Psychoakoustics

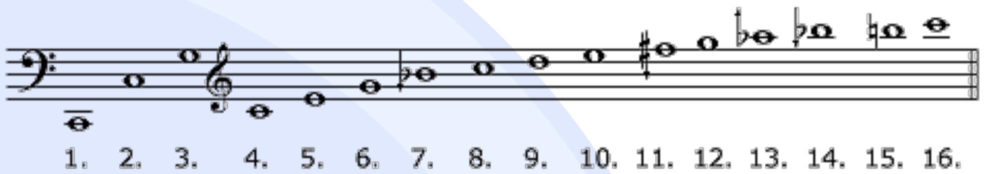
5th Lesson

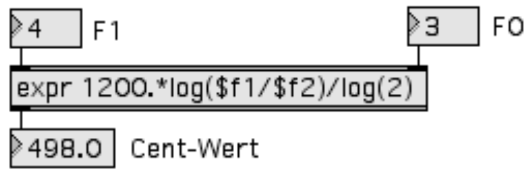
Pitch, Intervals and Key Areas

Frequency and Pitch

Frequency (in cents) and perceived pitch are in logarithmic relation. As with the volume, the pitch must be specified in relation to a reference tone (Interval I). The unit of measure is cents = 1/100 semitone or 1/1200 octave:

$$I = 1200 \log_2(F_1/F_0) = 1200 \log_{10}(F_1/F_0)/\log_{10}(2).$$





The following just intervals are derived from the overtone series, using the formula (the ratios correspond inversely to the string ratios Pythagoras identified):

Intervall (Name)	Frequenzverhältnis	Intervall (Größe in Cent)	temperierte Stimmung
R1	1/1	0	0
K2	16/15	112	100
G2	9/8	204	200
K3	6/5	316	300
G3	5/4	386	400
R4	4/3	498	500
V5	7/5	583	600
R5	3/2	702	700
K6	8/5	814	800
G6	5/3	884	900
K7	16/9	996	1000
G7	15/8	1088	1100
R8	2/1	1200	1200

Pitch

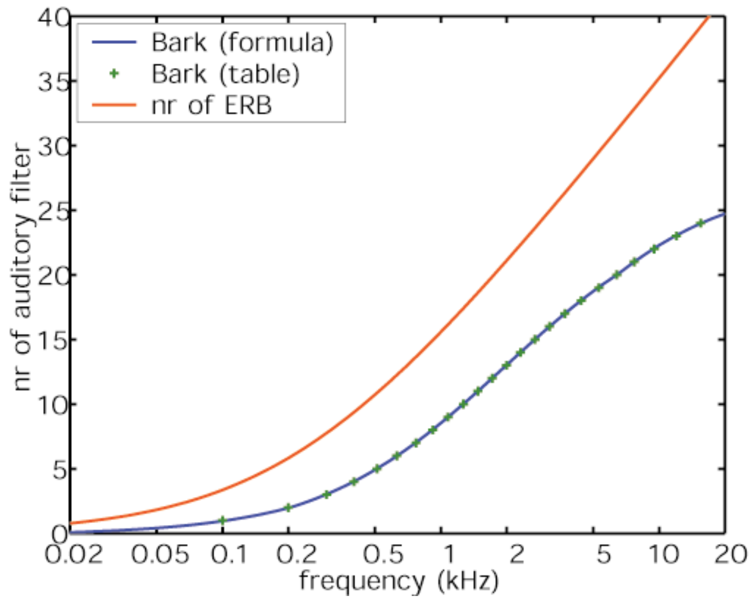
- Spectral composition and temporal development of a sound determines pitch and timbre
- Unambiguous pitch only for harmonic sounds
- Ambiguity in inharmonic sounds caused by competing virtual pitches

Residual pitch

- The brain recognizes the fundamental pitch in harmonic and some inharmonic sounds even in the absence of lower partials. Prerequisite: three adjacent partials.
- Periodicity remains intact in the absence of fundamental.
- However, this does not explain the perception of strike tones in bells.
- Therefore, Terhardt has formulated the theory of pattern recognition (comparable to subjective contour in vision, see Kanizsa triangle).

