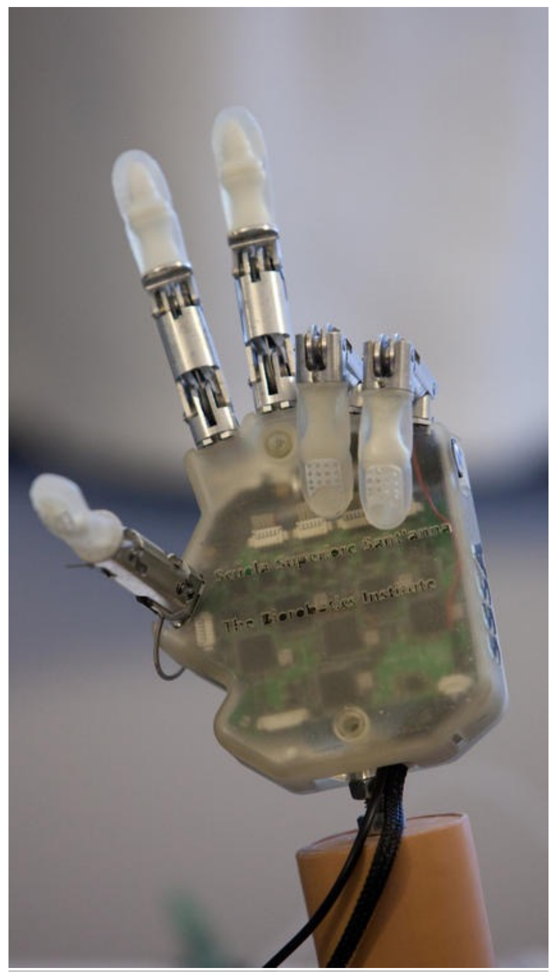
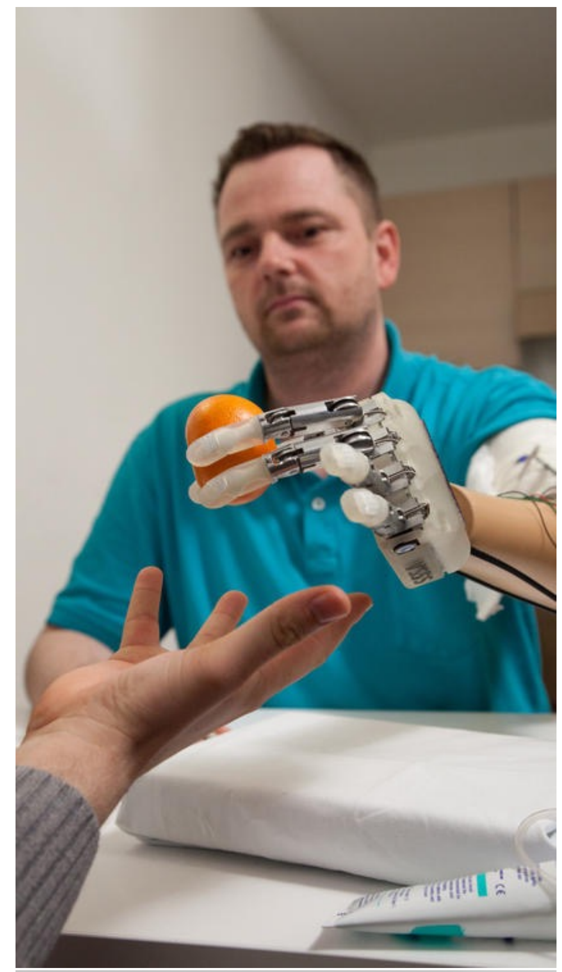
BRAIN-COMPUTER INTERFACE (BCI)

Norbert Fortin, PhD





Bio Sci 38: Mind, Memory, and the Brain

(Note that I lost track of the source of many of the images included. My apologies!)

OVERVIEW

- What are Brain-Computer Interfaces (BCIs)?
- Restoring sensory function using BCIs
- Restoring motor function using BCIs
- Restoring cognitive function using BCIs

WHAT ARE BRAIN-COMPUTER INTERFACES?

DEFINITION AND OBJECTIVES

An experimental approach in which scientists establish a direct communication pathway between the brain and an external device

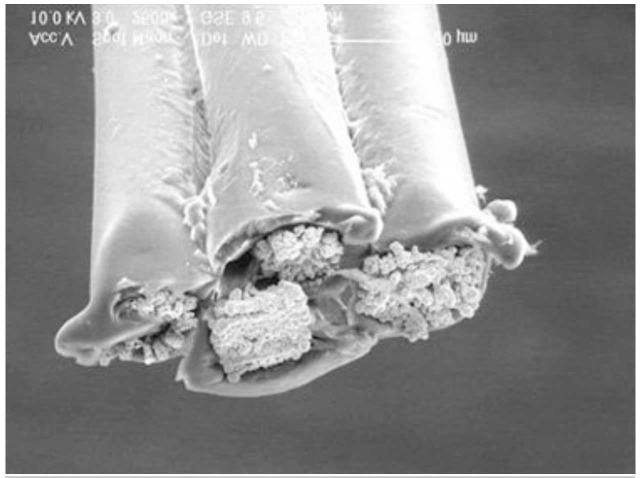
The main objectives of this approach are to:

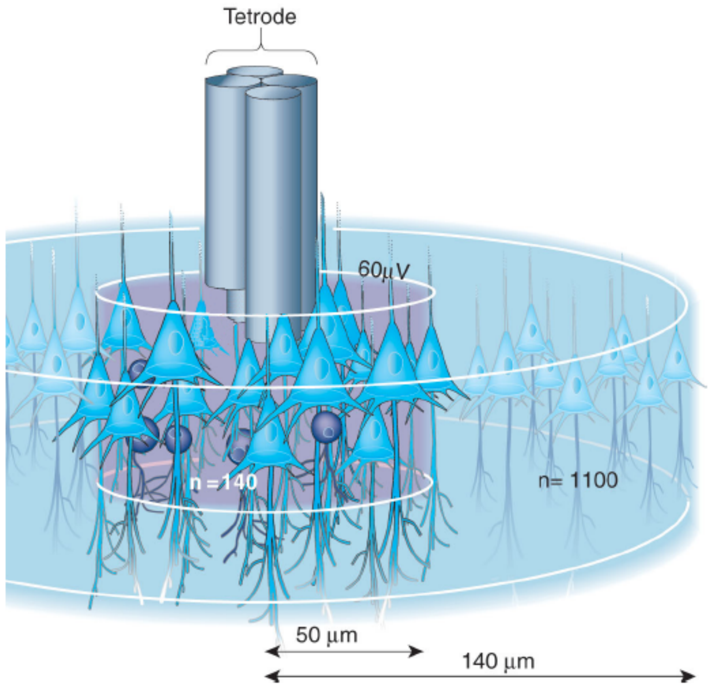
1) understand how the brain processes information
2) restore sensory, motor, or cognitive function

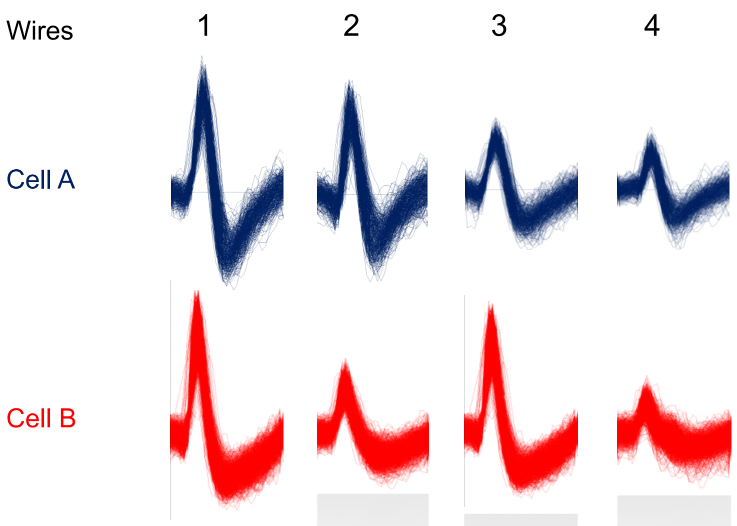
WHAT ARE BRAIN-COMPUTER INTERFACES?

