Salvatore Giugliano

# Analysis and interpretation of EEG signals with Machine Learning techniques

Tutor: Roberto Prevete co-Tutor: Francesco Isgrò

Cycle: XXXV Year: Second

# My background

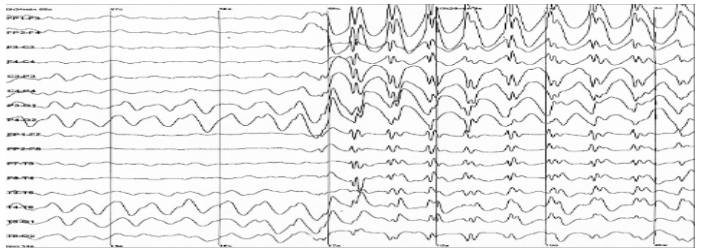
- Master's degree (cum laude) in Computer Science at Università degli Studi di Napoli "Federico II"
  - Thesis: "Activation functions for deep neural networks: a theoretical and experimental analysis "
- Research laboratory
  - Artificial Intelligence, Privacy & Applications (AIPA) Lab


  - Augmented Reality for Health Monitoring Laboratory (ARHeMLab)

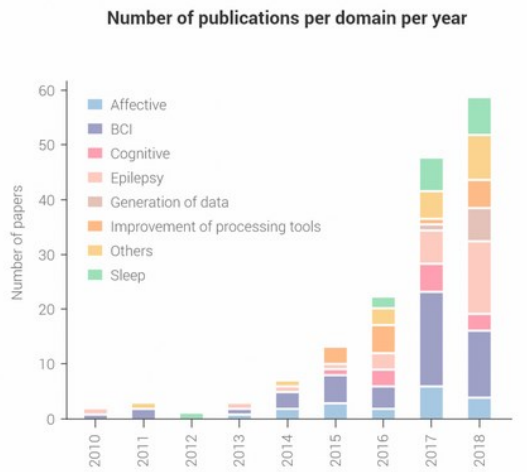

- Scholarship type
  - No scholarship

# Research activity: overview 1/3

- EEG (electroencephalographic) signals
  - not easy to interpret
    - a lot of noise and artifacts
    - vary significantly between individuals
    - even for the same person, they change substantially over time
  - temporal and spatial filters
    - to reduce noise and artifacts



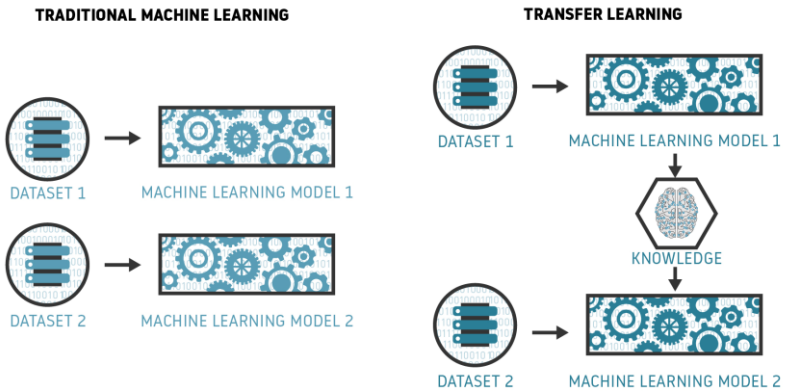
- Machine Learning techniques
  - for analysis and interpretation
    - automating and improving the EEG data analysis
  - applications:
    - cognitive and emotional classification
      - Brain-Computer-Interface (BCI)




Statistics on DL applied to EEG data copied from (Roy, 2019).

