Artificial Intelligence and Machine Learning for HEP

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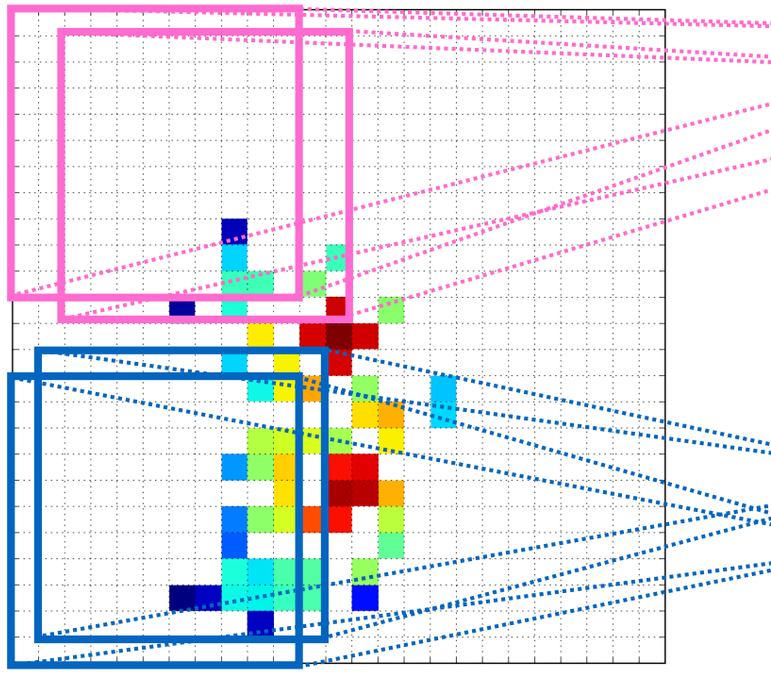


