# Music Performance Analysis

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NATIONAL ENDOWMENT FOR THE Humanities

# Introduction

Why study musical performance?

- **Performances convey musicians' interpretations**
- **Performances are what listeners actually hear**
- **Studying performance can help us gain insight into**
  - the available range for extended techniques
  - how an individual's performance practice evolves as they gain more experience
  - how performance practices evolve over time
- **Observing how performance practices relate to musical materials can help us develop models of "expressive" performance**

# Introduction

What do I mean by analyzing musical performances?

- **Recorded performances**
- **Measuring performance parameters**
  - timing
  - dynamics
  - **tuning**
  - timbre
- **Assessing relationship between performance of various parameters and musical materials**

# Introduction

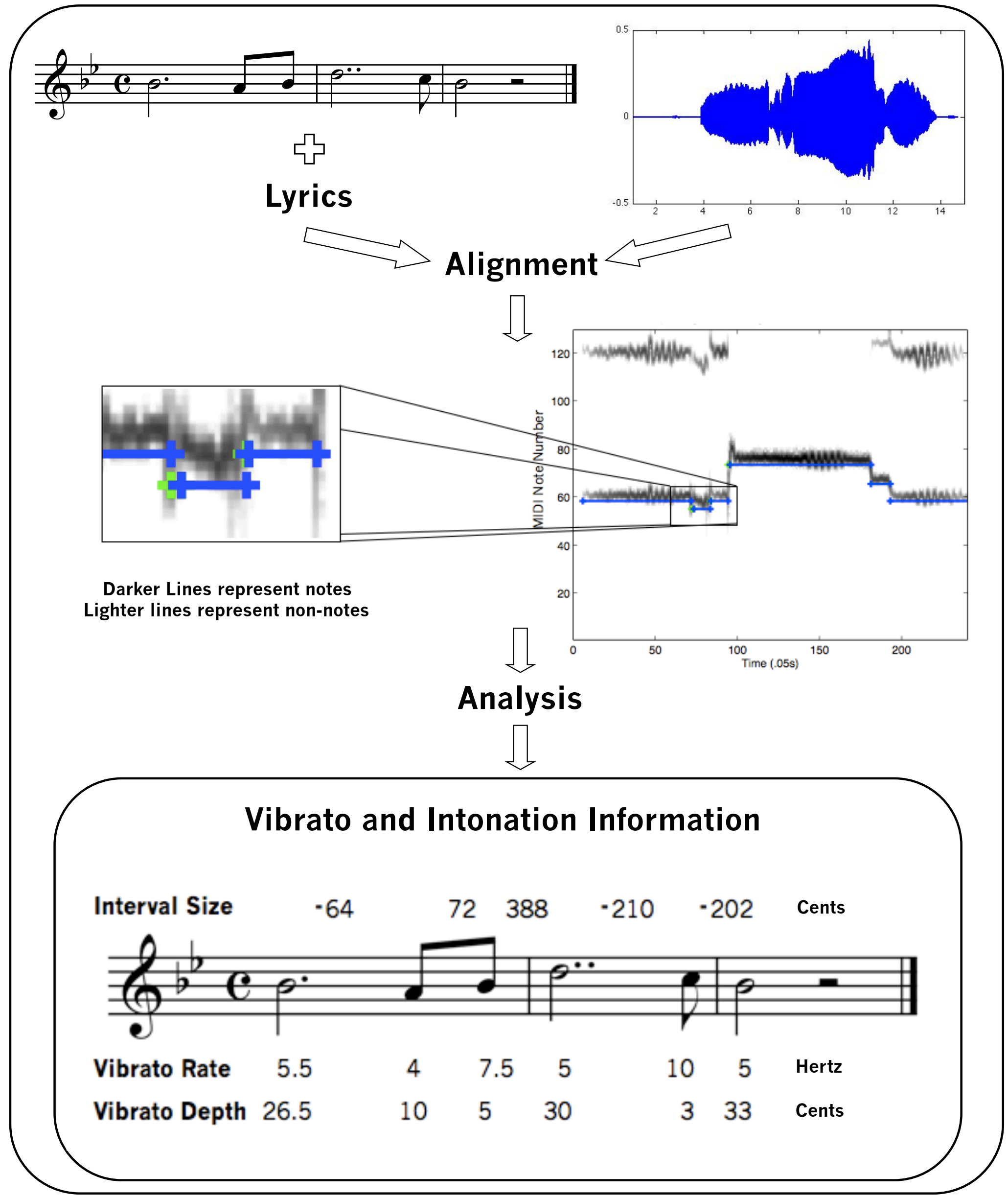
## Challenges

- **Accurately extracting low-level data (especially when more than one instrument is playing)**
  - Note locations, frequency, and power
- **Modeling the low-level data in a perceptually meaningful higher-level parameters**
- **Encoding these parameters in a sharable way that is appropriately linked with other musical information**

# AMPACT

## Automatic Music Performance Analysis and Comparison Toolkit

**www.ampact.org**



## Introduction 1

Motivation and challenges.

## A brief history 2

Quantitative approaches to musical performance analysis.

## Extracting Performance Data 3

AMPACT for automatic analysis of recorded performances.

## Conclusions 4

Summary and future directions.

# Quantitative Performance Analysis

## A brief history

**Pioneers**
Binet and Courtier
Sears
Miller

# Quantitative Performance Analysis

## A brief history

**Pioneers**
Binet and Courtier
Sears
Miller

1895–1930

1920–40s

1960s

1980s and 90s

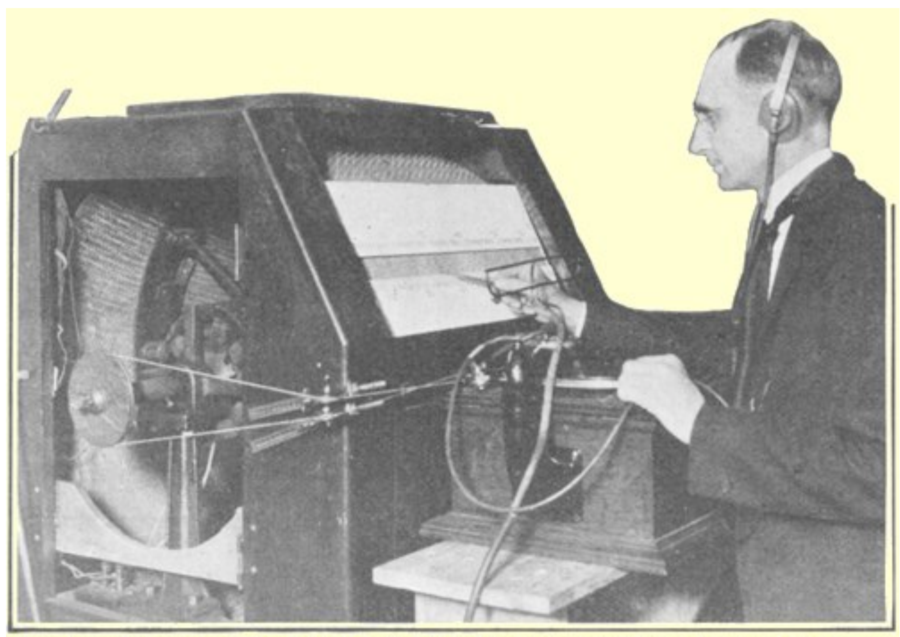
1990s and 2000s

**University of Iowa**
Seashore and colleagues

# Quantitative Performance Analysis

University of Iowa

- **Carl Seashore (1938) and colleagues studied timing, dynamics, intonation, and vibrato in pianists, violinists, and singers**
  - Equipment: piano rolls, films of the movement of piano hammers during performance, phono-photographic apparati

