Analyze Your Sound: Spectrogram

Background

Have you ever put your hand over a music speaker that is blasting loud music? How did it feel? It must have felt tingly. It is because the speaker is pushing the air particles around it, and these particles are tickling your hand! We cannot see the air particles because they are so small. The sound is created when the speaker wiggles or vibrates, and that vibration is transferred to the air particles near it. It causes the air particles to be squeezed, relaxed, squeezed, relaxed, etc. This pattern carries as the air moves (Figure 1). This pattern of squeezing and relaxing is what we call a "sound wave." When the sound wave hits our eardrums, our ears transform the sound waves into the sounds we hear.
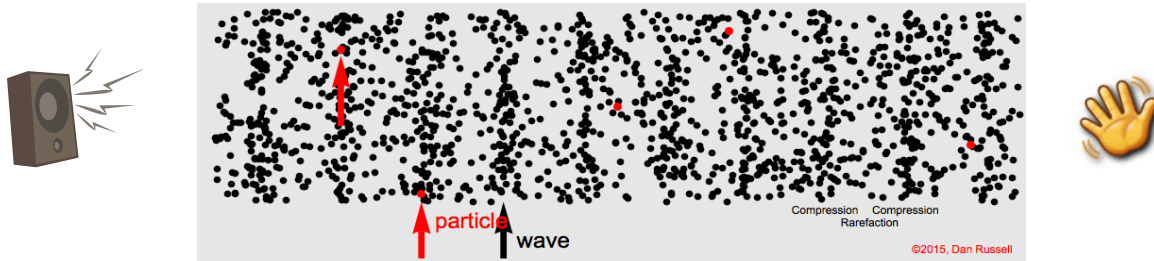

Figure 1: Between the loud sound speaker and your hand, there are air particles. The speaker wiggles or "vibrates", it causes the air particles around it to move in waves, and it tickles your hand, or your ear catches it as a sound. From: https://dosits.org/science/sound/what-is-sound/

The squeezing of the air particles causes a segment of the air to compress and creates high density of particles while relaxing causes lower density. These actions of compressing and relaxing are called compression and rarefaction, as shown in Figure 1. If particles compress, relax, and compress, and so forth **slowly**, it will sound to our ears as a **low pitch**. If they do so **fast**, it will sound as a **high pitch**. As an example, propellers rotating slowly will disturb the air particles with less energy therefore they produce low pitch sound, as they pick up a speed and rotate faster, they will vibrate the air particles more vigorously and cause high pitch sound.

Pitch, or **frequency**, shows how many times the particles compress, relax, and compress in one second. Hertz (Hz) is a unit of measurement for frequency that means "one event per second". If for instance a particle completes the cycle of compressing and relaxing 100 times in a second, the frequency is said to be 100 s^{-1} (per second) or 100 Hz (hertz). If it does it 8,000 times, the frequency is 8,000 s^{-1} or 8,000 Hz.

Depending on the person, the human ear can conceivably detect sounds as low as 20 Hz and as high as 20,000 Hz, but for most humans the upper limit is 15,000 – 17,000 Hz. Examples of lower range sounds include low-bass sounds, like terrestrial animal grumbling noises (elephants) or aquatic animals like the blue whale (https://dosits.org/galleries/audio-gallery/marine-mammals/baleen-whales/blue-whale/). Most people perceive sounds in this range as pulsing sounds, without a distinct pitch. Human speech perception ranges between 250 - 4000 Hz. Chirping birds and crashing cymbals range around 10,000 Hz. A Bottlenose dolphin emits a vocalization ranging between 8 – 20 Hz (https://dosits.org/galleries/audio-gallery/marine-mammals/toothed-whales/bottlenose-dolphin/).

