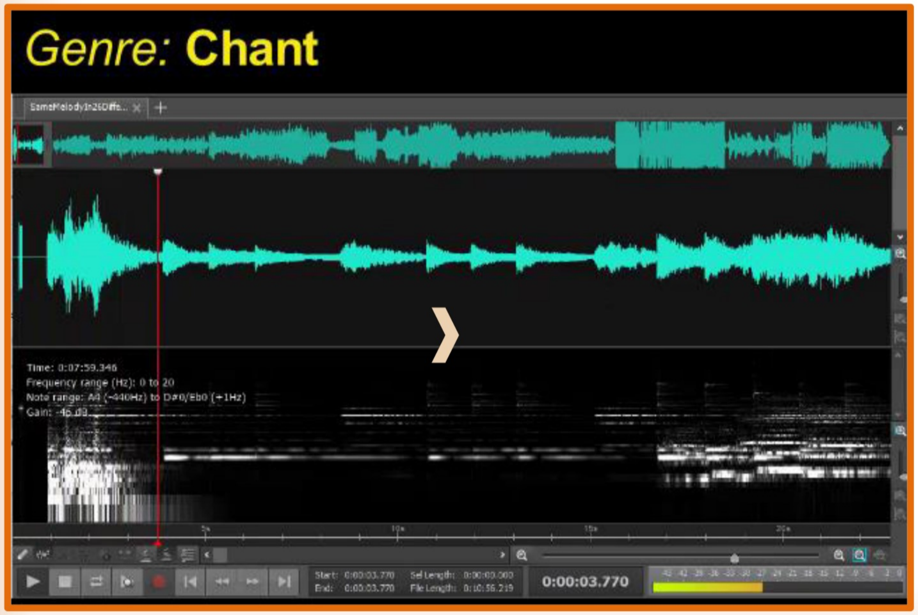
OSHER LIFELONG LEARNING INSTITUTE

An Ear for Music

Same Melody in 26 Different Genres
Trevor Hamer *ca* 2019



Session 1
Building Blocks

OLLI at Illinois
Spring 2024

D. H. Tracy

An Ear for Music

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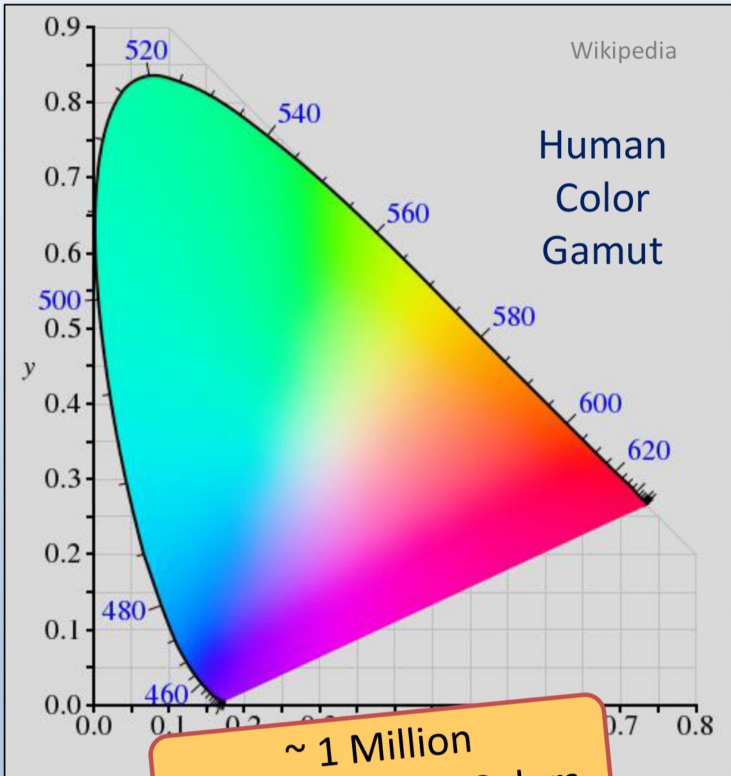
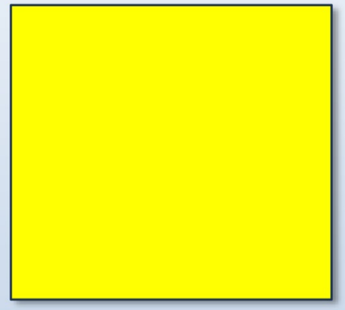
An Aside

What Colors Can We Distinguish?



~ 1 Million Distinguishable Colors

"Morning Banana"



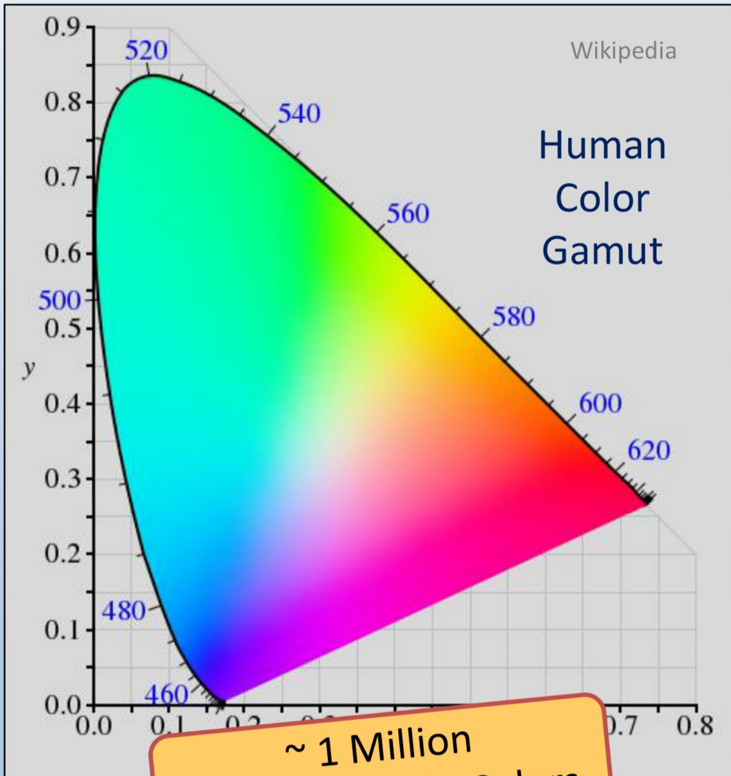
"Sirius Sky"

?

?

An Aside

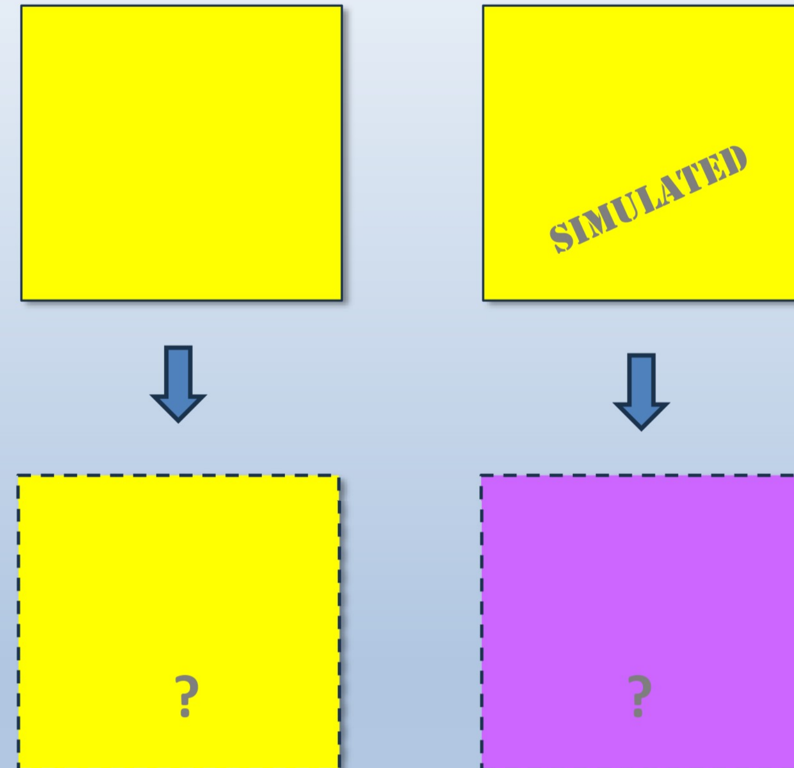
What Colors Can We Distinguish?



~ 1 Million Distinguishable Colors

“Morning Banana”

“Sirius Sky”



An Aside

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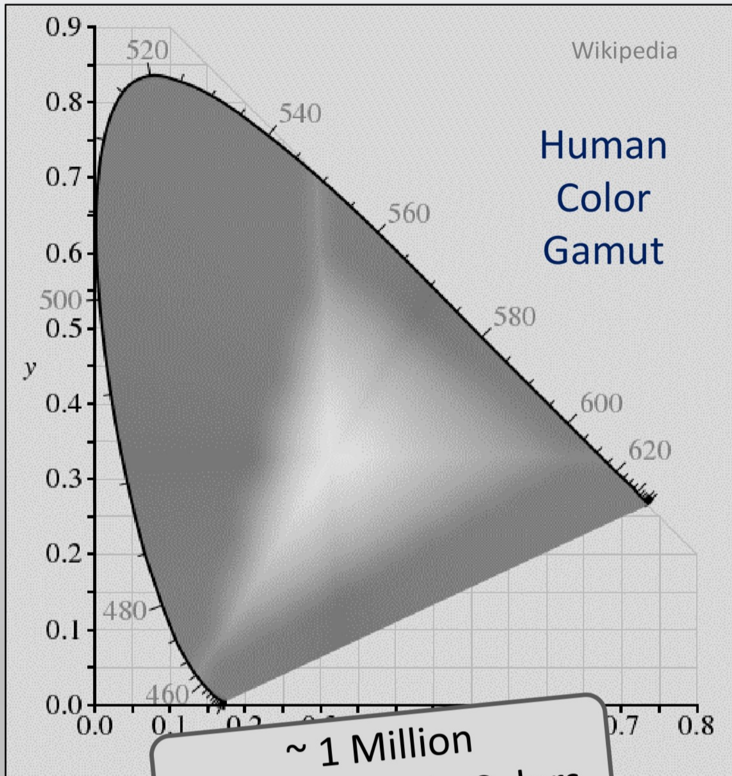
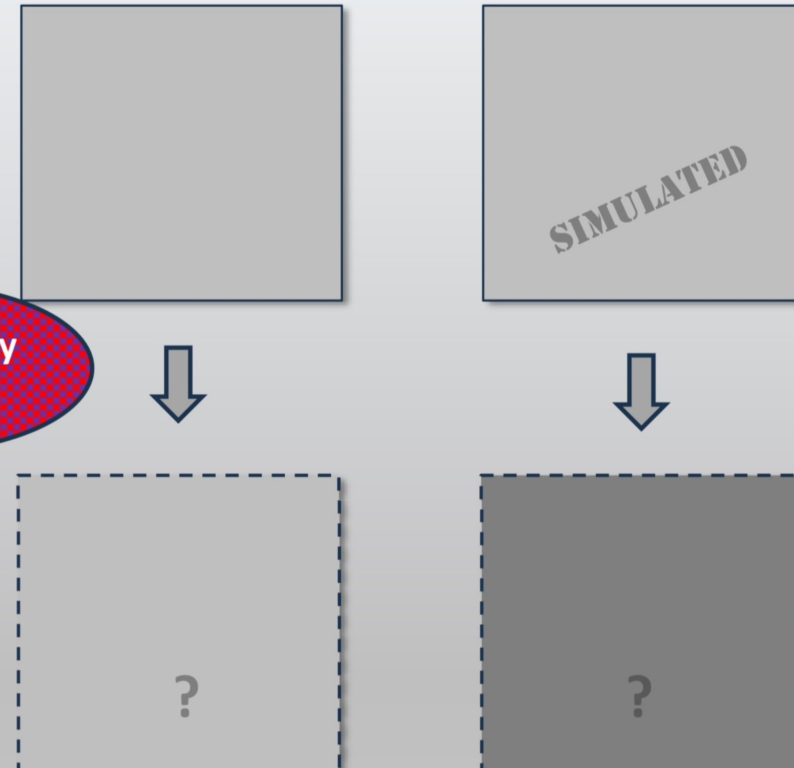


~ 1 Million
Distinguishable Colors

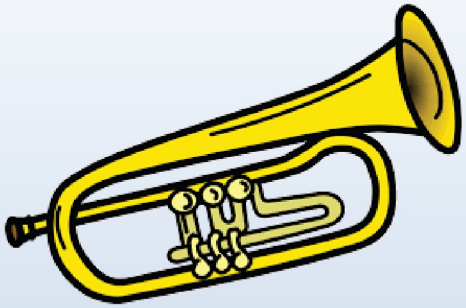
“Morning Banana” “Sirius Sky”



So, we Humans have a rather profound Color Blindness.

Are we also "Sound Deaf" ?

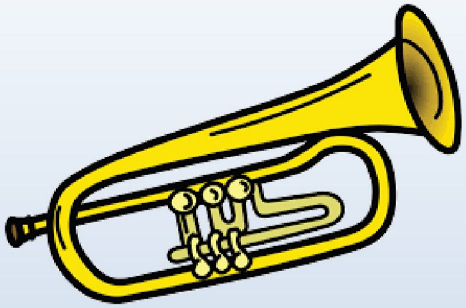
Are there very different Musical Sounds
that we can *hear* perfectly well,
but cannot *distinguish*?



What Sounds *Can* We Distinguish?

A little Different

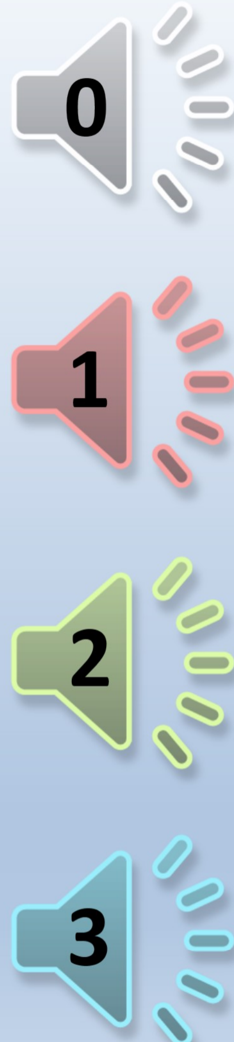
What Sounds Can We Distinguish?



Another Comparison

A *tiny* bit Different

What *Alien* Sounds *Can* We Distinguish?



What *Alien* Sounds *Can* We Distinguish?

0

1

2

3

All 4 are Very Different Sounds

Course Outline

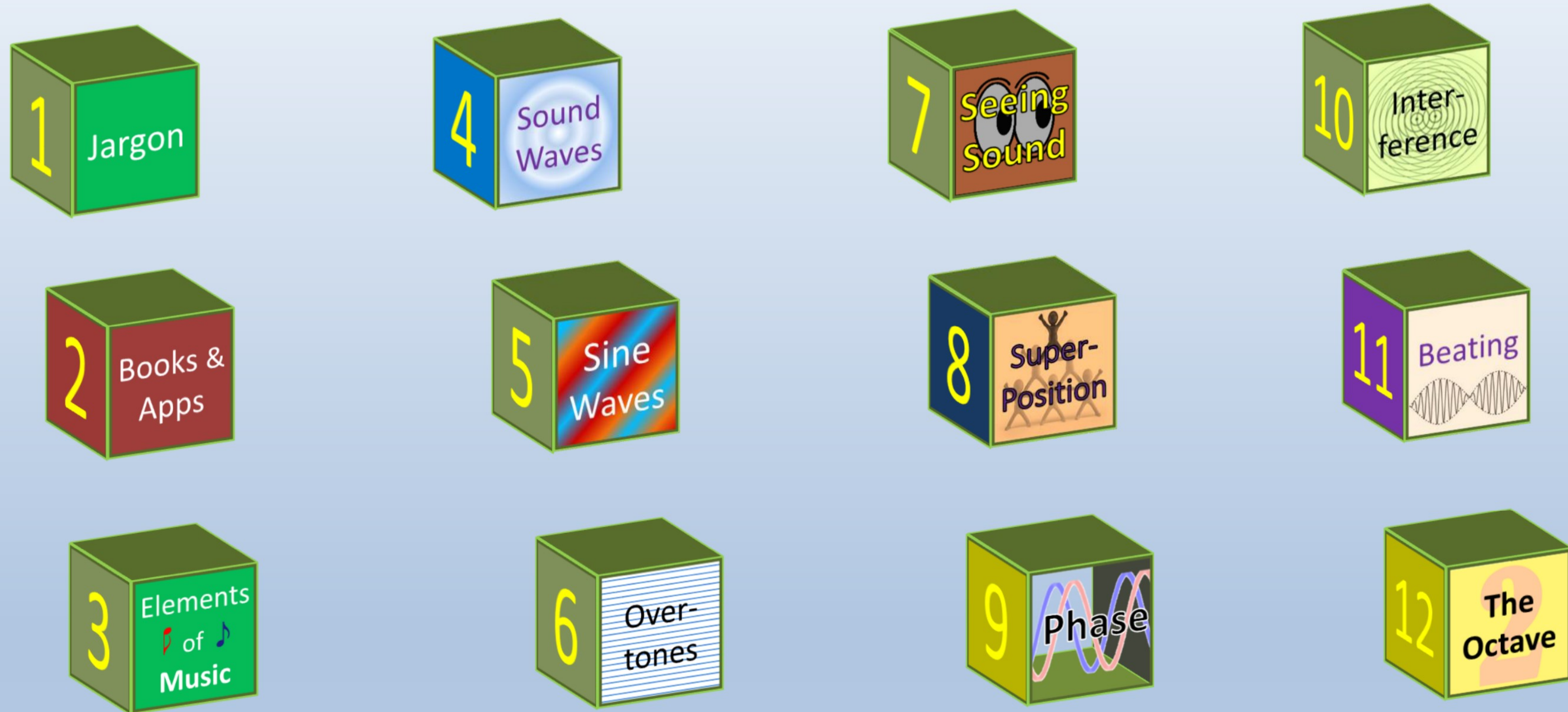
1. **Building Blocks: Some basic concepts**
2. Resonance: Building Complex Sounds
3. Hearing and the Ear
4. Musical Scales and Musical Notation
5. Musical Instruments: Strings and Timbre
6. Musical Instruments: Pipes
7. Human Voice and Singing
8. Harmony and Dissonance; Chords

Question Times

- Zoomland
- In Person

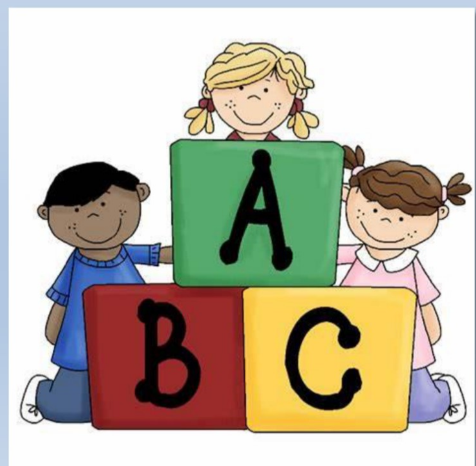
- Halfway Through
- At the End

Session 1 Outline: Building Blocks

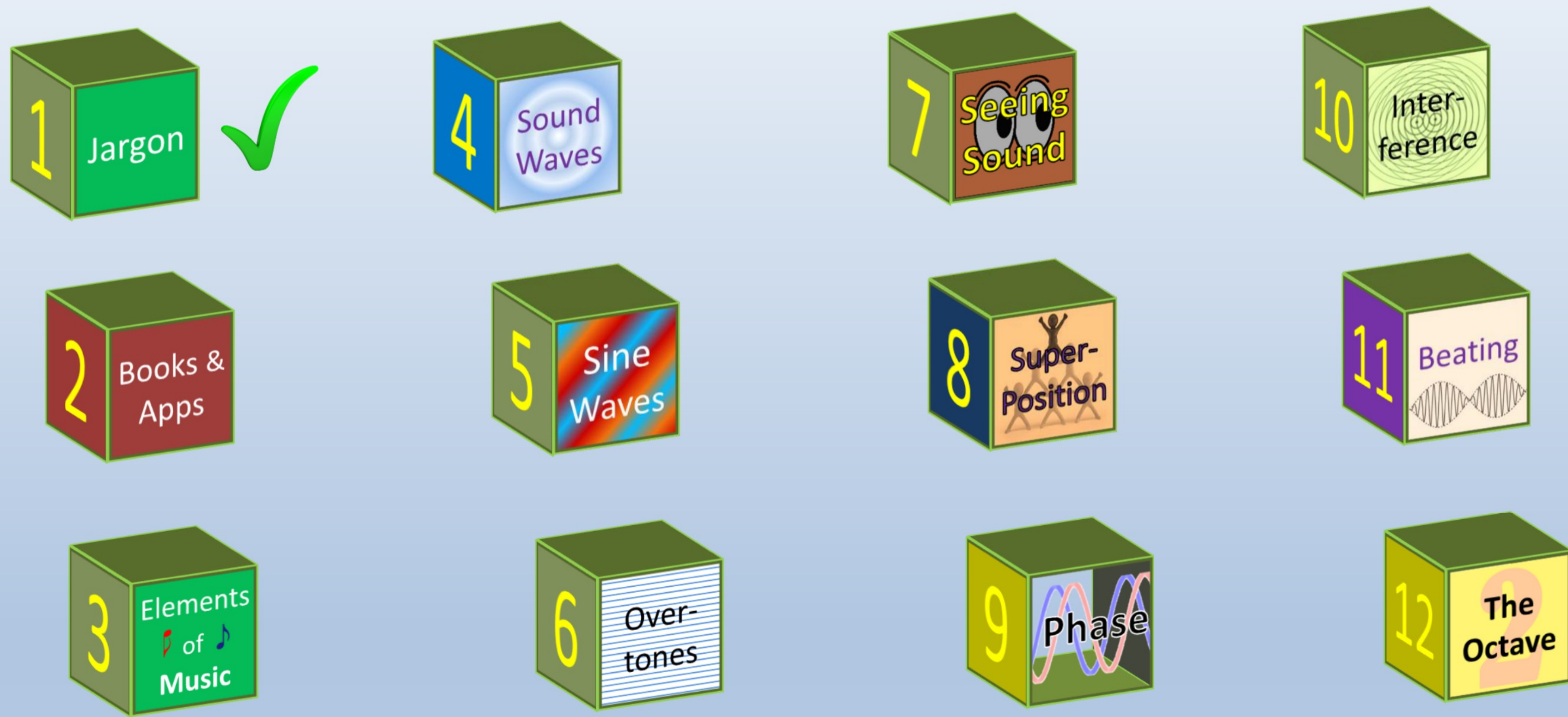


Jargon

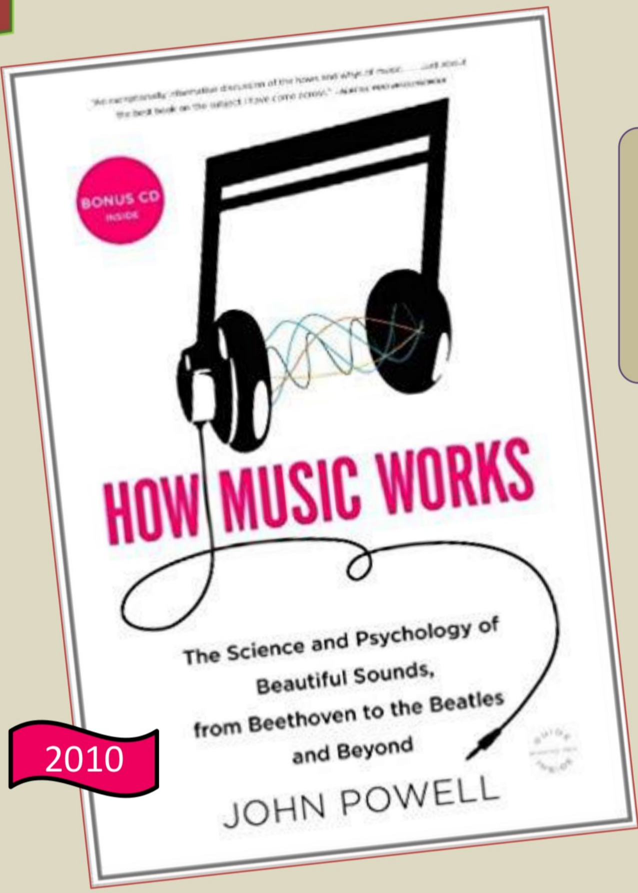
- We'll try to *avoid* Jargon (as much as possible)
- Music has a very long history
  - Vocabulary, concepts, notation, even instruments have deep roots
  - Lots of baggage…Legacy terminology
  - Potential for obscuration or confusion!



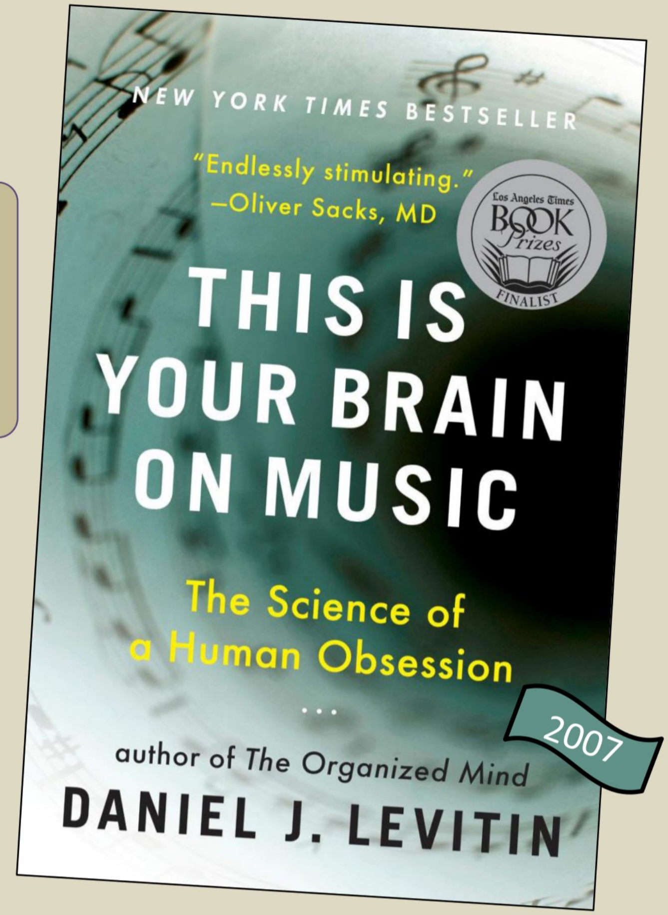
Building Blocks



Books

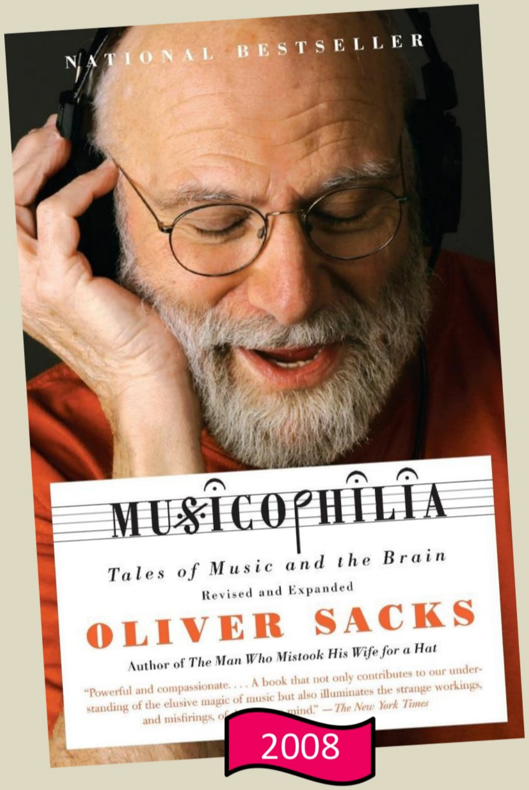


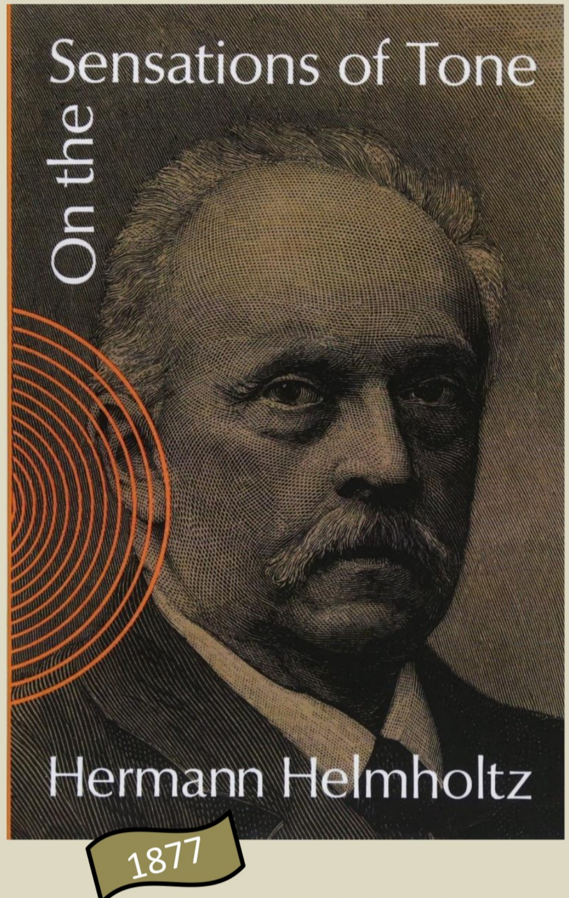
Both Authors are
Scientists
and
Musicians

