

Virtual Soundscapes & the AudioDome

**Center for Brain and Mind: Methods Lunch
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AudioDome



Acknowledgements



Derek
Quinlan



Karsten
Babin



Ewan
Macpherson



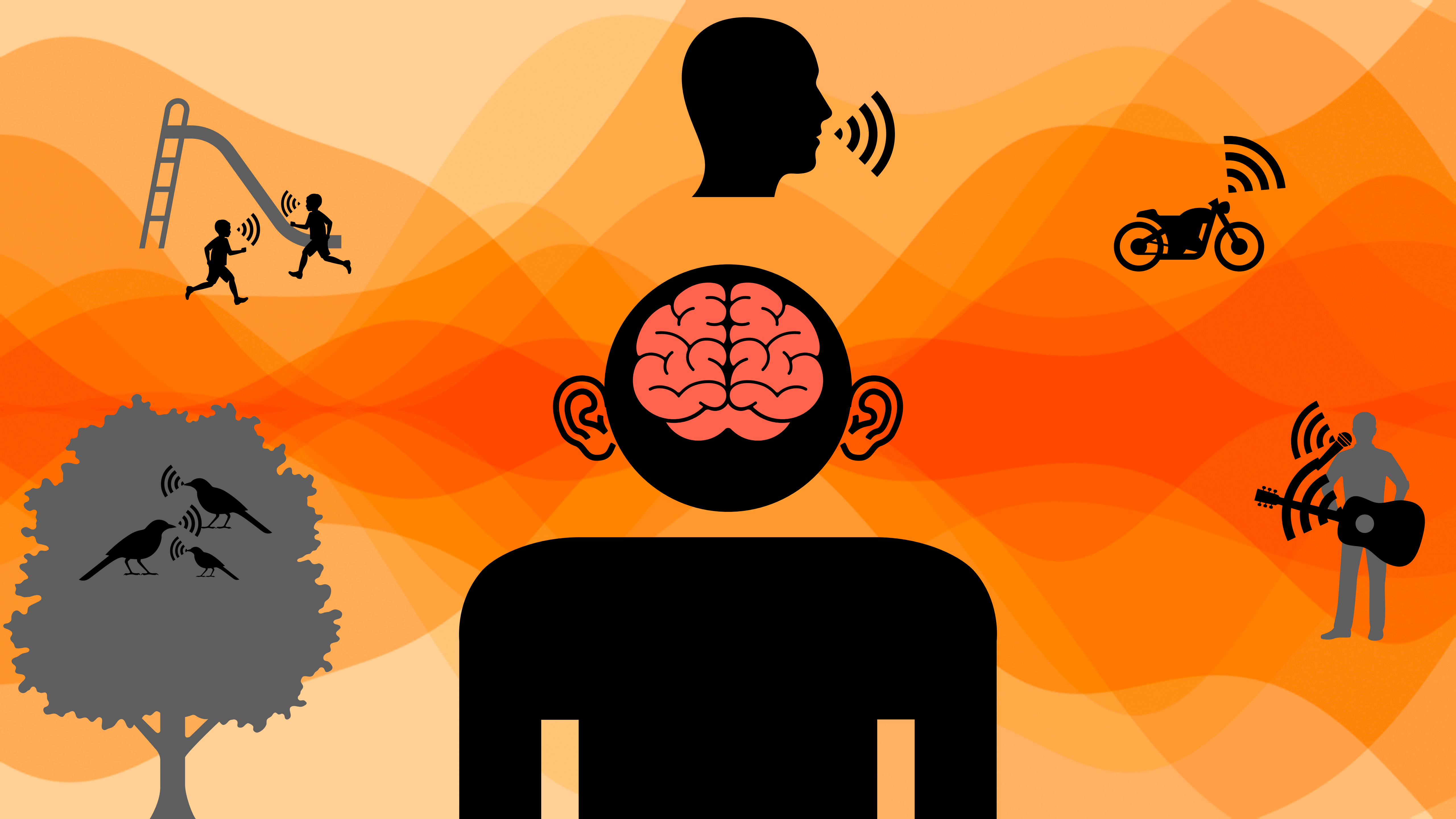
Ingrid
Johnsrude



Bruno
Mesquita

Part I: Fundamentals

What exactly is the AudioDome capable of?

