Slightly Out of Tune: The Story of Musical Temperament

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Introduction

I'd like to start the lecture by explaining something about the phrase in the title, "slightly out of tune." It's intended to be a play on words. On the one hand, it's a reference to one of my favorite songs, *Desifinado* by Antonio Carlos Jobim. The title *Desafinado* means *stonato* in Italian; in English the title has been translated as "slightly out of tune."

That's the one side of the play on words. But the other side refers to the subject of today's lecture. The great Andres Segovia once said that guitarists spend half their time tuning their guitars – and the other half playing out of tune. And he was right in a sense he didn't even intend: even guitars that are *correctly* tuned are in fact slightly out of tune. Moreover, there are very few of us who have *ever* heard music that is truly in tune. We are only used to hearing music that is a bit dissonant. Everyone grows up hearing badly formed chords until our ears are "burned in" on dissonance and we don't really even know what genuinely in-tune music sounds like.

How this rather surprising situation came about is the topic of today's lecture, inspired by a delightful book by Stuart Isacoff (a reference is given at the end of the text). It is the story of musical tuning, or what is also known as musical *temperament*. If it doesn't seem to you like a particularly interesting topic, consider some people who have been involved in this story over the centuries: Pythagoras, Aristotle, Plato, St. Thomas Aquinas, Leonardo da Vinci, Galileo, Kepler, Bach, Descartes, and Sir Isaac Newton.

The Role of the Computer

So what does the computer have to do with all this? For several years in my lectures to the Club, the topics were mostly about the computer itself (such as e-mail and the Web). But in the last couple of years I have tried to lecture on topics that aren't about the computer itself, but where the computer has played an important role. For example, last year I talked about the science of Chaos, where the computer is important in doing research.

Although at first it might not seem that something as "cold and mathematical" as computers would have anything to do with something as "warm and artistic" as music, in fact they are inextricably entwined with each other.

The most basic relationship between music and mathematics is the very nature of a musical tone: it is a sound wave, at some frequency. That frequency is represented by a number. That's all there is to it. That is the connection between them.

So if a computer is outfitted with a sound system of some sort, then you can program that system with the frequency numbers and produce sounds. That's what a musical synthesizer is, of course.

I have a program on this computer called Scala, with which you can re-create musical tunings and hear what they sound like. It is the program most used by musical scholars to study musical tuning.

For example, here is the normal piano keyboard: [*Scala keyboard*]. This keyboard has what is today called **12-tone equal temperament**. All of the 12 notes are equally spaced. Did you ever wonder exactly where this came from? Why exactly these notes? Was it always this way? Well, it wasn't, and the computer is going to help us see how it was before, and how it is still evolving today. And the computer makes it possible to show you without having to actually build a musical instrument.

The computer is going to help us go back in time over 2500 years, to the beginning of the story of the musical scales that we know today.

Pythagoras

Those of you who have studied mathematics in high school will have heard of Pythagoras. He is most famous for the Pythagorean Theorem: the sum of the squares of the sides of a right triangle is equal to the square of the hypotenuse.

Figure 1: Pythagoras

But Pythagoras was much more than that. In his definitive book, the *History of Western Philosophy*, Bertrand Russell introduces him in the following way: "I do not know of any other man who has been as influential as he was in the sphere of thought. Pythagoras was intellectually one of the most important men that ever lived, … *both when he was wise and when he was unwise*." (By the way, Bertrand Russell, in spite of his reputation as a very serious intellectual, also had a fine sense of humor.)

Let's start with some facts about Pythagoras's life. He lived during the period of about 500 B.C. Although he was a native of the island of Samos, in Greece, his period of real accomplishment and fame was in Italy. Why that? Recall that much of Southern Italy *was* Greece: Magna Grecia. Pythagoras lived in the city of Crotone, down on the Ionian coast of Calabria. Today, Crotone is a bit run down, but back then it was very prosperous.

Russell goes on to say, "Pythagoras is one of the most interesting and puzzling men in history. Mathematics … begins with [Pythagoras], and in him is intimately connected with a peculiar form of mysticism." What kind of mysticism?

Russell again: "Pythagoras founded a religion, of which the main [principles] were the transmigration of souls and the sinfulness of eating beans."

