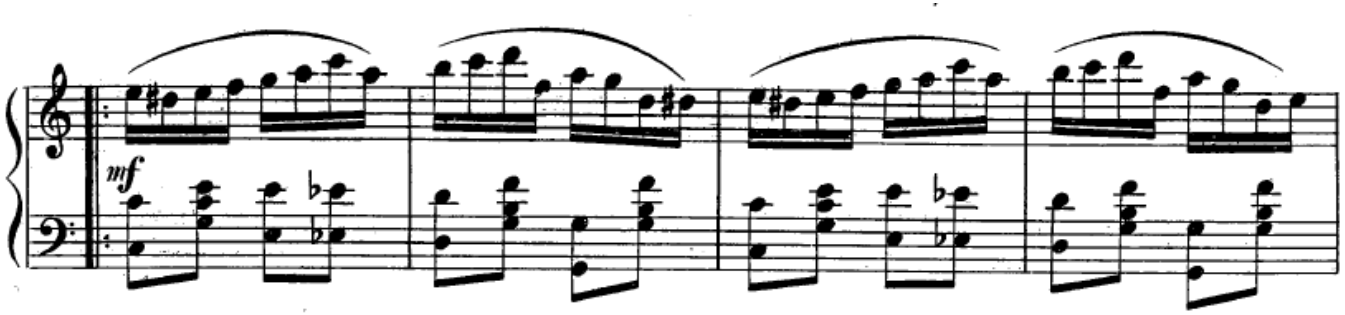


Physics of the Blues

scales, harmony and the origin of blues piano styles

J. Murray Gibson

Dean, FAMU-FSU College of Engineering

February19th 2019, Challenger Center Razor Lecture

FAMU-FSU Engineering

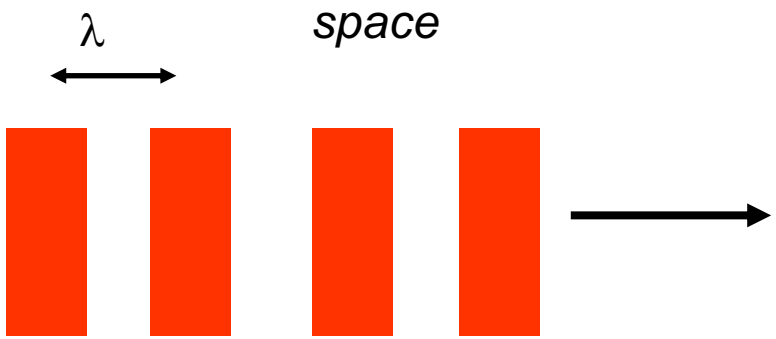
Symbiosis of art and science

Science and technology drives art

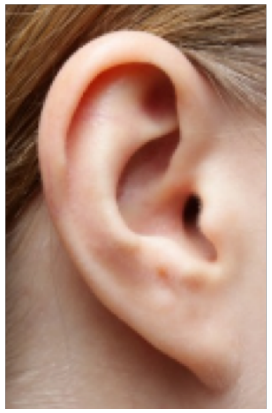
Art drives science and technology

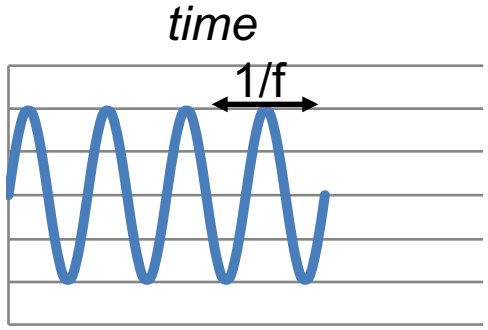
$$\nabla^2 \phi = 0$$

Key physical aspects of sound



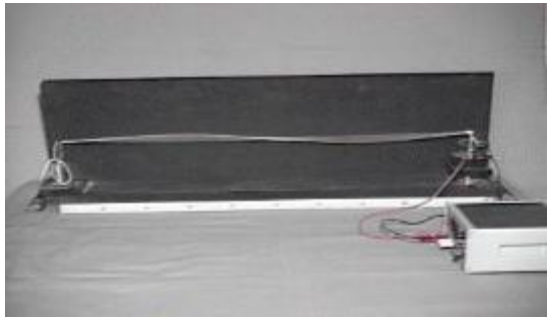
Sound is a pressure wave
(red is high)





"Pitch" is frequency
Concert A = 440Hz

Vibrating objects produce "harmonics" which are often integer multiples of the basic frequency

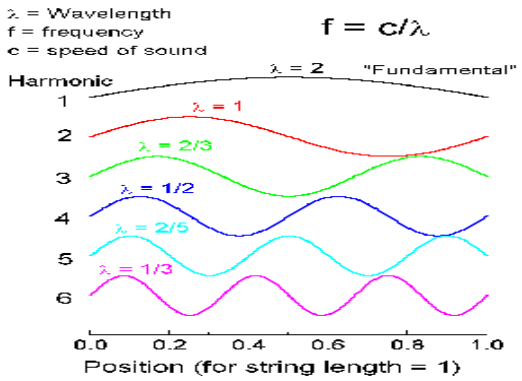


Musical timbre is determined by the harmonic content *(Fourier analysis)*

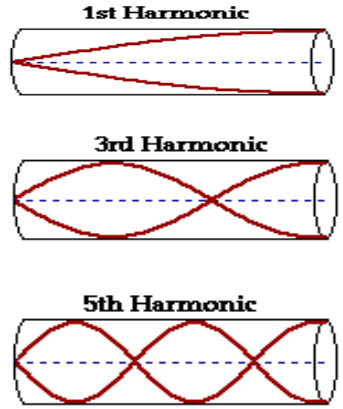
Two notes with overlapping harmonics sound "consonant"

This consonance is the basis of harmony and musical scales

f_0, 2 f_0, 3 f_0,...

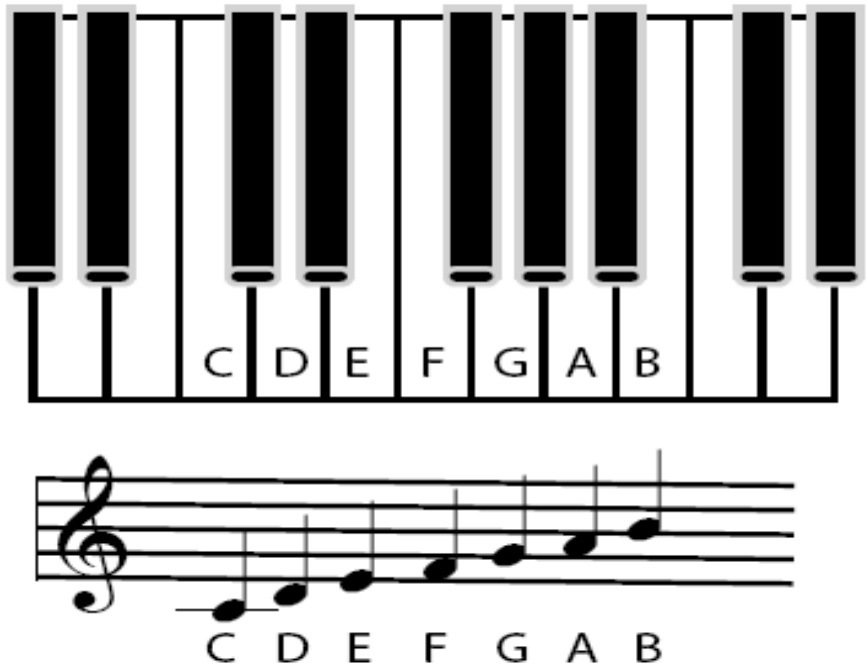


f_0, 3 f_0, 5 f_0,...



