To explore the mechanism that allows music recognition apps to work.

Cephas Yeung

10/2/2025

Contents

Abstract

For the purpose of this project, the replica of a music recognition app is created.

The algorithm first creates a fingerprint for each audio file from its spectrogram. Which are added to a database as a hashed value.

When record songs through the interface, the algorithm repeats the process of fingerprinting, but instead compare hash value with matched songs.

CHAPTER 1

Introduction

In the modern world, billions of songs are created, the demand for recognising music increases. This article answer how does modern music recognition app work.

Aim for this research is to understand and replicate how modern day music recognition algorithms work.

From using a very concrete and credible source of a patent created by the original founder and Chief Scientist of Shazam®(Now part of Apple Inc®.) [8] which Shazam®is the industry leader in music recognition. The patent are cited 771 times. [10] However, due to the age of the source, some information might not be as relevant.

This source creates how it was made.

During the creation process, it was created using different resources to make the resource (e.g: patent, research paper) and also methods to test the success criteria set out by the algorithm.

CHAPTER 2

Methodology / Design Choice

The artefact is separated in different pieces. (Structure: Figure A.1).

The software is run inside a container as the patent suggested. By containerizing the program (using docker). It allows it to be run in a "Distributed system".

Next, the program is separated into two parts. The web app allows user to interact graphically. (Screenshots: Figure C.1). And the main algorithm allows the processing of the audio.

When the program first register the song in to the database. It will go through the process of "fingerprinting" the piece of music. The algorithm consist of spectrogram produced from the SciPy signal library [9] where it uses STFT (Short-time Fourier Transform is a variation of the Fast Fourier transform built for making spectrogram). In this case, Fast Fourier transform are used to convert from time and amplitudes domain to a representation in the frequency domain. Illustrated in Figure A.3. [2] And the data are processed using the library of NumPy. [5]

The spectrogram is being filtered through maximum filter in the SciPy library [9]. The two spectrograms are compared to use to pick peak points. The peaks used to construct the pairs. The pairs of points hashed using the default hashing function (Hashing function is a set of things to do to make an output that is always the same length from some other input data. Hash functions and their associated hash tables are used in data storage to access data in a fast time. [6]) from python which generate an almost unique hash values in the program. Illustrated in Figure A.4, Figure A.6 and Figure A.5.

The hash point is than placed into a database alongside with its song name and where the point A's real time. The song data (metadata) such as author and copyright detail are placed in a different database. Database example: Figure A.7.

When the user record the sample through the user interface from the web app, the recording sample is sent to the server. It is processed where it applies the same algorithm from above. First it constructs a spectrogram, peak point are picked and hash values are created, the hash value searched inside the *points* table. Same as the bottom row in Figure A.6.

The list of successfully matched song are than going through the process of "scoring". The score calculated by constructing a histogram with the point A's real time value. (The forth column of

Figure A.6) The highest score would be the correctly matched song. Using score system ensures accuracy results. [10, 7, 11]

CHAPTER 3

Testing method

The program is tested using the method described in this paper [11] and also a meeting from professional. An evidence from all the song from (most) of the fingerprinted music collection is used to test the program, this is so that it reduce the likelihood of a flawed test.

The test have increasing level of difficulty:

- Test 1: original song file (unmodified digital file)
- Test 2: original song file but shifted
- Test 3: original song file but with controlled level of noise. (E.g.: a sine wave)
- Test 4: original song file but played over the air and recorded.
- Test 5: original song but perform by different people.
- Test 6: transposed song

The test results is inside Figure B.1.

The program overall worked as expected but test 5,6 doesn't work because this algorithm is not designed for this.

CHAPTER 4

Discussion

As discussed in the test conducted, this artefact is not capable to detect a transposed song. Because this song only matches the exact frequency that the song produces.

One way that the problem can solve is to change the mechanism entirely to not rely purely on the raw frequency data, instead by using the MIDI file of the song which contains a series of message like note. [1] Then from it, create a database of melody. Which can recognise songs from it by recording the song and passing into the algorithm to process for results. This allows a wider error range for recognizing song such as made from "humming". [4, 11]. However, this would make the algorithm costly and slow to run.

In addition, extra research might be needed to improve the speed, making it more commercially viable which is the goal set out by the Shazam®team where they designed it so that it's high performance. [10]

The research can also be further extended not limited to searching for songs, such as searching for patten inside picture or video.

