X is the operator, g is the sensor suite, S is the "amplifier", and u is the improvement.

Ashby points out that S will generally operate within a range (subset m), and will use a selection criteria on the input.

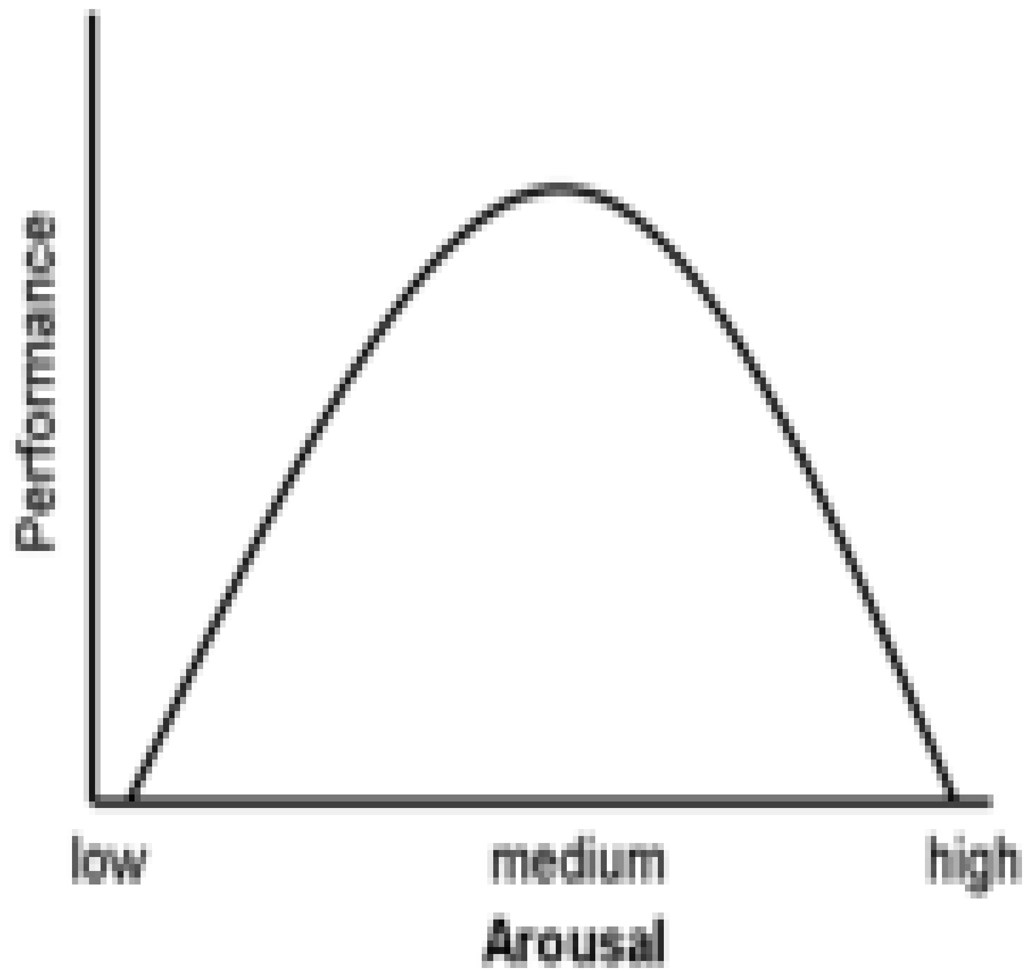
This results in X and subsequent inputs of g (in the absence of perturbations) achieving an equilibrium state n.

Yerkes-Dodson and Modulation

Today, a “mitigation stategy” is used to maintain homeostasis (control policy):

* concrete example -- the Yerkes-Dodson (Y-D) curve characterizes the need for system mitigation.

* if arousal is above or below a certain optimal range, then the augmented cognition mitigation (treatment) is employed.



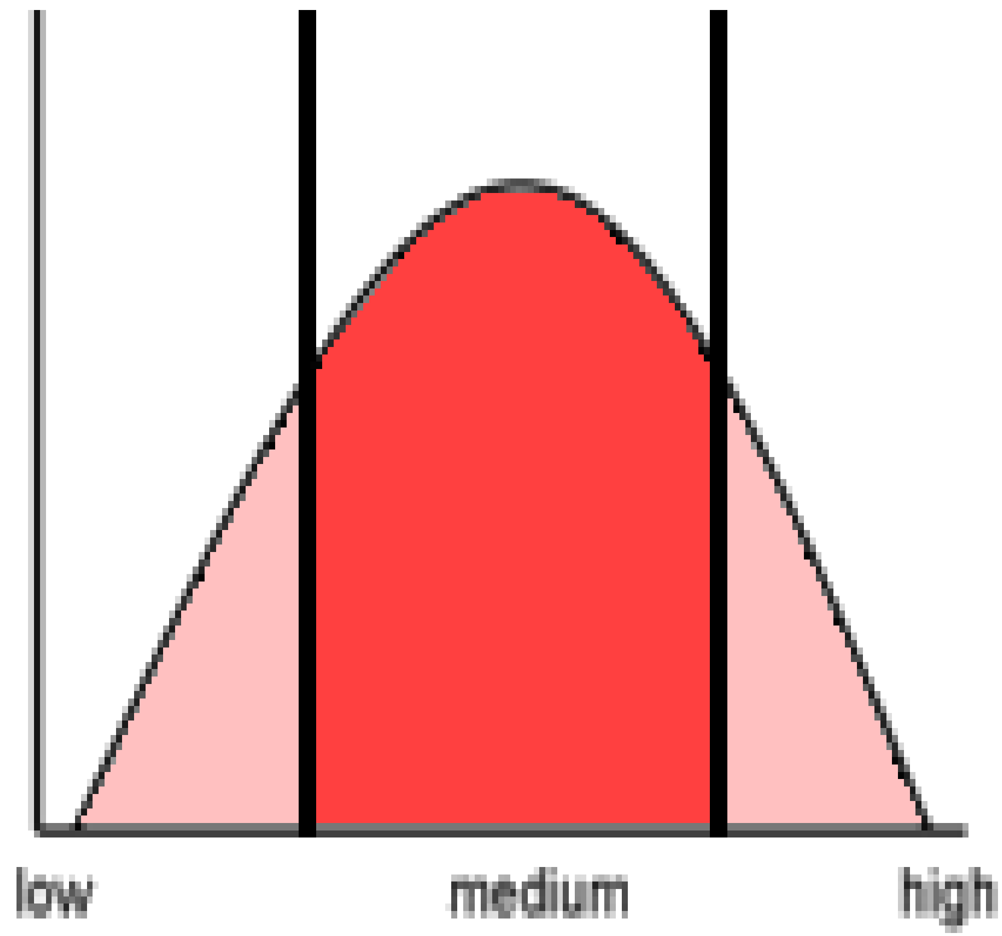
Yerkes-Dodson and Modulation (con't)

