Spatial Acoustics Library for MATLAB (SALM): A Computational Toolkit for Spatial Audio Processing

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** SALM is available at: https://github.com/cesardsalvador/SpatialAcousticsLibraryMATLAB

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2. Structure of SALM
3. Geometry
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1. Introduction

- Spatial audio is central to VR, AR, binaural rendering and room acoustics
- Existing MATLAB/Octave libraries for spatial audio:
  - SOFiA (B. Bernschutz *et al.*, 2011)
  - SFS Toolbox (H. Wierstorf and S. Spors, 2012)
  - Aktools (F. Brinkmann and S. Weinzierl, 2017)
  - ITA Toolbox (M. Berzborn *et al.*, 2017)
- Motivation of SALM
  - Each library brings unique strengths and has advanced spatial audio functions
  - SALM complements these efforts by offering a unified framework
  - Emphasis on transform-domain tools and reproducible workflows

1. Introduction – Existing MATLAB/Octave Libraries for Spatial Audio

Library	Description	Spatial-domain processing	Transforms	Transform-domain processing
SOFiA Toolbox [13]	MATLAB library to analyze a sound field captured with a microphone array.	Microphone-array handling; spherical-grid management; visualization of measured fields.	Spherical Fourier transforms.	Modal beamforming; plane-wave decomposition; radial filtering for rigid/open spheres.
Sound field synthesis toolbox [14]	MATLAB/Octave library to synthesize a sound field in an area surrounded by a loudspeaker array.	Driving functions for loudspeaker-array rendering; convolution engine.	Spherical Fourier transforms.	Modal driving filters; binaural rendering from arrays.
AKtools [15]	MATLAB library for the capture, processing, analysis and rendering of spatial audio signals.	Signal generation; convolution engine; room analysis.	Spherical Fourier transforms.	Radial filtering; binaural rendering.
ITA Toolbox [16]	MATLAB toolbox for acoustic measurements and audio signal processing.	Impulse-response measurement; convolution engines for auralization.	Spherical Fourier transforms.	Radial filtering; modal analysis.
SALM	MATLAB library for sound field analysis, processing and synthesis with circular and spherical arrays.	Diffuse-field filter for equalization; free-field translation operator for acoustic centering.	Circular, semicircular, and spherical Fourier transforms.	Distance-varying filter (DVF) for radial extrapolation; boundary-matching filter (BMF) for array signal conversion.

2. Structure of SALM

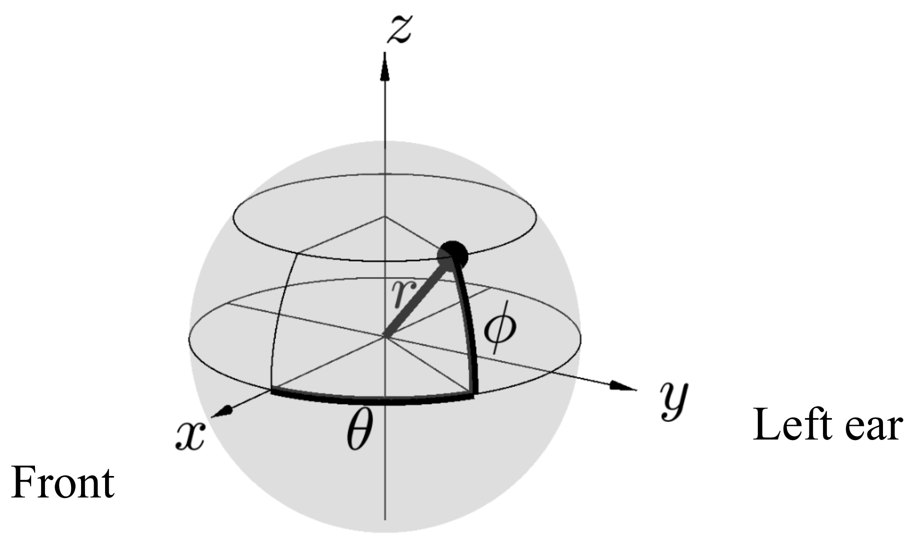
Special functions
`pnm`: associated Legendre polynomial
`ynm`: spherical harmonics
`besseljsph`: spherical Bessel function
`besselysph`: spherical Neumann function
`besselhsph`: spherical Hankel function
`dbesseljsph`: derivative of `besseljsph`
`dbesselhsph`: derivative of `besselhsph`

