Implementation of 3D Audio using Interpolated Head-Related Transfer Functions

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Terms / Acronyms

HRIR: **H**ead-**R**elated **I**mpulse **R**esponse

HRTF: **H**ead-**R**elated **T**ransfer **F**unction

CIPIC: **C**enter for **I**mage **P**rocessing and **I**ntegrated **C**omputing (University of California Davis)

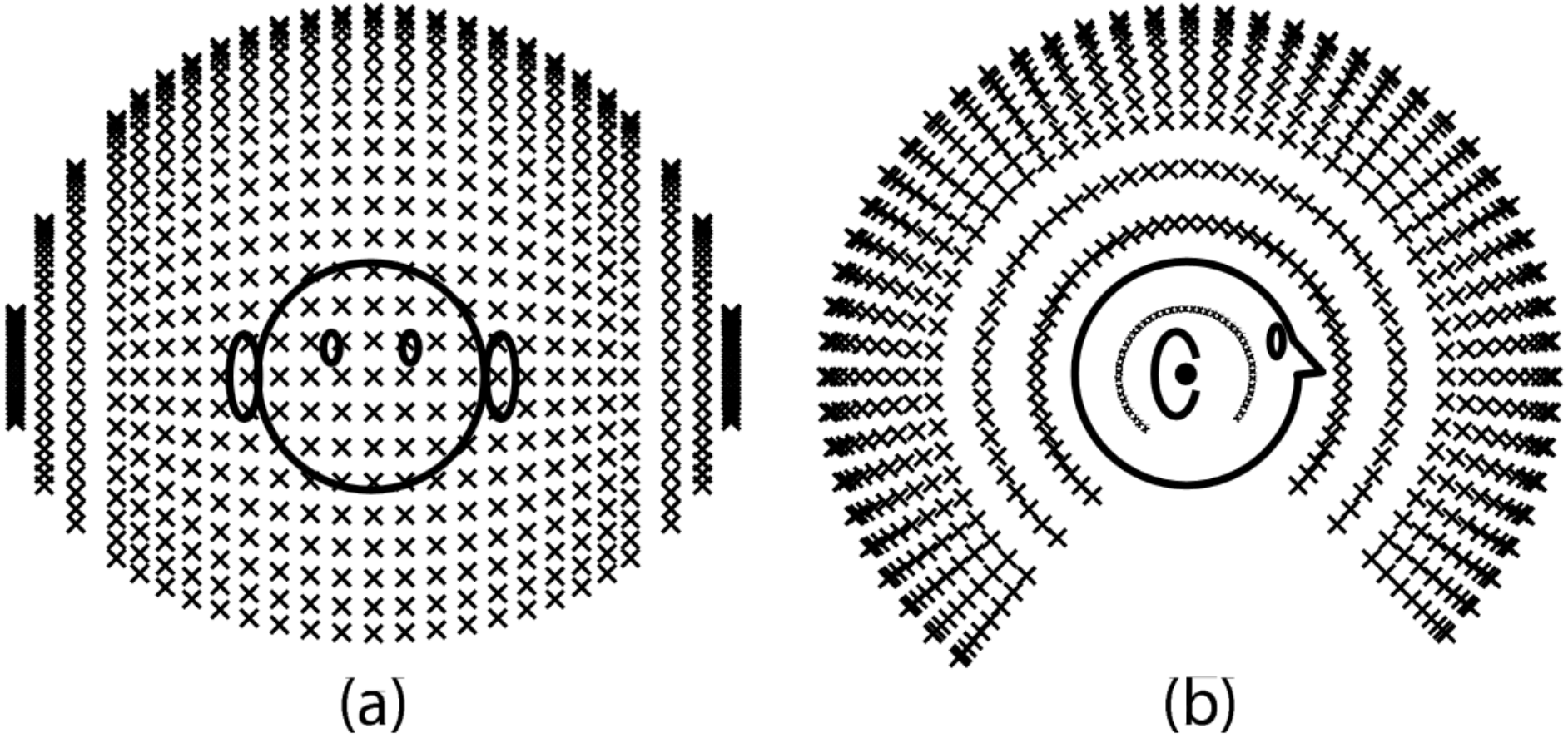
Azimuth: horizontal angle (from directly ahead)

Elevation: vertical angle (from directly ahead)

