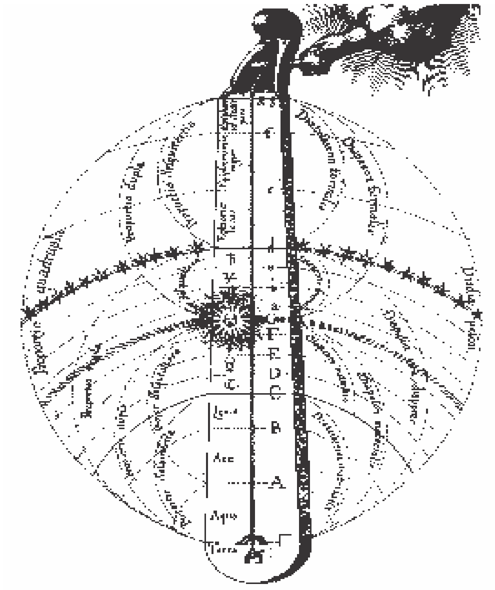

The World Music Menu

Mysteries of Music and Math

An Introduction to

Tuning

Stephen Nachmanovitch

Blue Cliff Records

The *World Music Menu* & Just Intonation

An Introduction to Tuning

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Contents

This booklet provides some background theory to whet your appetite for deeper exploration into the how and why of tuning. In the following pages, you – a musician or music lover – will have an opportunity to rethink some basic aspects of music that you may have taken for granted.

Fundamentals of Music

"The ear is the road to the heart"
— *Voltaire*

The World Music Menu / Just Intonation

enables you to play music that is not represented by the twelve notes we are familiar with.

Music consists

… of three basic elements: pitch, rhythm, and timbre or tone color. (Well, four; let's not forget silence). This exploration is about pitch.

In exploring pitch we are really exploring *intervals*. In music there is no such thing as absolute pitch. We always perceive the pitch of a tone in relationship to some fundamental or reference tone.

A note is not a tone

We commonly say that a musician plays notes on his or her instrument. But, in the words of George Gershwin, it ain't necessarily so. Musicians do not play notes, they play tones. A *t-o-n-e* is an actual musical sound. An *n-o-t-e* is a round blob of ink on a piece of paper: a notation, a culturally defined symbol that represents a sound. Notes are a way of mapping the territory of sound. And as you know, the map is never quite the same as the territory.

Notes

… that is, the representation of sounds by round dots on a staff, were invented in the eleventh century by a Benedictine monk named Guido of Arezzo. We now tend to think of notes and other conventions taught in music theory, such as chords, keys, and equal tempered intervals, as being God-given. But they are not. They are peculiar to our own culture.

Tones

… that is, actual sound vibrations, *are* God-given, in the sense that they – and the laws that describe them – are built into the very structure and functioning of our universe. The person who is credited with discovering the laws by which tones and intervals relate to each other was Pythagoras of Samos, who lived in the sixth century BCE. But centuries earlier, similar discoveries were made in ancient Mesopotamia by Chaldean musician-mathematicians, and in China by Ling Lun, who is supposed to have lived anywhere from the 12th to the 26th century BCE.

Pythagoras and his monochord

Just intonation is based on the Pythagorean discovery that musical intervals can be understood, and expressed, as ratios of whole numbers.

According to legend, Pythagoras arrived at his insights into tuning by watching a blacksmith hammering on his anvils. If hammer B weighed half as much as hammer A, it made a tone twice as high – the octave as we now call it.

Pythagoras worked out the implications of his discovery on a monochord – a simple one-stringed instrument. A string was stretched taut between two bridges at the top and bottom of a fingerboard. Perhaps some sort of ruler was attached so he could measure the length of string that produced different tones. He and his students and successors found the ratios and relationships of tones to each other by measuring the proportions of vibrating string on the monochord. In this way they deduced the basic mathematics of musical tones, intervals, and scales.

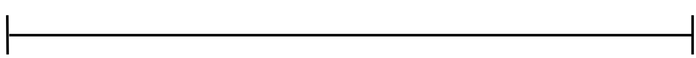
Strings, winds, and skins

To keep our discussion graphic and consistent, we refer in these pages to the tones produced by a stretched string, as in a monochord, violin or guitar. The same principles apply to any sound-producing body – the column of air in a flute or saxophone, the vibrating skin of a drum, etc.

The tone produced by a string is affected by its length (longer strings produce deeper tones), its thickness (fatter strings produce deeper tones), its tension (tighter strings produce higher tones), and the material of which it is made. In experimenting with the monochord, we are assuming thickness, tension, and material to be constant; therefore we can measure our tones by the length of the string only.

The Tonic

This line represents the monochord's string, at rest, stretched between the two bridges of the instrument:

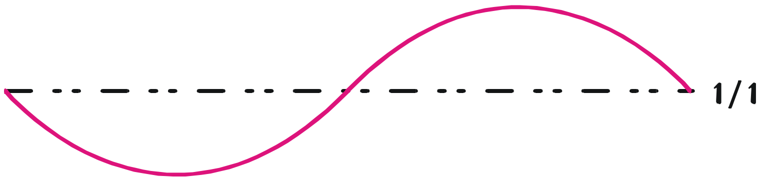


In the case of a violin, this active part of the string might be 13 inches long, but whatever kind of string it is, we will call its length One.

