



Extended Source-Filter Model of Harmonic Instruments for Sound Synthesis, Transformation and Interpolation

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Introduction

Extended Source Filter Model

Model Results

Subjective Evaluation

Conclusions

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Sample Based Synthesis (Overview)

- ▶ an electronic instrument
- ▶ based on 'playback' of prerecorded instrument sounds
- ▶ playback is triggered by some input device (MIDI Keyboard)

- ▶ instrument characteristics are preserved
- ▶ synthesized sounds static
- ▶ no expressive control

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- ▶ extended source-filter model
- ▶ digital synthesis
- ▶ sampled sounds
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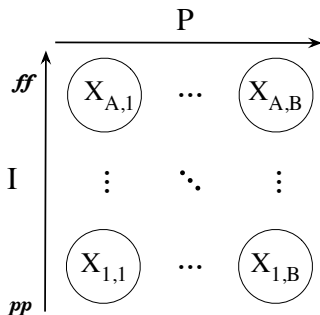
Sample Based Synthesis (State of the art)

- ▶ recordings on a semitone scale
- ▶ recordings at several intensities
- ▶ transformations based on local Source-Filter approach

- ▶ soundspace is described by a limited knowledge of a few intermediate values
- ▶ transformations do not account for real world usage generalities

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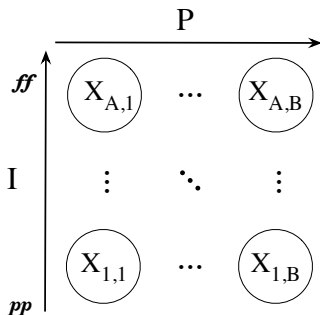
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I : Intensity {a=1...A}

P : Pitch {b=1...B}

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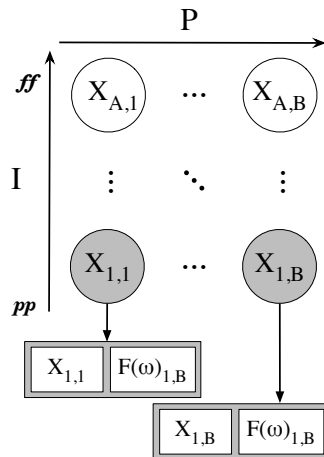
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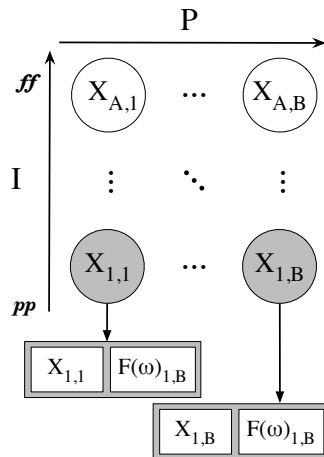


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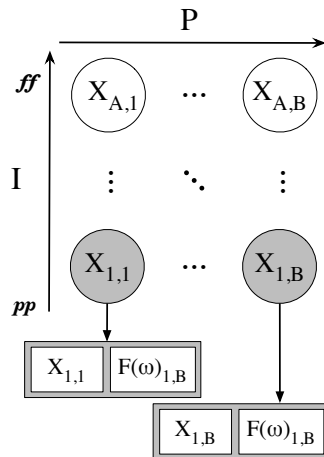


