Deep Generative Models for Fundamental Physics

March 17, 2021

BIDS
BERKELEY INSTITUTE FOR DATA SCIENCE

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PHYSICAL SCIENCES

Organizing Committee

- Ellianna Abrahms, Department of Astronomy, UC Berkeley
- Vanessa Boehm, Department of Physics, UC Berkeley
- Aishik Ghosh, UC Irvine / Physics Division, Berkeley Lab
- Yue Shi Lai, Nuclear Science Division, Berkeley Lab
- Mustafa Mustafa, NERSC, Berkeley Lab
- Ben Nachman, Physics Division, Berkeley Lab
- Giuseppe Puglisi, Space Science Laboratory, UC Berkeley

Meeting participation

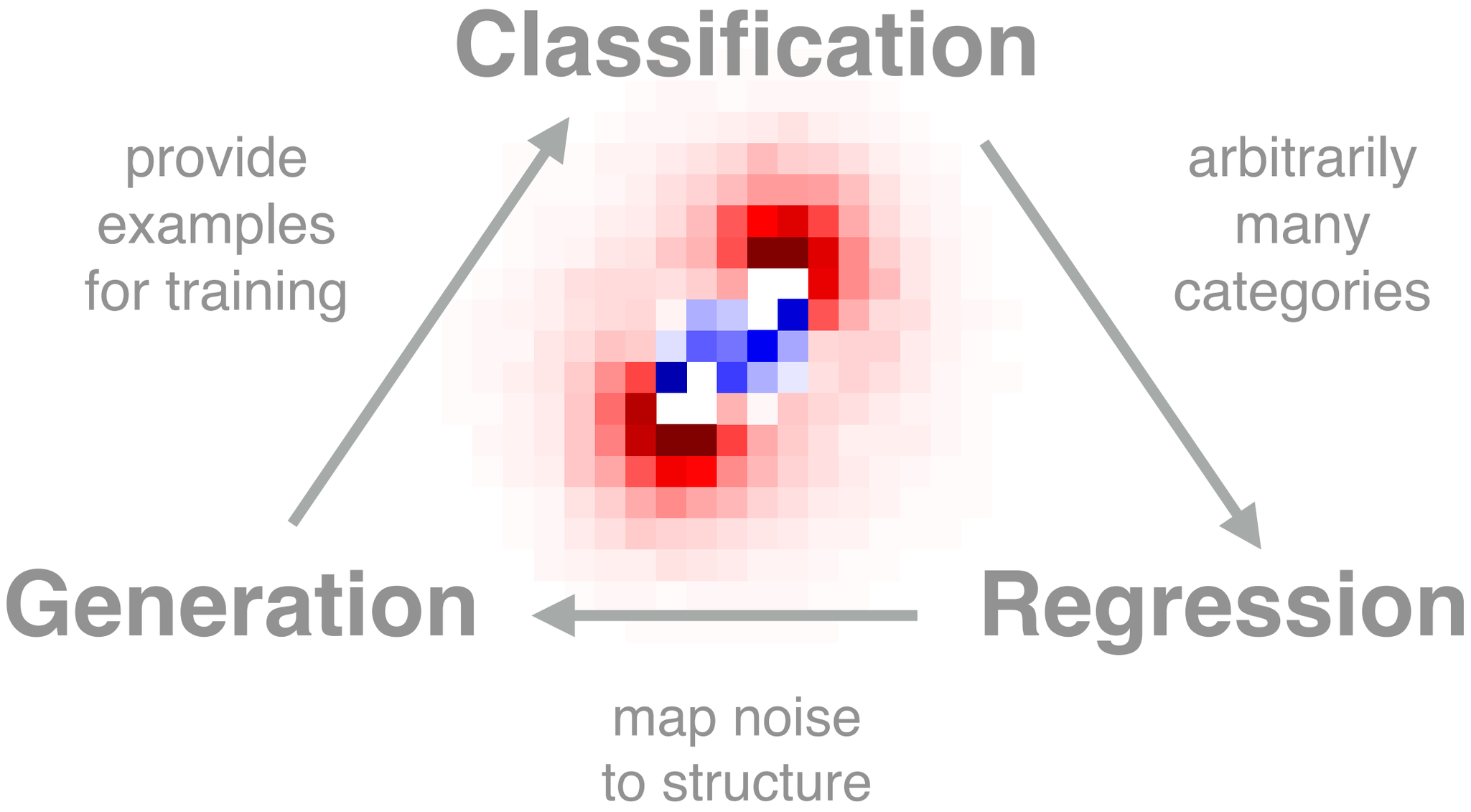
Code of Conduct

We are committed to making the meeting productive and enjoyable for everyone, regardless of gender, sexual orientation, disability, physical appearance, body size, race, nationality or religion. We will not tolerate harassment of participants in any form. Please follow these guidelines:

Behave professionally. Harassment and sexist, racist, or exclusionary comments or jokes are not appropriate. Harassment includes sustained disruption of talks or other events, inappropriate physical contact, sexual attention or innuendo, deliberate intimidation, stalking, and photography or recording of an individual without consent. It also includes offensive comments related to gender, sexual orientation, disability, physical appearance, body size, race or religion. All communication should be appropriate for a professional audience including people of many different backgrounds. Sexual language and imagery are not appropriate. Be kind to others. Do not insult or put down other attendees. Participants asked to stop any inappropriate behavior are expected to comply immediately. Attendees violating these rules may be asked to leave the event at the sole discretion of the organizers.

Any participant who wishes to report a violation of this policy is asked to speak, in confidence, to any of the meeting organizers.

Generative Models



Generative Models for Fundamental Physics

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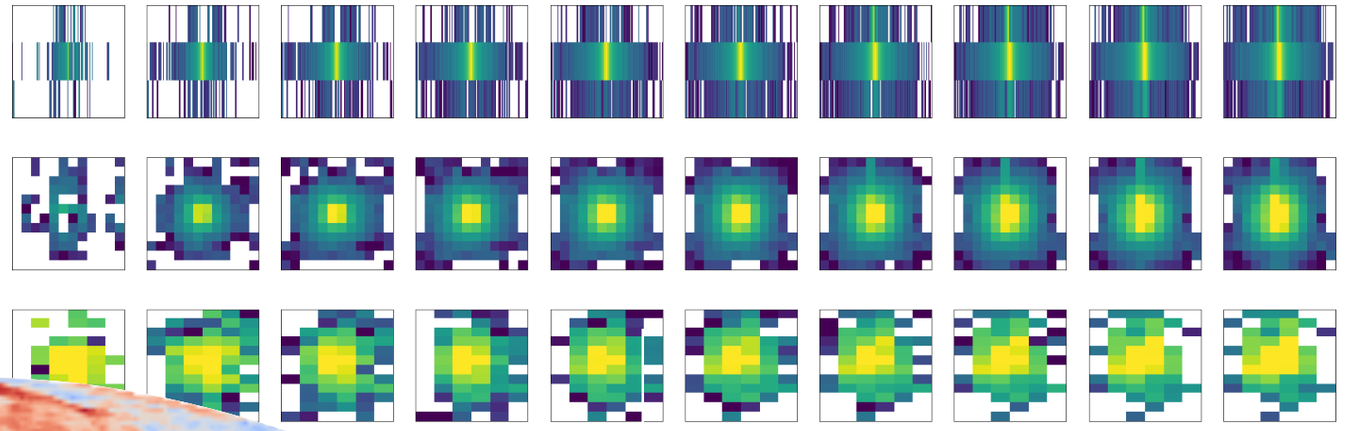
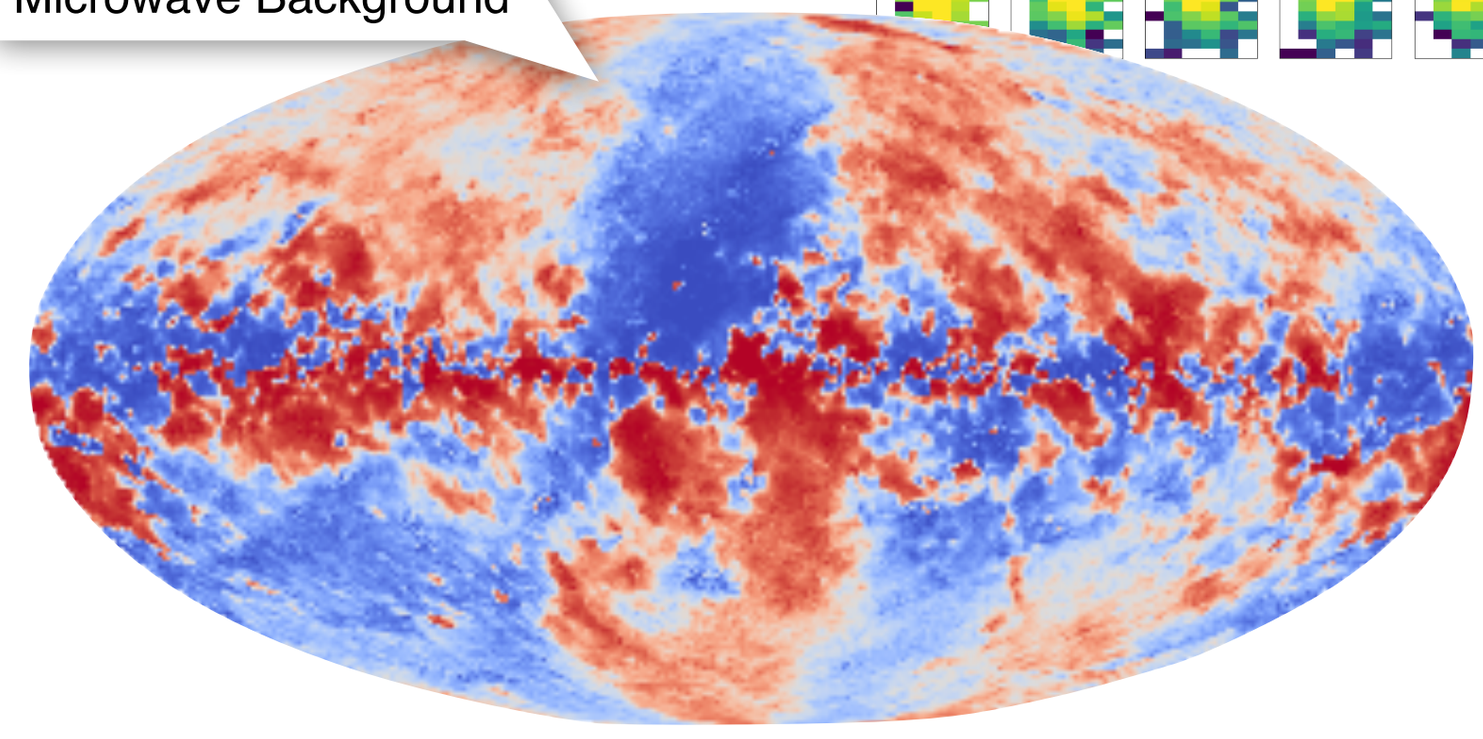
All of these pictures are fake!

