1 Introduction

Recently, the necessity and the demand for the large number of large N-body simulations have been increased in astronomy due to the precision required for measurements to understand cosmic acceleration, like the Baryon Oscillation Spectroscopic Survey (BOSS) and the proposed Mid Scale-Dark Energy Spectroscopic Instrument (MS-DESI). As the area covered by those current and future spectroscopic galaxy surveys get larger, galaxy mocks necessary to the cosmological analysis also have to be generated from N-body simulations with the corresponding large volume, which is computationally expensive. Besides the large volume required for the N-body simulations, we need many realizations to achieve the precision required for those measurements.

There are several reasons for why we need large number of N-body simulations. One is to understand and to calibrate systematics caused by non-linear gravitational evolution and galaxy formation. Since those systematics are cosmology dependent, ideally we want to generate galaxy mocks from N-body simulations with various cosmologies. Another reason is to reduce noise for a covariance matrix estimation. Even when 50 realizations are used, the directly estimated covariance matrix is still noisy. Since it is unrealistic to run N-body simulations enough number of times to obtain a smooth directly estimated covariance matrix, there have been several efforts to obtain a smooth covariance matrix mainly in two directions. One approach is to estimate a covariance matrix from theory or by fitting to a modified form of the Gaussian covariance matrix (citations...). There are many different methods to estimate, but a peculiarity common to all the methods included in this approach requires some assumptions to compute the covariance matrix. Those assumptions often prevent those covariance matrices from properly accounting the effects due to non-linear gravitational evolution such as non-gaussianities and non-localities.

Other approach is generating enough number of galaxy mocks by using 2nd Order Perturbation Theory (2LPT) and computing a covariance matrix estimation directly (Scoccimarro and Sheth 2002, Manera et al. 2012, Pinocchio?). Using 2LPT makes generation of galaxy mocks significantly faster than the full N-body simulations, because 2LPT allows us to compute final positions of particles only with their initial positions without any steps in-between. The aim of our method is the same as this approach in the sense that we want to shorten computational time to generate those mocks. The problem of using 2LPT is that those simulations cannot capture non-linear gravitational evolution and therefore this approach requires to tune halo definitions (i.e., the linking length for the Friends-of-Friends (FOF) algorithm) and halo masses. Also, it is hard to resolve small halos in this approach, and therefore galaxies which reside in those small halos are placed on randomly selected dark matter particles in the mocks. It is, however, important to keep relatively high mass resolution to understand the systematics caused by non-linear gravitational evolution.

Our N-body simulations are consist of two components: a long time step for solving the PM force and a set of short range sub-cycle steps for a direct particle-particle interaction. The idea behind is reducing the number of both time steps as much as we can preserve enough mass resolution to correctly describe the large scale distribution of galaxies.

In the following, we first briefly describe the mechanism of our approximated N-body simulations. In Section 3, we test and compare our method to the full N-body simulation and explain how we calibrate our samples. In Section 4, we populate halos in our samples with galaxies and compute correlation functions based on BOSS Data Release 9/11(?) geometry, and compare it with the observed correlation function.