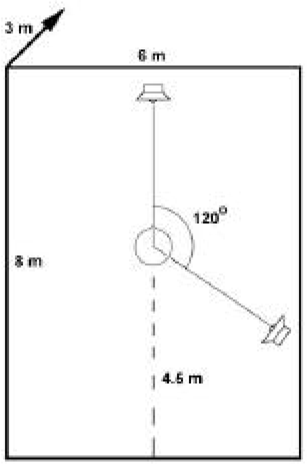
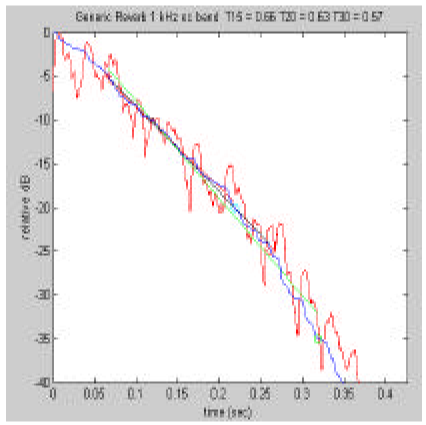
Application-driven design of Auralization Systems





Acoustical Society 147th Meeting, New York NY, May 2004

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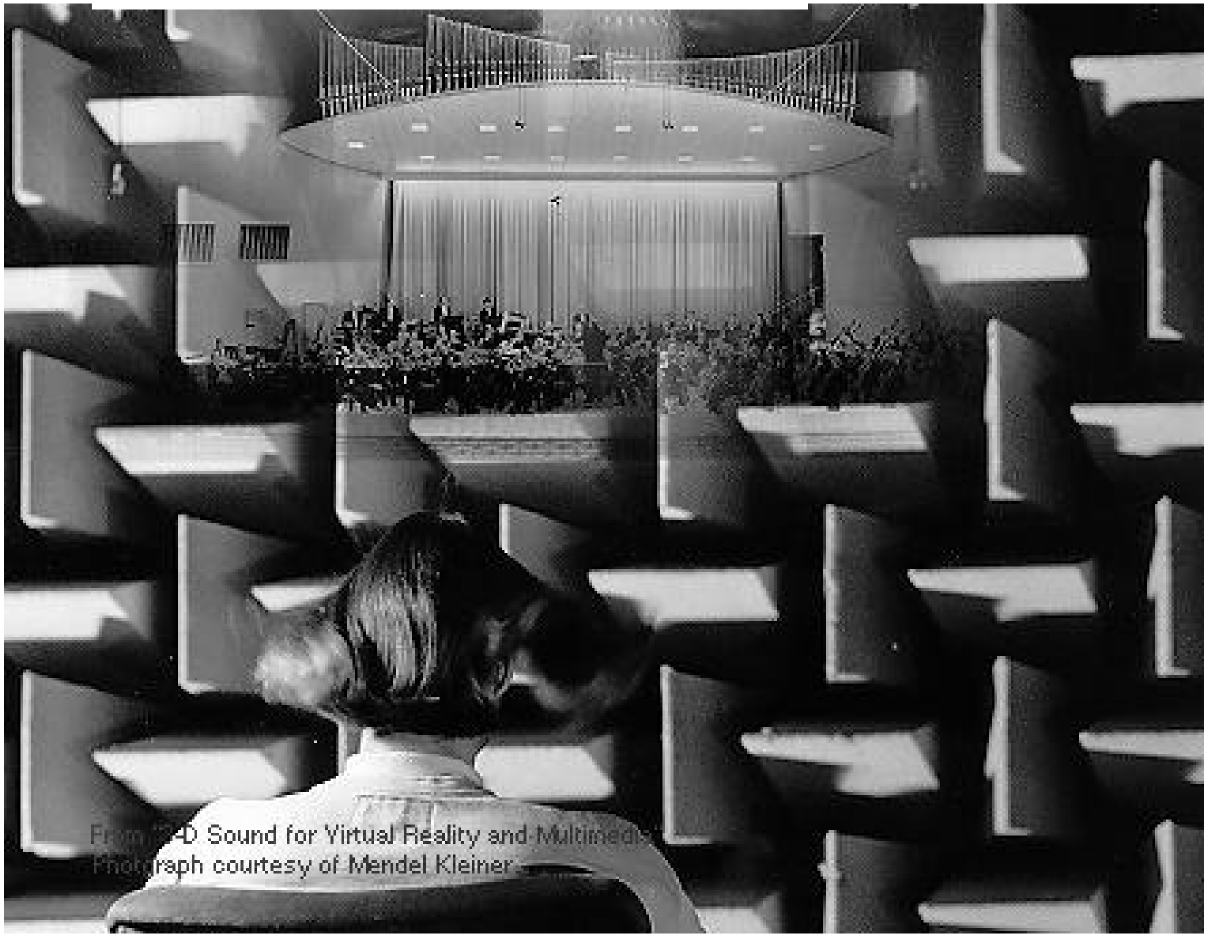
Two questions pertinent to auralization applications:

“What degree of fidelity is possible”?

“What degree of fidelity is necessary- does it matter”?

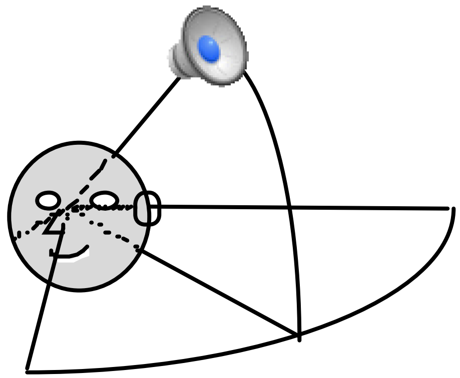
- *hardware, software, data limitations*
- *how can system demands be minimized*
- *how some applications can use “simple” auralization other applications will require full multimodal capacity*

Auralization is...



...the process of rendering audible, by physical or mathematical modeling, the sound field of a source in a space, in such a way as to simulate the binaural listening experience at a given position in the modeled space"
(Kleiner, Dalenbäck and Svensson, JAES, 1993)

Auralization involves simulation of the location of a sound source at a point in space (azimuth, elevation, distance)...



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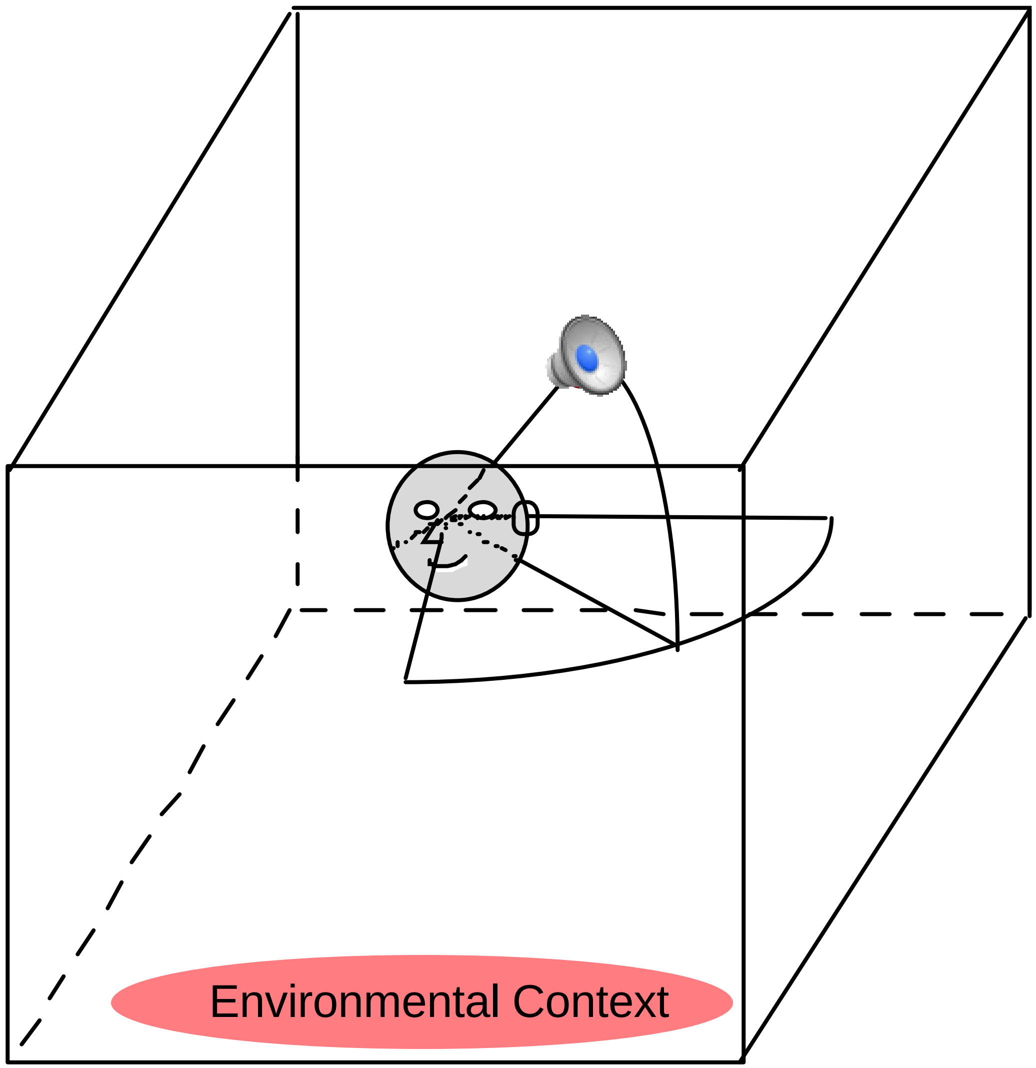
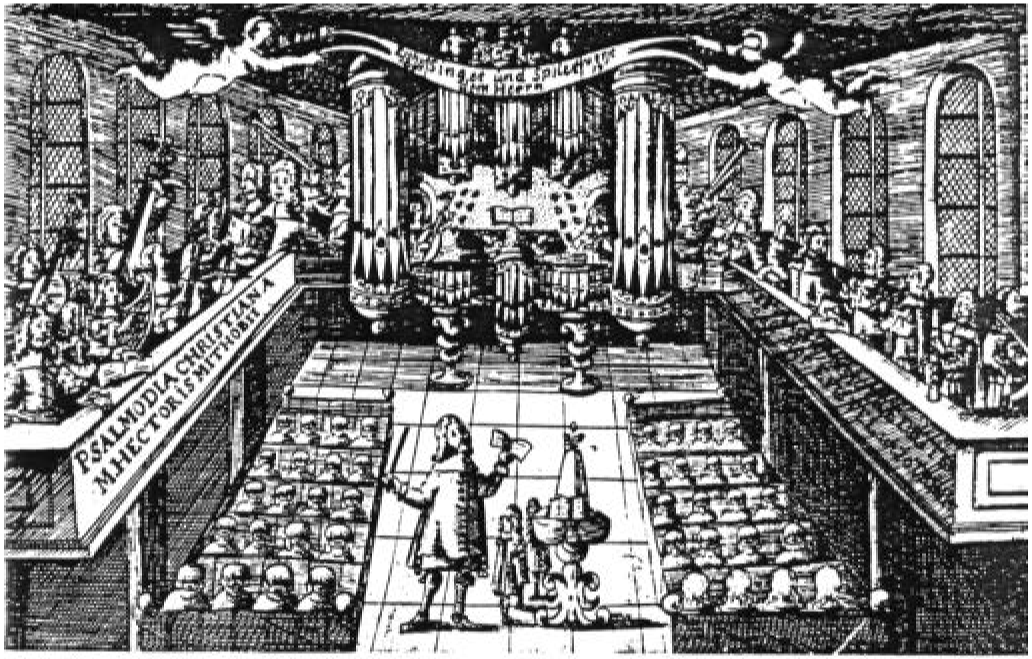


...and how the sound source simultaneously reveals information about its environmental context.