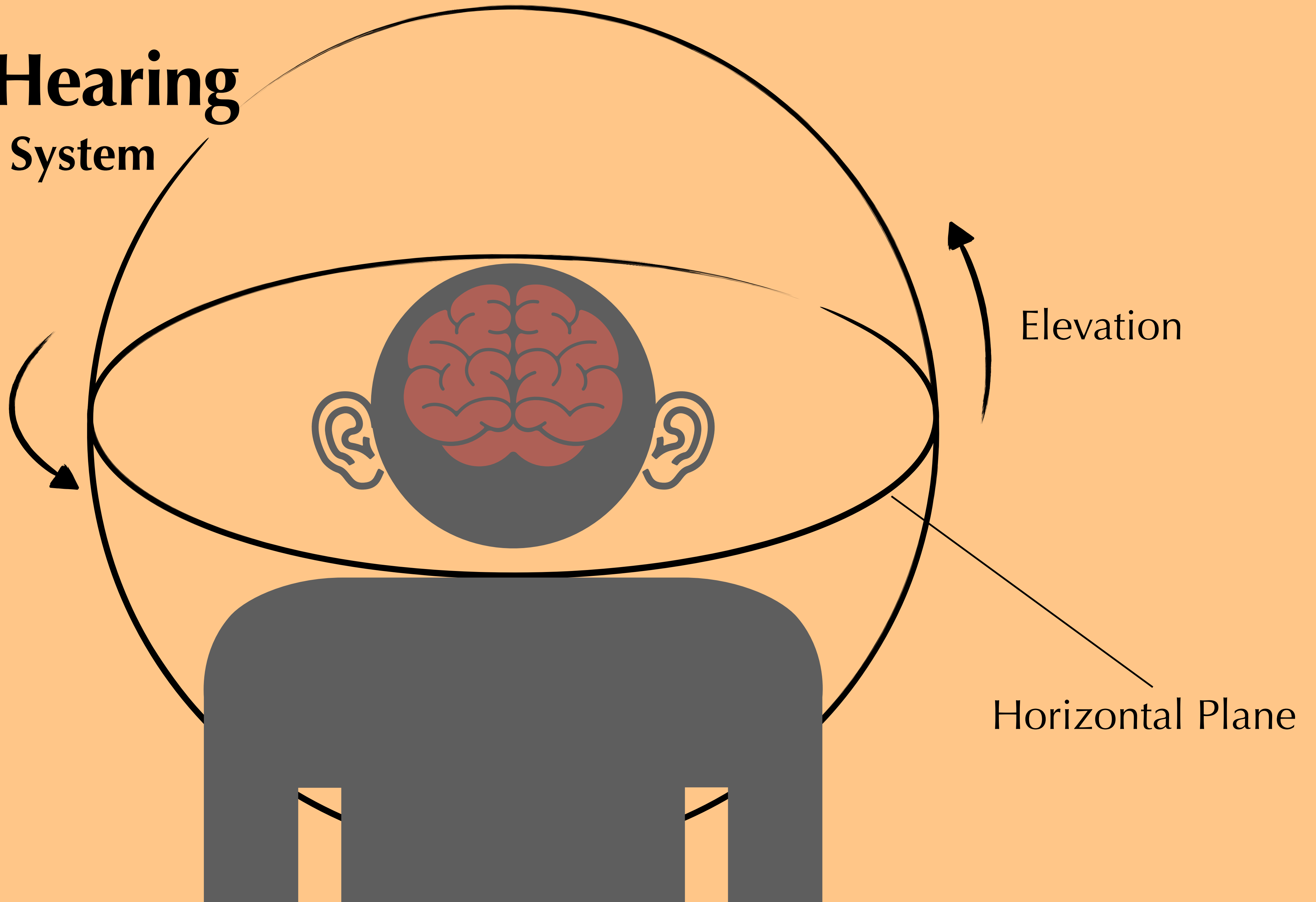


Spatial Hearing Coordinate System

Azimuth

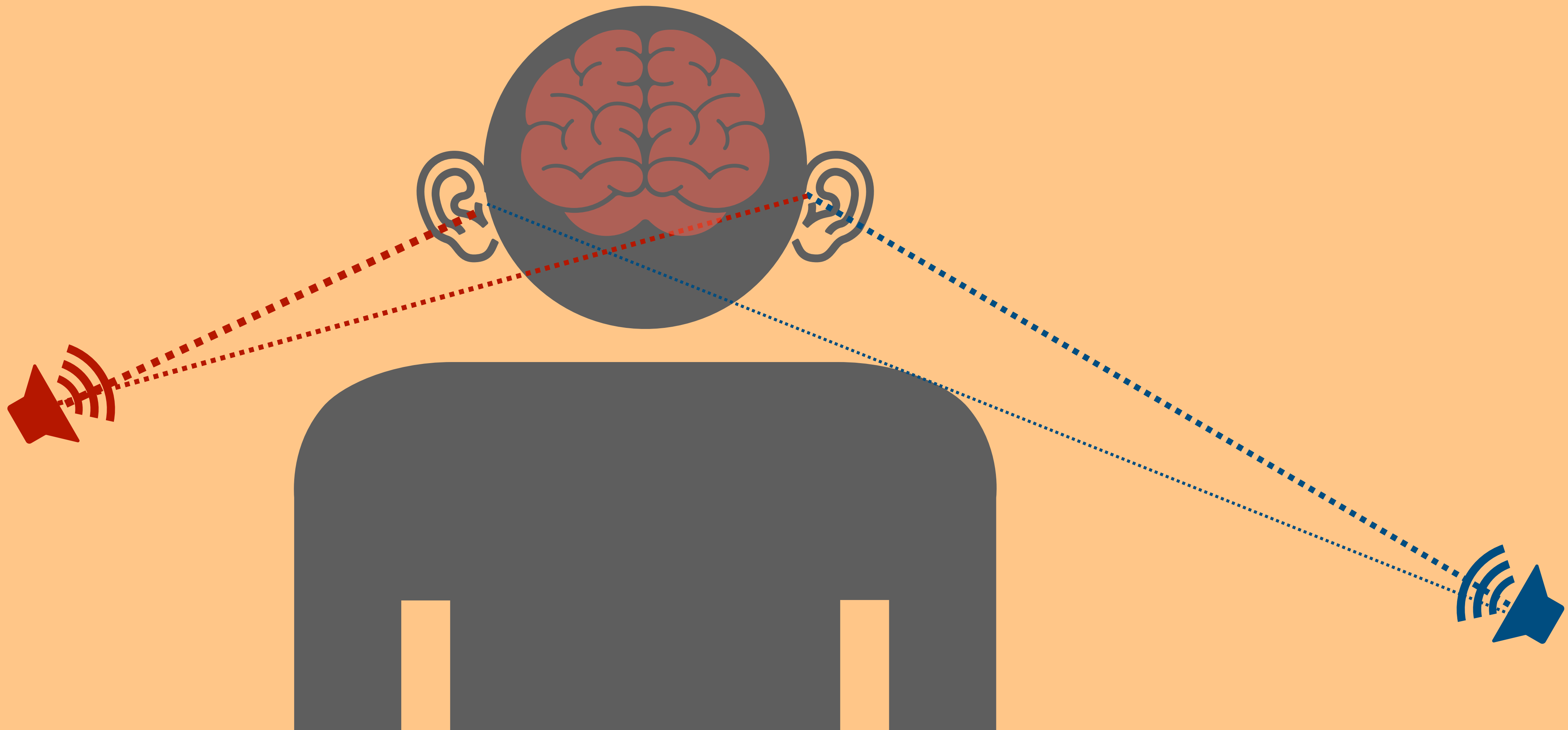
Elevation

Horizontal Plane



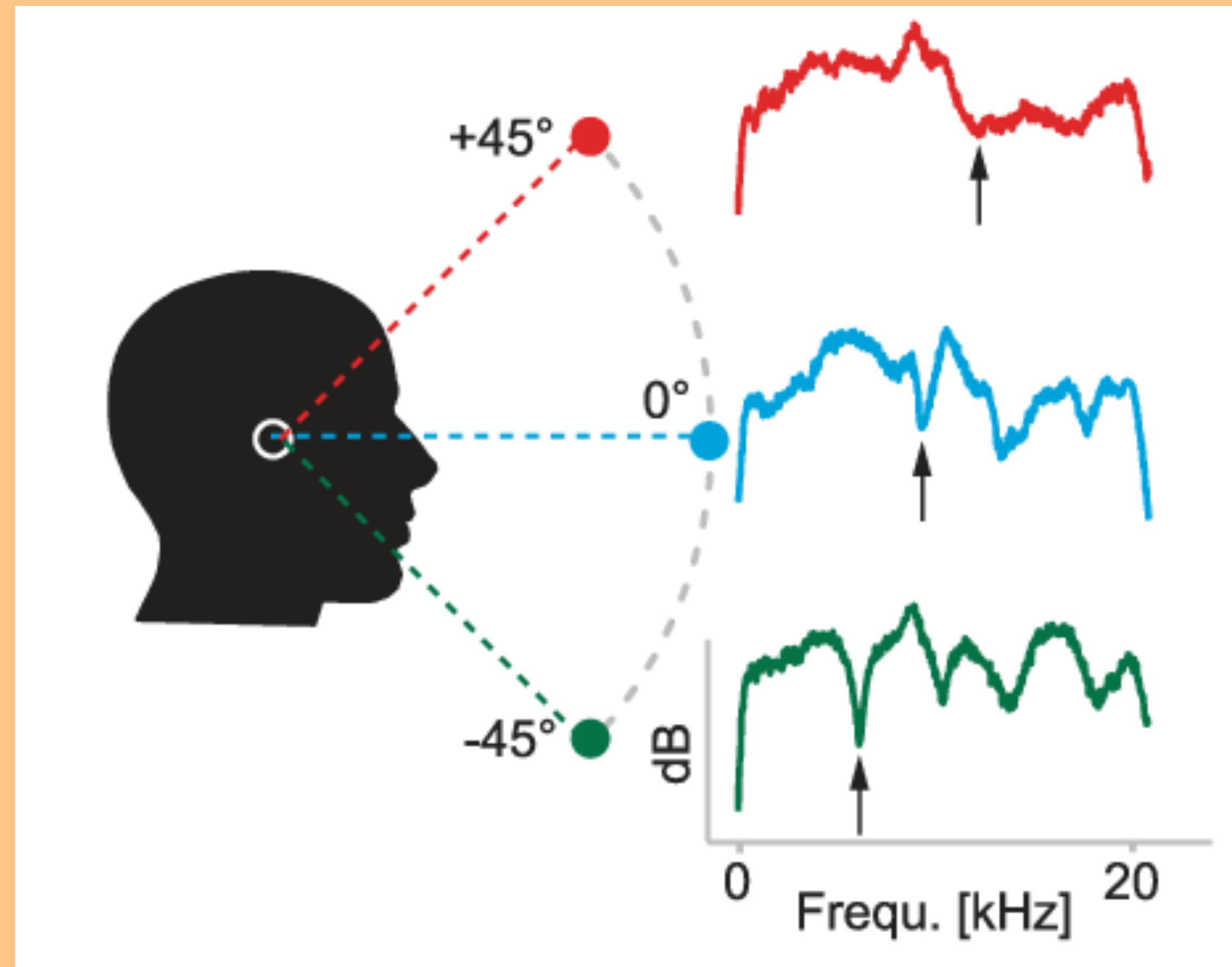
Spatial Hearing

Binaural Localization Cues



