Deep Learning for Observational Cosmology

What are you saying R2? We can learn cosmology?

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SDSC projects information day, Bern 20 April 2018
Cosmology in 1 minute

- Afterglow Light Pattern 380,000 yrs.
- Dark Ages
- Development of Galaxies, Planets, etc.
- Dark Energy Accelerated Expansion
- Inflation
- Quantum Fluctuations
- 1st Stars about 400 million yrs.
- Big Bang Expansion
  13.7 billion years
Evolution of cosmic structures

credit: Ralf Kaehler
Using mass maps of the Universe to learn physics and cosmology

$\kappa_F; \ 0.2 < z < 1.3$
Cosmological parameters

amplitude of matter fluctuations

matter density (vs dark energy)

DES Collaboration (+TK) 2017 (astroph: 1708.01530)
Traditional inference

Observations → Statistics: power spectrum → Theory prediction: analytical → Cosmology measurement

\[ C_l = \frac{9}{16} \left( \frac{H_0}{c} \right)^4 \Omega_m^{2} \int_0^{\chi_h} d\chi \left[ \frac{g(\chi)}{a r(\chi)} \right]^2 \mathcal{P} \left( \frac{l}{r}, \chi \right) \]
Cosmological measurements with Deep Learning

low $\sigma_8$ low $\Omega_m$

high $\sigma_8$ high $\Omega_m$
Cosmological measurements with Deep Learning

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Inference with Deep Learning

observations → statistics: deep convolutional network → theory prediction: simulations → cosmology measurement
Deep learning captures more information

30% increase in constraining power!

to achieve this increase with power spectrum, one would need **2x more observed area**

Fluri, TK, AL, NP et al, in prep
Inference with Deep Learning

- Observations
- Cosmology measurement
- Statistics: deep convolutional network
- Theory prediction: simulations

...
Theory prediction using simulations

N-body technique is very expensive computationally order of days for one Universe realisation
Fast simulations using Generative Adversarial Networks

Train on existing simulations
Generate new Universe in a fraction of a second on a laptop

image by AL and Andres Rodrigues
Fast simulations using Generative Adversarial Networks

problem: 3D data

by Ankit Srivastava, NP
Creating Artificial Universes using Generative Adversarial Networks

3D cubes

by Ankit Srivastava, NP
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3D cubes

REAL N-body

GAN generated

by Ankit Srivastava, NP
Problem: high resolution
Idea: multiscale approach
Extensions

Conditional GANs dependent on time
(Jonathan Rosenthal MSc)

Convolutions on the sphere
(np, tk, al et al, in prep)
Thank you
Problem: scaling-up GANs

Idea: multiscale approach
Deep learning captures more information

Fluri, TK, AL, NP et al, in prep
GANs: comparison of statistics

**Power of Fluctuations**

- Power spectrum
- Spatial separation (l)

**Density Histograms**

- Number of pixels
- Pixel value