THE CALCULATION OF THE IMPULSE RESPONSE IN THE BINAURAL TECHNIQUE

Lamberto Tronchin*,, Angelo Farina**, Michele Pontillo*, Valerio Tarabusi***

* DIENCA - CIARM , University of Bologna, Viale Risorgimento 2 - 40136 Bologna Italy

** Ind. Eng. Dept., University of Parma, Viale delle Scienze - 43100 Parma, Italy

Goals

- Creation of synthetic filters for the auralization of the acoustic response of a room
- Computation of binaural impulse response starting from the results of room acoustic programs
- Use of experimental HRTF sets coming from dummy heads (Kemar, B&K, Ambassador, Sennheiser)
- Development of the algorithm for creating the binaural impulse response in standard WAV format

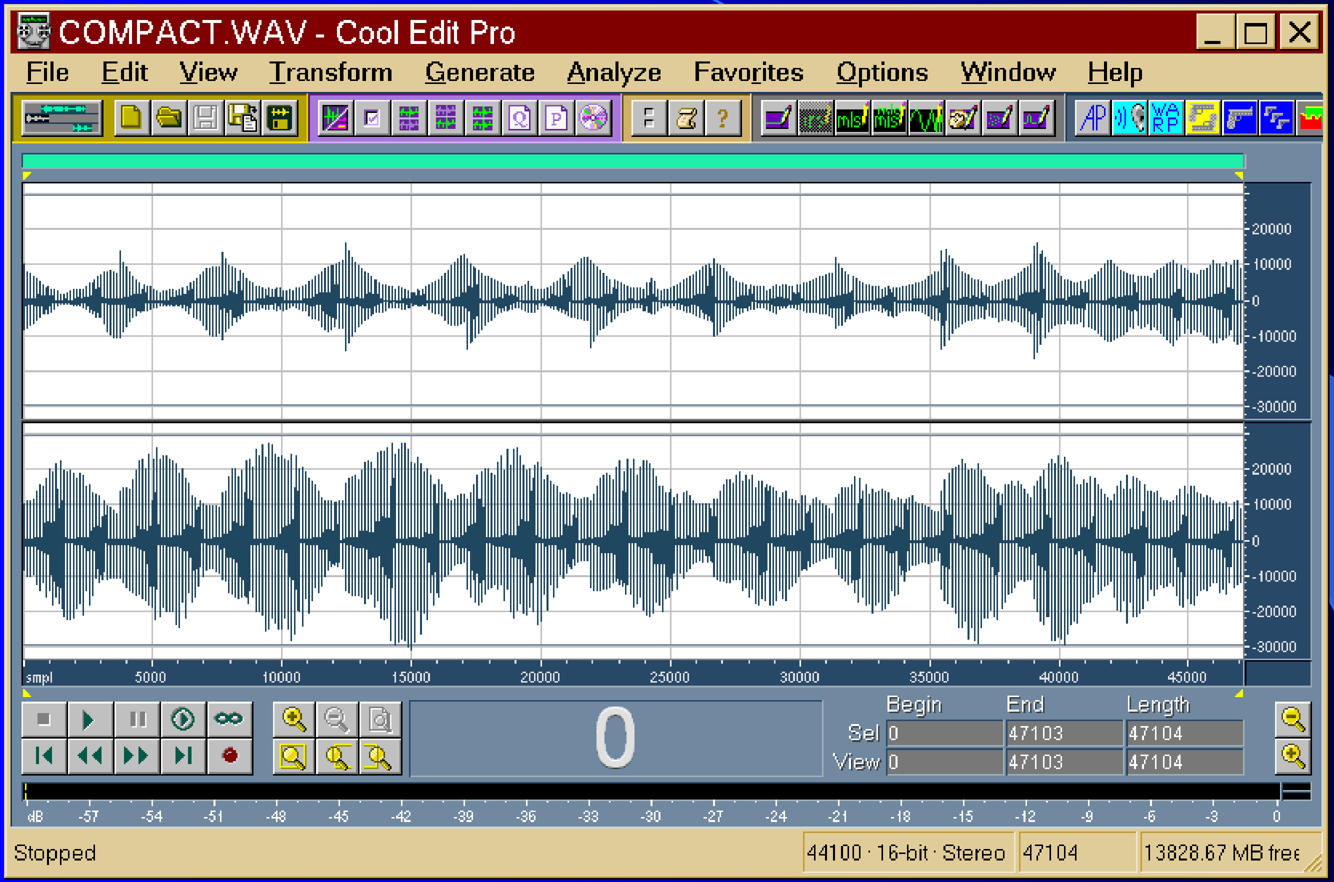
Methods

- The room acoustic program employed here (Ramsete) produces two output files:

1. the complete energetic impulse response (typically with a resolution of 1ms) without any directional information
2. The discrete energy arrival of low-order reflections, with exact arrival time and director cosines

- The new algorithms processes these two files, together with a third WAV files containg the experimental HRTFs of the chosen dummy head

Measurement of HRTF of



- The complete set of binaural IRs measured on the Kemar dummy head at MIT-Medialab

Geometry of the HRTF data-base

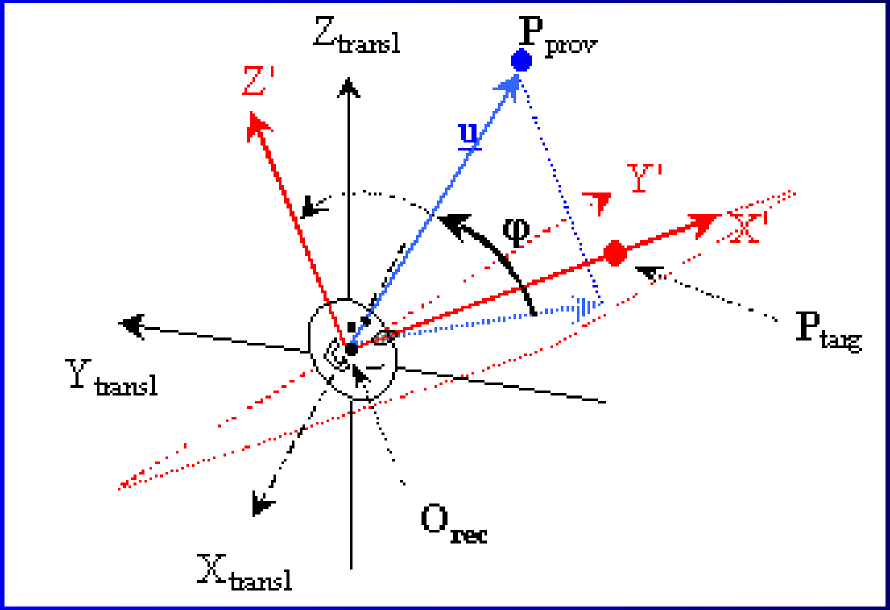
- Number of measurements at each elevation

Elevation φ (°)	Number of Measurements	Azimuth Increment (°)
± 90	1	***
± 80	12	30
± 70	24	15
± 60	36	10
± 50	45	8
± 40	56	6.43
± 30	60	6
± 20	72	5
± 10	72	5
0	72	5

Thus: complex interpolation required on a spherical surface

Reference system definition

- A local cartesian reference system is assumed solidal with the listener head; X' axis is pointing forward (nose), Y' axis is pointing on the left ear, and the Z' axis towards the top of the head.



We are searching for the local arrival angles of the incoming ray: elevation (φ) and azimuth (θ)

Conversion formulas between absolute points and local angles

- The Ramsete program saves the coordinates of three points in the absolute reference system:
  - $\mathbf{P}_{\mathrm{prov}} \equiv (\mathbf{x}_{\mathbf{prov}}, \mathbf{x}_{\mathbf{prov}}, \mathbf{x}_{\mathbf{prov}}) =$ provenience point of the ray;
  - $\mathbf{O}_{\mathrm{rec}} \equiv (\mathbf{x}_{\mathbf{rec}}, \mathbf{y}_{\mathbf{rec}}, \mathbf{z}_{\mathbf{rec}}) =$ receiver origin;
  - $\mathbf{P}_{\mathrm{targ}} \equiv (\mathbf{x}_{\mathbf{t}}, \mathbf{y}_{\mathbf{t}}, \mathbf{z}_{\mathbf{t}}) =$ receiver target point.

