



Physics of the Blues

scales, harmony and the origin of blues piano styles

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Symbiosis of art and science

Science and technology drives art



Art drives science and technology

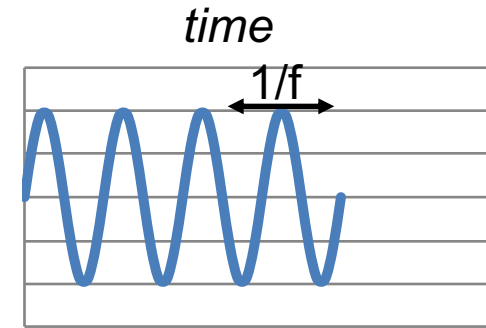
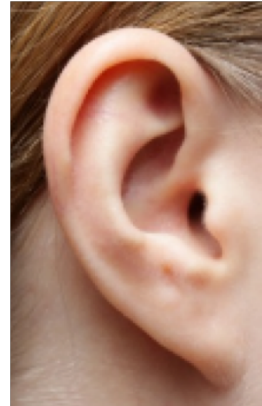
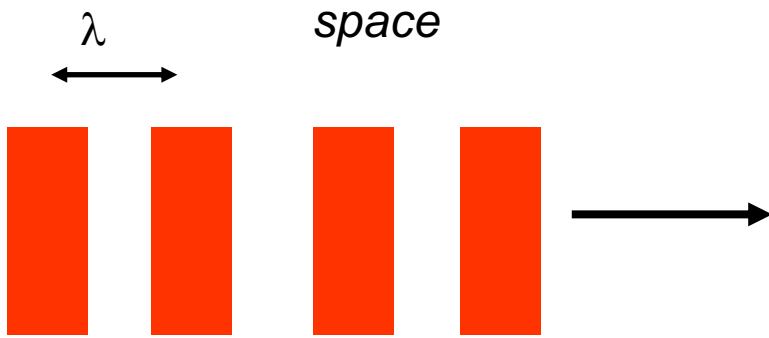


$$\nabla^2 \phi = 0$$



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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



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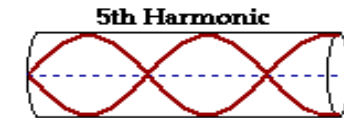
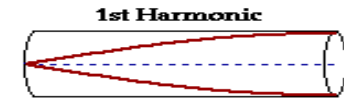
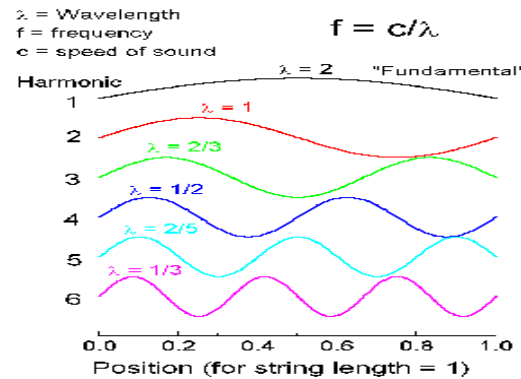
Musical timbre is determined by the harmonic content *(Fourier analysis)*

$$f_0, 2 f_0, 3 f_0, \dots$$

$$f_0, 3 f_0, 5 f_0, \dots$$

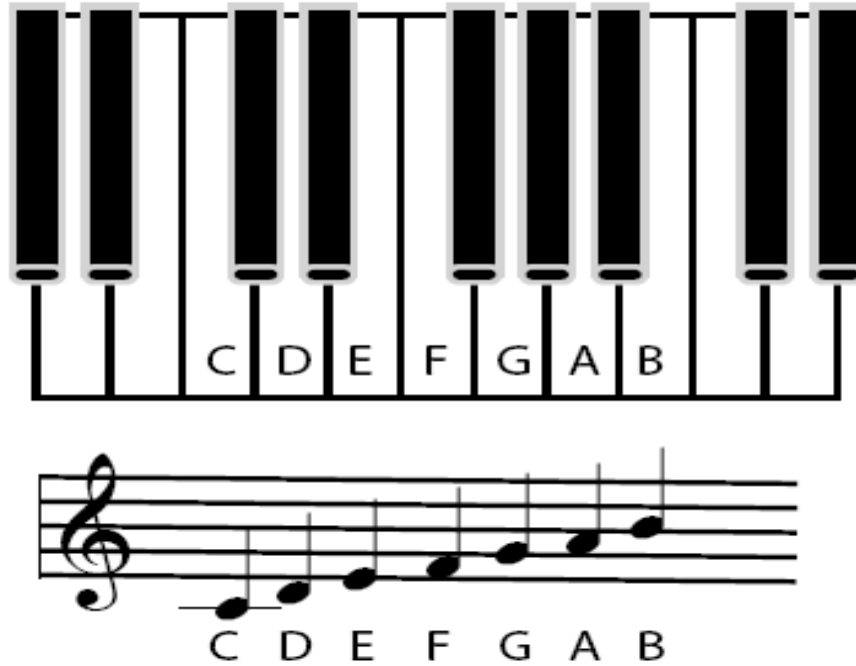
Two notes with overlapping harmonics sound “consonant”

