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Christoph Reuter[1], Saleh Siddiq[1], Isabella Czedik-Eysenberg[1,2], Michael Oehler[2]

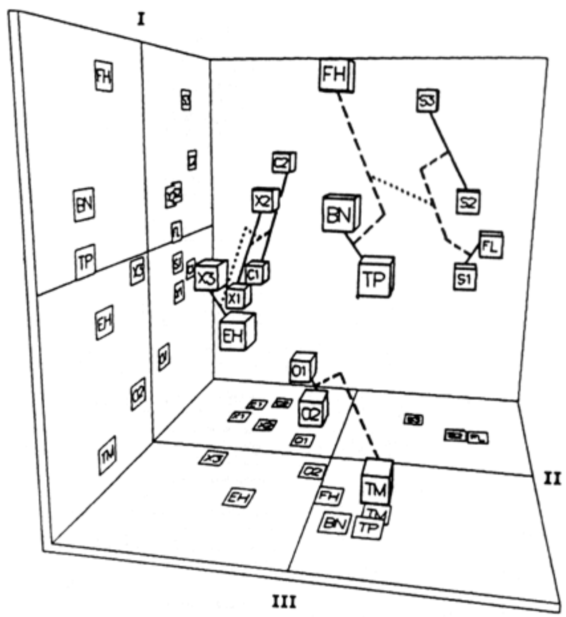
VIENNA SYMPHONIC LIBRARY

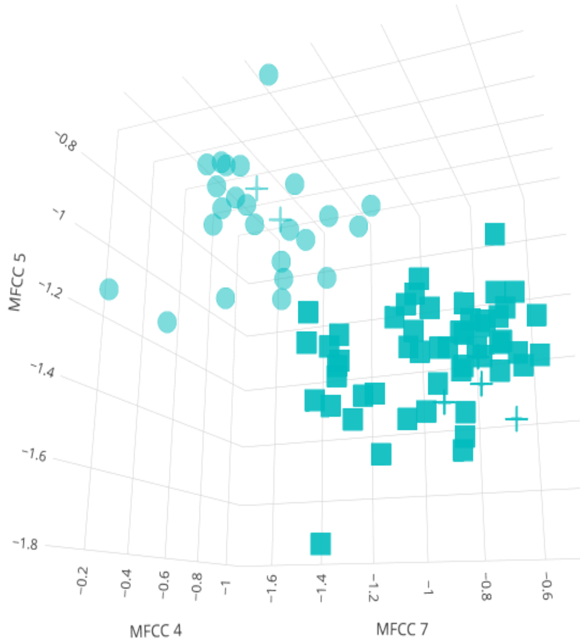
TIMBRE TOPOLOGIES 2023
Zurich, 3.-4.2.2023

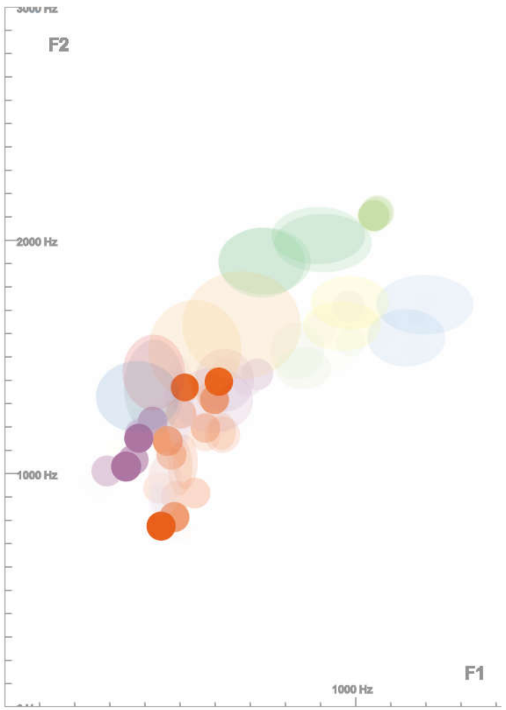
Institute for Computer Music and Sound Technology (ICST), Zurich University of the Arts (ZHdK)

To Infinity and Beyond …

Timbre Dimensions and their Visualization







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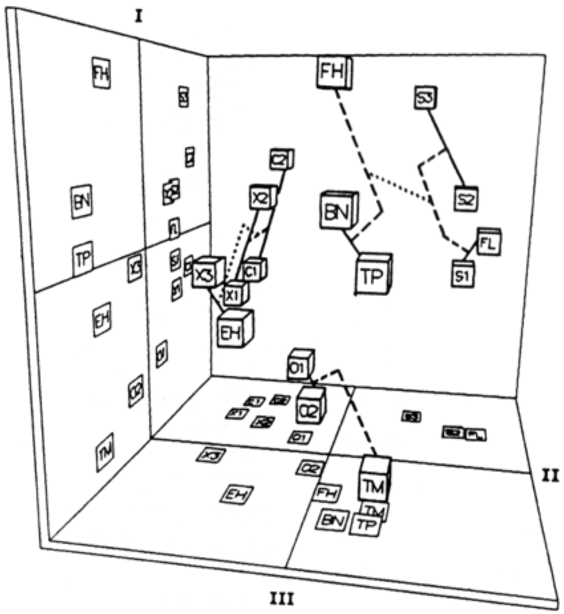
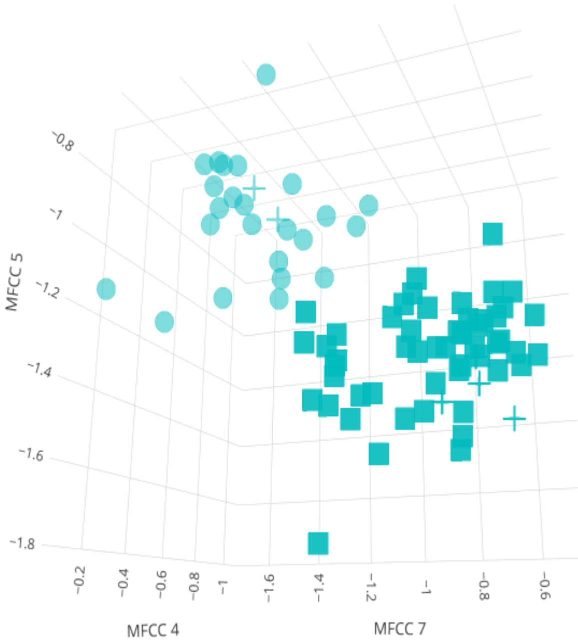
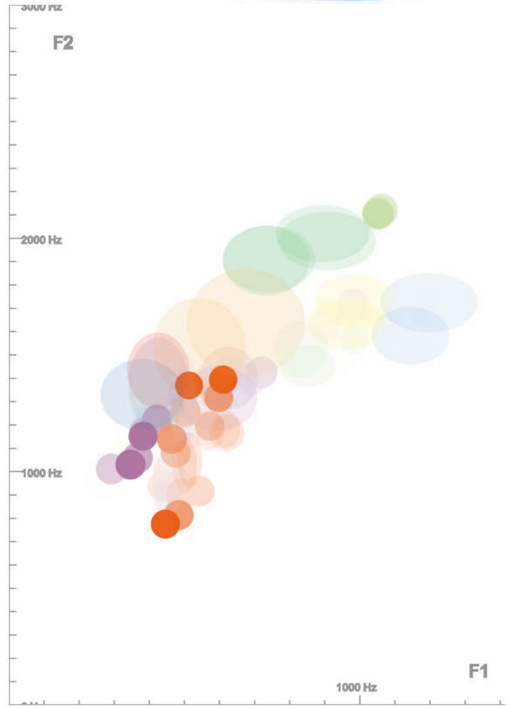






