Universität Rostock
Traditio et Innovatio

Localization Properties of Data-based Binaural Synthesis including Translatory Head-Movements

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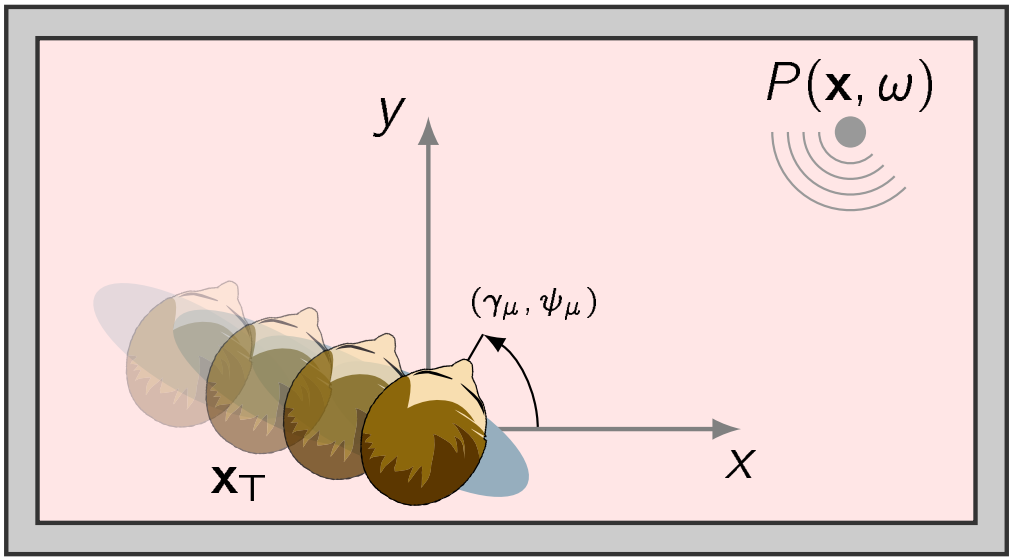
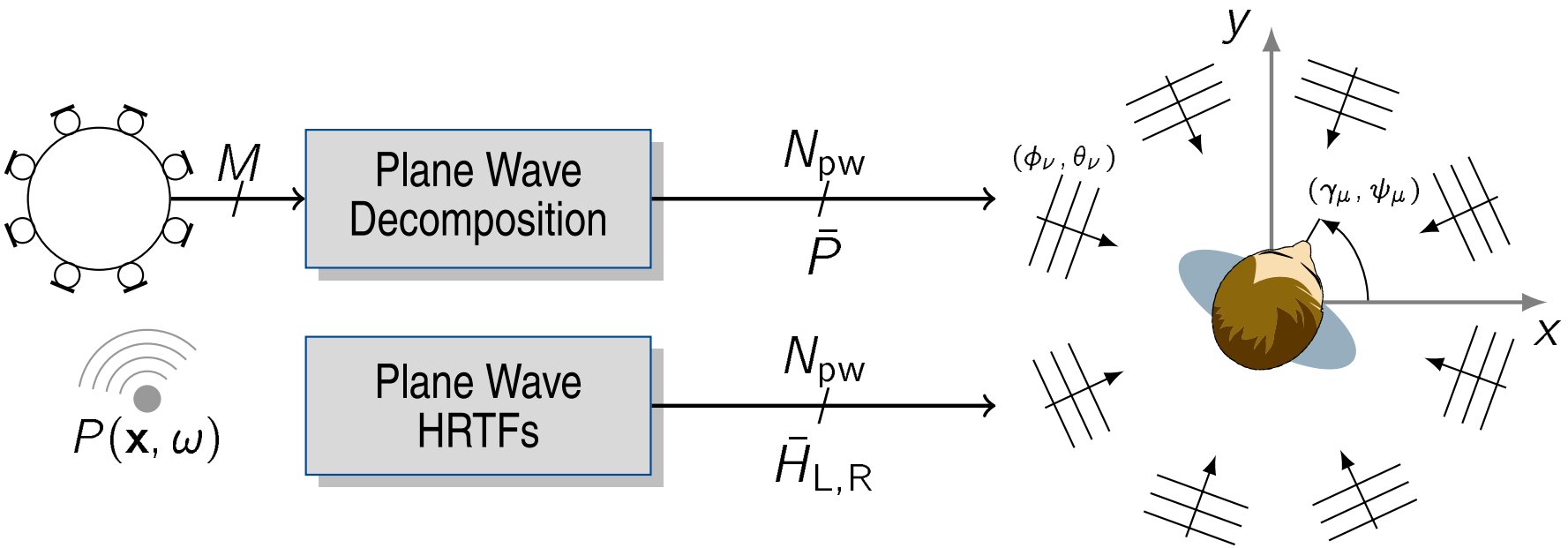
Binaural Synthesis using BRTFs