Here are some of the rules of the Pythagorean order:

- To abstain from eating beans
- Not to pick up what has fallen
- Not to stir the fire with iron
- Not to eat from a whole loaf of bread
- Not to eat the heart
- Not to walk on highways
- Do not look in a mirror beside a light

(I think that this is where Bertrand Russell probably thought that Pythagoras was unwise.)

Most of all, Pythagoras is famous for having said, "All things are numbers" – and this is where the mysticism occurs in the form of numerology, still practiced today. For Pythagoras, each number had its own personality - masculine or feminine, perfect or incomplete, beautiful or ugly. For example, the number ten was the most perfect number, because it contained the sum of the first four numbers: 1+2+3+4=10.

His disciple Philolaus later said: "Number became great, all-powerful, all-sufficing, the first principle and the guide in the life of gods, of heaven, of men. Without it, all is without limit, obscure, indiscernible."

In many ways, Pythagoras was right – numbers *are* part of nearly everything around us. Russell writes: "It was Pythagoras who discovered the importance of numbers in music, and the connection which he established between music and arithmetic survives in the mathematical terms 'harmonic mean' and 'harmonic progression.'"

And finally, Aristotle summed it up as well as anybody: "Pythagoras thought … that the whole cosmos is a scale and a number."

The Story of the Blacksmith

How did Pythagoras discover the relationships between numbers and music? The legend has it that he was passing in front of a blacksmith's shop one day when he was transfixed by the sounds he heard. The blacksmith was banging hammers against the anvils, and of course they were creating a completely chaotic, discordant chorus. Every once in a while, though, suddenly a beautiful harmony emerged. He wanted to know why this happened.

He discovered that it was the weights of the hammers that made the difference. When the weights of the hammers formed three simple proportions, they produced beautiful harmonies. The proportions were 2:1, 3:2, and 4:3.

It's a great story, but it can't be true, notes Isacoff – the laws of acoustics and the way metal weights work make it impossible. BUT: the rest of the story is true: that he repeated the experiment with an instrument called a monochord. This is an instrument like a violin or guitar, except that it only has one string.

Figure 2: A modern monochord

The octave

The first of these proportions, 2:1, produced the octave. The octave is the one inviolable proportion of all Western music. It is the one interval that is seen by everybody as the most natural. As Isacoff writes: "Though a leap separates them, the two *dos* sound so much alike, they share the same name. Listening to them, you might think you are perceiving two reflections of a single object, or two points along the same straight line. *Do* reaches to *do* like an image meeting its reflection; together they define the edges of the musical world."

The fifth

The second of these proportions, 3:2, produced the fifth, which also is known as the *perfect fifth*.

Isacoff writes: "the perfect fifth sounded together as a harmony gives the impression of a melding of complementary parts, a marriage between two willing partners. Its hollow, open sound also suggests two luminous parallel lines, their glow vanquishing the space that separates them." He then quotes what Galileo wrote about the perfect fifth: " … a tickling of the eardrum such that its softness is modified with sprightliness, giving at the same moment the impression of a gentle kiss and of a bite."

The fourth

The last of the three intervals found by Pythagoras is 4:3, and this is called a *perfect fourth*. The fourth sounds similar to the fifth, and in fact it is a kind of inverted fifth. For example, E to A is a fourth, and inversely, A to E is a fifth. In that sense, you could say that they are "the same note."

The circle of fifths

Given these three important relationships (and in some ways, only two, since the fourth and fifth are related to each other in a kind of inversion), Pythagoras constructed his scale. The octave was inviolable. On the two ends of the scale there had to be two notes one octave apart. The only issue was to fill in the notes between the octaves.

Pythagoras filled in these notes by identifying them so that they would be able to create these heavenly harmonies that he had discovered.

He constructed the scale as a circle of fifths. Starting from the bottom note of the octave, he went up fifth, in a ratio of 3:2 on his monochord, to identify the next note. Then he went up another fifth. Whenever he went over the octave, he would simply "wrap it back" down one octave to stay inside the octave interval. One by one, this produced twelve notes, each a ratio of 3:2 apart, that is, a perfect fifth, returning to the octave above the original note.

The Pythagorean Comma

But there was a problem: it didn't.

It didn't return exactly to the octave. It was close, but it wasn't *exactly* there. It was a little higher.