Spatial Hearing

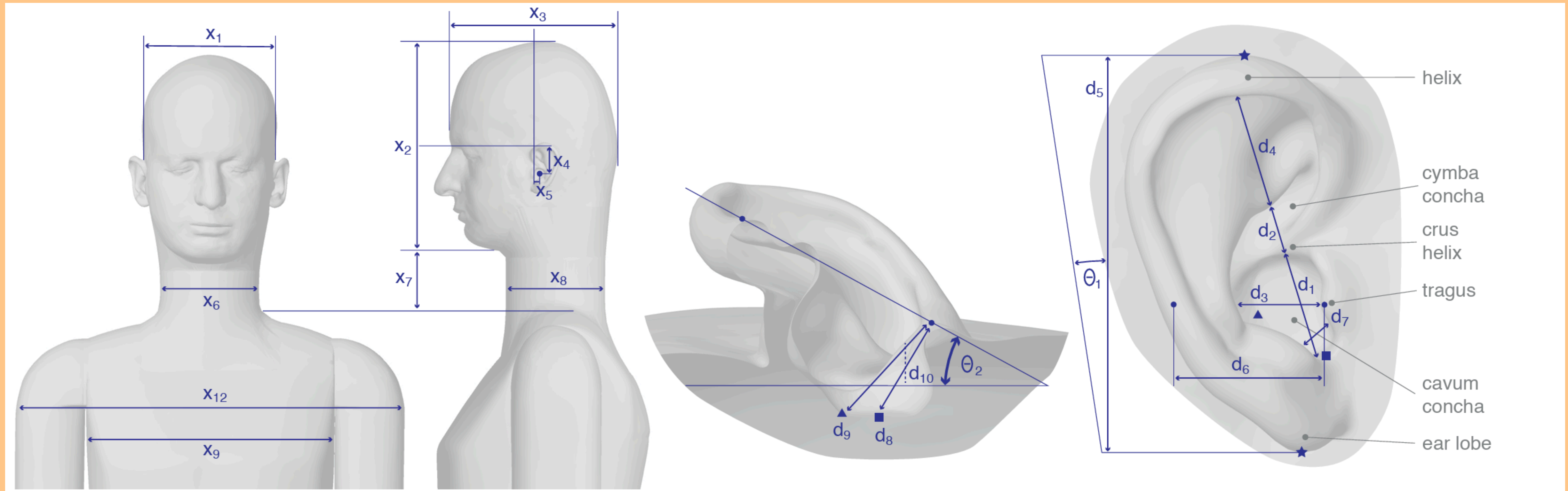
Spectral Cues



(Grothe et al., 2010)

Spatial Hearing

Head-Related Transfer Function and Individual Variability

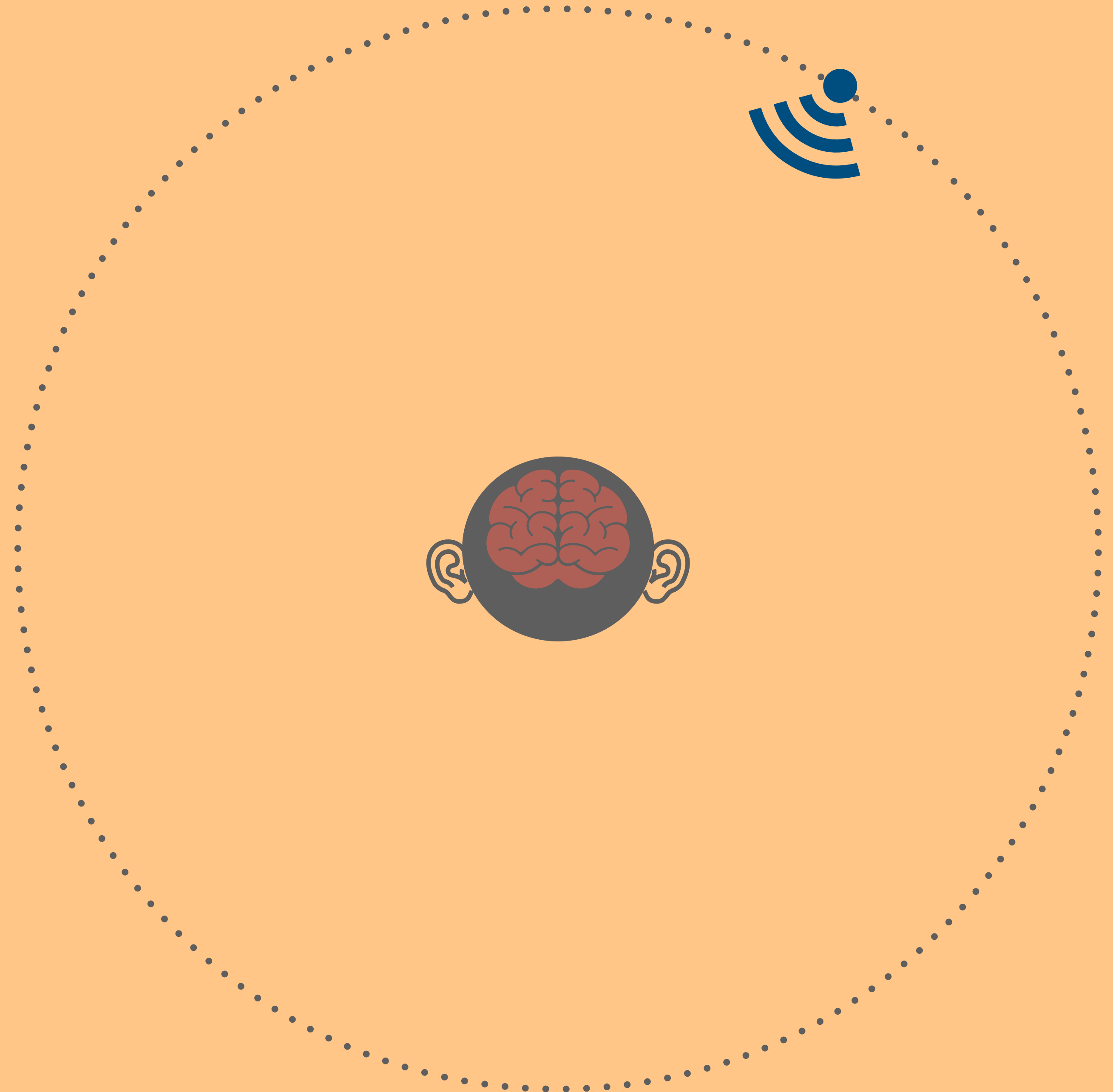


(Fabian et al., 2019)