"Overlapping" percepts:

-image broadening
-envelopment
-distance

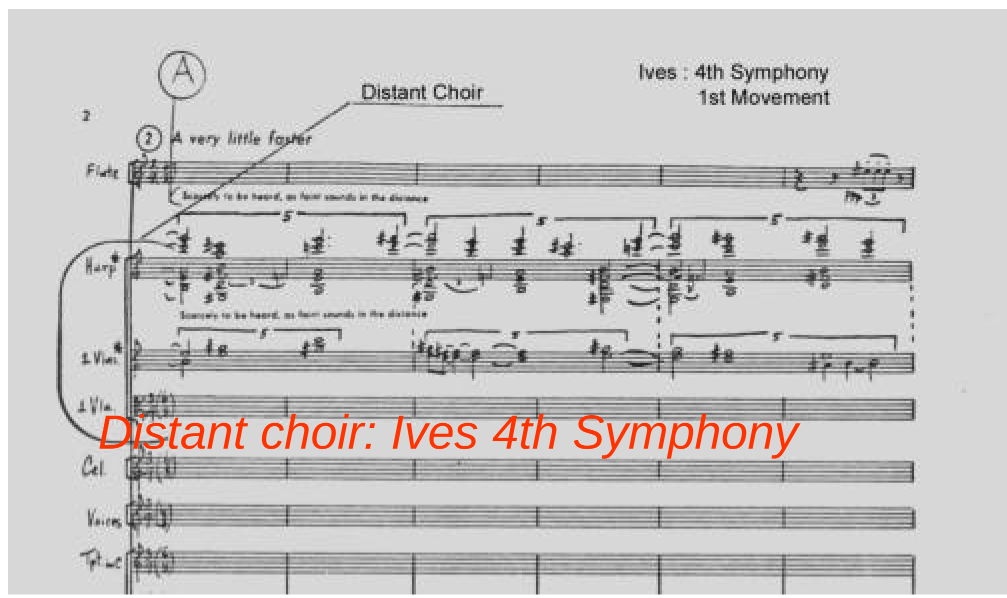
Acoustical environment simulation has historical basis in music



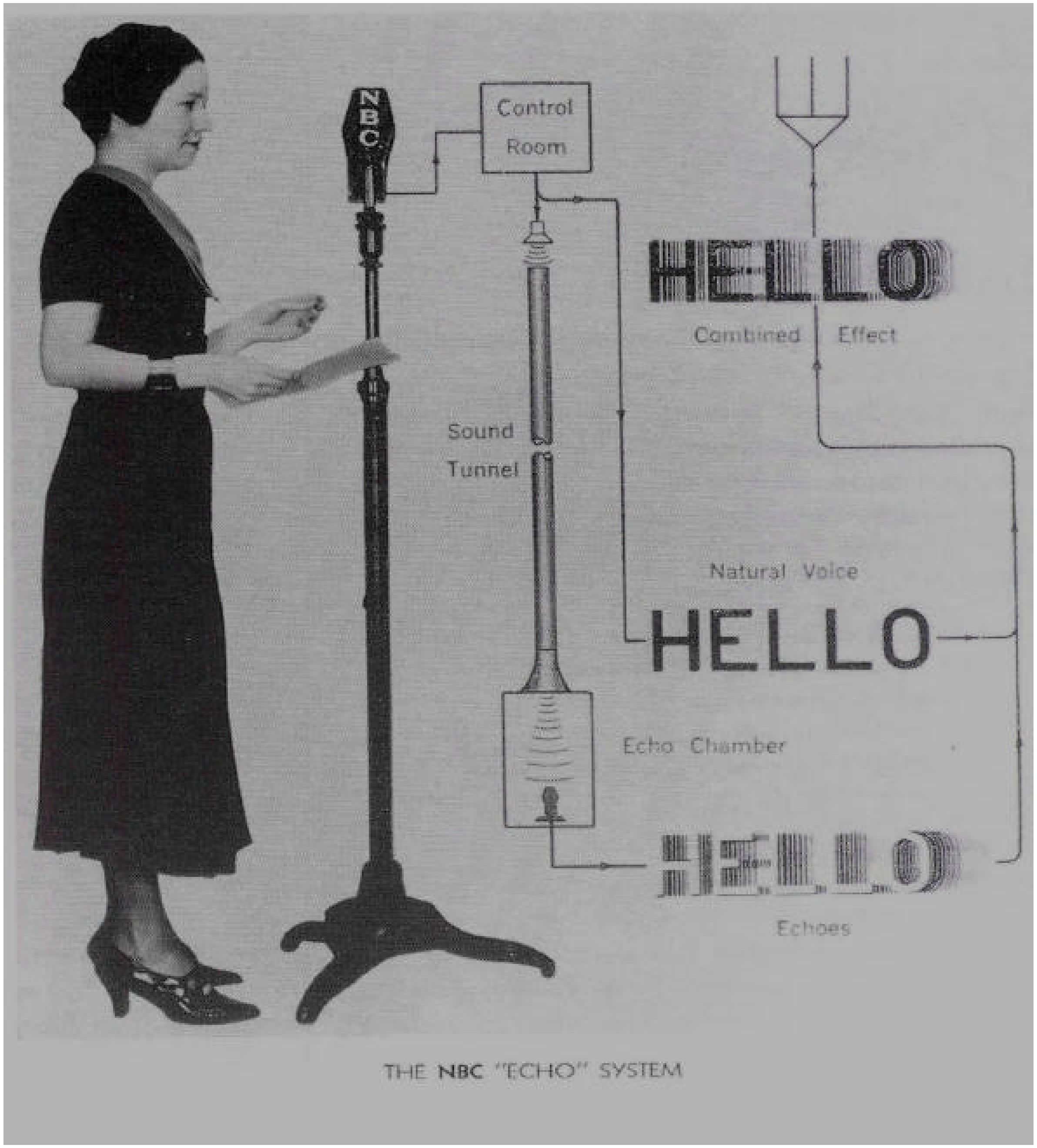
(Renaissance- baroque)
Antiphonal music:
articulation-exaggeration
of host room characteristics

Echo music:
Haydn: *Das Echo*

Romantic era (1830-19XX)
Program music;
notations in scores for simulating
distance, remote locations within
a simulated environment
Mahler: *2nd symphony ("Apocalypse")*

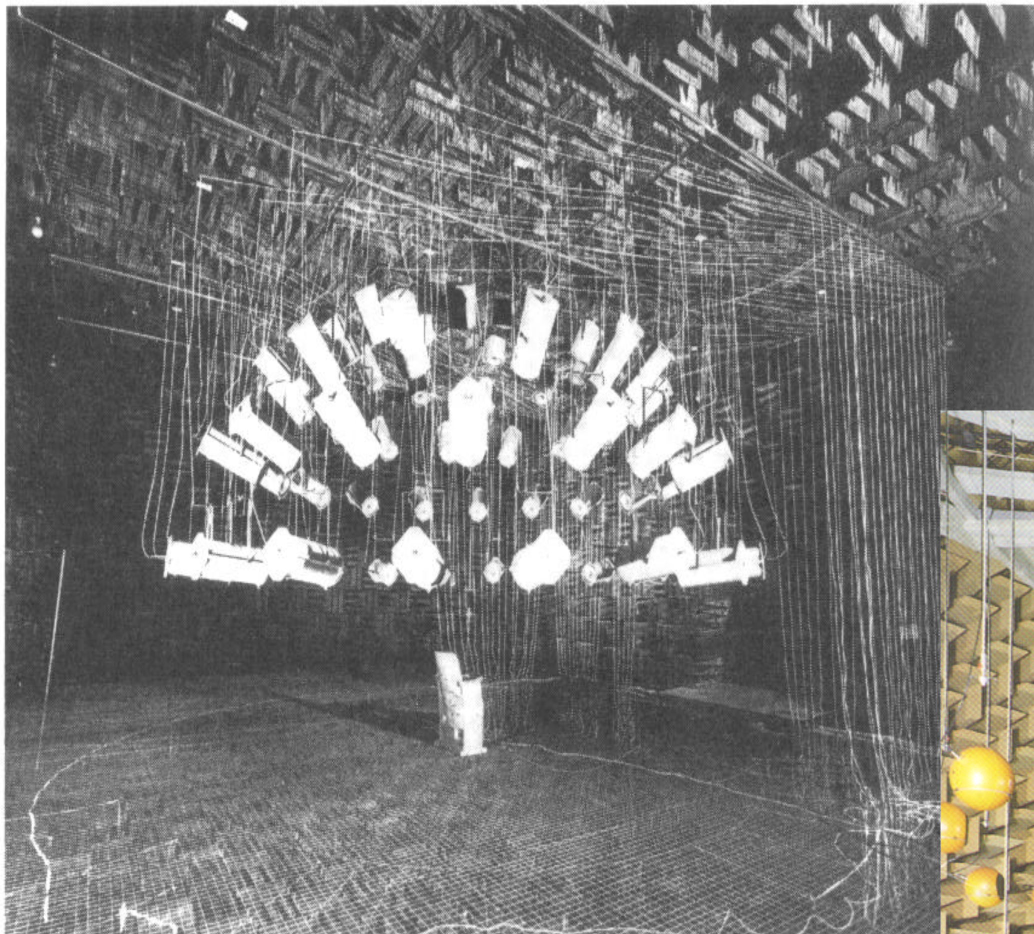


Distant choir: Ives 4th Symphony



Reverberation using echo chamber, 1930s

Acoustic spaces have long been simulated electronically since the beginnings of signal processing.... either by echo chambers, plates and springs...

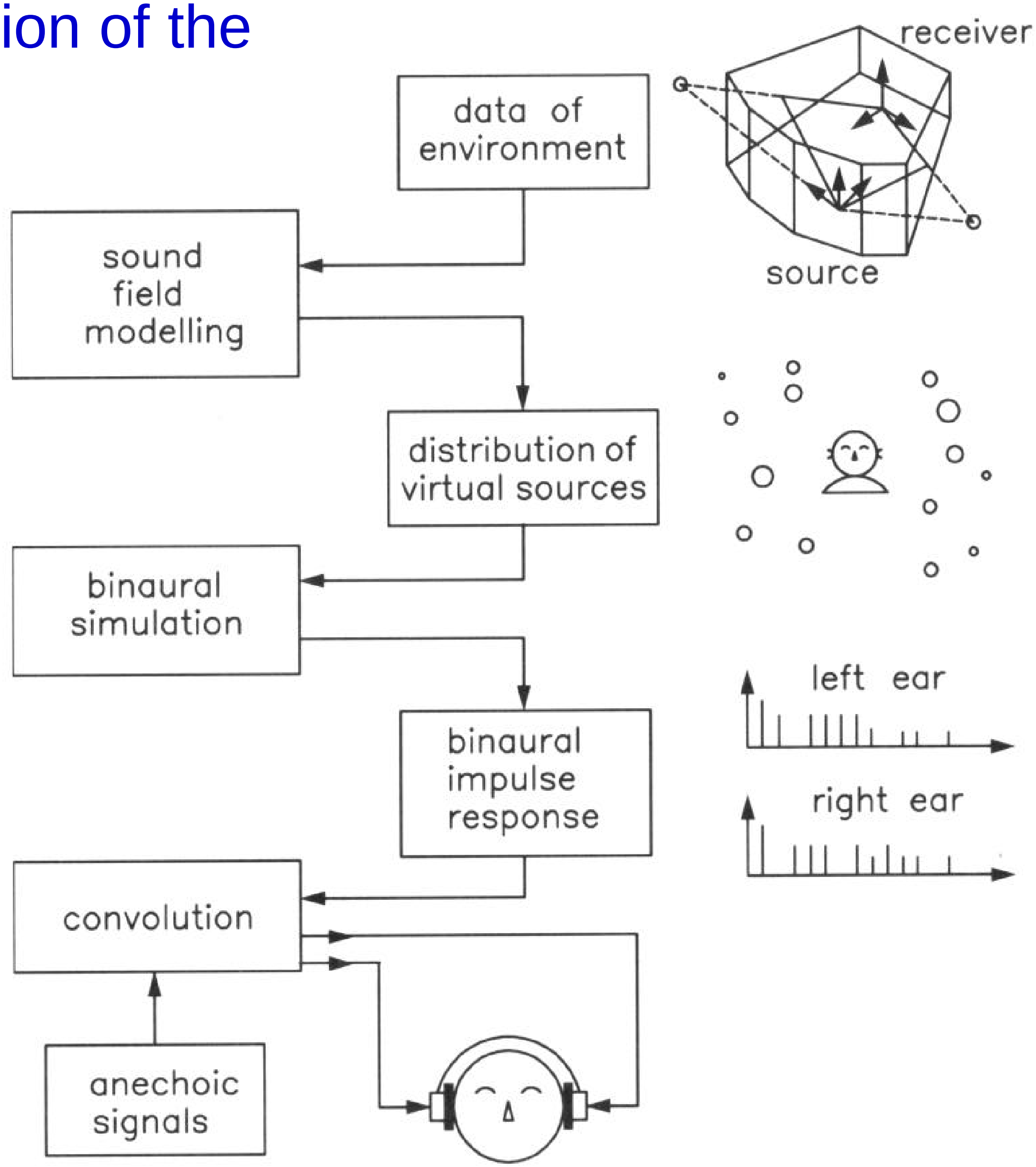


...by use of loudspeakers arrays corresponding to sound reflections....

