DECODING THE BRAIN TIME SERIES

Session Session at

IEEE International Workshop on Machine Learning for Signal Processing (MLSP) 2025

1 Special Session Description

The ongoing deep learning revolution of the last decade has changed how we develop machine learning models in numerous research fields. However, its adoption in areas like time series has been slower and more constrained compared with images and text domains. This measured progress underscores the significant challenges in the field.

In the neuroscience application, we face a dual challenge that calls for both clinical neuroscience expertise and machine learning skills to handle complex signals. Brain decoding aims to extract meaningful information from neural signals to understand brain function or develop applications in healthcare and brain-computer interfaces. EEG decoding, in particular, presents unique challenges due to the variability across subjects, the limited amount of data, and the need for short calibration times in real-world applications Chevallier et al. [2024]. Addressing these challenges requires a combination of neuroscience insights and machine learning techniques.

Although deep learning and foundation models hold great promise for these brain decoding problems, current research is in its infancy. Recently, a growing number of works have treated large models to learn common representations across different brain signals [Jiang et al., 2024, Wang et al., 2025, Yang et al., 2024, Mohammadi Foumani et al., 2024]. Despite these advancements, research into EEG decoding still lacks fundamental bases that attempt to compare models fairly and helpfully for real applications Borra et al. [2024, 2025].

This special session will explore Machine Learning for Signal Processing in the EEG decoding community, examine their clinical applications and interpretable approaches, and discuss the field's shift toward incorporating more deep learning models.

2 Organizing Committee

Our organizing committee benefits from extensive backgrounds, and the research experience of its members spans a broad range of brain signal processing: Electroencephalogram Decoding, Brain-Computer Interface, Neuroscience, Functional connectivity, Deep Learning, and Riemannian Geometry. Additionally, the team comprises academic researchers at different levels of seniority, including one PhD student, a research scientist, an associate professor, and a full professor.

- Bruno Aristimunha (Université Paris-Saclay)
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  - Google Scholar: https://scholar.google.com/citations?user=2Gd5gOQAAAAJ
  - Bio: Bruno Aristimunhais, a PhD candidate in Computer Science at the Université Paris-Saclay and Federal University of ABC. His research uses deep learning tasks to learn representations from electroencephalograms (EEG). He is particularly interested in transfer learning, benchmark, diffusion models, and

deep learning in other geometries, such as the Riemannian manifold. Bruno is also a Junior Research Engineer at Institut national de recherche en sciences et technologies du numérique (INRIA) TAU and a maintainer of open-source libraries focused on developing the community for deep learning and EEG decoding.

- Florian Yger (LITIS, INSA-Rouen Normandy)
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  - Google Scholar: https://scholar.google.com/citations?user=NF_1_38AAAAJ
  - Bio: Florian Yger is an associate professor at INSA Rouen Normandie, affiliated with the LITIS laboratory. He earned his PhD in Computer Science from the University of Rouen in 2013, focusing on machine learning and signal processing. Following his doctoral studies, he was a JSPS postdoctoral fellow at the University of Tokyo in Professor Masashi Sugiyama's laboratory from 2014 to 2015. In 2015, he joined Université Paris Dauphine-PSL as an associate professor and researcher in the MILES team at LAMSADE, where he served until 2024. His research interests include representation learning under prior geometrical knowledge or constraints. He has been a visiting researcher at RIKEN AIP in Japan since 2017.
- Marie-Constance Corsi (ICM, Inria NERV, INSERM, Paris-Sorbonne Université)
  - E-mail: marie-constance.corsi@inria.fr
  - Google Scholar: https://scholar.google.com/citations?user=KR61ojYAAAAJ
  - Bio: Marie-Constance Corsi is an Inria research scientist at the Paris Brain Institute in the NERV Lab since 2022. She previously completed a PhD at the University of Grenoble Alpes (France) on the development of Helium 4 optically-pumped magnetometers for MCG and MEG. Her research focuses on developing tools to improve Brain-Computer Interfaces (BCI), reflected by a non-negligible portion of users who cannot control the device even after several training sessions. She essentially considers three main approaches: the search for neurophysiological markers of BCI training, the integration of multimodal data to enrich the information provided to the classifier, and the development of portable systems.
- Sylvain Chevallier (A&O/TAU team director LISN, Université Paris-Saclay, Inria)
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  - Bio: Sylvain Chevallier is a full professor at the University Paris-Saclay, a board member of the DATAIA/ClusterIA Institute of Saclay, and a co-leader of the TAU team. He works on frugal learning and transfer learning, which are applied to time series analysis with applications such as BCI computing. He contributed to several open-source Python toolboxes for signal processing and machine learning using Riemannian geometry. He is leading the Codalab/Codabench framework for benchmark and data competition.

