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SYNTHESIS OF AUDIO SIGNALS

SYNTH CHALLENGE 2021

SOUND AND MUSICAL INSTRUMENT SYNTHESIS USING SOFTWARE ENVIROMENT MATLAB

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INTRODUCTION

In this challenge we must submit three different tasks using the MATLAB environment:

1) Musical instrument synthesis of **'Bohemian Rhapsody'** by Freddie Mercury, which consists of 11 instruments and 15 percussion sounds.
2) Three octaves of the Major music scale for all the synthesized musical instruments.
3) An arbitrary realization of own audio synthesis.

For the realization of the tasks we are provided some MIDI files type 0 to MATLAB interpreter:

- Function 'main.m': contains examples of the solo instrument and polyphony synthesis.
- Function 'synth.m': In which the instrument functions may be written.

And more MATLAB files like 'synthchallenge.m', 'writemidi.m', 'readmidi.m', etc. They help us with the synthesis of the different instruments.

Using the MATLAB file 'main.m' we can get the instruments and percussion sounds that appear in the song:

- Channel 1: instrument no. 1, **Acoustic Grand Piano** (1920 notes)
- Channel 2: instrument no. 34, **Fingered Electric Bass** (480 notes)
- Channel 3: instrument no. 49, **String Ensemble 1** (779 notes)
- Channel 4: instrument no. 53, **Choir "Aah"** (262 notes)
- Channel 5: instrument no. 66, **Alto Sax** (138 notes)
- Channel 6: instrument no. 61, **French Horn** (142 notes)
- Channel 7: instrument no. 63, **Synth Brass 1** (154 notes)
- Channel 8: instrument no. 70, **English Horn** (137 notes)
- Channel 9: instrument no. 31, **Distortion Guitar** (273 notes)
- Channel 10: instrument no. 1 (1114 notes)
    - Percussion no. 35, **Bass Drum 2** (334 notes), 40, **Snare Drum 2** (132 notes), 41, **Low Tom 1** (2 notes), 42, **Closed Hi-hat** (114 notes), 43, **Low Tom 2** (52 notes), 45, **Mid Tom 2** (30 notes), 46, **Open Hi-hat** (94 notes), 47, **Mid Tom 1** (1 notes), 49, **Crash Cymbal 1** (66 notes), 51, **Ride Cymbal 1** (141 notes), 52, **Chinese Cymbal** (7 notes), 55, **Splash Cymbal** (2 notes), 57, **Crash Cymbal 2** (13 notes), 81, **Open Triangle** (126 notes).
- Channel 11: instrument no. 48, **Timpani** (178 notes)
- Channel 12: instrument no. 31, **Distortion Guitar** (273 notes)
- Channel 13: instrument no. 56, **Orchestral Hit** (75 notes)

COMPETITION ASSIGNMENT

1. TASK 1: Musical instrument synthesis of "Bohemian Rhapsody" by Freddie Mercury using MIDI files.

There are 11 instruments in the song "Bohemian Rhapsody":

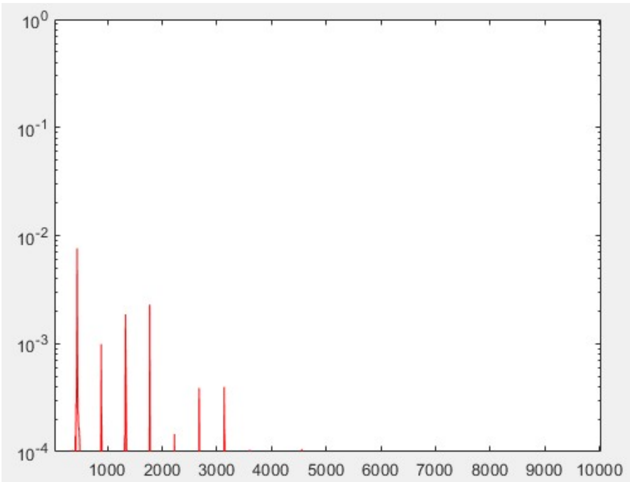
Acoustic Grand Piano, Fingered Electric Bass, String Ensemble 1, Choir "Aah", Alto Sax, French Horn, Synth Brass 1, English Horn, Distortion Guitar, Timpani and Orchestral Hit. The rest of the notes are related to Percussion sounds.