Material Interactions with High Energy Particles



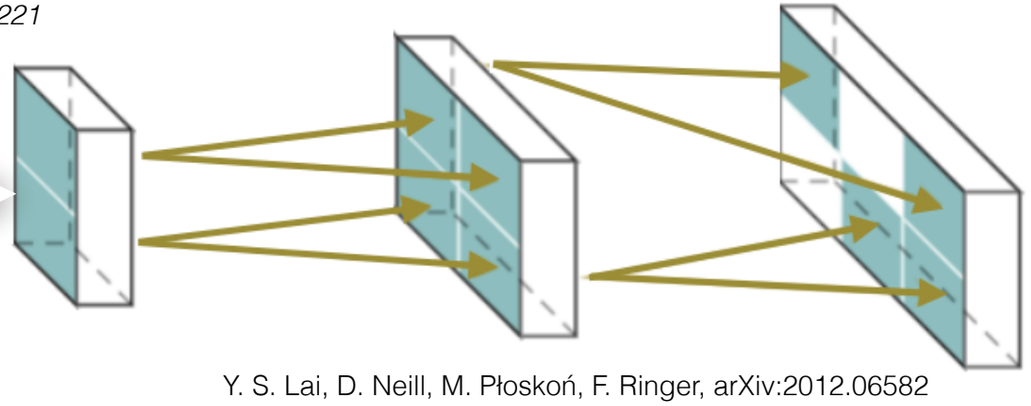
M. Paganini, L. De Oliveira, B. Nachman, Phys. Rev. Lett. 120 (2018) 042003