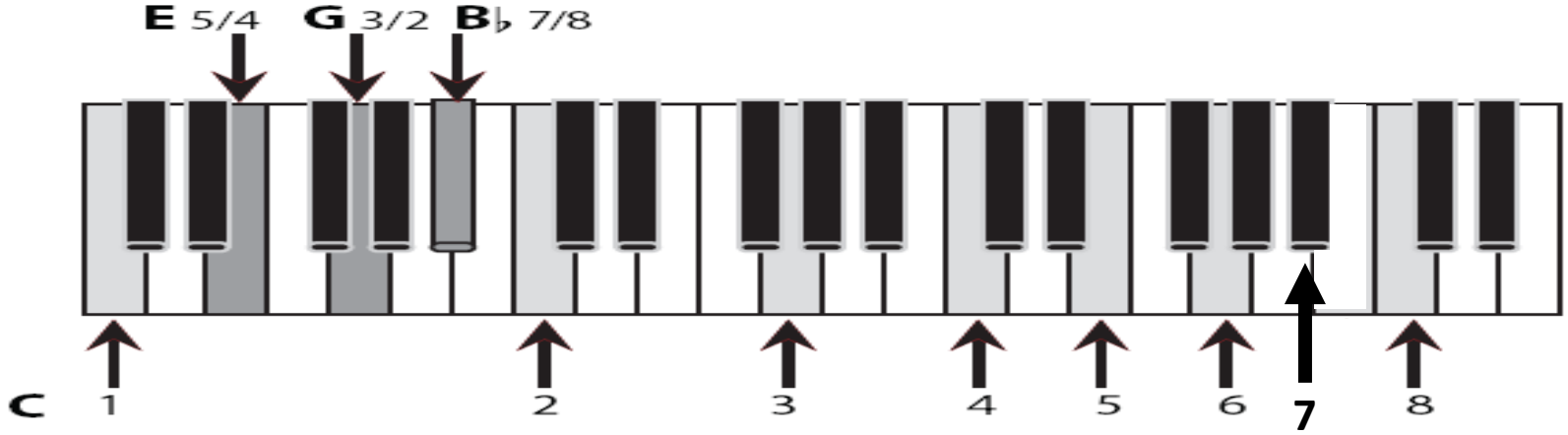
FAMU-FSU Engineering

Some points of reference



An interval (“second”, “third”..) is two notes played close together
-described by the separation (+1)
e.g. a second, third, fifth…

Let's build a musical scale based on the harmonics...

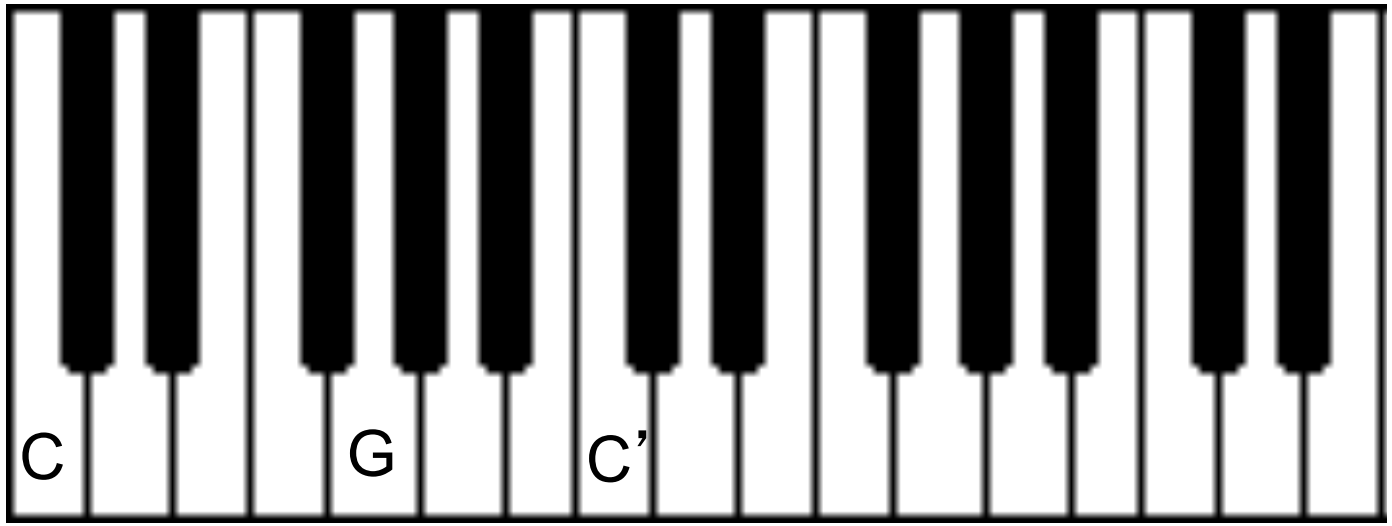


Harmonic intervals have low integer frequency ratios

piano keyboard is a logarithmic frequency scale (slide rule)