This consonance is the basis of harmony and musical scales



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Some points of reference

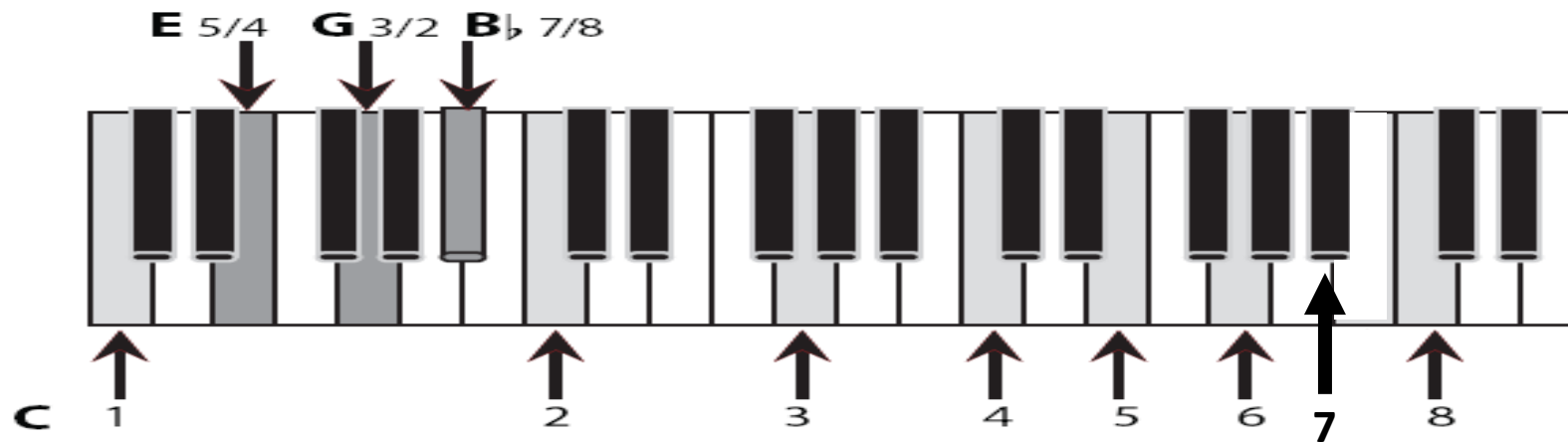


An interval (“second”, “third”..) is two notes played close together
-described by the separation (+1)
e.g. a second, third, fifth...



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



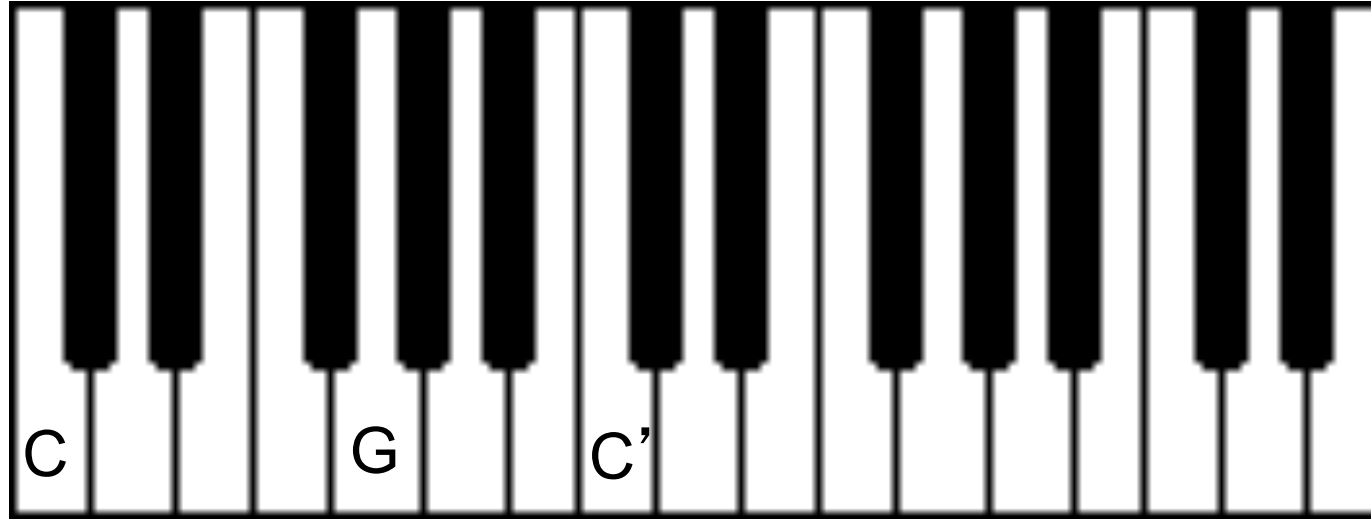
Harmonic intervals have low integer frequency ratios

piano keyboard is a logarithmic frequency scale (slide rule)