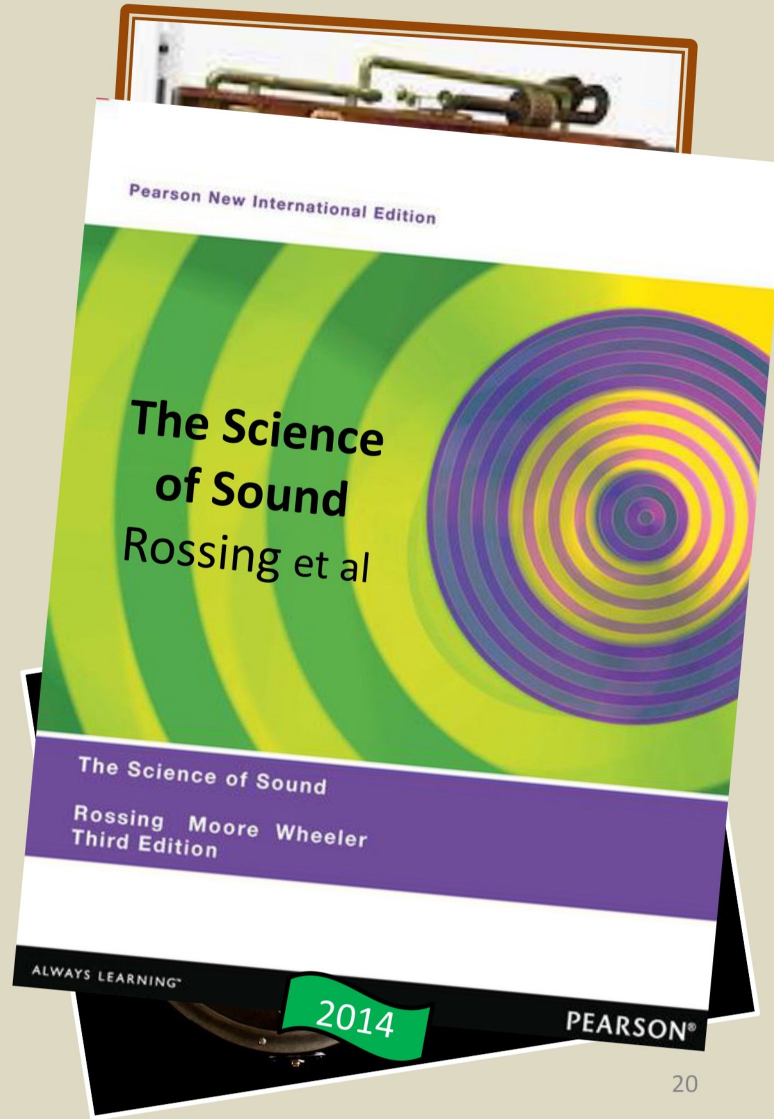



2
Books &
Apps

More Books


NATIONAL BESTSELLER
MUSICOPHILIA
Tales of Music and the Brain
Revised and Expanded
OLIVER SACKS
Author of The Man Who Mistook His Wife for a Hat
2008


On the
Sensations of Tone
Hermann Helmholtz
1877


Pearson New International Edition
The Science of Sound
Rossing et al
The Science of Sound
Rossing Moore Wheeler
Third Edition
ALWAYS LEARNING
PEARSON
2014

Books & Apps

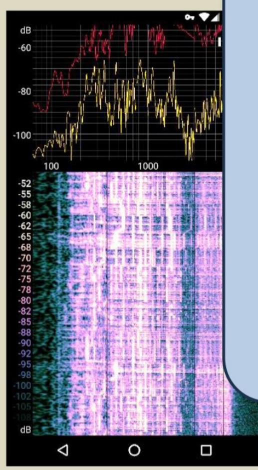
SmartPhone Apps

In App Store, search for **"Audio Analyzer"**

android iOS

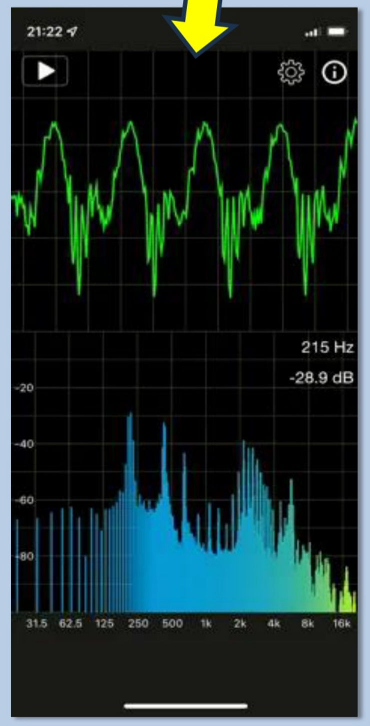
Advanced Spectrum Analyzer Pro

Spectroid



Audio/Spectrum Analyzer

Free (IOS)

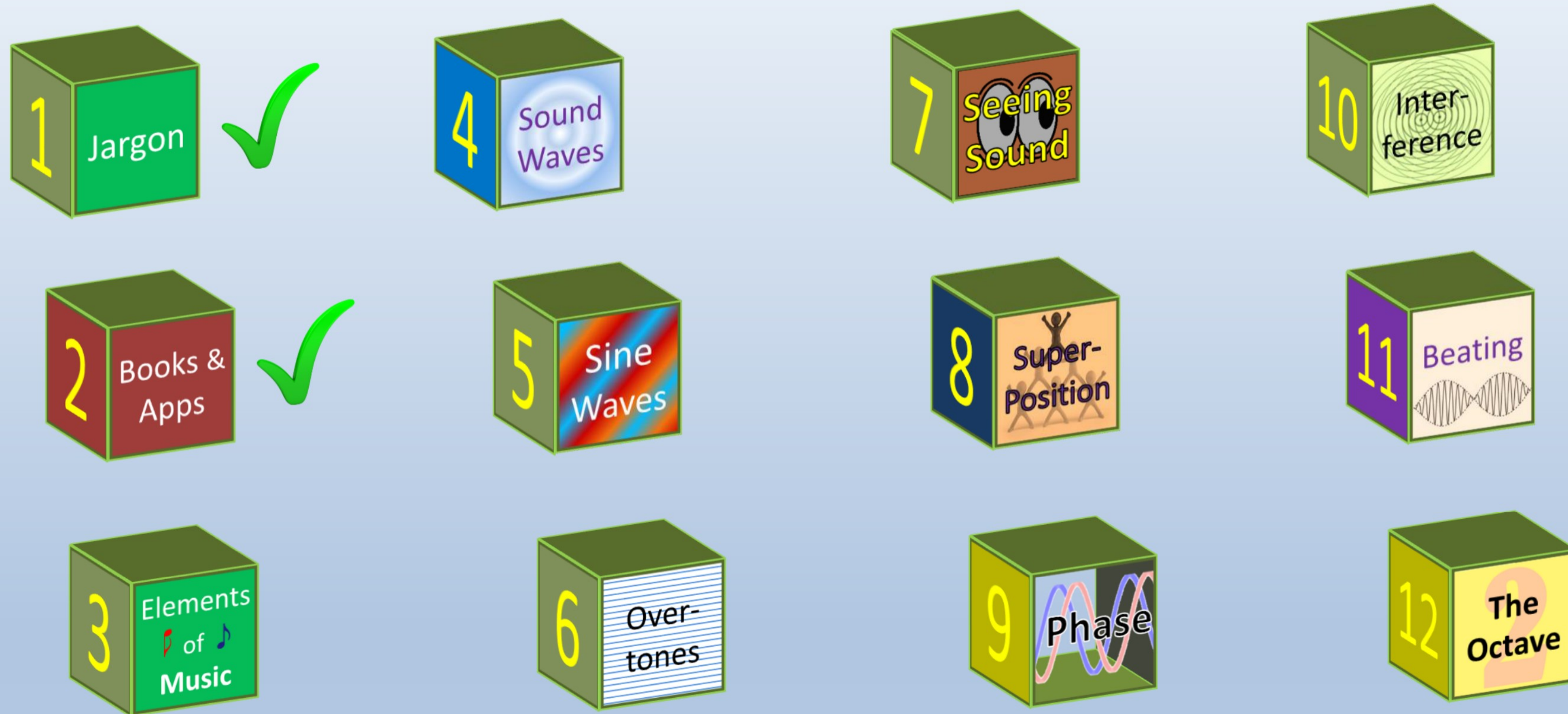


FFT Wave

Free for Android *and iOS*

Hz

Building Blocks



Elements of Music

- Rhythm

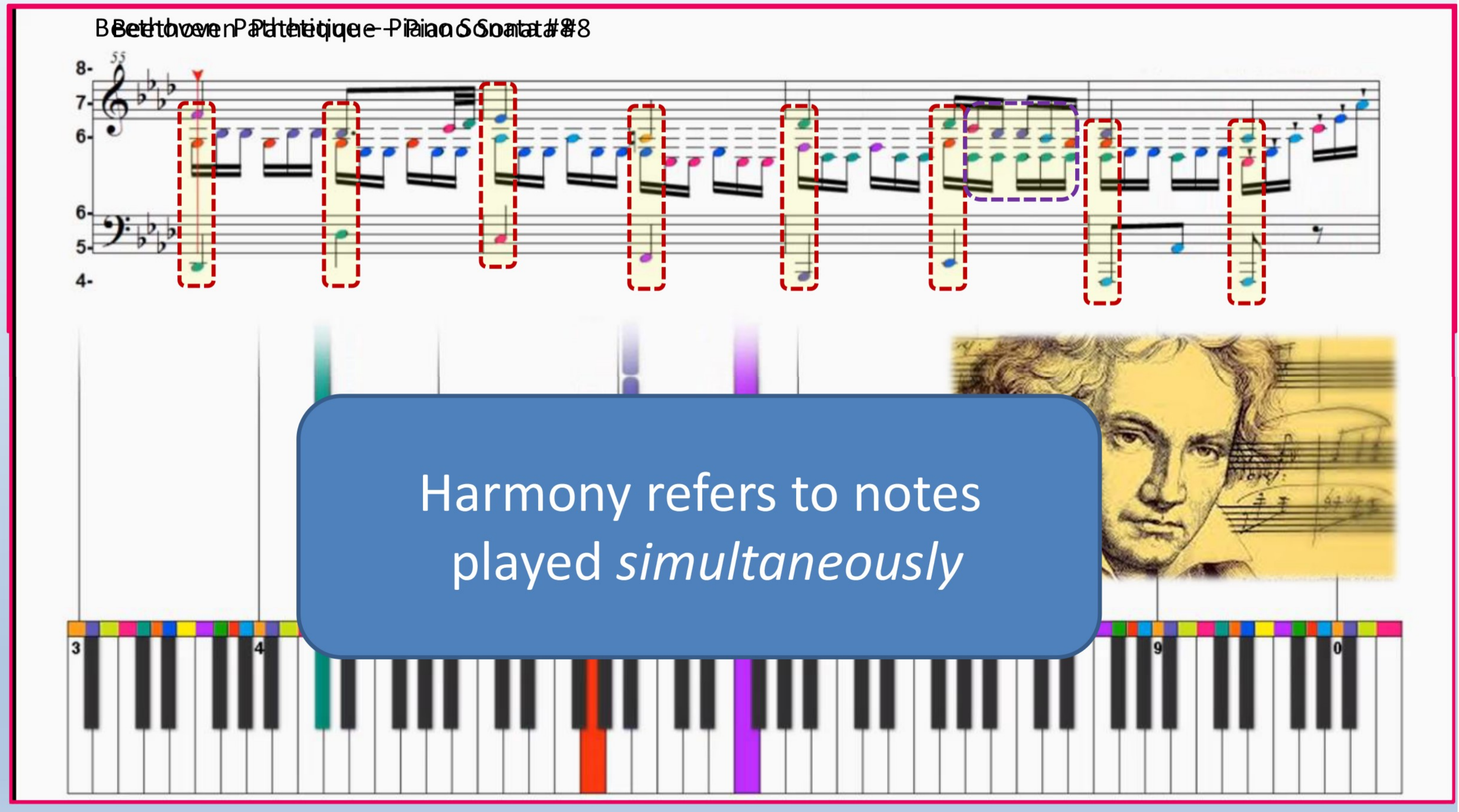
Elements of Music

- Rhythm
- Melody

Tchaikovsky Swan Lake Easy Notes Sheet Music for Violin Flute Oboe

Elements of Music

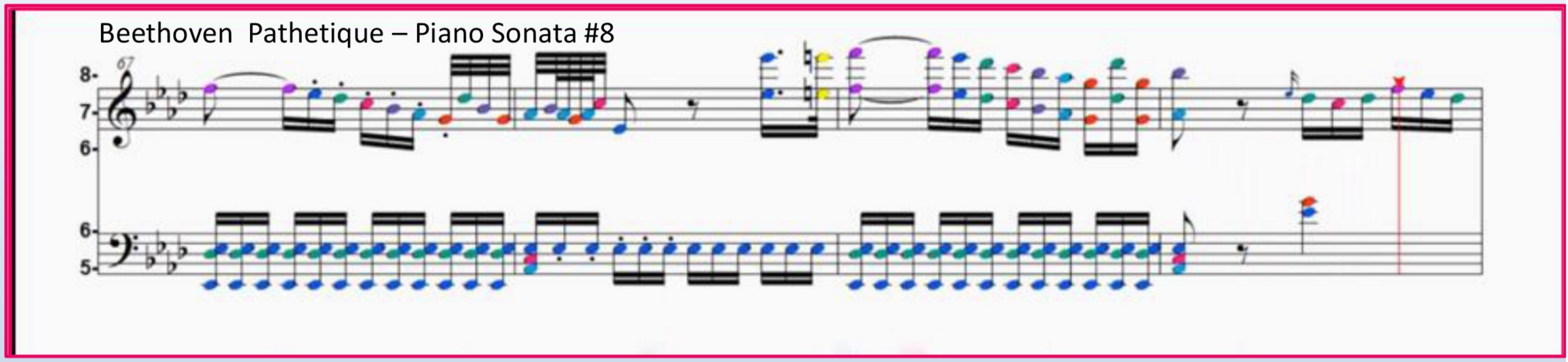
- Rhythm
- Melody
- **Harmony**



Harmony refers to notes played *simultaneously*

Elements of Music

- Rhythm
- Melody
- **Harmony**



Elements of Music

- Rhythm
- Melody
- Harmony

Elements of Music

- Rhythm
- Melody
- **Harmony**

Elements of Music

- Rhythm
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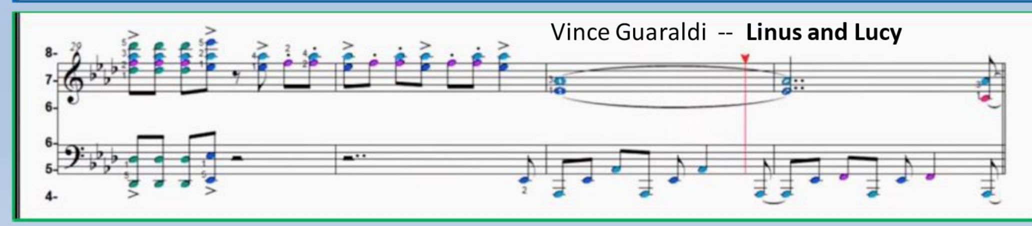
- **Harmony**

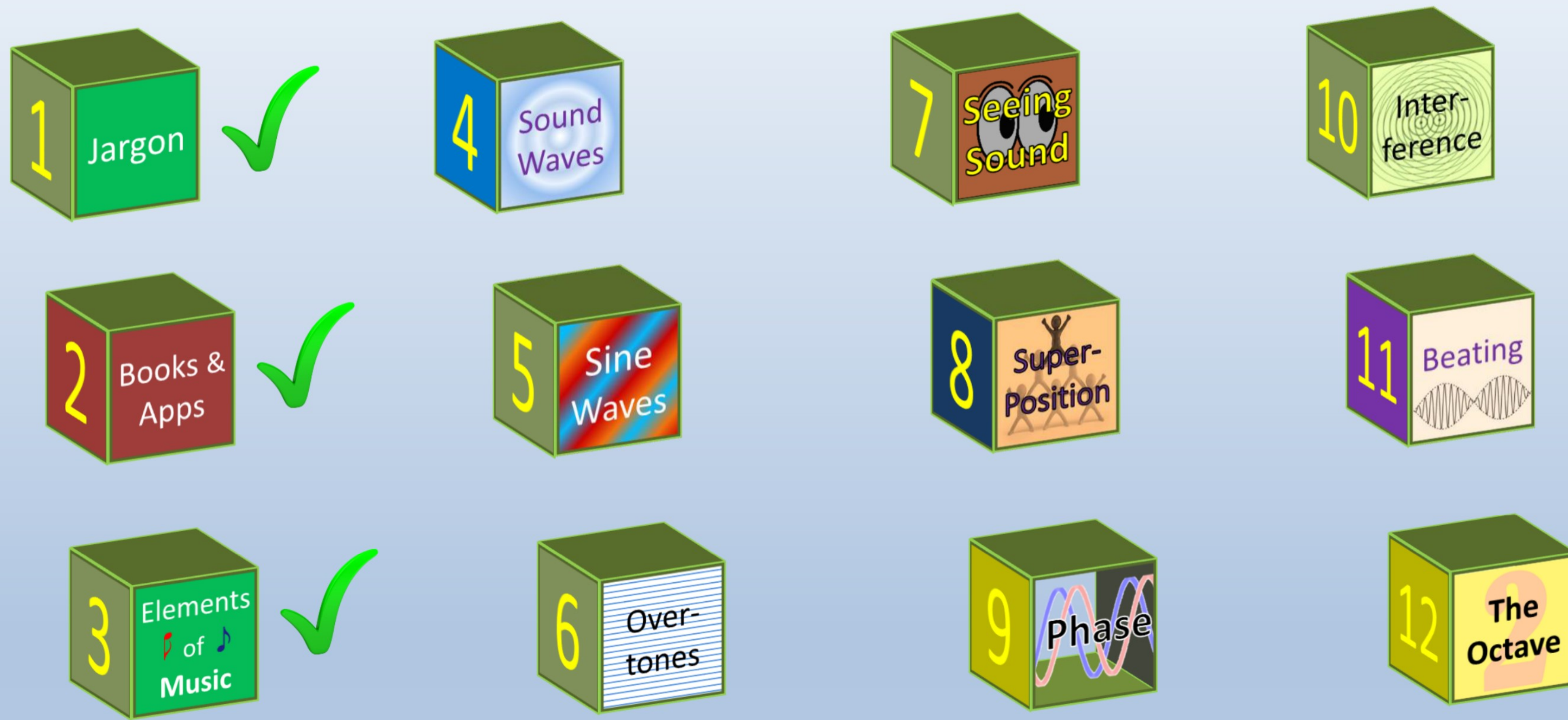


Elements of Music

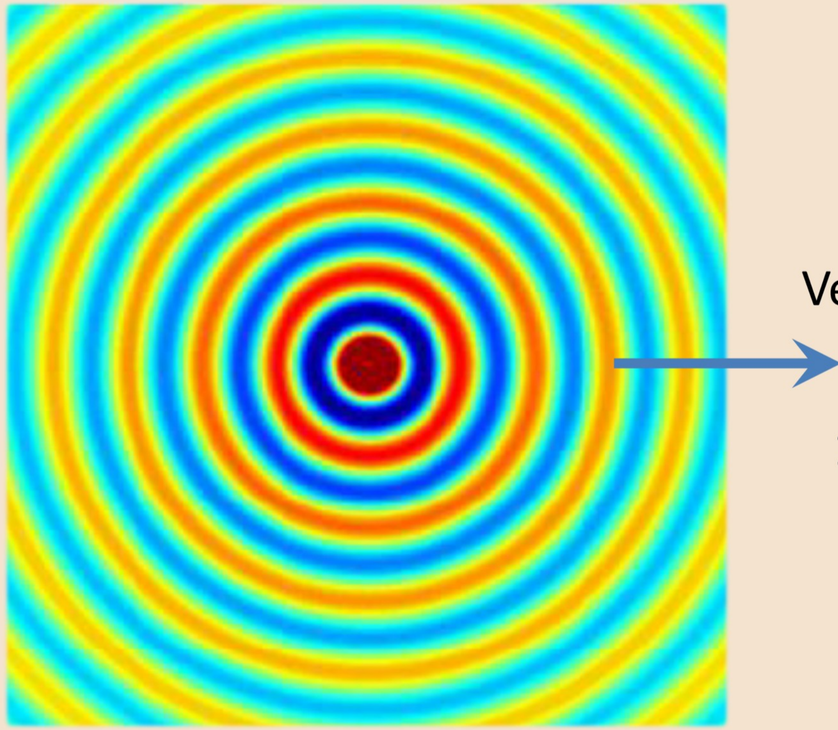
- Rhythm
- Melody
- Harmony
- **Tonality**

Tchaikovsky: Swan Lake Theme (A minor)

Building Blocks



Sound Waves in Air



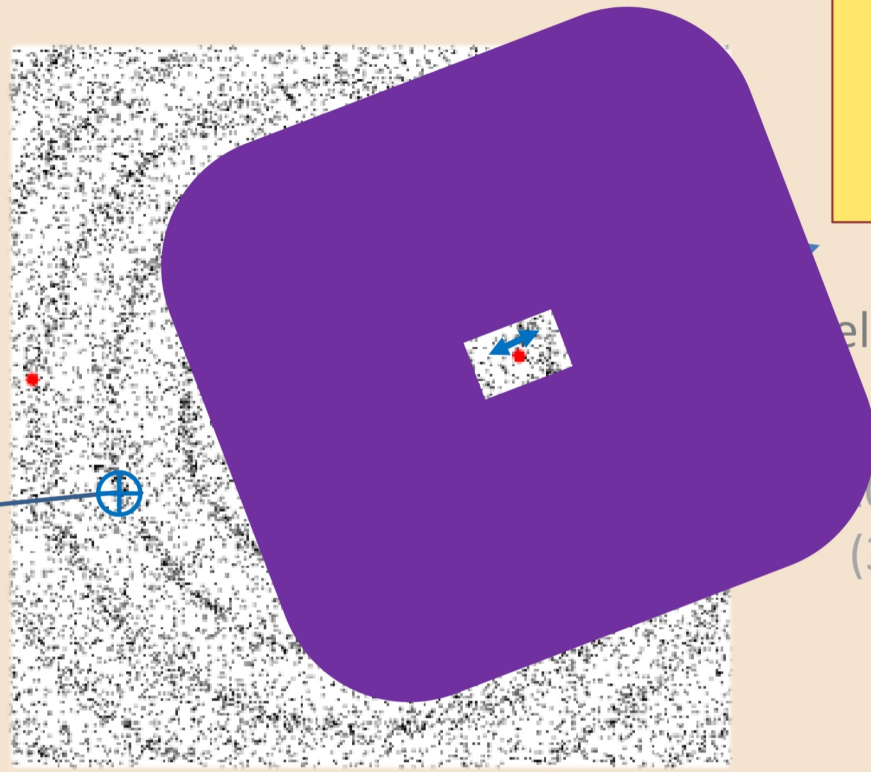
Velocity:

1000 ft/sec
(300 m/s)

Sound Waves in Air

Longitudinal Wave

Air molecules move *back and forth* along direction of wave propagation



elocity:

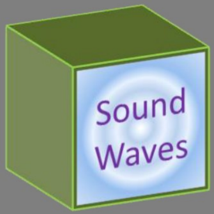
000 ft/sec
(300 m/s)

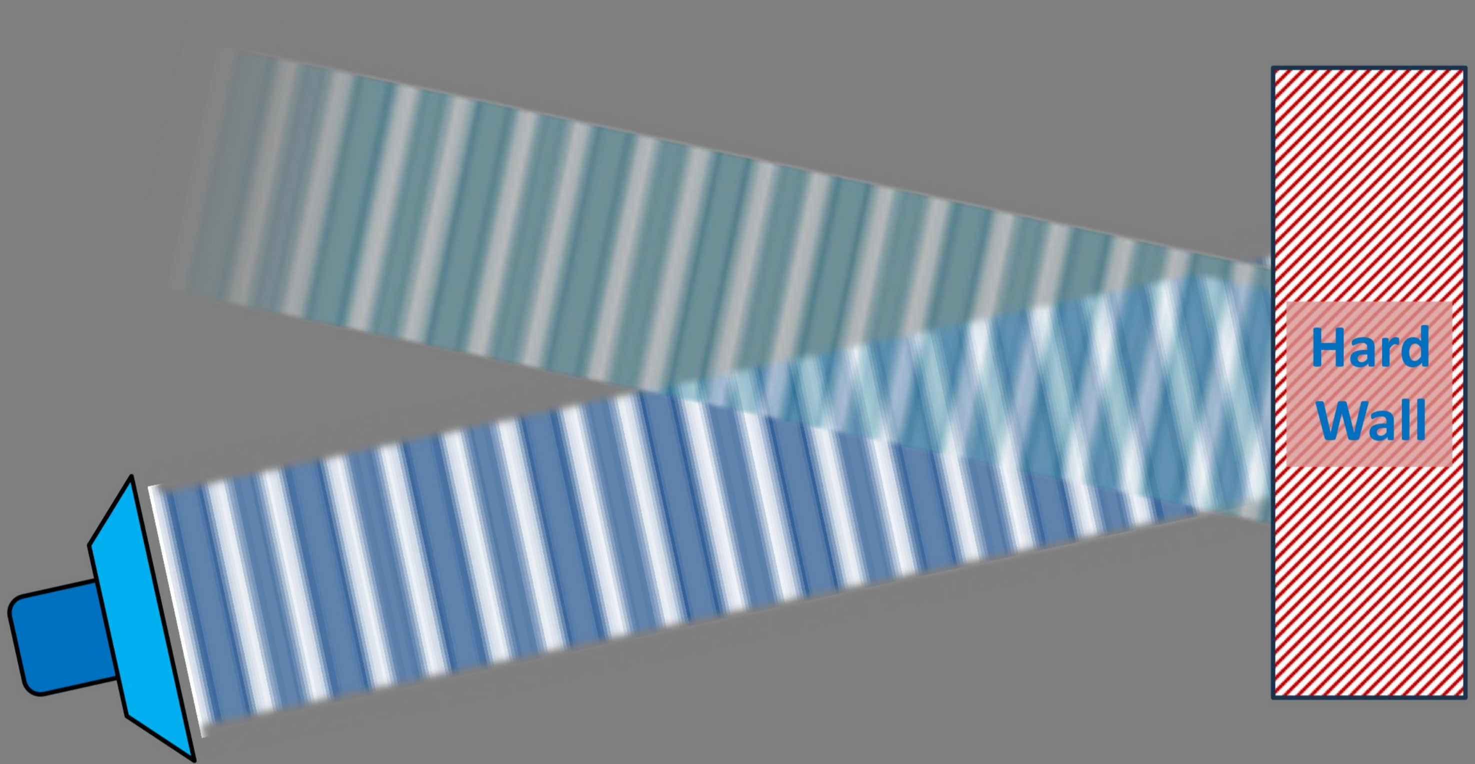
Air Pressure

bobs up and down as waves pass by any point

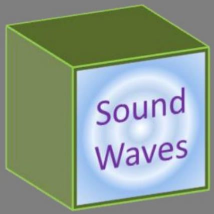
< 1 ***millionth*** of an atmosphere right now

