Using GAN for fast event generation

A.Kryukov*
SINP MSU

The 3-d Int. workshop
"Data Life Cycle-2019"
Irkutsk, 03-04.04.2019

Supported by RSF
grants No.18-41-06003

**E-mail:*
kryukov@theory.sinp.msu.ru

The problem

- Develop fast event generator for astroparticle physics application aria, for example IACT.

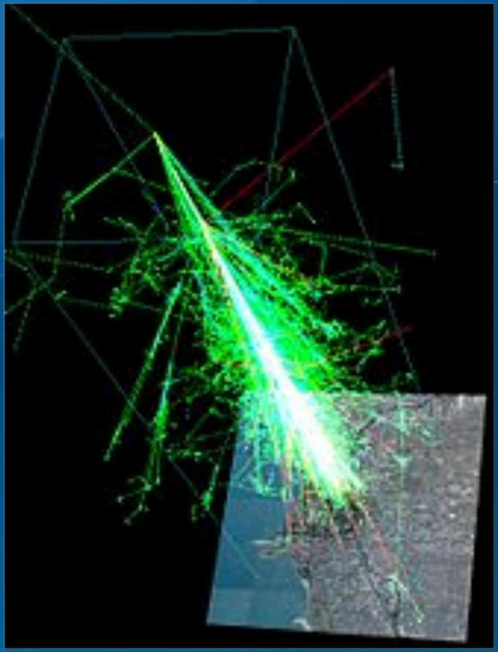
Mathematically:

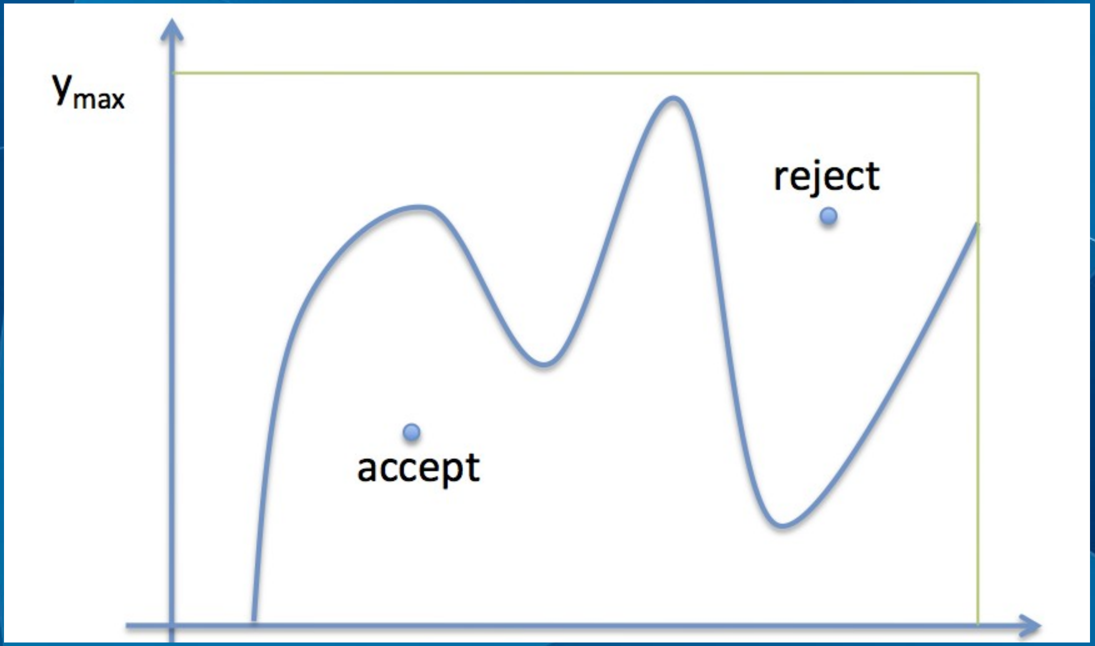
- Let us x is a random variable with probability density P(x)
- How to generate sample $\{x_1,x_2,\ldots\}$ that has the same probability density?

