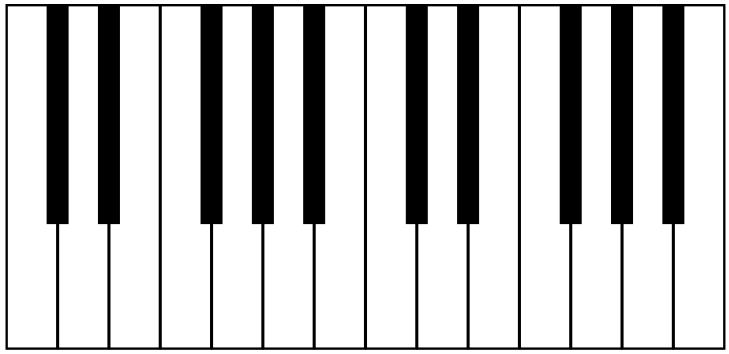

# Music by Pictures

Michael Redman

February 6, 2016

IN GOD WE TRVST.

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# Contents

# 1 Drums

The basic unit of time in music is the **beat**. The **tempo** of a piece of music is the number of beats per unit time, usually beats per minute, with each beat being equal. Most music has a tempo in the range of 60-180 BPM.

A **metronome** is a device, now often computer software, that produces a "click" or "tock" or other sound periodically at a tempo that you can set. More powerful gear like an audio editor or a digital piano will often have a metronome or the ability to create a "click track" built in as a feature.

A metronome or "click track" provides musicians with an objective standard for when the notes ought to be played that they can listen to and compare their play against. A metronome is an essential tool in practice and some cases of recording (it allows musicians to record tracks independently and then mix them together).

**Exercise 1.** Get a metronome and familiarize yourself with how to adjust its tempo. There are numerous free metronome application programs and web applications available on the Internet.

**Exercise 2.** Using any objects you like as drums and drumstics, practice hitting notes on your "drums" exactly in time with the metronome. Start with a slow tempo like 50 BPM to make the exercise easier. Listen for the difference between what it sounds like when you hear two sounds because you missed the beat (the metronome, and then your drums, or vice versa), versus what it sounds like when you only hear one sound (the "compound" sound of the metronome and your drum note hitting exactly together). Notice how it feels enjoyable when your timing is right. Experiment with different tempos.

**Exercise 3.** Practice dividing a beat in half. So play one "drum" in time with the metronome clicks, and the other exactly in between those notes. Like in the first exercise listen for how good you are doing staying in time with the metronome. This time also listen for whether the notes in between the metronome clicks are equally spaced in between the others.

You might notice that the drum part in a song usually follows a basic pattern, with some more complicated sequences added every now and then. These basic patterns of drum notes are also called "beats" and the more complicated parts used for emphasis or transition are called "fills".

**Exercise 4.** Find on the Internet at least one introduction to drums for beginners video that you like, and learn at least one common drum beat from it.

# 2 Intervals

## 2.1 Half steps and whole steps

If you haven't already learned otherwise, you might think that the black keys on a piano keyboard are somehow "special" or different from the white keys. After all, someone takes the care to make them a different color.

No keys on the piano, white or black, are special, at least as far as concerns the way they sound and how they can be used in making music. The black keys don't have their own letters for their names (they use the letters from the white keys, with a sharp (♯) designating the black key to the right of a white key, and a flat (♭) designating the black key to the left of a white key, so every black key has two names), but this is an aribitrary convention unrelated to the musical properties of sound waves. Every key on the piano is equally spaced in **pitch** - how "high" or "low" it sounds - from the key to its right or its left, regardless of whether you start on a white or a black key, and regardless of whether the key to the right or left is white or black. The difference or distance in pitch, or **interval**, between two neighboring keys is always a **half step**, also called a **semitone**. Two half steps is a **whole step**.

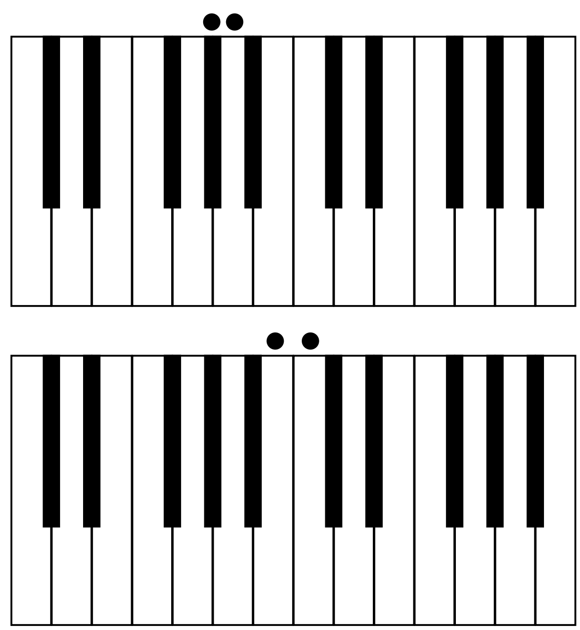


Figure 1: In each picture, the keys marked with dots are a half step apart.

The pattern of white and black keys works more like the pattern of yard lines on an American football field, to help your hands have reference points for what notes they're on. On an American football field, there are little hash-marks in the center of the field to mark off every yard, and then every five yards there is a line that goes all the way across the field, and then every ten yards that line all the way across the field is labeled with the distance from the goal line.