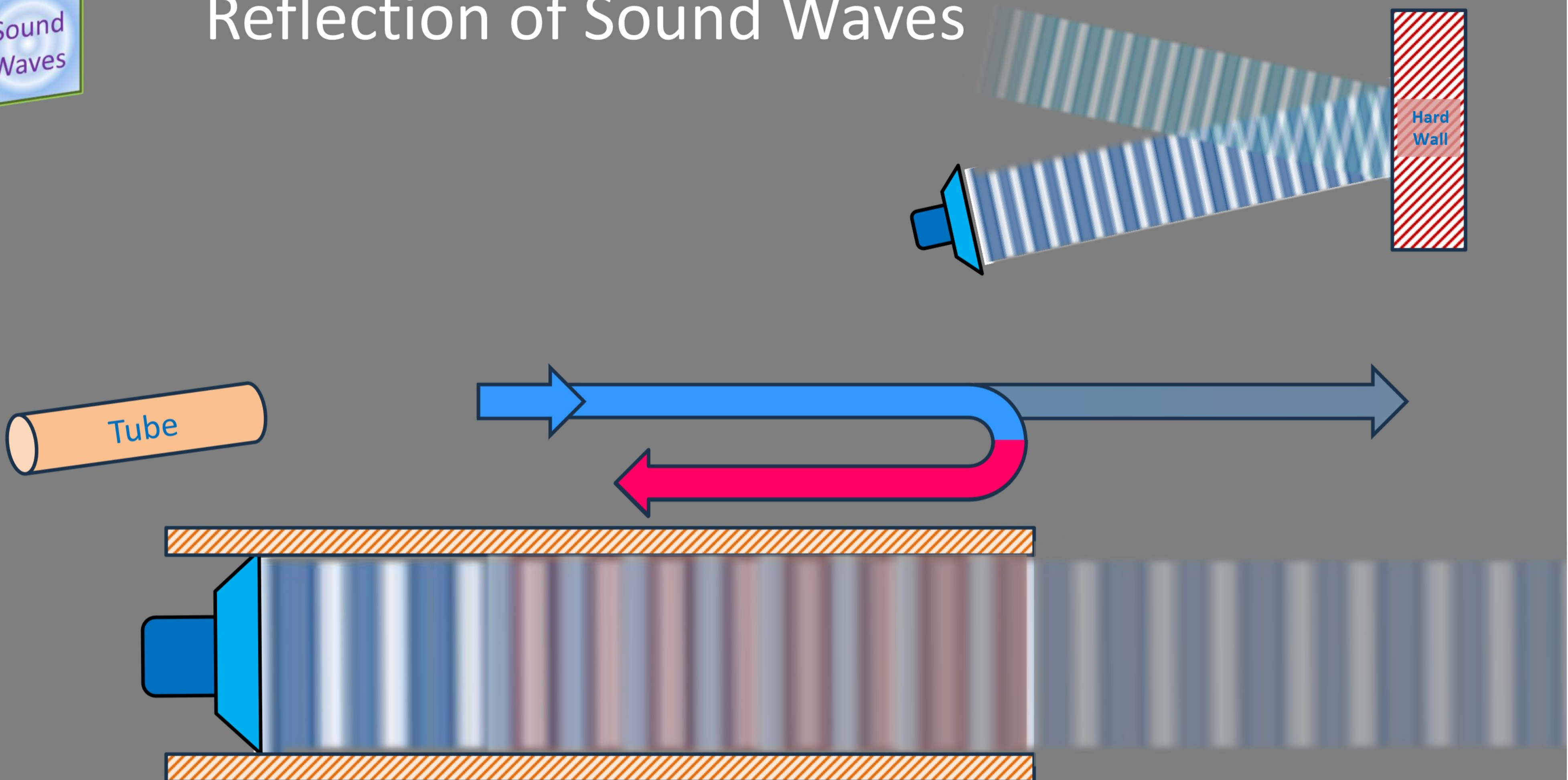
Reflection of Sound Waves



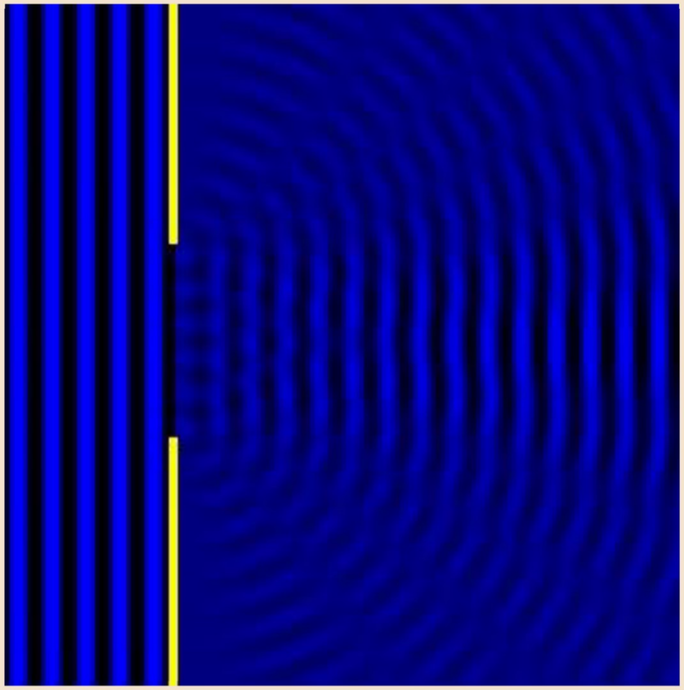


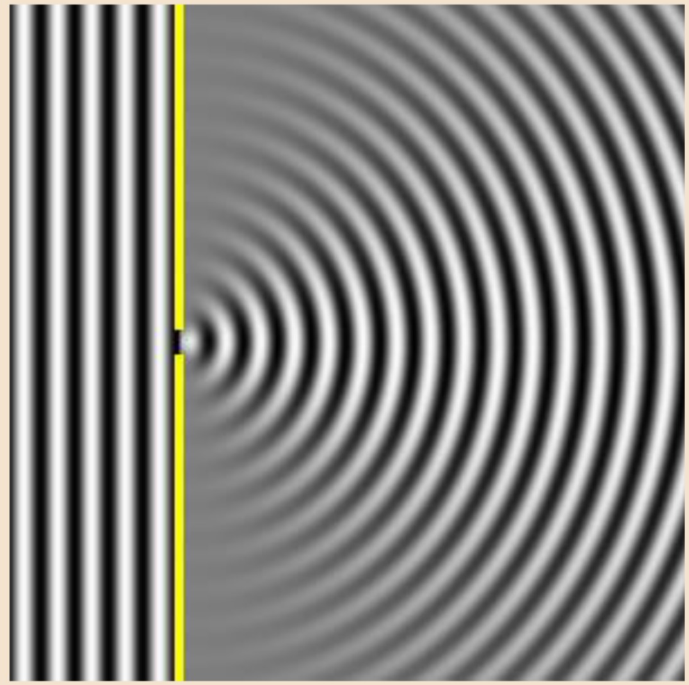
Reflection of Sound Waves



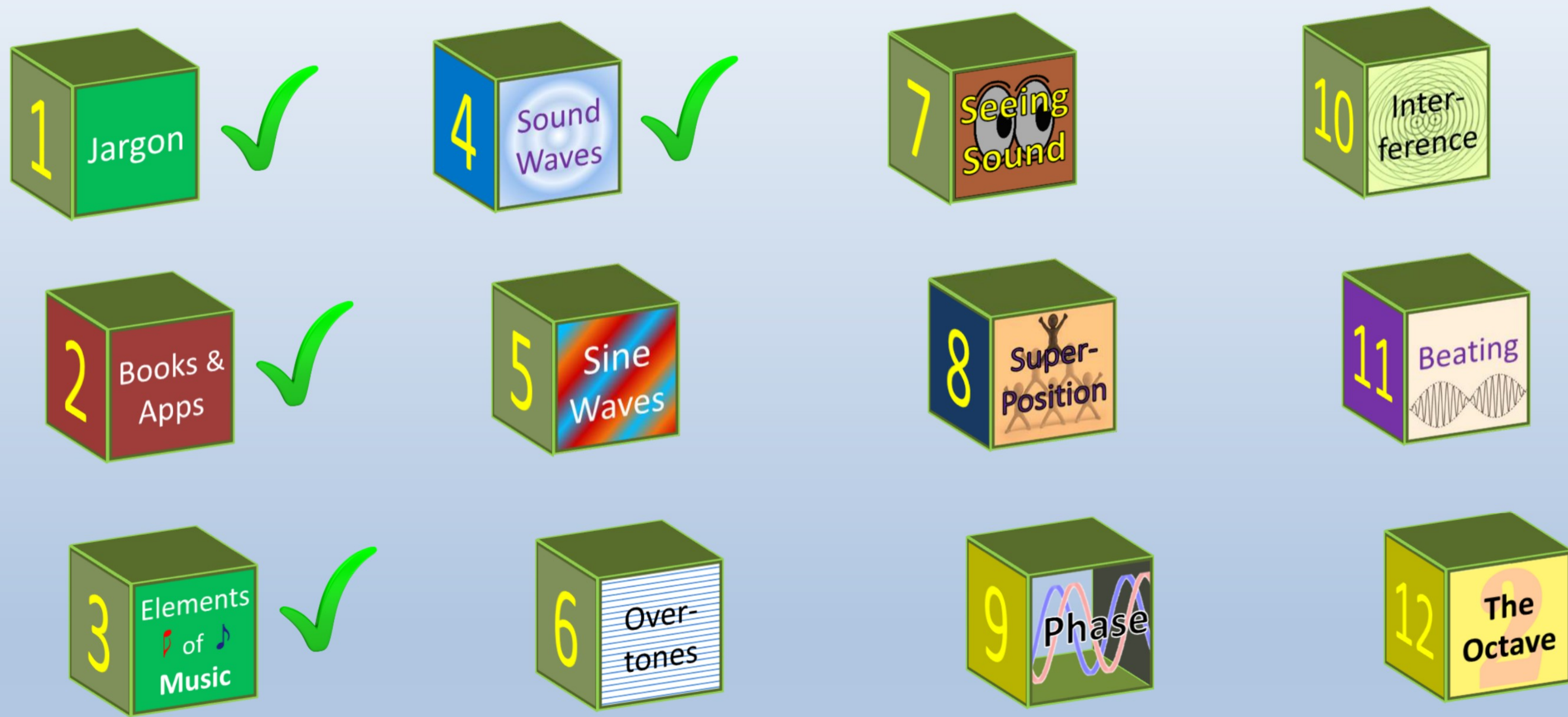


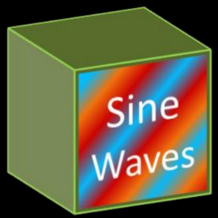
Sound Wave Diffraction



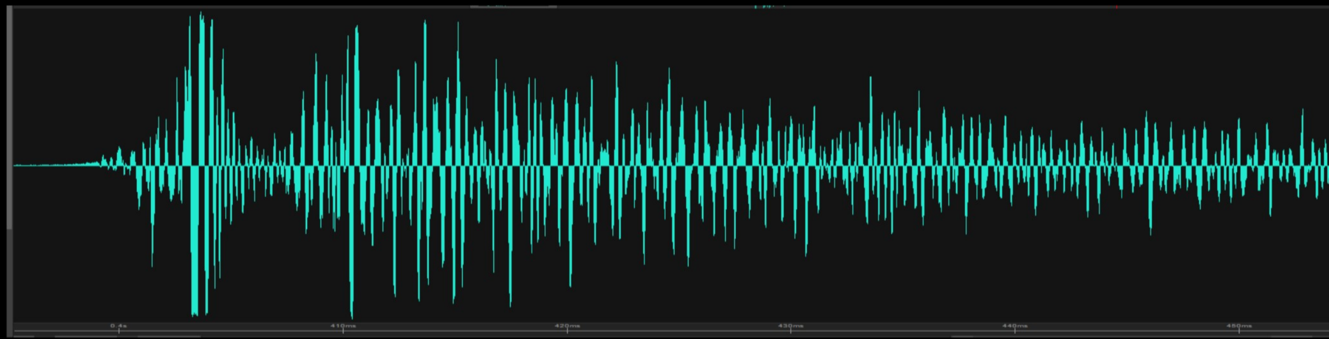


Building Blocks



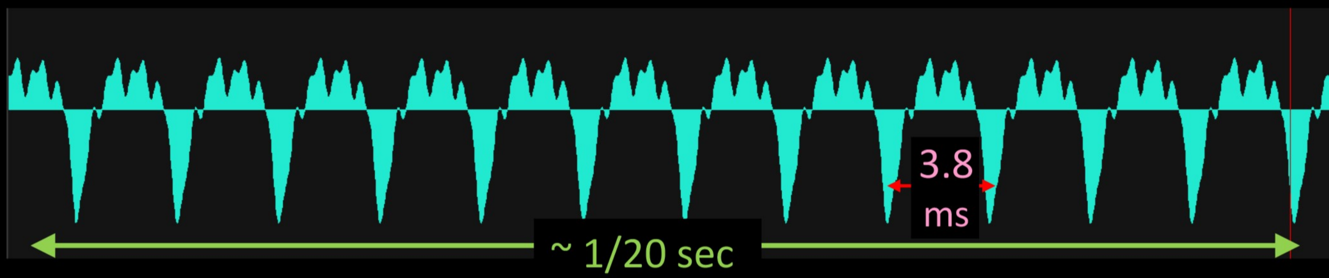


Types of Sound Waves



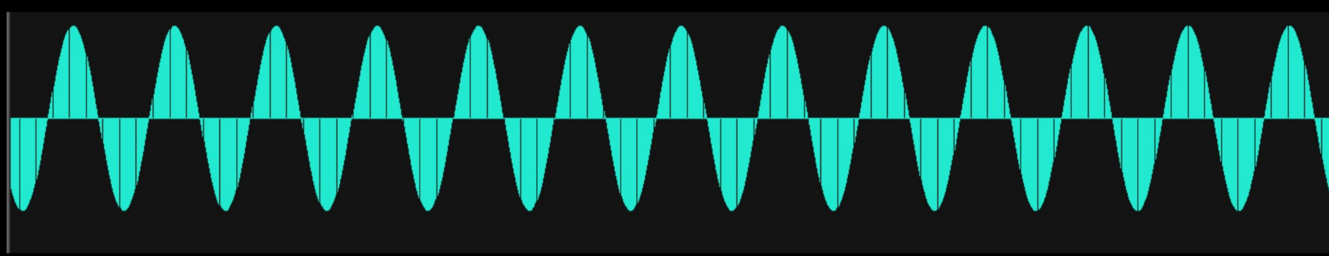
Non-periodic

e.g. Click sound



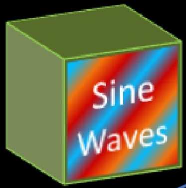
Periodic

e.g. Musical Note

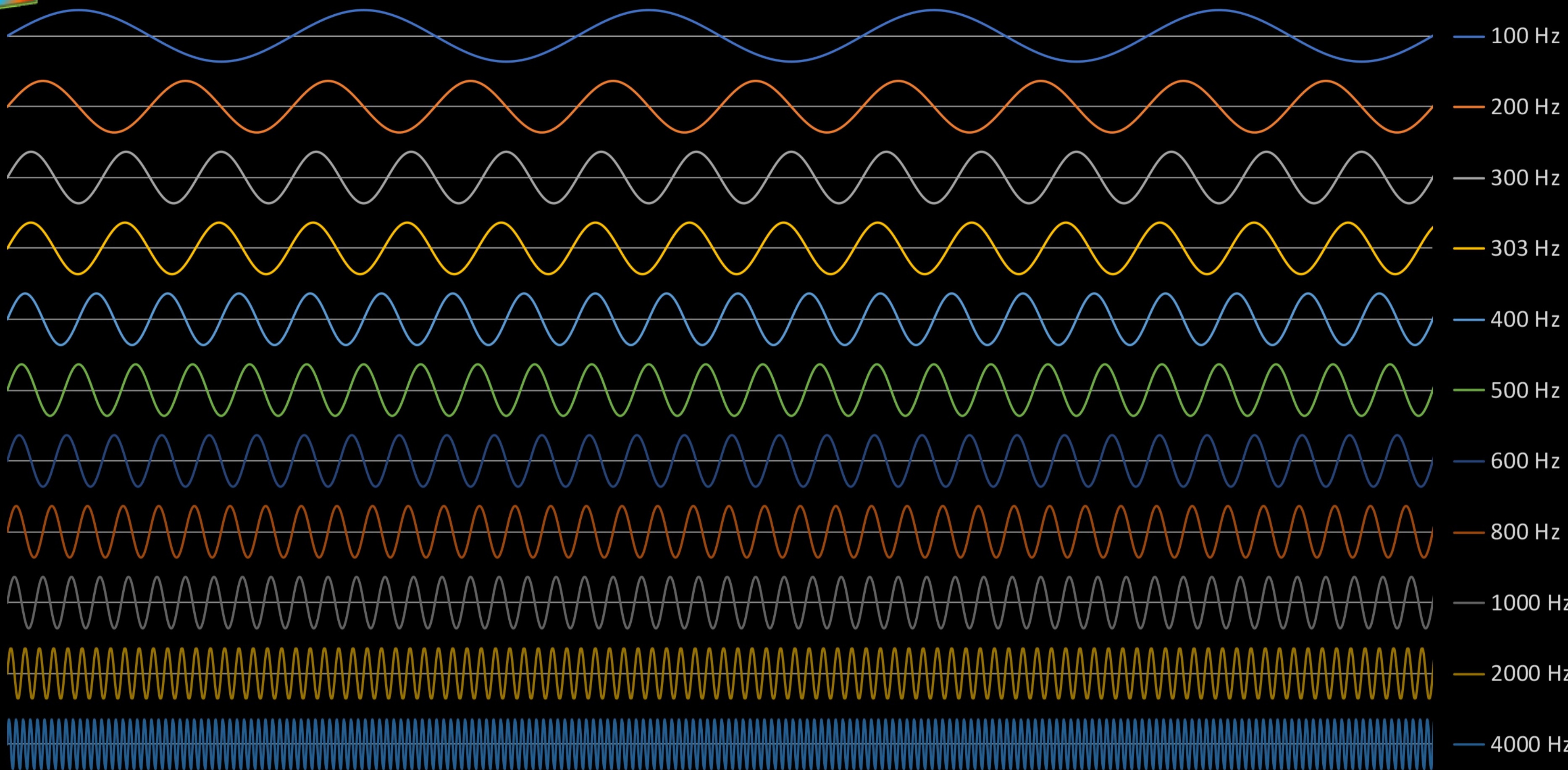


Sine

e.g. Hum



Sine Waves Characterized by Frequency



Sine Waves Characterized by Frequency

100 Hz
200 Hz
300 Hz
303 Hz
400 Hz
500 Hz
600 Hz
800 Hz
1000 Hz
2000 Hz
4000 Hz

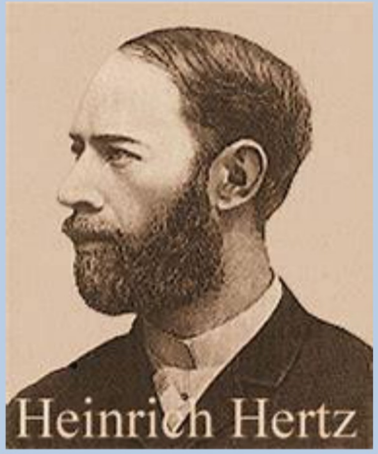
Frequency:

~~Vibrations per Second~~
~~or~~
~~Cycles Per Second~~

As of 1960, officially changed to

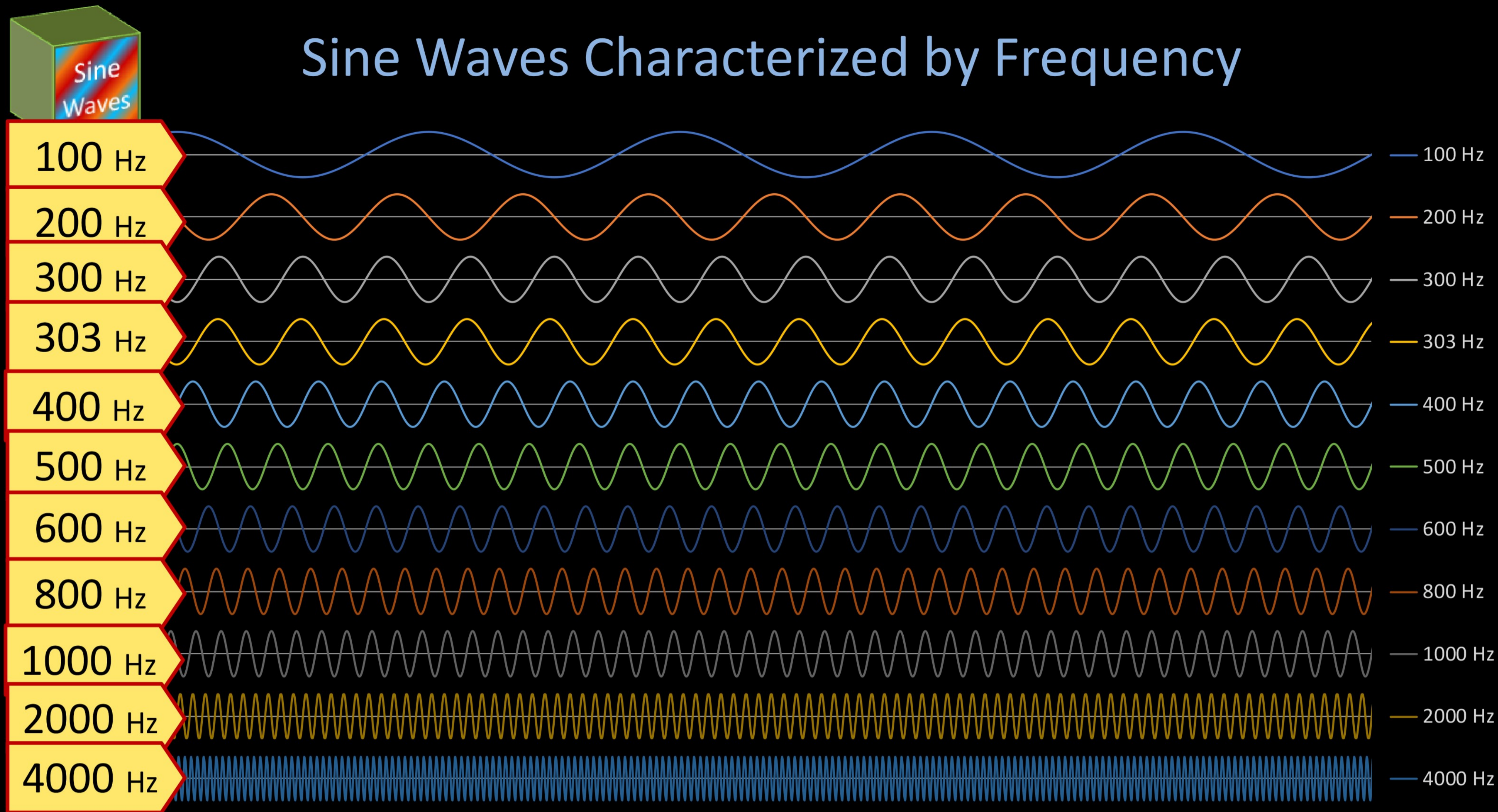
Hertz

Hz

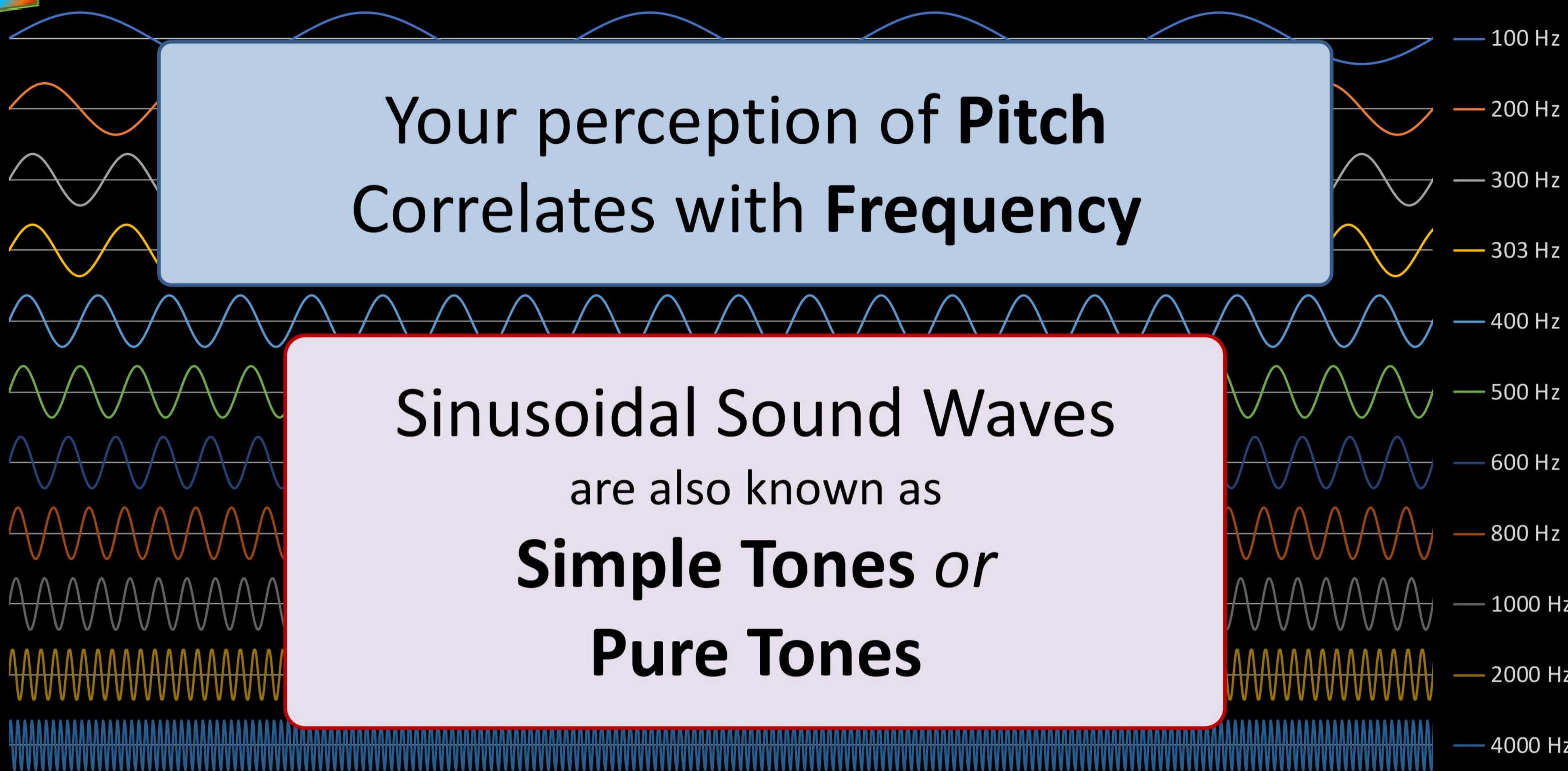


1857-1894

Sine Waves Characterized by Frequency



Sine Waves Characterized by Frequency



Your perception of **Pitch**
Correlates with **Frequency**

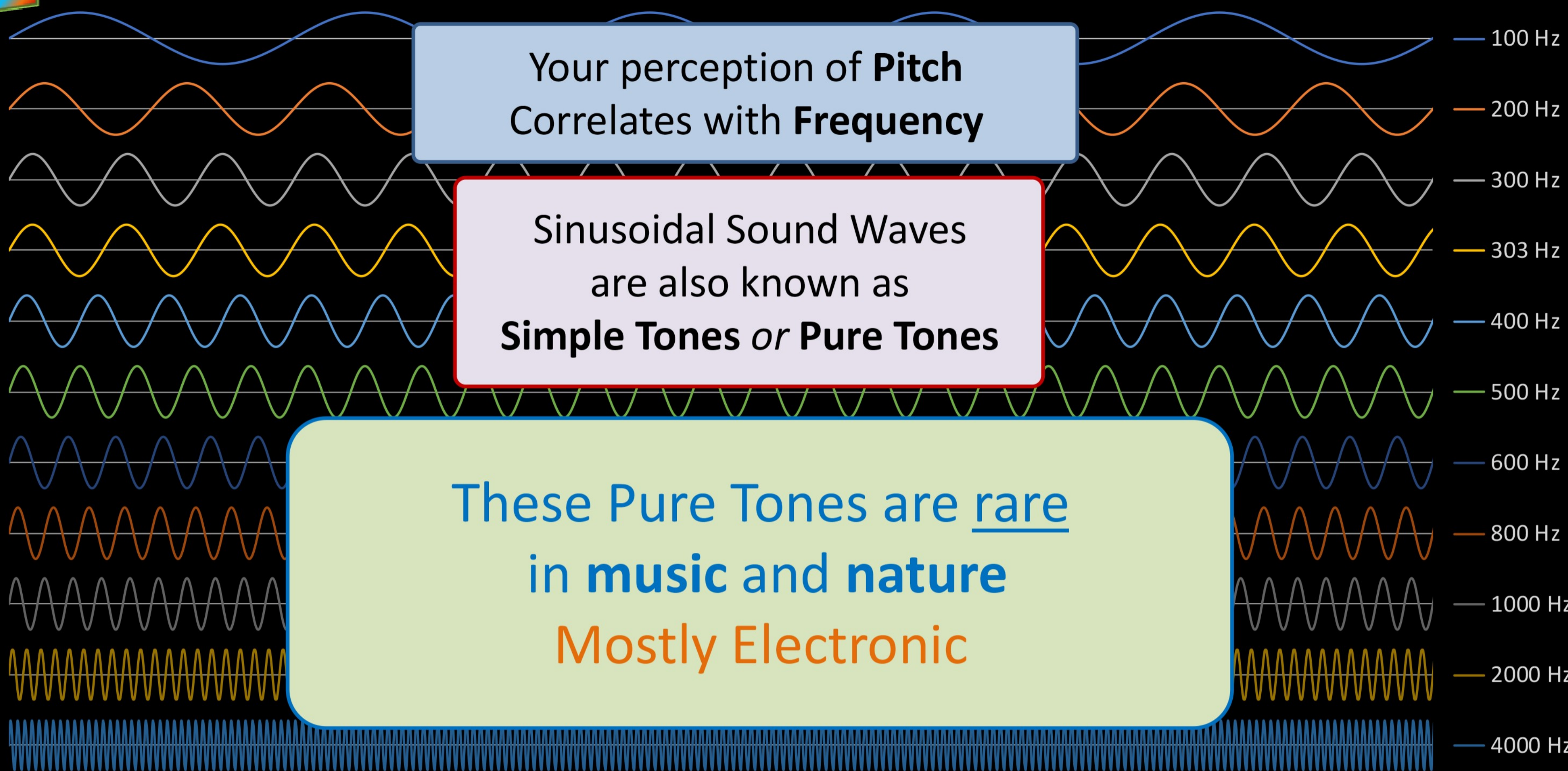
Sinusoidal Sound Waves

are also known as

Simple Tones *or*

Pure Tones

Sine Waves Characterized by Frequency

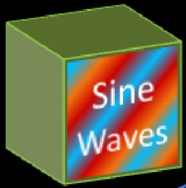


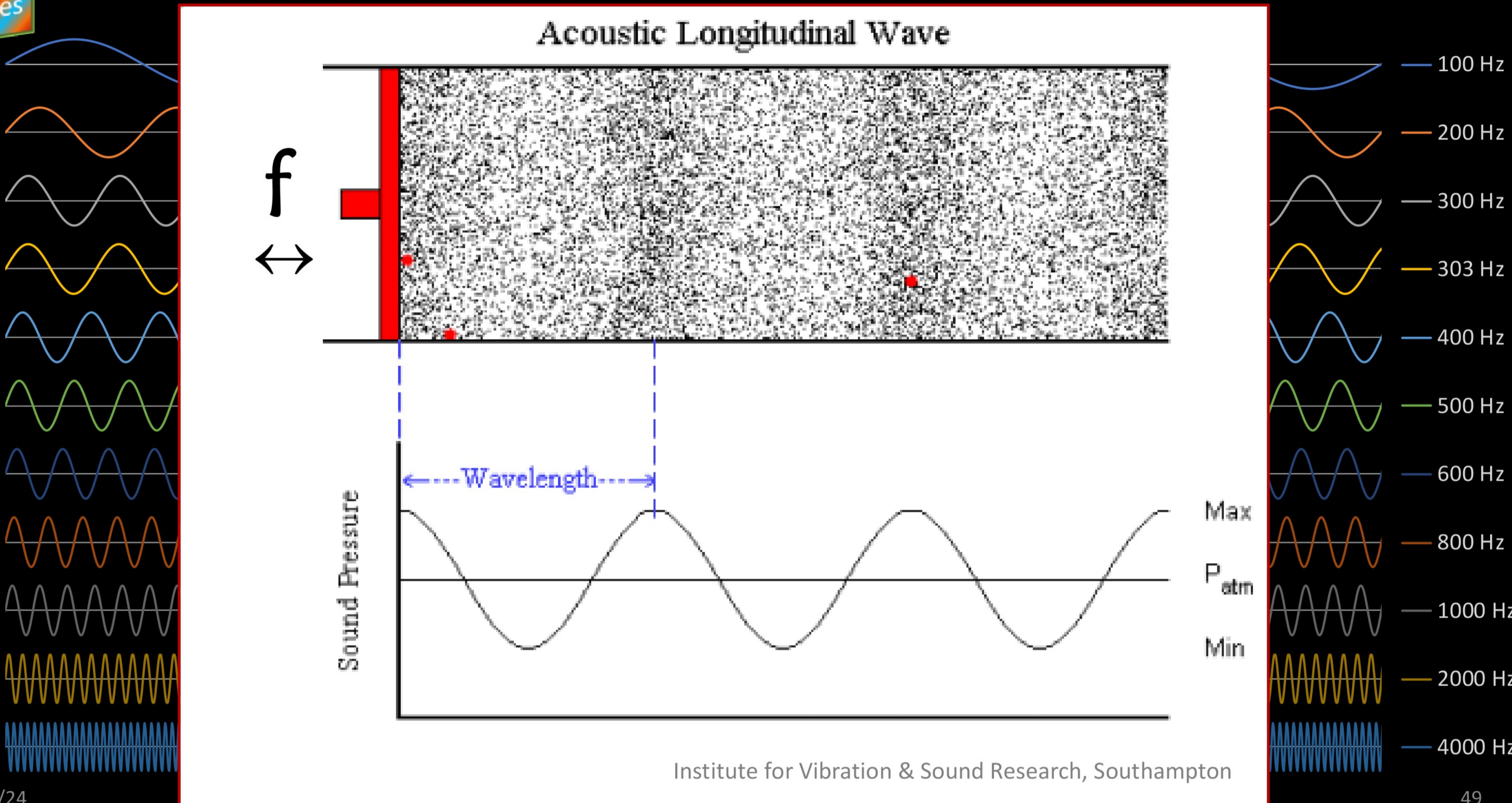
Your perception of **Pitch**
Correlates with **Frequency**