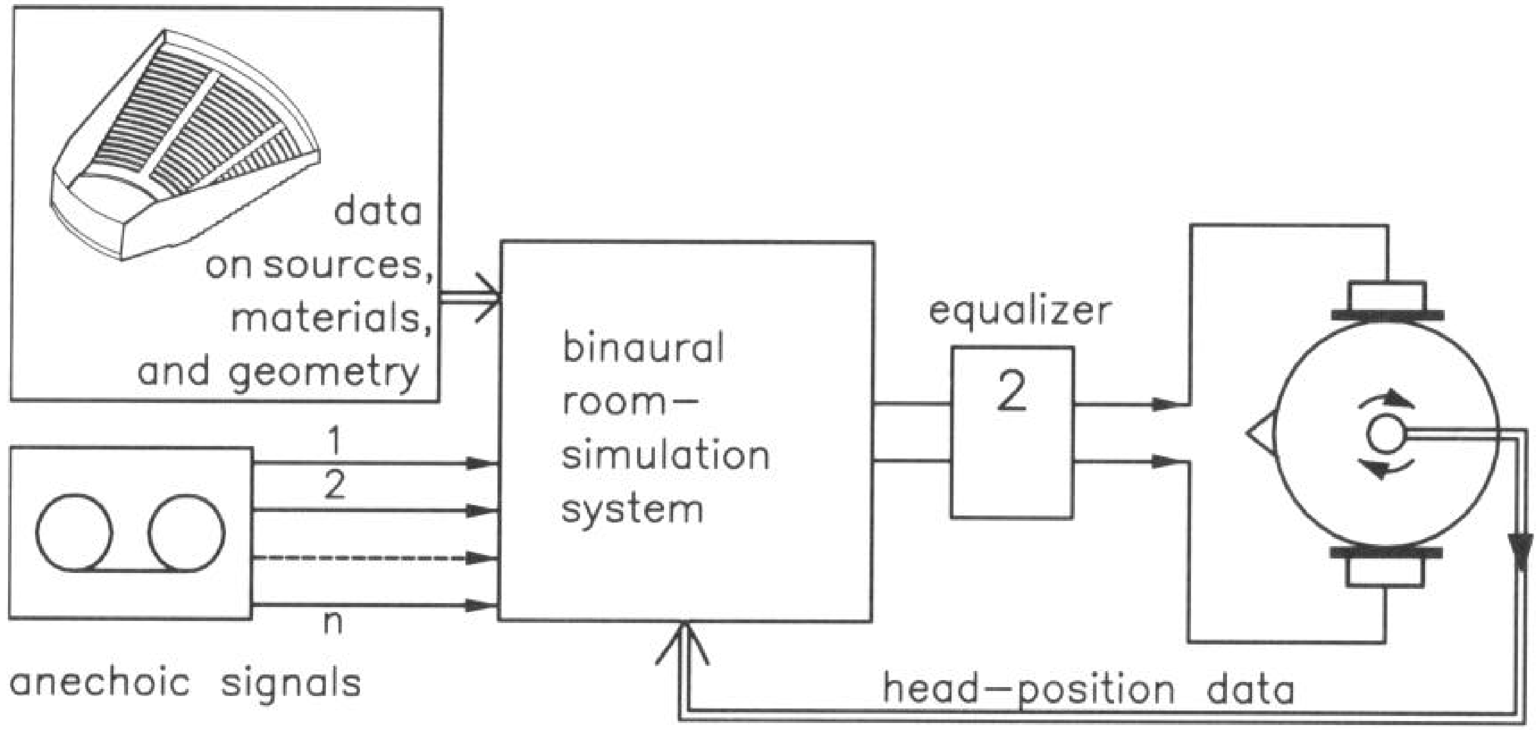
University of Göttingen 1965.

Technical University of Denmark, Lyngby, 1992.

..or by virtual simulation of the reverberant field



Head-tracked systems increase realism of the simulation

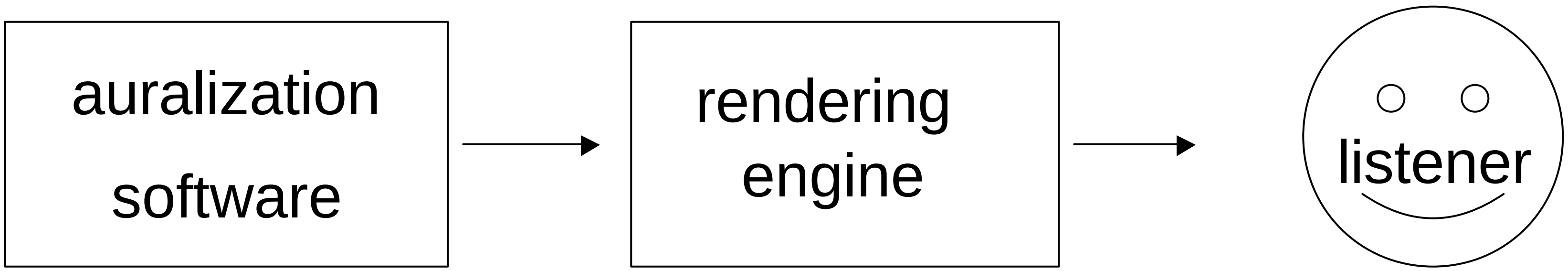


Relevant operating factors

- room model accuracy
- IR generation method
- absorption & diffusion data
- low frequency behavior
- measurement detail

- scenario update rate
- latency
- threshold data

- acoustic transfer function difference
- dynamic interaction motivation, response
- cognitive association
- multimodal cues



Outputs

- prediction of acoustic measures
- comparison between model and real room

- quality of specific simulation
- perceptual measure (e.g., SI)
- task performance (e.g., localization)

Relevant operating factors

- room model accuracy
- IR generation method
- absorption & diffusion data
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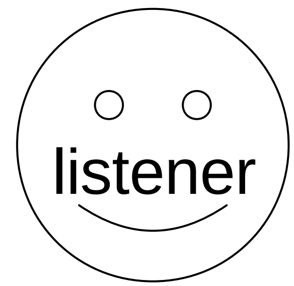
- measurement detail

auralization software →

- scenario update rate
- latency
- threshold data

rendering engine →

- acoustic transfer function difference
- dynamic interaction motivation, response
- cognitive association
- multimodal cues



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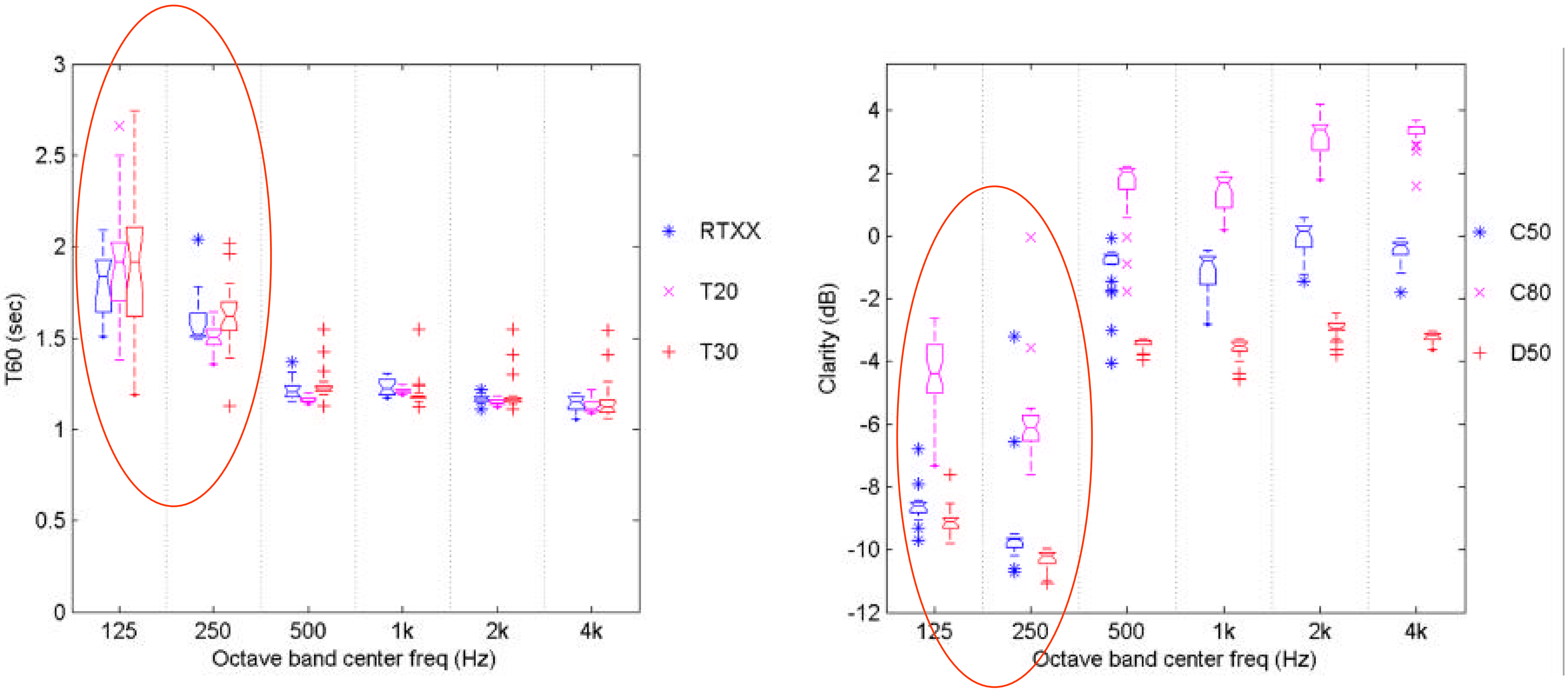
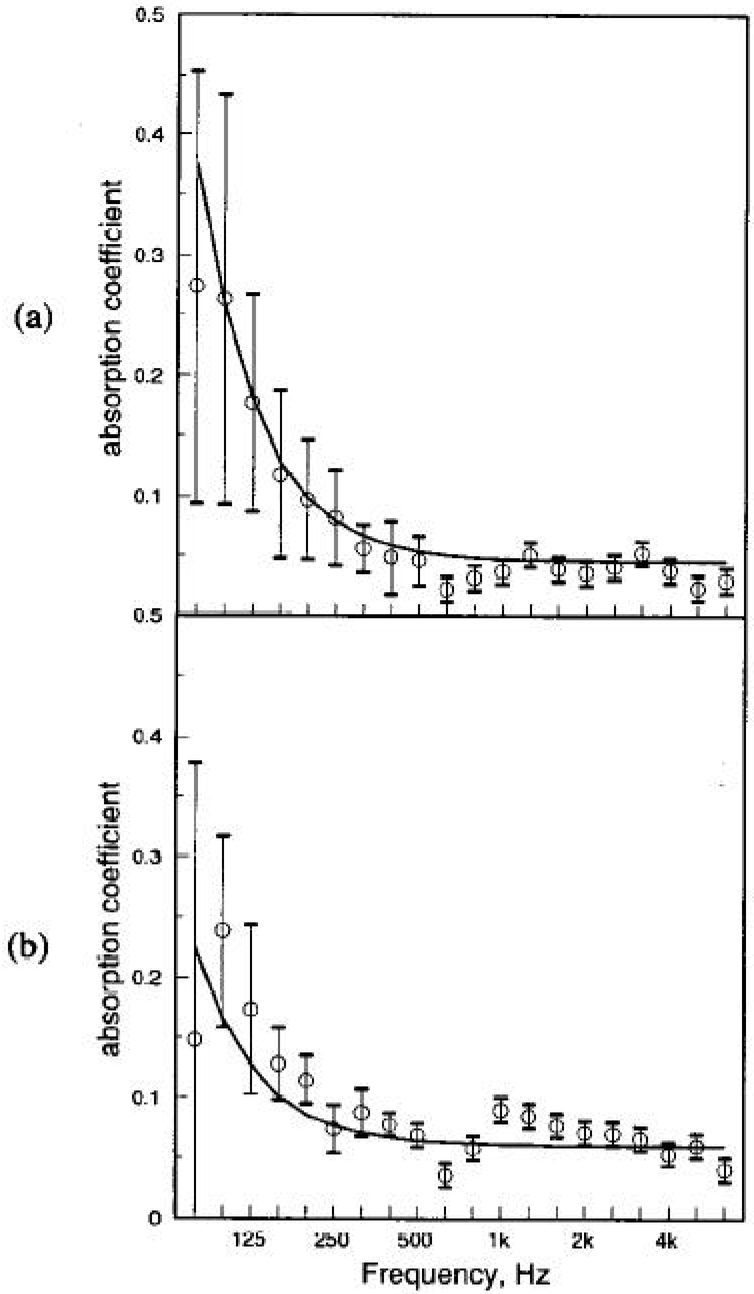
ISO 3382 software calculations (n=37) from real room IRs indicate wide variability at low frequencies with non-linear decays



Brian F.G. Katz: *International Round Robin on Room Acoustical Impulse Response Analysis Software 2004,* In-press, ARLO (July 04?)



