A Brief Introduction to Musical Acoustics

EELE217

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Harmonic and Inharmonic Sounds

- Musical instruments with simple oscillators usually produce periodic waveforms
- Periodic waveforms have a fundamental frequency, f_0, and a *harmonic* spectrum: spectral energy just at frequencies that are integer multiples of f_0.
- These harmonic components are called *harmonics*, *overtones*, or *partials* .
- Some musical instruments produce inharmonic sounds: bells, drums, etc.

Pitch

- Musical sounds often have a *pitch* that is related to the sound's spectral content
- The pitch of a harmonic sound is usually close to the fundamental frequency of that sound
- Inharmonic sounds may have a perceived pitch, but it is not merely the fundamental of some harmonic series

Organization of Western Music

- Two harmonic sounds with different fundamental frequencies can lead to interesting frequency coincidences among their partials
- When the fundamentals have a low integer ratio relationship, this is a *consonant* interval

Consonant Intervals

Unison	3rd	4th	5th	Octave
1/1	5/4	4/3	3/2	2/1
100	125	133.33	150	**200**
200	250	266.67	**300**	**400**
300	375	**400**	450	**600**
400	**500**	533.33	**600**	**800**
500	625	666.67	750	**1000**
600	750	**800**	**900**	**1200**
700	875	933.33	1050	**1400**
800	**1000**	1066.67	**1200**	**1600**
900	1125	**1200**	1350	**1800**
1000	1250	1333.33	**1500**	**2000**
1100	1375	1466.67	1650	**2200**
1200	**1500**	**1600**	**1800**	**2400**
1300	1625	1733.33	1950	**2600**
1400	1750	1866.67	**2100**	**2800**
1500	1875	**2000**	2250	**3000**
1600	**2000**	2133.33	**2400**	**3200**

Musical Scales and Temperament

- European music is based on the notion of a diatonic pitch *scale*. The scale specifies the allowable musical pitches: 8 scale steps out of 12.
- Problem: if integer frequency ratios are used (*Just* intonation), chords only sound in tune if based on fundamental (*tonic*) pitch. Changing musical "key" is not possible.

Equal Tempered Scale

- To solve the musical "key" problem, keyboard instruments now use *equal-tempered* tuning.
- Note frequencies are distributed uniformly in a logarithmic span:

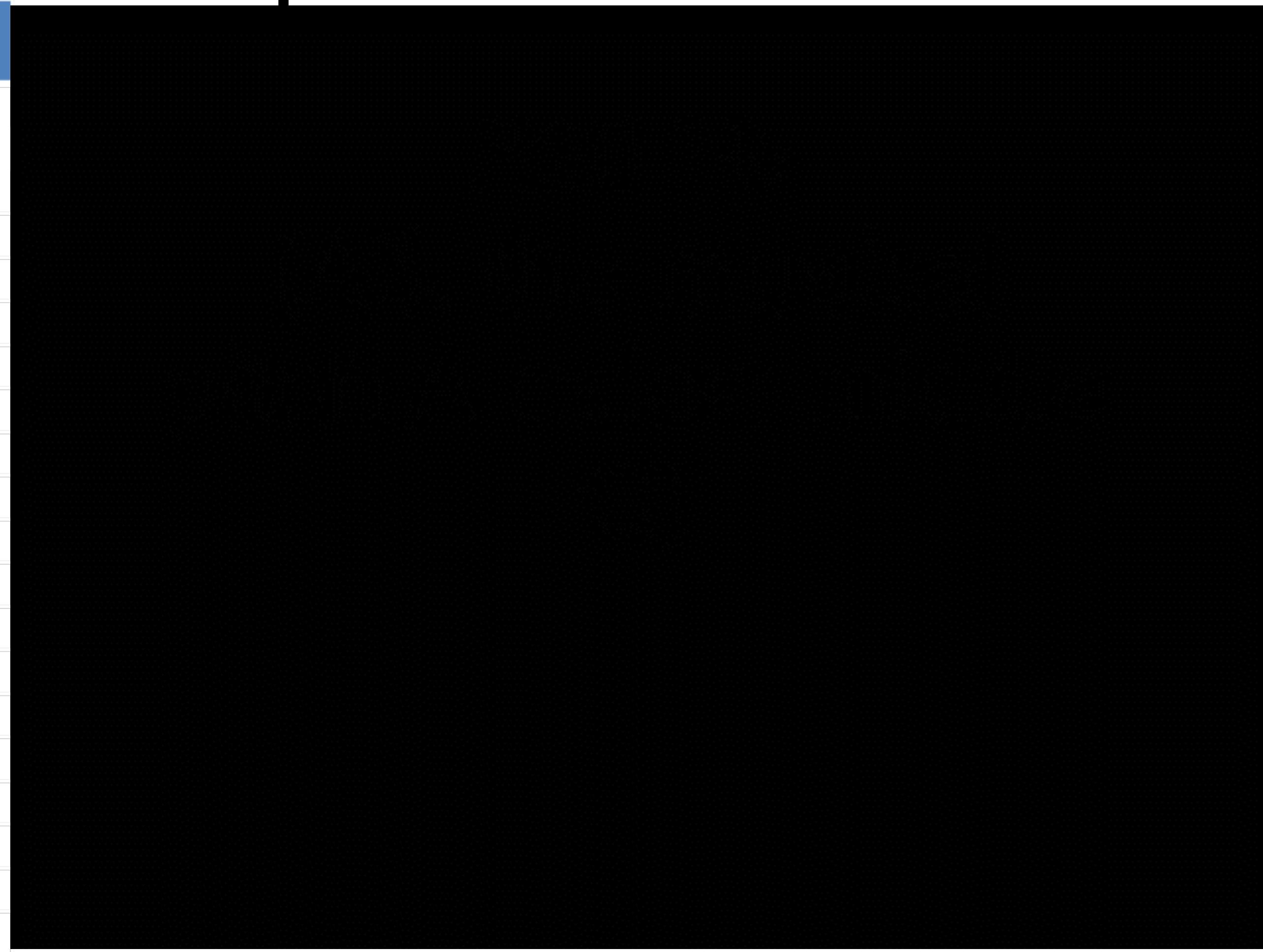
$$f_n = f_0 \times 2^{n/12}$$

- Just vs. equal tempered tuning:

Unison	3rd	4th	5th	Octave
100	125.0000	133.3333	150.0000	200.0000
100	125.9921	133.4840	149.8307	200.0000

Tuning Example

Unison	3/2 (5th)	Octave		ET 3/2 (et 5th)	delt f
220					
	330			329.63	0.37
440		440			
660	660			659.26	0.74
880		880			
	990			988.88	1.12
1100					
1320	1320	1320		1318.51	1.49
1540					
	1650			1648.14	1.86
1760		1760			
1980	1980			1977.77	2.23
2200		2200			
	2310			2307.39	2.61
2420					
2640	2640	2640		2637.02	2.98



Equal Temperament vs. Just

	3rd		4th		5th		octave
1/1	*5/4*	*1.259921*	*4/3*	*1.33484*	*3/2*	*1.498307*	*2/1*
100	125	125.99	133.33	133.48	150	149.83	200
200	250	251.98	266.67	266.97	300	299.66	400
300	375	377.98	400.00	400.45	450	449.49	600
400	500	503.97	533.33	533.94	600	599.32	800
500	625	629.96	666.67	667.42	750	749.15	1000
600	750	755.95	800.00	800.90	900	898.98	1200
700	875	881.94	933.33	934.39	1050	1048.81	1400
800	1000	1007.94	1066.67	1067.87	1200	1198.65	1600
900	1125	1133.93	1200.00	1201.36	1350	1348.48	1800
1000	1250	1259.92	1333.33	1334.84	1500	1498.31	2000
1100	1375	1385.91	1466.67	1468.32	1650	1648.14	2200
1200	1500	1511.91	1600.00	1601.81	1800	1797.97	2400
1300	1625	1637.90	1733.33	1735.29	1950	1947.80	2600
1400	1750	1763.89	1866.67	1868.78	2100	2097.63	2800
1500	1875	1889.88	2000.00	2002.26	2250	2247.46	3000
1600	2000	2015.87	2133.33	2135.74	2400	2397.29	3200