Most sounds are a mixture of frequencies and **intensities**. Intensity of a sound is how loud or soft the sound is, which is different from the frequency. The loudness of the sound is expressed

in the unit of **decibel**. If the sound is loud, that means the sound source wiggled or vibrated with lots of energy and it gets passed to the other air particles more vigorously thus it produces loud sound, which we call it a high decibel. If the sound is soft, the sound source did not move as much, thus it ends in softer sound, which we call a low decibel. Figure 2 shows the typical sounds around our daily lives and their decibels. See https://dosits.org/science/advanced-topics/introduction-to-decibels/ for more information on decibels.

Figure 2: Typical sounds in our daily lives and their decibels. From: https://www.faa.gov/regulations_policies/policy_guidance/noise/basics

Sound can travel through the different mediums of gases, liquids, and solids. Of these three mediums, sound waves travel the slowest through gases, faster through liquids, and fastest through solids.

Marine animals, fishes, and other ocean creatures produce and detect sound in water for a variety of reasons, including to communicate, navigate, and locate prey and predators. Scientists and engineers have created technologies which utilize how sound travels through water to measure objects and generate images that are otherwise impossible to do with other means and methods.

The analysis of sound is important in many fields of study. For example, in the ocean, scientists study the sounds produced by the marine animals so that we can better understand their behaviors and improve or protect habitats. In the field of music, sports, or other entertainment settings, sound and audio engineers work to produce live music concerts, sport events, or assist in producing recordings for musicians. In medicine, sound is used to diagnose and treat

diseases and injuries. In order to achieve all of these applications, there are a variety of technologies used to send, receive and "visualize" and analyze sounds.
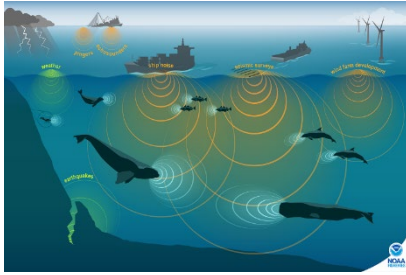

Figure 3: In the ocean, sounds come from various sources. from: https://www.fisheries.noaa.gov/national/science-data/ocean-noise

A visualization of sound is called a **spectrogram**. A spectrogram is a graph of a sound's frequency over time. See an example of a spectrogram of a humpback whale "grunt" (https://dosits.org/galleries/audio-gallery/marine-mammals/baleen-whales/humpback-whale/) (Figure 4). As you hear the sound of the whale, watch how the blue wiggle line on top of the figure. The louder it grunts, the more the blue wiggle line goes up and down. From left to right, it shows time in seconds. In the bottom of the blue wiggle line figure, it shows how low or high it grunts, in other words, the frequencies produced by the whale. The lower the grunt is, the more yellow it shows towards the bottom. The higher the grunt, the more yellow on top.
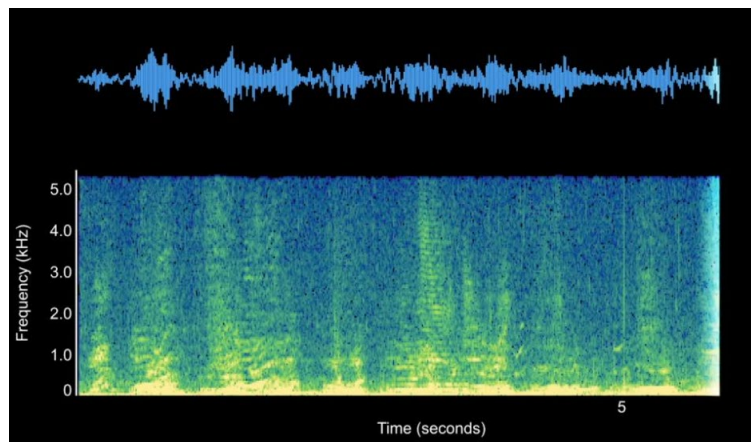

Figure 4: Humpback Whale "grunt" from: https://dosits.org/galleries/audio-gallery/marine-mammals/baleen-whales/humpback-whale/

