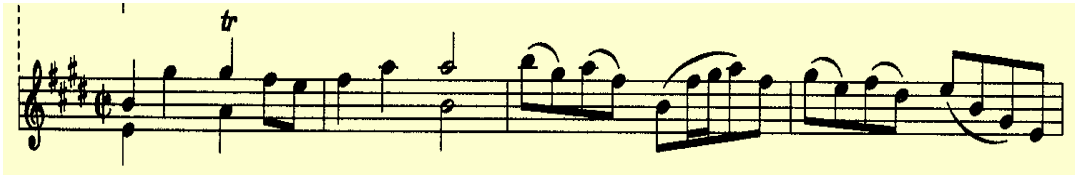
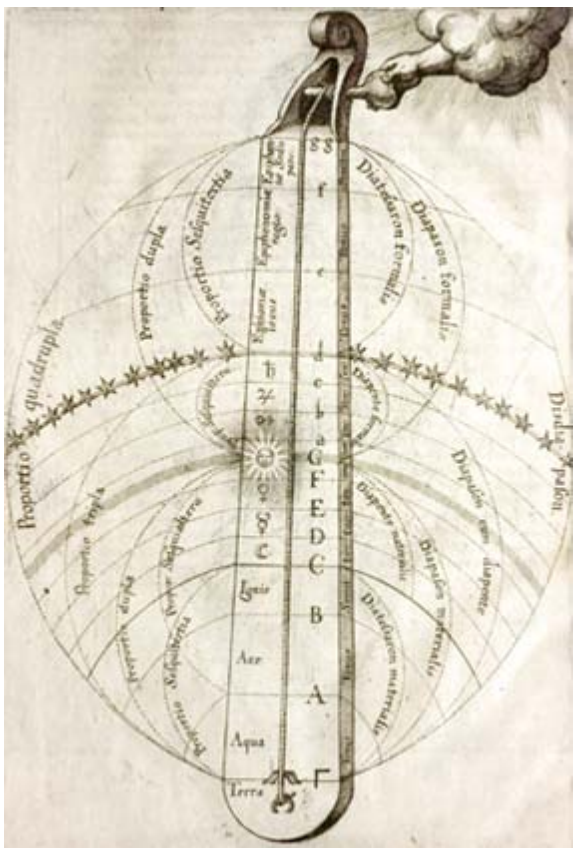


Systems of pitch relations: Scales, tunings and notations



What are scales, and why do we have them?

- Systems of discrete pitches & intervals between them
- Determine tonal systems
- Wide variety of scales in the world
- Octaves, fifths, & fourths very common
- Numbers of notes:
  - pentatonic (5 notes/octave)
  - diatonic (7 notes/octave)
  - chromatic (12 notes/octave)
  - "microtonal" (from Western perspective, > 12 notes/octave)
  - Arab music (24-TET), 31-TET
- Possible reasons for numbers of notes (7±2)
  - although musicians & listeners easily keep track of more

Scales: which intervals are included, sequence of intervals

- **Scales have reference points** (first note in a scale)

  tonic, key, frame of reference, often first note played

  action of auditory short-term memory & relative pitch
- Ordering of musical intervals within the scale
- Modes (Greek or ecclesiastical modes)
- **Major scale** pattern T-T-S-T-T-T-S (T whole tone, 12%, S semitone 6%)
- **Minor scale** pattern: T-S-T-T-S-T-T
  - Note same sets of intervals in related major & minor scales that use same notes (C major, A minor), and interval sets but w. different interval relationships to the tonic
- Circle of fifths: which scales share the same notes,
  - therefore have many common harmonics & subharmonics
  - and are therefore related in pitch space; distance reflects difference
- Ascending vs. descending intervals
- Scale notes vs. expressive deviations from them ("ornaments")

Note similarity/compatibility and contrast as a basis for scale

Tonal hierarchy
of similarity relations

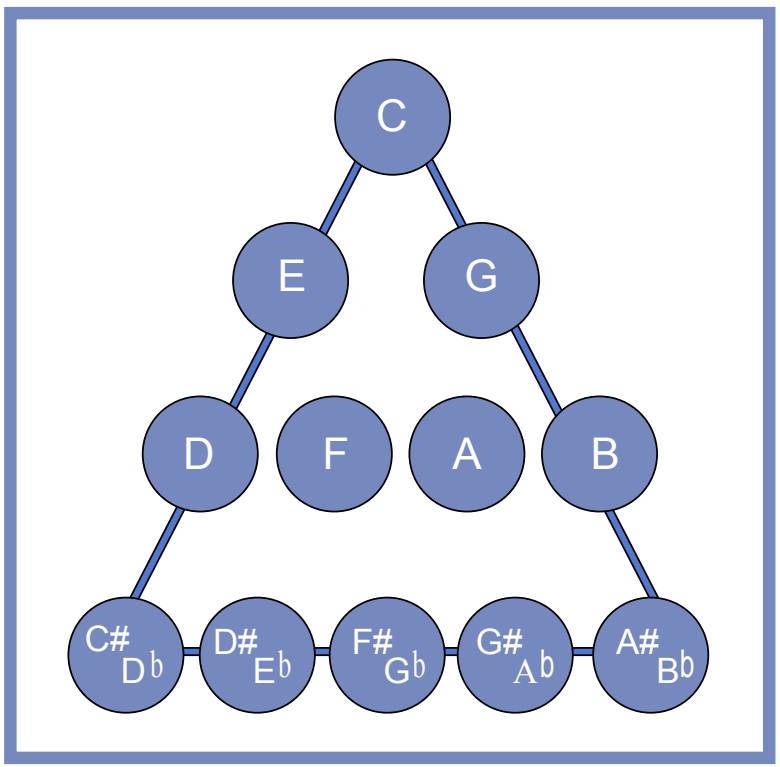


Figure by MIT OpenCourseWare.

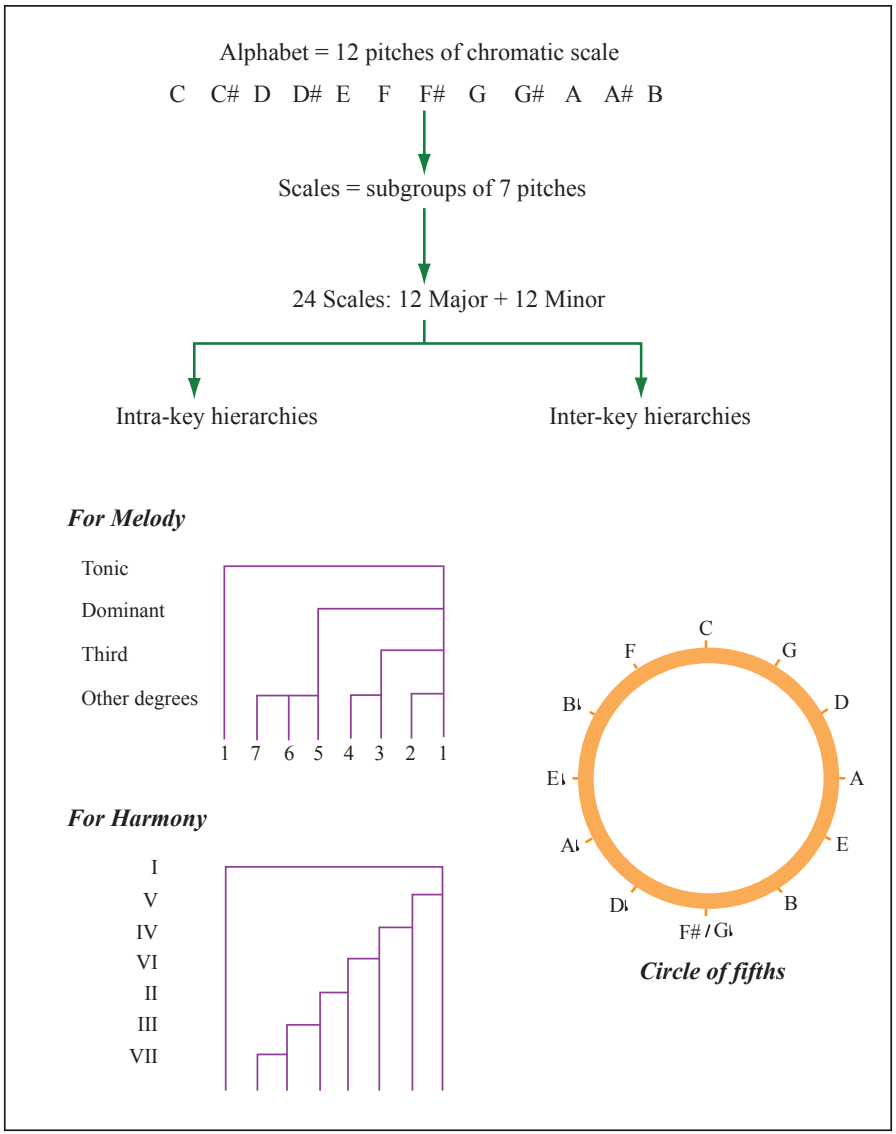


Figure by MIT OpenCourseWare.

Tuning systems and scales

We will discuss tuning systems first, then scales, but the two are interrelated and affect each other.

Design constraints: **What intervals to include?**
How many notes in the scale?

- **Presence of human voices (tendency for just intervals)**
- **Contrast: similar and dissimilar notes (re: tonic)**
- **Small numbers of notes (recognizability)**
- **Choice of note combinations: consonance, roughness**
- **Musical instruments available**

Design constraints: **What intervals to include?**
How many notes in the scale?