FAMU-FSU Engineering

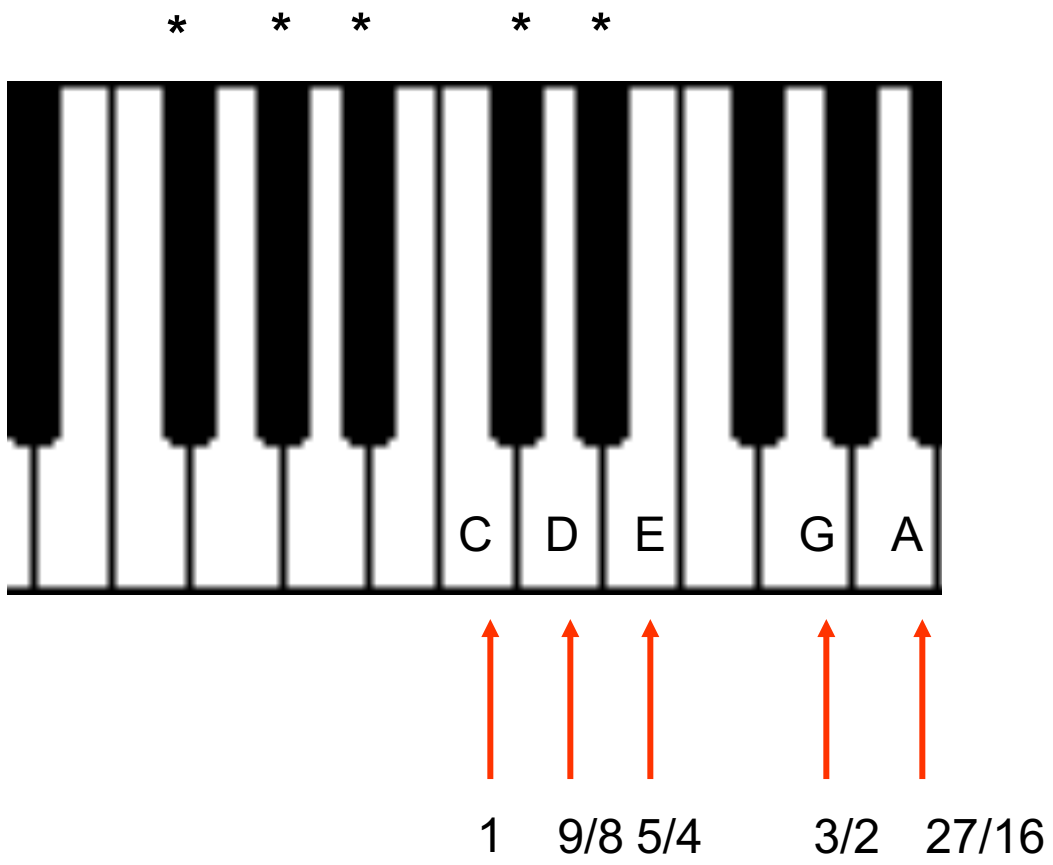
Unison, octave and perfect fifth



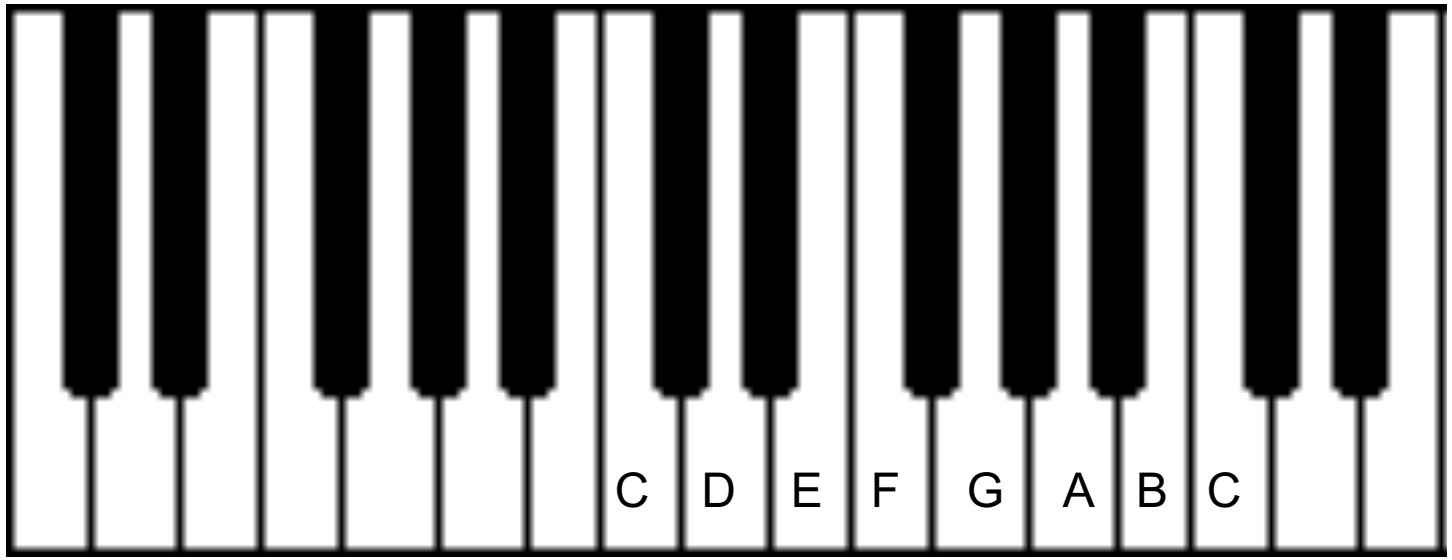
C-C Unison (1:1)
C-C’ Octave (2:1)
C-G Perfect fifth (3:2) <- key interval for making scales

A simple scale - the pentatonic obtained using fifths

Common to many civilizations and used in jazz



Diatonic scale

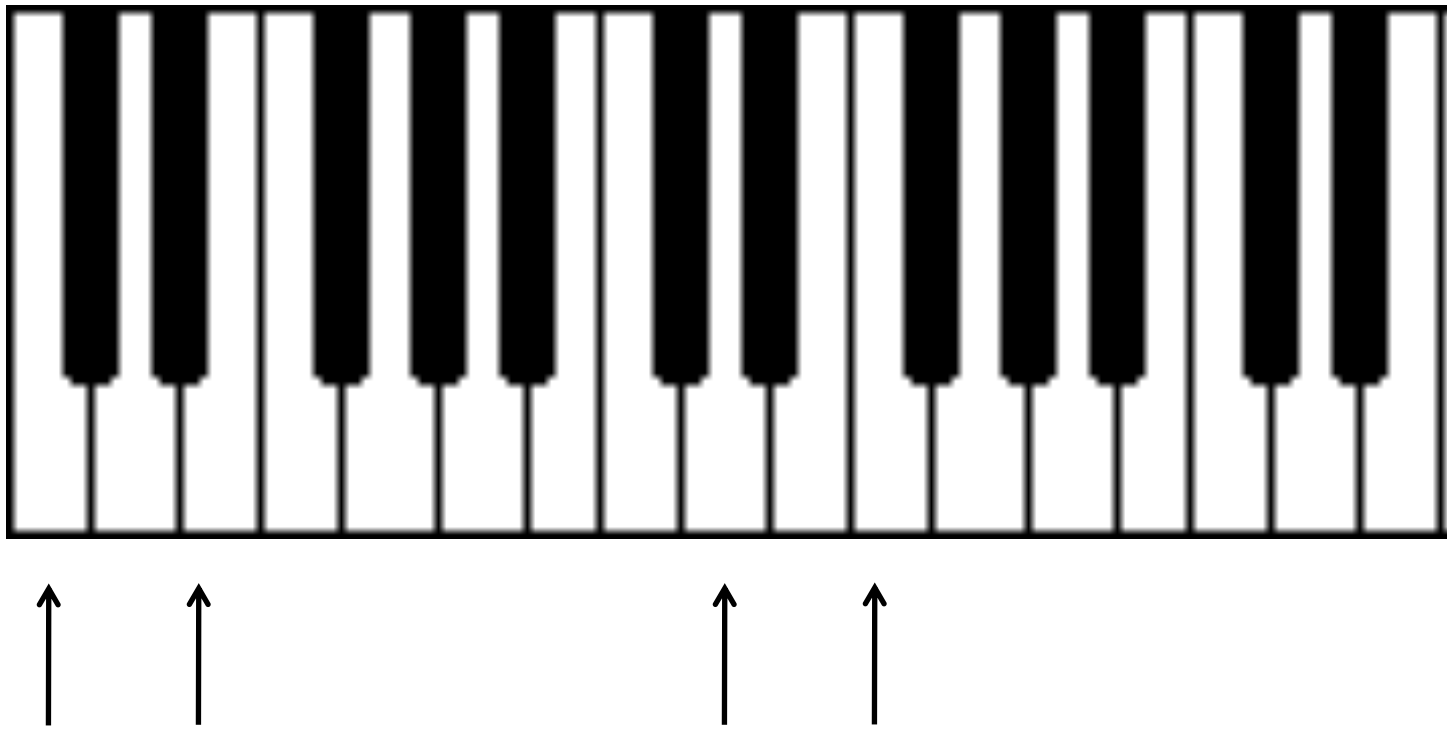


"Tonic" is C here

Doh, Re, Mi, Fa, So, La, Ti, Doh….

notes are all in low integer frequency ratios –
so they sound harmonic in almost any combination