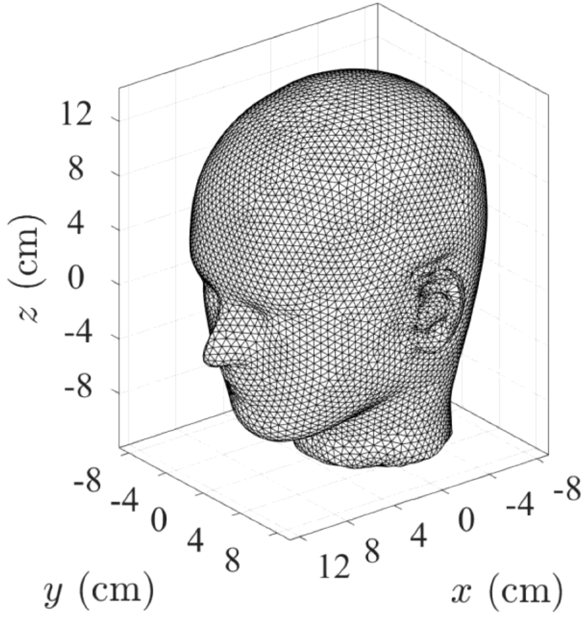
Spatial-domain functions
`diffuseFieldFilter`
`freeFieldtranslationOperator`

Transform functions
`cft`: circular Fourier transform
`icft`: inverse circular Fourier transform
`flt`: semicircular Fourier-Legendre transform
`iflt`: inverse semicircular Fourier-Legendre transform
`sft`: spherical Fourier transform
`isft`: inverse spherical Fourier transform
`pinvreg`: Tikhonov regularized pseudoinverse

Transform-domain functions
`dvf`: distance-varying filters
`bmf`: boundary-matching filters