✳**Musical instruments and scale systems**

Make specialized tunings possible

Technology to implement tunings (logarithms)

Versatility, compatibility w. other instruments

Ability to sound reasonably good in all keys

Equal temperament (log ratios)

(beginning late 16th with Vincenzo. Galileo, Zhu Zaiyu, China)

Non-equal temperament produces “colors” or “moods” for different keys (for better or worse)

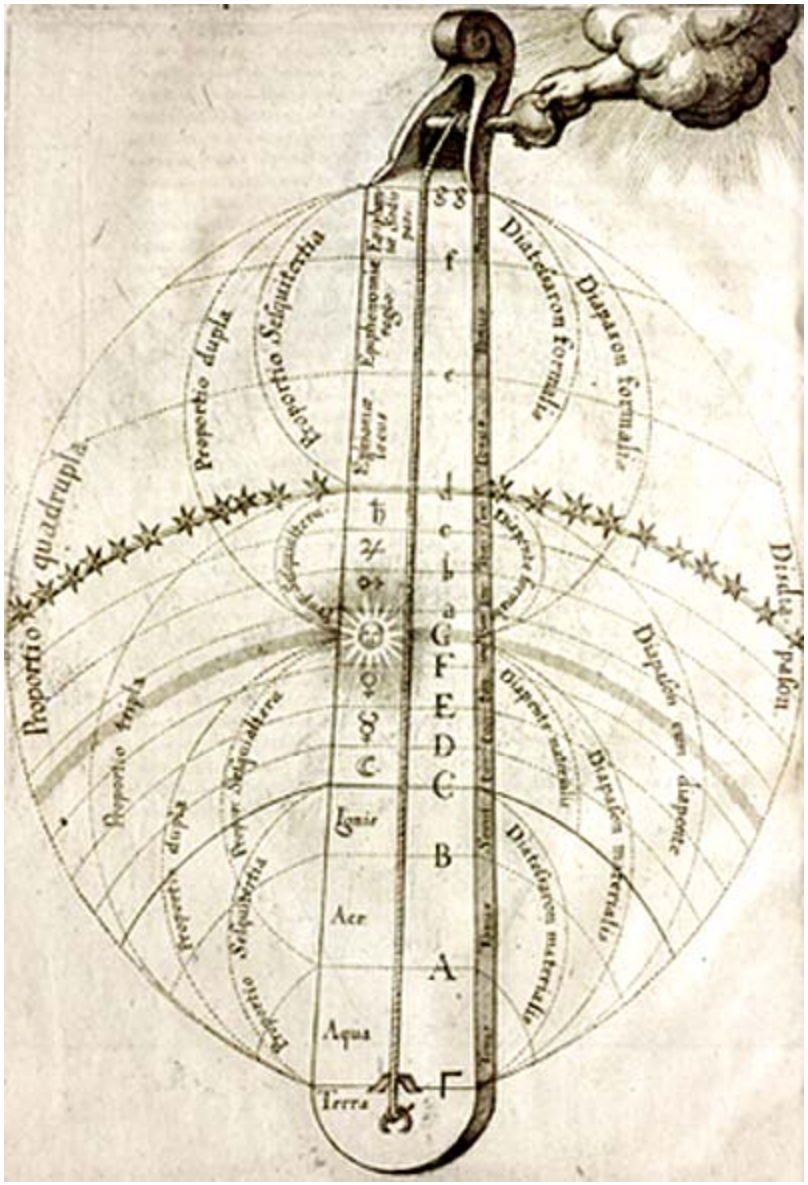
Pythagorean ratios

Images removed due to copyright restrictions.
Figure 2-5 and 2-6 in Pierce, John R. *The Science of Musical Sound.* Revised ed. New York, NY: W. H. Freeman, 1992.

Figure 2-5. Greek citharis. The cithara was sacred to Apollo.

Pierce, The Science of Musical Sound

Mathematics, numerology music, and mysticism



Drawn by Robert Fludd, the **Monochord** invented by Pythagoras, showing correspondences between pitch, proportion and astral bodies. http://www.elodielauten.net/concept.html

Monochords & tuning

The monochord consisted of a single string stretched over a sound box, with the strings held taut by pegs or weights on either end. It used a moveable bridge to change pitch, and was usually plucked. A later instrument of the same principle was played with a bow, called the "trumpet marine" (Adkins, New Grove). It was used as an instrument as early 300 BC by Euclid (Ripin, New Grove), and as a scientific instrument by Pythagoras as early as the 6th century BC No one knows when it first appeared, as its origins extend into prehistory.

Scales begin with musical practice -- what sounds best is the criterion for a good scale does it give the composer a beautiful palette of notes?

Images removed due to copyright restrictions.
Figure 2-6 in Pierce, John R. *The Science of Musical Sound.* Revised ed. New York, NY: W. H. Freeman, 1992.

11th century: Guido of Arezzo (fl. ~991/2-1033). "By laying out the notes of a scale on a monochord, he was able to teach choir boys how to sing chant and also to detect incorrect chanting. The tones intervals used in chants were M2, m2, m3, P4, and P5. These six intervals were the "consonantiae", and (according to Guido) no chant uses any other intervals. **Guido admits one could find more on the monochord if "art (did not) restrain us by its authority"** (Palisca)." Cottrell, History of the Monochord

Courtesy of Jeff Cottrell. Used with permission.

Note similarity/compatibility as a basis for scale

Include just ratios (voices)

Minimize clashing of tones, i.e. roughness
Max fusion
(Sethares: optimize spectrum for tunings to min beating e.g. 10-TET)

Provide contrast between consonant & dissonant relations

Systematicity: allow for chord/key modulations

K & K psychophysical data (circles)

Image removed due to copyright restrictions.

Kameoka, A., and M. Kuriyagawa. "Consonance Theory I. Consonance of Dyads." *J Acoust Soc Am* 45 (1969): 1451-1459.

Some history of tuning systems (consult Wikipedia, many books for more)

Just tuning -- ancient & folk traditions, integer ratios

Pythagorean tuning -- pre-Renaissance, fifths & octaves

Meantone temperament -- Renaissance, tempered fifths

Well-temperament - Baroque, "moods & colors" of keys

Some keys more out of tune, Bach, Tartini advocates

Equal-temperament (12-TET)

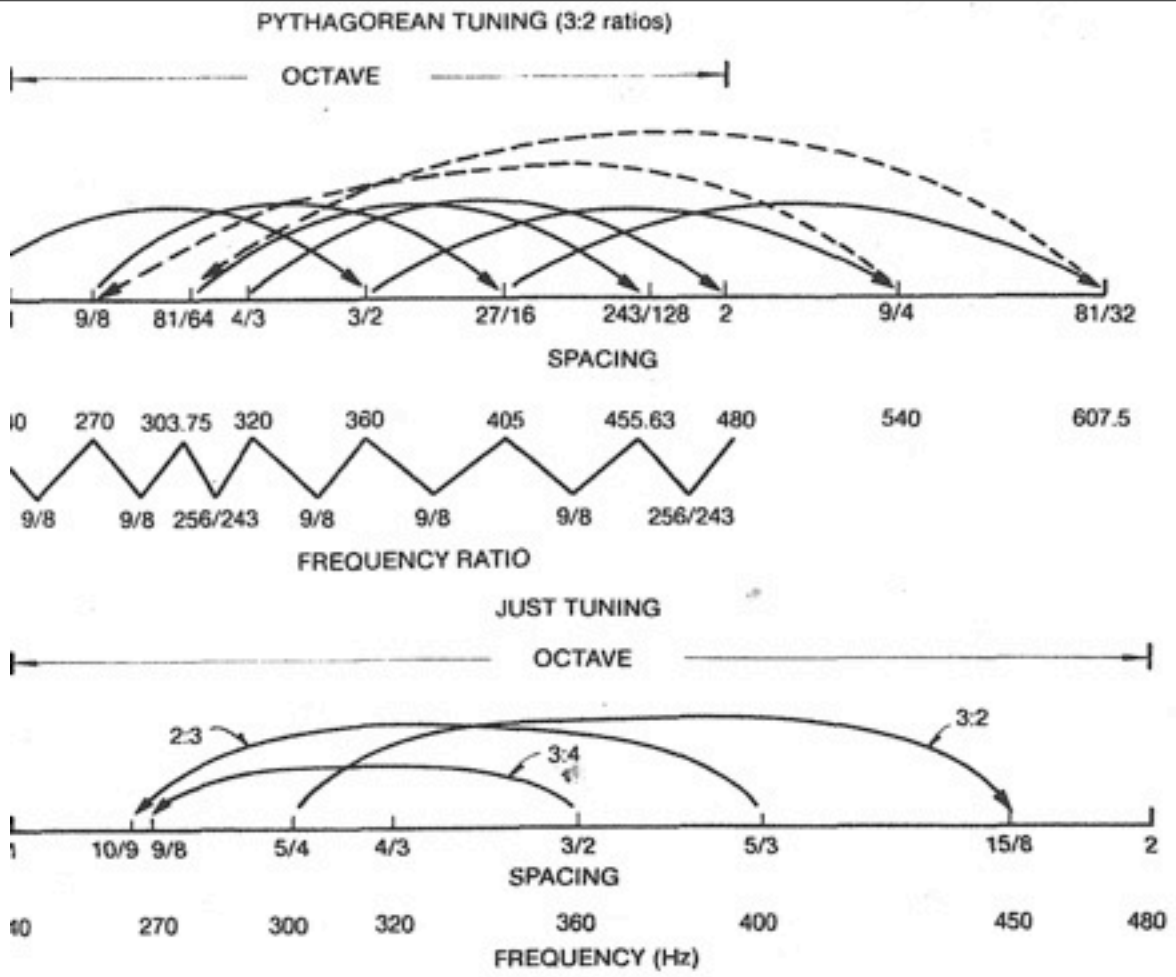
Common Practice Period of Western music (~1600-1900)

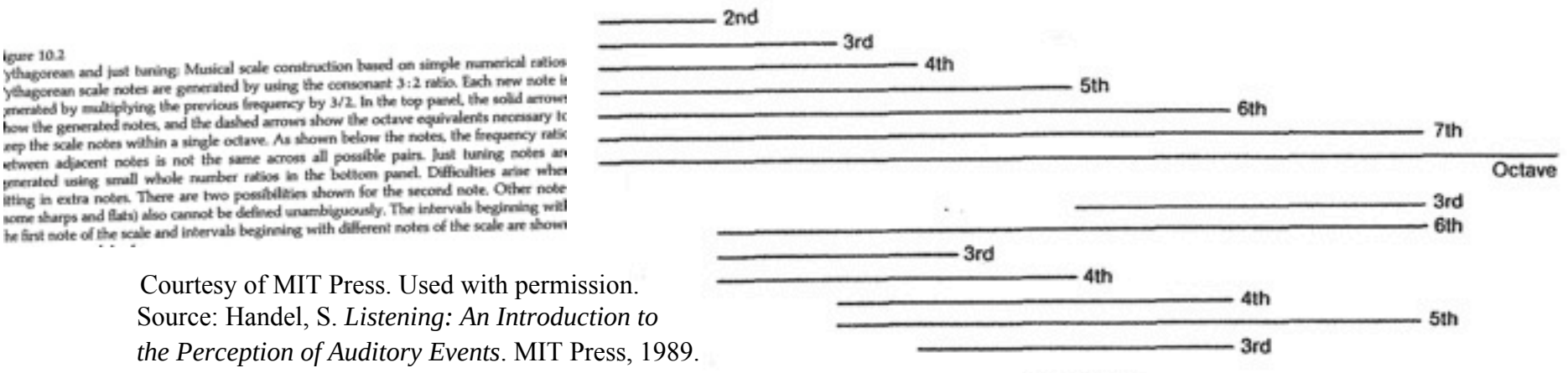
Vincenzo Galileo (1581)