MC generators

- Algorithm von Neumann

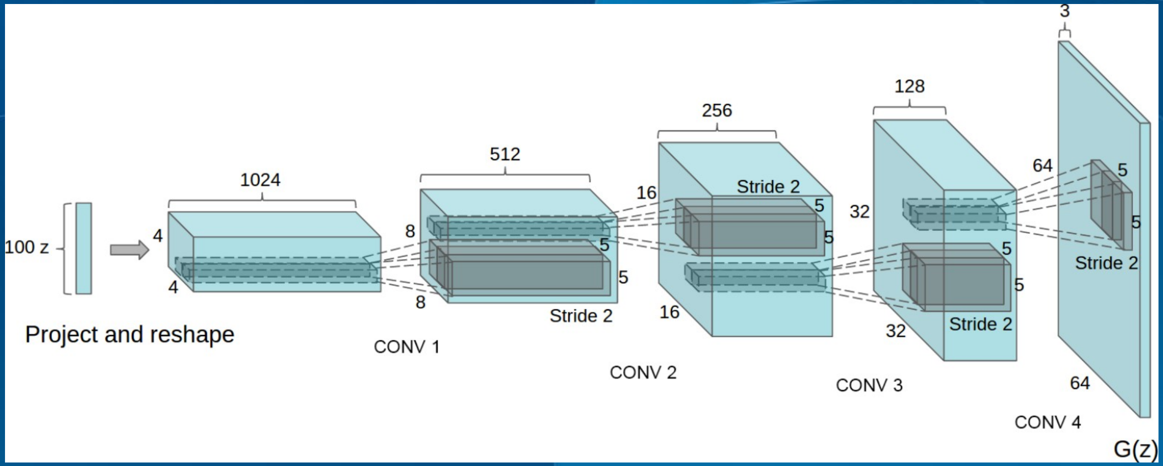
A simple method for generating random points with distribution P(x) was deduced by von Neumann. The idea is extremely simple. In one dimension, if you have a function with known everywhere on a specific domain (i.e. [x_{min}, x_{max}]) and with a known supremum M over that domain, you can sample from it as follows:





Sample Training

- Sampling procedure
  - Traditionally this is a neural network

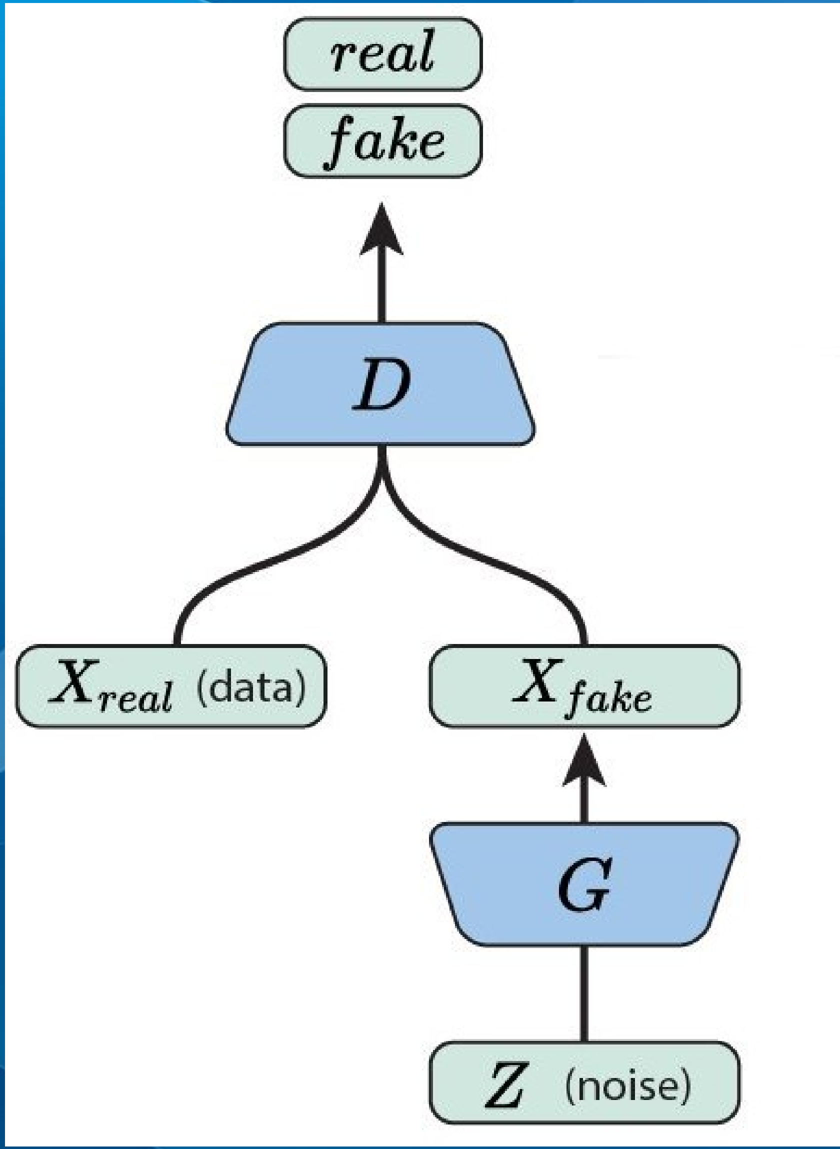


Generator vs probability function

- A probability density function P(x) is hard:
  - normalization is the main issue;
  - sampling might be computationally costly (usually, long MC);
    - CORSIKA: hours and days of works per shower.
- Learning a generator is easier:
  - x = G(z) where:
    G - a parameterized deterministic function;
    z - predetermined and easy to sample.

Generative adversarial networks

Generative adversarial networks



- The discriminator tried to distinguish between fake (generated) and real data
- Input data either generated or from the real dataset
- The generator turns the input noise into fake data to try and fool discriminator
- Input noise

Adversarial training

- Generator is trained to maximize goodness of produced samples.
- GAN defines goodness of a generator via a classifier D :
  - learns to discriminate X against X ' ;
  - if quality is close to a random guess:
    X ' is similar to X ;
  - if quality is high: G should be improved.

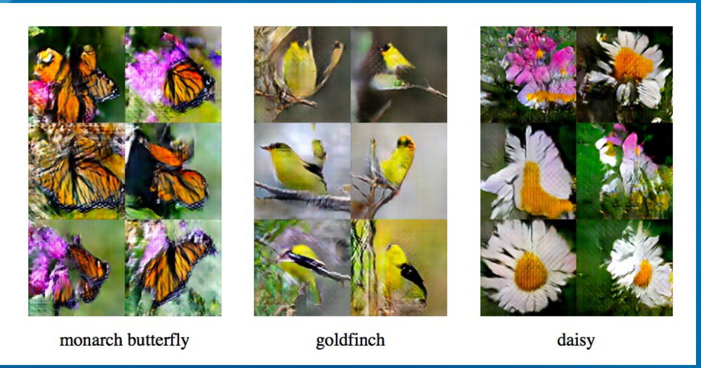
Discriminator

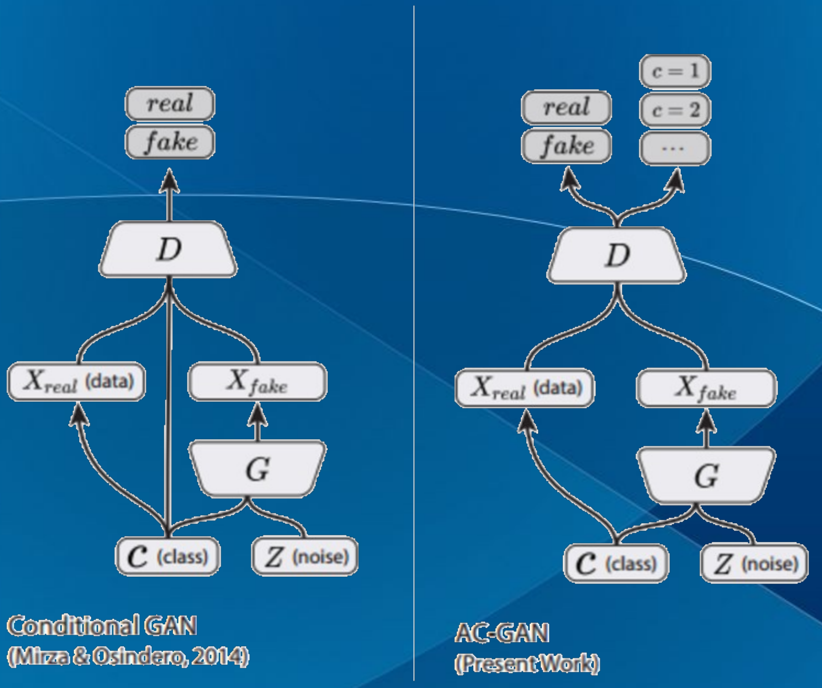
- Usually called adversary or critic
- Traditionally, also a neural network
- Discriminator defines goodness of generated samples:
  - rich set of methods for classification;
  - easy to identify important properties of good generator and use inside discriminator;
  - produces interpretable quality metric.