3. Geometry





$$\vec{r} = (r, \theta, \phi)$$

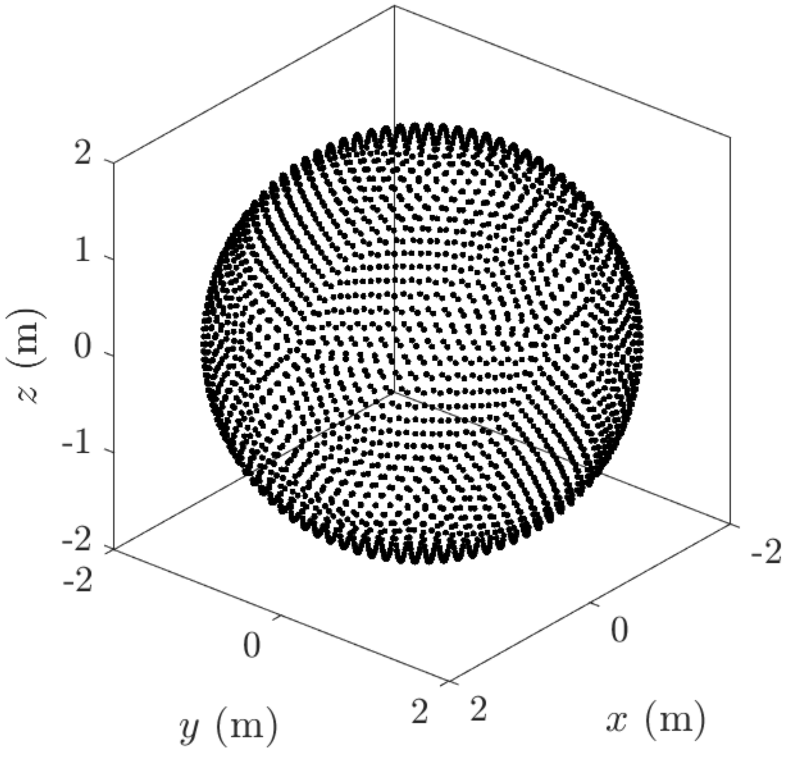
radial distance r

azimuthal angle $\theta \in [-\pi, \pi]$

elevation angle $\phi \in [-\frac{\pi}{2}, \frac{\pi}{2}]$

Interaural-polar spherical coordinates are also supported. See `cart2isph` and `isph2cart`.

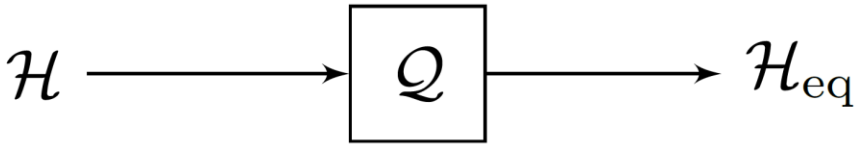
4. Use Case 1: Diffuse-Field Equalization of HRTFs



$$\{\mathcal{H}_\ell\}, \ell = 1, \ldots, L,$$

where L is the number of directions.

`diffuseFieldFilter`

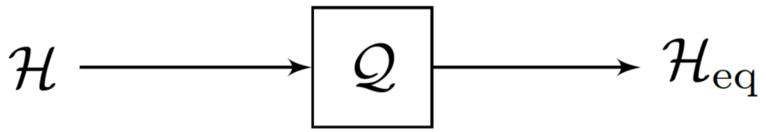


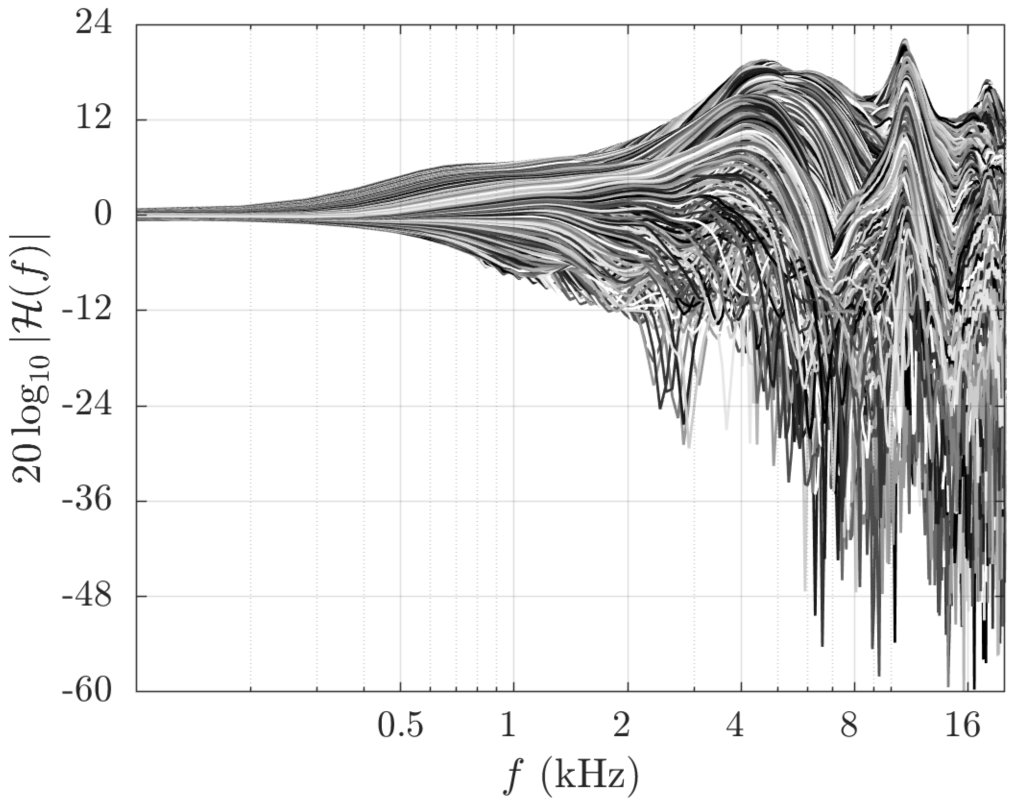
$$\mathcal{Q} = |\mathcal{Q}| \exp(j\angle\mathcal{Q})$$

