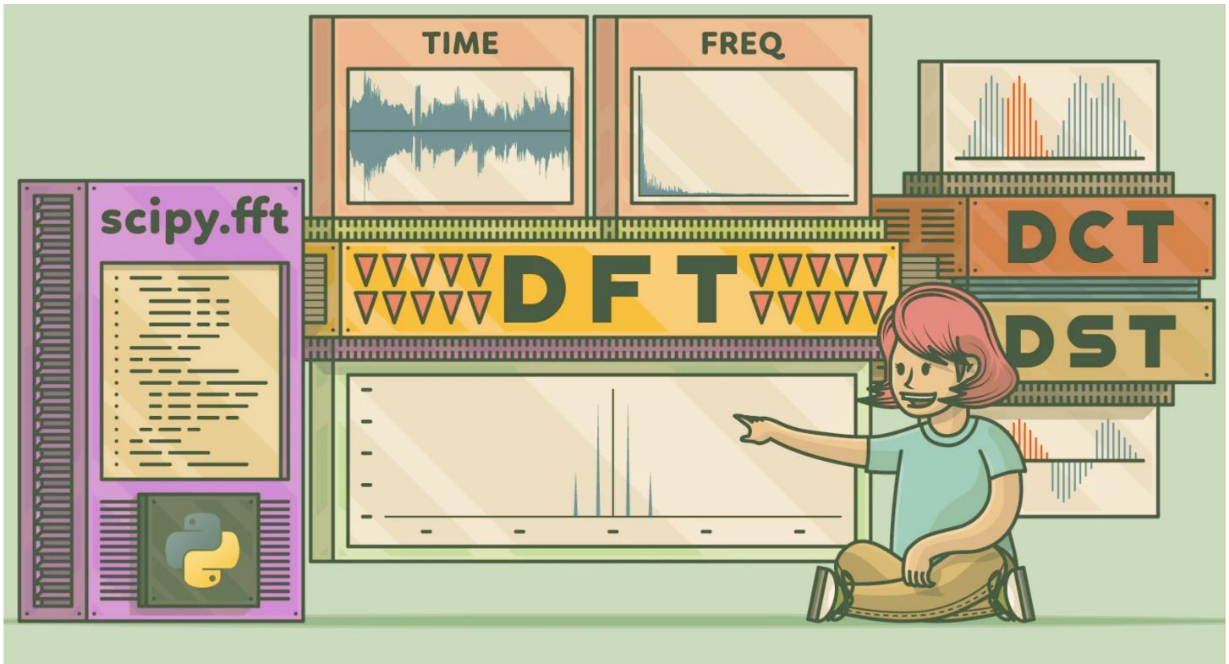

Project Proposal

Detection of Underground Nuclear Explosions

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16 April, 2023

TABLE OF CONTENTS

REAL-WORLD PROBLEM

1.1. Background

Underground nuclear testing refers to the detonation of nuclear devices, such as nuclear bombs or warheads, below the surface of the Earth. This type of nuclear testing was prevalent during the Cold War era (1945-1992) when several countries, including the United States, the Soviet Union, and other nuclear-armed nations, conducted numerous nuclear tests in various geological settings, such as deserts, mountains, and islands, to develop and improve their nuclear weapons capabilities.

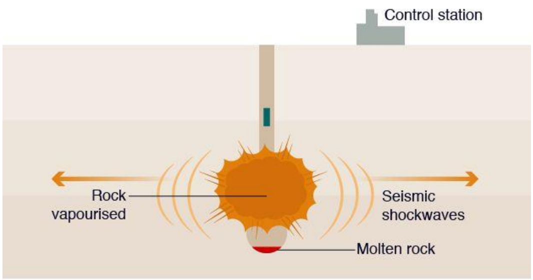

Figure 1: Image of an underground nuclear explosion

Underground nuclear testing involves drilling a borehole into the ground and placing a nuclear device, typically contained in a steel or concrete casing, at the bottom of the hole. The device is then detonated, creating a release of energy in the form of an explosion, which results in the vaporization of surrounding rock and formation of a cavity. The energy released in the explosion can cause seismic waves to propagate through the Earth, which can be detected and measured by seismometers located at various distances from the test site.

1.2. The Problem's Crucial Importance

The detection of underground nuclear explosions is a critical issue due to significant implications:

1. **Global Security:** Underground nuclear explosions may be associated with clandestine nuclear weapons testing by countries that are not compliant with international agreements such as the Comprehensive Nuclear-Test-Ban Treaty (CTBT), which aims to ban all nuclear explosions. Detecting such explosions can provide crucial information about potential violations of nuclear disarmament treaties and help prevent the proliferation of nuclear weapons.

2. **Environmental and Human Health:** Underground nuclear explosions can have significant environmental and human health impacts, including release of radioactive materials into the atmosphere and ground, contamination of soil and water, and potential harm to nearby populations. Detecting and monitoring underground nuclear explosions can provide early warning of such events, enabling timely response and mitigation measures to protect the environment and human health.

3. **Seismic Hazard Assessment**: Seismic signals generated by underground nuclear explosions can provide valuable data for seismic hazard assessment, which is important for understanding earthquake activity and improving earthquake prediction and mitigation strategies. Accurate detection and characterization of underground nuclear explosions can help differentiate them from natural earthquakes, ensuring that seismic hazard assessments are based on reliable data.

