



UNIVERSITY of  
ROCHESTER

# PHY 103

# Auditory Illusions

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# Reading

▶ Reading for this week:

- *Music, Cognition, and Computerized Sound: An Introduction to Psychoacoustics* by Perry Cook

# Auditory Illusions

- ▶ Pitch
- ▶ Scale
- ▶ Beat
- ▶ Timbre

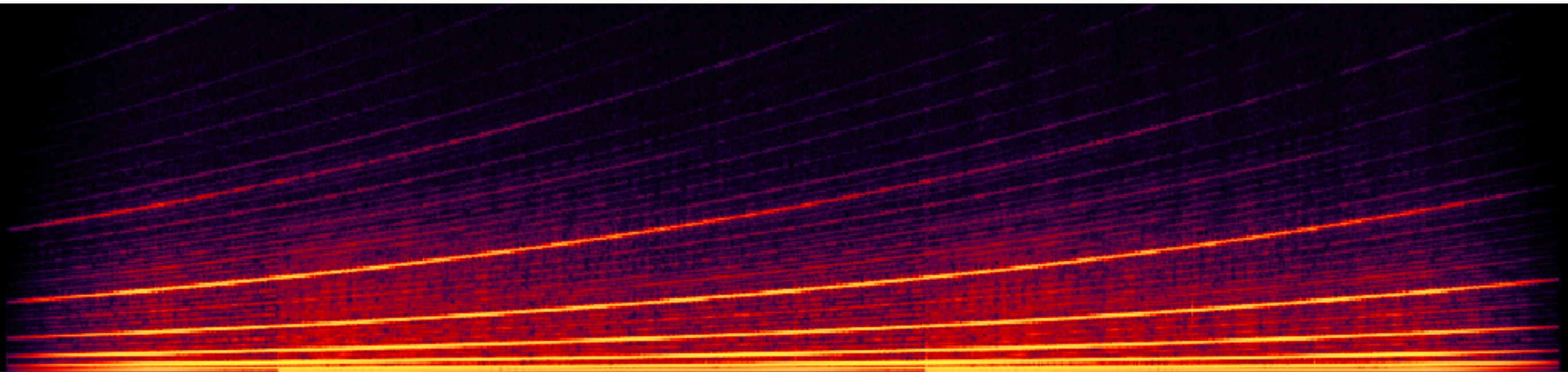
# Rising Pitch

- ▶ Listen to this tone. What happens to the pitch from start to finish?
- ▶ Now, listen to the **same exact clip** once again. I promise you it's the same audio file, played in the same way
- ▶ What do you hear? How is this possible?
- ▶ Let's try a similar clip, this time with continuous notes



# Shepard Tone

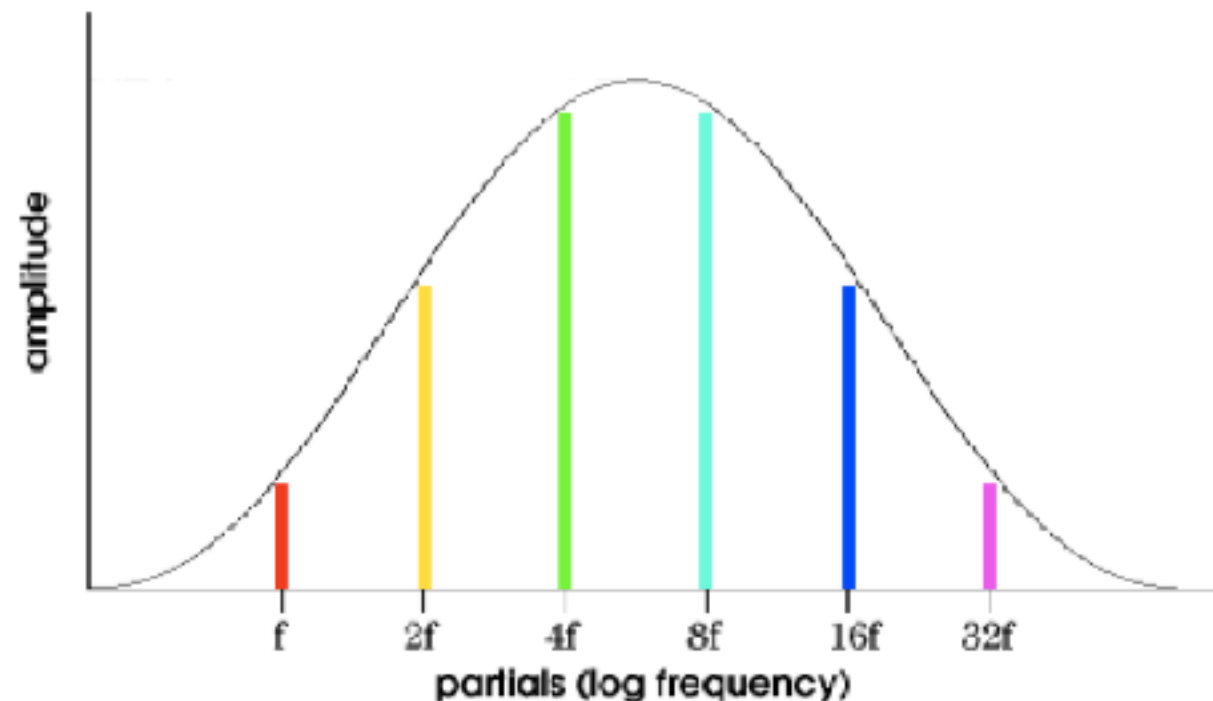
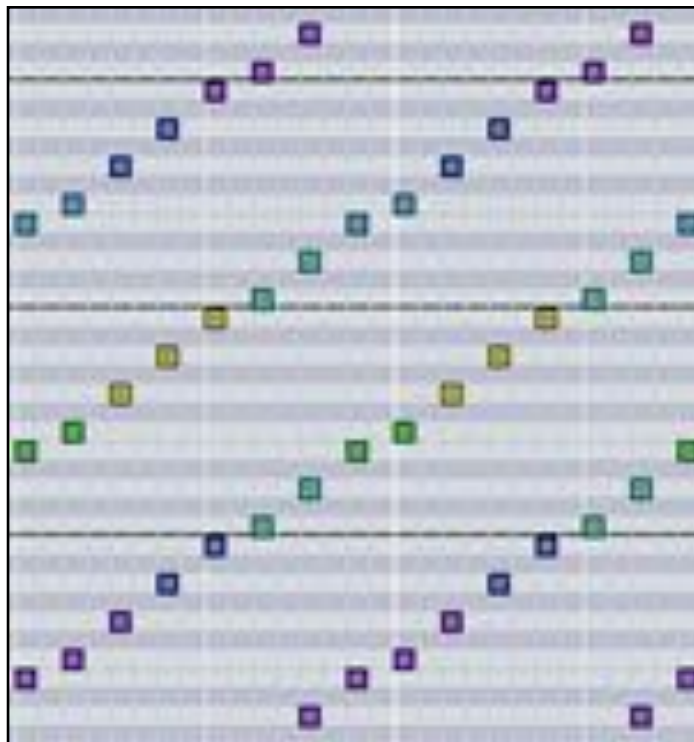
- ▶ The clips you heard are examples of Shepard tones (after Roger Shepard, cognitive scientist)