In addition, this project only uses copyright-free music, as there would be legal and ethical implication to using contemporary music.

The biggest ethical implication that most music recognition app faced are privacy violation, as some app record the audio in the background even without user interaction. The project would not be concerned about this because it only records when user intended to.

CHAPTER 5

Conclusion

Further research might be needed into improving the accuracy, making it able to recognise variation of the same song. [11]

In conclusion, It met the expectation of the project end goal which are tested using a vigorous testing method set out by a professional opinion and an article.

Bibliography

[1] amandaghassaei. *What Is MIDI?* Instructables. URL: https://www.instructables.com/What-is-MIDI/ (visited on 01/31/2025).

[2] *Fast Fourier transform*. In: *Wikipedia*. Page Version ID: 1273240384. Feb. 1, 2025. URL: https://en.wikipedia.org/w/index.php?title=Fast_Fourier_transform&oldid=1273240384 (visited on 02/06/2025).

[3] FFmpeg developers. *ffmpeg: A complete, cross-platform solution to record, convert and stream audio and video*. Version n7.1. URL: https://www.ffmpeg.org/.

[4] Asif Ghias et al. "Query by humming: musical information retrieval in an audio database". In: *Proceedings of the third ACM international conference on Multimedia - MULTIMEDIA '95*. the third ACM international conference. San Francisco, California, United States: ACM Press, 1995, pp. 231–236. ISBN: 978-0-89791-751-3. DOI: 10.1145/217279.215273. URL: http://portal.acm.org/citation.cfm?doid=217279.215273 (visited on 01/31/2025).

[5] Charles R. Harris et al. "Array programming with NumPy". In: *Nature* 585.7825 (Sept. 17, 2020), pp. 357–362. ISSN: 0028-0836, 1476-4687. DOI: 10.1038/s41586-020-2649-2. URL: https://www.nature.com/articles/s41586-020-2649-2 (visited on 01/12/2025).

[6] *Hash function*. In: *Simple English Wikipedia, the free encyclopedia*. Page Version ID: 9718140. Aug. 22, 2024. URL: https://simple.wikipedia.org/w/index.php?title=Hash_function&oldid=9718140 (visited on 01/30/2025).

[7] Cameron MacLeod. *abracadabra: How does Shazam work? - Cameron MacLeod*. URL: https://www.cameronmacleod.com/blog/how-does-shazam-work (visited on 10/28/2024).

[8] Danielle Newnham. *INTERVIEW: Dr Avery Wang, Principal Research Scientist at Apple and Co-Founder and Chief Scientist...* Medium. Feb. 2, 2023. URL: https://daniellenewnham.medium.com/fostering-innovation-and-choosing-the-right-founding-team-6287f7eed9f (visited on 02/02/2025).

[9] Pauli Virtanen et al. "SciPy 1.0: fundamental algorithms for scientific computing in Python". In: *Nature Methods* 17.3 (Mar. 2020). Publisher: Nature Publishing Group, pp. 261–272. ISSN: 1548-7105. DOI: 10.1038/s41592-019-0686-2. URL: https://www.nature.com/articles/s41592-019-0686-2 (visited on 10/28/2024).

[10] Avery Li-Chun Wang and Julius O. Smith III. "Systems and methods for recognizing sound and music signals in high noise and distortion". U.S. pat. 8386258B2. Shazam Investments Ltd. Feb. 26, 2013. URL: https://patents.google.com/patent/US8386258B2/en?assignee=Shazam+Investments+Ltd&num=25 (visited on 12/25/2024).

[11] Cheng Yang. *Music Database Retrieval Based on Spectral Similarity*. Technical Report 2001-14. Backup Publisher: Stanford InfoLab. Stanford, 2001. URL: http://ilpubs.stanford.edu:8090/489/.