# Research activity: overview 2/3

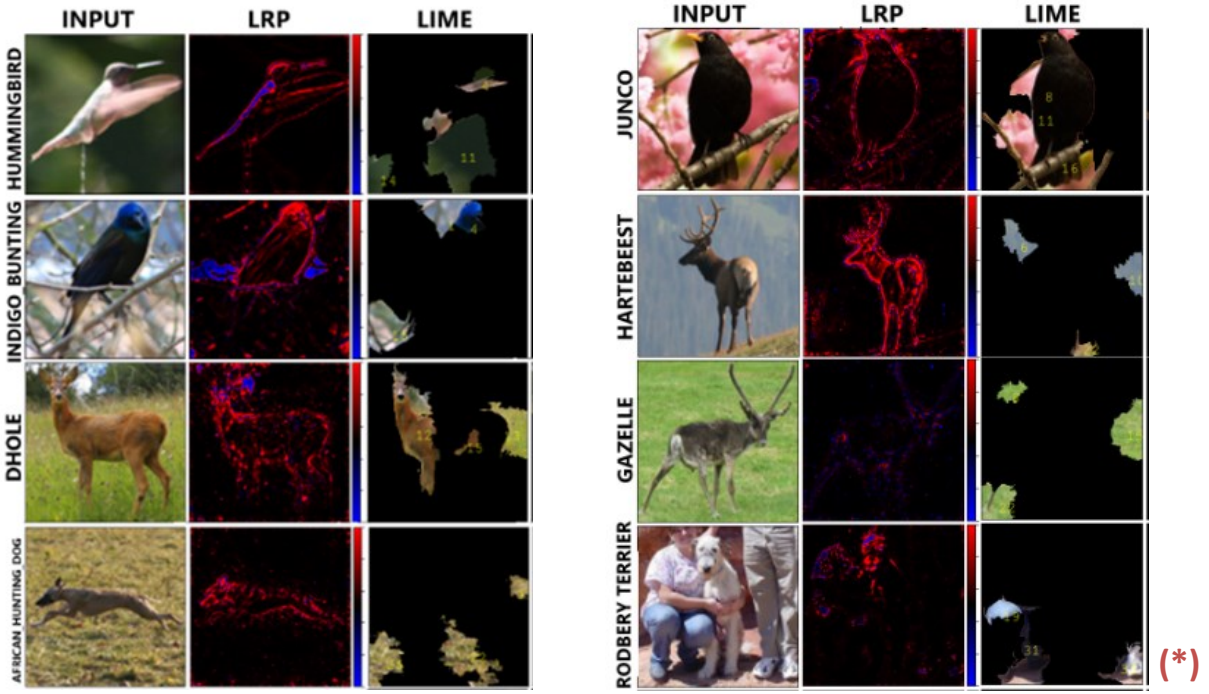
- Transfer Learning (TL) on EEG data
  - Take a model trained on a large dataset and **transfer its "knowledge"** to another dataset




  - TL is usually applied to domains of the same type
    - Applying the TF from a pre-trained model on images Dataset and transferring the knowledge on an EEG signal Dataset is really a **challenge**

# Research activity: overview 3/3

- eXplainable Artificial Intelligence (XAI)
  - *Explanations of the model's output that can be easily interpreted by the human beings*
  - White-box (LRP) or Black-box (LIME) methods
  - Low-level (LRP) or middle-level (LIME) feature approaches

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(*) "A general approach to compute the relevance of middle-level input features", Apicella, A., Giugliano, S., Isgrò, F., & Prevete, R. (2021, January), In International Conference on Pattern Recognition (pp. 189-203). Springer, Cham.

# Research activity: EEG signals with Machine Learning techniques

- High-wearable EEG-Based transducer for Engagement Detection in Pediatric Rehabilitation

  - Unbalanced data by class and by session
    - balancing the training set with synthetic data
      - Synthetic Minority Over-sampling Technique (SMOTE) methods

  - Machine Learning techniques
    - k-NN, SVM, ANN models
      - cognitive and emotional engagement classifiers

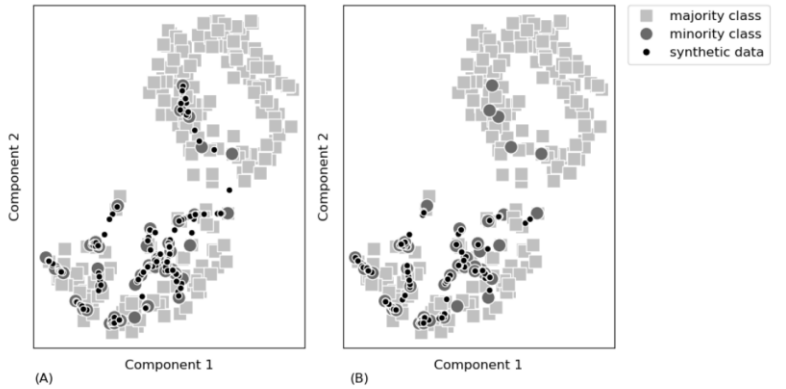


Fig. 4: t-SNE projection of unbalanced EEG data (subject 4) oversampled with two different methods. The SMOTE method (A) randomically interpolates the data of the minority class. The KMeansSMOTE method (B) realizes a clustering before interpolation, attenuating the noise.