$$B_{\mathrm{L,R}}(\gamma_\mu, \psi_\mu, \mathbf{x}_\mathrm{T}, \omega)$$

- (densely) sampled grid of BRTFs for head rotations and translatory shifts required
- no efficient realization for multiple sound sources or diffuse sound fields
- individual BRTFs require repetition of measurements for each room

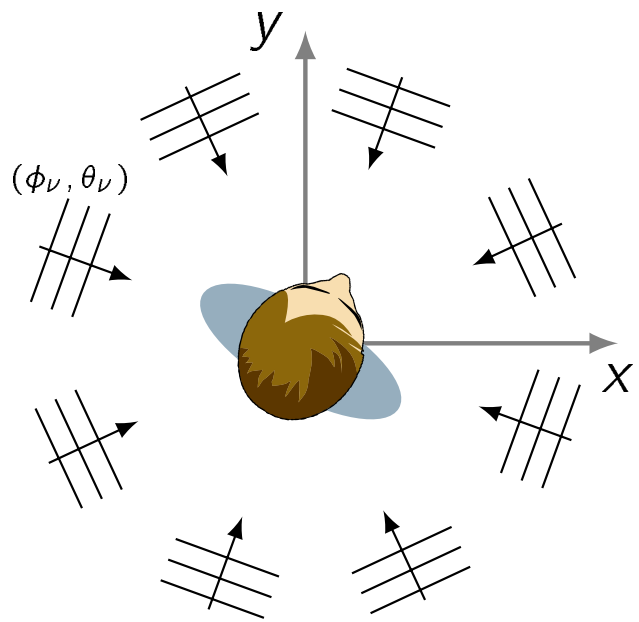
Binaural Synthesis using MRTFs and Plane Wave HRTFs



$$B_{\mathrm{L,R}}(\gamma_\mu, \psi_\mu, \mathbf{x}_\mathrm{T}, \omega) = \sum_{j=1}^{N_{\mathrm{pw}}} \bar{H}_{\mathrm{L,R}}(\phi_\nu - \gamma_\mu, \theta_\nu - \psi_\mu, \omega)\, \bar{P}(\phi_\nu, \theta_\nu, \mathbf{x}_\mathrm{T}, \omega)$$

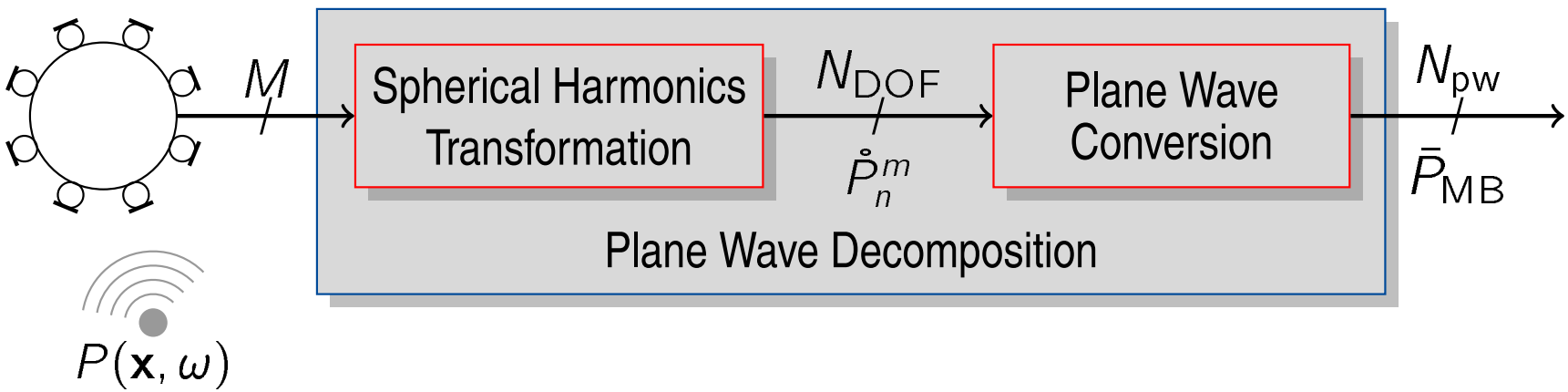
+ separation of HRTF data capture and sound field acquisition
+ translatory shift can be considered by phase shift of plane waves