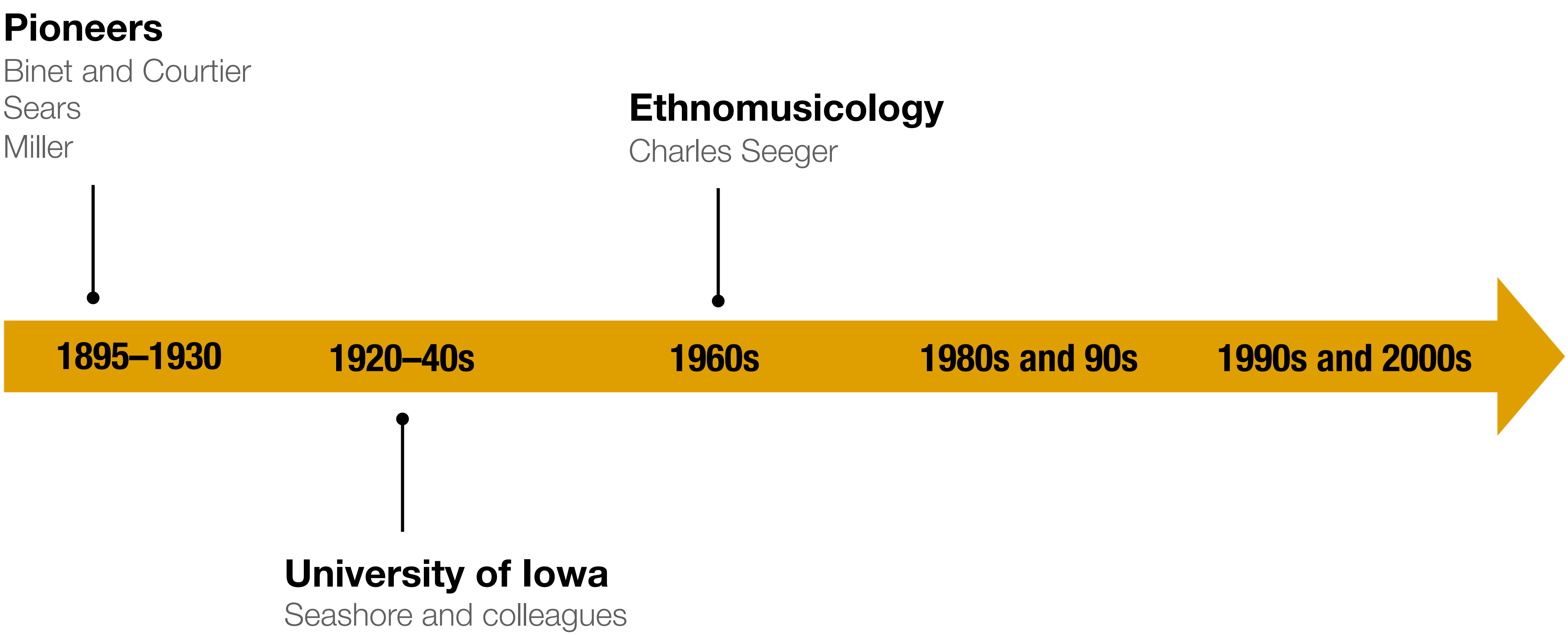


The tonoscope for analyzing the pitch of the tones on a disk phonograph record

Cary (1922)

