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Multidimensional timbre analysis of melody

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Perceptual importance of timbre

- Timbre described as the most important and relevant feature of auditory events.
- We show acute memory for timbral qualities (Schellenberg *et al.*, 1999).
- We have an immense ability to distinguish timbres in everyday life.
- Timbre has been implicated in the mechanism of absolute pitch perception.
Secondary role of timbre in the analysis of western tonal music:

Reasons

- Unlike pitch and rhythm, timbre is difficult to notate.

- Dominance of harmonic pitch relations as musical structuring force in WTM.

However...

- Timbre does play an important role in WTM.

- Is exploited by composers, particularly in 20\textsuperscript{th} century compositions.
In absence of harmony as principle way of structuring music could timbre play a stronger role?

Evidence from ethnomusicology:
- “…has western music lost something by eliminating the melodic possibilities inherent in smaller, less regular intervals which music of other cultures still value?” (Theodore Finney, 1947: p720)
- Ethnomusicologist, David Morton (1976) described the Thai musical tradition as having “…developed melodic possibilities rather than harmonic ones”
In absence of harmony as principle way of structuring music could timbre play a stronger role?

Evidence from perceptual studies:

- Grouping by timbre similarity; adjacent sounds group in preference to others (Bregman, 1990).

- Expressive changes increase perceptual salience of pitch events (Gjerdingen, 1993).

Characterising timbre: ordinal point of view

- Cannot be satisfactorily related to a single physical dimension like:
  - Pitch $\rightarrow$ frequency.
  - Rhythm $\rightarrow$ duration/time.

Thus...

- It is described as **multidimensional** and
- sounds create a **multidimensional timbre space**.

- **Spectral** and **temporal** descriptors of timbre $\rightarrow$ describe the multidimensional timbre space.
Multidimensional timbre space
<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Physical Correlate</th>
<th>Perceptual Correlate</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irregularity</td>
<td>Spectral</td>
<td>Fluctuating energy between adjacent partials</td>
<td>Richness</td>
<td>Amplitude variation of adjacent components.</td>
</tr>
<tr>
<td>Roughness</td>
<td>Spectral</td>
<td>Beating of overlapping partials</td>
<td>Harshness/Smoothness</td>
<td>Inharmonic and noise components in spectrum.</td>
</tr>
<tr>
<td>Harmonicity</td>
<td>Spectral</td>
<td>Harmonic/Inharmonic</td>
<td>Cohesive/Diffuse</td>
<td>Ratio of harmonic to inharmonic spectral components.</td>
</tr>
<tr>
<td>Attack/Decay times</td>
<td>Temporal</td>
<td>Slope of attack and decay</td>
<td>Instrument identification</td>
<td>Time taken to reach max. amp from 0 (attack).</td>
</tr>
</tbody>
</table>
Timbre analysis of melody: Aims

- To employ measures of timbre that have perceptual relevance.
- To take account of the multidimensional characteristic of timbre.
- To analyse the timbre evolution over time in the melody.
- To extract a relationship between characteristics of timbre in the melody and the melodic structure.
- To extract a melodic timbre structure that goes some way towards perceptually relevance.
Timbre analysis of melody: Difficulties

- Deriving perceptually relevant timbres.
- Absolute timbre values or relative timbre values?
- How to deal with multidimensional representation of timbre in…
  - Investigating timbre evolution over time.
  - Extracting and interpreting a timbre structure.
- Interpreting relation between timbre and melodic structure.

Perceptual Relevance
Timbre analysis: Stage I

- Initial time-frequency analysis
- Application of auditory processing techniques
- Calculation of timbre descriptors
- Time integration of timbre contours

- Time-Frequency Analysis (STFT)
- Peak Detection
- Equal-Loudness Curves
- Equal-Loudness Curves
- Temporal Integration ($t = 0.2$ seconds)

- Spectral Centroid
- Irregularity
- Roughness
- Harmonicity
Time integration of timbre contours

Non-integrated spectral centroid of piano A3

Integrated spectral centroid of piano A3

Unintegrated against integrated irregularity: piano A3

Unintegrated against integrated roughness: piano A3
Multidimensional timbre analysis stage II: Absolute or relative timbre values?

In an analysis of timbre in melody, the timbre is presented over time. Therefore, the analysis can focus on either:

- Absolute timbre values (left)
  or..
- Relative timbre values, i.e. measures of timbre change (right).
Multidimensional timbre analysis II: Dealing with a multidimensional timbre space

**Problem:** I wish to represent timbre evolution over time but still use a multidimensional timbre space.

**Required:** Means of projecting multidimensional timbre space onto a 2D timbre against timbre space.

**Current solution:** Use of an unsupervised neural network, a Kohonen Self-Organising Feature Map (SOFM) (Kohonen, 1984)

- To extract patterns of interrelations in the multidimensional space
- To project them onto a space of lower dimensionality.
SOFM Clustering: 2D example
SOFM Clustering: Considerations

- **Number of clusters:**
  - High number of clusters => higher resolution clustering => difficult to extract general structure.
  - Lower number of clusters => lower resolution clustering => less noise and easier to extract general structure.

- **Dimensionality of clustering (2D, 3D or 4D):**
  - Need to be aware of range of the timbre space of each descriptor.

Current implementation focuses on:

- **2D 3×3, 3D 5×5 and 4D 10×10** clustering.
Extracting timbre change information

Steps:

1. Time-dependent descriptors assigned to derived timbre clusters (expressed as weights, $w$) => finding $w$ that minimises the Euclidean distance, $d$.

   \[ x = \frac{d}{d_{\text{max}}} \]

   We still have absolute values!!

2. Compare values of $d$ between derived clusters with maximum distance between clusters, $d_{\text{max}}$ as follows:

3. The change, $x$, is assigned to one of 3 types depending on value:
   
   1. If $0 \leq x \leq 1$, strong prolongation (repeat)
   2. If $0.1 < x < 0.7$, weak prolongation (intermediate change)
   3. If $0.7 \leq x \leq 1.0$, progression (large change)
Timbral change plots

3D 5'S timbre reduction against mean timbre contour: oboe A4 (CIR)

3D 5'S timbre reduction against mean timbre contour: piano A3 (CIR)
Timbral change analysis: shakuhachi melody “Kokû” motif A.

Section I: Kokû (Kitahara)

Tone cells: Kokû (Kitahara)
Timbral change analysis: shakuhachi melody “Kokû” motif A.
Summary timbral reductions:
“Koku” motif A.
Further work: main considerations

- Verify perceptual relevance of timbre change analysis.

- Apply analysis technique to several versions of the same melody → attempt to reveal general aspects of structure.

- Apply analysis to different melodies of the same tradition.

- Apply analysis to melodies of different traditions.

- Use different timbre descriptors → the analysis captures significant timbre characteristics.