Unsupervised neural decoding of auditory attention using a Binary Quadratic Program

1st Nicolas Heintz
Dept. of Electrical Engineering, STADIUS
Dept. of Neurosciences, ExpORL
KU Leuven
Leuven, Belgium
nicolas.heintz@esat.kuleuven.be

2nd Tom Francart
Dept. of Neurosciences, ExpORL
KU Leuven
Leuven, Belgium
tom.francart@kuleuven.be

3rd Alexander Bertrand
Dept. of Electrical Engineering, STADIUS
KU Leuven
Leuven, Belgium
alexander.bertrand@esat.kuleuven.be

***Abstract*—Auditory attention decoding algorithms attempt to decode from brain signals to whom a person is listening, for example using electroencephalography (EEG) recordings. These algorithms are typically first trained in a supervised environment for optimal performance [1], [2]. However, such supervised training sessions are cumbersome and undesired in practice, as they require a lot of time from the end user and they can sometimes deliver incorrect ground truth labels [3]. Furthermore, once the decoder is trained during such a supervised session, it is fixed and its performance starts to drop over time due to changes in brain responses, electrode impedances or listening environments [4].**

There is therefore a need for unsupervised training and classification of auditory attention. State-of-the-art unsupervised algorithms iteratively retrain a least-squares regression model that reconstructs the attended speech from EEG signals. The iterative procedure contains a feedback process in which the classification decisions of the decoder obtained in the previous iteration are used as labels to train a new decoder in the current iteration [4], [5]. We show that an instantaneous instance of this iterative feedback procedure can be used to reformulate the attention decoding problem into a so-called Binary Quadratic Program (BQP). The aforementioned iterative procedure leads to solutions of this BQP that are biased by the initialisation and converge to a local optimum.

However, by reformulating the unsupervised auditory attention problem as a BQP, we can compare the iterative algorithm to other BQP solvers, such as the heuristic diversification-driven tabu search algorithm [6] and a globally optimal branch-and-bound algorithm from CPLEX [7]. Both algorithms significantly outperform the iterative algorithm, while we find no significant difference between the tabu search and the more expensive branch-and-bound algorithm.

This research is funded by Aspirant Grant 1S31522N from the Research Foundation - Flanders (FWO) (for N. Heintz), the Research Foundation - Flanders (FWO) project nr. G0A4918N, the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 802895 and grant agreement No 637424), and the Flemish Government (AI Research Program). The scientific responsibility is assumed by its authors.
N. Heintz and A. Bertrand are also affiliated with Leuven.AI - KU Leuven institute for AI, Belgium.

References

[1] J. A. O'Sullivan, A. J. Power, N. Mesgarani, S. Rajaram, J. J. Foxe, B. G. Shinn-Cunningham, M. Slaney, S. A. Shamma, and E. C. Lalor, "Attentional Selection in a Cocktail Party Environment Can Be Decoded from Single-Trial EEG," *Cerebral Cortex*, vol. 25, no. 7, pp. 1697–1706, 2015.

[2] S. Geirnaert, S. Vandecappelle, E. Alickovic, A. de Cheveigné, E. Lalor, B. T. Meyer, S. Miran, T. Francart, and A. Bertrand, "Neuro-Steered Hearing Devices: Decoding Auditory Attention From the Brain," *IEEE Signal Processing Magazine*, vol. 38, pp. 89–102, 8 2021.

[3] A. de Cheveigné, D. E. Wong, G. M. Di Liberto, J. Hjortkjær, M. Slaney, and E. Lalor, "Decoding the auditory brain with canonical component analysis," *NeuroImage*, vol. 172, pp. 206–216, 2018.

[4] S. Geirnaert, T. Francart, and A. Bertrand, "Time-adaptive Unsupervised Auditory Attention Decoding Using EEG-based Stimulus Reconstruction," *bioRxiv*, p. 2022.01.07.475386, 3 2022.

[5] S. Geirnaert, T. Francart, and A. Bertrand, "Unsupervised Self-Adaptive Auditory Attention Decoding," *IEEE Journal of Biomedical and Health Informatics*, pp. 1–1, 2021.

[6] F. Glover, Z. Lü, J.-K. Hao, F. Glover, Z. Lü, and J.-K. Hao, "Diversification-driven tabu search for unconstrained binary quadratic problems," *4OR*, vol. 8, pp. 239–253, 1 2010.

[7] C. Bliek, P. Bonami, and A. Lodi, "Solving Mixed-Integer Quadratic Programming problems with IBM-CPLEX: a progress report," in *Proceedings of the Twenty-Sixth RAMP Symposium*, (Tokyo), 2014.