IRIS-HEP Fellowship Project Proposal:

Developing an automatic differentiation and initial parameters optimisation pipeline for the particle shower model

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July 2023

Project Details:

During the HEP-experiment it is always interesting to trace the evolution of particle and energy distribution in the detector material, i. e., where the particles initially hit the material, what was happening in between and where they were eventually absorbed. Such distributions heavily depend on experimental conditions like detector geometry.

The goal of this project is to develop a differentiable simulation and optimization pipeline to solve an inverse problem to the one described above. The problem of finding the best, in a certain sense, geometry of detector material and optimal starting conditions for the experiment, given the target properties of particle hits inside a detector.
An approach, which is similar to the one used in differentiable ML models like artificial neural networks, will be used to achieve the project's goal.
The envisioned pipeline will iteratively function in the following sequence: first by passing the initial detector design parameters through the particle shower simulation, then backpropagating the signal and subsequently adjusting the parameters to improve them.

A challenge that is important to tackle during the project is the following: fundamentally the simulations in question are dominated by the stochastic branching processes and these processes are fundamentally non-differentiable. Established stochastic averaging methods for unbiased gradient estimation will be explored in order to adapt the backpropagation procedure for this particular case, where inherently non-differentiable operations are present.

The narrow task of this Fellowship project is to develop a trial automatic differentiation and backpropagation pipeline for the Markov-like stochastic branching process that is modeling a particle shower spreading inside a detector material in three spatial dimensions. That pipeline will be based on a previously developed simplified exemplary pipeline for such branching process only in two dimensions.
This software pipeline will be implemented using a combination of generic programming languages and differentiable programming frameworks.

The ultimate strategic goal to which this Fellowship project will contribute is to obtain efficient automated means of designing hardware for future detectors.

This project will be done under the mentorship of Dr. Lukas Heinrich and Dr. Michael Kagan

Timeline:

- Weeks 1-2: Reading on EM shower model / study existing code
- Weeks 3-5: Prototyping simple EM shower
- Weeks 6-8: Implementing gradient estimation
- Weeks 9-10: Setting up and running optimization task
- Weeks 11-12: Documenting & packaging of implementations