REVIEW OF SINGLE-CELL RECORDINGS

Remember the lecture on single-cell recording techniques?







BCIs are based on information gathered using electrophysiological techniques like the ones we discussed

WHAT ARE BRAIN-COMPUTER INTERFACES?

HOW DO THEY WORK?

The idea is to mimic the brain (or nerve) signals that are naturally going on as you perceive sensory information (e.g., retina) or produce motor movements

Sensory prosthetic: The device sends the brain input it can understand, so the brain can “perceive” or “feel” from the device

Motor prosthetic: The device interprets the brain (or nerve) activity producing movements to control robotic limbs

WHAT ARE BRAIN-COMPUTER INTERFACES?

BCI VS NEUROPROSTHETICS

The difference between BCIs and neuroprosthetics is mostly in how the terms are used:

- **neuroprosthetics** typically connect the nervous system to an artificial <u>device</u> (e.g., prosthetic limb)
- **BCIs** usually connect the brain with a <u>computer system</u> (e.g., when lots of info processing is needed)

But the terms are often used interchangeably

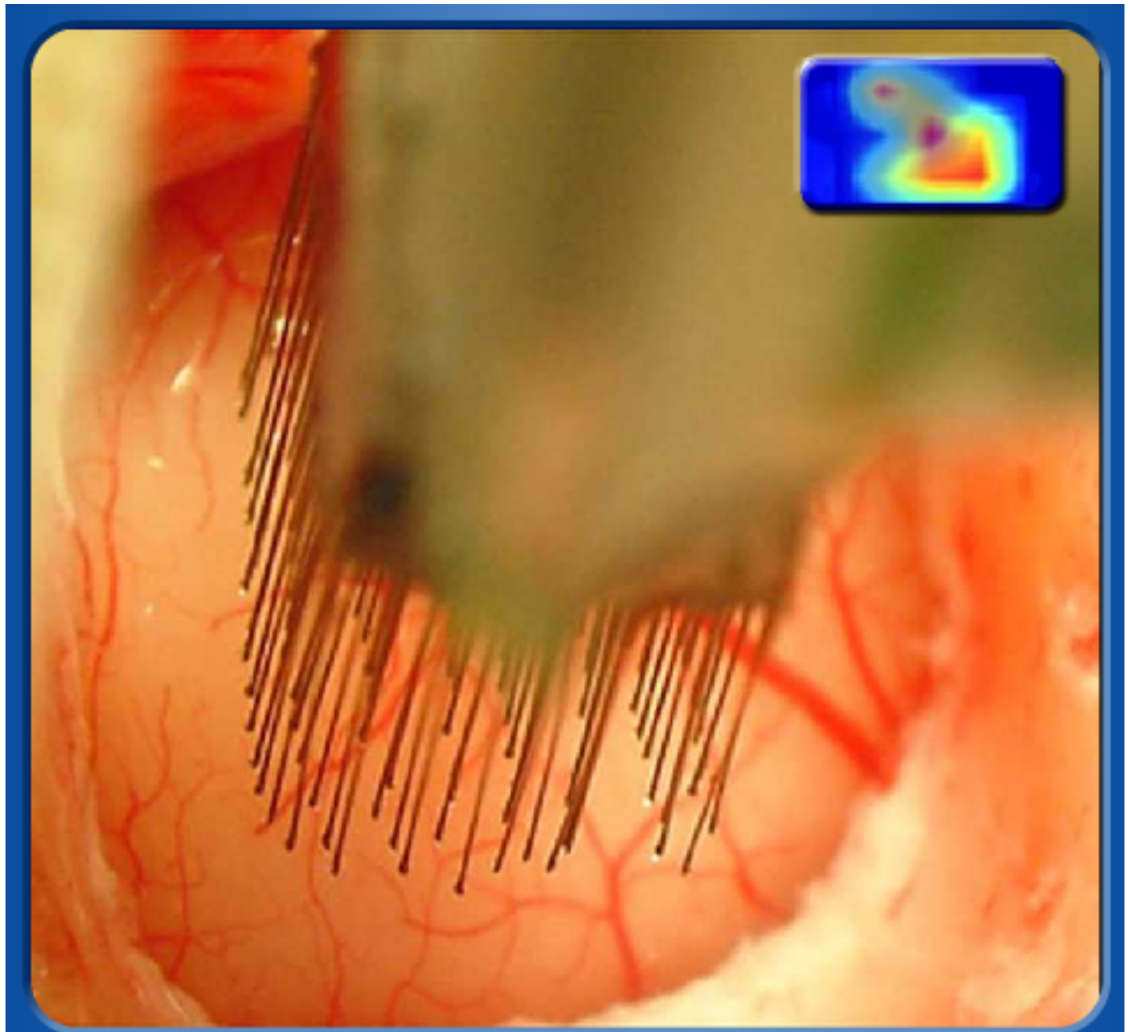
WHAT ARE BRAIN-COMPUTER INTERFACES?

DEGREES OF INVASIVENESS

Invasive BCIs: Electrodes are implanted directly into the brain

- highest accuracy
- higher surgical risk
- low long-term stability

  (prone to scar tissue buildup and loss of signal over time)



Implantation of the Duke high density array with 128 microwires in the motor cortex.

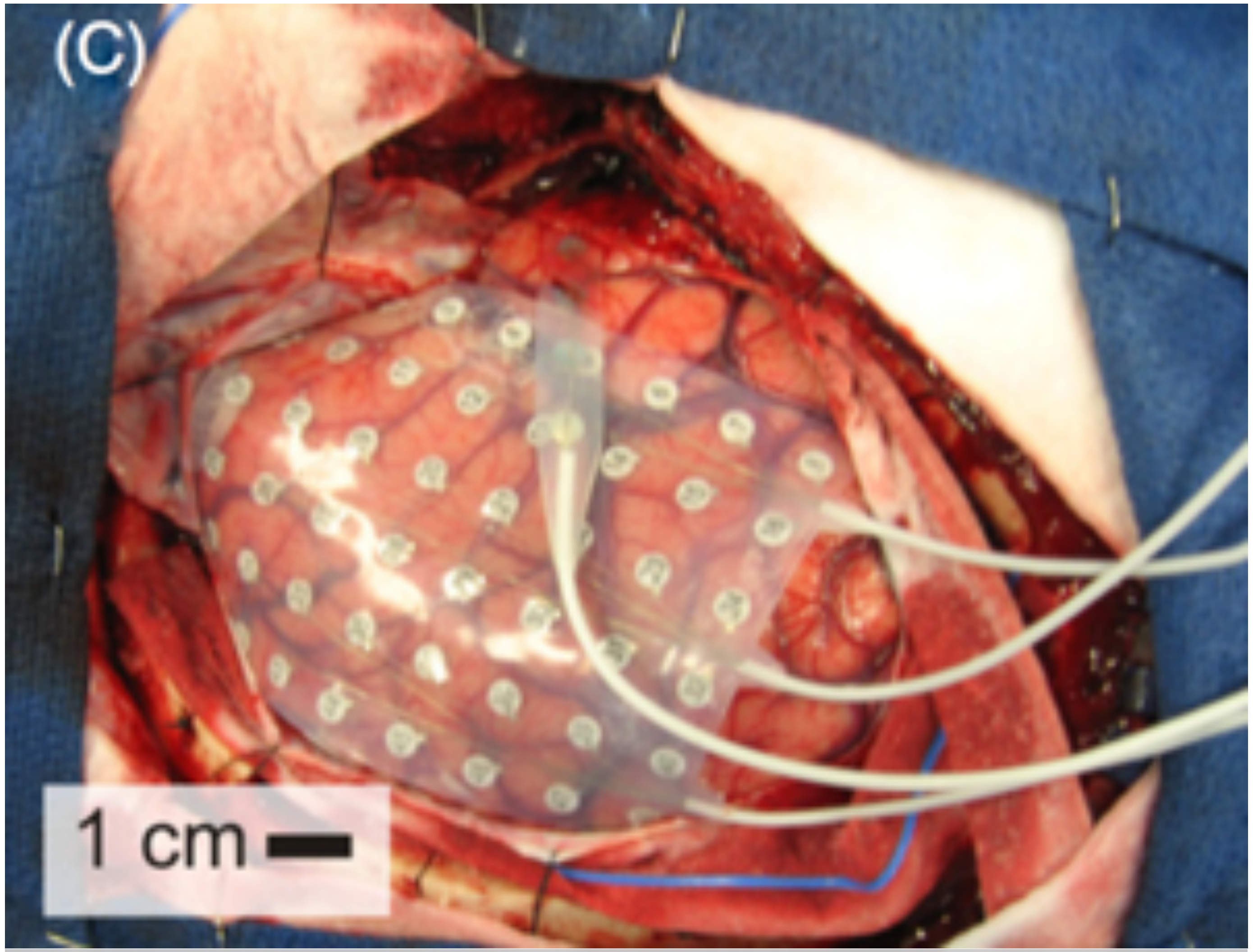
WHAT ARE BRAIN-COMPUTER INTERFACES?