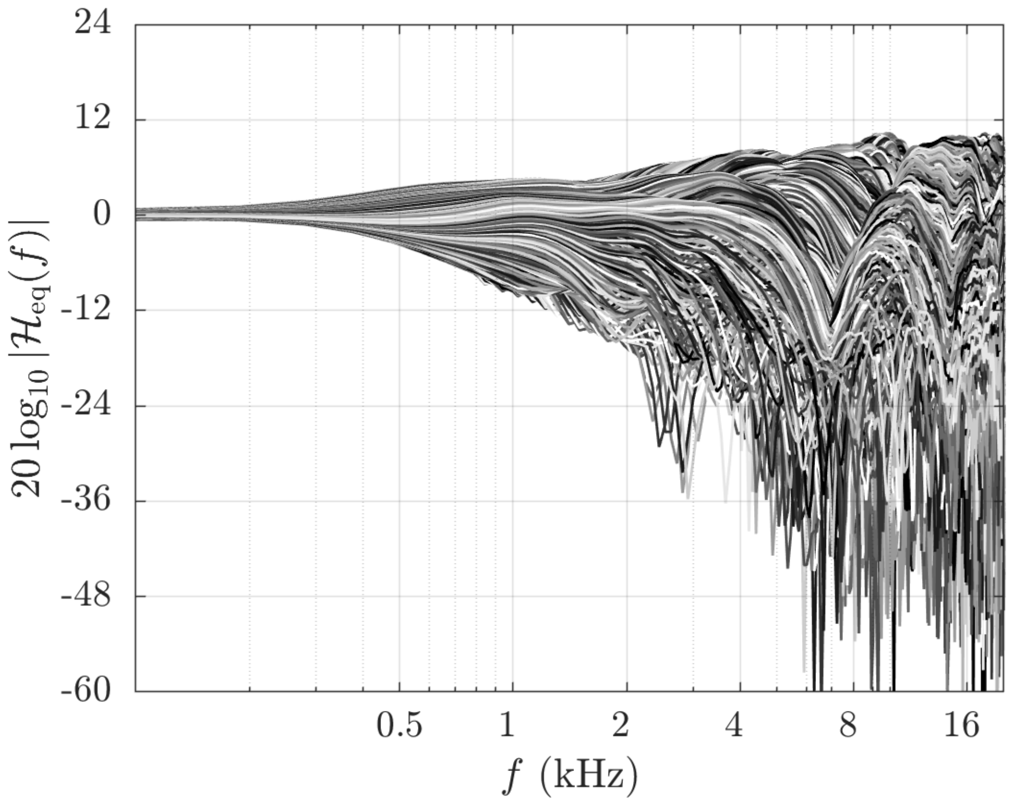
$$|\mathcal{Q}| = \left(\frac{1}{\sum_{\ell=1}^{L} |\mathcal{H}_\ell|^2 w_\ell} \right)^{\frac{1}{2}}$$

$$\angle\mathcal{Q} = \begin{cases} 0, & \text{zero-phase,} \\ \mathfrak{H}\left\{\log \frac{1}{|\mathcal{Q}|}\right\}, & \text{minimum-phase,} \end{cases}$$