Place theory

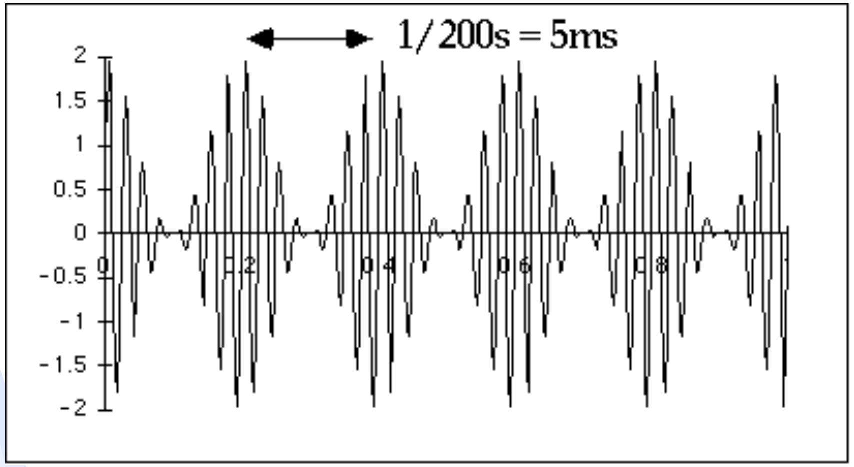
- According to Helmholtz, the ear is a frequency analyzer: Sounds create "resonances" on the basilar membrane that trigger nerve impulses. The basilar membrane acts like a filter bank (bandpass filter) whose individual widths are described by the so-called critical bandwidth.
- The hearing range is divided into 24 barks (critical bandwidths), which in the middle roughly corresponds to the size of a minor third (border between step vs. leap perception).



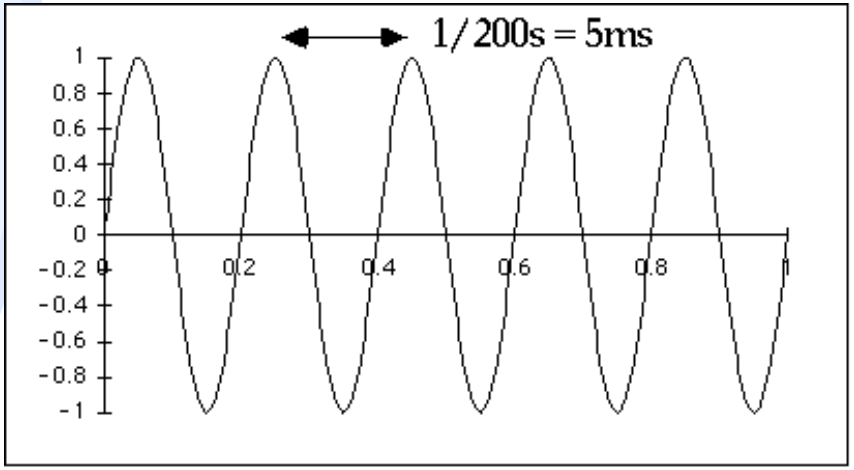
Temporal theory

- According to Schouten, the ear is a counter and can count the peaks and troughs of a wave and pass this information by nerve impulses to the brain.

Hohe Teiltöne:

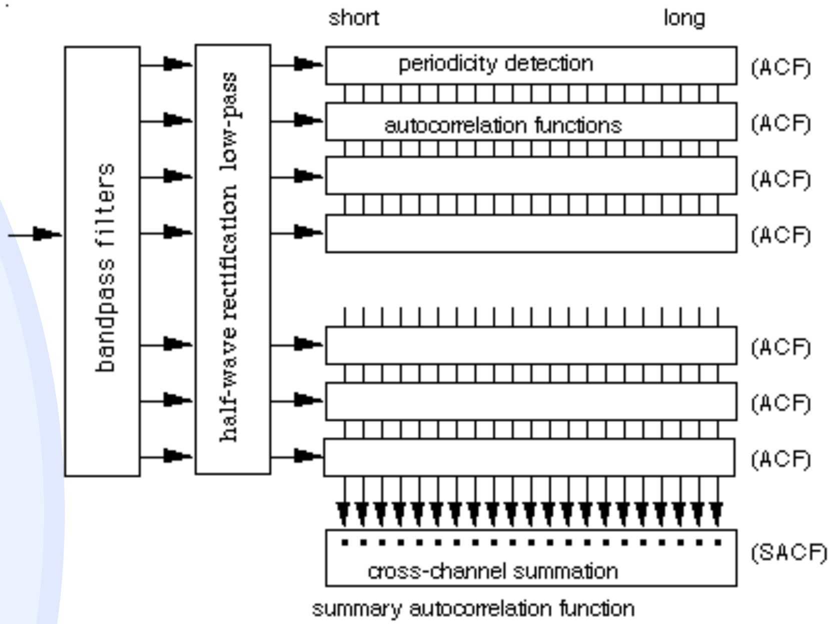


Grundton:



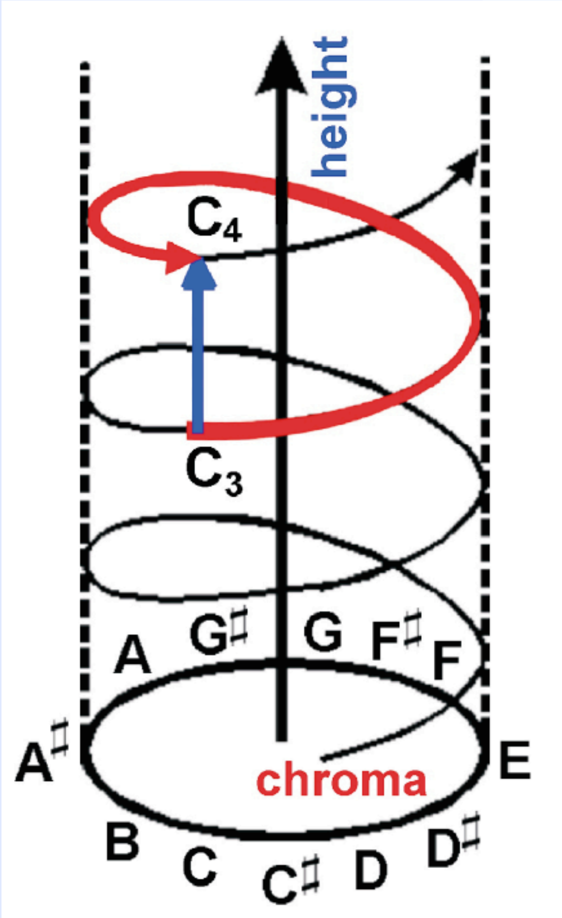
Place and temporal theories of pitch perception

- Truth is probably somewhere in between:
- Template theory (Terhardt, Parncutt). The brain creates a template.
- Model of the summation autocorrelogram (Lyon / Slaney, Patterson). The brain searches for periodicity in the output of bandpass filters (channels) and sums them up. As a result, some phenomena can now be explained, which arise by instance by detuning lower partials or transposing sounds with just odd partials.

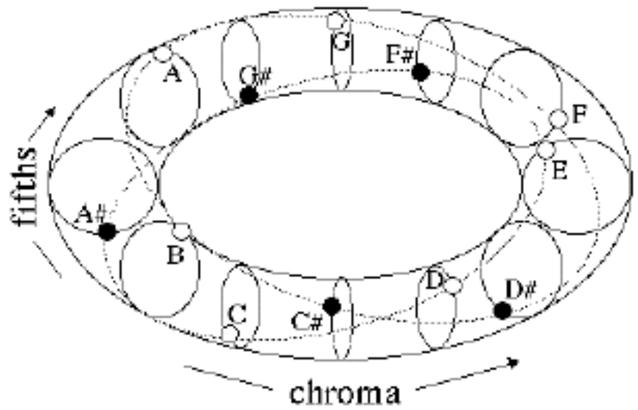


Cognitive Psychological Models

American psychologist Roger Shepard has developed a cognitive psychological model that represents pitch in a helix. In this case, the circular chroma circle (horizontal) can be distinguished from height (vertical). Octaves are always on the same side of the helix. By a clever construction tones can be formed, in which the dimension of the height is eliminated. These sounds, called "Shepard tones", are useful for constructing auditory illusions, e.g. endlessly rising or falling glissandi or scales. The so–called Tritonus paradox can be demonstrated with Shepard tones. A tritone is heard depending on its context either as falling or rising.