To Infinity and Beyond …

Timbre Dimensions and their Visualization

To Infinity…: Popular approaches of timbre description

1 Timbre Spaces
2 MFCCs
3 Formants

… and Beyond: Dynamic Timbre Maps

4.1 Dynamic Spectral Centroid/Flux Map
4.2 Dynamic MFCC Map
4.3 Dynamic Formant Map

Back on Earth: Take Home Message

To Infinity and Beyond …

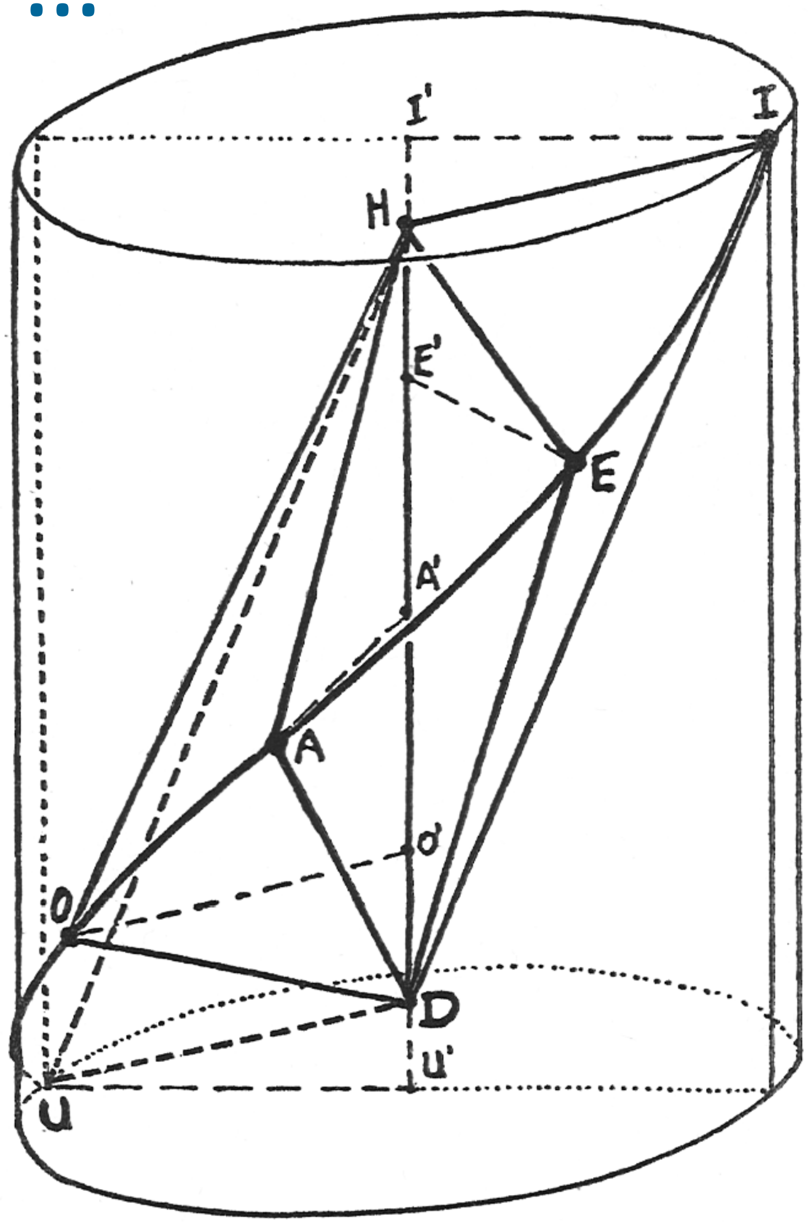
Popular methods of timbre description

1 Timbre Spaces

Albersheim 1939: First unknown Timbre Space

Acoustical cylinder of sound colors
(„Akustischer Farbenkörper“)

- Middle axis: **brightness**
- Perimeter (helical hue): **type of vowel**
- Radius: saturation (**vowel-likeliness**)



Acoustical cylinder of sound colours
Albersheim 1939, p. 353

To Infinity and Beyond …

Popular methods of timbre description

1 Timbre Spaces

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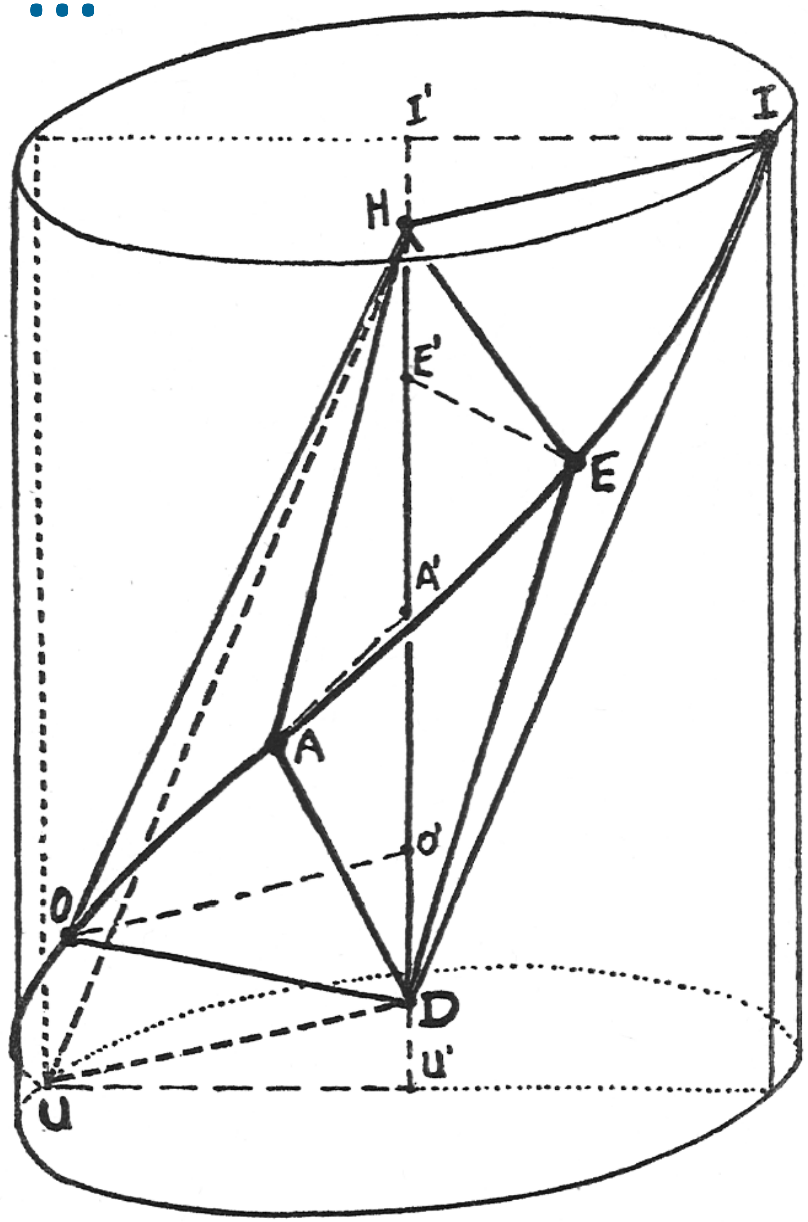
only imagined by Albersheim, not calculated,
but what would it have sounded like?



Acoustical cylinder of sound colours
Albersheim 1939, p. 353

To Infinity and Beyond …

Popular methods of timbre description

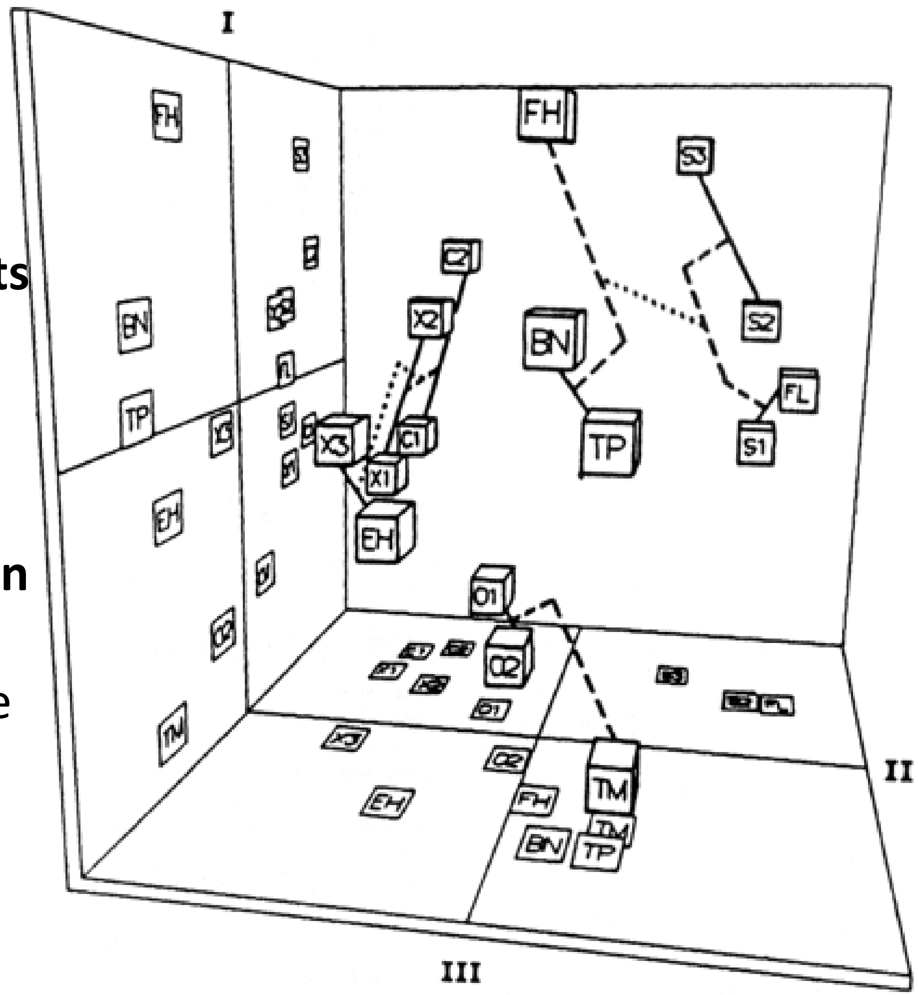
1 Timbre Spaces

Grey 1975: First known Timbre Space

Transfering subjective **similarity judgments** into **spatial distribution** using MDS.