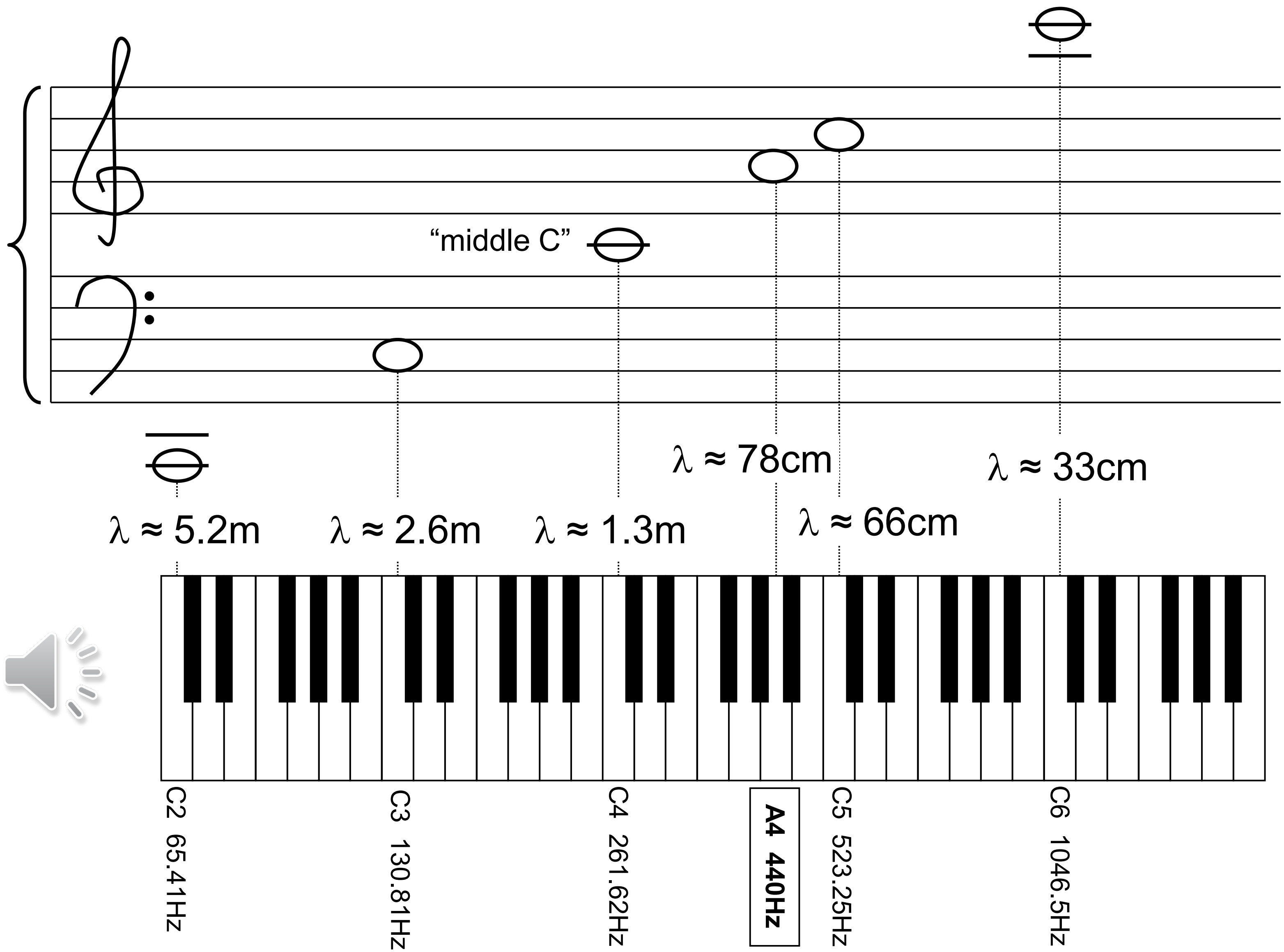
Rhythm

- Beats per minute
- Beats per measure (time signature)
- Duration of musical notes specified in fractions:
  whole, half, quarter, eighth, sixteenth, 32^{nd}

Musical Notation

- Notation specifies pitches, durations, and time evolution
- Representation is like a spectrogram: frequency vs. time

Standard Tuning Frequencies



Musical Timbre

- The relative spectral energy at different frequencies is perceived as a distinct *tone color*, or timbre (pronounced as either *tam--burr* or *tim-burr*)
- Timbre: The combination of qualities of a sound that distinguishes it from other sounds of the same pitch and volume

