MUTOR *TiddlyWiki* Unit 5 on Pitch

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PsycheLoui, 7 August 2006 (created 8 June 2006)

tags: Unit

Unit5Introduction

PsycheLoui, 14 July 2006 (created 7 July 2006)

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Pitch is one of the most important attributes of music. This unit will cover the different types of pitch we may perceive in music. We start with the relationship between frequency in the physical world and pitch in the perceptual world. We continue to discuss the cases when pitch may occur in the absence of energy at the perceived frequency, and propose models which may account for this perceptual phenomenon. Different types of pitch perception will be discussed, includng the qualities that makes it form transposable melodies and harmonies. Finally, we will discuss pitch spaces and tuning systems that enable the systematic use of pitch as a musical medium.

FrequencyAndPitch

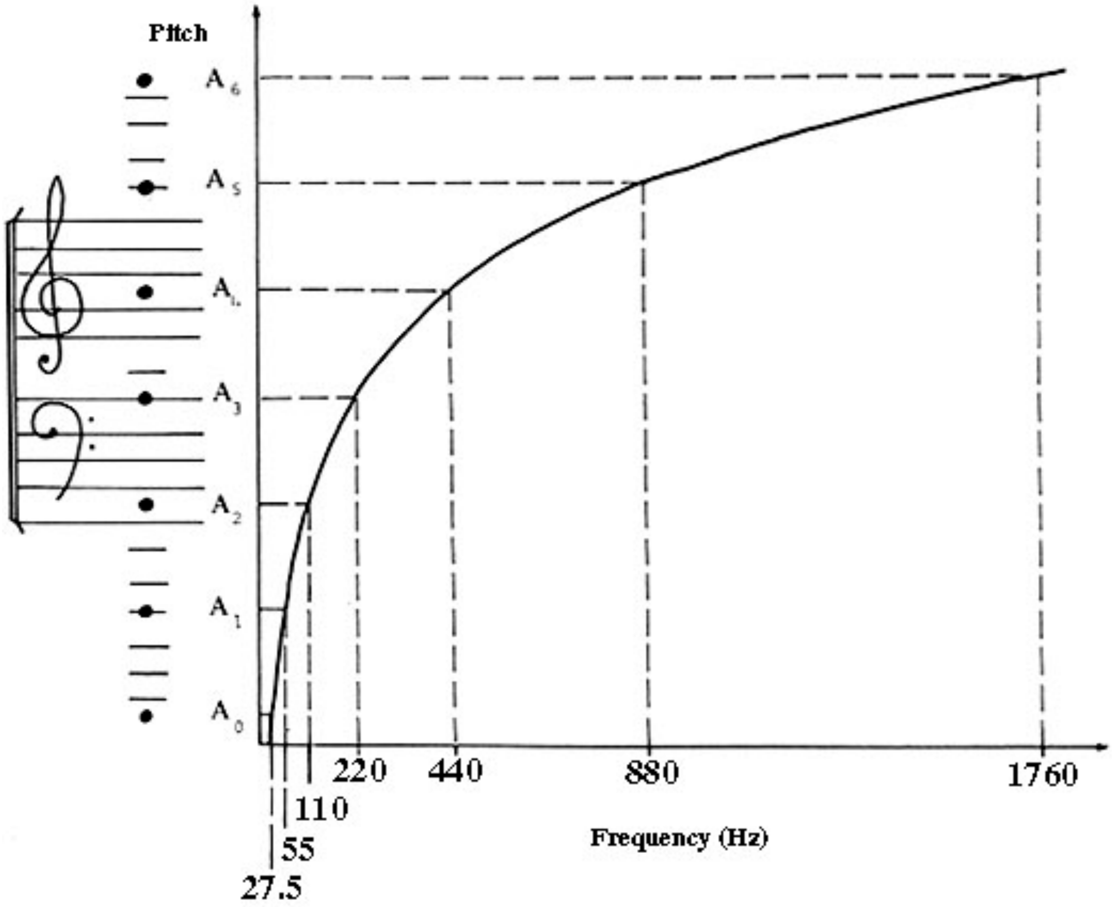
PsycheLoui, 3 August 2006 (created 14 July 2006)

tags: Unit

The concept of sound frequencies was first introduced in Unit 1. While frequency is a *physical* attribute which characterizes waves of sound energy, pitch is a *perceptual* attribute which describes our experience of tones. Generally, the higher the frequency of a sound, the higher the perceived pitch.
Pitch is perceived in sounds that are periodic; i.e. sounds with features which recur at regular frequencies. Aperiodic sounds are more likely to be perceived not as pitches, but as noise or transient (quickly-changing) clicks. Thus, pitch perception depends on frequencies of sounds entering the ears.

The orchestra tunes to the pitch of concert A4, which usually corresponds to sounds with the fundamental frequency of 440Hz. This means that while energy of sound waves may be at 440Hz or above, we perceive sounds to be equivalent in pitch as a pure tone at 440Hz.

Our percept of pitch is **logarithmically organized** such that an octave above concert A is twice its frequency, therefore, 880Hz; whereas the next octave above 880Hz is twice 880Hz, which is 1760Hz. Thus each octave corresponds to a doubling in frequency, resulting in a logarithmic function relating frequency to pitch.



(image source: Campbell, M. and Greated, C. (1987). The Musician's Guide to Acoustics. New York: Shirmer Books.)

FundamentalFrequency

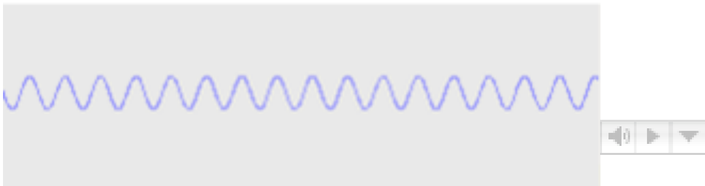
PsycheLoui, 3 August 2006 (created 19 July 2006)

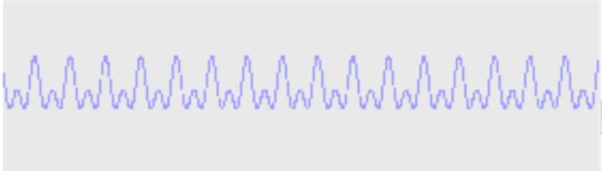
tags: Unit

The percept of pitch generally correlates with the **fundamental frequency** of sound waves. The fundamental frequency is defined as the highest common factor of all sound waves from the same source, which gives rise to the pitch percept.

