BAYESIAN INFERENCE AND GRAVITATIONAL WAVES IN UNDERGRADUATE COMPUTATIONAL PHYSICS

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In undergraduate physics coursework, students learn about principles and theories which underpin important research, some of which are supplemented by experimental and computational projects offered in laboratory-oriented subjects. The discovery of gravitational waves (GW) was awarded the Nobel Prize in 2017 as it has opened countless windows of opportunities for new research in astronomy and astrophysics. In this talk, we discuss how we can introduce the detection of GWs, both in theory and in practice, in third year undergraduate physics coursework via hands-on laboratory projects. The aim of this lab is not only to give students an insight to a cutting-edge research topic, but also to introduce Bayesian inference. Bayesian inference is a widely used statistical tool which prevails among diverse research areas including science, engineering, health care, social science, sports etc. Despite its broad applicability in various physics experiments, Bayesian inference is often overlooked or under-discussed in undergraduate physics courses. Furthermore, undergraduate coursework strongly focuses on the theoretical aspect of physics with a lack of mention about ongoing research work.

The third-year Laboratory and Computational physics subject at The University of Melbourne, offers 17 laboratory projects ranging from experimental condensed matter physics, observational astrophysics to theoretical particle physics. Students are required to select four projects of their own preference and are given 18 supervised hours (3 hours x 6 days) across 2 weeks to work on each project. We take advantage of the flexibility of laboratory subjects to introduce Bayesian inference, a versatile statistical tool, while discussing its application in the context of GW data analysis.

We now discuss the design of this laboratory project. In the first half of this lab project, we introduce the concept of Bayesian inference in two separate sections: (i) analytically through simple mathematical exercises and (ii) using Markov Chain Monte Carlo (MCMC), a widely used method for random sampling, to demonstrate practical applications of Bayesian inference in data analysis. Students write their own MCMC algorithm in the Python programming language for two separate scenarios: (a) to reconstruct the provided dataset using MCMC sampling, and (b) to find the posterior distribution of a model parameter, assuming an appropriate model for the dataset. Students plot their results and discuss the performance of the algorithm they have written in both cases.

In the second half of the lab project, students are given a set of mock output data of a real GW search algorithm (*BayesWave)*. The algorithm is fundamentally built on Bayesian inference, but students are not required to know in detail how the algorithm works due to the time constraint and the complexity of the algorithm. Upon discussing the general principles of *BayesWave*, students are required to extract relevant information from the data, perform the relevant analysis and interpret their findings using plots. Again, all of the analyses are done in Python. Students are required to report their daily progress, present their results and discuss their findings via a laboratory log book.

This abstract intends to put forward a new teaching activity that has been developed recently and offered as part of the third-year Laboratory and Computational physics subject at The University of Melbourne since March 2023. No formal study and/or survey has been conducted to assess student feedback. However, this lab has received positive responses in terms of enrollments. Students who have completed the lab have also found it to be engaging and thought-provoking, based on informal conversations. Furthermore, it is evident through lab reports and assessments that students are able to take away important key concepts, as well as learnt to present their work (written and visually) in a scientific manner. This work is supported by the Laby Foundation.

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