The Rendition of Black Hole using Pattern Matching

Makalah IF2211 Strategi Algoritma

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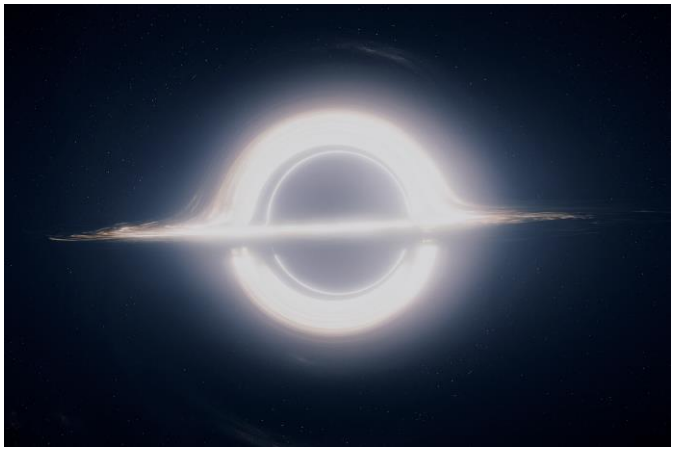
***Abstract*—A black hole is a region of spacetime with gravitational pull so strong, that nothing—not even light and particles could escape from the pull. Since its discovery in the 18th century, scientists have tried to imagine what a black hole would look like. Many attempts failed, because to create a photograph out of something, photons from light particles are required, and a black hole absorbs the entirety of it. In 2019, computer scientist Dr. Katie Bouman and her team successfully rendered the first photograph of a black hole.**

Keywords—black hole, event horizon, EHT, pattern matching, best-fit, outer space, imaging

I. INTRODUCTION

Due to its properties, capturing the image of a black hole was deemed an impossible feat for scientists. One might ask how do we capture an image something that absorbs light, while taking a picture of something needs light particles. The powerful gravitational pull of a black hole might have something to do with its size. A black hole might be tiny and small comparable to other objects that orbit around it, but they wouldn't be orbiting around a black hole if its pull isn't strong.



Picture 1.1 Illustration of a black hole
(Source: Interstellar, 2014)

Black holes have a certain region where nothing could escape from its "grasp", once they have entered the area. This region is called the event horizon. Although the event horizon has an enormous effect on the fate and circumstances of an object crossing it, no locally detectable features appear to be observed. Light emitted from inside the event horizon can never reach the outside observer, and the outside observer cannot see beyond the event horizon. Moreover, any object approaching the horizon from the observer's side appears to slow down and never quite pass through the horizon, with its image becoming more and more redshifted as time elapses.

A real photograph of a black hole will contribute so much to the science society, and to prove if Einstein's equation and theory of general relativity still hold until today.
In 2019, Dr. Katie Bouman of MIT and an international team consisted of 200 scientists managed to render an image of a black hole captured using Event Horizon Telescope (EHT). Three years ago, Bouman led the creation of an algorithm that eventually helped capture this first-of-its-kind image: a supermassive black hole and its shadow at the center of a galaxy known as M87. They took the "sparse and noisy data" that the telescopes spit out and tried to make an image. For the past few years, Bouman directed the verification of images and selection of imaging parameters. The algorithm used in the program generated not one, but many possible renders of a real black hole. Capturing an image of M87 requires a telescope dish with size almost as big as the Earth. Such thing isn't possible, but they managed to do that in another way: to use the Earth as its dish. EHT essentially connects telescopes around the world, so it would collect data simultaneously from different location as the Earth rotates.

Bouman developed an algorithm called CHIRP, Continuous High-resolution Image Reconstruction using Patch priors, and used another algorithm called EHT Imaging or ehtim. Images must be reconstructed using algorithms that find the best-fit images to data under a (hopefully minimal) set of additional assumptions about the source structure.