BERKELEY LAB

BIDS
BERKELEY INSTITUTE FOR DATA SCIENCE

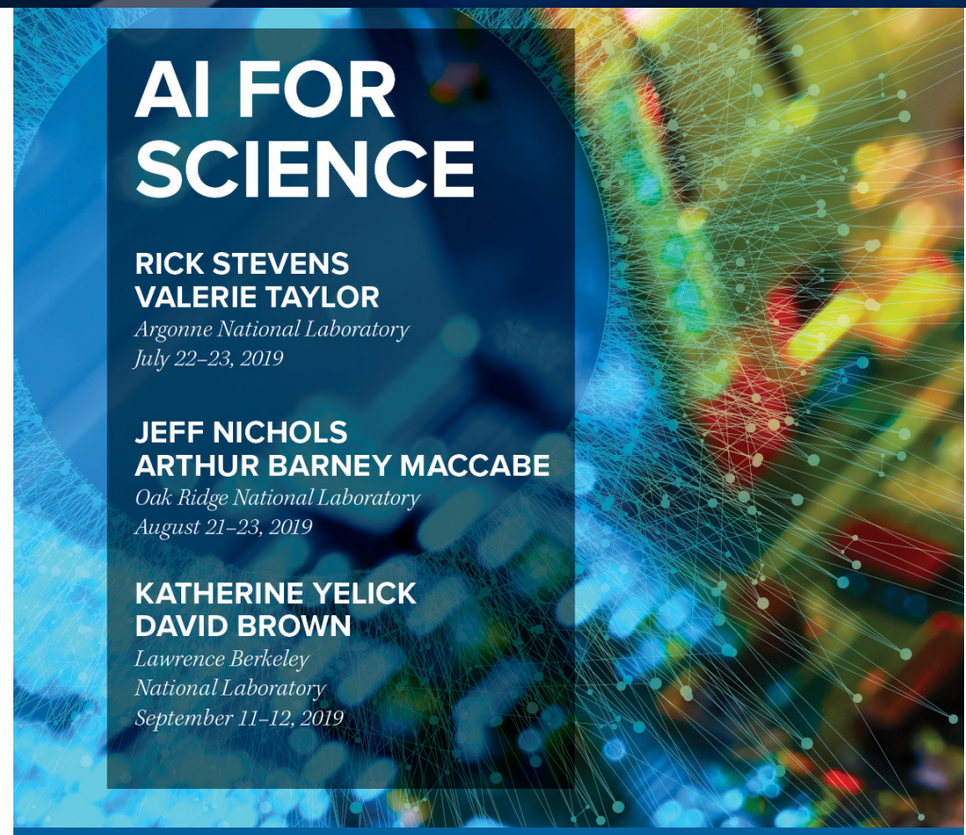
P5 Town Hall - Feb. 2023

NATIONAL ARTIFICIAL INTELLIGENCE INITIATIVE

OVERSEEING AND IMPLEMENTING THE UNITED STATES NATIONAL AI STRATEGY

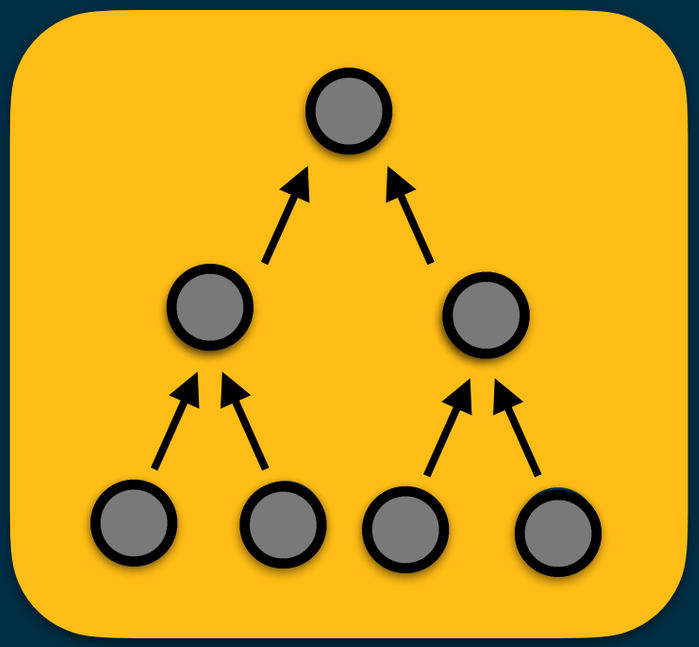
ai.gov

Today: how can HEP benefit **from national initiatives** and how can our nation benefit **from AI/ML in HEP**?

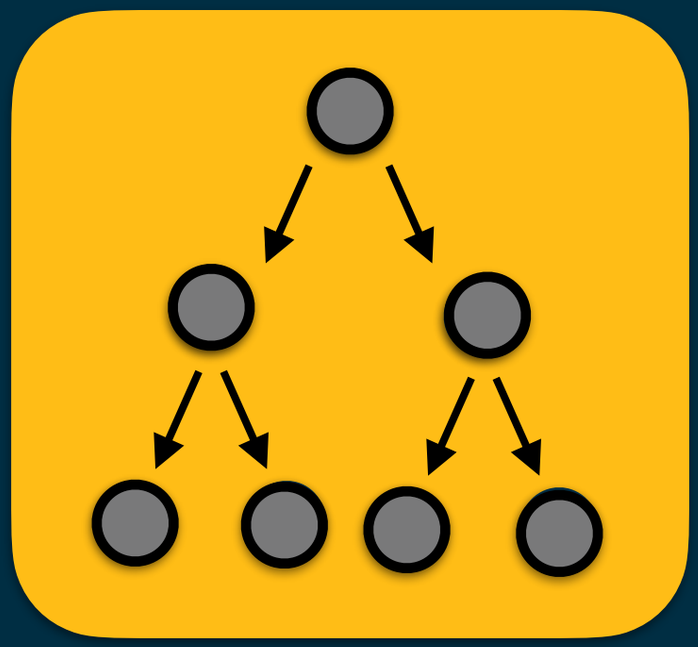


https://science.osti.gov/Initiatives/AI/

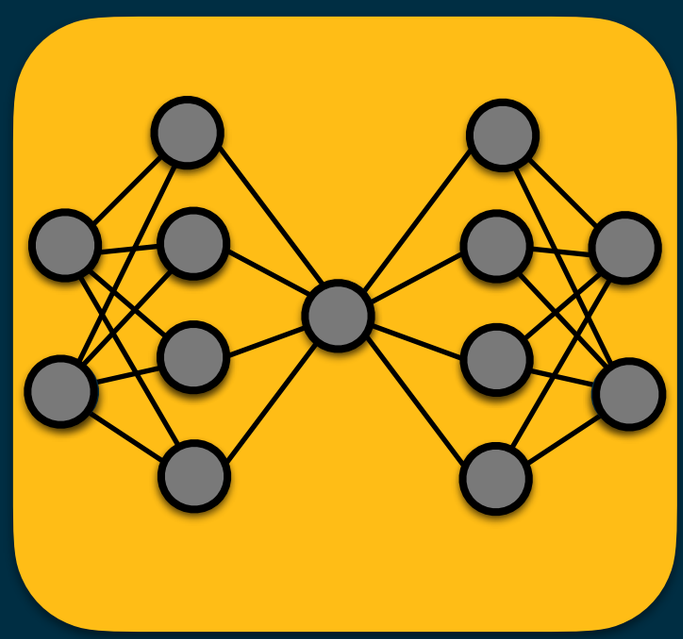
see also https://www.nsf.gov/cise/ai.jsp



