# New trends in brain computer interfaces and computer vision


A.M. Alvarez-Meza, Ph.D.

amalvarezme@unal.edu.co

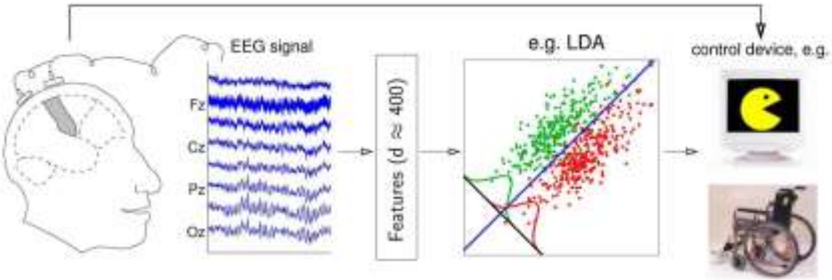
Signal processing and recognition group
Electrical, Electronic, and computational engineering department
Universidad Nacional de Colombia - Manizales


*Simposio 4ª Revolución Industrial*
*8/11/2018 - UNAL Manizales*

# Outline

# Outline

# Brain Computer Interfaces (BCI)




source: TU Charite Campus Benjamin Franklin - Machine learning for BCI

BCI: translation of human intentions into a technical control signal without using activity of muscles or peripheral nerves

# BCI interesting remarks

Grey Walter demonstrated use of **non-invasively brain recordings** from a human subject **to control** a **slide projector** (1964) [Graimann et al., 2010].

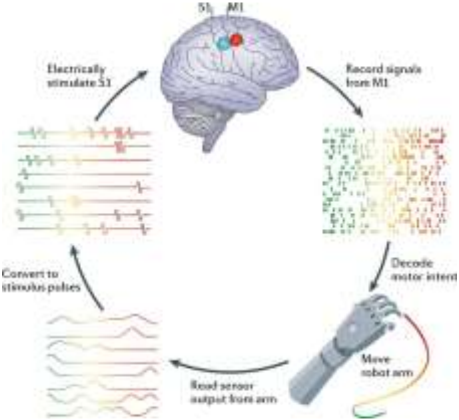
Fetz demonstrated **increase** of the **firing rates** of neurons in the **motor cortex** in non-human primates along with **auditory** or **visual feedback** (1969) [Fetz, 1969].

BCI was coined by Jaceques Vidal in1971aiming to interface human brain with computers (University of California) [Vidal, 1977].

- Assistive care
- Gaming and entertainment
- Cognitive improvement
- Restoring neural and/or behavioral function

BCI has become one of the most interesting alternatives to support automatic systems able to interpret brain functions

# Idealized bidirectional BCI




*Decoding*: extracting information from neural responses

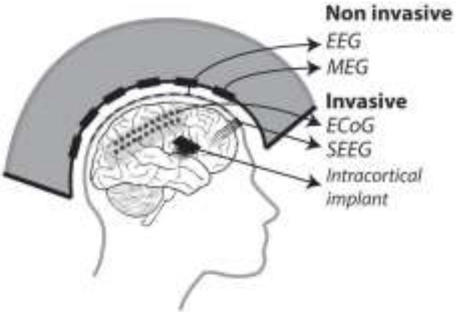
*Encoding*: representing the information of neural responses

# BCI technologies

**Invasive**: detection of *single neuron activity* by intra-cortical electrodes into the gray matter (rats and monkeys).

**Partially invasive**: recording electrocorticographic (ECoG) implants inside the skull but outside the gray matter.

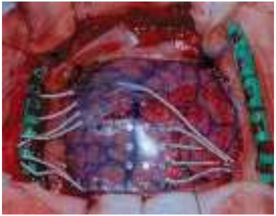
**Noninvasive**: recording of the brain activity at a *macro level*.