- ▶ The tone is actually a set of sinusoidal partials one octave apart, with an envelope that goes to zero at low and high frequencies
- ▶ Increase frequencies by a semitones, giving impression of rising pitch. After 12 semitones, we arrive back where we started

# The Shepard Scale

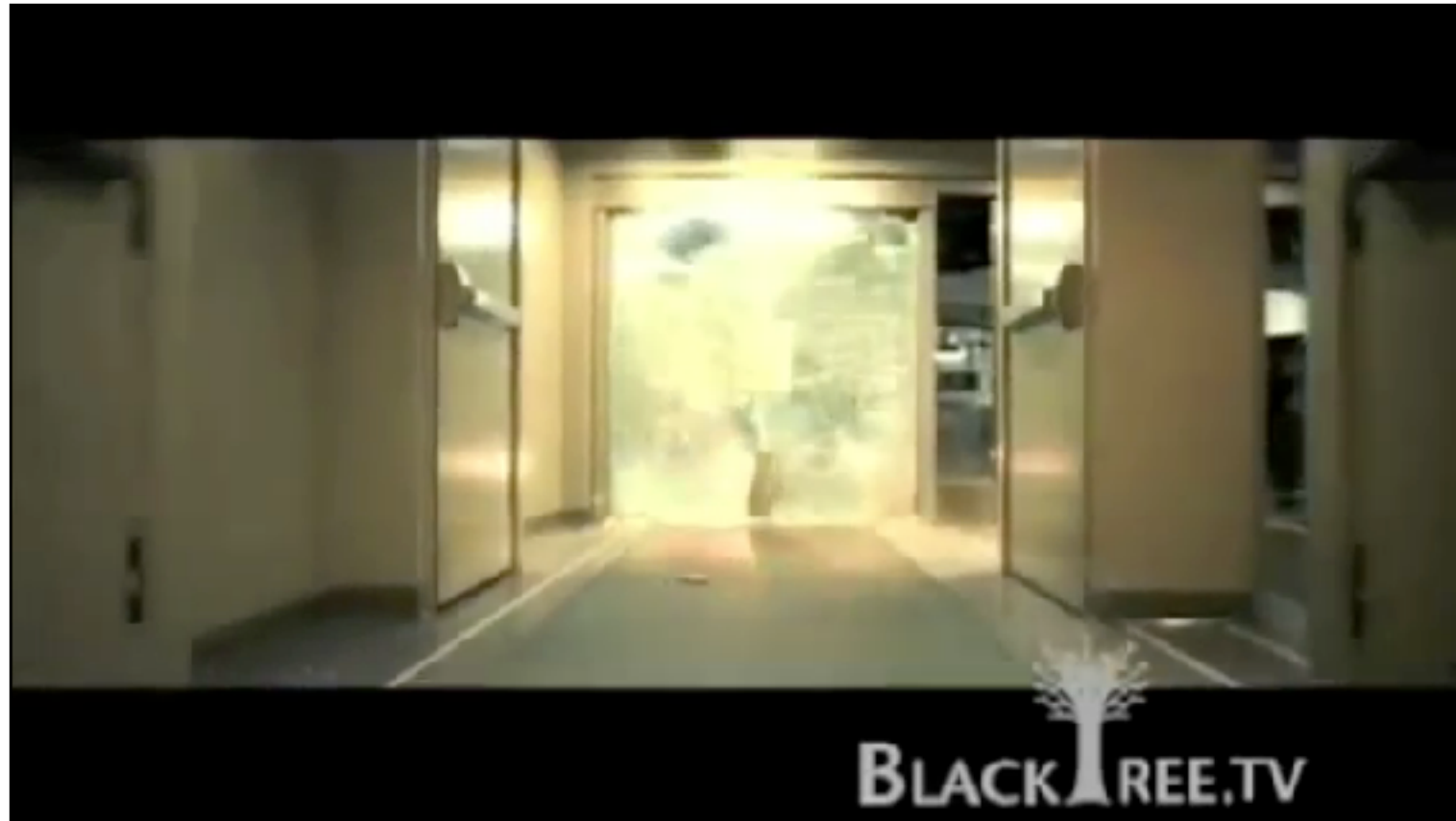
- ▶ The tones in the Shepard scale are shown at left, and the intensity envelope is shown on the right



- ▶ Overlapping tones are one octave apart
- ▶ We can't hear the tones at the ends, so it's hard to perceive the repetition point in the pitch

# Shepard Tone in Pop Culture

*The Dark Knight*, Warner Bros. (2008)