Ancient China (7-TET), **and Zhu, Zaiyu** (12-TET,1584)

Early tuning systems

Pythagorean & Just tuning systems





igure 10.2
ythagorean and just tuning: Musical scale construction based on simple numerical ratios
Pythagorean scale notes are generated by using the consonant 3:2 ratio. Each new note i
enerated by multiplying the previous frequency by 3/2. In the top panel, the solid arrows
how the generated notes, and the dashed arrows show the octave equivalents necessary to
eep the scale notes within a single octave. As shown below the notes, the frequency ratio
etween adjacent notes is not the same across all possible pairs. Just tuning notes are
enerated using small whole number ratios in the bottom panel. Difficulties arise when
itting in extra notes. There are two possibilities shown for the second note. Other note
some sharps and flats) also cannot be defined unambiguously. The intervals beginning with
he first note of the scale and intervals beginning with different notes of the scale are shown

Some history of tuning systems (consult Wikipedia, many books for more)

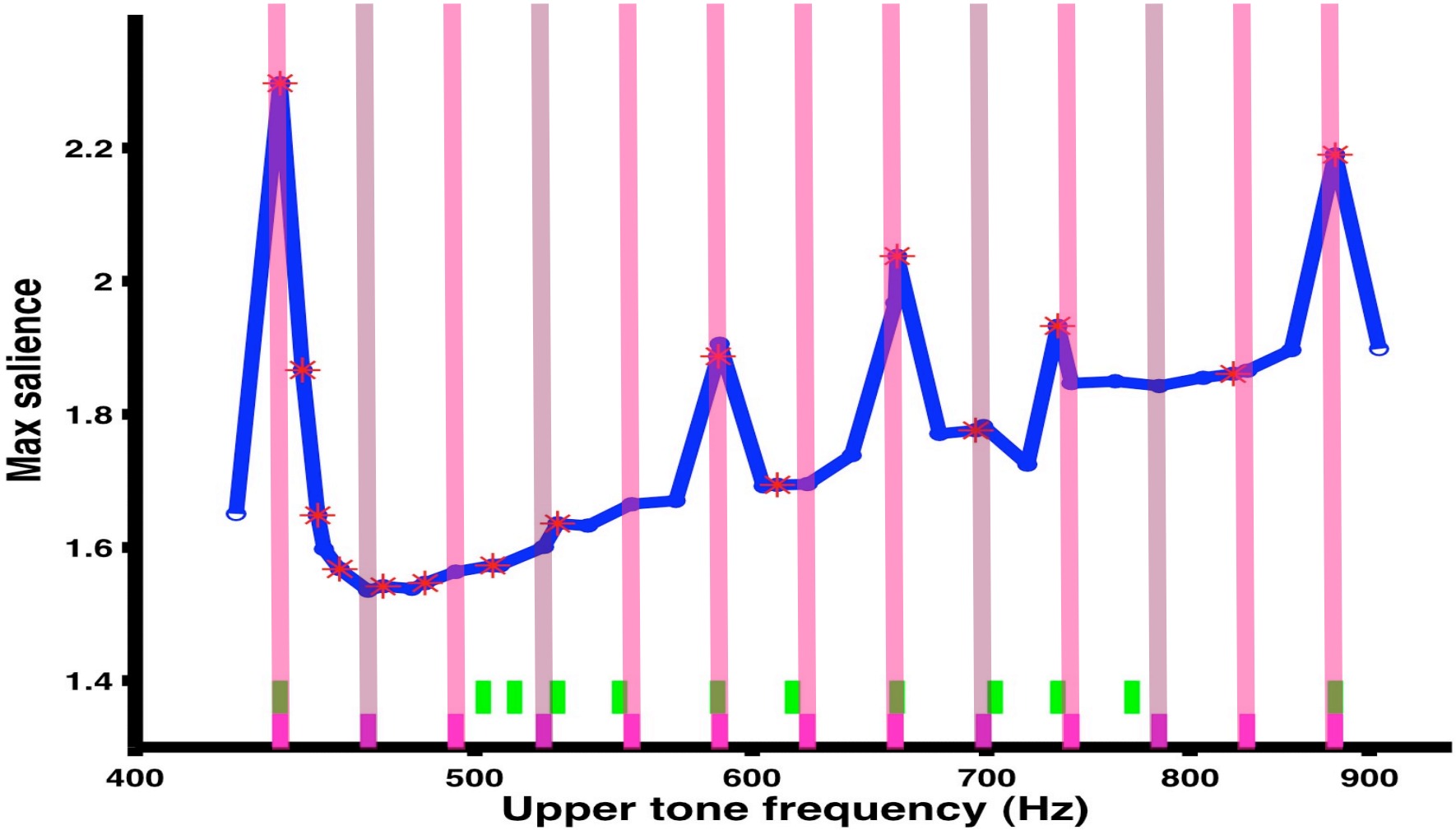
Twelve tone equal temperament took hold for a variety of reasons.

It conveniently fit the existing keyboard design, and was a better approximation to just intonation than the nearby alternative equal temperaments.

It permitted total harmonic freedom at the expense of just a little purity in every interval.

This allowed greater expression through enharmonic modulation, [a means of shifting between keys using chords that are shared by two keys].... Equal temperament became the standard gradually during the Romantic era.

Designing a scale system - 12 equally tempered notes/oct.



Problems that tuning creates and solves.... (Wikipedia, Musical temperament)

"Just intonation has the problem that it cannot modulate to a different key (a very common means of expression throughout the Common practice period of music) without discarding many of the tones used in the previous key, thus for every key the musician wishes to modulate to, the instrument must provide a few more strings, frets, or holes for him or her to use. When building an instrument, this can be very impractical.

Well temperament is the name given to a variety of different systems of temperament that were employed to solve this problem, in which some keys are more in tune than others, but all can be used. This phenomenon gives rise to infinite shades of key-colors, which are lost in the modern standard version: 12 tone equal temperament (12-TET). Unlike Meantone temperament, which alters the fifth to **temper out** the Syntonic comma, 12-TET tempers out the Pythagorean comma, thus creating a cycle of fifths that repeats itself exactly after 12 steps. This allowed the intervals of Tertian harmony, thirds and fifths, to be fairly close to their just counterparts (the fifths almost imperceptibly beating, the thirds a little milder than the Syntonic beating of Pythagorean tuning), while permitting the freedom to modulate to any key and by various means (e.g. *common-tone* and *enharmonic* modulation, *see modulation*). This freedom of modulation also allowed substantial use of more distant harmonic relationships, such as the Neapolitan chord, which became very important to Romantic composers in the 19th century."

C-Major diatonic scale

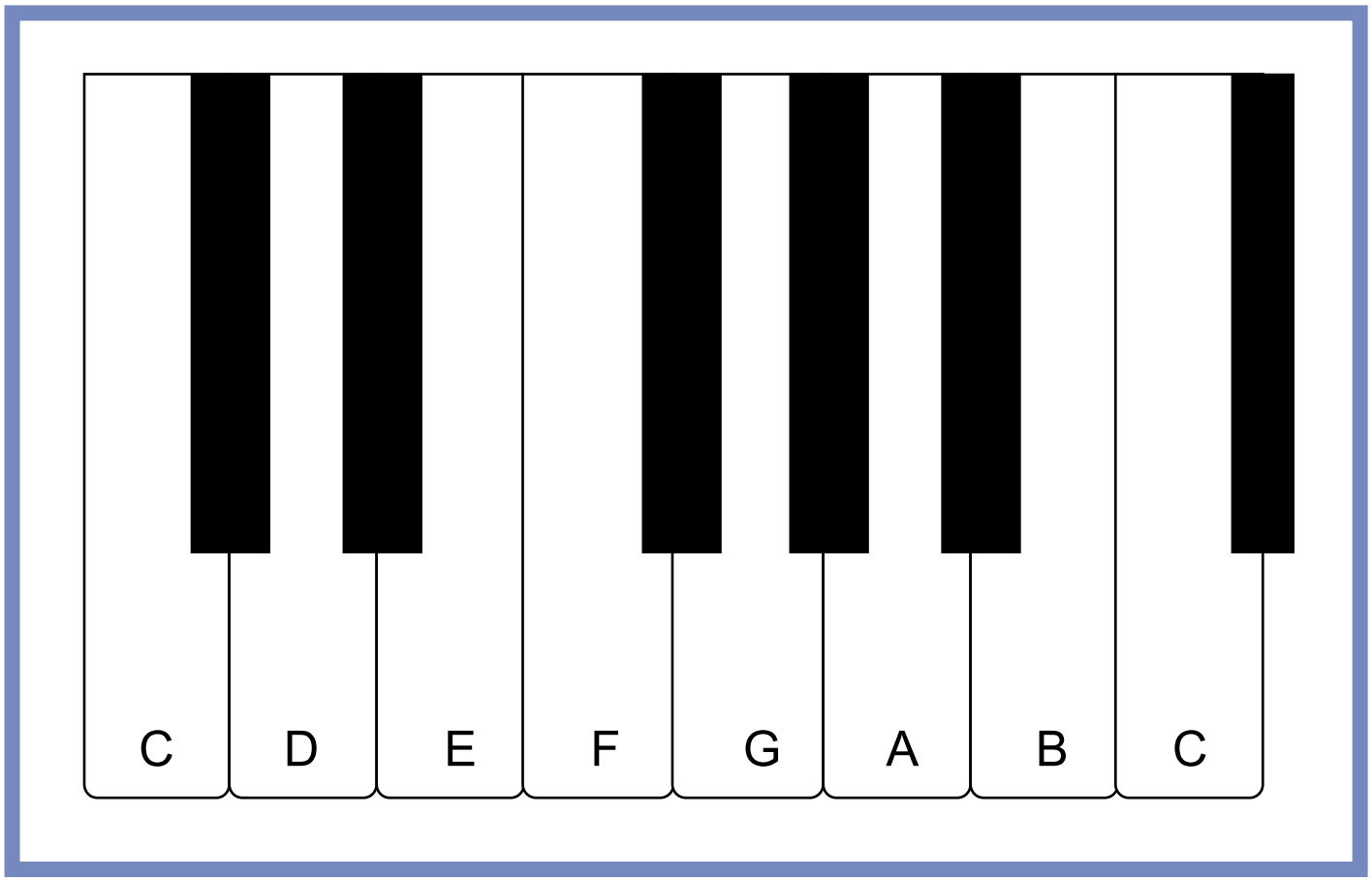


Figure by MIT OpenCourseWare.