DEGREES OF INVASIVENESS

Partially invasive BCIs: Electrodes are placed into the skull but outside the brain

e.g., Electrocorticography (ECoG)

- high accuracy
- lower surgical risk
- good long-term stability



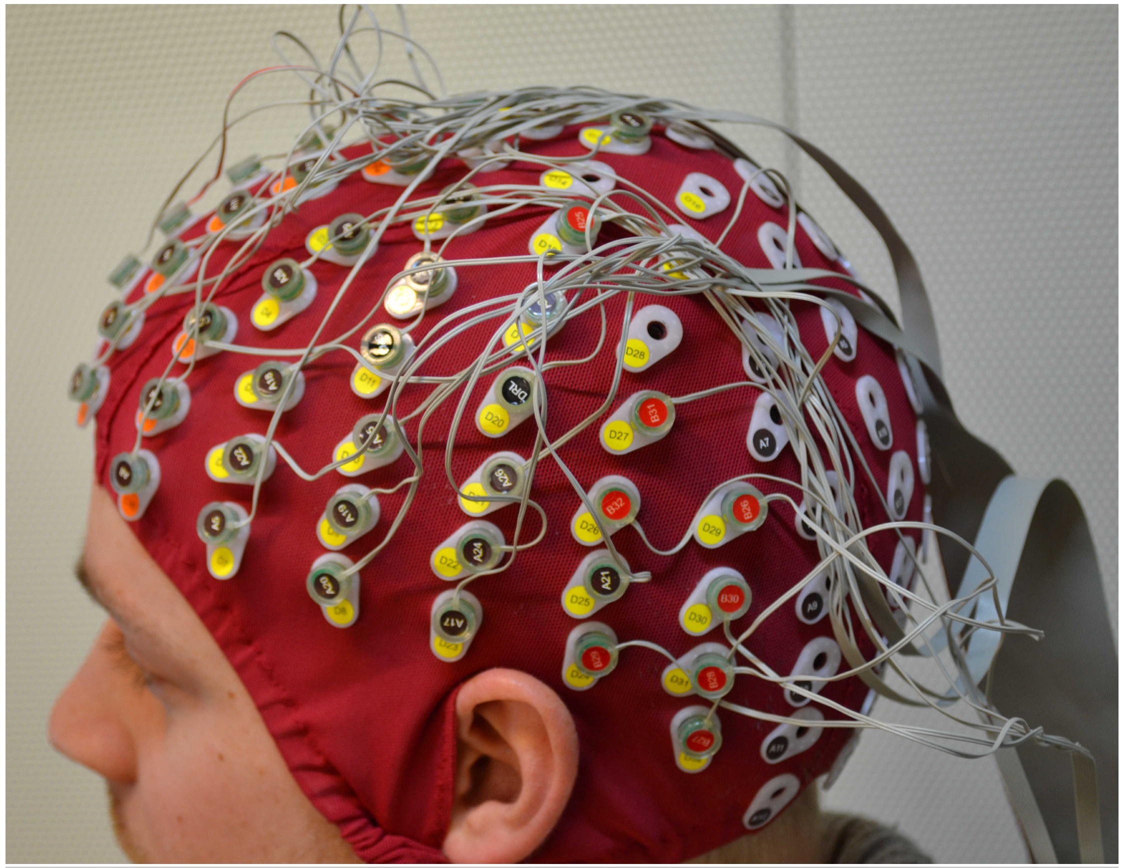
WHAT ARE BRAIN-COMPUTER INTERFACES?

DEGREES OF INVASIVENESS

Noninvasive BCIs: Activity is recorded from outside the skull

e.g., EEG

- low accuracy
- requires extensive training by the subject
- no surgical risk
- good long-term stability



OVERVIEW

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RESTORING SENSORY FUNCTION

AUDITORY NEUROPROSTHETICS: A SUCCESS STORY

Cochlear implants can help people with deafness hear again

(> 350,000 implants so far)

An implant has the following parts:

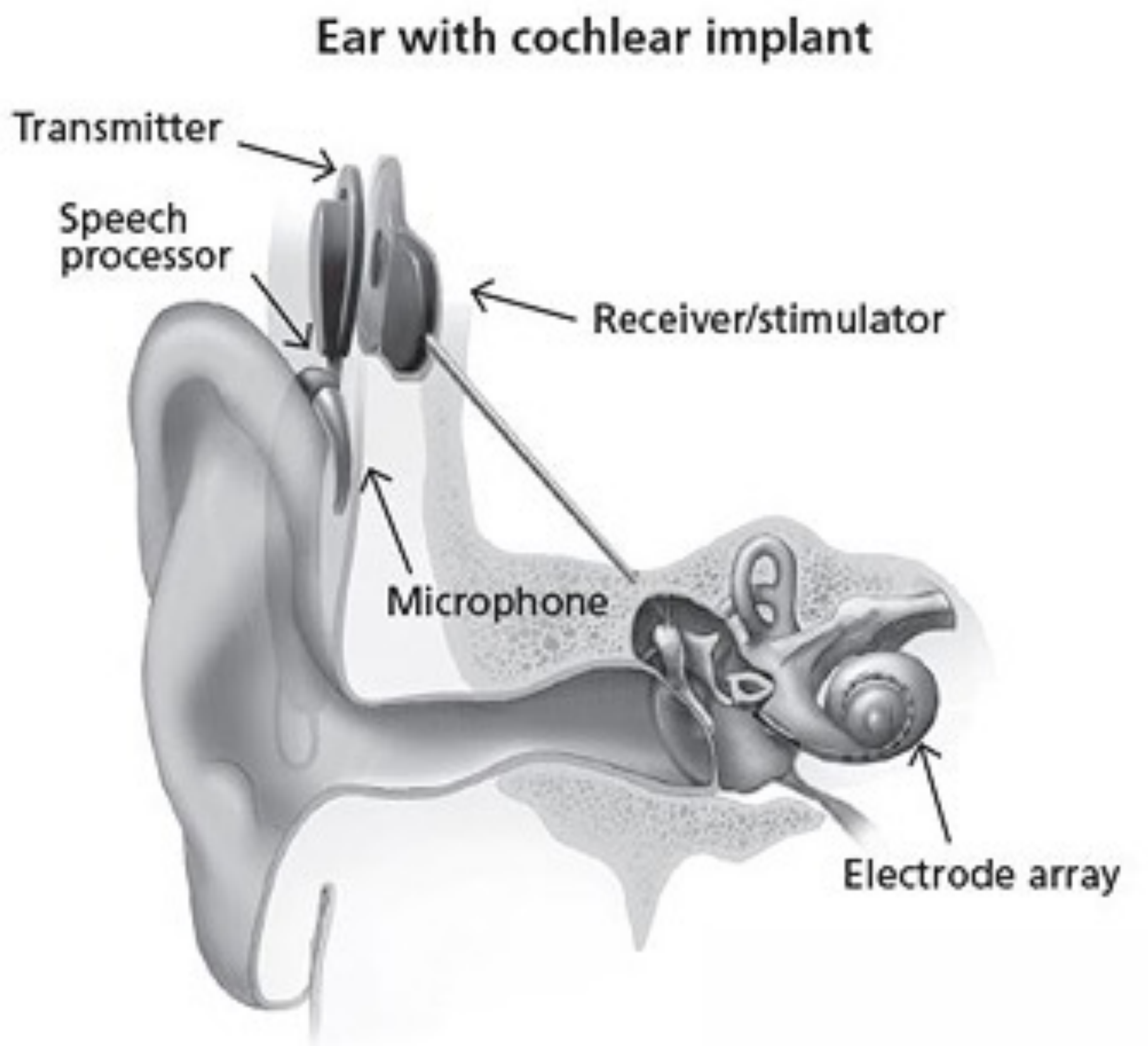
A microphone, which picks up sound from the environment.