Synthetic Galactic radiation for Cosmic Microwave Background



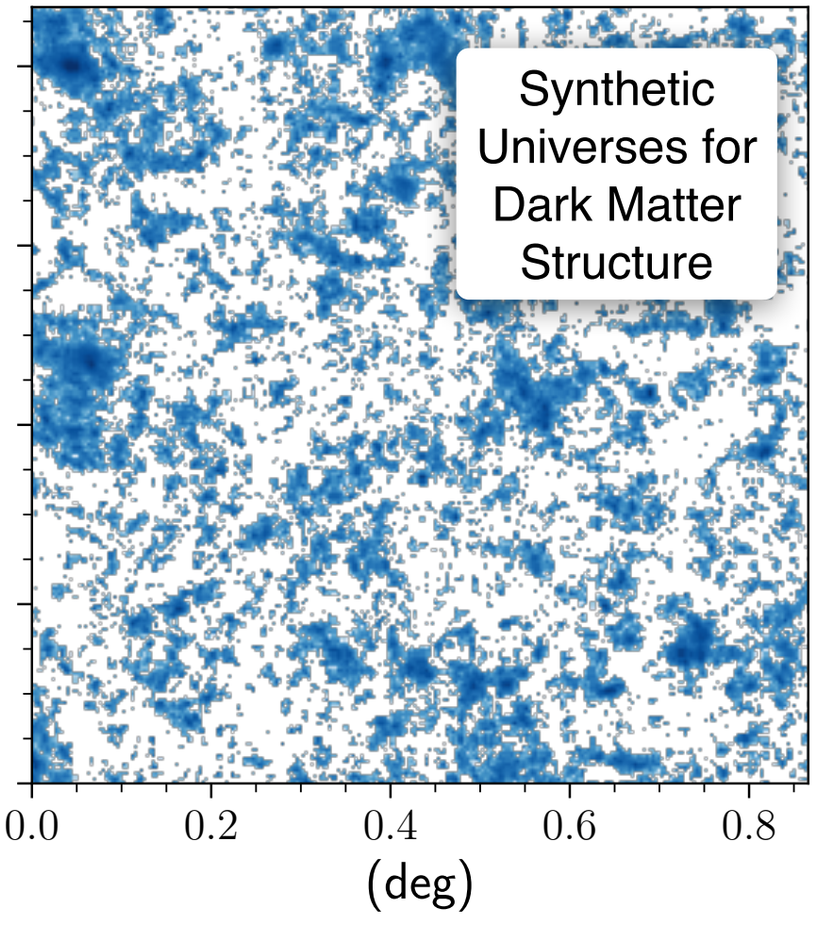
N. Krachmalnicoff and G. Puglisi, arXiv:2011.02221

The Structure of Radiation in the Quantum Strong Force



Y. S. Lai, D. Neill, M. Płoskoń, F. Ringer, arXiv:2012.06582

Synthetic Universes for Dark Matter Structure



M. Mustafa, et al., Comp. Astrophysics and Cosmology 6 (2019)

Fund. Physics + Deep Gen. Models

Deep generative models can be used to replace/ supplement slow physics-based simulations

They can allow us to build unbinned approximations of (conditional) densities via sampling (or directly)

They can be trained directly on unlabeled data to infer the underlying physical processes of our data

…

GANs

Generative Adversarial Networks

NFs

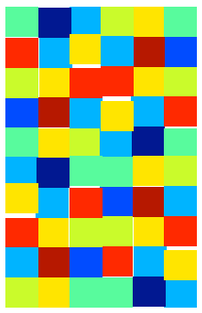
Normalizing Flows

VAEs

Variational Autoencoders

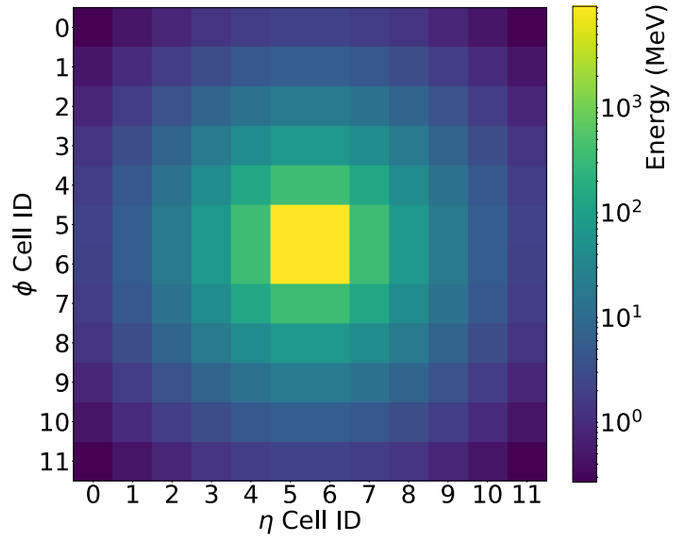
Reminder: GANs

Generative Adversarial Networks (GANs):
*A two-network game where one **maps noise to structure** and one **classifies images as fake or real**.*