Sinusoidal Sound Waves
are also known as
Simple Tones *or* **Pure Tones**

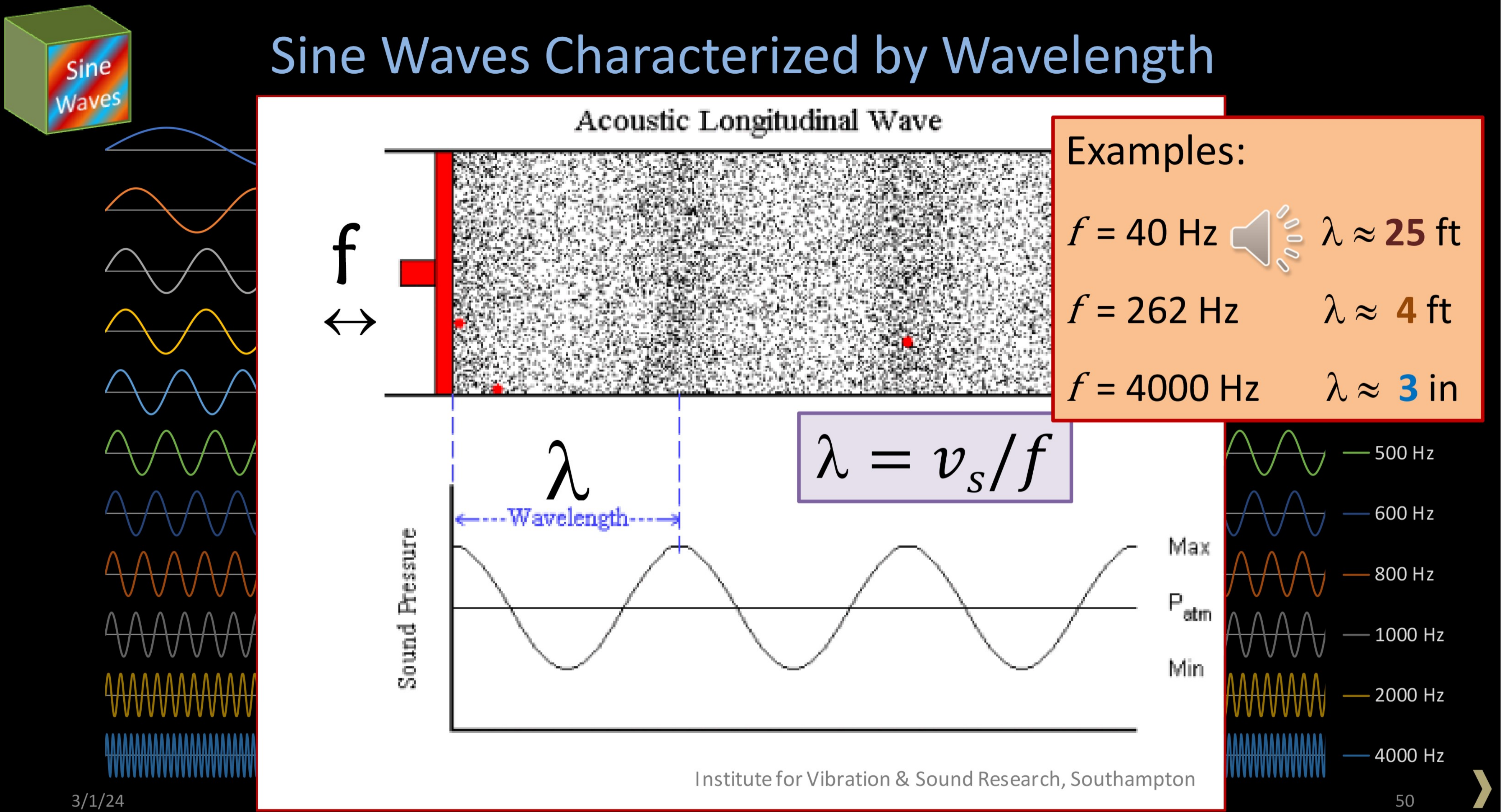
These Pure Tones are rare
in **music** and **nature**
Mostly Electronic

Sine Waves Characterized by Wavelength





Sine Waves Characterized by Wavelength



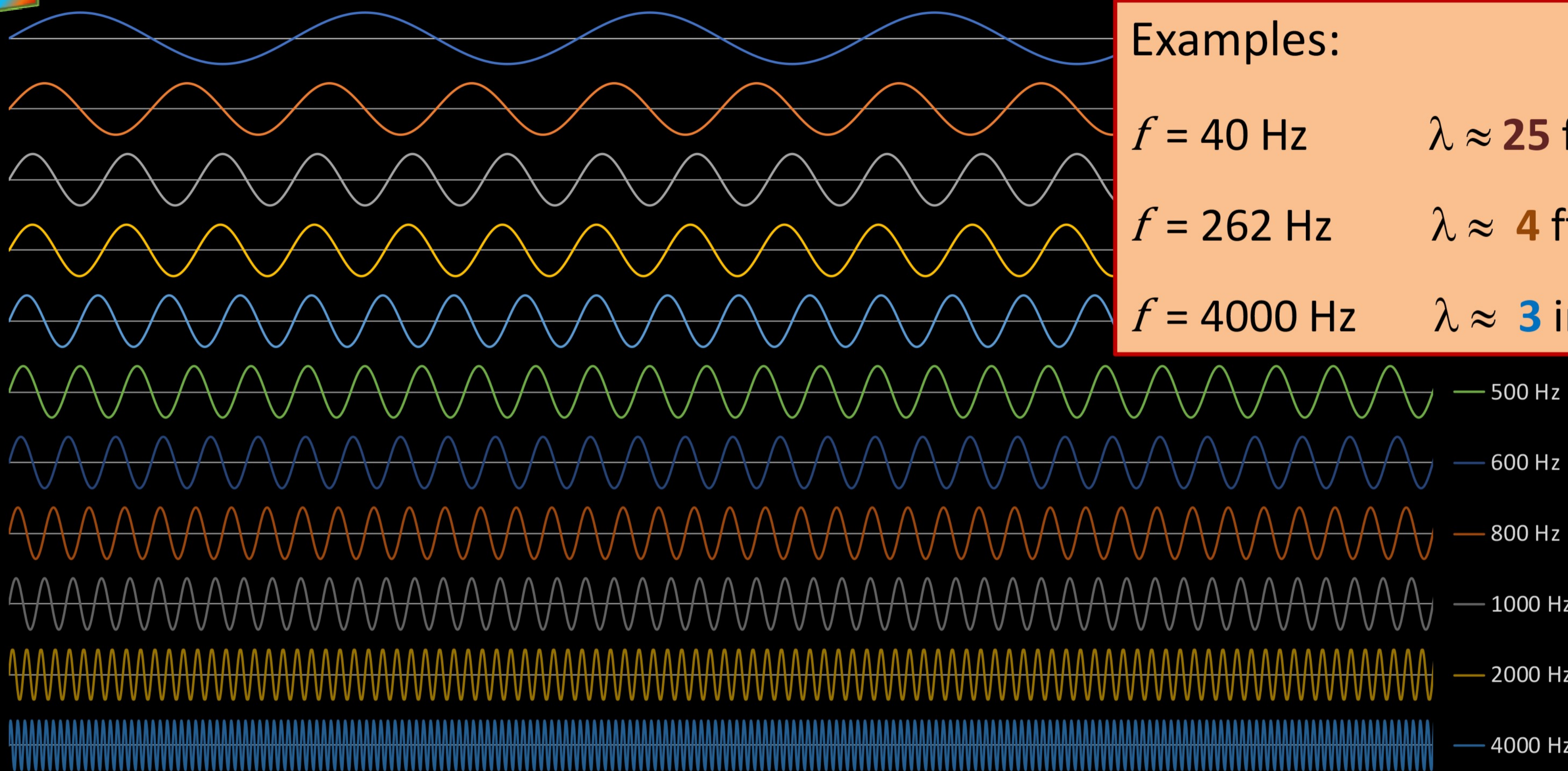
Examples:

f = 40 Hz λ ≈ **25** ft

f = 262 Hz λ ≈ **4** ft

f = 4000 Hz λ ≈ **3** in

Sine Waves Characterized by Wavelength



Examples:

f = 40 Hz $\lambda \approx$ **25** ft

f = 262 Hz $\lambda \approx$ **4** ft

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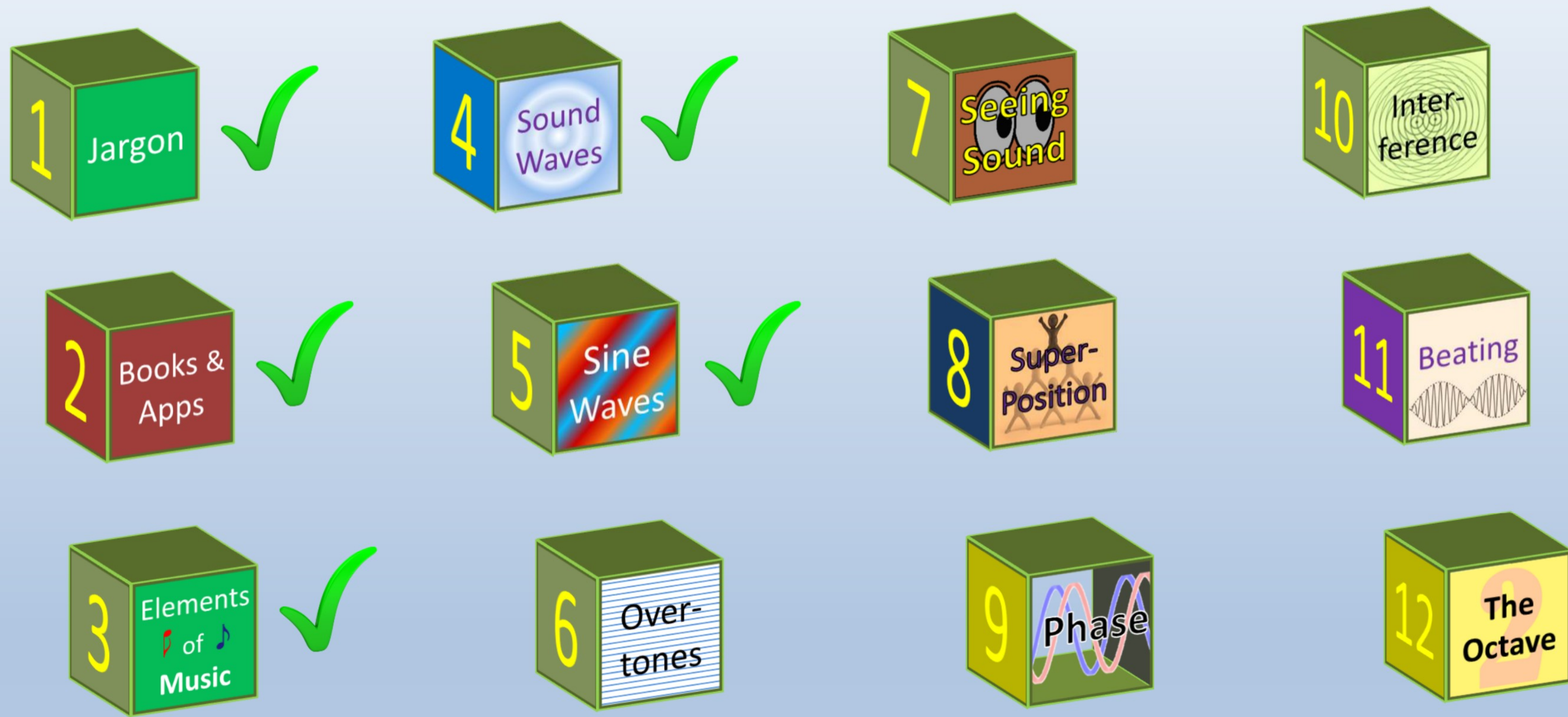
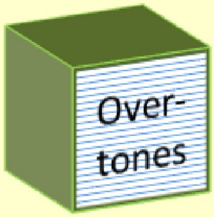
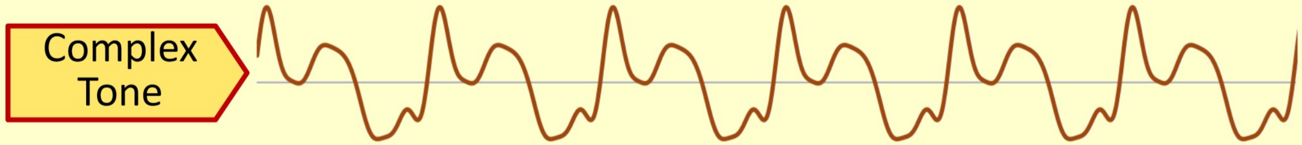
Building Blocks





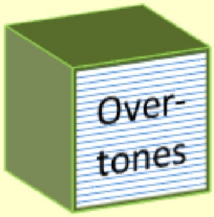
Real Musical Notes are *not* Pure Sine Waves

- Complex tones



  - Fundamental frequency f_0

  - Several (or many) higher frequencies
(Overtones or Partials)
    - Usually multiples of f_0 called **Harmonics**



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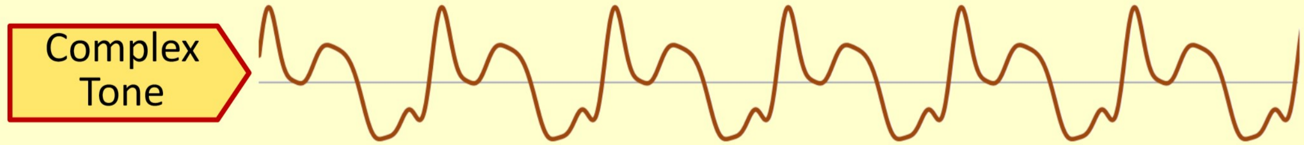

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  +

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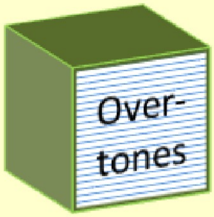

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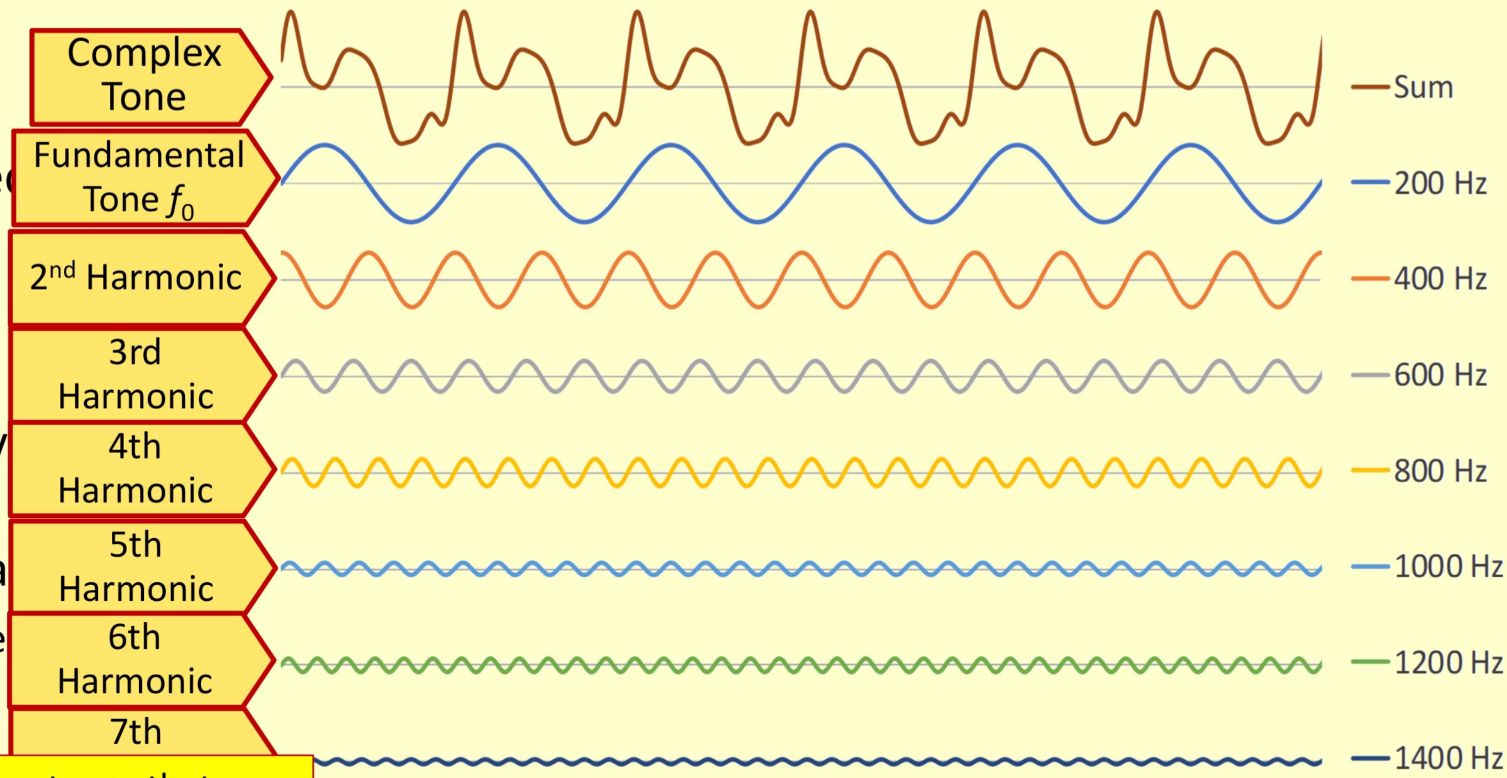
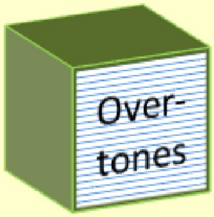


Harmonics are overtones that are simple integer multiples of fundamental tone… 2x,3x,4x, etc.



Real Musical Notes are *not* Pure Sine Waves

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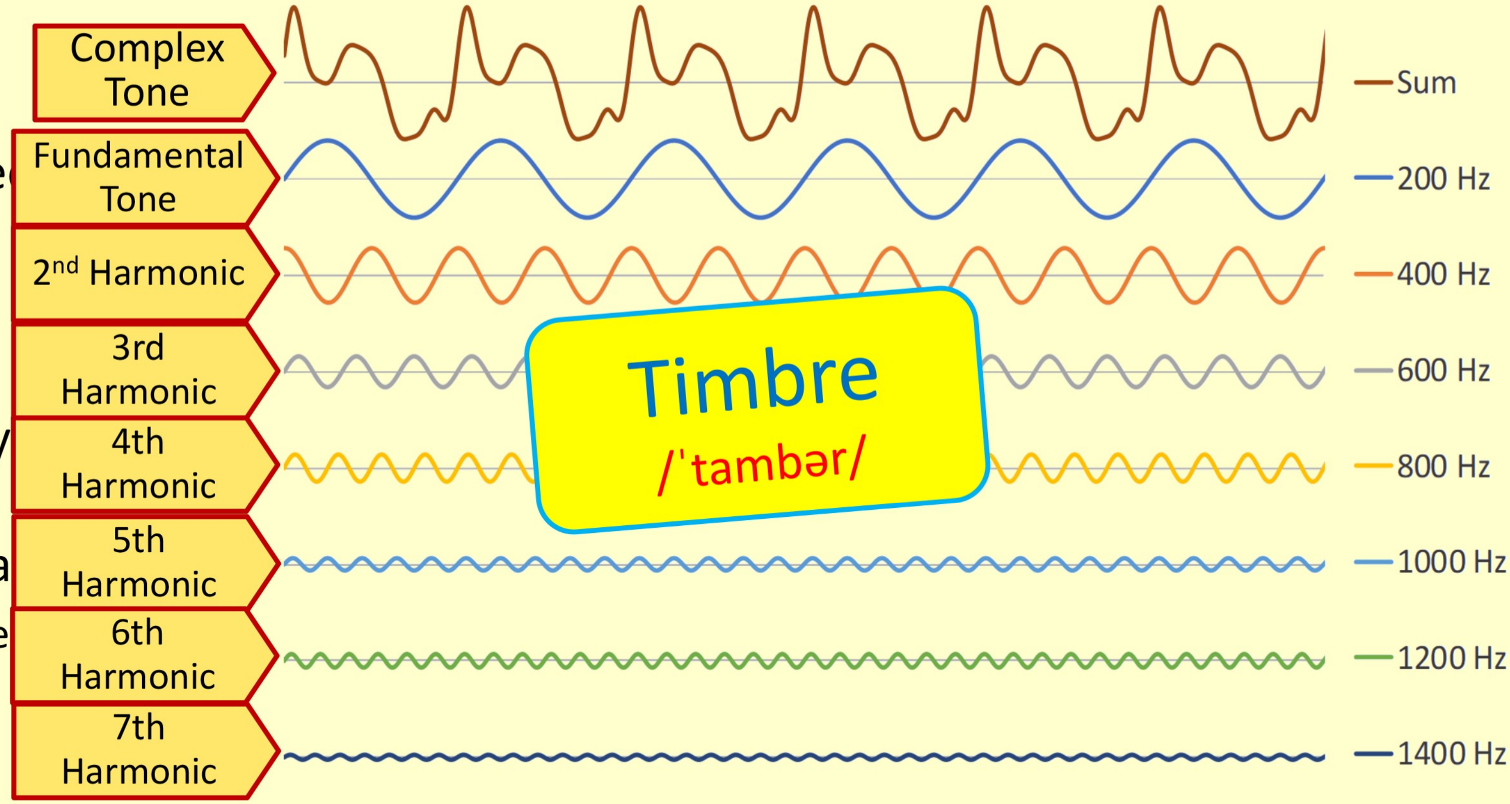
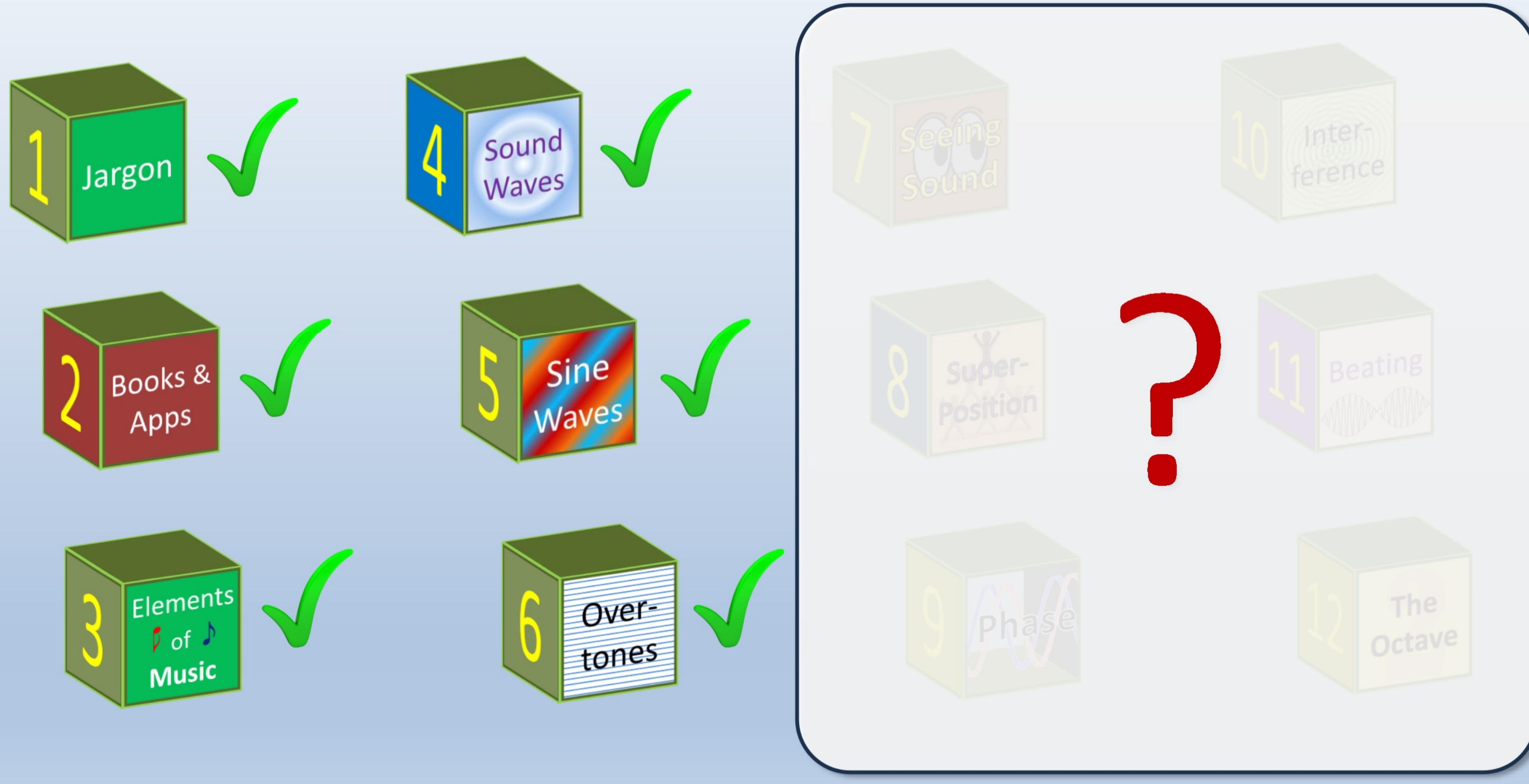
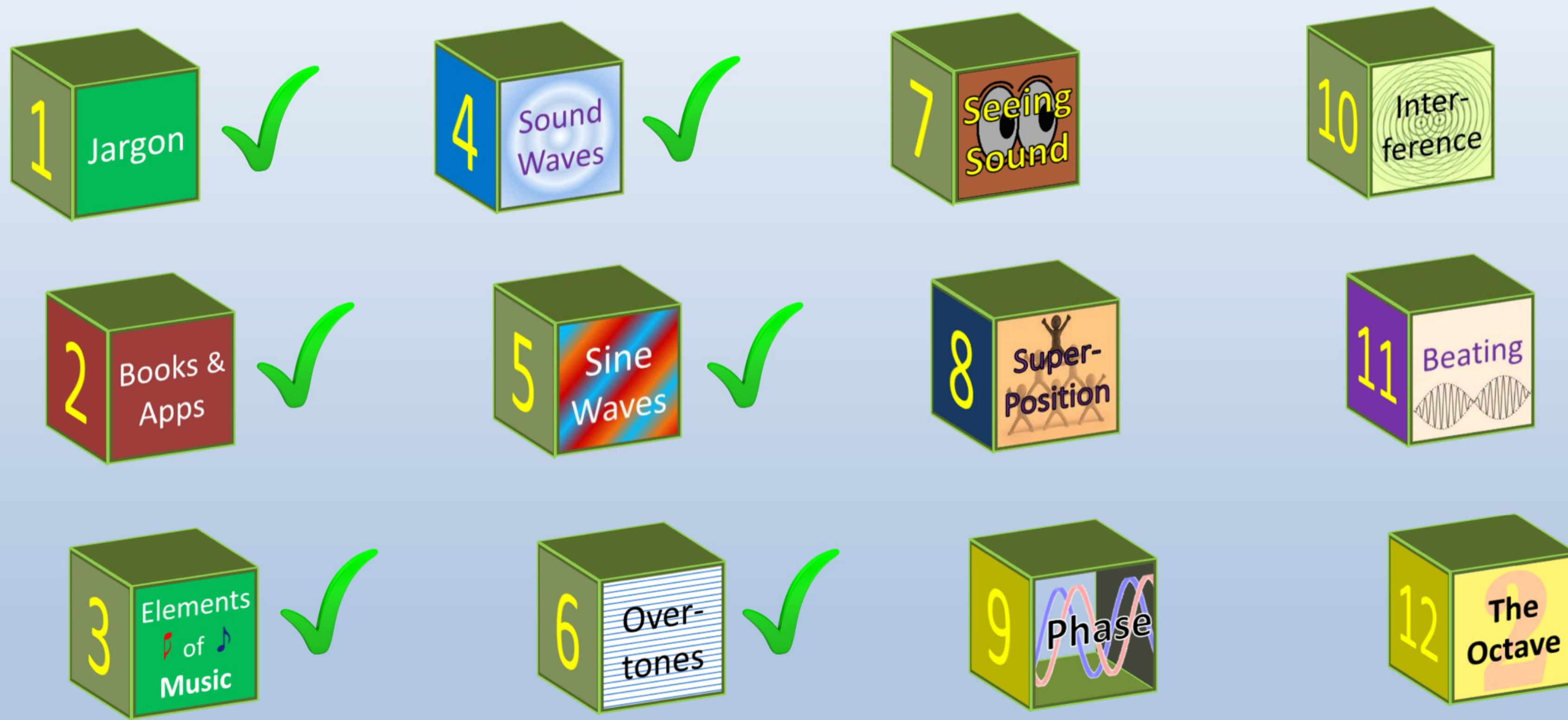