A speech processor, which selects and arranges sounds picked up by the microphone.

A transmitter and receiver/stimulator, which receive signals from the speech processor and convert them into electric impulses.

An electrode array, which is a group of electrodes that collects the impulses from the stimulator and sends them to different regions of the auditory nerve.

An implant does not restore normal hearing. Instead, it can give a deaf person a useful representation of sounds in the environment and help him or her to understand speech.



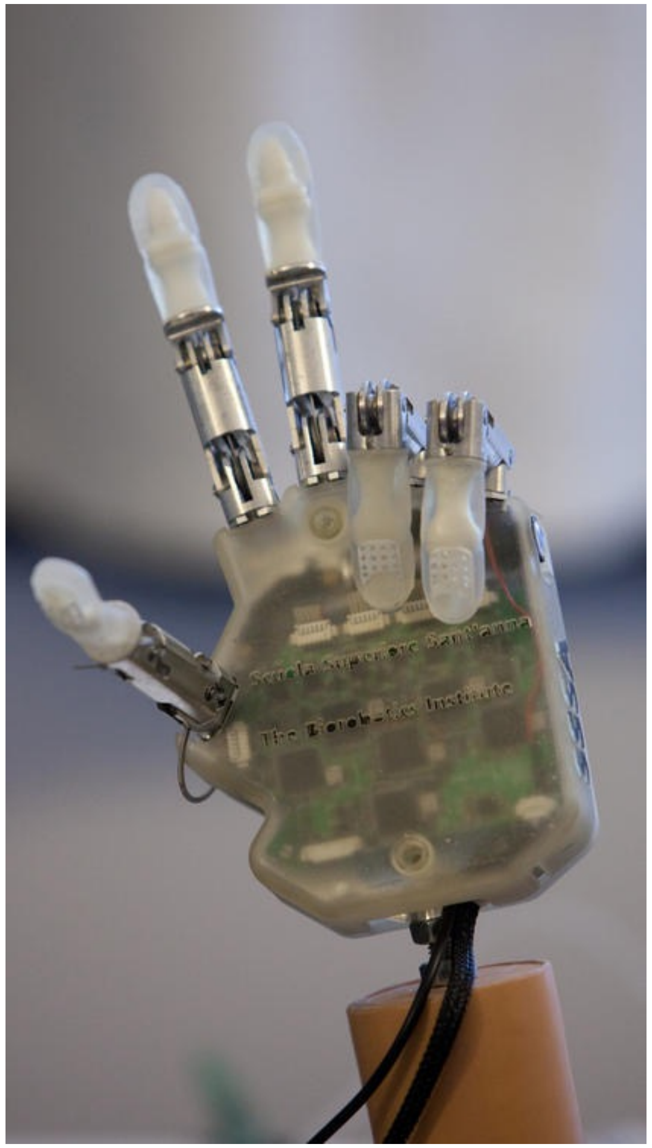
Is this invasive, partially invasive, or noninvasive?

RESTORING <u>SENSORY</u> FUNCTION

SOMATOSENSORY (TOUCH) NEUROPROSTHETICS

First prosthetic hand that can “feel”

The “hand” sends signals to electrodes implanted in a nerve of the upper arm, which then go to the brain.