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- ▶ usage of **State of the Art** databases
- ▶ **parametric** model to describe the whole instrument sound characteristic along **pitch / global intensity**
- ▶ account for **temporal evolution** of a sound (**ASR**) denoted **local Intensity**
- ▶ separately treat **harmonic** and **noise** components
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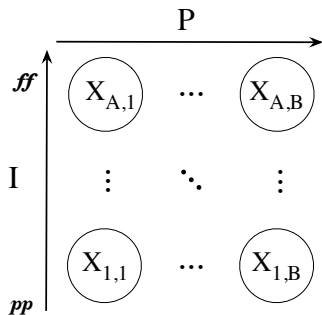
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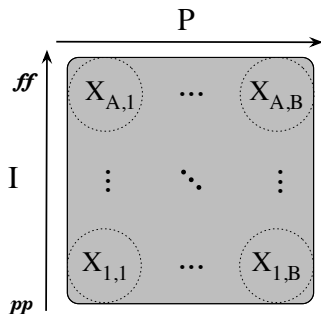
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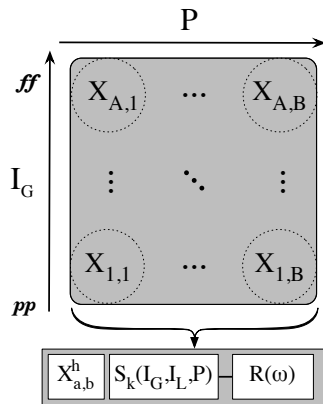
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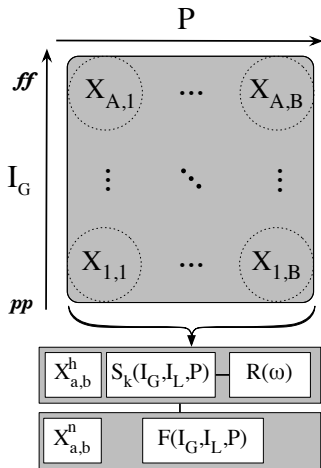
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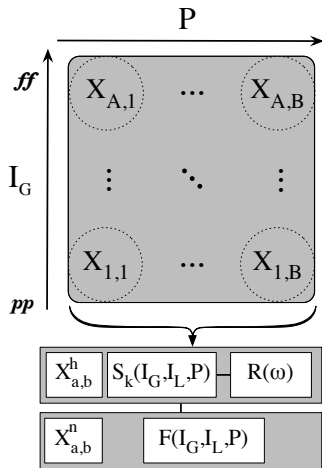
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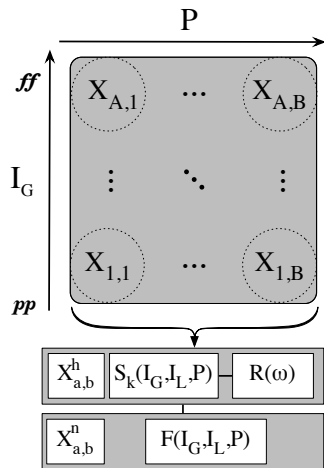
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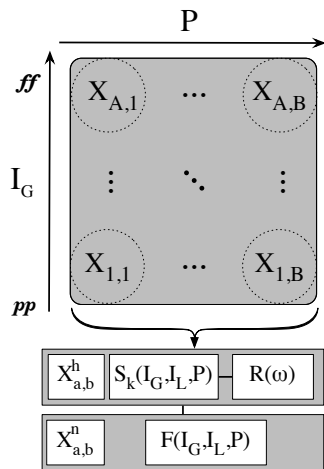
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- ▶ Sound synthesis with continuous pitch and intensity values
- ▶ Interpolation between sounds
- ▶ Cross synthesis between different instruments
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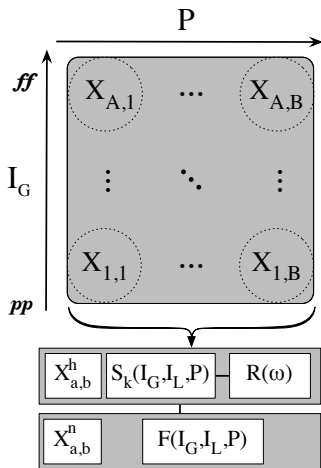
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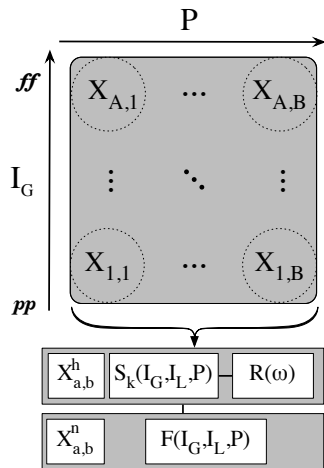
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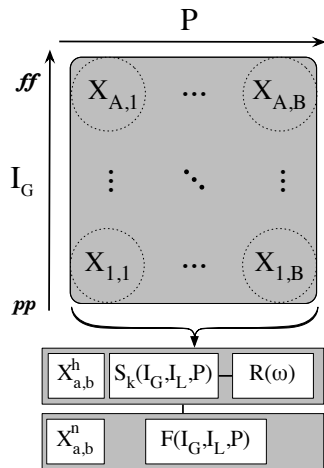
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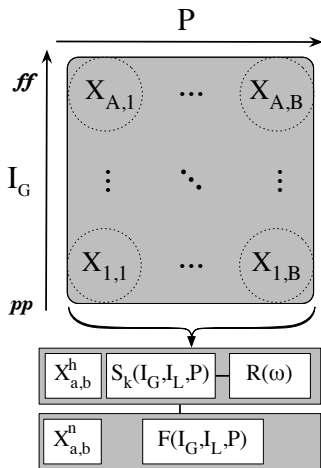
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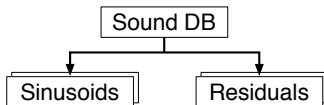
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Sound DB