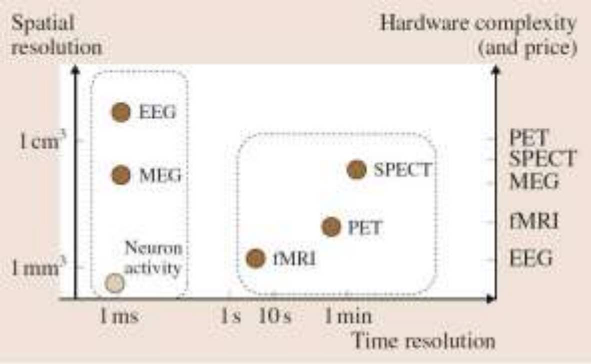
# BCI technologies

**Invasive** techniques are more reliable and less noisy.
Drawbacks: neurosurgery is required, long-term use or periodical replacement.

**Noninvasive** are more safe and cheap. Subject preparation is fast being possible to perform real-time analysis.
Drawbacks: noisy signal, time/spatial resolution issues.



# BCI technologies




Neuron activity - micro-array electrodes

EEG: Electroencephalography

MEG: magnetoencephalography

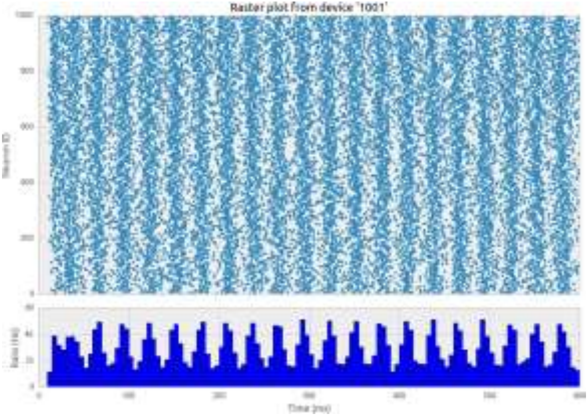
fNIR: functional near-infrared systems

fMRI: functional magnetic resonance imaging

SPECT: single photon emission computerized tomography

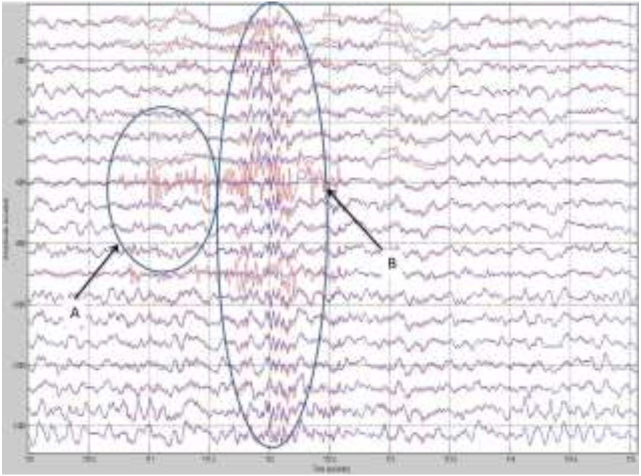
PET: positron emission tomography

# BCI technologies

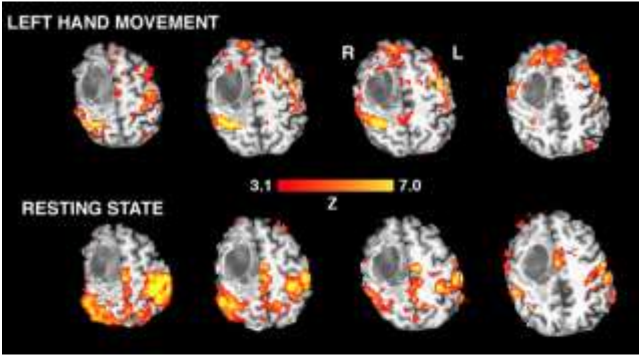



Neuron activity - spikes

# BCI technologies

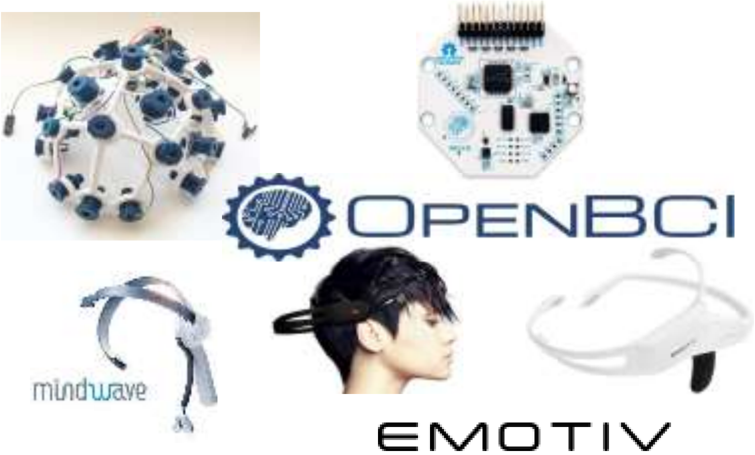



EEG




fMRI

# Brain Computer Interfaces: technologies




Cheap EEG sensors

# Outline

1 Decoding and encoding the human brain