noise

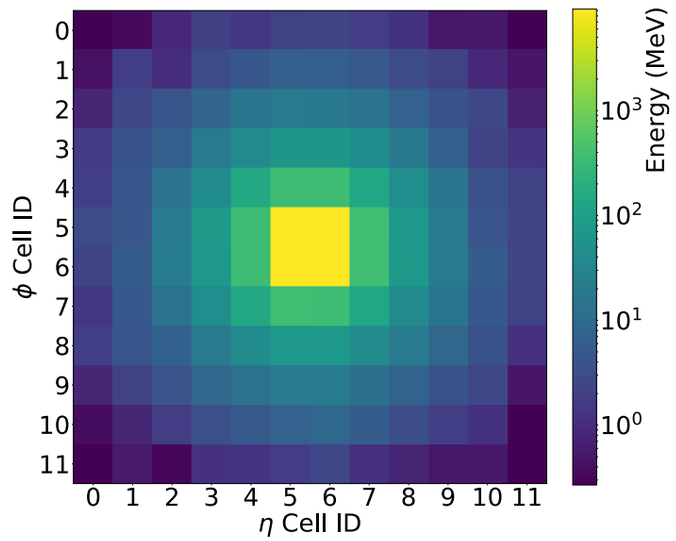
G



D

{real,fake}

When **D** is maximally confused, **G** will be a good generator

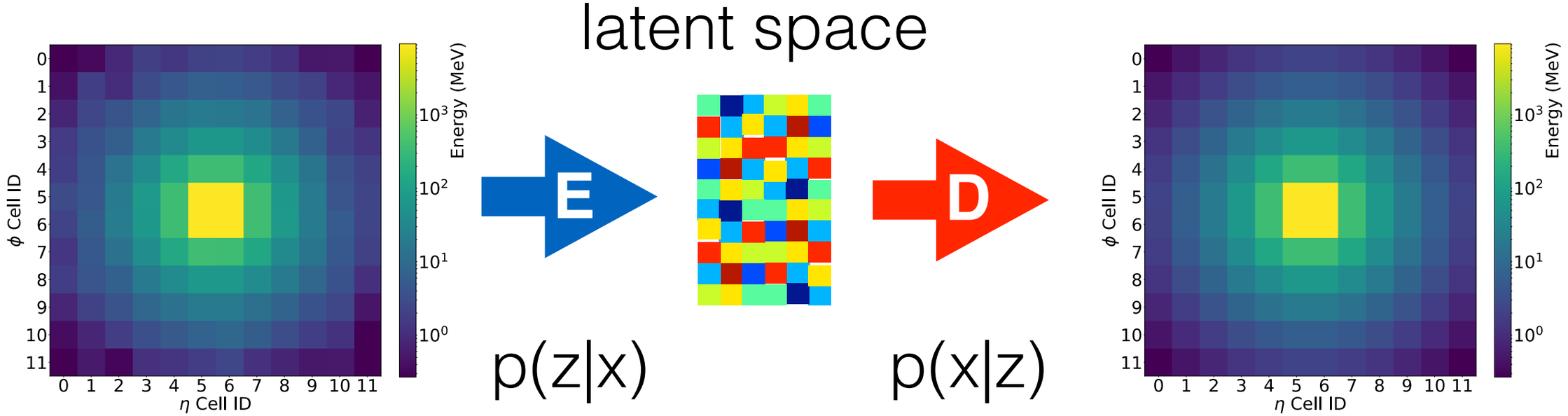


D

Physics-based simulator or data

Reminder: VAEs

Variational Autoencoders (VAEs):
A pair of networks that embed the data into a latent space with a given prior and decode back to the data space.