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Unison, octave and perfect fifth



C-C Unison (1:1)

C-C' Octave (2:1)

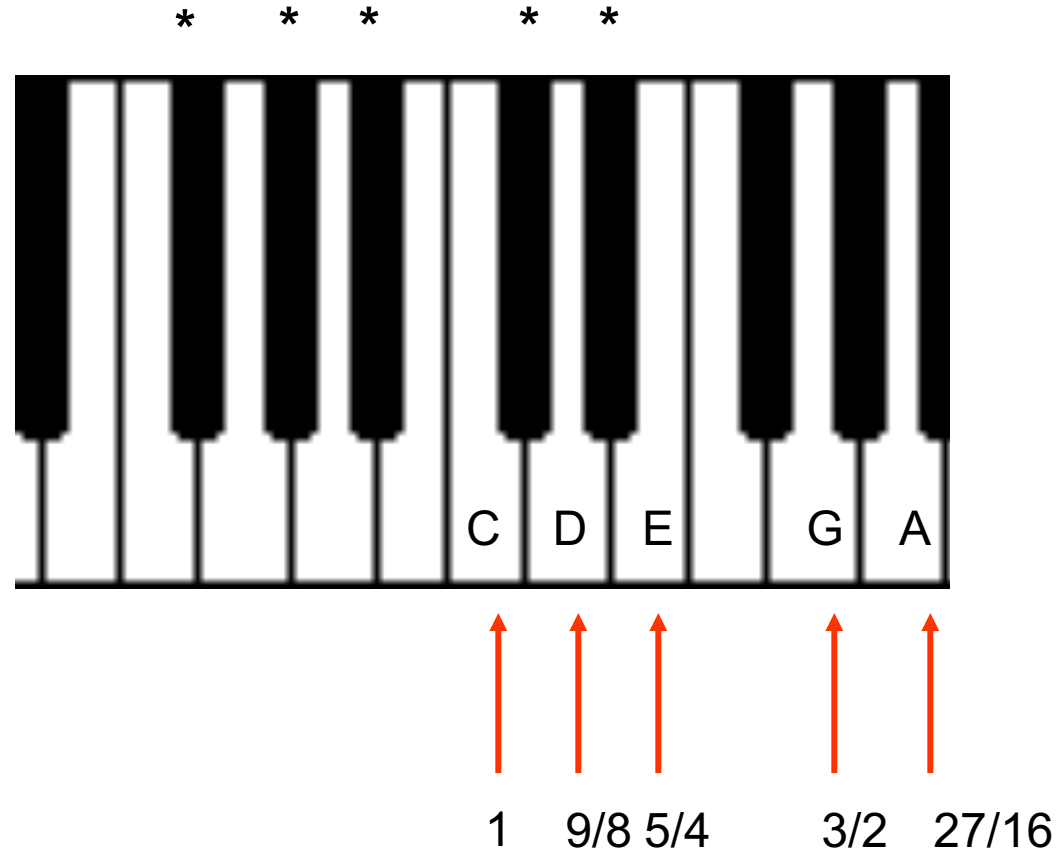
C-G Perfect fifth (3:2) <- key interval for making scales



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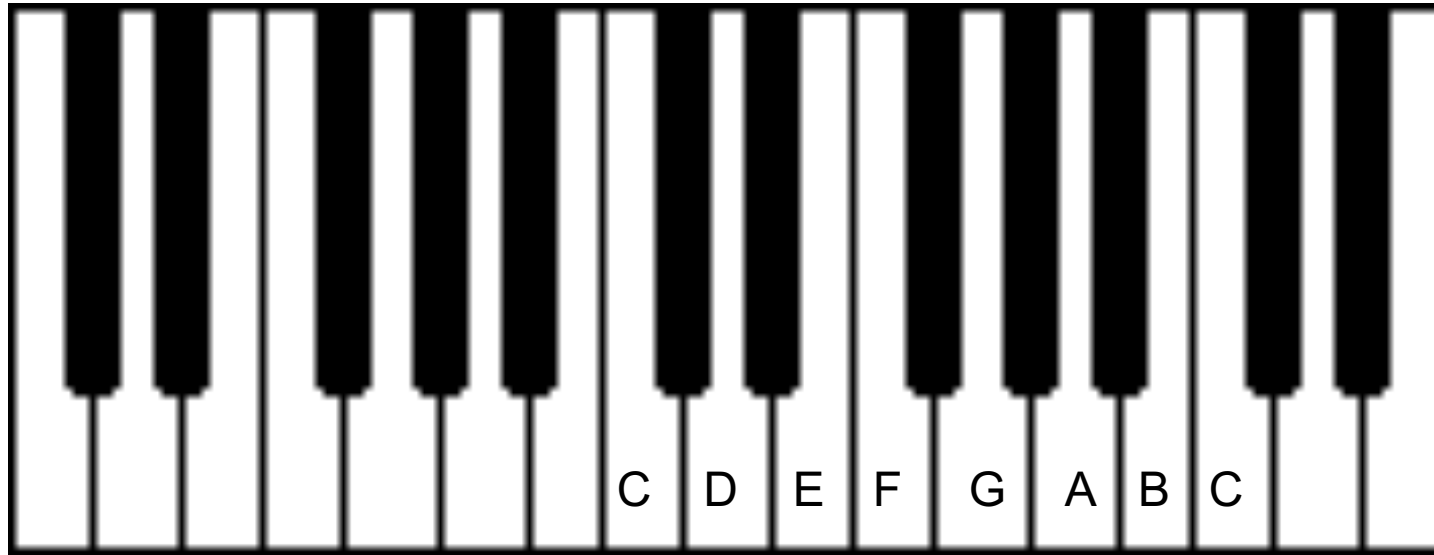
A simple scale - the pentatonic obtained using fifths