The gap between the last note and the octave was a little larger than all of the others. And it therefore produced a sound that was definitely out-of-tune. This produced what is now known as the *Pythagorean Comma*, the gap between the last note in the circle of fifths and the octave.

And the interval in that last fifth is what is known as a *wolf* interval, because it sounds like the howling of a wolf. (The name is thought to have been invented sometime in the Middle Ages.)

Figure 3: The Pythagorean Comma and the Wolf

The Irrational Numbers

How did this happen? What was the underlying cause? Pythagoras knew the underlying cause, but he kept it a secret – and he made the members of his cult swear to keep it a secret, because it was a terrible secret. Isacoff describes it in this way: sometimes his calculations gave rise to wild, unfathomable numbers, which they called in Greek *alogon*, which means "the unutterable." These are the irrational numbers.

The Pythagorean theorem itself gives rise to irrational numbers: a right triangle with equal sides has an hypotenuse of the square root of 2. This is different from an integer, or even a ratio of two integers. The most famous irrational number is Pi. Here is Pi calculated to 2462 decimal places. Scary, isn't it?

3.141592653589793238462643383279502884197169399375105820974944592307816406286208998628034825342117067982148
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2639141992726042699227967823547816360093417216412199245863150302861829745557067498385054945885869269956909
2721079750930295532116534498720275596023648066549911988183479775356636980742654252786255181841757467289097
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3142980919065925093722169646151570985838741059788595977297549893016175392846813826868386894277415599185592
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Today we easily work with irrational numbers, but in those days it endangered the entire philosophy of Pythagoras. For example, it meant a line could be infinitely indivisible, a frightening concept. And so Pythagoras swore his followers to secrecy.

It turns out that the same problem exists in his musical proportions. The octave and fifth are based on ratios involving 2 and 3. They are prime numbers, and we now know that powers of relative primes can never be equal. It is like using two lengths of bricks to build a wall, and never being able to line them up perfectly. The only way you could ever make it work is for the interval to be an … irrational number.

But nobody was ready for that … and in any case, they wouldn't have known how to calculate it. So what did Pythagoras do? Nothing. He kept his secret, and people simply learned to avoid using that wolf interval.

And this stayed that way for *nearly two thousand years* …

From Ancient to Medieval Times

But even the full Pythagorean scale in all of its twelve notes wasn't used most of the time in the early centuries. Why? Because instruments couldn't be built yet to produce all of those tones. The technology wasn't good enough yet, not precise enough. Much of the time they used a simpler scale, for example with just eight notes. Ptolemy the astronomer devised one such simplified scale, the 8 tone diatonic scale. In fact, in the early days only a five-tone scale was used, the pentatonic scale. This was good enough for the music that was being written at the time, because it was simple, and the instruments were simple. Instruments like wooden flutes could only play a simple scale in one key. Even today, there are simple instruments like that, such as the standard blues harmonica with a single diatonic scale.

The divine nature of music

Almost immediately after Pythagoras a very important phenomenon began that would be fundamental to the battle over musical tuning that would take place over the centuries: the association of music with "the natural state of things." In his dialogue, the Timaeus, Plato says that the universe *is structured according to musical ratios*. In other words, Plato suggests that the principle of harmony is at the heart of the universe.

In the second century, Clement of Alexandria took that one step further by declaring that it was Jesus Christ, the Son of God, who composed the melodious order of creation. Many Popes emphasized this, too. (They needed all the help they could get in those early centuries: Isacoff reminds us that fully one-third of all the popes elected from 872 to 1012 died from strangulation, suffocation, mutilation, or other violent acts.)

I would like to stress once again the importance of this argument: it says that the musical proportions of Pythagoras don't just sound nice, but that they are the reflection of nature itself, or even more strongly, of God – and therefore they are in some sense inviolable *and should not be changed*.

The increasing sophistication of musical instruments

Another important phenomenon that began to manifest itself over the centuries was the increasing sophistication of musical instruments – in particular, keyboard instruments.

The organ was the first important keyboard instrument, and Isacoff gives us several surprising examples of its early use. The emperor Nero boasted that he played the organ. By the second century, it was played at gladiator contests. Charlemagne received one in 812 from the king of Constantinople. Throughout the centuries the organs became more and more precise, more able to play more different notes. Then, in 1397, the clavicembalo was invented by Dr. Hermannus Poll from Vienna. Unfortunately Poll was later executed in Nuremberg because he tried to poison the king – but the clavicembalo, known as the harpsichord, was to be very important in the history of music.

