Bootcamp: Computational tools for physics

Wednesday 19 March 2025 - Friday 21 March 2025

Malott Hall

Book of Abstracts

Contents

Invited talks / **1**

Offline Neutrino Filtering using a Convolutional Neural Network at the Radio Neutrino Observatory Greenland

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Neutrino astronomy is a vibrant field of study in astrophysics, offering unique insights into the Universe's most energetic phenomena. The combination of a low cross section and zero electromagnetic charge ensure that a neutrino retains most information about its original source while traversing the universe. On the other hand, these low cross sections, combined with a reduced flux at higher energies, make the neutrino one of the most elusive particles to detect in the standard model. The Radio Neutrino Observatory in Greenland (RNO-G) aims to detect sporadic neutrino interactions in the Greenlandic ice sheet by means of electromagnetic signals in the radio frequency range, induced by the produced charged secondary particles. The low incoming neutrino flux forces the detector to set a low trigger threshold, leading to the measured data being overwhelmed by thermal noise fluctuations. Hence, a sophisticated and robust filter is needed to differentiate between neutrino-like signals and noise. In this talk we present the application of a convolutional neural network to identify noise events. The network employed uses real RNO-G data and simulated
neutrino signals to categorize measured data as noise or neutrino-like events

Invited talks / **2**

Monte Carlo Simulations

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Monte Carlo methods are a tool to estimate probability distributions or simulate physical processes, that is commonly used in physics as well as other fields like chemistry, biology, finance and artificial intelligence.
This talk will give a general introduction to the use of Monte Carlo methods for physics simulations, with some example and practical considerations.

Invited talks / **3**

Statistical Tools for Neutrino Signal Search

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Neutrinos are vital messengers for understanding the most extreme astrophysical processes, capable of traveling across cosmic distances without deflection. The Askaryan Radio Array (ARA), deployed at the South Pole, searches for these elusive particles by detecting radio pulses generated when neutrinos interact with Antarctic ice. However, identifying these rare signals is particularly challenging due to the overwhelming presence of background noise.

To isolate potential neutrino events, ARA employs a suite of signal characterization techniques, including signal-to-noise ratio (SNR), root power ratio (RPR), correlation, impulsivity, and more. These statistical tools help distinguish neutrino-like signals from both thermal noise and anthropogenic interference.

In this presentation, we will explore how different analysis variables are calculated and implemented in the search for neutrino signals.

Invited talks / 4

Singular Value Decomposition for RFI Denoising

Author: Curtis McLennan[1]

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Radio-based physics experiments like the Radar Echo Telescope frequently require analysis techniques that can recover signals at or below the level of noise. Singular Value Decomposition is a versatile tool for signal processing, allowing complex signals to be efficiently analyzed, denoised, and reconstructed, even when signal characteristics are not known. This talk highlights the methodology of singular value decomposition and presents a practical example of using SVD to accomplish weak signal extraction.

Invited talks / 5

Artificial Intelligence at the High Energy Frontier

Author: Margaret Rose Lazarovits[1]

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Whether searching for dark matter or measuring Standard Model parameters, analyzing data from the Large Hadron Collider is no easy task. Leveraging machine learning in high energy physics (HEP) is not a new idea, but recent AI advancements have accelerated analysis efforts. Methods like transformer models, variational auto-encoders, and graph neural networks have strengthened HEP analysis workflows. Further, domain-specific approaches, like Lorentz-invariant networks and embedded inductive biases, have tailored these approaches to this field. These techniques and other powerful machine learning analysis methods are currently being successfully deployed in a range of contexts, including at the high energy frontier.

Overview lecture / 6

Version Control, Shell Scripting and Remote Computing for Academic Research

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The increased computational research approach demands efficient management of code, automation of tasks, and access to high-performance computing resources. Acquiring such skill sets can have a positive impact on the productivity of researchers and increase throughput. This talk will provide an introduction to three fundamental tools: version control, shell scripting, and remote computing. Version control systems, such as Git and GitHub, help researchers track their code, monitor code changes, collaborate seamlessly, and maintain reproducibility in research projects. Meanwhile, shell scripting allows automation of repetitive tasks, data processing, and job scheduling. Remote computing facilitates large-scale simulations, data analysis, and access to cloud-based resources. This talk aims to provide participants with practical knowledge of these tools, demonstrating their applications in academic research. Attendees will gain hands-on insights into repository management, scripting fundamentals, and remote computing workflows, empowering them to streamline their research processes effectively.

Overview lecture / 7

Modeling Data: Fitting, Inference, and Machine Learning

Author: Christopher Rogan[1]

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This lecture will cover the relationship between "models" and "data", such that "learning" corresponds to making inferences about the parameters of our model. We will see that this paradigm covers everything from curve fitting to contemporary machine learning with neural networks. The theory of general model fitting will be explored with practical examples, with some discussion of the concepts of "goodness-of-fit" and model selection.

Invited talks / 8

Source Modeling in Large Astronomical Imaging Surveys

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Source modeling is the process of modeling the flux distribution of astronomical objects such as galaxies and stars to enable accurate photometric measurements. However, conventional source modeling pipelines applied on wide imaging surveys often struggle with large, nearby galaxies, which are frequently "shredded" into multiple smaller components. This fragmentation leads to inaccurate flux measurements and misclassification of sources. In this talk, I will discuss this problem and present two methods one can use to improve photometry for such galaxies: (1) aperture photometry, which provides a straightforward way to measure total flux, and (2) scarlet, a novel tool introduced by Melchior et al. 2018, that enables source deblending and non-parametric modeling of sources.

Overview lecture / 9

Introduction to machine learning

Author: Elliot Reynolds[1]

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These days, machines often perform tasks that were previously far beyond their capabilities, and they are increasingly outperforming humans too! Machine learning has been around for a long time, however, so what has changed? Since, ˜2006 we have been in the "third wave"of deep learning, and it has become possible for machines to learn complex "nested representations", and this has revolutionized their capabilities. The impact on science has been transformative, and it is hard to say where the limit is! This talk will give a conceptual overview of machine learning and deep learning, give an introduction to some of the core concepts, and cover examples of machine learning in action.

Invited talks / 10

Interferometric Reconstruction

Author: Aishwarya Vijai[None]

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The Radio Neutrino Observatory in Greenland (RNO-G) is located at Summit Station and is designed to detect Askaryan emission from ultra-high energy (UHE) neutrinos above 100 PeV. The detector is made up of an array of antennas buried at a depth of 100 meters with the purpose of triggering on and reconstructing neutrino-like signals in the radio regime. Interferometry can be used to find the source of these radio signals as received by an array of antennas. This talk will outline how interferometric reconstruction works and a python-based implementation of the technique which is used by the RNO-G. This technique is broadly used in other neutrino detection experiments and radio astronomy as well.

Invited talks / 11

Machine Learning for Applications in Condensed Matter Physics Research

Author: Gabriella Townsley[None]

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How can you use a machine learning model in your research? This talk will outline when and where a model is most useful in materials science, how it's created with different methods, and some of the advantages and disadvantages of each. I will also discuss my own research on phase change materials and its machine learning model as a more in-depth example.