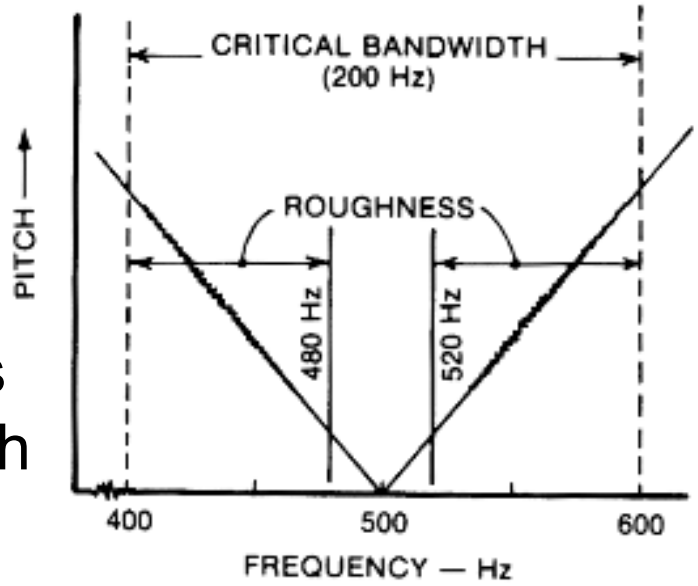
Physics 1240: Sound and Music

<u>Today (7/18/19)</u>: Music: Pythagoras, Intervals, Scales

<u>Next time</u>: Music: Temperament, Non-Western Scales

Critical Bands

Two pure tones played together



Critical band: region of frequencies inside of which you can't distinguish two tones

- Below 500 Hz critical bandwidth is about 100 Hz (±50 Hz)
- Above 500 Hz critical bandwidth is about **20%** of the center frequency (±10%)

Each of the cochlea's 24 critical bands is about 1.2 mm on the basilar membrane and has about 1300 hair cells

Clicker Question 7.1 (revisited)

Two pure tones of the same loudness level are played together. In Case 1, they have frequencies of 100 Hz and 500 Hz, and in Case 2, the frequencies are 100 Hz and 110 Hz. In which case is the combined sound louder?

A) Case 1
B) Case 2
C) Same in both cases

Review

- Octave equivalence
- Missing fundamental
  - Combination tones (based on frequency difference)

1000 Hz  1500 Hz  combined  500 Hz 

steady  falling  combined 

- Speech-to-Song Illusion

recording  responses before 10 repeats  after 10 repeats 

Music

- Music: ordered patterns of sound in time

- Quadrivium (medieval curriculum) consisted of
  - ❖ arithmetic ↔ numbers
  - ❖ geometry ↔ numbers in space
  - ❖ music ↔ numbers in time
  - ❖ astronomy ↔ numbers in space and time

- Time signature: how many beats are in each measure

Examples:

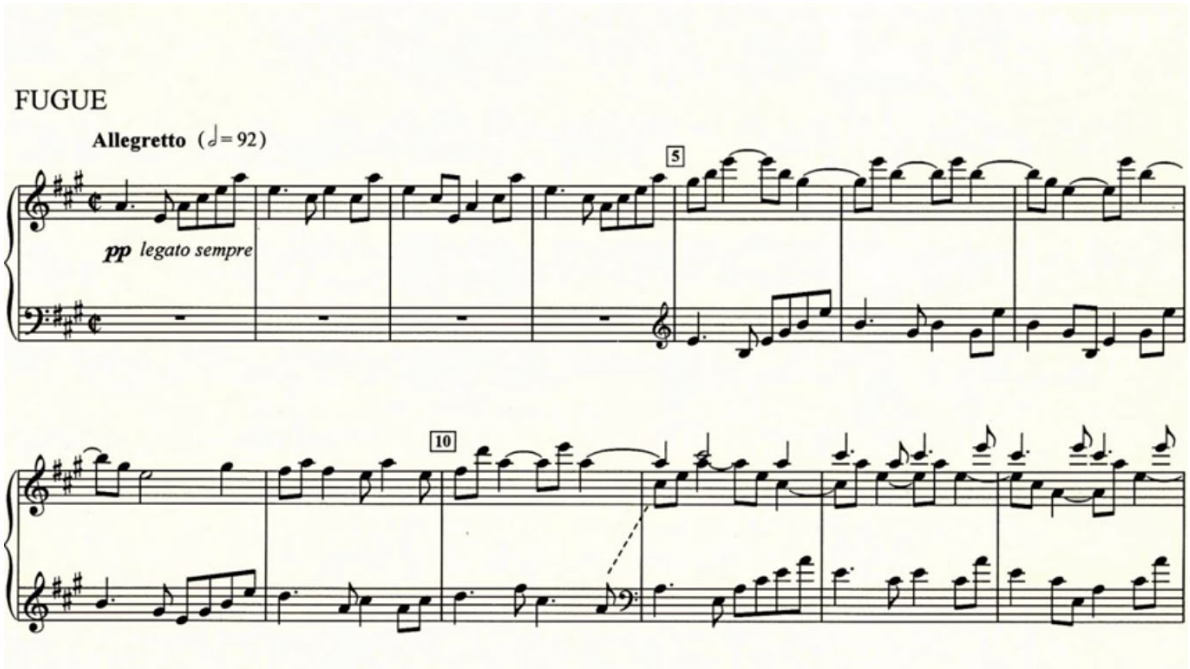
Yankee Doodle $\binom{4}{4}$, Dave Brubeck's "Take Five" $\binom{5}{4}$, Pink Floyd's "Money" (_)