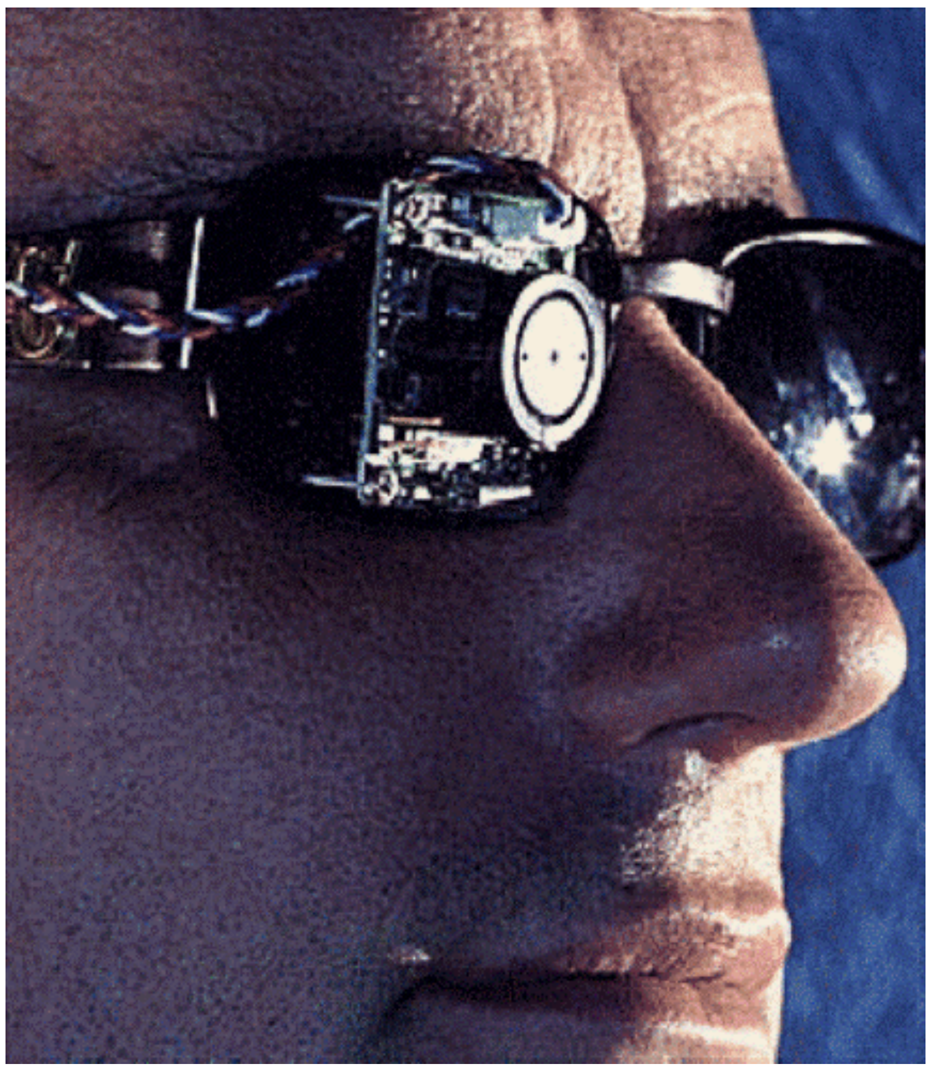


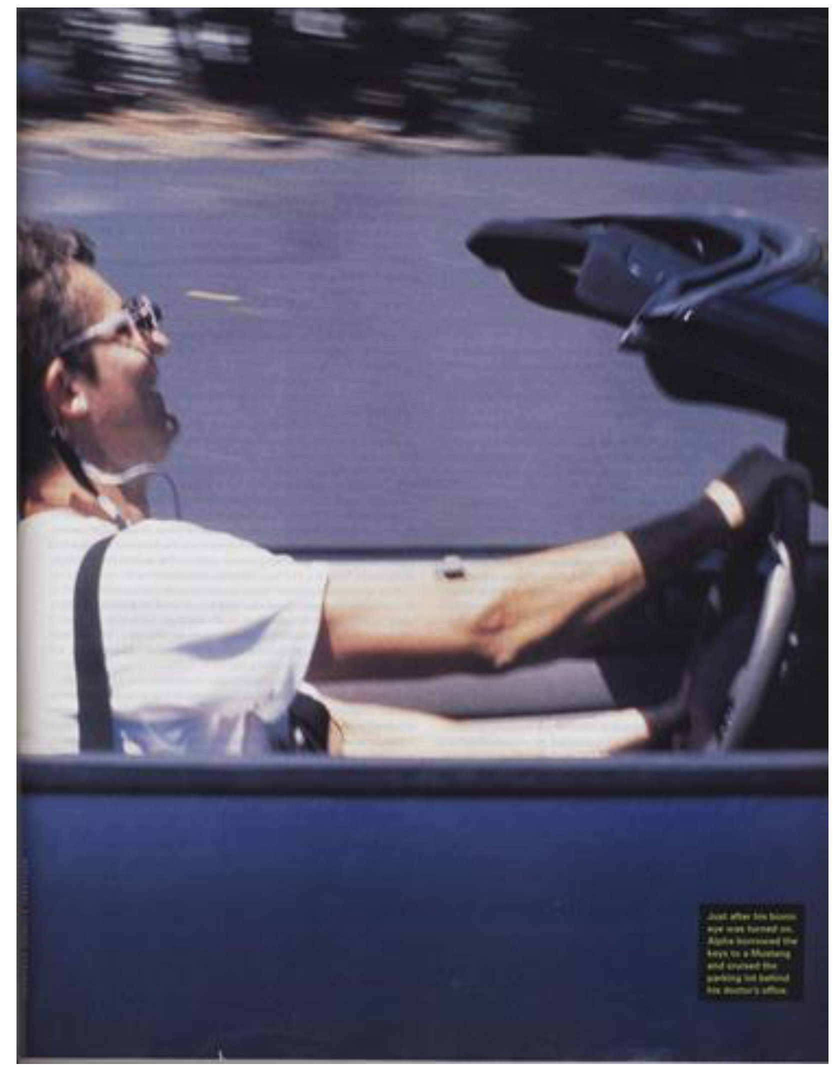
Is this invasive, partially invasive, or noninvasive?

RESTORING SENSORY FUNCTION

VISUAL NEUROPROSTHETICS

Retinal implants are a much more complicated problem, but the basic logic seems to work (for a while)





http://www.jensnaumann.net

Is this invasive, partially invasive, or noninvasive?

OVERVIEW

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RESTORING <u>MOTOR</u> FUNCTION

APPROACH #1: TARGETED REINNERVATION

Method by which doctors use amputees spare muscles and nerves to control and “feel” from a robotic arm

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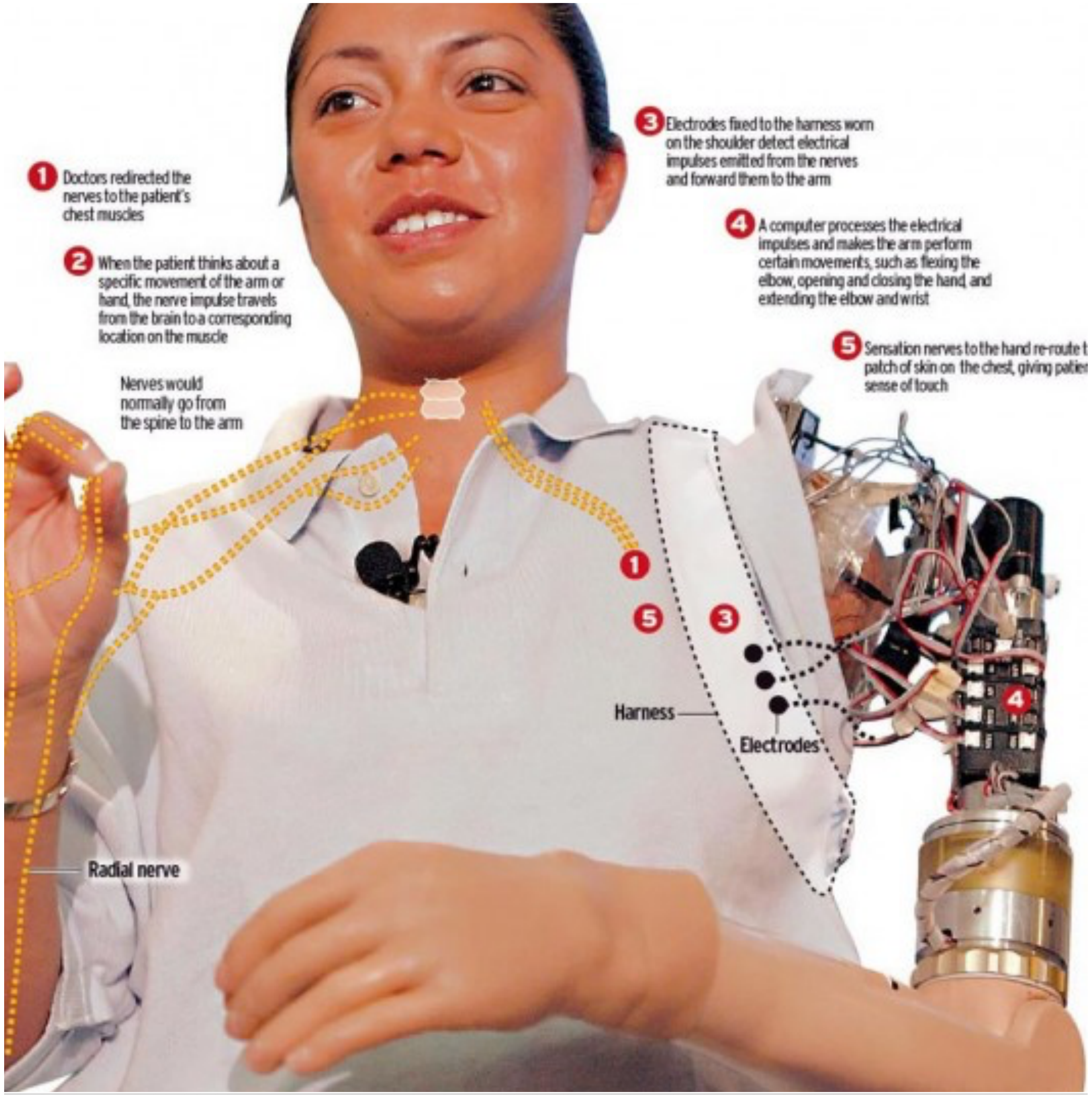
Physiatrist and engineer Todd Kuiken is building a prosthetic arm that connects with the human nervous system — improving motion, control and even feeling. Onstage, patient Amanda Kitts helps demonstrate this next-gen robotic arm.

RESTORING <u>MOTOR</u> FUNCTION
APPROACH #1: TARGETED REINNERVATION



How it works:

(1) A spare muscle (the target muscle) of an amputated patient is denervated (i.e., its original nerves are cut)

(2) The target muscle is then reinnervated with residual nerves of the amputated limb

