EAR GYM

A project for CMRM and ACTAM courses

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The idea

This project is the combination of two courses, the ACTAM an CMRM courses of the MAE Master of Science of the Politecnico di Milano. The idea came from during the homeworks of the CMRM course, where we realized that **we needed to improve our hearing system abilities** in recognizing different notes, chords, progressions. So we decided to use the project opportunity to realize something useful in that sense. We decided to develop the project as a game, because we thought that with a game the player can be encouraged to perform better and better in order to achieve better results. This continuous improvement is the successful strategy to reach a significant improvement in our abilities.

The development

To develop our project we use the method studied in the ACTAM course, so we use HTML, CSS, Javascript as programming languages to create the whole project. We add also a DataBase, Firebase (a Google DB explained in the course), in order to keep track of the statistics of the game. To reproduce the sound we use a specific library (tone.js) that helps us to play all the note of a classic piano.

The game

The game is very simple and consists in identifying the right note, interval or chord played by the computer. We divided the piano keyboard in 8 groups, each one composed by two octaves. The game is divided in 3 levels: notes, intervals, chords. Each level has 3 different difficulties: low, medium, hard. With the low difficulty is possible to listen the sound as many times the play want. With the medium is possible to listen the sound just one and with the hard there is also a 1 point penalty if the player choose the wrong answer. Before starting the session the player has to choose the settings. In the settings he can modify the level (notes, interval, chords), the difficulty (low, medium, hard), the piano octave and the input type. For the interval and chords levels is possible to choose also the tonal reference. A game session is composed of 10 sounds and at the end is possible to compare the personal results with the previous statistics of the game. In this way it is possible to understand the personal improvements or also to challenge other players. The player can choose between two types of input: mouse input or midi-keyboard input. The mouse input is an easier way to play this game for the players that are not familiar with the keyboard. With this type of input the player has just to click on one of the different boxes present on the screen trying to guess the correct answer. The midi keyboard helps the players to start putting the hands on the keyboard and to understand how it works. To help the players, after his answer we also highlight the correct one on the keyboard.

Notes

In the notes section the player has to identify the note played by the computer.

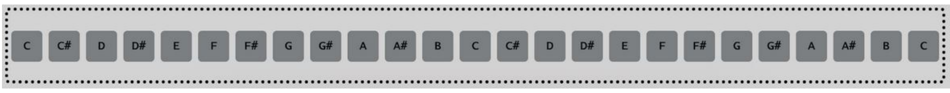

Figure 1: Screenshot of the 25 notes box bar in the game.

This above is the box with the 25 notes that form a group in our game. The player has to identify the correct note among all the note in the box. The range varies with the octave setting that the player has done before starting the session.

Intervals

In the interval level the player has to distinguish between 12 types of interval.

Figure 2: The intervals bar box.

The intervals are:

- m2: minor second interval (C - C#)
- M2 : major second interval (C - D)
- m3 : minor third interval (C - D#)
- M3 : major third interval (C - E)
- P4 : perfect fourth interval (C - F)

- A4 : augmented fouth interval (C - F#)
- P5 : perfect fifth interval (C - G)
- m6 : minor sixth interval (C - G#)
- M6 : major sixth interval (C - A)
- m7 : minor seventh interval (C - A#)
- M7 : major seventh interval (C - B)
- O : perfect octave (C3 - C4)

In the parenthesis there is an example for each type of interval in the C tonal reference. Learning the difference between each type of interval and learning to distinguish them is the basic operation in order to start identifying the different chords, in fact each chord can be thought as composed by 2 interval.

Chords

In the chords level the player has to identify the right type of chord between 6 types.

Figure 3: The chords bar box.

The types are:

- maj : major chord
- maj7 : major seventh chor or delta chord
- min : minor chord
- min7 : minor seventh chord
- dom7 : dominant chord
- hdim7 : half diminished chord

THEORY FOR BEGINNERS

How the ear works

Many stages are involved in the process of transduction i.e. the complex process by which sound waves are transformed into electrical signals, which are then conveyed by the auditory nerve to the brain. When we hear a sound, it is transmitted as a wave and reaches the outer ear. The sound waves pass through the ear canal, a slender passage, leading to the eardrum. When the eardrum is struck, the vibrations are sent to the ossicles in the middle ear. These small bones are responsible for amplifying the vibrations and sending them to the cochlea. A rippling effect is caused by the vibrations in the cochlea, and this results in the formation of a traveling wave along the basilar membrane. The sensory cells present on the top of the basilar membrane, called hair cells, recognize the sound waves. Detection of a sound is dependent on its pitch - while high-pitched sounds are detected by the hair cells near the wide end of the cochlea, low-pitched sounds are identified by the hair cells closer to the center of the cochlea. Stereocilia are vital for the process of electro-mechanical transduction. They are the microscopic hair-like projections that rest on and protrude from the top of the hair cells. It is important to understand the terms pitch and loudness, as together they are used to describe characteristics of a sound. The pitch, or sound frequency, is measured in hertz (Hz) and the loudness, or the intensity, of the sound is measured in decibels (dB). Typically, the most important sounds that humans hear daily are in the range of 250–6,000 Hz where the normal ranges are 20-20,000 Hz. However, hearing becomes most sensitive in the 2000–5000 Hz frequency range. The audible range for humans is 0-140 dB. While 0 decibels is the quietest, a whisper is around 25–30 dB and conversations are usually 45-60 dB, as speech is a combination of low- and high-frequency sounds. So our suggestion is to set at the beginning the range C4-C6 as octave, for two reasons. The first one is that our ear is most sensitive in this frequency range and the second one because we are used to listen to 440 Hz music and so this is the range which we are most familiar with.