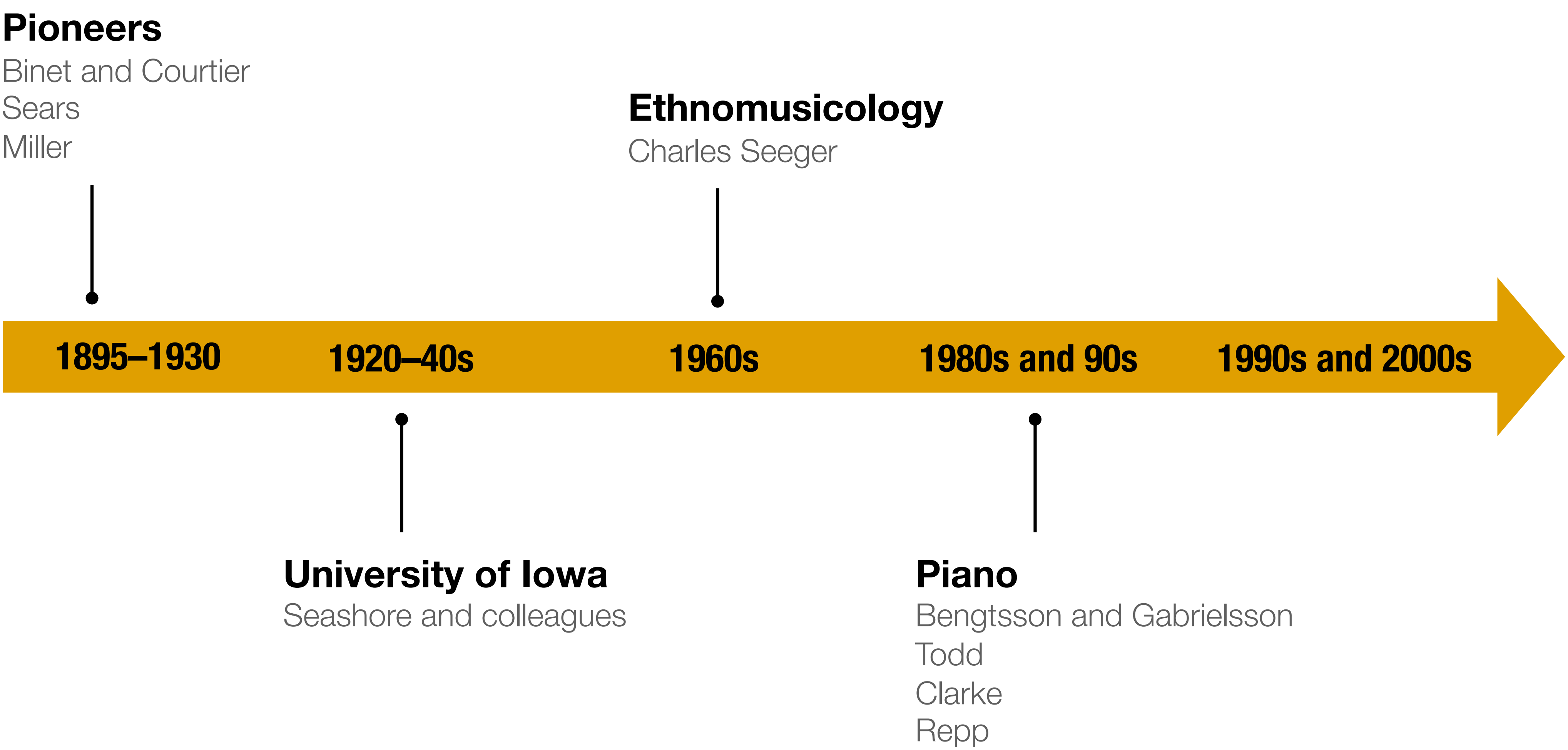
# Quantitative Performance Analysis

## A brief history



# Quantitative Performance Analysis

A brief history



# Quantitative Performance Analysis

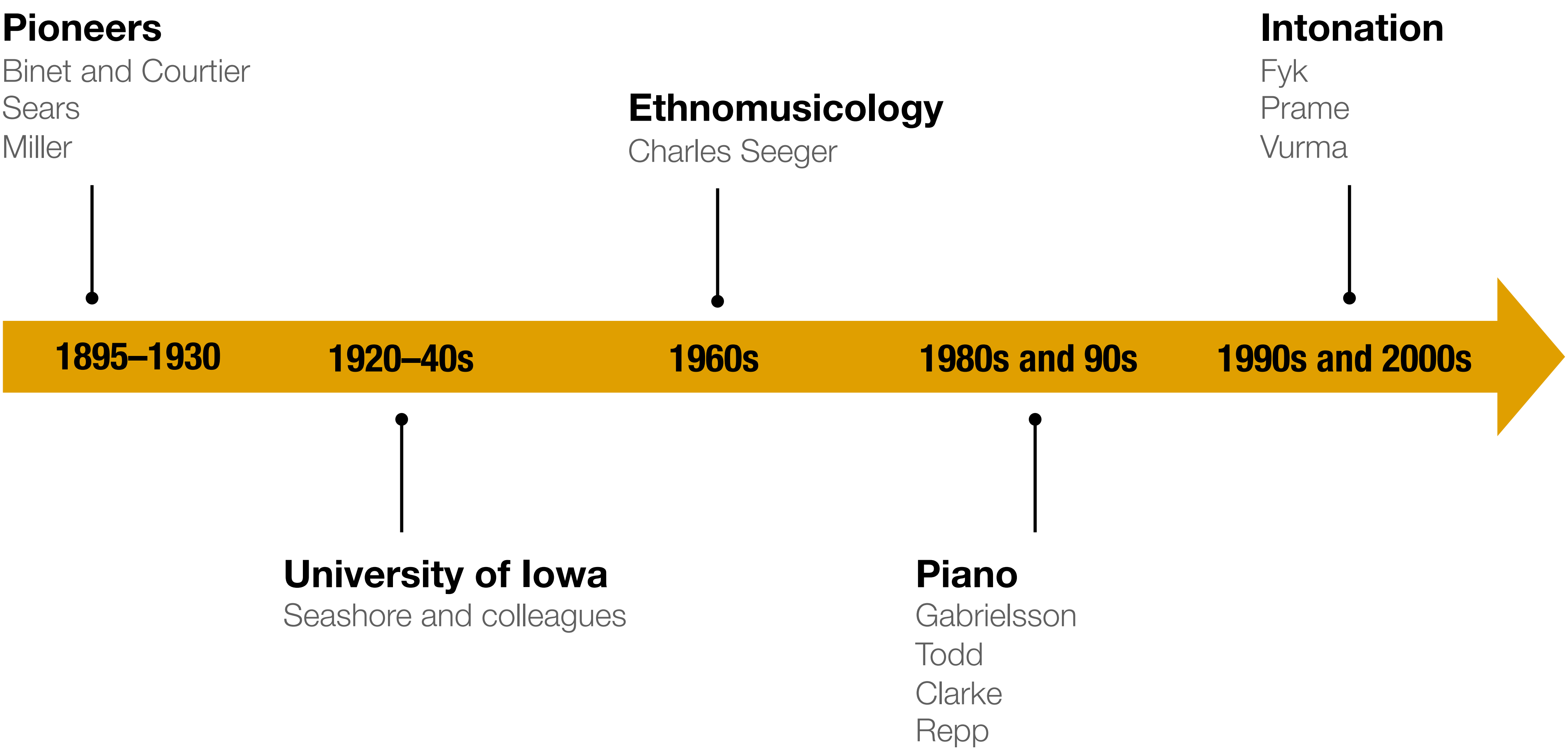
## Popularity of the piano

- Large amount of solo repertoire
- Instrument's percussive nature
- Feasibility of using specially equipped pianos (e.g., MIDI)
  - cannot study existing recordings
  - new recordings are typically done in a lab environment

**Bosendorfer SE piano at BRAMS, Montreal**

# Quantitative Performance Analysis

A brief history



# Quantitative Performance Analysis

## A brief history

**1895–1930**

**Pioneers**
Binet and Courtier
Sears
Miller

**1920–40s**

**University of Iowa**
Seashore and colleagues

**1960s**

**Ethnomusicology**
Charles Seeger

**1980s and 90s**

**Piano**
Gabrielsson
Todd
Clarke
Repp

**1990s and 2000s**

**Intonation**
Fyk
Prame
Vurma

**Computational Models**
Friberg
Mazola
Widmer

## Introduction
Motivation and challenges.

1

## A brief history
Quantitative approaches to musical performance analysis.

2

## Extracting Performance Data
AMPACT for automatic analysis of recorded performances.

3

## Conclusions
Summary and future directions.

4

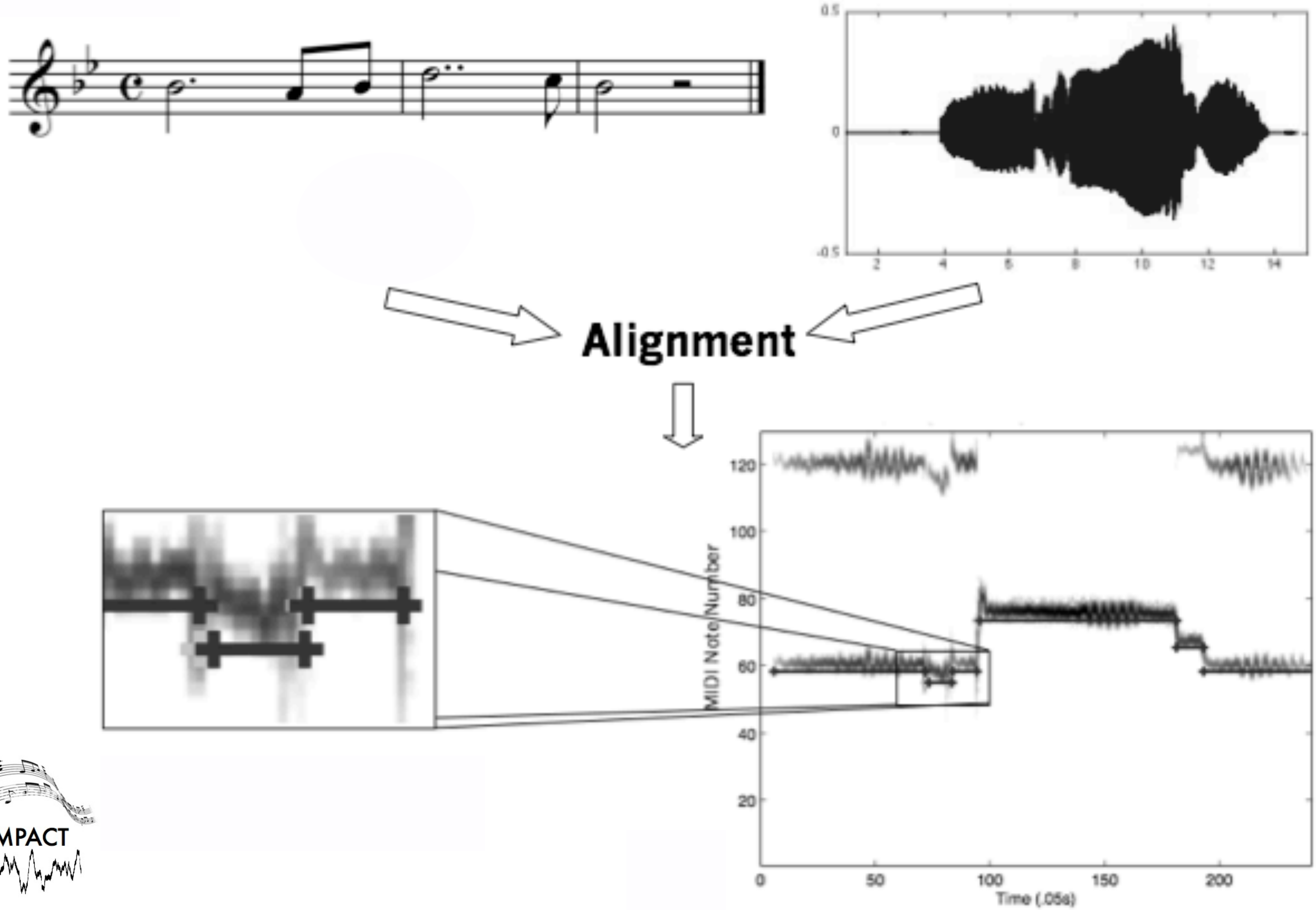
# Brief History of AMPACT

Automatic Music Performance Analysis and Comparison Toolkit

- **AMPACT 0.1 (2011): monophonic alignment**
- **AMPACT 0.2 (2011): monophonic pitch and loudness estimation**
- **AMPACT 0.3 (2014): polyphonic alignment**
- **AMPACT 0.4 (2017): polyphonic pitch, loudness, and timbre**
- **AMPACT 0.5 (*2018*): encoding formats**