Common to many civilizations and used in jazz



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Diatonic scale



“Tonic” is C here

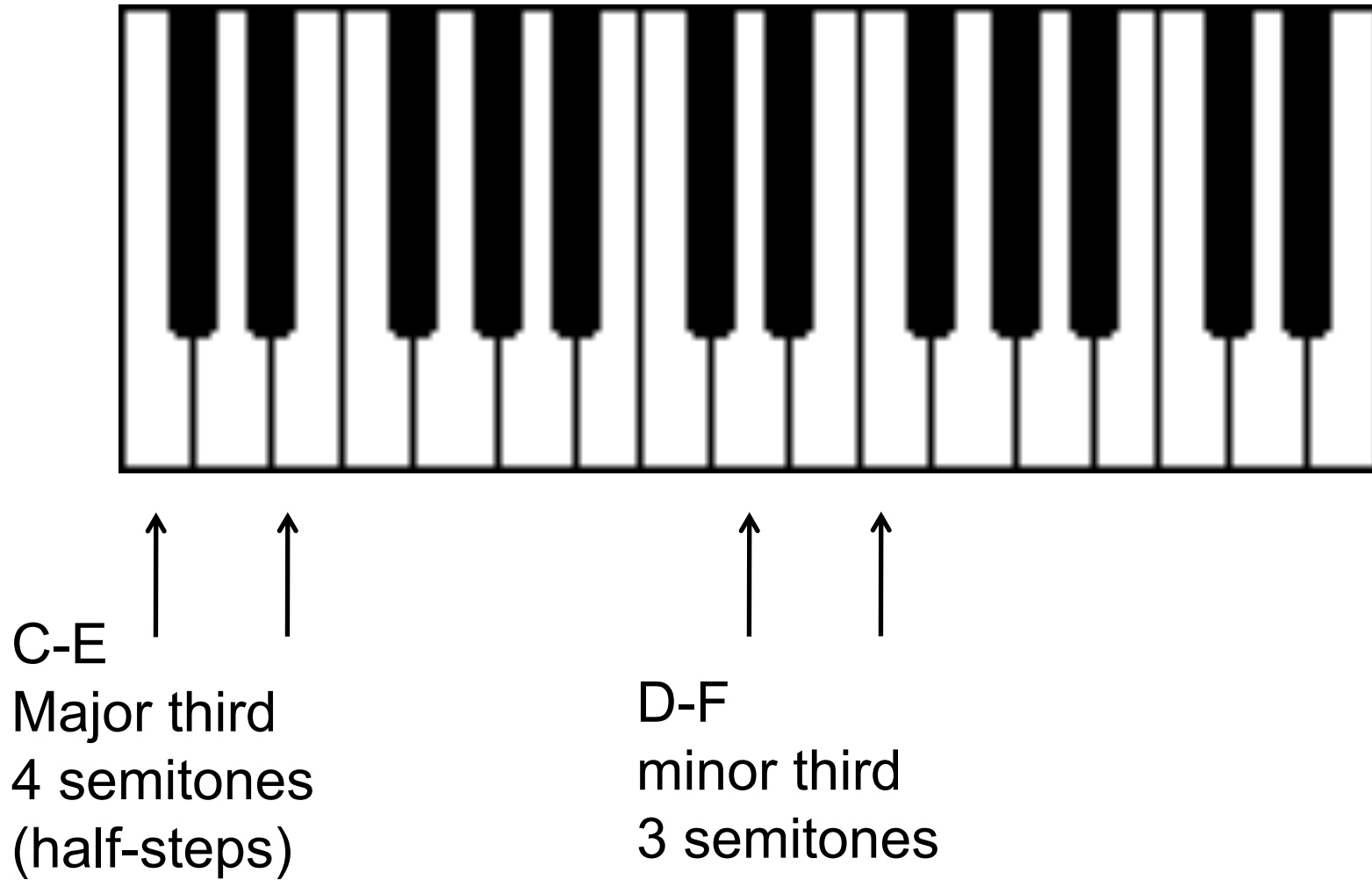
Doh, Re, Mi, Fa, So, La, Ti, Doh....

