J. S. Bach's *canon per tonus*

A very famous example of an endlessly rising melody is the *canon per tonus* from Johann Sebastian Bach's Musical Offering. The melody rises two half-tones each time the canon is repeated (this should illustrate the rising glory of Frederick the Great to whom the Musical Offering was dedicated). The canon starts in C minor. After the first run it ends in D minor, so the second turn begins two half-tones higher than the first one. When the canon is repeated further, it begins in: c₁, d₁, e₁, f♯₁, g♯₁, bb₁, c₂, d₂.
Canon circularis per tonos (Bach)
A musical offering

etc.
Descending Pitch Illusion

http://asa.aip.org/demo27.html
Falling bells

• Pitch is actually rising even though it sounds like it is falling

From:
http://listverse.com/2008/02/29/top-10-incredible-sound-illusions/
• Each tone contains separations $7/6$ of an octave with an envelope that is fixed
• Each tone is shifted by 100 center or 1 semitone
Opening song from anime series GunXsword
A Melody of Silences

http://www.kyushu-id.ac.jp/~ynhome/ENG/Demo/illusions.html

c2000 Yoshitaka Nakajima
Reflection as a compositional theme

• Bartok “Subject and Reflection”, Mikrokosmos, vol 6, #141 played by Jeno Jando
• Can your ear pick out the reflective tonal symmetry without seeing the music?
• Two melodies played one goes up while the other goes down and vice versa
Now with the music
Now with the spectrum?

- Is the reflective tonal symmetry obvious in the spectrum?
- Compare how easy it is to SEE this pattern compared to how easy it is to HEAR this pattern
Earthquakes from somewhere in Ethiopia – Cindy Ebinger

- Original file sampled to 50Hz
- We multiplied by 400 to 20KHz
- 2 hours of data reduced to 18s

No time reversal symmetry in hearing
Can we pick out time reversal symmetry (tune followed by itself played in reverse order)?

Without the music  Anton Webern, Opus 27
Reflection in time
-- now with the music
Axis of symmetry is a time

Example from Larry Solomon)
Anton Webern, Opus 27
Sensory Integration Illusion

- What you see affects what you hear
- McGurk effect

http://www.youtube.com/watch?v=aFPtc8BVdJk

- Music dubbing
Gap Transfer illusion

- A bounce is often perceived in the gliding tones
- [http://www.kyushu-id.ac.jp/~ynhome/ENG/Demo/2nd/01.html](http://www.kyushu-id.ac.jp/~ynhome/ENG/Demo/2nd/01.html)

Figure and clip by Yoshitaka Nakajima
More on Gap-Transfer Illusion

- Often perceived the same

Figure and clip by Yoshitaka Nakajima
Split off effect

- The listener typically perceives one long tone, which rises and then falls, and a short tone in the middle.

Figure and clip by Yoshitaka Nakajima
More on the split off effect

Figure and clip by Yoshitaka Nakajima
More on split off effect

Figure and clip by Yoshitaka Nakajima
Streaming

• When do two alternating pitches sound like one galloping sound?
  ASA demo 19

• Yodeling - apparent motion in music
  Cook demo 33
Phantom Melodies

- Christian Sinding’s Frühlingsrauschen (“Rustle of Spring”) original recording: [www.classicalmidi.co.uk](http://www.classicalmidi.co.uk) / Slow recording courtesy of Karle-Philip Zamor)
Fast rhythm even in presence of timbre variations can lead to hearing groups of sounds as single sounds “perceptual groupings”
Overlapping piano tones

- forward
- backward

Overlaps aren’t really heard
Illusory Continuity

- Speech is heard and understood despite noise interruptions

Figure and clip by Yoshitaka Nakajima
Temporal Induction of Speech

Interrupted by cough
Interrupted by silence

Pitch depends on partial frequencies

- Butler example 3.5b

- Second of each pair has partials 10% sharp. Perceived pitch change depends on frequency
Timbre depends on frequency

- First tone has partials 1,2,3,4,5
- Second tone has partials 1,3,5,7,9
- Difference in timbre depends on frequency of fundamental
- Butler example 3.5a
A Discontinuous Change in Time Perception Caused by Time-Shrinking

• When the difference between the first and the second duration is up to about 100 ms (the sixth pattern), 'time-shrinking', i.e., the second duration is under-estimated

<table>
<thead>
<tr>
<th>(a) First Series [ms]</th>
<th>(b) Second Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  160</td>
<td>1  160</td>
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<tr>
<td>2  150</td>
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<td>10 70</td>
<td>10 250</td>
</tr>
<tr>
<td>11 60</td>
<td>11 260</td>
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</tbody>
</table>
Timing and music

Scott Joplin’s The Peacherine

• MIDI from http://www.geocities.com/BourbonStreet/2783/sjmidi.htm

• Played by Dick Hyman

Joplin sounds pretty good in MIDI
--- it was played on piano rolls
Quickening Beat

Tempo appears to be quickening

From: http://listverse.com/2008/02/29/top-10-incredible-sound-illusions/
Combination tones!

- Listening example 4.5 Butler.
- Only 440 and 660 Hz played, but sometimes can hear a 220 Hz signal (difference) in addition to the other two.
- Lower tone is manufactured by your ear/brain
Stereo Auditory illusions

- Here I have focused on illusions that don’t involved stereo --- however Diana Deutsch has a series of very interesting stereo illusions. Alternating pitches between ears often perceived as continuous patterns.
Chromatic illusion

Figure 5. The pattern that produces a version of the chromatic illusion, and a way that it is often perceived.
Deutsch’s Tritone paradox

• A tritone is two pitches $\frac{1}{2}$ an octave apart (e.g. C to F#)
• One pair of tritones is followed by another.
• The listener is asked to judge whether the tones ascend or descend
• Musicians often disagree
Tritone paradox

- Transposition often causes one listener to change his/her mind even though music when transposed is perceived as the same.
- Most listeners have a preferred orientation for the pitch circle in perceived tritones--- a form of absolute pitch that every listener has.
- Listeners from different cultures can disagree on their pitch orientation.
Zwicker Tone

- Noise with a gap. A tone can be heard following the noise.
- The gap should be about the size of the critical band.
- I tried this but could not get the illusion to work. Perhaps needs to be done in a quiet environment.
Expectations

• The unresolved leading tone that ends one of the movements of Iphigenia in Brooklyn (PDQ). Looking for the clip!