# AMPACT 0.1

Monophonic score-audio alignment



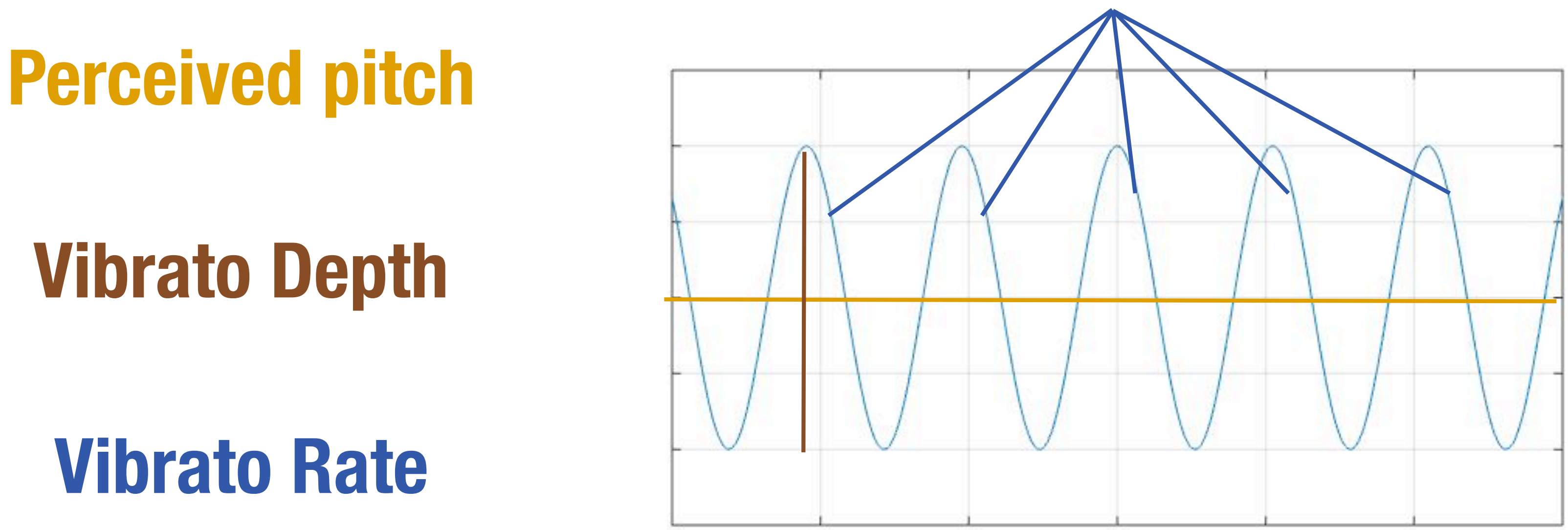
# AMPACT 0.1

## Monophonic alignment

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% [allstate selectstate spec yinres]=seeAlignment(audiofile,midifile,...
% numNotes, stateOrd, noteNum, means, covars,learnparams)
%
% Description:
%  Calls the DTW alignment function and refines the results with the HMM
%  alignment algorithm, with both a basic and modified state spaces (based
%  on the lyrics). This function returns the results of both the state
%  spaces as well as the YIN analysis of the specified audio file.
%
% Inputs:
%  filename - name of audio file
%  midiname - name of MIDI file
%  numNotes - number of notes in the MIDI file to be aligned
%  stateOrd2 - vector of state sequence
%  noteNum - vector of note numbers corresponding to state sequence
%  means - mean values for each state
%  covars - covariance values for each state
%  learnparams - flag as to whether to learn means and covars in the HMM
%
% Outputs:
%  allstate - ending times for each state
%  selectstate - ending times for each state
%  spec - spectogram of the audio file
%  yinres - structure of results of funning the YIN algorithm on the
%           audio signal indicated by the input variable filename
%
% Automatic Music Performance Analysis and Analysis Toolkit (AMPACT)
% http://www.ampact.org
% (c) copyright 2011 Johanna Devaney (j@devaney.ca), all rights reserved.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

# AMPACT 0.2

Notewise summaries




**Pitch**

- perceived pitch
- vibrato rate and depth
- F0 slope and curvature

**Loudness**

- perceived loudness

# AMPACT 0.2

## Pitch and vibrato estimation

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% [vibratoDepth, vibratoRate, noteDynamics, intervals]
%    =getPitchVibratoDynamicsData(times,sr)
%
% Description: Calculate vibrato depth, vibrato rate, perceived pitch, and
%              interval size for the notes in the inputted cell array cents
%
% Inputs:
%  cents - cell array of cent values for each note
%  sr - sampling rate
%
% Outputs:
%  vibratoDepth - cell array of vibrato depth calculations for each note
%  vibratoRate - cell array of vibrato rate calculations for each note
%  intervalSize - cell array of interval size calculations between
%                 sequential notes
%  pp - cell array of perceived pitch calculations for each note
%
% Automatic Music Performance Analysis and Analysis Toolkit (AMPACT)
% http://www.ampact.org
% (c) copyright 2011 Johanna Devaney (j@devaney.ca)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

# AMPACT 0.2

F0 slope and curvature estimation

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% [coefs approx] = noteDct(x, Ndct, sr)
%
% Description: Compute the DCT of a signal and approximate it with the
%              first Ndct coefficients  x is the signal  Ndct is the number
%              of DCT coefficients to be calculated sr is the sampling rate
%              of the signal
%
% Inputs:
%  x - signal to be analyzed
%  Ndct - number of DCT coefficients to be calculated
%  sr - sampling rate
%
% Outputs:
%  coefs - DCT coefficients
%  approx - reconstruction of X using the Ndct number of DCT coefficients
%
% Automatic Music Performance Analysis and Analysis Toolkit (AMPACT)
% http://www.ampact.org
% (c) copyright 2011 Johanna Devaney (j@devaney.ca) and Michael Mandel
%                     (mim@mr-pc.org), all rights reserved
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

# AMPACT 0.2

## Loudness estimation

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% nmat=getTimingData(midifile, times)
%
% Description: Get loudness estimate based on Glasberg and Moore (2002)
%              for time-varying sounds using the Loudness Toolbox
%
% Inputs:
%  audiofile - name of audiofile
%  times - onset and offset times
%
% Outputs:
%  loudnessEstimates - maximum short-term loudness (in sones) vs time
%  loudnessStructure - complete structure returned by
%                      Loudness_TimeVaryingSound_Moore
%
% Dependencies:
%   Genesis Acoustics. 2010. Loudness Toolbox for Matlab.
%    Available from http://www.genesis-acoustics.com/index.php?page=32
%
% Automatic Music Performance Analysis and Analysis Toolkit (AMPACT)
% http://www.ampact.org
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%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```
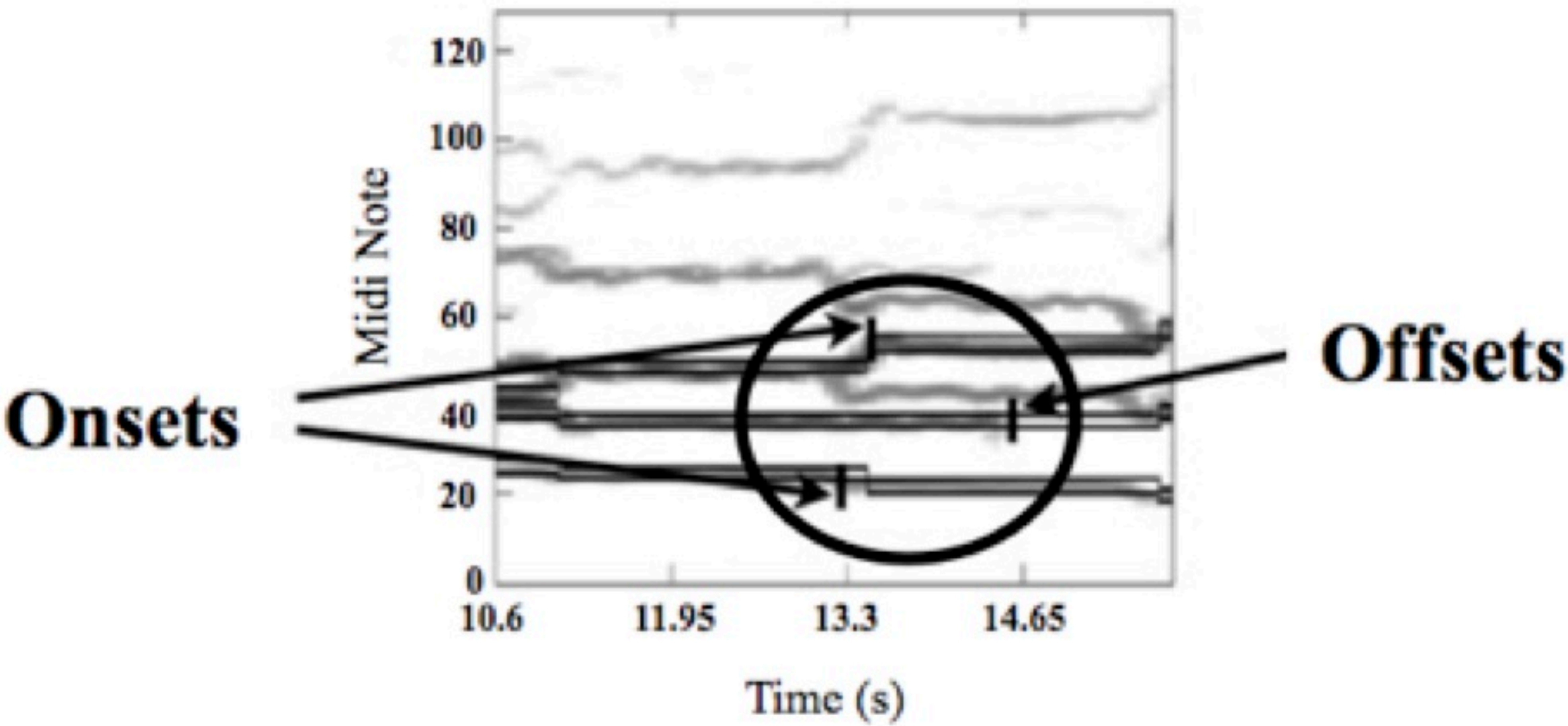

