Intonation Tendencies in Polyphonic Vocal Ensembles

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Goals

- to reliably extract pitch information from recordings of polyphonic vocal ensembles in order to observe intonation tendencies
- to develop a model of the observed intonation tendencies in polyphonic vocal ensembles

Technical Challenges

- polyphonic pitch estimation
- further complicated by the presence of
  - vibrato
  - reverberation
  - glissandi between notes
  - homogeneity of timbre

Musical Challenges

- at any given point in a piece a vocal ensemble's tuning cannot be consistently related to a single reference point
- a combination of horizontal and vertical musical factors form the reference point for the tuning
- the weighting of these factors likely differs both within and across pieces

Horizontal

- the seventh of the home key functions differently in a piece that modulates
  - B is the leading tone of C Major and the mediant of G Major
    - in C Major it is an unstable pitch that generally resolves to the tonic (C)
    - in G major it is a stable pitch

Horizontal vs Vertical

- even within a single chord there are potential tuning conflicts
- in the context of a G Major chord in C major, B is both the leading-tone of the key and the third of the chord
  - it is commonly held that leading-tones are tuned sharp
  - theories of sensory consonance suggest that a vertical major third will be tuned flat

Vocal Intonation Studies

- Seashore and colleagues' work at the University of Iowa (1930s)
- "Speech, Music, and Hearing" group, Royal Institute of Technology, Stockholm (1980s-present)
- Prame's study of vibrato and intonation in solo singers (1997)

Applications

- singing pedagogy
  - it is not known if general tendencies exist
  - if they exist and can be generalized, the results of this work will be a useful baseline when training vocalists to sing in different tuning systems
- expressive performance
  - MIDI Renditions
  - theories of musical expression

Signal Processing

- need to
  - extract the pitch of multiple voices in polyphonic contexts
  - measure tuning differences that are far smaller than a semitone
  - estimate the perceived pitch over the duration of the note
- can exploit prior knowledge of the score

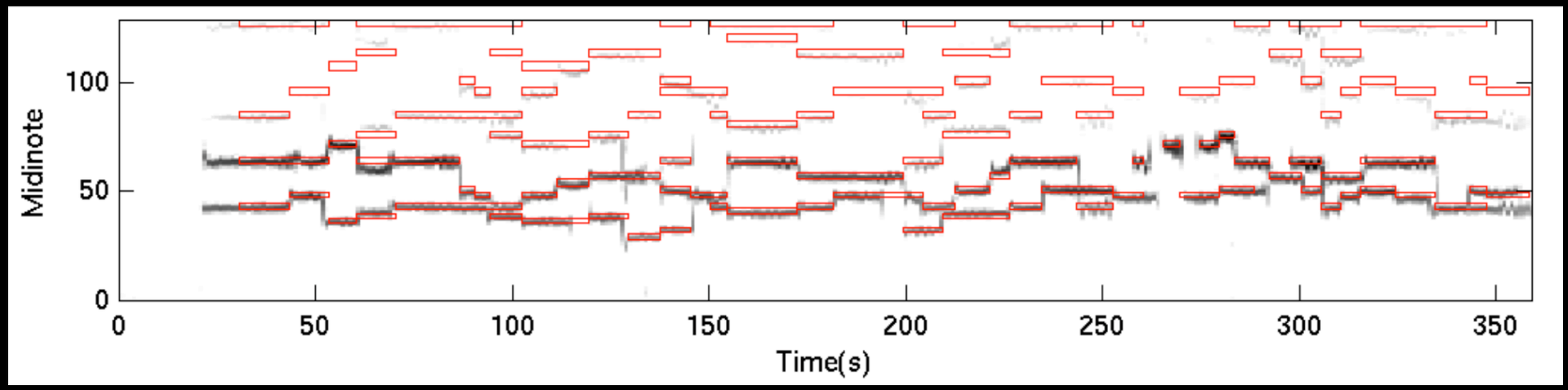
Test set

- multi-tracked recordings of a movement from Machaut's *Notre Dame Mass*
- note onsets and offsets manually annotated using Audacity
- test sets of one, two, three, and four voices
- addition of artificial reverb

Alignment

- dynamic time warping
- features
  - peak structural distance (Orio and Schwarz 2001)
  - chromagrams (Hu et al. 2003)
  - cosine difference of spectral power and first order difference in frequency (Turetsky and Ellis 2003)

Demonstration of Alignment



Instantaneous Frequency (IF)