2 Neuro-inspired computer vision

3 Relevant applications

4 Home made approaches

5 The open issue

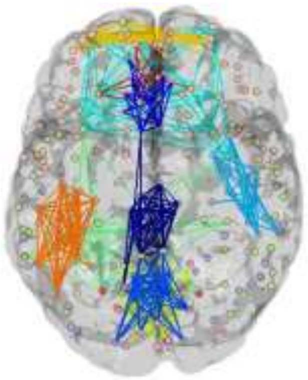
# Neuro-inspired machines

Descartes explains the mind in terms of **hydraulic analogies** and the **movement of fluids**.

Freud said the brain was like a **steam engine**, distributing and releasing pressure [Leary, 1994].

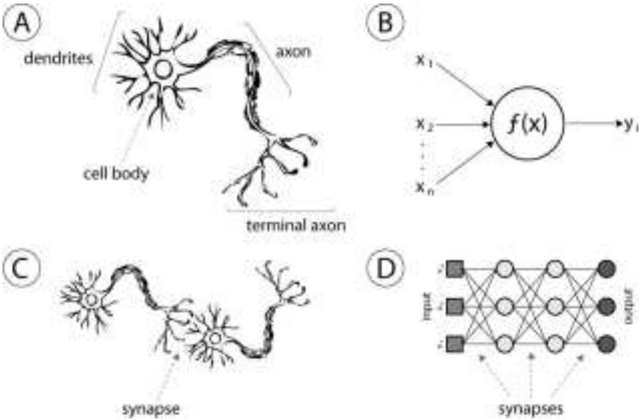
The era of radio: brain was described in terms of **channels** and **frequencies**.

Nowadays, we talk of **neuronal computations**; distant brain regions communicate to form **networks of activity**.



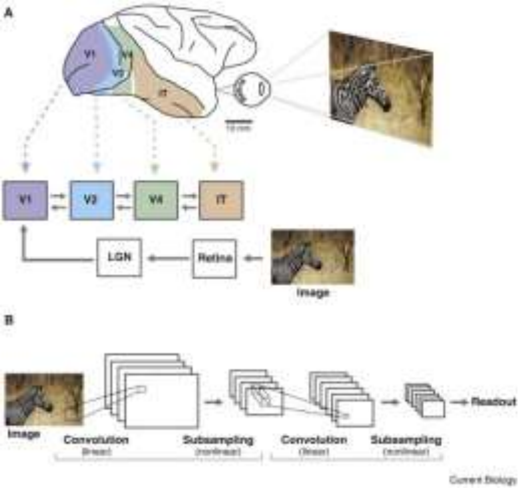
Human Brain: A complex computational system

# Neuro-inspired machines




Artificial Neural Networks: The nonlinear activation functions and the hidden layers overcame the theoretical limitations of the perceptron.

# Visual neuroscience and computer vision




Convolutional Neural Network: Computer vision has played a leading role in the development of biologically inspired computing.