Typically, cut-off points around the mean are employed as "triggers":

Too little arousal can result from fatigue, tiredness.

Too much arousal can result from sensory overload.

Both will negatively impact performance.



Augcog: improving performance in every way every day?

Dennis Profitt and colleagues have devised a strategy for augmenting cognition called “task queuing”:

1) cognitive processes that activate separate brain areas can be carried out simultaneously with no interference.

2) cognitive processes that activate similar areas of the brain cannot be carried out simultaneously (the person suffers “interference”, which degrades performance).

* brain activation measured in vivo using an optical imaging system.

Augcog: improving performance in every way every day (con't)?

Using this method, tasks can be “queued” by an adaptive interface. The adaptive interface uses an algorithm that presents tasks in a predictive manner:

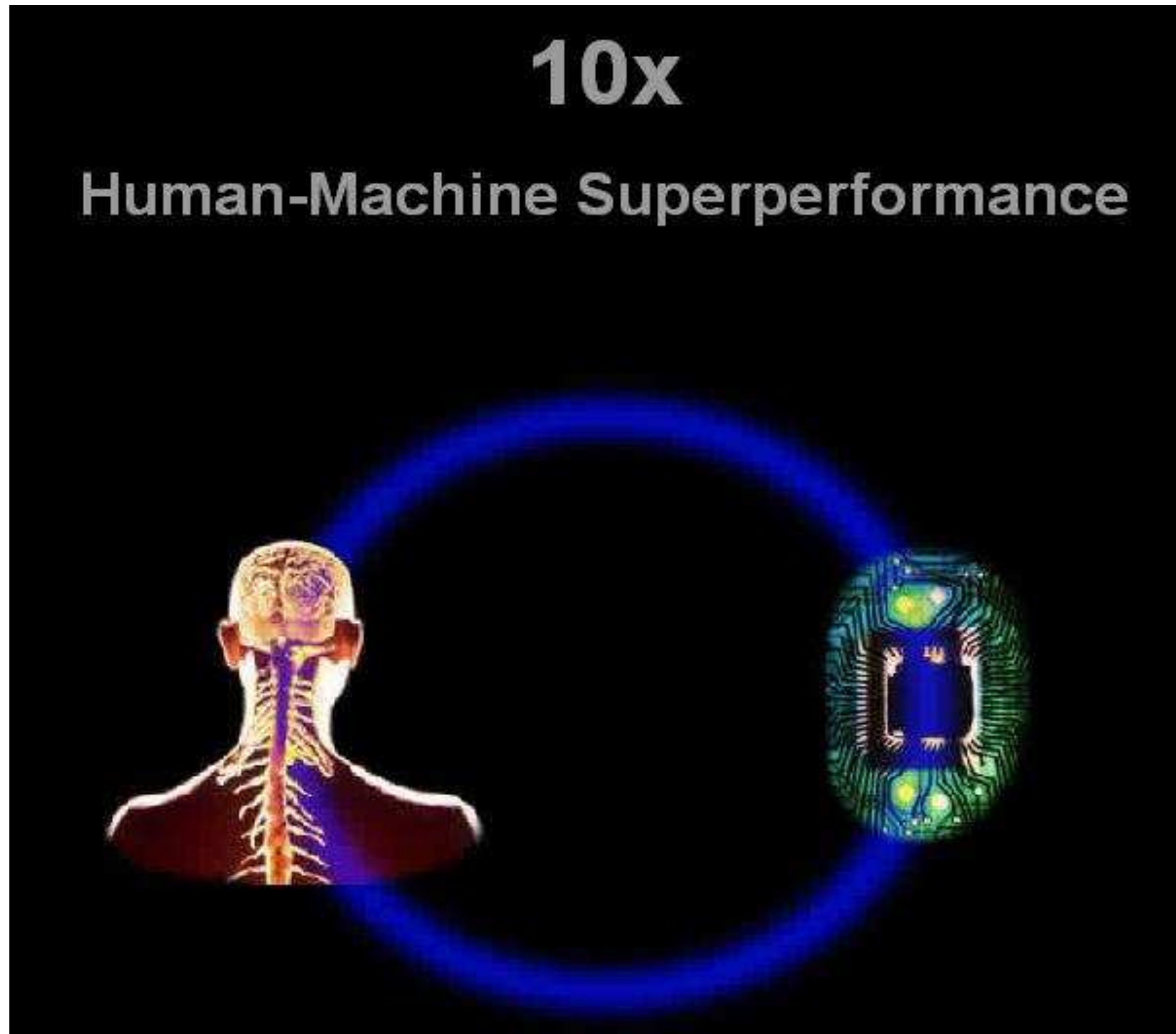
* those tasks requiring processes that do not interfere with each other in terms of brain activity are presented in parallel.

* those tasks requiring processes that overlap in their ability to elicit brain activity are presented serially.

* this improves performance time and other measures of behavior.

Augcog: improving performance in every way every day (con't)?

The 10x initiative out of MIT aims for a ten-fold improvement in human performance.



* along various cognitive and physical dimensions.

* How do we measure these? How do they become embodied in a technology?

Augcog: improving performance in every way every day? (con't)

Various proposals for augmenting human performance “by a factor of 10”:

10x memory: strategically combine human (biological) with artificial (computational) abilities.