Interpretation of spatial dimensions:

- Dimension I: **Spectral energy distribution**
- Dimension II: **Attack transients** and synchronicity of the higher partials there
- Dimension III: **Fluctuations** and inharmonicity



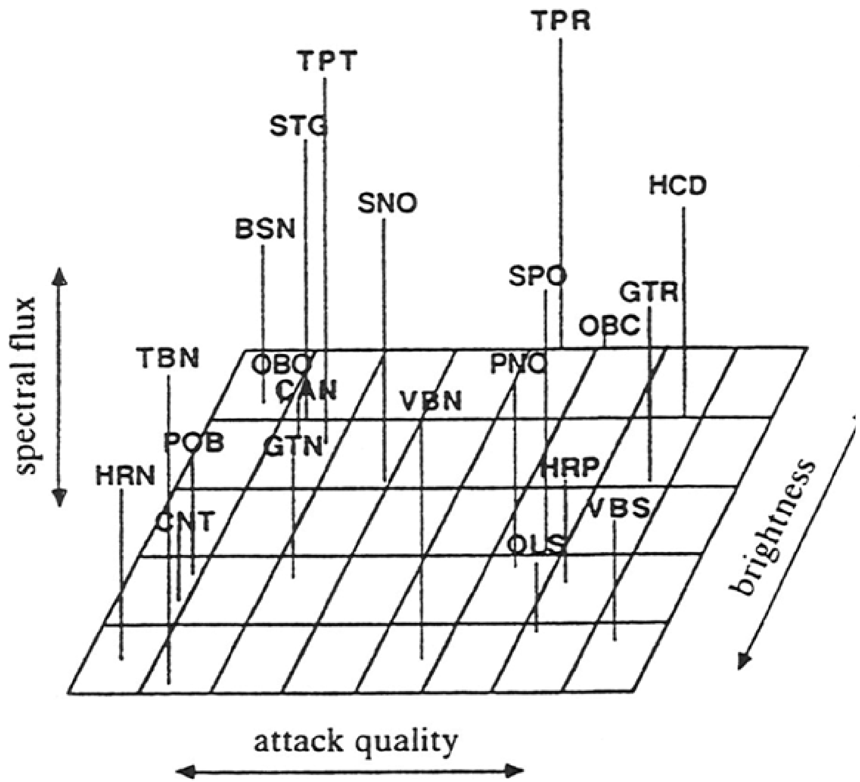
Timbre Space
(Grey 1975, p. 62)

To Infinity and Beyond …

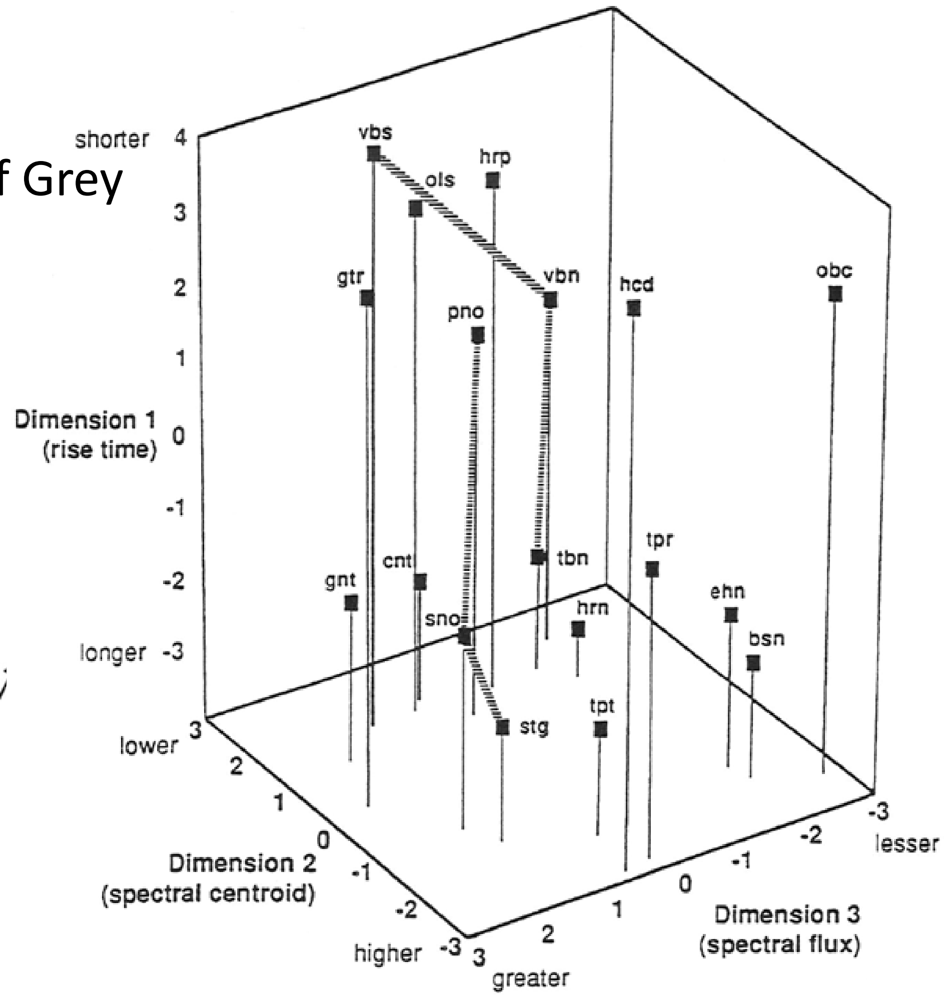
Popular methods of timbre description

1 Timbre Spaces

Further Timbre Spaces in the tradition of Grey
(most known: Krumhansl 1989, McAdams et al. 1995)



Timbre Space based on synthetic FM sounds
(Krumhansl 1989, p. 47)



Timbre Space based on synthetic FM sounds
(McAdams et al. 1995, p. 185; McAdams 1999, p. 89)

To Infinity and Beyond …

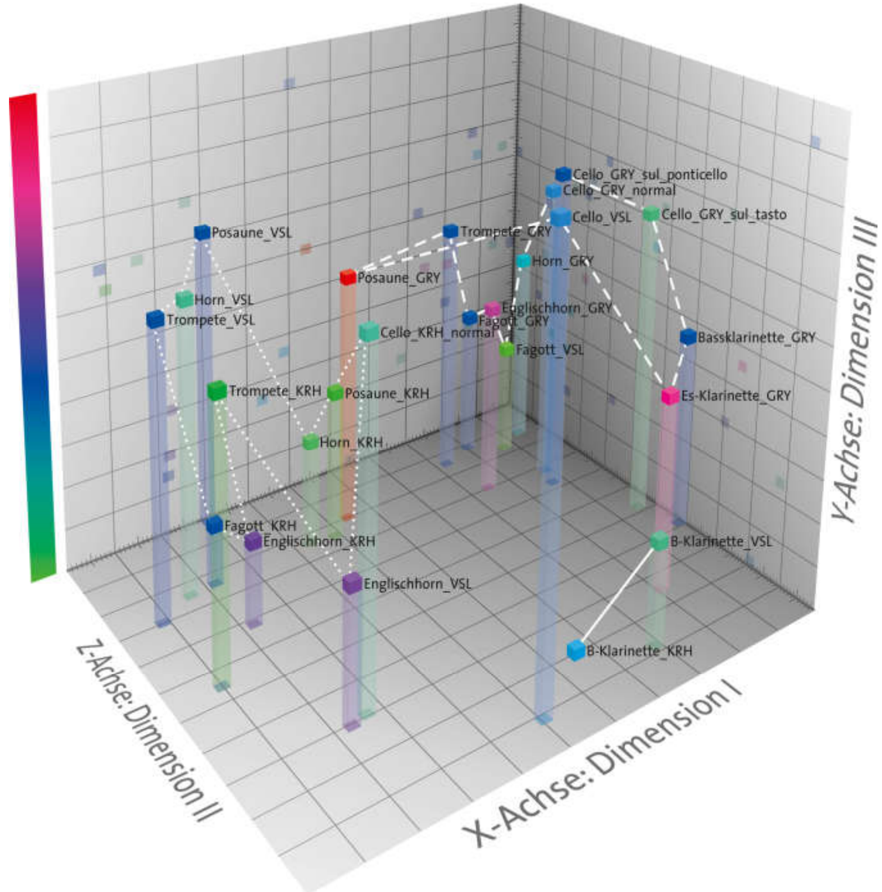
Popular methods of timbre description

1 Timbre Spaces

Siddiq et al. 2015: Meta Timbre Space

Empirical comparison of 3 Timbre Spaces:

- **Grey** (10 sounds, GRY)
- **Krumhansl** 1989/**McAdams** et al. 1995 (7 sounds, KRH)
- **Vienna Symphonic Library** (7 sounds, VSL)



[Meta Timbre Space based on the sounds of Grey, Krumhansl/McAdams and Vienna Symphonic Library (Siddiq, Reuter, Czedik-Eysenberg, Knauf 2015, p. 812)]

To Infinity and Beyond ...

Popular methods of timbre description

1 Timbre Spaces

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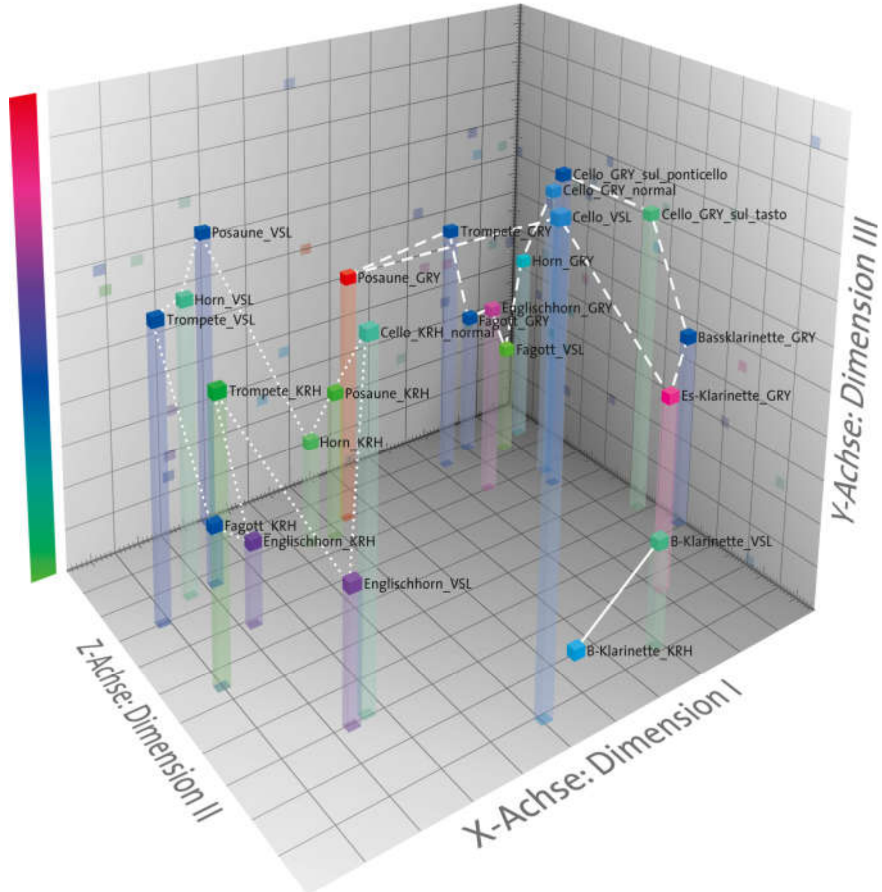
- **Grey** (10 sounds, GRY)
- **Krumhansl** 1989/**McAdams** et al. 1995 (7 sounds, KRH)
- **Vienna Symphonic Library** (7 sounds, VSL)