diatonic scale

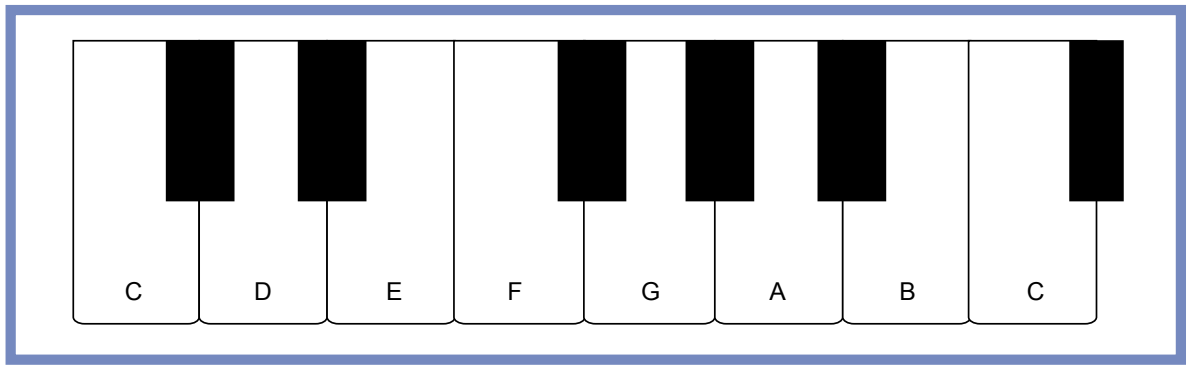
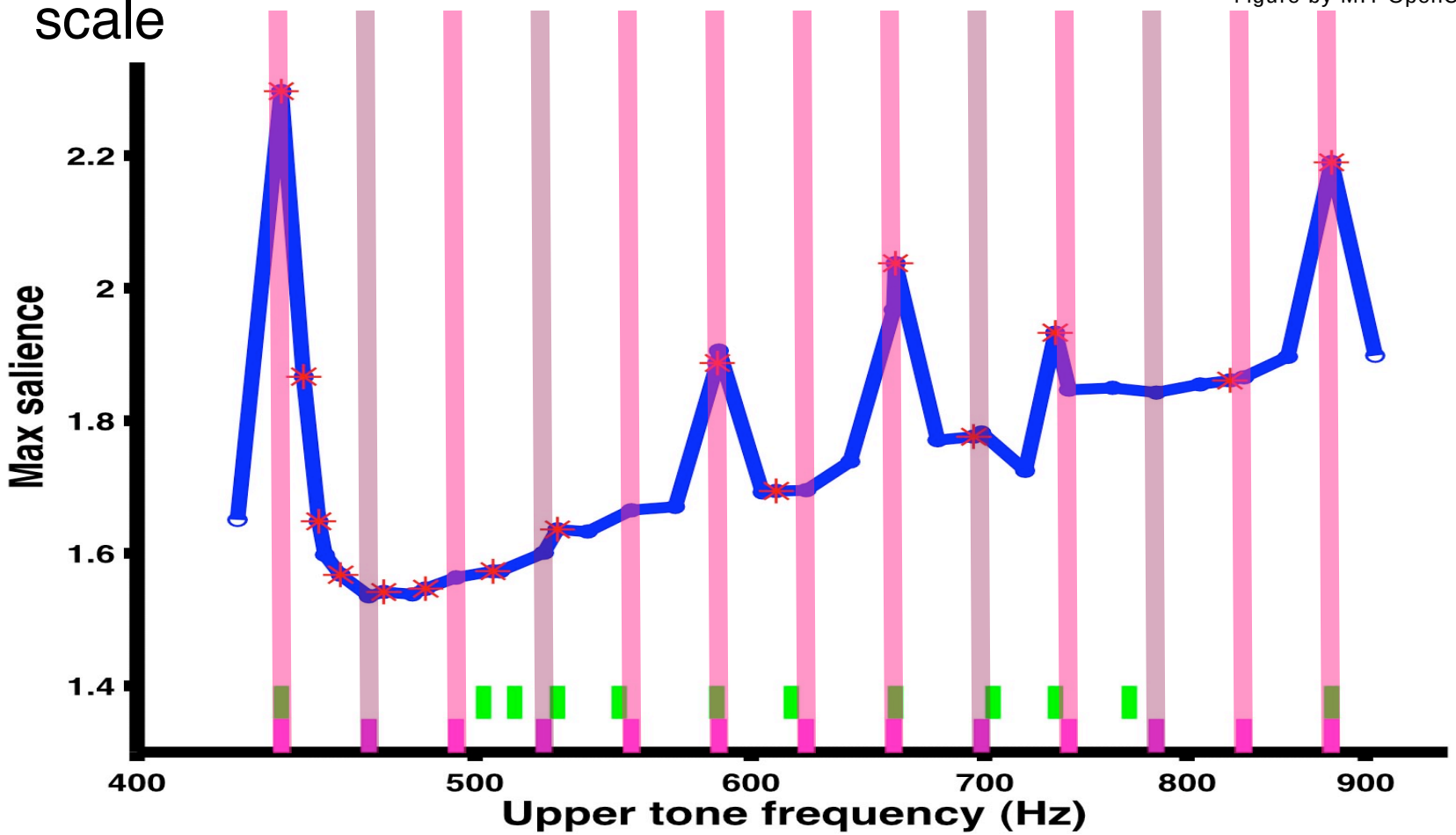


Figure by MIT OpenCourseWare.



Diatonic scale

"In Music theory, the diatonic major scale is a fundamental building block of the Western musical tradition. The diatonic scale is composed of two tetrachords separated by intervals of a whole tone. The pattern of intervals in semitones is as follows 2-2-1-2-2-2-1. The major scale begins on the first note and proceeds by steps to the first octave. In solfege, the syllables for each scale degree are "Do-Re-Mi-Fa-Sol-La-Ti-Do". The natural minor scale can be thought of in two ways, the first is as the relative minor of the major scale, beginning on the sixth degree of the scale and proceeding step by step through the same tetrachords to the first octave of the sixth degree. In solfege "La-Ti-Do-Re-Mi-Fa-Sol." Alternately, the natural minor can be seen as a composite of two different tetrachords of the pattern 2-1-2-2-1-2-2. In solfege "Do-Re-Mi-Fa-Sol-La-Ti-Do." All of non-folk Western harmony from the some point in the late Renaissance up to the late nineteenth century is based upon these two objects and the unique relationships created by this system of organizing 7 notes. It should be kept in mind that most pieces of music change key, and thus scale, but are still related to the beginning diatonic scale. The white keys on a piano correspond to the diatonic scale of C major (C-D-E-F-G-A-B-C), with the notes a whole tone apart, except for E-F and B-C, which is an interval of a semitone (half a tone). Diatonic comes from the greek "diatonikos" or "to stretch out". It is sometimes used to refer to all the modes, but is generally used only in reference to the major and minor scales."

-- Wikipedia

Three tuning systems

Pythagorean, Just, and Equal Temperament Tuning Systems

Interval name	Solfeggio	Letter notation	Pythagorean tuning (PT) Numerical origin	PT Frequency ratio	PT Cents	Just intonation (JI) Numerical origin	JI Frequency ratio	JI Cents	Equal temperament (ET) Frequency ratio	ET Cents
Unison	DO	C	1:1	1.000	0.0	1:1	1.000	0.0	1.000	0
Minor second		D♭	$2^8:3^5$	1.053	90.2	16:15	1.067		1.059	100
		C♯	$3^7:2^{11}$	1.068	113.7	16:15	1.067	111.7	1.059	100
Major second	RE	D	$3^2:2^3$	1.125	203.9	10:9	1.111	182.4	1.122	200
						9:8	1.125	203.9		
Minor third		E♭	$2^5:3^3$	1.186	294.1	6:5	1.200	315.6	1.189	300
		D♯	$3^9:2^{14}$	1.201	317.6	6:5	1.200	315.6	1.189	300
Major third	MI	E	$3^4:2^6$	1.265	407.8	5:4	1.250	386.3	1.260	400
Fourth	FA	F	$2^2:3$	1.333	498.1	4:3	1.333	498.1	1.335	500
Tritone		G♭	$2^{10}:3^6$	1.407	588.3	45:32	1.406	590.2	1.414	600
		F♯	$3^6:2^9$	1.424	611.7	64:45	1.422	609.8	1.414	600
Fifth	SO	G	3:2	1.500	702.0	3:2	1.500	702.0	1.498	700
Minor sixth		A♭	$2^7:3^4$	1.580	792.2	8:5	1.600	813.7	1.587	800
		G♯	$3^8:2^{12}$	1.602	815.6	8:5	1.600	813.7	1.587	800
Major sixth	LA	A	$3^3:2^4$	1.688	905.0	5:3	1.667	884.4	1.682	900
Minor seventh						7:4	1.750	968.8		
		B♭	$2^4:3^2$	1.788	996.1	16:9	1.777	996.1	1.782	1000
		A♯	$3^{10}:2^{15}$	1.802	1019.1	9:5	1.800	1017.6	1.782	1000
Major seventh	TI	B	$3^5:2^7$	1.900	1109.8	15:8	1.875	1088.3	1.888	1100
Octave	DO	C	2:1	2.000	1200.0	2:1	2.000	1200.0	2.000	1200

SOURCE: Burns and Ward 1982 and Martin 1962 by permission of publisher.

Note F0 frequencies

Equally-tempered scale

The subscripts indicate octave (register). Note that the octave boundaries are at C, not A

Table removed due to copyright restrictions.
Frequencies of notes in tempered scale.

Just Intonation Network

http://www.justintonation.net/

Text description of just intonation and musical examples removed due to copyright restrictions.

Just intonation -- conclusions

- Although differences between just and equally-tempered tunings might not be discriminable when notes are presented sequentially (as for measuring JNDs),
- these differences can become apparent when notes are sounded together.

- The differences are somewhat subtle, but are most obvious when the notes are sustained harmonic complexes, e.g. organ-like.

