MOTIVATION

- Why do composers spend tremendous effort for the “right” combination of musical instruments?

- Inspiring from...
  - Emotional predisposition exists among different music instruments compared with each other – Wu et al., 2013

AGENDA

- Music, Emotion, and Timbre
- A study of non-sustaining instrument sounds
- The piano
- The correlation of emotion and the sounds of
  - Bowed string instruments
  - Pitched percussion instruments
MUSIC AND EMOTION

- **Conveyed** emotion – the message of feelings in the sound
- **Elicited** emotion – the feeling aroused when listening

**Aspects of music**
- Harmony – Liebetrau et al., 2012
- Rhythm & tempo – Plowa & Kostel, 2012
- Lyrics – Hu et al., 2009
- Localization cues – Elman & Kajastila, 2009
- Chords – Lahdelma & Eerola, 2014

**Types of music**
- Environmental sounds – Ellermeier et al., 2004
- One-second sounds – Bigand et al., 2009
- Very short excerpts – Krumhansl, 2010

TIMBRE AND EMOTION

- **Timbre** – the tone colour
- Difference between musical instruments
- Not a single measurement

**Early example of correlating timbre and emotion**
- Scherer & Oshinsky, 1977
- Rapid recognition of timbre
  - Gjerdingen & Perrott, 2008
  - Krumhansl, 2010
  - Filipic et al., 2010
- Acoustic features for mood estimation
  - Baume, 2013

INSPIRING WORKS

- **Eerola et al., 2012**
  - 110 isolated, monophonic instrument sounds
  - 3-dimensional model
    - Valence
    - Energy Arousal
    - Tension Arousal
  - Ratings, affective similarity comparison
  - Results: Important timbral features
    - Valence: Attack slope & envelope centroid
    - Energy: Ratio of HF-LF energy, spectral flux

- **Wu et al., 2013**
  - Isolated tones of 8 sustaining instruments
  - 8 emotional categories
    - Happy, Sad, Heroic, Scary, Comic, Shy, Joyful, and Depressed
  - Comparison of original tones, and further experiments on spectrally modified tones
  - Results:
    - Spectral centroid correlates strongly
    - Even/odd harmonic ratio is a salient feature

MEASURING THE TIMBRE SPACE

- Measurements of the spectrum
- Spectral centroid and centroid deviation
- Spectral incoherence, irregularity, and variation
- Even/odd harmonic ratio
- Tristimulus
**Density of Significant Harmonics**

- A novel measurement
- How tightly the important harmonics are packed together?
- Proven significant in our preliminary study

\[
\text{Density} = \frac{\text{# significant harmonics}}{\text{bandwidth}}
\]

**How do different non-sustaining instruments evoke emotion?**

**The research questions**

**Phases of a Sound**

- Guitar
- Marimba

**Non-sustaining musical instruments**

- A study to investigate emotional characteristics of non-sustaining instrument sounds
  - Guitar, harp, plucked violin
  - Marimba, vibraphone, xylophone
  - Harpsichord, piano

- Equalized pitch, duration, loudness
- ICMC 2014, 2015
- JAES 2015
HOW DO PITCH & DYNAMICS AFFECT EMOTION OF PIANO SOUNDS?

The research questions

EMOTION ON THE PIANO

- A study on the emotional characteristics of piano sounds
  - Effects of pitch
  - Effects of dynamic levels

- ICMC 2015
- JAES 2016

EXPERIMENT STIMULI

- Short isolated sounds of duration 1 second
- Avoid effects of melody, rhythm, etc.
- All C pitches (C1–C8)
  - Avoid effects of interval & harmony
- Loud “forte”, medium “mezzo”, soft “piano”
- 24 sounds in total, obtained from RWC Music Database
Many emotional categories show an **arch-shape** with pitch
- Peak often at around C6
- Significant differences between dynamic levels
  - Loud: strong for “active” emotions
  - Soft: strong for “inactive” emotions
    - Loud and low → **Angry**
    - Soft and high → **Shy**
    - Soft and low → **Sad**
    - Loud and extreme register → **Scary**

**DOES THE DIFFERENCE APPLY TO OTHER MUSICAL INSTRUMENTS?**

The research questions
COMPARISON OF THE PIANO SOUNDS TO:

Bowed strings
- A family of homogenous instruments
- Equalizing temporal features
- ICMC 2016
- JAES 2017

Pitched percussion
- Further varieties of non-sustaining instruments
- Variation of playing techniques
- ICMC 2016
- JAES — to appear

EXPERIMENT STIMULI

Bowed strings
- Violin, Viola, Cello, Double Bass
- Pitched percussion
- Glockenspiel, Xylophone, Vibraphone, Marimba

