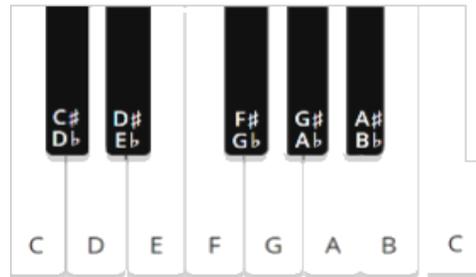


Lab 4. Musical Chords and Harmonics

Glen Bull and Rachel Gibson

In the previous lab we learned that a series of harmonics that are multiples of the base frequency of a sound (i.e., the fundamental frequency) give a sound its richness. The perceived quality of a sound created by its harmonics is known as its *timbre*.

Harmonics also influence whether two musical notes are perceived as pleasing when they are played together. A span of notes on the piano keyboard that begins with one note (such as the note “C” in the illustration below) and ends in the same note is known as an octave. The octave that begins with middle C is in the fourth octave (counting from the left) on the keyboard. This can also be written “C4” (where “C” refers to the note and “4” refers to the octave).



The fundamental frequency of the note C4 is approximately 264 Hz. The note C5, which begins the next octave, is double the frequency of C4. In fact, the note that begins each octave is double the octave before. The span between C4 and C5 is divided into twelve intervals with seven white keys (C, D, E, F, G, A, and B) and five black keys (known as sharps and flats).

The Western chromatic scale, reflected in the set of piano keys shown above, is the scale that is used for most music in the Western world today. The ratio of the frequencies of any two adjacent notes in this scale is always the same. For example, if the frequency of C#4 is divided by the frequency of the previous note, C4, the result is:

$$277.2 \text{ Hz divided by } 261.6 \text{ Hz} = 1.059$$

The resulting ratio, 1.059, is the twelfth root of 2. (That is, 1.059 multiplied by itself twelve times yields the number two.)

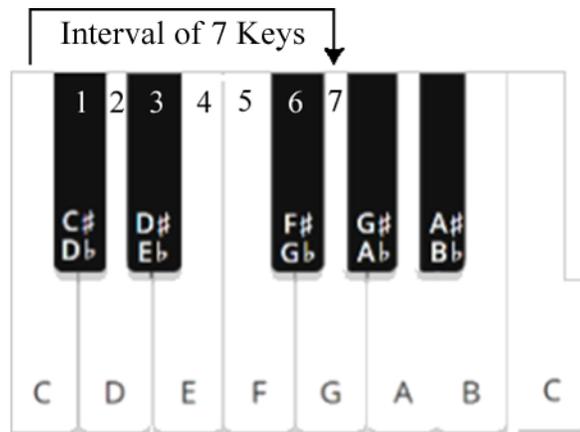
Ratios of Frequencies of Musical Notes													
Note	C4	C#	D4	Eb	E4	F4	F#	G4	Ab	A4	Bb	B5	C5
Hz	261.6	277.2	293.7	311.1	329.6	349.2	370	392	415.3	440	466.2	493.9	523.3
Ratio		1.059	1.059	1.059	1.059	1.059	1.059	1.059	1.059	1.059	1.059	1.059	1.059

Organizing the intervals between musical notes in this way has a number of advantages in terms of musical composition. When two notes are combined, the harmonics of the two notes can either reinforce or disrupt one another. When the harmonic series of the two notes are in alignment, the combined notes are also perceived as harmonious. When two notes are an octave apart, there is a 2:1 ratio between the frequencies of the two notes. Therefore, the harmonics of the two notes are also aligned. When C4 and C5 are played together, they are sometimes perceived as one single note rather than two separate notes.

For example, if Tone 1 has a fundamental frequency of 100 Hz, the overtones will be at 100 Hz intervals above the fundamental frequency. If Tone 2 has a fundamental frequency of 200 Hz, the overtones will be at 200 Hz intervals above the fundamental frequency. The first three overtones of Tone 2 will align with the second, fourth, and sixth overtones of Tone 1. Because these notes are in alignment, the two tones will be perceived as harmonious when played together.