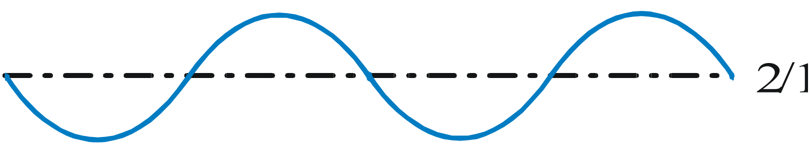
The tone made by this open string is what we call the tonic, or fundamental. Everything else we play sounds in relation to that tonic. The tonic might be a tone of any pitch – the most natural resonant frequency of your relaxed singing voice, a particular guitar, a concert hall, a canyon, or a cave.

Waves and Vibrations

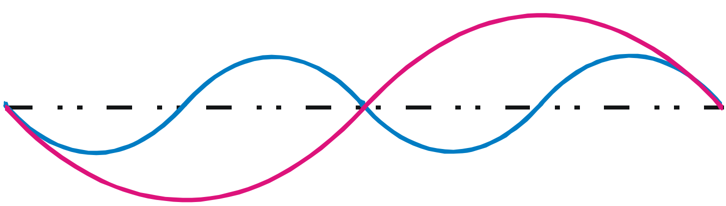
Now we set the string in motion by plucking or bowing it. It vibrates, and makes a sound wave. This is our tonic, or in the language of ratios, 1/1 (one vibration to the length of the open string).



If you put your finger exactly halfway between the monochord's two bridges, and again pluck or bow the string, you have stopped half the string from vibrating. The half that is free to vibrate will vibrate twice as fast as the whole string. It will produce a sound in a 2/1 ratio to the fundamental sound.



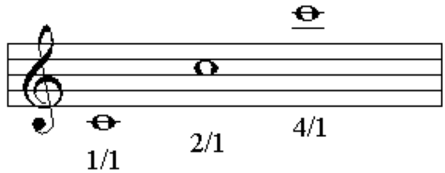
If you mix the two vibrations you get a pleasing consonance:



This doubled wave is what we call the octave of the first wave. If, for example, the 1/1 is a "Middle C," which wiggles at 256 cycles per second, the C above Middle C, wiggling at 512 cycles per second, makes a ratio of 512/256 or 2/1.

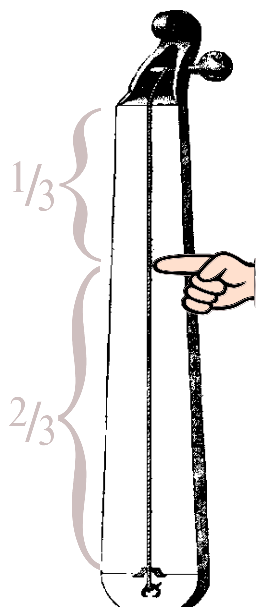
In Western music we call this interval an *octave*, implying the number eight. This is because on our familiar black-and-white piano keyboard there are eight white keys from one C to the C above. But actually, an octave is a 2-to-1 ratio, which we write as 2/1. That is, the higher C is a sound wave that vibrates exactly twice as fast as the lower C.

Here are three C's in regular music notation and ratio notation.



The second C vibrates exactly twice as fast as the low C; the higher C vibrates twice as fast as the second C. The three tones together vibrate in a 4:2:1 ratio.

3/2, 4/3, 5/4, 6/5 …



If you press your finger exactly one third of the way between the monochord's bridges, and pluck or bow the string, you have stopped 1/3 of the string from vibrating. The 2/3 of the string that is free to vibrate will vibrate 3/2 as fast as the whole string. It will produce a sound in a 3/2 ratio to the fundamental sound. This is what we call a perfect fifth. We call it a "fifth" because on the piano keyboard, which became the *de facto* benchmark for pitch, there are five white keys between a note and its 3/2 (between C and G, for instance). But while "fifth" is a culturally derived term in our Western language of notes, the ratio 3/2 describes the actual relationship of the tones.

Similarly, if you stop the string at the 1/4 mark, 3/4 of the string will vibrate, and produce a tone 4/3 higher than the tonic. This is what we call a "perfect fourth". A "major third" is actually 5/4, a "minor third" is 6/5. We use the term "major second" to denote either a 9/8 or 10/9 depending on context. A 9/8 is audibly different from a 10/9, but in the West we lump them together as a major second, the interval from 'C' to 'D' on the piano. Once again, terms like "fifth" and "third" are modern music theory terms that did not exist in Pythagoras's day. I use them here because most musicians are familiar with them. But the ratio terminology, even though it may be less familiar to you, represents the actual reality of musical sound.

Thinking in ratios

You combine ratios by multiplying them. In the arithmetic of Western music theory, a fifth plus a fourth equals an octave. This is somewhat illogical, because five plus four does not equal eight. In the arithmetic of ratios, you express the same idea by saying that

$$\frac{3}{2} \times \frac{4}{3} = \frac{12}{6} = \frac{2}{1}$$

This is actually a lot more logical once you get the hang of it.