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



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Major and minor third



The “triads” in the key of C



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

C Major Triad *M3 P5*



4+3 semitones

D Minor Triad *m3 P5*



3+4

E Minor Triad *m3 P5*



3+4

F Major Triad *M3 P5*



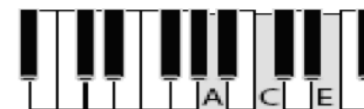
4+3

G Major Triad *M3 P5*



4+3

A Minor Triad *m3 P5*



3+4

B Diminished Triad *m3 d5*



3+3



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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

CANON IN D

JOHANN PACHELBEL
Arranged for Piano by Robert Schultz

Moderato grazioso

(poco staccato)
mp
pedal simile
p *espressivo*
pp

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



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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!



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“Mostly Mozart” – taking advantage of equal temperament

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

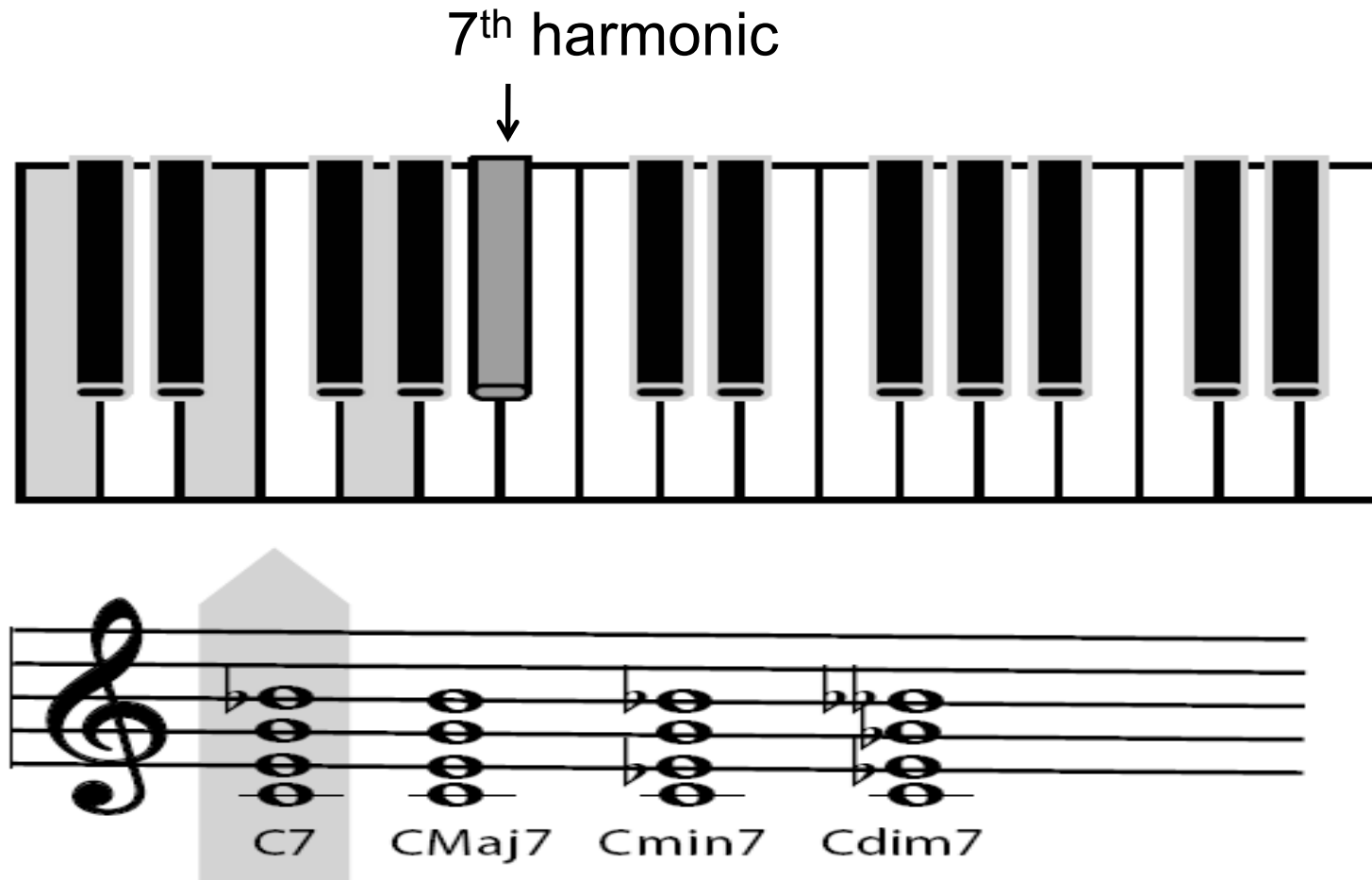


from his Sonata in A Major

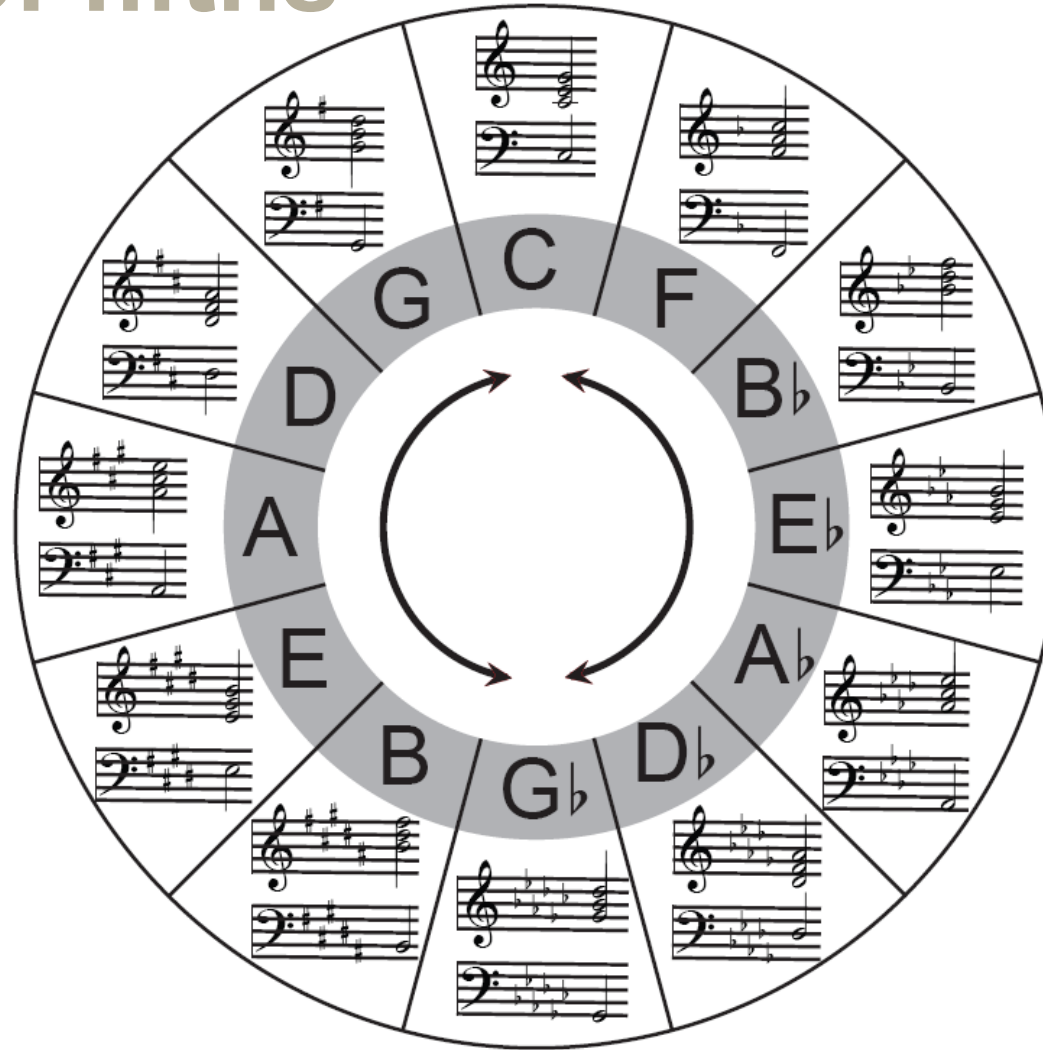


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The dominant seventh chord



The circle of fifths



The Girl from Ipanema

129

8066A NOVA

A F#m7

Tall and tan and young and love - ly the girl from I - pa - ne -

G#m7 Gb7(b9) (Am7 Ab9 D#9 G#9) F#m7 Gb7(b9)

ma goes walk - ing, and when she pass - es, each one she pass - es goes "aah!"