Tone 1	Tone 2
100	
200	200
300	
400	400
500	
600	600

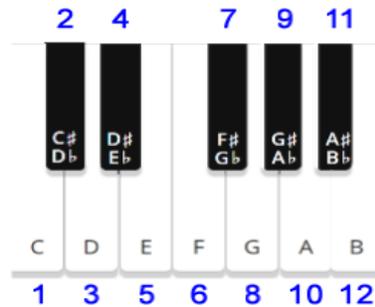
In general, notes whose frequencies are low whole-number ratios have better harmonic alignment. The number of steps between any two piano keys is known as the interval between the two keys. For example, there are seven piano keys between the notes “C” and “G” in the illustration below.



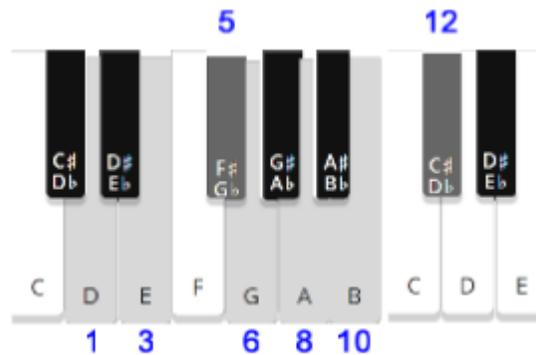
An interval of seven notes results in a ratio of approximately 3:2. An interval of five notes results in a ratio of approximately 4:3. An interval of four notes results in a ratio of 5:4. For that reason, notes that are separated by intervals of four, five, or seven notes are perceived as harmonious when played in combination with one another.

Table of Musical Intervals												
Interval	1	2	3	4	5	6	7	8	9	10	11	12
Ratio	25:24	9:8	6:5	5:4	4:3	45:32	3:2	8:5	5:3	9:5	15:8	2:1

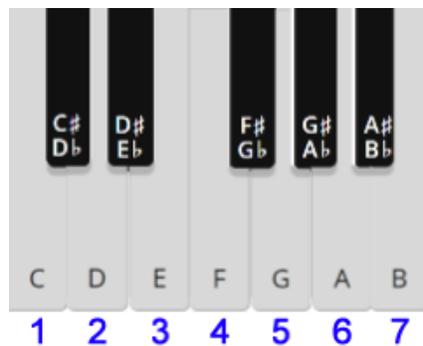
Musicians and composers often work within a subset of notes within the larger twelve-note chromatic scale. These subsets of notes are selected because they yield combinations of notes that are harmonious when played in combination with one another. For example, the *major scales* are a series of seven note scales. These seven-note scales consist of notes that are judged to be harmonious in combination with one another. The C Major scale consists of the seven white keys. These keys are numbered 1, 3 5, 6, 8, 10 and 12 in the illustration below.



There are twelve major scales, one for each note in the chromatic scale. The notes for each major scale are always drawn from the same relative position in the chromatic scale. For example, the notes that form the D Major scale are drawn from the same relative positions of the chromatic scale. This scale consists of the notes numbered 1, 3, 5, 6, 8, 10, 12 (beginning with D).

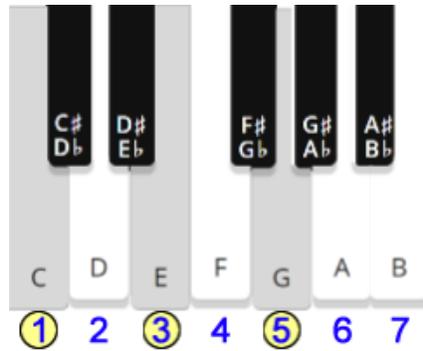


Major chords are three-note combinations of notes within a seven-note major scale. For example, the C Major chord consists of the seven white keys, numbered one through seven in the illustration below.