Just as in our conventional note-oriented notation, tones and intervals repeat themselves from octave to octave. So we can express our intervals as fractions ranging from 1/1 to 2/1. That is the universe of the octave. If intervals are larger than 2 or smaller than 1, you can multiply or divide by 2 to bring them within the octave. If a sound wave vibrates 5/2 as fast as the tonic, it reduces to 5/4 × 2/1, so musically it is a 5/4 ratio. (To say the same thing in conventional "note" language: if the tonic is C, then the 5/2 interval is the E in the next higher octave, which is musically still an E or 5/4).

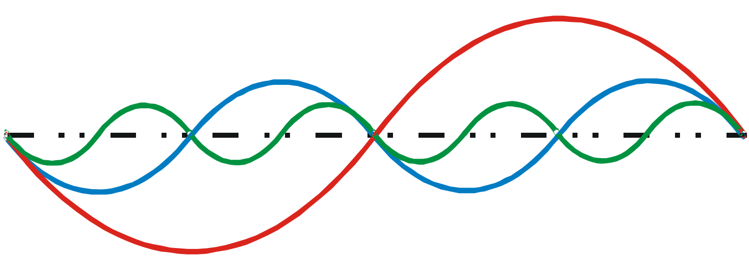
Consonance and dissonance

Pythagoras' next great discovery was that musically consonant sounds consist of waves tuned to each other in perfect whole number ratios.

As a rule, the simplest and closest consonances are ratios of small whole numbers; larger whole numbers produce intervals that sound more and more unusual to our ears. The most consonant interval is the unison (1/1), then the octave (2/1), then the perfect fifth (3/2), then the perfect fourth (4/3), and so on. Higher numbers result in more dissonant sounds. But even very high number ratios come out even at some point. You will find some very high-number intervals in the *World Music Menu*, like 729/512 from the Chinese "Seven Liü," or 262144/177147 from the Arabic "Rahawi." Although they may sound foreign to our ears at first, they have their own inherent beauty that grows on us as we use them.

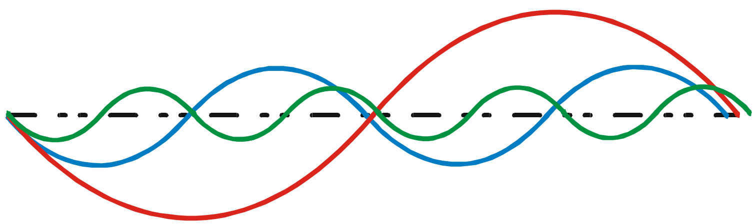
The only intervals that *never* come out even in the ear are intervals based on irrational numbers. You will remember from school that rational numbers are those that can be expressed as a ratio of two whole numbers, while irrational numbers are those numbers that can never be reduced to a ratio. No matter how many decimal places you take them to, irrational numbers never "come out even."

Here is a group of waves that harmonically fit into each other:

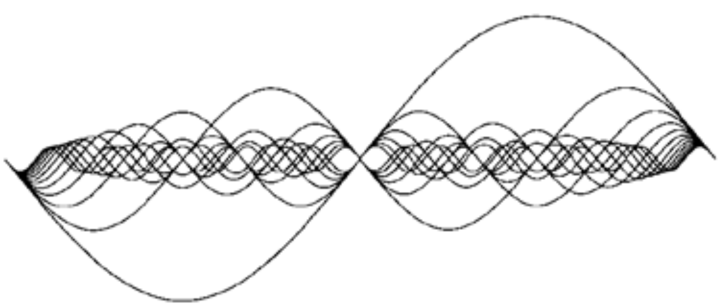


Even though there are several different frequencies pictured here, they start together and end together. Imagine them coming into your ear, fitting and meeting each other at regular intervals. They enter into your ear all nicely lined up, and therefore sound consonant.

If these vibrations were not in a ratio relationship, there would be no point where they come out even. Here is a depiction of some sound waves that are just a little off from a perfect ratio relationship. Not being perfect whole number ratios, these waves relate to each other as *irrational* numbers. Their sound is jarring to the ears.



We have looked at small number ratios of tones in these examples, but even ratios of high orders of complexity sound pleasing to the ear if they are based on rational numbers.



Rhythm & Ratios

The *World Music Menu* does not deal with rhythm, but just as in the realm of pitch, musical rhythms can be understood, and expressed, as ratios of whole numbers. From the simple 4/4 time of much of Western popular and classical music, to the complex polyrhythms of African drumming, in which 5 may be played against 7 against 13, different numbers of beats weave in and out of each other and resolve into the fundamental beat, 1, which is the human heartbeat.

