Contribution ID: **21** Type: **not specified**

ML4GW: An AI-based Ecosystem for Real-time Gravitational Wave Analysis

Wednesday 25 September 2024 10:40 (20 minutes)

Deep learning algorithms have excelled in various domains. Despite this success, few deep-learning models have seen full end-to-end deployment in gravitational-wave searches, both in real-time and on archival data. In particular, there is a lack of standardized software tools for quick implementation and development of novel AI ideas. We address this gap by developing the *ML4GW* and *HERMES* libraries. We show how these libraries enhance efficiency and AI model robustness in the context of a broad range of gravitational wave analyses with an emphasis on real-time application, scalability to heterogeneous computing resources, and streamlining the training to deployment cycles for machine learning models. Building on this toolkit, we introduce specific machine learning pipelines that are currently running or set to run in real-time during the ongoing LIGO-Virgo-KAGRA observing run. These searches include *Aframe*, a low-latency machine learning pipeline for compact binary sources of gravitational waves; *DeepClean*, a deep learning-based denoising scheme for astrophysical gravitational waves; *AMPLFI*, a pipeline for deep learning based parameter estimation using likelihood-free inference; and *GWAK*, a semi-supervised strategy to identify unmodeled gravitational wave transients using embedded spaces. In addition, we discuss how such pipelines can lead to latency improvements for multi-messenger targets. Finally, we show how *ML4GW* and *HERMES* can quickly integrate the plethora of deep learning based algorithms being developed for gravitational wave identification across the broader astrophysics community.

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Session Classification: Astroparticle

Track Classification: Astroparticle Physics