* biological (analogical) vs. artificial (capacity) – different strengths and weaknesses (recent example, Amazon's “human-assisted search”)

10x listening: selectively amplify sounds from certain sources based on head position.

10x physical skills: robots as 'skins' that supercharge body movements.

Augmenting Performance by “Extending” Physiological Homeostasis

A number of researchers have looked at ways to improve human performance by artificially modifying physiological parameters:

* physiological processes operate on a principle called “homeostasis' (the human body operates as a series of self-regulating systems).

* if a system gets too hot, it needs to be cooled down. If an organism gets too tired, it must go to sleep.

* there are a number of cellular, physiological, and environmental subsystems that mediate homeostasis.

Augmenting Performance by “Extending” Physiological Homeostasis (con't)

One way to augment human physiology is to move the amount of allowable variation surrounding the equilibrium point beyond the range of normal function:

* homeostasis relies on a physiological system maintaining an equilibrium point in the face of internally and externally-induced fluctuations.

* for example, our body temperature averages out to be 98.6 degrees F. However, there are daily and individual fluctuations in this value (body temperature increases with metabolism, other factors).

Augmenting Performance by “Extending” Physiological Homeostasis (con't)

Craig Heller and Vinh Cao have developed a glove that cools muscle in the hand, improving the stamina of the individual across training:

* hypothesis was that muscles fatigue because they get too hot, sweating equilibrates the system some, but overheating causes fatigue and disrupts performance.

* over a six-week training period, one person went from doing 180 pushups at a time to doing 600 at a time.

* the glove acts as a “super radiator”; technology serves the same purpose as natural systems (blood vessels, metabolic transport), but artificially extends the parameters of human performance.

Augmenting Performance by “Extending” Physiological Homeostasis (con't)

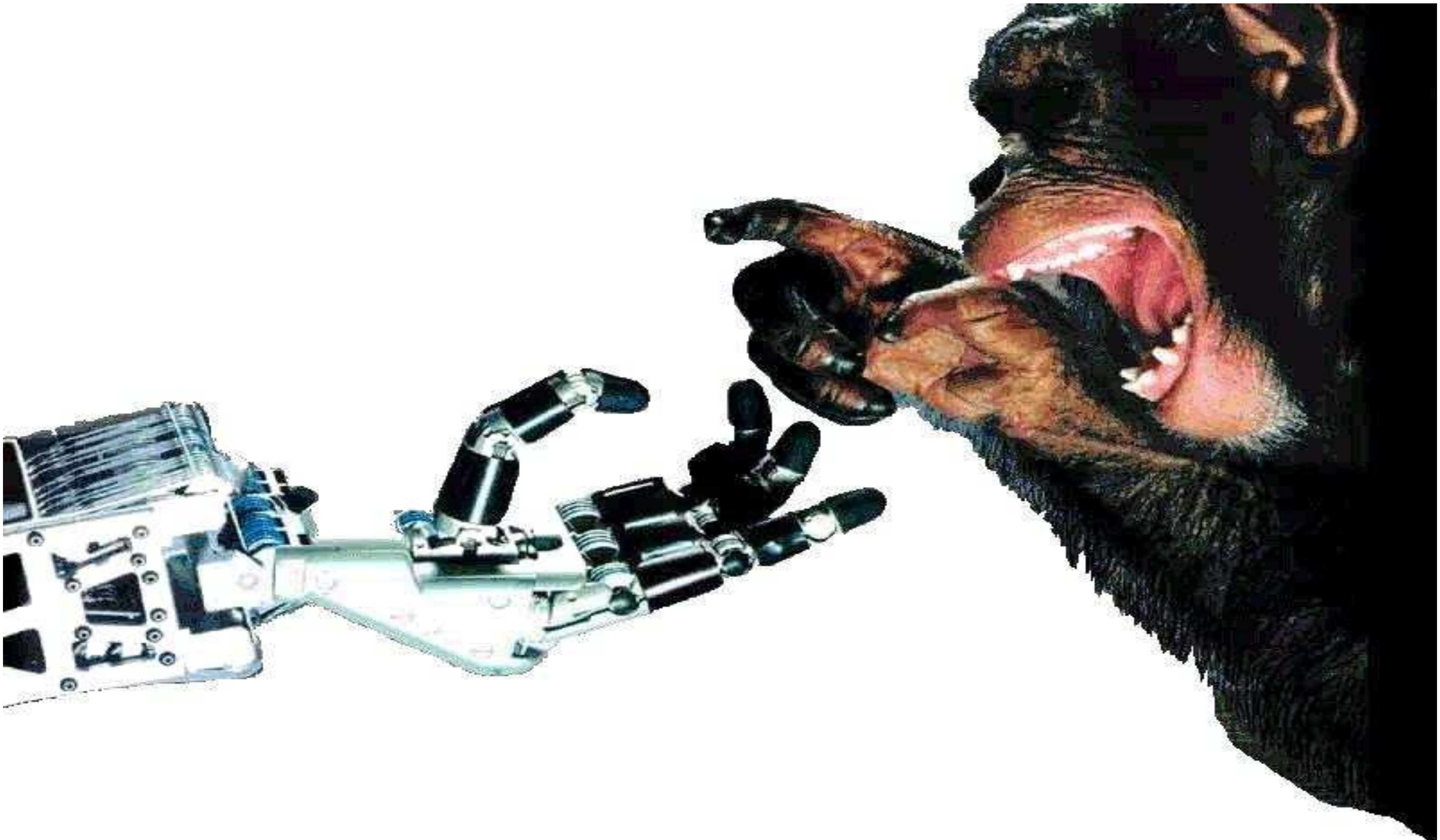
One way in which this can be made clearer is by examining the work of Mark Roth:

* his experiments explore something called “metabolic flexibility” in humans.

* his goal was to slow metabolism in humans. Solution: look at the rate of oxygen consumption. Fishes and insects go into suspended animation when environmental oxygen concentrations plummet.

* Roth has proposed using a hydrogen sulfide-rich air supply (H_2S binds to mitochondria in cell cytoplasm, slows baseline metabolism).