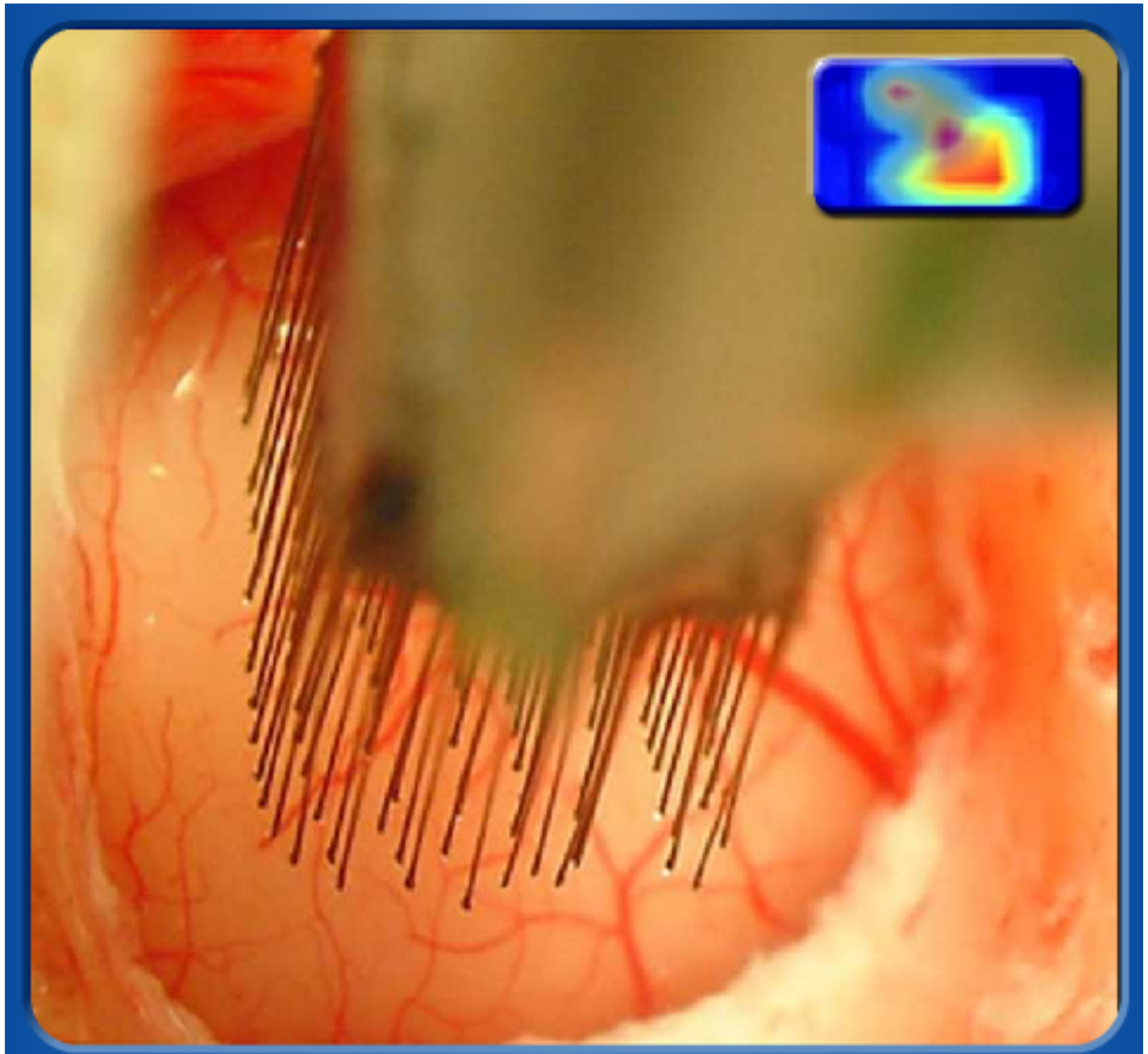
(3) Brain signals sent to the target muscle now represent the motor commands to the missing limb, and are used to drive the motorized prosthetic arm.

Is this invasive, partially invasive, or noninvasive?

RESTORING MOTOR FUNCTION

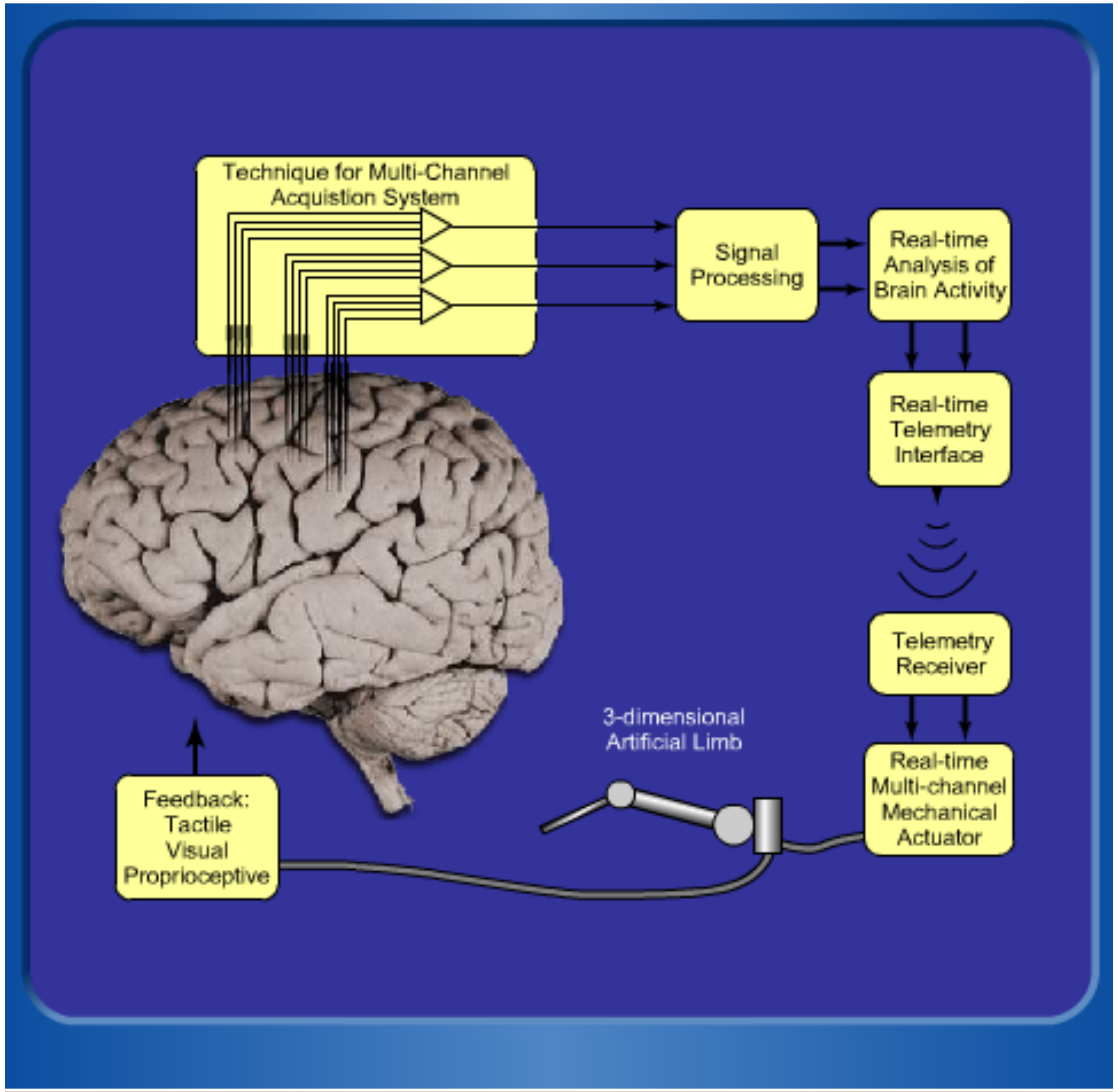
APPROACH #2: INTERPRETING MOTOR COMMANDS FROM THE BRAIN

Record activity of large groups of neurons in areas controlling body movement



Implantation of the Duke high density array with 128 microwires in the motor cortex.