F#m7 G#9

When she walks she's like a sem - ba that swings so cool and sways so gun - tie that when

G#m7 Gb7(b9) F#m7 B G#m7

she pass - es, each one she pass - es goes "aah!" Oh,

B9 F#m9

but I watch her so sad - ly How can I tell her I

D9 G#m9 Eb9

love her? Yes, I would give my heart glad - ly but each

Am7 D7(b9) G#m7 C7(b9) C F#m7

day when she walks to the sea, she looks straight a - head not at me. Tall and tan and young

G#9 G#m7

and love - ly, the girl from I - pa - ne - ma goes walk - ing, and when she pass - es I smile,

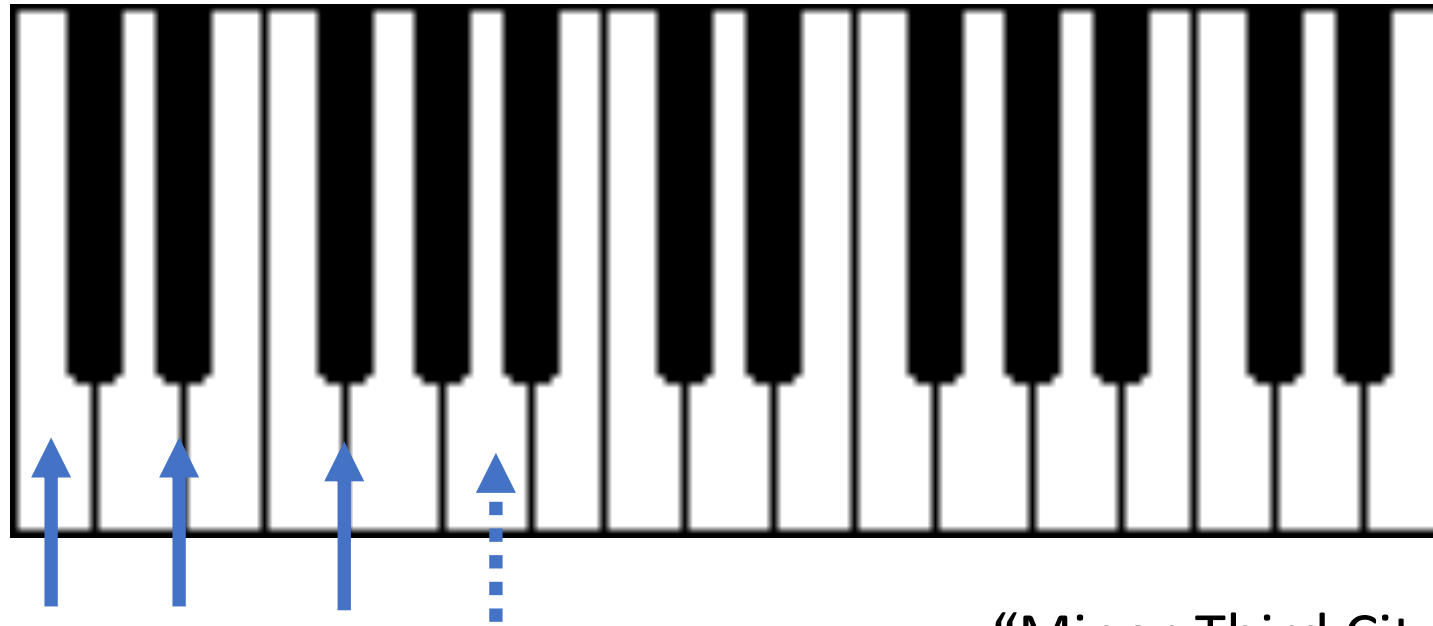
7(b9) F#m7 Gb7(b9) Gb7(b9) F#m7 Gb7(b9) F#m7

but she does - n't see. She just does n't see. No, she does - n't see.