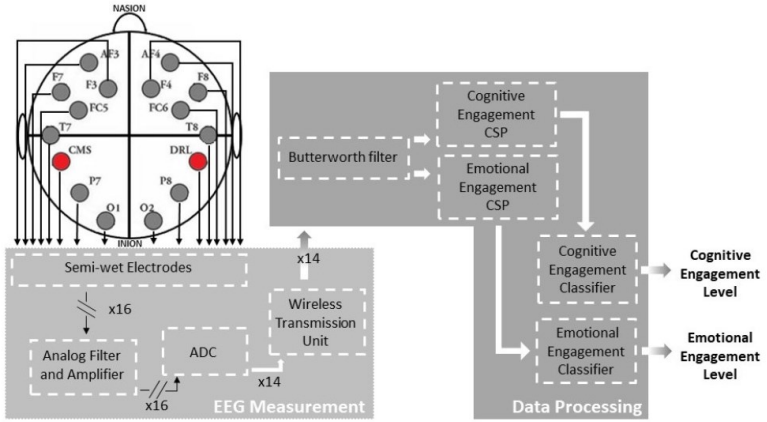


Fig. 1: The proposed cognitive and emotional engagement detection method.

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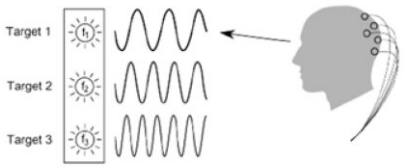
(*) "High-wearable EEG-Based transducer for Engagement Detection in Pediatric Rehabilitation", Andrea Apicella, Pasquale Arpaia, Salvatore Giugliano, Giovanna Mastrati. Nicola Moccaldi, Brain-Computer Interfaces.

# Research activity: EEG signals with Machine Learning techniques

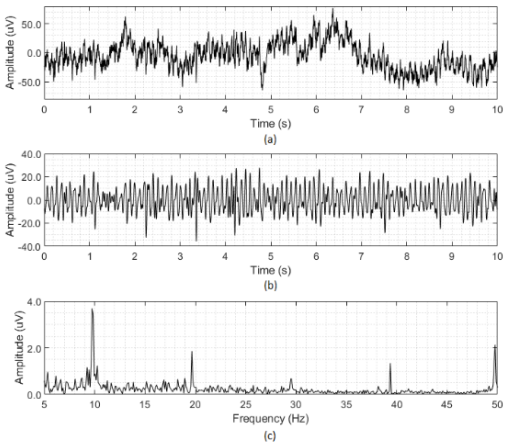
- Enhancement of SSVEP detection for wearable Brain-Computer Interfaces by means of Machine Learning and Convolutional Neural Networks

  - SSVEP (Steady State Visually Evoked Potential)
    - Flickering stimuli at chosen fixed frequency




  - RAW Data
    - Convolutional Neural Networks models

  - Extracted Features Data
    - time and frequency domain features
    - k-NN, SVM, ANN models




(*) Fig. 1. EEG in time domain (a) Filtered EEG in time domain (b) EEG in frequency domain (c).