Decode the activity to control robotic limbs



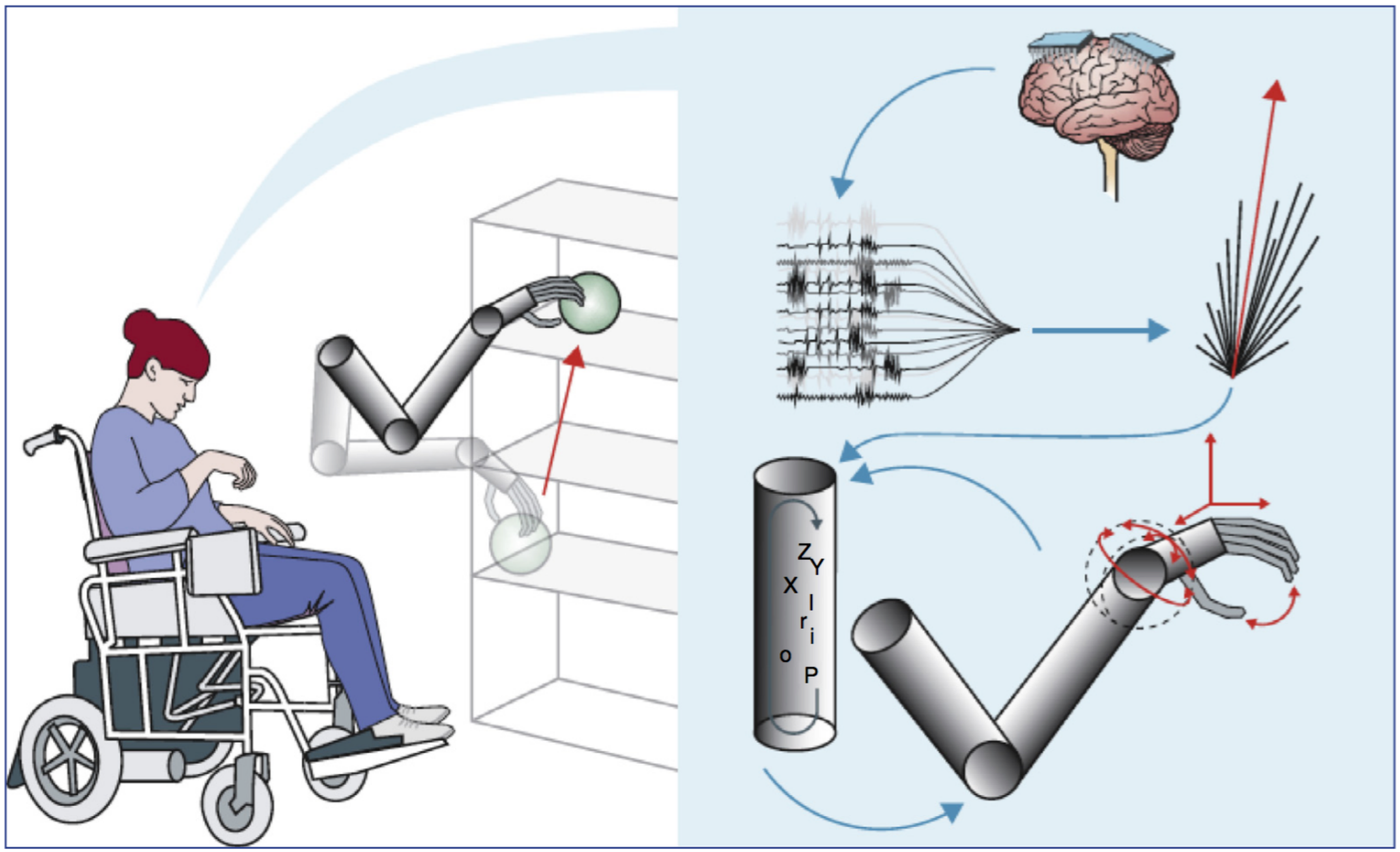
Nicolelis lab, Duke University

Is this invasive, partially invasive, or noninvasive?

RESTORING MOTOR FUNCTION

APPROACH #2: INTERPRETING MOTOR COMMANDS FROM THE BRAIN

Figure 1

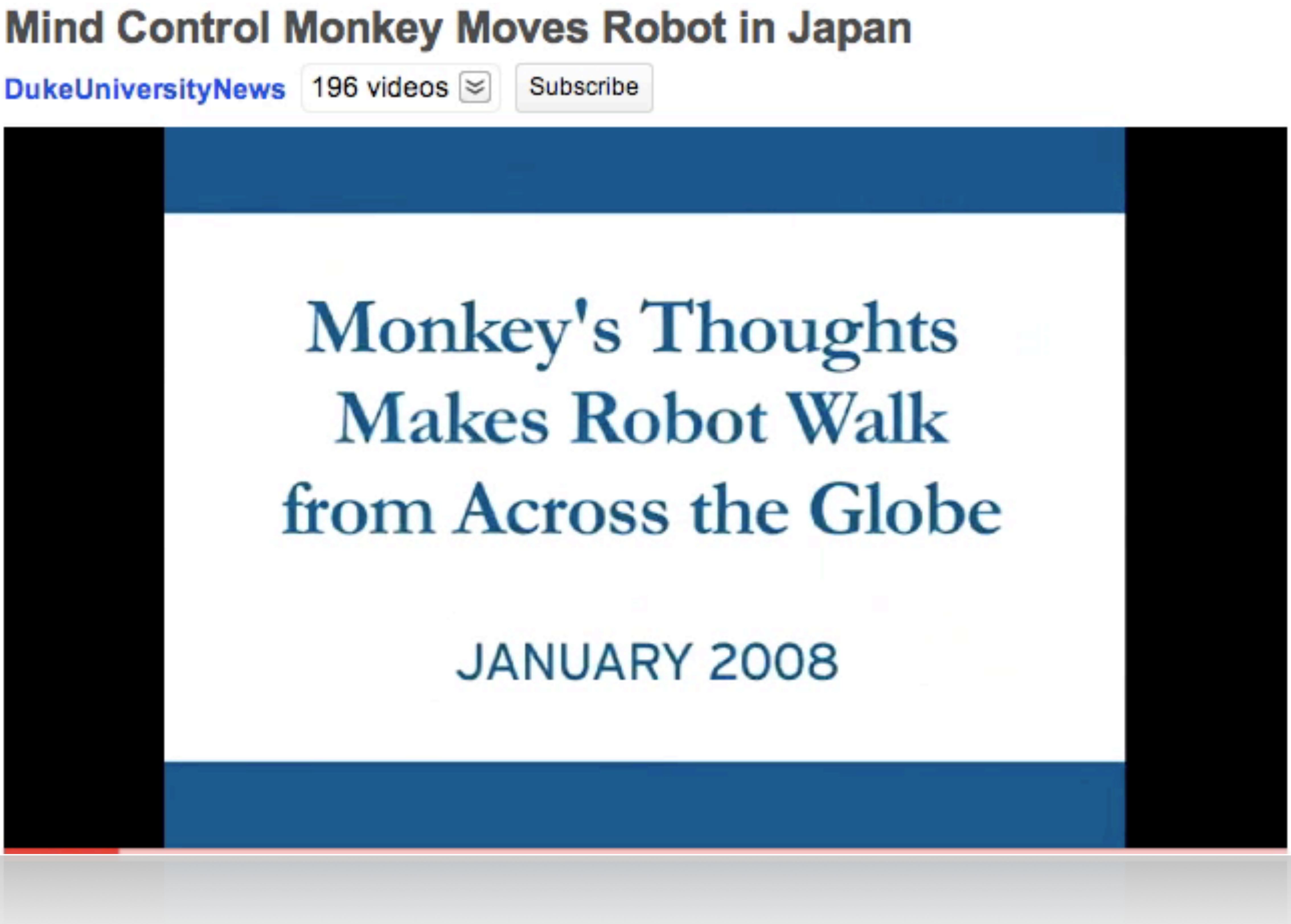


Current Opinion in Neurobiology

A tetraplegic woman is sitting in her wheelchair with an anthropomorphic prosthetic arm on her side. Two silicon-substrate microelectrode arrays surgically implanted in the motor cortex allow recordings of ensemble neuronal activity. A population vector algorithm translates brain waves into intended movement commands. This brain-derived information is conveyed to a shared controller that integrates the participant's intent, robotic position feedback, and task-dependent constraints. Using this bioinspired brain–machine interface, the paralysed woman could manipulate objects of various shapes and sizes in a three-dimensional workspace. Figure and legend from [26•].