Consonance and Dissonance

- Consonance: when notes “sound good” together (sweet, pleasant, acceptable)
- Dissonance: when notes “sound bad” together (harsh, unpleasant, unacceptable)

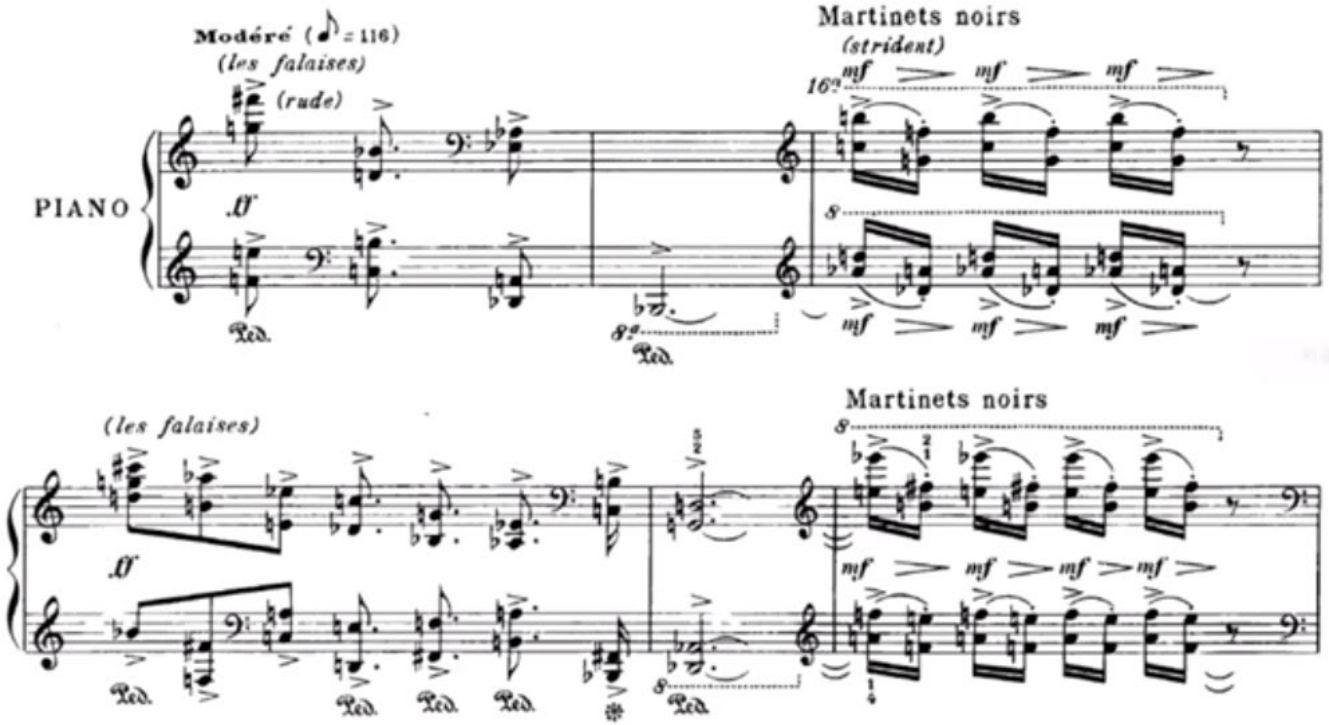
Shostakovich's Fugue in A Major

(complete consonance)



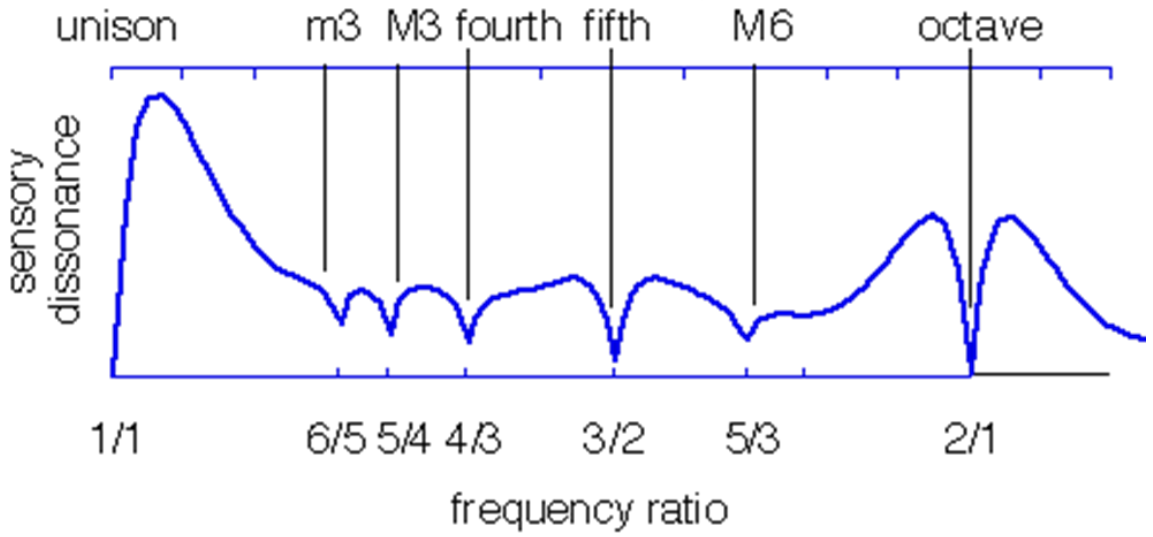
Messiaen's *Catalogue d'oiseaux*

(complete dissonance)

