AI Institute: Planning: Improving astroparticle physics outcomes through evolutionary machine learning applied to the design of instruments

We propose to use Evolutionary Computation (EC) to revolutionize detector design across the field of astroparticle physics. Building on the foundation of evolved antenna designs used in neutrino experiments with GENETIS (Genetically Evolving NEuTrIno TeleScopes), we intend to build a first instrument designed using EC as a proof-of-principle. Simultaneously, we will build the infrastructure necessary to reach a wide range of scientists interested in applying our machine learning techniques and pipeline to astroparticle instrument design.

This proposed work builds from multi-institutional, undergraduate research for improved neutrino telescopes deployed in deep ice. This initial phase sets the stage for a broader program that will use genetic algorithms (GA) and other types of machine learning to improve science outcomes of current and planned astroparticle physics experiments, increasing sensitivity, streamlining operations, and reducing logistics and costs.

Intellectual Merit

- Foundations of AI: GENETIS currently employs EC and will expand to other types of machine learning. GENETIS will make important contributions to the body of AI experience by documenting the effectiveness of various algorithms applied to this new frontier.
- Trustworthy AI: The GENETIS team employs EC for its reliability, transparency, and effective application to small datasets and limited parameters. All GENETIS designs and solutions will be tested against traditional techniques, prototypes, and field measurements.
- AI for Discovery in Physics: We aim to accelerate the scientific outcomes in experiments across the field of astroparticle physics. GENETIS has uniquely developed the capability to evolve new antenna designs for in-ice neutrino telescopes, looking toward of an expanded IceCube-Gen2 array. This proof of principle opens a new realm for optimizing the design and operations of experiments across the field of astroparticle physics.

One of four cosmic messengers, neutrinos are unique to the cosmos at macroscopic energies, and can probe fundamental physics at energies unparalleled by accelerators on Earth. By applying EC to novel antenna designs tailored for neutrino detection, we expect to invoke a leap in the sensitivity of detectors, expedite a first discovery, and advance the field by a decade. This project is unique for its combined use of EC for 1) *design*, and 2) *physics outcomes* for optimization.

Broader Impacts: Multi-messenger astrophysics is an ideal platform from which to inspire young scientists. Not only is the science exciting, but the techniques employed are forefront to a number of modern arenas: cross-discipline collaboration, applied machine learning, data analysis and visualization, additive manufacturing, and design, development, and field deployment of mission critical equipment. Accordingly, we will continue to engage secondary schools, undergraduate and graduate students in cutting-edge research, providing hands-on experience in machine learning techniques, 3D printing, lab testing and field deployment.

The GENETIS collaboration understands how to maintain integrity over long-duration research projects, having already witnessed the transition of two generations of students. Moving forward, GENETIS will serve as a pipeline for young scientists, giving them a clear path from high school to undergraduate to graduate studies in experimental physics.