Biomechanotronics and Other Prostheses



Biomechanotronics and Other Prostheses

Biomechanotronics:

MIT Media Lab’s Biomechanotronics: http://biomech.media.mit.edu

Exoskeletons:

http://science.howstuffworks.com/exoskeleton.htm

Augmentation Devices:

Brainport Tactile Interface:
http://science.howstuffworks.com/brainport.htm

Biomechanotronics and Other Sensorimotor Prostheses (con't)

These two videos should give a sense of what biomechatronic applications look like in action (these applications are not yet marketable, but there exists a need for such technologies):

Tour of the Biomechanotronics Lab (MIT):
http://biomech.media.mit.edu/images/video/mi_herr_31.wmv

Artificial muscle in a robotic fish (with applications to humans):
http://www.personal.umich.edu/~bobden/robot_b1b-a.avi

Exoskeletons: aiding locomotion

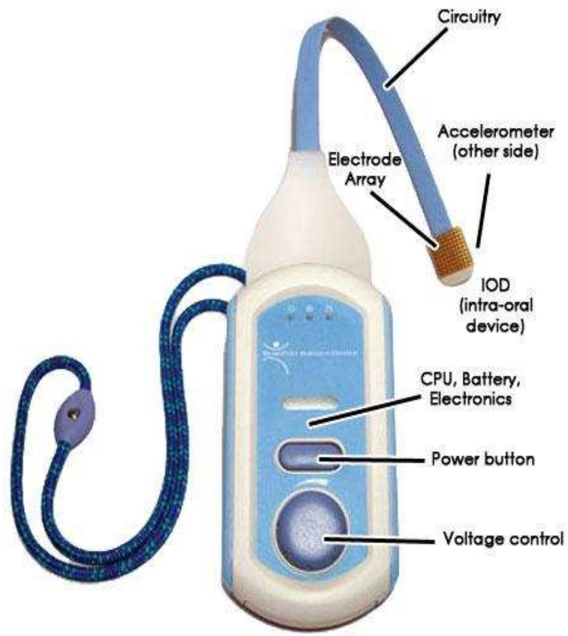
Exoskeletal systems have been found to aid physical performance in a couple of ways :

* wearable devices add mechanical power to a locomotory or upper-body system.

* improves endurance as well (reduces fatigue).

* devices designed to cool selected muscles increase endurance and muscle power.

BrainPort: sensory substitution



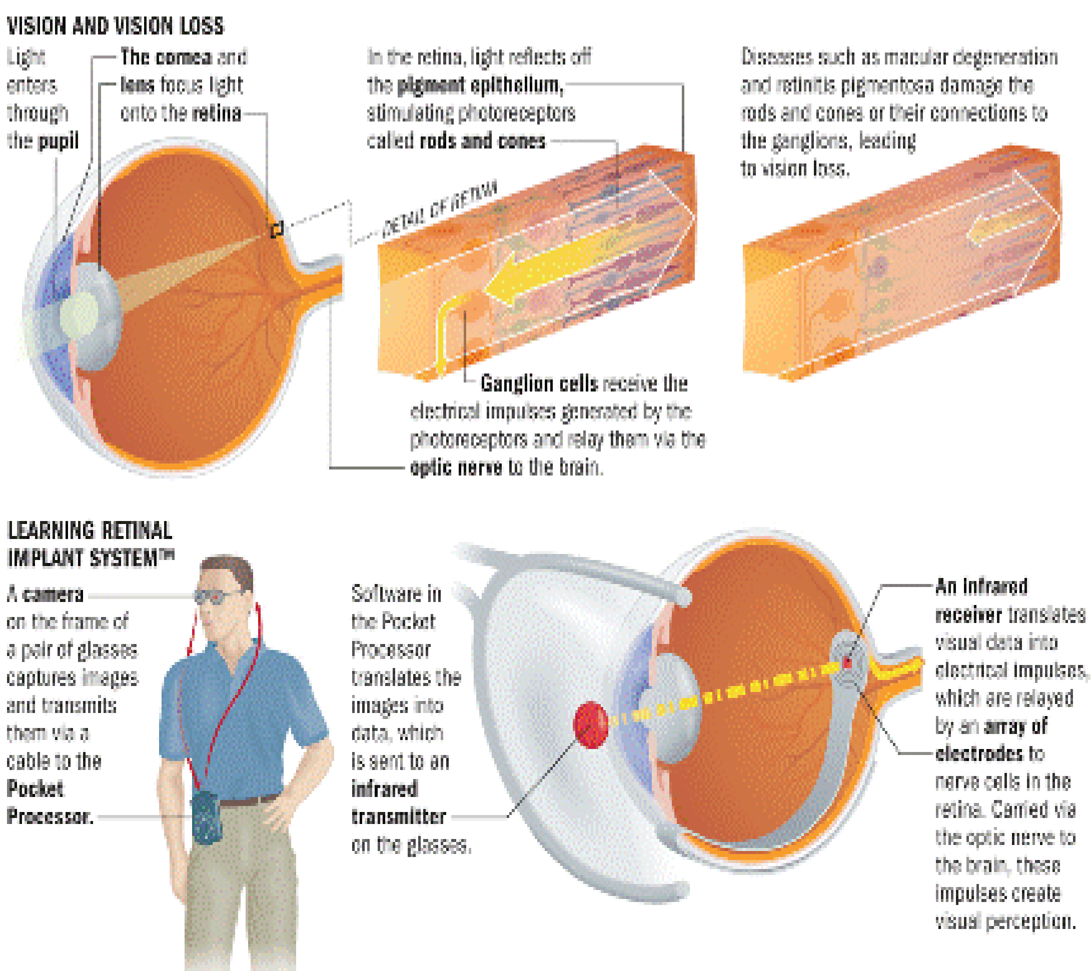
Wicab manufactures a system called BrainPort, originally invented by Paul Bach y Rita.

There are two versions:

* vision (visual information transduced by tongue).

* balance training (vibratory information reduces nervous system tremors).