# AMPACT 0.3

Polyphonic score-audio alignment

Identifying asynchronies between voices




Devaney and Ellis (2009)
Devaney (2014)

# AMPACT 0.3

## Polyphonic score-audio alignment

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% estimatedOns estimatedOffs]=runPolyAlignment(audiofile, midifile)
%
% Description: Main function for runing polyphonic MIDI-audio alignment
%              An intial DTW alignment is refined to estimate asychroncies
%              between notated simultaneities
%
%               Note that this current version assumes that each note ends
%               immediately before it starts again (i.e., no rests)
%
% Inputs:
%  audiofile - audio file file
%  midifile - midi file
%  meansCovarsMat - specifies means and covariance matrix to use
%  voiceType - vector indicating which voice (or instrument) to use for
%              each musical line
%
% Outputs:
%  estimatedOns - cell array of onset times
%  estimatedOffs - cell array of offset times
%
% Dependencies:
%  Ellis, D. P. W. 2003. Dynamic Time Warp (DTW) in Matlab. Available
%   from: http://www.ee.columbia.edu/~dpwe/resources/matlab/dtw/
%  Ellis, D. P. W. 2008. Aligning MIDI scores to music audio. Available
%   from: http://www.ee.columbia.edu/~dpwe/resources/matlab/alignmidiwav/
%  Toiviainen, P. and T. Eerola. 2006. MIDI Toolbox. Available from:
%   https://www.jyu.fi/hum/laitokset/musiikki/en/research/coe/materials
%          /miditoolbox/
%   Murphy, K. 1998. Hidden Markov Model (HMM) Toolbox for Matlab.
%    Available from http://www.cs.ubc.ca/~murphyk/Software/HMM/hmm.html
%
% Automatic Music Performance Analysis and Analysis Toolkit (AMPACT)
% http://www.ampact.org
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%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```
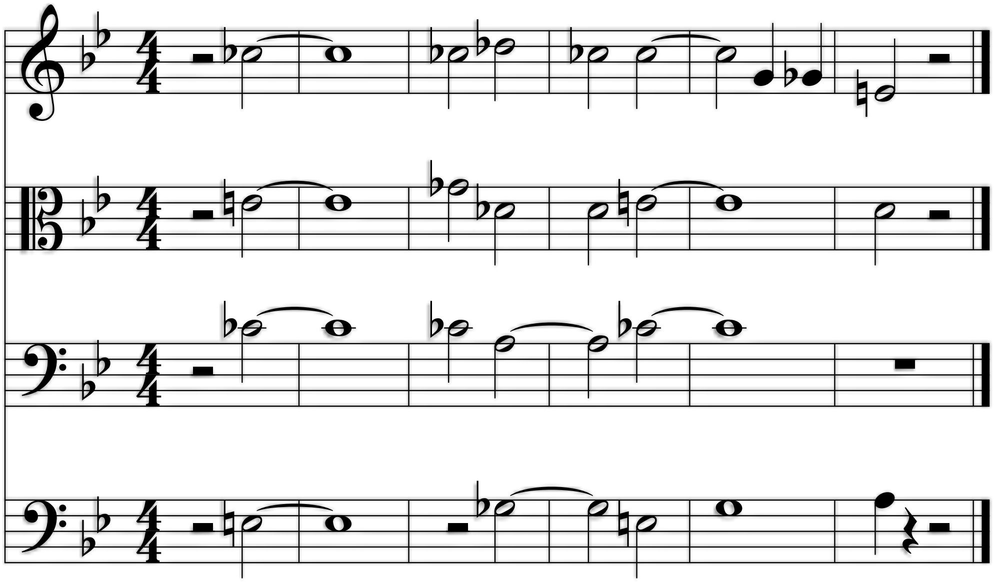
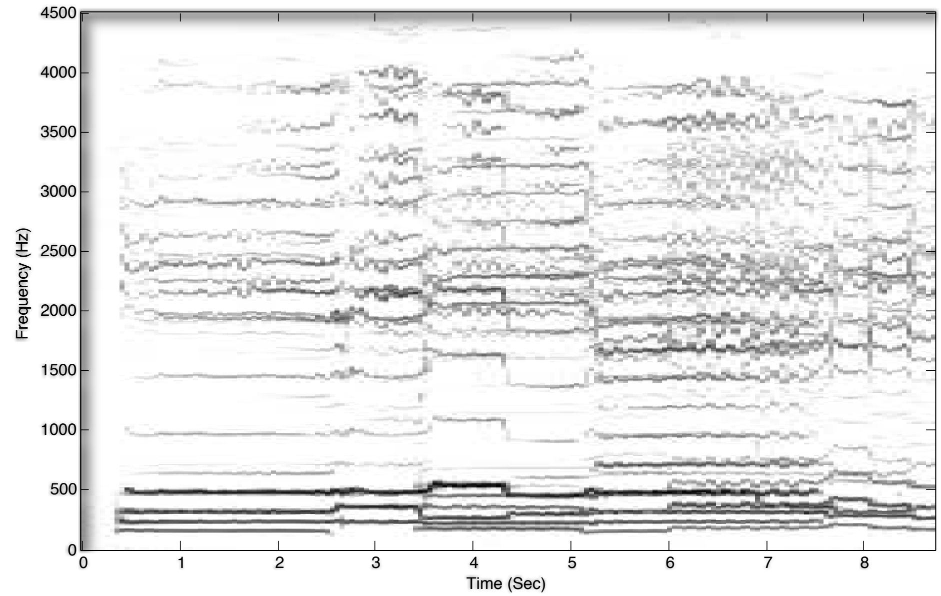

