

Current and Future Approaches to Brain-Computer Interface Technology

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ASA 2017 Annual Meeting

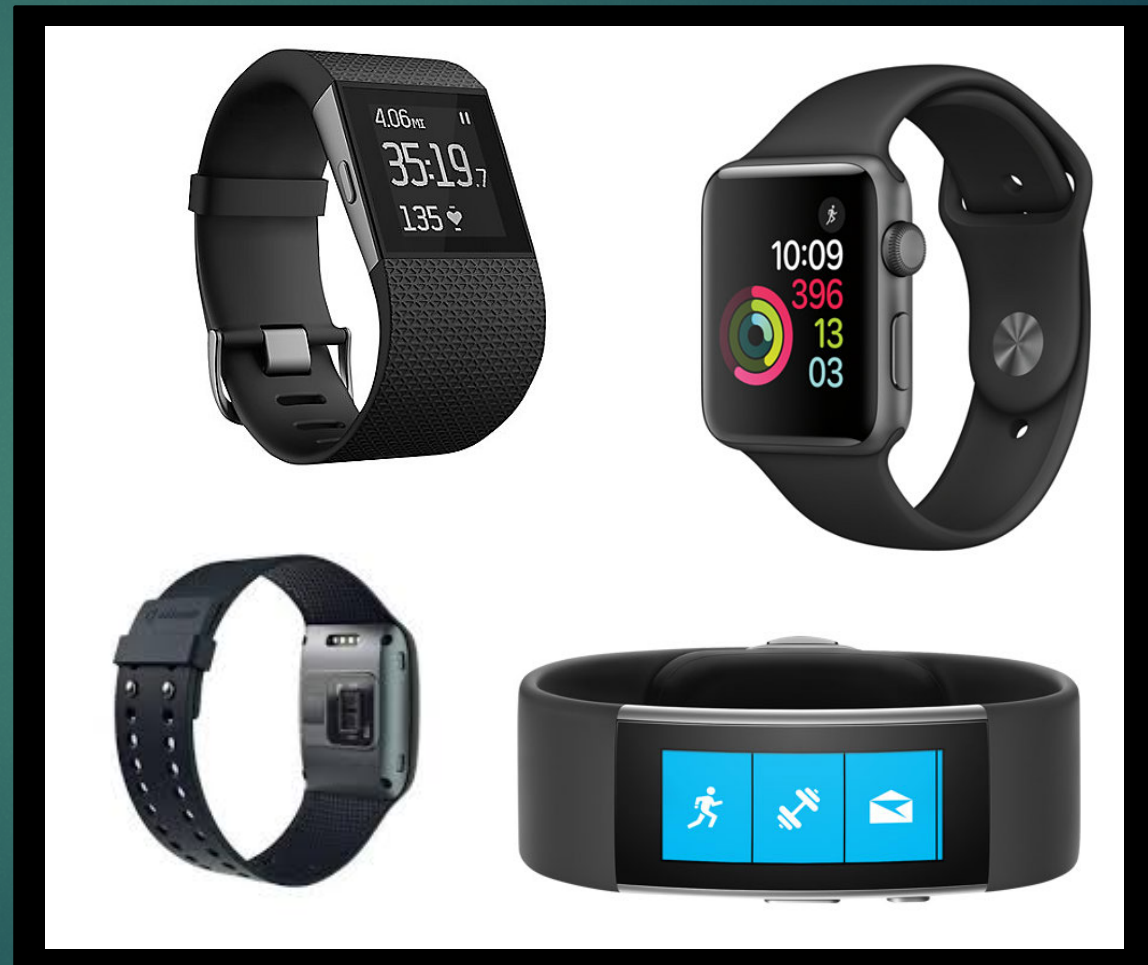
Overview

- ▶ What is a brain-computer interface (BCI)?
 - ▶ The revolution in physiological sensing
- ▶ Types of BCI
 - ▶ Invasive vs non-invasive
 - ▶ Active, reactive, and passive
 - ▶ Examples
 - Spelling
 - Face Recognition
- ▶ Classification of Brain Signals
- ▶ Reality vs Hype
- ▶ Implications and Concerns
- ▶ Christian Perspective



Revolution in Physiological Sensing

- ▶ Microsoft Band
- ▶ Fitbit Surge
- ▶ Apple Watch
- ▶ Empatica e4



Revolution in Physiological Sensing

- ▶ Personal physiological monitoring
 - ▶ Steps (pedometer)
 - ▶ Distance (GPS)
 - ▶ Activity (3-axis Accelerometer)
 - ▶ Temperature (Infrared thermopile)
 - ▶ Heart Rate (ECG or PPG)
 - ▶ Affective State or Stress (HRV or EDA)
 - ▶ Cognitive State?
- ▶ The Quantified Self movement
 - ▶ "self-knowledge through self-tracking with technology." – Wikipedia