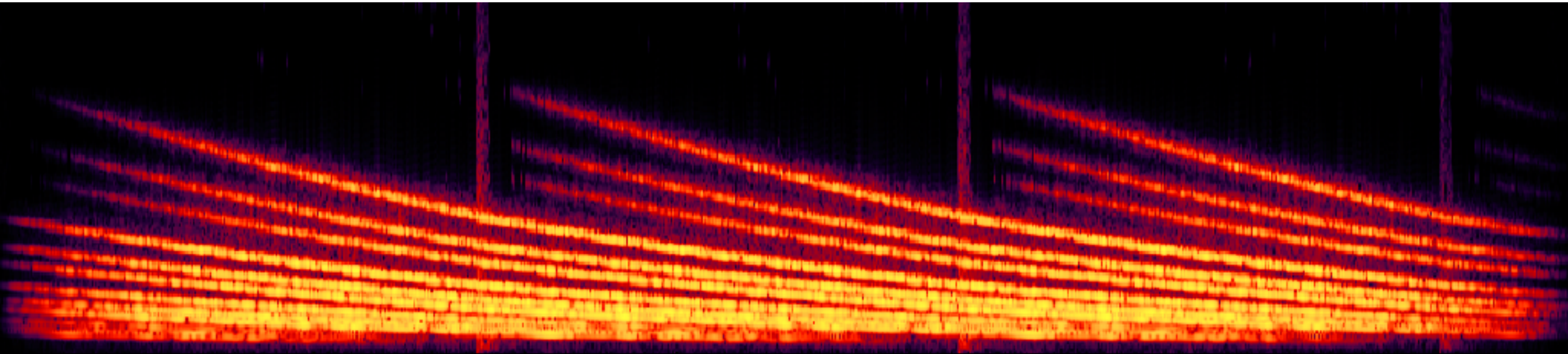


- ▶ Richard King, Sound Designer (*The Dark Knight*), *LA Times*, February 2009: “I used the concept of the **Shepard tone** to make the sound appear to continually rise in pitch. The basic idea is to slightly overlap a sound with a distinct pitch (a large A/C electric motor, in this case) in different octaves. When played on a keyboard, **it gives the illusion of greater and greater speed**; the pod appears unstoppable.”



# Descending Shepard Tone

- ▶ No reason that the sequences has to step up by semitones
- ▶ We can also create an infinitely descending sonic staircase

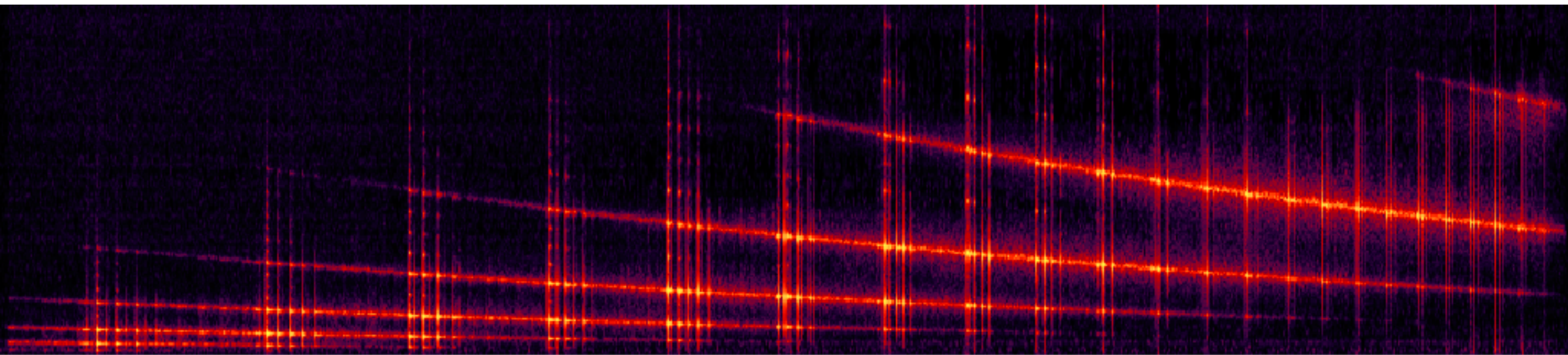


- ▶ A little depressing?



# Falling Bells Illusion

- ▶ Bells sound as if they are falling through space, and the pitch drops continuously
- ▶ Actually, the pitch ends **higher** than where it started

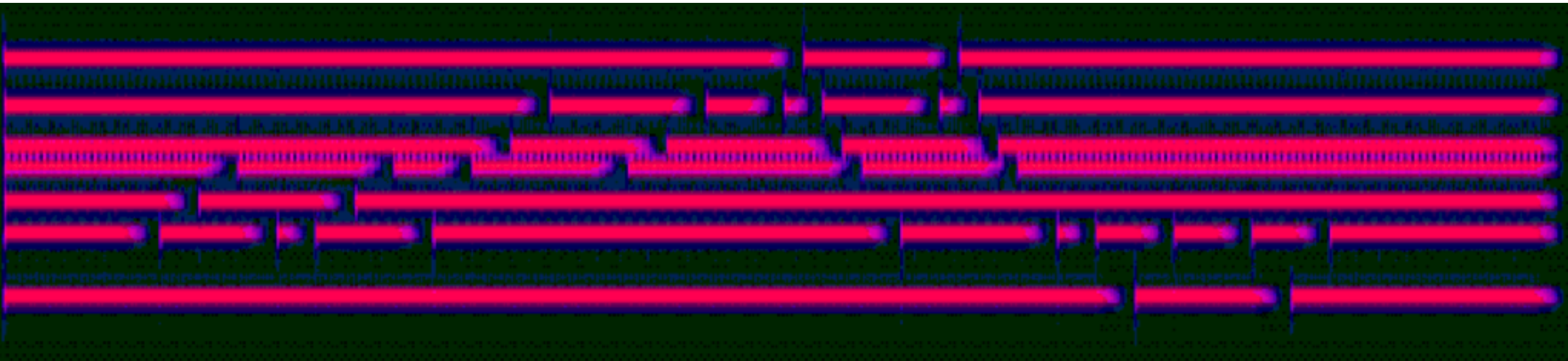


- ▶ Same trick as the Shepard scale, plus playing a bit with stereo

# Filling in Melodies

- ▶ Start with a set of tones and then insert silences
- ▶ We don't perceive the silences, but we do perceive the tones when they restart

Yoshitaka Nakajima et al., *Demonstrations of Auditory Illusions*



- ▶ We interpret the result as a clear melody. Do you hear it?