Artificial Retinas: bypassing the biological eye to augment the biological eye



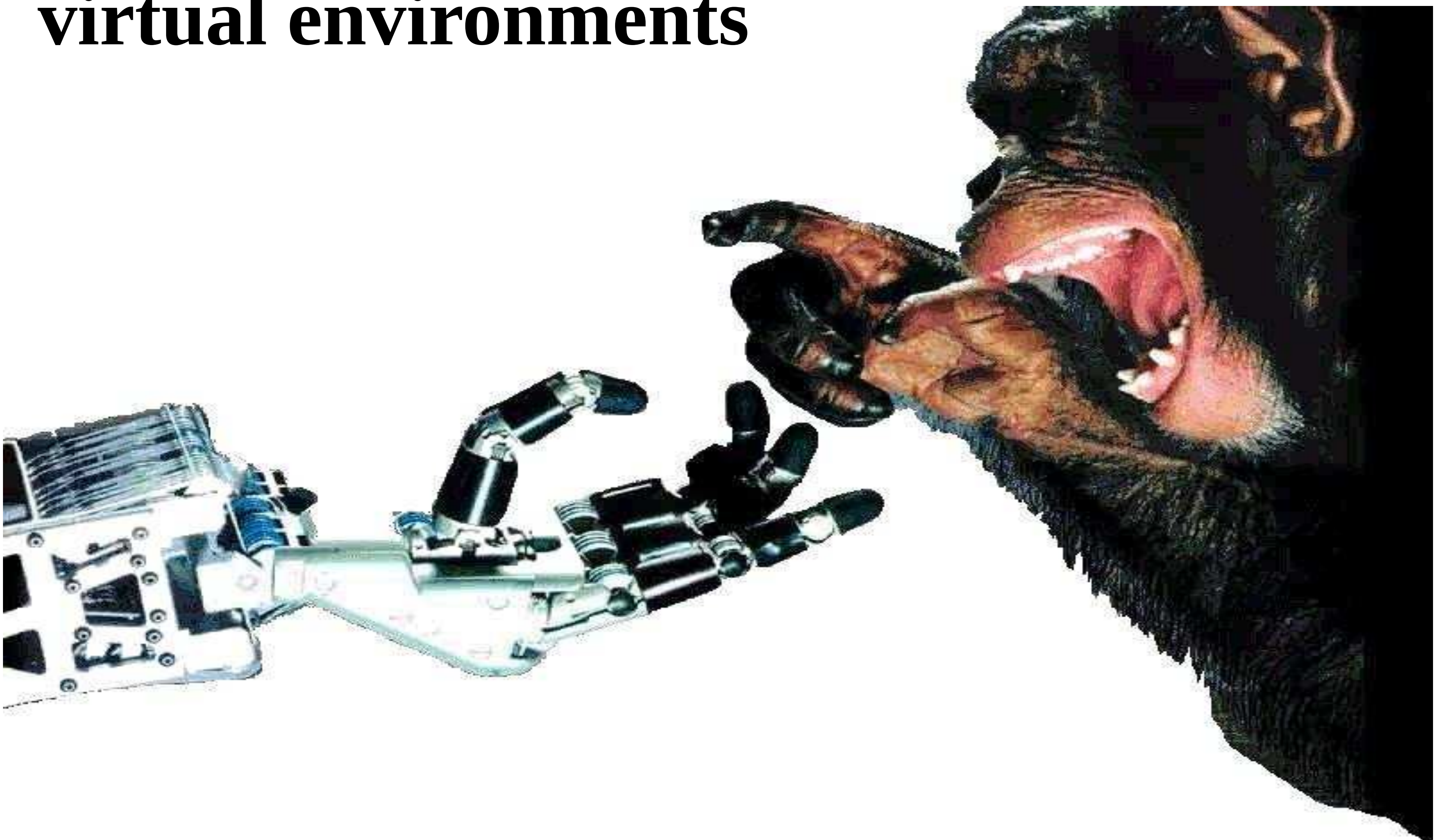
Two components (bypass the injured system component) :

* pair of glasses capture image from environment.

* image relayed to box (worn on belt).

* image information relayed to implant (in visual pathway, upstream of retina).

Achieving “real-time ergonomy”: integrating neurotechnology with virtual environments



Neurotechnology in silico

Many of the major advances in brain-machine interfaces have involved virtual environments:

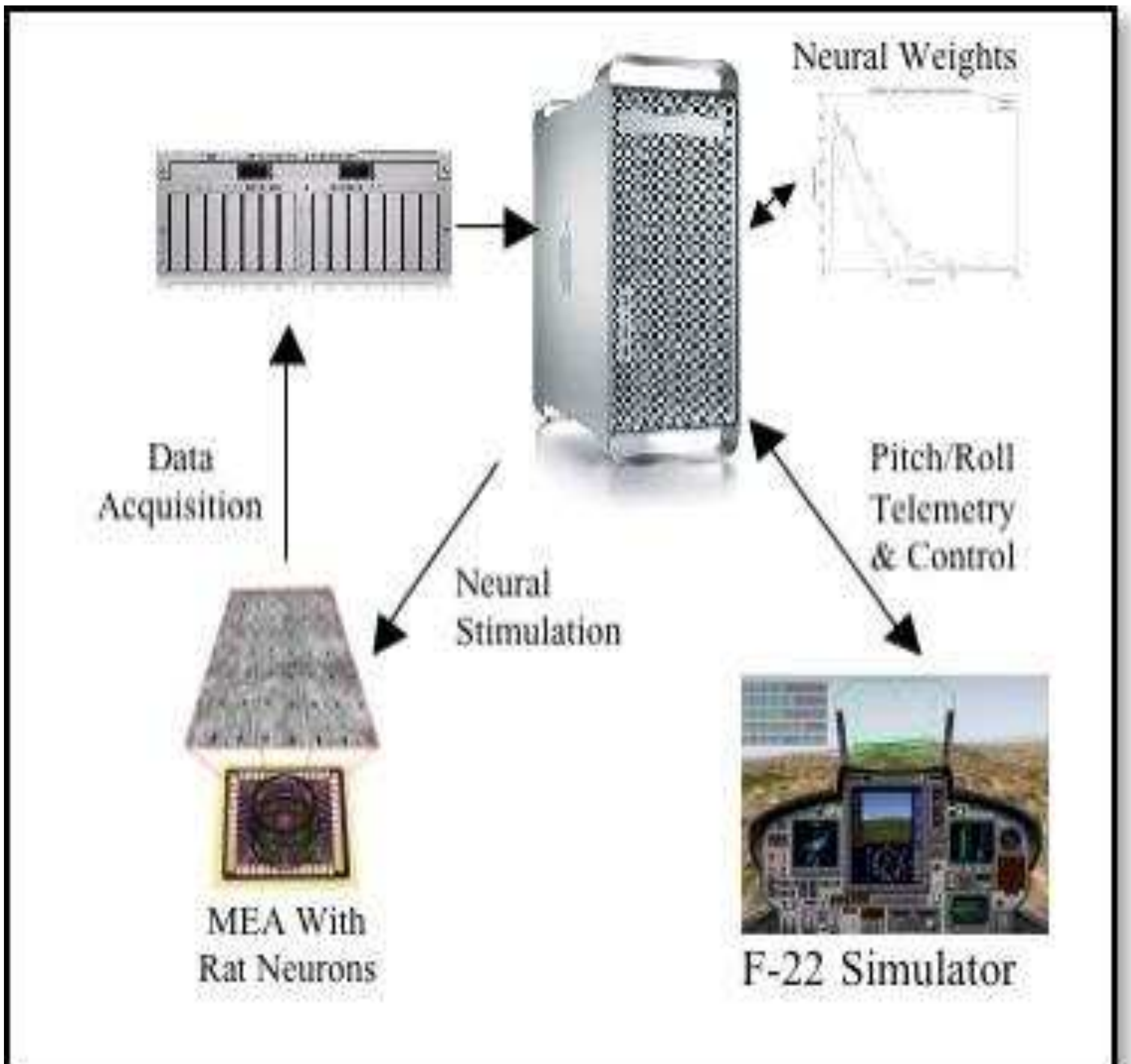
* cursor control

* training for neuroplasticity, adaptive control

* future applications of neurotechnology will involve integration with virtual environments:

* fortunately, groups at Georgia Tech and the University of Florida have figured out how disembodied neural tissue can be used to control objects in a virtual environment.

Neural flight control ex vivo



At left is an example of an adaptive flight control system.

* notice that the technological loop is the same.

* software is used to "weight" the neural output.

* signals "mapped" to degrees of freedom in the simulation (roll, pitch, and yaw).

Neural flight control ex vivo

The flight simulator application achieves stable flight through homeostasis:

* in many early applications, the system “crashed” (signals from the neuron dish could not stabilize flight).

* takes many training trials to establish a stable state of flight (like supervised learning in AI).

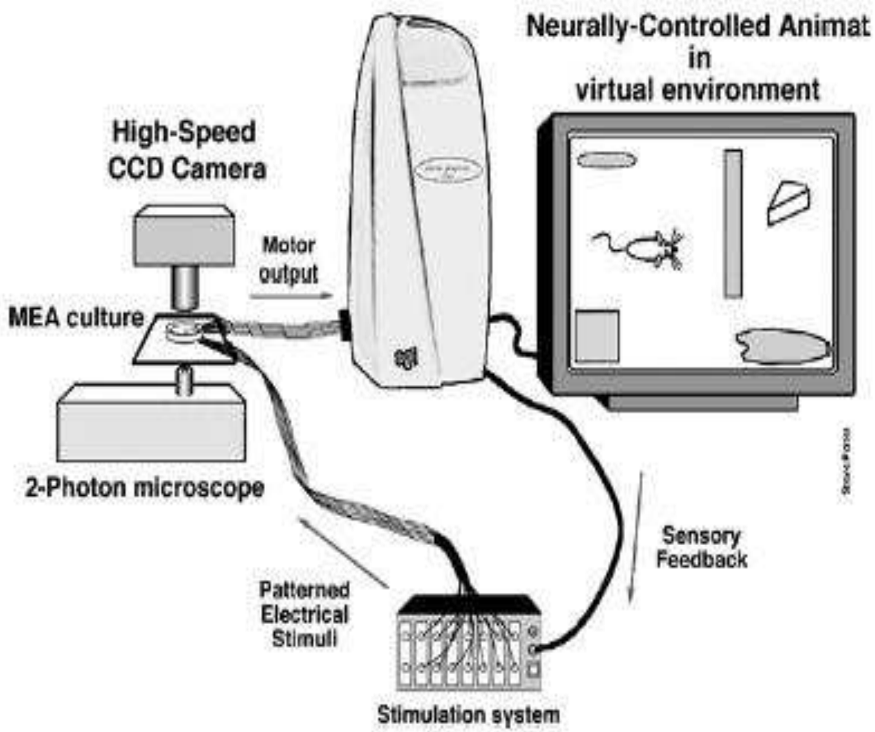
Flight control is only one potential application:

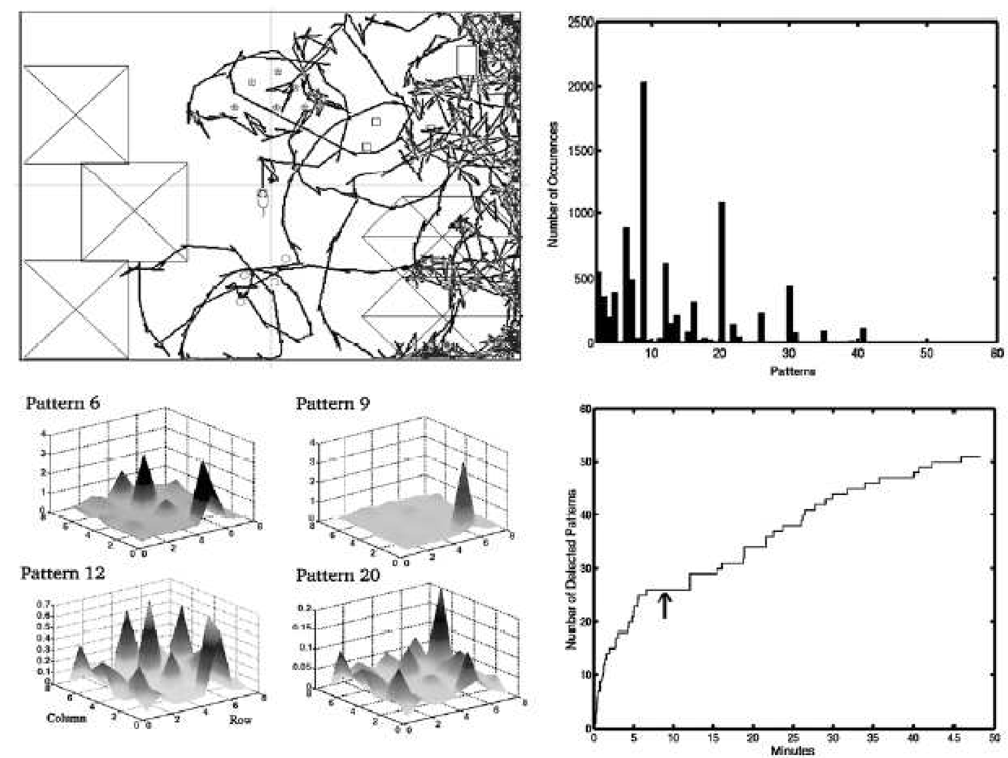
* the basic control mechanisms (filters, mappings) can be used in any virtual environment.