Results: Timbres of the **same stimuli set** are **more similar** than timbres of the same instrument.

Timbre Spaces are hardly generalizable or comparable.



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To Infinity and Beyond …

Popular methods of timbre description

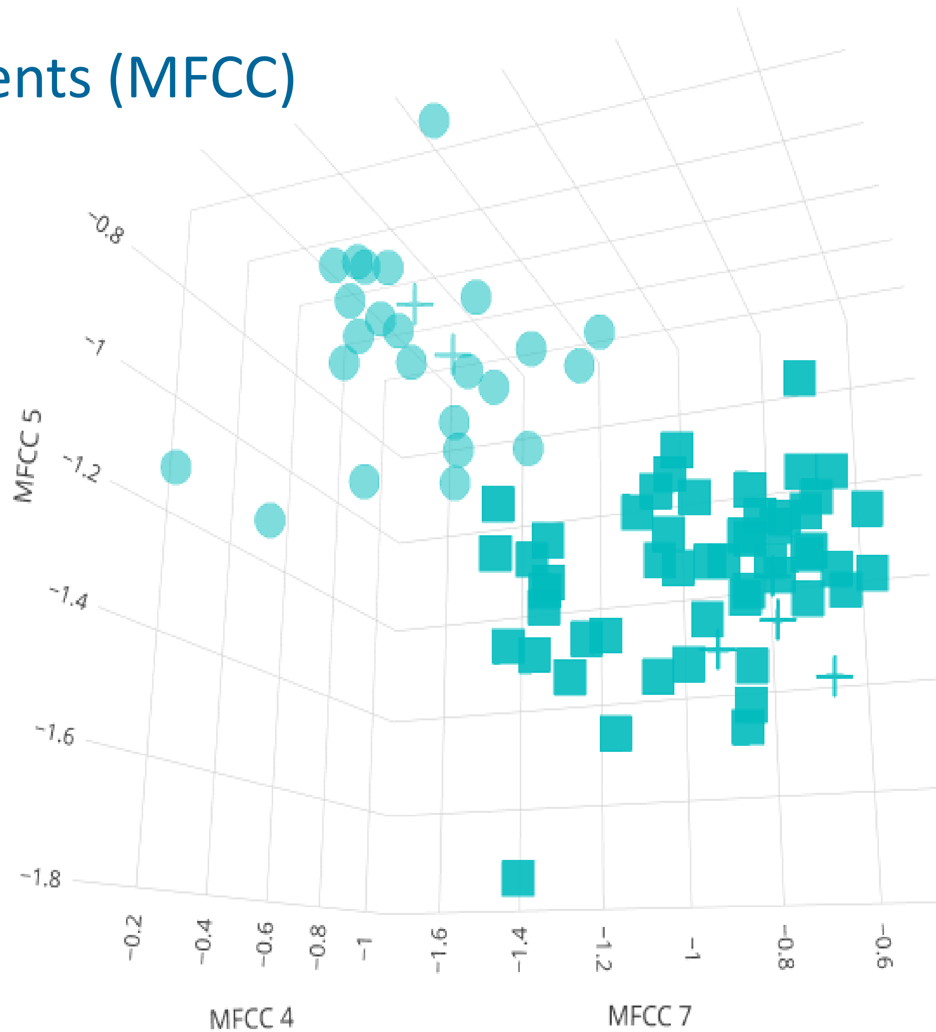
2 Mel Frequency Cepstral Coefficients (MFCC)

Davis & Mermelstein 1980:
Automatic calculation for **speaker recognition** and **speech similarity** rating

Pros: well suited for calculating similarities in speech / music / noises / instrumental timbres

Cons: Less intuitive, numerical output is difficult to understand by humans.

MFCCs play a **key role** in modern sound similarity computation



Using MFCC4, 5 and 7 to distinguish between dove perch and courtship coos (Reuter, Quigley 2020)

To Infinity and Beyond …

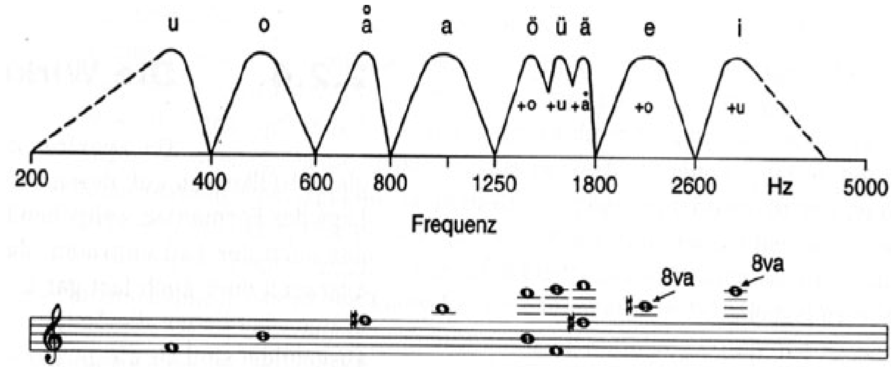
Popular methods of timbre description

3 Formants

Schumann 1929: Typical **maxima** in spectra of (mostly) wind instruments.

- **pitch-independent** (stable)
- like **vocal formants** (characteristic)

In the German-speaking realm, formants are often used to describe the sound of instruments based on their **vowel character.**



Vowel formants and their frequency ranges
(Meyer 2015, p. 33)

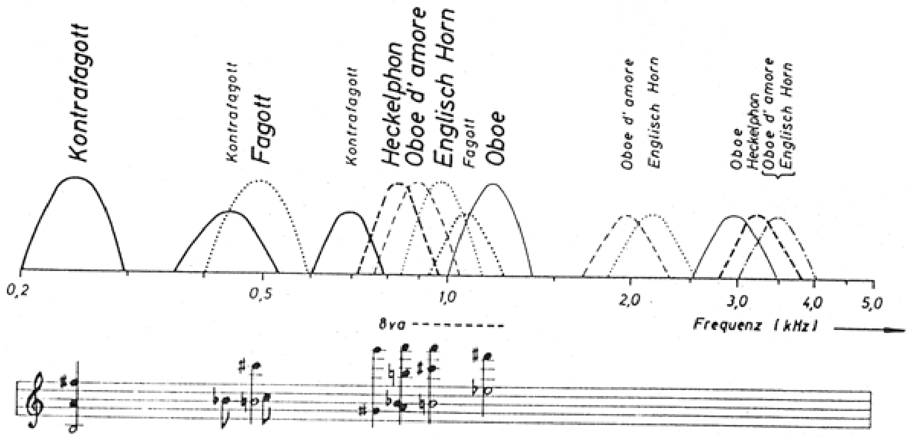


Abb. 6 Frequenzlage der Formanten für die Doppelrohrblattinstrumente, zusammengestellt nach Angaben von E. Meyer und G. Buchmann [3] (Oboen und Englisch Horn) und eigenen Messungen des Verf. (Fagotte [11] und Heckelphon)

Formants of double-reed instruments
(Meyer 2015, p. 63)

To Infinity and Beyond …

Popular methods of timbre description

3 Formants

Schumann 1929: Typical **maxima** in spectra of (mostly) wind instruments.