On a piano, notice how the black keys alternate in sets of two and sets of three. The white key to the left of the

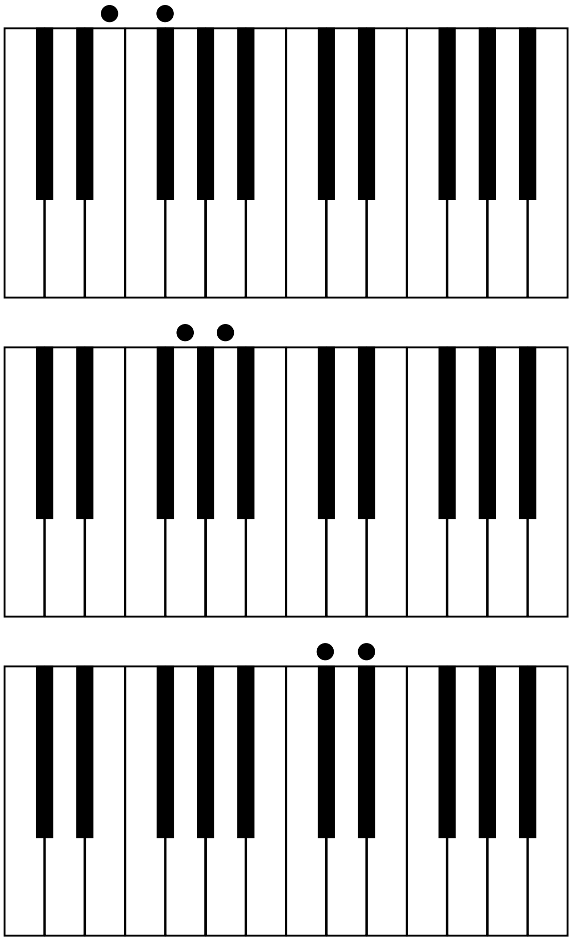


Figure 2: In each picture, the keys marked with dots are a whole step apart.

left black key in a set of two black keys, is always a "C". Continuing to the right on the white keys from C, the names are D, E, F, G, and then the white key to the right of G is A, and the white key to the right of A and to the left of the next C is B. **Middle C** is the fourth C (from the left) on a standard 88 key piano (so there are 3 Cs to the left of Middle C and four to the right). The leftmost key on a standard 88 key piano is an A and the rightmost key is a C.

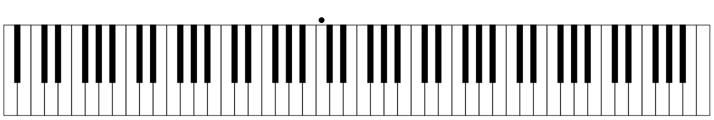


Figure 3: Middle C on an 88 key piano keyboard

**Exercise 5.** Familiarize yourself with how the pattern of white and black keys on a piano repeats every 12 keys. Learn the names of the keys.

## 2.2 Octaves

If you start at any key on the piano, and count up (to the right) or down (to the left) 12 half steps (12 keys including all white and black, not counting the key you start on or else counting it as zero), so that the key you arrive at is in the same position in its group of 12 as the key you started at is in its group, then the interval between those two keys is an **octave**.

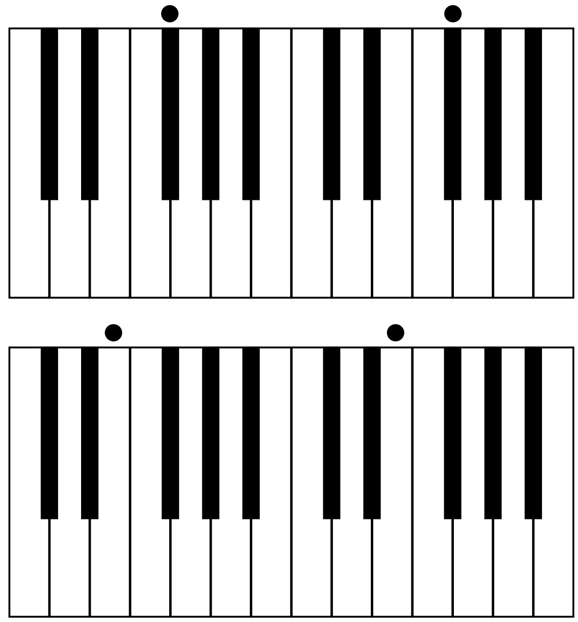


Figure 4: In each picture, the keys marked with dots are an octave apart.

**Exercise 6.** Practice finding octaves on the piano until it is easy for you to find them at random.

**Exercsie 7.** Compare, by playing each, how octaves sound with how half steps sound. Choose a few other intervals at random and compare how those sound with octaves and half steps.

If your piano is in tune, the octaves sound "cleaner" or "crisper" or more **consonant** than the half-steps, which sound **dissonant**.

The consonance occurs in the case of octaves because the sound waves of the two pitches combine or interfere in a more regular pattern.

In the case of two instruments producing the same pitch (for example, if you sing the same pitch you are playing on the piano, or play the same pitch on two different strings on a guitar), the waves "fit" together almost exactly. The zero interval is the most consonant interval and is called **unison** or **perfect unison**, although the word "unison" also has other uses in music.

In the case of an octave, the wave from the higher note (further to the right on the piano keyboard) is double the **frequency** (number of oscillations per second) and half the **wavelength** (distance between consecutive "crests" or "peaks" in the wave) of the lower note (further to the left on the keyboard). So higher sounding pitches have higher frequencies and shorter wavelengths. The octave is the most consonant interval you can play both notes of simultaneously on the piano.

Because the consonance of octaves is so pure, often pitches that differ only by whole numbers of octaves are considered to be the same musical note (they have the same letter in the naming convention), and the word “unison” can also describe when different instruments or voices simultaneously produce pitches that are either the same pitch or differing only by whole numbes of octaves.

Doubling the frequency and halving the wavelength for each octave means that a pitch that is two octaves up from another is four times the frequency and one fourth the wavelength, and a pitch three octaves up from another is eight times the frequency and one eighth the wavelength. This inverse **geometric** relationship between pitch and wavelength is visible in the distances between the frets on a guitar. On the same string, every fret is a half step in pitch different than the next, just like neighboring keys on a piano, so to keep these intervals the physical distances between the frets shorten as the length of string they allow to vibrate also shortens (the frets closer to the body of the guitar get increasingly closer together).