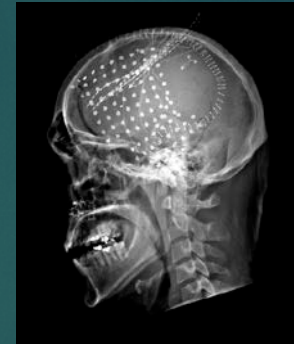


ECG = electrocardiography
PPG = photoplethysmography

HRV = heart rate variability
EDA = electrodermal activity

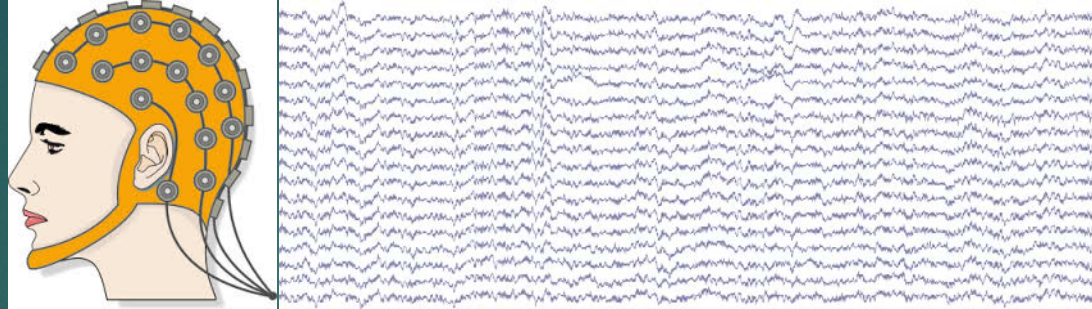
Brain-Computer Interface (BCI)

- ▶ “a direct communication pathway between the brain and an external device. BCIs are often directed at researching, mapping, assisting, augmenting, or repairing human cognitive or sensory-motor functions.” – Wikipedia
- ▶ **Invasive** (intra-cranial)
 - ▶ Electrodes placed on the cortical surface or penetrating cortical and sub-cortical structures
 - ▶ Requires surgery
- ▶ **Non-invasive** (scalp)
 - ▶ Electrodes or sensors places on the scalp surface
 - ▶ May require conductive medium (gel)



Brain-Computer Interface (BCI)

- ▶ EEG:



μV (10^{-6})

- ▶ Active BCI:

Derives its outputs from brain activity which is directly and consciously controlled by the user, independent of external events, for controlling an application.

- ▶ Reactive BCI:

Derives its outputs from brain activity arising in reaction to external stimulation, which is indirectly modulated by the user for controlling an application.

- ▶ Passive BCI:

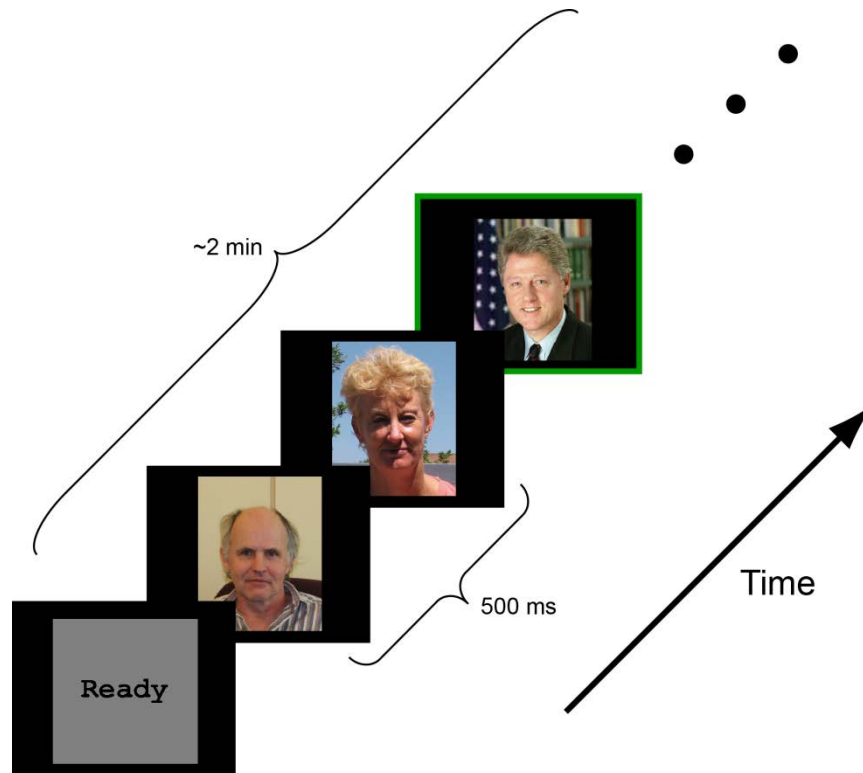
Derives its outputs from arbitrary brain activity arising without the purpose of voluntary control, for enriching a human-machine interaction with implicit information on the actual user state.

- ▶ So what can they do?