APPENDIX A

Figures

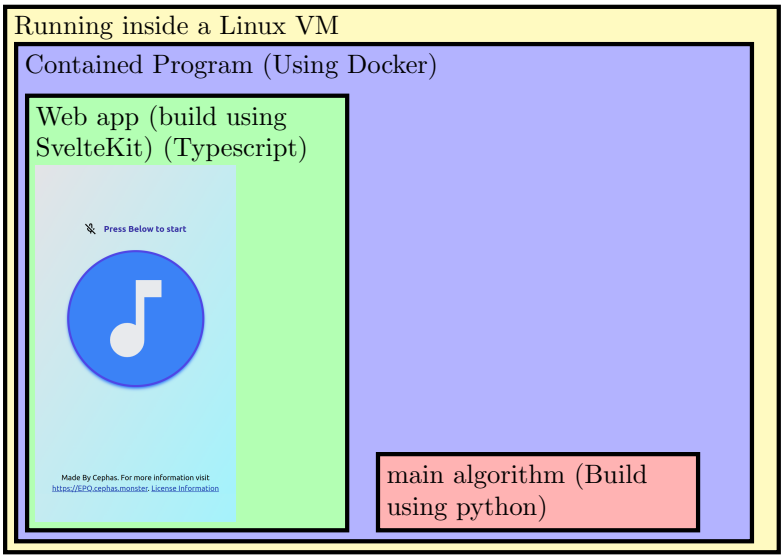


Figure A.1: Overall Architecture

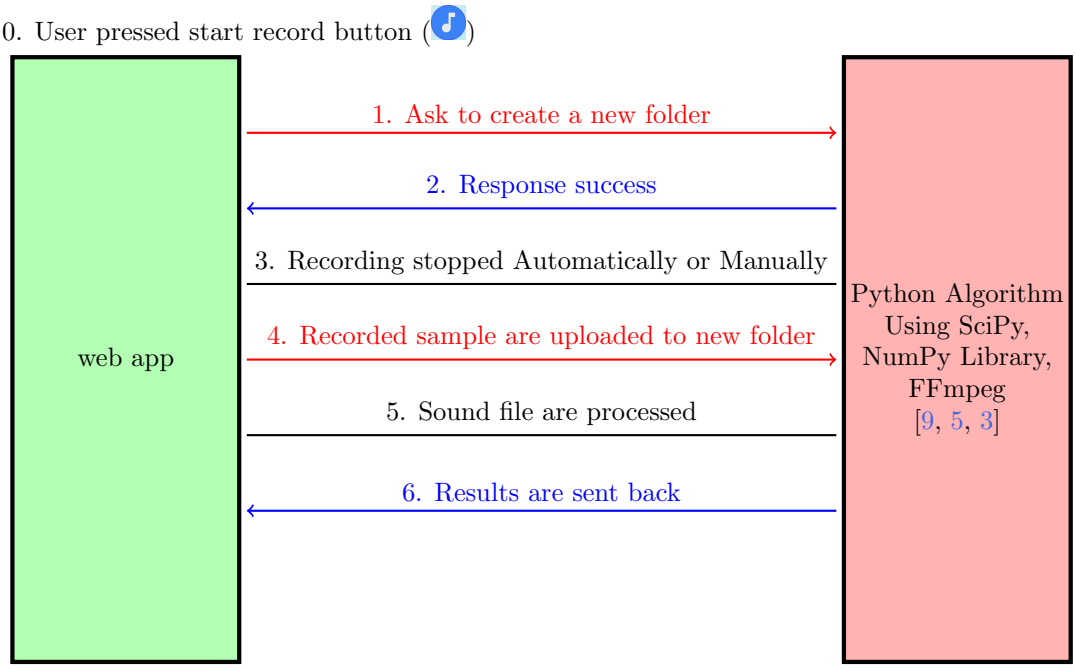


Figure A.2: Overall Architecture (app)

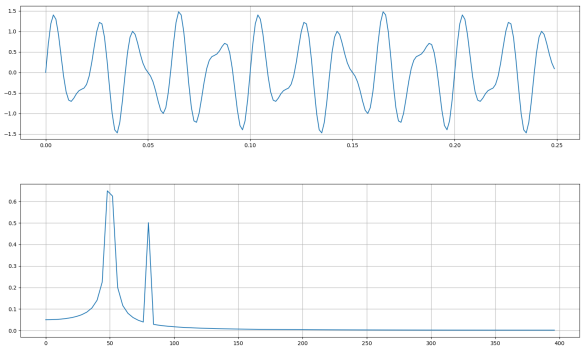


Figure A.3: Fast Fourier Transform as an example through transforming the top signal in to representation in the frequency domain at the bottom.