The geometric relationship between pitch and frequency also complicates the issue of choosing what pitches a “quantized-pitch” instrument like a piano or fretted guitar (as compared with instruments that can produce any pitch within a continuous range, like your voice, or a fretless guitar), should be able to produce. Because of this problem, the intervals on a piano or fretted guitar are slightly different from the mathematically perfect or **just** frequency ratios like 2:1 for an octave. The chapter on **tuning** further presents this issue.

## 2.3 Fifths and fourths

There are two other intervals for which it is easy to hear some of the same consonance you hear in octaves. Other intervals besides the most consonant ones are useful in making music, but the consonant intervals are the most important ones to know because of their special sound.

The interval with the most consonance besides the octave, is the **fifth** (also **perfect fifth**). Its frequency ratio is 3:2, and it is 7 half steps (or 7 keys on the piano - starting at any key, don’t count that key or else count it as zero, and then count up or down 7 keys including all white and black; that is a fifth).

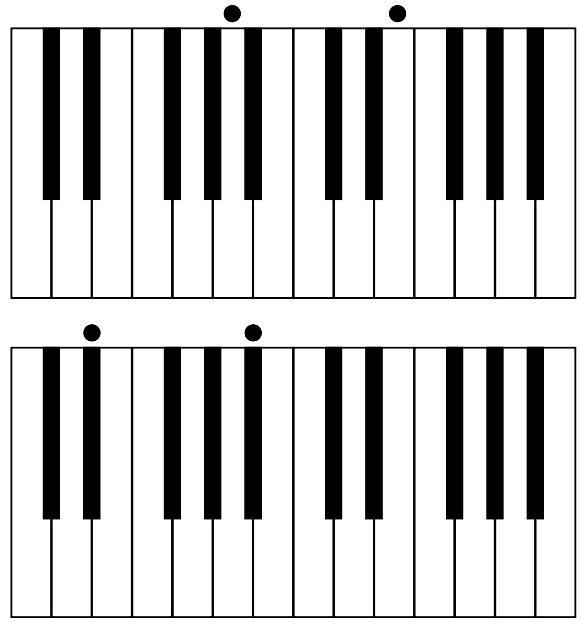


Figure 5: In each picture, the keys marked with dots are a fifth apart.

The next “cleanest” interval is the **fourth** (also **perfect fourth**), which has a frequency ratio of 4:3, and is 5 half steps.

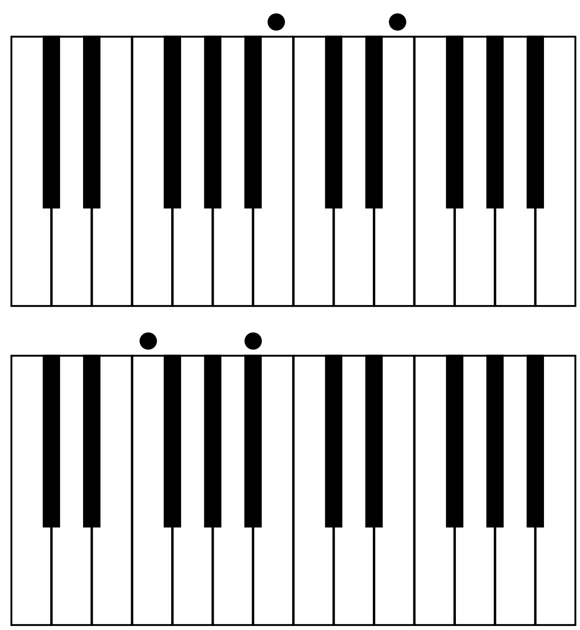


Figure 6: In each picture, the keys marked with dots are a fourth apart.

**Exercise 8.** Find fifths and fourths at random on the piano until it is easy for you to find them, going either up or down from any starting point. Play them and compare what they sound like to octaves.

The interval of 6 half steps (a half step wider than a fourth, and a half step narrower than a fifth), is called a **tritone**.

You will notice it is dissonant.

## 3 Chords and inversions

A **chord** is a combination of pitches (often three) played together.

Any two notes in the chord will have some interval between them. Therefore you can identify chords by the patterns in the intervals between the notes in the chord.

Since all the adjacent notes on a piano are a half step apart, we can record the notes making up a chord by counting half steps from some starting point or **root** note. For example, if 0 is the note that you choose as the starting point, then 1 is the note a half step up (to the right) on the keyboard from that, 5 is the note a fourth up from the starting point, -7 is the note a fifth down (to the left) from the starting point, etc.

Because you can make the same pattern of intervals starting from any note, in order to completely identify a chord you need to identify both the name of the pattern and the name of the root note.

Because two pitches an octave apart sound alike, you can move any of the notes in a chord up or down an octave to change their ordering in the chord, and the chord will sound similar. Chords that are the same except for notes that have been moved up or down by an octave to reorder them, are **inversions** of each other.

**Exercise 9.** The intervals you have already learned allow you to cook up some useful chords. Familiarize yourself with these chords from various random starting points on the keyboard:

1. 0,7,12. Using any starting point you choose, play that starting note, together with the note a fifth to the right of the starting note, and also together with the note an octave to the right of the starting note. Notice the middle note also forms a fourth with the top note in the octave.