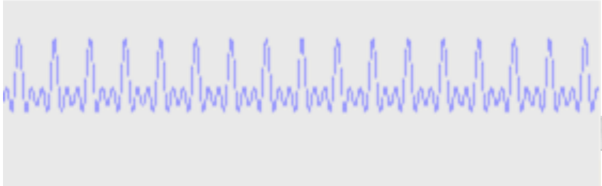
As an illustration of fundamental frequency and its relationship with pitch, consider four tones, each with different numbers of components, but where all the components are integer multiples of 440Hz. The perceived pitch of these four tones should be the same, although the frequencies which comprise them are different. The higher components in frequencies of n times 440Hz do not change the perceived pitch, but they do influence the percept of timbre.

The following are four tones with differing numbers of partials, but with the same fundamental frequency and thus the same perceived pitch.

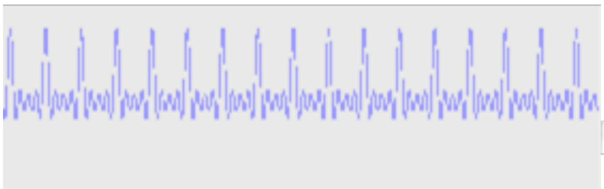
Pure tone at 440Hz 



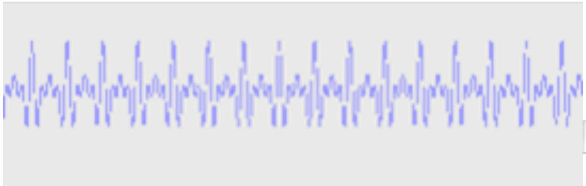
Two-tone complex with fundamental frequency of 440Hz



Three-tone complex with F0 of 440Hz



Four-tone complex with fundamental frequency of 440Hz



Three-tone complex with **missing fundamental** of 440Hz

The fundamental frequency of a sound is also known as its periodicity pitch, and is shorthanded as F0.

VirtualPitch

PsycheLoui, 10 August 2006 (created 19 July 2006)

tags: Unit

Sometimes, pitch is perceived at a fundamental frequency even when energy is nonexistent at the frequency of the fundamental. This is known as virtual pitch. Virtual pitch, also known as the missing fundamental, is a classic phenomenon in audition where sound is perceived at a frequency where no energy is present. When energy from harmonic components other than the fundamental is present at integer multiples of the fundamental frequency, the brain is able to infer a virtual pitch at the missing fundamental. Mechanisms that the brain may be using to infer virtual pitch is still an issue of debate, although various **models of pitch perception** have been proposed to explain this perceptual phenomenon.
Virtual pitch is only perceived if the missing fundamental frequency lies within the existence region for pitch, which is approximately the frequency range of 30Hz to 3.2 kHz (Pressnitzer et al, 2001).

Virtual pitch audio demonstrations (from ASA demonstration CD):
Spectral and virtual pitch: you will hear a tune of Westminster chimes presented in virtual pitch, due to the configuration of spectral components harmonically related to the missing fundamental. The spectral and virtual pitches will each be masked in the second and third clips.
1 2 3

Synthetic vs. Analytic pitch perception

PsycheLoui, 7 August 2006 (created 19 July 2006)

tags: Unit

Having made the distinctions between fundamental frequency, frequency components, and pitch, one question that arises concerns the hearing of partials versus the fundamental pitch of a complex sound. When do we hear a complex of partials as a chord, and when do we hear it as unified sound? What determines whether we synthesize sound components into a unified percept, or analyze sounds into their components?

The distinction between **synthetic** and **analytic** pitch perception - i.e. taking sounds apart into its frequency component vs. combining them - seems to depend somewhat on the **comodulation** of the partials. When a sound contains frequency components that modulate together, they are more likely to be heard as a whole. One example of comodulated partials is in speech, where frequency components tend to be highly correlated. Thus speech sounds are usually heard as unified percepts rather than individual components.

There is also some evidence for individual differences in synthetic versus analytic pitch perception. Evidence shows that left-handed listeners are more likely to hear frequency components whereas right-handed listeners are more likely to listen synthetically (Laguitton, Demany, et al, 1998). This may have to do with differential hemispheric asymmetries in the Heschl's gyrus of the auditory cortex (Schneider et al, 2005).

One effective assessment of synthetic versus analytic pitch perception depends on use of virtual pitch. In the demo here, you will hear two harmonic complexes with frequencies of 800 and 1000Hz, followed by 750 and 1000Hz. The first complex implies a missing fundamental of 200Hz, whereas the second implies a 250Hz virtual pitch. Try judging whether you hear the tones go up or down; if you hear them going down you are a **analytic pitch listener**, whereas if you hear an ascending interval you are a **virtual pitch listener**.

PitchPerceptionModels

PsycheLoui, 7 August 2006 (created 20 July 2006)

tags: Unit

For centuries, hearing and musical scientists have attempted to build an optimal model that would account for pitch perception. An accurate model of pitch perception must describe how components of frequencies are converted into pitch in the logarithmic scale; it must also explain how fundamental frequencies are calculated, as well as the phenomenon of virtual pitch. Early pitch perception models fall under two categories: **spectral models** and **temporal models**.

Spectral models of pitch perception, which are based on the frequency spectrum of sounds, tend to start with the Fourier analysis, which convert sound waves into its frequency components. One of the early spectral or **place models** was proposed by Helmholtz who speculated that each sinusoidal component of a sound triggers sensation at a place coding for pitch. In contrast, temporal models make use of the periodicity of waveforms comprising sounds. By calculating the time between periodic points in the waveform, the fundamental frequency can be calculated.