# Relevant milestones

1936: Linear discriminant analysis

1953: Machine learning

1958: Perceptron (Single layer)

1974: Backprop (Multilayer)

1980: Neocognitron (1st CNN)

1987: NETTalk
(English text to speech)

1989: ConvNets (Handwritten recognition)

1995: Support Vector Machines

2006: Backprop, revived
(Handwritten recognition record)

2012: Deep Learning
(one year thinking and **16 years of progress in computing**)

2012: AlexNet (Deep-CNN to classify 1000 classes)

# Neuro-inspired machines: silicon computers vs human brain

- Individual computational elements in **man-made computers** run at amazingly fast clock speeds (nearly **speed of light**).
- Biological neurons in mammals: **action potentials** propagates at 1 m/s to just over 100 m/s [Rushton, 1951].
- Visual signals from the eye **don't reach primary visual cortex** until around **50 ms** after photons reach the retina [Vanni et al., 2004].

# Neuro-inspired machines: silicon computers vs human brain

Signals reach later visual processing stages until almost 200 ms after the retina is stimulated [Bötzel et al., 1995].

What **brains lose** in the **speed of individual elements**, they potentially **make up** for in **parallelism** and **connectivity**.

GPU: **thousands of cores**.

BRAIN: **billions of neurons** operating in parallel (only consuming 20 watts!).

# Outline

# BCI highlights: DARPA

- The Defense Advanced Research Projects Agency (DARPA) has funded innovative scientific BCI research since the 1970s.
- BCI efforts aimed at **restoring neural** and/or **behavioral function**.
- BCI efforts aimed at **improving human training** and **performance**.
- Promoting interdisciplinary collaborations among researchers, **engineers**, and **clinicians**.

source:http://edition.cnn.com/2015/09/15/health/.html

# DARPA BCI projects: main goals

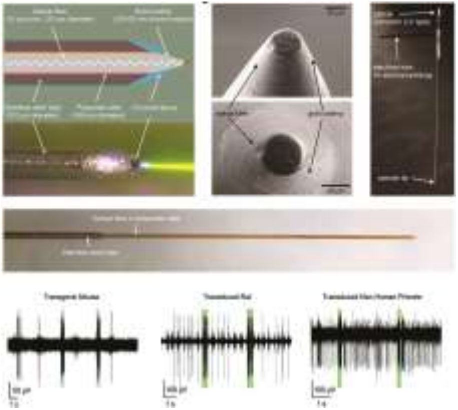
**Detect** – Develop diagnostics, models, and devices to characterize and mitigate threats to the human brain.

**Emulate** – Leverage inspiration from functional brain networks to efficiently synthesize information.

**Restore** – Reestablish behavioral and cognitive function lost as a result of injury to the brain or body.

**Improve** – Develop brain-in-the loop systems to accelerate training and improve functional behaviors.

# DARPA BCI projects: reorganization and plasticity to accelerate injury recovery



Optogenetics are employed to perform precise, reversible perturbations of brain activity

# DARPA BCI projects
## restorative encoding memory integration neural device

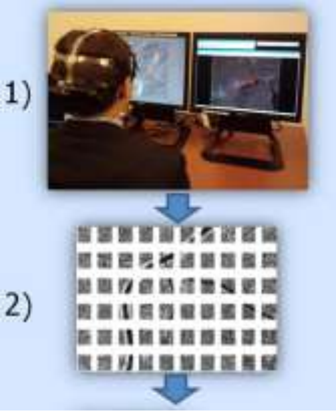
Very few have attempted to develop a **cognitive prosthesis**.

REMIND: development of a BCI system for **memory restoration**.

Ability to **detect patterns** of **functional brain connectivity** in the hippocampus and prefrontal cortex associated with **successful memory encoding** and **retrieval**.

Studying the spatiotemporal patterns of
hippocampal activity during memory encoding

# DARPA BCI projects
# Cognitive Technology Threat Warning System




To detect potential threats during real-time surveillance operations

# BCI highlights: DARPA

Brain Research through Advancing Innovative Neuropsychologies (BRAIN) Initiative (April 2013).

DARPA is currently supporting new research efforts aimed at the development of BCI technologies.

Restoring human function in human clinical populations with either neuropsychiatric of memory dysfunction.

**System-based Neurotechnology for Emerging Theraphies (SUBNETS)**: treating complex neuropsychiatric and neurologic disorders.