First of all, the position of the provenience point of the ray is recomputed in the local reference system:

$\mathbf{P}_{\mathrm{prov}} \equiv> \mathbf{P'}_{\mathrm{prov}} (\mathbf{x'}_{\mathbf{prov}}, \mathbf{y'}_{\mathbf{prov}}, \mathbf{z'}_{\mathbf{prov}})$

Conversion formulas between absolute points and local angles

- Elevation angle φ :

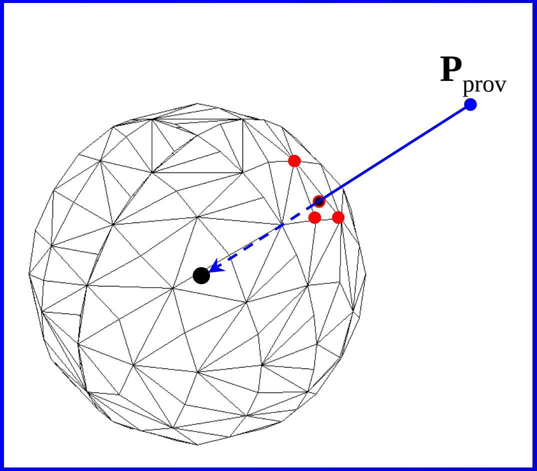
$$\varphi = 90^{\circ} - \arccos\left[z'_{prov} \Big/ \sqrt{\left(x'_{prov}\right)^2 + \left(y'_{prov}\right)^2 + \left(z'_{prov}\right)^2} \right]$$

- Azimuth angle θ :

$$\theta = \arccos\left[x'_{prov} \Big/ \sqrt{\left(x'_{prov}\right)^2 + \left(y'_{prov}\right)^2} \right]$$

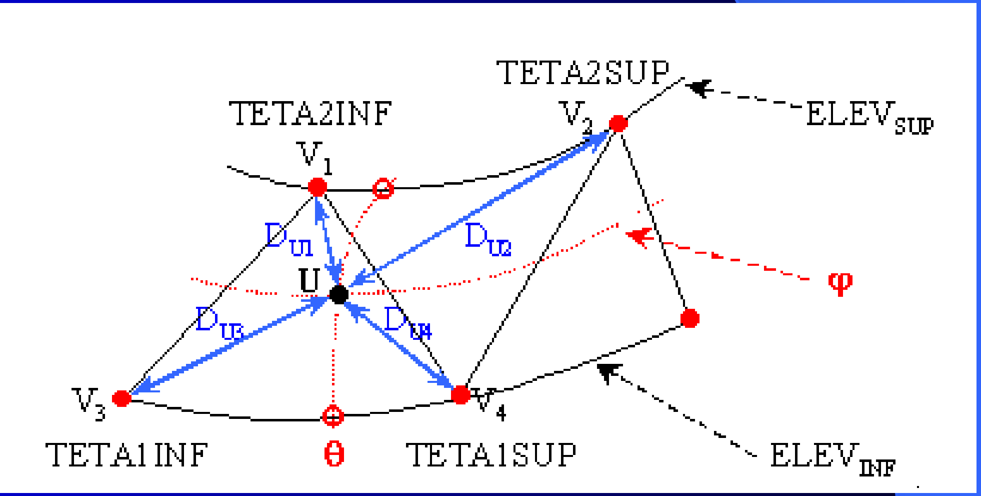
if $\mathbf{y'_{prov} < 0} \quad \Rightarrow \quad \boldsymbol{\theta = 360° - \theta}$

Interpolation of the three nearest HRTFs



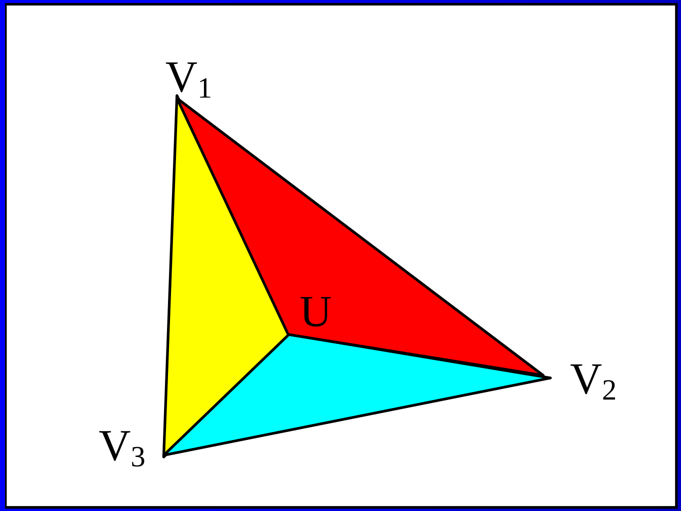
First, 4 possible nearest measurement points are located, choosing the values of φ and θ which are just lower and higher than the theoretical ones.