Microtonal music

- http://infohost.nmt.edu/~jstarret/microtone.html
- **"Most of the music we hear in based on a system called 12 tone equal temperament (or 12TET for short), where the octave is divided into 12 equal parts. Microtonal music is generally defined as any music that is not 12TET. Some folk musics are based on the harmonic series, some divide the octave into 19 or 31 equal parts, some divide the octave into 43 unequal parts, some don't divide the octave at all.... There are an infinite number of ways to choose your tonal resources."**

see also http://www.corporeal.com/cm_main.html

Bill Sethares:

1. Relations between tuning systems & dissonance:

For inharmonic instruments, there are situations where just tunings sound more dissonant. (His explanation for Gamelan tunings)

Book cover image removed due to copyright restrictions.
Sethares, W. A. *Tuning, Tibre, Spectrum, Scale.*

2. Experiments with alternate scales and tunings -- 10 TET music.

"Ten Fingers: If God had intended us to play in ten tones per octave, he would have given us ten fingers."

Harry Partch

- Harmonic Canons: there are two types. The simpler type is Harmonic Canon II; these box-like instruments have 44 strings and adjustable bridges which are uniquely configured for each piece. Harmonic Canon I has two planes of 44 strings each. The planes intersect near the middle of each string and thus the player may play on either plane or both at once. Also a moveable pyrex rod controls the pitch on some strings in one plane. The harmonic canons are both melody instruments and as providers of the harmonic underpinning, hence its name, canon, used in the sense of "law". It is played with picks or fingers and is strikingly used in cascades of pitches. Partch built his first canon in 1945, and continued to refine the instrument into the 70

http://www.newband.org/instruments.htm#partch%20instruments

Photos by Bob Vergara, A.P.S. Used with permission.

History of scales

Pentatonic (5-note), heptatonic scales

Diatonic scales (Western tradition, 7 notes, “heptatonic”)

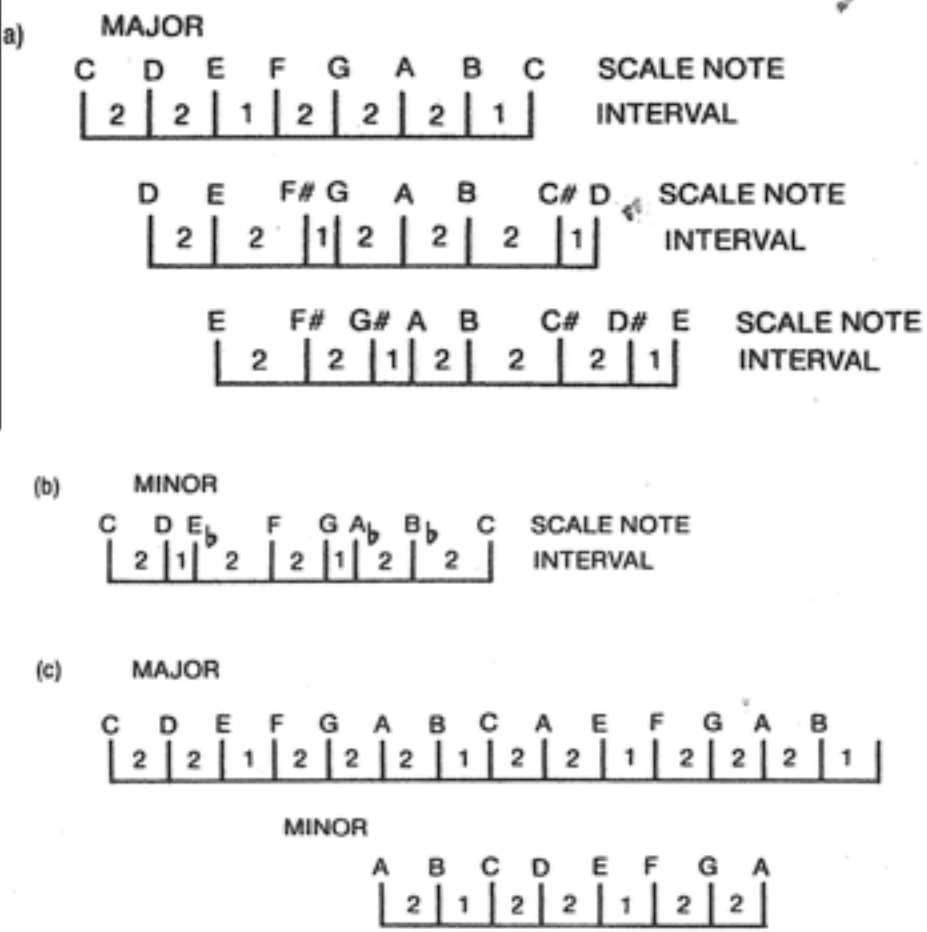
Ecclesiastical modes (traditional & medieval church music)

Common practice period (1600-1900) streamlined scale systems to two modes, Ionian (major scale) and Aeolian (minor scale), for reasons that may have to do with the difficulties of harmonic construction (e.g. in modulating between keys).

We will discuss major and minor scales first, then modal scales.

Major and minor scales

- **Major scale** pattern:
- T-T-S-T-T-T-S
- **Minor scale** pattern:
- T-S-T-T-S-T-T



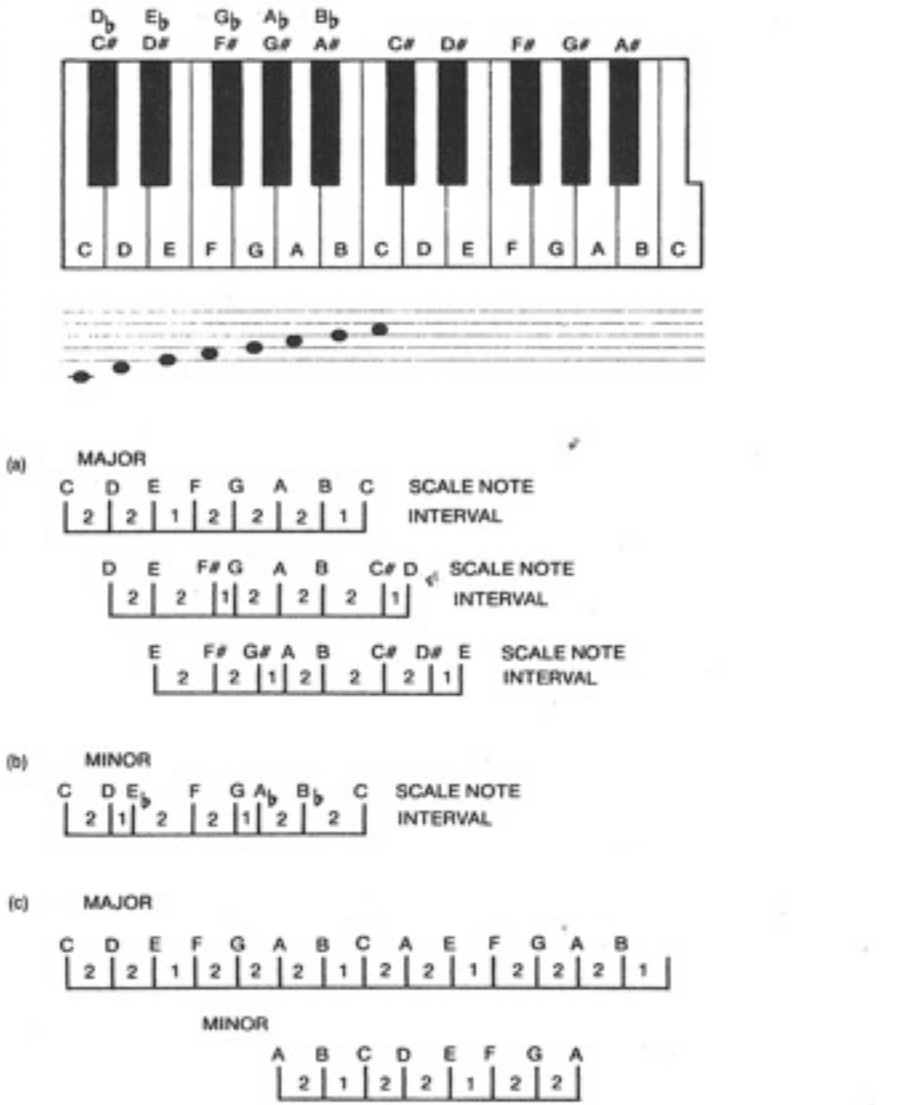


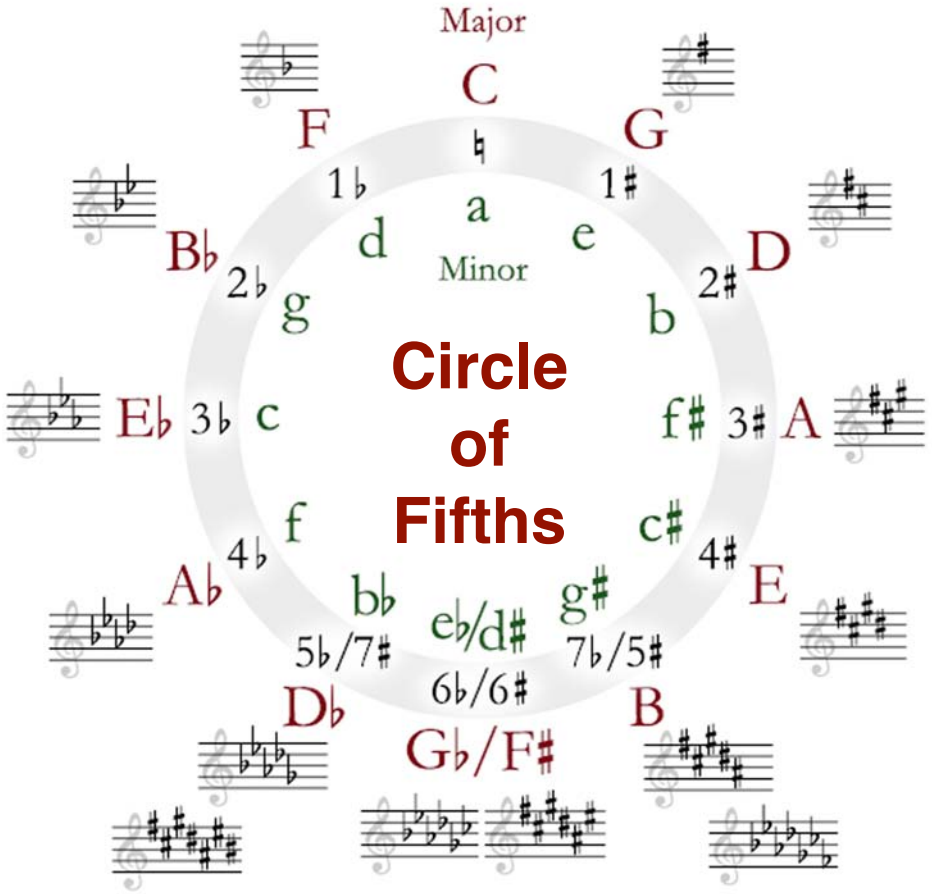
Figure 10.3
Major and minor scales. Two octaves on the piano keyboard are sketched at the top. Each black key has two possible note names: the sharp above the lower white key and the flat below the upper white key (e.g., C♯/D♭, D♯/E♭, etc.). Major scales beginning on the first three white keys are illustrated in (*a*). The scale note and the interval size are indicated. The minor scale beginning on the first white key is illustrated in (*b*). The equivalence of one major and one minor scale is illustrated in (*c*). The sixth note of the major scale is the first (or tonic) note of the minor scale.