Scales

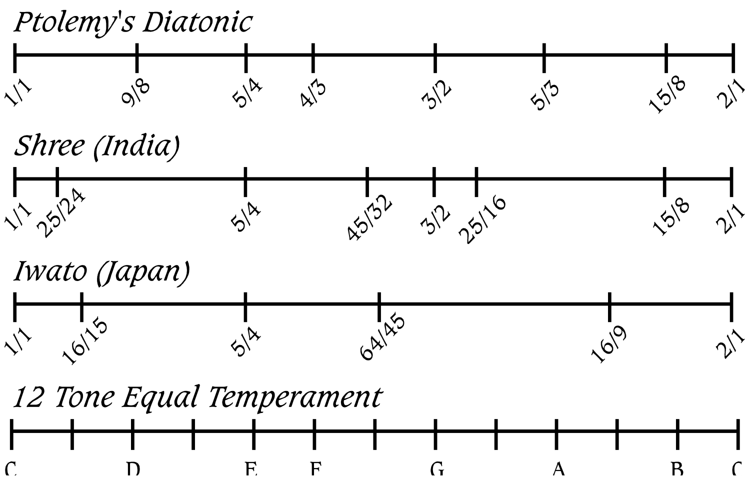
Now we can put together a series of intervals into a scale, and we have the raw material of melody.

A scale (meaning "staircase") is a path of steps from 1/1 to 2/1. It provides the palette of sounds from which a musician selects his or her tones.

Along the length of the monochord, there are infinitely many possible tones. From these infinite possibilities, we choose just a few tones at a time. We divide our monochord into a series of intervals, usually 5, 7, or 12 intervals, though any number is possible.

This is where the *World Music Menu* comes in. The mathematics of ratios and intervals is done for you automatically, so you can hear and play scales that are made from these ratios without having to be a mathematician or musicologist.

Here are three different examples of world scales. The first, Ptolemy's Diatonic, is the "in tune" Greek ancestor of our modern major scale. Shree is an Indian raga scale. Iwato is a Japanese koto scale. As a point of comparison, the 12-tone equal temperament (piano) scale is shown below them:



Close but no cigar

You can see (and hear, quite dramatically, if you tune them up on your synthesizer with the *World Music Menu*) how each of the three scales has its own flavor and coloration, and also how the 12-tone piano keyboard doesn't quite match any of the ratios except for 1/1 and 2/1.

The piano's E is higher than the harmonically true interval of 5/4. The piano's C♯ is a little lower than the 16/15 of Iwato, but higher than the 25/24 of Shree.

If you compare the Shree with the Iwato and both of them with the piano tuning, you notice that all three have as their middle tone what Western musicians call a tritone or augmented fourth, which would be F♯ (or G♭) on the piano. The Shree has an interval of 45/32, which is a little lower than the piano's tritone, while the Iwato has a 64/45, which is a little higher than the piano's tritone. These small differences in pitch make a big difference in the flavor or emotional tone of the scales.

Again, a note is not a tone

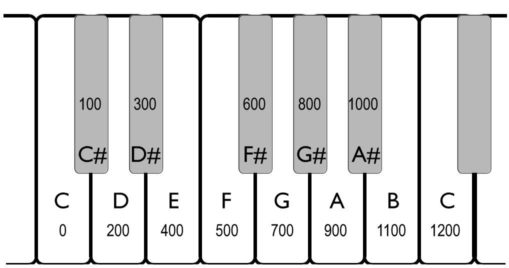
You may have been told in music courses that an A♯ is actually not the same as a B♭. But we play both of these notes on the same black key on the piano. We have been led to believe that the 12-tone piano keyboard is the objective measure of pitch.

Each note in our scale (A, B♭, etc.) represents a wide variety of actual tones. The B that is the sixth degree of a D major scale is different than the B that is the fifth degree of an E major scale. So there are actually a great many A's, a great many A♯'s, a great many B♭'s, all very close together on the string but still distinct from each other. So the note "A" does not represent a tone, but rather a whole region of tones that are very close together but distinct from each other. Which of the many possible A's you play depends on the musical context.

Making cents of ratios

But how on earth are you supposed to know that 64/45 is higher than 45/32?

In 1885, musicologist Alexander Ellis invented a scheme that we still use today for comparing ratio-tunings to each other and to the equal tempered keyboard. A *cent* is a hundredth of an equal tempered semitone.



Converting ratios to cents gives us a quick comparison between different scales. Like equal temperament, cents are a logarithmic system. The formula is:

$$cents = \frac{\log(ratio)}{\log(2)} \times 1200$$

This gives 100 cents per equal-tempered semitone. The octave or 2/1 consists of 1200 cents. So, for example, the interval of a true or just fifth, which is a ratio of 3/2, translates into 702 cents, whereas the equal-tempered fifth of the piano is 700 cents. That is not off by much, but you can hear the difference if you tune the intervals up with your computer and listen very carefully. A more glaring example is the just "major third" which is 5/4, or 386 cents, whereas the piano's "major third" is 400 cents. In this case, the piano is sharp by quite an audible margin.

In our example above, 45/32 is 590 cents, 64/45 is 610 cents, while the piano's tritone (F♯ if the tonic is C) is 600 cents.

Cents are useful for comparing different tunings, and are also used to measure the exact tunings of non-Western and folk instruments when ratios are not known.

A similar system to cents was developed in China, based on powers of 3.

A singer or violinist does it intuitively

Needless to say, a singer or violinist does not go around with a ruler and logarithm table measuring out by ratios or cents how they're going to flex their vocal cords, or where they're going to put their fingers. The ear, hands, vocal cords, and feelings make these calculations in no time at all.

Listen to the pure intervals sung by the Beatles, or in Gregorian Chant.