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The diminished chord



C E flat G flat A

“Minor-Third City”
Sweet consonance *and*
disturbing dissonance

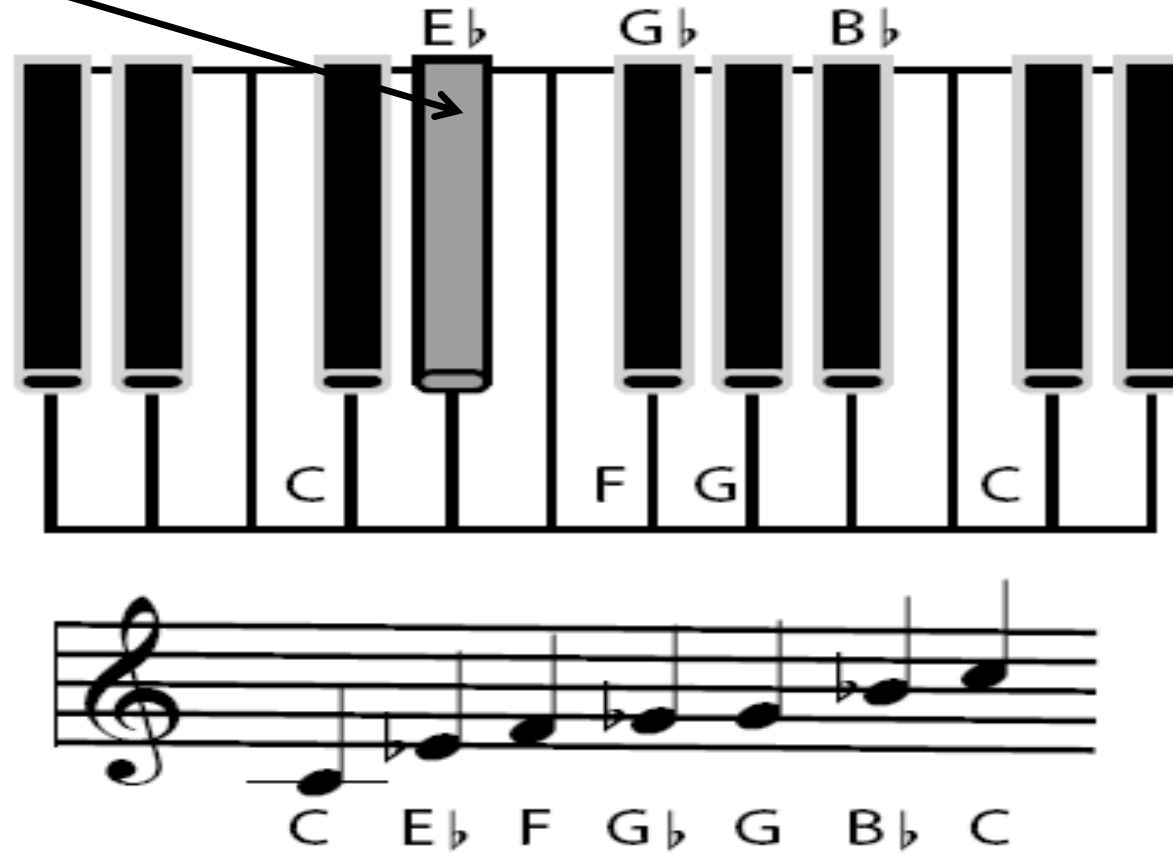
Romantic fuel – Chopin and Beethoven



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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

blue note

$5/4 f_c$



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Crushed notes and the blues



Not quite ready for the blues

THE CASCADES.

A RAG.

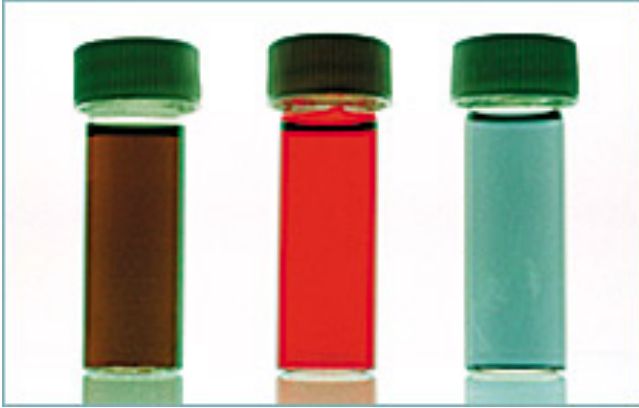
SCOTT JOPLIN.
Composer of "Maple Leaf Rag."

Tempo di Marcia.

The musical score for "The Cascades" by Scott Joplin is presented in a standard musical notation format. It begins with a piano introduction in 2/4 time, marked *Tempo di Marcia*. The main melody is written in the treble clef, starting with a *mf* (mezzo-forte) dynamic. A red arrow points to the first measure of the main melody, which contains a half note G4 and a half note A4. The bass line is written in the bass clef, starting with a *mf* dynamic. The score includes various musical notations such as notes, rests, and dynamic markings.



Semiconductor bandgaps and nanotechnology – Electrons as waves



Nano-organ pipes



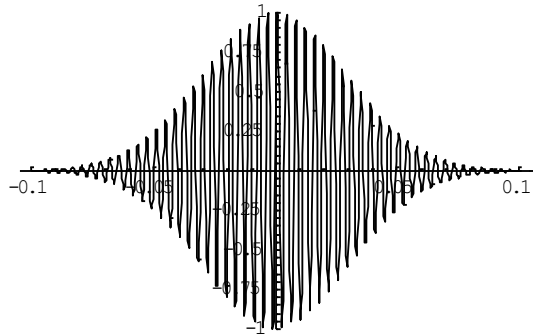
Harmonic analysis can give insights into science and technology



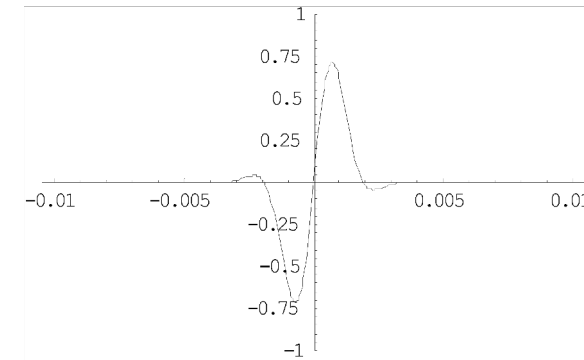
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Musical waves and particles – quantum mechanics and the uncertainty principle

wavepackets with fwhm ~ 0.1 s



wavepackets with fwhm ~ 0.03 s



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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, ISBN 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



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