Key relations of diatonic scales in terms of shared notes

Major scales & minor scales sharing same notes

Each step around the circle is a change of 1 note in common.

Distance around the circle is a measure of key distance



Source: Wikipedia.

Johannes Brahms
Capriccio
Opus 76 no. 2

Note relatedness, distance
from each other
from the tonic

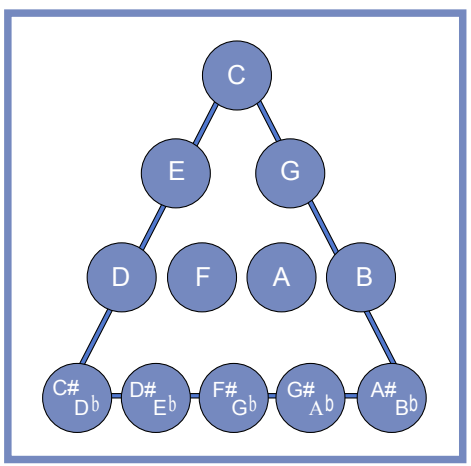
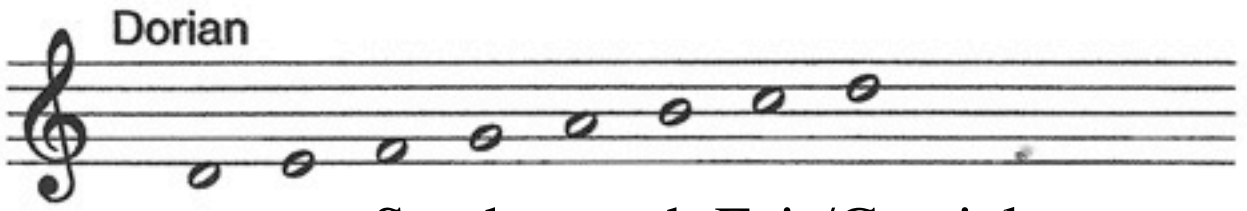


Figure by MIT OpenCourseWare.

Modes show the effects of different scale types



Scarborough Fair/Canticle

Simon&Garfunkel

http://www.8notes.com/articles/modes/

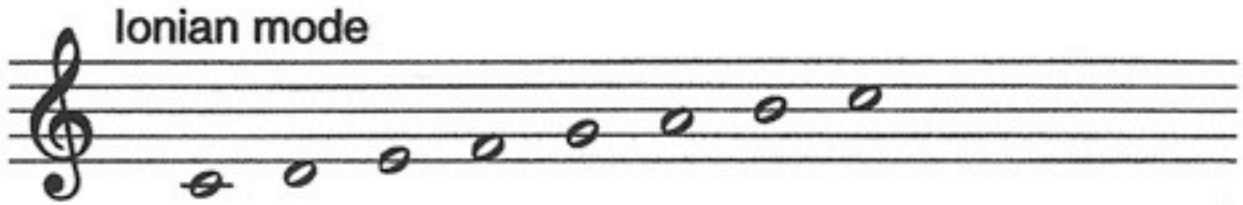
Musical example removed due to copyright restrictions.

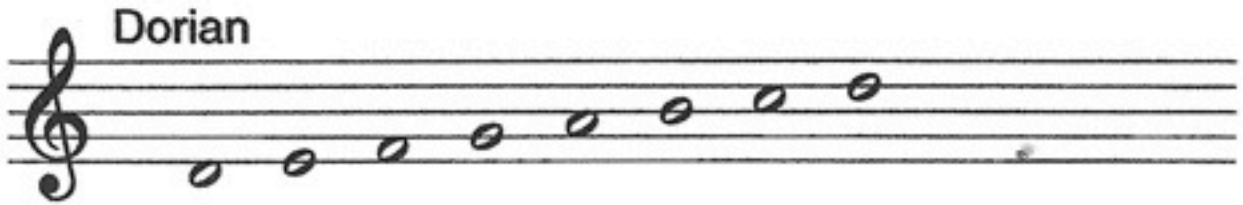
Gaillarde I-II-II

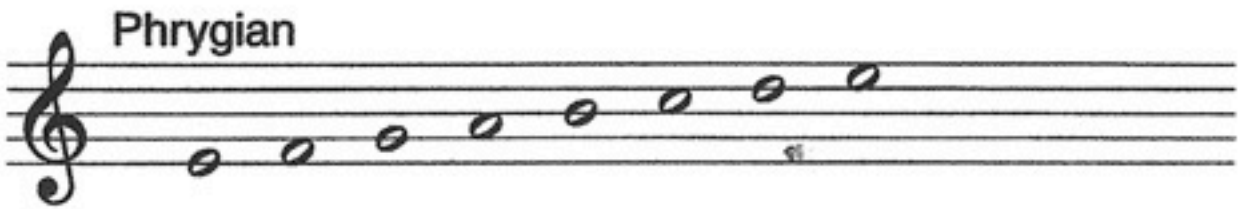
Convivum Musicum Gothenburg

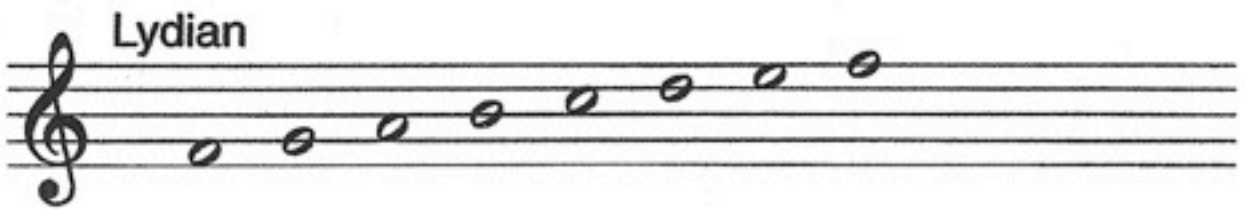
Modes

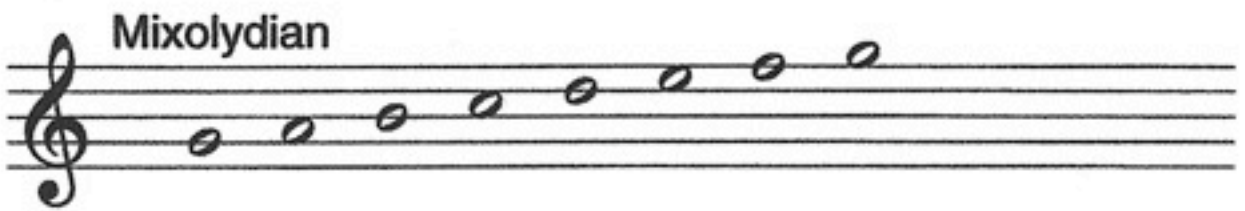
Major scale



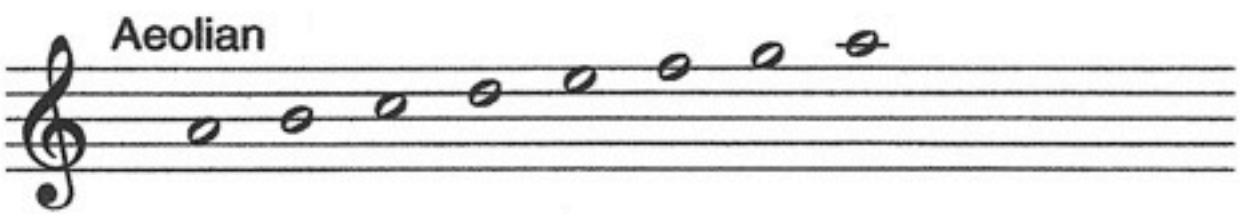








Minor scale

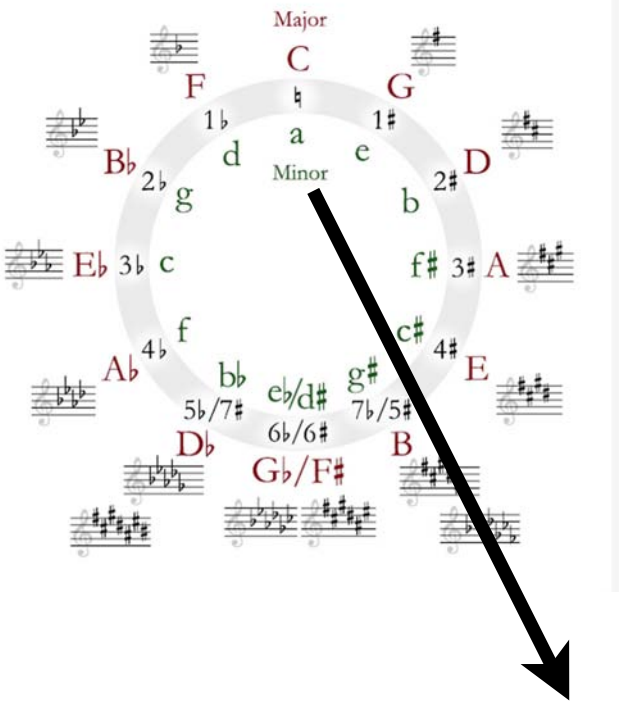


Why do they sound different, despite the same note set?

Because the notes have different patterns of relations to the tonic, and particular musical intervals may be present or absent from a given modal scale.