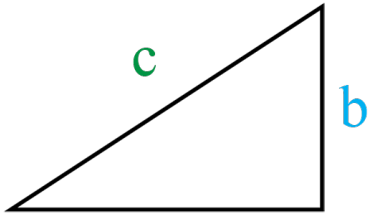


Consonance and Dissonance

- Cause?
  - Dissonance when 2 tones are within the same critical band (beats)
  - Dissonance when upper harmonics interfere (beats)
  - Consonance at “nice” whole number frequency ratios, when some upper harmonics exactly match



Pythagoras of Samos

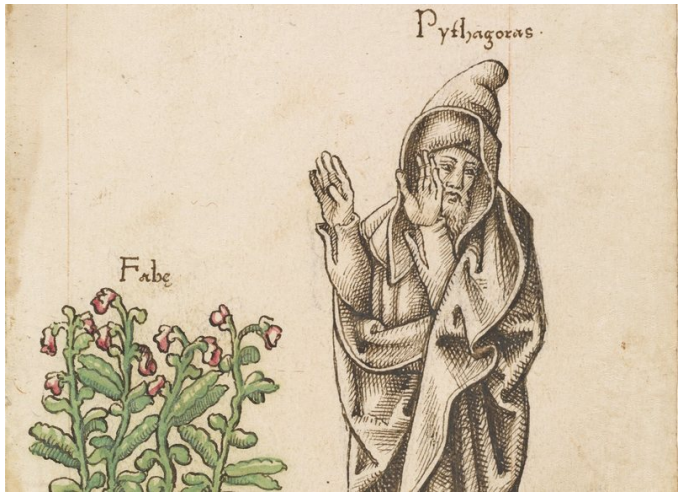


$a^2 + b^2 = c^2$

- 500s BCE
- Founded school of numerology
- Music of the spheres

- Pythagorean Hypothesis:

Consonant musical intervals are related to low integer ratios of frequencies

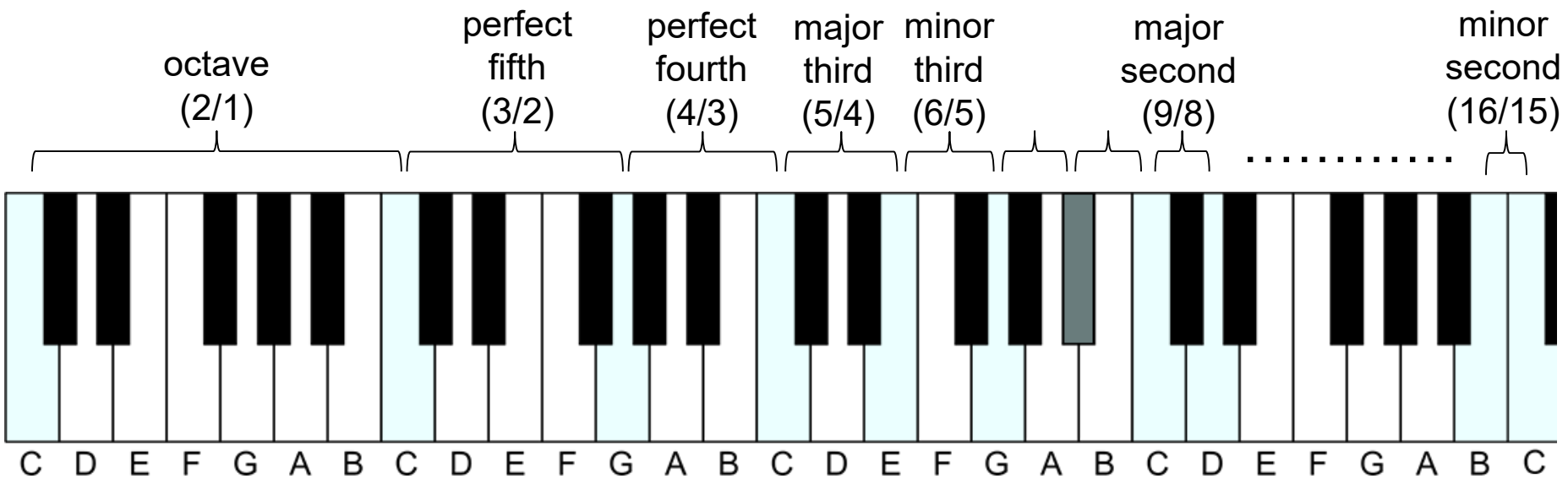


Pythagorean Intervals

- Harmonic Series:

$f,\quad 2f,\quad 3f,\quad 4f,\quad 5f,\quad 6f,\ldots$

	octave	perfect fifth	perfect fourth	major third	minor third
$(f_2/f_1=)$	(2/1)	(3/2)	(4/3)	(5/4)	(6/5)



BA

Clicker Question 8.1

If you sing a note at 300 Hz, what is the frequency of the note that is an interval of a perfect fifth above this note?

A) 200 Hz
B) 400 Hz
C) 450 Hz
D) 500 Hz
E) none of the above

BA

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If you sing a note at 300 Hz, what is the frequency of the note that is an interval of a perfect fifth above this note?