# Reflection in Composition

- ▶ Bartók, Mikrokosmos Vol. 6, No. 141, “Subject and Reflection”
- ▶ Two melodies are played: one goes up while the other goes down, and vice versa
- ▶ Can you pick out the reflective tonal symmetry without seeing the music?

# Reflection in Composition

141

Allegro, ♩ = 136 - 144

*f, ben ritmato* *più f*

This system contains measures 141 through 144. It features a treble clef and a bass clef. The tempo is marked 'Allegro' with a quarter note equal to 136-144 beats. The first measure of measure 141 is marked with a first ending bracket. The dynamics are 'f, ben ritmato' and 'più f'.

*p* *mf*

This system contains measures 141 through 144. It features a treble clef and a bass clef. The dynamics are 'p' and 'mf'.

Più mosso, ♩ = 156

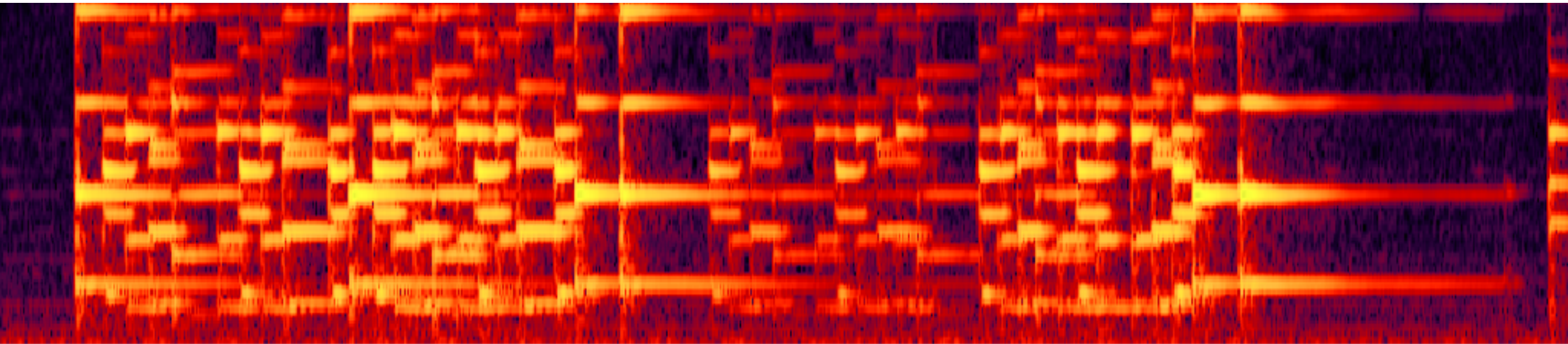
*f* *p* *f*

This system contains measures 141 through 144. It features a treble clef and a bass clef. The tempo is marked 'Più mosso' with a quarter note equal to 156 beats. The dynamics are 'f', 'p', and 'f'. There are triplets in the bass line of measures 142 and 143.



# Reflection in Composition

- ▶ Is the reflective tonal symmetry easy for you to see in the spectrogram?



- ▶ Is it easier for you to *see* the reflective tonal symmetry rather than *hear* it?

# Time Reversal

- ▶ There is also a long tradition of arranging music in so-called crab canons (or retrograde canons)
- ▶ Two lines are arranged complementary and backwards, like a palindrome

Canon a 2.

1.

The image displays a musical score for 'Canon a 2.' by J.S. Bach. It consists of two staves of music. The first staff is the original melody, and the second staff is its retrograde (time-reversed) version. The music is in G minor (three flats) and 3/4 time. The first staff begins with a treble clef and a common time signature (C), which is then changed to 3/4. The second staff begins with a bass clef and a common time signature (C), which is then changed to 3/4. The music is written in a single system, with the two staves connected by a brace on the left. The first staff is labeled '1.' and the second staff is labeled '2.'. The music is written in a single system, with the two staves connected by a brace on the left. The first staff is labeled '1.' and the second staff is labeled '2.'. The music is written in a single system, with the two staves connected by a brace on the left. The first staff is labeled '1.' and the second staff is labeled '2.'.

- ▶ Example: *A Musical Offering* by Bach

# Sensory Integration Illusion

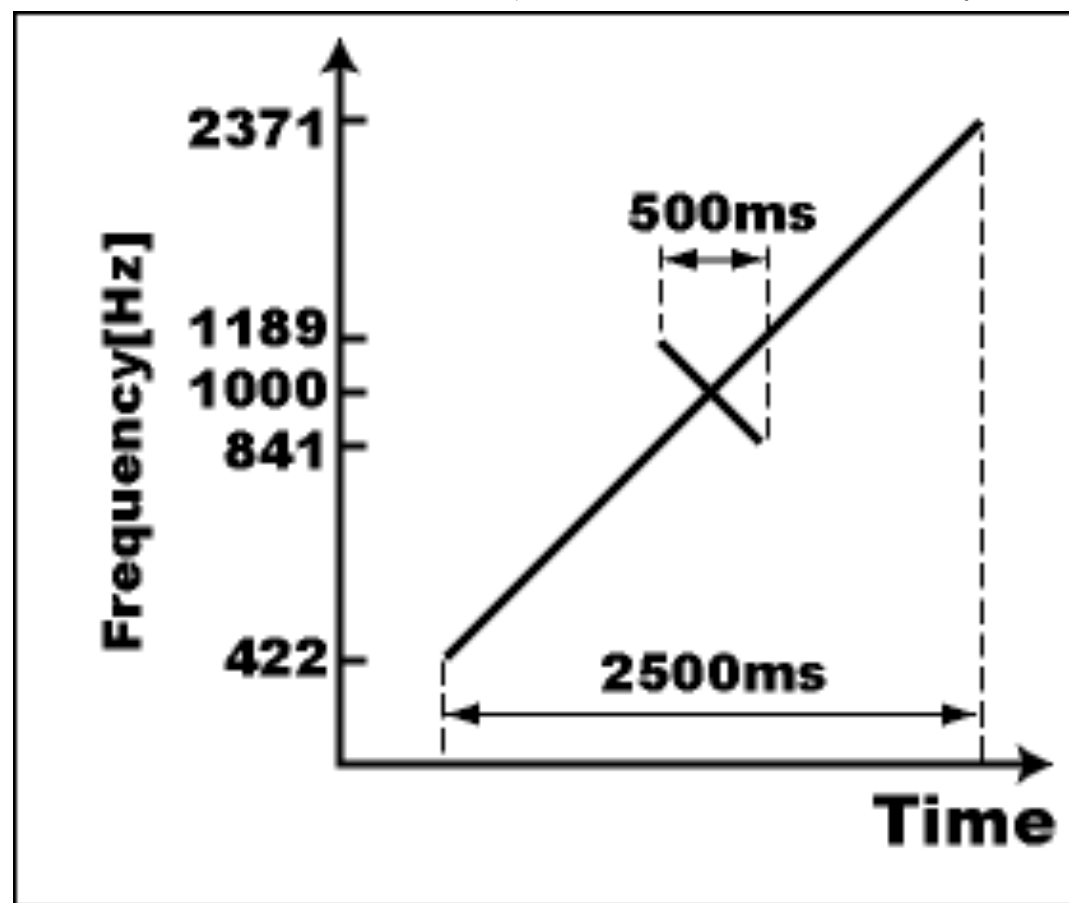
- ▶ McGurk Effect: “hearing” with the visual system first!