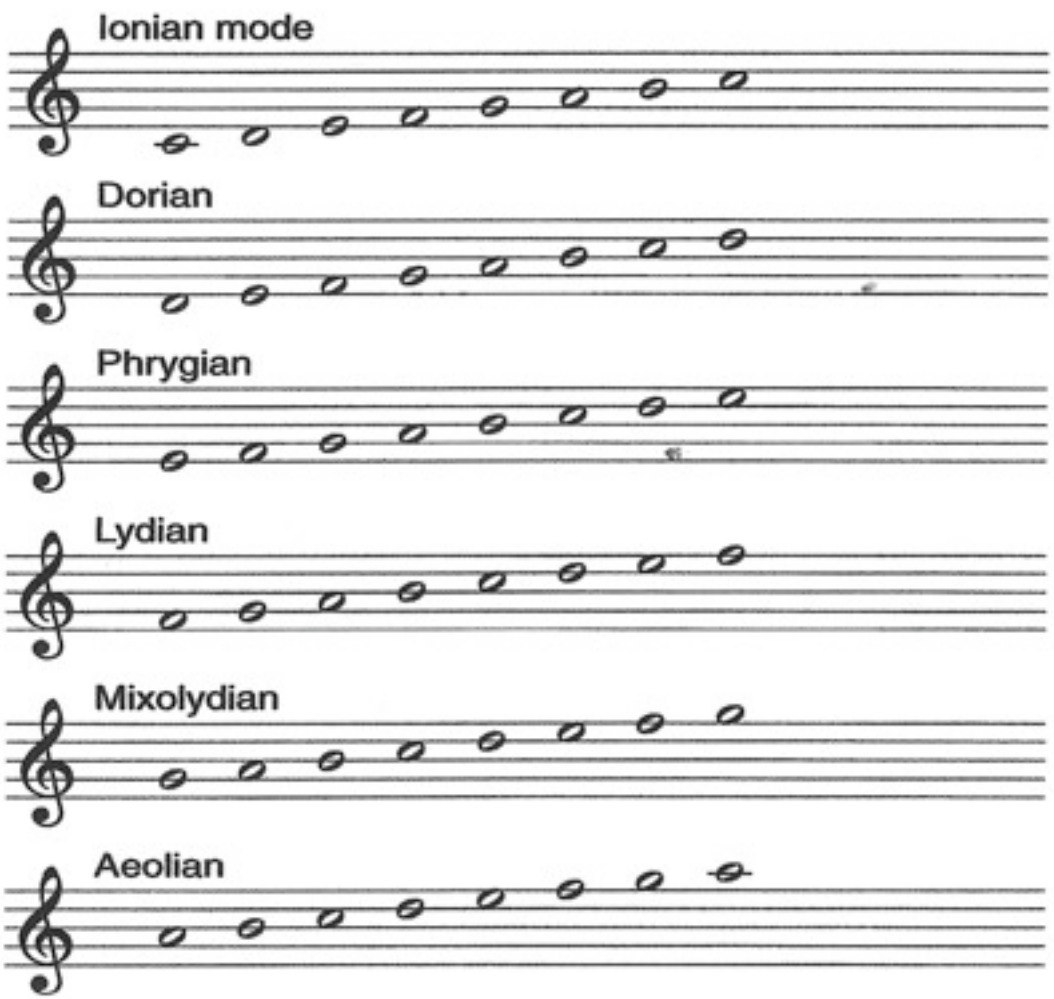
“Happy Birthday” in different modes

C Major scale



Source: Wikipedia.

A M



How would we distinguish C-major from A-minor key (or any of the other modes below, for that matter) if they have the same note set?

Establishment of the tonic, and its consonant intervals.

4th & 5th
No tritone

- **Major scale** pattern:
- T-T-S-T-T-T-S

- T-S-T-T-T-S-T

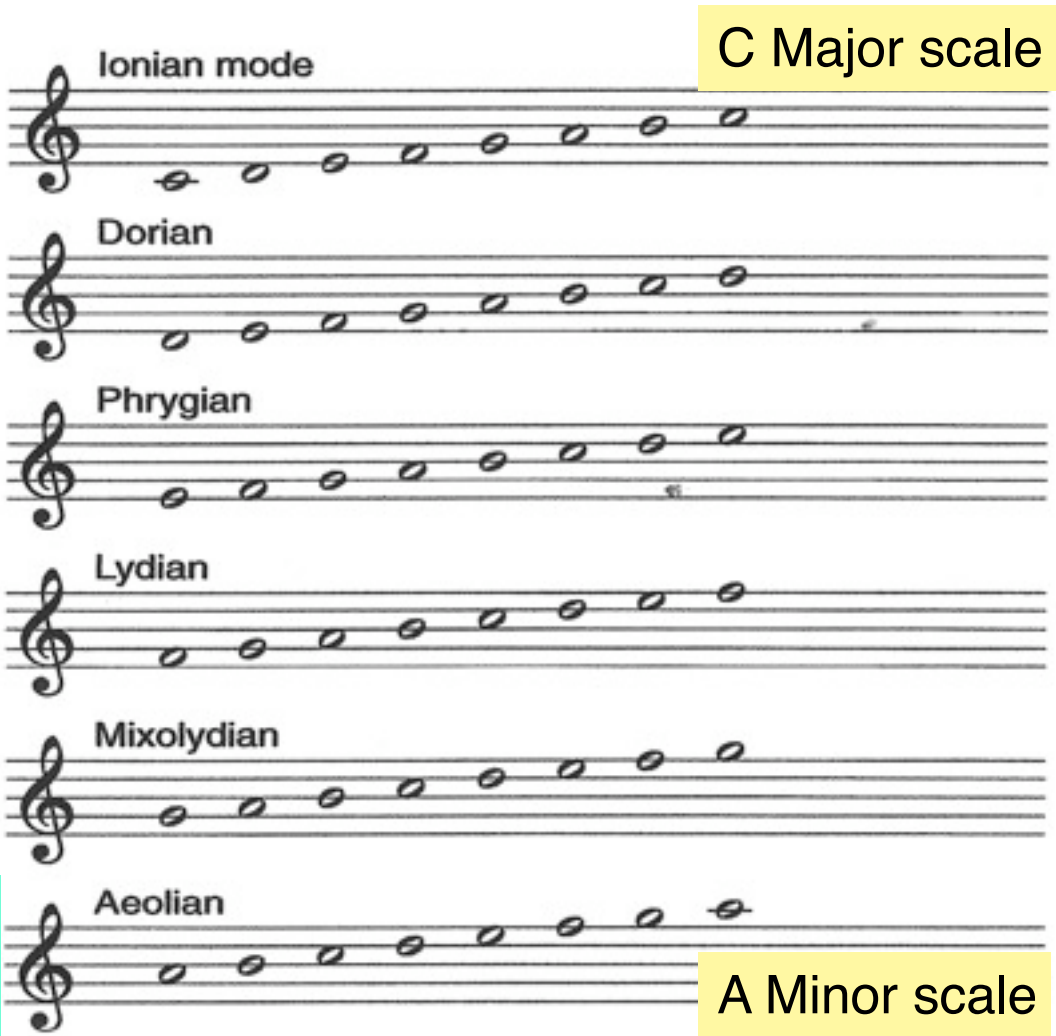
S-T-T-T-S-T- T-

No 4th
Tritone

T-T-T-S-T- T-S

T-T-S-T-T-S-T

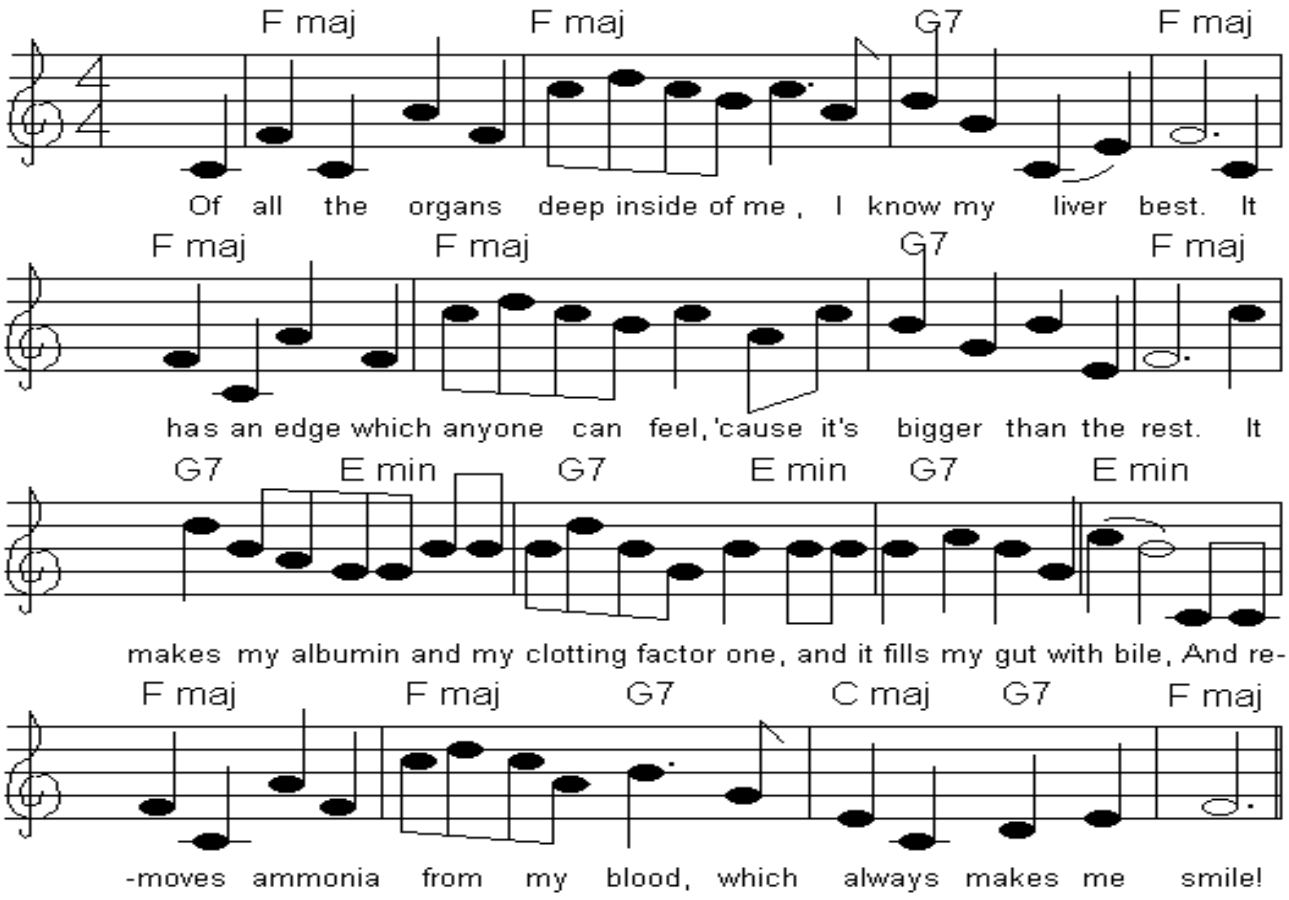
- **Minor scale** pattern:
- T-S-T-T-S-T-T



