IRIS-HEP Fellowship Proposal

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1. Background

The analysis of high-energy-physics data is often based on simulation tools that use Monte-Carlo techniques to sample multitudinous paths through which a particular hard scattering might develop. However, such simulations cannot calculate the likelihood or likelihood ratios for particular observations as doing so would require integrating all possible histories that lead to the observation[1]. Multiple methods have been proposed to address this issue, one of which exploits matrix element information to learn the likelihood with machine learning-based models.[2]

MadMiner is a Machine Learning-based inference tool that automates all steps necessary for this newer type of modern multivariate inference technique[3]. It uses simulated events that can be re-weighted to describe distributions with different values for the physics parameters of interest. Such re-weight/morph procedures introduce statistical uncertainties which can limit the performance of the MadMiner approach.

2. Project Proposal

Currently, the available morphing technique in Madminer requires an inflexible distinct number of default physics parameter values (basis points) needed to use (the number varies depending on the physics process of interest). Thus, we propose to implement a new approach that relaxes the requirement which would allow researchers to pick additional physics parameter values as basis points while still being able to reweight to any other position in parameter space.

This project allows researchers to have more flexibility on the number of basis points, which allows them to reduce statistical uncertainties due to the morphing procedure to appropriate values for the given setup.

The project will be conducted remotely(earlier period) and locally(later period) under the guidance of Dr. Alexander Held and Professor Kyle Cranmer.

3. Software Deliverables

The deliverable of the project should be the code implementation of the morphing function within MadMiner, which allows researchers to increase the number of basis points for parameter morphing. The figure below shows an example of basis points in a plane of two parameters (θ1 and θ2), and the statistical uncertainty incurred when morphing to different points in this parameter space (darker color = larger uncertainty). As the implementation will not limit the number of basis points in the simulation, researchers can adjust the number by themselves based on their needs.

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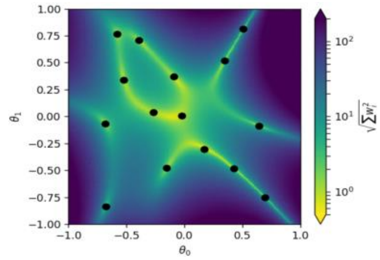
[1] J. Brehmer et al. A Guide to Constraining Effective Field Theories with Machine Learning. p.63.
[2] J. Brehmer et al. MadMiner: Machine learning-based inference for particle physics. p.3.
[3] J. Brehmer et al. Github: https://github.com/madminer-tool/madminer



4. Timeline

I plan to work Full-Time (40 hrs per week) for a duration of 3 months/12 weeks for this project this summer. The planned starting date of the project is May 25th and should be completed by August 17th.

1) **Week 1 - 2**
- Familiarize with MadMiner(specifically the morphing/reweighting) by reading scholarly articles, documentation, and code related to Madminer
- Set up the environment for the implementation and get code running on the local machine.

2) **Week 3 - 4**
- Learn and understand the mathematical approach of the new proposed morphing method and learn how to convert it into code implementation
- Learn to use the tools (APIs, etc) needed for the implementation
- Start implementing the code

3) **Week 5 - 6**
- Continue implementing the function and design test cases for the implemented parts
- Validating the correctness of the implemented parts and document the changes in the implementation

4) **Week 7 - 8**
- Finalize implementation of the method
- Compare the effectiveness of morphing methods for various physics examples

5) **Week 9 - 10**
- Start the general documentation of the implementation
- Create tutorial material comparing the available morphing methods to each other

6) **Week 11 - 12**
- Finish the full documentation of the implementation, merge changes into the MadMiner repository
- Present the implementation to the public

References

J. Brehmer, K. Cranmer, G. Louppe, and J. Pavez. A Guide to Constraining Effective Field Theories with Machine Learning. Phys.Rev.D 98, 052004 (2018).

J.Brehmer, F. Kling, I. Espejo and K. Cranmer. MadMiner: Machine learning-based inference for particle physics. *Comput Softw Big Sci* 4, 3 (2020). https://doi.org/10.1007/s41781-020-0035-2

J.Brehmer, F. Kling, I. Espejo, S. Perez, and K. Cranmer. MadMiner: Machine learning-based inference for particle physics. Github: https://github.com/madminer-tool/madminer