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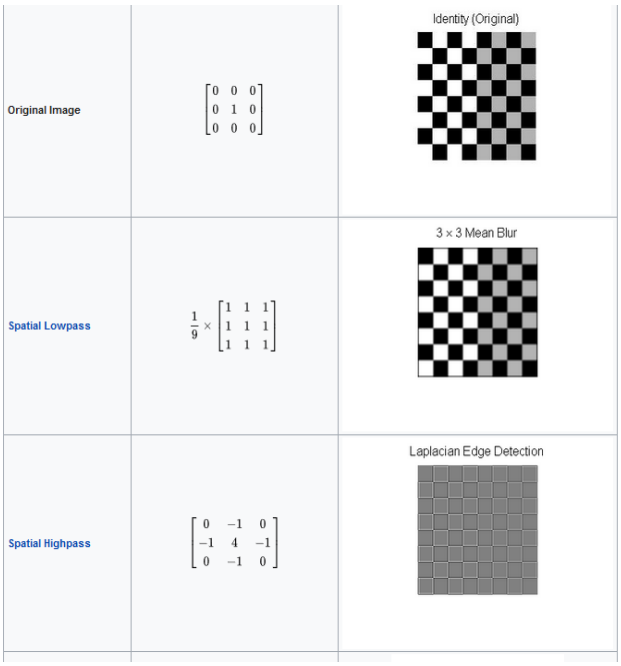
II. Theoretical Basis

To process an image using the EHT Imaging, some concepts are required to understand how the algorithm works. This part will explain concepts needed and necessary to explain how the algorithm could produce the image of the black hole.

A. Digital Image Processing

In the field of computer science, digital image processing is one of the use of computer algorithms to process digital images. Digital image processing has a lot of advantages over analog image processing. Digital image processing makes it possible for a wide range of algorithms to be applied to the data. It also helps to avoid problems that often arrived in latter part of processing. An image being processed uses a matrix contains value that later determines what the program should do.



Picture 2.1 Examples of digital image processing (Source: https://en.wikipedia.org/wiki/Digital_image_processing)

Digital image processing is heavily used in industrial machine vision systems and the creation of visual effects for ciinema and broadcast.

B. Fast Fourier Transform (FFT)

In digital image processing, is an algorithm that computes the discrete Fourier transform (DFT) of a sequence, or its inverse (IDFT). Fourier analysis converts a signal from its original domain (often time or space) to a representation in the frequency domain and vice versa.

$$F(x) = \sum_{n=0}^{N-1} f(n) e^{-j2\pi(x\frac{n}{N})}$$

$$f(n) = \frac{1}{N} \sum_{n=0}^{N-1} F(x) e^{j2\pi(x\frac{n}{N})}$$

Picture 2.2 Fast Fourier Transform and its inverse (Source: https://en.wikipedia.org/wiki/Fast_Fourier_transform)

Fourier Transform breaks down an image into its real and imaginary components. If the input is an image, then the number of frequencies in the frequency domain is equal to the number of pixels in the image. Image smoothing and compression is some of FFT's biggest application. The FFT is very useful in many fields but computing it directly from the definition can hurts the system, as it is too slow to be practical. An FFT rapidly computes such transformations by factorizing the DFT matrix into a product of sparse (mostly zero) factors. As a result, it manages to reduce the complexity of computing the DFT from:

$$O(n^2)$$

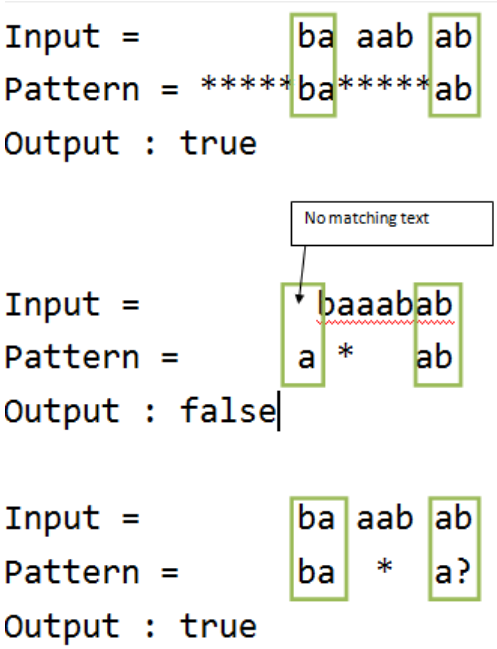
which arises if one simply applies the definition of DFT, to:

$$O(n \log n)$$

where n is the data size.