Virtual Auditory Environments

A Virtual Sound Source

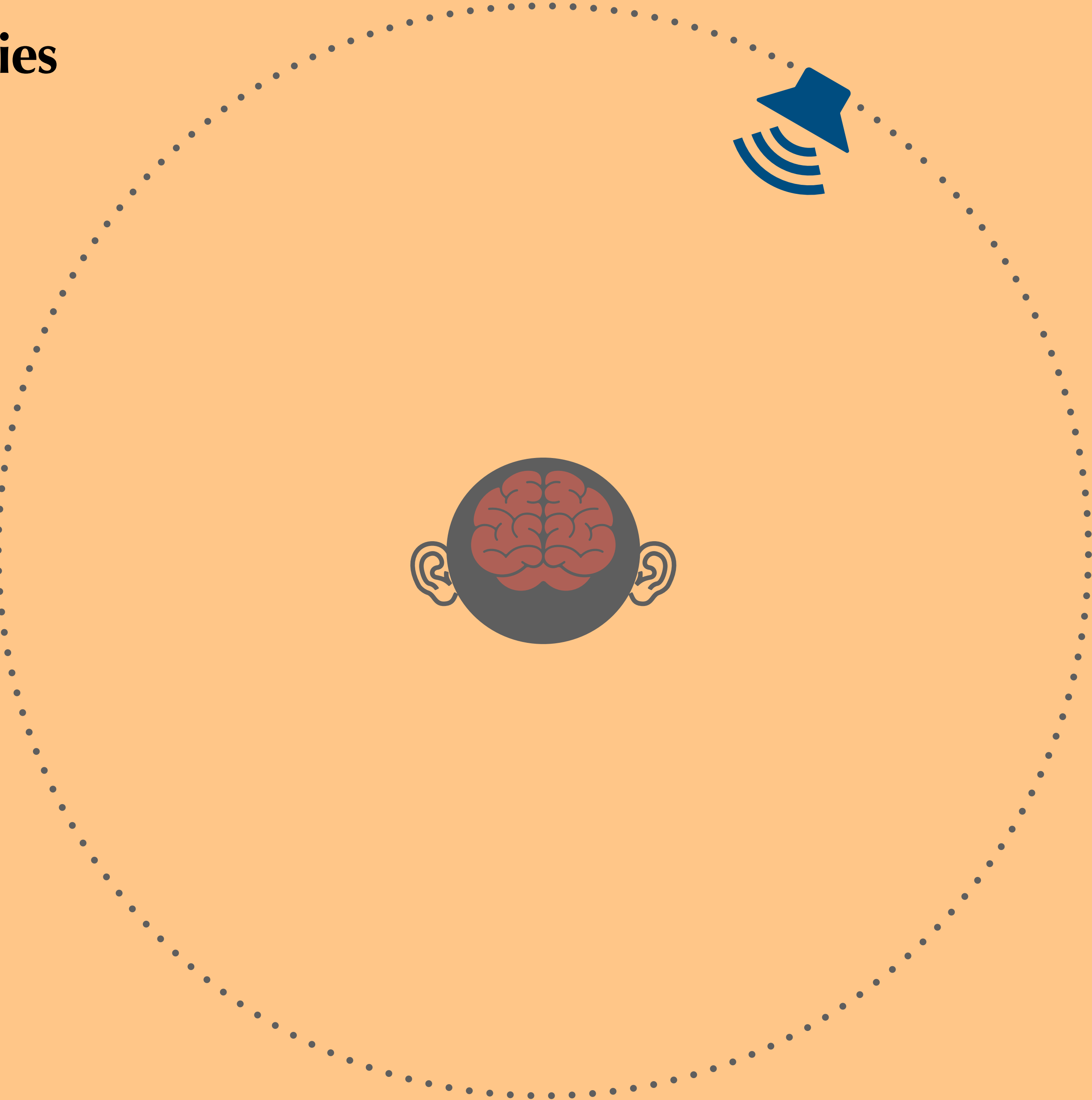
They are tools to present the outside acoustic world to listeners.