Neural flight control ex vivo

The flight control application stabilizes after a certain length of time. How does the system learn?

Hybrid Robotic/Neural Systems:Virtual environment character control





We can better understand the parameters of this learning process by looking a similar system; the neural animat.

Hybrid Robotic/Neural Systems: Virtual environment character control (con't)

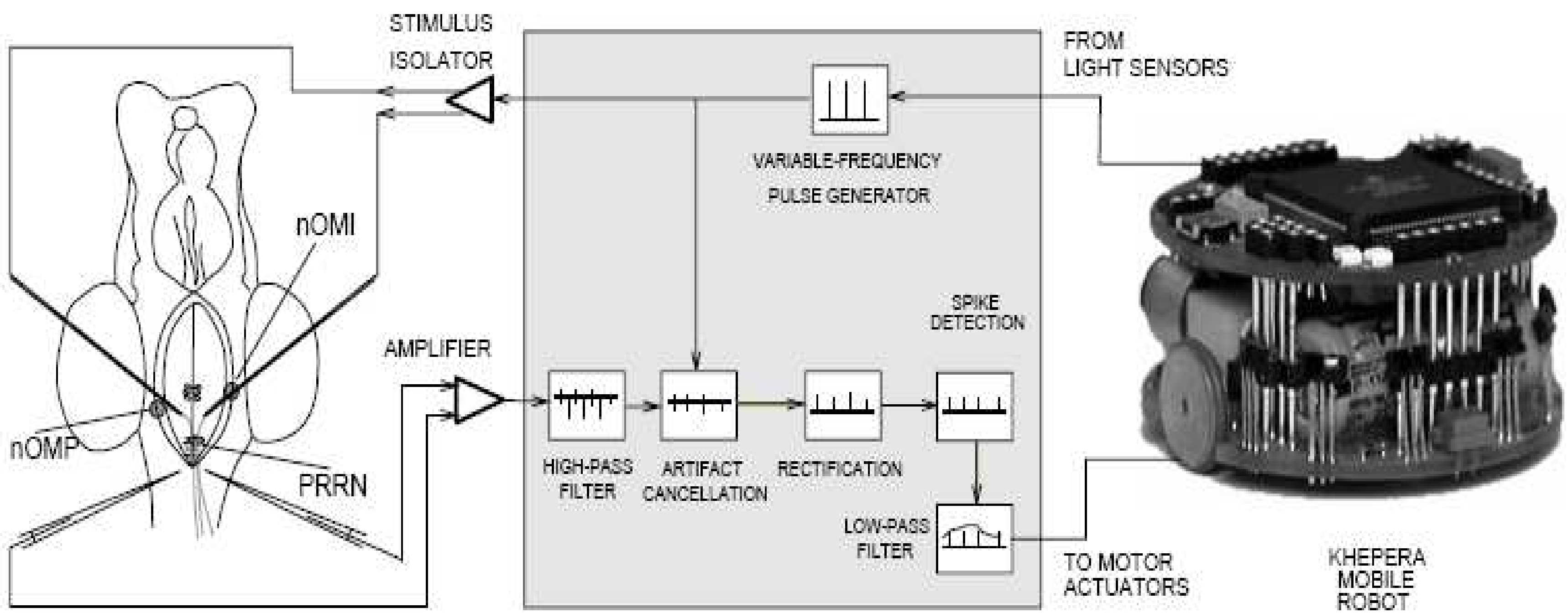
The animat application uses a clustering algorithm to classify and analyze feed-forward signals from the neural population:

* recurrent patterns of activity identified. Many patterns recur frequently, a few patterns occur only occasionally.

* these activity patterns could be mapped onto existing behaviors.

* allows for a better understanding of how neural behaviors are adaptive.

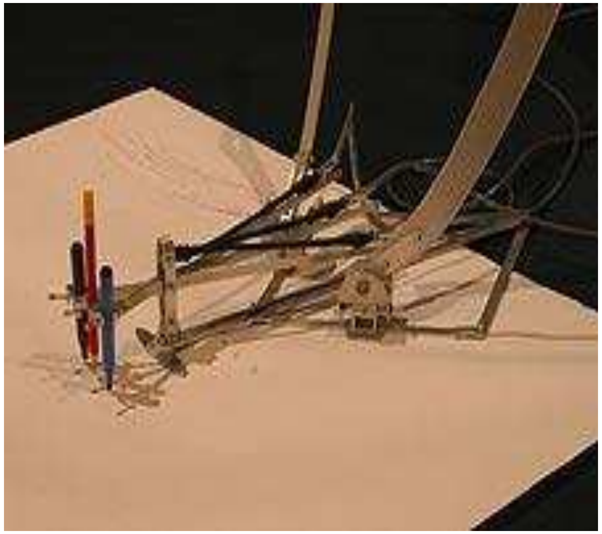
Hybrid Robotic/Neural Systems: the Lamprey-Khepera