- At low frequencies (> 500 Hz), absorption coefficients difficult to quantify
- Absorption coefficients will vary depending on mounting and surface extent of the material
- Wide-range diffusion properties difficult to calculate

13 mm (0.5”) gypsum board absorption coefficients (from J.S. Bradley, JAES) 1 and 2 layers

Vorlander: Int. round robin on room modeling programs

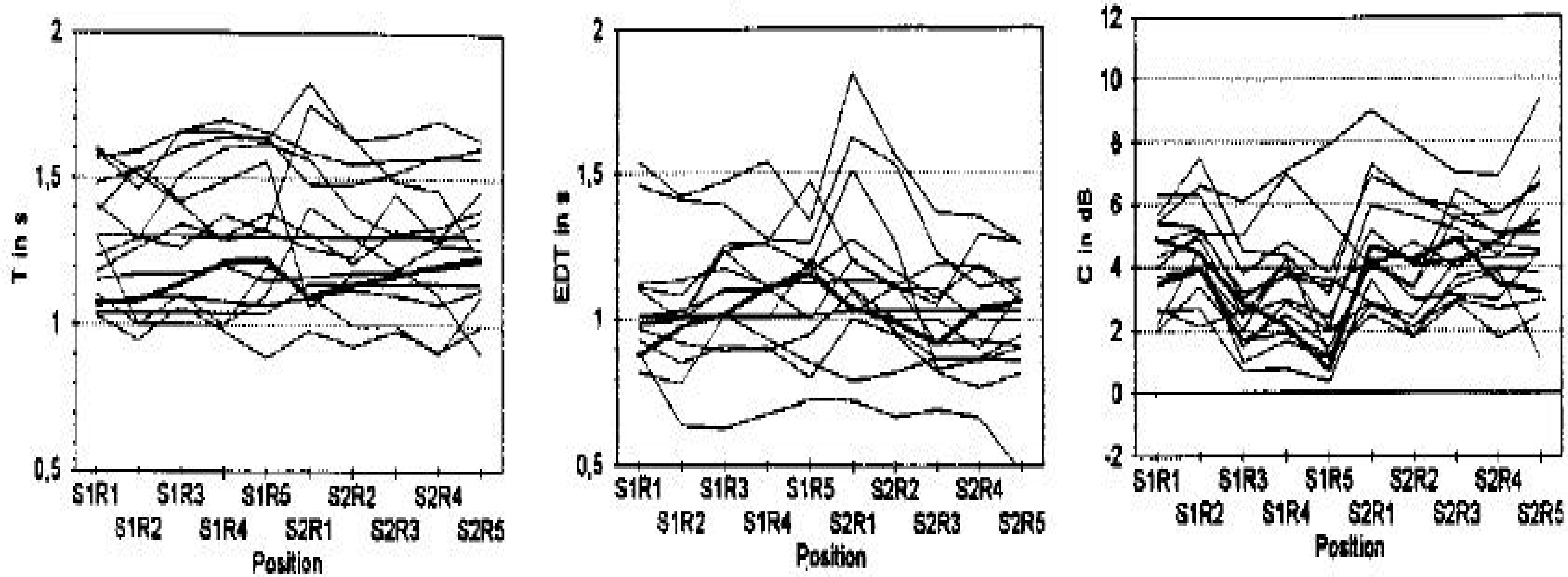
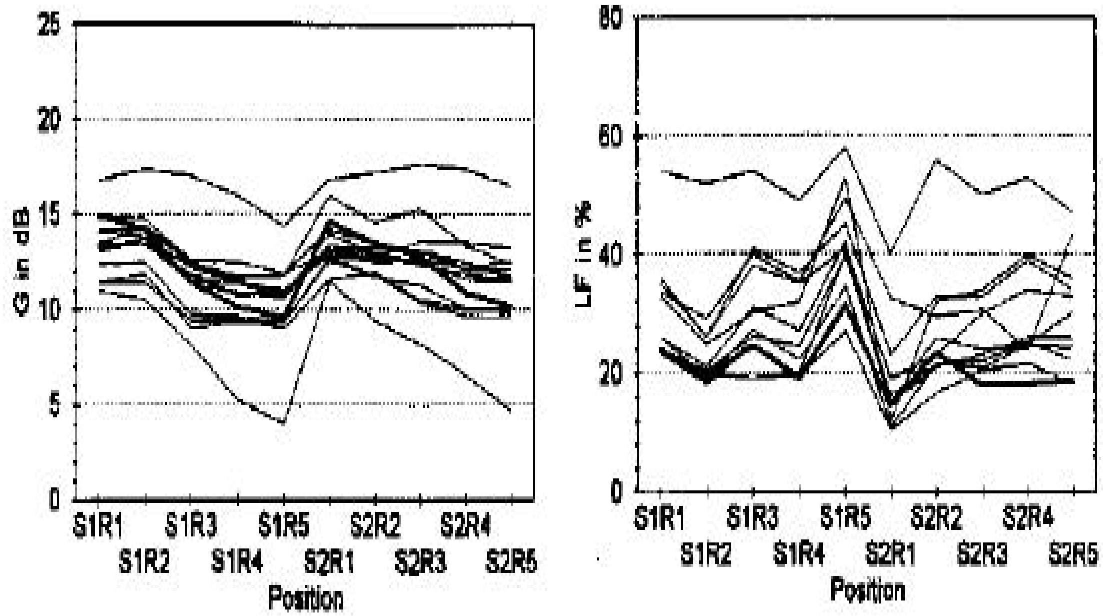


Fig. 2. Individual results of phase I (thin lines) for parameters T, EDT, C, G and LF. The thick line marks the average measurement result. As the results shown here are only intended to indicate the large differences, the curves are not marked by symbols.



"Low" frequencies not accurately modeled by geometrical acoustics (below "Schroeder Frequency");

$$Fs = 2000 \sqrt{\frac{T60\ (s)}{V\ (m^3)}}$$

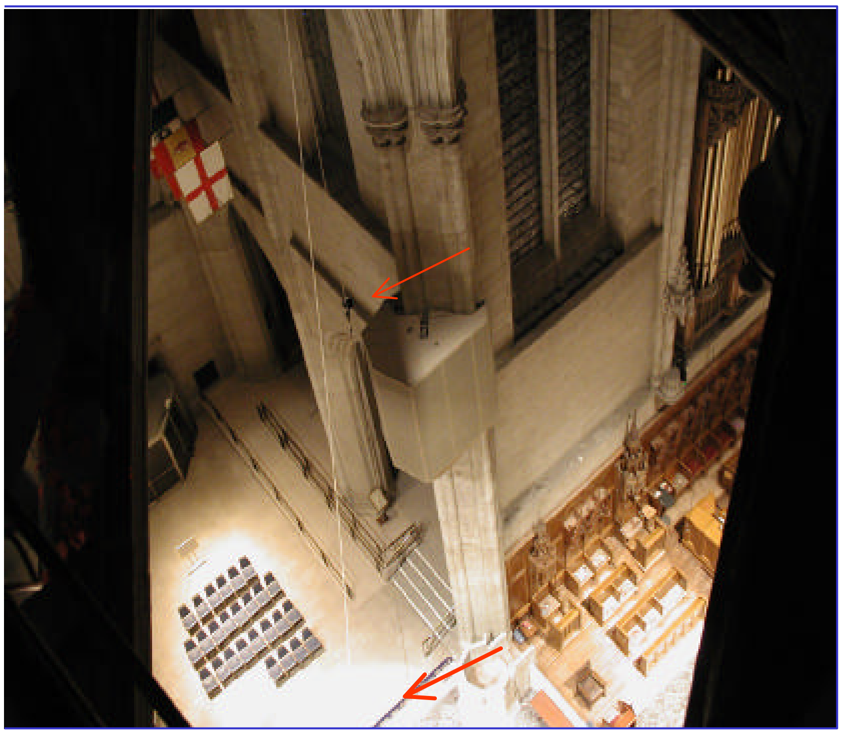
Hybrid methods using Finite Element Modeling or BEM for low frequencies are possible

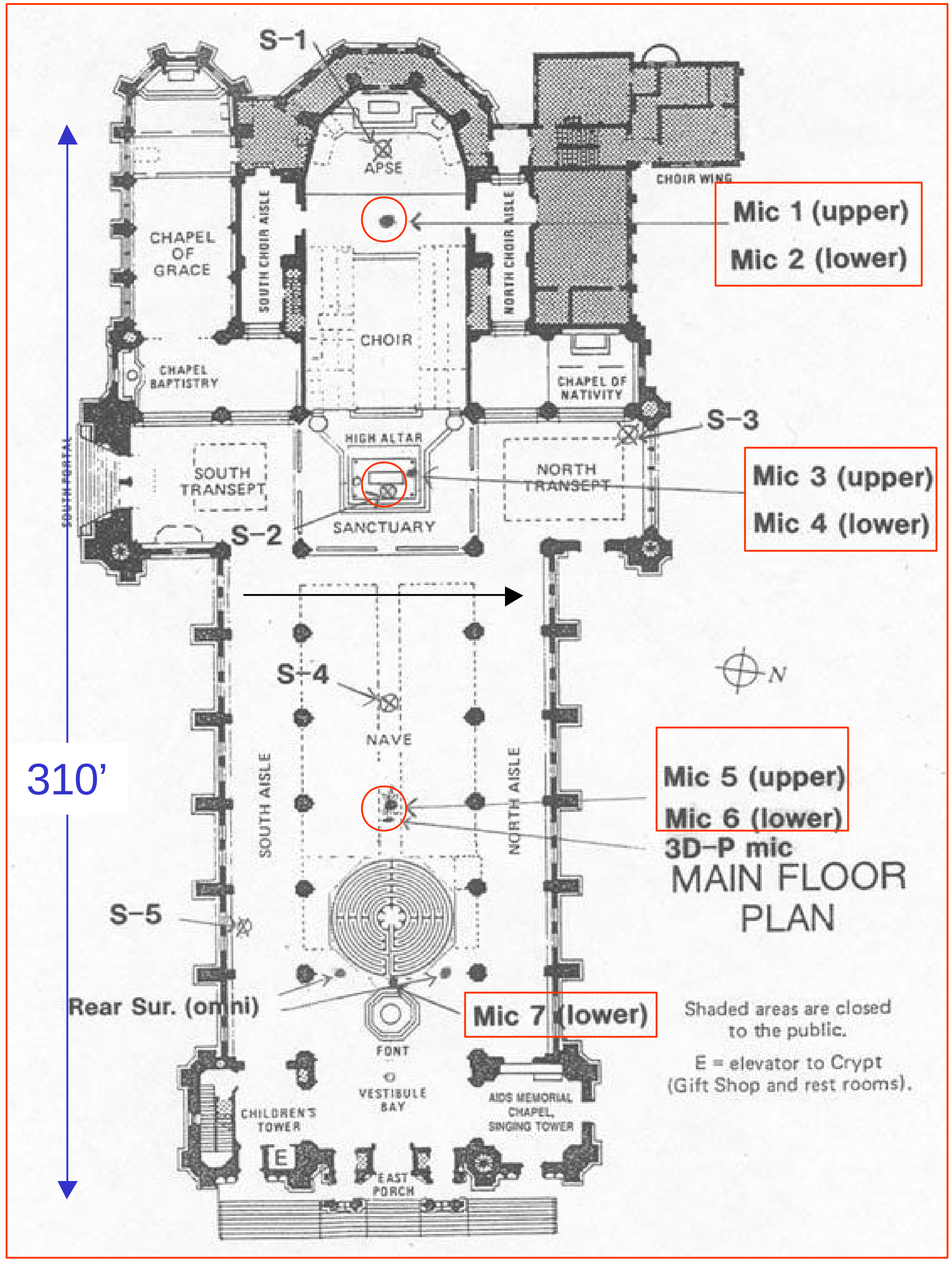
QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Granier, Kleiner, Dallenbäck and Svensson, "Experimental Auralization of Car Audio Installations", J. Audio Eng. Soc. (1996)