Horizontal Plane

Virtual Auditory Environment Technologies

Single-Channel (SC) Presentation

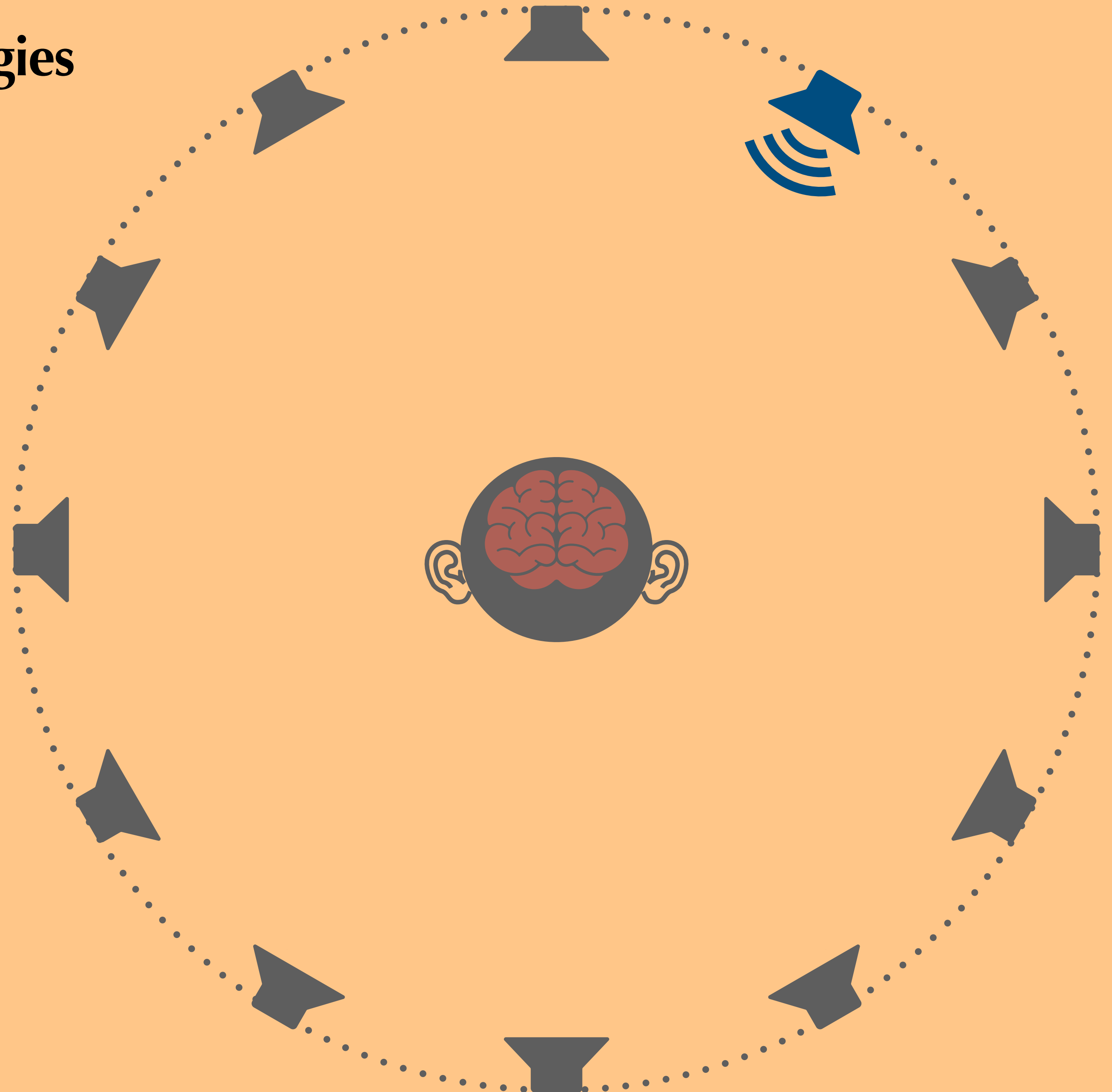


Horizontal Plane

Virtual Auditory Environment Technologies

Single-Channel (SC) Presentation

✓ Precisely focal sound sources

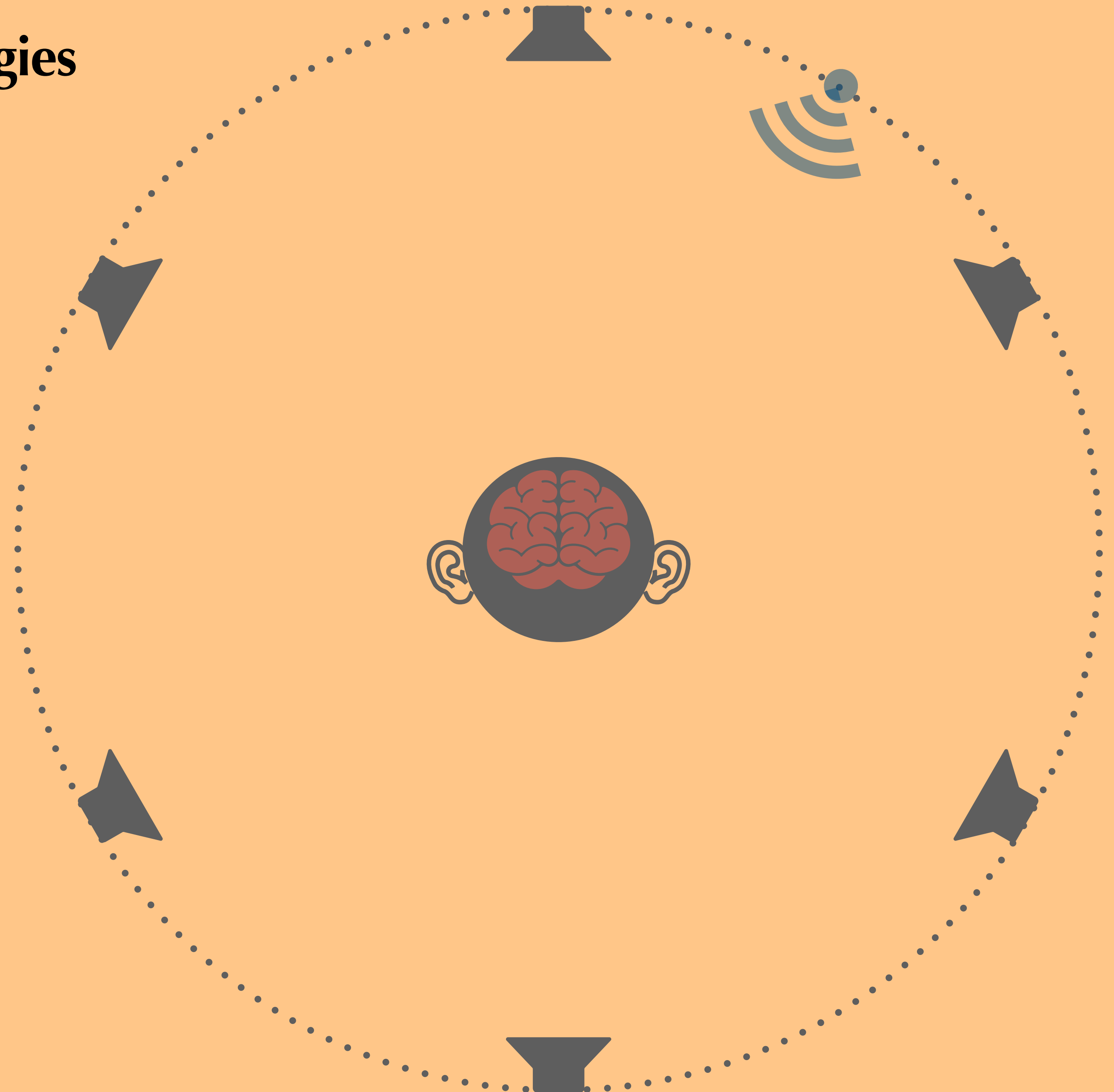


Horizontal Plane

Virtual Auditory Environment Technologies

Single-Channel (SC) Presentation

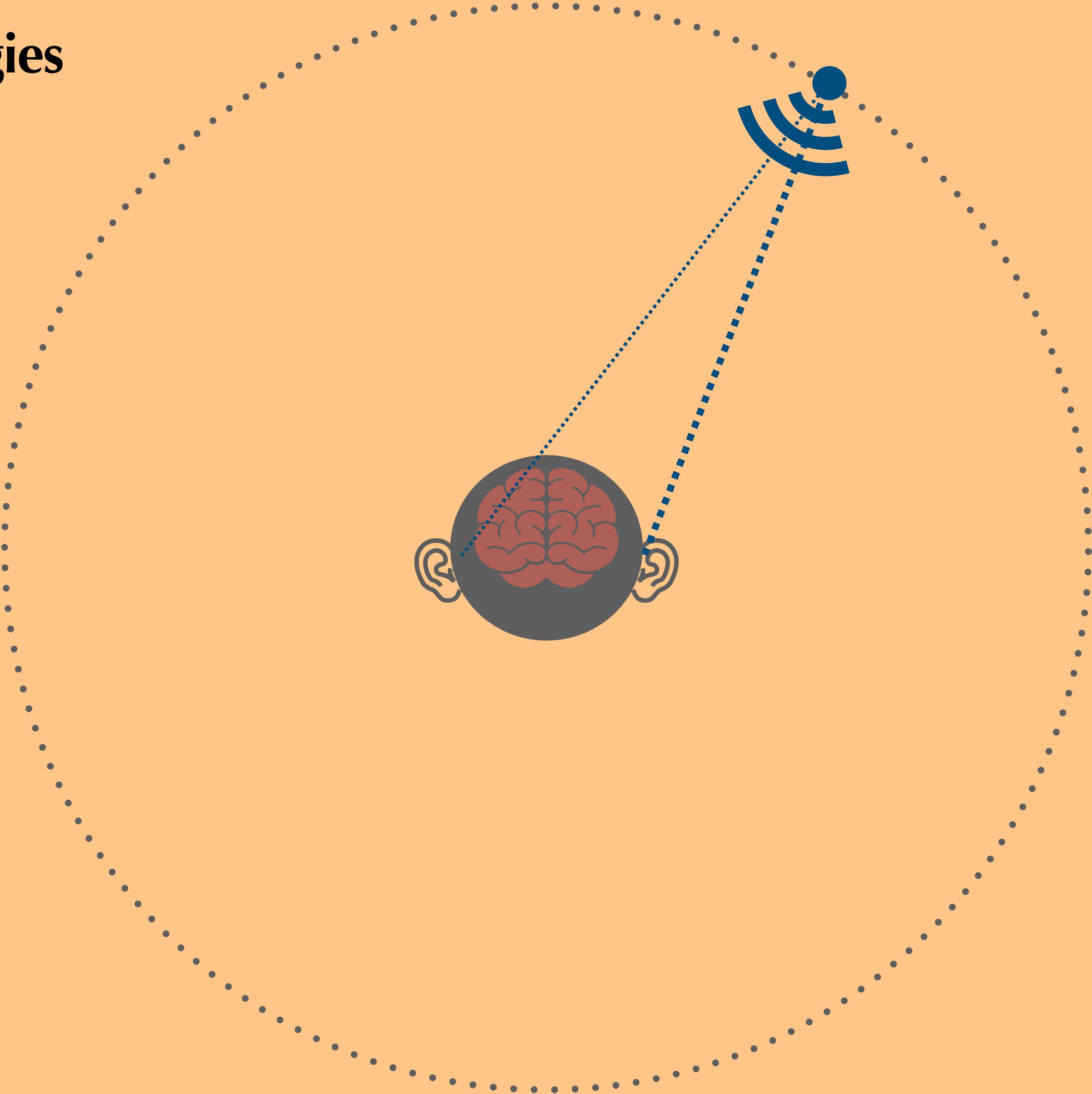
- ✓ Precisely focal sound sources
- ✗ Resolution limited to the location and number of channels