If you play an instrument that can be continuously varied (an analog instrument like the acoustic bass, the slide trombone, or your voice) you instinctively go for the just (perfect whole number ratio) intervals. If you play the violin or cello you will notice that your finger instinctively slides up and down the string to find the true pitch that your ear wants to hear. You make subtle, quick adjustments in pitch, intuitively seeking the perfect whole number ratios. Of course, this is just what intuition is – very precise, complex calculations that happen so fast your body just *moves* with them without your even knowing they took place.

Two problems

arise here. There are many A's many B's; and a violinist or vocalist instinctively reaches in real time for the right one depending on the musical context. But these instinctive calculations do not work on an instrument that has fixed pitches, like the piano or fretted guitar. There you have to decide on a single tuning system that will be good for any context.

A just "major third" is 5/4, and you probably learned in music school that three major thirds add up to an octave. But if you multiply 5/4 × 5/4 × 5/4 you get 125/64, which is a little less than a 2/1 (128/64). Similar problems arise with all the other intervals. That little difference in pitch is called a "comma." If you wish to change keys in the middle of a piece (modulation), that extra little comma throws off the tuning of the whole instrument. The comma is the musical equivalent of February 29th. Music theorists for centuries have devised schemes, called temperaments, for getting rid of the comma by spreading it around the scale.

If you tune your instrument in a just intonation based on a tonic (the 1/1) such a C, and then play a tune in that scale, it sounds absolutely sweet and crystal clear. The problem with just intonation arises when you want to change the harmonic context or "key" as we usually call it. If you keep your instrument tuned in a just scale based on C, and then play your melody in the key of D instead of in C, the whole thing will sound rather sour in comparison with the original scale.

In the case of non-Western music, this problem seldom arises, because most world music is modal, playing against a real or implied drone. The Indian *sitar*, like the guitar, has frets, but unlike the guitar, the frets are movable, so the player can adjust the frets, and the instrument's sympathetic strings – to the exact tuning of the raga she is playing that evening.

Similarly, in the case of early Western keyboard instruments, such as the clavichord, the player would actually re-tune the instrument between pieces so that it would be adjusted to true pitch for that particular piece's context.

So: tuning our instruments by perfect whole-number ratios results in music that is context-dependent. That is the first problem that Equal Temperament was meant to solve. The second problem is that musicians became heavily invested in the piano, which takes hours (and a specialist) to re-tune. Therefore we wanted a tuning system that would be "good enough" for all contexts.

Equal Temperament — One size fits all

E.T. – Equal Temperament – is a compromise tuning worked out in the 18th century and now the established standard of tuning in Western music. A "tempered" interval is one that has been adjusted or averaged in some way. Equal Temperament in particular means that all the intervals of the scale have been tempered so that they come out being exactly the same size.

In this system, all the intervals go into each other evenly, and music can be played in any context or key with equal ease. All the intervals fit together regardless of your starting point or tonic. But there is only one problem with this system: *all* the intervals are slightly out of tune.

Equal temperament divides the octave into 12 half steps or semitones, each exactly 1/12th of an octave. From the above discussion, we know that all consonant intervals can be expressed as rational numbers (ratios of whole numbers). E.T. is based on an irrational number, the twelfth root of two. An equal tempered semitone equals $\sqrt[12]{2}$. By definition, if you multiply $\sqrt[12]{2}$ by itself 12 times then you get 2, thus the intervals will come out even in the 2/1 octave. Since $\sqrt[12]{2}$ is an irrational number, any interval based on it is inherently dissonant. On the piano, the only interval that is not dissonant is the octave itself.

The sound waves produced by E.T. intervals are more like the slightly out-of-phase waves pictured on page 13 than the harmonically pure waves pictured above them.

E.T. imparted a certain homogeneity to tuning that is not present in any of the lively and highly colored scales that you can find in the world's cultures. Its use is based on that beguiling thought that is so common in our society: "Nobody will notice the difference."

On the positive side, E.T. made possible the magnificent flexibility and scope of the symphony orchestra. It gave us the ability to do modulation, key changes, and all the other technical apparatus of Western music. These developments have carried over into jazz, rock, and other popular musics as well. These techniques made possible a vast body of music that we love dearly. But there was a trade-off: we lost our natural precision of hearing, and became, to some extent, deaf to the inherent power of pure intervals. Pitch lost its natural texture and feel through this quasi-averaging technique.

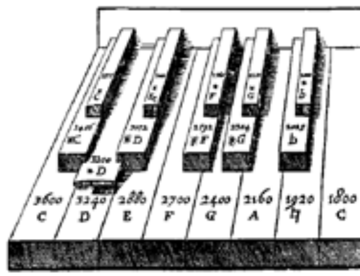
E.T. made possible the development of the piano and the fretted guitar, two instruments which have dominated our musical thinking ever since.

It is interesting to note that the shift to E.T. happened during the Industrial Revolution and was part of that same huge social change in our society. In the days of hand-made artifacts, a coat would be made for *you*. Now you have the choice of buying a size 40 or a size 42, but nothing in between.

On the piano, you can play an equal-tempered A or an equal-tempered B♭, but none of the infinitely many tones that fall in the "crack" between them.