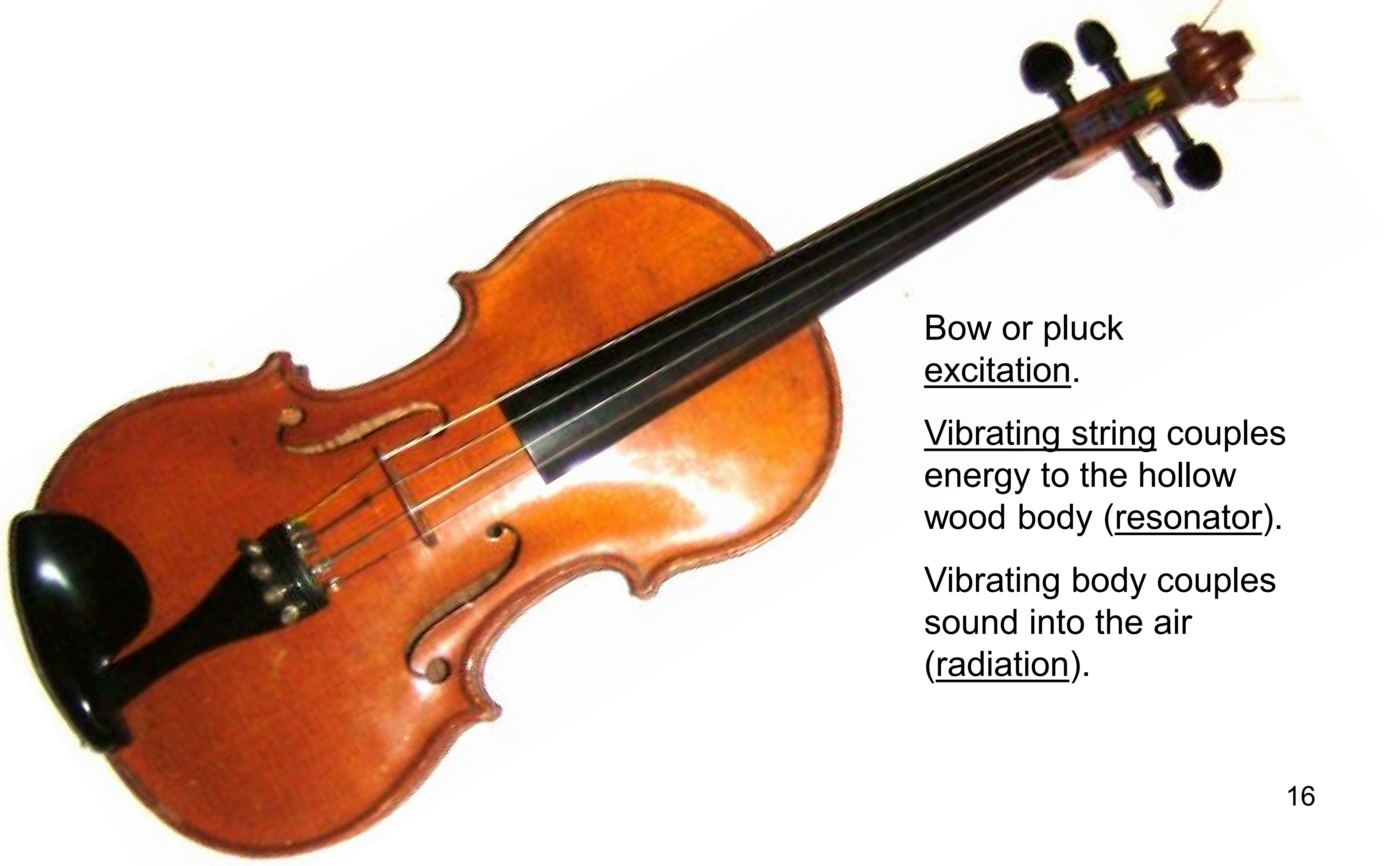
Musical Instruments

- Almost any object can be considered a musical instrument
- Most *conventional* musical instruments have
  - an *excitation source*
  - a *vibrating element*
  - a *resonant body*
  - a means of *coupling* the vibrations so that they radiate into the air as sound waves

Musical Instruments (cont.)

- The excitation is a motive force
- The vibrating element usually creates many harmonics
- The resonant body emphasizes some frequencies and deemphasizes others
- The coupling means takes energy from the vibrating element and “loses” it (radiates) into an acoustical wave through the air