# Gap Transfer Illusion

- ▶ Long ascending glide and short descending glide tones cross

Yoshitaka Nakajima et al., *Demonstrations of Auditory Illusions*



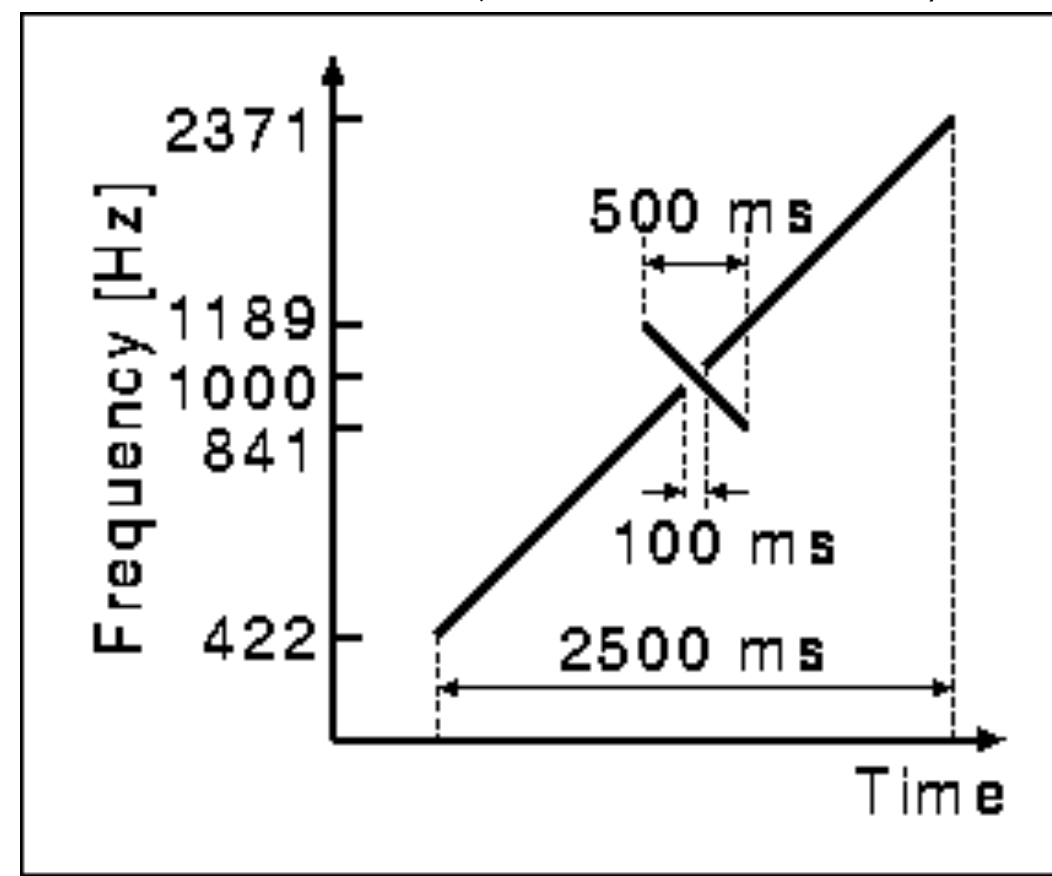
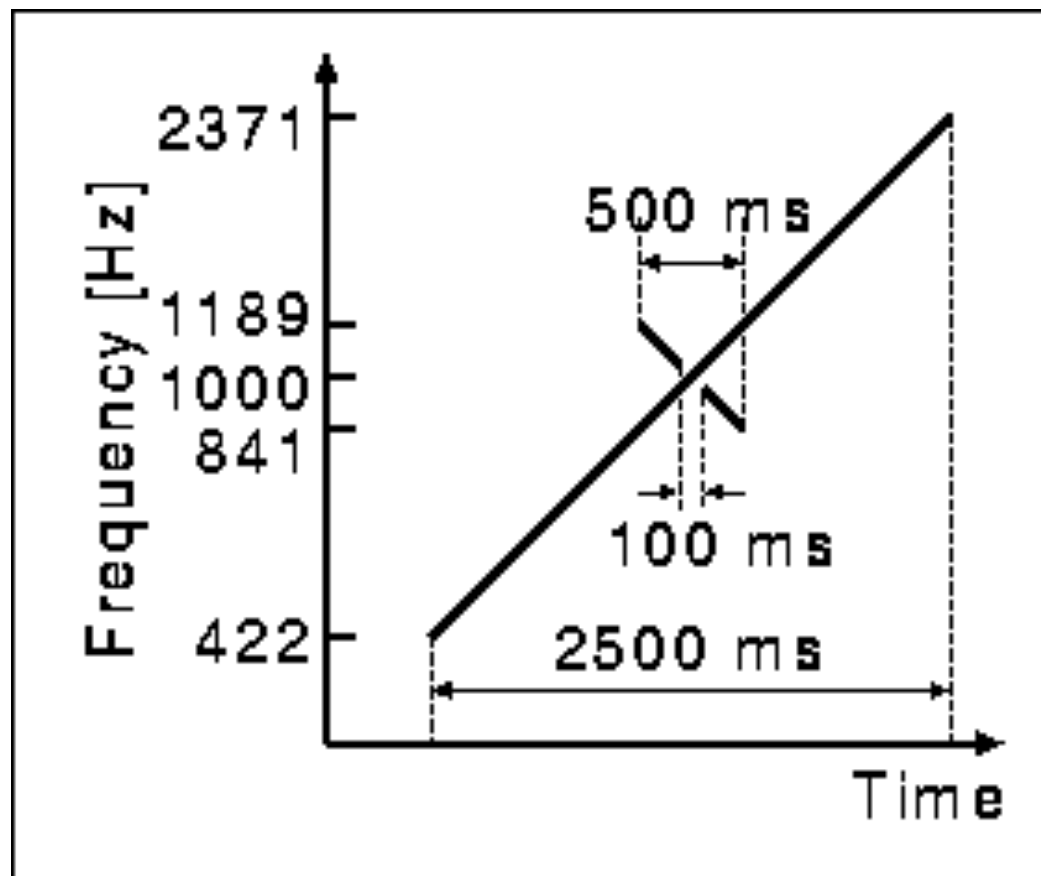
- ▶ A “bounce” is often **perceived** in the gliding tones