Musical Instruments and Nature Rarely Make Pure Sine Waves

Building Blocks



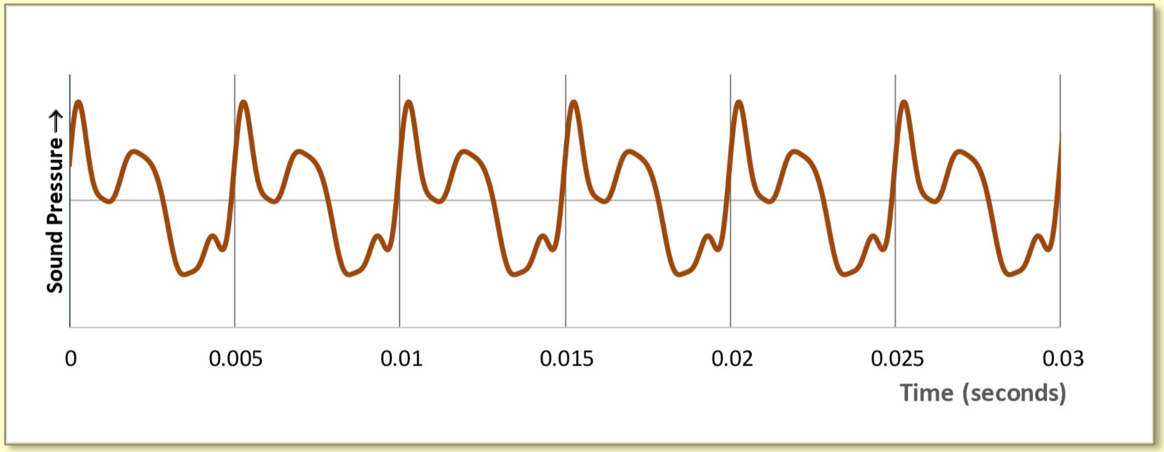
Building Blocks



Visualization of Sound

Two main approaches:

- Waveform Display

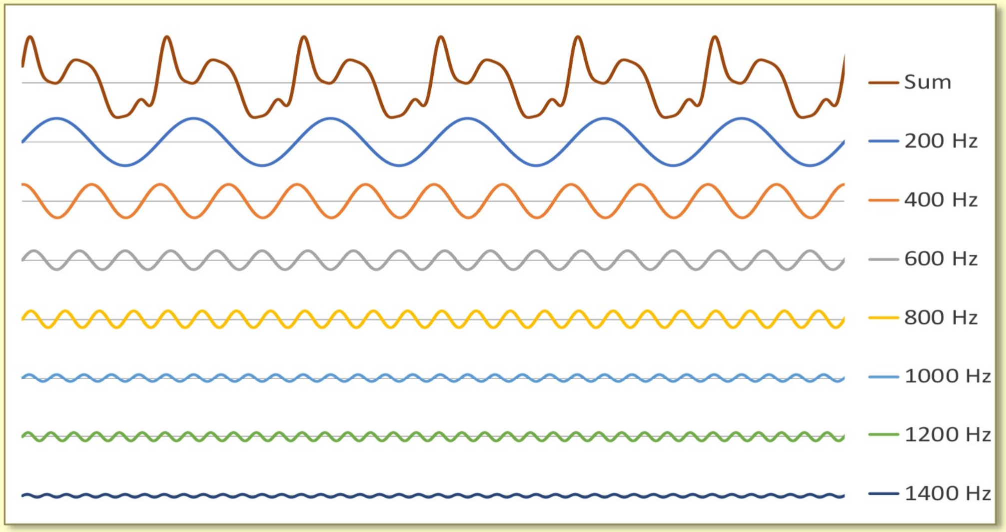


- Spectrum Display

Visualization of Sound: Spectrum

- Remember how our complex waveform was built of sinusoidal harmonics?
- We could just list the constituent Partials:

Partial #	Frequency (Hz)	Amplitude
1	200	100%
2	400	71%
3	600	40%
4	800	35%
5	1000	16%
6	1200	18%
7	1400	6%



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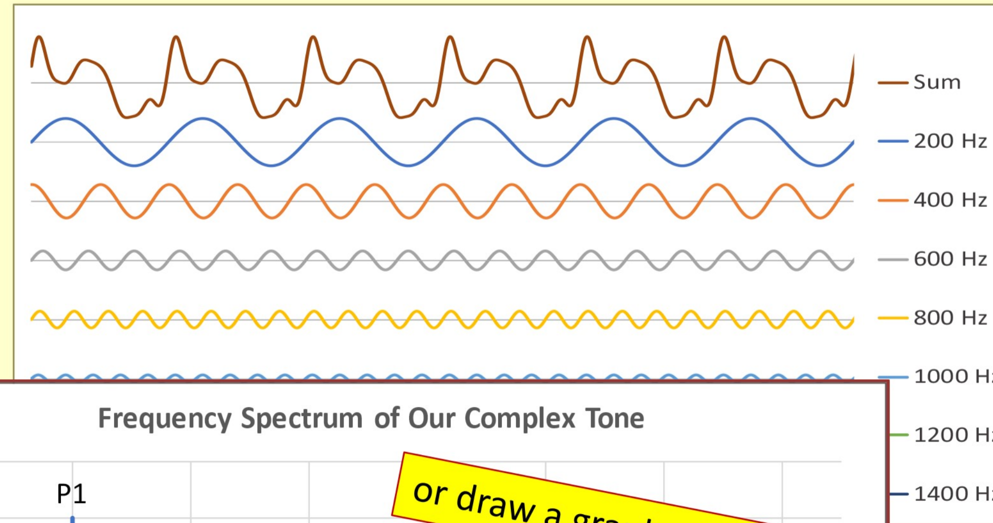
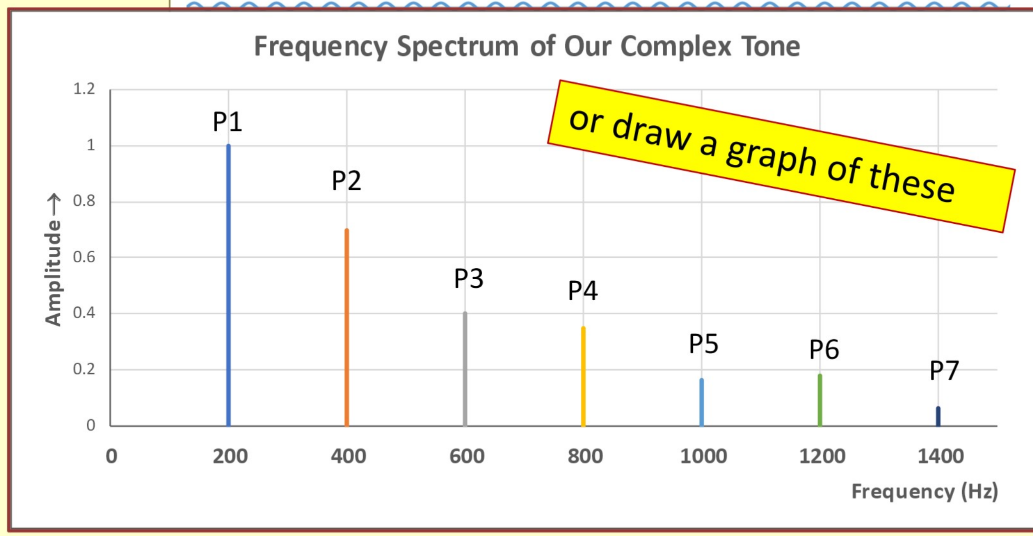
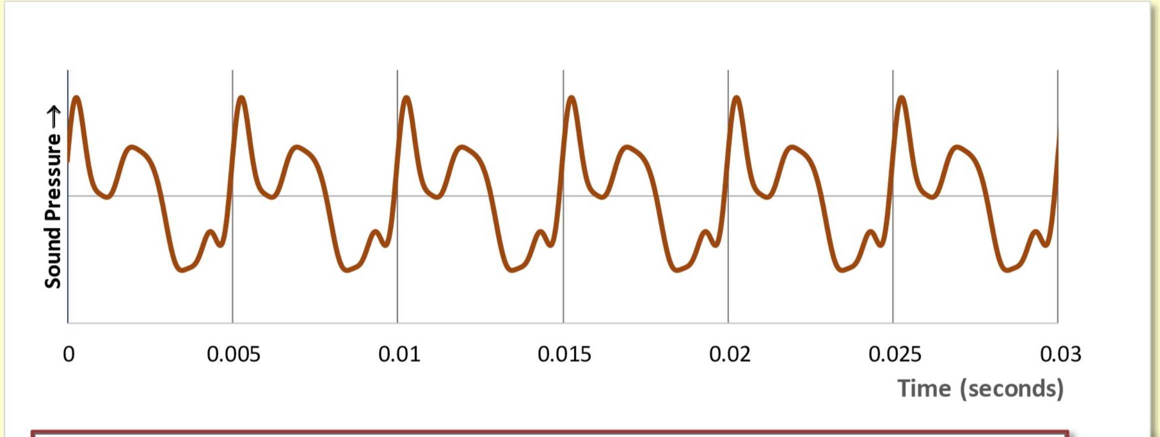




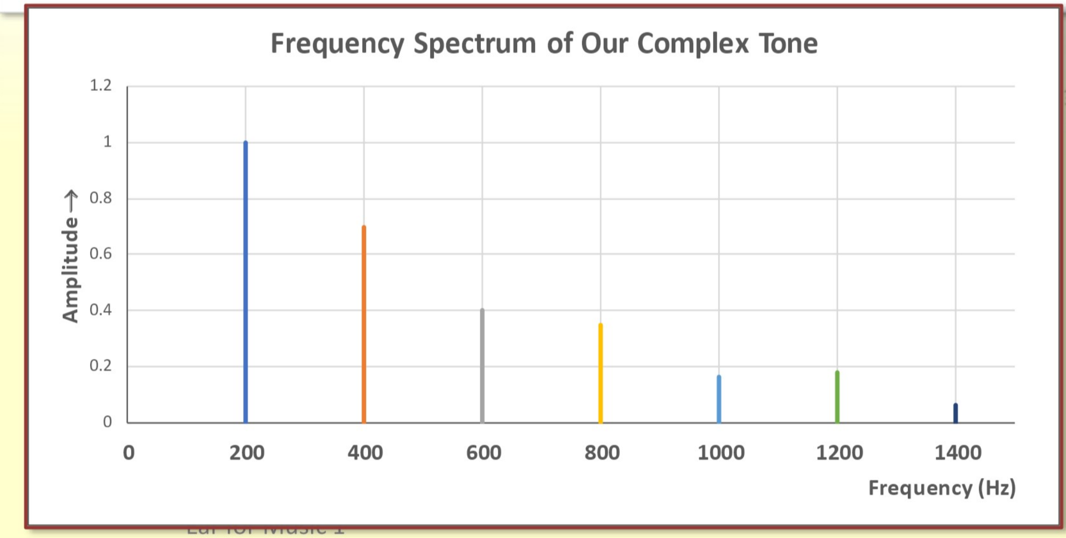
Visualization of Sound

Two main approaches:

- Waveform Display



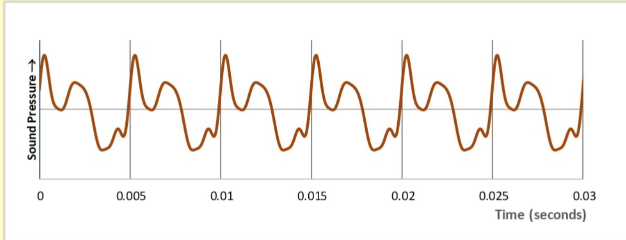
- Spectrum Display



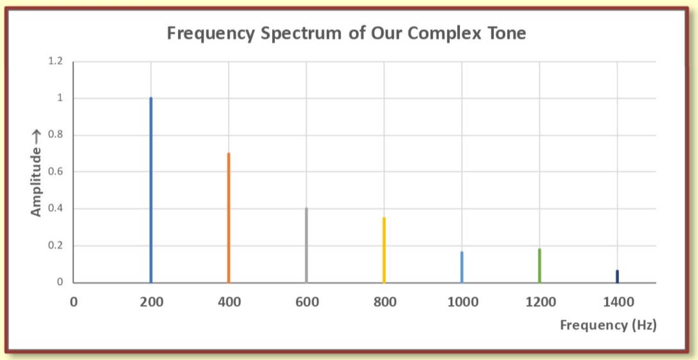
Visualization of Sound

Two main approaches:

- Waveform Display

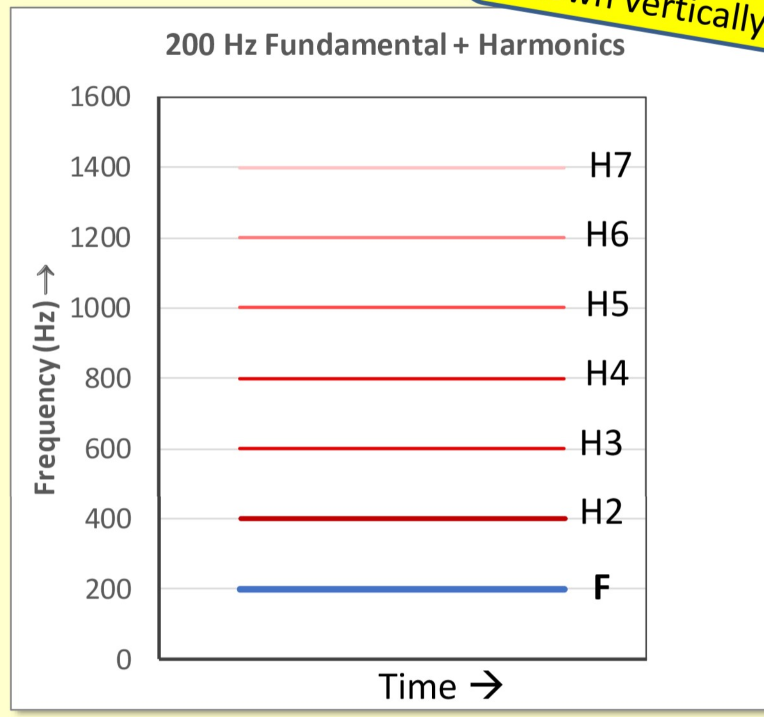


- Spectrum Display

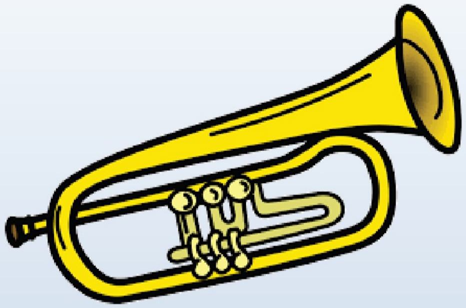


Alternate Spectrum Presentation

So, sometimes Frequencies are shown vertically

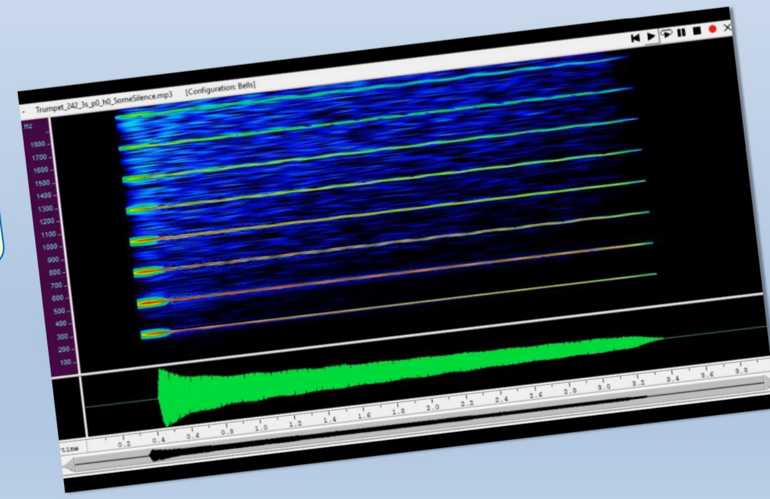


What Sounds ***Can*** We Distinguish?



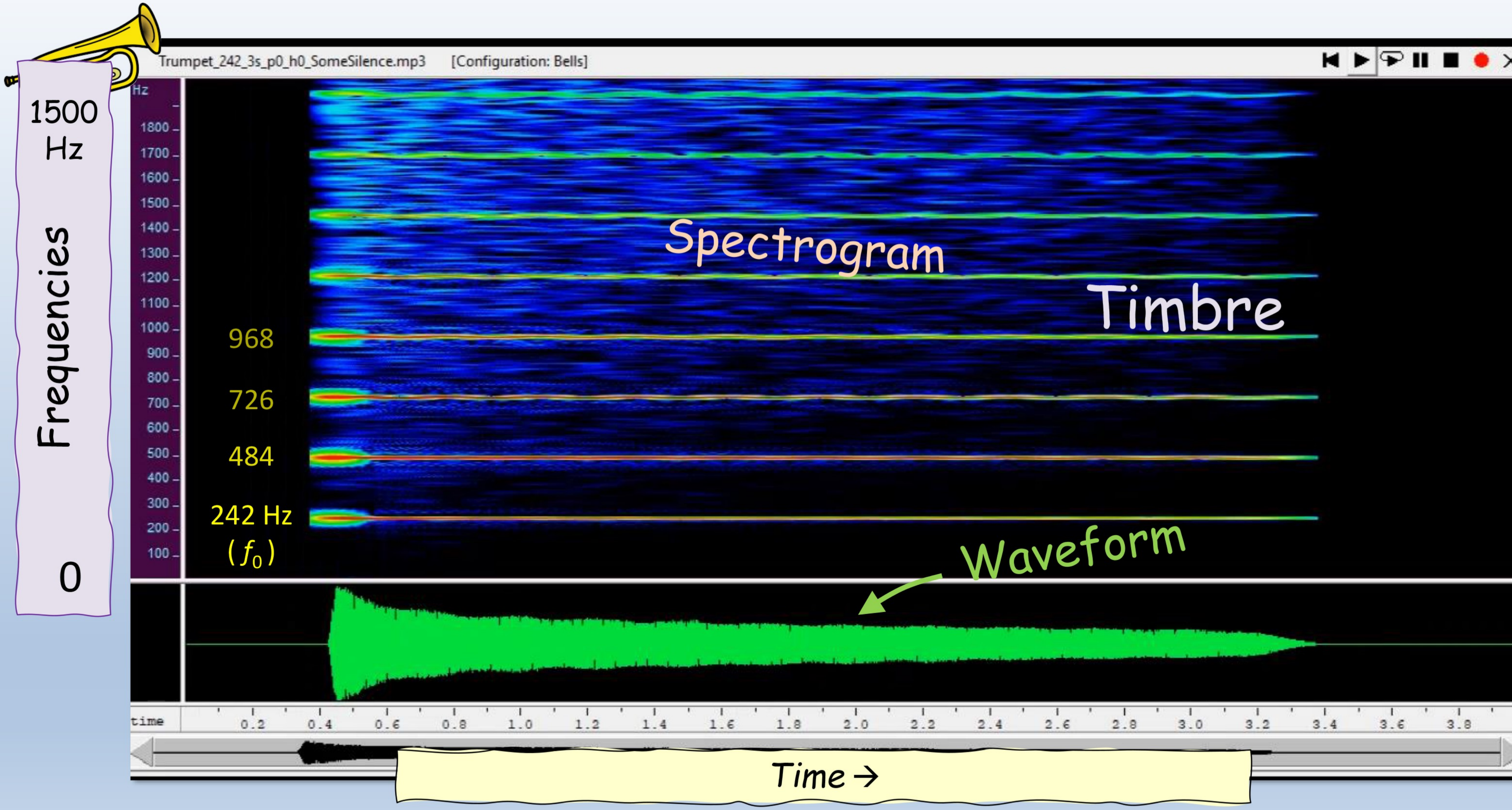
Remember
our
Trumpet?

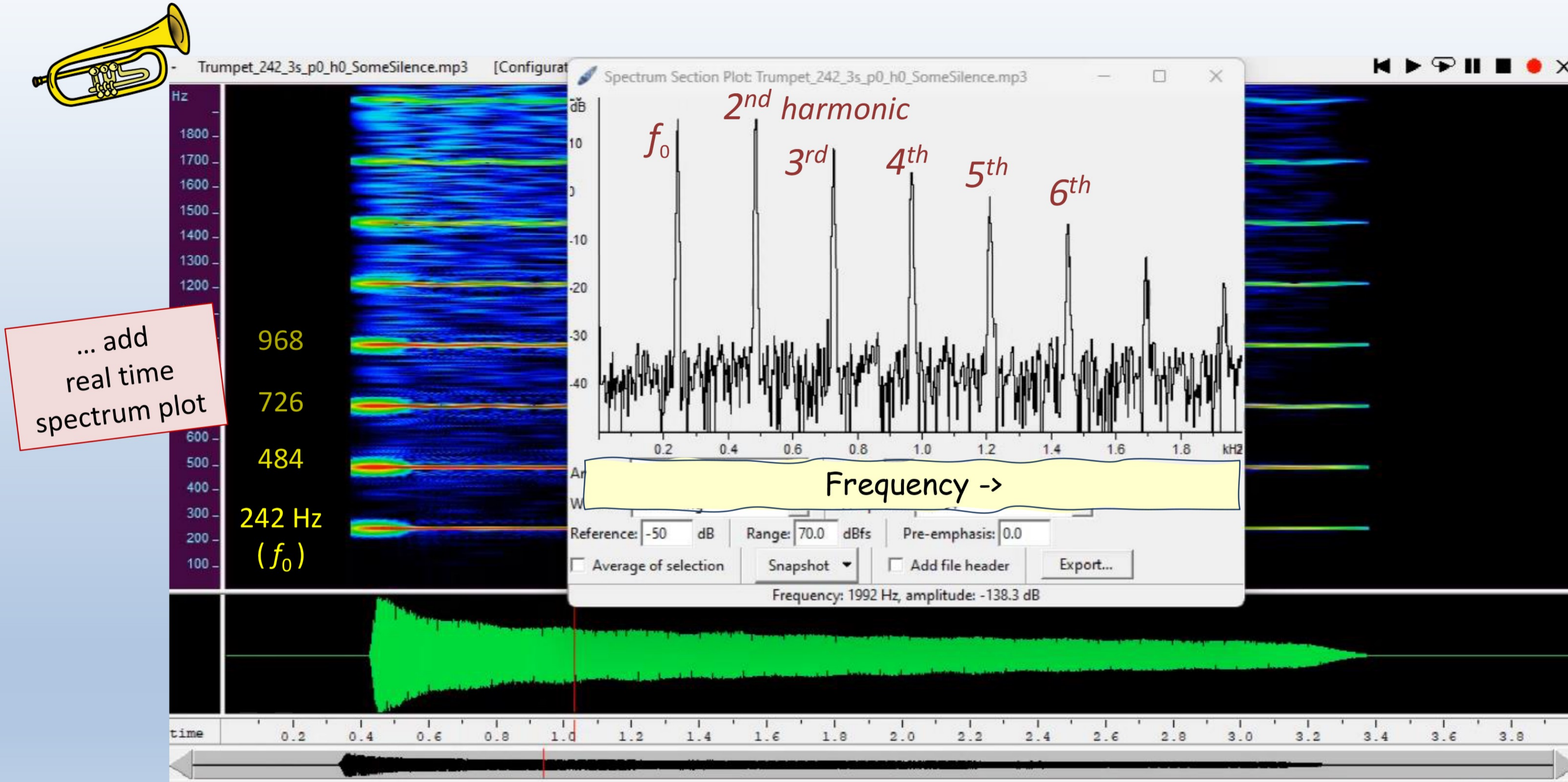
We can visualize
the Waveform and
Spectral Content using
free Software



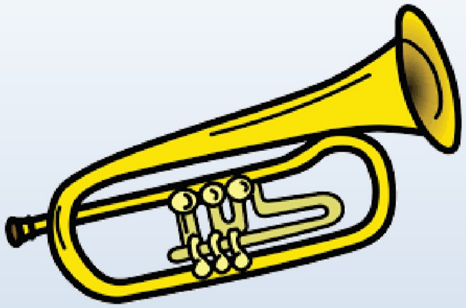
"WaveSurfer"

Or, using smart
phone Apps like
"FFT Wave"


Trumpet_242_3s_p0_h0_SomeSilence.mp3 [Configuration: Bells]
1500 Hz
Frequencies
0
Spectrogram
Timbre
968
726
484
242 Hz
(f_0)
Waveform
Time →



Trumpet_242_3s_p0_h0_SomeSilence.mp3
Spectrum Section Plot: Trumpet_242_3s_p0_h0_SomeSilence.mp3
... add real time spectrum plot
968
726
484
242 Hz
(f_0)
f_0
2^{nd} harmonic
3^{rd}
4^{th}
5^{th}
6^{th}
Frequency ->
Reference: -50 dB
Range: 70.0 dBfs
Pre-emphasis: 0.0
Average of selection
Snapshot
Add file header
Export...
Frequency: 1992 Hz, amplitude: -138.3 dB
time



What Sounds *Can* We Distinguish?

Remember this one?