A) 200 Hz
B) 400 Hz
C) <u>450 Hz</u>
D) 500 Hz
E) none of the above

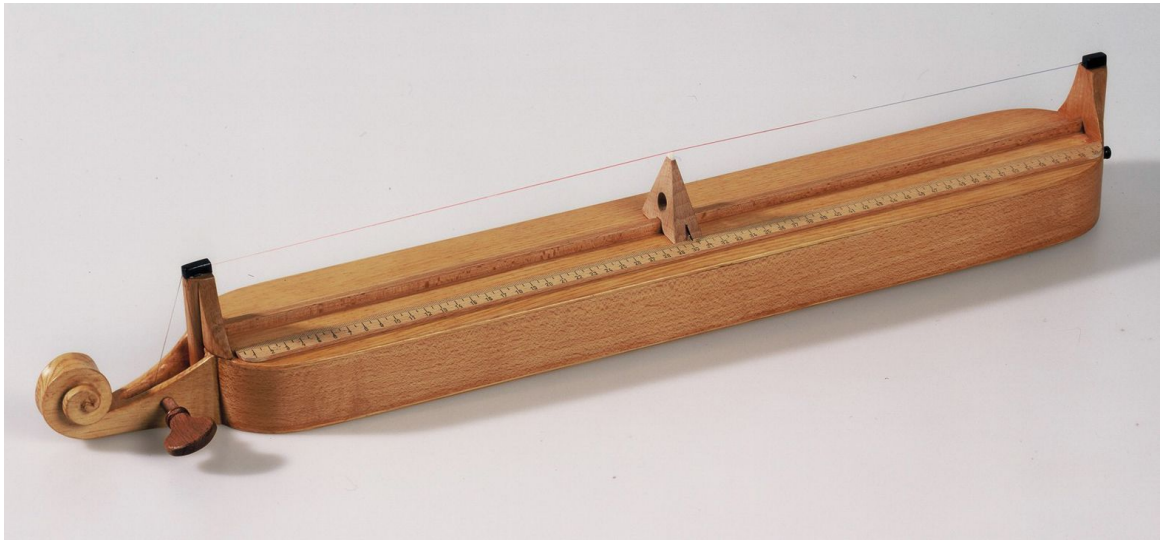
Perfect fifth = 3/2 ratio

$$(300\ \text{Hz}) \times \left(\frac{3}{2}\right) = 450\ \text{Hz}$$

Clicker Question 8.2

Two monochords are plucked to produce sound. One string is 50 cm long, and the other is 40 cm long. What is the musical interval between these plucked notes?

A) octave
B) tritone
C) perfect fourth
D) major third
E) minor third



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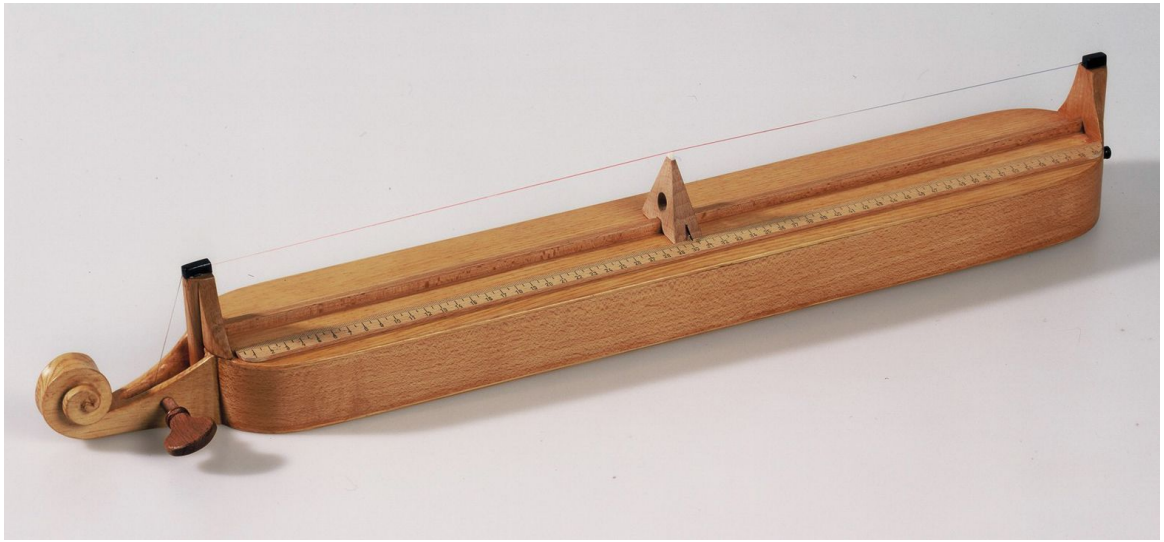


BA

Clicker Question 8.3

A note is played at 100 Hz. Then, the pitch moves up by a perfect fourth, then it moves up by a perfect fifth. What is the new frequency?