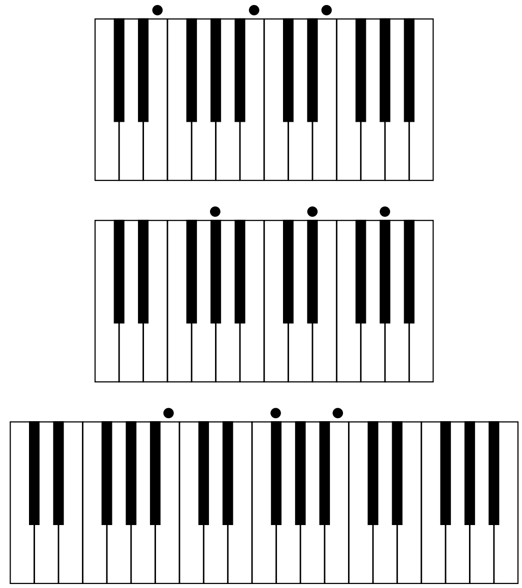
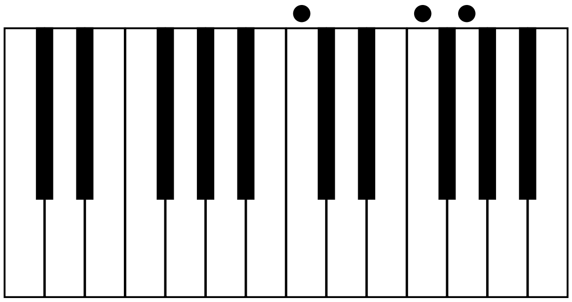


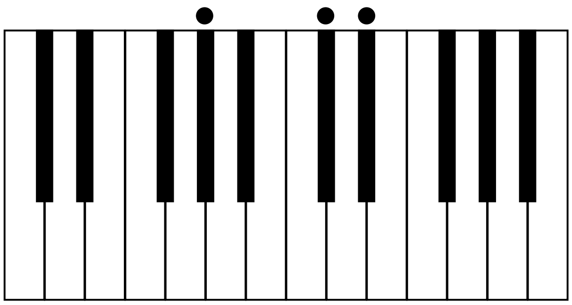
Figure 7: The 0,7,12 chord using different notes as the root. Notice how in each picture the intervals are the same.

2. 0,5,12. From any starting point, play that note, together with the note a fourth up from where you started, and also together with the note an octave up from where you started. Notice the middle note also forms a fifth with the top note in the octave.

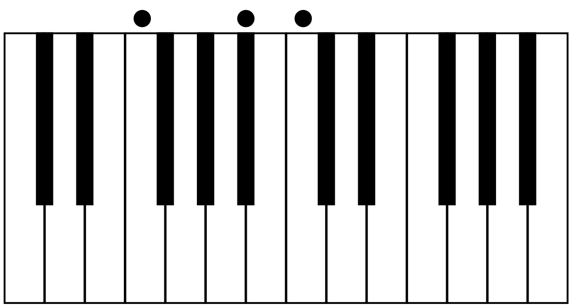
3. 0,5,7. From any starting point, play that note, together with the note a fourth up from where you started, and also together with the note a fifth up from where you started. Notice the dissonance in this chord because the top two tones are a whole step apart (compare with all consonant intervals in the previous two chords). The 0,5,7 chord is called the **suspended fourth**, written **sus4**. If you play this chord starting from a C, that would be written Csus4.



(a) Csus4



(b) Absus4

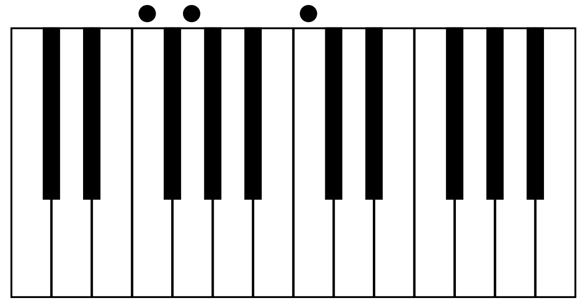


(c) Fsus4

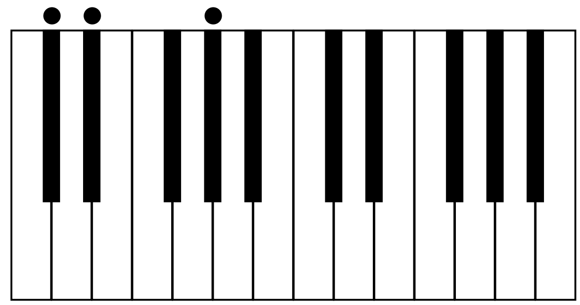
Figure 8: Suspended fourth chords using different notes as the root. Notice again how in each picture the intervals are the same.

4. 0,7,14. From any starting point, play that note, together with the note a fifth up from your starting point, together with the note a fifth up from the higher of those two notes.

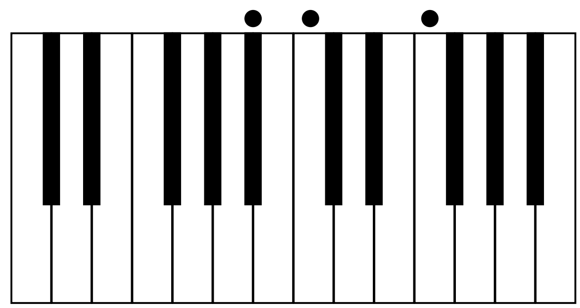
5. Start with the 0,7,14 chord you just made. Do not change which note you are using as “0”. Move the top (14) tone down an octave to make an inversion; now you have 0,2,7. The 0,2,7 chord is the **suspended second**, written **sus2**. Notice if you again move the top tone down an octave to make -5,0,2 then you get the suspended fourth chord. So the suspended fourth and suspended second are inversions of each other. For example, Csus4 and Fsus2 are inversions of each other.



(a) Fsus2



(b) D♭sus2



(c) B♭sus2

Figure 9: Suspended second chords using different notes as the root. Notice how each chord is an inversion of the corresponding suspended fourth chord pictured in the previous figure.

6. 0,5,10. From any starting point, play that note, together with the note a fourth up from the starting point, together with the note a fourth up from the higher of those two notes. Note how if you move the top pitch down an octave to make the -2,0,5 inversion you get a suspended second chord again.