C. Pattern Matching

Pattern matching is one of the heavily used kind of algorithm in computer science. It basically searches for an exact match in a sequence, different from pattern recognition where in pattern recognition it doesn't have to be the exact same match in every case. Pattern matching also applies in images as data, where it searches for images with same characteristics and patterns.



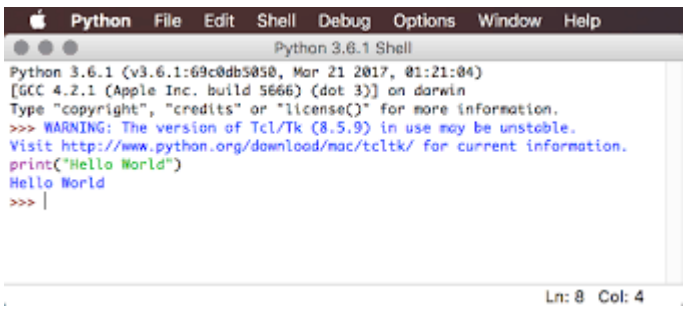
Picture 2.3 An example of pattern matching in string (Source: https://www.geeksforgeeks.org/wildcard-pattern-matching/)

A tree pattern is usually created to help programmer with pattern matching algorithms. For simplicity and efficiency reasons, these tree patterns lack some features that are available in regular expressions.

D. Python Programming Language

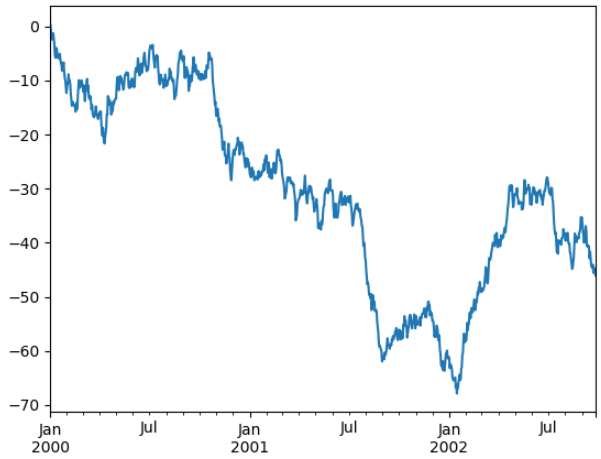
The EHT Imaging algorithm is based in Python, an interpreted, high-level, general-purpose programming language. Python was created by Guido van Rossum and first released in 1991. Python supports multiple programming paradigms, such as procedural, object-oriented, and functional programming. Inside the EHT Imaging algorithm, it is fully based on Python with multiple libraries added, such as astropy, pandas, matplotlib, and scipy.

Python has been quite popular in the recent decade, because of its simplicity and is meant to be an easily readable language. Python has a design philosophy that emphasizes code readability, notably using significant whitespace. This philosophy creates a programming language that has no use of curly brackets or semicolon, and raising the importance of using a whitespace indentation.



Picture 2.3 An example of program in Python (Source: https://www.quackit.com/python/tutorial/python_hello_world.cfm)

Python also supports the use of multiple libraries that can extend the power of the programming language beyond what is imagined. Some libraries used in this algorithm, such as pandas and matplotlib, helps programmers do statistics around the data they have and visualize it using graphs and histograms. Libraries like scipy shorten the use of scientific formulas, making the programmers only have to call the function built inside the libraries.



Picture 2.4 Basic data plotting with pandas (Source: https://pandas.pydata.org/pandas-docs/stable/user_guide/visualization.html)

Python also a language that is mainly used in machine learning (ML), as it is a good language to create automation from, also called as a scripting language. Python is also commonly used in artificial intelligence, with the help of external libraries such as TensorFlow and Scikit-learn. As a scripting language with modular architecture, simple syntax and rich text processing tools, Python is often used for natural language processing.