Example (Spelling)



Example (Face Recognition)



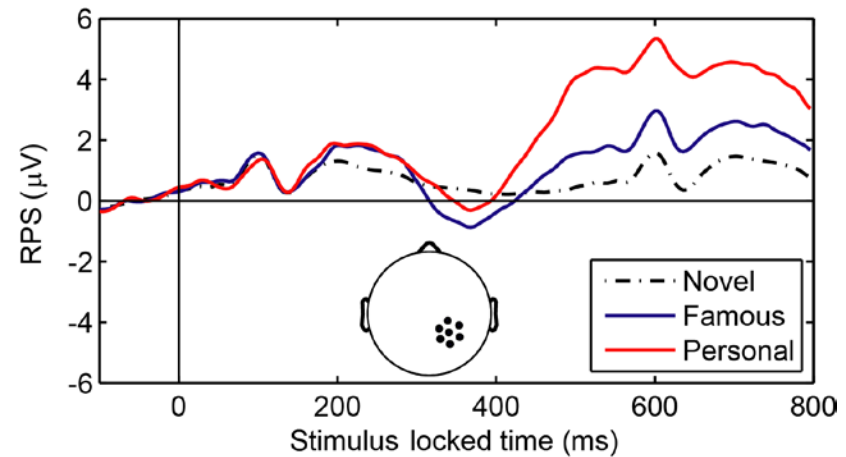
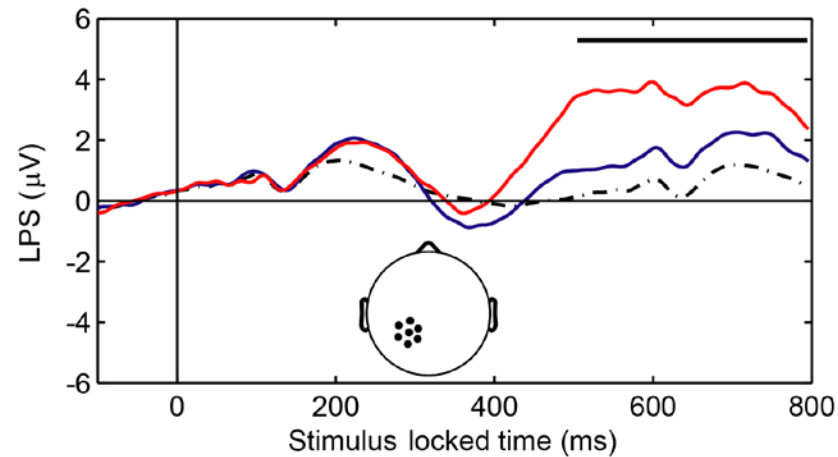
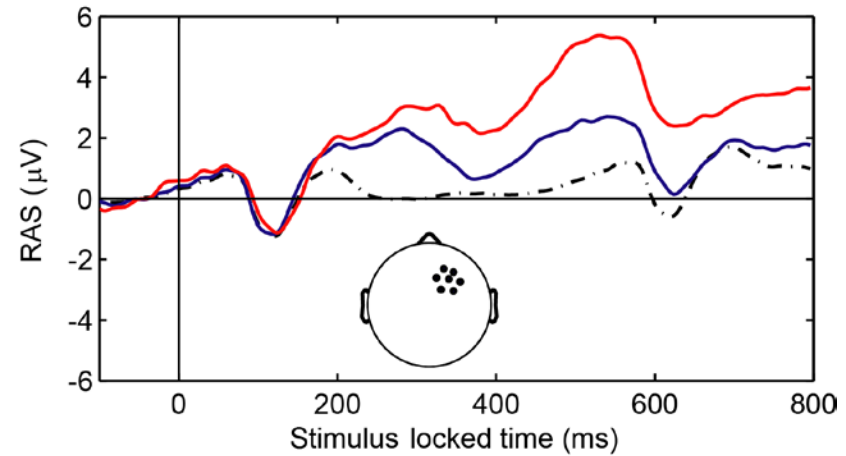
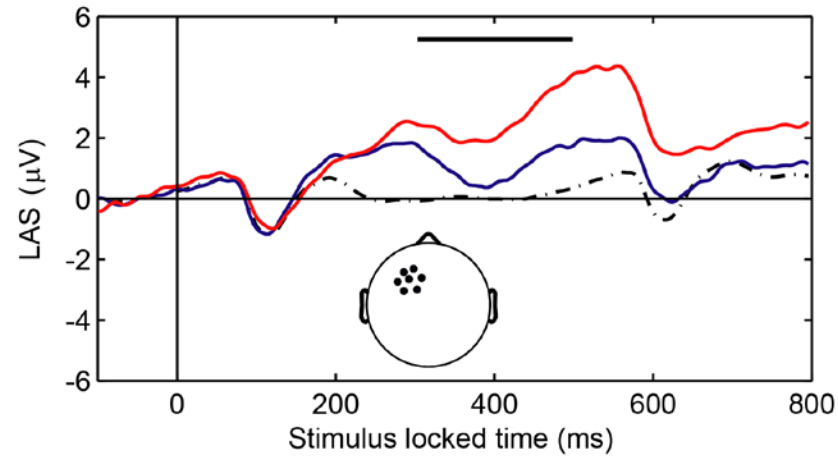
Four types of faces:

1. **Novel** individuals unknown to the participant
2. **Famous** individuals selected by the participant
3. **Personal** friends, coworkers, relatives
4. Current and former presidents