**Restoring Active Memory (RAM)**: computational models to characterize the complex organization of memory in the human brain.

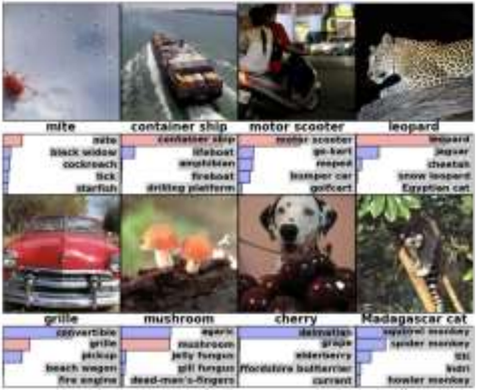
DARPA is working with U.S. Food and Drug Administration

# Computer vision highlights

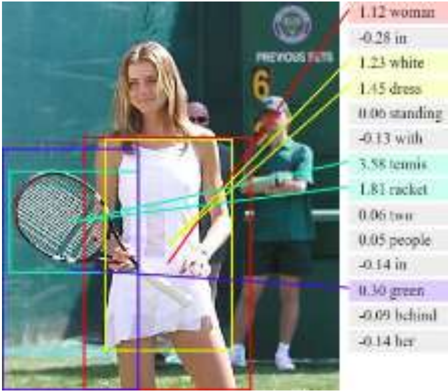
## ImageNet Challenge

IMAGENET

- 1,000 object classes (categories).
- Images:
  - 1.2 M train
  - 100k test.



# Computer vision highlights



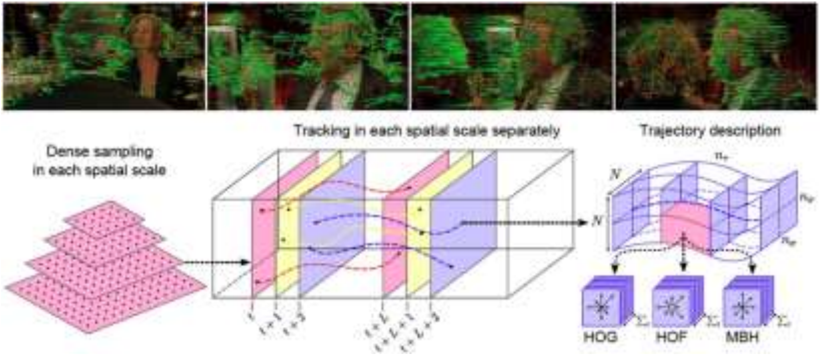

RNN and CNN working (Standford Vision Lab)

# Computer vision highlights

"black and white dog jumps over bar"

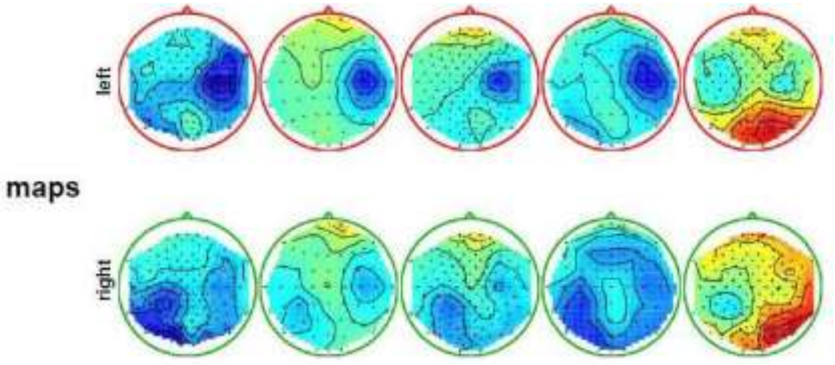
RNN and CNN working (Standford Vision Lab)