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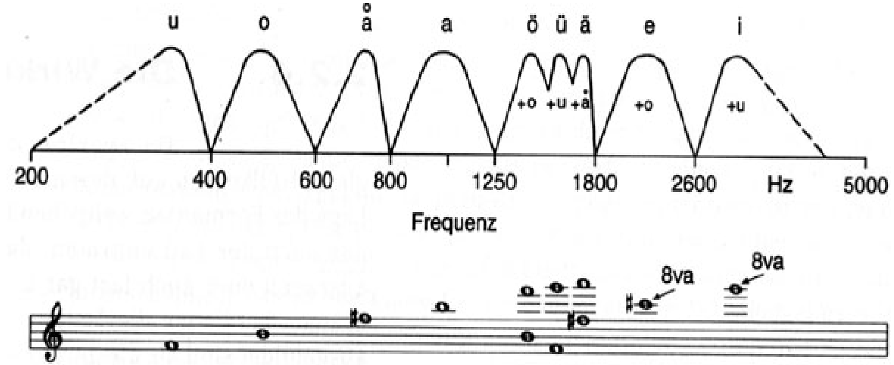
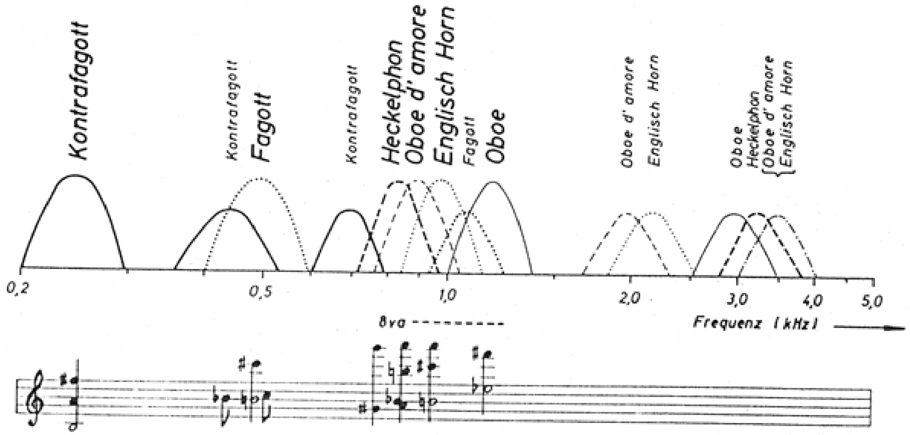
- like **vocal formants** (characteristic)

In the German-speaking realm, formants are often used to describe the sound of instruments based on their **vowel character.**

If formants are removed from a timbre (or the spectral gaps between them), it no longer sounds typical for the respective instrument.



Vowel formants and their frequency ranges (Meyer 2015, p. 33)



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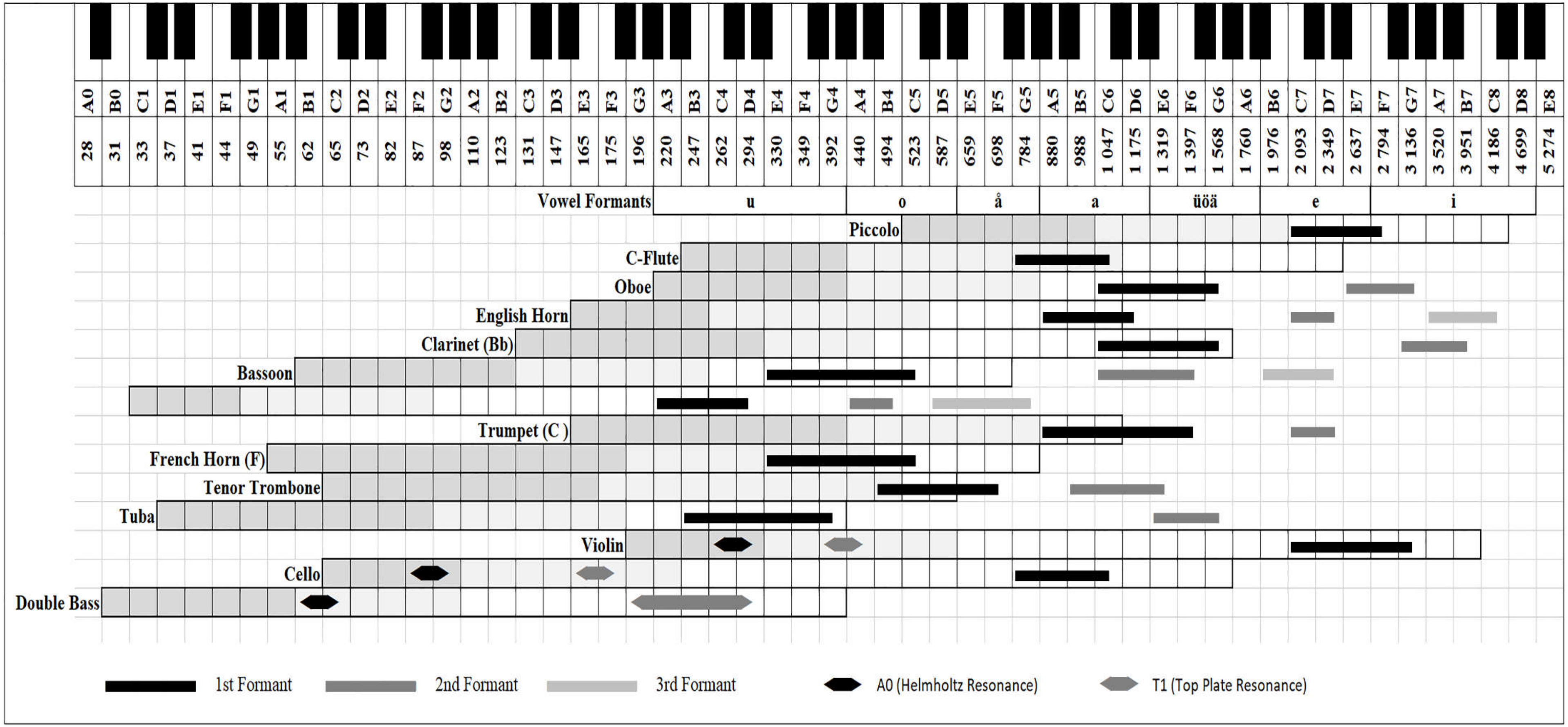
To Infinity and Beyond …

Popular methods of timbre description

3 Formants



Formant areas and main resonances of various orchestral instruments
(based on Reuter 2014, p. 401; Register boundaries after Siedenburg et al. 2021, p. 3717)

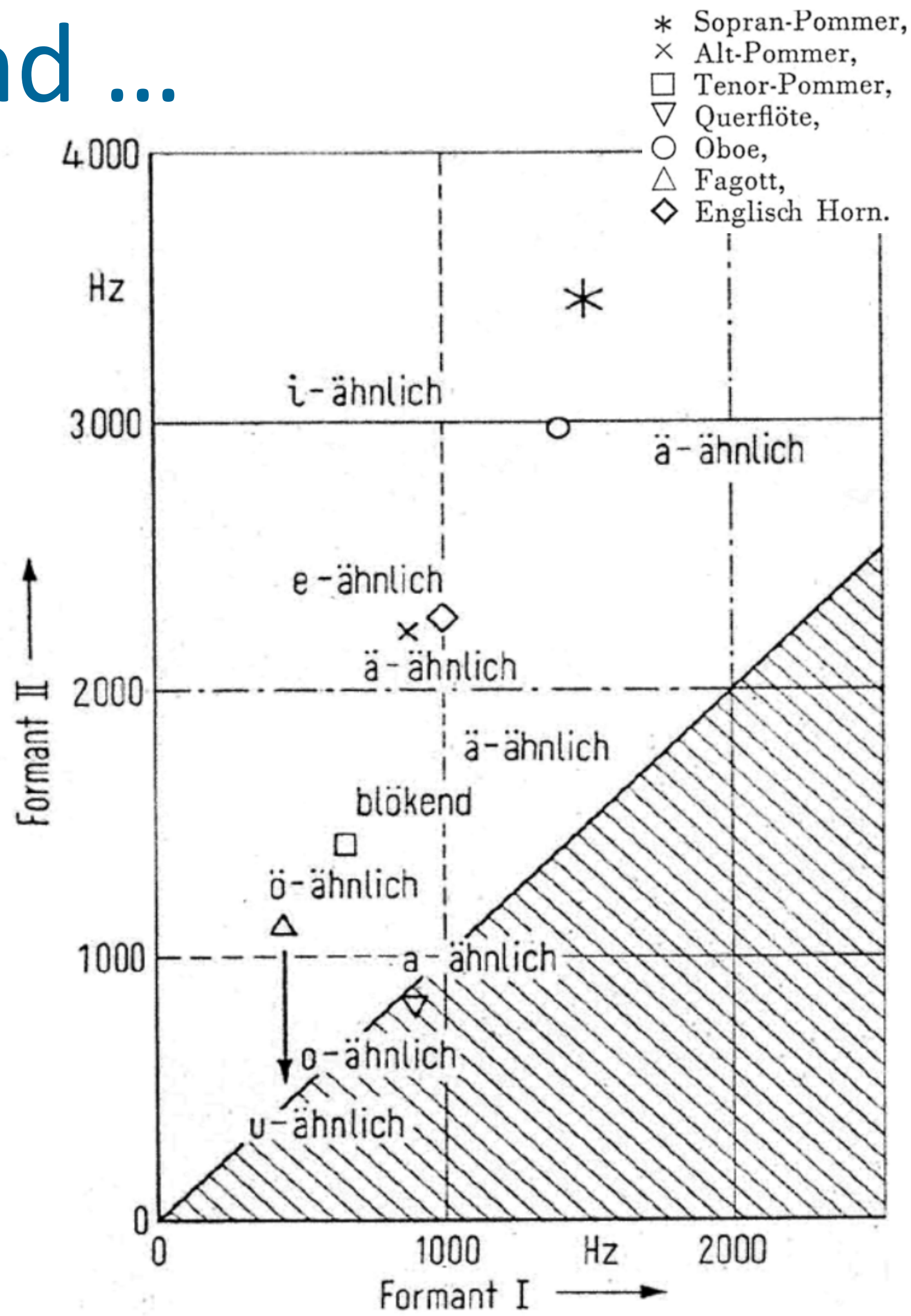
To Infinity and Beyond …

Popular methods of timbre description

3.1 Early Formant Maps

Sirker 1974: First Formant Map: “**Perceptual Space for two-formant Sounds**“

Matching **double reed instruments** to **vowels** based on their first two formant areas (determined from the strongest amplitudes in their respective spectra).