HEP Science



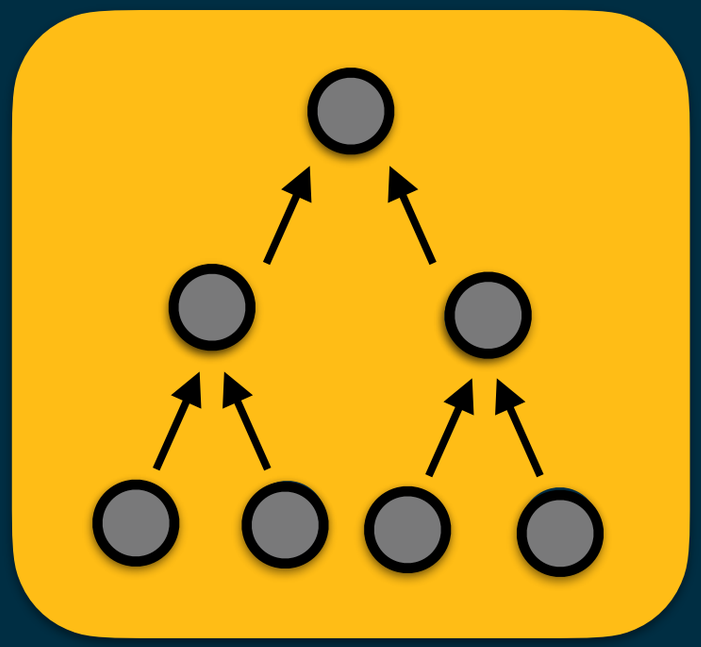
Research Connections
(beyond HEP)



Connections to Society at Large

Artificial Intelligence and Machine Learning in High Energy Physics

(HEP ML)



HEP Science

Research Connections
(beyond HEP)

Connections to Society at Large

Artificial Intelligence and Machine Learning in High Energy Physics

(HEP ML)

Science of HEP

Theory of everything

↓

Physics simulators

↓

Detector-level observables

↓

Pattern recognition

Nature

↓

Experiment

↓

Detector-level observables

↓

Pattern recognition

Science of HEP + Machine Learning

matrix element / lattice calculations, …

Theory of everything

Fast simulation / phase space

Parameter estimation / unfolding

Physics simulators

Detector-level observables

Pattern recognition

Nature

Experimental design & control

Experiment

Online processing & quality control

Detector-level observables

Pattern recogn

Data curation

Inference

event selection
background estimation
hypothesis testing
…

calibration
clustering
tracking
noise mitigation
particle identification
…

Connections to all areas!

HEP ML @ Science

We have been using ML for a long time. However, the deep learning revolution is a **new paradigm**.

Supercharging existing techniques & new methods allow us to do innovative science that was **unthinkable** before!

This is enabled by both **project-dependent** and **project-independent** researchers developing, adapting, and deploying new methods.

(N.B. we need career paths for these researchers! … plenty of postdoc opportunities, **but a lack of faculty/staff positions**)

Impact is **O(1)** - comparable to better instruments (!)

We are already embracing ML4HEP

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PHYSICS DIVISION

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Machine Learning for Fundamental Physics

Vision: To advance the potential for discovery and interdisciplinary collaboration by approaching fundamental physics challenges through the lens of modern machine learning.

Mission: The Physics Division Machine Learning group is a cross-cutting effort that connects researchers developing, adapting, and deploying artificial intelligence (AI) and machine learning (ML) solutions to fundamental physics challenges across the HEP frontiers, including theory. While most of the ML group members will have a primary affiliation with other areas of the division, there will be unique efforts within the group to develop methods with significant interdisciplinary potential. We have strong connections and collaborations with researchers in the Computational Research Division, the National Energy Research Scientific Computing Center (NERSC), and the Berkeley Institute of Data Science (BIDS).

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Research and Development

Artificial Intelligence

AI for Physics, Physics for AI

At Fermilab, we are committed to artificial intelligence (AI) research and development to enhance the scientific mission of particle physics.

The unique challenges of high-energy physics research present opportunities for advancing AI technologies. From massive and rich data sets to building and operating some of the world's most complex detector and accelerator systems, the technologies we are developing have potential connections to a broad domain of cutting-edge AI research.

- Research Areas
- People
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Machine Learning at SLAC

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AI Seminar

Tobias Boltz (SLAC)

Micro-Bunching Control at Electron Storage Rings with Reinforcement Learning

Reinforce yourself to be there!