Five-dimensional model of pitch



Tonality and Probe Tone Method

siehe auch: http://people.cs.uct.ac.za/~dnunez/psy205s/tut4/

Shepard and his student Carol Krumhansl developed the *Probe Tone* method, aimed to explain the notion of tonality. Tonality is a hierarchical phenomenon in which the tones arranged in a system have varying amount of tension with each other. This raises the not yet fully answered question, whether the types of sound used in music (for example, with harmonic partials) ultimately determine how the music manifests itself.

In this method, subjects listen to cadences and scales, with the target sound (the tonic) being replaced by a so-called probe tone. The subjects are asked on a scale of 1 to 7 to judge how well the probe tone "fits".
By analyzing the data, three groups emerged which, depending on their musical background, were more or less able to perceive tonal hierarchies in major or minor context (the figure on the right shows results typical of experienced musicians).

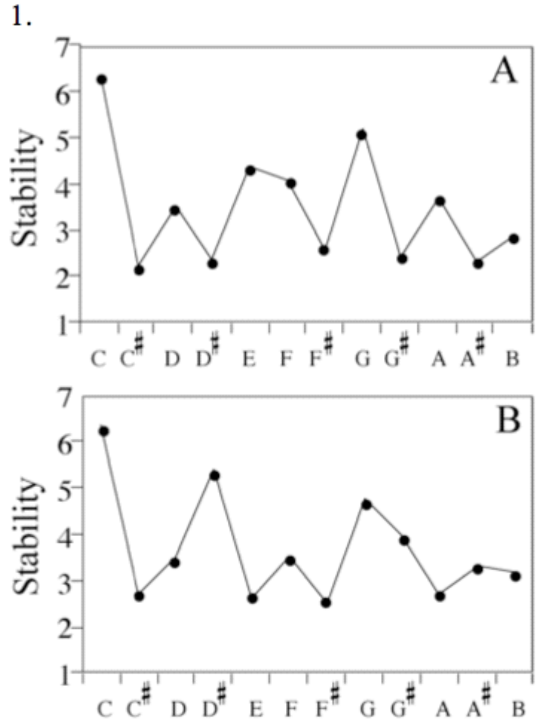
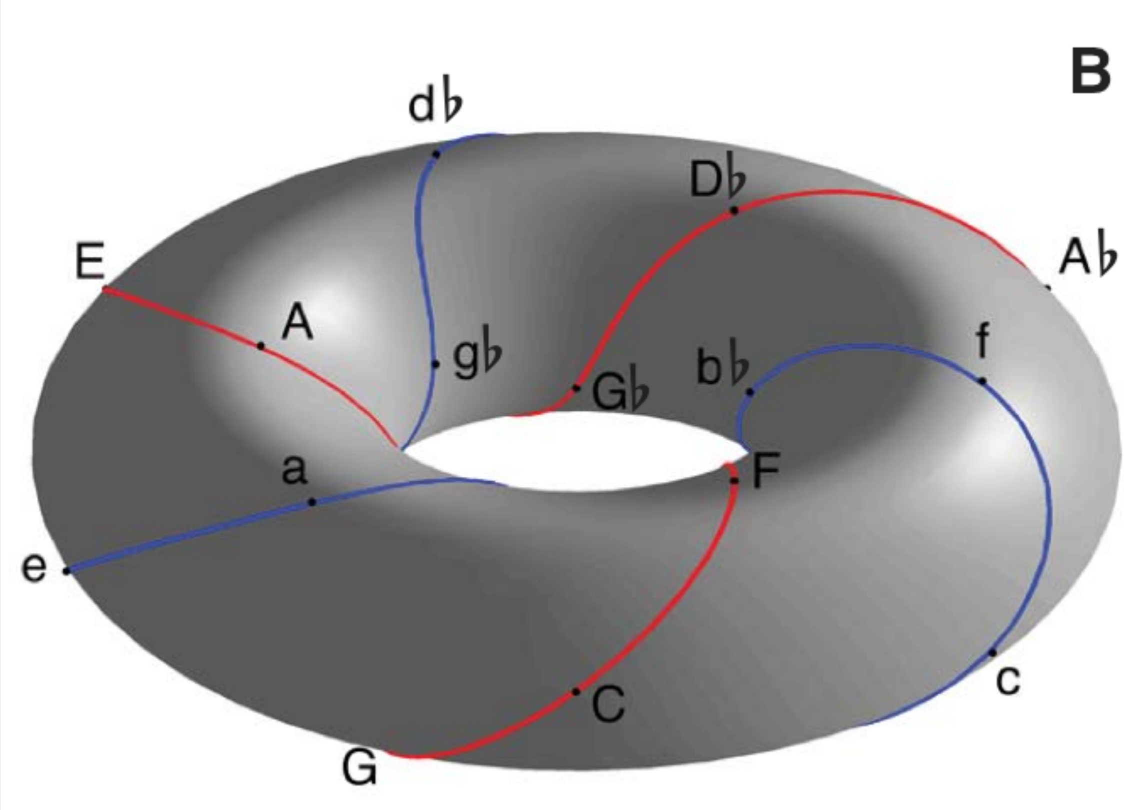
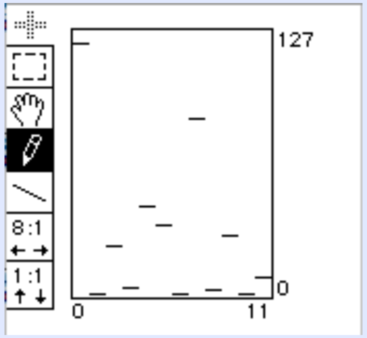