„Wahrnehmungsraum bei zweiformantigen Klängen“ (Sirker 1974, p. 52)

To Infinity and Beyond …

Popular methods of timbre description

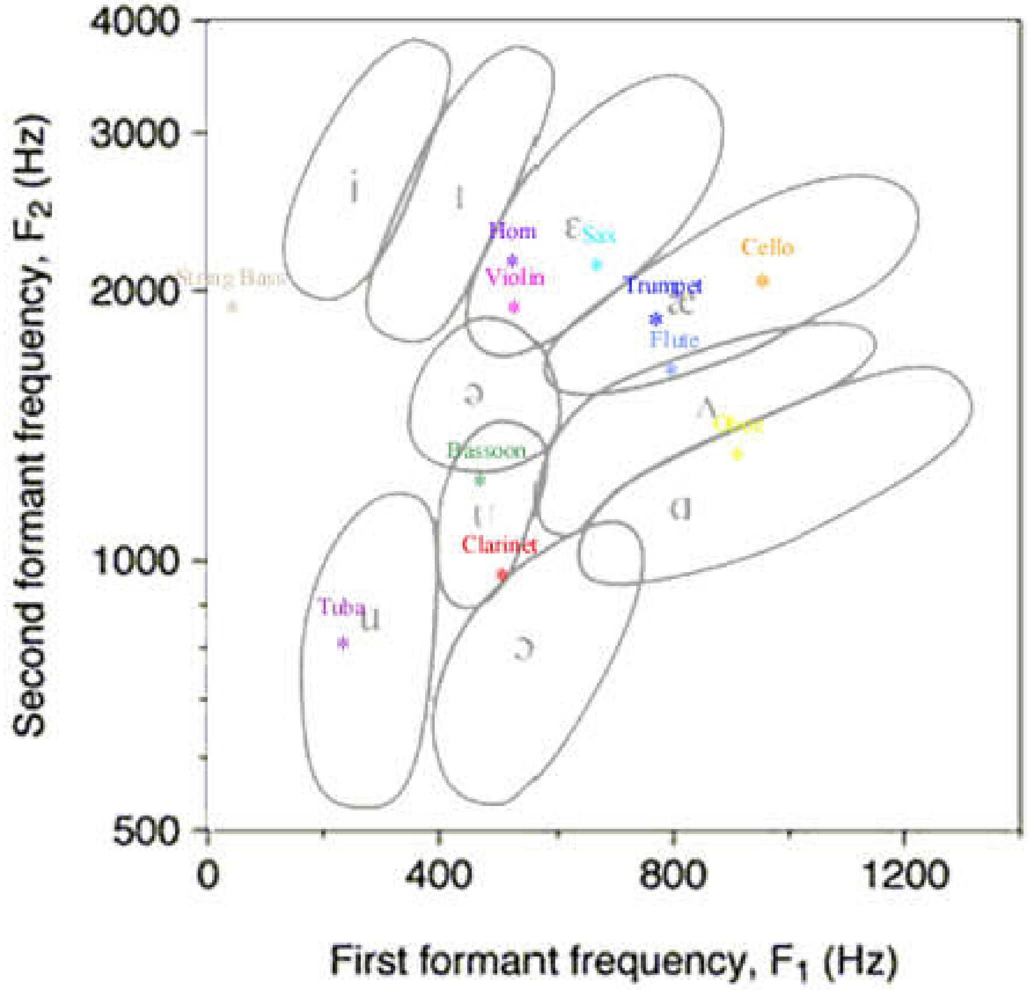
3.1 Early Formant Maps

McCarty 2003: Timbres of common orchestral instruments in a "**vowel space**"

- **one pitch** (different for each instrument)
- Formants estimated via **Colea**

“Now I can say that the tuba's timbre has a 'U' sound or (oo) as in the word who, or the trumpet has an 'ae' timbre like the work actor.“

(McCarty, Stanford.edu 2003)



Sounds of saxophone, flute, oboe, clarinet, bassoon, horn, trumpet, tuba, violin, cello, bass in the "Vowel Space". (McCarty, Stanford.edu 2003)

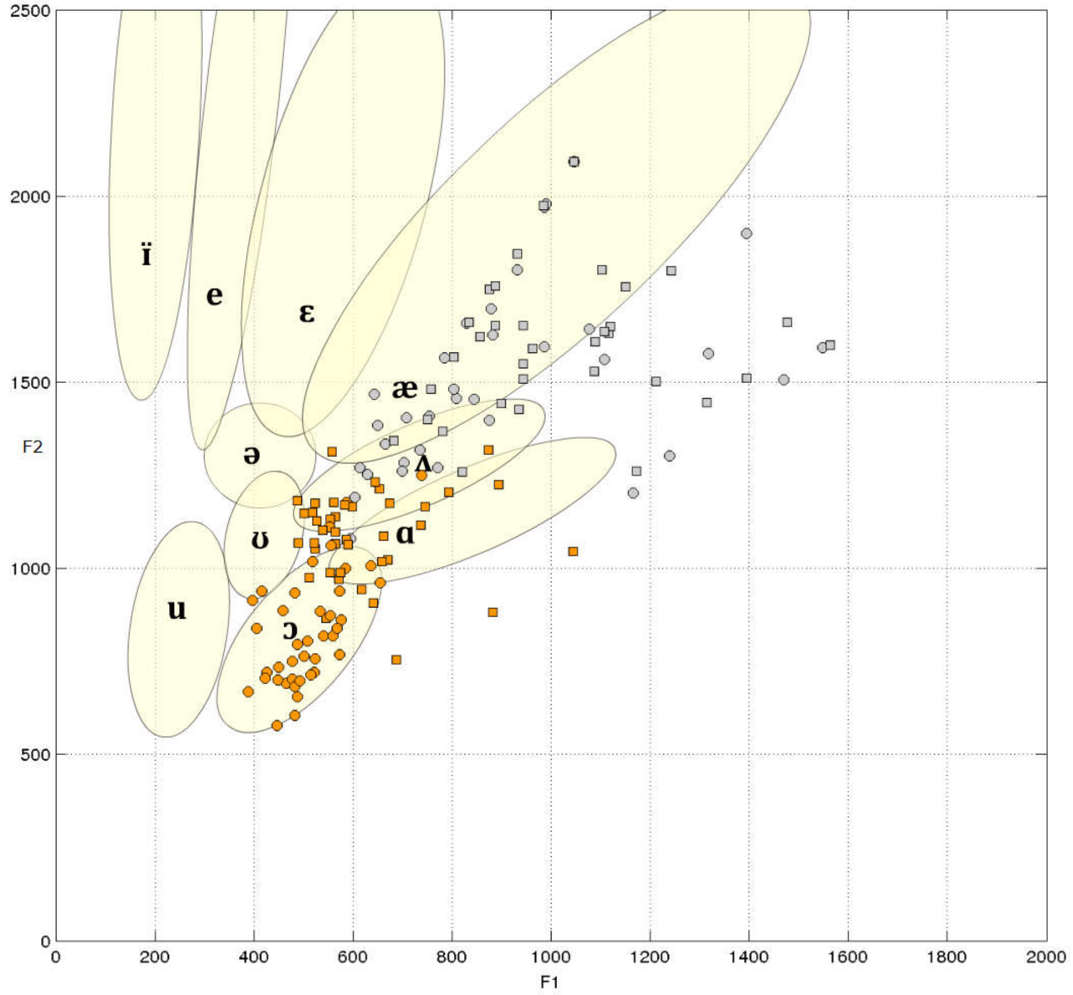
To Infinity and Beyond …

Popular methods of timbre description

3.2 Formant Map

Reuter et al. 2016: Interactive Formant Map

- common **woodwind** and **brass** instruments from the VSL
- **all reachable** pitches
- **two** dynamic levels (***ff*** and ***pp***)
- **593** single sounds



Interactive Formant Map with the sounds of bassoon (orange) and oboe (gray) in all reachable pitches in ***ff*** and ***pp*** (Reuter, Czedik-Eysenberg, Siddiq, & Oehler, 2017).