Modern theories of pitch perception take into account both spectral and temporal components of sound. Two types of modern pitch perception theories which receive the most support today are the pattern matching models and the autocorrelation models. Pattern-matching models of pitch perception, such as the **harmonic template matching model** (e.g. Lin & Hartmann, 1998), postulate that we have stored in our brains a set of templates which, when frequency components are activated, we overlay onto the pattern of activation in order to calculate the fundamental pitch.

The autocorrelation models (Licklider, 1959) use a measure of *self-similarity* of a waveform in order to derive its fundamental. It is based on the idea that a periodic waveform, when phase-shifted to exactly one period of its fundamental away from a starting point, should correlate perfectly with itself. By comparing the time lag between perfectly correlated frequency components, the model can derive the period of the complex sound, and thus the fundamental frequency.

The debate between pattern matching and autocorrelation models have received widely discussed among hearing researchers in recent years. While new data continues to emerge in support of either model, results from neuroscience looking for autocorrelators or harmonic templates in the auditory system may contribute to resolve these debates.

ExistenceRegion

PsycheLoui, 20 July 2006 (created 20 July 2006)

tags: Unit

The **existence region** for pitch is the range in frequency at which melodies are transposable and can be perceived as a reasonable musical medium, e.g. can be used in melodies. Pressnitzer et al. (2001) define the existence region of melodic pitch as 30Hz to 3.2 kHz; however, the exact range of the practical existence region of melodic pitch is still under debate.

Pressnitzer, D; Patterson, R; & Krumbholtz. (2001). The lower limit of melodic pitch. JASA, 2076-2084.

FormBearingMedium

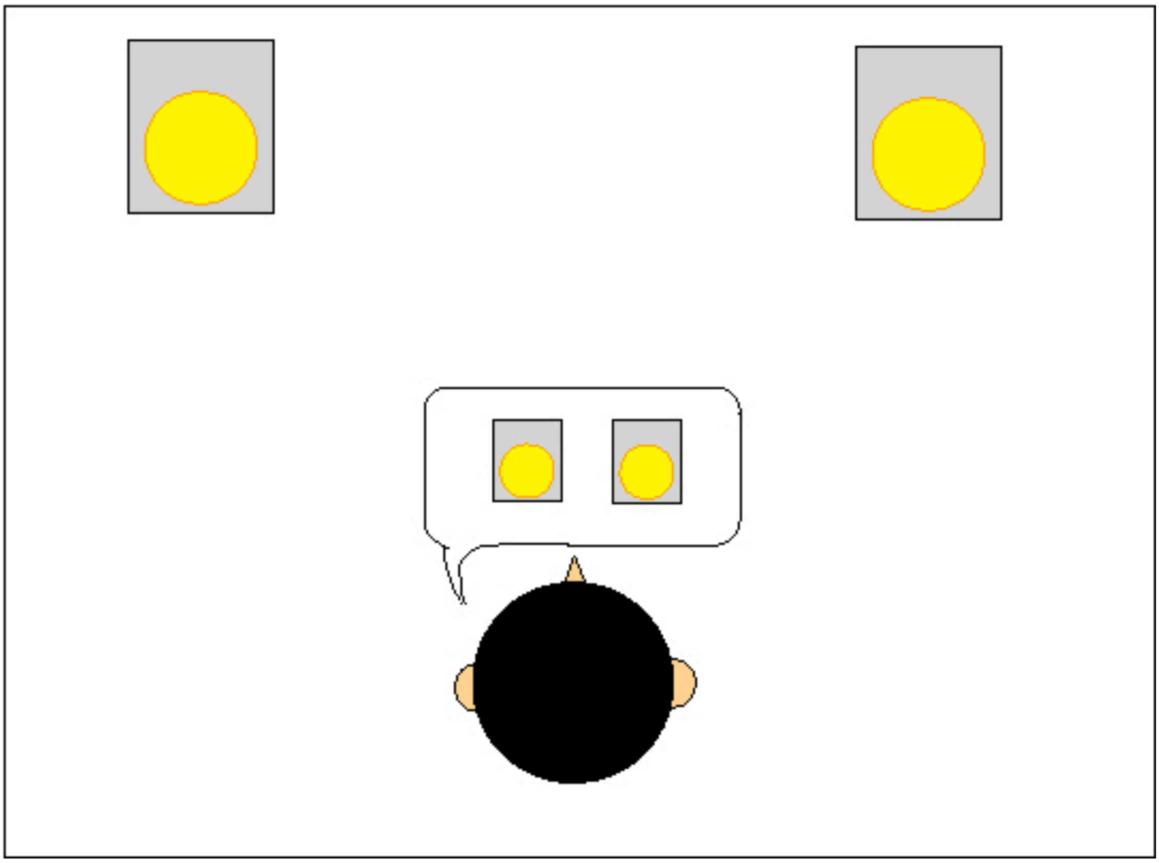
PsycheLoui, 9 August 2006 (created 19 July 2006)