A) 100 Hz
B) 133 Hz
C) 150 Hz
D) 180 Hz
E) 200 Hz

BA

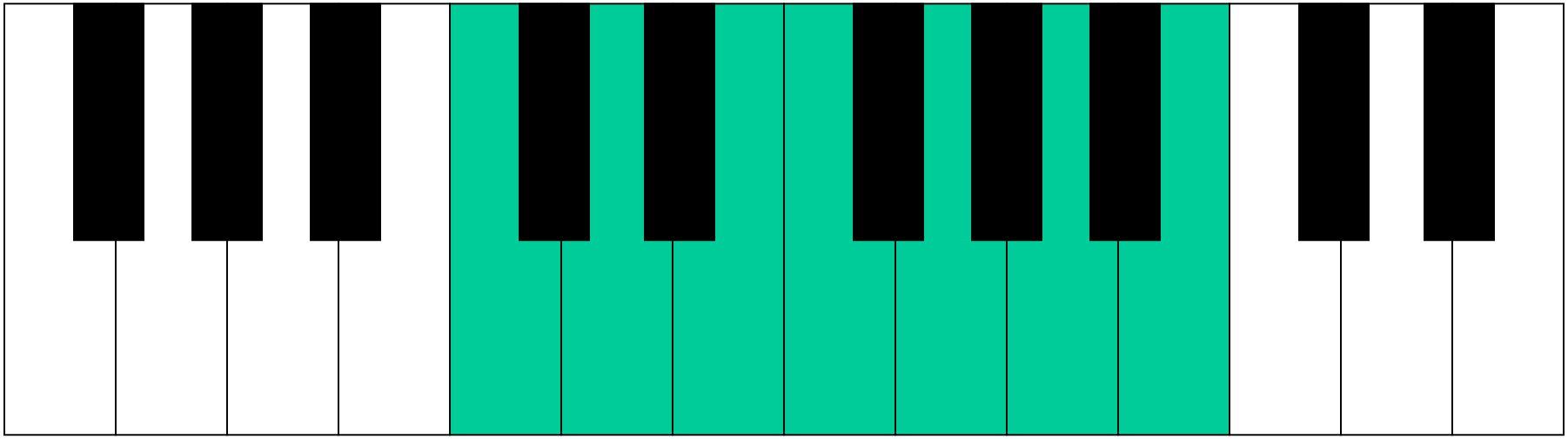
Clicker Question 8.3

A note is played at 100 Hz. Then, the pitch moves up by a perfect fourth, then it moves up by a perfect fifth. What is the new frequency?

A) 100 Hz
B) 133 Hz
C) 150 Hz
D) 180 Hz
E) 200 Hz

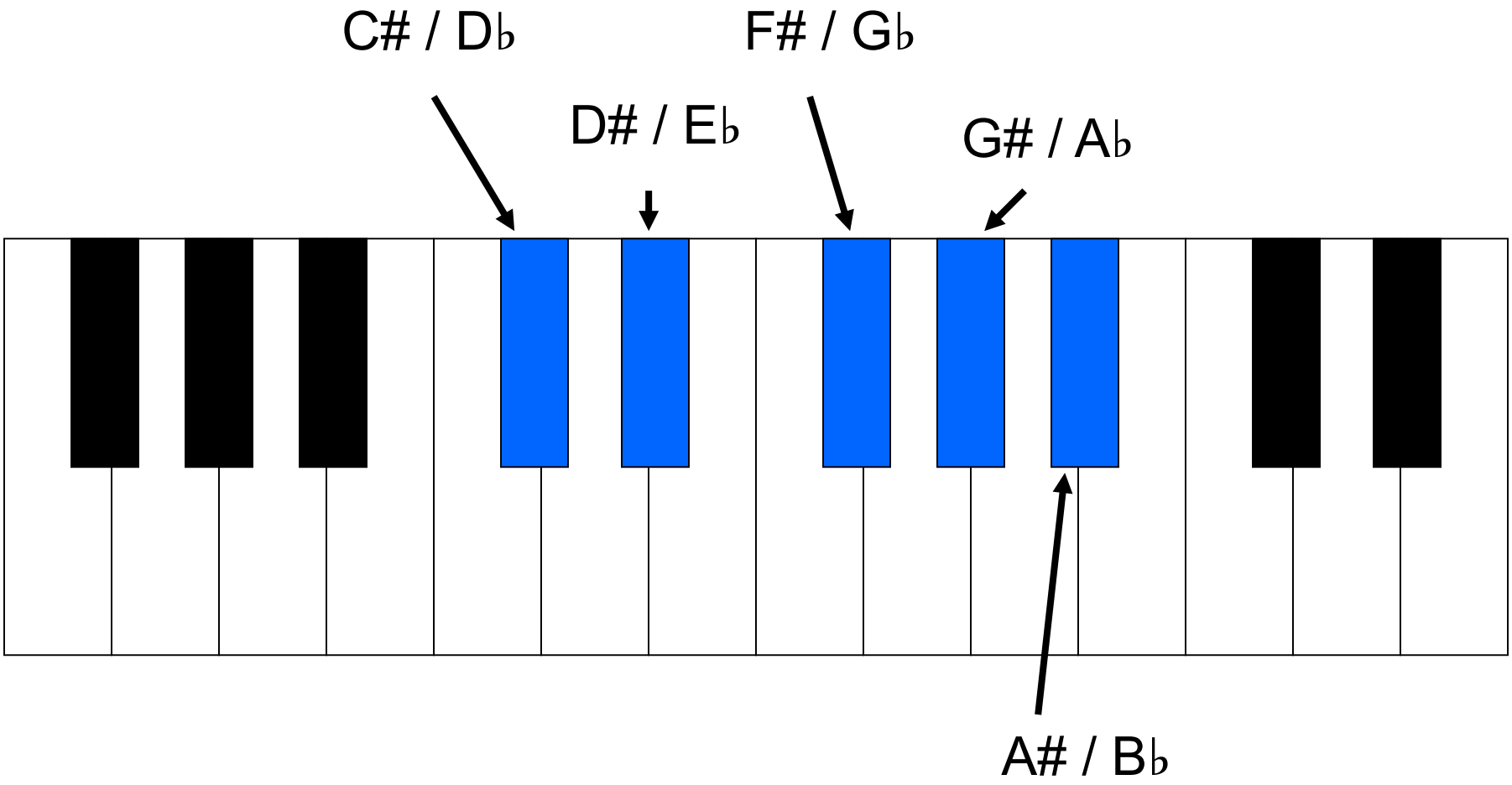
$$(100\ \text{Hz}) \times \left(\frac{3}{2}\right) \times \left(\frac{4}{3}\right) = 200\ \text{Hz}$$