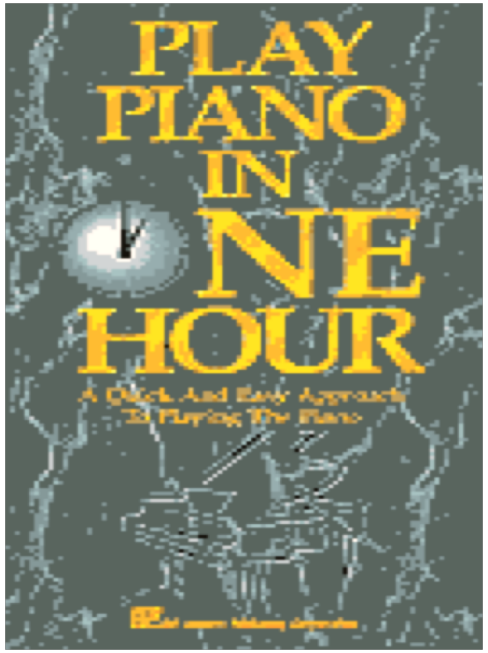
Major and minor third

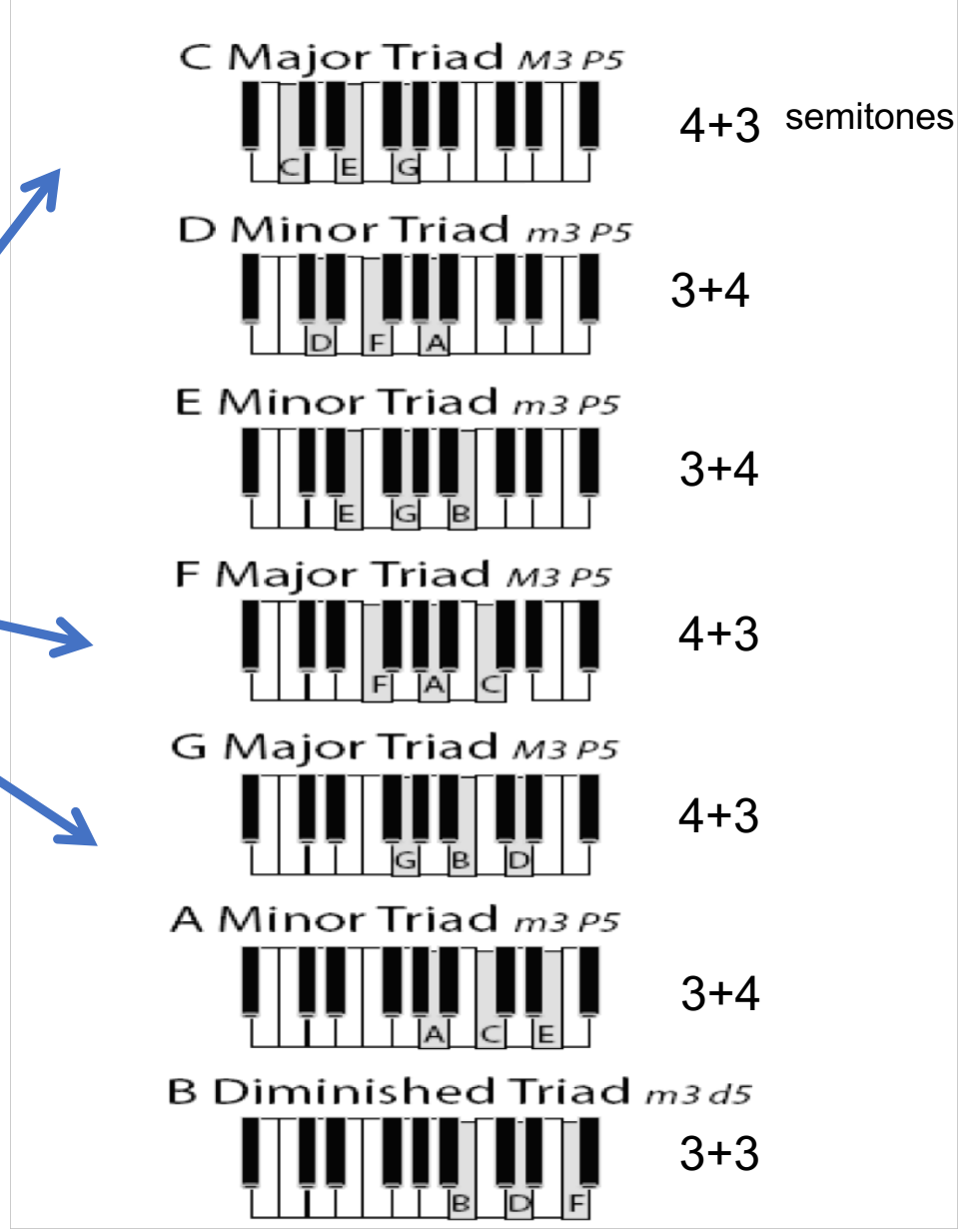


C-E
Major third
4 semitones
(half-steps)

D-F
minor third
3 semitones

The “triads” in the key of C





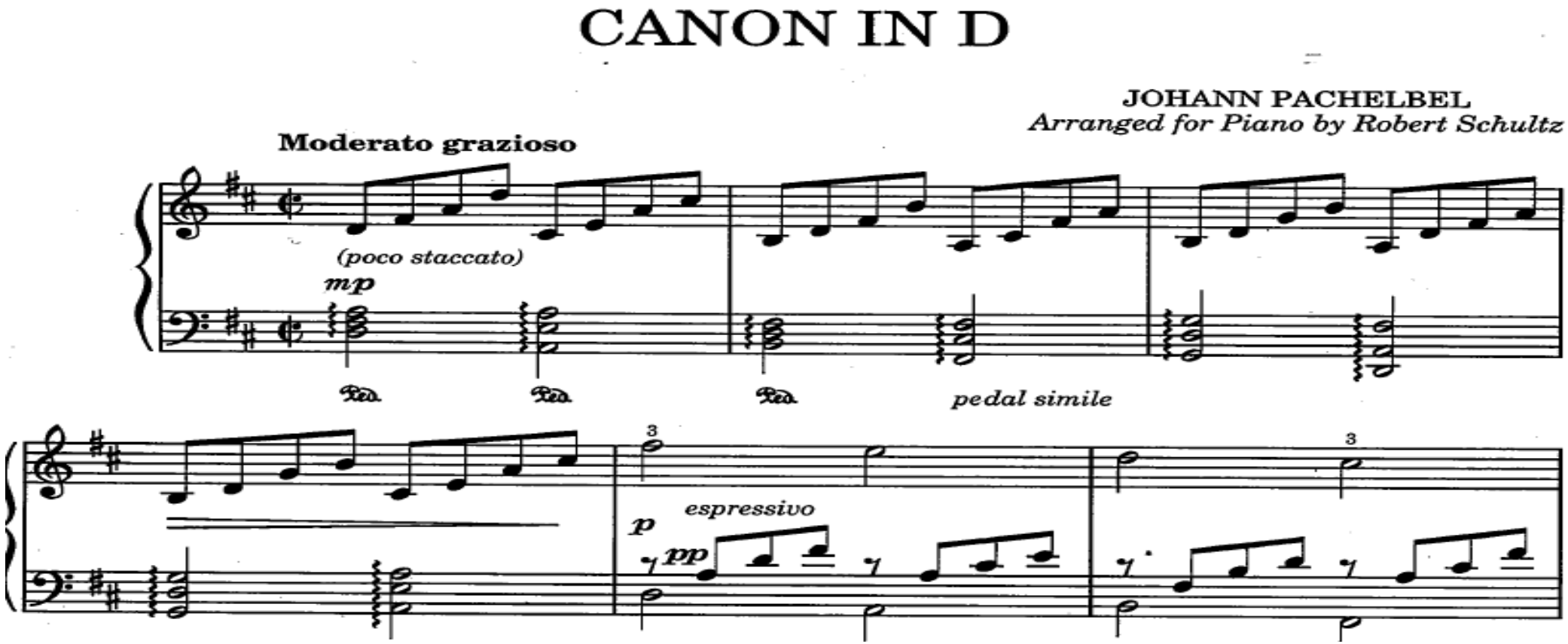
A lot of folk music, blues etc. relies on chords C, F and G

Natural (Just) scale pitch ratios

Note	Pitch Ratio to C	Frequency of Upper Note based on C (Hz)
C	1	261.63
C#	25/24	272.54
D	9/8	294.33
D#	6/5	313.96
E	5/4	327.04
F	4/3	348.83
F#	45/32	367.93
G	3/2	392.45
G#	8/5	418.61
A	5/3	436.06
A#	9/5	470.93
B	15/8	490.56
C’	2.0000	523.26

looks fine and dandy – so why didn’t we stick with this?

Baroque music



Based only on diatonic chords in one key (D in this case)