The computer to the rescue

In the past, musical pioneers developed acoustic instruments which could be tuned to perfect intervals. Pictured here, for example, is a keyboard built to a design by Mersenne in the 1630's, which gives the player lots of extra options within the octave to choose which ratio-based tone he wants to play. In our time, a number of pioneers, most notably Harry Partch and Lou Harrison, have designed exquisite instruments – string, wind, percussion, and keyboard – based on ratio tuning. Harrison works with, among other things, gamelan instruments derived from the Balinese tradition. Partch invented some wild and beautiful instruments like the Chromelodeon, the Zymoxyl, the Harmonic canon, the Mbira bass dyad – hand-crafted instruments based on traditional and ethnic constructions and adapted for just intonation. But these instruments are one of a kind museum-pieces, available to only a few people.



Until now, just intonation remained in the realm of the esoteric and the academic, because very few people could have access to these instruments. The big change has come with computers and synthesizers, because now we have mass-produced instruments that can do the ratio calculations in a flash.

With the computer, we can have our cake and eat it too. The inherent dissonance of equal temperament became our standard because the piano could not be retuned after every piece, and because some compromise was necessary to allow music that modulates from key to key. But with the computer, you can easily retune your instrument precisely and instantaneously. Furthermore, we do not have to choose between the flexibility of E.T. and the purity and rich coloration of just intonation. We can have them both. Your synthesizer can be tuned in E.T. one moment, and in the Mesopotamian Ishartum scale in the next moment.

Using the *World Music Menu*, you can find the scale that works for a particular piece and a particular feeling.

Paradoxically we are using digital computers to remedy some of the compromises the Industrial Age brought to our music. The speed and accuracy of the digital realm can bring us back home to the natural, body-and-universe based tuning of ancient civilizations. This magical turnabout is what William Blake referred to as "Piercing Apollo with his own bow."

Some additional questions

Are we talking about quarter tones here?

In connection with non-equal-tempered tunings, you may have heard of quarter tones. This term is at best misleading. Equal tempered tuning is based on 12 artificial semitones. A quarter tone is a half a semitone but is still a tempered interval. The octave is divided into 24 steps based on the 24th root of 2. These intervals are even more dissonant than E.T.! *Microtuning* is a somewhat better term, in that it implies playing with intervals smaller than a semitone. But the point is not that the intervals we are talking about here are larger or smaller than a semitone – but rather that the intervals, or stopping places on a scale, are simply *different* that the stopping places of the piano keyboard. You may want to look back at the diagram on page 15. The scales we can play with in in world music are often seven tones to the octave, like the major scale; but they are tuned to different stopping places along the monochord string. I prefer a term like ratio tuning or just intonation.

Just intonation

… has had two different meanings, depending on whom you read: "Just intonation" can refer to any tuning system in which all the intervals are perfect whole number ratios. It is also used more specifically to refer to tuning systems that are based entirely on the octave (2/1), the fifth (3/2), and the major third (5/4).

In this discussion I use the first meaning — just intonation mean all scales based on perfect whole number ratios, as opposed to tempered intonations such as E.T., which are based on irrational numbers.

In Indian music

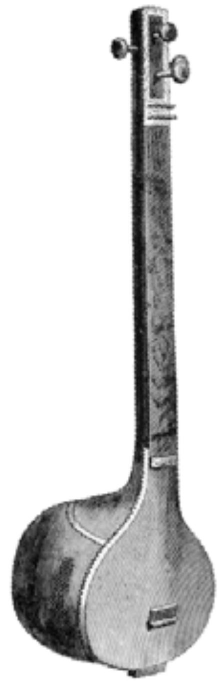
the tones of a scale are chosen from among 22 microtonal intervals, called *srutis*. Each *raga* scale chooses (usually) seven out of the 22 srutis. In addition to the tones that are chosen to make up the scale, certain tones are emphasized, others are de-emphasized, certain slides between the tones are prescribed, certain tones are especially avoided.

Blue notes

The blue notes are tones that arise from ratios of seven. The characteristic sound of the blues comes from the blue third, which is an interval of 7/6. There are also the blue seventh (7/4) and the blue second (8/7). These intervals are common in African music, but the Western E.T. scale and piano keyboard don't even come close to hitting them. The blue third (referring back to our earlier discussion) is 267 cents. This is noticeably smaller than the "minor third" or 6/5 (316 cents), which is approximated on the keyboard by 300 cents, and larger than the major second, which on the keyboard is 200 cents. Similarly, the blues seventh (7/4) is noticeably smaller than the minor seventh. Blues pianists give the flavor of these intervals by playing the minor third or the minor seventh, while "crushing" them together with the neighboring notes.

Perfect pitch?

A person with perfect pitch is someone who, on hearing any tone, can identify it as a B♭ or a G or whatever. What that person has actually done is memorize and internalize some tone or tones, like A = 440 cycles per second, or Middle C = 256 cycles per second. She is matching the tones she hears to the tones of the black-and-white piano keyboard. This is a wonderful ability and musicians can benefit greatly from this skill. But the concept is somewhat misleading, because we assume that the black-and-white piano keyboard is the only game in town, and we further assume that notes like B♭ or G are the God-given elements of music. They are not. B♭ and G are *labels* that are empty of inherent existence. They exist always in context and relationship.