Your Turn!
In this activity, you will use a sound analyzing app on your phone to investigate the sound around you (soundscape) and detect what frequencies and intensities are being produced by these sound sources. From this activity, you will learn how to read a spectrogram of frequency versus time, as well as a spectrum of intensity versus time. You will also explore how sounds around us are made of combinations of frequencies by analyzing sounds such a violin, marine animals, fish, and any other sounds of your choice!
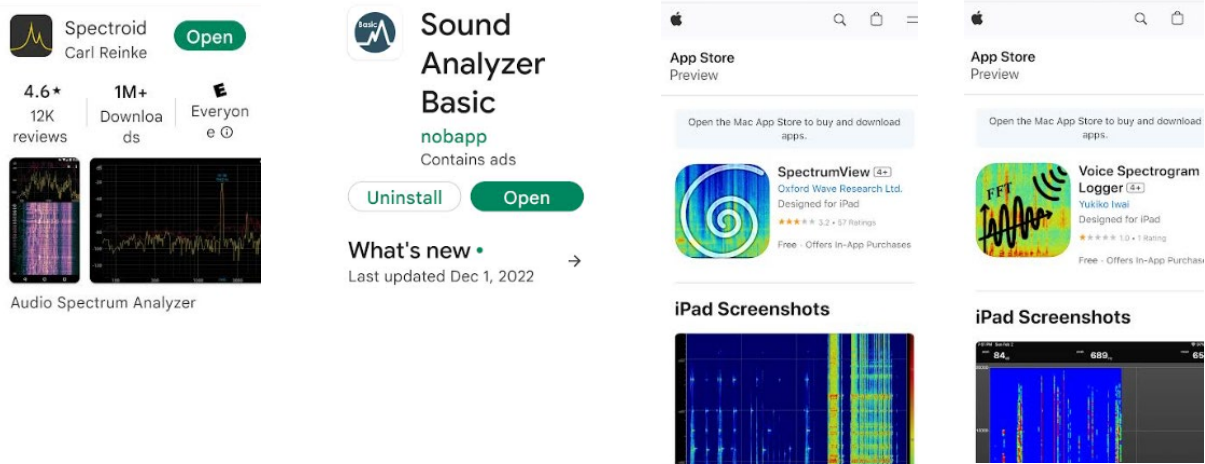
Materials

- Mobile phones or another digital device with microphone
- Any Sound analyzer apps that produce a spectrogram

  Recommended apps for Android:

  - Spectroid:
    https://play.google.com/store/apps/details?id=org.intoorbit.spectrum&pli=1

  - Sound Analyzer Basic:
    https://play.google.com/store/apps/details?id=jp.nokubi.nobapp.soundanalyzer.free

  Recommended apps for Apple:

  - SpectrumView: https://apps.apple.com/app/id472662922

  - Voice Spectrogram Logger: https://apps.apple.com/app/id1277134462

Procedure

Preparation:

1. Install one of the sound analyzer apps mentioned above or any other analyzer of your choice on your phone (or other digital device).
2. Play a sound from any sound source: clapping hands, singing, stomping, pounding, etc. It has to be loud enough to produce a responding spectrogram.
3. Record various sounds and produce different spectrograms and/or spectra (graphs) of intensity of the sound versus frequencies. In some apps, intensity of the sound is labeled as "**decibel**" as the unit of loudness of the sound, or "**energy**" of the sound.

Experiment No.1: 25Hz increment digital sound

Data Collection

1. Go to: https://dosits.org/science/measurement/how-are-sounds-viewed-and-analyzed/
   Read and study the page.

2. On the page, locate a sound player under a line "First, listen to a series of tones ranging from 200 Hz to 475 Hz at 25 Hz intervals." as shown in Figure 5.
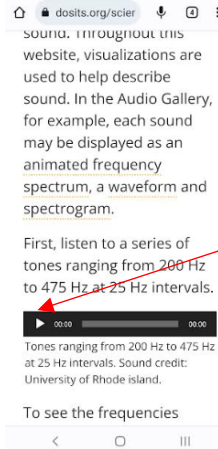