Many GAN flavors

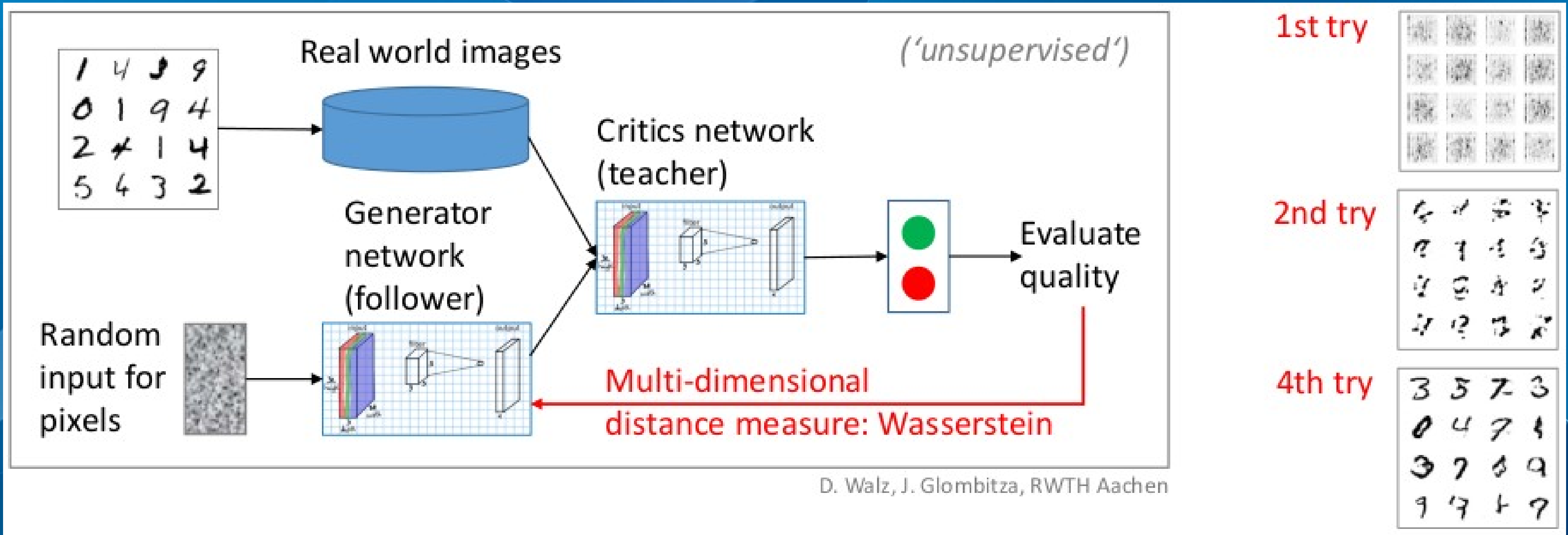
astroparticle.online

- Original GAN was based on MLP in 2014
- Deep Convolutional GAN in 2015
- Conditional GAN
  - Extended to learn a parameterized generator p model (x|θ);
  - Useful to obtain a single generator object for all θ configurations
  - Interpolate between distribution
- Auxiliary Classifer GAN
  - D can assign a class to the image