# Computer vision highlights



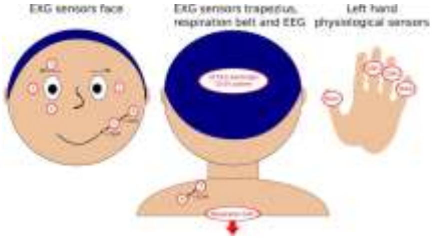
# Outline

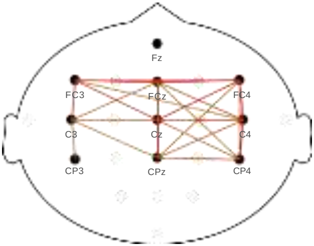
# Motor imagery systems




EEG map of a left vs right hand motor imagery task
(One subject on different days)

# Neural decoding from EEG




The goal:to find neural patterns that are related to a given stimulation (the intention of the movement, visual, etc).

The issue:Dealing with hidden spatio-temporal relationships.

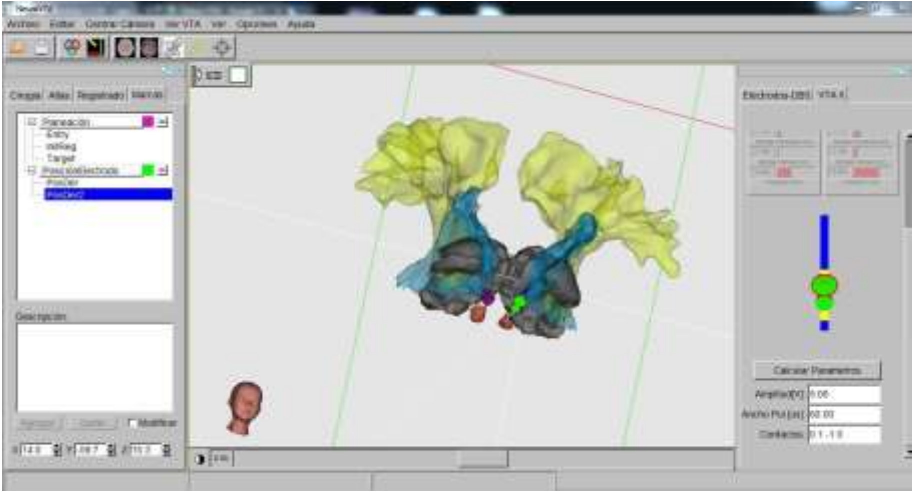
The goal:to control a robotic sphere based on a motor imagery classification system.

The issue:Dealing with hidden spatio-temporal relationships.

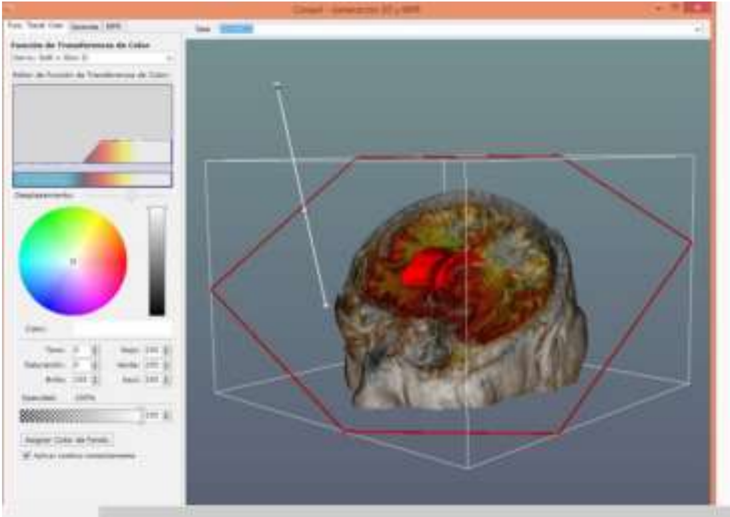
The goal:to support the Deep Brain Stimulation (DBS) parameter tuning based on signal processing approaches.

The issue:Dealing with high-dimensional data and ill-possed problems.