December 16, 2022

Machine Learning Overview

Machine Learning (ML) algorithms are found across all scientific directorates at SLAC, with applications to a wide range of tasks including online data reduction, system controls, simulation, and analysis of big data. An important design principle of ML algorithms is the generalization of learning patterns across different tasks, which motivates shared tool-development and R&D at an inter-directorate level. ML-at-SLAC is a hub for ML activities at the lab, providing resources and connections between ML experts and domain scientists.

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Research Areas

People

Publications

This investment is fantastic,
BUT it is not the end of the story!

We need to strengthen our support of existing initiatives and build a long-term foundation (e.g. base funding) in these areas.

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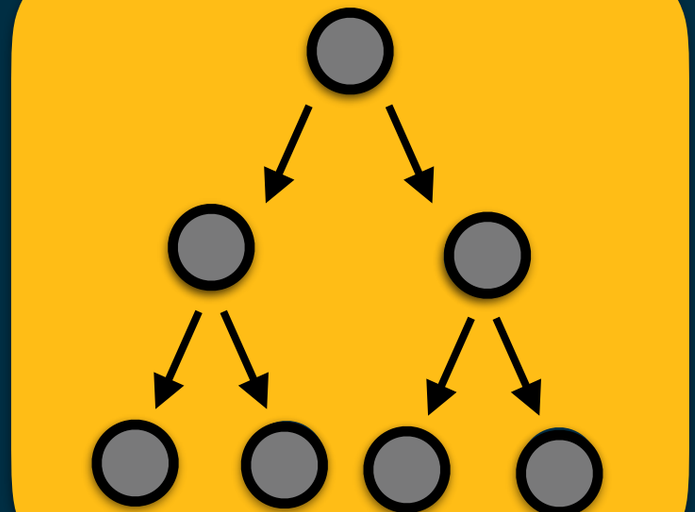

Research Connections
(beyond HEP)

Connections to Society at Large

Artificial Intelligence and Machine Learning in High Energy Physics

(HEP ML)

Beyond HEP

NSF CISE is already making a big investment across science.

DOE ASCR (and DOE HEP) is also investing, but the “big” investment (beyond exascale) is likely on the horizon.

Where can we contribute? We have unique challenges that place our researchers at the forefront of AI/ML developments; our datasets can also inspire AI/ML researchers.

Simulation-based inference (combining simulations w/ ML)

Not exhaustive!

Fast inference w/ custom hard/firmware

Anomaly detection & uncertainty quantification

XGBoost 1603.02754

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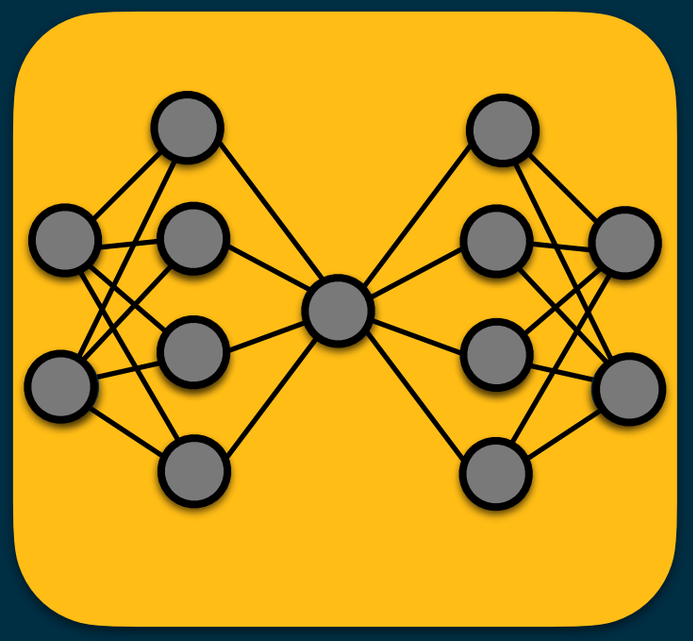


Connections to Society at Large

Artificial Intelligence and Machine Learning in High Energy Physics

(HEP ML)

Beyond Science

AI/ML is a fantastic vehicle for broadening participation in HEP.

barrier to entry is lower and more universally understood at all levels (< college, undergrad, …). See also DOE RENEW & NSF ExpandAI.

(N.B. but also need to train people on the "traditional" path!)

Our methodologies and technologies may also have broader implications.

e.g. decorrelation = fairness, fast inference (…)

decorrelation means making some ML model ~independent from certain features. One aspect of fairness is to make decisions ~independent of protected features like race. The underlying concept is the same!