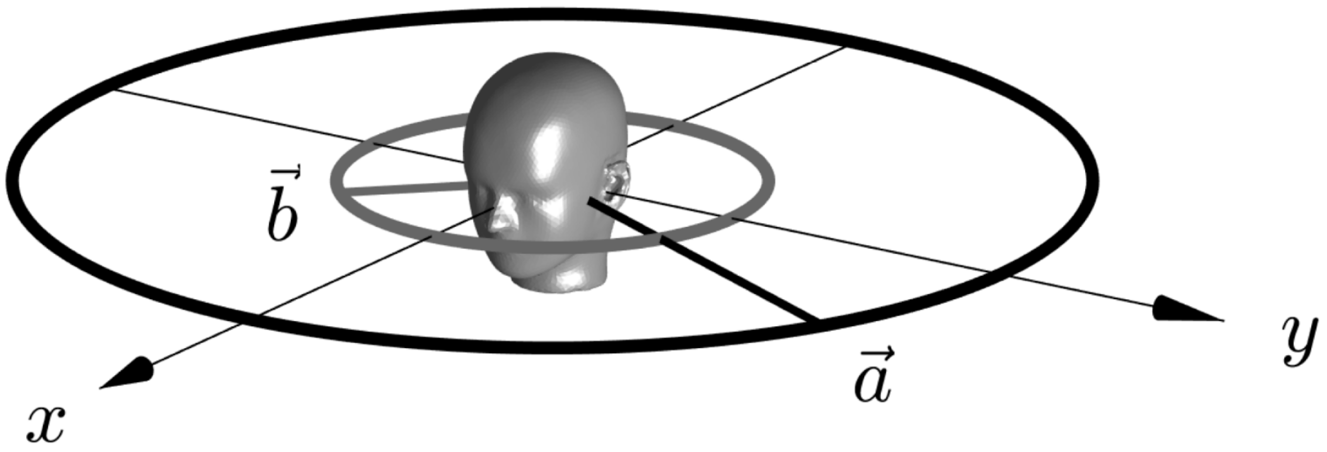
4. Use Case 1: Diffuse-Field Equalization of HRTFs