tags: Unit

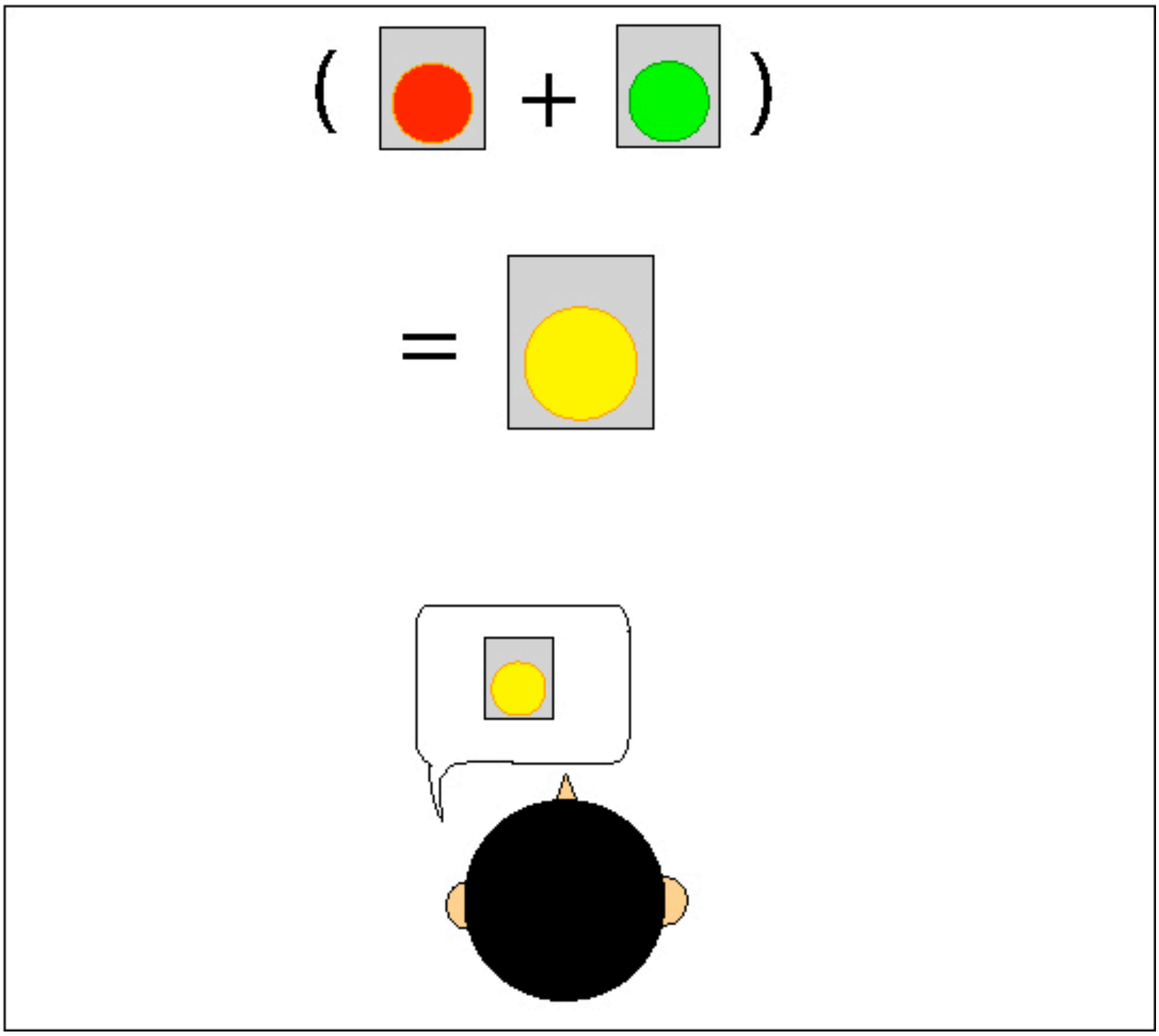
Pitch is thought of as a **morphophoric**, or form-bearing, medium. This means that patterns of pitch can take on a certain form (i.e. melody) which can be transposed - shifted up or down in pitch - and remain invariant in its perceptual structure. Musically, this accounts for how the same melody can be transposed into different keys and still be recognizable as the same theme. Again, the transposability of pitch only works if the frequencies are within the **ExistenceRegion** of pitch. Another form-bearing medium is duration, where patterns of durations, i.e. rhythms, can be transposed into longer or shorter durations (i.e. different tempos), but the overall pattern remains the same. Ths accounts for how pieces can be played at different tempos and still retain their recognizability.

The opening measures of the two violin solo parts in Bach's Double Concerto in d minor, BWV 1043. Notice that the same theme is transposed between the two parts, but the melodic material is the same.

Consider the following *Gedanken* experiment (thought experiment): lights of the same color are projected simultaneously on two separate locations. You are asked to judge whether you see one light or two.