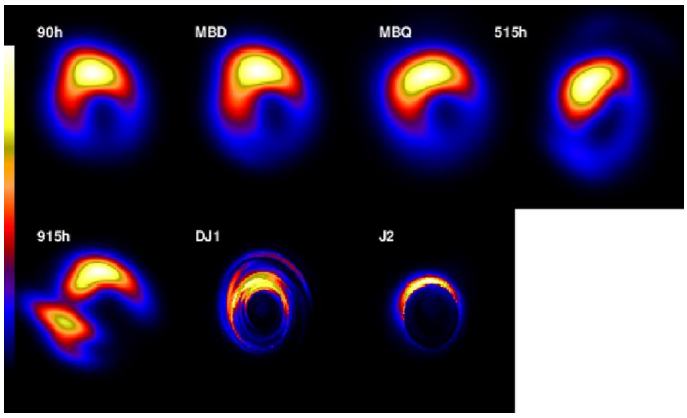
III. Analysis

The implementation of FFT and digital image processing is heavily used in the EHT Imaging algorithm. It relies on multiple libraries to sustain the result of the algorithm to be better than ever.

A. EHT Imaging

To create a rendition of the object with crisp quality and as close as possible to the original object's shape, the scientists working around the project uses an algorithm called EHT Imaging. EHT Imaging is a Python module for simulating and manipulating VLBI data and producing images with regularized maximum likelihood methods.

Andrew Chael, the creator of EHT Imaging, developed a new Bayesian imaging methods that push the EHT's imaging capabilities to higher fidelity and resolution.

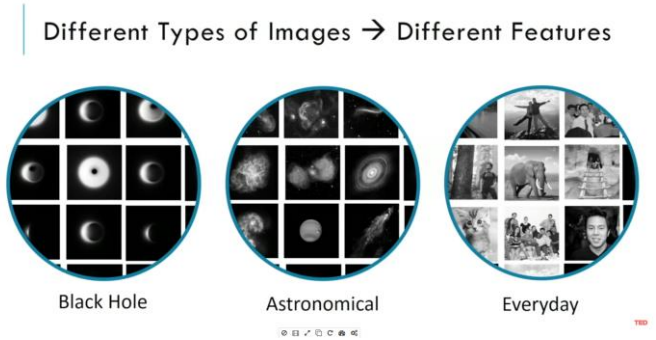


Picture 3.1 False color black hole used in EHT simulation (Source: https://www.researchgate.net/figure/False-color-black-hole-images-from-numerical-models-of-Sgr-A-top-and-915h-and-M87-DJ1_fig1_266856659)

EHT Imaging basically processes a whole lot of data collected from different telescopes connected around the world, and then the simulation projected images that deemed as the best-fit image that represents the object as close as possible. That's why results of the simulation might not be as sharp as the others, but to require that kind of sharpness, the algorithm requires information that they cannot yet acquire from a black hole.

B. Pattern Matching

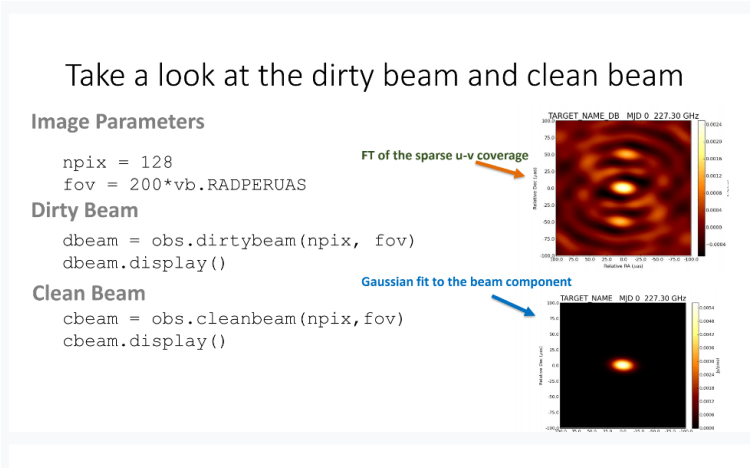
As the EHT Imaging processes collected data, it also distinguishes between everyday-objects, astronomical-objects, and the black hole itself. To distinguish it properly, it uses algorithms that implements best-fit properties. One of the algorithms is pattern matching. The pattern matching algorithm compares the pattern of the object and compares it to the rest of the data. The algorithm is helped with machine learning system, so it could create heuristic to tell the algorithm that certain images lean towards certain types.