These ever more sophisticated keyboard instruments created a desire to create ever more sophisticated musical harmonies – much more sophisticated than those of the earlier centuries.

And it was this sophistication that made the old problem of Pythagoras and the wolf come out.

Medieval Times

The new harmony that began to bring the Pythagorean wolf out of his 2000-year-old hiding arrived from England in the late 15^{th} century. It was a harmony that had not been used before in Europe up until then. This new "English" harmony was called the *third*. The third is formed by a proportion of 5:4, and here is how Isacoff describes its sound: "If the open harmony of a fifth symbolically bridges the dust of the earth and the ceiling of heaven, the sound of a third fills that chasm with something warm and delicious: in a way, the song of the human heart."

There are actually two kinds of thirds: the major third, and the minor third. The minor third is "sadder," more "melancholy" in spirit. It is the famous "blues" interval.

The third began to find its way into music, and this is where the problems began. People were used to fifths, of course; and now they were used to the beautiful harmonies of thirds. They wanted *both*. The third and fifth take together form a triad, which is the harmonic foundation of Baroque and Classical music.

Just Intonation

This desire to have both so that triads could be preserved was the beginning of the great battles. A Spanish man named Ramos de Pareja invented a new way of tuning in 1482. He was able to construct a scale so that in the same key, both thirds and fifths were pure, that is, they preserved their pure ratios of 5:4 and 3:2. A scale in which both thirds and fifths are pure is called **Just Intonation**.

And he went around defending it fiercely against his enemies who still defended the Pythagorean system. This included the Catholic Church, as Isacoff recounts. A priest named Nicholas Burtius wrote a pamphlet against "the Spanish prevarication of the truth." Ramos responded against these critics, "I wish to destroy the head, so that the whole body of errors becomes a corpse and cannot live any longer." Friendly fellow …

But the problem is that the scale of Mr. Ramos was full of errors, too: because the ratios of thirds and fifths are incompatible. The intervals are different sizes. It can be possible to get one set of harmonies right in one key, but if you move it down just one step, everything is wrong. If you adjust it in this new key so that the fifths are right, then the thirds become wrong. But if you re-tune the tones so that the thirds are right, then the fifths become wrong. *There is no way to get both of them right at the same time*. It is mathematically impossible.

The introduction of temperament

And this is when the unthinkable happened: rumors began to circulate that some organists were violating the sacred principle of perfectly tuned fifths – that is, fifths that were made from the Pythagorean ratio of 3:2. They were tuning those keys just a little bit away from those perfect fifths, in order to make their music work. Pragmatism was triumphing over divine principle.

This adjusting of tuning away from the natural proportions was called *temperament*. The word comes from the Latin *temperare*, meaning "to tamper with." This communicates the idea of "adjusting."

During the early Baroque period, keyboard players began adjusting the tuning of their instruments so that certain chords were "perfect," and the remaining ones were "sacrificed to the wolves," so to speak. This became known as **mean-tone temperament**.

In mean-tone temperament, as long as you stayed in one key, or at least in a few selected keys, everything was fine. But there were other places that were wolves' dens, and you could not musically "go" there. And so prior to 1700, musical keyboards did not play music in many keys. They just stayed in the more harmonious ones.

One thing to understand is that there wasn't just one single mean-tone temperament: every composer invented his own – or even many of his own! They would widen this interval, or shorten that one, etc. So there were actually many mean-tone tunings floating around during that time.

But what about the physical instruments themselves? Did the composer re-tune his instrument every time he played something in a different key? One solution was to offer all the different tones on the instrument. And so many instruments were built with much bigger keyboards, which offered far more notes than the usual 12 notes we know today.

One such person who suggested this approach was a French monk named **Father Marin Mersenne**. Many people think he was a Jesuit, but actually he was a member of the French order called the Minims. He was also another example of a mathematician who was interested in music. In fact, he is most known today as the inventor of so-called Mersenne Primes (primes of the form 2^p-1, where p is prime). The so-called Great Internet Search for Mersenne Primes (GIMP) is very active today.