- ▶ Harmonic/Noise Segregation
- ▶ Parameter Analysis
 - ▶ Global Intensity / Pitch
 - ▶ Local Intensity (ASR scheme)
- ▶ Model adaption for harmonic/noise component
- ▶ Remove estimated instrument sound from signal components
- ▶ yields database of 'flat' residual sounds
- ▶ Interpolate 2 'flat' residuals (harmonic / noise separately)
- ▶ Apply any parameter change to estimate new envelopes to use on 'flat' residuals

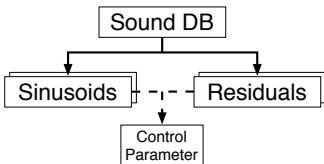
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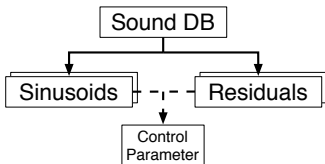
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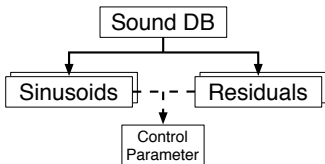
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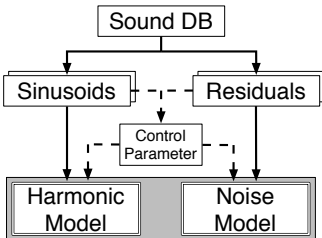
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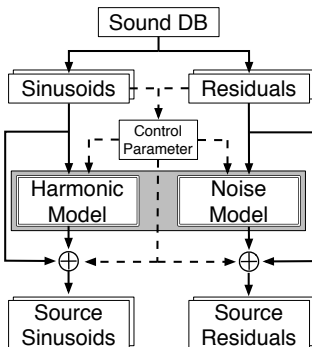
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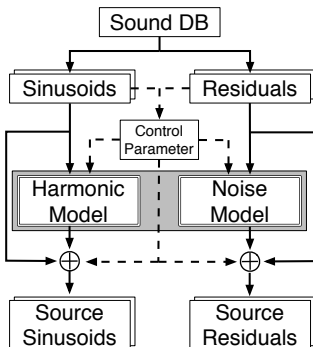
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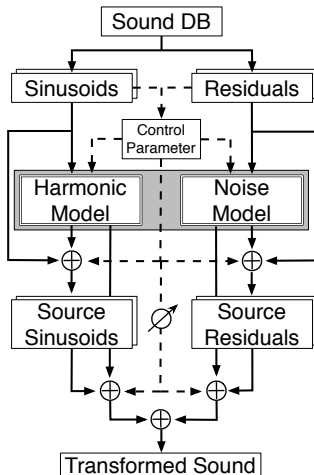
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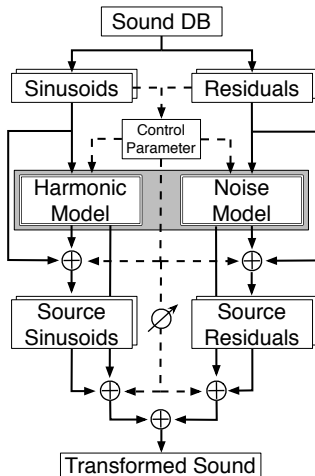
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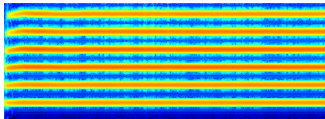
Harmonics/Noise Segregation