Horizontal Plane

Virtual Auditory Environment Technologies

Stereo Headphones

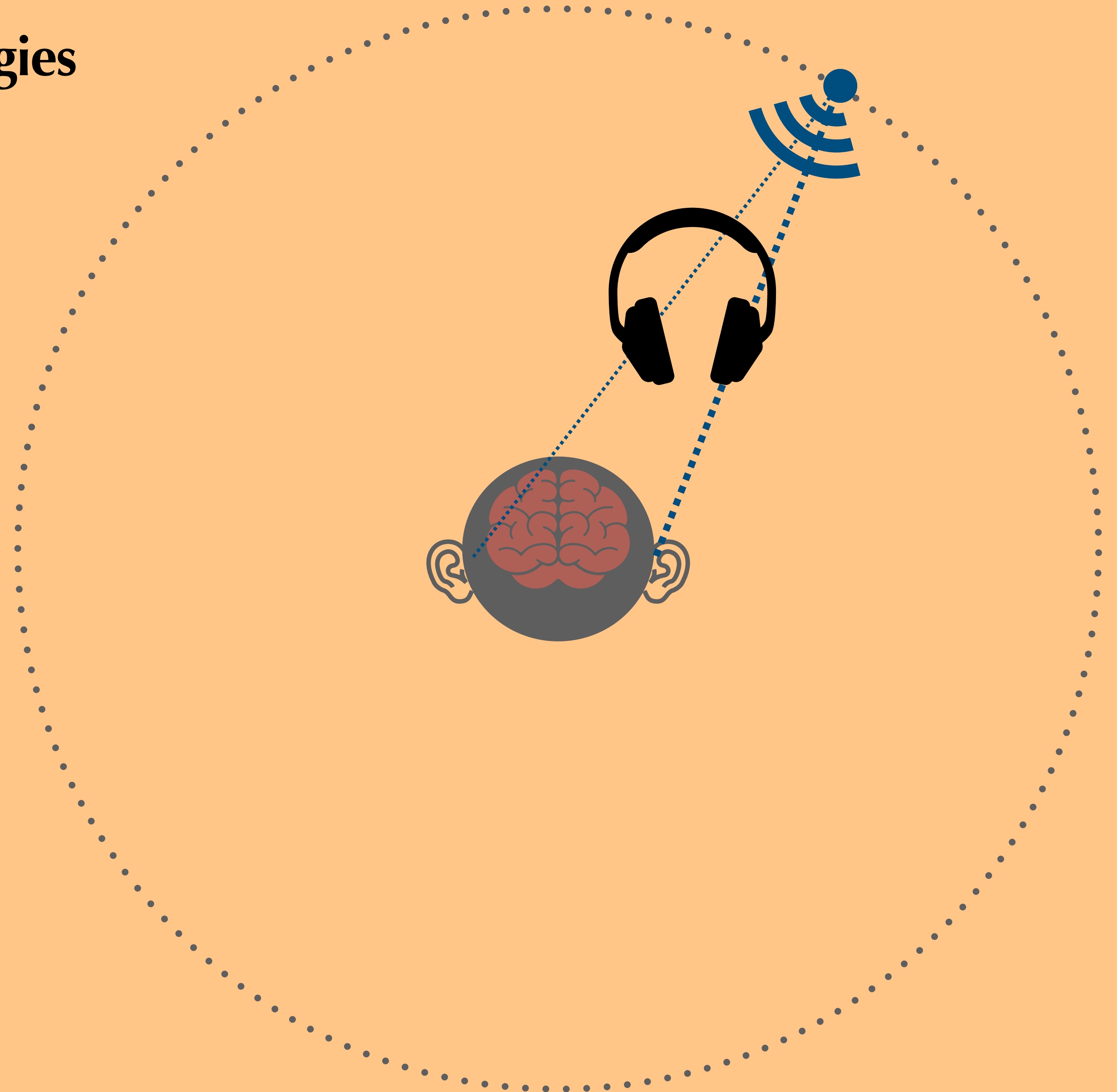


Horizontal Plane

Virtual Auditory Environment Technologies

Stereo Headphones

- ✓ Infinite spatial resolution
- ✓ Accessible, affordable, and portable

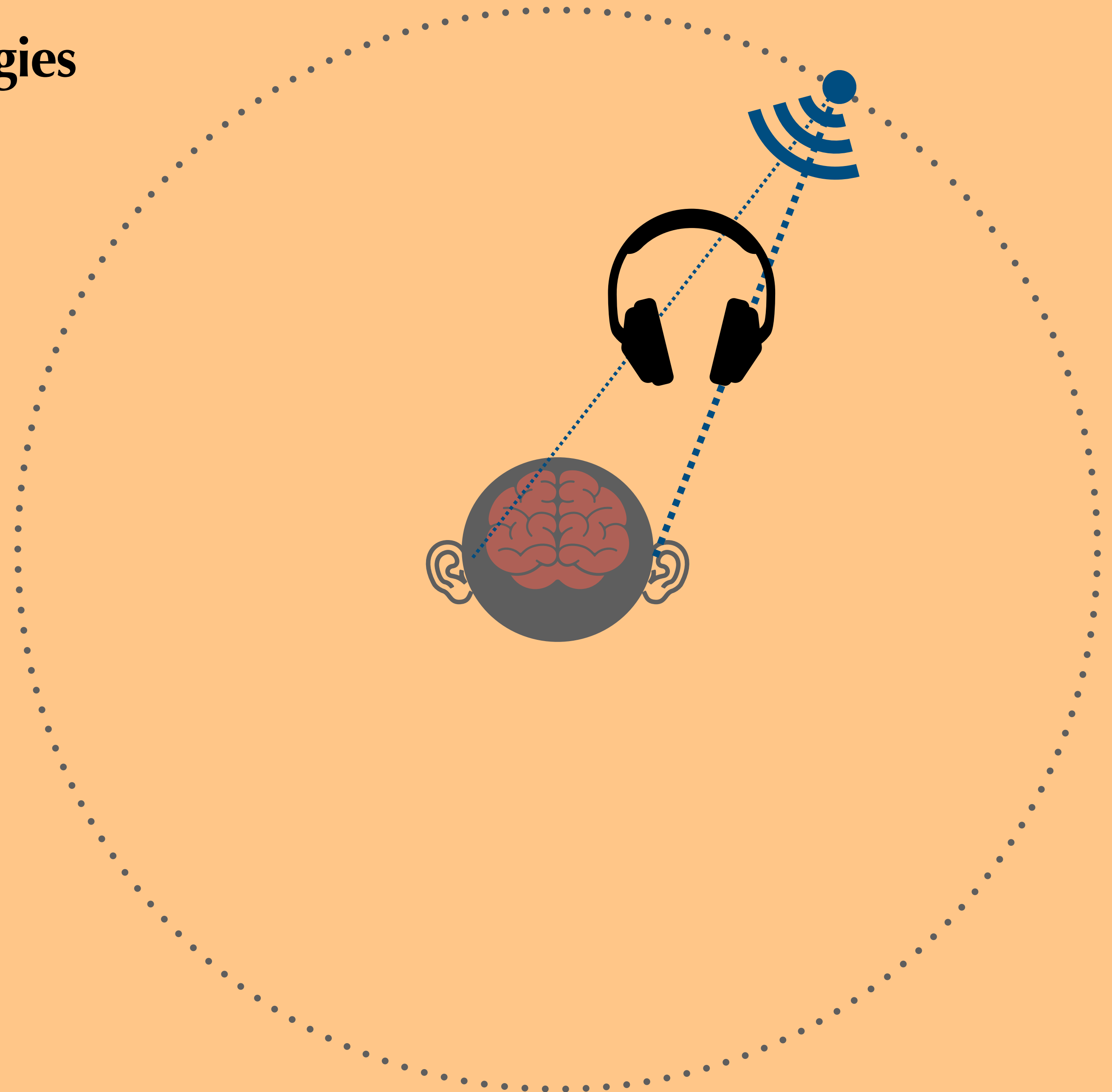


Horizontal Plane

Virtual Auditory Environment Technologies