Picture 3.2 Different picture composition and pattern (Source: https://www.youtube.com/watch?v=BIvezCVcsYs)

In Picture 3.2, certain astronomical objects might have the same pattern and characteristics as a black hole. In this part the algorithm plays a big part whether to determine the object as a black hole or a non-black hole.

The problem that arise from this algorithm is that to process such a far and gigantic object, scientists need to collect data for years. Moreover, the use of an Earth-sized telescope dish requires great coordination between each station where the satellite is.

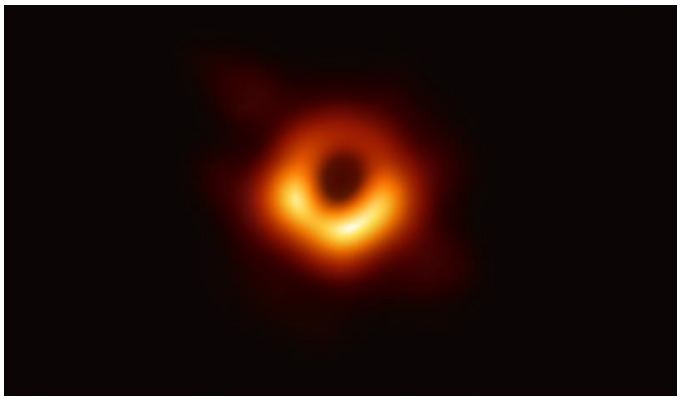


Picture 3.3 Example of EHT Imaging processing

(Source: EHT Imaging Tutorial, https://www.dropbox.com/s/7533ucj8bt54yh7/Bouman_Chael.pdf?dl=0)

C. CHIRP Algorithm

After the image is processed into the EHT algorithm, the scientists in the station collects the data using an algorithm previously mentioned before, the CHIRP algorithm. CHIRP, stands for Continuous High-resolution Image Reconstruction using Patch priors. Bouman had theorized that black holes leave a background shadow of hot gas; the machine learning algorithm fills in gaps in data produced by telescopes from around the world. The algorithm fills the stitch together data collected across the EHT network. CHIRP acts like some kind of validation program that ensures that the result from EHT is not the result of technical glitch or an error.



Picture 3.4 A black hole image processed from CHIRP

(Source: https://girlgeek.io/katherine-l-katie-bouman-supermassive-black-hole-algorithm-event-horizon-telescope-eht/)

IV. Conclusion

Dr. Katie Bouman has created something that a lot of scientists has dreamt to do. In 2019, she and an international team successfully created the real photograph of a black hole. This proves that Einstein's theory of general relativity still holds, a theory proposed a century ago. The usage of pattern matching algorithm in image recognition also plays a vital role in this project. Without the use of pattern matching, it would take longer for them to recreate the image, having to sort each of the result to determine which astronomical objects those are.

Picture 4.1 Margaret Hamilton, computer scientist who developed on-board flight software for Apollo space program (left); Katie Bouman, computer scientist who created the first image of a black hole (right)

(Source: https://girlgeek.io/katherine-l-katie-bouman-supermassive-black-hole-algorithm-event-horizon-telescope-eht/)

This discovery has sparked many minds that we, as human being, can do so much more if we emphasize what it means to be a scientist and never stopped learning to achieve more. Among some other fields of science, space exploration and computer science must coexist to sustain its development, and it could propel each other to achieve their peak.

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PERNYATAAN

Dengan ini saya menyatakan bahwa makalah yang saya tulis ini adalah tulisan saya sendiri, bukan saduran, atau terjemahan dari makalah orang lain, dan bukan plagiasi.

Bandung, 26 April 2019

Nama dan NIM