For this task we will use different techniques for the synthesis of some of the instruments:

- **Additive Synthesis**: Consists on the summing up of individually generated sinusoids (deeply rooted in Fourier series). It is accepted as one of the most powerful and flexible spectral modeling methods, which is why this synthesis is the one I mostly used in my project.
- **Formant Synthesis**: It is a special case of Subtractive Synthesis. Part of what makes the timbre of a voice or instrument consistent over a wide range of frequencies is the presence of fixed frequency peaks, called formants.
- **Waveshaping Synthesis**: Also called "nonlinear distortion" or "nonlinear processing". It spectrum is composed by nonlinear distortion of simple signal, using waveshaper and transfer function.

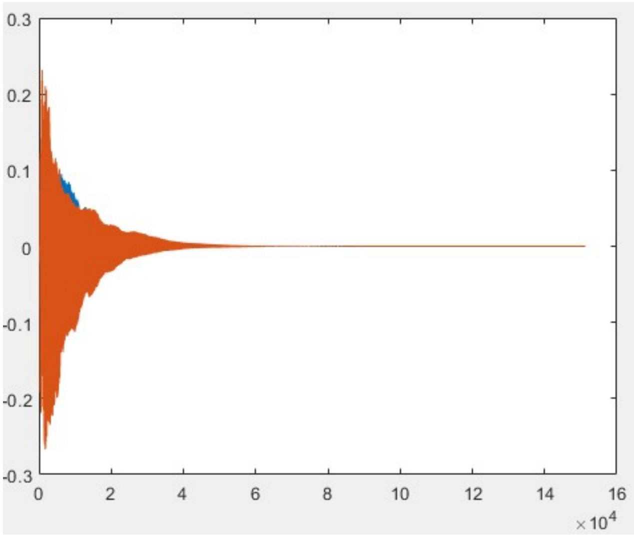
- Acoustic Grand Piano (instrument 1)

For Acoustic Grand Piano we use Additive synthesis with coefficients extracted from a real sample of the sound of the instrument using spectral analysis (function analysis.m). With this function we can analyze the harmonics of the sound and their correspondent amplitudes:



We must create a vector of amplitude coefficients (in this case with 7 harmonics). The synthesized signal consists on a sine as the oscillator type with the mentioned amplitudes. We implement the fundamental frequency by the number of harmonics. At the end we apply exponential envelope and normalization to the final signal.

We decided to use exponential envelope by visualizing the .wav signal on time domain:



The used sample is called ‘*Grand Piano.wav’.*

- ## Fingered Electric Bass (instrument 34)

Similar to Acoustic Grand Piano. We apply Additive Synthesis, but using 8 harmonics and the sample *‘Alesis-Fusion-Fretless-Bass-C3.wav’*.

- ## Distortion Guitar (instrument 31)

Similar to Acoustic Grand Piano. We apply Additive Synthesis, but substituting the instrument for **Acoustic guitar**. We use 8 harmonics and the sample *'Alesis-Fusion-Nylon-String-Guitar-C4.wav'*.

- ## English and French Horn (instruments 61 and 70)

In this case we substituted both instruments for **violin**, but using Formant Synthesis. The first step is to create a source signal with added vibrato in each harmonic, which provides a raw signal shaped by a resonator. The resonator modifies the signal generated by source.

By choosing the resonator coefficients (B and C) and the filtering characteristics (frequencies and bandwidth, based on the model of violin) the last step is to filter the signal and apply an ADSR envelope to the resulted signal. The function ‘interp1’ allows us to choose the position of the envelope. Finally we normalize the signal.