Goals

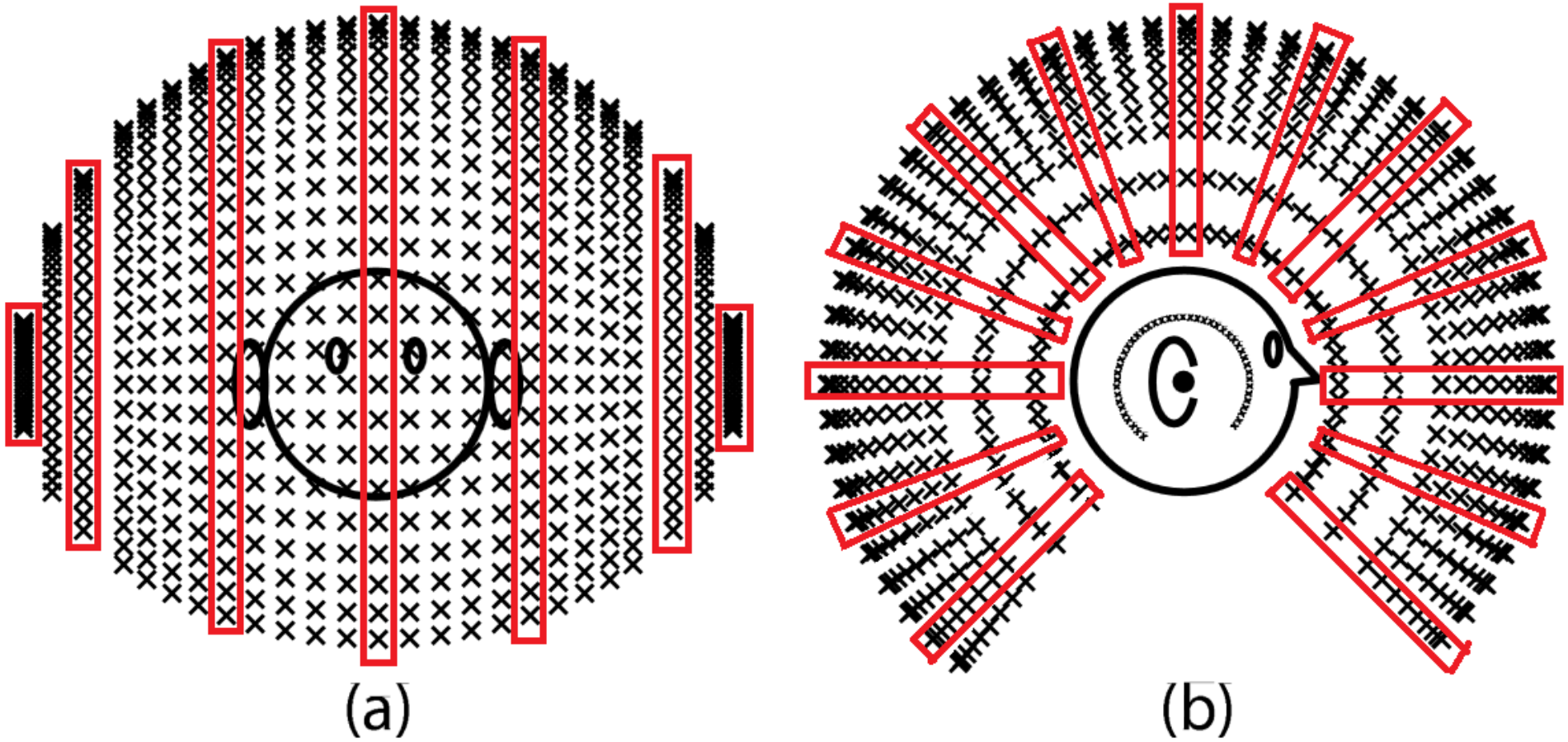
- Understand existing HRTF code for Matlab
- Choose method for interpolating impulse responses
- Modify existing Matlab code using interpolation algorithms in attempt to reduce number of stored impulse responses necessary to recreate 3D soundfield
- Investigate real-time applications of 3D audio

CIPIC HRTF Database



Locations of data points (a) front (b) side

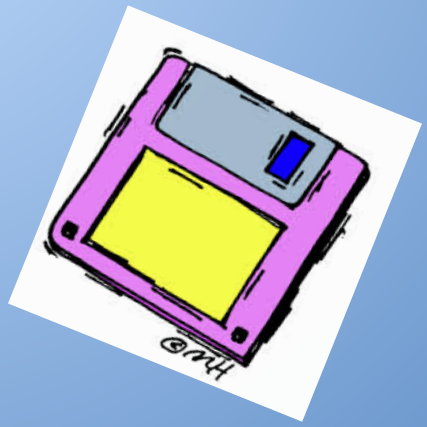
CIPIC HRTF Database



Locations of data points (a) front (b) side

Advantages of Interpolation

- Won't have to physically measure impulse response at as many points
- Reduce size of HRIR array to maximize memory efficiency
- Allows for smoother transition between points



http://school.discoveryeducation.com/clipart/clip/flopdisk4c.html

Interpolation Method

Vector-Based Amplitude Panning:

$$\boldsymbol{p} = g_n \boldsymbol{l^n} + g_m \boldsymbol{l^m} + g_k \boldsymbol{l^k}$$

$$\boldsymbol{p}^t = \boldsymbol{g}\boldsymbol{L}_{nmk}$$

$$\boldsymbol{g} = \boldsymbol{p}^t \boldsymbol{L}_{nmk}^{-1} = \begin{bmatrix} p_1 & p_2 & p_3 \end{bmatrix} \begin{bmatrix} l_1^n & l_2^n & l_3^n \\ l_1^m & l_2^m & l_3^m \\ l_1^k & l_2^k & l_3^k \end{bmatrix}^{-1}$$

$$y(t) = g_n \cdot (x * h_n)(t) + g_m \cdot (x * h_m)(t) + g_k \cdot (x * h_k)(t)$$

$$\hat{h} = g_n \cdot h_n + g_m \cdot h_m + g_k \cdot h_k$$

G. de Sousa & M. Queiroz, “Two Approaches for HRTF interpolation”

Description of Matlab Functions

- getNearest3.m
  - in - elevation, azimuth, HRIR struct
  - out - three nearest points in sound field and corresponding impulse responses
- SweepTest.m
  - user declares two azimuth and elevation values
  - will sweep audio in a straight line between two points using three point interpolation