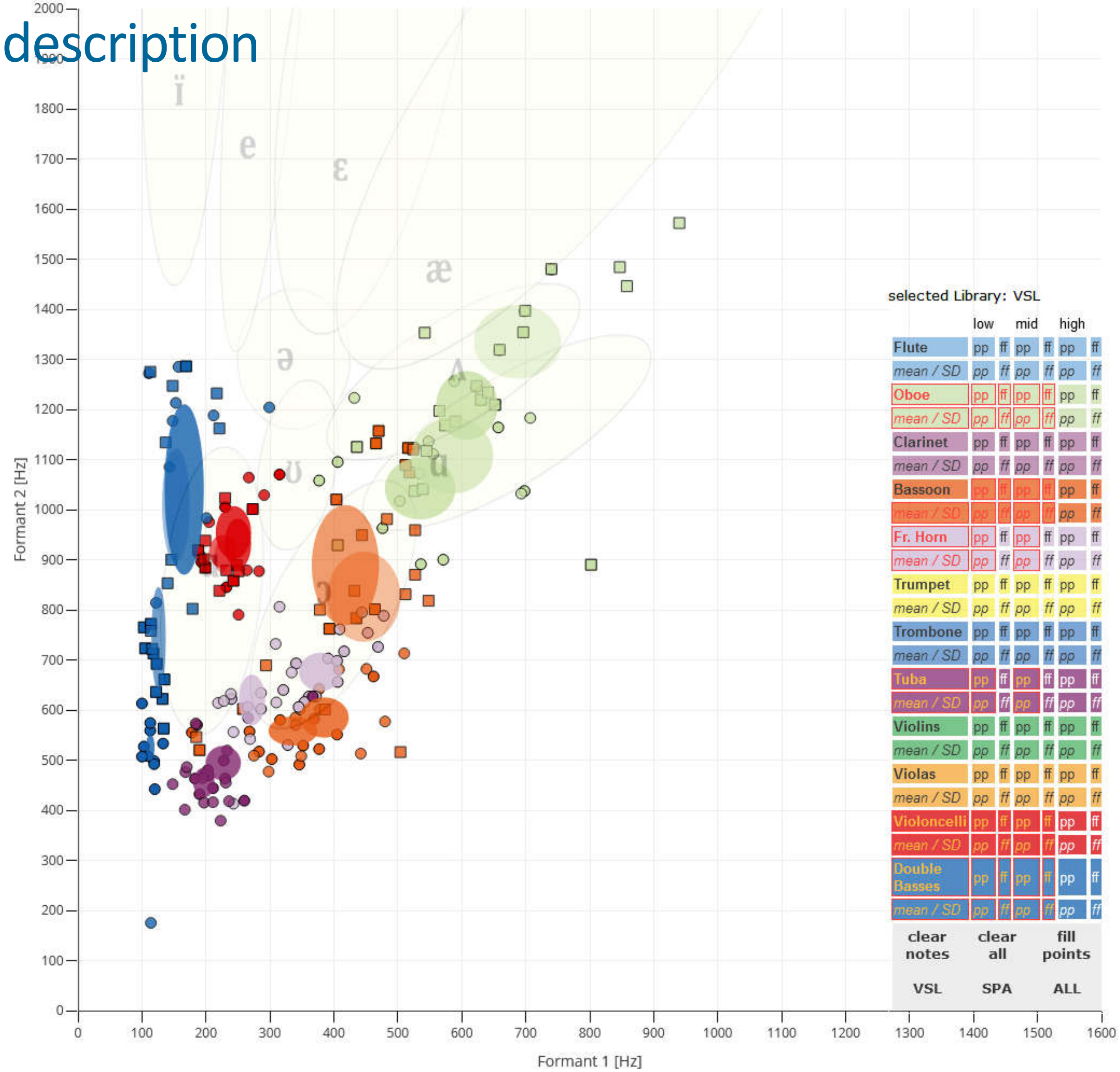
To Infinity and Beyond …

Popular methods of timbre description

3.2 Formant Map 2.0

Reuter 2020: Update of the Interactive Formant Map:

- **Javascript** (instead of Flash)
- Extension with **strings** (violin, viola, cello, bass)
- Additional Library: **Spitfire Audio**
- **1100** single sounds



[Formants and their mean values and standard deviations of oboe, bassoon, horn, tuba, cello and bass iin the low and middle registers. (Reuter 2020)]()

To Infinity and Beyond …

Dynamic Timbre Maps

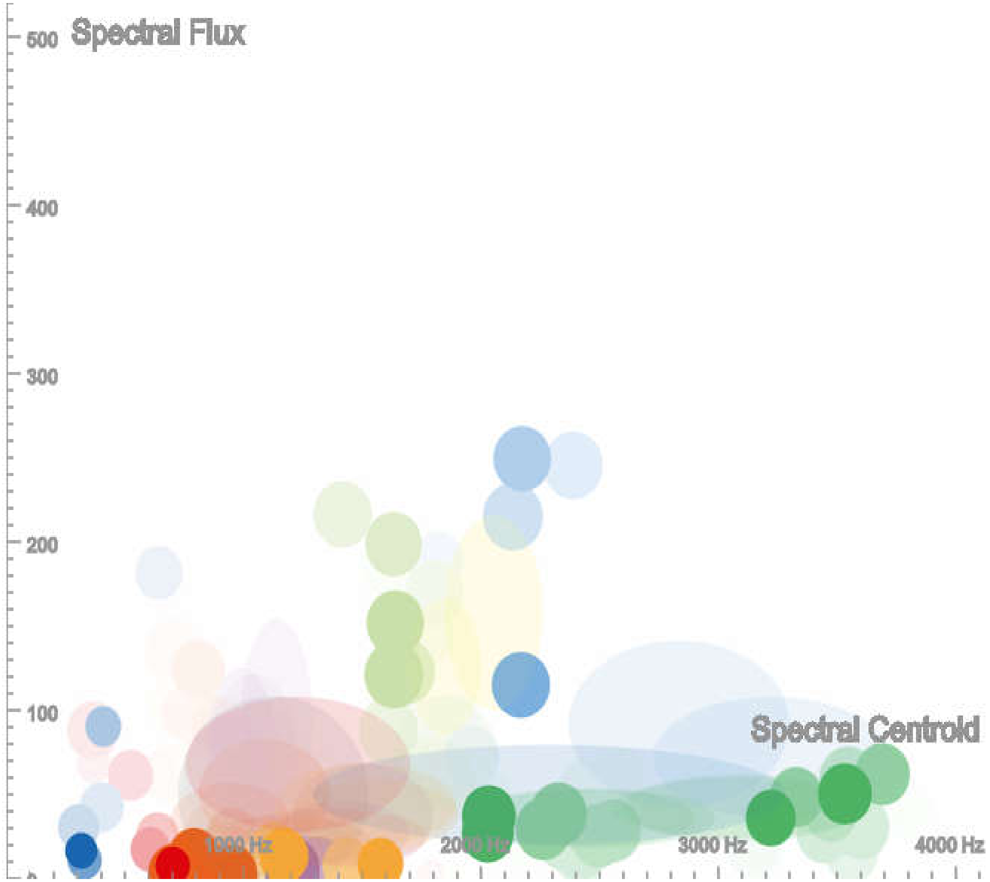
Example: 1st movement of Beethoven's 7th symphony
(Recordings of the single tracks by Pätynen et al. 2008)

4.1 Dynamic Spectral Centroid/Spectral Flux Map

- Tracking the **spectral centroid** and **spectral flux** of all single instruments with the MIRToolbox
- **Synchronization of audio and tracked features** in an interactive timbre map via Plotly and P5.

Behavior of instrumental timbre features can be visualized in "**free wilderness**":

•Instrument timbres have their **own territories.**
•Instruments position depends on **dynamic behaviour**



Mean values and standard deviations of the orchestral instruments involved, here in interaction: flutes (light blue), oboes (light green), bassoons (orange), violins (green), violas (light orange), cello (red) and bass (blue)

To Infinity and Beyond ...

Dynamic Timbre Maps

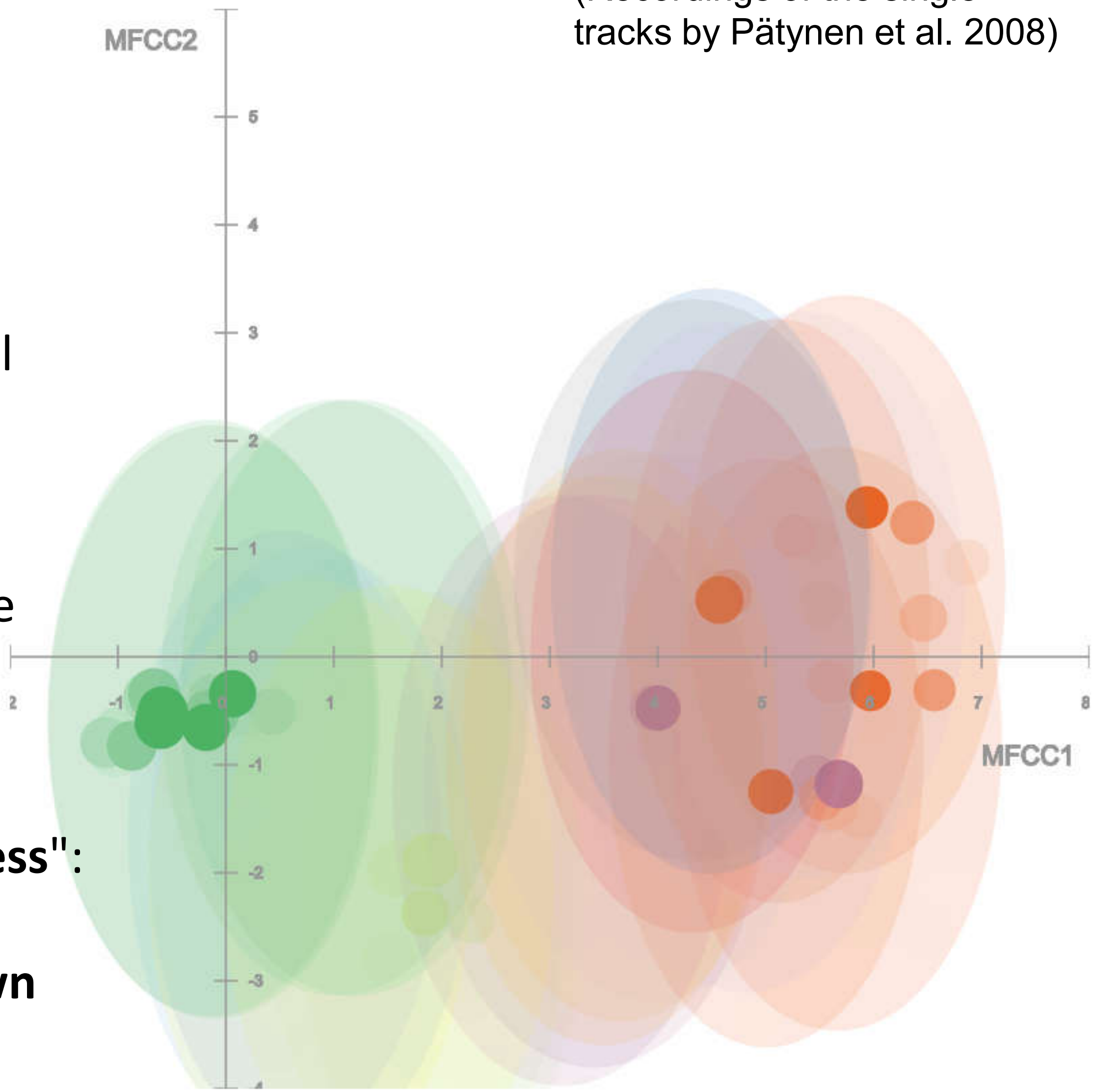
Example: 1st movement of Beethoven's 7th symphony
(Recordings of the single tracks by Pätynen et al. 2008)

4.2 Dynamic MFCC Map

- Tracking the **MFCC1 and 2** of all single instruments with the MIRToolbox
- **Synchronization of audio and tracked MFCCs** in an interactive timbre map via Plotly and P5.