Fig. 1. Listeners ratings of stability of each pitch class after the presentation of a) C major; and b) C minor tonal contexts (after [2]). Tonal hierarchies for other keys are obtained by shifting the stability values circularly.

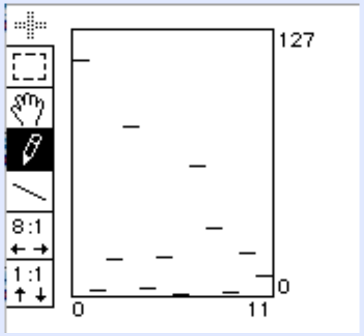
The arrangement of the 24 keys on the surface of a torus can now be derived from the experimentally obtained data by multidimensional scaling (https://en.wikipedia.org/wiki/Multidimensional_scaling). Multidimensional scaling is a process capable of constructing a two-dimensional map from a list of distances (such as the route Cologne-Hamburg or Stuttgart-Berlin). Taking now the tonality profiles as the starting point for all 24 major and minor keys, the comparison of the profiles yields a map depicting the distances (i.e., degree of relationship) of the keys as points on the surface of a torus (“donut"). It is noticeable that the two fifths (major = red, minor = blue) spiral around the torus.



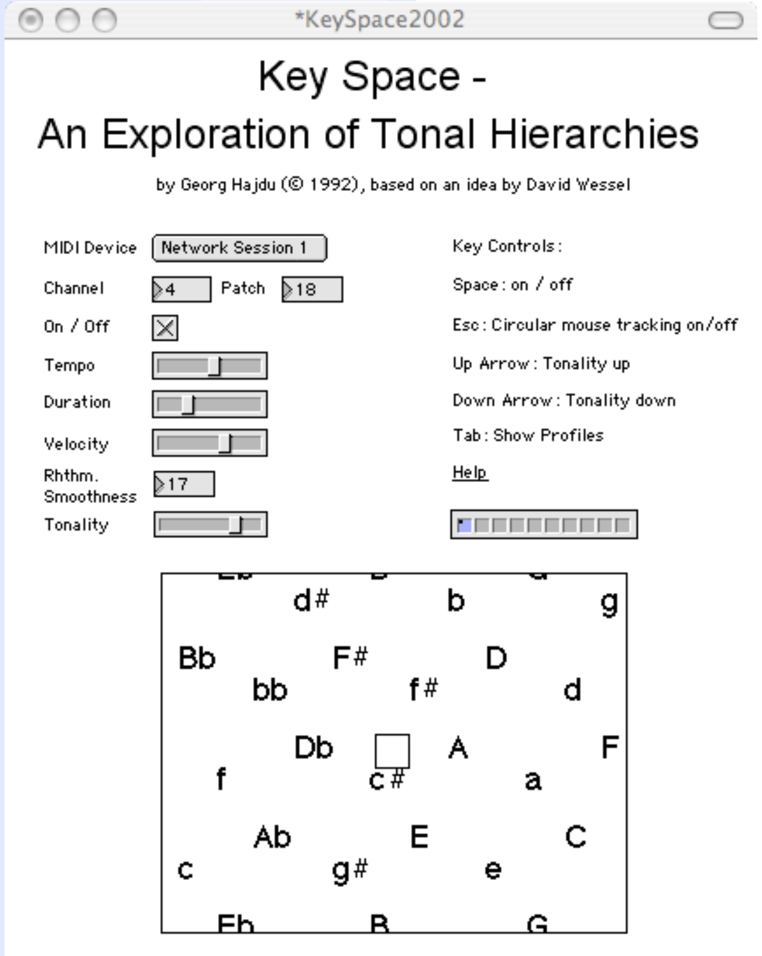
At the University of California, Berkeley, David Wessel has instigated a program that uses the opposite approach: users move their mouse over the surface of the torus, controlling a generative process that generates profiles according to the melodies; the height of each bar for a given tone determines the frequency of its appearance. This makes it possible to continuously modulate from key to key. In the lower illustration, the torus has been cut in two dimensions and "laid flat".