A **chord progression** is a sequence of chords that you can use as a “building block”.

You want to learn as many chords and chord progressions as you can so you have more building blocks. “Learning” them means both knowing in your creative mind what the chord or progression is going to sound like when you play it, and knowing in your muscle memory how to find and play it on the instruments of your choice. There are many resources on the Internet discussing chord theory.

Although important for their own reasons, the ideas in the next chapter will also further help you figure out the relatioships inside different chords and progressions you might play or encounter, and understand what other musicians are saying when they name them in certain ways.

# 4 Scales and key

If you have been doing the exercises, you have already experienced how different combinations of pitches sound different, according to the intervals between the pitches. For this reason a composition will use some combinations of pitches more than others, according to how its author intended it to sound.

A **scale** is any finite selection of pitches.

Normal scales span one octave and then repeat. The **chromatic scale** is a special scale consisting of all 12 half-steps in an octave.

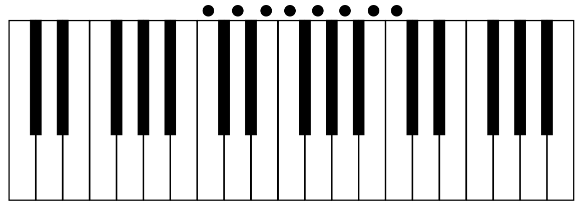
When musicians study scales, the pitches are in ascending order and they mostly consider the relationships the pitches have to the lowest note. When musicians play and compose, they might use the notes of the scale in any order.

You have also already experienced from the exercises how the relationship between pitches does more to determine how a chord sounds, than what specific pitch you started the chord pattern at. For this reason, it is sometimes useful to think just about the relationship between the notes in a scale, and sometimes useful also to consider at what pitch the pattern starts in a specific chord or composition. When you identify both the pattern and the starting pitch, you have identified what **key** the composition is "in". Many compositions change keys part way through.

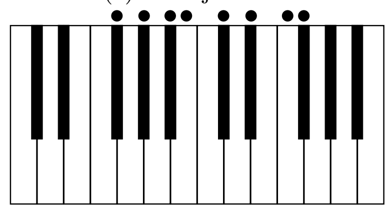
## 4.1 Modal scales

There is a set of scales that has become so common in music that the piano keyboard is made to follow its pattern.

If you start on any C, and you consider the sequence of intervals between neighboring white keys as you go to the right towards the next C, you will notice that the pattern is WWHWWWH, where 'W" represents a whole step and "H" represents a half step. This scale is named the **major scale**.



(a) C major scale

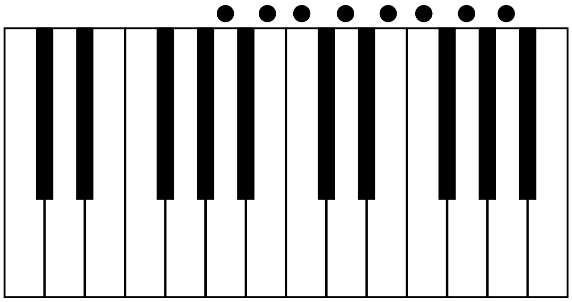


(b) G♭ major scale

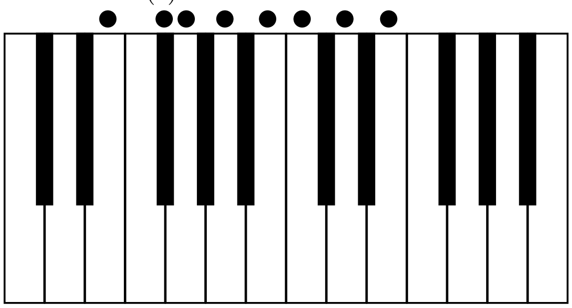
Figure 10: Major scales. Notice how the intervals are the same in each picture, WWHWWWH, and how the C major scale uses all white keys.

If you start on any other white key, and proceeding to the right play consecutive white keys until you have played an entire octave, you will be following the same WWHWWWH pattern, just starting in a different place. The intervals between the white keys haven't changed, just where you started your octave. For example if you start at D then the pattern is WHWWWHW. Each of the 7 possible scales you get by staring on a different white key, is said to be a different **modal scale** or **mode** of the scale. The modes have ancient names like "Phrygian" and "Mixolydian"; the major scale is the **Ionian** modal scale.

Starting the pattern at A on the piano makes WHWWHWW. This is the **Aeolian** mode, and also known as the **natural minor** scale. The traditional Christmas song "God Rest Ye Merry Gentlemen" uses this scale; in the key of E minor it uses the notes D-E-F♯-G-A-B-C-D-E (even though the song uses one note lower, the minor scale starting at E still "describes" its musical structure best), with most of the notes between the E and the B (a fifth above the E), and the song opening with those notes. E minor is also popular in heavy metal and other guitar music because the guitar's strings are tuned to important notes in that scale (including two E strings, the lowest and highest).



(a) A natural minor scale.



(b) E natural minor scale

Figure 11: Natural minor scales. Notice again how the intervals are the same in each picture, WHWWHWW, and how the A natural minor scale uses all white keys.

The most characteristic distinction between major and minor is in the third element of the scale. In a major scale, it is four half steps up from the starting point (which is also one half step below the fourth); this interval is a **major third**. The **minor third** is three half steps up from the starting point, or a half-step lower than the major third.

In both the major and natural minor scales, the fourth tone in the scale is a fourth above the lowest tone, and the fifth is a fifth above the lowest, which is how those intervals got their names, and why they aren't instead named for their frequency ratios or something more sensible. It is typical to name intervals according to what step in some scale makes that interval with the starting pitch of the scale. For example, a major sixth is the interval from the lowest to the sixth pitches in the major scale, which is 9 half steps, or the distance from C to A on the piano.