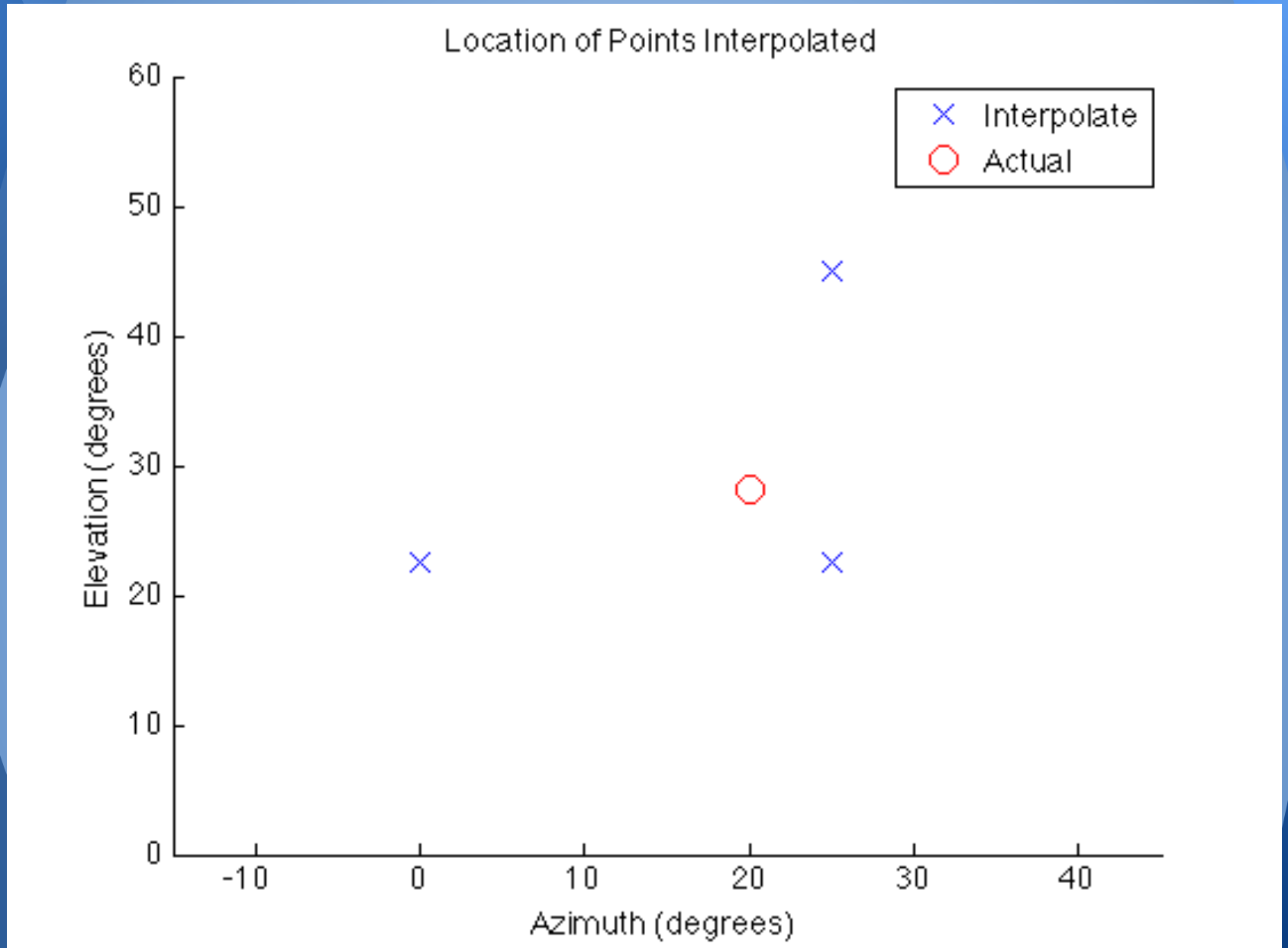
Reduction of Data Points

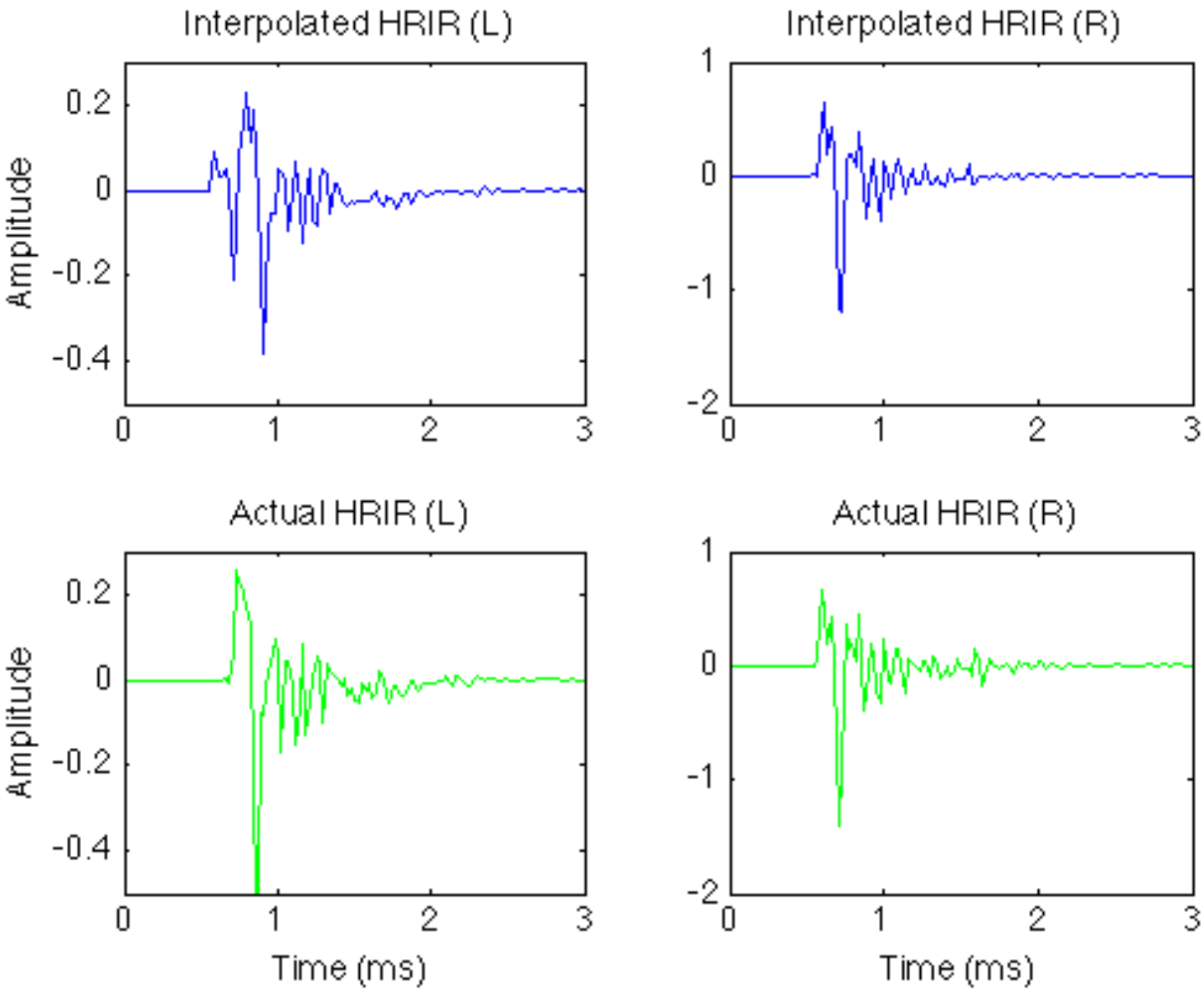
- Original HRIR Points
  - Azimuths - 25
  - Elevations - 50
  - Total Pts - 1250
- Points Needed with Interpolation
  - Azimuths - 7
  - Elevations - 13
  - Total Pts - 91