He was also a physicist – it was Mersenne who made Galileo famous outside of Italy by translating his works. But he is also known as the father of acoustics. His most famous musical work was *Treatis on Universal Harmony* (1627), a work on music, musical instruments and acoustics. Mersenne suggested the adoption of an instrument with nineteen keys to the octave, which would give the player the opportunity to choose the right notes to make perfect chords at any time: all of the notes were there to choose from.

What about the difficulty of playing these instruments (much less building them!)? This is what Mersenne said: "Although the [many] keys of its octave may be, it seems, more difficult to play, nevertheless the perfection of the harmony and the facility there is in tuning organs which use this keyboard abundantly repays the difficulty of playing, which organists will be able to surmount in the space of one week or in very little time."

Well-Temperament and Bach

Into this mess, where the tones were uneven distances from each other and you could only play in certain keys and had to avoid the others, came a new system of tuning, which was made famous, as we all know, by Johann Sebastian Bach: Well temperament.

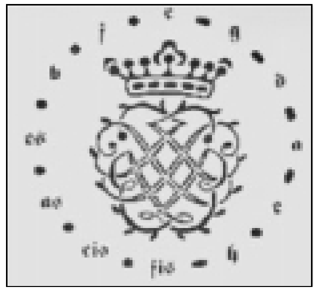

Figure 4: Bach's Well Tempered System

Bach's musical temperament consists of **5** well tempered fifths and **7** perfect fifths. This system *wohltemperirt* – the composer's own authentic spelling - is generally considered to be the musical tuning for *Das wohltemperirte Clavier*. The well-tempered fifths are (practically) all equal, being reduced by 1/5 Pythagorean comma. An important point: this system permits you to play in all 24 keys, major and minor.

As a matter of fact, there is still a controversy today about whether Bach's music was in well temperament or equal temperament. There are people on both sides who present evidence. Each side is convinced of being right. But it is certainly true that his music could have been in either one, because both of them "work."

Key Character

Well temperament gave us something that has been lost in modern music. I can think of no better way to explain it than to let David Foote speak in this extract from his excellent treatise on temperament:

> Associations between emotional response and musical harmony are very old; they were discussed in ancient Greece. Certain tunings, were considered warlike, others were felt as peaceful. Some tuning, according to Plato, should not be heard by developing young minds, while exposure to others was considered essential to the full development of one's potential.
>
> The defining characteristic of Well Temperament is the tonal variety that exists between the keys. The comma is neither condensed into a few combinations nor spread evenly among all; rather, it is dispensed into the various keys in differing amounts. … Hence, there was a range of harmony and dissonance available to the composer.
>
> By Beethoven's day, the concept of "Key Character" (in which different keys conveyed specific emotional meanings) was much refined. A widely read and influential list of keys and their affective qualities, written by Christian Friedrich Daniel Schubart and published posthumously in 1806, contained the fashionable descriptions for all major and minor keys. In this list, he describes the "character" of keys thusly:
>
>> *"**C minor**. Declaration of love and at the same time the lament of unhappy love. --- All languishing, longing, sighing of the love-sick soul lies in this key."*
>>
>> *"**E major**. Noisy shouts of joy, laughing pleasure and not yet complete, full delight lies in E major."*
>>
>> *"**C# minor**. Penitential lamentation; sighs of disappointed friendship and love lie in its radius."*
>>
>> *"**C major** is completely pure. Its character is: innocence, simplicity, naivety, children's talk."*

Zarlino versus Vincenzo Galilei

It is interesting, points out Isacoff, that the battle between pragmatism and the natural ratios in music mirrored the battle between the focus on the human and the divine in all of art. In the visual arts, up through the Middle Ages, only divine subjects were depicted. Then with the coming of the Renaissance, the emphasis became the individual. Man was the measure of all things. And so it was in musical tuning: with the Renaissance, came those who argued that there were no divine ratios. What counted was what sounded right to the human being. But there were still those who defended the divine argument.

As usual, Italy was in the center of the battle. Two of the most prominent players in the battle were Gioseffo Zarlino and Vincenzo Galilei. (Vincenzo was the father of Galileo Galilei.)

Gioseffo Zarlino wrote one of the milestone musical treatises in history in 1558, called *Le istitutioni harmoniche*. Isacoff: "[Zarlino believed that music] is a force that can balance body and soul, and bind together the parts of the world; it can do all this because it is a system built on harmonious proportion – the ratios discovered by Pythagoras." And in fact Zarlino developed a scale based on Just Intonation – one that preserved the Pythagorean fifths and perfect thirds.