The drone

If you have ever gone to a concert of Indian music, you have seen a big string instrument called a *tanpura*, which consists of four or five strings stretched over a gourd. The *tanpura* is strummed continuously during the entire concert. It unvaryingly plays a single reference tone and one or two of its overtones. It sets the tonic, the bass over which the other instruments improvise. It has been said that this tone establishes a relationship with the sound of the soul itself. This fundamental drone, which gives meaning to the other tones, was called the *Mesa* in ancient Greek music, the *Ison* in Byzantine music, *Yekah* in Arabic, *Sa* or *sadja* in India.

In Indian concerts the tuning of the instruments easily takes half an hour, while the audience is present. Tuning in this context is not some preliminary, mechanical act that has to be taken care of before the performance can begin. It is, rather, an integral part of the performance, because not only are the instruments being tuned, the players are being tuned, the environment is being tuned, and the audience is being tuned as well.

There is a Sufi story

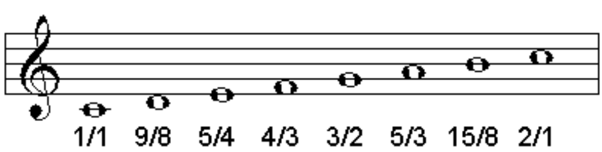
about an old man with a cello. He sits day after day droning out the same tone. A young fellow comes up to him and says, “Usually when people play that instrument, they move their hands up and down." The old man said, "They are looking for their sound. I have found mine."

Modal music versus tonal music

Most of these world scales lend themselves to being played as modal music – that is, melodic playing that is based on a fundamental tone or drone. The drone may be played by a real instrument, as in the case of the Indian *tanpura,* or it may be implied. Western music, on the other hand, has evolved in the direction of tonal music based on harmonic structures like chords and key changes. Think of melodic lines, not of chords. An exception to this rule would be any of the diatonic scales (for example, all the Mesopotamian scales) – these would allow you to play harmonies and polyphony in the Western sense, and still come out with pure intonation.

Tetrachords

The Greeks divided their scales into two tetrachords — two groups of four tones separated by a whole tone or 9/8. Most (but not all!) seven-tone scales contain the interval of a perfect fifth (3/2). The first tetrachord starts on the 1/1 and the second starts on the 3/2.



This is a fortunate arrangement for musicians playing modern instruments like the violin or keyboard – because four consecutive tones make a nice, comfortable handful for four fingers. On the violin family this is especially felicitous, because the strings are tuned at intervals of a fifth or 3/2. You can play the first tetrachord on one string and the second tetrachord in the same hand position on the second string.

In India there is a similar division of the scale. An octave is a *saptaka* ("set of seven"), and is divided into two tetrachords (*angas,* or "limbs").

Descending and ascending

The scale pictured above is actually an inaccurate representation of the Greek tetrachords, simply because for familiarity's sake I pictured it as a rising scale. Today we tend to automatically think of a scale as a rising progression from one tone to its higher octave. The Greeks, on the other hand, thought of their scales as descending from the tonic to its lower octave.

In your own musical explorations, you can play with ascending and descending scales. You will find that new ideas come to you if you reverse our automatic thinking about ascending scales. Also, as you play with the *World Music Menu*, you will find certain scales, the enharmonic scales (there are some in the Greek menu, and also the Gunakali in Indian 2, the Tibetan 12 tone, and others) lend themselves to being played differently in the upward and downward directions. The Archytas Enharmonic, for example, is presented as a seven-tone scale, tones 1-7 plus 8, the octave of 1, but as an enharmonic series it can be played as a pair of related pentatonic scales: 8, 6, 5, 4, 2, 1 in the downward direction, and 1, 3, 4, 5, 7, 8 in the upward direction.

Digital and analog

As our culture developed towards the industrial way of life, we came to prefer calibrating our ears by digital instruments such as the piano or the guitar. By *digital* I am not referring to computers, but to the opposite of *analog*. *Analog* refers to information that is coded in some continuous fashion. An analog instrument – like the violin or cello, the slide trombone, or the human vocal cords – can be continuously varied. Between point 1 and point 2, there are infinitely many tiny variations of pitch. You can slip and slide around an analog instrument with great subtlety, rendering microtones in a natural and fluid way. *Digital* refers to information that is coded in a discrete, all-or-nothing fashion. In this sense, the piano is a digital instrument: you can play the white key called A, you can play the adjacent black key called B♭, but you cannot play in the crack between the keys. (This is why we refer to present-day computers as being digital: they code all information as combinations of ones or zeroes. Each *bit* of information is either a one or a zero, period). Similarly, on the guitar you have frets, little barriers that digitize the pitch. The frets help you find your pitch, but they also limit you to the equal tempered 12 tone scale like that of the piano.

Note that while the piano and guitar are digital instruments from the point of view of pitch selection, they are analog in many other ways. On the guitar you can bend the string around the frets, and on both instruments, there are infinitely many ways of striking each tone with your fingers. You can get a subtlety of dynamics, color and power out of acoustic instruments that you can never get with even the finest synthesizers.