Figure 5: Tones ranging from 200 Hz to 475 Hz at 25 Hz intervals. Sound credit: University of Rhode Island. from: https://dosits.org/science/measurement/how-are-sounds-viewed-and-analyzed/

3. Have your spectrogram analyzer of your choice ready. Hit "play" on the "Tones ranging from 200 Hz to 475 Hz at 25 Hz intervals" sound bite. Record the sound.
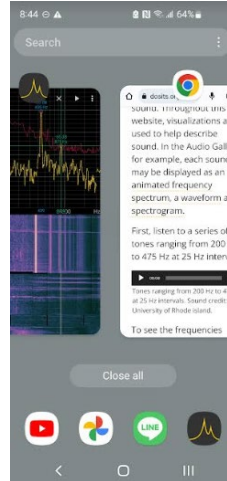

Figure 6: Have your sound analyzer app running in the background as you are ready to hit the button on Figure 6.

4. Stop the recording on your analyzer after the player in Figure 6 finishes playing all notes.

Experiment No.1: 25Hz increment digital sound

Data Analysis

1. Copy and paste your spectrum of decibel versus frequencies to the space below.

2. How many peaks can you count?

3. Can you read off the frequency of each measured peak? You will have to move the cursor in the sound analyzer app to do so. If it is not possible, use the x-axis in your spectrum to read off the frequency. Mark each peak with the frequency.

4. How big are the gaps between each peak? In other words, can you measure the differences between one peak to the next closest peak? Mark each gap with the frequency.

5. Did you see the increment of 25 Hz between the peaks as noted in the player?

   Yes, totally, or somewhat close! / No, not at all…

6. What are similarities between Figure 7 from the dosits.org website?

Figure 7: Frequency spectrum of a series of tones. Image credit: University of Rhode Island. from: https://dosits.org/science/measurement/how-are-sounds-viewed-and-analyzed/
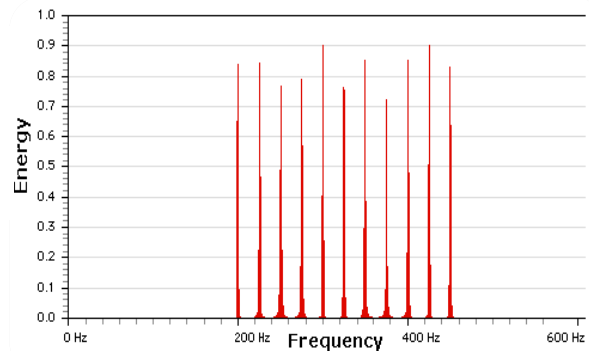
Experiment No.2: 440 Hz Violin string

Data Collection

1. Go to your choice of sound source for A-string on violin. If you are a violin player, go ahead and play the A-string! If you'd like to use other sources such as YouTube please go to;

    https://www.youtube.com/watch?v=aJQ_nmv4AAg or
    https://www.youtube.com/watch?v=j0FynYzQvcM

2. Let's make a prediction. You are going to hear a note that is at 440 Hz that is going to be played on a violin. How many peaks do you expect to see in the spectrum of intensity (decibel) versus frequency?   Number:_____

3. Repeat steps 5 and 6 from "Experiment No.1: 25Hz increment digital sound." Play the A-string sound, record, and create a spectrum of intensities versus frequency on your spectrogram analyzer.

Data Analysis and Questions

1. Copy and paste your spectrum to the space below.

2. How many peaks did you see? Number:_____
    Did this number match the number you predicted in Step 2 in "Data Collection" section?