The Piano Keyboard

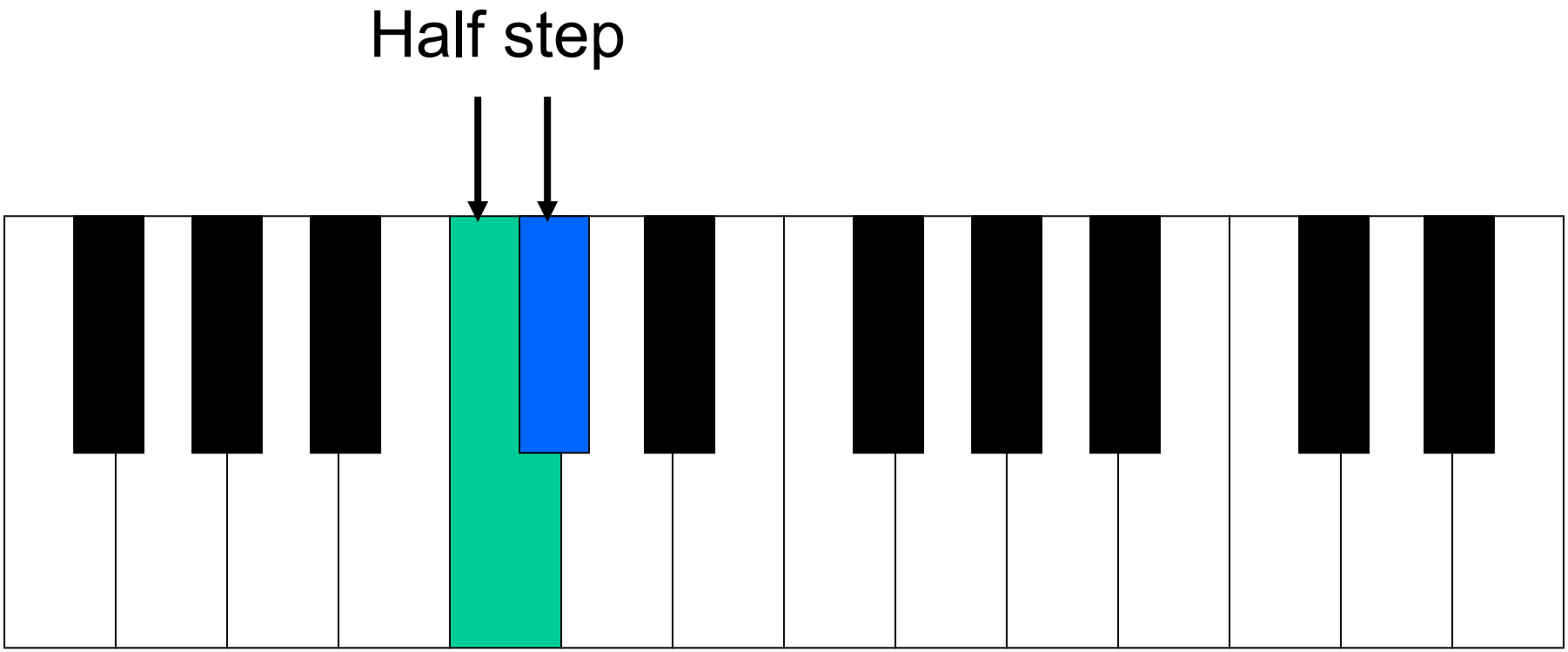


C D E F G A B

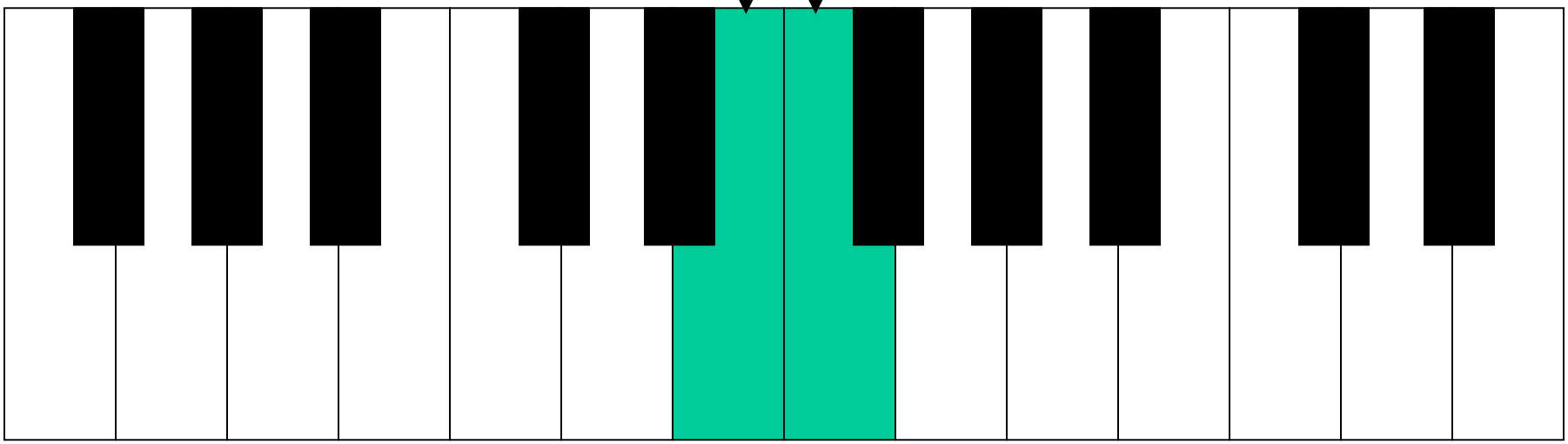
The Piano Keyboard



Half step or semitone

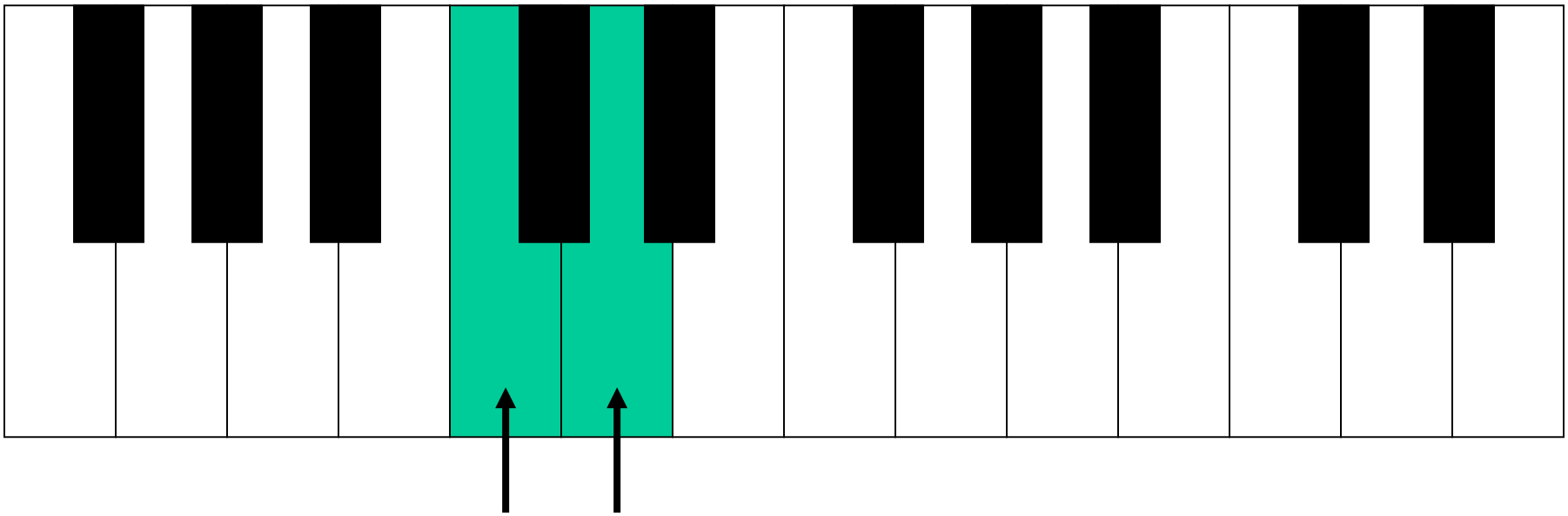


Half step



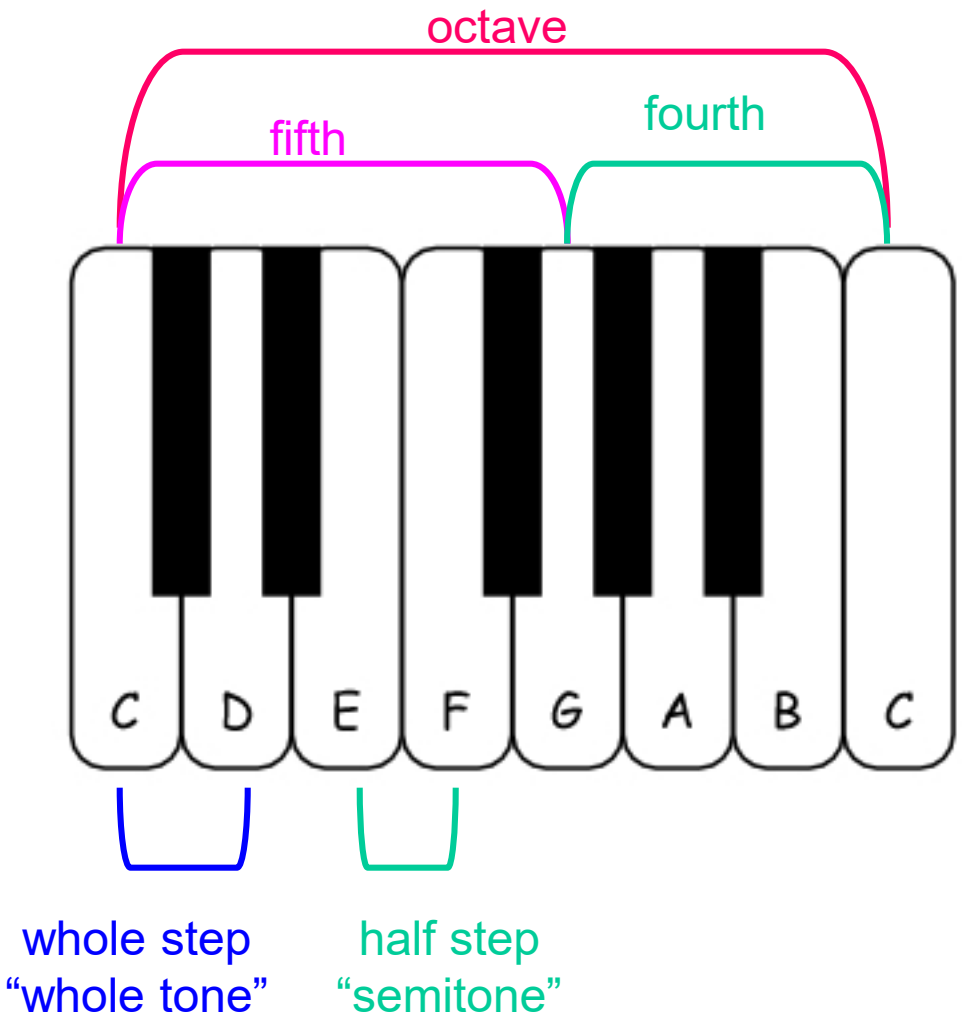
Whole step or whole tone

whole step = two half steps



Whole step

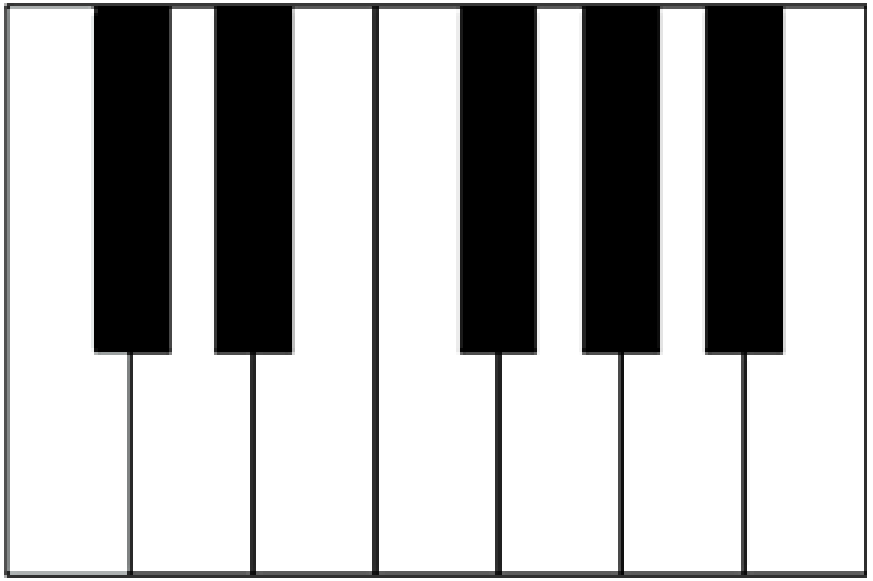
Intervals on the Piano Keyboard



Interval	Frequency ratio	# of half steps
Octave	2/1	12