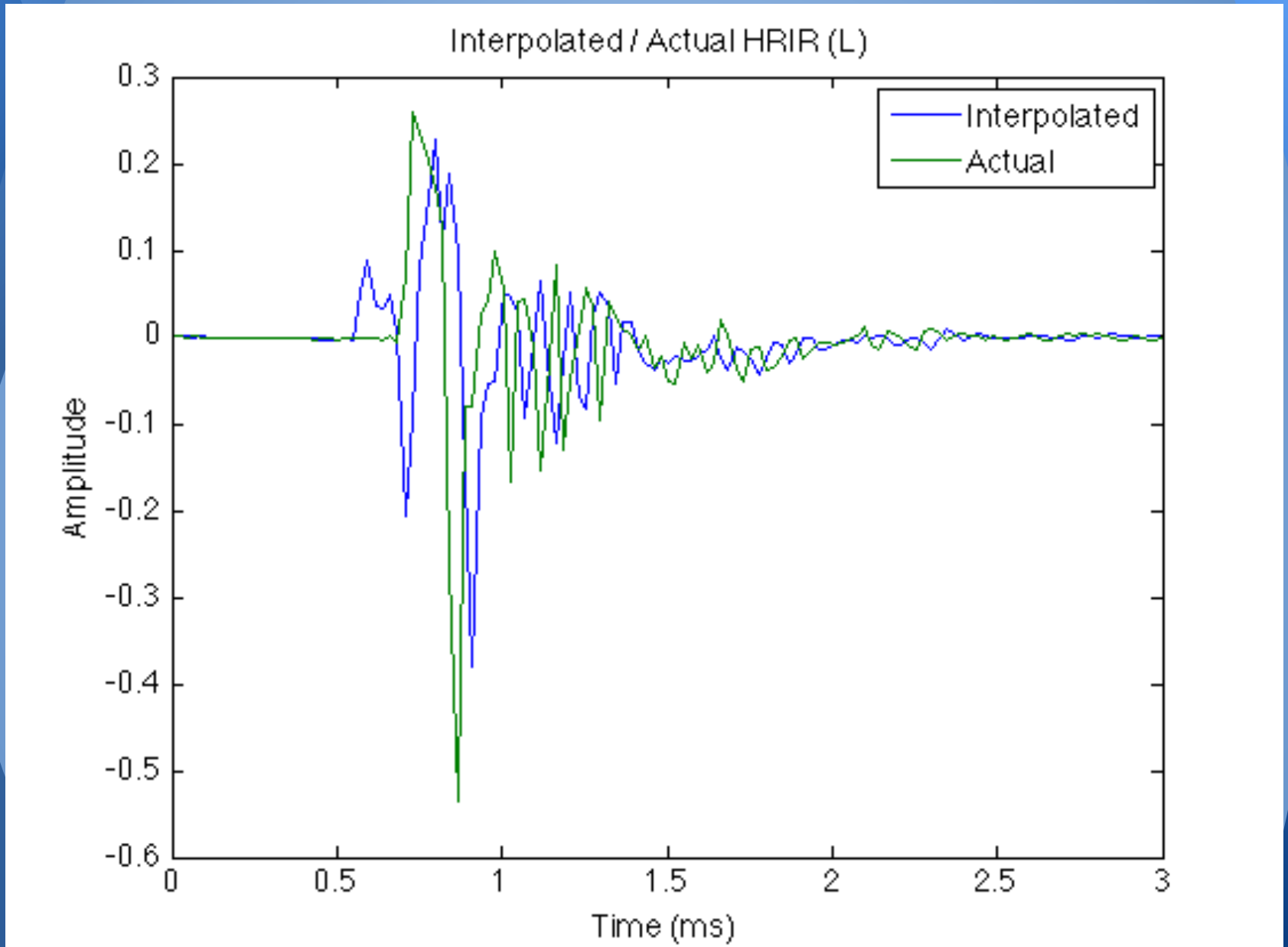
Time/Frequency Response Comparison

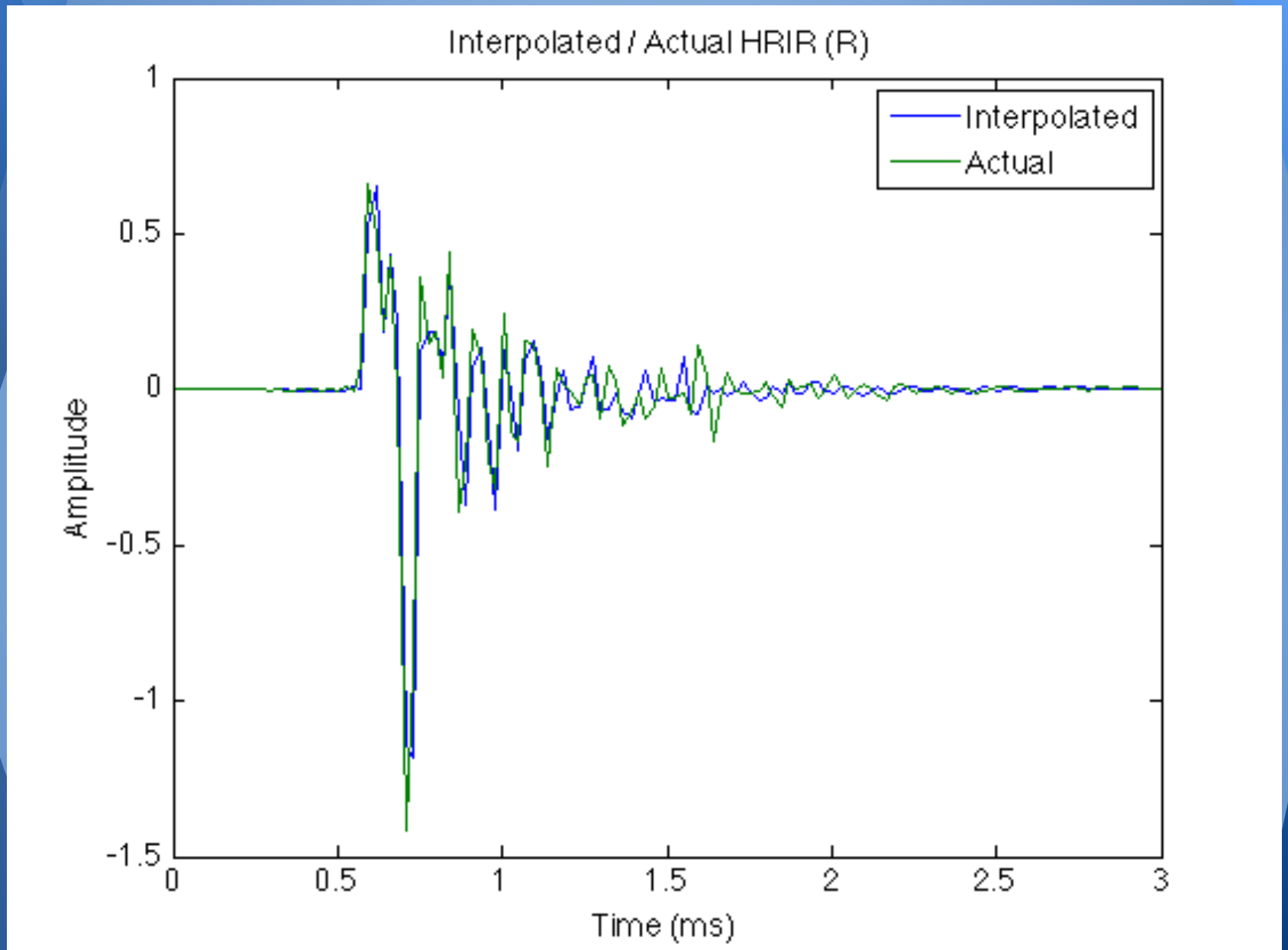
The following figures use this example point:

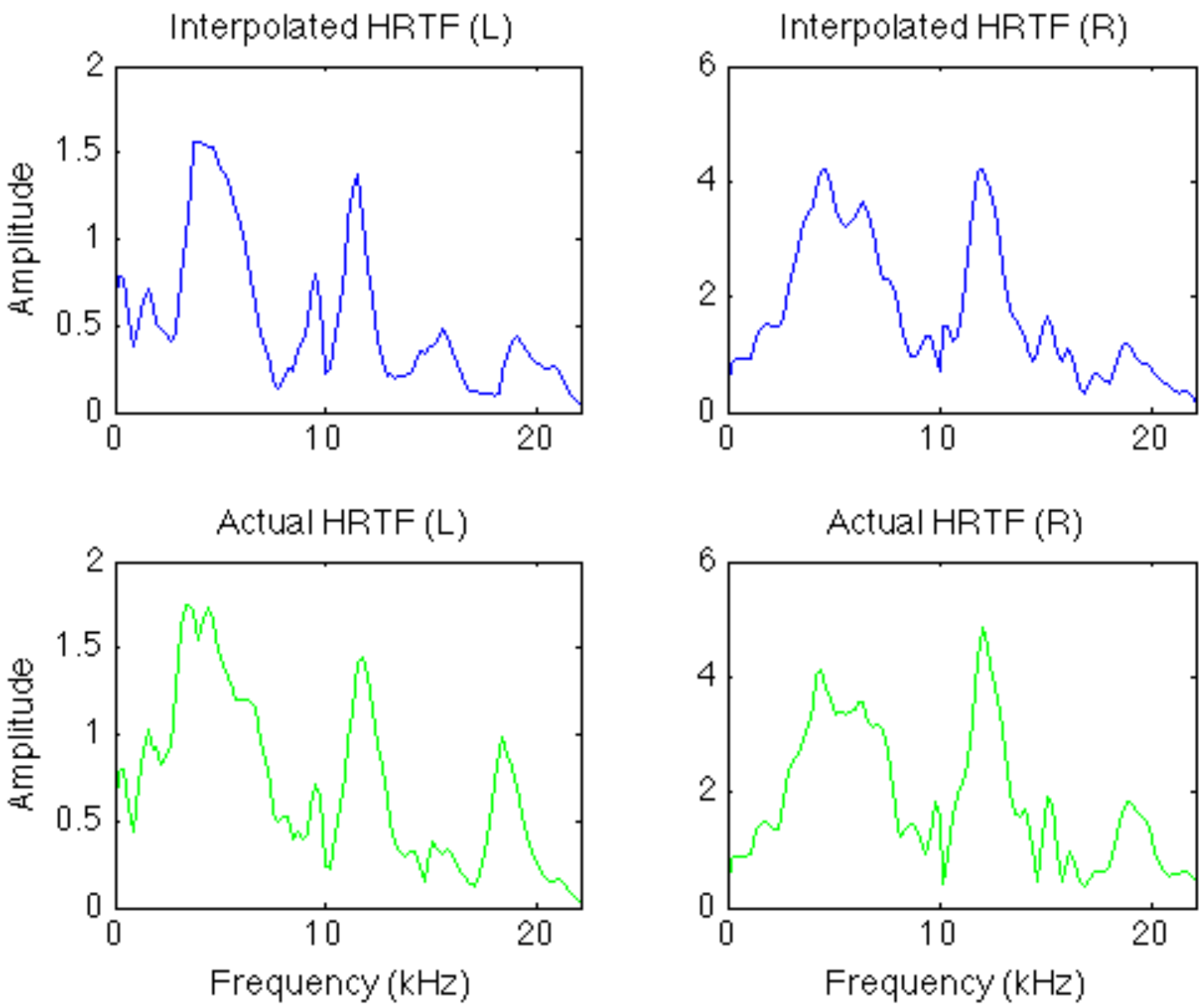
Azimuth = 20 degrees
Elevation = 28.125 degrees