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$$A(k, n) \quad | \quad f(k, n)$$

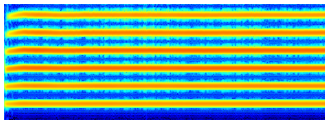


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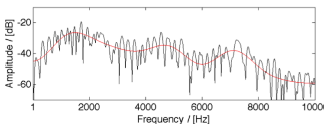
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- Noise is modeled as envelope using its smoothed Short Time Cepstrum $C(l, n)$

$$C(l, n)$$



Parameter Analysis

Global Intensity / Pitch Analysis

- ▶ Obtained from meta data provided by the Database

Local Intensity

- ▶ Local intensity reflects amplitude envelope over time: $I_L(n)$.
- ▶ Threshold method to determine attack/release time frames n_A, n_R

Temporal Segmentation

- ▶ Segmentation using an overlapping scheme to define $n_S = \{n_a, n_r\}$

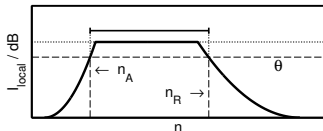
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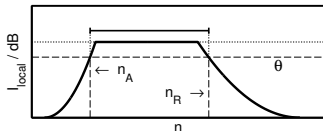
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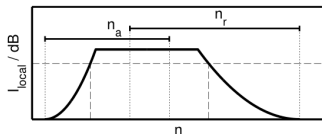
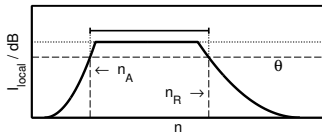
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Features by partial index k

- ▶ function for each k depending on **pitch** m (MIDI) and **both intensities** I_G and I_L
- ▶ separate functions s for **attack-sustain** and **sustain-release**
- ▶ may refer to a vibrating string / air pipe

Partial function

$$S^{k,s}(I_G, I_L, m)$$

Features by frequency f

- ▶ invariant filter
- ▶ refers mainly to the instrument corpus

Resonance filter

$$R(f)$$

- ▶ using log-domain values

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Harmonic Model

Features by partial index k

- ▶ function for each k depending on **pitch** m (MIDI) and **both intensities** I_G and I_L
- ▶ separate functions s for **attack-sustain** and **sustain-release**
- ▶ may refer to a vibrating string / air pipe

Partial function

$$S^{k,s}(I_G, I_L, m)$$

Features by frequency f

- ▶ invariant filter
- ▶ refers mainly to the instrument corpus
- ▶ using log-domain values

Resonance filter

$$R(f)$$

Harmonic Model

$$\hat{A}^{k,s}(I_G, I_L, m, f(k, n)) = S^{k,s}(I_G, I_L, m) + R(f(k, n))$$

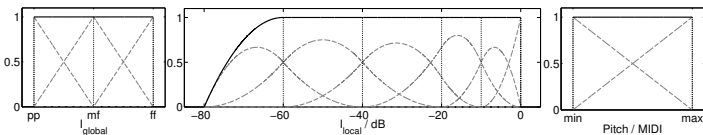
► Model of partial function using tensor-product B-splines:

Harmonic Model

$$\hat{A}^{k,s}(I_G, I_L, m, f(k, n)) = S^{k,s}(I_G, I_L, m) + R(f(k, n))$$

- Model of partial function using tensor-product B-splines:

$$S^{k,s}(I_G, I_L, m) = \sum_{p,q,t}^{P,Q,T} B_p(I_G) B_q(I_L) B_t(m) \cdot \gamma_{p,q,t}^{k,s}$$



B-Spline functions for $B_p(I_G)$, $B_q(I_L)$, $B_t(m)$

Harmonic Model

$$\hat{A}^{k,s}(I_G, I_L, m, f(k, n)) = S^{k,s}(I_G, I_L, m) + R(f(k, n))$$

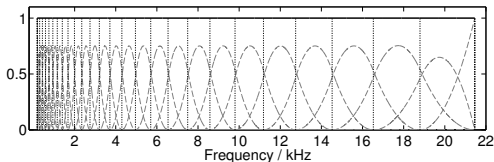
► model of resonance filter using one-dimensional B-splines

Harmonic Model

$$\hat{A}^{k,s}(I_G, I_L, m, f(k, n)) = S^{k,s}(I_G, I_L, m) + R(f(k, n))$$

- ▶ model of resonance filter using one-dimensional B-splines

$$R(f(k, n)) = \sum_v^V B_v(f(k, n)) \cdot \lambda_v$$

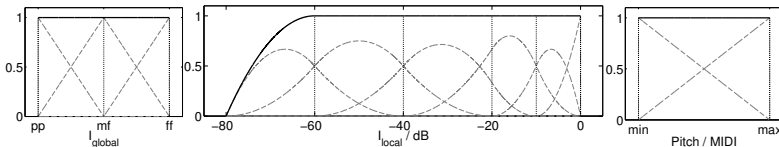


B-Spline functions for $B_v(f(k, n))$

Noise Model

- ▶ Cepstral coefficients are described using a single tensor-product B-spline model:

$$\hat{C}^{k,s}(l_G, l_L, m) = \sum_{p,q,t}^{P,Q,T} B_p(l_G) B_q(l_L) B_t(m) \cdot \delta_{p,q,t}^{k,s}$$



B-Spline functions for $B_p(l_G)$, $B_q(l_L)$, $B_t(m)$

Parameter Estimation

Iterative method using Conjugate Gradient

$$\mathcal{O}_h = \frac{1}{2} \sum_{s=1}^2 \sum_{k, n_s}^{K, N_s} |A(k, n_s) - \hat{A}^{k,s}(l_G, l_L(n_s), m, f(k, n))|^2$$

$$\mathcal{O}_n = \frac{1}{2} \sum_{s=1}^2 \sum_{l, n_s}^{L, N_s} |C(l, n_s) - \hat{C}^{k,s}(l_G, l_L(n_s), m)|^2$$

Introduction

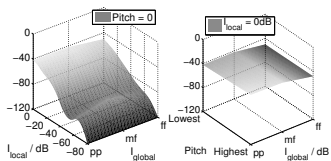
Extended Source Filter Model

Model Results

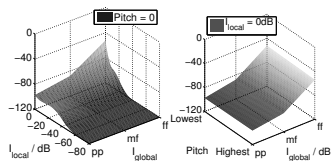
Subjective Evaluation

Conclusions

Model Results: Trumpet

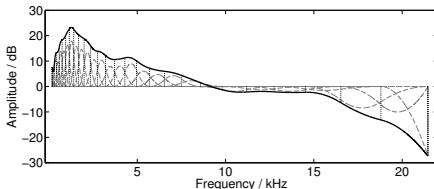


$$S^{k,s}, k = 1$$



$$S^{k,s}, k = 40$$

$R(f)$:



Introduction

Extended Source Filter Model

Model Results

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Subjective Evaluation

- ▶ Tests have been made for **trumpet** and **clarinet**

- Interpolation between different pitches (12st and 24st)
- Interpolation between different intensities (*pp-mf* - *mf-ff* - *pp-ff*)

Sequence of 3 sounds has always been presented, framing the interpolated by their original sounds.