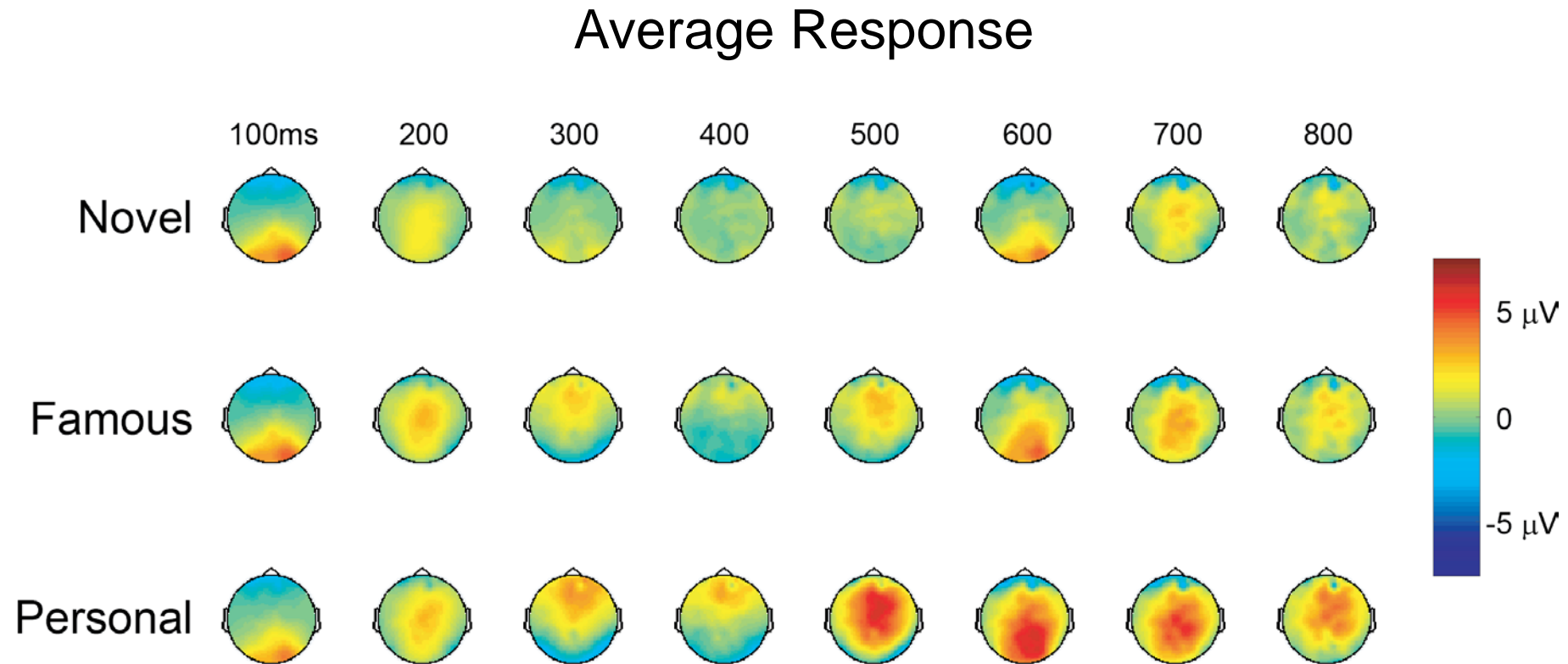
Simple Task:

Press a button when you see a President's face

Example (Face Recognition)



Example (Face Recognition)



N = 22 participants, 2500 trials per participant

So how does it work?

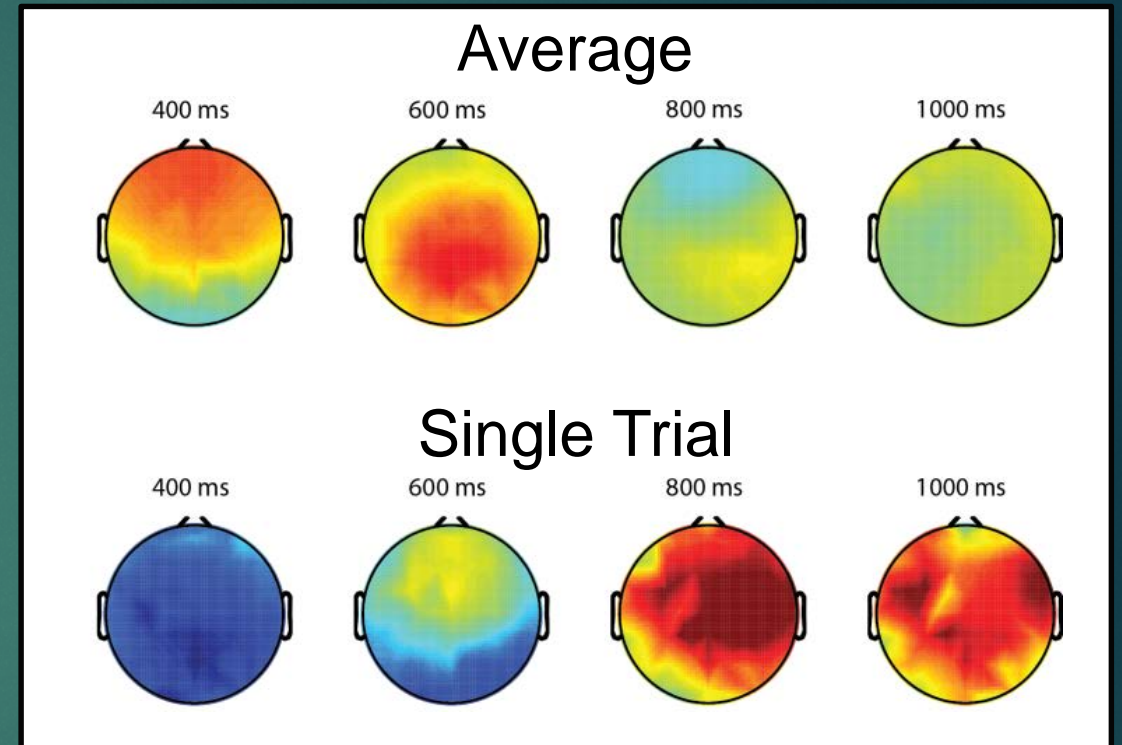
Two principal challenges:

- ▶ Low signal-to-noise

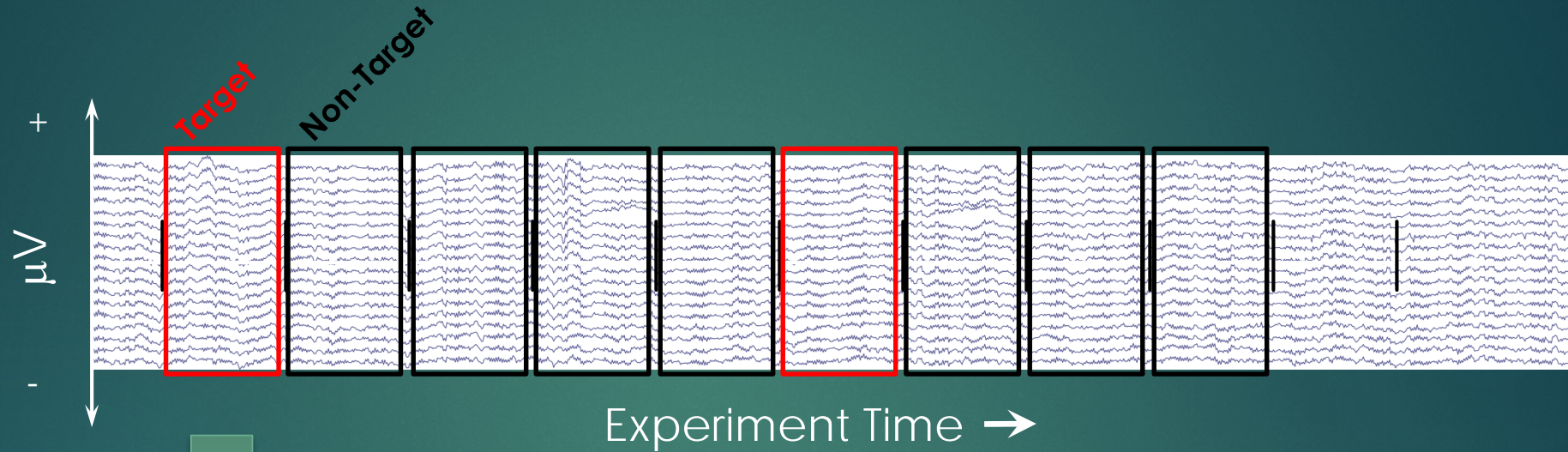
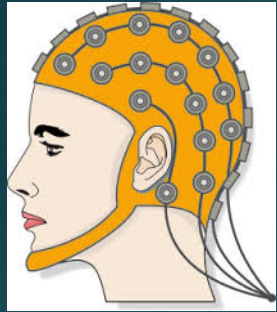
- ▶ Ongoing, dynamic neural activity
- ▶ Large muscle and ocular artifacts
- ▶ Variable electrode impedance
- ▶ External electro-magnetic noise
- ▶ ...

- ▶ High dimensionality

- ▶ EEG with 256 channels and a sampling rate of 500 Hertz has a one second epoch with 128,000 dimensions in the amplitude space alone