Physics-based simulator or data

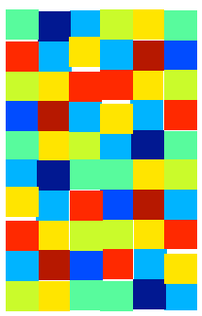
Probabilistic ***encoder***

Probabilistic ***decoder***

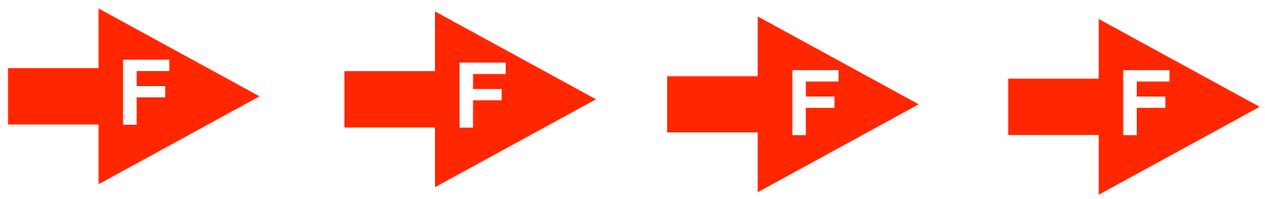
Reminder: NFs

Normalizing Flows (NFs):
A series of invertible transformations mapping a known density into the data density.

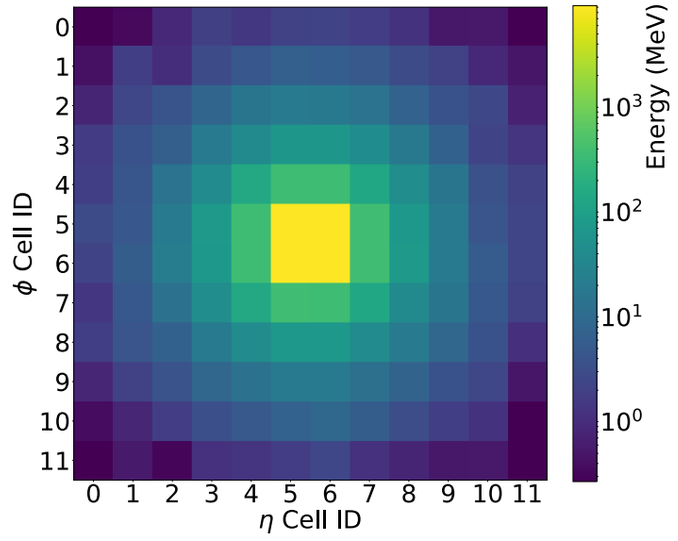
Optimize via maximum likelihood



latent space



Invertible transformations with tractable Jacobians



Challenges for Fund. Physics

How to optimize training, when to stop?
(Harder to validate than classification)

How to diagnose and avoid mode collapse?

How to incorporate physics knowledge?
Our data are often very different than cats/dogs/celebrities

What is the statistical power of generated samples?
(See e.g. 2008.06545)

How do we achieve precision? How about uncertainties?

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Plan for today

- 1:00-1:20: Introduction
- 1:20-1:40: 15′+5′ Talk (Colliders), Speaker: **Raghav Kansal (UCSD)**, Title: Graph Generative Adversarial Networks for High Energy Physics Data Generation
- 1:40-2:00: 15′+5′ Talk (Nuclear Physics), Speaker: **Felix Ringer (LBNL)**, Title: GANs for parton shower development
- 2:00-2:20: 15′+5′ Talk (High Energy Physics), Speaker: **Yadong Lu (UC Irvine)**, Title: Sparse Autoregressive Models for Scalable Generation of Sparse Images in Particle Physics
- 2:20-2:40: 20′ break
- 2:40-3:00: 15′+5′ Talk (Cosmology), Speaker: **Biwei Dai (UC Berkeley)**, Title: Normalizing Flows for data with Translational and Rotational Symmetry
- 3:00-3:20: 15′+5′ Talk (Astronomy), Speaker: **Jorge Martinez-Palomera (BAERI)**, Title: Deep Generative Modeling of Periodic Variable Stars Using Physical Parameters
- 3:20-3:40: 15′+5′ Talk (Astrophysics), Speaker: **David Shih (Rutgers / LBNL)**, Title: Via Machinae: Discovering Stellar Streams and Modeling the Galaxy with Normalizing Flows
- 3:40-4:00: 15′+5′ Talk, (CMB), Speaker: **Ben Thorne (UC Davis)**, Title: A Generative Model of Galactic Dust Emission Using Variational Inference
- 4:00-4:15: 15′ break
- 4:15-5:00: Moderated discussion
- 5:00: Brief closeout

Please enjoy the workshop!

Please ask questions and if we run out of time during the talks, please bring it up again during the discussion at the end!