Lydian mode example

The Lydian Liver

Church Lydian Mode



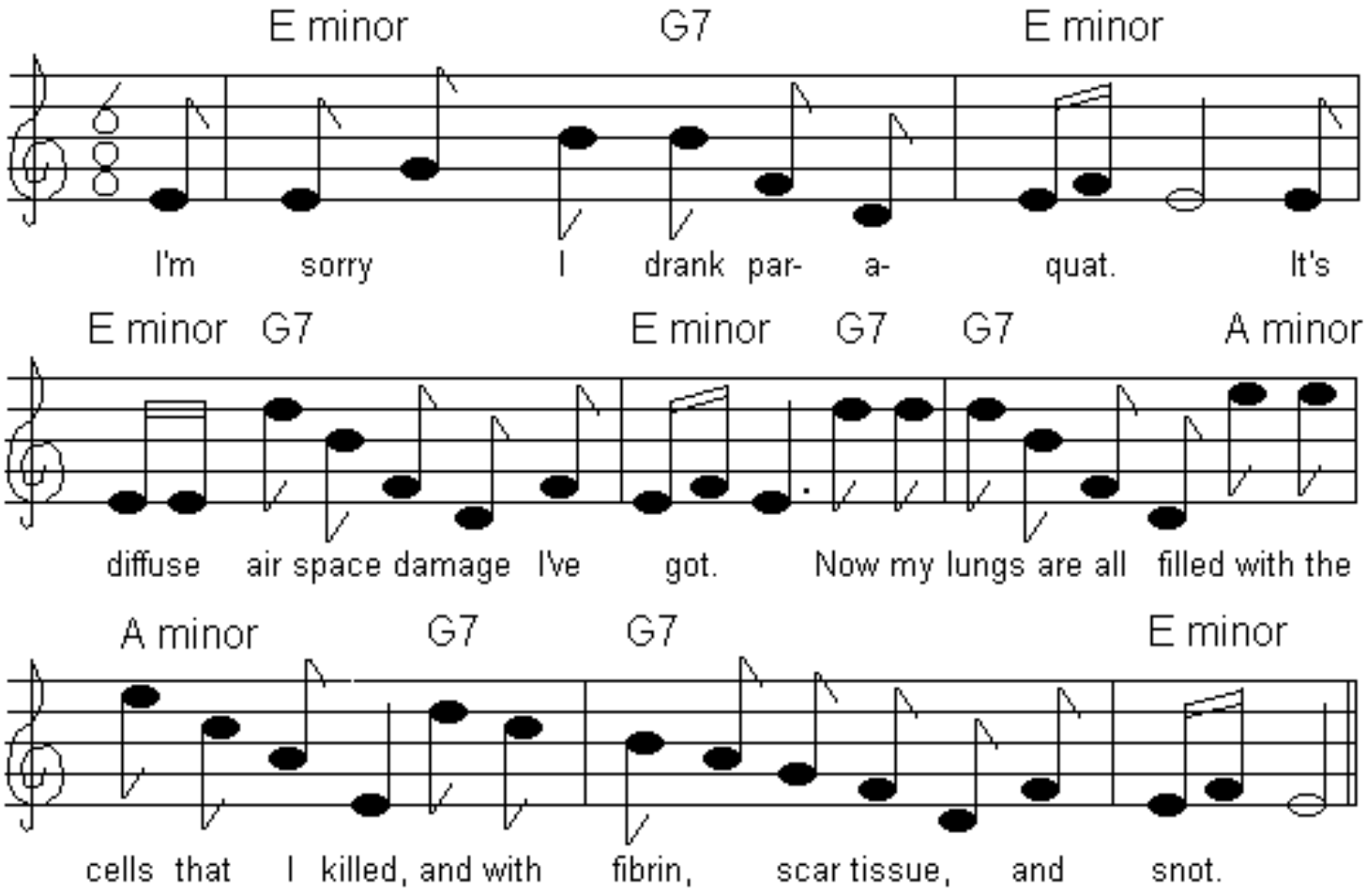
Courtesy of Ed Friedlander.

http://www.pathguy.com/modes.htm#phrypara

Phrygian mode

Phrygian Paraquat Dirge

Church Phrygian Mode



Courtesy of Ed Friedlander.

http://www.pathguy.com/modes.htm#phrypara

An "exotic" mode

"The Answer is Dark" is an example of one of those more exotic modes. It's in a mode of a scale that uses 3 half-step intervals, causing one interval to be an augmented second. In the chart below, the bottom line designates the type of interval between each member of the scale where: h = half step a = augmented whole step w = whole step

G# A B# C# D# E# F# G#

h a h w w h w i.e. S,T+,S,T,T,S,T

Listen to a MIDI file of the scale mode:

It would be in G# Mixolydian except that the A# has been lowered to A. This is sometimes called a "mixed mode" because it has characteristics of two diatonic modes.

http://www.elvenminstrel.com/tolkien/modes.htm

Modes (Reference slide)

According to the nomenclature of medieval music theorists, who were dealing largely with unchorded plainsong, our natural major is the church "Ionian Mode" (C-D-E-F-G-A-B-C), and our natural minor is the church "Aeolian mode" (C-D-D#-F-G-G#-A#-C). I became curious about modes when I learned that "Wreck of the Edmund Fitzgerald" and "Scarborough Fair" use the old balladic scale which matches the church "Dorian Mode" (C-D-D#-F-G-A-A#-C). I used the eerie church "Mixolydian mode" (C-D-E-F-G-A-A#-C) for my intranet version of "The Pathology Blues", on our quizbank. You can also hear the church "Mixolydian mode" in "The Beat Goes On", "Luck Be a Lady Tonight", "Norwegian Wood", "Day Tripper", "Sundown" (Gordon Lightfoot), "Cats in the Cradle", "City of New Orleans" (verse but not chorus), and the theme to "Star Wars". Caedmon recordings used it for the tune for the mystical first song in Yeats's play "The Only Jealousy of Emer". The other church modes are novelties at best. Some of the old Gregorian chant "Sing my tongue..." seems to be Phrygian mode. There is some of the church "Phrygian mode" in "Fiddler on the Roof", and if the song is fully transposed into the church Phygian mode, it still sounds okay. My own attempt to write a song using the church Phrygian mode was dismal. I wrote a little song in an unabashed church "Lydian mode". The mode itself suggested the subject. Unless you only use the subdominant as a leading tone for the dominant, any melody you write in this "mode" will be unnerving -- the subdominant is equidistant from the lower and upper tonics. A correspondent pointed out that the "Lydian" mode makes up some of the "Jetsons" and "Simpsons" theme. Bartok wrote a short piece in the Lydian mode .In the Locrian mode, the dead-center position of the dominant makes this even more unmusical. A music professional told me once that no ethnomusicologist has ever documented a folk tune in what medieval theorists called the "Locrian mode". I browsed a little in Plato, Aristotle, pseudo-Plutarch's "De Musica", and of course the Oxford History of Music, and came away wondering if the medieval music theorists (Boethius, Gregory the Great, their successors) really meant the same thing as did the Greeks who named the modes. Today most people (following a scholar named Westphal) tell us that the Greek modes were indeed used as "scales" with the tonic notes being the low-pitched one, just as the church mode theorists say. This seems to be based on statements in Plato and Aristotle that the modes had distinct emotive qualities, as our major and minor scales do. Another school of thought (that of Munro) claims that for the ancients, the modes were actually keys, i.e., you could play any melody in any mode. If this is true, then the ancient Greeks had either perfect pitch or a standard pitchpipe. I think people have probably liked similar tunes in different eras. I tried to figure out how the ancient Greeks would have played some of our favorites. Ancient Greek lyres typically had seven strings. (Some Hebrew lyres must have had ten strings -- see Psalm 33.) The system of modes is also called "harmoniae", which meant "fitting" or "tuning". Greek writers on music talk about the normal tuning comprising two tetrachords, i.e., a series of four notes with the lowest and highest separated by a major fourth and sharing the center string. Pythagoras and Terpander are both credited with the idea of having the highest string be an octave of the lowest string.

http://www.pathguy.com/modes.htm

Courtesy of Ed Friedlander.

Scala (Program for calculating scales)

Scala is a freeware software application for experimenting with musical tunings.
See http://www.huygens-fokker.org/scala/

Modes

What are Modes of a Scale?

"A modal melody is one that is not in a "key" of the major or minor sort common in music of the Western world in the past 300 to 400 years. Instead, its scale may be comprised of almost any set of tones, not only those that imply 3-part harmony. In fact, generally it should not imply 3-part harmony and a bass line. Many of the modal melodies I like best are virtually impervious to triadic harmonization. There are two common types of modal scales: pentatonic and heptatonic, meaning 5-tone and 7-tone, respectively. Folk music from many parts of the world, including Celtic, American, African, and Chinese, often use modes of pentatonic scales."

Listen to a MIDI file of two pentatonic modes:

http://www.elvenminstrel.com/tolkien/modes.htm

Important points

- Scales are anchored pitch systems
- The anchor is the tonic, first note in the scale
- The pitch intervals of the notes re: the tonic
  give the scale its characteristic tonality
- Scales include both consonant and dissonant
  intervals that provide tonal contrast.
- Equal temperament tuning systems use logarithmic frequency spacings to achieve systematicity (equality of keys good for key modulations).
- The 12-TET system represents just frequency ratios (2:1, 3:2, 4:3, 5:4, 5:3) fairly well -- important because of consonance, fusion, pitch stability.

Balance between consonance and dissonance
stability and uncertainty
tension and relaxation

"As Frank Zappa explained it, "The creation and destruction of harmonic and 'statistical' tensions is essential to the maintenance of compositional drama. Any composition (or improvisation) which remains consistent and 'regular' throughout is, for me, equivalent to watching a movie with only 'good guys' in it, or eating cottage cheese."[2] In other words, a composer cannot ensure a listener's liking by using exclusively consonant sounds. However, an excess of tension may disturb the listener. The balance between the two is essential." (Wikipedia)

Reading/assignment for next meeting

Book reviews due TODAY
Harmonics & Scales Problem set due next MONDAY.

- **We will do Harmony & Melody next time.**
- **Reading:**
- You may find Wikipedia entries on consonance and dissonance, melody and harmony useful.
- Do read Chapters 8 & 9 in Aiello on melody (Butler & Brown) and tonal expectancies (Bharucha).
- Handel, Chapter 10, "Grammars of music and language" on Blackboard also covers similar territory.

HST.725 Music Perception and Cognition

Spring 2009