Sounds from Prosonus library
- Forte and piano
- Equalized attack/decay

Pitched percussion
- Equalized loudness

LISTENING TEST PROCEDURES

- Around 30 UST undergraduate students as subjects in each experiment
- Listening in a quiet room, using professional studio earphones
- Dictionary definitions of emotion categories provided
- Pairwise comparisons
- ALL combinations of sounds within each category

EMOTIONAL CATEGORIES

<table>
<thead>
<tr>
<th>Category</th>
<th>Example of Italian musical terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Happy</td>
<td>“giocoso”</td>
</tr>
<tr>
<td>Heroic</td>
<td>“grandioso”</td>
</tr>
<tr>
<td>Romantic</td>
<td>“appassionato”</td>
</tr>
<tr>
<td>Comic</td>
<td>“capriccio”</td>
</tr>
<tr>
<td>Calm</td>
<td>“tranquillo”</td>
</tr>
<tr>
<td>Mysterious</td>
<td>“misterioso”</td>
</tr>
<tr>
<td>Shy</td>
<td>“timido”</td>
</tr>
<tr>
<td>Angry</td>
<td>“furioso”</td>
</tr>
<tr>
<td>Scary</td>
<td>“terribile”</td>
</tr>
<tr>
<td>Sad</td>
<td>“lacerimoio”</td>
</tr>
</tbody>
</table>

Why emotional categories instead of ratings (e.g. Valence—Arousal)?
- For non-specialists to understand
- Judged more easily than numerical values
PAIRWISE COMPARISON

- Fast decision-making from experiment subjects
- Simple decision than absolute rating
- Removing spammers: keystroke pattern
- Further process: BTL scale values
  - Probability $p=[0,1]$ of a sound to be chosen among tested sounds

AN EXAMPLE OF BTL VALUES

RESULTS

Strings:
28C2 combinations $\times$ 10 categories = 3780 trials

Percussion:
30C2 combinations $\times$ 10 categories = 4350 trials
“ACTIVE” EMOTIONS

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Happy</th>
<th>Heroic</th>
<th>Comic</th>
<th>Angry</th>
<th>Scary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piano</td>
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<tr>
<td>Strings</td>
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<tr>
<td>Percussion</td>
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</tr>
</tbody>
</table>

“INACTIVE” EMOTIONS

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Romantic</th>
<th>Calm</th>
<th>Mysterious</th>
<th>Shy</th>
<th>Sad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piano</td>
<td></td>
<td></td>
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<tr>
<td>Strings</td>
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<tr>
<td>Percussion</td>
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</tr>
</tbody>
</table>

INSTRUMENT-DEPENDENT CHARACTERISTICS

* Cases of an instrument being more significant than others at the same conditions

[Graph showing instrument dependence]
DO ACOUSTIC FEATURES AFFECT EMOTIONAL CHARACTERISTICS?

The research questions

CHARACTERIZING THE EMOTION OF INDIVIDUAL PIANO AND OTHER INSTRUMENT SOUNDS — PHD THESIS DEFENCE

**Correlating Emotions and Acoustic Features**

- **Pearson correlation** was used to study the relationship
- A linear relationship can be visualized easily
  - BTL scale values vs. acoustic feature
- The varying features are also considered:
  - Pitch ➔ Log of fundamental frequency
  - Dynamics ➔ Peak RMS amplitude
  - Mallet hardness ➔ Attack/decay slope

**THE PIANO SOUNDS**

Only entries with p<0.05 is shown. +/− indicates sign of correlation

<table>
<thead>
<tr>
<th></th>
<th>Happy</th>
<th>Heroic</th>
<th>Romantic</th>
<th>Calm</th>
<th>Excited</th>
<th>Angry</th>
<th>Scared</th>
<th>Sad</th>
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<tbody>
<tr>
<td>Log of Fundamental Frequency</td>
<td>+</td>
<td></td>
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<td>+</td>
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<tr>
<td>Peak RMS Amplitude (dB)</td>
<td></td>
<td>+</td>
<td></td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Attack time (ms)</td>
<td>+</td>
<td>+</td>
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<td></td>
<td>−</td>
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<tr>
<td>Peak shape (per ms)</td>
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<tr>
<td>Decay (per ms)</td>
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<td>Density of Significant Harmonics</td>
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<td>+</td>
<td>+</td>
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<td>+</td>
<td>+</td>
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<tr>
<td>Spectral Centroid</td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Spectral Centroid Deviation</td>
<td>−</td>
<td></td>
<td>−</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Spectral Incoherence</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Spectral Irregularity</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
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<tr>
<td>Tristimulus (harmonic 1)</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
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</table>