Vincenzo Galilei wrote *Dialogo della musica antica et della moderna* in 1580, and refuted all of this. He said that pure thirds and fifths may be an ideal, but in practice it is a fantasy. For example, singers continually adjust their singing together to produce exactly the intervals needed to be harmonious – they are never exactly thirds or fifths. In other words: there was nothing sacred about the ratios of thirds and fifths.

Zarlino was mortified: In his view, Galilei's willingness to distort music's true proportions was not only ridiculous but also immoral, an assault on God himself. To say that singers can sing any interval at all, whether its ratio is one of the perfect Pythagorean ones or not, is similar to claiming that "since man is capable of both good and evil, it is legitimate for him to commit any sin and act contrary to ... all that is proper and just."

Galilei said that Zarlino was ridiculous: "All scales, are, after all man-made. Whether we sing the fifth in the 3:2 ratio or not is of no more importance to Nature than that a crow or a raven lives three hundred or four hundred years and a man only fifty or sixty."

And furthermore, Galilei added, "Let Zarlino trouble his head about it as much as he wishes."

It seems like an odd, even silly battle to us today, but it was fierce and lasted for many years. It contained the essence of the debate: should musical temperament be based upon natural, even divine numbers, or should it be pragmatic and based upon what the musical performer needs to play and hear music?

Romanticism, the Industrial Revolution, and Equal Temperament

Slowly but surely, Mr. Zarlino and his followers lost the war. And it was quite a war indeed, with luminaries as prominent as Descartes – the father of modern philosophical thought – speaking out against equal temperament along the way.

There is actually some argument about exactly when equal temperament finally won and became the dominant one we have today, but there are two important movements that are thought by many to have finally led to its triumph.

One of these movements was the *Industrial Revolution*, when there was a general fascination with science and mathematics. By that time irrational numbers were not only understood but were familiar, so it was not a problem that the interval between notes in the equal tempered scale is an irrational number: 12 times the square root of 2. One of the important mathematical discoveries that made the division into twelve equal tones possible was the discovery of logarithms by John Napier. Of course, notes Isacoff, Napier then used his new discovery to predict that the end of the world would occur sometime between 1688 and 1700 – so it's not clear that even he fully understood what was going on. Yet, even renowned scientists like Sir Isaac Newton were still against equal temperament, saying that it only "assists towards continuing the imperfections of music."

The other important movement was *Romanticism* in piano music, epitomized by such composers as Chopin. Romantic music was real virtuoso music, which changed keys often. Isacoff: "The ability to play in any key without fear of producing ugly, 'wolf' tones, is crucial in Romantic music, where the harmonic 'center of gravity' of a piece is constantly shifting."

Tunings Today

Equal temperament is used everywhere today. It "won the war," and it's all that most of us know. But is the war really over? In fact, today there is a very active revival of interest in the tunings of earlier centuries. After all, equal temperament is actually a compromise – everything is just a little bit out of tune so that overall there are no more wolves. But that means that when we hear a Beethoven piano concerto played in a concert today, *we are not hearing it in the original tuning in which it was written by Beethoven*. In particular, there is a revival of interest in the **just intonation** – recall that this is the tuning where thirds and fifths retain their purity.

A modern composer named Kyle Gann has summarized much of modern thinking about just intonation this way:

> Many recent composers have come to feel that the compromise of equal temperament was a mistake. They feel that the musical logic of moving from any key to any other key became a priority at the expense of music's sonic sensuousness. Equal temperament chords do have a kind of active buzz to them, a level of harmonic excitement and intensity. Equal temperament could be described as the musical equivalent to eating a lot of red meat and processed sugars and watching violent action films. By contrast, just-intonation chords are much calmer, more passive; you literally have to slow down to listen to them.

Three famous contemporary Just Intonation composers

Three of the most famous composers today using Just Intonation are Michael Harrison, Terry Riley, and Philip Glass.

Figure 5: Michael Harrison, Terry Riley, and Philip Glass

Michael Harrison's composition *In Flight* was used in the trailers for the movie *Awakenings*, starring Robert de Niro. Harrison has a piano with 24 keys per octave. His latest tuning is called the "Revelation Tuning," which he says he woke up with the morning after a concert in Rome in which Riley and Glass participated.