Translatory Head-Movements



$$\bar{P}(\phi_\nu, \theta_\nu, \mathbf{x}_\mathsf{T}, \omega) = \bar{P}(\phi_\nu, \theta_\nu, \mathbf{0}, \omega) \exp\left(+\mathrm{i}\frac{\omega}{c}\mathbf{n}_\nu^\mathsf{T}\mathbf{x}_\mathsf{T}\right)$$

Modal Beamformer

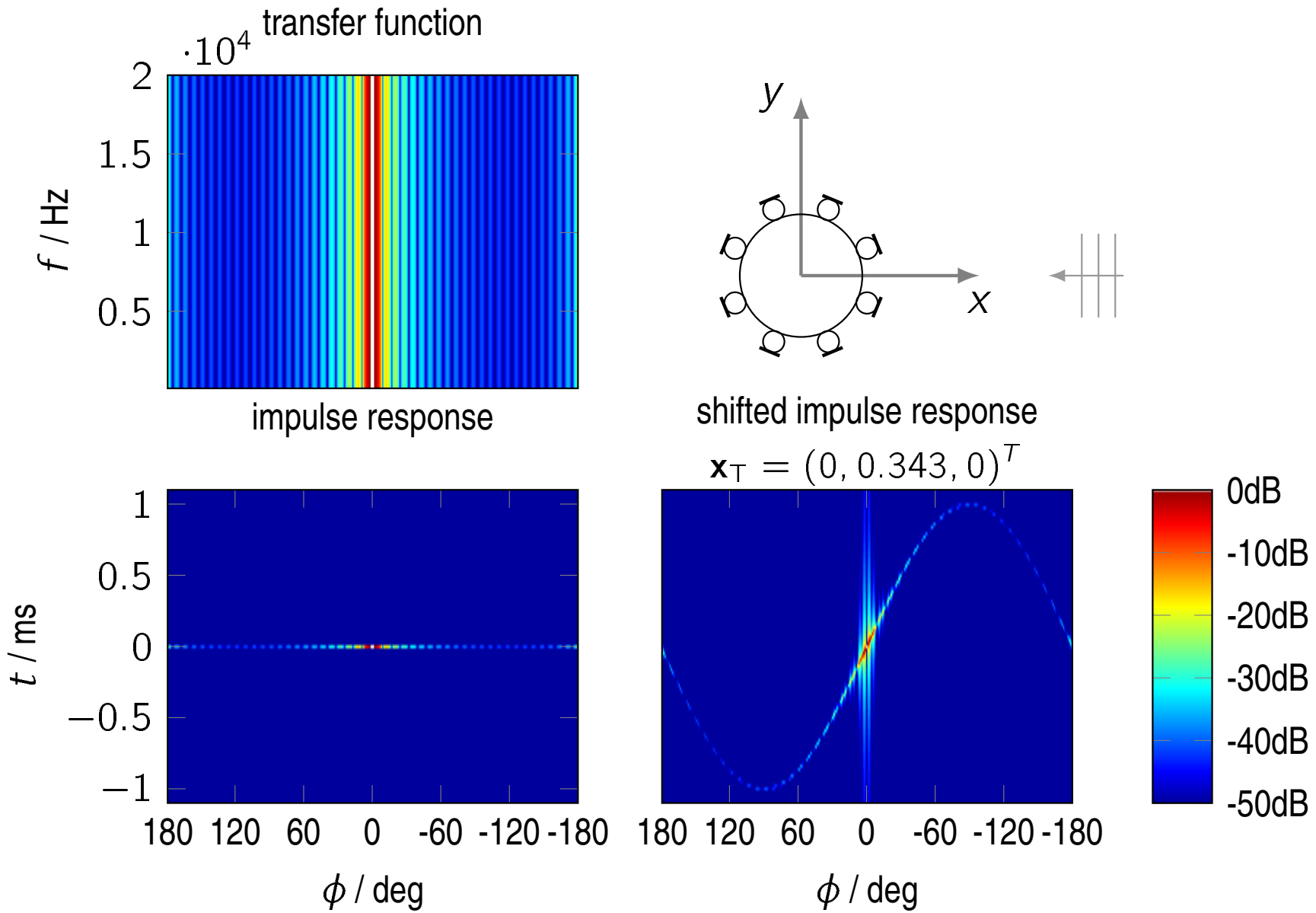


$$\bar{P}_{\mathrm{MB}}(\phi_\nu, \theta_\nu, \mathbf{0}, \omega) \propto \sum_{n=0}^{N_{\mathrm{SHT}}} \sum_{m=-n}^{n} \frac{\mathring{P}_n^m(\omega)}{d_n(\omega)} Y_n^m(\phi_\nu, \theta_\nu)$$