Stereo Headphones

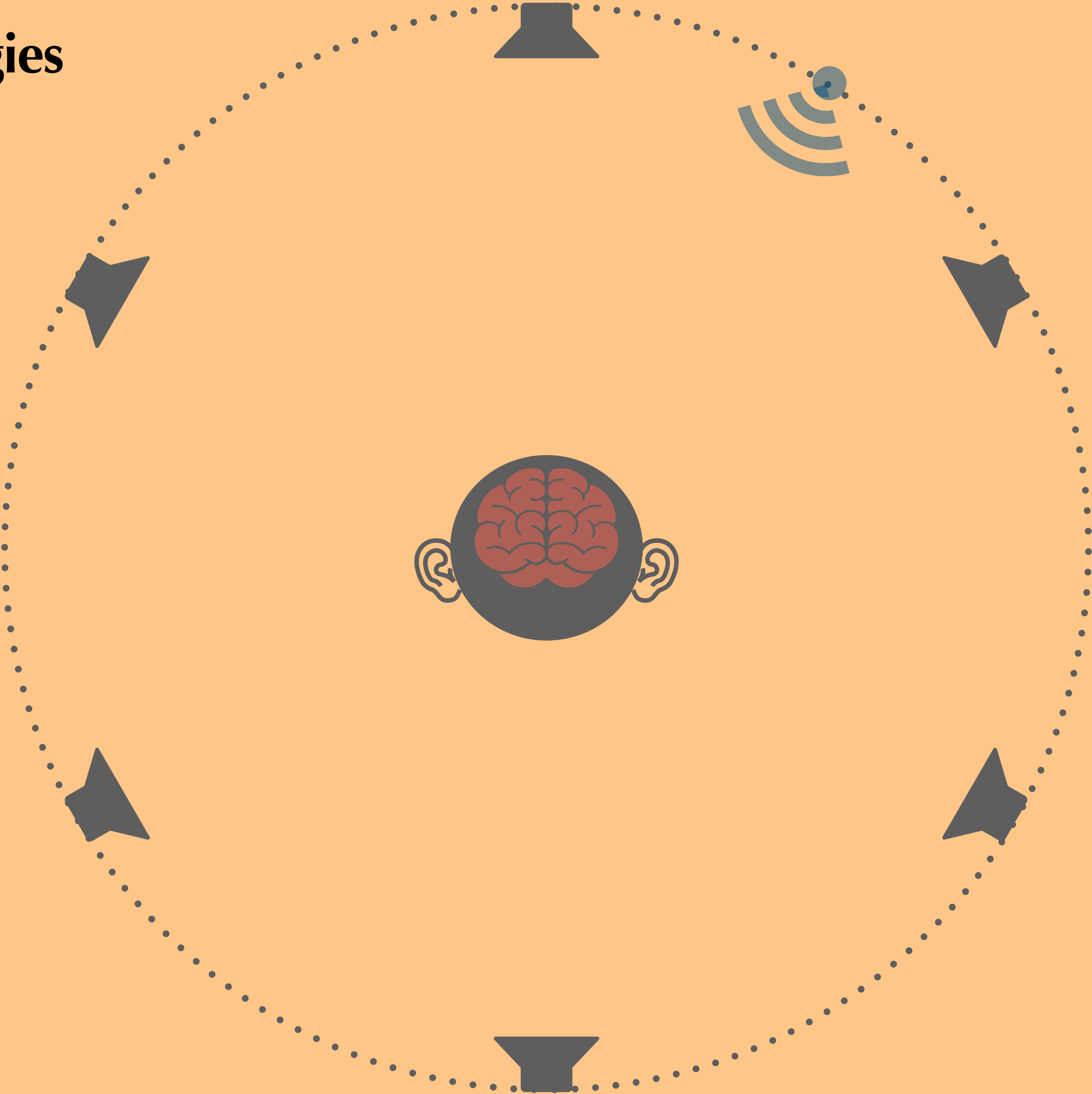
- ✓ Infinite spatial resolution
- ✓ Accessible, affordable, and portable
- ✗ Requires HRTF estimates/models
- ✓ Perfect for fully lateralized scenarios
- ✗ Source location does not update as the listener moves their head



Horizontal Plane

Virtual Auditory Environment Technologies

Vector-Based Amplitude Panning (VBAP)