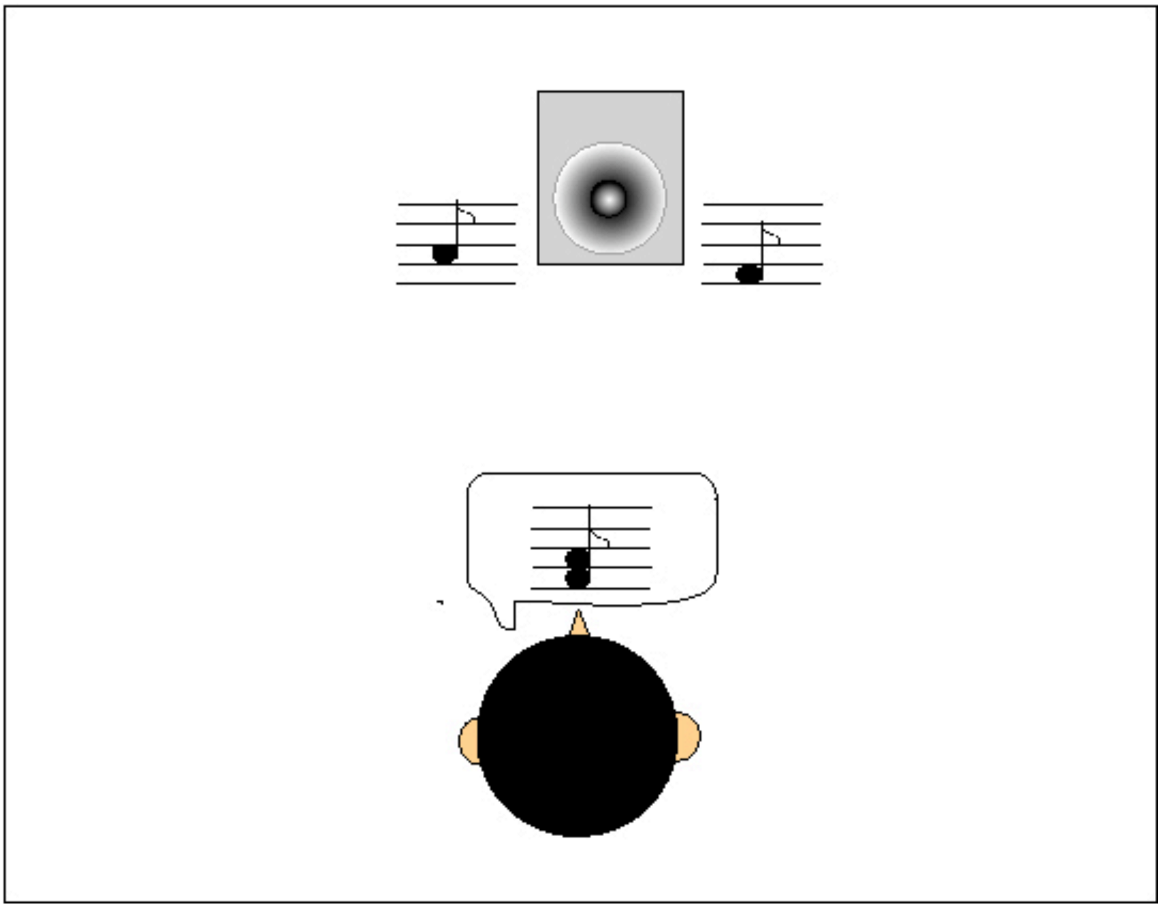


Now lights of two colors are projected onto the same location. Do you see one light or two?

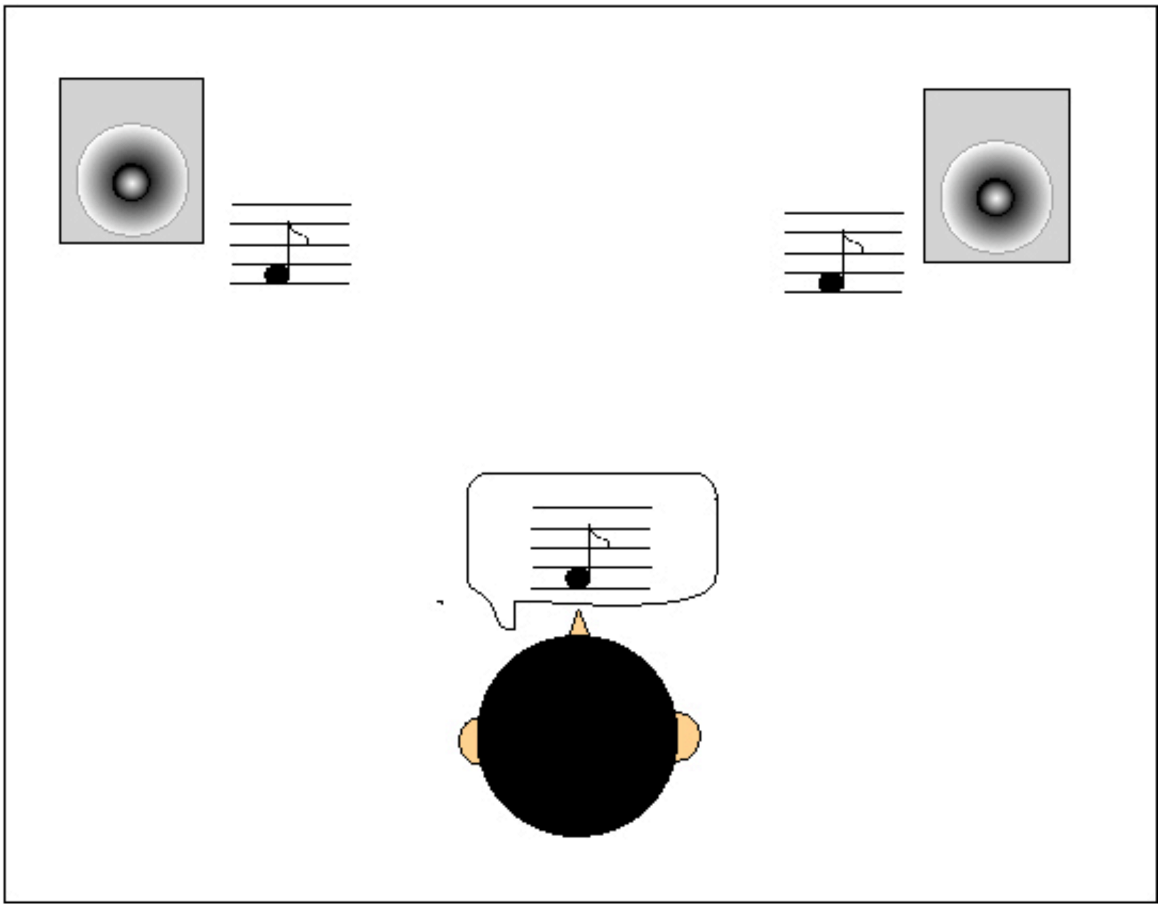


This *Gedanken* experiment demonstrates that in the visual modality, separation of location is **indispensable** to our perception of an object as a whole, whereas separate colors do not necssarily imply separate objects. Thus, we say that color is a **dispensable attribute** of visual object perception, whereas location is an **indispensable attribute**.

Now consider an auditory analogy to the above visual *Gedanken* experiment. Two tones are played simultaneously on the same speaker. One is of a higher frequency than the other. Do you hear two tones or one?



Now let's say two tones of the same frequency are played simultaneously on two speakers from separate locations. Do you perceive two tones or one?



Most people would say that when two frequencies are played, they perceive two tones, whereas when the same frequency is played in two spatially-separate speakers, they perceive one tone overall. Thus we can conclude that spatial location is a dispensable attribute of auditory perception whereas frequency is an indispensable attribute.

Take-home message: in the visual modality, color is dispensable whereas location is indispensable. In the auditory modality, location is dispensable whereas frequency is indispensable.

AbsolutePitch

PsycheLoui, 9 August 2006 (created 19 July 2006)

tags: Unit

Absolute pitch, commonly also known as **perfect pitch**, refers to the ability to identify notes by their note names, without being given a reference note. For instance, a person with absolute pitch is able to provide the note name of A4 when presented with a tone of 440Hz. Some individuals with perfect pitch are also able to produce (sing or play) a note when given the note name without any external reference.

Absolute pitch is thought to be a rare trait. The precise incidence of individuals with absolute pitch is still under debate, as the criterion used to define absolute pitch possessors differ among studies; nonetheless, most researchers agree that the percentage of individuals in America with absolute pitch is less than 1%. However, absolute pitch seems to be more common among individuals with musical training early in life, as well as native speakers of tonal languages (languages that use pitch and pitch inflections to convey meaning, e.g. Mandarin, Vietnamese) (Deutsch et al, 2004).