$$\bar{P}_{\mathrm{MB}}(\phi_\nu, \theta_\nu, \mathbf{x}_{\mathrm{T}}, \omega) = \bar{P}_{\mathrm{MB}}(\phi_\nu, \theta_\nu, \mathbf{0}, \omega) \exp\left(+\mathrm{i}\frac{\omega}{c}\mathbf{n}_\nu^{\mathrm{T}}\mathbf{x}_{\mathrm{T}}\right)$$

- Degrees of Freedom (3D): $N_{\mathrm{DOF}} = (N_{\mathrm{SHT}} + 1)^2$
- Radial Filter $d_n(\omega)$ depends on array geometry

Modal Beamformer - Example



Experiments

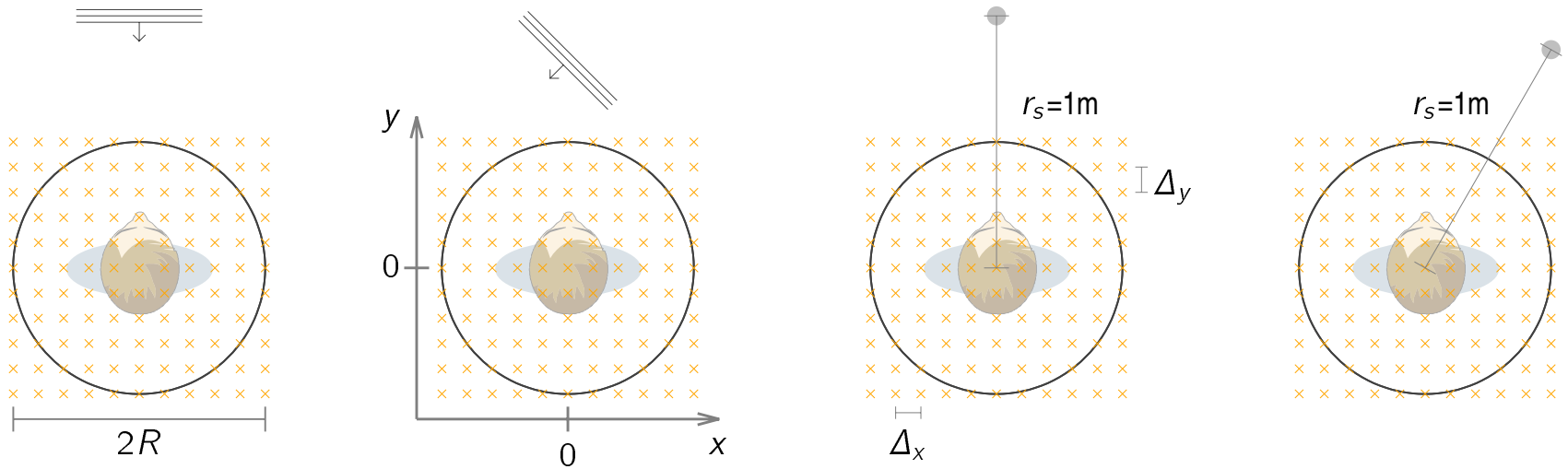
Influence of Parameters on Human Localization