Equal temperament scale

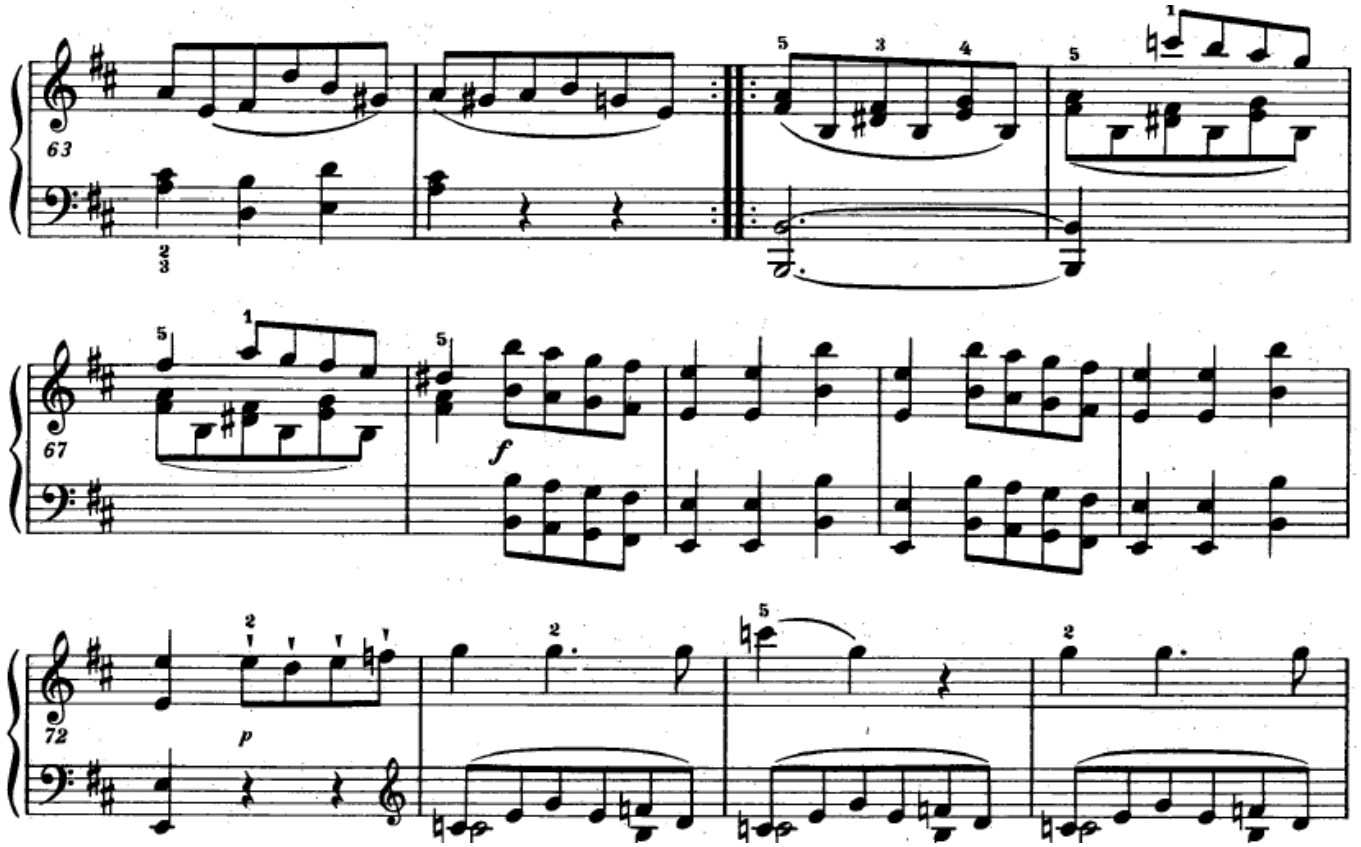
Note	Frequency (Hz)	Difference from Just Scale (Hz)
C	261.63	0
C#	277.18	4.64
D	293.66	-0.67
D#	311.13	-2.83
E	329.63	2.59
F	349.23	0.4
F#	369.99	2.06
G	392.00	-0.45
G#	415.30	-3.31
A	440.00	3.94
A#	466.16	-4.77
B	493.88	3.32
C’	523.25	0

half-step (semitone) = 2^1/12

Pianoforte needs multiple strings to hide beats!

“Mostly Mozart” – taking advantage of equal temperament

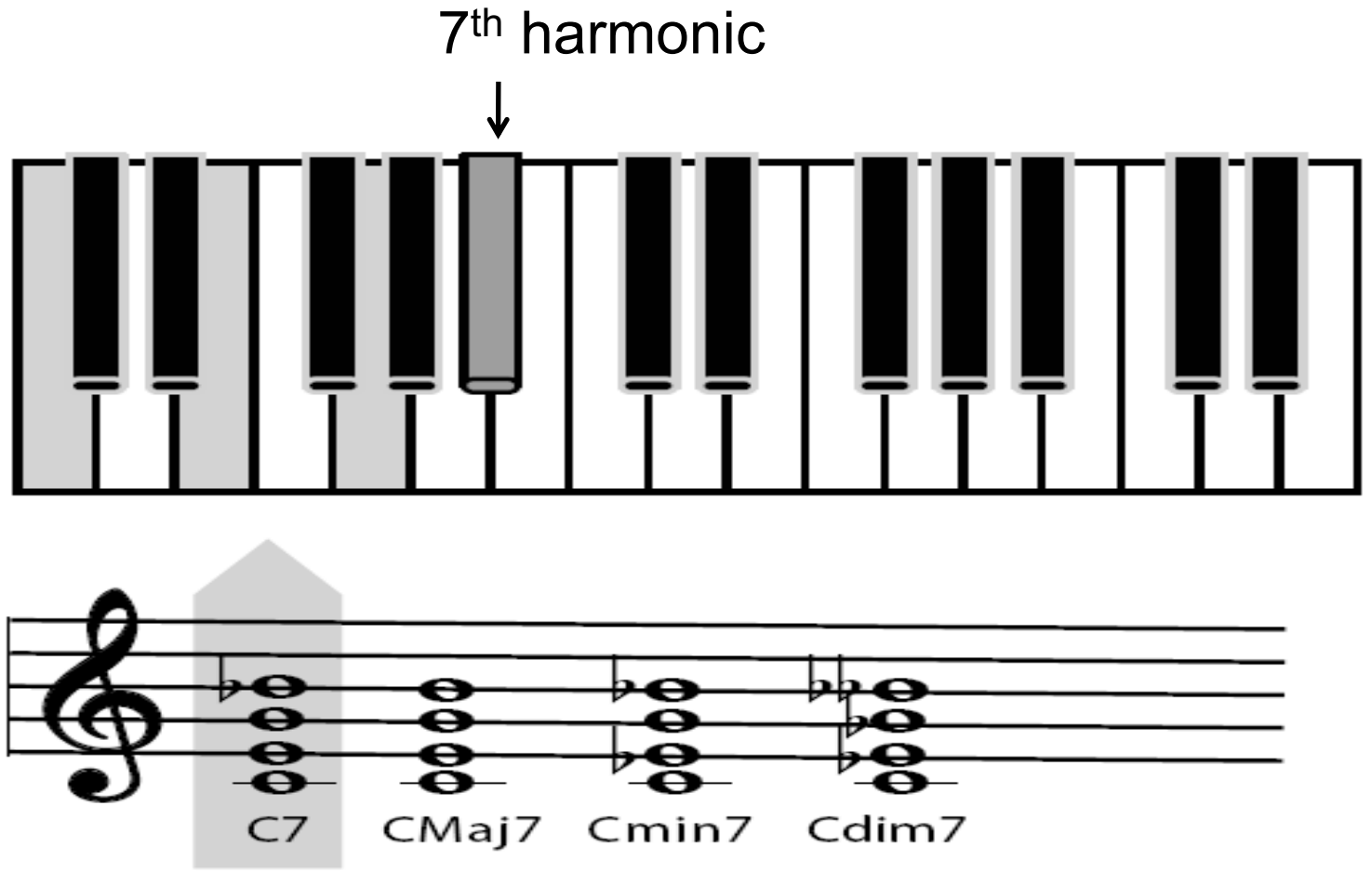
followed pioneering “Well-tempered Clavier” by J.S. Bach



