UNIVERSITY
OF OSLO

Master's thesis

-sometitle-

Classifying N-body simulations with and without relativistic corrections
using machine learning techniques

Johan Mylius Kroken

Computational Science: Astrophysics
60 ECTS study points

Institute of Theoretical Astrophysics
Faculty of Mathematics and Natural Sciences

Autumn 2023

Johan Mylius Kroken

-sometitle-

Classifying N-body simulations with and without relativistic corrections using machine learning techniques

Supervisors:
A David Fonseca Mota
B Julian Adamek
C Francisco Antonio Villaescusa Navarro

Abstract

Here come 3–6 sentences describing your thesis.

Sammendrag

Here comes the abstract in a different language.

Contents

List of Figures

List of Tables

Preface

Here comes your preface, including acknowledgments and thanks.

Chapter 1

Introduction

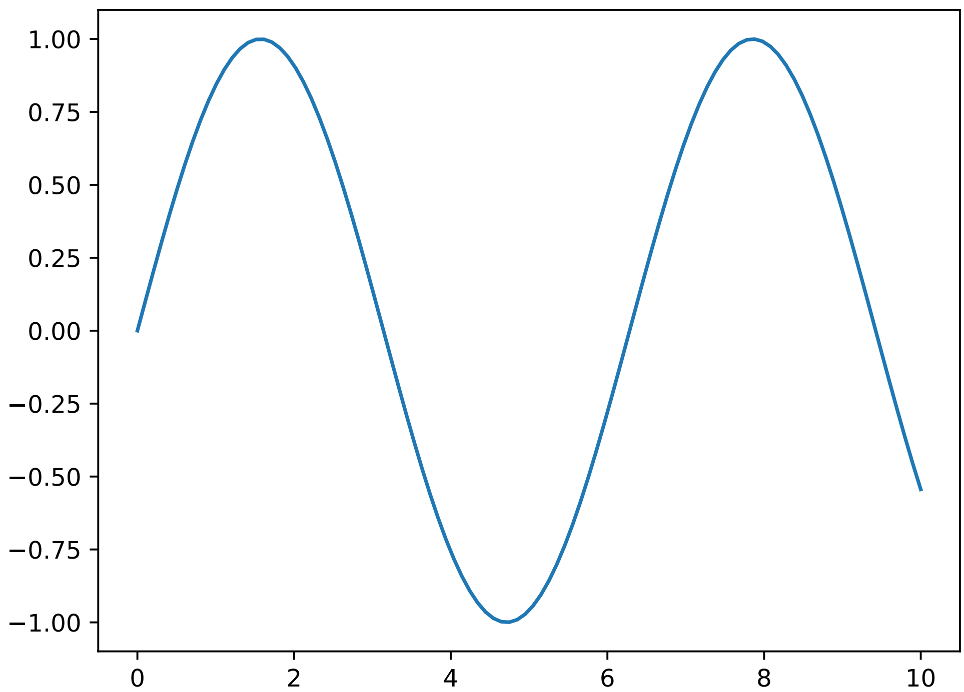
This is the introduction that will shortly be written. How fast does things change.

1.1 Motivation

1.2 Outline

1.3 Aim

1.4 Nomenclature


1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
0
2
4
6
8
10

Part I

Cosmological Structure Formation

Chapter 2

Preliminaries

2.1 General Relativity

2.1.1 Einstein's Field Equations

$$G_{\mu\nu} = 8\pi G T_{\mu\nu} \tag{2.1}$$

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R \tag{2.2}$$

$$R = g^{\mu\nu} R_{\mu\nu} \tag{2.3}$$

$$R_{\mu\nu} = \partial_\rho \Gamma^\rho_{\mu\nu} - \partial_\nu \Gamma^\rho_{\mu\rho} + \Gamma^\rho_{\mu\nu} \Gamma^\sigma_{\rho\sigma} - \Gamma^\rho_{\mu\sigma} \Gamma^\sigma_{\nu\rho} \tag{2.4}$$