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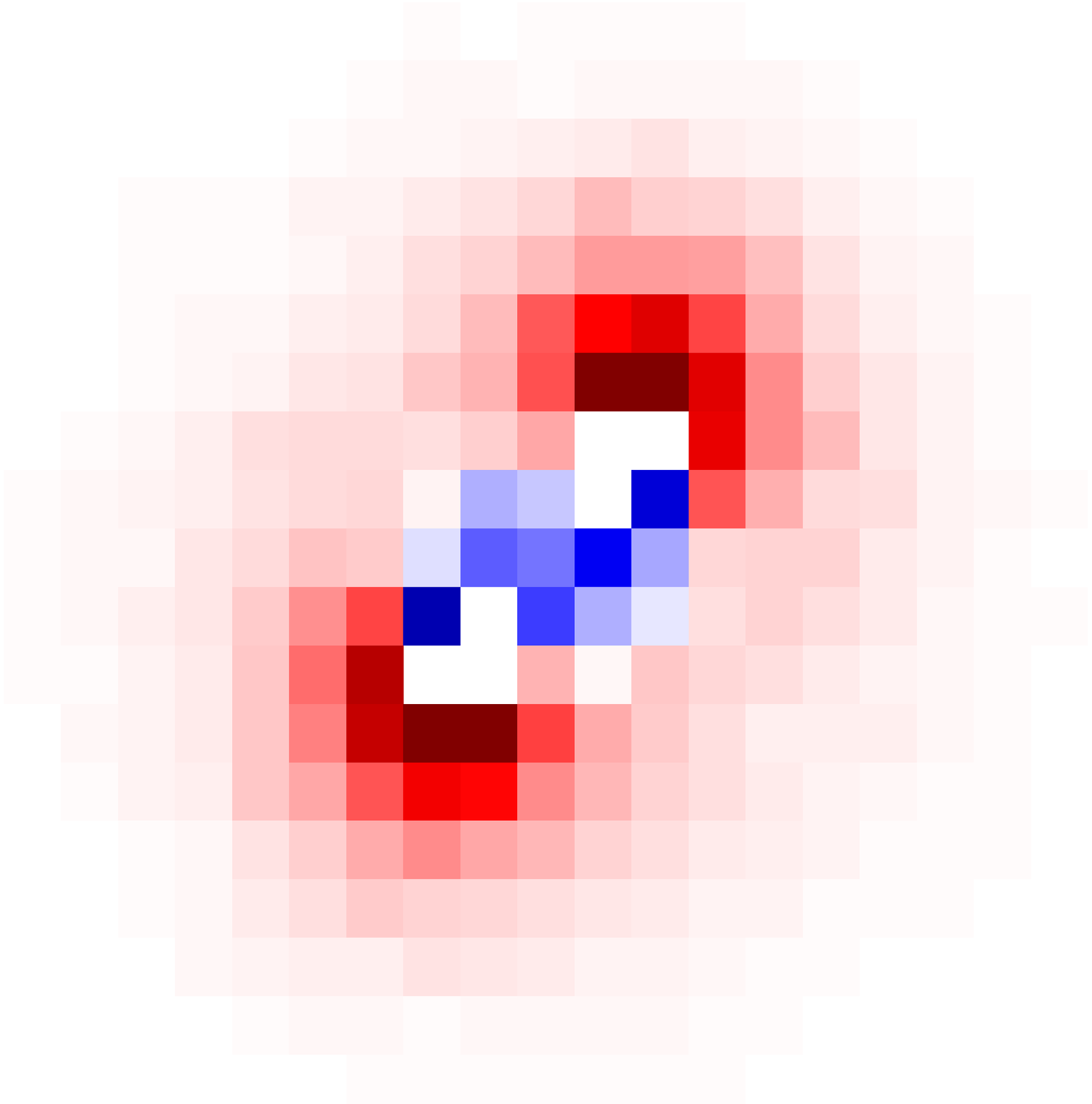
If you have ideas for future focused workshops, please let us know.

Additional resources

NERSC summer school:
Emily Denton (Google Brain) [2019],
Aditya Grover (Stanford) [2020]

Unsupervised learning course at UC Berkeley:
https://sites.google.com/view/berkeley-cs294-158-sp20/home

Living review for HEP:
https://iml-wg.github.io/HEPML-LivingReview/
(see specialized reviews section
for generative models)



Fin.