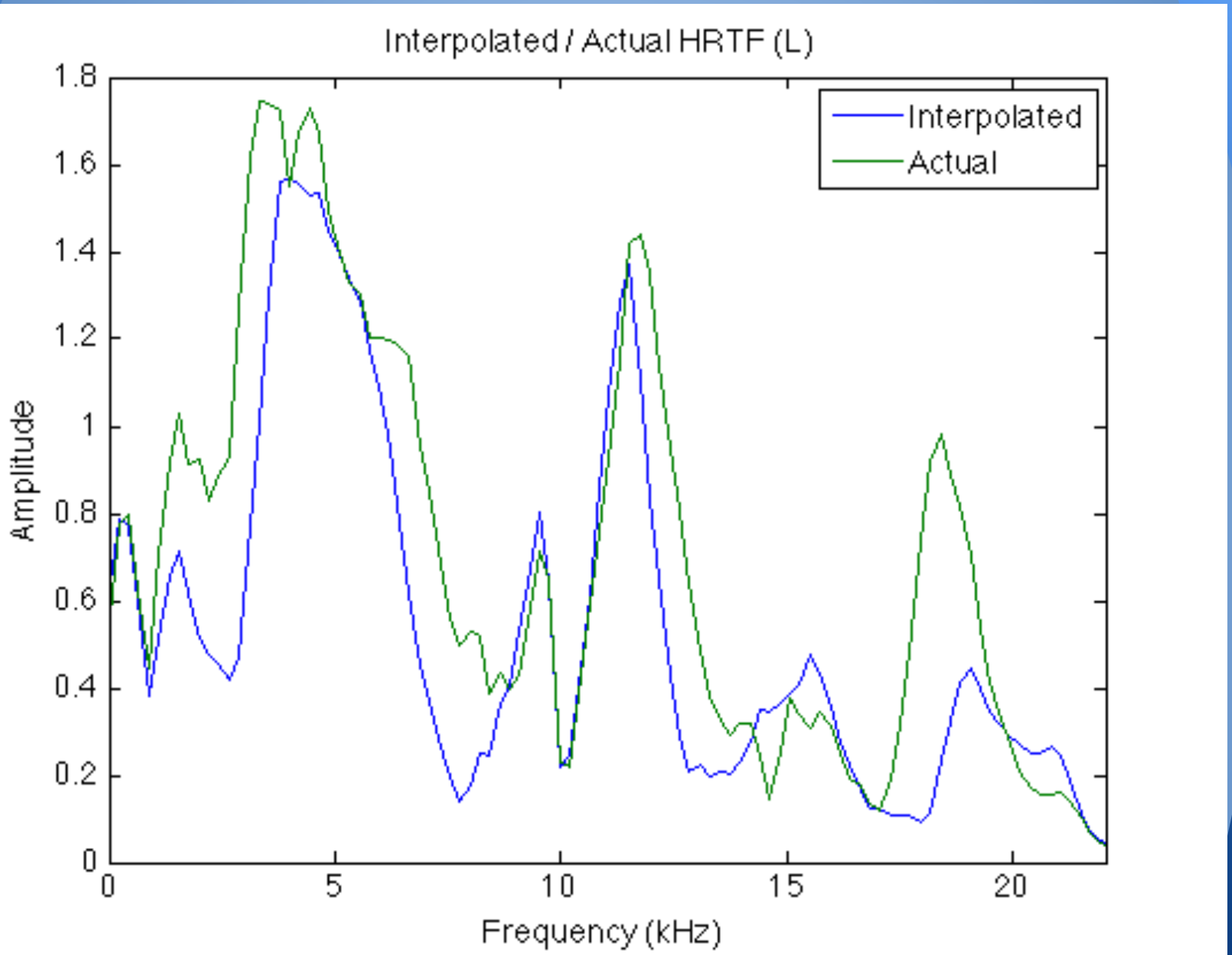

Location of Points Interpolated
Interpolate
Actual
Elevation (degrees)
Azimuth (degrees)
60
50
40
30
20
10
0
-10
0
10
20
30
40

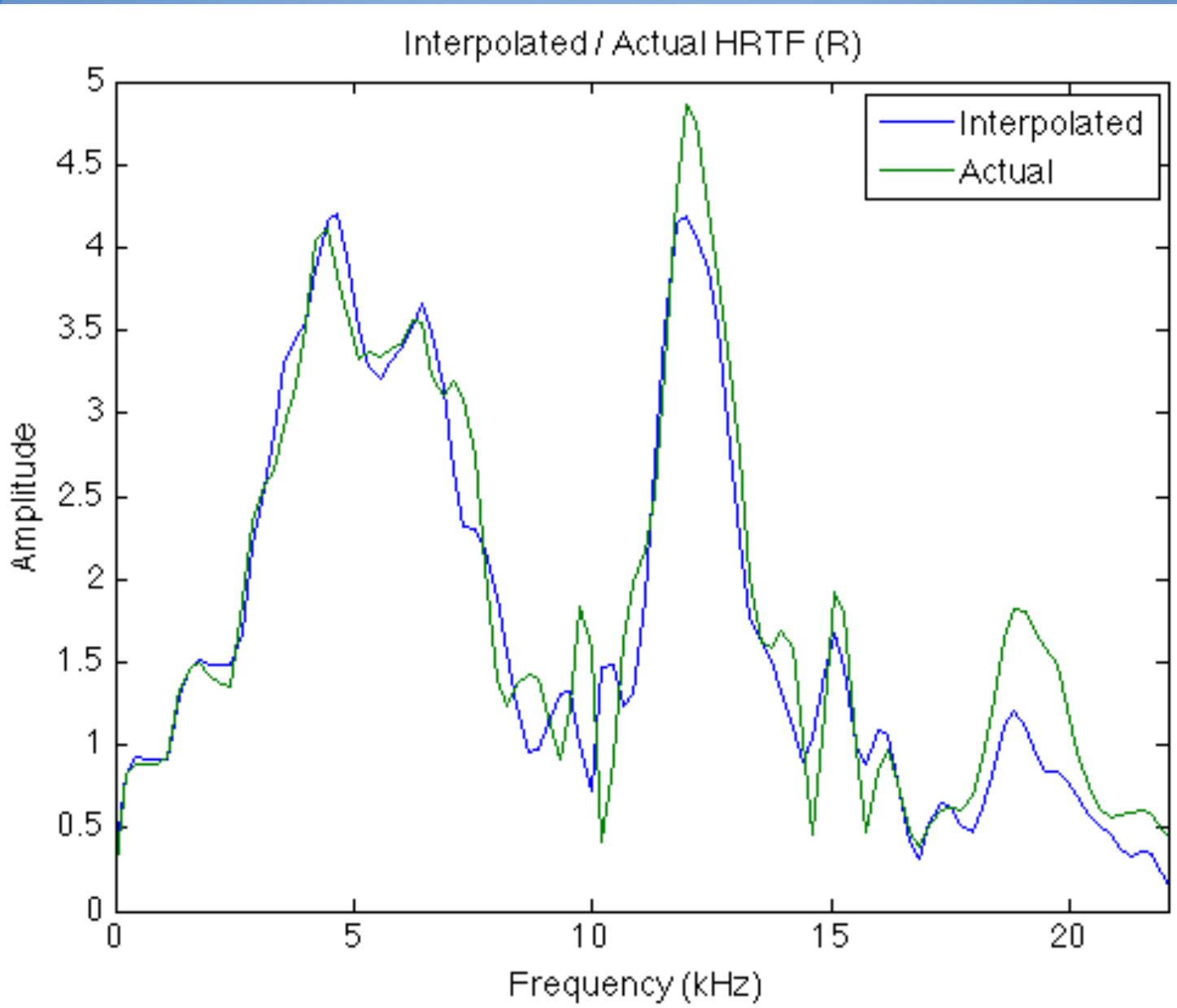

Interpolated HRIR (L)
Interpolated HRIR (R)
Actual HRIR (L)
Actual HRIR (R)
Amplitude
Amplitude
Time (ms)
Time (ms)
0.2
0
-0.2
-0.4
1
0
-1
-2
0
1
2
3


Interpolated / Actual HRIR (L)
Interpolated
Actual
Amplitude
Time (ms)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0
0.5
1
1.5
2
2.5
3


Interpolated / Actual HRIR (R)
Interpolated
Actual
Amplitude
Time (ms)
1
0.5
0
-0.5
-1
-1.5
0
0.5
1
1.5
2
2.5
3


Interpolated HRTF (L)
Interpolated HRTF (R)
Actual HRTF (L)
Actual HRTF (R)
Amplitude
Amplitude
Frequency (kHz)
Frequency (kHz)
0
0.5
1
1.5
2
0
2
4
6
0
10
20