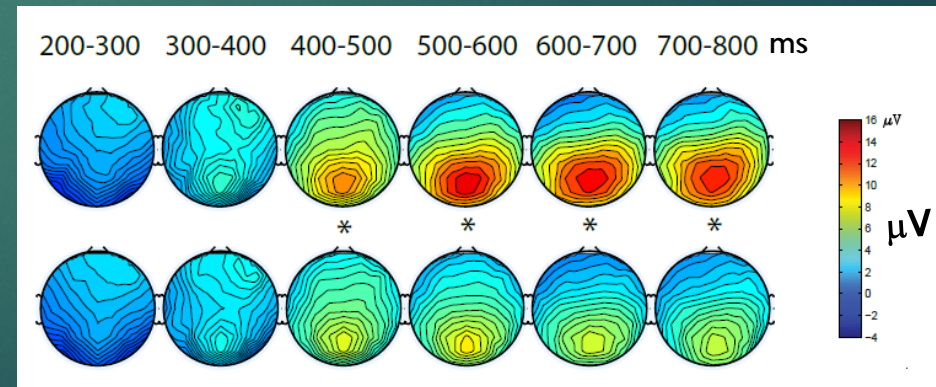
Average Response



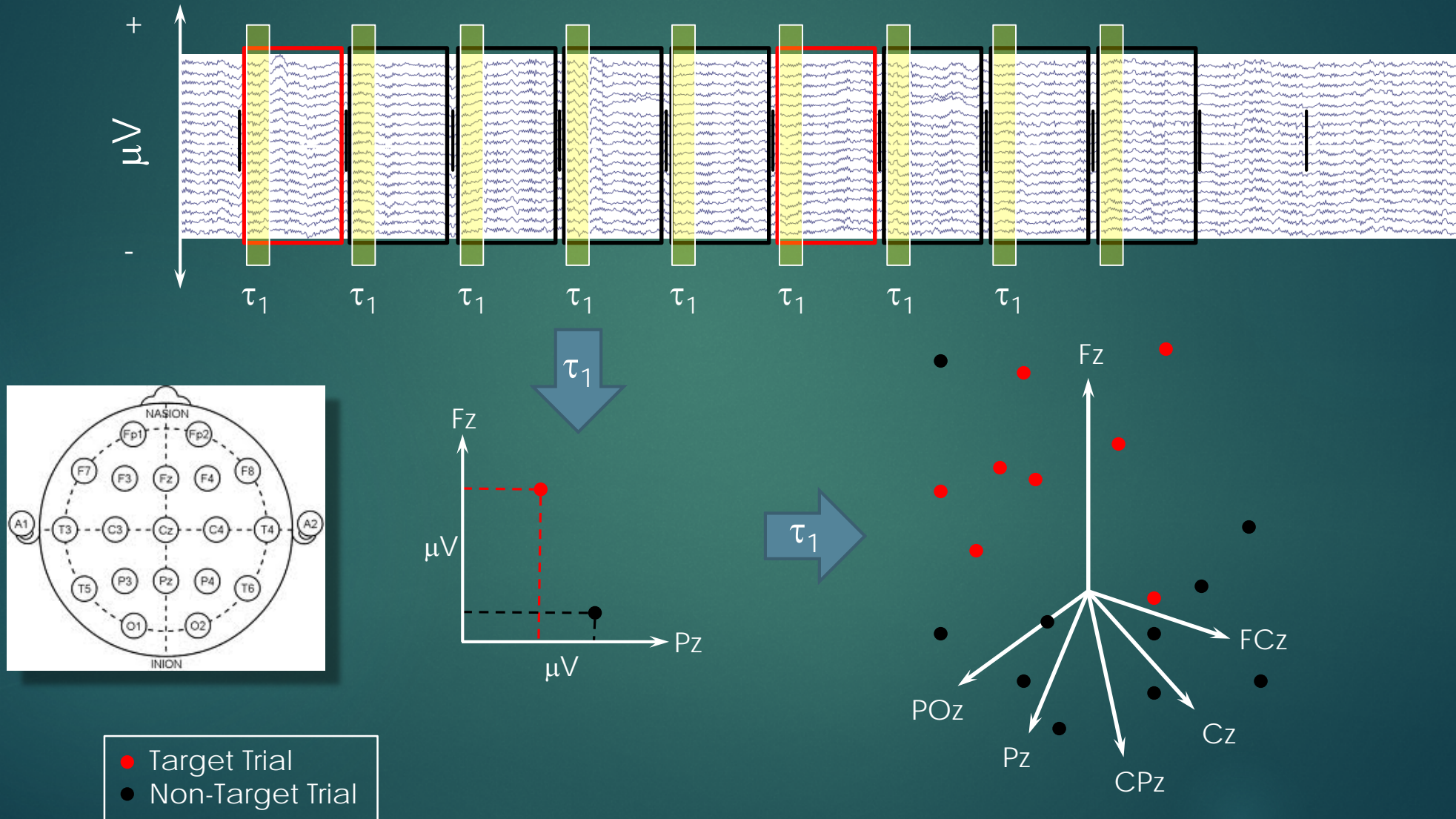
Target ERP

Non-Target ERP

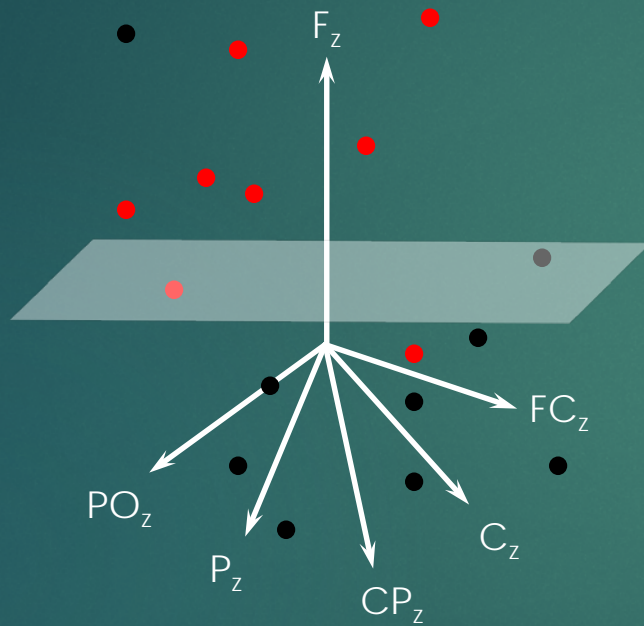
Event Related Potential (ERP)