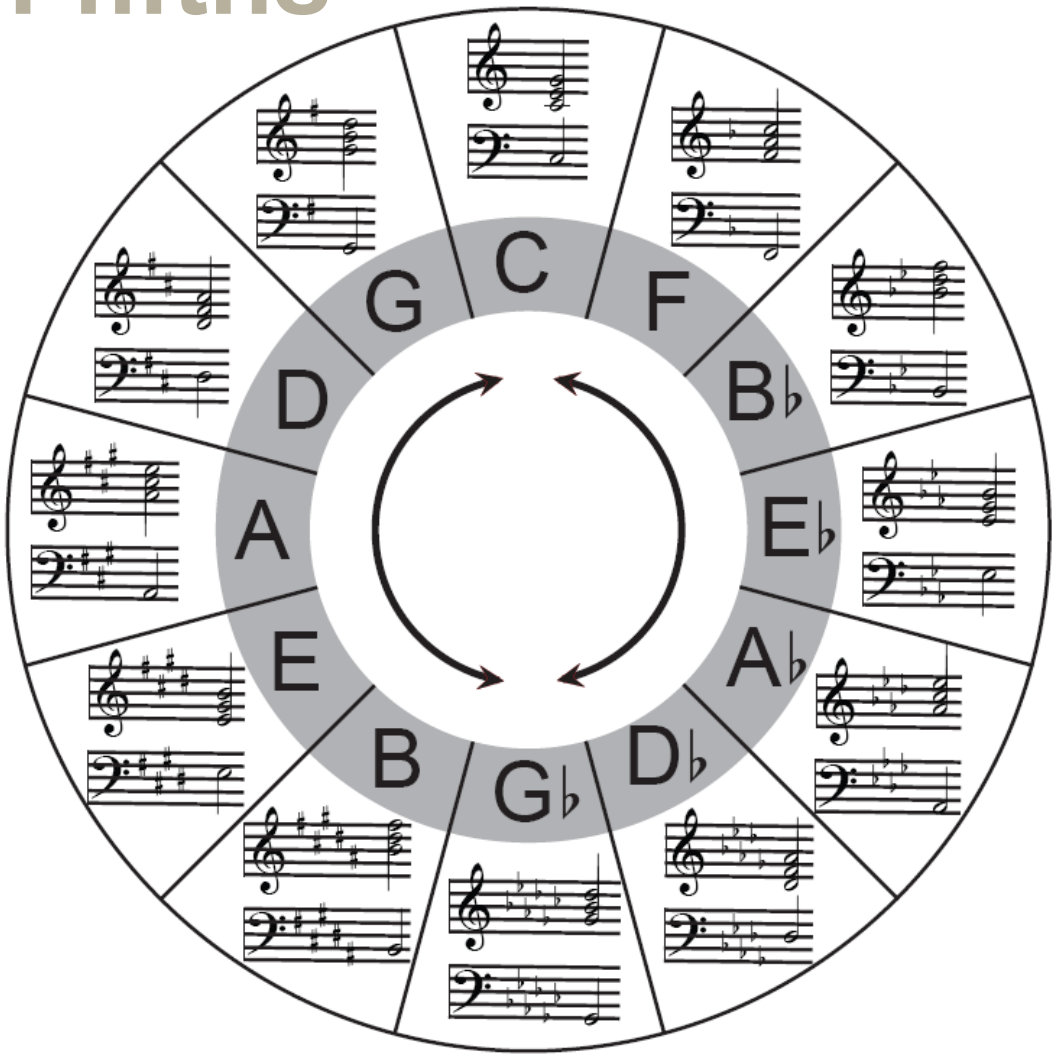
from his Sonata in A Major

FAMU-FSU Engineering

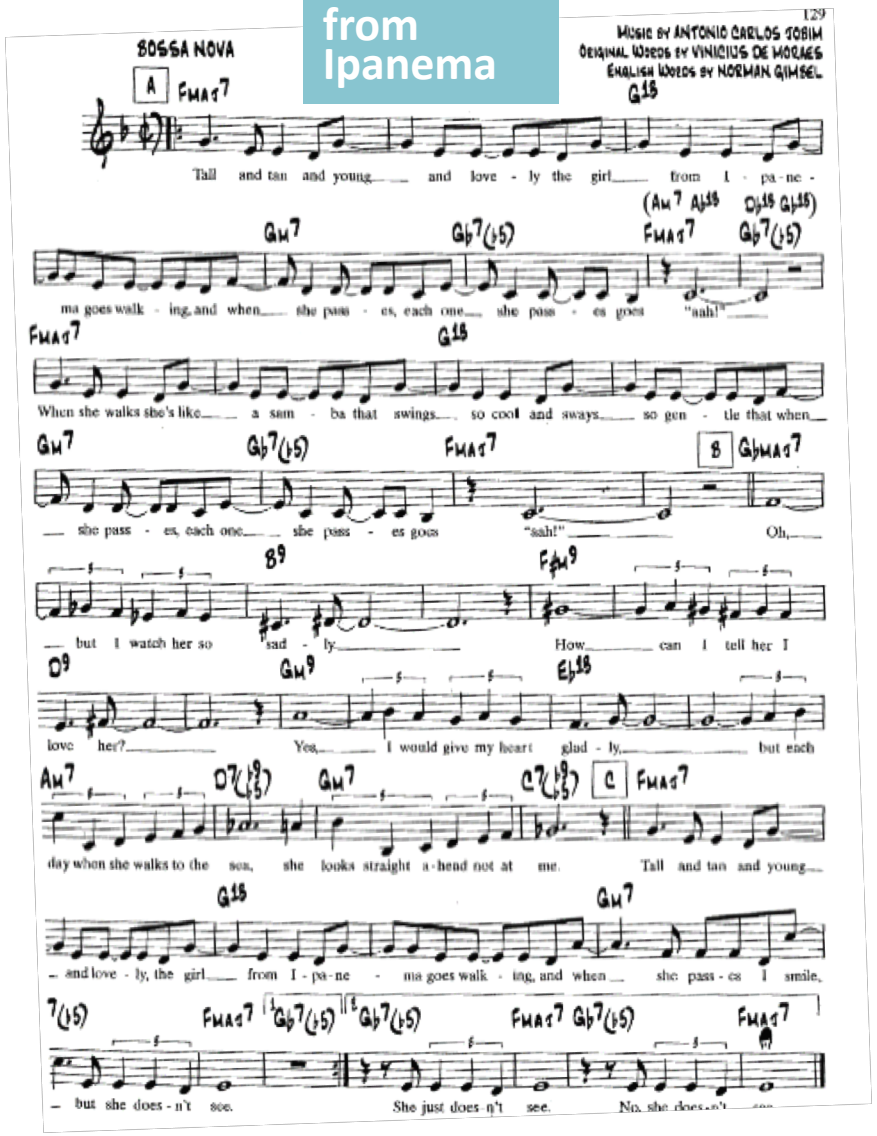
The dominant seventh chord



The circle of fifths

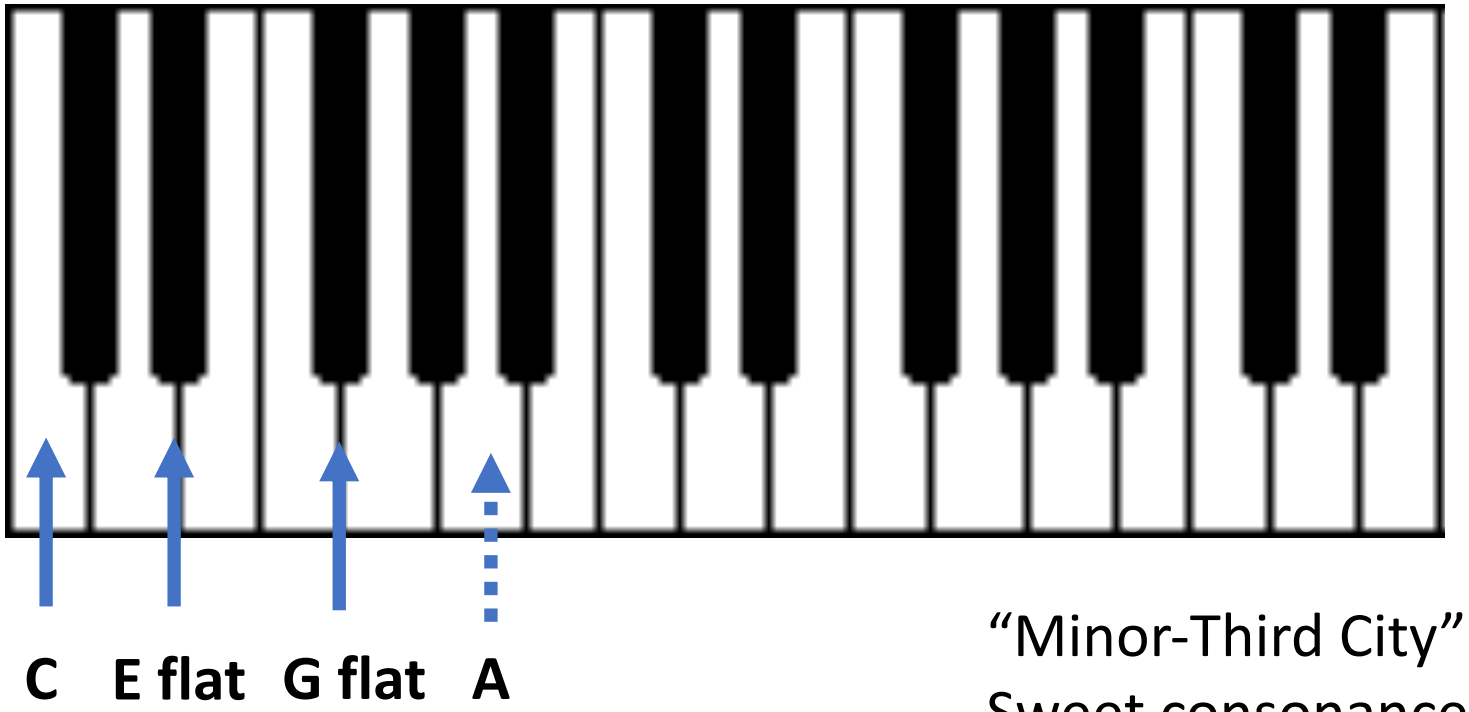