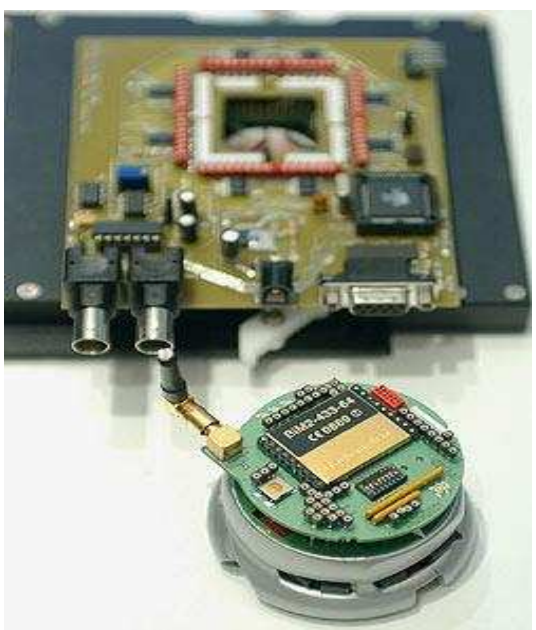


In another set of experiments, the hindbrain of a lamprey was explanted and connected to a Khepera robot.

The sensors on the robot's body were then used as inputs to the neural system. The resulting feedback loop allowed for adaptive behavior.

Hybrid Robotic/Neural Systems: the "Hybrot"



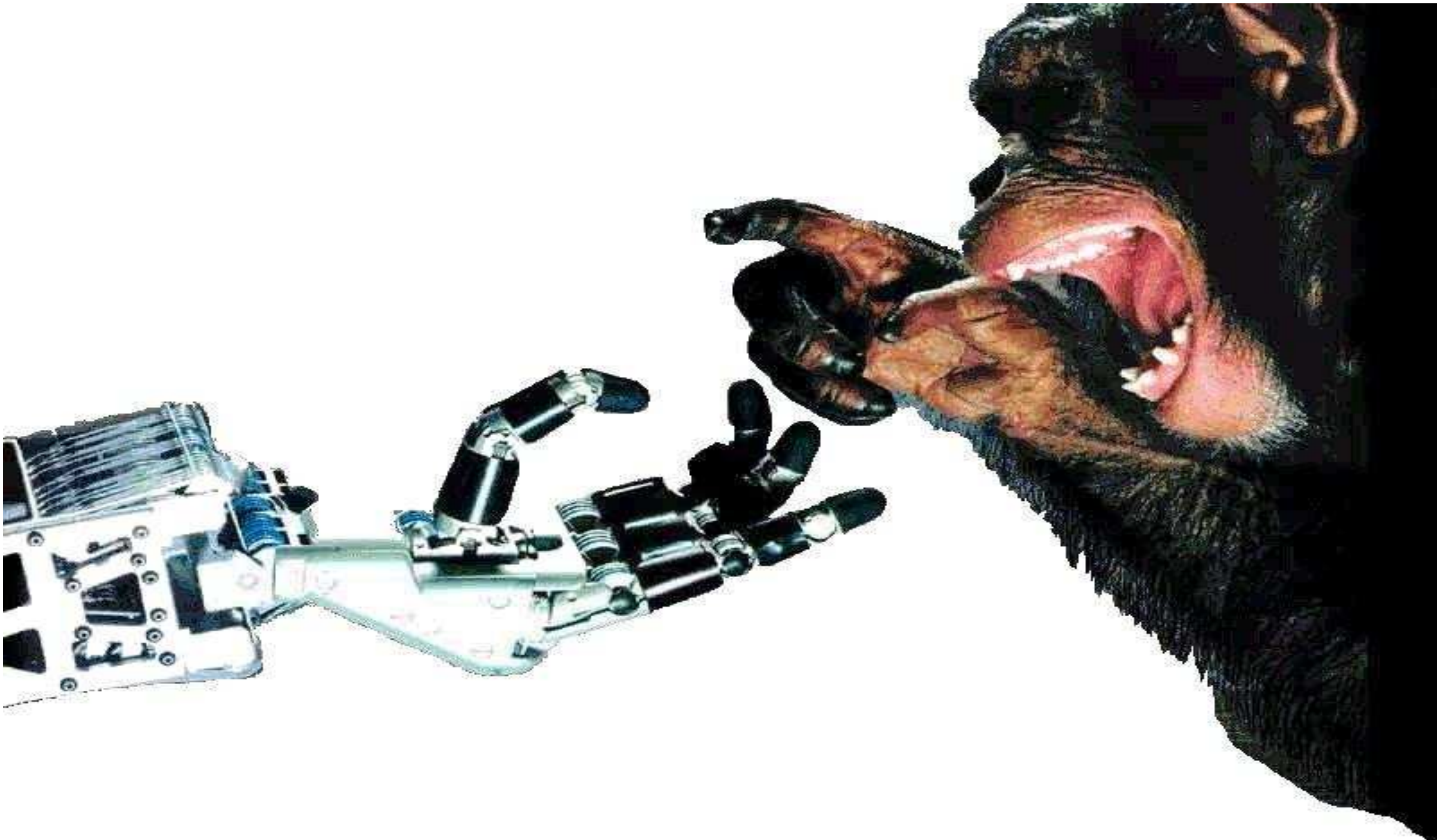


Such systems (called hybrots) can be used to produce "skilled" behaviors, such as drawing on an easel.

* application to the physical world requires no more software than connecting system to the virtual world.

* these systems tell us something about general processes behind learning and memory.

Future Directions



Future Directions (con't)

This talk has featured several up-and-coming areas of Neurotechnology:

* Neurotechnology Interface Overview

* Augmenting Cognition

* Biomechanotronics and Other Prostheses

* Achieving Real-time Ergonomy

These areas are largely experimental; very few large-scale applications have been introduced to the marketplace. However, they may not be far off.

Future Directions (con't)

Contact Bradly Alicea at freejumper@yahoo.com
for more information

Or visit the MIND Lab in 251 CAS (www.mindlab.org) for related research opportunities.