Music theory

The sound is a periodic or non periodic vibration the molecules of an object and the transmission of this vibration into a medium. The sound propagates between the object and the molecules into the medium, reaching the human hear. Where molecules are not present, than the sound won't propagate (ex. the void in space). It is possible to talk about physics of sound in terms of the study of the sound behaviour. It is possible to distinguish some first level parameters such as frequency, amplitude, intensity envelope, spectrum and duration, and then we can derive other parameters such as the speed of particles, the reflection and diffraction between the sound and the objects (echo - reverberation). It is possible to extract from every sound an envelope, that is the temporal evolution of the macro-level of the sound pressure. The envelope tells us a lot about the origin of the sound and its propagation. When we manage sound, we always refer to an exciter (the hammer of the piano), a resonator (where the vibration take place, and where most of the timbre is generated. We have a transmission mean, that is responsible for the sound propagation, and a receiver (ear, microphone).

The pitch

Almost all sounds that give a sensation of pitch are periodic, and their spectrum consists of harmonics that are integer multiples of the fundamental. Even if the fundamental is missing, is still perfectly possible to distinguish the The pitch of a note is something that is possible to detect precisely with an algorithm, but is also something that is **dependent from a subjective sensitivity**. Some people have trained a perfect ear with which they can determine both the perfect pitch of a note and the relative position on a keyboard. Some others can only find the position of a note on the keyboard only after they received a pitch cue. Some others need to fully train this aspect from the beginning. **This is the purpose of our Ear-Training game.**

Generally it is possible to discriminate a number of 1400 different pitches. We in fact use more or less 120 pitches in the occidental scaled we are in use to hear. Our level of ear training actually is relative to our background, to where we born or grow up. Some cultures have a really fine ear, due to their intricate traditional songs.

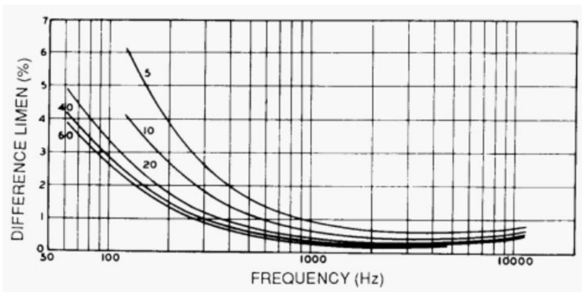

Figure 4: Graph of the relation between the frequency and the minimum pitch variation in percentage.

Why do we feel a pitch "higher" or "lower" than the one heard before? And how much I need to increase or decrease a note in order to feel a difference in pitch? The JND (Just Noticeable Difference) is defined as **the smallest variation of frequency that is possible to perceive**. This value changes with the frequency. We are more sensible to pitch variations in some frequency ranges than in others, like explained above.

How a keyboard is made

The keys disposition on the keyboard follows the twelve note of the chromatic scale of the equal temperament system: this disposition is called **chromatic scale**. We have the keys that belong to the diatonic scale that are white, while the chromatic alterations are in black. The keys disposition is repeated every octave, and the modern keyboards can reach 7 or 8 octaves. The **equal temperament** is a musical system that is used to build a musical scale based on the subdivision of the octave into equally spaced intervals.

Usually the octave is subdivided into 12 parts, called semitones and the relationship between two semitones is the twelve root of two.

The difference to the diatonic scale from the chromatic scale is that the latter is made from chromatic and diatonic semitones. We will encounter a scale made from 12 equidistant tones inside an octave. For this reason is a symmetric scale and has only one possible transposition: It always remains identical regardless of the starting note. This scale is therefore not referable to any musical mode or tonality. Usually we tend to use the sharp (#) for the ascending notes, and the flat (♭) for the descending ones. The chromatic scale instead uses a set of notes and alterations that remains unchanged for both rising up and down from the scale.

$G^{\#}_4/A^{b}_4$	415.30
A_4	440.00
$A^{\#}_4/B^{b}_4$	466.16
B_4	493.88
C_5	523.25
$C^{\#}_5/D^{b}_5$	554.37
D_5	587.33
$D^{\#}_5/E^{b}_5$	622.25
E_5	659.26
F_5	698.46
$F^{\#}_5/G^{b}_5$	739.99
G_5	783.99
$G^{\#}_5/A^{b}_5$	830.61
A_5	880.00

Figure 5: Relation between the chord and the frequency.

Figure 6: Example of chromatic scales on a staff.

Chords

In musical theory, a chord is a simultaneity of three or more sounds with a defined pitch. A chord can be ordered trough intervals of a third, a fifth, or more. The sounds that constitute a chord are counted only once, regardless to the octave they belong to.

We have different types of chords, depending on how many voices are made of:

- 3 voices- Triads
- 4 voices- Seventh chords
- 5 voices- Ninth chords
- 6 voices- Eleventh chords
- 7 voices- Thirteenth chords

Conclusion and future developments

The libraries used for the project and listed above give us the chance to create scales and chord progressions too. The idea for a future development is to make the game always more ”challenging”, introducing levels where it’s possible to recognize the note scales and maybe different type of scales that don’t belong to the occidental which we are in use to hear. The library gives the possibility to create chords: A development idea is to add another level in which you test the ability to create and recognize the chord progressions, with always increasing difficulty between different chords. We could also add for example the possibility to guess the resolving chord from a given progression. The customisation and challenging ideas are endless.