The Girl from Ipanema



FAMU-FSU Engineering

The diminished chord

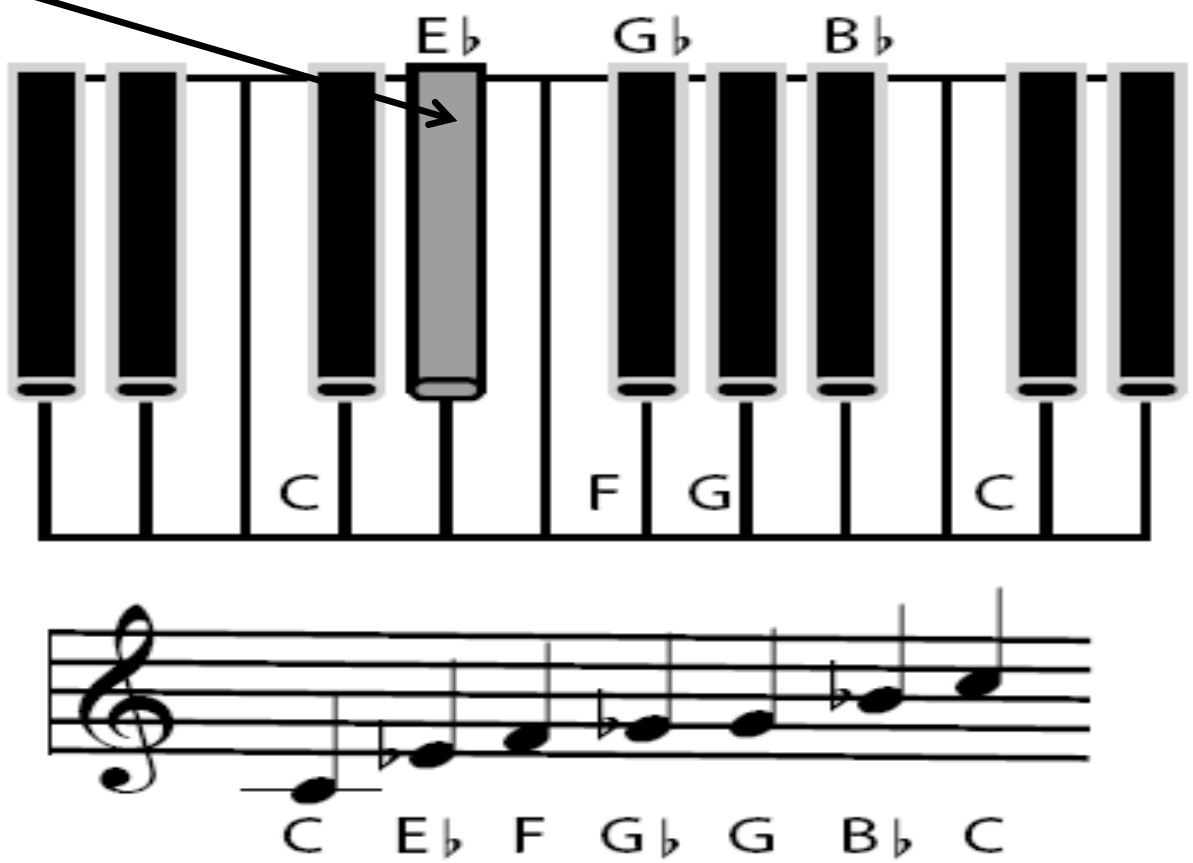


"Minor-Third City"
Sweet consonance *and*
disturbing dissonance

Romantic fuel – Chopin and Beethoven

The blues scale and the “blue note”