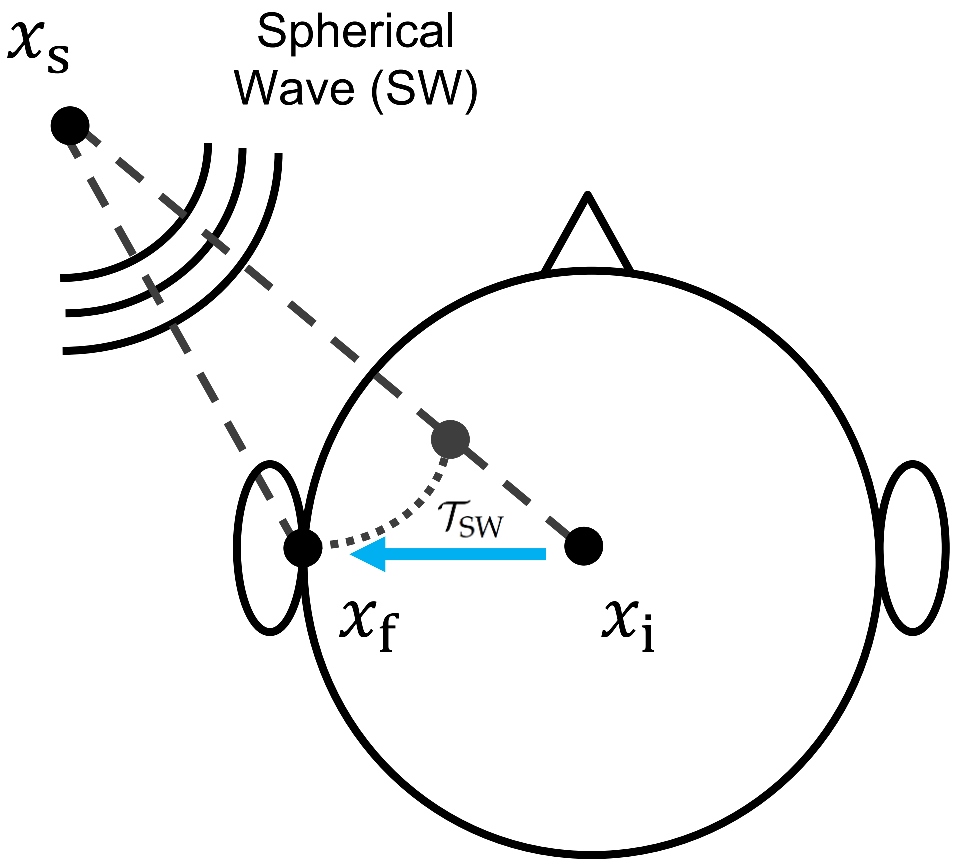




5. Use Case 2: Distance Extrapolation of HRTFs – Geometry



5. Use Case 2: Distance Extrapolation of HRTFs – Ear Centering



`freeFieldTranslationOperator`

$$\mathcal{T}_{\mathrm{SW}}(\vec{x}_\mathrm{i}, \vec{x}_\mathrm{f}) = \frac{\|\vec{x}_\mathrm{s} - \vec{x}_\mathrm{i}\|}{\|\vec{x}_\mathrm{s} - \vec{x}_\mathrm{f}\|} e^{jk(\|\vec{x}_\mathrm{s}-\vec{x}_\mathrm{i}\| - \|\vec{x}_\mathrm{s}-\vec{x}_\mathrm{f}\|)}$$

5. Use Case 2: Distance Extrapolation of HRTFs

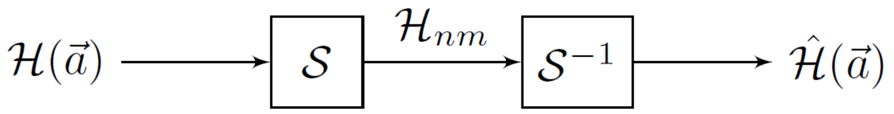


Fig. 5. Interpolation along direction using the direct and inverse spherical Fourier transforms $\mathcal{S}$ and $\mathcal{S}^{-1}$.

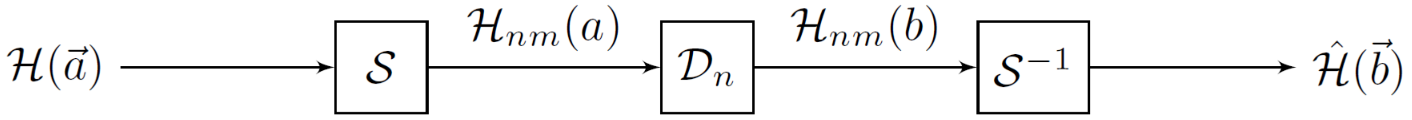


Fig. 6. Extrapolation along distance using the distance-varying filter $\mathcal{D}_n$.

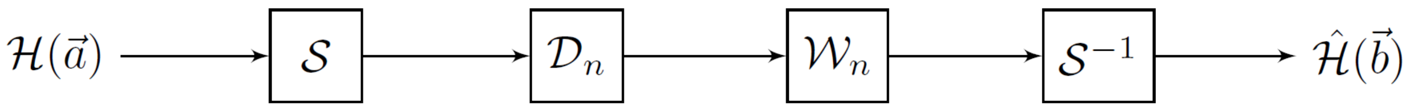


Fig. 7. Regularized extrapolation along distance using the window $\mathcal{W}_n$.