# Gap Transfer Illusion (2)

- ▶ Pattern is disrupted by a 0.1 second gap, first in the descending glide, then in the ascending

Yoshitaka Nakajima et al., *Demonstrations of Auditory Illusions*

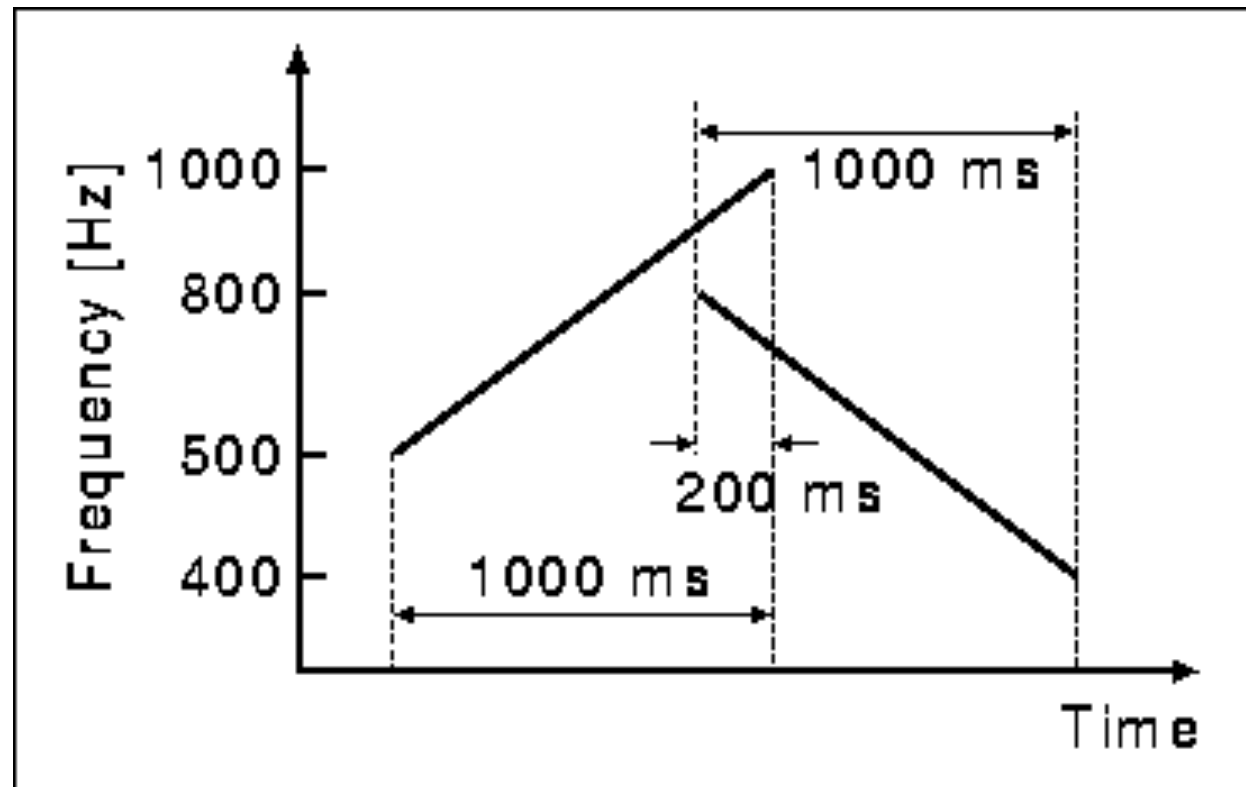


- ▶ People tend to **perceive these as identical**

# Split-Off Illusion

- ▶ An ascending and descending glide tone overlap for 0.2 s