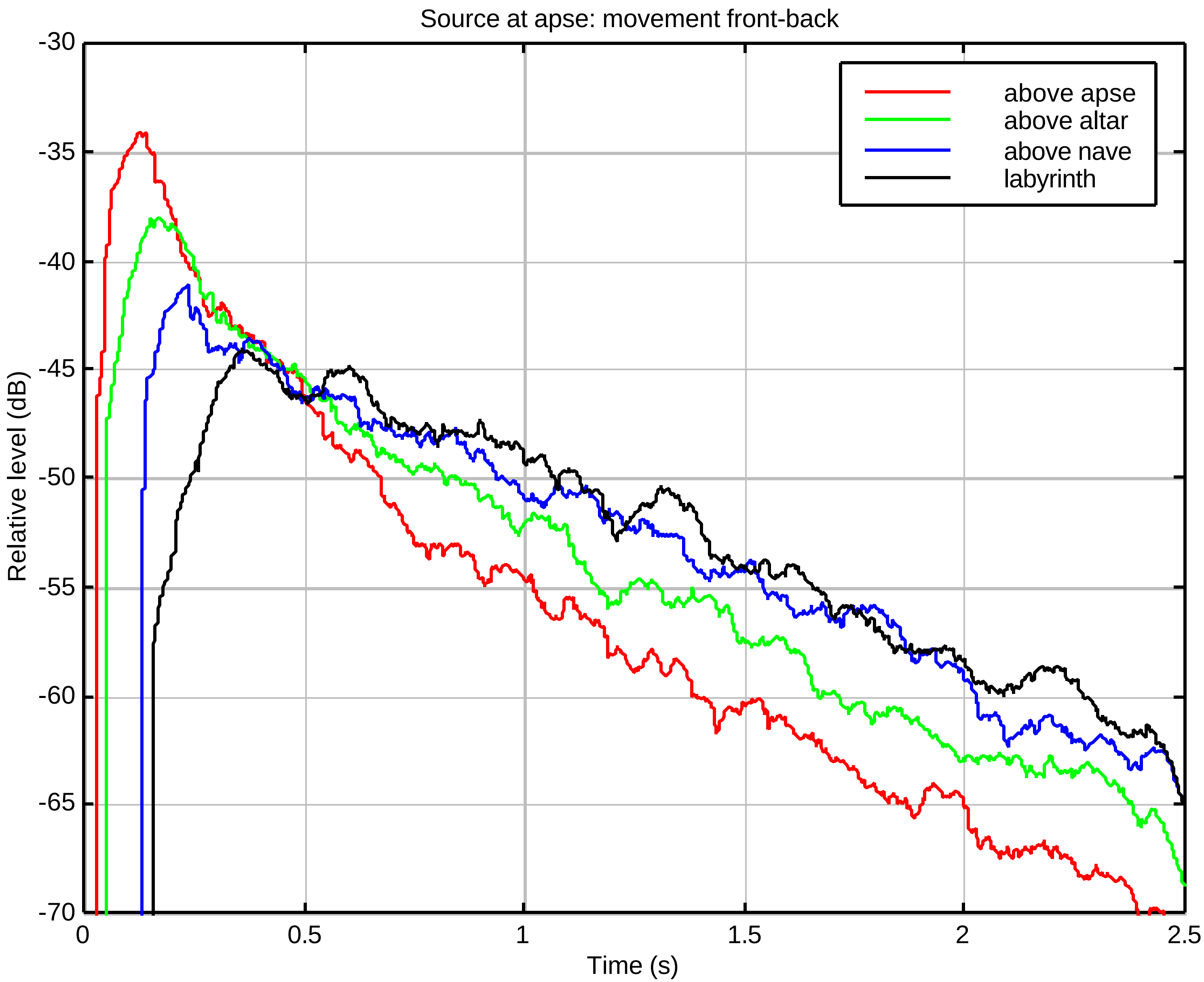
“Movement” of late reverberation due to coupled spaces

Calibrated measurements
using 7 microphones
in Grace Cathedral,
San Francisco





Front-back movement for sound source at apse



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- room model accuracy
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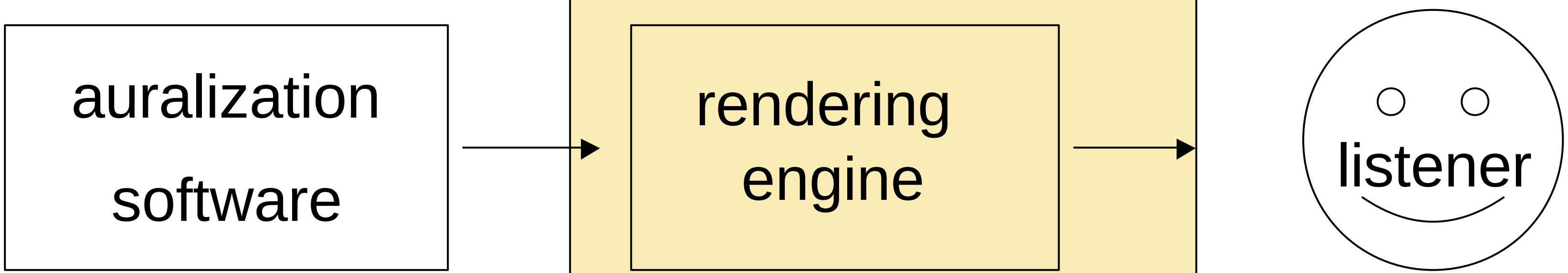
- threshold data

- acoustic transfer function difference
- dynamic interaction motivation, response
- cognitive association
- mutlimodal cues



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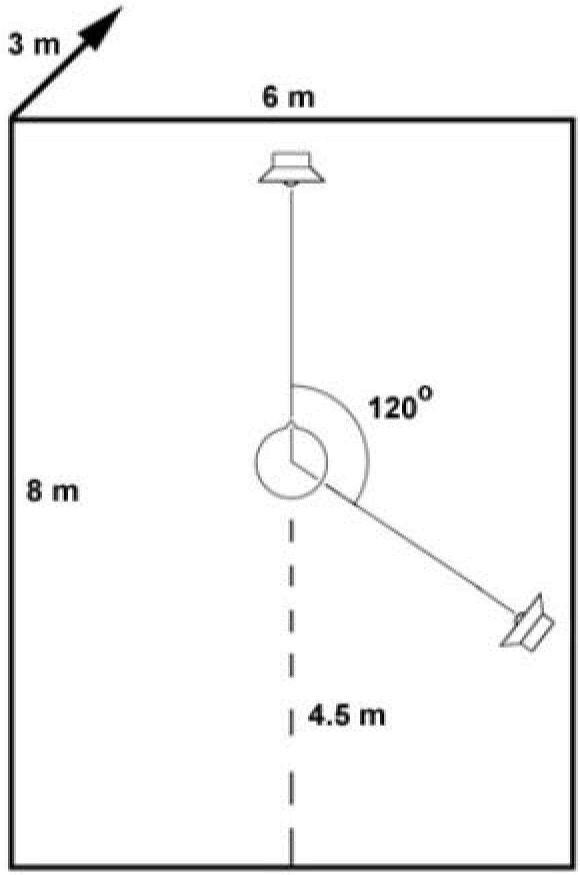
Provide real-time processing of the direct path and early reflections with good system dynamics
(latency: < 70 to 100 ms, update rate: > 10 Hz minimum)

NASA SLAB system 1 direct 6 early reflections:
latency 8 - 24 ms
scenario update rate 120 Hz

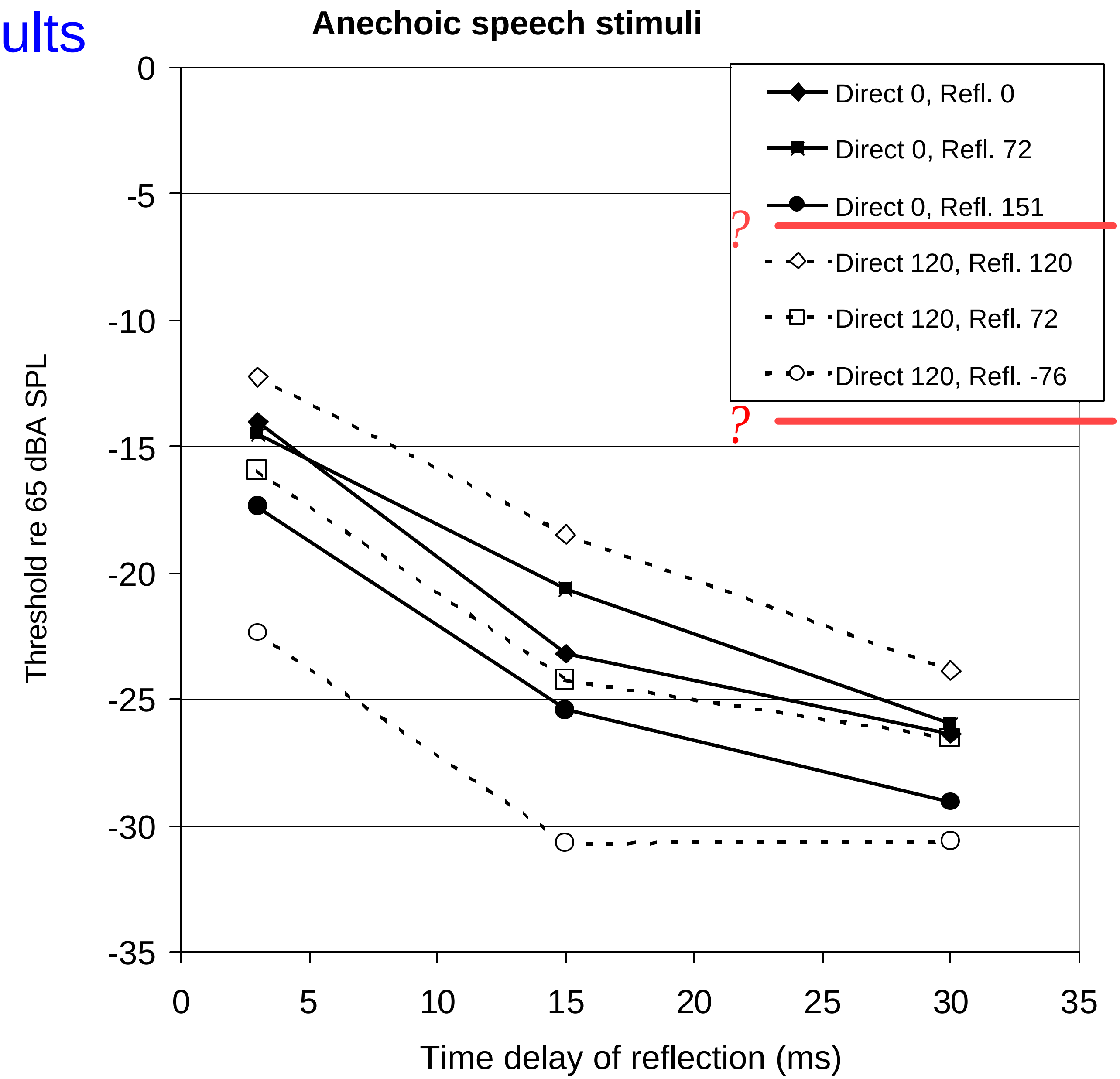
Timings and directions of direct sound and reflections

Derivation from a "primary" model



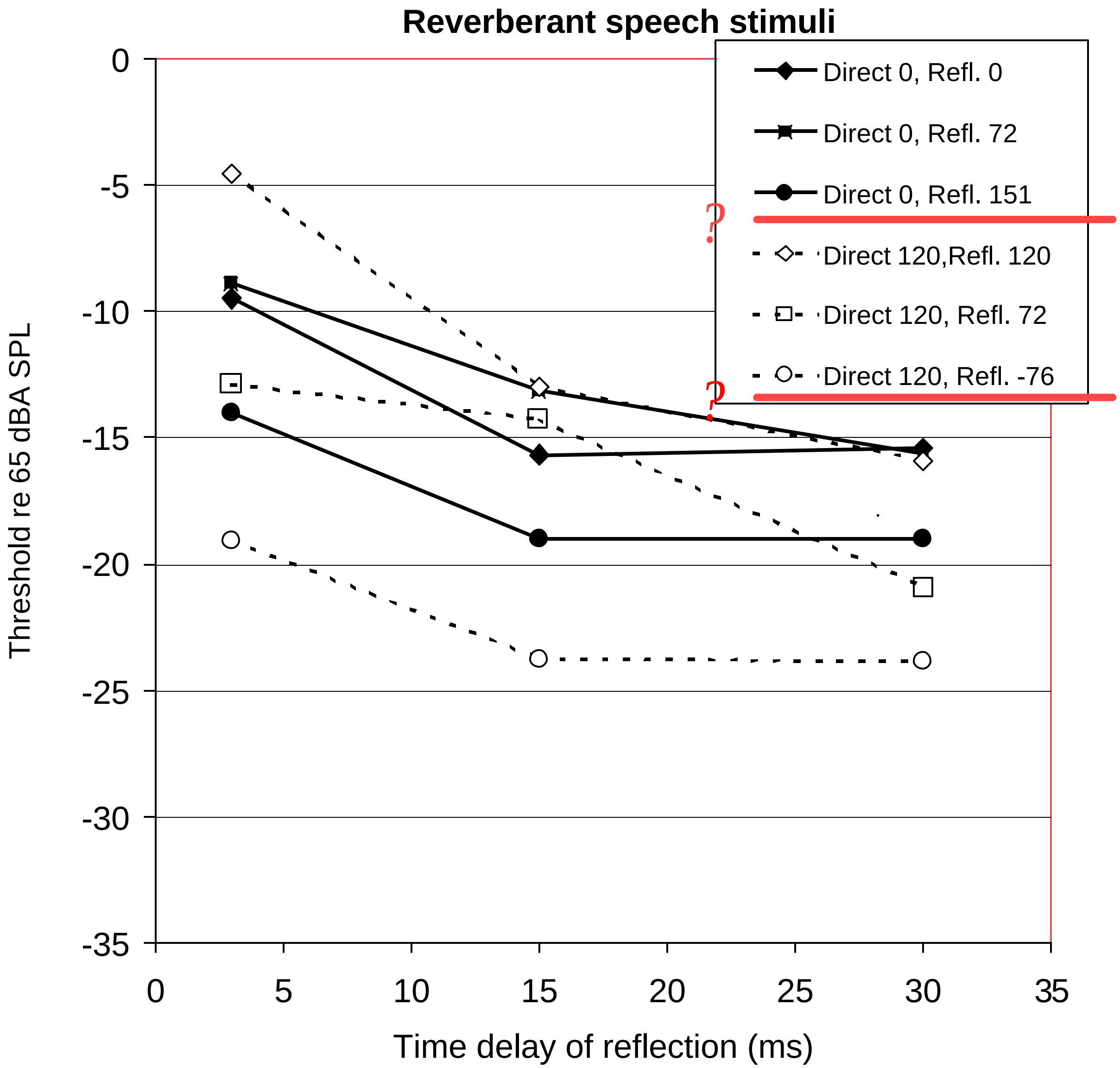
- Room dimension and absorption coefficients based on listening room standard *(ITU)*
- Direct sound at 0 and 120 degrees
  ('center' and 'surround' loudspeaker positions)
- 1st and 2nd order reflections calculated via image model
  ('most significant' reflections identified)

