Classification, Induction and Brain Decoding

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I. Abstract

Machine Learning (ML) techniques are provoking wide interest in brain-computer interface (BCI) research and neuroimaging-based neuroscience research. These techniques are most frequently applied according to a paradigm called *brain decoding* [1], which is based on the prediction of stimuli provided to a subject from the concurrent brain activity.

In [1] three specific tasks are recognized as part of the brain decoding approach. *Pattern discrimination* is the task that addresses the question whether and how accurately the brain activity can predict the triggering stimulus. This task is mainly focused on the quantitative assessment of the classification error rate. Means for interpretation of how the classification algorithm exploited the available information, e.g. brain maps, are not directly provided. Pattern discrimination is of special interest for BCI research and neuroscience research for different reasons: while the first is mainly concerned with getting the most accurate predictions based on the brain activity, the latter uses pattern discrimination for inductive reasoning and frequently for comparing different theories/hypotheses in the light of the evidence provided by the experiment, i.e. for confirmatory data analysis. In this case the primary interest is the reliability of the error estimate of the predictor, which can be in terms of a confidence interval or posterior probability.

To the best of our knowledge the use of classification algorithms for inductive reasoning in scientific research is marginal to the mainstream ML literature. Moreover the reliability of the strategies proposed in the neuroscience-related literature [1], [2] is often difficult to assess [3], especially from small high-dimensional samples typical of this domain. This work wants to raise the attention on the use of classification algorithms for inductive reasoning and proposes the application of the Bayesian hierarchical modeling and the Bayesian hypothesis testing (BHT) framework to the analysis of classification results. In order to support the proposed approach we present two recently-published applications:

1) A model and a test about the *information* between stimuli and brain data in single subject studies. See [4].
2) A multi-subject model and test to make inferences about the population of interest from the result of a brain decoding study on a group of subjects. See [5].

Our implementation of these two applications has been carried out in Python language on top of NumPy and SciPy, the Python software stack for scientific applications. This software stack proved to be extremely efficient both from the software development point of view and for computational aspects. In particular the broadcasting features of the NumPy `ndarray` are fully supported by the random sampling routines in the `numpy.random` subpackage allowing an extremely concise code that fully exploits the speed of C code.

The implementations of the two applications [1] [2] are available under a Free Software / Open Source license. Their integration within PyMVPA [3], the Python package for statistical learning analyses tailored to the neuroimaging domain, is under discussion.

References

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[1] http://github.com/emanuele/information_test

[2] http://github.com/emanuele/Bayes-factor-multi-subject.

[3] http://www.pymvpa.org