The blue note really lies between E flat and E

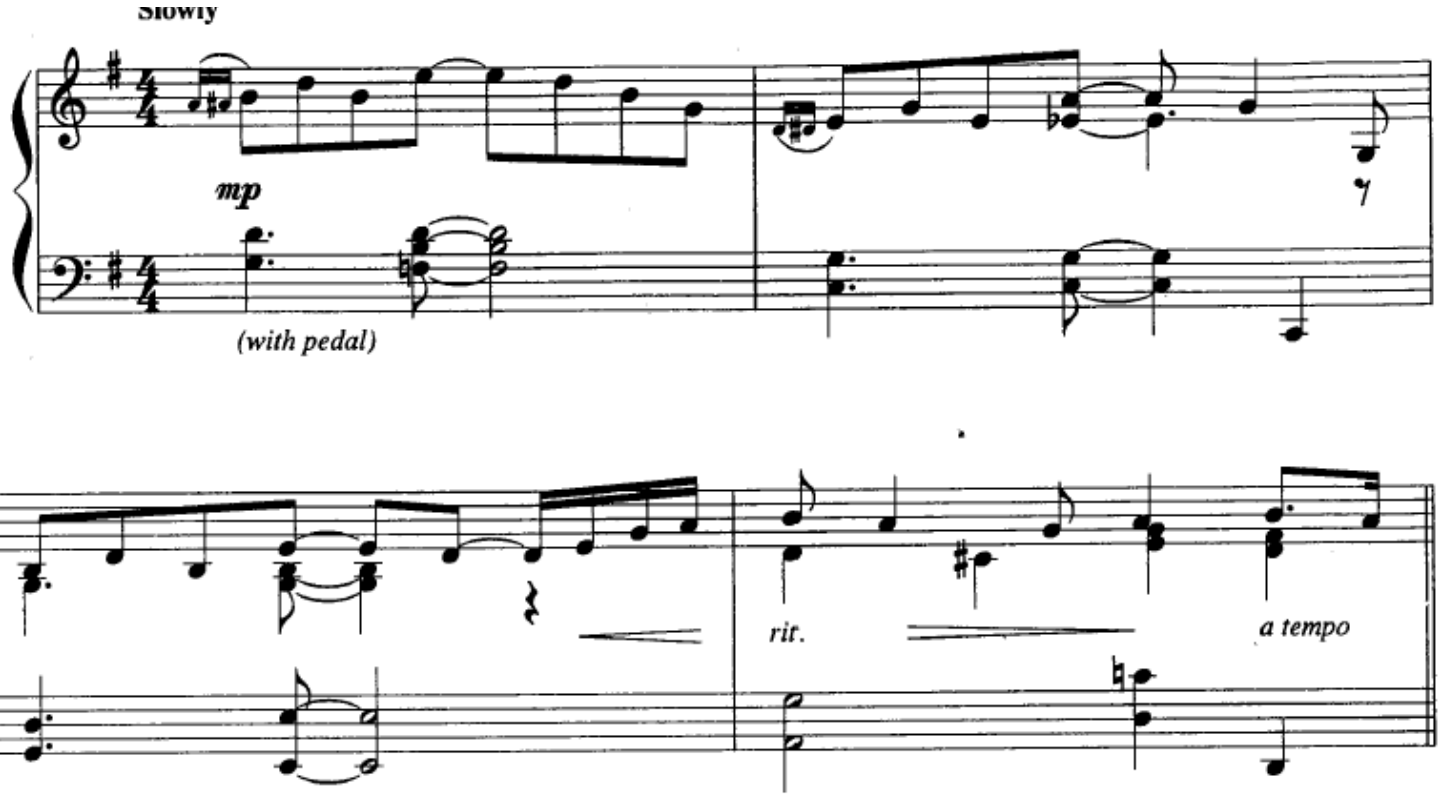


Equal temperament scale

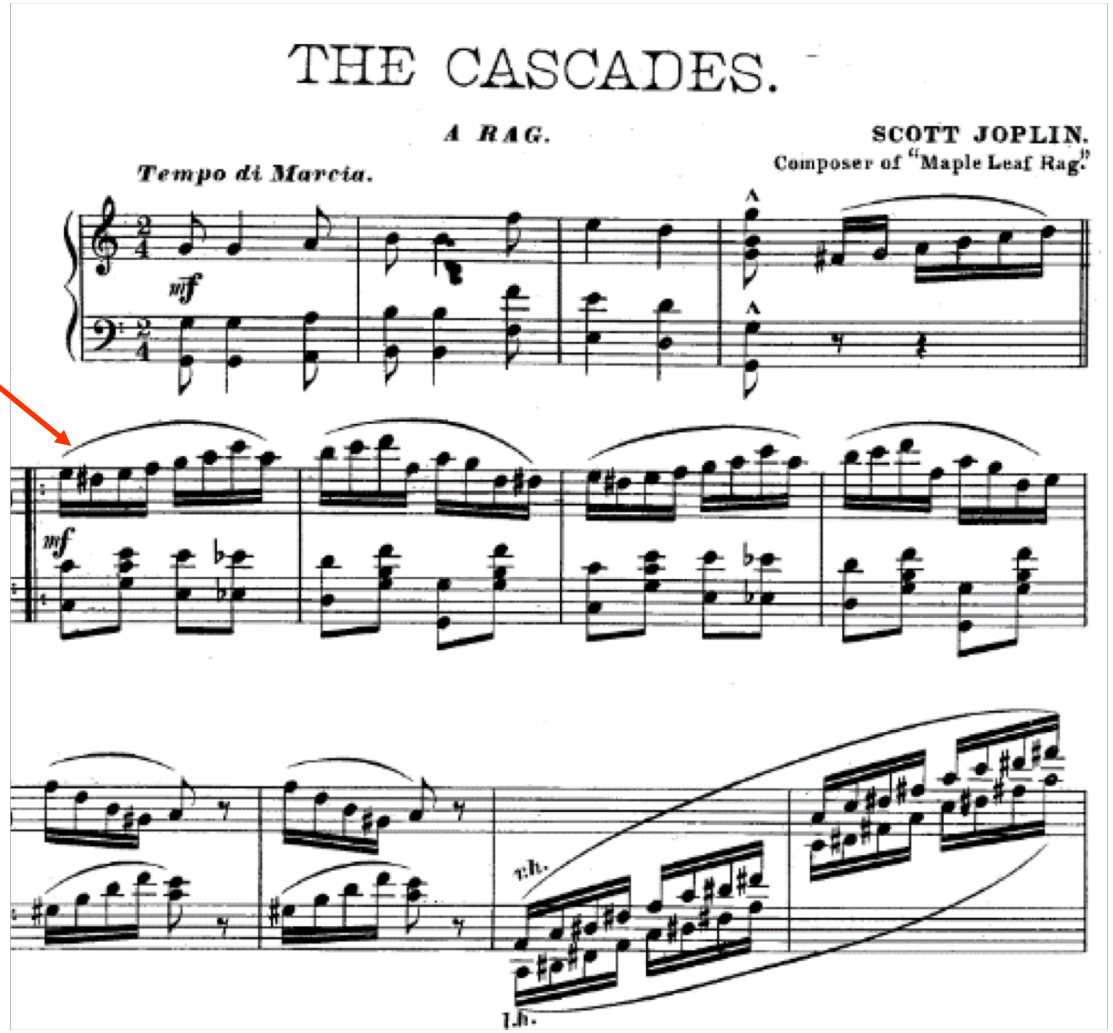
Note	Frequency (Hz)	Difference from Just Scale (Hz)
C	261.63	0
C#	277.18	4.64
D	293.66	-0.67
D#	311.13	-2.83
E	329.63	2.59
F	349.23	0.4
F#	369.99	2.06
G	392.00	-0.45
G#	415.30	-3.31
A	440.00	3.94
A#	466.16	-4.77
B	493.88	3.32
C’	523.25	0

5/4 f_c

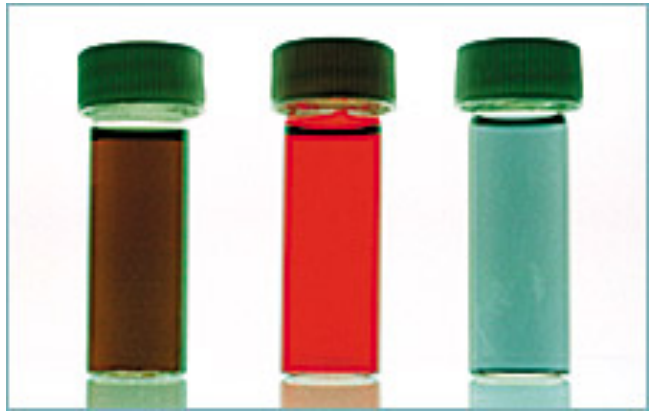
Crushed notes and the blues



Not quite ready for the blues



Semiconductor bandgaps and nanotechnology – Electrons as waves

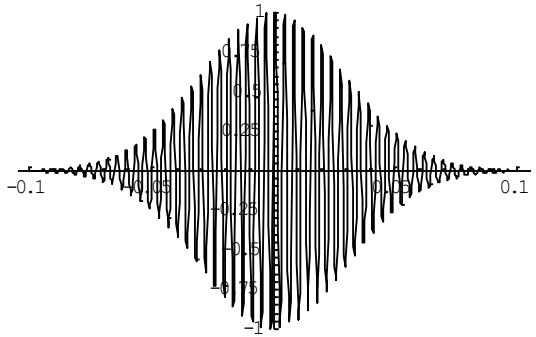


Nano-organ pipes

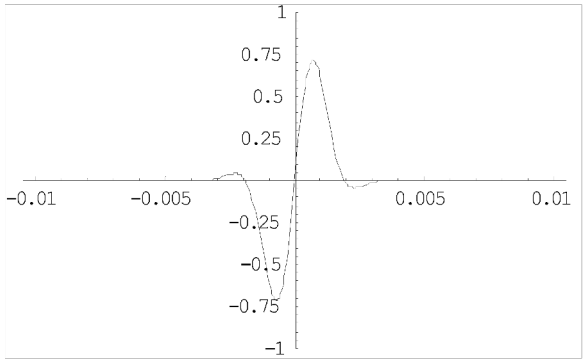
Harmonic analysis can give insights into science and technology

Musical waves and particles – quantum mechanics and the uncertainty principle

wavepackets with fwhm ~0.1s



wavepackets with fwhm ~0.03s



FAMU-FSU Engineering

Summary

- Music is underpinned by physics and mathematics
- Science and art are not as different as many think
  - Creativity and constraints
- Development of musical scales was driven to expand the palette for creative composition
- The “blue note” in piano blues is a treasured artifact of the development of scales
- Music is a great tool for teaching physics and engineering by analogy with harmonic analysis

To learn more…

- Article "**The birth of the blues – how physics underlies music**", by J.M. Gibson Reports on Progress in Physics, **72** 076001 (2009).
- "**Measured Tones: The Interplay of Physics and Music**", Ian Johnston, Institute of Physics (Philadelphia) 1989, ISBM 0-85274-236-3
- **Harmony and Theory : A Comprehensive Source for All Musicians** by Keith Wyatt and Carl Schroeder
- **A Student's Guide to Fourier Transforms : With Applications in Physics and Engineering** by J. F. James (Author) - for math and physics students
- Many web resources, on musical acoustics, Fourier analysis, physics of musical instruments….
- *This lecture will be on the web at* bit.ly/physicsofblues

  Contact – dean@eng.famu.fsu.edu with questions