The higher incidence of absolute pitch among certain groups of people has led to questions about whether absolute pitch is innate or learned. Ongoing research efforts on absolute pitch entail the attempt to discover the gene associated with perfect pitch (see UCSF Absolute Pitch Study), as well as the attempt to correlate absolute pitch with age of onset of musical training. Both sides of the nature vs. nurture debate on absolute pitch has received much support, but one theory merging the two views proposes that humans are born with absolute pitch, but lose it as they grow up, possibly due to a shift in processing associated with aspects of language learning (Saffran & Griepentrog, 2001). More evidence that absolute pitch is more common than previously thought comes from Levitin's (1999) experiment, in which undergraduate students were asked to sing their favourite pop song in the laboratory. Participants produced starting pitches that were very close to the actual starting pitch of the song. In another experiment, Levitin asked subjects to carry around a tuning fork for a week. Afterwards subjects were asked to hum the note of the tuning fork. Interestingly, most subjects hummed pitches that were within two semitones of the target pitch (i.e. the pitch of the tuning fork). These experiments provide support that most individuals, even nonmusicians, have some absolute memory for pitch material.

(image source: Cook, 2001.)
Data from Levitin's tuning fork study, where subjects were asked to reproduced the pitch of a tuning fork. Results approximate a normal curve centered around the target pitch.

PitchAndHarmony

PsycheLoui, 10 August 2006 (created 19 July 2006)

tags: Unit

While melodic material is generally composed of pitches presented one after another, simultaneously-presented pitches give rise to chords, from which we derive the sense of harmony. This has led to melody being referred to as the **horizontal** dimension of music, and harmony as the **vertical** dimension of music.

In addition to simultaneously-presented pitches, however, harmony also refers to sequences of chords, or chord progressions. The study of how certain arrangements of pitches fit together to construct tonal centres and develop the sense of harmony is fundamental to traditional music education.

Although the key or tonal centre of music is generally established by chords, it can also be built up using sequences of pitches that outline the chord. The use of **implied harmony** is heavily employed, for example, in Bach's cello suites. The ability of the human brain to infer chords from sequential pitches suggests that we have some implicit knowledge of musical harmony.

Since harmony depends critically on the existence and configuration of multiple pitches, harmony can be regarded as an **emergent property** of pitch.

TuningSystems

PsycheLoui, 10 August 2006 (created 20 July 2006)

tags: Unit

We have discussed how frequencies give rise to the emergent property of pitch, and how collections of pitches give rise to harmony. But how are pitches chosen to form harmonies together? What determines what pitches are chosen to be in a scale, and what pitches go in a chord?

Low integer multiples

One central tenet to pitch, scales, tuning systems, and harmonies is the principle that low-integer ratio multiples sound more consonant together. Frequencies of integer multiples are said to be **harmonic** to each each other; for example, two tones of 200Hz and 100Hz, which relate to each other in a 2:1 ratio, form the interval of an octave and sound very consonant together.

One example of the use of harmonics is in a stringed instrument when the string is touched lightly at fractions of its length, so as to produce frequencies harmonically related (i.e. related in whole-integer multiples) to the fundamental frequency of the whole string.

The Western scale, like most scales of the world, is based on an octave, which is a 2:1 frequency ratio. Within the octave, many pitches can be chosen which are related in low-integer multiples in frequency. A **justly tuned** major triad contains pitches related in ratios of 4:5:6 in frequency. In the justly-tuned Western musical system, pitches conform to the lowest integer multiples. In contrast, the modern Western tuning system uses **equal temperament**, in which an octave is divided *evenly* into 12 tones arranged in the logarithmic scale. This means that some tones are stretched in frequency such that they do not adhere exactly to low-integer multiples, but only *approximate* these ratios, leading to only approximately consonant tuning in chords. Equal temperament tuning systems allow for **transpositional invariance** of pitch material, such that the same chords and melodies can retain their form (see **FormBearingMedium**) when shifted in pitch.

The ASA demonstration CD contains a demonstration of the effects of stretched harmonic partials on the sense of harmony:
1. Normal four-part Bach chorale with 9-partial tones. (Harmonic instruments playing in a harmonic scale.)
2. Both melodic and harmonic scales stretched 2.1:1. (Inharmonic instruments playing in an inharmonic scale.)
3. Only melodic scale stretched. (Harmonic instruments playing in an inharmonic scale.)
4. Only the partials of each voice are stretched. (Inharmonic instruments playing in a harmonic scale.)

Other common scales with different numbers of divisions of the octave are pentatonic scales e.g. jazz modes, Chinese and Persian scales, slendro & pelog Indonesian gamelan scales. Pentatonic scales have only five divisions of an octave, and are usually not equal-tempered. A number of contemporary art music composers have also written in **microtonal** scales, which generally include all scales with steps smaller than a semitone. Notable examples of microtonal composers are Francois Paris, who has used scales involving 12 divisions of a major sixth or even a major third. Easley Blackwood is another composer who has explored microtonal modes in his *Microtonal Etudes*, which divide the octave up to anywhere from 7 to 24 steps. Most scales of the world use octave equivalence, with noticeable examples of exceptions being some Arabian music which has two-octave equivalence, gamelan music where octaves are not 2:1, and the Bohlen-Pierce scale which has 13 logarithmic divisions of a 3:1 frequency ratio (a "tritave"). John Chowning, in his piece *Stria*, uses a tuning system based around the **Golden Ratio**, or 1.618:1.

Different tuning systems give rise to different harmonies. It is interesting to speculate on the effects of different tuning systems on the feeling of the music.