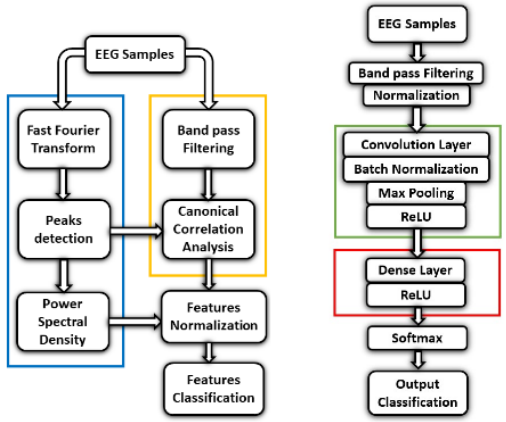
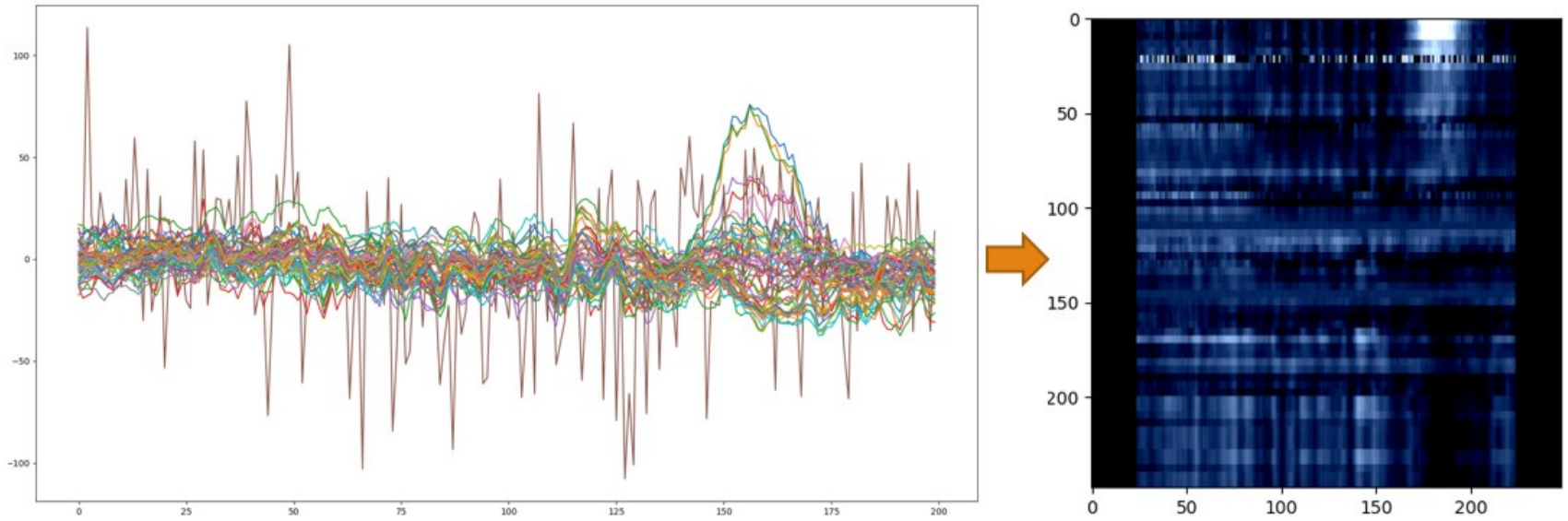



Fig. 3. Block Diagram of the Features Extraction (a) and DeepSCU (b) classification algorithms. For the Feature Extraction architecture, the two boxes represent a processing conducted in frequency (blue box) and time (yellow box) domain. For the DeepSCU architecture, the SCU and Dense blocks are highlighted in green and red, respectively.

(*) "Enhancement of SSVEP detection for wearable Brain-Computer Interfaces by means of Machine Learning and Convolutional Neural Networks", Andrea Apicella, Pasquale Arpaia, Egidio De Benedetto, Nicola Donato, Luigi Duraccio, Salvatore Giugliano, Roberto Prevete.

# Research activity: Transfer Learning (TL) on EEG data

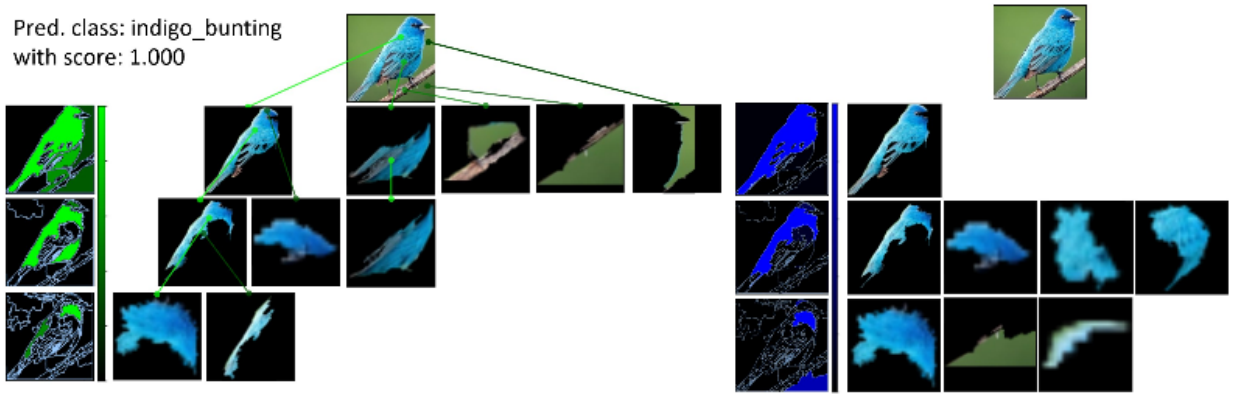
- TL on EEG data (SEED Dataset)
  - EEG (Raw) to images