The magic number 7 plus or minus 2

The vast majority of scales worldwide contain either seven or five tones to the octave. There are a few with six or eight, a few (notably in Arabic music culture) with 13 or 17 tones. But such exceptions are rare. This nearly universal pattern accords with a fact of how the nervous system reacts to color, light, and other physical stimulation, called "The magic number seven plus or minus two." This means that if you present people with some sensory stimuli to memorize and recognize – colors, pitches, smells, random numbers, whatever – most people are able to hold in mind and recognize about seven at a time. This is why five-digit zip codes were a success while nine-digit zip codes were a failure – nobody pays attention to them. Of the infinitely many pitches between 1/1 and 2/1, most cultures, whatever their musical ideas, tend to select seven plus or minus two stopping points along the way for any given musical event.

Shrinking scales

The ancient Greeks developed dozens of scales and modes. During Mediæval times, the Greek modes devolved into the eight church modes. Pope Gregory I (540-604), after whom Gregorian chant was named, shuffled the names of all the modes. The Greek Lydian became the Ecclesiastical Ionian. The Greek Dorian became the Ecclesiastical Phrygian, while the Phrygian became the Dorian – and so forth.

In modern times (meaning the Classical and Romantic eras of music) the available scales were further reduced to only two: the major and minor modes that we are familiar with today. No wonder composers like Schoenberg and John Coltrane felt that they had to break out in new directions!

The number of musical scales that come from India dwarf everything else produced by the other world civilizations. There are hundreds of *raga* scales and variants. Like the Greeks, the Indians felt that each scale was connected with a particular state of mind. Each mode or scale was associated with a color, a mood, a season, a time of day. The Chinese, the Arabs, and other peoples developed complex and beautiful mathematical structures for understanding musical intervals. Alain Danielou's book is a Rosetta Stone of correspondences between the systems of ancient Greece, India, and China. And he never delved into the vast tonal storehouses of Africa, Indonesia and Meso-America.

Infinite possibilities

The *World Music Menu* offers a simple and powerful approach to expanding our musical resources. Just tune in to any of the thousands of delicious and exotic scales from India, Greece, Japan or other cultures. They are different from ours, yet in beautiful tune with themselves; they have mostly 5 or 7 tones per octave, so listeners will be able to easily follow them; and they are based on long centuries of practice and refinement.

There are infinitely many possibilities to play with in the universe of musical tone. Ancient tunings can be rediscovered, reinvented, and combined in new ways. This universe is yours to enjoy.

Music of the Spheres

The ancient forbears of our civilization – as well as the musical pioneers of India, China, and ancestral cultures too numerous to mention – felt that playing in certain modes had a powerful spiritual effect on people. Each mode or scale was associated with certain kinds of passions or ideas.

Each of these ancient peoples felt a powerful link between the Three M's: Music, Mathematics and Mysticism. The scale was not only a mathematical structure, but a totem pole upon which the human body, the solar system, the universe, and the mind could be mapped.

For Pythagoras and his successors, music was not only an art, but a key to investigating mathematics, philosophy, natural science, and spirituality. Art and science were not separate activities. This tradition of musical thought spread throughout the ancient world and was passed on in Mediaeval times to both European and Arabic explorers of music and the mind. In the Renaissance, the idea of music as a template of knowledge flourished among such scientists as Johannes Kepler, Vincenzo Galilei, and Robert Fludd.

The picture by Robert Fludd that appears on the cover of this booklet depicts the hand of God tuning up the World Monochord. The Monochord is rooted in the Earth and spreads up through the cosmos. The sun, moon, and stars, all the elements of the universe are mapped onto the perfect whole number intervals. In another such diagram, he maps the same intervals onto the human body.

The Pythagoreans saw the musical ratios as governing forces in the cosmos as well as in the realm of sounds. The centuries-long tradition of the music of the spheres sees the soul and the world as structured according to these same musical ratios. Many scientists and philosophers, from Plato to Heisenberg, have seen themselves as continuing this traditional way of looking at the universe as a musical entity. Since we have come to understand the quantum workings of the atom, we see a great many phenomena of harmony, perfect whole number scales, and other patterns that would have delighted Pythagoras. Kepler found that the arcs swept by the planets of the Solar System relate to each other in a harmonic series. 300 years later, Erwin Schrödinger found that the orbitals or energy levels of electrons as they buzz about the atom relate to each other in a harmonic series – a Pythagorean scale. In Hindu thought, the intervals of the different musical modes correspond to – and talk to, in their own mysterious way, the chakras. In Balinese thought, the structures and functions of music bring us into harmony with the structures and functions of nature. We are still in the process of learning that the world is made of music, the body is made of music. But that is another story …

Bibliography

This short manual has been meant as a very cursory introduction to the theory of tuning. Many of the ideas here need to be very much expanded and elaborated for anywhere near a complete understanding of scales and intonation.

Here are some references for further exploration—

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The image on the cover of this manual and on the main screen of the *World Music Menu* is “The Divine Monochord” by Robert Fludd, first published in his *History of the Macrocosm and Microcosm*, London, 1617.