Deep Neural Networks for Identification and Characterization of Black Hole Images

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Abstract

The Event Horizon Telescope (EHT) Collaboration were the first to release the first image of a black hole at the center of M87 Galaxy using Computer vision and Machine learning techniques. With the Very Long Baseline Inteferometry (VLBI) technique, the EHT group leveraged the highest possible resolution on the surface of the Earth. Based on this, further simulations were performed to get more black hole images. Using this simulated data, previous work proposes a new AI-assisted parameterization method that extracts important physical parameters from the high resolution images of M87 black hole. However, each of this simulation is computationally expensive and is time consuming. Hence, in this work we propose predicting the observing conditions choices to get particular spin and magnetization values for image simulation or observation.

Contents

1 Introduction and Background **v**

2 Goals and Methodology **vii**

1

Introduction and Background

Supermassive black holes that typically reside at the nucleus of the galaxy have always been the most mysterious due to their extraordinarily far distance and exceptional energy emission that can be comparable to the luminosity of hundreds of billions of stars combined in a galaxy. Due to the enormous distance capturing an high resolution image directly has been a problem for astrophysicists.

To resolve this issue, EHT collects light from the black hole using multiple telescopes distributed around the Earth by focused observation. This measured data gives information about the structure of the black hole. However, this information is not complete and hence they use imaging algorithms to fill in the gaps of data in order to reconstruct a picture of the black hole.

This imaging algorithm uses the sparse data collected from the telescopes, to fill in the missing gaps with the most natural looking image. However, there are an infinite number of number of possible images that are perfectly consistent with the data we measure. But not all images are created equal— some look more like what we think of as images than others. To chose the best image, we essentially take all of the infinite images that explain our telescope measurements, and rank them by how reasonable they look.

This imaging process is computationally heavy and consumes plenty of time since each of the large number of images and choosing usable ones. Previous work use these simulated images for parameterization of super-massive black holes i.e. leverage a set of machine learning techniques to estimate the spin and mass. This work is considered as a primary reference for our thesis work.

2

Goals and Methodology

Black holes have very simple mathematical structure, as they are completely characterized by three physical parameters: mass, angular momentum, and electric charge. Electric charge can be ignored in the case of astrophysical macroscopic objects. In this work we aim to estimate the observing conditions to obtain a black hole image with specific parameters i.e the spin and magnetization. The observing conditions include (and are not limited to) the frequency, telescope to query and the size of the lens.

DATA AUGMENTATION

In this project, the primary source of data is the General Relativistic Magnetohydrodynamics

(GRMHD) simulations that have been proven to resemble the actual image of the M87 black hole. Even the GRMHD simulations are extremely computationally expensive, as they have to be run for weeks on dedicated HPC clusters. Therefore, we generate additional data by valid transformations such as rotating the existing images by 90, 180, and 270 degrees, thus quadrupling the amount of data we have to train the model.

CONVOLUTIONAL NEURAL NETWORK (CNN)

The Convolutional Neural Network (CNN) is a variation of deep neural networks com- monly used in the analyzing imaging data. Essentially, the CNN will apply different filters to automatically capture the features on the image and use these information in making predictions based on a given image and the required physical parameters.

RECURRENT NEURAL NETWORK (RNN)

The Recurrent Neural Network (RNN) is a variation of deep neural networks commonly used in processing time series data. Compared with a vanilla feed-forward neural network, RNNs can store past information in the memory and effectively processing sequences of data as related quantities other than discrete data points.