2.1.2 Riemann Connection and Covariant Derivatives

$$\Gamma^\rho_{\mu\nu} = \frac{1}{2} g^{\rho\sigma} \left(\partial_\mu g_{\nu\sigma} + \partial_\nu g_{\mu\sigma} - \partial_\sigma g_{\mu\nu} \right) \tag{2.5}$$

$$\nabla_\mu T^\mu_\nu = \partial_\mu T^\mu_\nu + \Gamma^\mu_{\mu\alpha} T^\alpha_\nu - \Gamma^\alpha_{\mu\nu} T^\mu_\alpha \tag{2.6}$$

2.1.3 Geodesic Equation

$$\frac{d^2 x^\mu}{d\tau^2} + \Gamma^\mu_{\alpha\beta} \frac{dx^\alpha}{d\tau} \frac{dx^\beta}{d\tau} = 0 \tag{2.7}$$

2.1.4 The Stress-Energy Tensor

$$T_{\mu\nu} = (\rho + p) u_\mu u_\nu + p g_{\mu\nu} \tag{2.8}$$

2.2 Useful Relations

Chapter 3

Background Cosmology

3.1 The Geometry of Spacetime

3.1.1 The Cosmological Principle

3.1.2 The Robertson-Walker Metric

$$ds^2 = -dt^2 + a^2(t)\left[\frac{dr^2}{1 - kr^2} + r^2 d\Omega^2\right] \tag{3.1}$$

3.1.3 The Friedmann Equations

3.2 My Universe is loaded with...

3.3 Thermal History of the Universe

Chapter 4

Perturbation Theory

4.1 Initial Conditions

4.2 Transfer Functions

4.3 Power Spectra

4.4 Non-linear Evolution

4.5 Bispectra

The bispectra are powerful tools for studying the non-linear evolution of the density field. The bispectrum is defined as the Fourier transform of the three-point correlation function, and is given by:

$$\langle \delta(\mathbf{k}_1)\delta(\mathbf{k}_2)\delta(\mathbf{k}_3)\rangle = (2\pi)^3 \delta_D(\mathbf{k}_1 + \mathbf{k}_2 + \mathbf{k}_3) B(\mathbf{k}_1, \mathbf{k}_2, \mathbf{k}_3) \tag{4.1}$$

Well this is rather awkward. Adamek et al. 2016 or (Falck et al. 2017)

Chapter 5

Simulation theory

Some theory and history as to how to conduct N-body simulations.