Results



Increased angle relative to direct sound results in lower thresholds

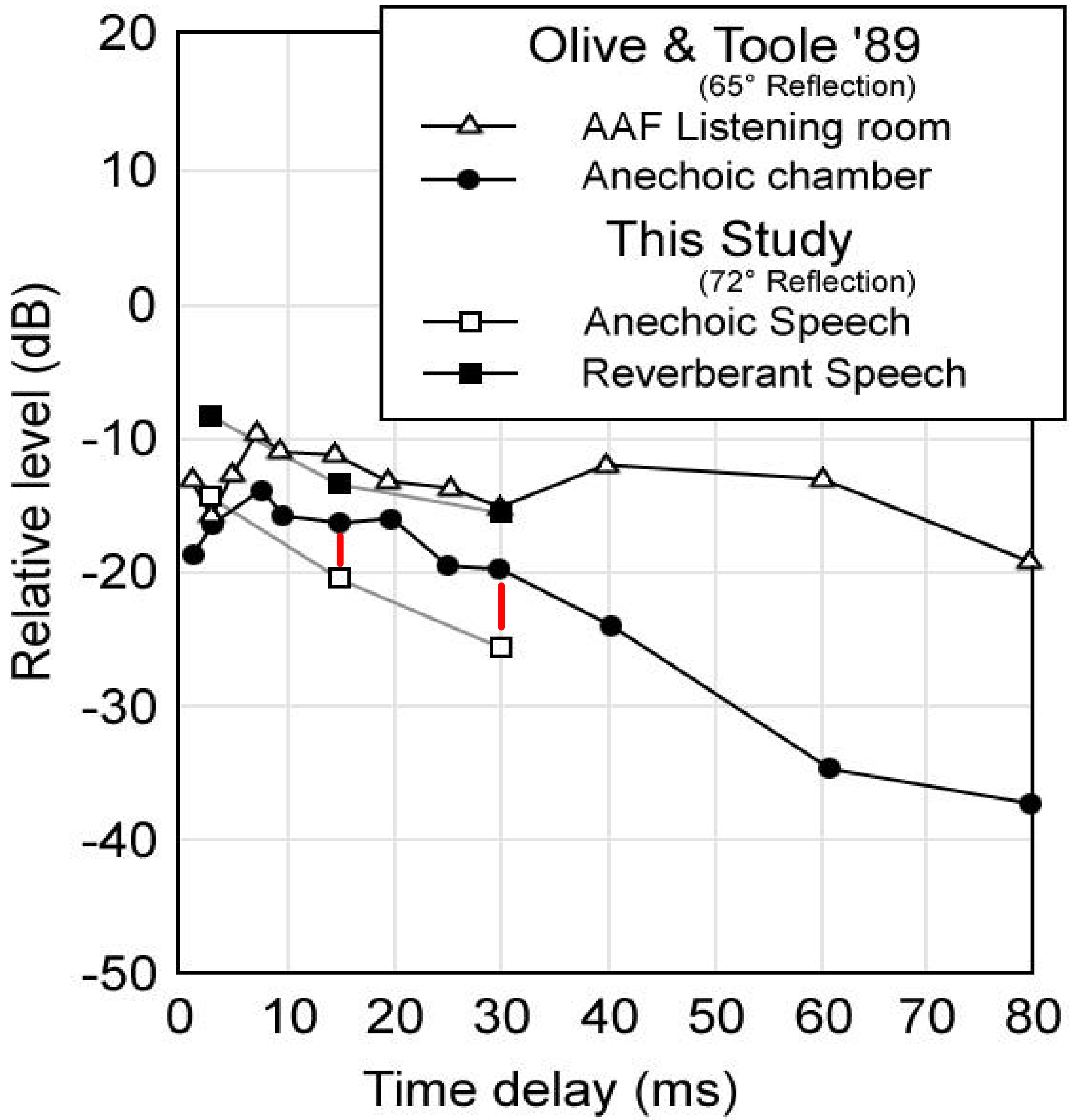
Results



Increased angle relative to direct sound results in lower thresholds

Overall levels about 10 dB higher re "anechoic" stimuli

Comparison to data from real rooms



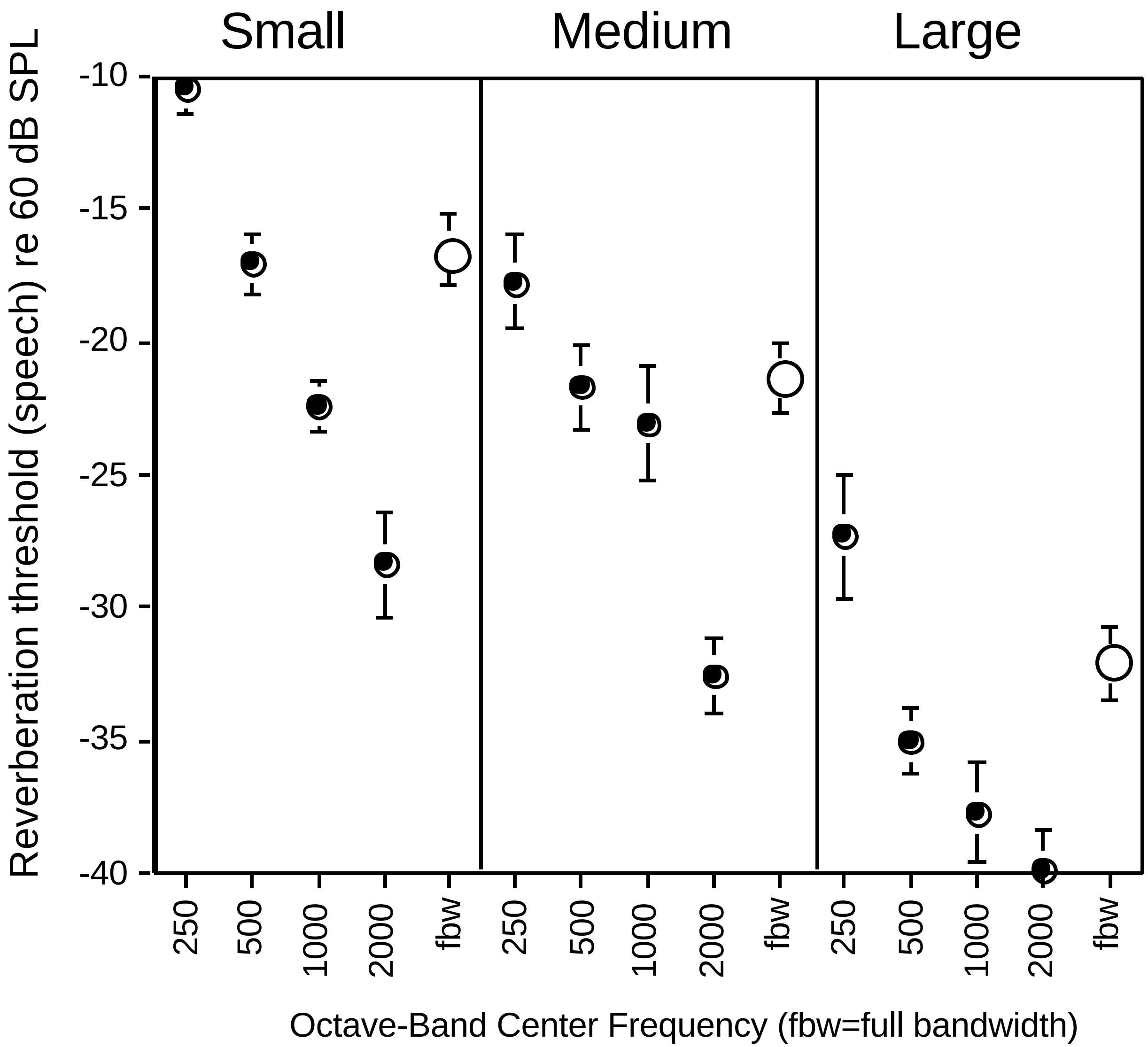
Useful guidelines for development of auralization rendering engines (example)

- Across all stimuli types and conditions, lowest thresholds correspond to largest lateral azimuth difference (direct sound at 120 degrees, reflection at –76 degrees).

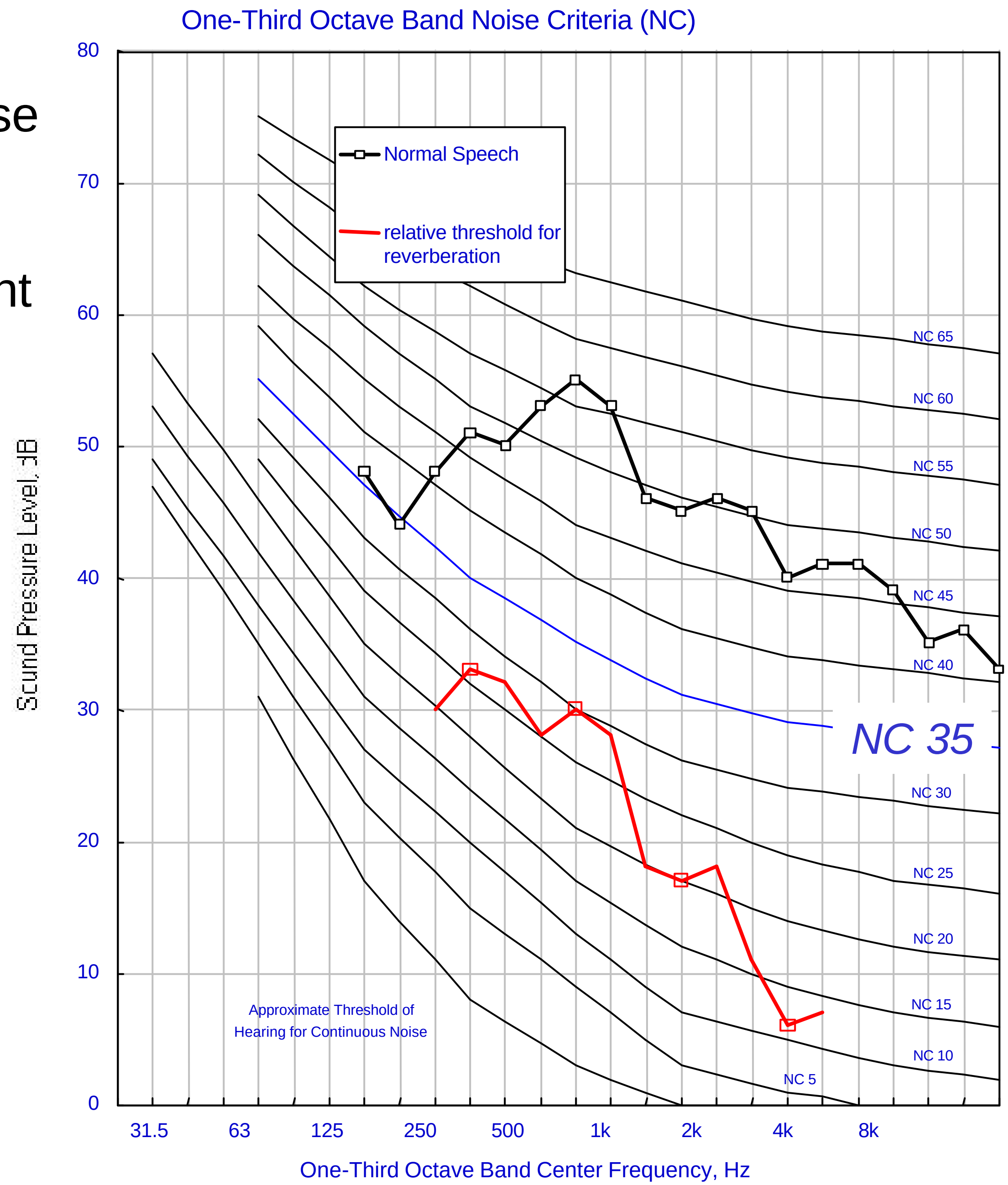
- Reverberation (R/D ratio -20 dB) increases threshold by about 10dB for speech stimuli.