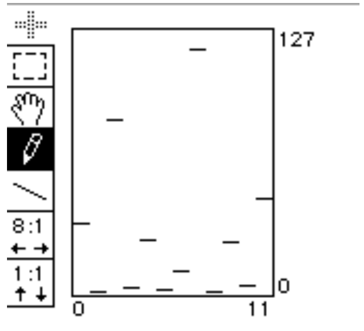


C-Dur



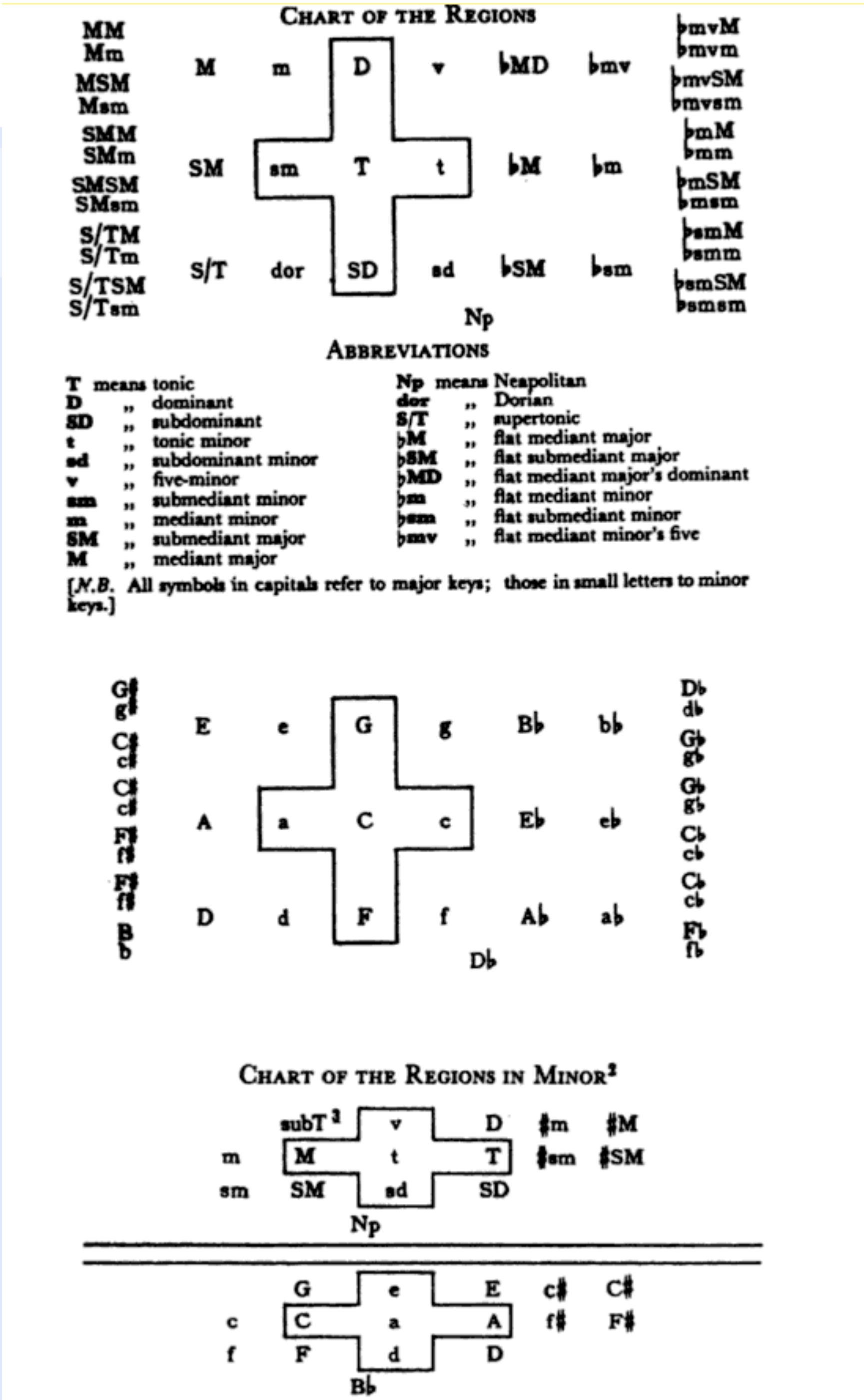
c-moll





G-Dur

Schönbergs "Chart of Key Regions"



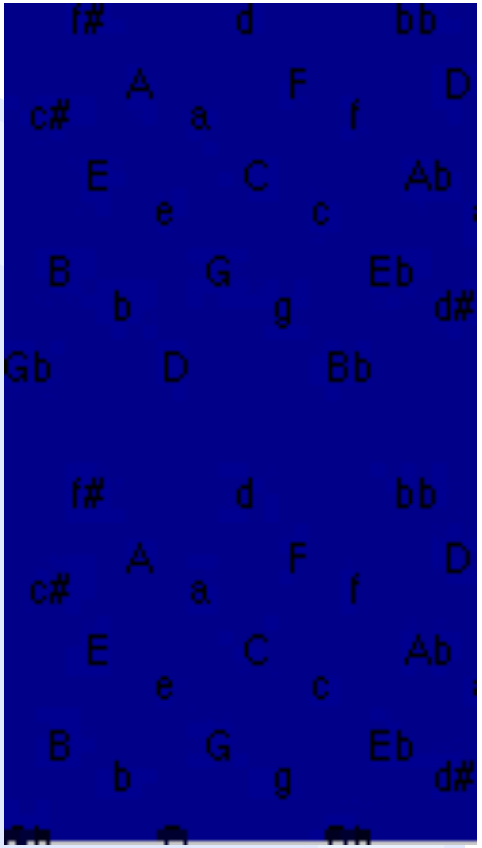
ABBREVIATIONS

T means tonic
D " dominant
SD " subdominant
t " tonic minor
sd " subdominant minor
v " five-minor
sm " submediant minor
m " mediant minor
SM " submediant major
M " mediant major
Np means Neapolitan
dor " Dorian
S/T " supertonic
♭M " flat mediant major
♭SM " flat submediant major
♭MD " flat mediant major's dominant
♭m " flat mediant minor
♭sm " flat submediant minor
♭mv " flat mediant minor's five

[*N.B.* All symbols in capitals refer to major keys; those in small letters to minor keys.]