- amount of translatory movement $\mathbf{x}_\mathrm{T}$
- modal resolution/order of Spherical Harmonics Transform N_SHT
- number of plane waves/resolution of HRTF dataset N_PW
- captured sound field $P(\mathbf{x}, \omega)$

Estimation of Localization

- horizontal localization binaural model [Dietz2011]
- a-priori training of ITD-Azimuth Lookup Table [Wierstorf2013]
- TU BERLIN QU KEMAR HRTFs, 3m distance, 1° azimuth resolution

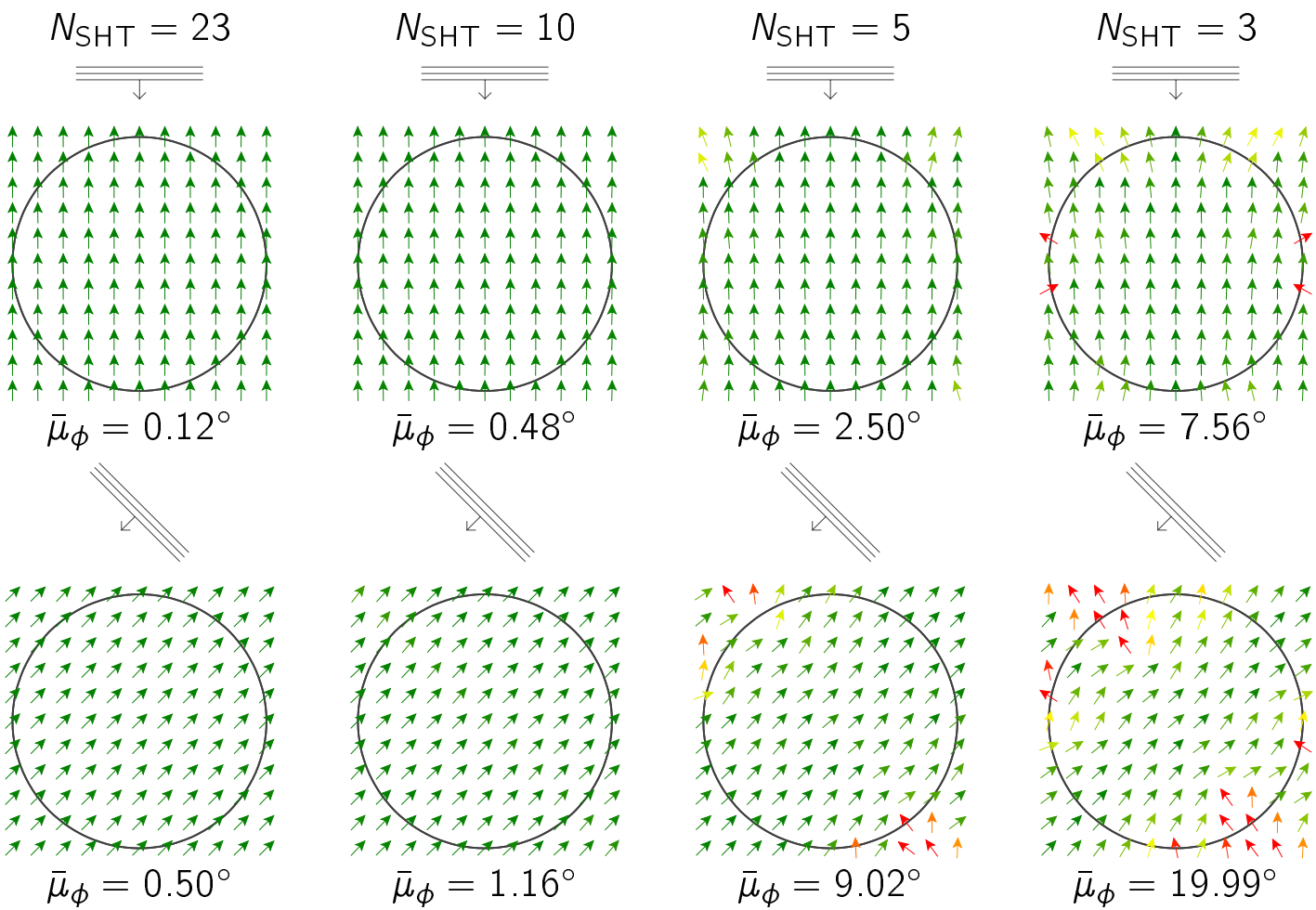
Simulation Setup



- translatory movement $\mathbf{x}_\top$ on regular grid ($\Delta_x = \Delta_y = 0.1\text{m}$)
- listener is looking into positive y ($\gamma = 90°, \psi = 0°$)