Perfect fifth	3/2	7
Perfect fourth	4/3	5
Major third	5/4	4
Minor third	6/5	3

Just Tuning

- Based on lowest integer frequency ratios



Ratio to C: $\frac{1}{1}$ $\frac{9}{8}$ $\frac{5}{4}$ $\frac{4}{3}$ $\frac{3}{2}$? ? $\frac{2}{1}$

Just Tuning

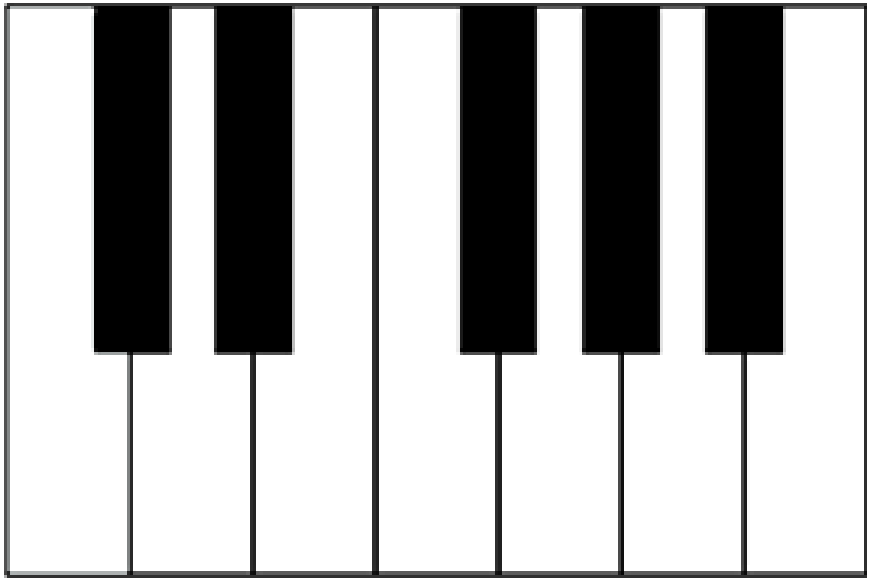
- For A, go up a perfect fourth then up a major third:
  $\left(\frac{4}{3}\right) \times \left(\frac{5}{4}\right) = \frac{5}{3}$
- For B, go up a perfect fifth then up a major third:
  $\left(\frac{3}{2}\right) \times \left(\frac{5}{4}\right) = \frac{15}{8}$

  or, from A, go up a major second:
  $\left(\frac{5}{3}\right) \times \left(\frac{9}{8}\right) = \frac{15}{8}$

Ratio to C: $\frac{1}{1}$ $\frac{9}{8}$ $\frac{5}{4}$ $\frac{4}{3}$ $\frac{3}{2}$? ? $\frac{2}{1}$

Just Tuning

- Based on lowest integer frequency ratios



	C	D	E	F	G	A	B	C
Ratio to C:	$\frac{1}{1}$	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	$\frac{2}{1}$