- calculate a phase derivative within each time-frequency cell of a conventional short-time Fourier transform (Abe et al. 1996)
- the IF in three spectrally-adjacent cells must differ by less than 25% to be considered stable

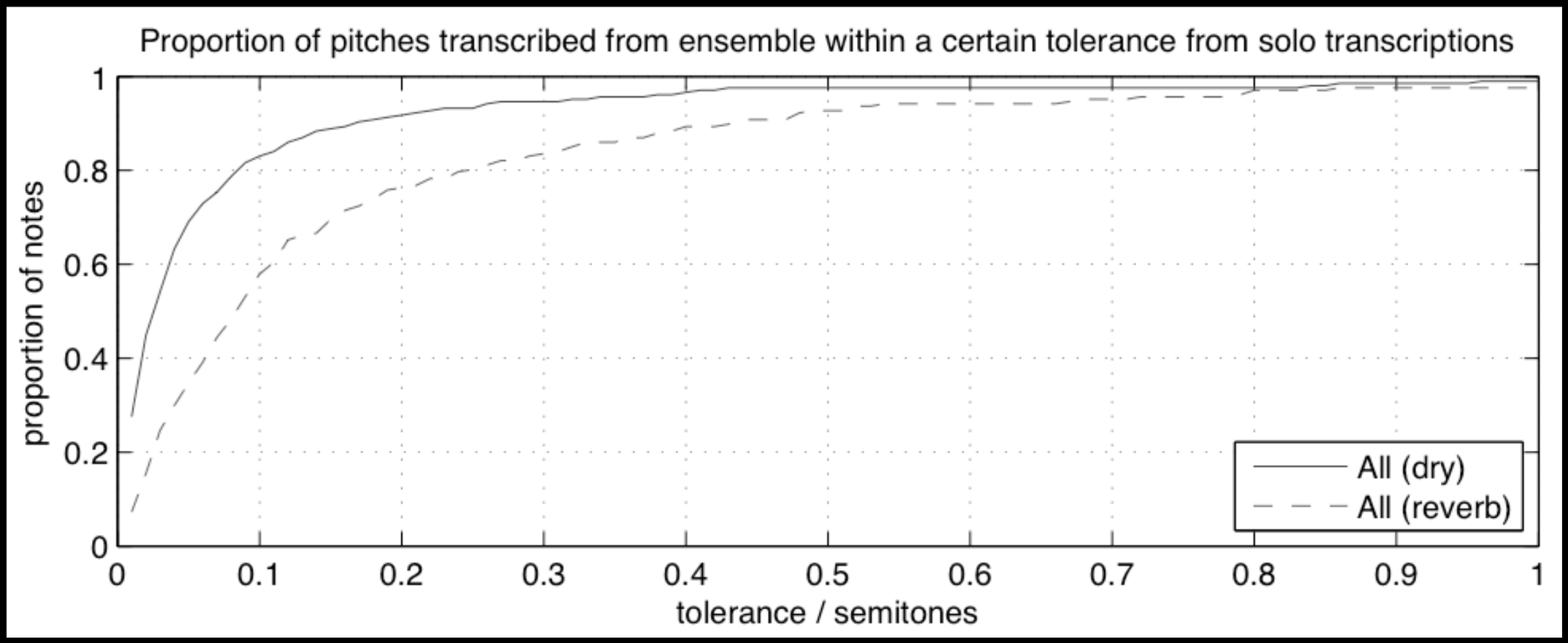
Instantaneous Frequency (IF)

- the generated IF spectrogram recovers the estimated energy and frequency of sinusoids at every time-frequency cell
- aligned MIDI file indicates the time-span for each expected note
- currently only using fundamentals - we are working with Christine Smit on expanding this to use harmonics

Calculating Perceived F0

- perceived F0 is assumed to be the mean frequency over the duration of the note (Brown and Vaughn 1993)
- we intuit this should only be the steady-state portion of the note
  - currently working on perceptual tests to confirm this

Accuracy of IF technique



Future Work

- once a sufficient number of recordings have been processed we will start to model the data
- short-term goal is to find if any generalities exist
- longer-term goal is to develop a theory of vocal intonation practices (Devaney and Ellis 2008)

Final Thoughts

- vocal intonation is a complex phenomenon
- empirical measurements of recorded performances are a useful way to observe intonation practices
  - this presents several non-trivial signal processing challenges for which workarounds are possible
- some of the code is available at
  - www.ee.columbia.edu/~dpwe/resources/matlab/

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