Behavior of instrumental MFCCs can be visualized in "**free wilderness**":

•Instrument timbres have their **own territories.**
•**Similar** timbres have **overlapping** MFCCs (next door territories).



Mean values and standard deviations of the orchestral instruments involved, here in interaction: violins (green), horns (purple), bassoons (orange) and oboe (light green)

To Infinity and Beyond ...

Dynamic Timbre Maps

4.1 Dynamic Formant Map

- Tracking the **Formants1 and 2** of all single instruments with Parselmouth
- **Synchronization of audio and tracked Formants** in an interactive timbre map via Plotly and P5.

Behavior of instrumental Formants can be visualized in "**free wilderness**":

- Instrument timbres have their **own territories**.
- **Similar** timbres have **overlapping** formants (next door territories).

Example: 1st movement of Beethoven's 7th symphony
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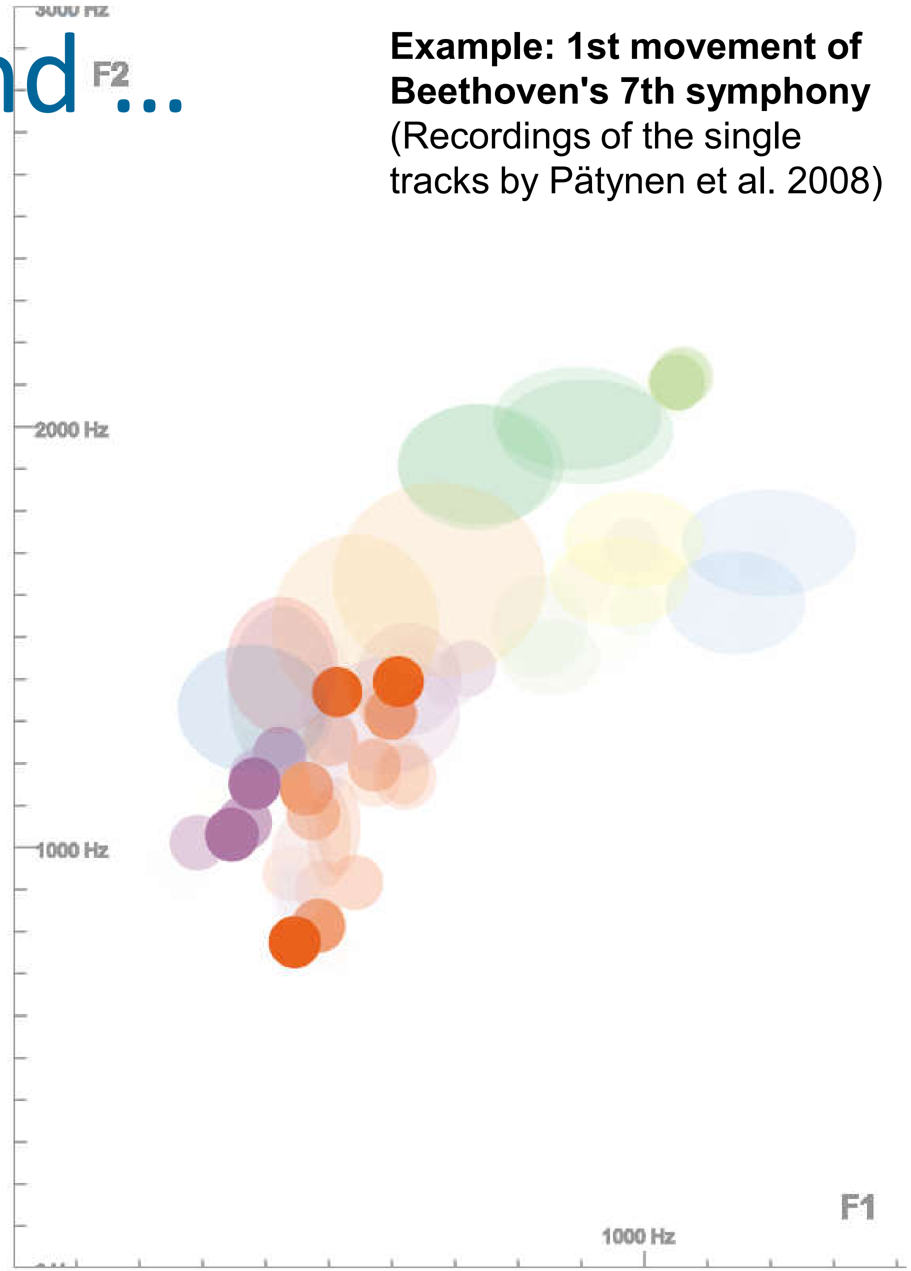

Mean values and standard deviations of the orchestral instruments involved, here in interaction: Horns (purple), bassoons (orange) and oboe (green)

To Infinity and Beyond ...

Take Home Message

Visualizations in **Timbre Spaces**:
- **Pros:** intuitive, very popular
- **Cons:** not comparable, not generalizable, only one pitch

Visualizations in **MFCC Feature Spaces**:
- **Pros:** very precise, very universally applicable.
- **Cons:** it is difficult to say what a single MFCC sounds like

Visualizations in **Formant Maps**:
- **Pros:** intuitive, sound imagination possible by comparison with vowels
- **Cons:** does not work for every instrument / register

Visualization in **Dynamic Maps**:
- **Real-life behavior** of timbre features in **musical interaction** becomes visible.
- Instruments show their **own territories** with **similar** sounding instrument timbres in their **neighborhood**

To Infinity and Beyond ...

Albersheim 1939: Acoustical Cylinder of Sound colors: https://muwiserver.synology.me/p5/fft_filter_albersheim.htm
Grey 1975: Timbfe Space: https://muwiserver.synology.me/timbrespaces/grey.htm
Krumhansl 1989, McAdams et al. 1995: Timbre Spaces: https://muwiserver.synology.me/formanten/more_timbre_spaces.htm
Siddiq et al. 2015 Meta Timbre Space: https://muwiserver.synology.me/timbrespaces/TS_mts3.htm
Reuter, Quigley 2020: Dove perch and courtship coos: https://muwiserver.synology.me/doves/doves2_sequence.htm
Bassoon without formants: https://muwiserver.synology.me/formanten/bassoonflattened.htm

Lartillot et al. 2007: MIRToolbox: https://www.jyu.fi/hytk/fi/laitokset/mutku/en/research/materials/mirtoolbox
Peeters et al. 2011: Timbre Toolbox: https://github.com/VincentPerreault0/timbretoolbox
Bogdanov et al. 2013: Essentia: https://essentia.upf.edu/
Yaafe 2013: https://github.com/Yaafe/Yaafe
Rawlinson 2014: Meyda: https://meyda.js.org/
McFee et al. 2015: Librosa: https://librosa.org/
Jillings 2016: JS-xtract: https://github.com/nickjillings/js-xtract
Aubio 2017: https://aubio.org/
Lartillot 2019: MiningSuite: http://olivierlar.github.io/miningsuite/

Loizou 1998: Colea: https://ecs.utdallas.edu/loizou/speech/colea.htm
Boersma, Weenink, since 2001: Praat: https://www.fon.hum.uva.nl/praat/
Jadoul et al. 2018: Parselmouth: https://github.com/YannickJadoul/Parselmouth
Kamath 2021: Formant Tracker: https://de.mathworks.com/matlabcentral/fileexchange/8959-formant-tracker
Rabiner et al. 2021: Formant Estimation: https://de.mathworks.com/matlabcentral/fileexchange/45315-formant-estimation

Sirker 1974: Perceptual Space for two-formant Sounds:
https://muwiserver.synology.me/formanten/formantkarte_instrumente.htm
McCarty 2003: vowel space: https://ccrma.stanford.edu/~jmccarty/formant.htm
Reuter et al. 2016: Formant Map 1.0: https://muwiserver.synology.me/formanten/formantregister4_english.htm
Reuter 2020: Formant Map 2.0: https://muwiserver.synology.me/formantmap/
Reuter 2022: Dynamic Formant Map: https://muwiserver.synology.me/dynamic/formants.htm
Reuter 2022: Dynamic MFCC Map: https://muwiserver.synology.me/dynamic/mfcc.htm
Reuter 2022: Dynamic SpectralCentroid/Flux Map: https://muwiserver.synology.me/dynamic/spectralcentroid.htm