PitchSpaces

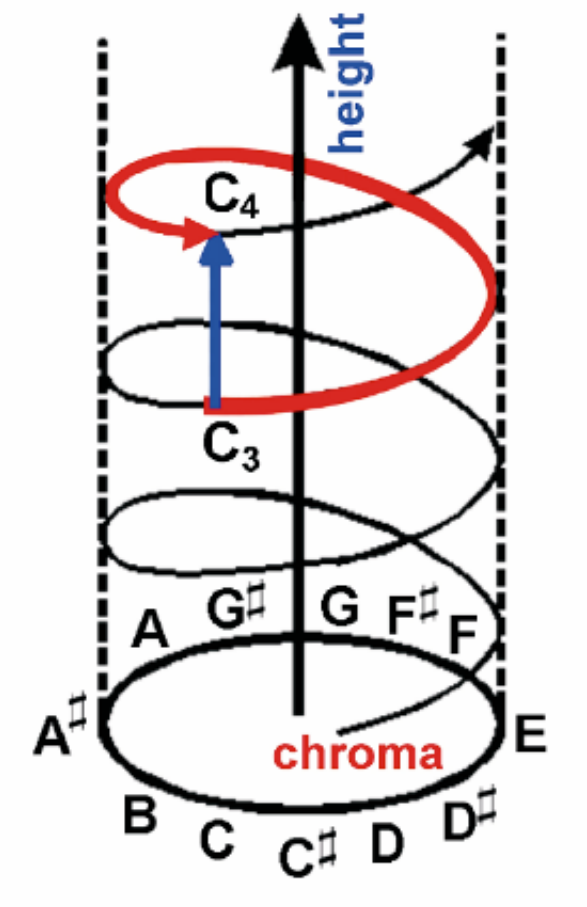
PsycheLoui, 11 August 2006 (created 19 July 2006)

tags: Unit

Throughout this unit we have discussed certain structural properties of pitch, including translational invariance and the importance of whole-number ratios. These structural properties have led various composers and music researchers to wonder about the structure of pitch material. Various attempts have been made to create visual representations of pitch structures. We will talk about a few of these representations, and how they are derived from perceptual experiments.

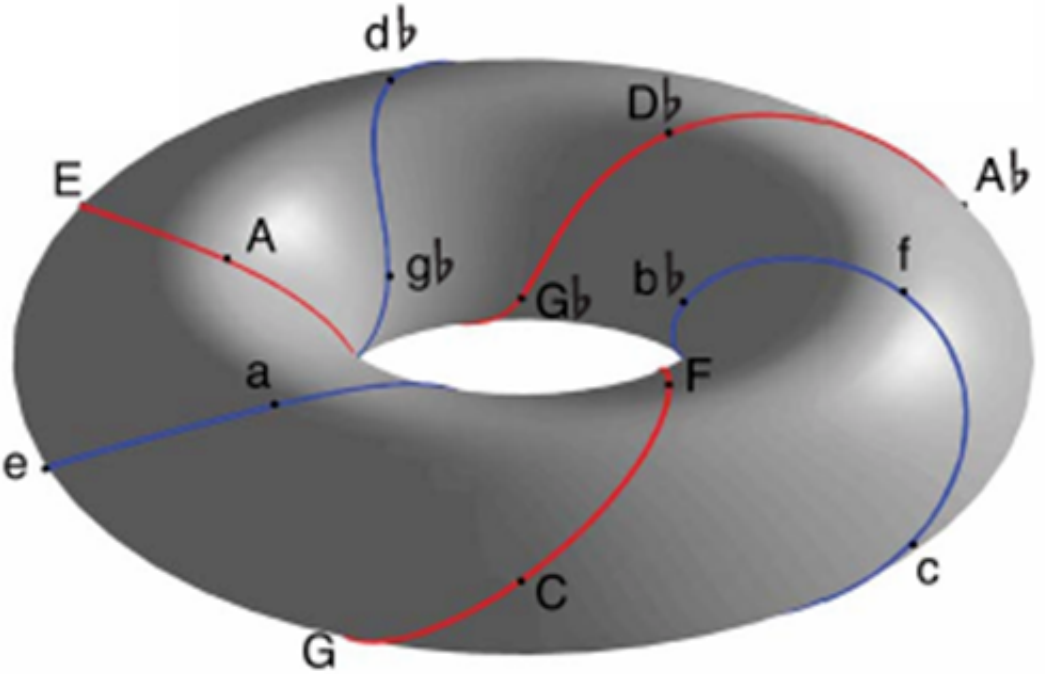
One method that has helped to derive pitch spaces is known as **multidimensional scaling**. Multidimensional scaling (MDS) is a quantitative method to map any series of items onto a perceptually meaningful space. In the typical multidimensional scaling experiment, the subject is given many pairs of items and asked to rate how similar they are to each other. These **dissimilarity judgments** are then fed into an MDS algorithm which defines a space that optimally represents all the judgments as distances such that items that are most similar are fitted closest together. These experiments have been performed on sets of pitches as well as on sets of chords. Krumhansl & Shepard? Kessler? did MDS on chords, I think, and the solution mapped out best on the surface of a TORUS.

Shepard's model of pitch as a helix showed that pitch could be specified as two dimensions: pitch chroma versus pitch height. The vertical dimension of the helix represents **pitch height**, where different vertical positions map onto the same pitch class in different octaves. The circular dimension of the helix represents **pitch chroma**, where different circular positions along the same level of the helix map onto different pitch classes in the same octave. In this representation, a **Shepard tone** is a tone that is held stable in pitch height, but moving around in pitch chroma.
Click here for a demonstration of Shepard tones and Risset glides, both of which involve moving partials within a stable spectral envelope.



(image source: http://www.pdn.cam.ac.uk/groups/cnbh/research/publications/WUPG03/WUPG03.htm) The helical representation of pitch chroma and height. Evidence that pitch chroma and pitch height activate different parts of the brain come from Warren et al (2003) who showed that changes in both chroma and height activate the auditory cortex, but changes in pitch chroma activate regions anterior to the regions activated by pitch height changes.