- ## Choir ‘Aah’ (instrument 53)

We substituted this sound for **banjo**. Firstly we applied Additive Synthesis, similar to Acoustic Grand Piano. But then we compared the result with the one by applying Waveshaping Synthesis and the sound turned out to be better.

This kind of synthesis uses Chebyshev Polynomials. They follow the next equation:

$$T_{n+1}(x) = 2xT_n(x) - T_{n-1}(x)$$

We calculate 10 polynomials. We get the final signal, apply an exponential envelope and normalization.

- Rest of the instruments

In any other case we substitute the sounds for **Acoustic Bass**, applying Additive Synthesis like in Grand Acoustic Piano. We use 8 harmonics and the sample *'Alesis-Fusion-Acoustic-Bass-C2.wav'.*

All the synthesis process is implemented in the script 'synth.m'. By using the script 'synthchallenge.m' we can save the result in the output file *'t1_bohemian_synth.m4a'*.

2. TASK 2: Three octaves of Major music scale of the synthesized musical instruments.

The major scale is one of the most commonly used musical scales. It is made up of seven notes, and the eighth duplicates the first at double its frequency.

For this task we will use the simplest major scale to write, which is C major. It consists on the pitches C, D, E, F, G, A, B.

The next equation gives us the frequency for the n^{th} key:

$$f(n) = 440 * 2^{\frac{n-49}{12}}$$

We will consider f = 440Hz as the reference frequency, which corresponds to note A4 (n = 49).

For each instrument I searched for the typical frequency range:

INSTRUMENT	f_{min} (Hz)	f_{max} (Hz)
Acoustic Grand Piano	130.813	1046.502
Fingered Electric Bass	32.703	261.626
Acoustic Guitar	130.813	1046.502
Violin	261.626	2093.005

I could not find the exact range for 'Banjo' instrument, also the range for 'Acoustic Bass' is the same as the one for 'Fingered Electric Bass', so I decided not to include them on the major scales signal.

I created in MATLAB a vector with all the notes one by one with a duration of 1 second each and using the equation above I got a new vector with the scale frequencies for each instrument, and other vector called 'final' which is initially empty. Then I synthesized every single note using 'synth.m' with the correspondent frequency, and added one by one the results in 'final', to end up saving it into an m4a file using 'audiowrite' function.

After all the process I finally get an audio file with the major scales of every instrument I synthesized, which I called *'t2_major_scale.m4a'*.

3. TASK 3: Arbitrary realization of audio signals.

For the last task I have been free to combine different type of sounds to create a personalized audio. My audio track consists of a mixture of 3 sounds: wind sound, rain sound and airplane flying sound. I decided to use common sounds of everyday life instead of non-musical sounds.

- Wind sound

Wind sound was made by Filtering Synthesis. First, we select an appropriate excitation signal with an interpolated control frequency. Then, we apply the resonator filter correctly to the source, to finally get the wished wind sound at fs = 44100 Hz.

- Rain sound

Rain sound is synthesized similarly as wind sound. In this case we start from a sawtooth signal and create a noise sample&hold signal to apply to the resonator. At the end we apply a High Pass filter to the signal to reduce the noise, so we finally get the wished rain sound at fs = 44100 Hz as well.

- Airplane sound

Airplane sound is also made by Filtering Synthesis. We start with a sawtooth signal too, which we apply the filtration and envelope to get the final airplane sound we wanted with fs = 44100 Hz too. We tried to simulate Doppler Effect with envelope, so the airplane seems to get closer at the beginning and ends up getting away.

The final sound is saved using 'audiowrite' function into *'t3_arbitrary_sound.m4a'* file.

REFERENCES

- Synthesis of Audio Signals course lectures and seminars available in Moodle: https://moodle.fel.cvut.cz/course/view.php?id=6206
- MIDI files from http://sami.fel.cvut.cz/synthchallenge2021/

- https://www.ece.iastate.edu/~alexs/classes/2016_Spring_575/HW/HW5/files/piano-key-freq-wikipedia.pdf
- https://freewavesamples.com