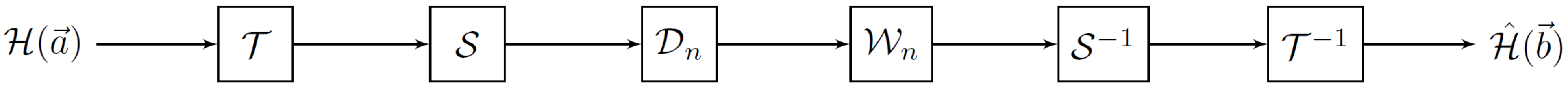
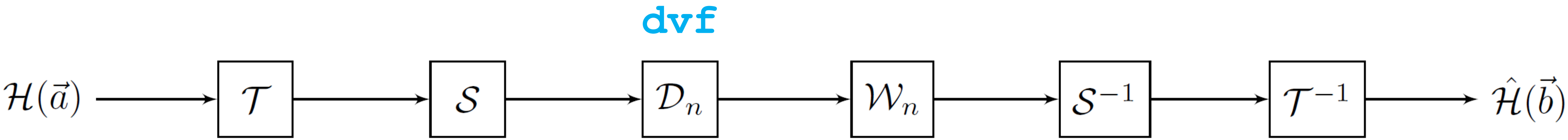
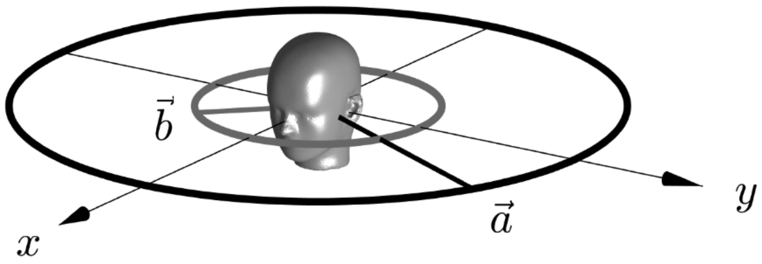


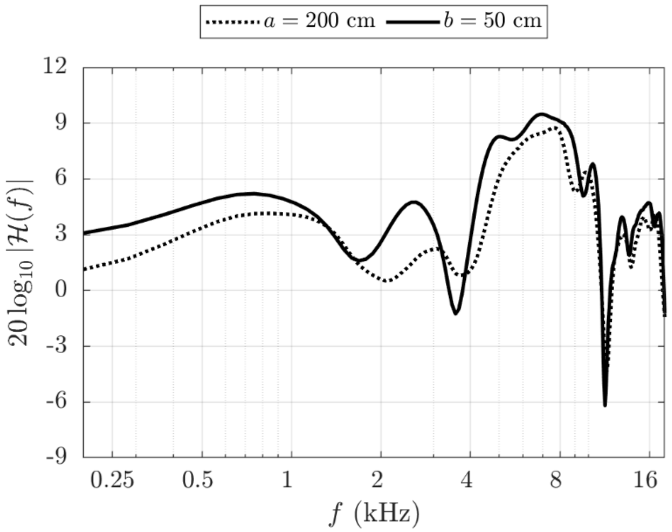
Fig. 8. Ear-centered extrapolation along distance using the direct and inverse translators $\mathcal{T}$ and $\mathcal{T}^{-1}$.

5. Use Case 2: Distance Extrapolation of HRTFs



$$\mathcal{D}_n(a,b) = \frac{h_n^{(i)}(kb)}{h_n^{(i)}(ka)} \qquad \mathcal{W}_n = \frac{1}{1 + \left(\frac{b}{a}\right)^2 |\mathcal{D}_n|^2}$$





6. Future Work

- Benchmarking with large SOFA datasets
- Extending to:
  - Circular DVFs
  - Spatial metrics for clarity
- Python port for wider accessibility: SALP
- Integration with perceptual testing frameworks

7. Conclusion

- SALM = unified, extensible, reproducible
- Bridges theory ↔ applications
- Applications: binaural rendering and architectural acoustics
- Contribution to the 3D audio research community

Thanks!

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