3. Label each peak with the frequency in your spectrum.

4. What trends do you see between the peaks you observed?

Explanation to multiple peaks:

You saw multiple peaks on a spectrum when A-string was played on the violin. Even though our ear hears one pitch, the violin at 440 Hz produces multiple frequencies. Why? The sound wave travels through the string, hits the tip of the violin, travels back towards the other end, and come back again, etc. This action (https://dosits.org/glossary/transverse-wave/) combined with its unique string length causes a phenomenon called **harmonic frequencies**. It causes the violin to produce increments of 440 Hz; 880 Hz, 1320 Hz, 1760 Hz, 2200 Hz, and so forth. The combination of these harmonic frequencies is what makes the instrument sound so rich and pleasing to the ear! (https://dosits.org/glossary/harmonic-frequency/)

Experiment No.3: Sound of Your Choice

Data Collection

1. Access the DOSITS Sound Gallery for sounds from marine animals, fish, other natural sounds (earthquakes, lightening, etc.) and anthropogenic sounds (wind turbines, personal water craft, etc.) at (https://dosits.org/galleries/audio-gallery/).

   Choice of sound source: _____

2. Let's make a prediction. After playing the sound, what do you think the spectrogram might look like?

3. Play the sound again, record the sound, and create a spectrum of intensities versus frequency on your spectrogram analyzer.

Data Analysis and Questions

4. Copy and paste your spectrum to the space below.

5. Label each peak with the frequency in your spectrum if possible.
6. What trends do you see among the peaks?

7. Compare your prediction from Step 2 in "Data Collection" section.

8. Make any observations based on your spectrogram and/or spectrum.

Make copies of the pervious page and experiment on as many as you'd like to try out different sound sources!

Discussion

What did you notice after collecting at least three different spectrograms and/or spectra? Did anything surprise you? What did you find most interesting?

What did you learn from the activity?

Extended Activity

1. Conduct an online research and find out what are areas of industries where sounds are used in practical applications. Can you picture future uses of sound waves in other area?
2. Conduct two experiments following the steps in "Experiment No.3: Sound of Your Choice" using two different sound sources picked from https://dosits.org/galleries/audio-gallery/. Compare and contrast the two sound sources. If they are both found in the ocean, how one might interact/affect the other?
3. Conduct two experiments following the steps in "Experiment No.3: Sound of Your Choice" using two different sound sources from anywhere. Compare and contrast the two sound sources.

Standards:

Next Generation Science Standards (NGSS)

MS-PS1-1 Matter and its Interactions
MS-PS2-1 Motion and Stability: Forces and Interactions
MS-PS2-2 Motion and Stability: Forces and Interactions
MS-PS2-5 Motion and Stability: Forces and Interactions
MS-PS4-1 Waves and their Applications in Technologies for Information Transfer
MS-PS4-2 Waves and their Applications in Technologies for Information Transfer
MS-PS4-3 Waves and their Applications in Technologies for Information Transfer
HS-PS4-1 Waves and their Applications in Technologies for Information Transfer
HS-PS4-2 Waves and their Applications in Technologies for Information Transfer
HS-PS4-5 Waves and their Applications in Technologies for Information Transfer

Objectives
1. Students will be able to describe that sound is produced by the disturbance in medium.
2. Students will be able to compare different sound waves.

References
https://dosits.org/science/sound/what-is-sound/

https://dosits.org/galleries/audio-gallery/marine-mammals/baleen-whales/blue-whale/

https://dosits.org/galleries/audio-gallery/marine-mammals/toothed-whales/bottlenose-dolphin/

https://dosits.org/science/advanced-topics/introduction-to-decibels/

https://www.faa.gov/regulations_policies/policy_guidance/noise/basics

https://www.fisheries.noaa.gov/national/science-data/ocean-noise

https://dosits.org/galleries/audio-gallery/marine-mammals/baleen-whales/humpback-whale/

https://dosits.org/science/measurement/how-are-sounds-viewed-and-analyzed/

https://www.youtube.com/watch?v=aJQ_nmv4AAg

https://www.youtube.com/watch?v=j0FynYzQvcM

https://dosits.org/glossary/transverse-wave/

https://dosits.org/glossary/harmonic-frequency/

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