3 Tentative Program

Below is the tentative agenda for the special session.

Table 1: Session Schedule

Time	Duration	Activity	Session Content
0:00–0:30	30 min	Introduction and opening remarks	– Welcome – Overview of the brain decoding area – Agenda & Logistics
0:30–1:00	30 min	Keynote - Fabien Lotte (to be confirmed)	EEG Decoding in the age of deep learning: challenges, pitfalls, and promises
1:00–1:30	30 min	Oral Session for the best papers	Detailed presentation of the works that had the best review process.
1:30–2:00	30 min	Demos for Session	Demonstration of open-source software and clinical cases.
2:00–2:50	50 min	Poster Presentation	Poster presentation of the papers.
2:50–3:00	10 min	Closing	–

4 Contributing papers

Here, we present a compilation of six papers related to the theme of EEG Decoding that has been confirmed for the special session at MLSP. All of them make contributions to the field of signal processing applied to neuroscience, one of the branches of the MLSP community.

We also indicate that more papers on the theme will be submitted, given the involvement of the EEG decoding community in proposing the conference; however, for this proposal, we selected those confirmed for presentation.

Title 1: Generating Effective Embeddings for Transformer-Based Brain-Computer Interfaces

Short Abstract:

Brain-computer interfaces (BCIs) enable direct control of external devices by decoding neural activity, often captured through electroencephalography (EEG) signals. While Transformer-based models have demonstrated strong performance in sequential data processing, their effectiveness in BCI applications depends heavily on the quality of input embeddings. Various embedding strategies exist, including time-based encodings, where each embedding represents a short time window across all electrodes; electrode-based encodings, where longer sequences from individual electrodes are used; and hybrid approaches combining both. The choice of encoding strategy not only impacts classification accuracy but also influences the transferability of learned representations across sessions and subjects, a critical factor in real-world BCI deployment. In this paper, we systematically compare different embedding generation strategies in terms of classification performance, cross-session and cross-subject transferability, and computational efficiency using three motor-imagery datasets. By employing a standard Transformer architecture, we isolate the effects of embedding selection from those of model-specific adaptations. This comparative analysis improves our understanding of how different embedding strategies influence Transformer performance in BCI applications, providing directions for architectures that generate more robust and generalizable neural representations.

Authors: José Mauricio Nunes de Oliveira Junior, Raphael Yokoingawa de Camargo

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- Federal University of ABC (UFABC), Santo André, Brazil

Title 2: Deep Learning of Mesoscale Cortical Dynamics for Real-Time Classification of Forelimb Movement in Mice

Short Abstract:

Recent studies suggest that mesoscale cortical activity patterns encode movement-related information, such as direction and speed. We developed an approach to decode forelimb movement direction from mesoscale cortical dynamics in mice using wide-field GCaMP6f imaging. By simultaneously recording cortical activity and 3D kinematics of specific body points, we constructed a dataset linking movement direction to 500 ms temporal windows of cortical activity. Using this dataset, we trained a convolutional neural network that processes cortical activity windows to predict movement direction. The model achieved 93% accuracy in distinguishing forward and backward movements. Finally, we implemented real-time decoding at 100 Hz, demonstrating the feasibility of high-speed movement classification from mesoscale cortical signals toward the control of an upper limb prosthesis.