The *C Major* chord consists of the first, third, and fifth notes of the C Major scale (i.e., the notes C, E, and G). The interval between C and G yields a ratio of 3:2 and the interval between C and E yields a ratio of 5:4. Therefore, we would anticipate these combinations of notes would sound harmonious when played together.

Because the note E is the third note in the seven-note major scale, the combination of C and E played together is known as a *Major Third*. Similarly, because G is the fifth note in the seven-note major scale, the combination of C and G played together is known as a *Perfect Fifth*. The term Perfect in this instance is used to indicate that the ratio of 3:2 is a low whole-number ratio, and therefore can be expected to sound harmonious.

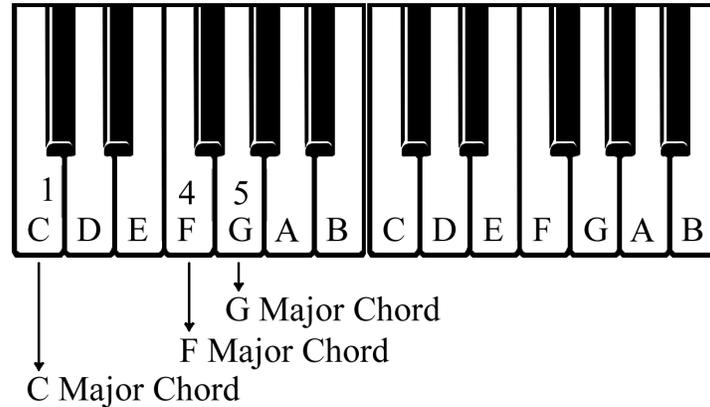


This pattern is repeated for all of the other major scales. For example, the D Major chord is composed of the first, third, and fifth notes of the D Major scale (i.e., the notes D, F#, and A). Earlier, it was noted that an equal tempered scale in which the ratios of the frequencies of adjacent notes offers advantages in terms of equal composition. One of these benefits is that any two notes separated by the same interval have the same ratio of frequencies.

Consequently, the combination of the first, third and fifth notes forms a major chord for any major scale. Although the absolute frequencies shift, the relationship of the ratios of frequencies within the scale remain the same. This is not the case for other scales such as a just tempered scale.

To sum up, the intervals selected for the Western chromatic scale are designed to produce as many combinations of harmonious notes as possible. Within this larger twelve-note scale, the seven-note major scales are designed to produce as many combinations of harmonious notes as possible. Within the major scales, three-note major chords are combinations of notes whose frequencies produce low whole-number ratios, and consequently sound harmonious when played together.

A chord progression consists of a series of chords, often used as a backing track that accompanies a melody consisting of individual notes. A common chord progression consists of the chords associated with the first, fourth, and fifth note in a major scale.



For example, the notes C, F, and G are the first, fourth, and fifth notes in the C Major scale. Therefore, the C Major chord progression would consist of the C Major chord, the F Major chord, and the G Major chord.

Because a Major Scale chord progression is established by the first, fourth, and fifth notes in the scale, the corresponding chords are often referenced as the I Chord, the IV Chord, and the V Chord. Roman numerals are used to reference chords to differentiate chords from notes. The I-IV-V chord progression for the C Major scale is summarized in the table below.

Chord Numbers	I	IV	V
C Major Chord Progression	C Chord	F Chord	G Chord

A chord progression beginning with a D Major chord would consist of the D Major Chord, the G Major Chord, and the A Major chord. Since these chords maintain the same relative positions in the D Major scale, the chord numbers remain the same.

Chord Numbers	I	IV	V
D Major Chord Progression	D Chord	G Chord	A Chord

There are many other chord progressions, but the I-IV-V chord progression is the basis of much of the popular music that employs the Western chromatic scale and major scales.