1

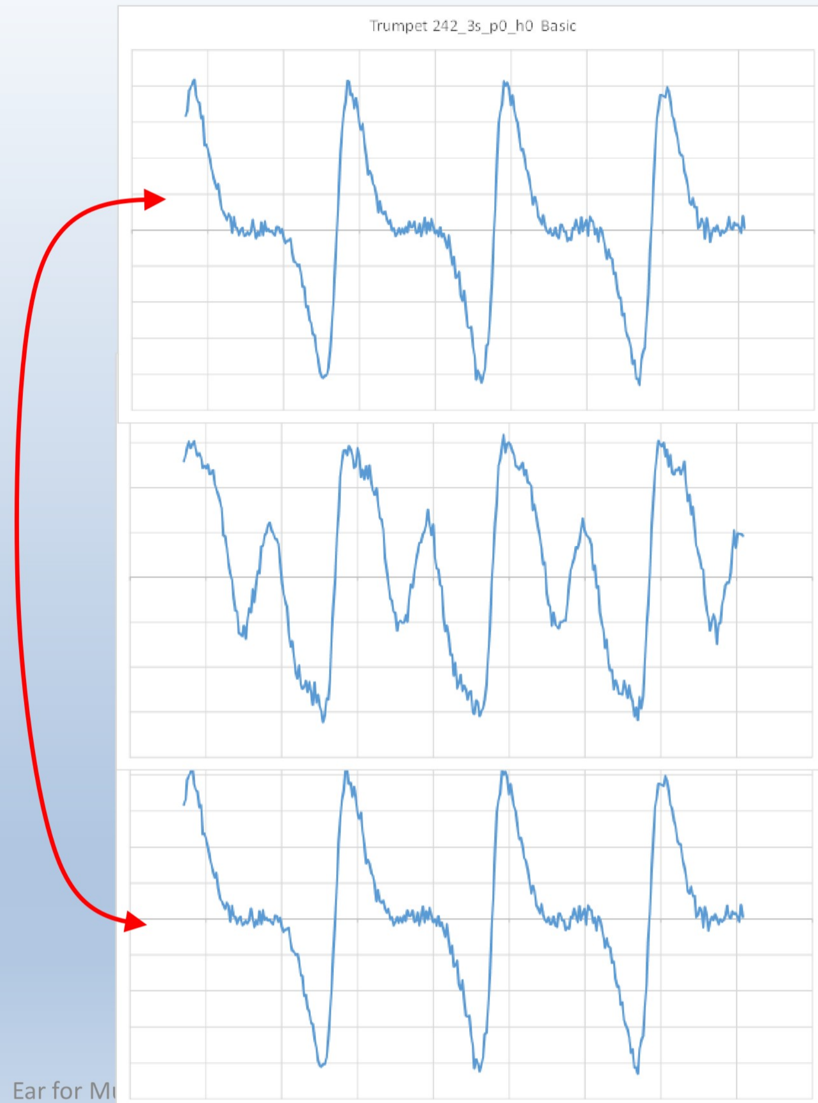
2

A little Different

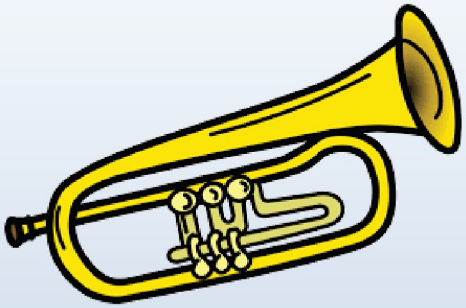
3

What Sounds Can We Distinguish?

Here's what the waveforms actually look like.



A little Different

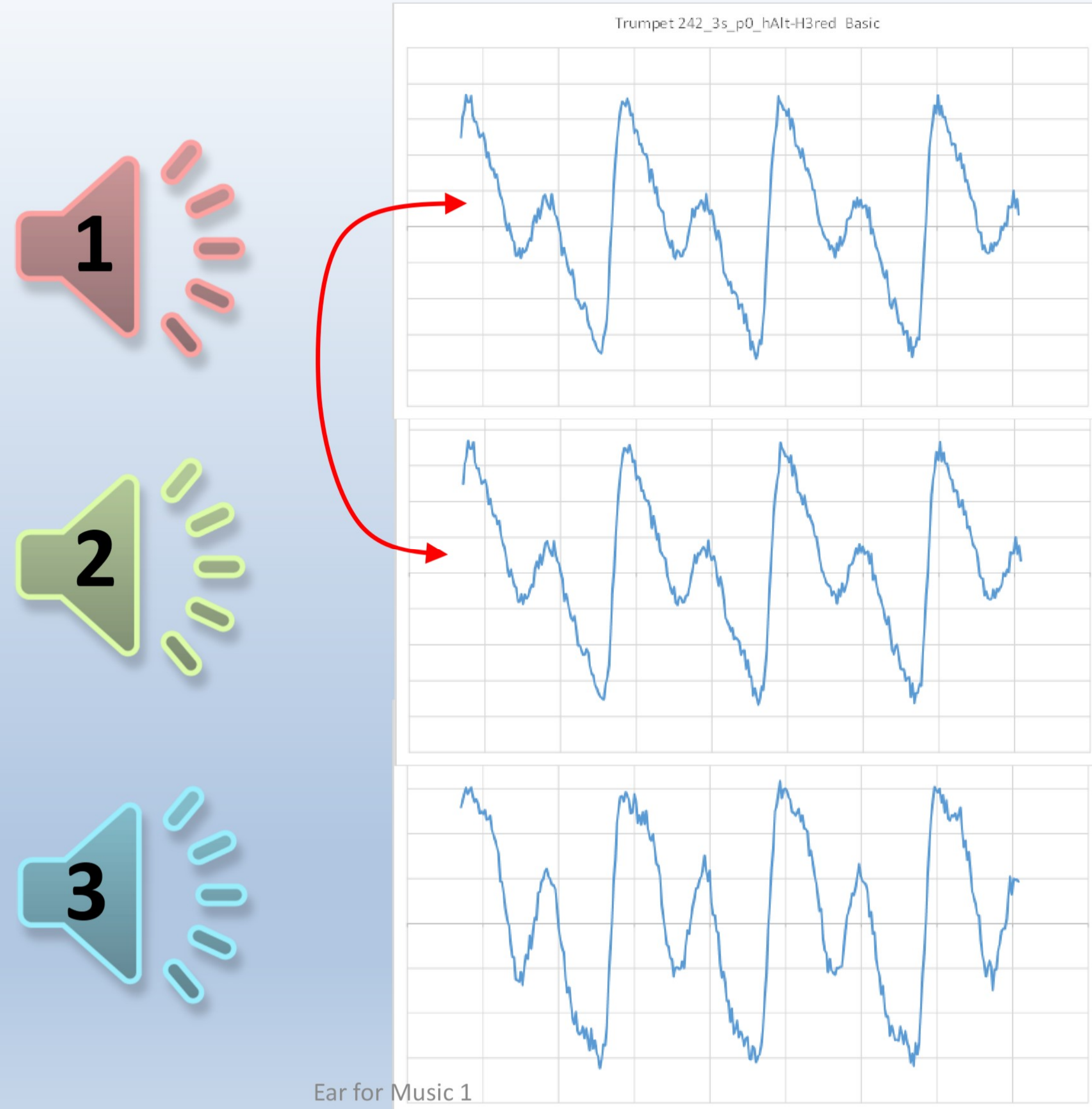


What Sounds Can We Distinguish?

And this one?

A *tiny* bit Different

What Sounds Can We Distinguish?



A *tiny* bit Different

What *Alien* Sounds *Can* We Distinguish?

0

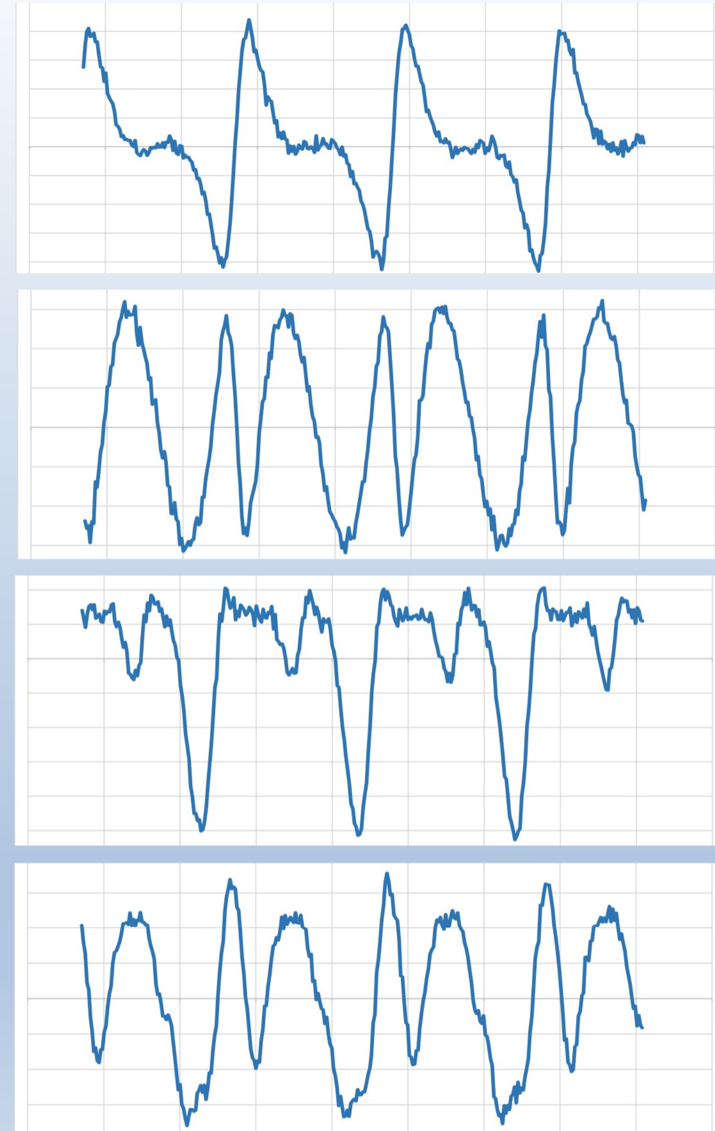
1

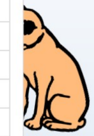
2

3

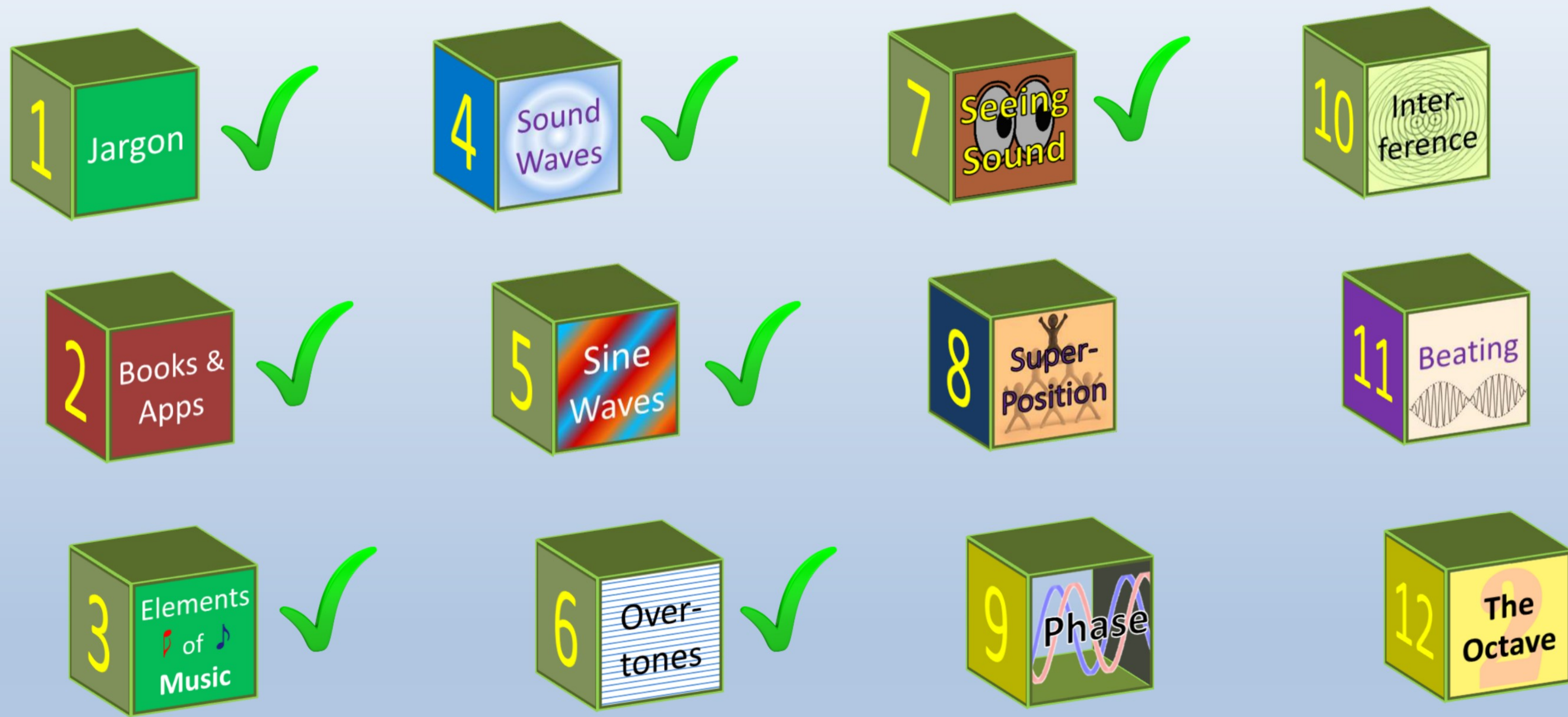
What *Alien* Sounds *Can* We Distinguish?

None !
But they're not remotely similar waveforms

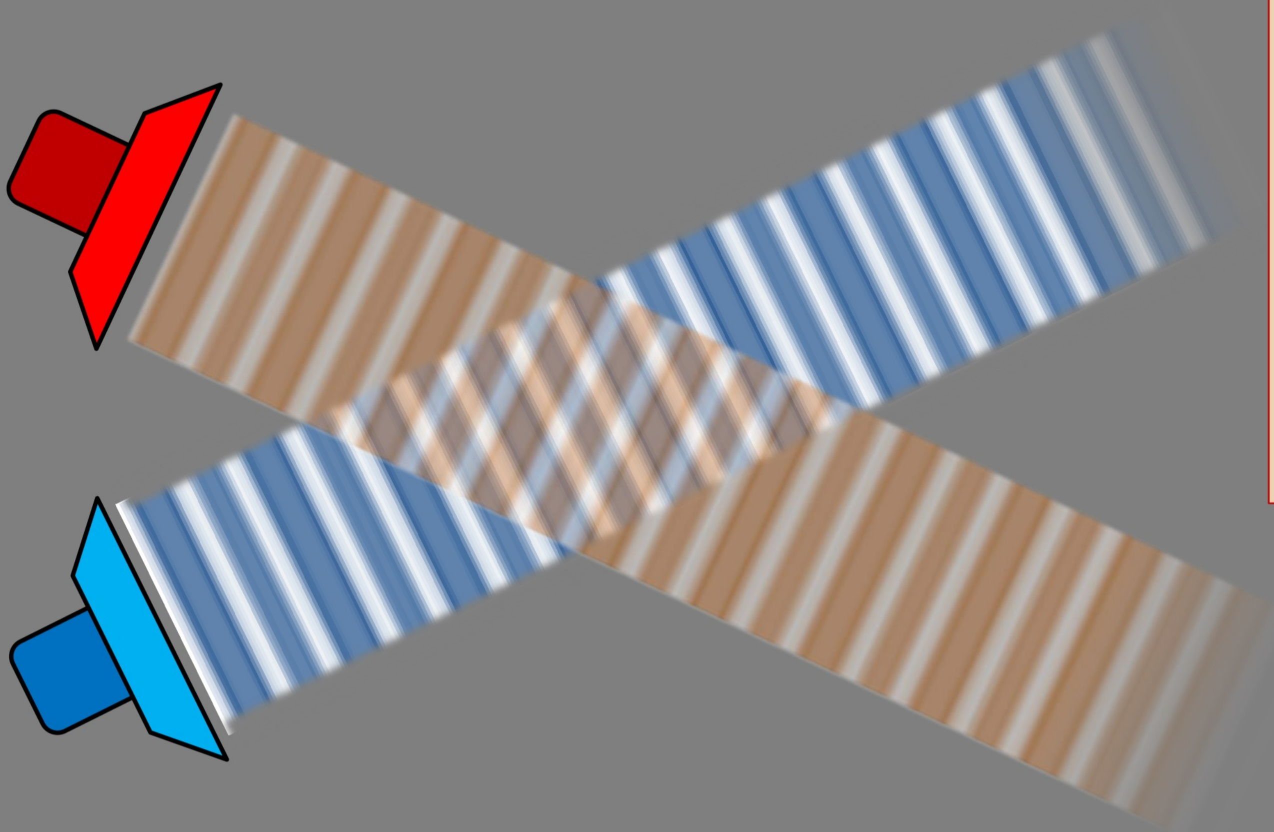




Building Blocks

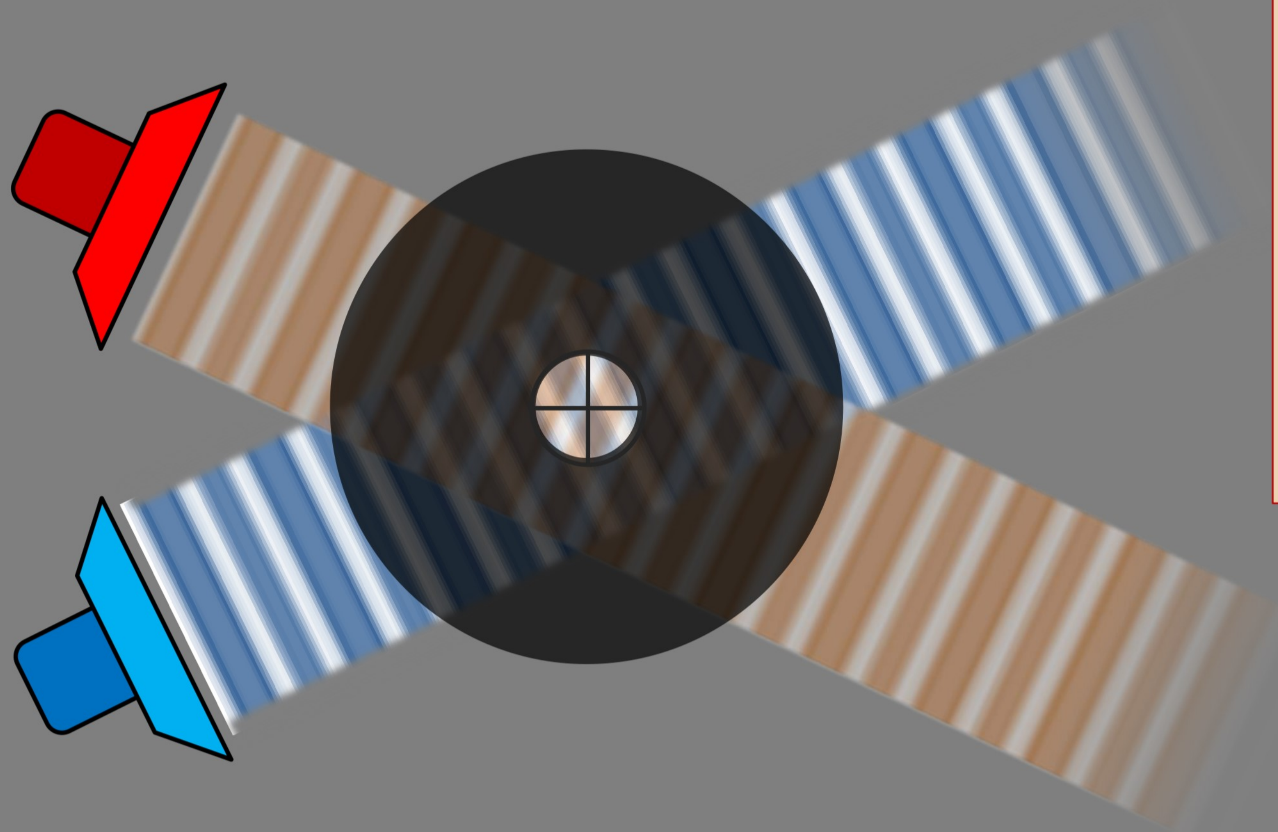


Superposition of Sound Waves



- Waves pass through one another without disruption
- Where they overlap, **Superposition** applies:
  --Pressures add up

Superposition of Sound Waves



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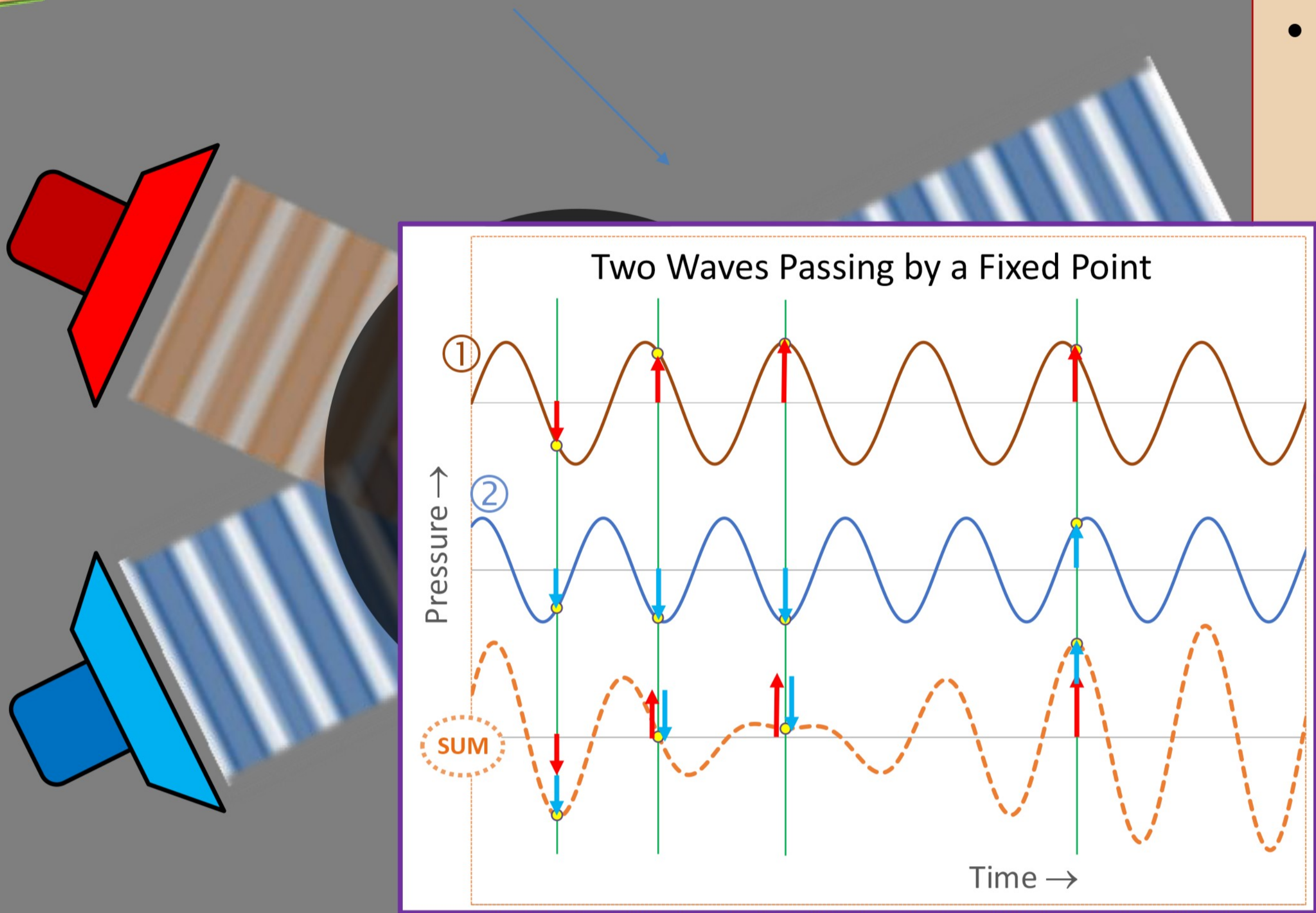
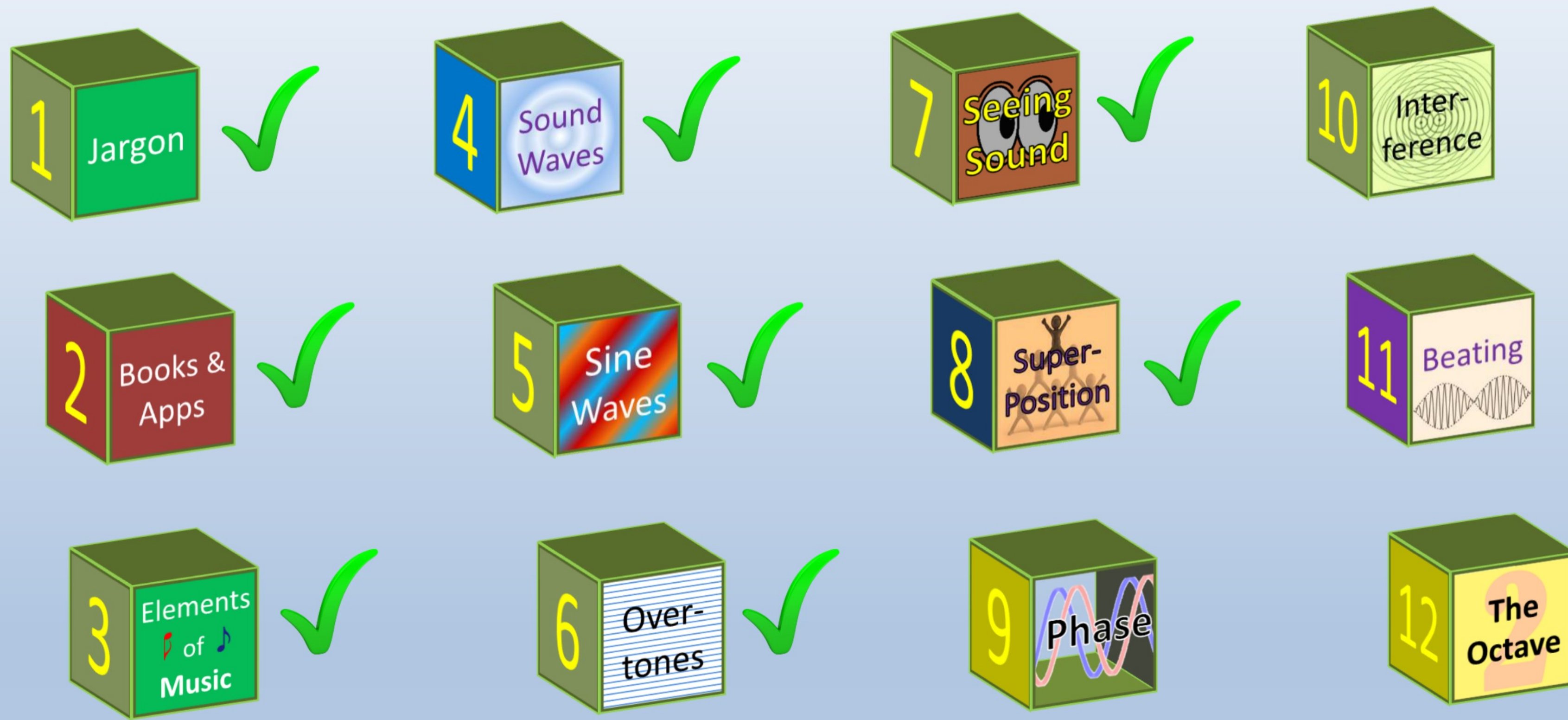
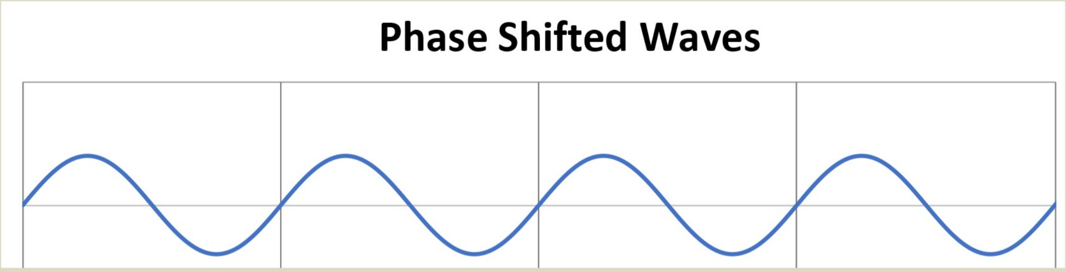