- Rule of thumb: early reflections re direct sound should be inaudible < -22 dB @ 3 ms and < -31 dB @ 15-30 ms

Late reverberation thresholds: speech, no early reflections



For loudspeaker playback, background noise can mask reverberant energy
(particularly the reverberant decay)



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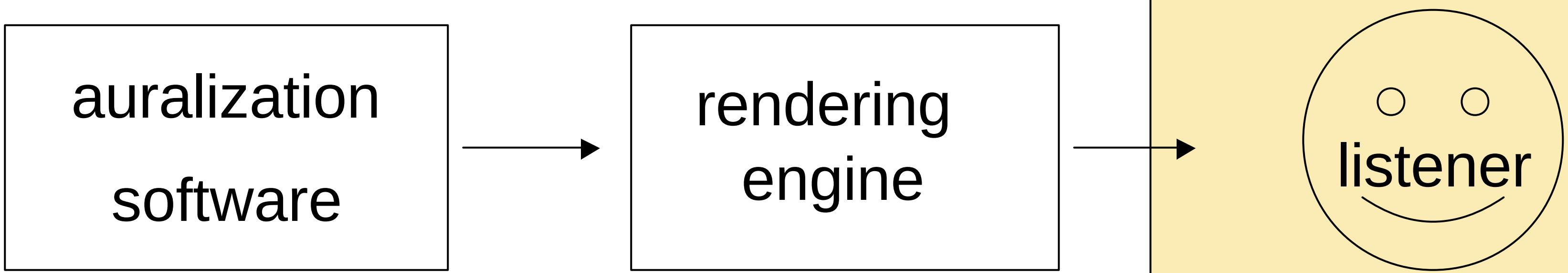
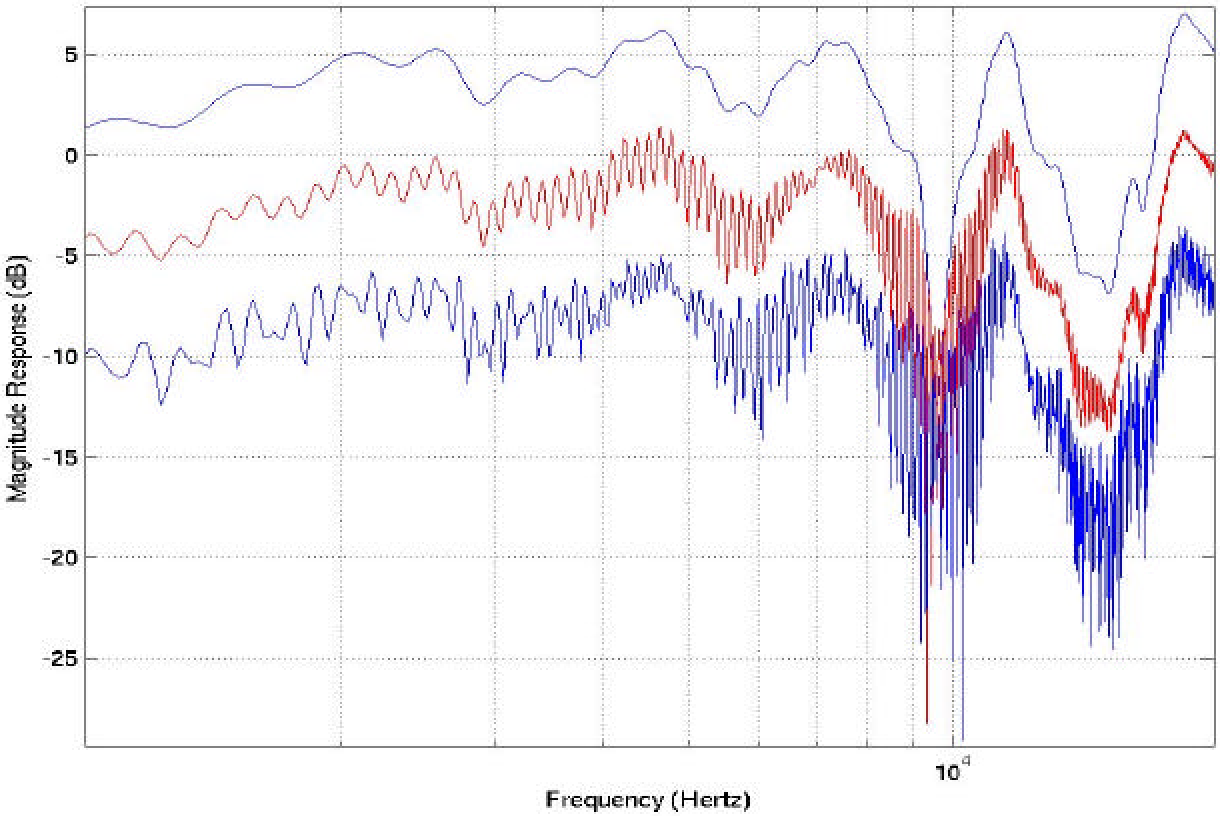


Outputs

- prediction of acoustic measures
- comparison between model and real room

- quality of simulation (e.g., externalization)
- task performance
- perceptual measure (e.g., SI, localization)

Simple approximations of rooms and smearing of HRTF magnitude detail

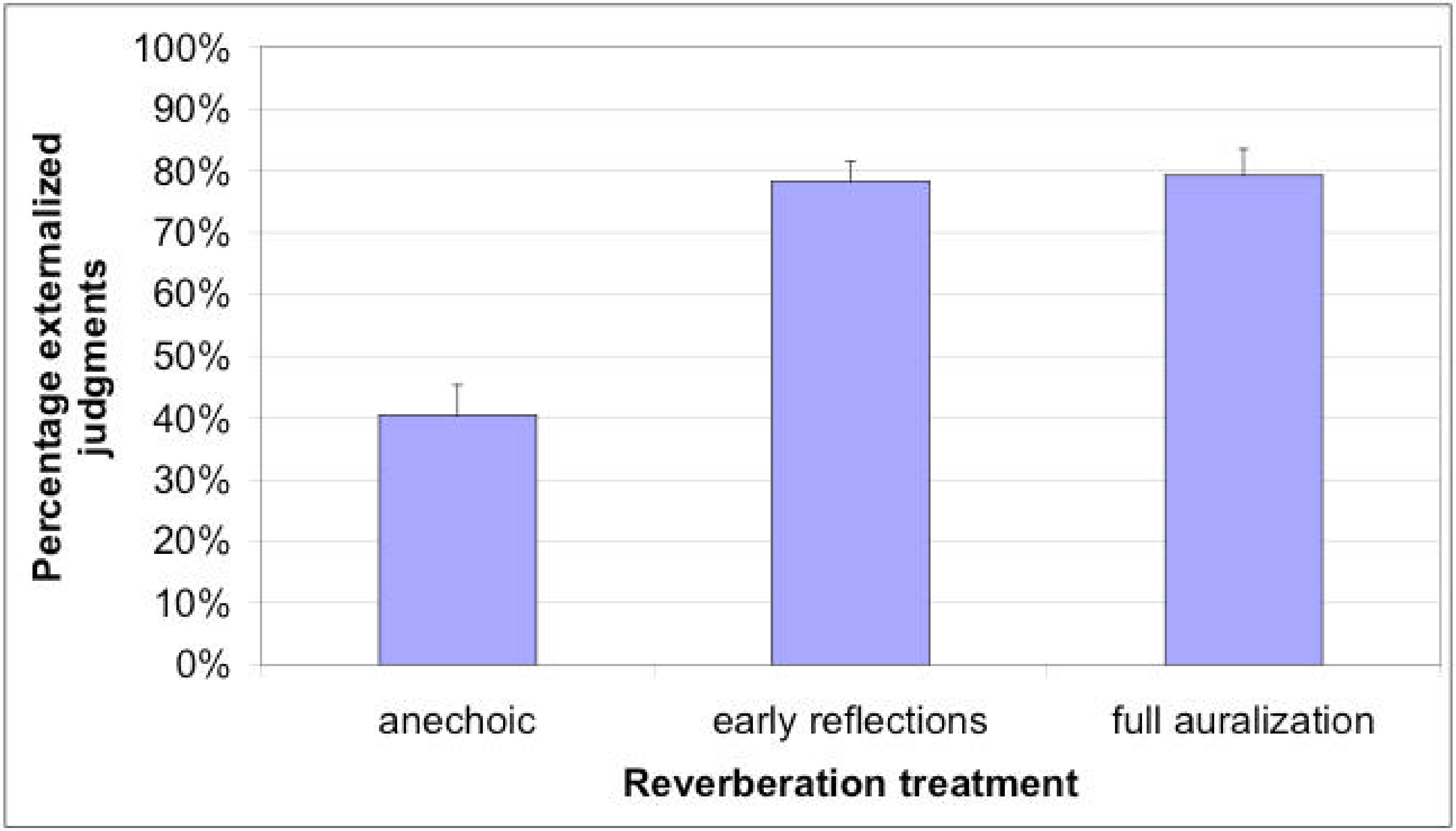


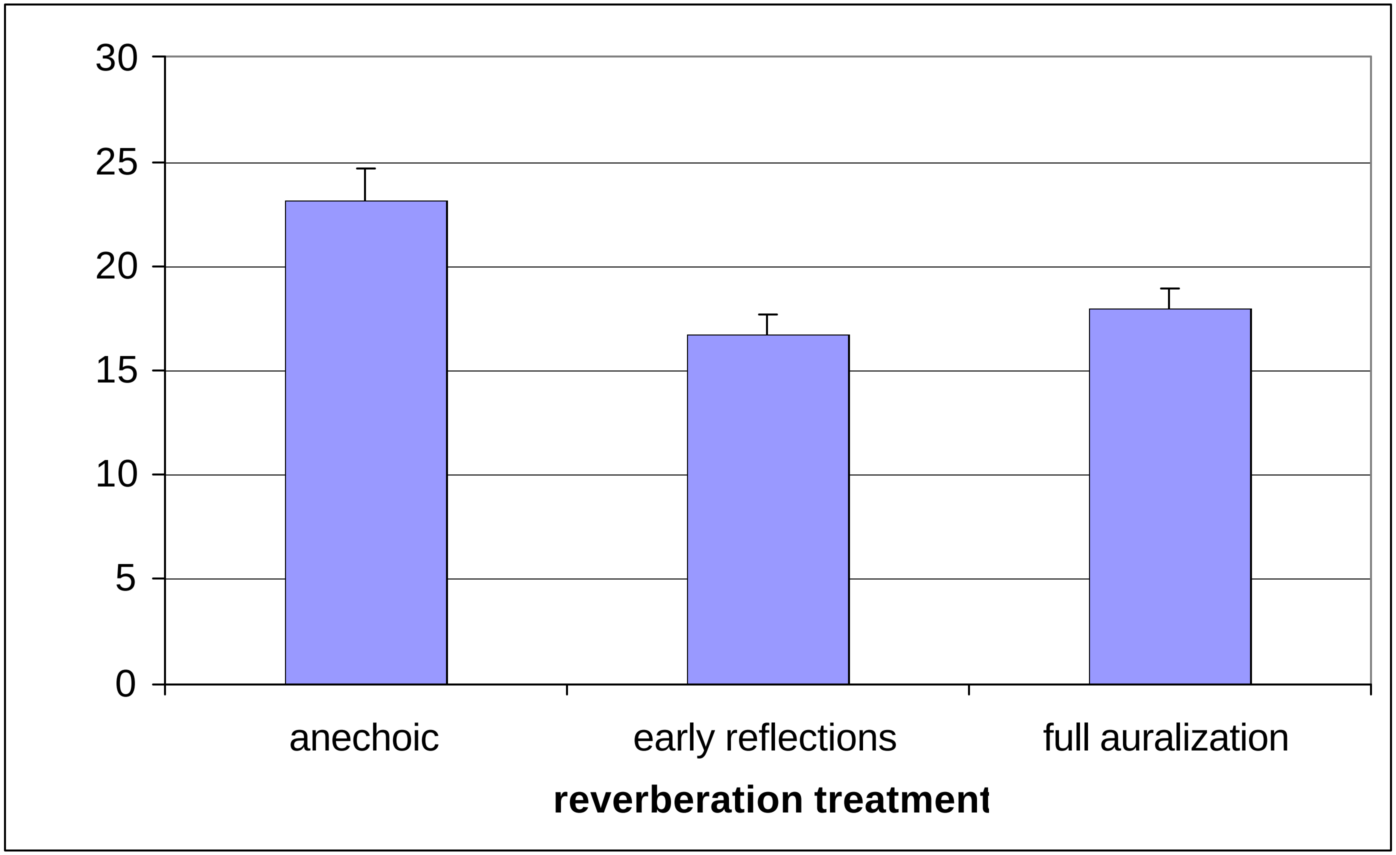
Direct sound path

direct + 1 coincident reflection

direct + 6 reflections (image model)