Example: String Instrument

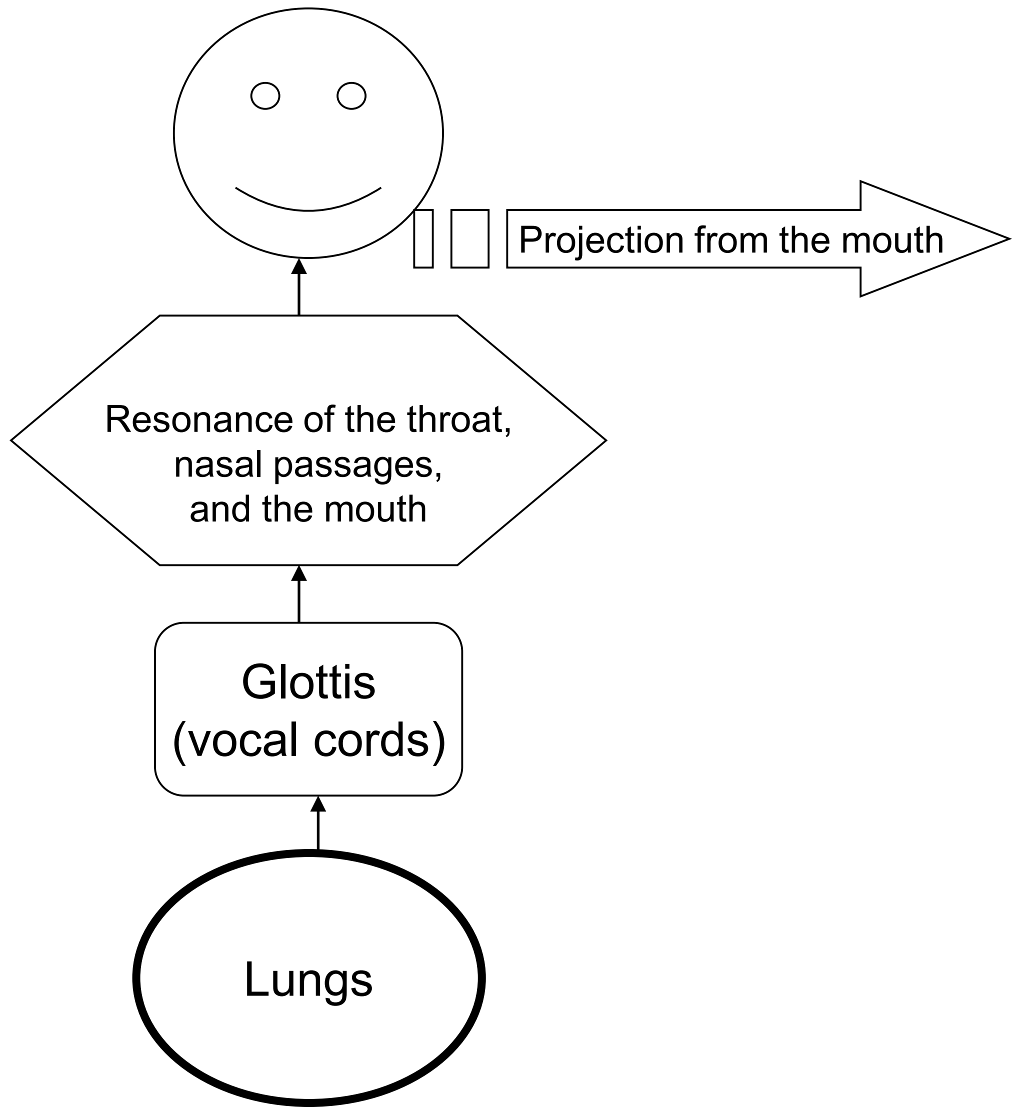


Bow or pluck <u>excitation</u>.

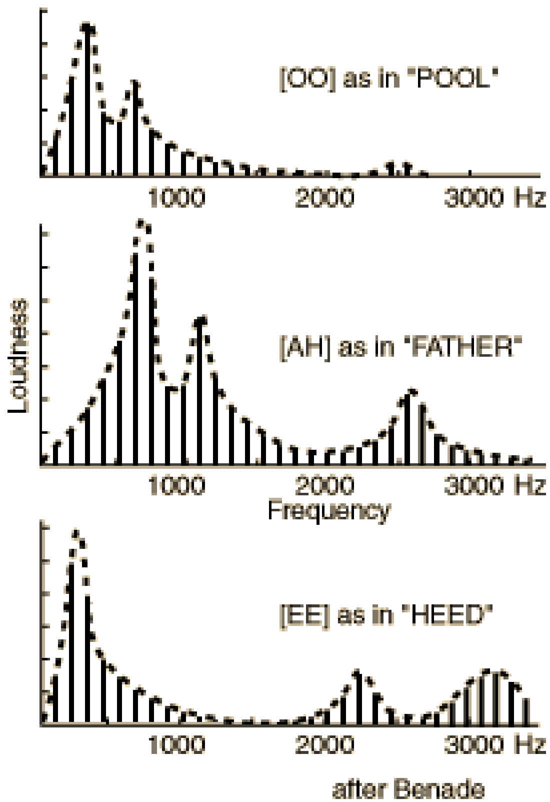
<u>Vibrating string</u> couples energy to the hollow wood body (<u>resonator</u>).

Vibrating body couples sound into the air (<u>radiation</u>).

Example: Singing Voice



Simulation: Excitation and Filter



- Signal rich in harmonics (a “buzz”) with spectral shaping

- Does it sound like singing? Does the vibrato help?