5.1 N-body simulations

5.1.1 Describing a box of particles

5.1.2 Forces and Fields

5.1.3 Mass Assignment Schemes

5.1.4 Validity of Box

5.2 Newtonian Approach

5.3 General Relativistic Approach

Part II

Machine Learning

Chapter 6

Neural Networks

6.1 Forward pass - Prediction

6.1.1 Activation functions

6.1.2 Loss functions

6.2 Backpropagation - Training

6.2.1 Gradient descent

6.2.2 Optimizers

6.2.3 Regularization

Chapter 7

Convolutional Neural Networks

7.1 Convolution

7.2 New Layers

7.2.1 Convolutional layers

7.2.2 Pooling layers

7.2.3 Dropout layers

Part III

Acquiring Data

Chapter 8

Simulations

Chapter 9

Data Verification

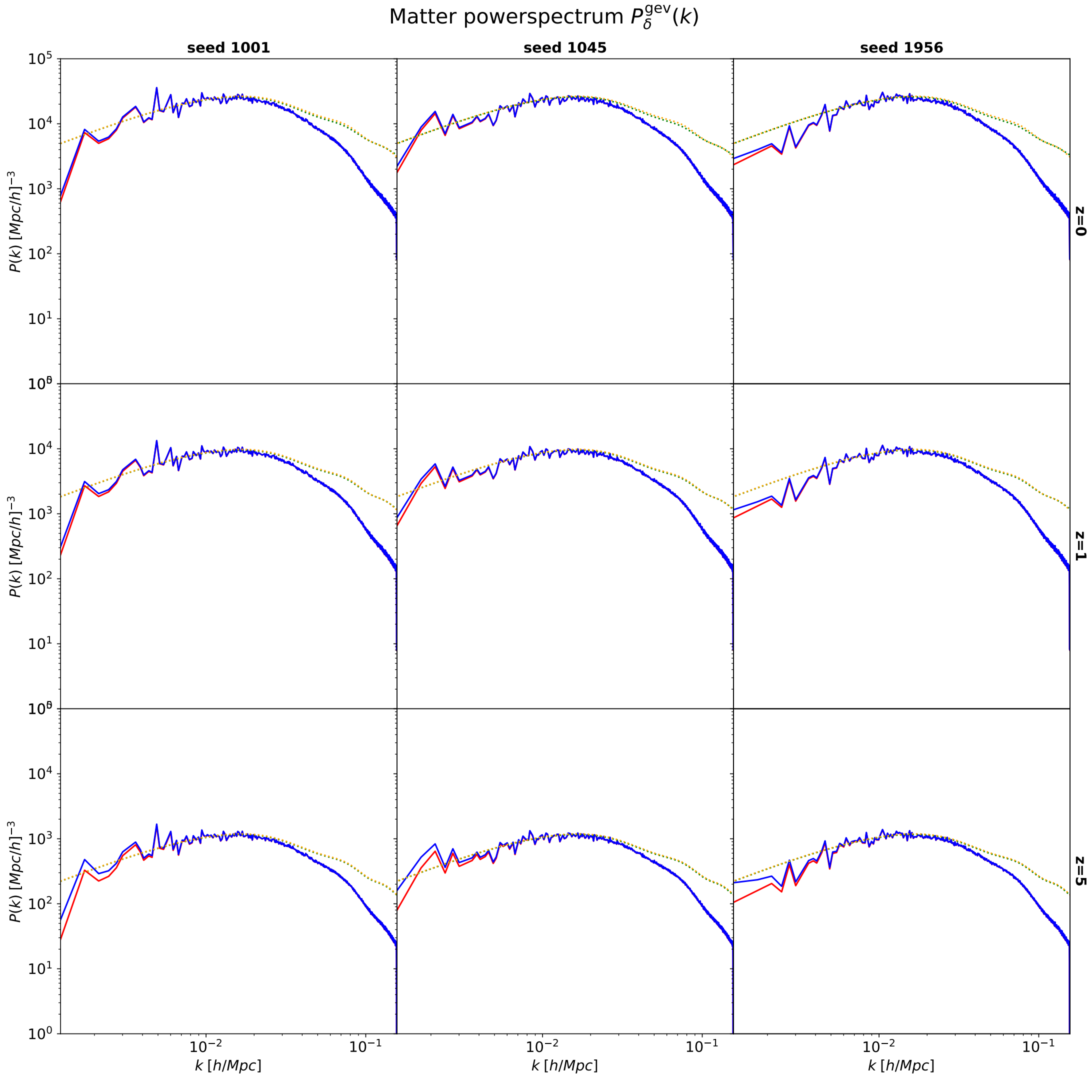
9.1 Slices of Datacubes

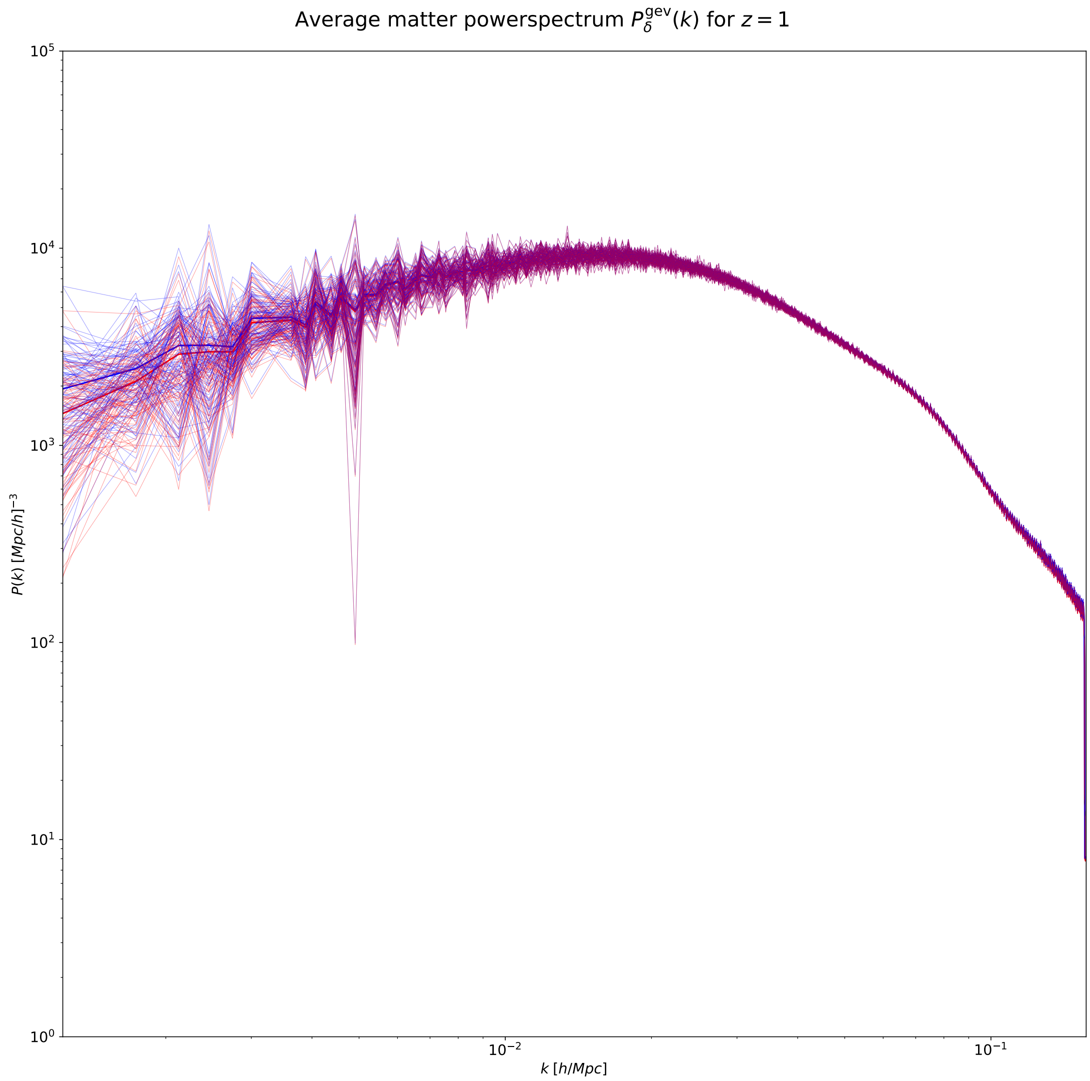
9.2 Power spectra from Theory

TODO: Provide some camb and class power spectra here.

9.3 Powerspectra from Simulations

9.4 Powerspectra from Datacubes


Matter powerspectrum $P_\delta^{gev}(k)$