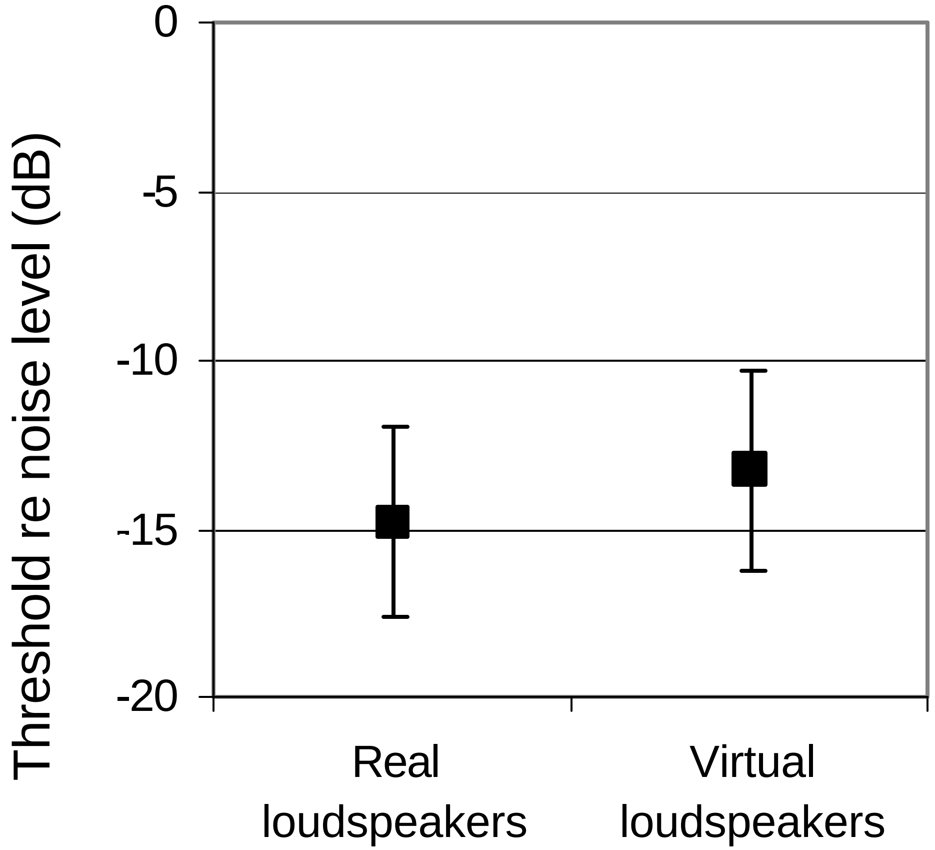
Sound source externalization can be enabled using a limited number of early reflections




30
25
20
15
10
5
0
anechoic
early reflections
full auralization
reverberation treatment

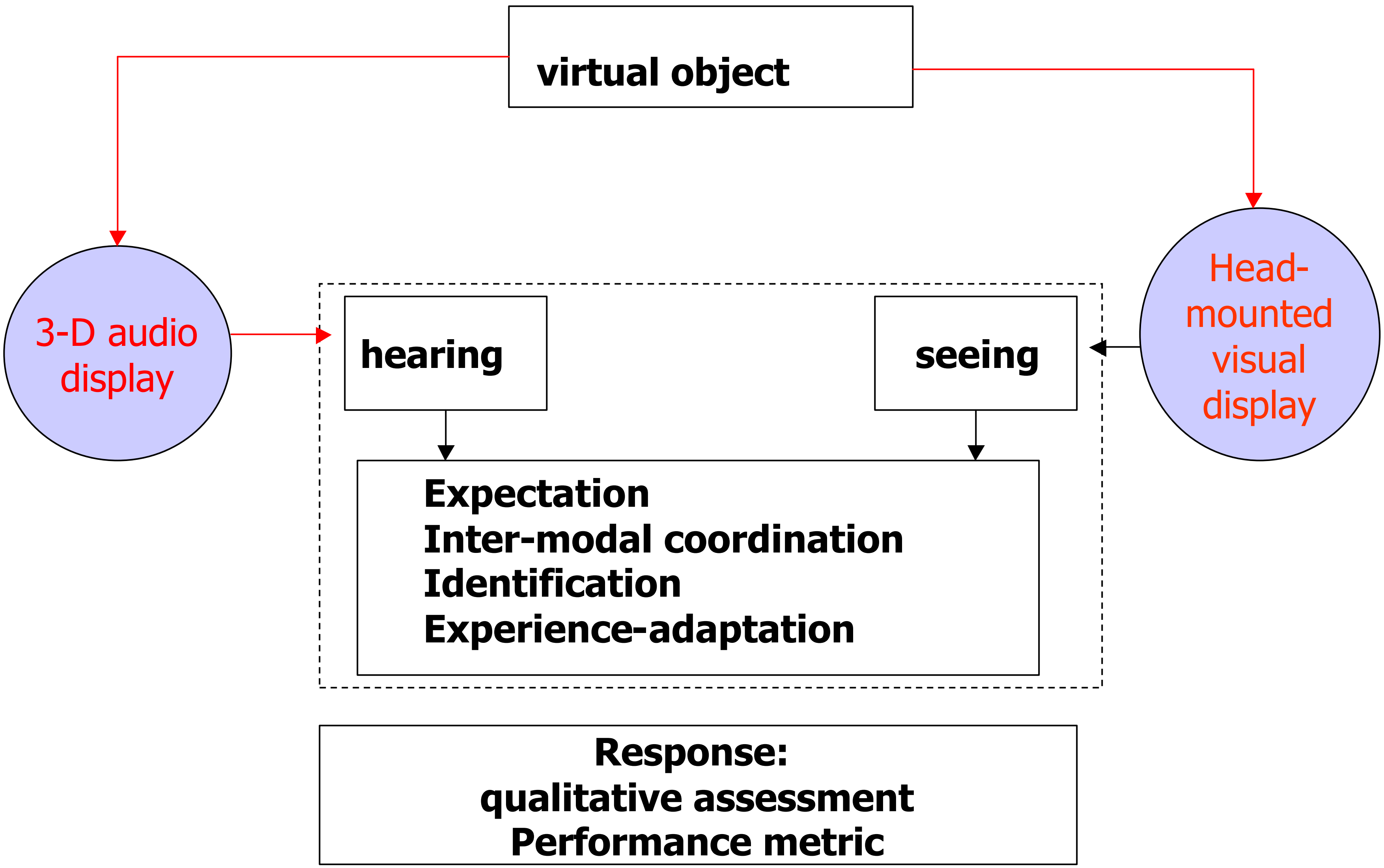
Some perceptual measures can be shown to be equivalent between real and auralized rooms

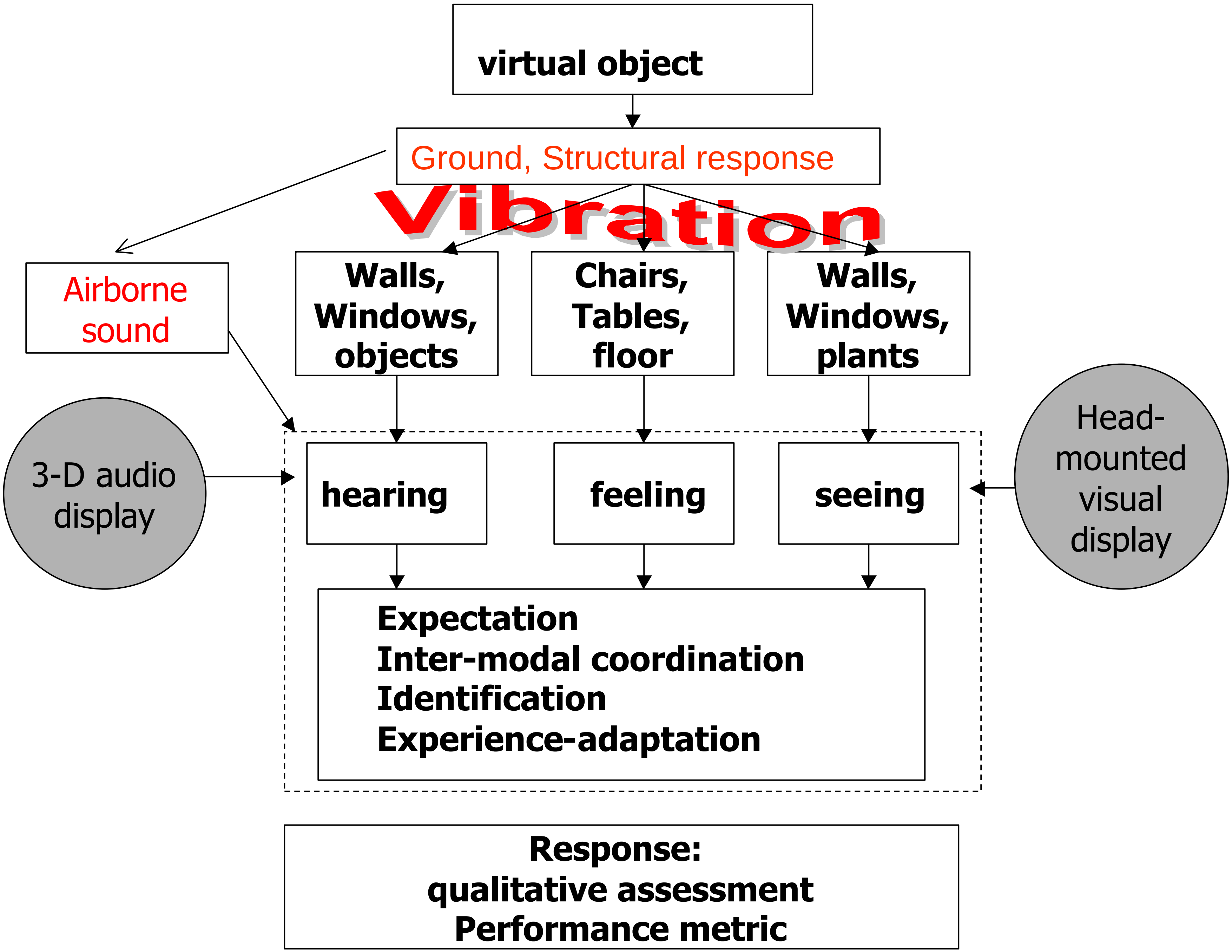
example: flight deck alarm



Begault, “Spatially modulated audio alerts” ICAD 2003

Given cross-modality effects, multimodal displays are also important for “accurate” auralization




virtual object
Ground, Structural response
Vibration
Airborne sound
Walls, Windows, objects
Chairs, Tables, floor
Walls, Windows, plants
3-D audio display
hearing
feeling
seeing
Head-mounted visual display
Expectation
Inter-modal coordination
Identification
Experience-adaptation
Response:
qualitative assessment
Performance metric

Summary

- Veridical representation of acoustical features depends on accuracy of input data base
  - -*This may limit use for specific applications*
- Threshold data can enable computationally-intensive rendering engines
  - -*Depends on specific room and application*
- Simple auralizations can provide useful perceptual cues for use in experiments and auditory displays
  - -*Externalization particularly useful*
  - *-Studies verify match for specific perceptual measures between simulated and real rooms*

Application-driven design of Auralization Systems

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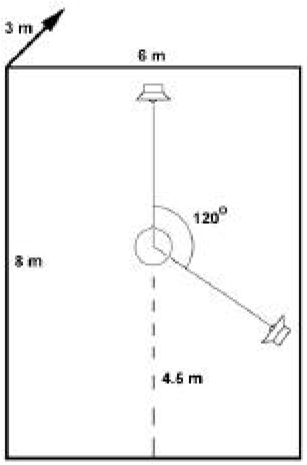
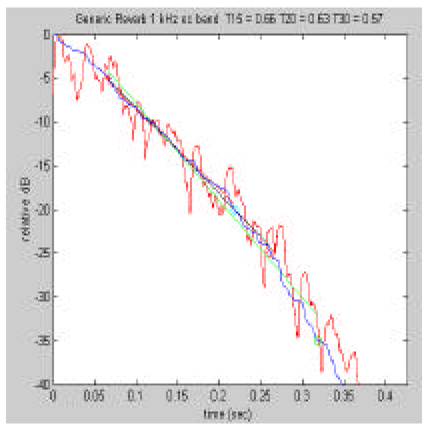
http://human-factors.arc.nasa.gov/ihh/spatial/





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