RESTORING MOTOR FUNCTION

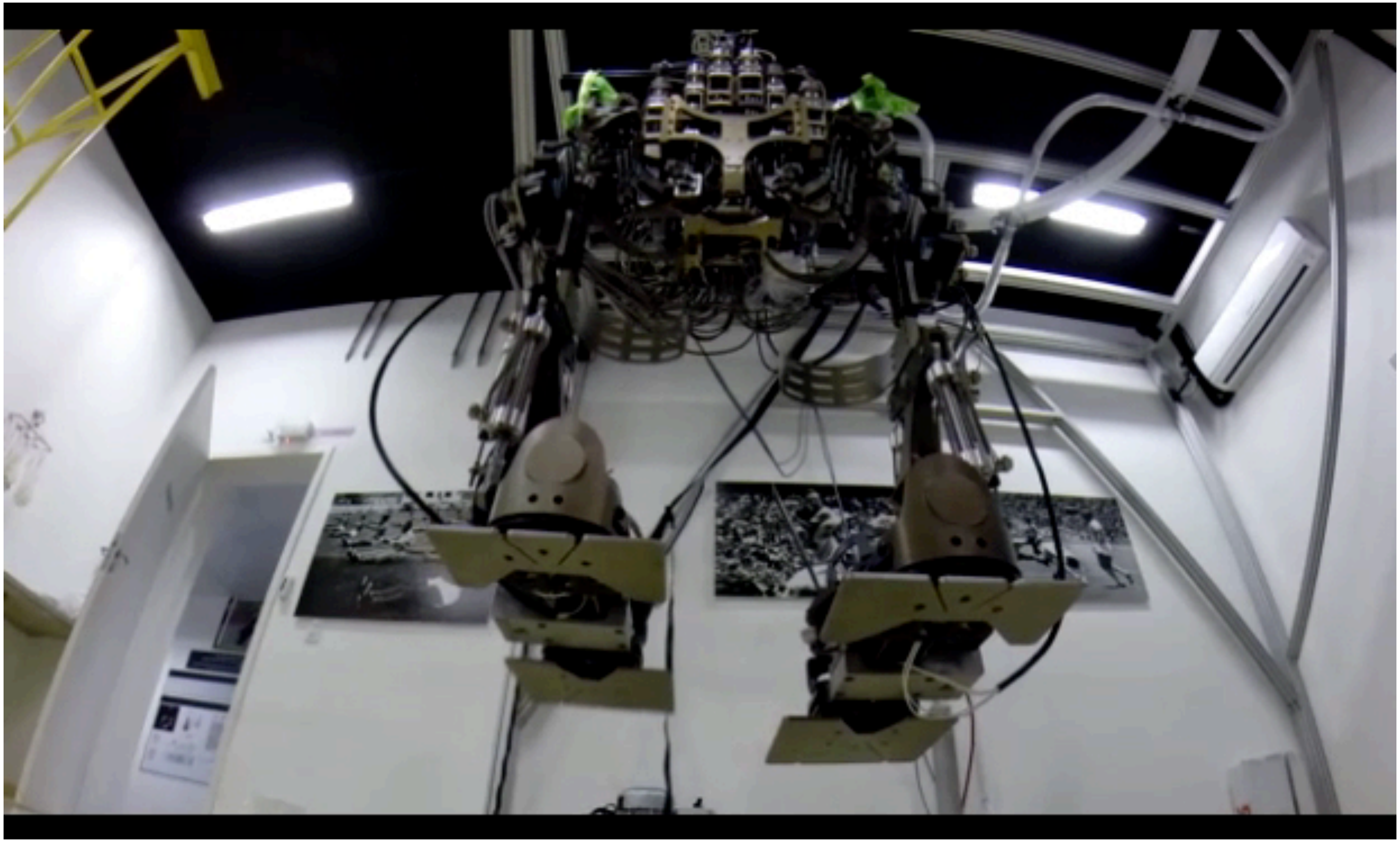
APPROACH #2: INTERPRETING MOTOR COMMANDS FROM THE BRAIN



RESTORING MOTOR FUNCTION

APPROACH #2: INTERPRETING MOTOR COMMANDS FROM THE BRAIN

Controlling an exoskeleton with your brain



Nicolelis lab, Duke University

http://www.theguardian.com/science/video/2014/apr/01/robotic-exoskeleton-world-cup-debut-video

RESTORING MOTOR FUNCTION

APPROACH #2: INTERPRETING MOTOR COMMANDS FROM THE BRAIN

For more details, check out Dr. Nicolelis' TED talk

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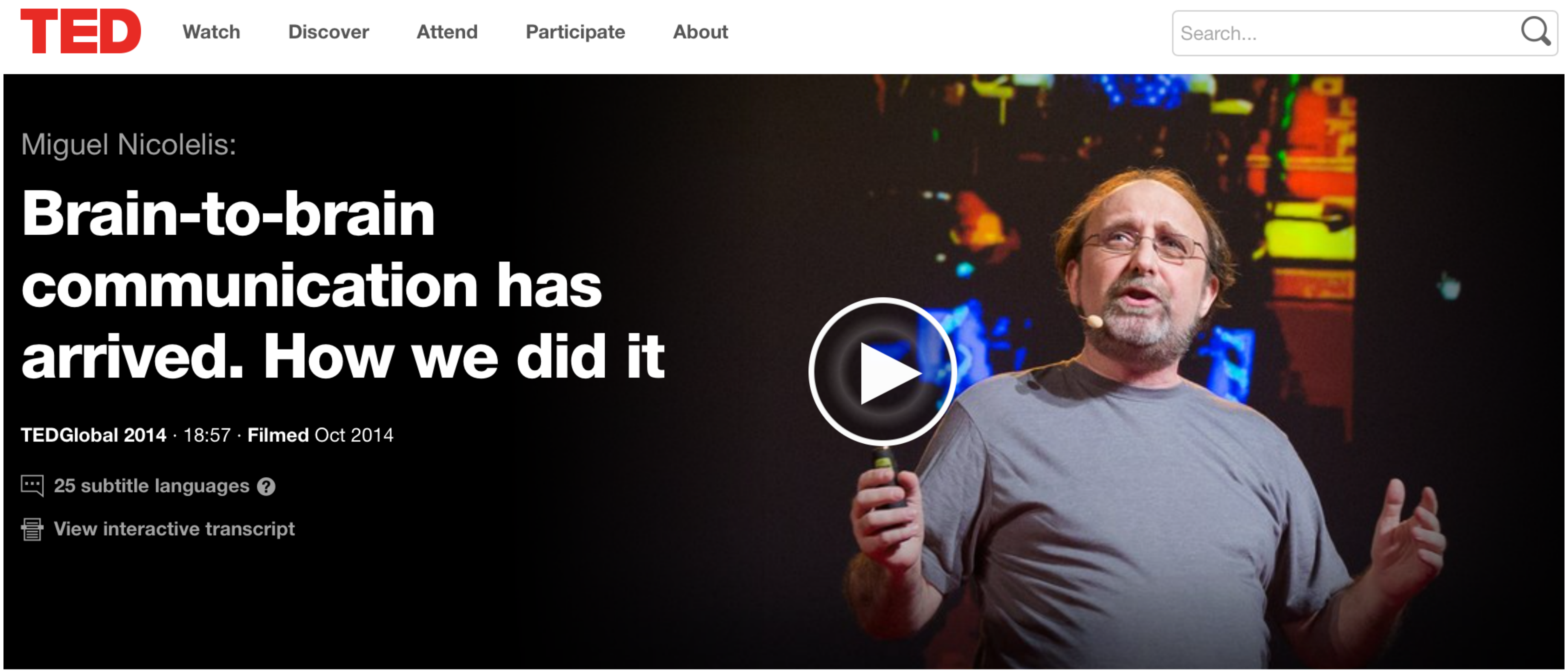
Can we use our brains to directly control machines? Miguel Nicolelis suggests yes, showing how a clever monkey in the US learned to control a robot arm in Japan purely with its thoughts. The research has big implications for quadraplegic people — and in fact, it powered the exoskeleton that kicked off the 2014 World Cup.

https://www.ted.com/talks/miguel_nicolelis_a_monkey_that_controls_a_robot_with_its_thoughts_no_really

RESTORING MOTOR FUNCTION

APPROACH #2: INTERPRETING MOTOR COMMANDS FROM THE BRAIN

Another fun lecture by Nicolelis… in case you're interested



https://www.ted.com/talks/miguel_nicolelis_brain_to_brain_communication_has_arrived_how_we_did_it#t-923952

OVERVIEW

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RESTORING COGNITIVE FUNCTION

DEVELOPING ARTIFICIAL BRAIN STRUCTURES

A number of scientists (e.g., Berger's group at USC, McNaughton's group at UCI) are working on developing an artificial hippocampus to restore memory function in patients with amnesia

The jury is still out on whether those approaches will be successful (memory is a much more complex problem than processing sensory or motor information).

Is this invasive, partially invasive, or noninvasive?