Authors: Clément Picard, Anton Dogadov, Daniel E. Shulz, Valérie Ego-Stengel, Isabelle Férézou, Luc Estebanez

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Title 3: Contrastive Learning for EEG Decoding: Addressing Cross-Subject Variability Through Multimodal Alignment

Short Abstract:

Inter-subject variability and within-class distribution shifts are key challenges in EEG decoding. We propose a multimodal contrastive learning framework that anchors EEG representations to their corresponding representations in a second modality, such as audio or images, using a reformulated CLIP-style contrastive loss. Audio or images paired to corresponding EEG recordings are used as a complementary modality to guide feature alignment, with a pre-trained encoder processing the second modality while the EEG encoder is trained to align with these stable representations. By explicitly tackling inter-subject distribution shifts within the loss formulation, our approach aims to improve cross-subject generalization and robustness. This framework provides a promising direction for leveraging multimodal data to advance EEG decoding, with potential applications in brain-computer interfaces and brain signals decoding.

Authors: G.Lioi, Y. El-Ouahidi, M. Pesola, N. Farrugia

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Title 4: Using Hidden Markov Models and CCA Coefficients Dynamics for Improving Self-Paced SSVEP-based BCI Accuracy

Short Abstract: Objective: One of the limitations of Brain-Computer Interfaces (BCIs) is the difficulty of inferring commands asynchronously, ie, at the user's will. In this paper, we propose a novel method based on Hidden Markov Models (HMMs) that exploits the temporal dynamics of Canonical Correlation Coefficients (CC-Coefficients) to achieve asynchronous Steady-State Visual Evoked Potential (SSVEP) recognition. Method: We recorded Electroencephalographic (EEG) data from 21 subjects under 4 conditions of SSVEP selections ie, one condition for each of the 3 flickering stimuli (10, 12 and 15Hz) and a no-control condition where the task was to gaze at a non-flickering fixation point located in the middle of the 3 flickering targets. Results: We first showed that the dynamics of Canonical Correlation Coefficients (CC-Coefficients) were specific to each target command and different from a no-control state, and second, we successfully used HMMs to exploit that dynamic and build a robust and fully self-paced SSVEP-BCI, that outperforms state-of-the-art approaches in offline evaluations. Our approach achieved a True Positive Rate (TPR), True Negative Rate (TNR), and accuracy of up to 96%, 87%, and 100%, respectively, for the best subjects, using 5s-long EEG epochs. When compared to a state-of-the-art method for self-paced SSVEP detection, our method was found to perform better. Significance: This paper is the first to demonstrate the benefits of using the temporal behavior of CC-Coefficients for self-paced SSVEP interaction and to successfully use HMM classifiers for this purpose

Authors 5: Hakim Si-Mohammed, Ferran Argelaguet, Camille Jeunet, Géry Casiez, Anatole Lécuyer, Fabien Lotte

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Title: Multimodal Innovative EEG-based Features to Detect Accidental Awareness during General Anesthesia

Short Abstract: Objective: The brain is a complex system that requires multimodal study to understand a specific cognitive or motor function. Thus, a large number of features from electroencephalographic data are available to provide a complementary view at different spatial, frequency, and temporal scales, such as brain connectivity, amplitude modulation analysis, complexity, and entropy measurements. But they are not usually investigated altogether. In this study, we will present, measure, and compare these features and introduce how they can provide a more precise model of brain activity. As an illustration, we will present the benefits and limitations of these innovative features on detecting accidental awareness during general anesthesia.

Authors 6: V. Marissens Cueva, Marie-Constance Corsi, S. Rimbert, F. Lotte, L. Bougrain

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Title: Towards interpretability in Riemannian methods in BCI

Short Abstract: Brain-computer interfaces (BCIs) leveraging Riemannian geometry have demonstrated strong classification performance in EEG-based tasks. However, the interpretability of these methods remains a challenge, limiting their practical deployment in neurophysiological and clinical applications. In this work, we propose agnostic approaches to enhance the interpretability of classifiers based on Riemannian geometry. Our methods facilitate the visualization of learned classifiers, enabling a more transparent understanding of model predictions. By generating topographic maps and embedding EEG datasets into lower dimensional Riemannian spaces, we provide insights into the spatial that drive classification. This work contributes towards bridging the gap between accuracy and interpretability in Riemannian-based BCI methodologies, fostering greater trust and usability in real-world scenarios.

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