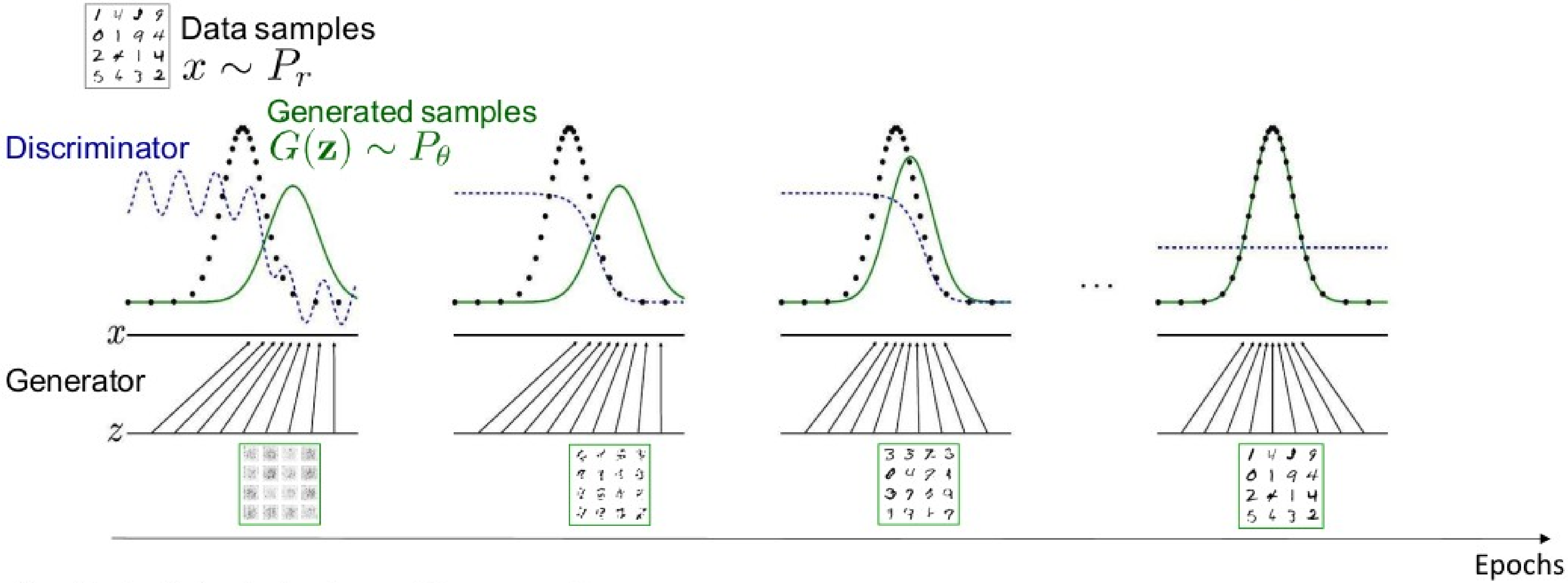


astroparticle.online



I.J. Goodfellow et al, arXiv:1406.2661

Optimal Evolution of GAN Training



Gradient of discriminator guides generator

→ G generates samples which are more likely identified as data

Wasserstein distance

Also known as Earth Mover's distance (EMD)

Ensure smallest cost | Expectation value | Travel distance

$$\mathcal{D}_W(P_r||P_\theta) = \inf_{\gamma \in \mathbf{\Pi}(P_r, P_\theta)} \mathbb{E}_{(x,y)\sim\gamma}[||x-y||]$$

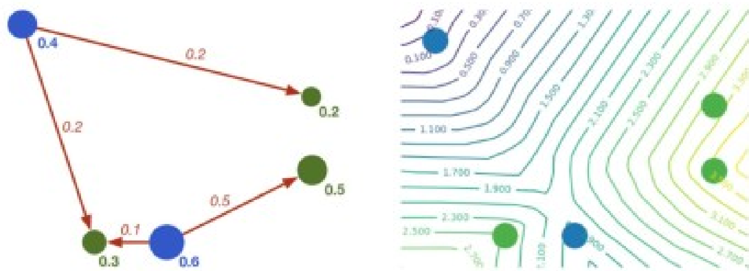
Transportation plans

Describes **minimal cost** to move distribution P_θ on P_r and vice versa (Cost: mass * distance)

Trick to calculate: Kantorovich-Rubinstein duality

$$D_W \rightarrow \min_{C \in \text{Lip1}} \mathbb{E}_{r\sim P_r} C(r) - \mathbb{E}_{q\sim P_q} C(q)$$

<u>Optimal transport plan:</u>
blue dots=earth heaps
green dots=target distribution
red arrows=optimal transport plan
numbers=amount of mass moved
Wasserstein distance=sum over all arrow weights multiplied by path length



Critics: Wasserstein distance =C(green) - C(blue)
Gradients of C parallel to optimal transport paths (red arrows), perpendicular to contour lines.

Conclusion

- It is very important to implement a fast generator for shower simulation
  - Corsika base solution require from hours to few days per one event.
- GAN nets are natural candidates to speedup simulation
  - Rely on the possibility to interpret “events” as “images”
  - First GANs applications to cosmic ray case looks very promising
- 3d GAN is the initial step of a wider plan to do DL based fast simulation within the GeantV project