Terry Riley is one of the legendary contemporary composers. Back in the 1970s all of the college students (including me) seemed to have his album called *Rainbow in Curved Air*. He also has commented on how pure tunings sound calmer and slower, saying "Western music is fast because it's not in tune."

Finally, Philip Glass is a legend in the field of "minimalist" composition. My wife has a Swatch-brand watch whose alarm plays a tune that he composed especially for the series.

Lucy Tuning

A particularly interesting case of modern nonstandard tunings is the story of a street guitarist in London named Charles Lucy. In the mid-1980s, Lucy had noticed that even after playing guitar for 25 years, he still couldn't tune his guitar so that it sounded perfectly in tune in two different keys. (Of course, we all know now that he had discovered the problem of musical temperament by himself.)

Figure 6: Charles Lucy

So he began a search on his own for the "perfect tuning." And he found his own personal answer in a very strange place: he had come to the conclusion that the secret of the perfect musical scale lay in the number *pi* (the same number we discussed previously in this lecture!). As he did research, trying to discover whether anybody had ever written about such a thing, he discovered that indeed somebody had.

And that person was John Harrison, who had lived from 1693 to 1776, and was the discoverer of longitude. He had made the most accurate clock in the world, and after the personal intervention of King George III, had received a 20-thousand Pound prize from the English Parliament. But Charles Lucy discovered that Harrison had also written a treatise with the title *An Account of the Discovery of the Scale of Musick*.

Figure 7: John "Longitude" Harrison

In that treatise, Harrison had written that "the natural scale of music is associated with the ratio of the diameter of a circle to its circumference" – that is, *pi*! And he went on to describe his theory.

It just so happened that Charles Lucy knew how to program computers, and so he wrote a program that followed the theory of Harrison and calculated the notes of this scale. Then he convinced the British Government to give him a grant of 20 thousand pounds to continue his research and have a guitar built that used this tuning. The new guitar actually had different frets in different places than the usual guitar.

This scale became known as "Lucy Tuning," and had its world premiere at the prestigious Barbican Center in London in 1987. One of Lucy's most interesting projects was the setting of lullabies from around the world in Lucy Tuning. Here is what he wrote about it:

> **Solving Bedtime Problems with High Tech Lullabies**. By using the latest understanding of musical tuning, and the human brain wave patterns found during sleep, Charles Lucy has produced a new recording. *LucyTuned Lullabies (from around the world)* encourage sleep with new renditions and special tunings of traditional lullabies from around the world. When played to small children they have the effect of making them drowsy and gradually they fall asleep. It also works on adults so avoid use when driving or using machinery.

Microtonal composers on the Internet

And finally, there are many, many composers and experimenters who post their music on the World Wide Web for anybody to listen to who is interested. Many of these composers write so-called "micro-tonal" music, in which the scale is divided up into many more tones than just the 12 tones of the Equal Temperament scale (similarly to what Mersenne proposed). This is where the central role of the computer in today's musical experimentation becomes evident: using programs like Scala, it is a snap to create new scales of any number of tones and hear what they sound like. This ease of experimentation was unthinkable before the computer – not only was it difficult to do the math, but then you had to find a way to play the music with your newly invented scale. A computer's synthesizer facilities make it instantly possible. One such example is music for a video game written by a composer named David Finnamore. He describes the tuning in the following way: "Octave equivalents of harmonics 19 through 29, 35, 45, 51, and 53. This tuning was chosen to give the ostinato pattern a set of intervals that increase in size as they descend." Another example is an experimenter who did a version of the American national anthem, "The Star-Spangled Banner," in Equal Temperament with 22 notes to the octave (as you might imagine, it sounds a bit unusual).

Conclusions

The history of musical tunings is by no means complete. People continue to experiment and discover new tunings. But Equal Temperament is here to stay, a temperament based upon precise mathematical calculations – just like its famous predecessor, invented 2500 years ago by Pythagoras. As Isacoff concludes: "Perhaps Pythagoras was right after all."

References

Temperament: The idea that solved music's greatest riddle, by Stuart Isacoff, Alfred A. Knopf, New York, 2001. A masterpiece of musical writing for a general audience, the inspiration for this lecture.

The `Scala` program can be downloaded free of charge from the Internet.