  - Several experiments (still in progress)
    - Raw Dataset / “extracted features” Dataset
    - inter-subjective / intra-subjective strategies
    - finetuning / “fixed feature extractor” scenarios

# Research activity: eXplainable Artificial Intelligence

- Explanations in terms of Hierarchically organised Middle Level Features
  - White-box method
  - Middle-Level Features approach
  - Hierarchical organizations




(a) Proposed approach (b) LIME

Fig. 3: An example of a three-layer hierarchical explanation of the class *indigo_bunting* correctly assigned to an input image (first row) by VGG16. (a) First column: segment heat map. Left to right: segments sorted in descending order. Top-down: the coarsest (second row) to the finest (last row) hierarchical level. (b) LIME explanation: same input, same segmentation used in (a). **(*)**

**(*)** "Explanations in terms of Hierarchically organised Middle Level Features", Andrea Apicella, Salvatore Giugliano, Francesco Isgrò and Roberto Prevete, AIxIA2021 (20th International Conference of the Italian Association for Artificial Intelligence).

# Products

- Paper in preparation
  - "**Enhancement of SSVEP detection for wearable Brain-Computer Interfaces by means of Machine Learning and Convolutional Neural Networks**", Andrea Apicella, Pasquale Arpaia, Egidio De Benedetto, Nicola Donato, Luigi Duraccio, Salvatore Giugliano, Roberto Prevete.
- Paper accepted
  - "**High-wearable EEG-Based transducer for Engagement Detection in Pediatric Rehabilitation**", Andrea Apicella, Pasquale Arpaia, Salvatore Giugliano, Giovanna Mastrati. Nicola Moccaldi, Brain-Computer Interfaces.
- Conference paper submitted
  - "**Explanations in terms of Hierarchically organised Middle Level Features**", Andrea Apicella, Salvatore Giugliano, Francesco Isgrò and Roberto Prevete, AIxIA2021 (20th International Conference of the Italian Association for Artificial Intelligence).
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  - **"A general approach to compute the relevance of middle-level input features",** Apicella, A., Giugliano, S., Isgrò, F., & Prevete, R. (2021, January), In International Conference on Pattern Recognition (pp. 189-203). Springer, Cham.

# Summary of study activities

- Ad hoc PhD courses
  - Data science for patient records analysis
  - Matrix Analysis for Signal Processing with MATLAB Examples
  - Real-Time Embedded Systems for I4.0 and IIoT

| | Courses | Seminars | Research | Tutorship | Total |
|---|---|---|---|---|---|
| Bimonth 1 | | 0.9 | 8 | | 8.9 |
| Bimonth 2 | | 1.1 | 9 | | 10.1 |
| Bimonth 3 | 2.5 | 0.6 | 7 | | 10.1 |
| Bimonth 4 | 2 | 0.4 | 8 | | 10.4 |
| Bimonth 5 | 2.5 | 0.8 | 7 | | 10.3 |
| Bimonth 6 | | 0.4 | 9 | | 9.4 |
| **Total** | 7 | 4.2 | 48 | | 59.2 |
| **Expected** | 10 | 5 | 45 | 0 | 60 |

# Next Year

- Research activities
  - Conclude the paper on the SSVEP paradigm
  - The ATENA project (at Villa delle Ginestre clinic)
    - Classification of burnout states to support the early diagnosis of autistic children (using EEG, ECG, EMG signals)
  - Domain Adaptation/Generalization on EEG data

- Draft topic of the thesis
  - Deep learning for the classification of EEG signals

Thanks for your attention