Interpolated / Actual HRTF (L)
Interpolated
Actual
Amplitude
Frequency (kHz)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
5
10
15
20

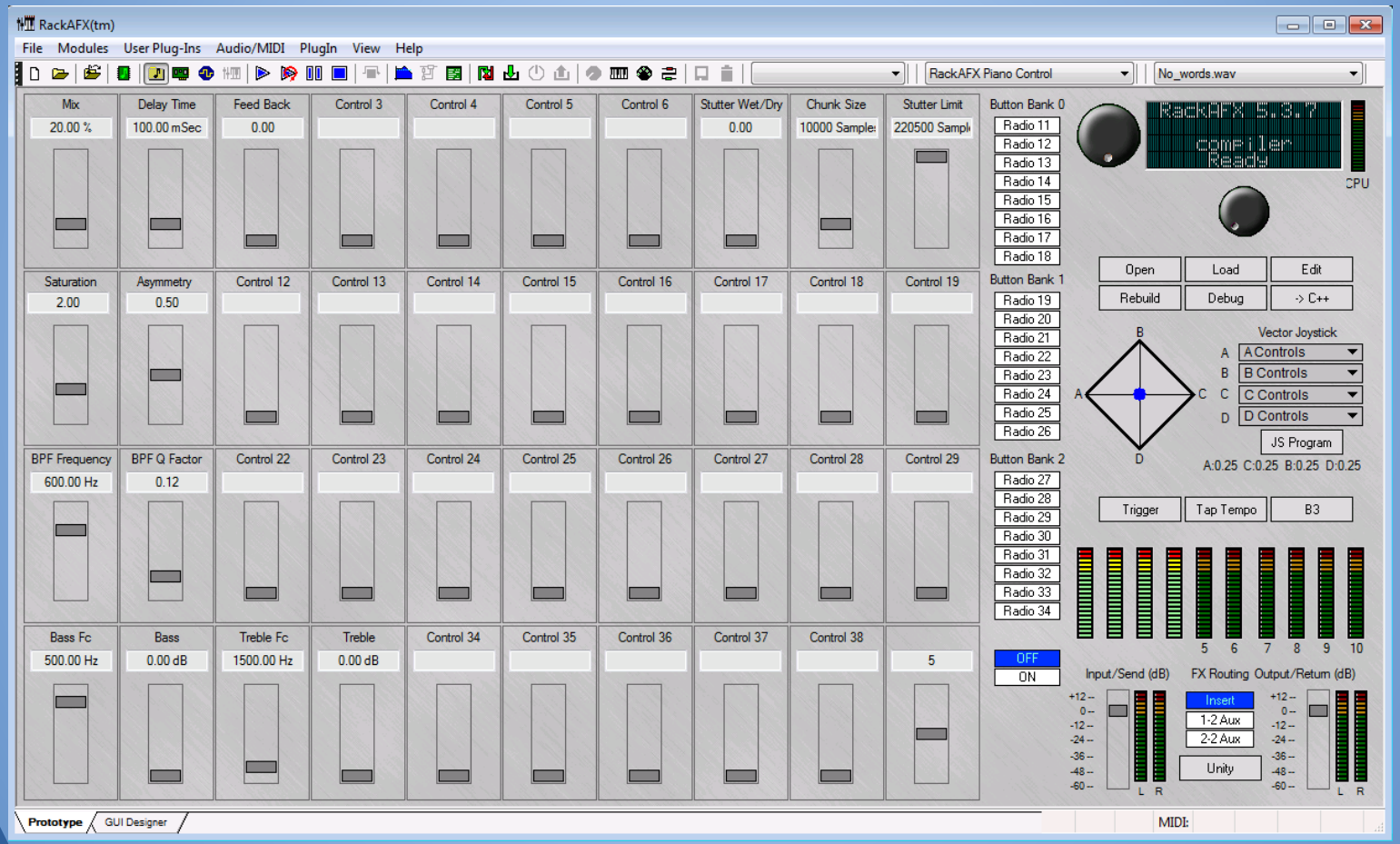

Interpolated / Actual HRTF (R)
Interpolated
Actual
Amplitude
Frequency (kHz)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
5
10
15
20

Audio Comparison

Files are in C:\HRTF examples

- example_act
- example_int
- example_int_corrected
- orbit1_all
- orbit1_reduced
- orbit2_all
- orbit2_reduced

Real-Time Aspects



Problems With HRTF Interpolation Method

- HRTFs are different for each person
- More sensitive to Left/Right changes than Up/Down or Forward/Back
  - Evolutionary Hearing
- All points were at same radius
- Time lag between interpolated pts.

http://www.clker.com/clipart-4337.html

Practical Applications

Video Games

- Who wouldn't want to be able to close eyes and feel like they are actually in the game?

Room Acoustic Evaluation

- Allows you to examine acoustic properties of a room under different sound sources and room conditions

Hearing Aids

- Frequency-dependent hearing loss compensation.

References

Algazi, V. R., Duda, R. O., Thompson, D. M., & Avendano, C. (2001). The CIPIC HRTF database. In *Applications of Signal Processing to Audio and Acoustics, 2001 IEEE Workshop on the Applications of Signal Processing to Audio and Electroacoustics* (pp. 99-102). IEEE.

Doukhan, D., & Sédès, A. C. (2009). A Binaural Synthesis External for Pure Data. In *PD Convention*.

de Sousa, G. H., & Queiroz, M. (2009, September). Two approaches for HRTF interpolation. In *The 12th Brazilian Symposium on Computer Music (SBCM 2009)*.

Questions???