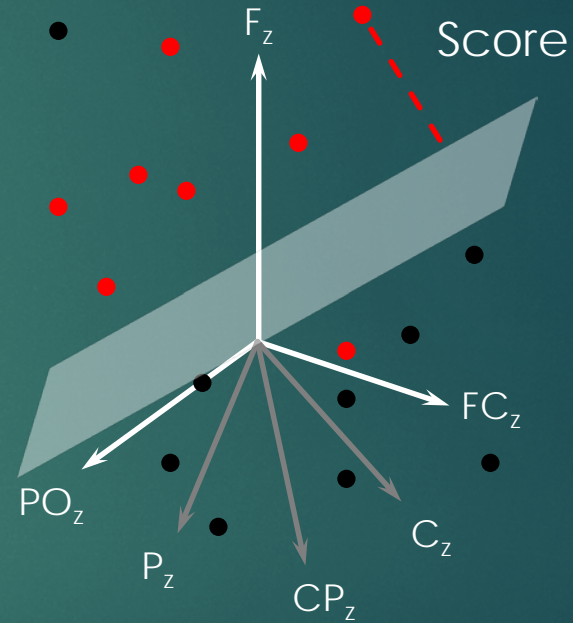
Single Trial Classification



Single Trial Classification



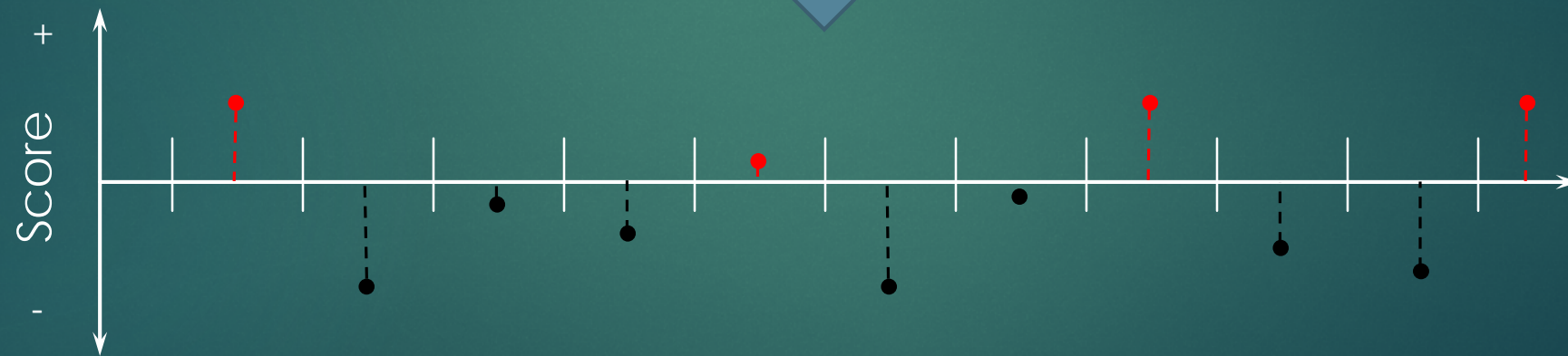
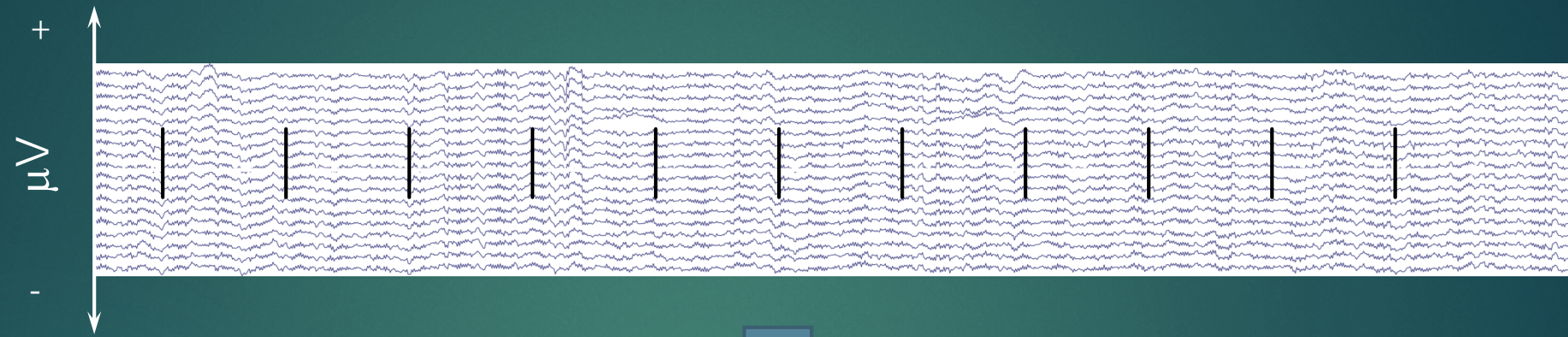
- ✓ Robust
- ✓ Sparse
- ✓ Smooth