# DBS for Parkinson's disease treatment: NeuroVTA

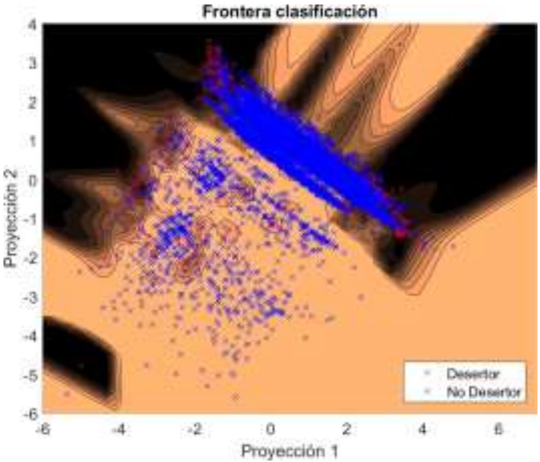


# Medical imaging processing



To support neurological diseases diagnosis and treatment

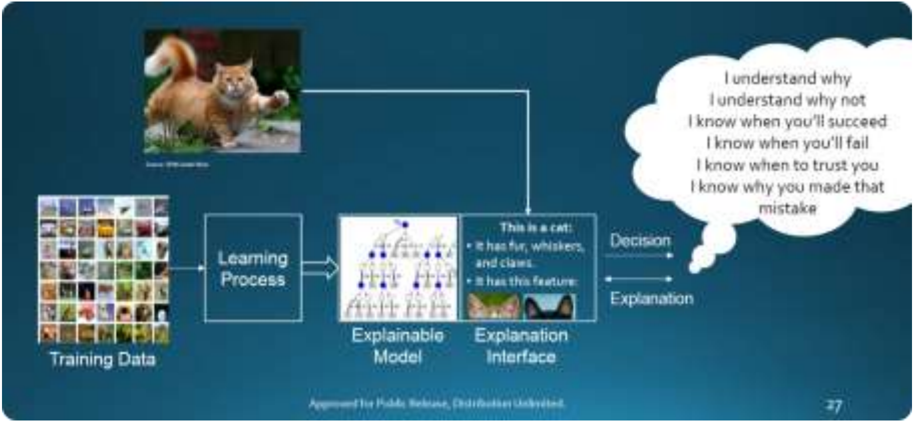
# Learning from data




Statistical learning-based systems to extract relevant information from data

# Outline

# The open issue: contextual learning




DARPA Perspective: Perceiving, Learning, Abstracting, and Reasoning
Sept 2018: more than $2 billion in "AI Next" campaign

# ReferencesI


B¨otzel, K., Schulze, S., and Stodieck, S. R. (1995).
Scalp topography and analysis of intracranial sources of face-evoked potentials.
*Experimental brain research*, 104(1):135–143.

Brockmeier, A. J. (2014).
*LEARNING AND EXPLOITING RECURRENT PATTERNS IN NEURAL DATA*.
PhD thesis, Citeseer.

Fetz, E. E. (1969).
Operant conditioning of cortical unit activity.
*Science*, 163(3870):955–958.

Graimann, B., Allison, B., and Pfurtscheller, G. (2010).
Brain–computer interfaces: A gentle introduction. In
*Brain-Computer Interfaces*, pages 1–27. Springer.

Leary, D. E. (1994).
*Metaphors in the history of psychology*.
Cambridge University Press.

Miranda, R. A., Casebeer, W. D., Hein, A. M., Judy, J. W., Krotkov, E. P., Laabs, T. L., Manzo, J. E., Pankratz, K. G., Pratt, G. A., Sanchez, J. C., et al. (2015).
Darpa-funded efforts in the development of novel brain–computer interface technologies.
*Journal of neuroscience methods*, 244:52–67.

Rushton, W. (1951).
A theory of the effects of fibre size in medullated nerve.
*The Journal of physiology*, 115(1):101–122.

# References II


Vanni, S., Warnking, J., Dojat, M., Delon-Martin, C., Bullier, J., and Segebarth, C. (2004).
Sequence of pattern onset responses in the human visual areas: an fmri constrained vep source analysis.
*Neuroimage*, 21(3):801–817.

Vidal, J. J. (1977).
Real-time detection of brain events in eeg.
*Proceedings of the IEEE*, 65(5):633–641.

**Contact:** amalvarezme@unal.edu.co