# AMPACT 0.4

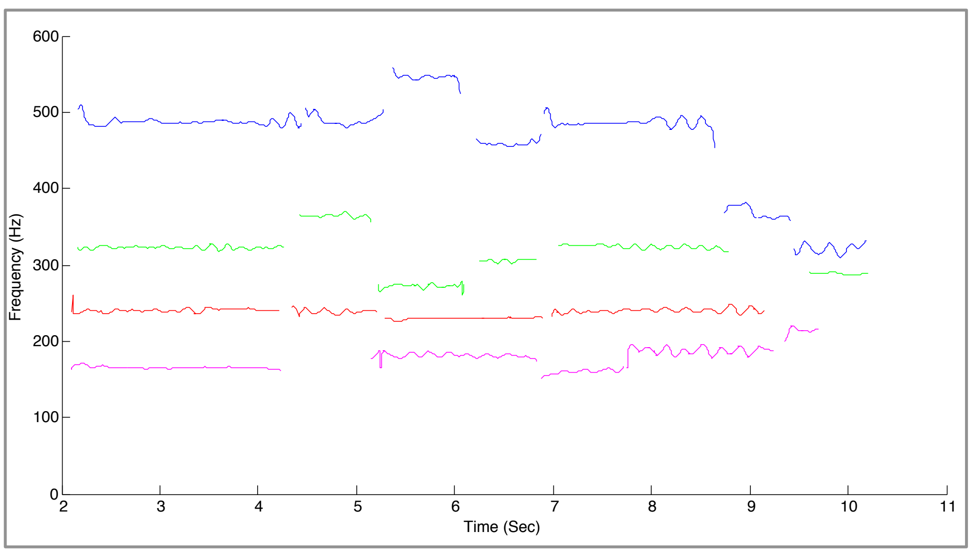
Polyphonic parameter estimation



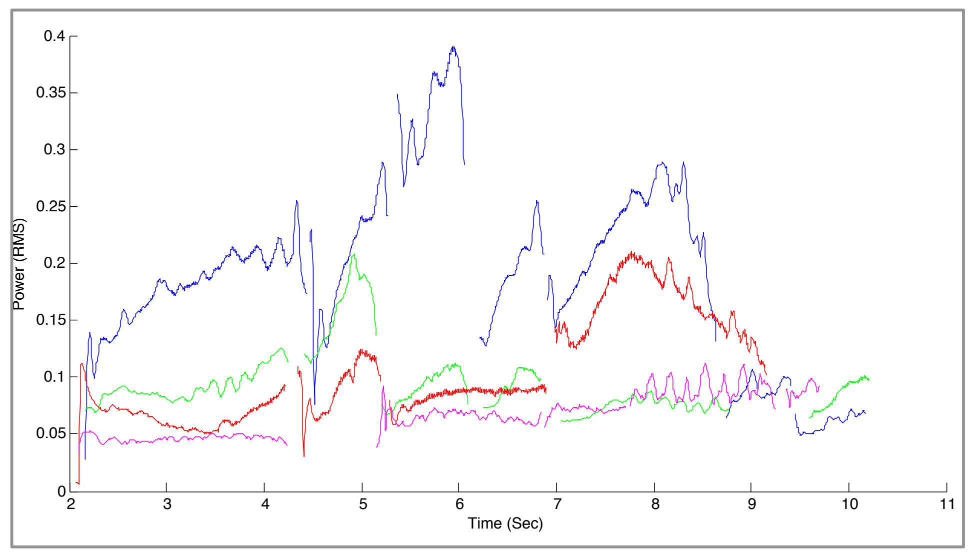



**Alignment**

## Note-wise $f_0$ estimations




## Note-wise power estimations




Devaney and Mandel (2017)

# Note-wise summaries

**Pitch**

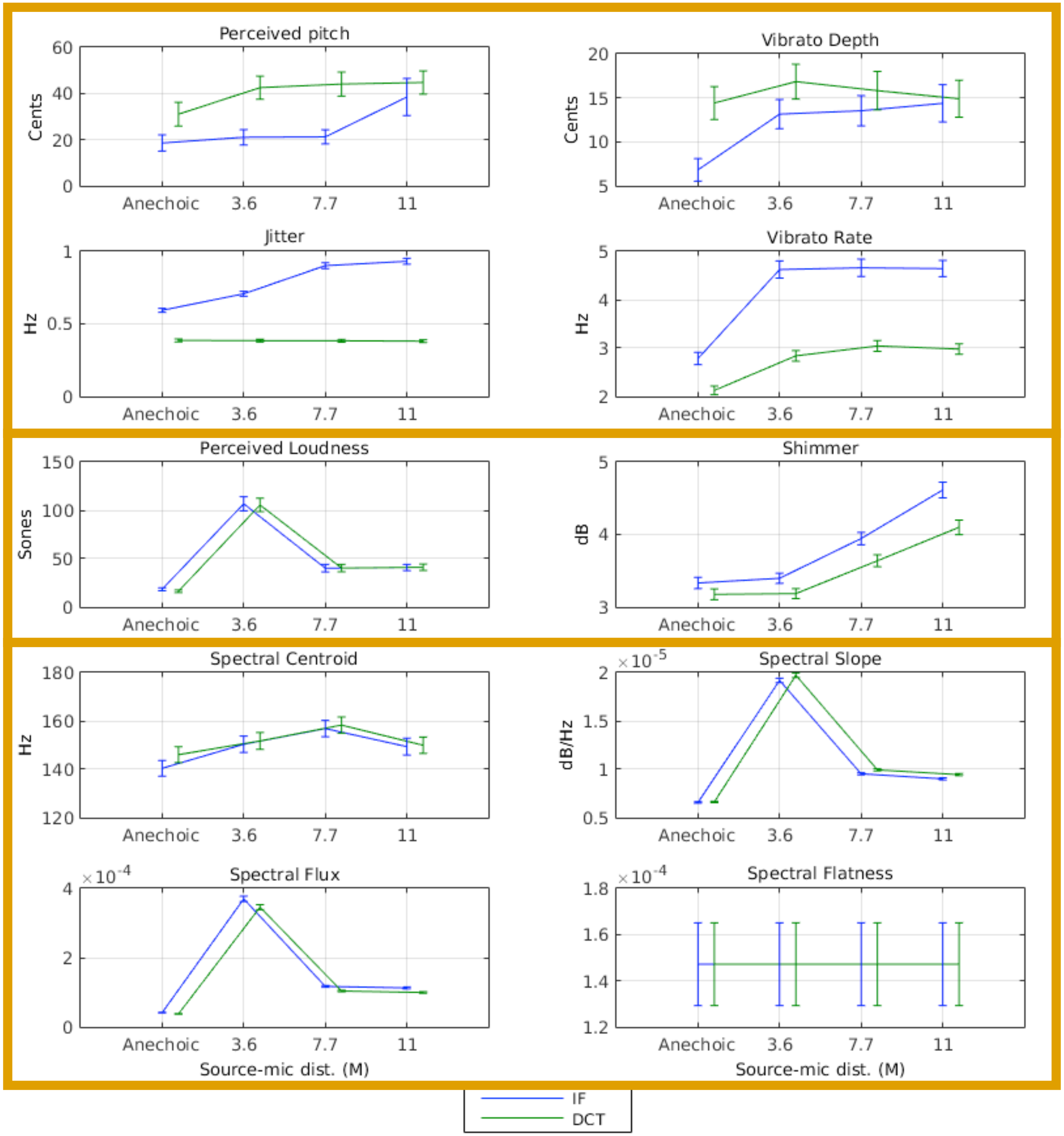
- perceived pitch
- vibrato rate and depth
- F0 slope and curvature
- jitter

**Loudness**

- perceived loudness
- shimmer

**Timbre**

- spectral centroid, slope, flatness, and flux
- harmonics to noise ratio



Perceived pitch
Cents
Vibrato Depth
Jitter
Hz
Vibrato Rate
Perceived Loudness
Sones
Shimmer
dB
Spectral Centroid
Spectral Slope
dB/Hz
$\times 10^{-5}$
Spectral Flux
$\times 10^{-4}$
Spectral Flatness
$\times 10^{-4}$
Anechoic
3.6
7.7
11
Source-mic dist. (M)
IF
DCT

# AMPACT 0.4

Encoding formats

| **specflat | **specslope | **specflux | **speccent | **hnr |
|---|---|---|---|---|
| * | * | * | * | * |
| * | * | * | * | * |
| * | * | * | * | * |
| * | * | * | * | * |
| =1 | =1 | =1 | =1 | =1 |
| 0.06444 | -0.00518 | 0.00089 | 0.02867 | 0.10361 |
| 0.0703 | -0.00516 | 0.001 | 0.02989 | 0.10961 |
| 0.06633 | -0.00518 | 0.001 | 0.02873 | 0.1223 |
| 0.05972 | -0.00517 | 0.00055 | 0.02913 | 0.13322 |

| **rtdur |
|---|
| *u=msec |
| *MM60 |
| * |
| * |
| =1 |
| 2900.5 |
| 417.56 |
| 484.86 |
| 3380.7 |

| **freq | **slopeF0 | **curveF0 | **vibdepth | **vibrate | **jitter |
|---|---|---|---|---|---|
| *clefG2 | * | * | * | * | * |
| *k[b-e-] | * | * | * | * | * |
| *M4/4 | * | * | * | * | * |
| *MM60 | * | * | * | * | * |
| =1 | =1 | =1 | =1 | =1 | =1 |
| 456 | -0.10373 | -0.15858 | 27 | 4.5 | 0.3 |
| 433 | -0.053198 | -0.09806 | 35 | 4.8 | 0.3 |
| 460 | -0.00041444 | -0.093974 | 16 | 6.2 | 0.3 |
| 581 | -0.030237 | -0.11501 | 10 | 4.1 | 0.1 |