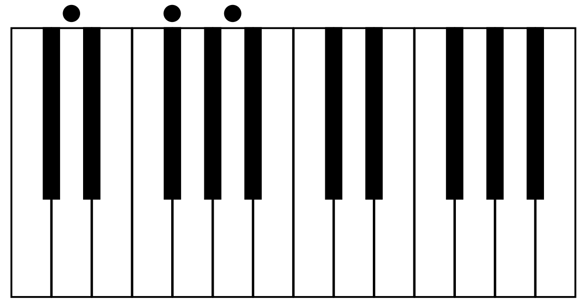
**Exercise 10.** Starting at different points randomly instead of going sequentially up or down the keyboard, familiarize yourself with the major and natural minor scales from all 12 possible starting notes, until it is easy for you to find them. If you wish to be thorough, learn all 7 modes of the scale from all 12 starting notes.

**Exercise 11.** Look up on your own and learn at least one scale that does not follow the modal pattern.

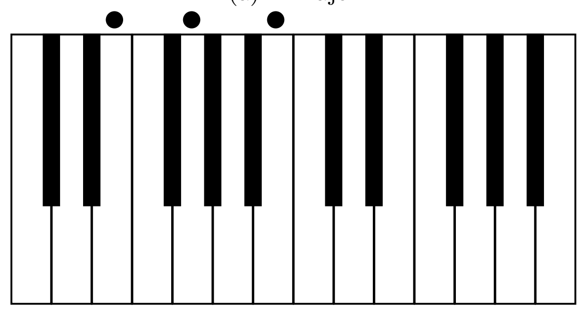
### 4.2 The tonic chord

The **tonic** is the first note in a scale. The **tonic chord** is the chord made of the first, third, and fifth notes of a major or minor scale.

In the major scale, the tonic chord is 0,4,7. In the minor scale, it is 0,3,7. The tonic chord is so important and commonly used, that if someone said "a C chord" without further qualification or context, they would probably mean the C major tonic chord or an inversion of it.



(a) D major



(b) E minor

Figure 12: Tonic chords

**Exercise 12.** Starting on different white and black keys at random, familiarize yourself with how to find all 3 inversions of the major and minor tonic chords from all 12 possible starting or tonic tones.

**Exercise 13.** Look up on your own and learn on the keyboard at least 2 other common chords not discussed in this book.

## 5 Analysis of an example riff

A **riff** is any "building block" of a song that helps give the song its identity or characteristic sound. Riffs are often repeated or varied upon in songs.

To illustrate how the ideas in the preceding chapters can help you think up building blocks and understand other people's that you encounter, this chapter will explain in terms of those ideas, each note and chord in a riff that you can play.

There is nothing special about this riff. It is an example composed for this book, although because it is made of simple musical building blocks it would be unsurprising if it has been independently composed numerous times before.

Rhythm and timing are part of what makes a riff, but that information is not represented in the simple keyboard diagrams and counting of notes that this book uses to communicate intervals and chords. So for purposes of this analysis, you can play this riff with whatever rhythm you like. Experiment until you find one you think sounds good.

Practice playing the riff until you can reliably play it with the rhythm you want, and it sounds reasonably musical to you.

Like for the descriptions of the chords in Chapter 2, if note 0 is your root tonic note, your reference point or starting key on the keyboard, then 1 is a half-step up from there (or one key to the right on the piano, regardless of whether white or black), -7 is a fifth lower than the reference note 0, etc.

The riff is:

1. 0,5,7
2. 0,3,7
3. 0,3,5
4. 0,2
5. 0,3
6. 2
7. -5
8. -2
9. 0

In A$\flat$ minor, the same riff in keyboard pictures is:

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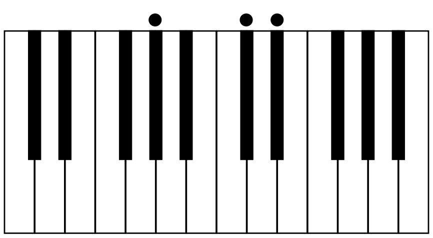

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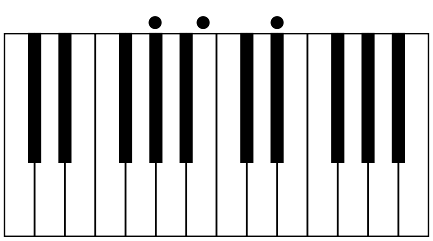

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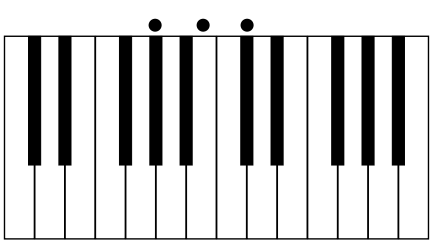

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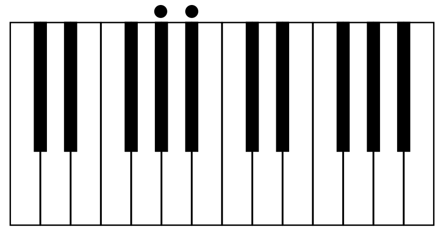

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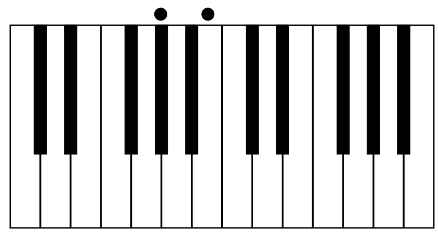

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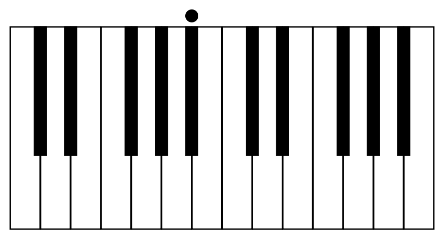