Each sequence was presented twice. Once containing the transformed and once the original counterpart

Participants were asked to judge for any audible artifacts and convincingness

Clarinet: *mf-ff*

Trumpet *pp-ff*

Clarinet A#3-A#5

Subjective Evaluation

- ▶ Tests have been made for **trumpet** and **clarinet**

- Interpolation between different timbres (10s) and (4s)
- Interpolation between different dynamics (*pp-mf*, *mf-ff*, *pp-ff*)

Sequence of 3 sounds has always been presented, framing the interpolated by their original sounds.

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Trumpet *pp-ff*

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Clarinet **A#3-A#5**

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Trumpet **pp-ff** 

Clarinet **A#3-A#5** 

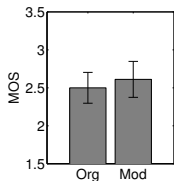
Subjective Evaluation: Results

- ▶ Measured the **Mean Opinion Score** for both instruments at once
- ▶ **Org** represents original samples, **Mod1** and **Mod2** represent synthesized ones.

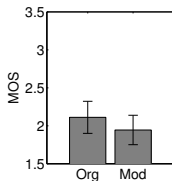
▶ MOS: 100% of subjects preferred the original samples over the synthesized ones

Subjective Evaluation: Results

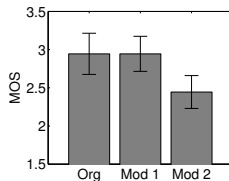
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Pitch Interpolation:
12st



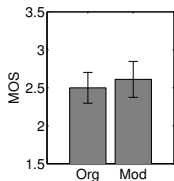
Pitch Interpolation:
24st



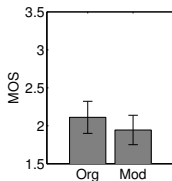
I_G Interpolation:
Mod1: ***pp-mf*** and ***mf-ff***
Mod2: ***pp-ff***

Subjective Evaluation: Results

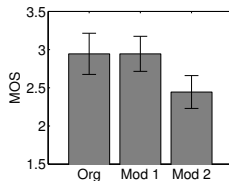
- ▶ Measured the **Mean Opinion Score** for both instruments at once
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Pitch Interpolation:
12st



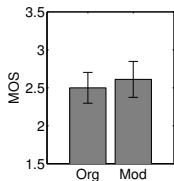
Pitch Interpolation:
24st



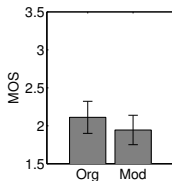
I_G Interpolation:
Mod1: ***pp-mf*** and ***mf-ff***
Mod2: ***pp-ff***

Subjective Evaluation: Results

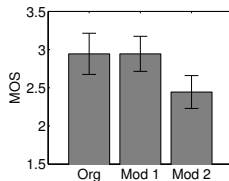
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Pitch Interpolation:
12st



Pitch Interpolation:
24st



I_G Interpolation:
Mod1: ***pp-mf*** and ***mf-ff***
Mod2: ***pp-ff***

- ▶ MOS for original value way too low. Need for a new test with different setup

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We presented

- ▶ A parametric model for harmonic instruments
- ▶ A model which separately represents harmonic and noise components utilizing tensor-product B-splines
- ▶ An harmonic model separately representing features by partial index and frequency
- ▶ An objective function to estimate model parameters iteratively
- ▶ A subjective evaluation showing promising results

- ▶ More instruments need to be addressed (strings, Piano, Guitar)
- ▶ A subjective evaluation needs to be repeated with a different setup

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- ▶ A subjective evaluation of the model compared with a filtered signal

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Fin

Thanks for listening