1.3. Issues and Challenges:

The detection and identification of underground nuclear explosions rely primarily on seismic signals, which are known to propagate to great distances. While these signals would ideally be sufficient for detection and identification, a challenge, however, arises as seismic signals from underground nuclear explosions often share characteristics with those from natural earthquakes. This makes it difficult to reliably distinguish between the two solely on seismic data.

The problem of detection is further complicated because deliberate modification of the explosion environment can reduce the strength of the seismic signal by a large factor or alter the explosion signal so that it will be misidentified as an earthquake signal.

Other factors that play a role in these challenges include production of weak seismic signals due to a lower yield explosion which can be hard to detect and identify, and varying depths of the explosion which can affect the characteristics of the seismic signals including their amplitude, frequency content, and propagation patterns.

Therefore, it becomes necessary to find a way to differentiate between all these varying factors to identify the occurrence of an underground nuclear explosion.

CHOSEN ALGORITHM

2.1. Brief Literature Review

To address this problem, we propose using the Fast Fourier Transform algorithm. The Fast Fourier Transform algorithm is a powerful signal processing technique that can analyze and identify the different frequency components of a signal. We will use this algorithm to analyze seismic signals generated by underground nuclear explosions and distinguish them from natural seismic activity.

Several studies have used FFT to analyze seismic data for the detection of underground nuclear explosions. One such study by Arora et al. (2017) used FFT to analyze seismic waveforms from various events, including nuclear explosions, earthquakes, and mining explosions. They found that the frequency content of the signal can be used to distinguish between these events. Another study by Kim et al. (2019) used FFT to analyze seismic data from the 2017 North Korean nuclear test and found that the signal had a distinct frequency peak.

2.2. Why the chosen algorithm is more suited for our problem

Criteria	**Fourier Transform (FT)**	**Fast Fourier Transform (FFT)**
Time Complexity	O(N^2)	O(N log N)
Computational Efficiency	Less efficient for large datasets	More efficient for large datasets
Real-time processing	Not suitable for real-time processing	Suitable for real-time processing
Frequency resolution	Less frequency resolution	High frequency resolution
Memory usage	High memory usage	Low memory usage
Implementation complexity	Complex implementation	Simple implementation
Accuracy of results	High accuracy	High accuracy
Ease of implementation	Difficult to implement	Easy to implement

The table above highlights the differences between using the Fourier Transform and Fast Fourier Transform for seismic signal analysis in detecting underground nuclear explosions. Here are some implications of using each approach:

I. **Time Complexity**: The Fourier Transform has a higher time complexity of O(N^2) than the FFT, which has a time complexity of O(N log N). This means that the FFT is more computationally efficient for larger datasets and can process seismic signals in real-time, while the Fourier Transform is not suitable for real-time processing.

II. **Computational Efficiency:** The FFT is more computationally efficient for large datasets, making it more suitable for processing seismic signals in real-time. In contrast, the Fourier Transform may take a longer time to process large datasets.

III. **Frequency Resolution:** The FFT provides high frequency resolution, allowing for more detailed analysis of the frequency components of seismic signals. In contrast, the Fourier Transform may have lower frequency resolution.

IV. **Memory Usage:** The FFT uses less memory compared to the Fourier Transform, which may be beneficial for applications where memory usage is a concern.

V. **Implementation Complexity:** The FFT has a simpler implementation compared to the Fourier Transform, which may make it more accessible to users with less technical expertise.

VI. **Accuracy of Results:** Both the Fourier Transform and the FFT provide accurate results for seismic signal analysis, although the FFT may provide higher accuracy for large datasets.

VII. **Ease of Implementation:** The FFT has a simple implementation that is easier to implement compared to the Fourier Transform, which may make it more accessible to users with less technical expertise.

Overall, both the Fourier Transform and the FFT are effective approaches for seismic signal analysis in detecting underground nuclear explosions. The choice of algorithm depends on the specific requirements of the application, such as the size of the dataset, frequency resolution, and the need for real-time processing. The FFT provides a more efficient and faster solution for larger datasets and real-time processing, while the Fourier Transform may be more suitable for applications where frequency resolution is crucial.

PSEUDOCODE

Rough Pseudo-code:

- Collect seismic data from different sources
- Preprocess data to remove noise and irrelevant signals
- Apply the Fourier Transform algorithm to the seismic signals
- Identify abnormal frequency components
- Classify the signals as either natural or artificial
- If artificial, determine the location and depth of the explosion

```
X_0,...,N-1 ← ditfft2(x, N, s):             DFT of (x_0, x_s, x_2s, ..., x_(N-1)s):
    if N = 1 then
        X_0 ← x_0                                  trivial size-1 DFT base case
    else
        X_0,...,N/2-1 ← ditfft2(x, N/2, 2s)        DFT of (x_0, x_2s, x_4s, ..., x_(N-2)s)
        X_N/2,...,N-1 ← ditfft2(x+s, N/2, 2s)      DFT of (x_s, x_s+2s, x_s+4s, ..., x_(N-1)s)
        for k = 0 to N/2-1 do                      combine DFTs of two halves into full DFT:
            p ← X_k
            q ← exp(−2πi/N k) X_k+N/2
            X_k ← p + q
            X_k+N/2 ← p − q
        end for
    end if
```

Figure 2: Pseudocode of FFT

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