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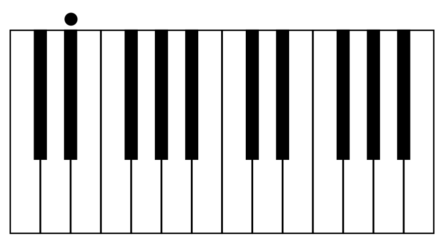

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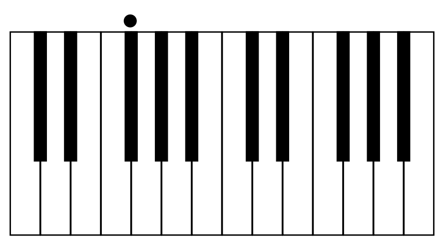

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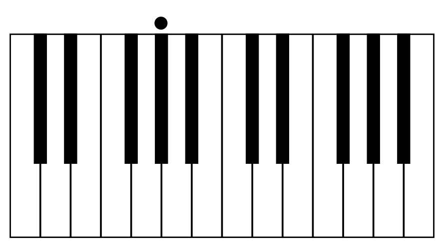

In terms of the ideas from the previous chapters, the chords and notes in the riff are as follows:

1. This is A$\flat$sus4. Chapter 2 introduced suspended fourth chords.
2. The minor tonic chord, from the preceding chapter.
3. The minor third and the fourth combined. This chord both keeps continuity in the riff by repeating the lowest

interval from the preceding chord, and moves the riff along because it is a chord that hasn't been used before.

4. The root note plus a whole step up. The "simplification" from 3 note chords down to a 2-note chord moves the riff along, while the whole step interval keeps the pattern of mixing dissonance into the tonal structure.

5. The minor third again.

6. A whole step up from the root again, but this time the riff again simplifies, now from chords to single notes.

7. A fourth down from the root.

8. A whole step down from the root.

9. The root note. Often riffs will conclude or "resolve" with a return to the root note, sometimes ending with a consonant-sounding chord built on it, although this riff proceeded from complex to simple all the way through.

**Exercise 14.** Analyze one of your favorite songs in terms of the ideas from the previous chapters, meaning identify as many of the relationships between the different notes and chords in the song as you can. The best way to do this is to play along on the instrument of your choice until you figure the song out by ear. However this is an advanced skill that takes a lot of time to develop, so if you need to "cheat" you can search on the Internet for a piano or guitar instructional video (many popular songs have these), or else search for the sheet music and an introduction to reading written music.

# 6 Harmony

**Harmony** is the use of some pitches to compliment others so as to give depth and complexity to a composition.

A **melody** is a sequence of single pitches (not chords) that sounds musical. You can play a melody on an instrument that can only produce one pitch at a time, like your voice.

**Exercise 15.** Figure out a melody from one of your favorite songs.

**Exercise 16.** Study any example of harmony in written music by identifying what notes are part of the melody and what notes are "extra". Identify any chords that you can.

**Exercise 17.** Harmonize any melody by playing with the melody notes additional pitches to complete chords that you know how to construct in the key you are in. Also experiment with introducing pitches that are outside the musical structures you have learned. If you like how any of the experimental pitches sound, make special note of how to find them in relation to the others.

# 7 Improvisation and composition

Almost everything in nature involves some balance between structure and randomness.

For eaxmple, yuo can prbobly raed thsi snetance even thuogh moost of the wrods ar mispleled. This is because the informational redundancy in written English - specifically the exclusion of certain pattern of letters and words from the language - allows your brain to infer what the words ought to be based on what your experience tells you is probable - "nearby" cases that the language does use. If every sequence of letters was equiprobable and they all made valid words, and if every sequence of words was equiprobable and they all made valid sentences, it would be impossible for your brain to make those inferences, and a typo would completely change the meaning of the message. Because we need to be able to reconstruct the meaning of natural language despite typos in writing and missed or mangled syllables in speech, each natural language uses some linguistic patterns more than others, just like different scales in music use different patterns of pitches.

Likewise in DNA guanine only pairs with cytosine, and adenine only pairs with thymine. This "reduces" the number of possible of combinations or "values" for a single pair from 16 (four choices for each half of the pair, if hypothetically all combinations were possible) to 4 (four choices for one half of the pair and one that can go with it for the other half), which means more DNA to encode the same amount of information, but makes it more likely that the DNA will go back together correctly after the strands are separated (like when electrical engineers design cable connectors so every cable will only plug into the right place the right way).

This balancing of redundancy and randomness is an important theme in information theory that manifests in nature in many ways. If you are interested in learning more about these ideas, see Claude Shannon and Warren Weaver, *The Mathematical Theory of Communication.*

In music, your challenge is for your work to be varied and creative in a way that appeals to you and others. If it is too structured, it is trivial, or maybe not even music (imagine playing only one note over and over without varying timing, loudness, or anything else - it's a beacon, not a song!). If it is too varied, it will also not sound like music - everyone has heard a small child "banging" randomly on a piano.

The patterns you have learned in this book are a starting point for how to exercise that creativity.

**Exercise 18.** Starting with any part of any composition, improvise more music with the same general sound.

**Exercise 19.** Improvise something completely original.

There is a great deal of music theory not presented in this book that you can add to your "cookbook" by experimenting on your own, studying other people's music, reading on the Internet and at the library, and learning from musicians you know.

Music is like a lot of other things in life, there is no limit to how good you can get at it. Never stop getting better.

# 8 Tuning

While ingesting the discussion on intervals in Chapter 1, you might have correctly intuited that the musical importance of certain frequency ratios like 2:1 and 3:2 is a feature of nature like gravity, not an arbitrary human convention like the right hand rule for screw threading or vector cross products. Other features of music theory, like dividing an octave into 12 tones, are arbitrary human conventions.