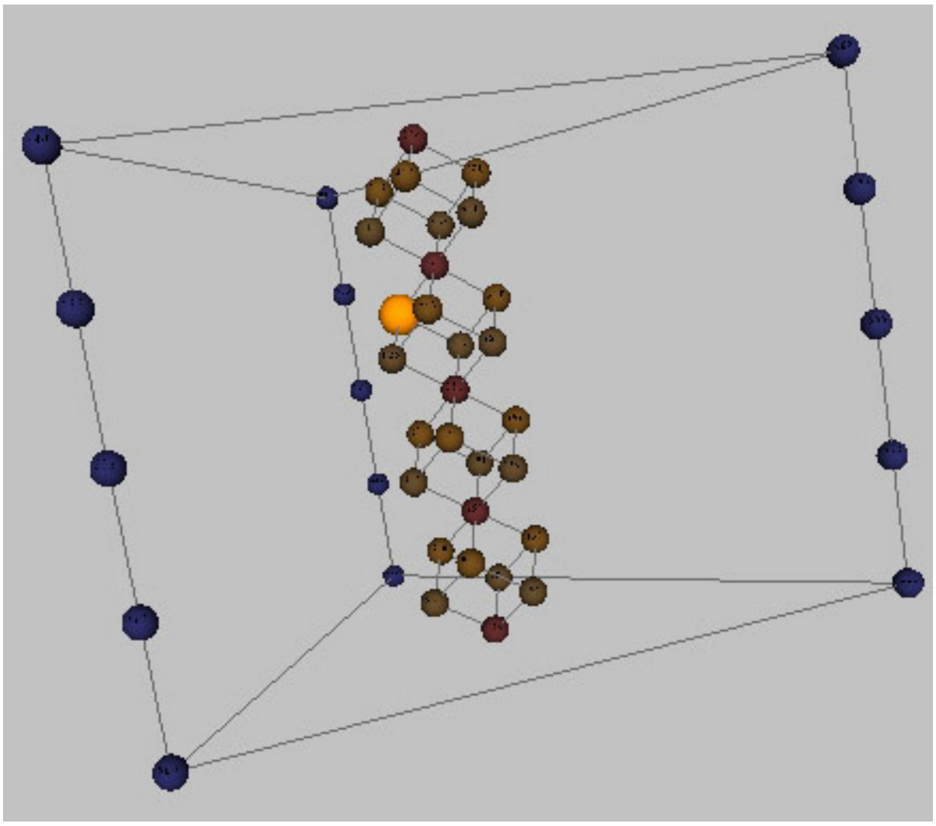
Another view of pitch and tonal material looks at harmony and key changes in addition to single pitches. Krumhansl, Kessler & Bharucha (1983) found that dissimilarity judgments of pairs of chords map best onto a torus. The toroidal representation allows different tonal relations to map along the different planes of the torus, such that the C major key, for instance, is closely related to G major (circle of fifths), a minor (relative minor), and c minor (parallel minor).



(image source: Zatorre & Krumhansl, 2003. http://www.sciencemag.org/cgi/reprint/298/5601/2138.pdf) The toroidal representation of tonal space, where keys that are more closely related to each other (e.g. adjacent along the circle of fifths, relative major or minor, and parallel major or minor) are located closer on the surface of the torus.
Janata et al (2003) found neural correlates of movement on the surface of the torus in the ventromedial prefrontal cortex. Stable voxels over many scanning sessions, but unstable as to which voxels correspond to which area in tonal space (key). It is as if the torus moves around in your head over different days.

Video showing continuously modulating melody activating the surface of the torus.
Also see Girl from Ipanema video.
Then there's also Lerdahl's cone-shaped pitich space. Lerdahl's book *Tonal Pitch Space*.

Dmitri Tymoczko has developed a number of non-Euclidean geometrical structures for the representations of musical chords. His software, Chord Geometries is a demo of several geometrical lattice structures which allow for chords and chord inversions in different keys to be represented on the geometrical space.


(image source: http://music.princeton.edu/%7Edmitri/ChordGeometries.html) Tymoczko's 3D geometrical space. The corners represent areas of tonal stability, the brown nodes in the lattice structure represent chords, and the larger orange node represents the currently active chord.

SumMary

PsycheLoui, 9 August 2006 (created 9 August 2006)

tags: Unit

We have discussed the various perspectives of pitch and perception. Pitch is a perceptual attribute correlated with **FundamentalFrequency** of periodic sounds. In situations where the fundamental frequency is not present but within the **ExistenceRegion** for pitch, we may perceive **VirtualPitch**. **PitchPerceptionModels**, such as autocorrelation and harmonic template matching, must explain the perception of virtual pitch. Sounds with comodulation are more likely to be heard as unified wholes instead of separate partials, although Individual differences also play a role in **Synthetic vs. Analytic pitch perception**.

The transpositional invariance of pitch material leads to pitch being a **FormBearingMedium**, which enables the formation of the same melodies in multiple keys. While melody is the sequential presentation of pitches, the simultaneous presentation of pitches gives rise to **harmony**. Different **TuningSystems**, based on the choosing of different pitches to form scales and chords, lead to different harmonies. **PitchSpaces**, which are structural descriptions of pitch material often derived from multidimensional scaling, are useful ways to describe pitch and harmonies.

AbsolutePitch is the ability to identify the note name of a pitch without any given referent. Although it is generally conceived as being quite rare in the population, it seems to be more common among musicians and speakers of tonal languages. Detailed study into **AbsolutePitch** may provide insight into the nature versus nurture debate of pitch perception.

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PsycheLoui, 10 August 2006 (created 3 August 2006)

tags: Unit

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LinksnDownloads

PsycheLoui, 4 August 2006 (created 4 August 2006)

tags: Unit

1. The software Transcribe! allows the viewing of harmonic templates overlaid on the spectrum.
2. Soundtracks from the ASA demonstration CD, with demonstrations of virtual pitch, Shepard Tone illusions, and other phenomena here.
3. Shepard tone Java applet demo here.
4. Try http://perfectpitch.ucsf.edu for a test on perfect pitch.

QuizItems

PsycheLoui, 10 August 2006 (created 9 August 2006)

tags: Unit

1. What pitch is perceived when three frequency components of 512Hz, 768Hz, and 1024Hz are presented simultaneously?
2. How is multidimensional scaling used to derive the toroidal tonal space?
3. Describe the autocorrelational model of pitch perception.
4. What are the horizontal and vertical dimensions of music?
5. What do we mean when we say that pitch maintains transpositional invariance?