- **limitation to horizontal plane** ($\theta = 0$) $\rightarrow N_{\text{DOF}} = 2N_{\text{SHT}} + 1$
- continuous ($M \rightarrow \infty$) array of radius $R = 0.5\text{m}$
- "open sphere"-array $d_n(\omega) = 4\pi \mathrm{i}^n j_n\left(\frac{\omega}{c}R\right)$

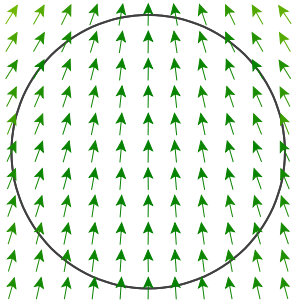
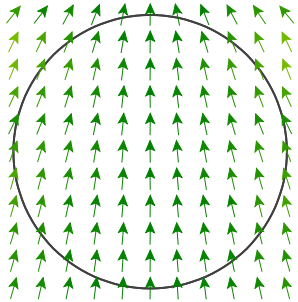
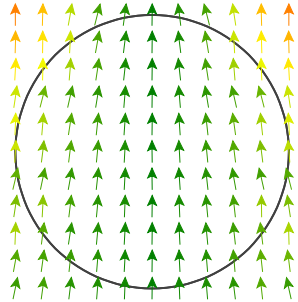
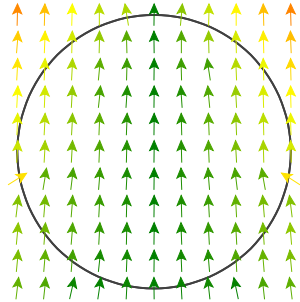
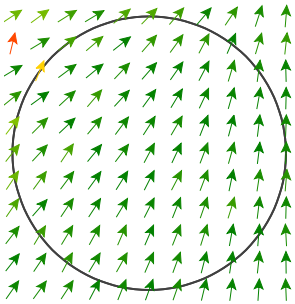
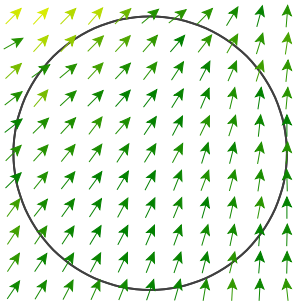
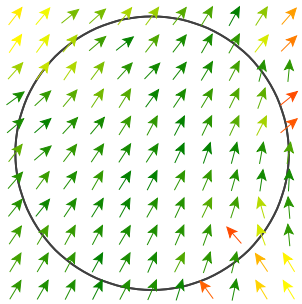
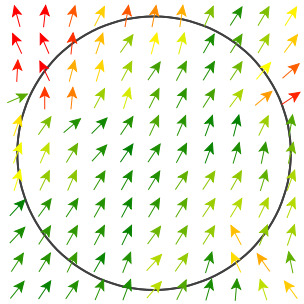
Results - Modal Resolution I