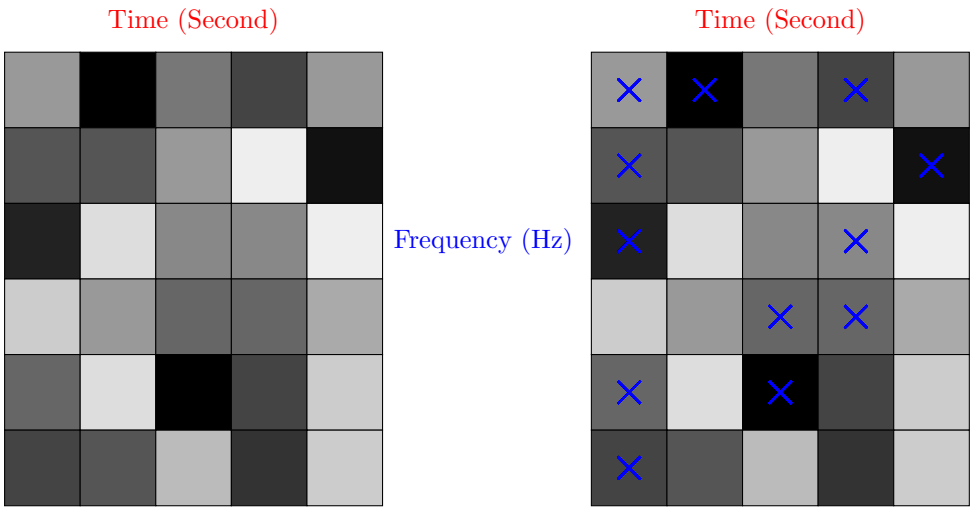


Figure A.4: Illustrating an example of a spectrogram picking of points. The darker the box, the higher the amplitude (value) represents

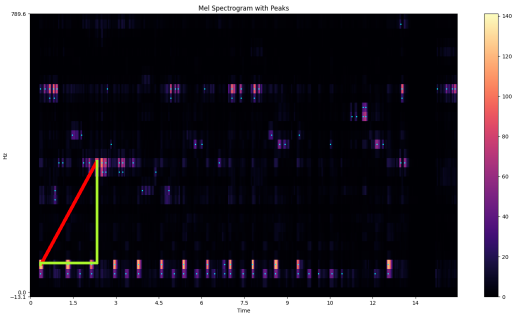


Figure A.5: The tip of the triangle represents Point A and Point B. Y-axis represents the time, X-axis represents the frequency, The amplitude scales are represented by the colour bar on the right.

Point A (Hz)	Point B (Hz)	Time delta (s)	Point A time (s)	Track UUID
20.1	302.1	1.8	0.3	*ea47a3c5*
2388532207457024332			2.1	*ea47a3c5*

Figure A.6: Demonstrate / example of how item are hashed. [7]

Song_ID	Name	Author	Genre
f633c47a	J. S. Bach: Prelude in C - BWV 846	Kevin MacLeod	Classical

Figure A.7: Example of a database entry

APPENDIX B

Testing results

Test 1: (tested on 100% of the song library)

filepath	passed	SUBTOTAL
test/test_1.py	46	46
TOTAL	46	46

Test 2: (tested on 100% of the song library)

filepath	passed	SUBTOTAL
test/test_2.py	46	46
TOTAL	46	46

Test 3: (tested on 100% of the song library)

filepath	passed	failed	SUBTOTAL
test/test_3.py	34	12	46
TOTAL	34	12	46

Test 4: Most works (Only tested 40% of the song library)