Then, one of the point is discarded, so that a triangle surrounding the arrival direction is defined



Evaluation of the weights

- the weight $\mathbf{P_i}$ (i = 1,2,3) relative to each HRTF is obtained calculating the opposite triangle area and dividing it for the total initial triangle area; so we have $\mathbf{P_1+P_2+P_3=}1$.



$P_1 = \mathrm{Area}(V_3,U,V_2)/A_{tot}$

$P_2 = \mathrm{Area}(V_3,U,V_1)\ /A_{tot}$

$P_3 = \mathrm{Area}(V_1,U,V_2)\ /A_{tot}$

Computation of the binaural IR

- At the exact arrival time of the received ray, an averaged binaural IR is added to the global impulse response.
- The averaged IR is obtained by a frequency domain interpolation between the three HRTF complex spectra:

$$\mathrm{HRTF}(\varphi,\theta) = P_1 * \mathrm{HRTF}(\varphi_1,\theta_1) + P_2 * \mathrm{HRTF}(\varphi_2,\theta_2) + P_3 * \mathrm{HRTF}(\varphi_3,\theta_3)$$

- The interpolation is actually done separately on the modulus and phase of the complex spectra
- FFT and IFFT are used for converting between time domain and frequency domain

Use of the binaural IR

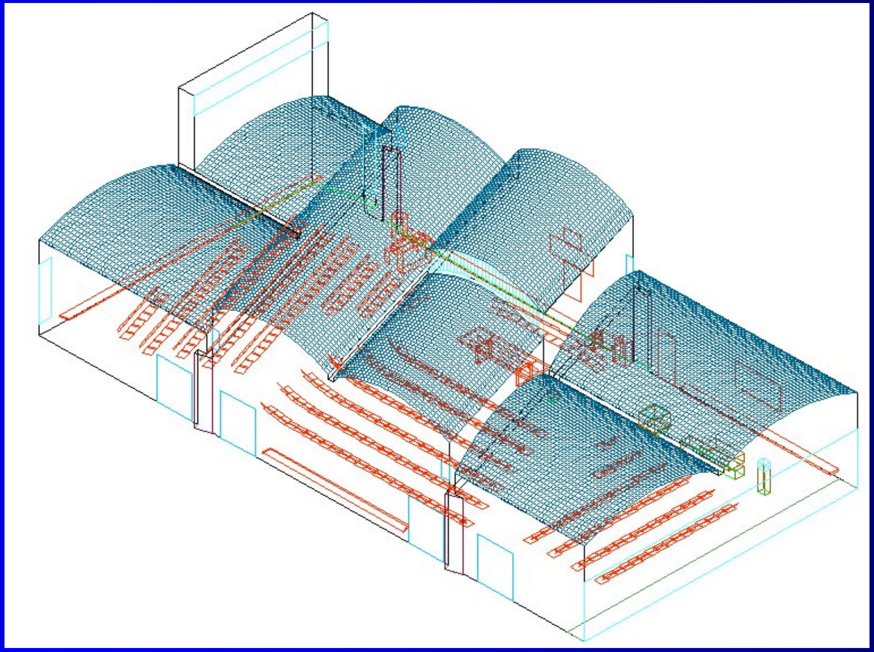
- Once the energetic impulse response has been converted into a binaural pressure impulse response, it can be used for auralization by means of a fast convolution algorithm (Select-Save)
- The auralized sound can be listened by means of an headphone, or it can played on a pair of loudspeakers thanks to a proper cross-talk cancelling set of inverse filters (Stereo Dipole)
- An example of the auralization of a sound field in a virtual room is provided at the end of this presentation

Conclusions

- The selection/interpolation algorithm developed allows for the use of HRTF data-bases measured with uneven angular resolution, as those provided by MIT-Medialab
- The reconstructed binaural IRs proved to produce realistic, high quality auralization
- Already available software allows for manipulation of the computed IRs (convolution, cross-talk cancellation), making the whole auralization process feasible on a low cost PC without dedicated hardware.

Demonstration

- S.Domenico Church - Udine



Movie sound