**THE BOWED STRINGS SOUNDS**

Only entries with p<0.05 is shown. +/− indicates sign of correlation

<table>
<thead>
<tr>
<th></th>
<th>Happy</th>
<th>Heroic</th>
<th>Romantic</th>
<th>Calm</th>
<th>Excited</th>
<th>Angry</th>
<th>Scared</th>
<th>Sad</th>
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</thead>
<tbody>
<tr>
<td>Log of Fundamental Frequency</td>
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<td>+</td>
<td>+</td>
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<td>Peak RMS Amplitude (dB)</td>
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<td>−</td>
<td>−</td>
<td>+</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Spectral Centroid</td>
<td>−</td>
<td>−</td>
<td>+</td>
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<td>Spectral Centroid Deviation</td>
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<td></td>
<td>−</td>
<td>+</td>
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<td>Spectral Incoherence</td>
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<tr>
<td>Spectral Irregularity</td>
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<tr>
<td>Density of Significant Harmonics</td>
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<td>+</td>
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<td>+</td>
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<td>+</td>
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<tr>
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<td>+</td>
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<td>+</td>
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</tbody>
</table>

**Brightness**

Only entries with p<0.05 is shown. +/− indicates sign of correlation
THE PITCHED PERCUSSION SOUNDS

Only entries with p<0.05 is shown, +/− indicates sign of correlation

<table>
<thead>
<tr>
<th></th>
<th>Happy</th>
<th>Heroic</th>
<th>Romantic</th>
<th>Comic</th>
<th>Calm</th>
<th>Mysterious</th>
<th>Shy</th>
<th>Angry</th>
<th>Scary</th>
<th>Sad</th>
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<tbody>
<tr>
<td>+/- Attack time (ms)</td>
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<tr>
<td>Attack slope (per ms)</td>
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<td>Decayment ratio</td>
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<td>Decayment slope (per ms)</td>
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<td>Density of Significant Harmonics</td>
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<tr>
<td>Spectral Centroid</td>
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<tr>
<td>Spectral Irregularity</td>
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<tr>
<td>Tristimulus T1 (harmonics 1)</td>
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<td>Tristimulus T2 (harmonics 2-4)</td>
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<tr>
<td>Tristimulus T3 (harmonics 5+)</td>
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</tbody>
</table>

REMOVING EFFECTS OF TESTING VARIABLES

- Partial Pearson correlation was used to eliminate variables

<table>
<thead>
<tr>
<th></th>
<th>Piano</th>
<th>Bowed strings</th>
<th>Pitched percussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decrease in correlated features</td>
<td>Heroic and Shy</td>
<td>Happy and Mysterious</td>
<td>Comic</td>
</tr>
<tr>
<td></td>
<td>Scary and Comic</td>
<td>Shy</td>
<td>Calm</td>
</tr>
<tr>
<td>Increase in correlated features</td>
<td>Density of Significant Harmonics</td>
<td>Spectral Centroid</td>
<td>Spectral Irregularity</td>
</tr>
</tbody>
</table>

GENERAL OBSERVATIONS

- In a very broad sense
  - High-Valence emotions intensify with increasing pitch
    - Valence: how pleasant a sound is
  - High-Arousal emotions intensify with increasing dynamics
    - Arousal: how energetic a sound is

- With a lot of instrument-dependent variations, e.g.
  - Heroic decreases with pitch on piano
  - Shy is not affected by pitch on bowed strings
  - Calm decreases with pitch on pitched percussion
CONCLUDING IDEAS

- We confirmed that there are statistically significant relationships between emotion and timbre for various musical instruments.
- We developed a methodology to characterize emotional characteristics of sounds with different variables.
  - Prominent timbral and acoustic features for emotional effects.

FURTHER POSSIBILITIES

- Only a subset of musical features and playing techniques can be explored in each experiment.
- Possible ways of exploration:
  - Playing techniques of instruments, e.g., piano pedal
  - Repeated notes of the same instrument
  - Blending or morphing of multiple instruments

AN EMOTION GUIDELINE FOR MUSICIANS

- Just like the “loudness curve”, the effects of sound perception can only be studied with careful experiments.
- The emotion maps will benefit musicians in different fields:
  - Composers and arrangers
  - Live performers and conductors
  - Audio or recording engineers
  - Sound designers or electroacoustic musicians

HOW ARE ALL THESE USEFUL? The contributions

- The contributions
AUTOMATED MUSIC EMOTION TRIGGER

- Algorithms to automatically adjust sound spectrum for emotional effect
  - E.g., triggers on musical instruments similar to EQ adjustment
- Algorithms for recommending mix of musical sounds basing on timbre emotion
- Music generation algorithms to create an emotional background music with emotion messages
  - E.g., film music and game music

EXPLORATION OF THE TIMBRE SPACE

- Timbre space — yet to be fully discovered
  - How to measure it?
  - How to represent it?
- Exploration of the timbre—emotion space
  - Decomposing timbre with the help of human perception

RELATED PUBLICATIONS