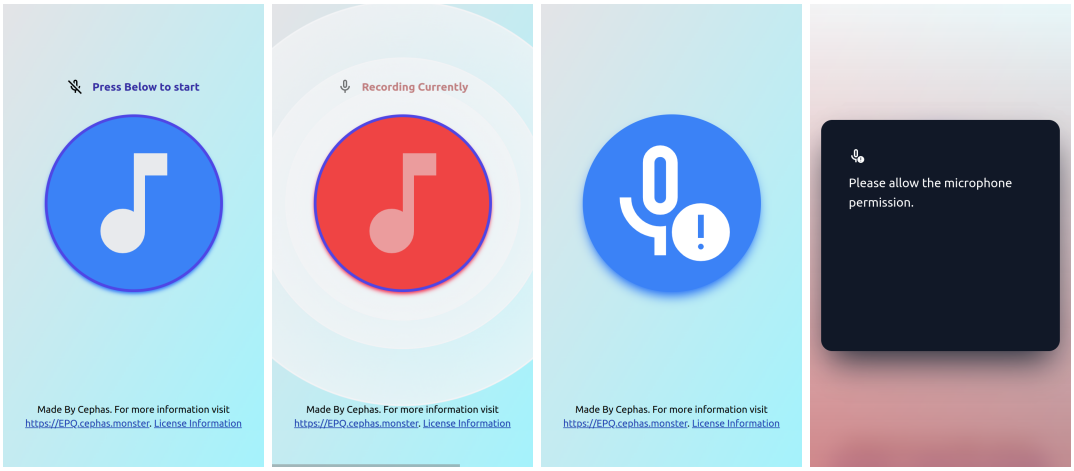
Test 5: Most failed (Only tested 20% of the song library)

Test 6: All failed (Only tested 10% of the song library)

Figure B.1: test result table

APPENDIX C

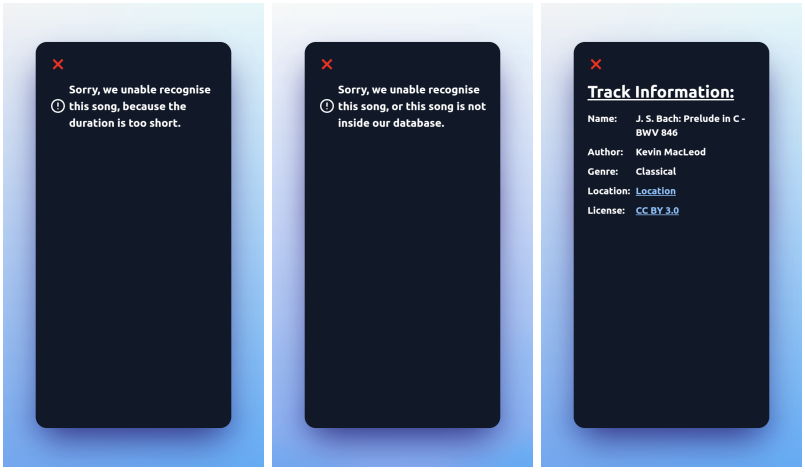
Screenshots



(a) (b) (c) (d)

Figure C.1: (a) "Home", (b)(c) "Microphone permission are disabled"

All the figures are simulated to the size of an iPhone®SE display.



(a) (b) (c)

Figure C.2: (a) "Too Short", (b) "No song", (c) "Recognized song (e.g: Prelude by Bach)"

APPENDIX D

Meeting logs

Meeting with the supervisor at 25 November 2024

Summary:

Improve on the part A of the production logs, with more details on the titles described and what resources I will be using (such as the URLs should be provided), the timescale and what is involve.

As things I should be including to create a great project is the benefit that this might bring to the society and the impact.

And a plan to see what I should be sending or showing to the examiner in the future such as:

- Send product log
- Presentation of the artefact
- Evidence of the artefact
- Critical bibliography
- Place that in the Appendix and write a reference back to the appendix through the production log.

Meeting with a professional at 13 January 2025

Summary:

I explained the background details during the meeting.

I have explained that the program can only detect sounds from following test that I conducted such as:

- A test where there are no modifications to the original sound,
- A test where the song has cropped and reduced to a smaller size.
- A test where there is a constant noise generated by a program with a constant sine wave in the background.
- A test where the songs are mixed with a normal acceptable background noise such as coughing.

All of those above works as expected.

However the test that I did by recording when the sound is played on a music player on a different device doesn't work.

As an additional note, he has mentioned that the program is slow because of a reason which might be caused by the hash point not being an integer, as the hash value using integer is faster than using string as hash. (It was diagnosed with a slow database reading speed prior to the meeting).

The project has concluded as partially successful from the results produced from the searching algorithm.

Summary of Improvement I need to make from the project.

I should use a different hashing algorithm for the fingerprinting part of the program.

Round up the frequency, and the changes in time that are fed into the hashing algorithm.

Additional note:

The meetings are conducted with the consent of the professional. (With regards to the ethical issues)

The professional is my computer science teacher, as he has a decent qualification of a university degree.