Yoshitaka Nakajima et al., *Demonstrations of Auditory Illusions*

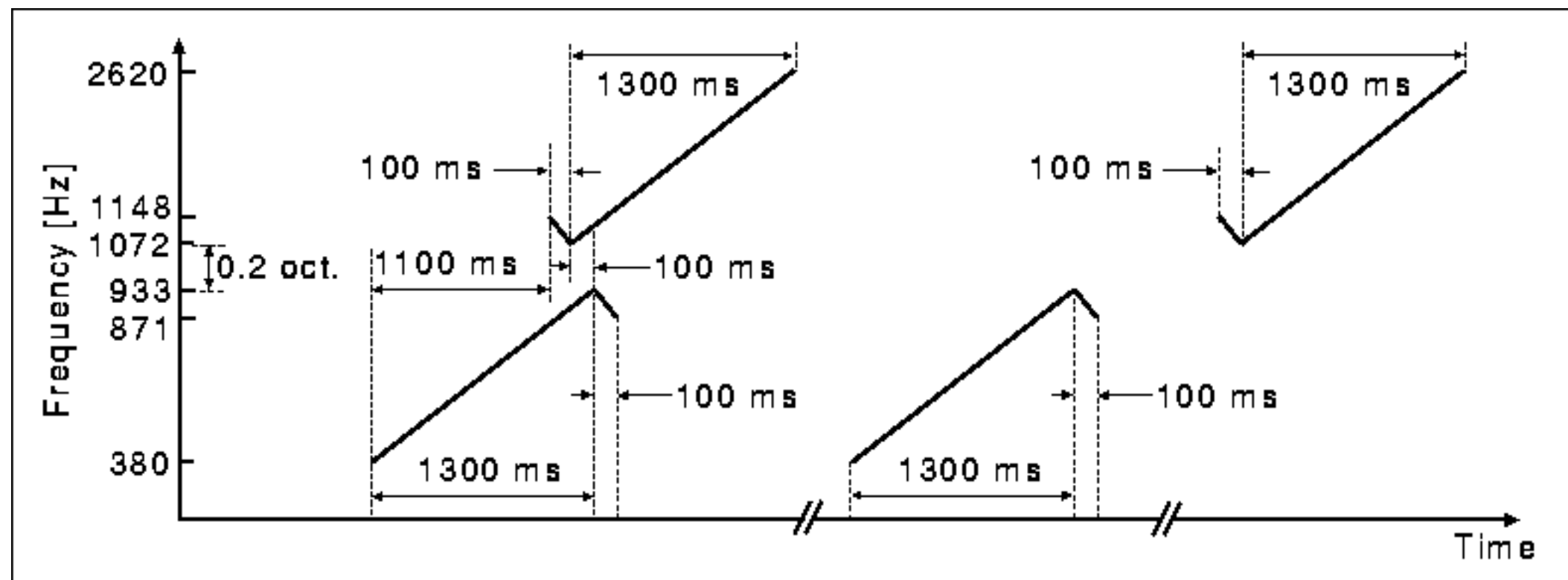


- ▶ Listeners tend to perceive **one long tone** which rises and falls, with a **short tone in the center** due to the termination of the ascending glide tone

# Split-Off Illusion (2)

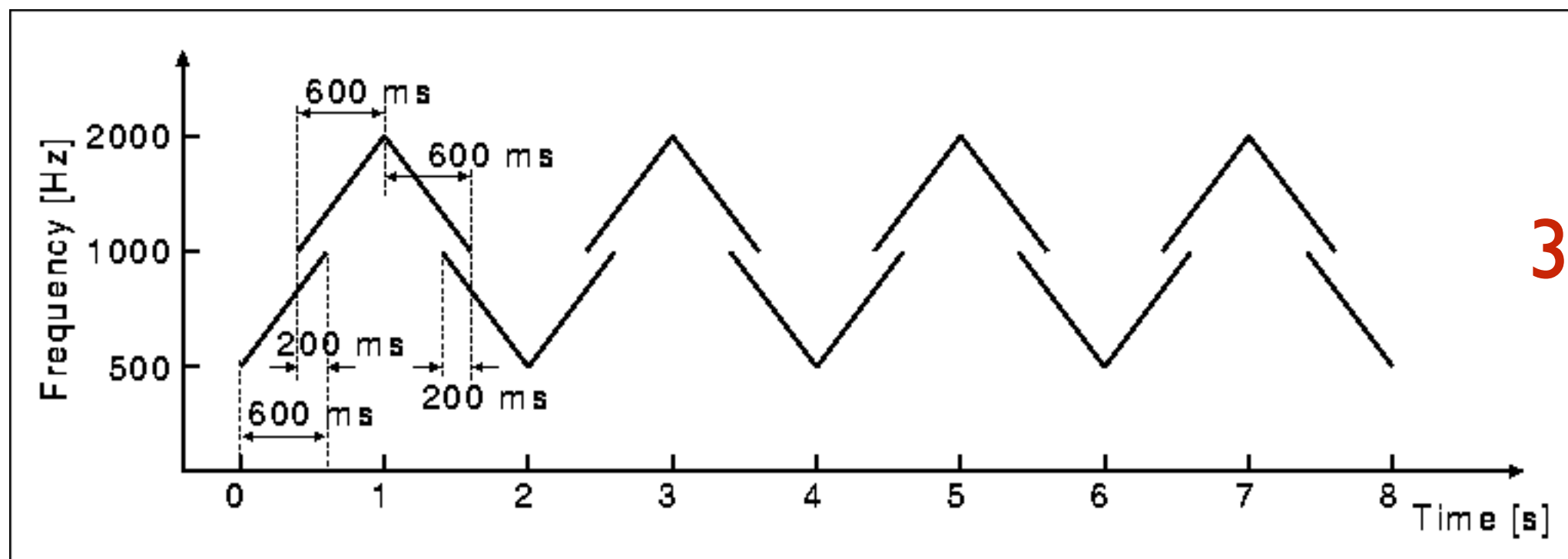
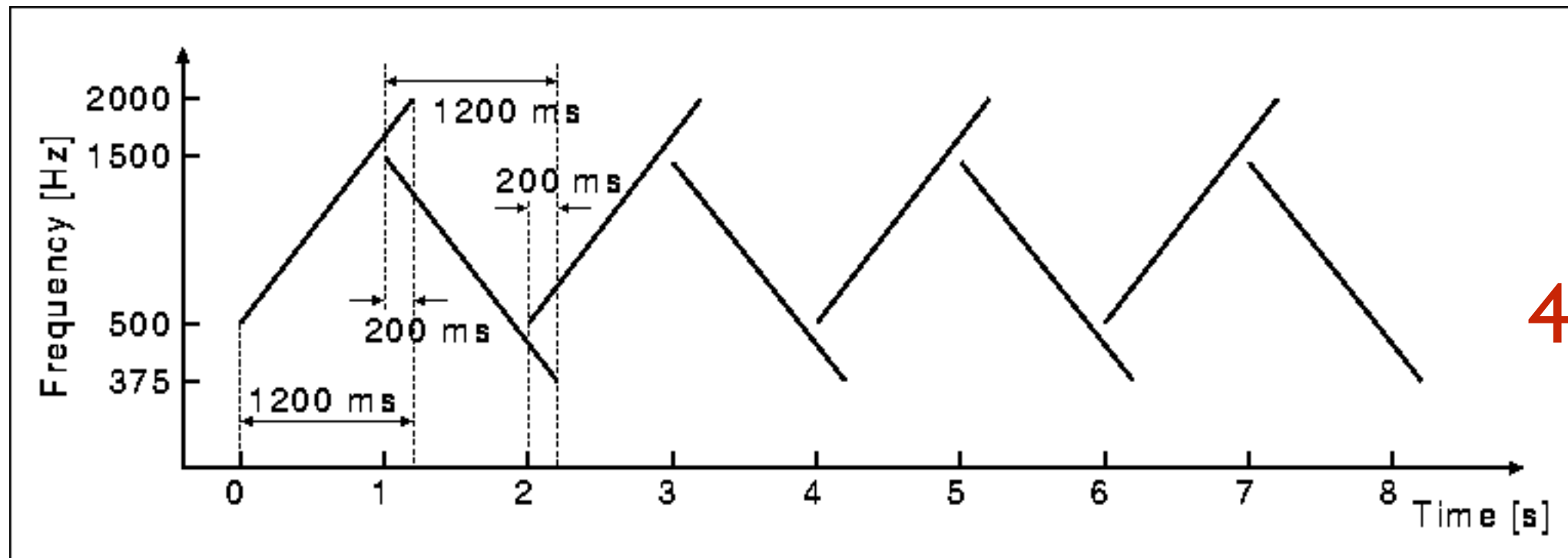
- ▶ Two glide tones bounce off each other