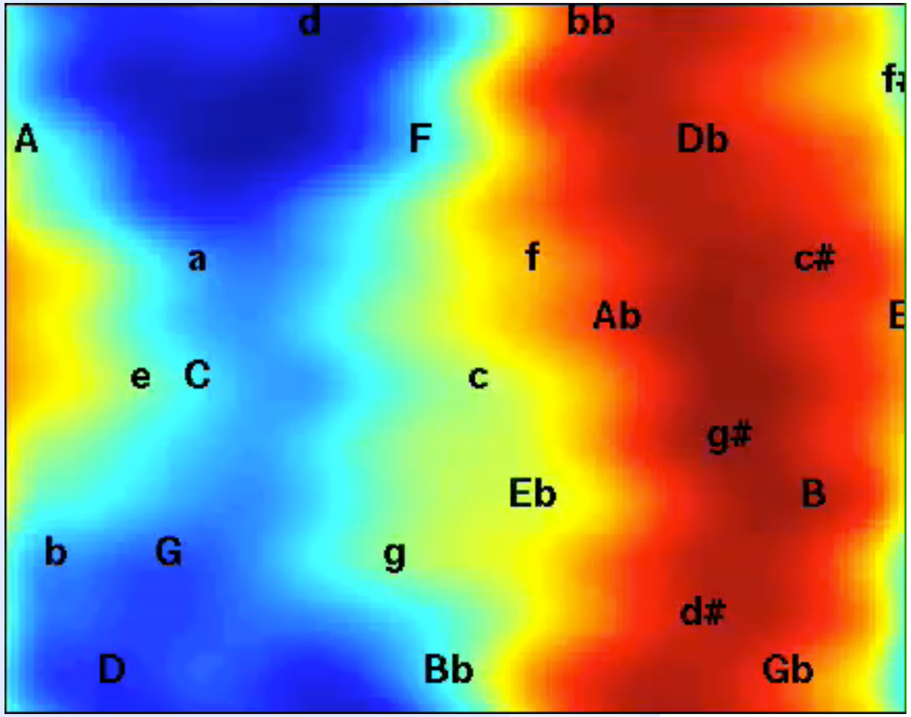
CHART OF THE REGIONS IN MINOR[2]

Key space



With the help of Krumhansl's model, when playing (tonal) music, it is possible to determine which key is currently predominant and how the music moves across the surface of the cut-open torus. The zones become brighter, the clearer the sense of tonality is. In the animation (modulation in a composition by J.S. Bach), the authors compared the answer of an expert (upper half) with the output of a computer program (lower half).

Other example: Girl from Ipanema



The Fifth as the Generator of Tonality

The fifth (3: 2) occupies an outstanding position in almost all musical cultures. In contrast to so-called imperfect consonances such as thirds and sixths, deviations of the fifth are not well tolerated by the listeners. It has a similarity with the octave, which is perceived as an identical sound.

The special significance of the fifth manifests itself in the fact that it appears on four different levels of music and thus indicates of the holistic, self-similar or fractal nature of (tonal) music.

1.Teiltonreihe
2. interval of complex tones
3. function: T-D
4. Sounds: C major - G major

In many cultures, the pentatonic scale is widespread. This scale can be derived by layering 5 fifths (Pythagorean tuning) and has the following properties:
1. contains stable intervals
2. is almost equidistant
3. is asymmetric
4. corresponds to the 7 +/- 2 rule of information processing

The Pythagorian Tuning

Stacks of fifth can be used to derive the pentatonic (5 fifths), the diatonic (7 fifths) as well as the chromatic tuning (12 fifths). After 12 fifths we reach an interval that corresponds to exactly 7 octaves. The deviation of about one-ninth of a tone(about 23 cents) is called the Pythagorean comma. In equal temperament, this deviation is distributed over the 12 fifths, making the tempered fifth 2 cents too low.

The Pythagorean tuning derives from the powers of the ratio 3/2: Fn = F0 * (3/2) n or the sum of the interval of 701.95 ≈ 702 cents.

Homework: Enter the missing steps of the Pythagorean tuning in the right column.

Intervall (Name)	Frequenzverhältnis	Intervall (Größe in Cent)	temperierte Stimmung	pythagoräische Stimmung
R1	1/1	0	0	0
K2	16/15	112	100	
G2	9/8	204	200	204
K3	6/5	316	300	294
G3	5/4	386	400	408
R4	4/3	498	500	498
V5	7/5	583	600	
R5	3/2	702	700	702
K6	8/5	814	800	
G6	5/3	884	900	906
K7	16/9	996	1000	996
G7	15/8	1088	1100	
R8	2/1	1200	1200	