Pick a key in the lowest octave on the piano, and from there go up a fourth, and from there go up another fourth, and so on, until you get to a note that is some number of octaves up from where you started. How many keys, fourths, and octaves is that interval? What is wrong with this picture?

Given the frequency ratios for an octave and for a fourth, it should be impossible to reach a point that is both whole number of octaves, and a whole number of fourths, from where you started. The frequency ratio for an octave is 2:1 and the ratio for a fourth is 4:3. Because of the geometric relationship between pitch and frequency discussed in Chapter 1, when you go up by octaves you are multiplying the frequency by 2, and when you go up by fourths, you are multiplying the fequency by 4/3. If your original frequency is $x$ (say 100 **Hertz**, or oscillations per second), there is no way to multiply by 4/3 any number of times, and get a number that is some number of 2s times $x$; this is because of the **Fundamental Theorem of Arithmetic**, that every number has a unique prime factorization (for example $8 = 2 \cdot 2 \cdot 2$; $10 = 2 \cdot 5$; 11 is prime; etc.)

You were able to find an interval on the piano that was both a whole number of octaves and a whole number of fourths, because modern instrument tuning "bends" the frequencies of all the notes to make them "fit". Different systems of tuning bend different intervals in different ways. A system of tuning that bends the pitches so that they are all equally spaced is called **equal temperament**. Our modern system of tuning divides an octave into 12 equally spaced pitches and is therefore called **12 tone equal temperament**. There are other systems of equal temperament that divide an octave into different numbers of pitches than 12.

**Just intonation** describes systems of tuning that use the true frequency ratios for the intervals instead of bending them.

Some tunings "blur together" intervals that are distinct in others, like how in our example 12 tone equal temperament "blurs" twelve fourths ($(4/3)^{12} \approx 31.569$ times the starting frequency) and five octaves ($2^5 = 32$ times the starting frequency) into the same interval; in a just tuning system the notes twelve fourths up, and five octaves up, from any starting tone would have to be different keys on the keyboard.

You have experienced how music is made of complimentary contrasts, like between consonance and dissonance, repetition and randomness, silence and sound. The challenge of tuning is to select a set of pitches that makes the most useful combinations for creatively using consonance and dissonance. The arithmetic of the fractions that represent the frequency relationships of pitches makes this challenge difficult and people have wrestled with it since ancient times.

**Exercise 20.** Compare the sound of some scales and chords, and some entire songs, in just intonation and equal temperament. You can find examples on the Internet.

# 9 Timbre

In its exposition of tonality this book has used two idealized characteristics of sound waves, frequency and its inverse counterpart wavelength.

This simplification overlooks the ways in which sounds of the same pitch differ in "quality". By analogy, consider how the mostly smooth, regular, **sinusoidal** waves you see dropping a single pebble into the center of a still pond (the mathematical functions that graph to this shape are **sine** and **cosine**), differ from the frothy complexity of ocean waves breaking on a beach.

**Timbre** is the aspect of music that concerns the structure of wave forms and how the same note (for example, middle C), sounds different on a piano versus a guitar.

When 100 years ago musicians were limited to a finite set of maybe 100 timbres (violin, clarinet, piano, etc.), today synthesizers and digital audio editing allow musicians to make any timbre they can imagine and express with their tools. For this reason timbre is a great new frontier in music.

**Exercise 21.** With an audio editor like Audacity, compare how sine, square, and sawtooth waves sound by generating a wave of the same frequency and **amplitude** ("height" of the wave) of each kind.

The **Fourier series** in mathematics expresses an arbitrary wave form as a (possibly infinite) sum of sinusoidal waves of different frequencies and amplitudes, sort of like how a chord is made up of constitutent notes. By comparing the amplitudes of the different frequencies in the series, we can figure out which frequencies were important in the wave form and "decompose" it into its constituents.

Musicians also think of the timbres of instruments in terms of the combinations of frequencies they produce when playing a note. The lowest frequency is the **fundamental** frequency and the higher frequencies are **harmonics**. For natural instruments like organ pipes and vibrating strings, the harmonics are integer multiples of the fundamental.

**Exercise 22.** With your audio editor, generate a sine wave of some frequency, and then generate harmonics above it. Note you may have to reduce the amplitude of each frequency to keep the combined amplitude of all of them from exceeding "1" or however your editor represents maximum amplitude. Listen to how differences in the intervals and amplitudes of the harmonics affects the timbre you are creating. Experiment with other wave forms your editor can generate and effects it can apply. Do any of the timbres you synthesized remind you of real instruments?

# 10 Vocals

Your voice offers you a great way to experience the principles of tonality and timbre discussed in this book.

**Exercise 23.** *Practice with an instrument tuner:*

Get an instrument tuning program for your computer, like gtkGuitune or Lingot. These programs tell you the frequency of the sound coming into the microphone and display either a visualization of the wave form or a visualization of its **Fourier transform** (graphing amplitude as a function of frequency).

First practice hitting individual notes. Try to sustain notes without varying a lot from the pitch you are trying to hit.

Also try experimenting with the timbre of your voice, by making your voice resonate using different parts of your throat and chest, and notice how those differences sound and how they visualize in the tuning program.

**Exercise 24.** Sing along with your favorite songs. Listen for whether you are hitting the notes; if you are at the same pitch as the vocalist in the recording then you will hear consonance like in an octave.

**Exercise 25.** *Practice a cappella*:

**A cappella** means without any instruments (or recordings) to help you find the notes.

Do not worry if at first you have to slowly "find" the notes of a song. The more you practice a song, the more you will hear and "feel" where the intervals and not need to "find" them each time. Eventually you will be able to hit them all the first time, in real time. This is a difficult skill that takes a lot of patience because everyone is so bad at first, but if you don't give up you will be surprised at how good you can get.

Thank you for reading. GOD bless and be with you.

Michael Redman

IN GOD WE TRVST.