Building Blocks



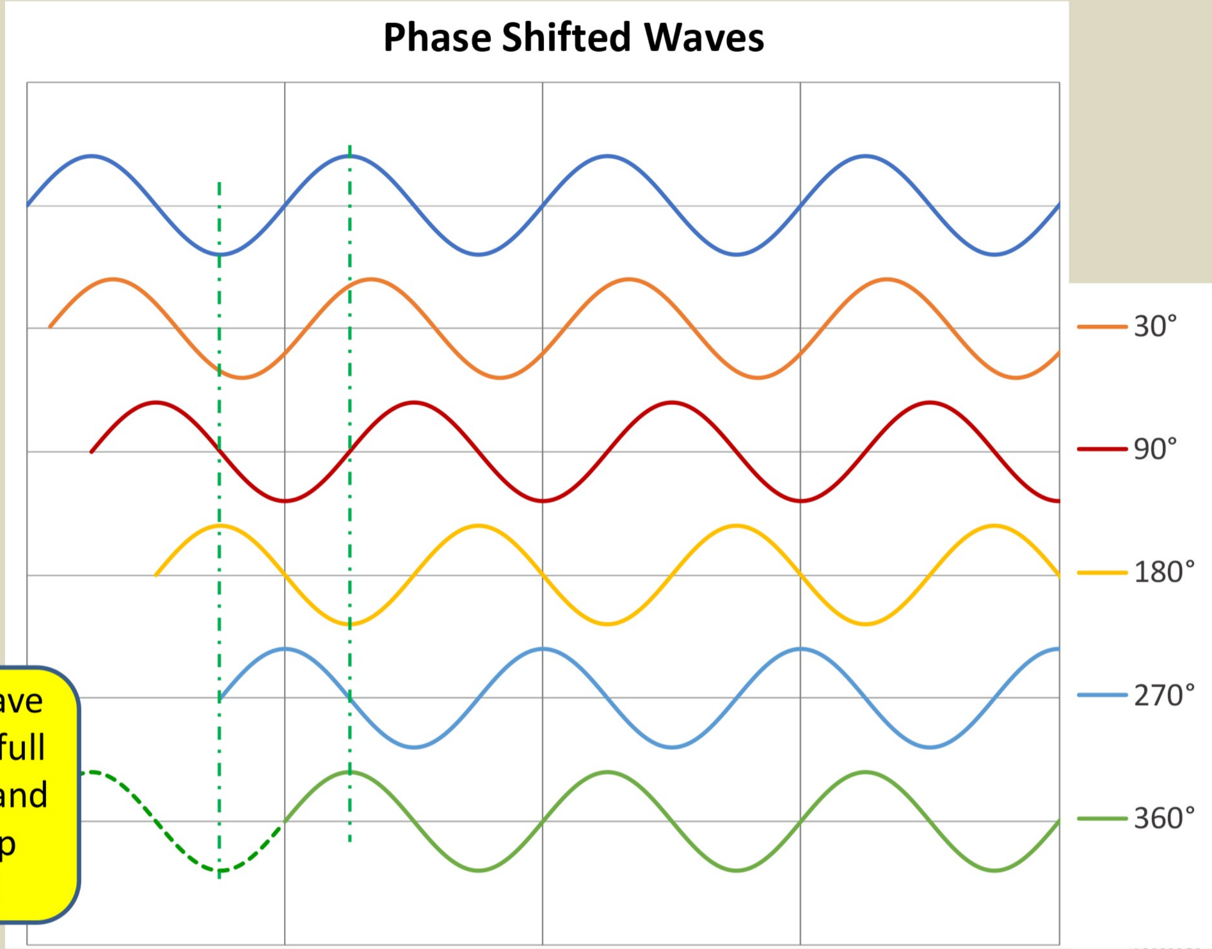
Phase: Delayed Waves



- Phase refers to time shifts between waves of the *same* or *similar* frequency

Start with a "base wave"

Phase: Delayed Waves

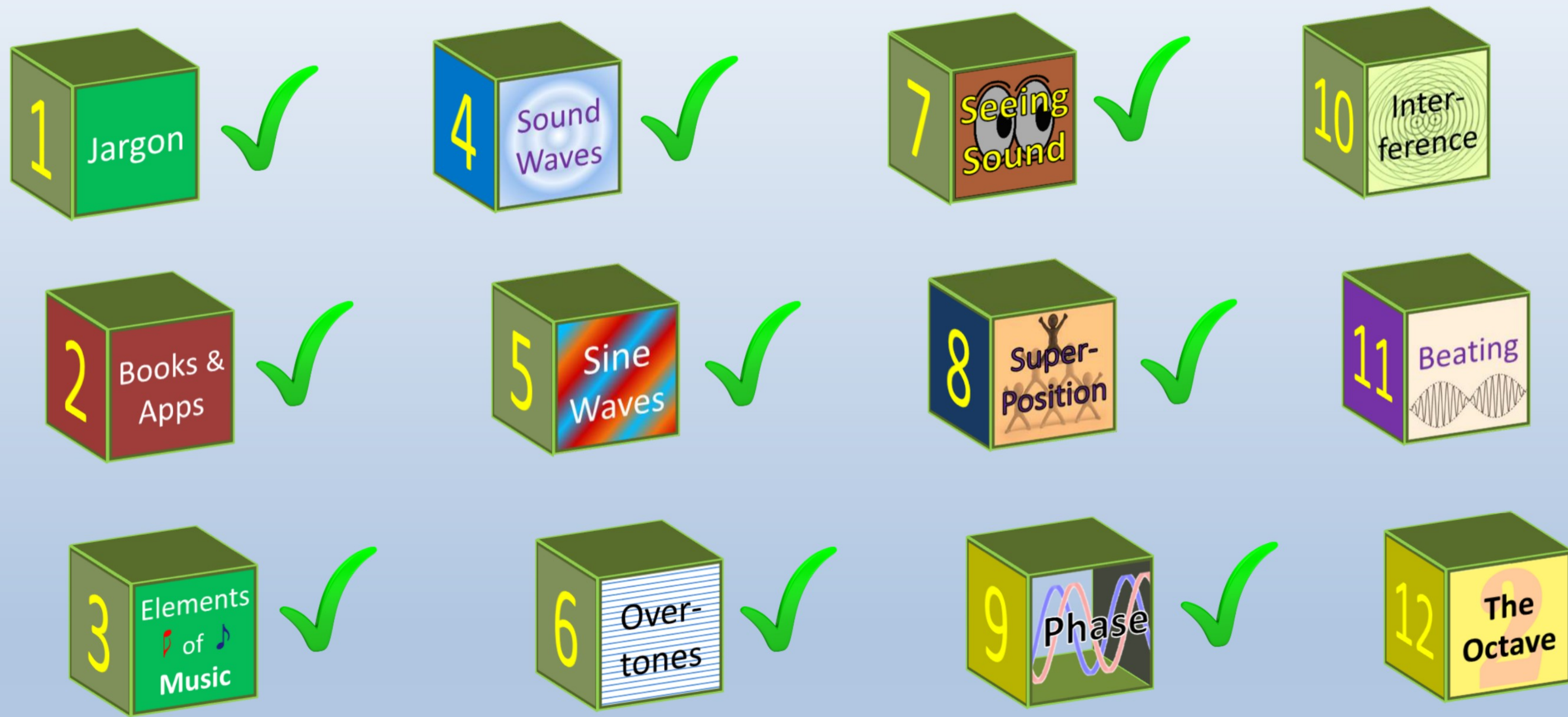


...this Green wave is delayed one full cycle, or 360º, and so matches up with original

- Phase refers to time shifts between waves of the *same* or *similar* frequency
- Measured in Degrees
  360° = Full Cycle

...then look at copies of the same wave shifted slightly in time, i.e. delayed

Building Blocks

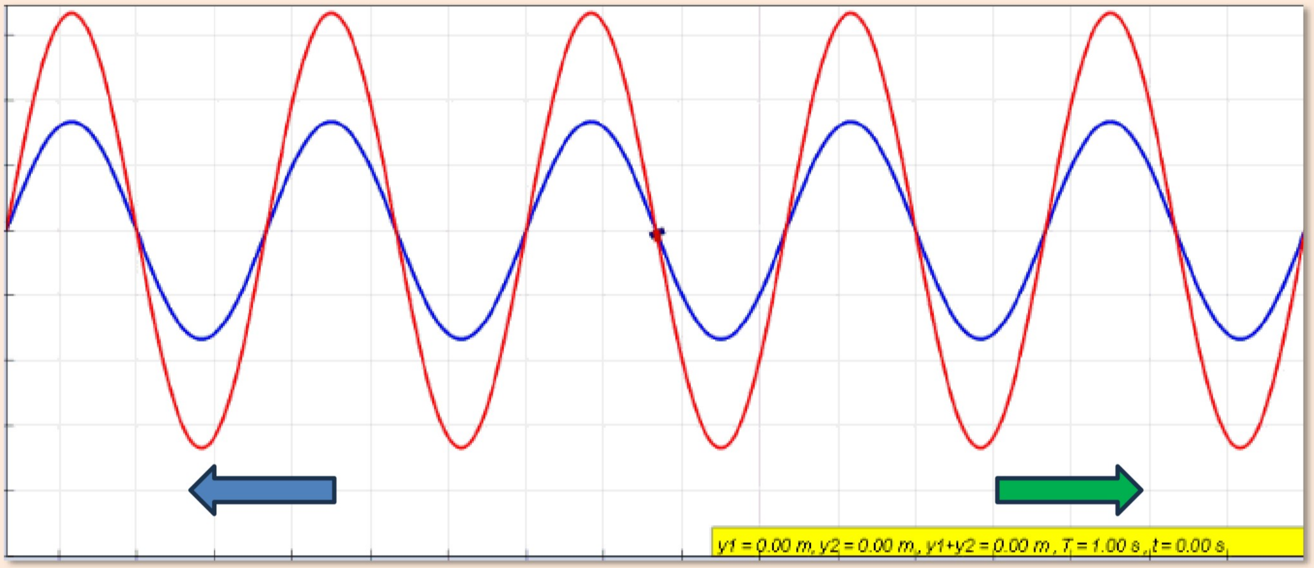


Interfering Waves

Blue wave *(moving left)* and

Green wave *(moving right)*

Add up to Red wave *(standing)*



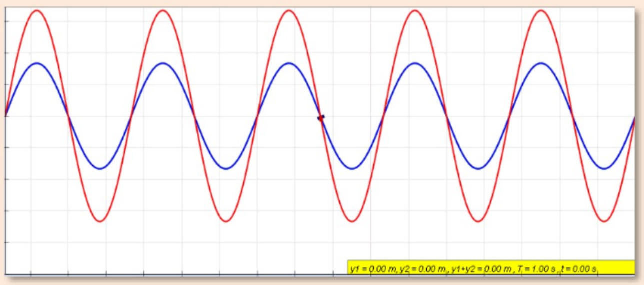
Interfering Waves

at a moment when the blue and green are almost in phase (10 deg apart)

⇐ Blue wave and

Green wave ⇒

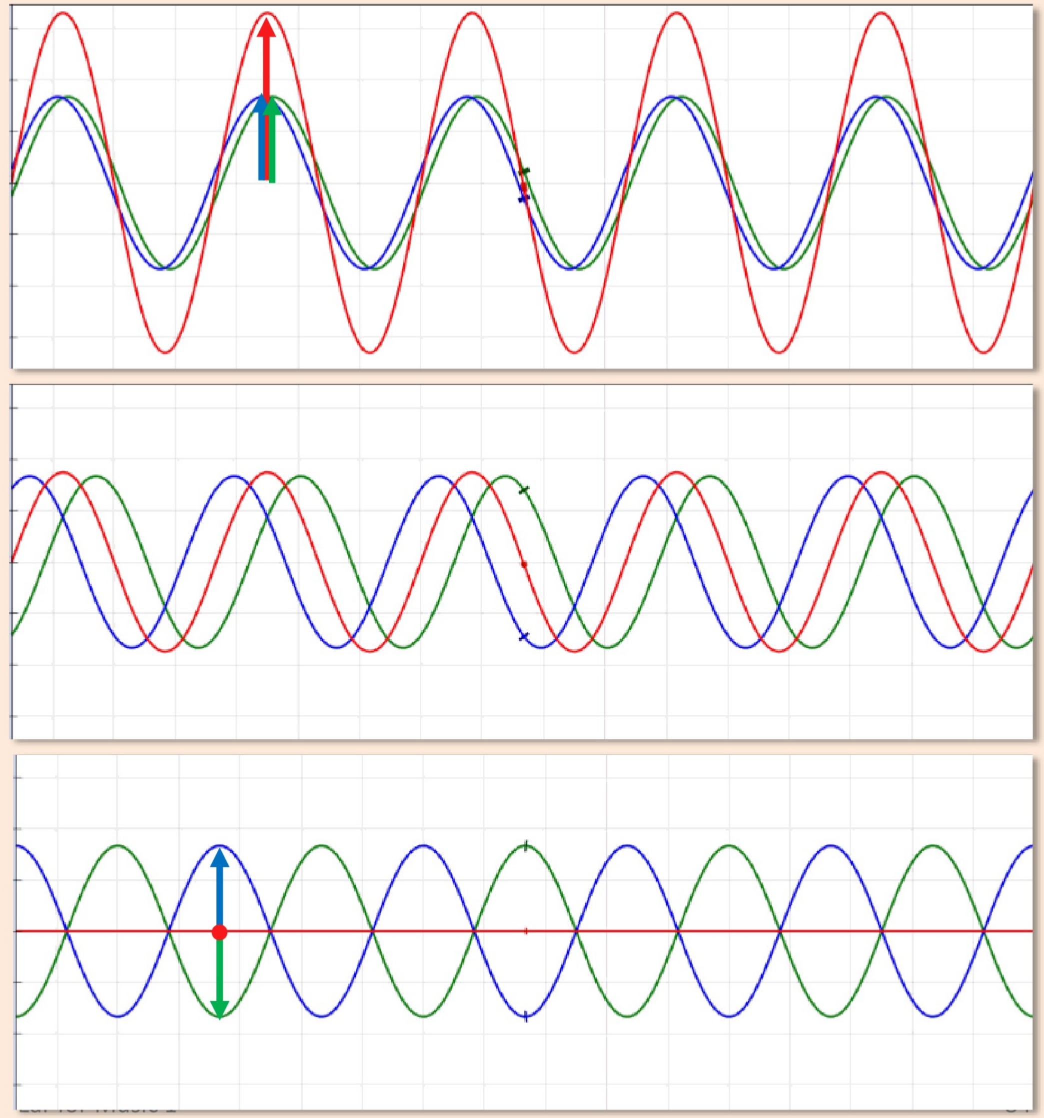
Add up to Red wave



10°

90°

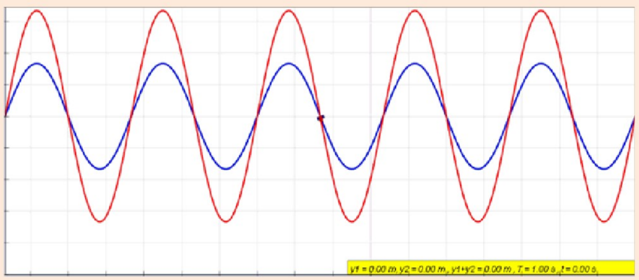
180°



this is at a moment when the blue and green are opposite in phase (180 deg apart), so the sum Red is flat zero!

Interfering Waves

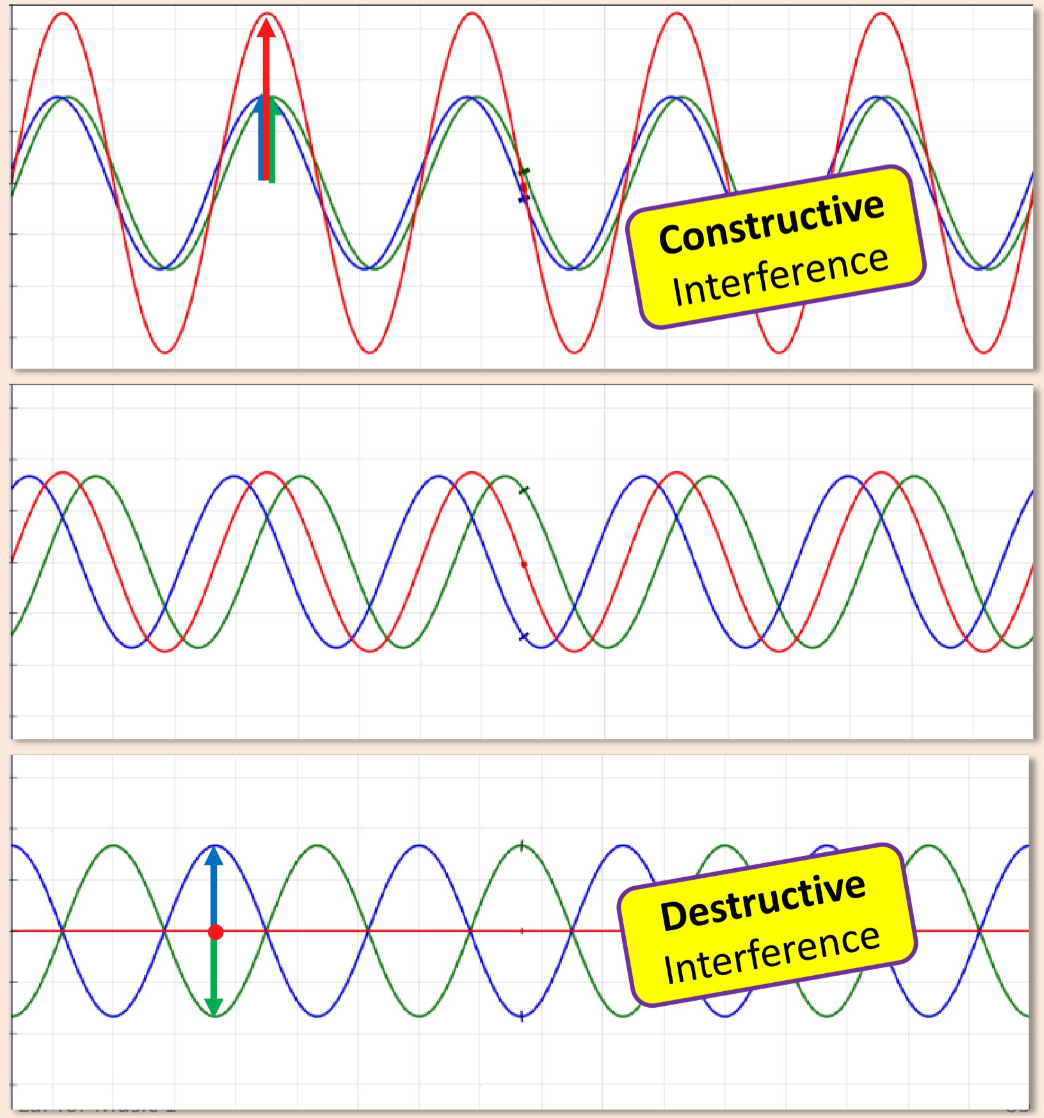
Blue wave and
Phase-Shifted Green wave
Add up to Red wave



10°

90°

180°



Interfering Waves

Blue wave and
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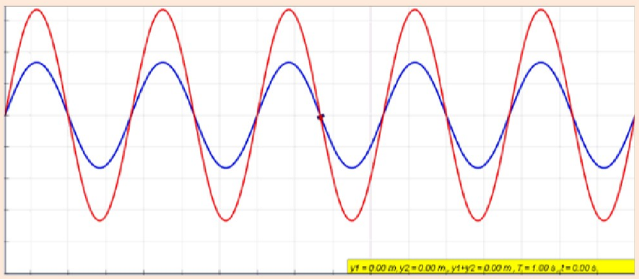
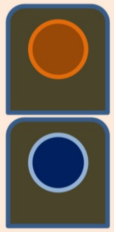
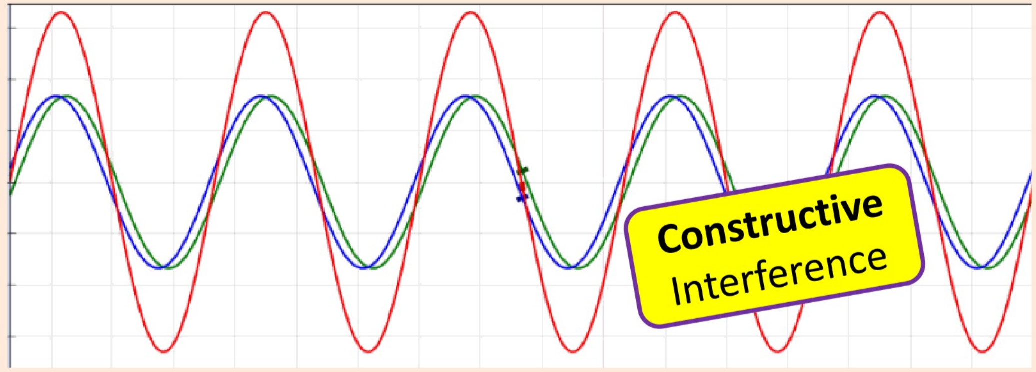