Yoshitaka Nakajima et al., *Demonstrations of Auditory Illusions*



- ▶ Perceptually, it sounds more like the glide tones are **crossing** instead of bouncing

# Split-Off Illusion (3)





# “Apparent Motion”

- ▶ If tones are far apart and alternated slowly you can track a melodic pattern
- ▶ But as the speed increases their order becomes indeterminate. Eventually you just hear beeps and boops. Example: yodeling

Yodeling Demo:  
Perry R. Cook  
Sample 33



# Phantom Melodies

- ▶ Frühlingsrauschen (“Rustle of Spring”) played fast and at 1/4 speed (exit slideshow)

Agitato Christian Sinding

The image shows a musical score for the piece 'Frühlingsrauschen' by Christian Sinding. The score is written for piano and is marked 'Agitato' and 'pp' (pianissimo). It consists of four systems of music, each with a treble and bass clef staff. The music is characterized by rapid arpeggiated figures in the right hand and more melodic lines in the left hand. The key signature has three flats (B-flat, E-flat, A-flat) and the time signature is 3/4.

- ▶ Fast: arpeggios blend together into a phantom melody.  
Slow: we hear the notes separately without the melody

# Perceptual Groupings

- ▶ Fast rhythm in presence of timbre variations leads to sounds joining into **perceptual groupings**
- ▶ Ex: Piano Phase, Steve Reich

$\text{♩} = \text{ca. } 72$   
Repeat each bar approximately number of times written. / Jeder Takt soll approximativ wiederholt werden entsprechend der angegebenen Anzahl. / Répétez chaque mesure à peu près le nombre de fois indiqué.

The musical score consists of six measures, each with a right-hand (r.h.) and left-hand (l.h.) part. Measure 1: r.h. has a repeat sign with '(x4-8)' above it; l.h. has a repeat sign with '(x4-16)' above it. Measure 2: r.h. has a repeat sign with '(x12-18)' above it; l.h. has a repeat sign with '(x4-16)' above it. Measure 3: r.h. has a repeat sign with '(x16-24)' above it; l.h. has a repeat sign with '(x4-16)' above it. Measure 4: r.h. has a repeat sign with '(x16-24)' above it; l.h. has a repeat sign with '(x4-16)' above it. Measure 5: r.h. has a repeat sign with '(x16-24)' above it; l.h. has a repeat sign with '(x4-16)' above it. Measure 6: r.h. has a repeat sign with '(x16-24)' above it; l.h. has a repeat sign with '(x4-16)' above it. Performance instructions include 'mf non legato' for the right hand, 'mf' for the left hand, 'fade in' for the left hand in measure 2, 'accel very slightly' for the left hand in measure 3, and 'hold tempo 1' for both hands in measures 3, 4, 5, and 6. The score also includes 'a.v.s.' (ad libitum) markings for the left hand in measures 3, 5, and 6.



# Scale Illusion

- ▶ Our brains like to group similar notes together, and will do so when separate melodies are played



- ▶ Effect discovered by Diana Deutsch (Psychologist, UCSD) in the 1970s



# Timbre and Auditory Streams

- ▶ Two melodies played simultaneously can produce a single **emergent melody**
- ▶ Example: auditory streaming in African xylophones
- ▶ However, if there is a **large difference in timbre** between the xylophones, the combined melody does not emerge. Similarly if there is an octave difference in pitch
- ▶ Instead, you just hear the two instruments separately

# Deutsch's Tritone Paradox

- ▶ Listen to the following tones.
- ▶ Are they ascending or descending in pitch?
- ▶ Why do you think so?

# Tritone Paradox

- ▶ A tritone is two pitches  $1/2$  an octave apart (e.g., C to F#)
- ▶ **Musicians often disagree** on whether or not the pitch is ascending or descending



- ▶ Issue: our brains have a preference for listening to the higher or lower tone. **It differs from person to person**