**Standard Humdrum notation:** **beat

**Timing Data**
**rtstart - msec since start of first note
**rtdur – duration of note in msec

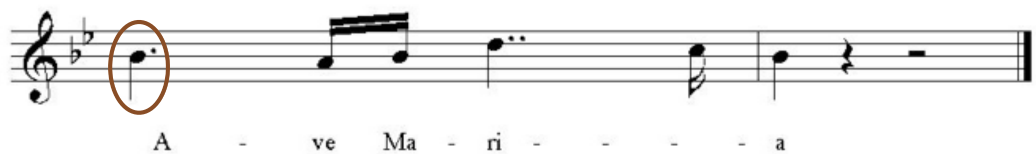
**Pitch Data**
**freq – perceived pitch
**slopeF0 – slope of fundamental frequency
**curveF0 – slope of fundamental frequency
**vibdepth – vibrato depth
**vibrate – vibrato rate
**jitter – mean frame-wise difference in F0

**specflat – mean spectral flatness
**specslope – mean spectral slope
**specflux – mean spectral flux
**speccent – mean spectral centroid
**hnr – mean harmonics to noise ratio

**Devaney and Leveillé Gauvin (2016, 2017)**

# Encoding

## MEI

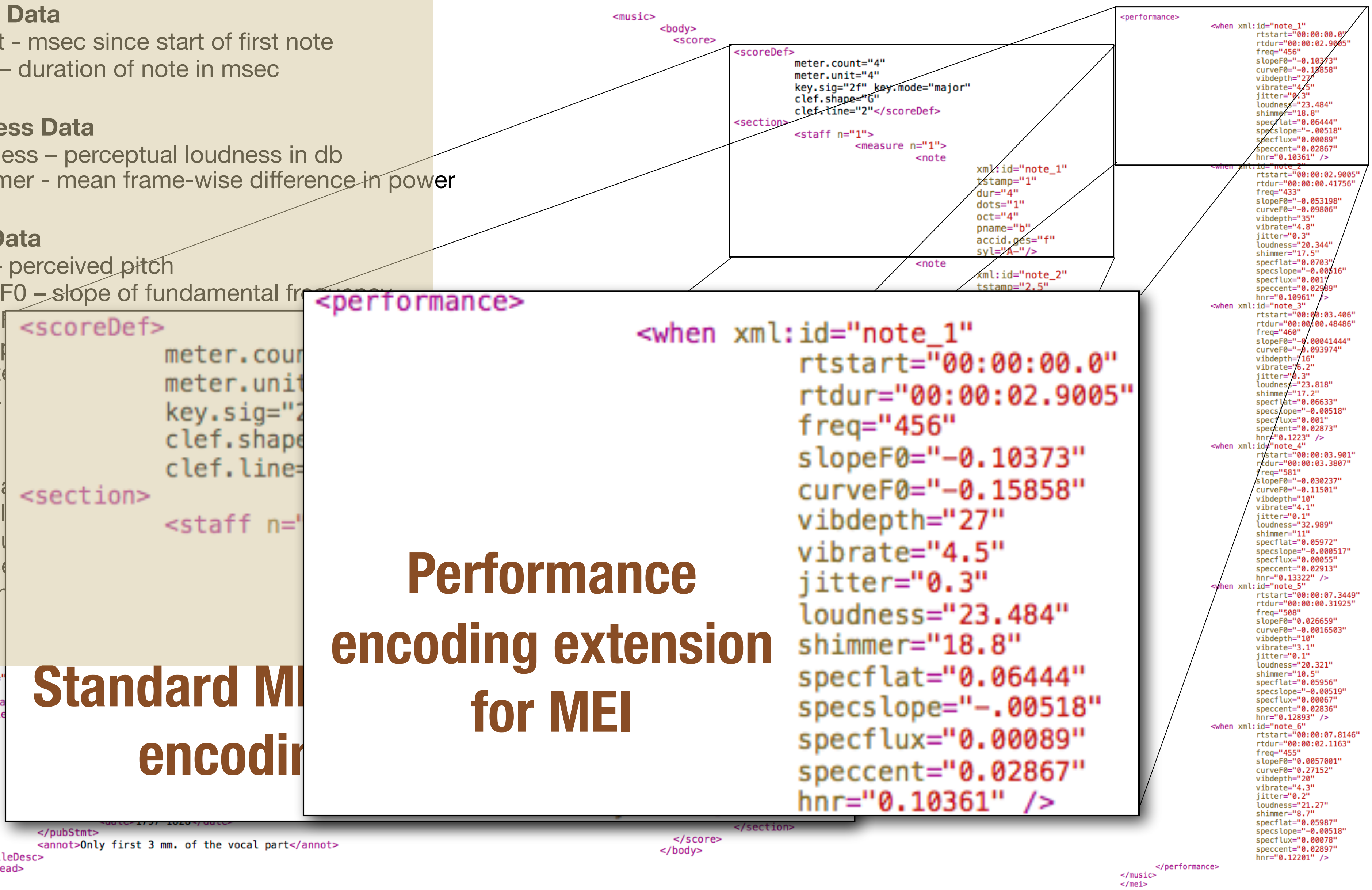


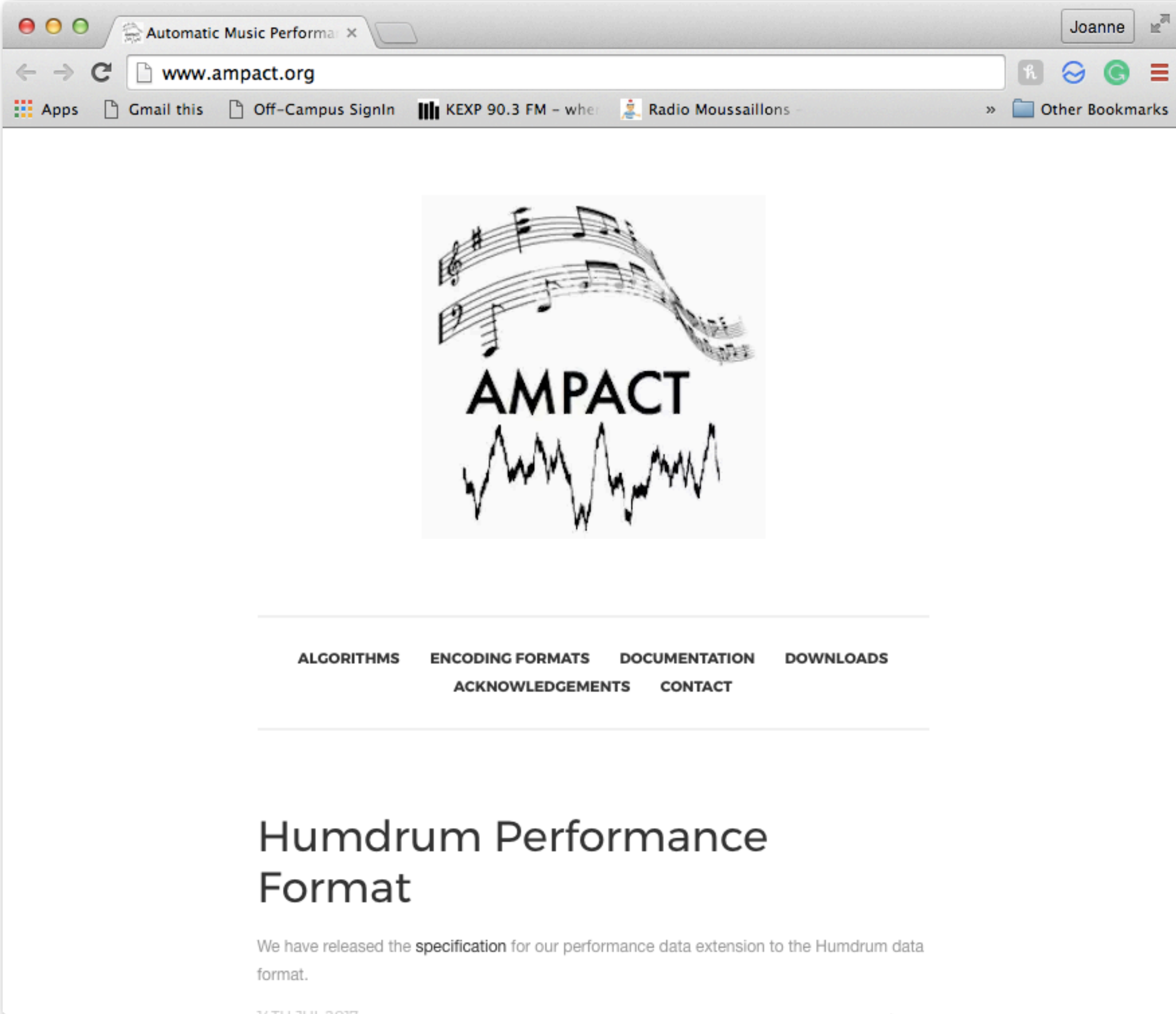

**Timing Data**
@rtstart - msec since start of first note
@rtdur – duration of note in msec

**Loudness Data**
@loudness – perceptual loudness in db
@shimmer - mean frame-wise difference in power

**Pitch Data**
@freq – perceived pitch
@slopeF0 – slope of fundamental fr
@curve
@vibdep
@vibrat
@jitter –

**Timbre**
@specfl
@specsl
@specfl
@specc
@hnr – r

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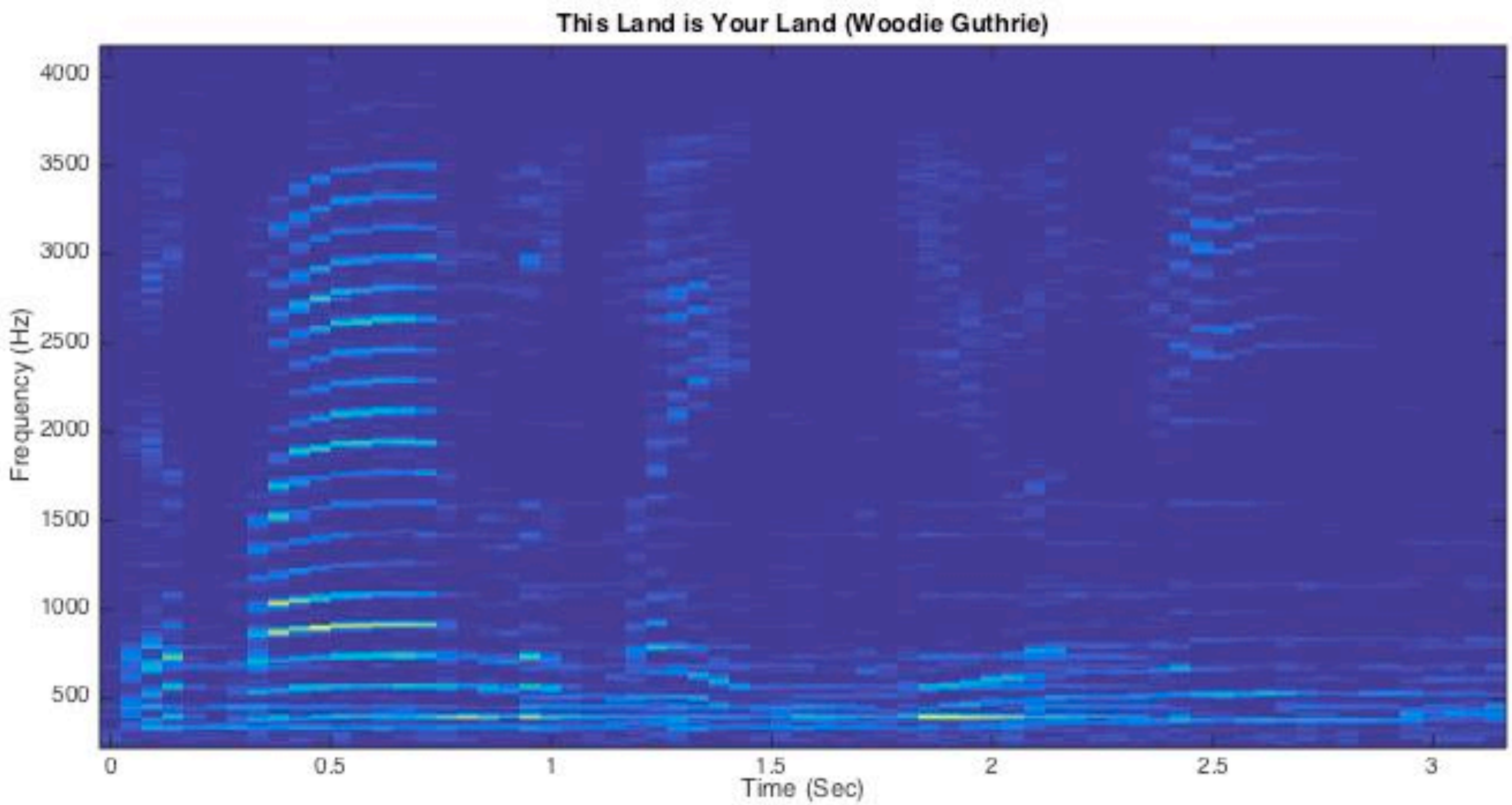
Off-Campus SignIn
KEXP 90.3 FM – whe
Radio Moussaillons
Other Bookmarks
AMPACT
ALGORITHMS
ENCODING FORMATS
DOCUMENTATION
DOWNLOADS
ACKNOWLEDGEMENTS
CONTACT
Humdrum Performance Format
We have released the specification for our performance data extension to the Humdrum data format.