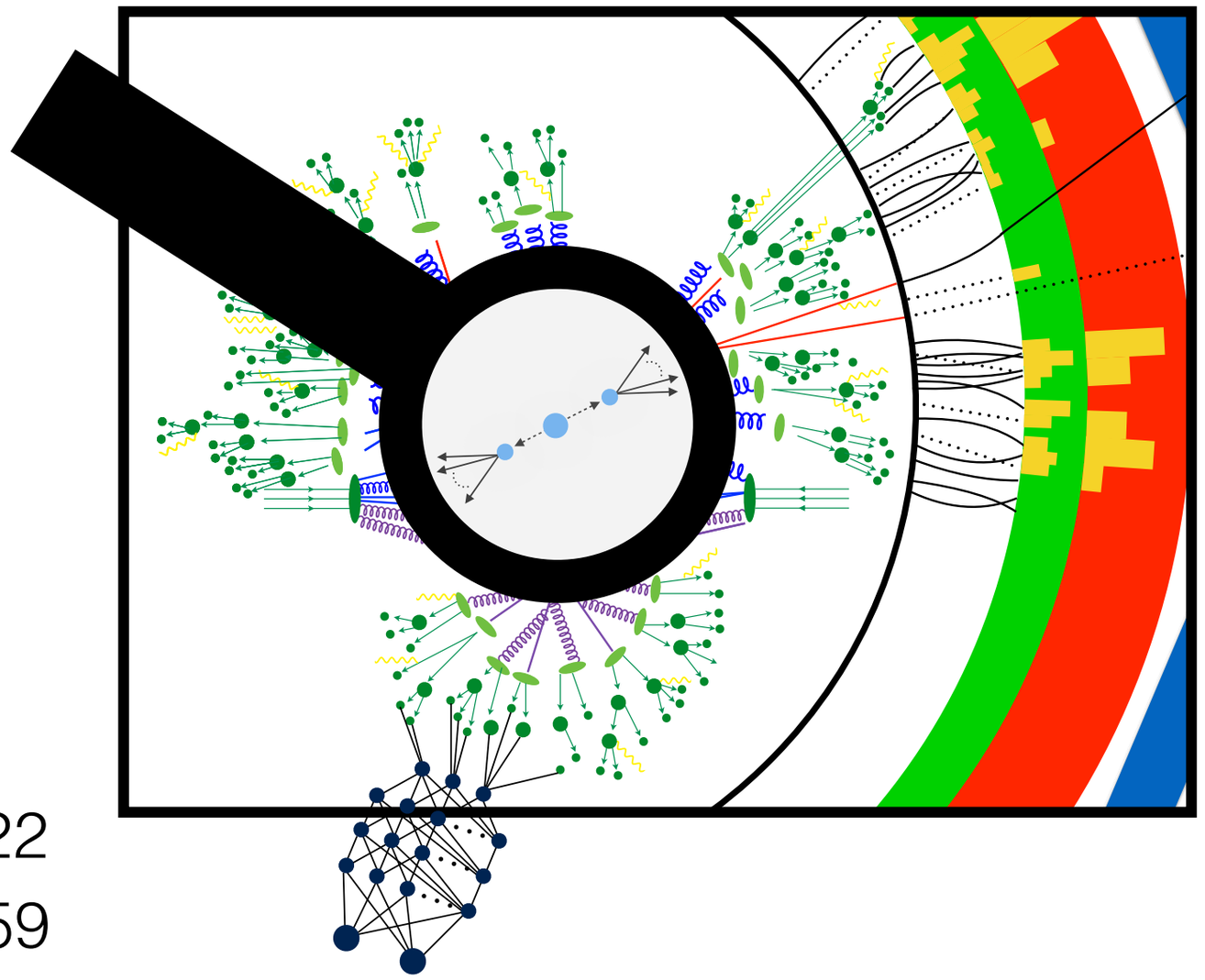
See also all of the people in HEP who are now playing leading roles in data science industry as engineers, managers, and researchers.

Conclusions and Outlook

We need innovative computational techniques to make the **data-driven discoveries of the future**.

This is not just about improving precision, it is about enabling new science!

I hope that P5 will make a strong statement(s) about AI/ML!



CompF Snowmass Report: 2210.05822

CompF3 Snowmass Report: 2209.07559

Questions?

Thank you to Paolo Calafiura, Kyle Cranmer, Aishik Ghosh, Peter Nugent, Nathalie Palanque-Delabrouille, Phiala Shanahan, Natalie Roe, Jesse Thaler, Nhan Tran, and Daniel Whiteson for feedback!