$$s(t) = \mathbf{W}^T \mathbf{x}(t) = \sum_{i=1}^D w_i x_i(t)$$

- Target Trial
- Non-Target Trial

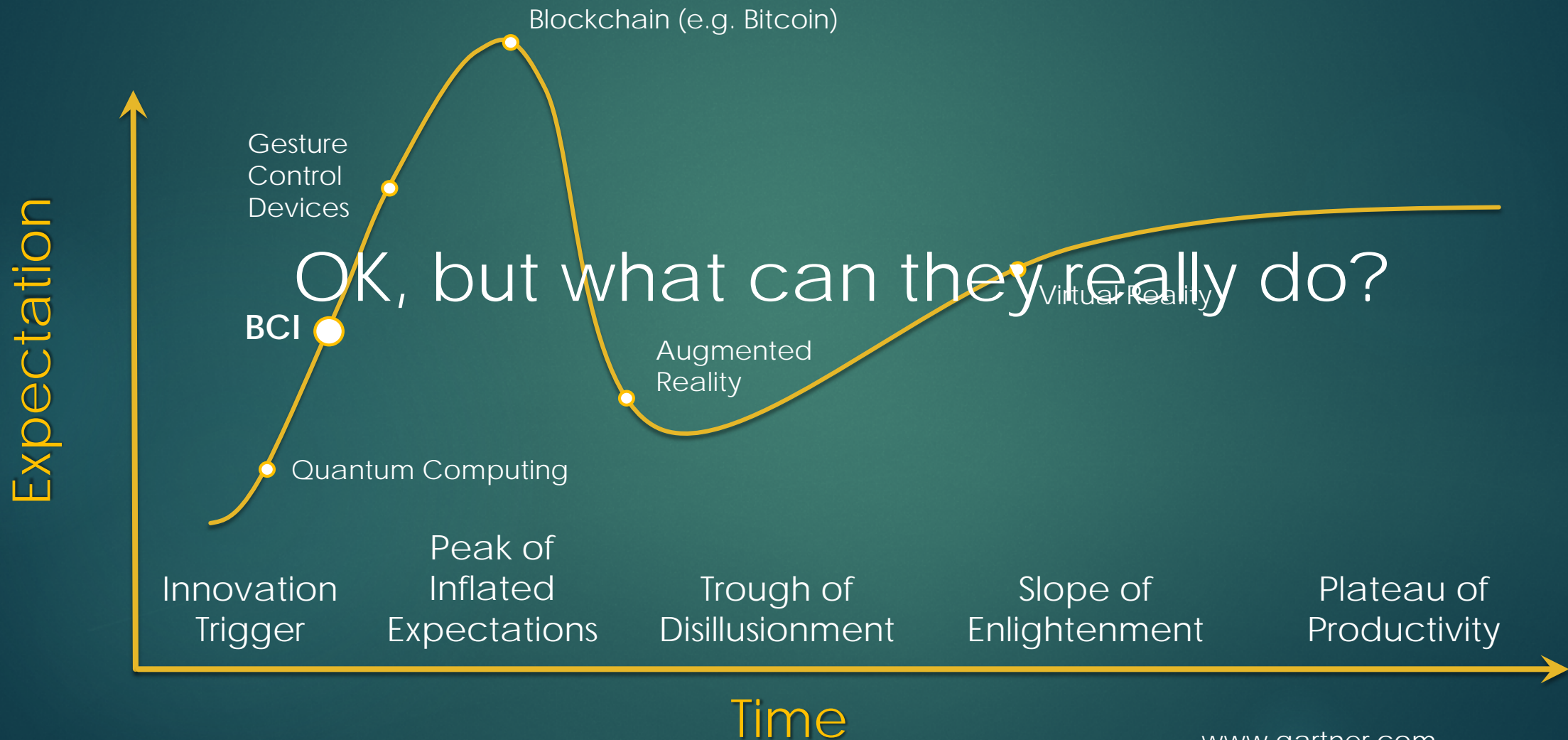
Single Trial Classification



Experiment Time →

- Target Trial
- Non-Target Trial

Gartner Hype Cycle for Emerging Technologies



Inflection Point

- ▶ Sensors
 - ▶ Inexpensive
 - ▶ Wearable
- ▶ Mobile systems
 - ▶ Small but computationally powerful
- ▶ “Big Data”
 - ▶ Deep Learning (e.g. Google’s Tensor Flow)
- ▶ Connected ecosystem
 - ▶ Cloud Computing
 - ▶ Internet of Things (IoT)
- ▶ R&D Funding
 - ▶ NIH, NSF, DARPA, IARPA, Air Force, Army

Implications and Concerns

- ▶ Privacy
 - ▶ Massive data troves of personal information
- ▶ Agency
 - ▶ Deterministic materialism: “My neurons made me do it”
- ▶ Vanity
 - ▶ Increase in self-focused activity (e.g. the Quantified Self)

Christian Perspective

▶ Privacy

“discretion will watch over you, understanding will guard you” Proverbs 2:11

“Be sober-minded; be watchful. Your adversary the devil prowls around like a roaring lion, seeking someone to devour.” 1 Peter 5:8

▶ Agency

“Do not be conformed to this world, but be transformed by the renewal of your mind, that by testing you may discern what is the will of God, what is good and acceptable and perfect.” Romans 12:2

▶ Vanity

“Set your minds on things that are above, not on things that are on earth.”
Colossians 3:2

“And the peace of God, which surpasses all understanding, will guard your hearts and your minds in Christ Jesus.” Philippians 4:7

Thank You

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