seed 1001
seed 1045
seed 1956
$P(k)$ $[Mpc/h]^{-3}$
k $[h/Mpc]$
z=0
z=1
z=5



Average matter powerspectrum $P_{\delta}^{\mathrm{gev}}(k)$ for $z = 1$
10^5
10^4
10^3
10^2
10^1
10^0
$P(k)$ $[Mpc/h]^{-3}$
10^{-2}
10^{-1}
k $[h/Mpc]$

Chapter 10

Trainable Dataset

Bibliography

Adamek, Julian et al. (29th July 2016). 'gevolution: a cosmological N-body code based on General Relativity'. In: *Journal of Cosmology and Astroparticle Physics* 2016.7, pp. 053–053. ISSN: 1475-7516. DOI: 10.1088/1475-7516/2016/07/053. arXiv: 1604.06065[astro-ph,physics:gr-qc,physics:physics]. URL: http://arxiv.org/abs/1604.06065 (visited on 23/08/2023).

Falck, B. et al. (16th Mar. 2017). 'The Effect of Corner Modes in the Initial Conditions of Cosmological Simulations'. In: *The Astrophysical Journal* 837.2, p. 181. ISSN: 1538-4357. DOI: 10.3847/1538-4357/aa60c7. arXiv: 1610.04862[astro-ph]. URL: http://arxiv.org/abs/1610.04862 (visited on 20/09/2023).