$N_{\mathrm{PW}} = 360$



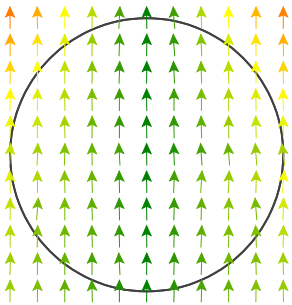
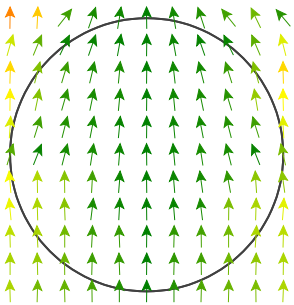
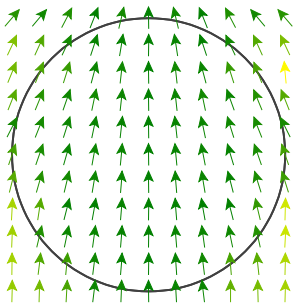
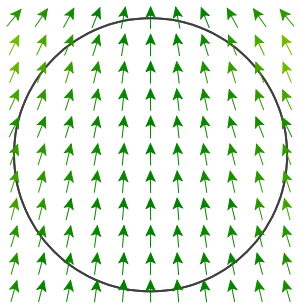
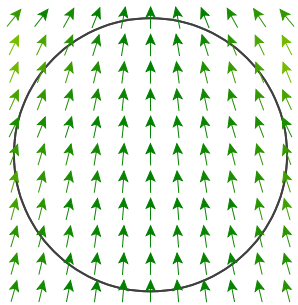
Results - Modal Resolution II

$N_{\mathrm{PW}} = 360$

$N_{\mathrm{SHT}} = 23$	$N_{\mathrm{SHT}} = 10$	$N_{\mathrm{SHT}} = 5$	$N_{\mathrm{SHT}} = 3$
			
$\bar{\mu}_\phi = 2.19°$	$\bar{\mu}_\phi = 3.03°$	$\bar{\mu}_\phi = 10.95°$	$\bar{\mu}_\phi = 13.75°$
			
$\bar{\mu}_\phi = 3.63°$	$\bar{\mu}_\phi = 3.94°$	$\bar{\mu}_\phi = 10.22°$	$\bar{\mu}_\phi = 19.26°$

Results - HRTF Resolution

$N_{\mathrm{SHT}} = 10 \rightarrow N_{\mathrm{DOF}} = 21$

$N_{\mathrm{PW}} = 10$	$N_{\mathrm{PW}} = 15$	$N_{\mathrm{PW}} = 18$	$N_{\mathrm{PW}} = 24$	$N_{\mathrm{PW}} = 360$
				
$\bar{\mu}_\phi = 16.04°$	$\bar{\mu}_\phi = 9.81°$	$\bar{\mu}_\phi = 4.60°$	$\bar{\mu}_\phi = 2.90°$	$\bar{\mu}_\phi = 3.03°$

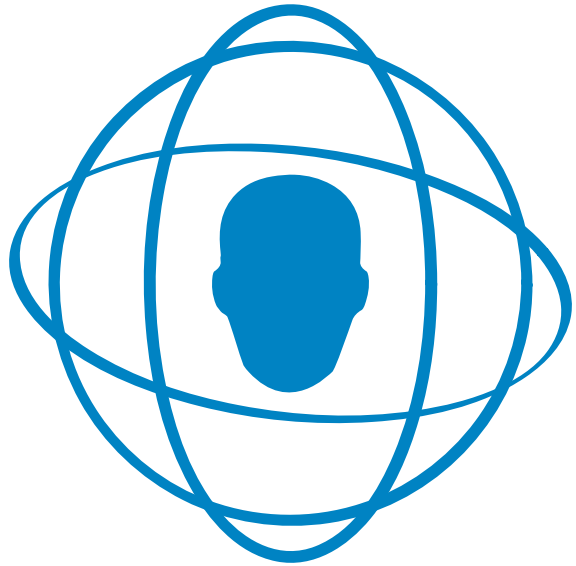
Discussion & Summary

Localization Properties

- localization more accurate for sources in look direction
- reduction of modal resolution leads to degradation of localization
- shifting orthogonal to the source direction increases localization error
- interpolation in plane wave domain does not lead to significant benefit

Future Work

- validation of localization model for binaural synthesis
- coloration and distance perception



TWO!EARS

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Binaural Model