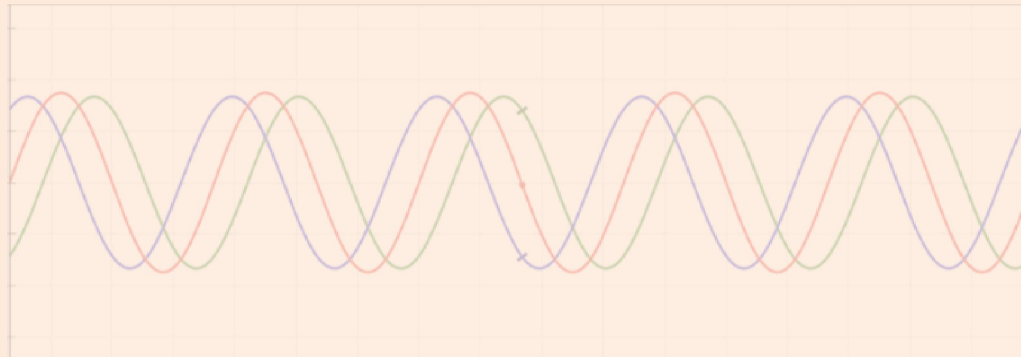
Demo



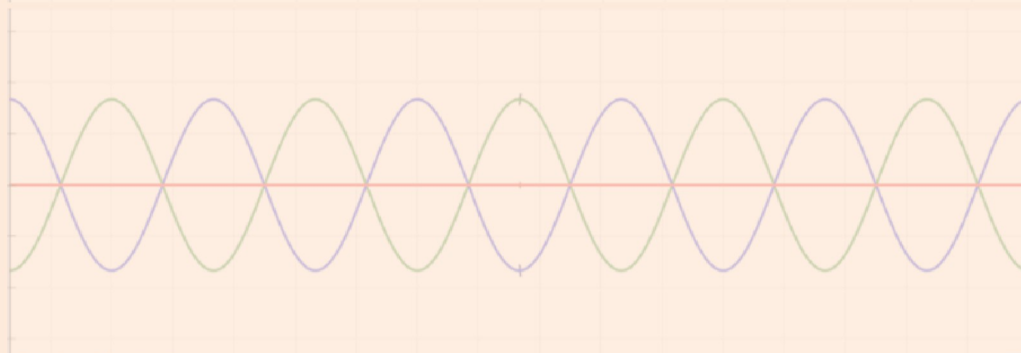
10°



90°

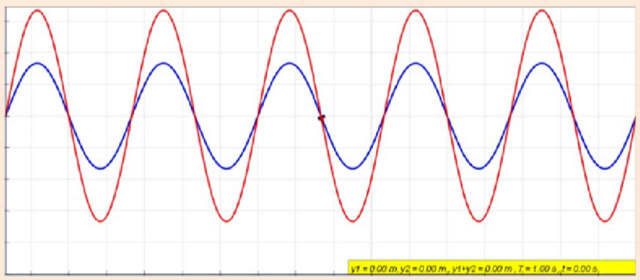


180°



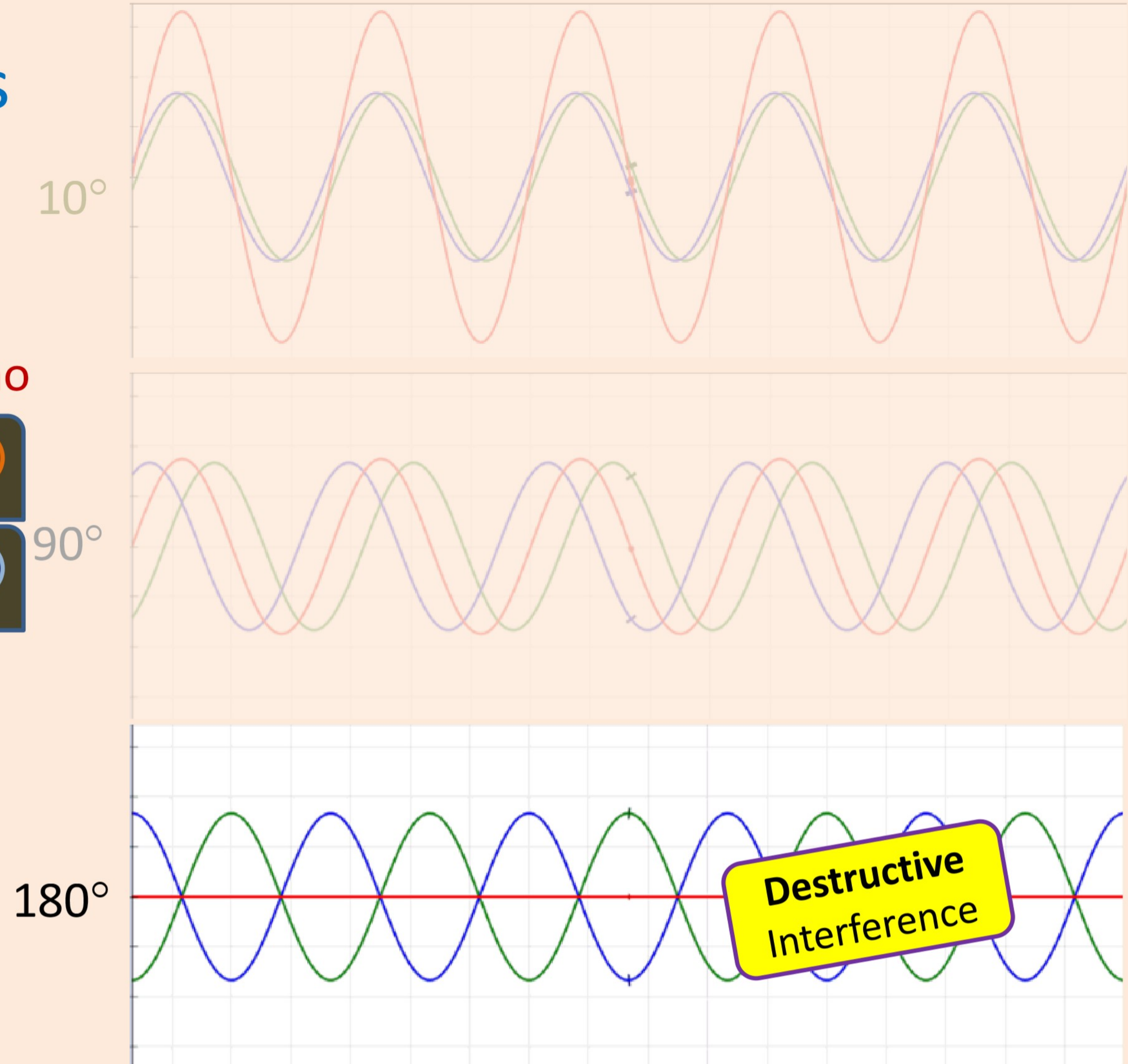
Interfering Waves

Blue wave and
Phase-Shifted Green wave
Add up to Red wave



Demo

Demo Failed Due to Signal Generator Failure



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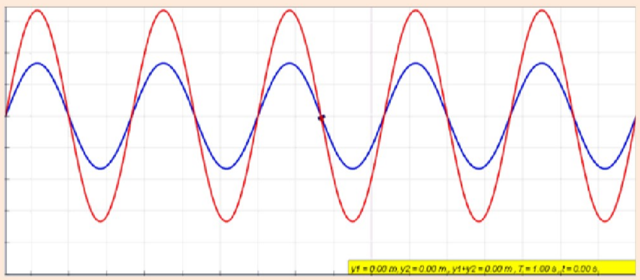
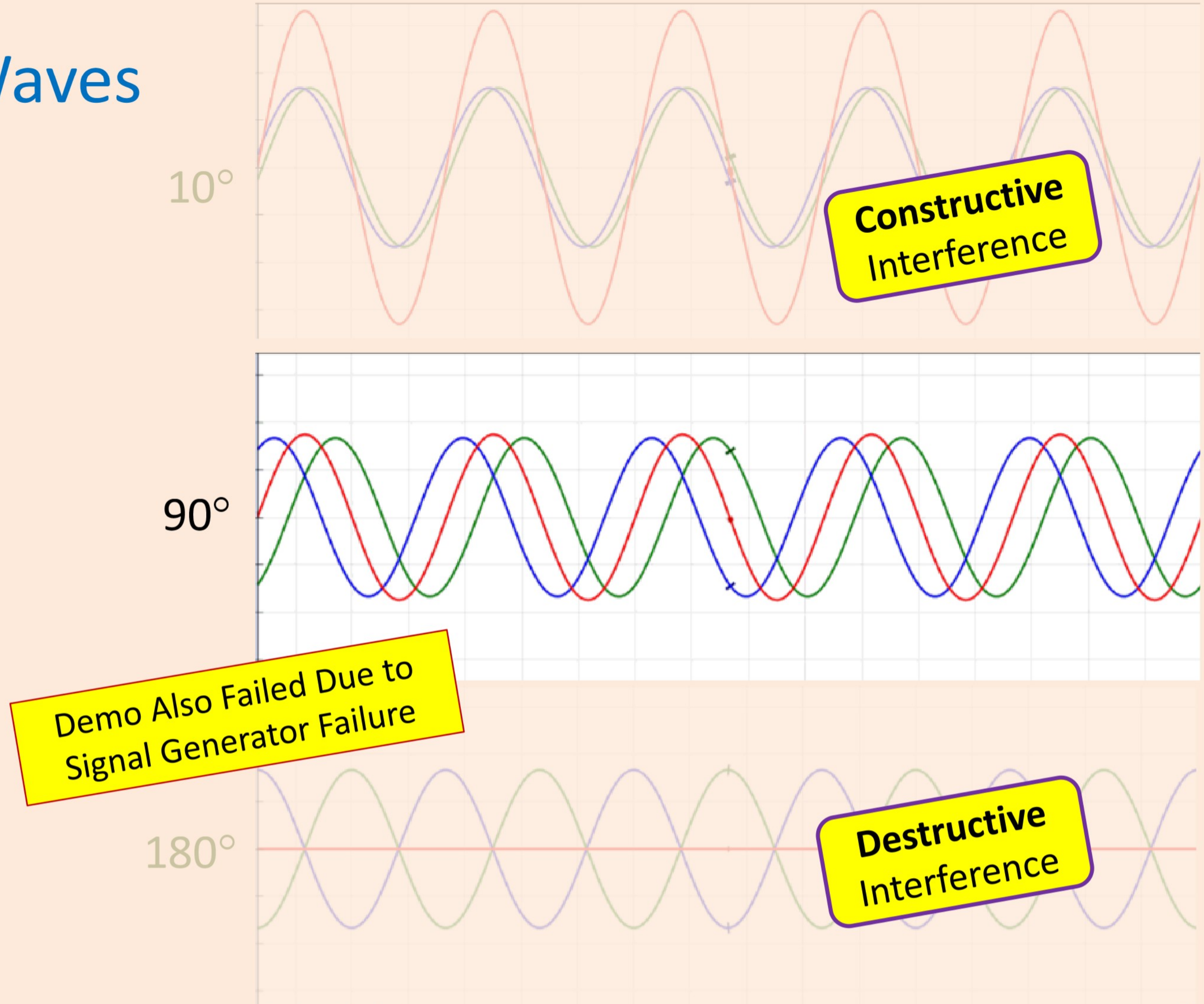
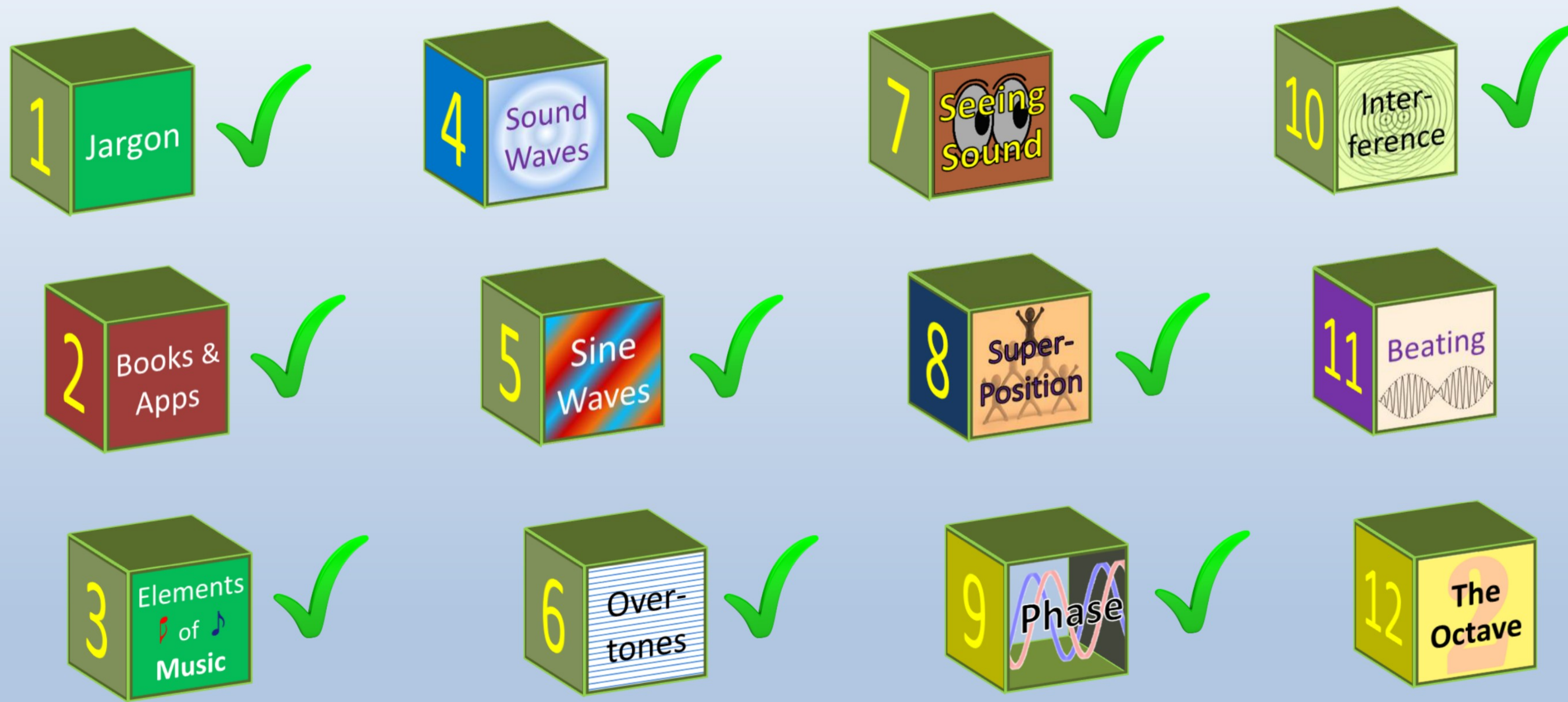




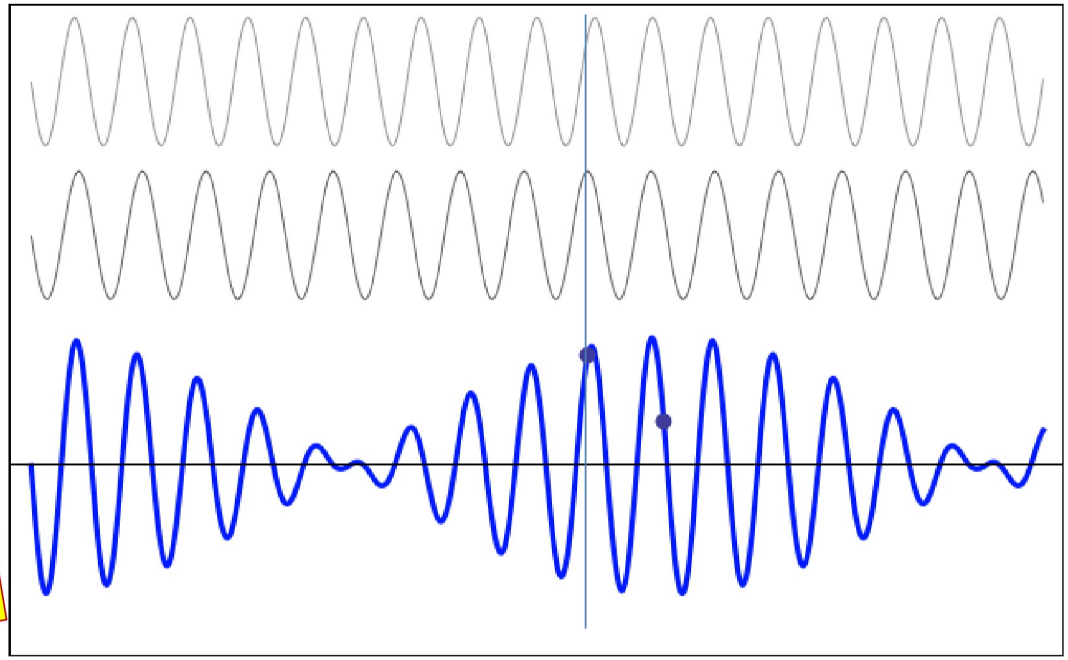
Building Blocks



Beating: *Interference in Action*

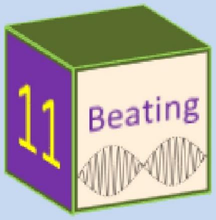
f_1

Lower f_2



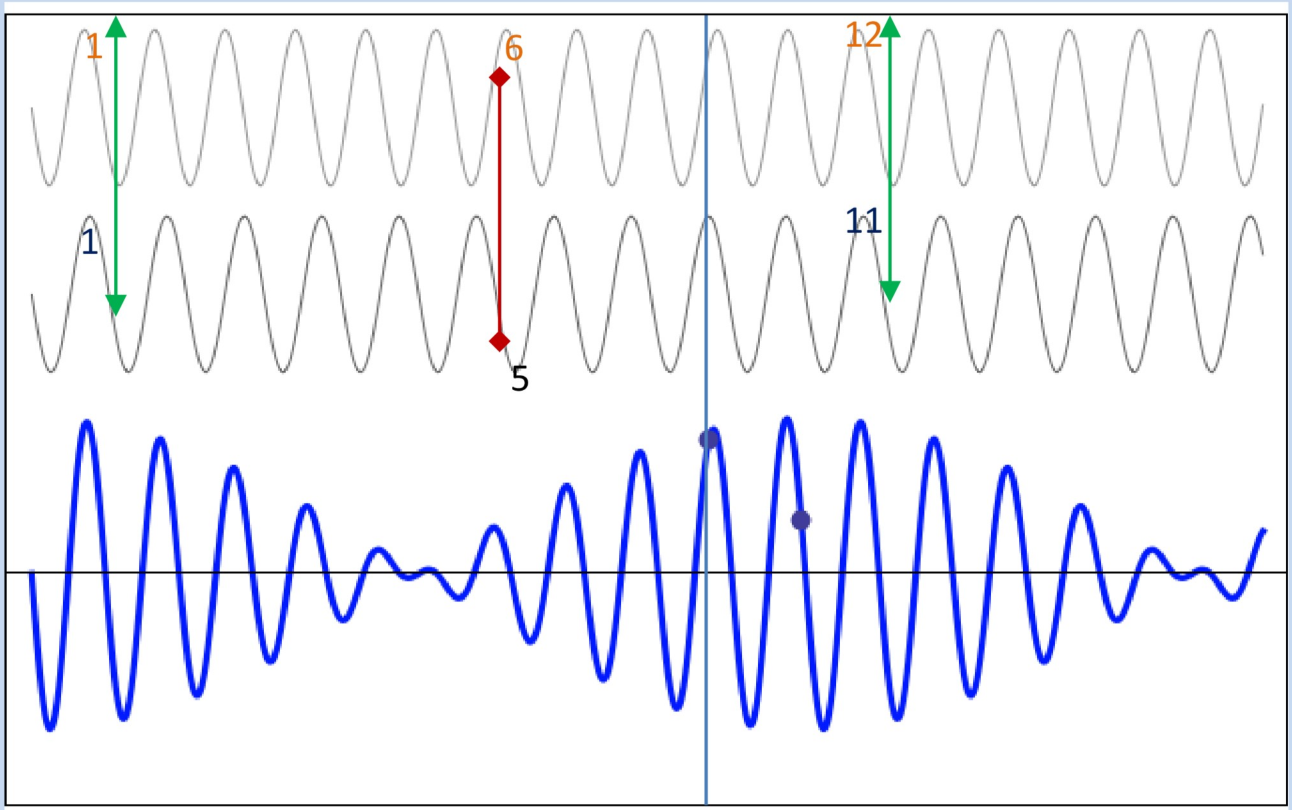
Two slightly different frequencies sometimes constructively interfere and sometimes cancel each other out

Beating: *Interference in Action*



Higher Frequency

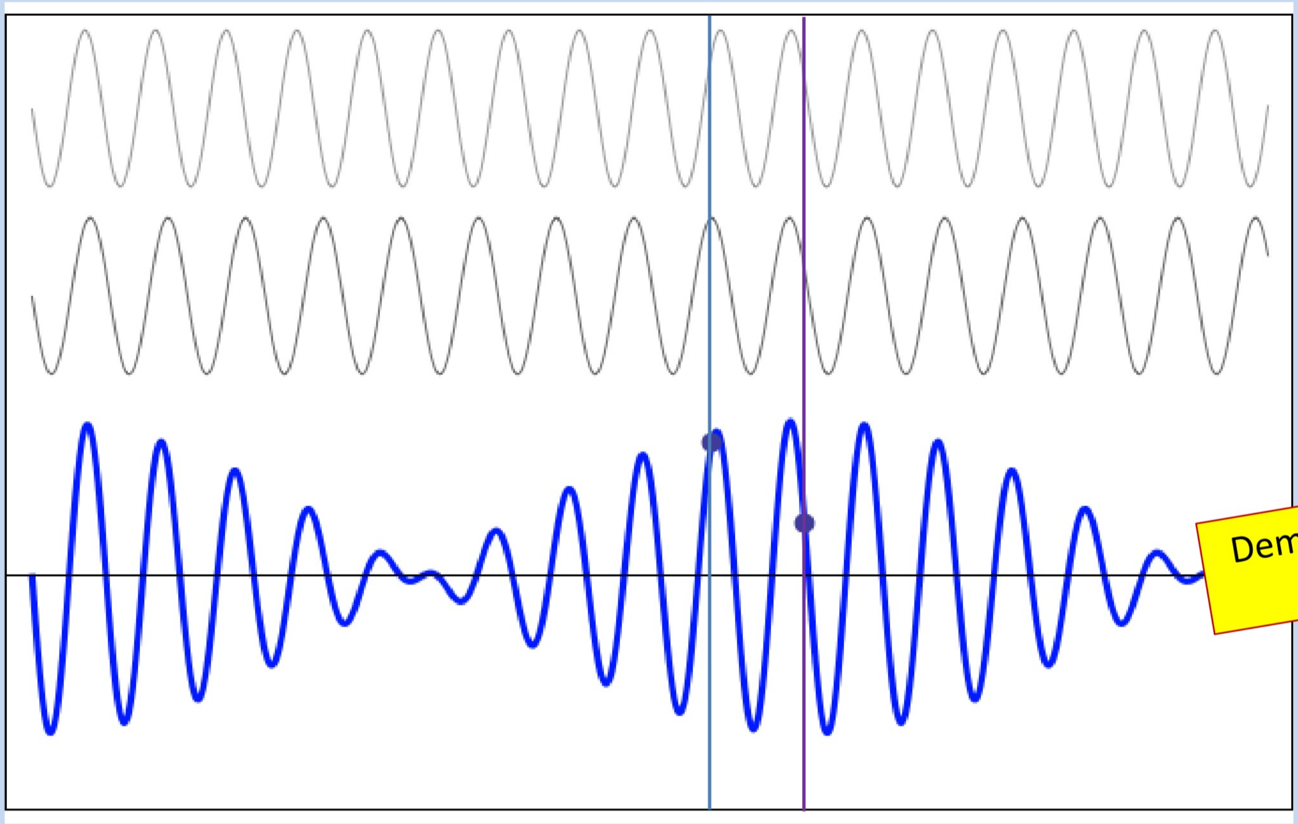
Lower Frequency



Beating: *Interference in Action*

Higher Frequency

Lower Frequency



Demo

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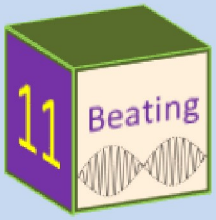


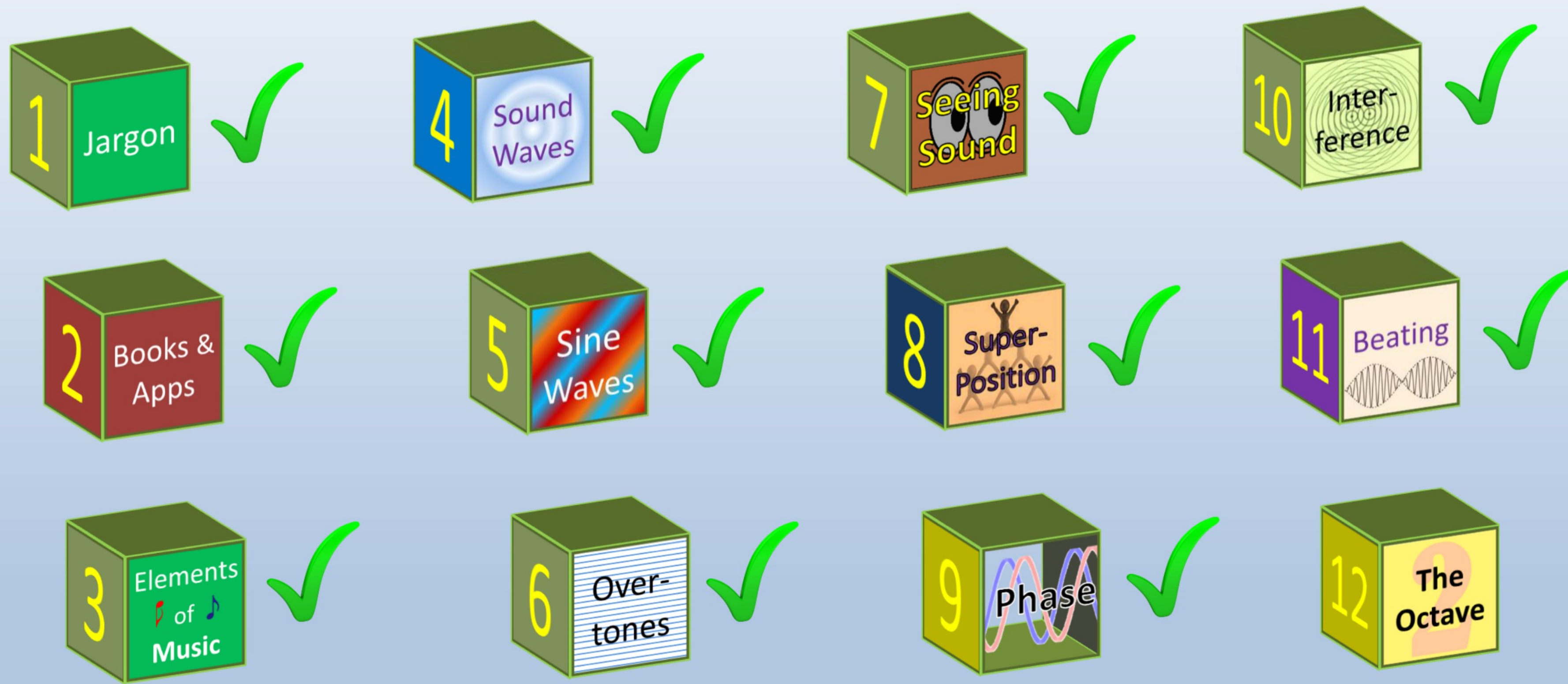
Beating: *Interference in Action*

Another Example:

3 Simultaneous Tones:

- 440 Hz
- 441 Hz
- 443 Hz

Building Blocks



The Octave: Doubling the Frequency

- Doubling or Halving the Frequency has special significance in all musical traditions.

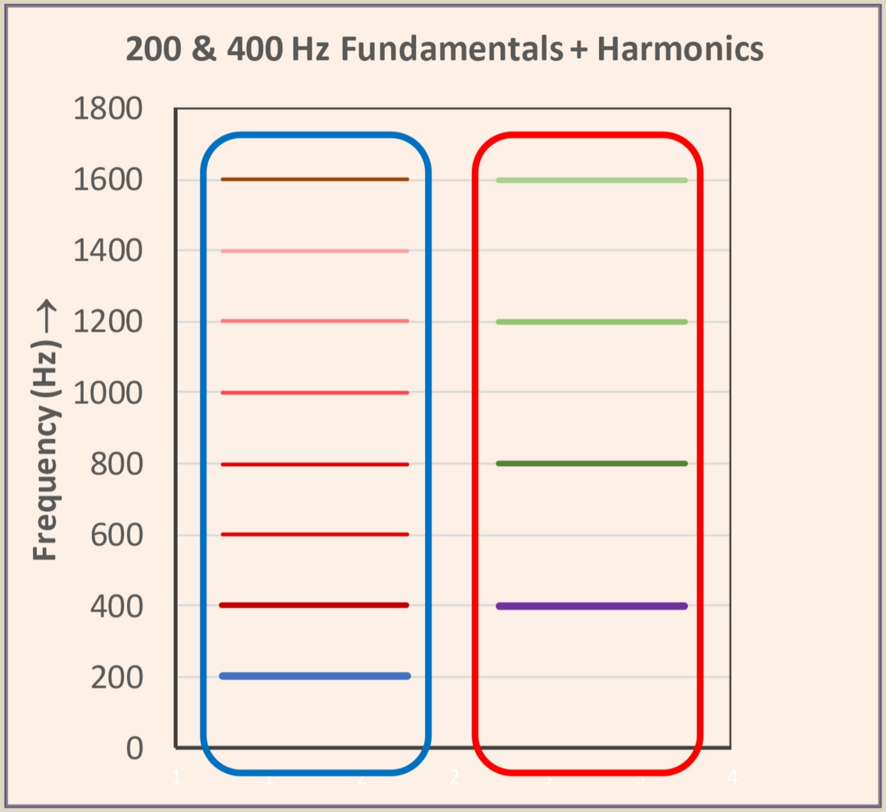
- A musical Note and its Octave (i.e. double f) sound *especially good* together.

  2:1 is the most harmonious ratio

- If a Note with Fundamental Frequency f exists in a musical tradition,

  then so does its Octave $2f$.

The Octave: Doubling the Frequency



These tones have 12 harmonics

400 Hz | 402 Hz | 410 Hz | 420 Hz

200 Hz

200 + 400 | 200 + 402 | 200 + 410 | 200 + 420

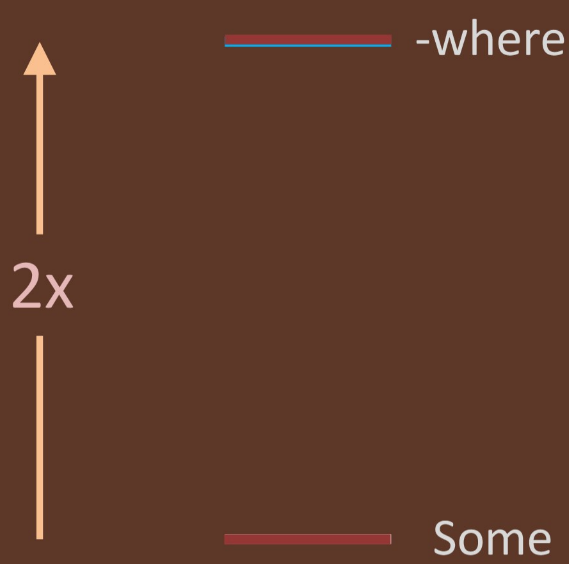
Sounds Nice

200 + 403

We hear beats

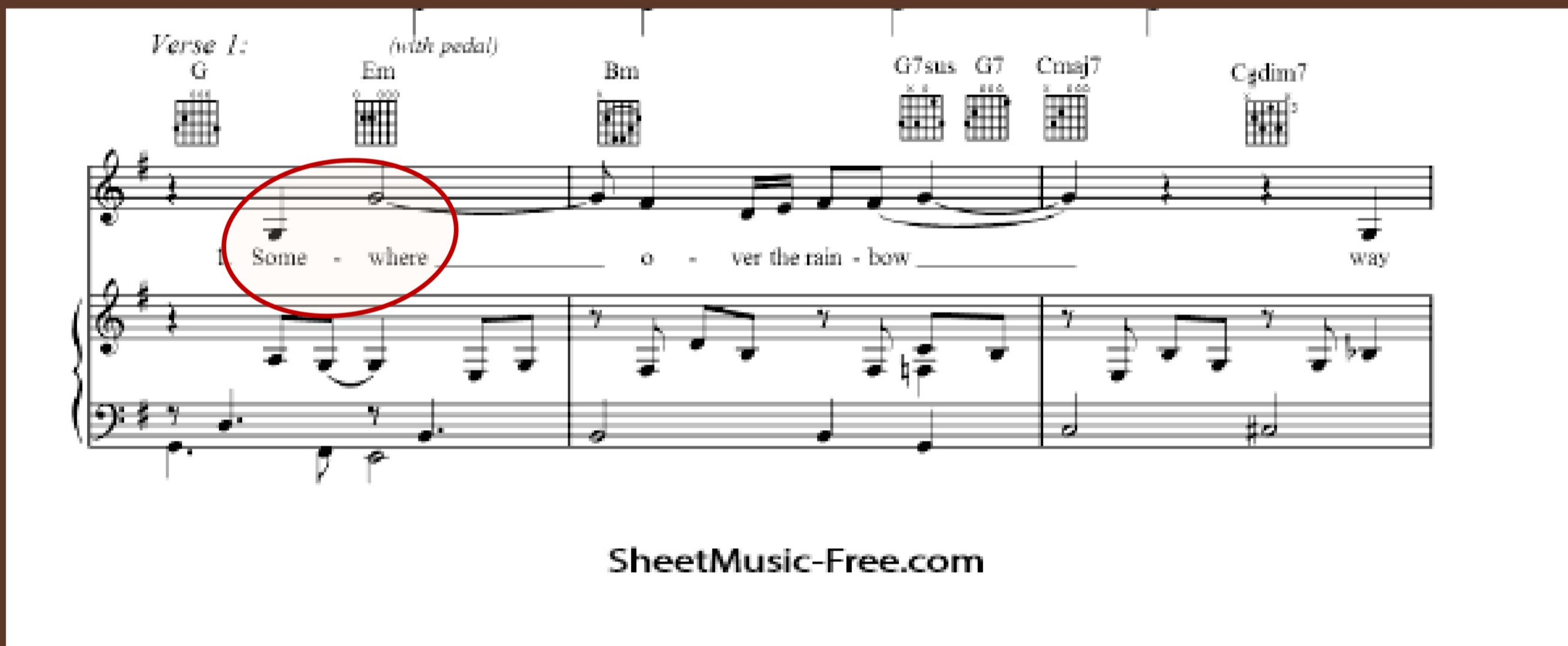
These sound rough

The Octave: Remembering It

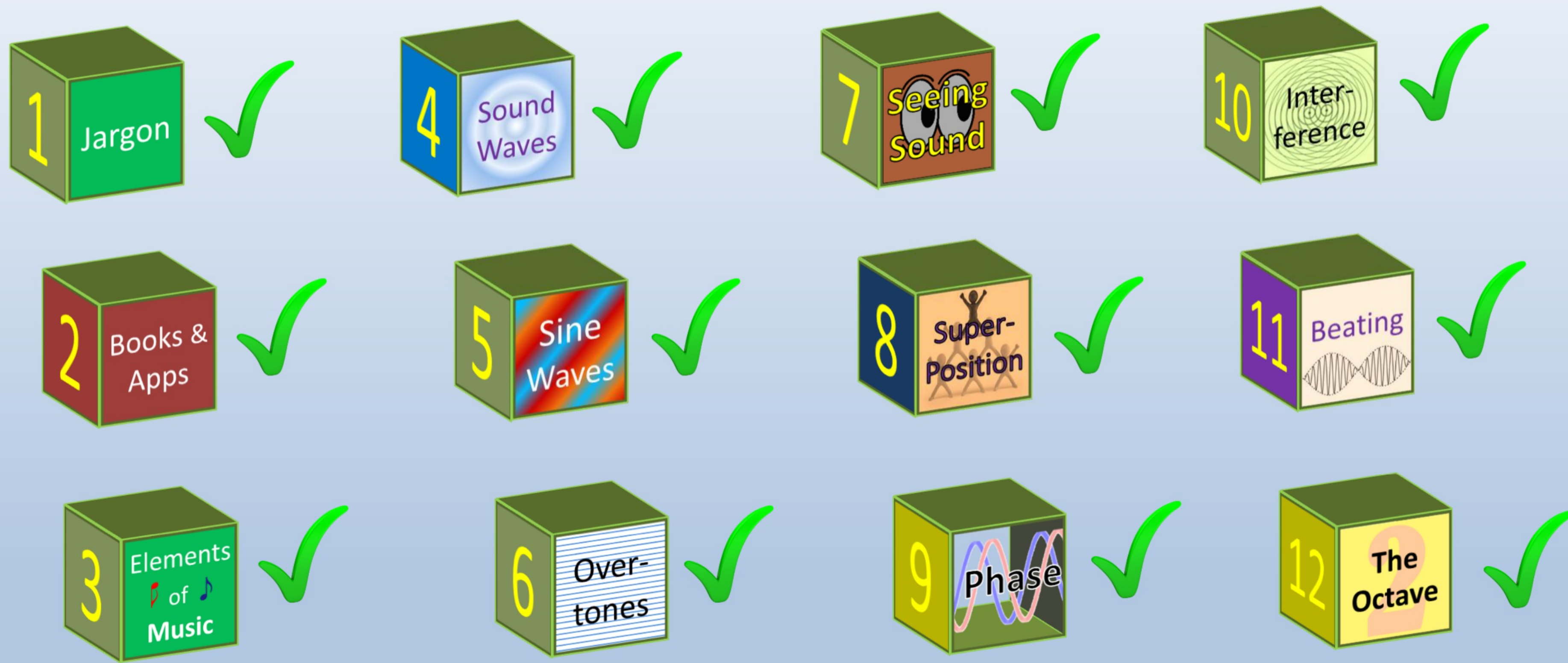


The Octave: Remembering It

G3-> G4



Building Blocks



Building Blocks

Course Outline

1. **Building Blocks: Some basic concepts**
2. Resonance: Building Complex Sounds
3. Hearing and the Ear
4. Musical Scales and Musical Notation
5. Musical Instruments: Strings and Timbre
6. Musical Instruments: Pipes
7. Human Voice and Singing
8. Harmony and Dissonance; Chords