# Future Directions

Using other knowledge to inform estimation

- **Melody estimation can be used as a proxy for the information in musical scores**



# Future Directions

## Longitudinal studies

This land is your land This land is my land
From California to the New York island;
From the red wood forest to the Gulf Stream waters
This land was made for you and me.

As I was walking that ribbon of highway,
I saw above me that endless skyway:
I saw below me that golden valley:
This land was made for you and me.

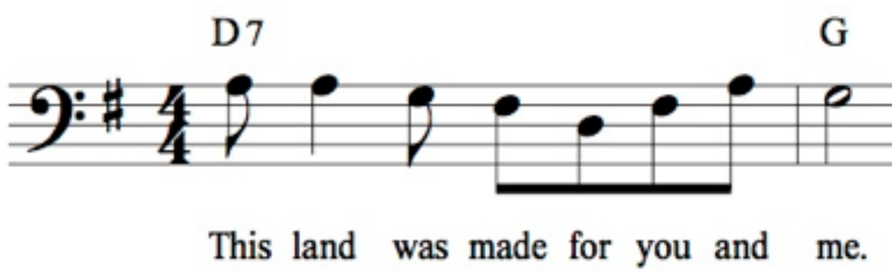
I've roamed and rambled and I followed my footsteps
To the sparkling sands of her diamond deserts;
And all around me a voice was sounding:
This land was made for you and me.

When the sun came shining, and I was strolling,
And the wheat fields waving and the dust clouds rolling,
As the fog was lifting a voice was chanting:
This land was made for you and me.

As I went walking I saw a sign there
And on the sign it said "No Trespassing."
But on the other side it didn't say nothing,
That side was made for you and me.

In the shadow of the steeple I saw my people,
By the relief office I seen my people;
As they stood there hungry, I stood there asking
Is this land made for you and me?

Nobody living can ever stop me,
As I go walking that freedom highway;
Nobody living can ever make me turn back
This land was made for you and me.



Thank you!

Questions?