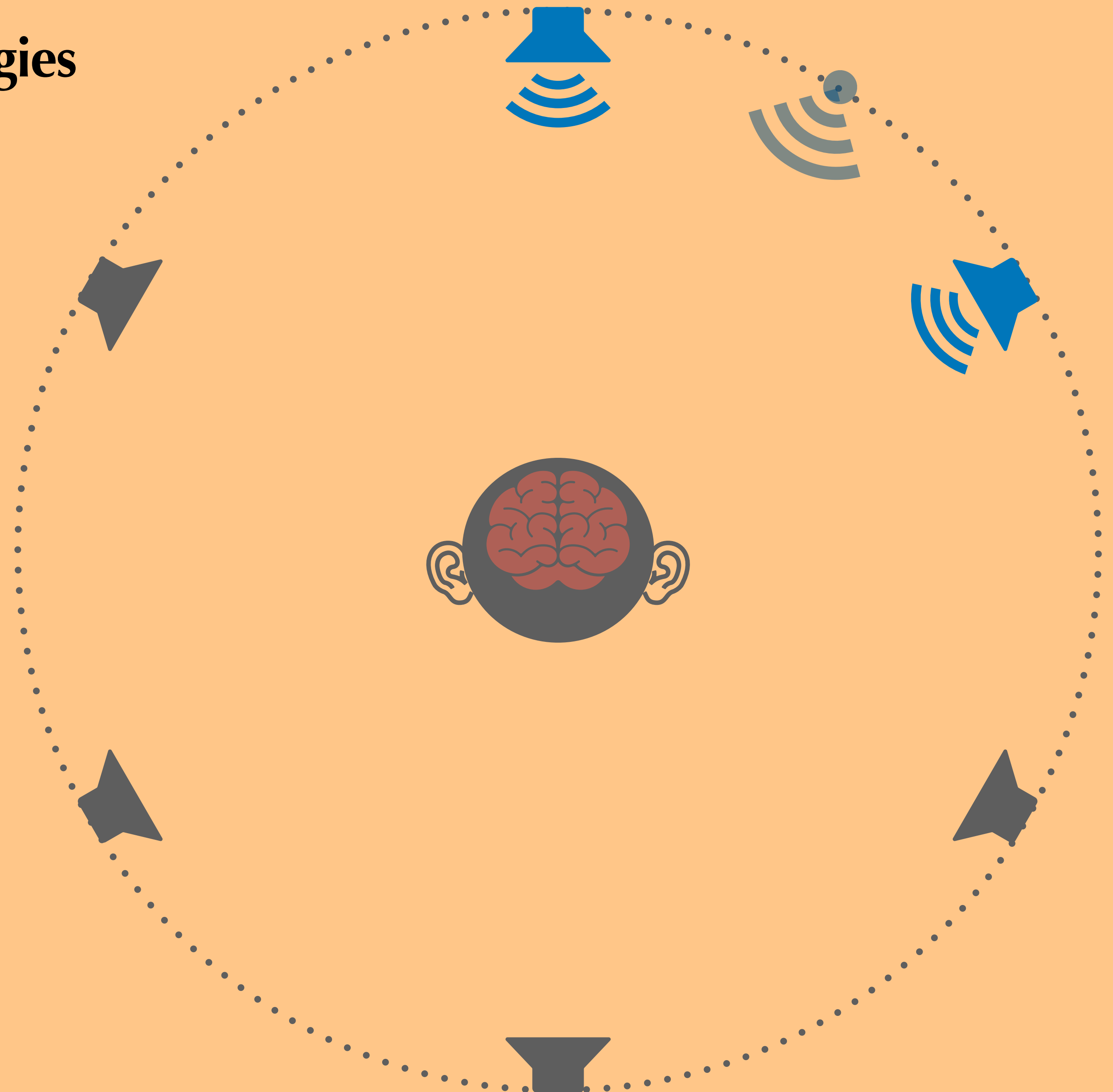


Horizontal Plane

Virtual Auditory Environment Technologies

Vector-Based Amplitude Panning (VBAP)

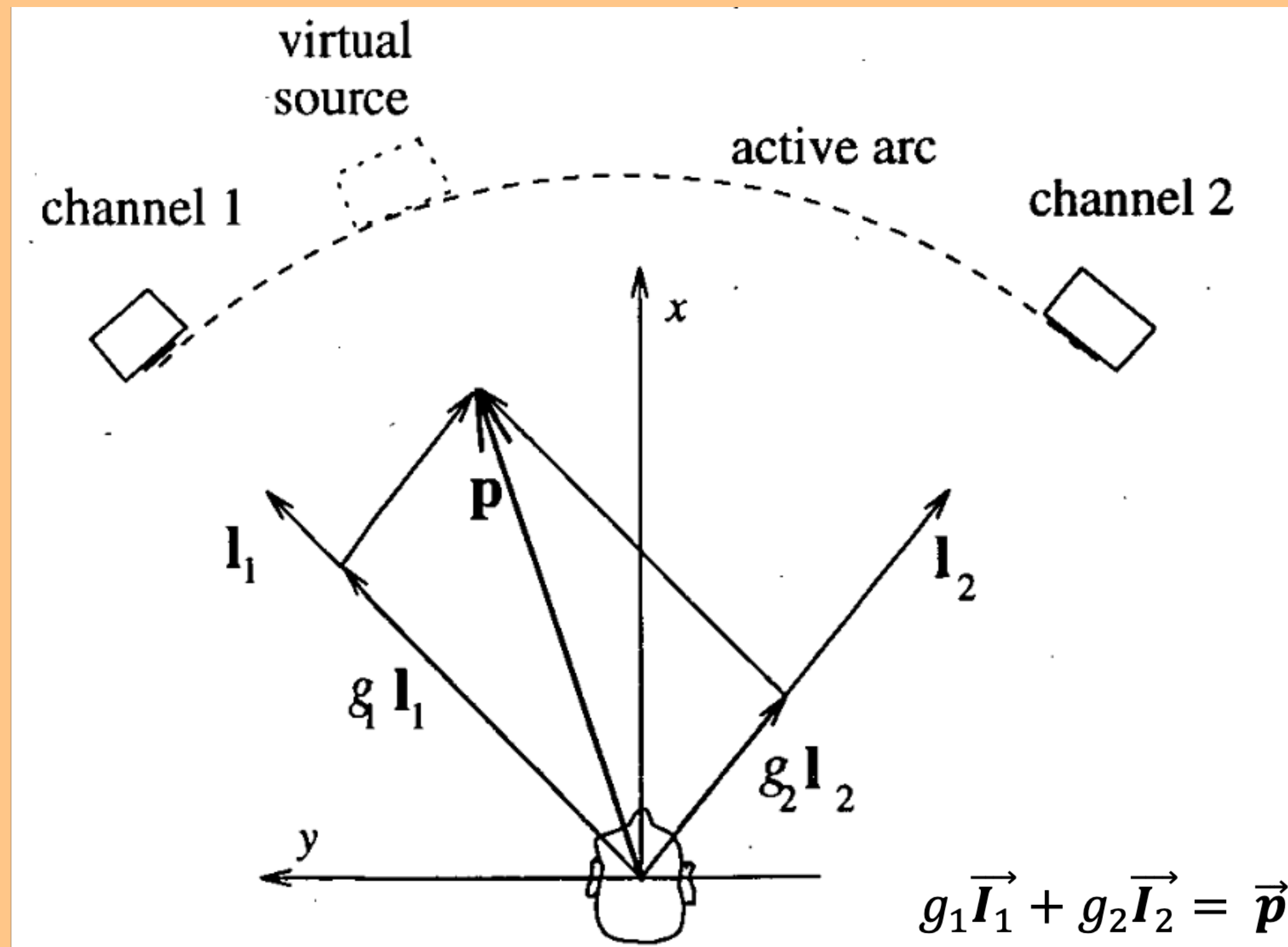
- ✓ No HRTF estimation required; all listeners will hear with their own ears!



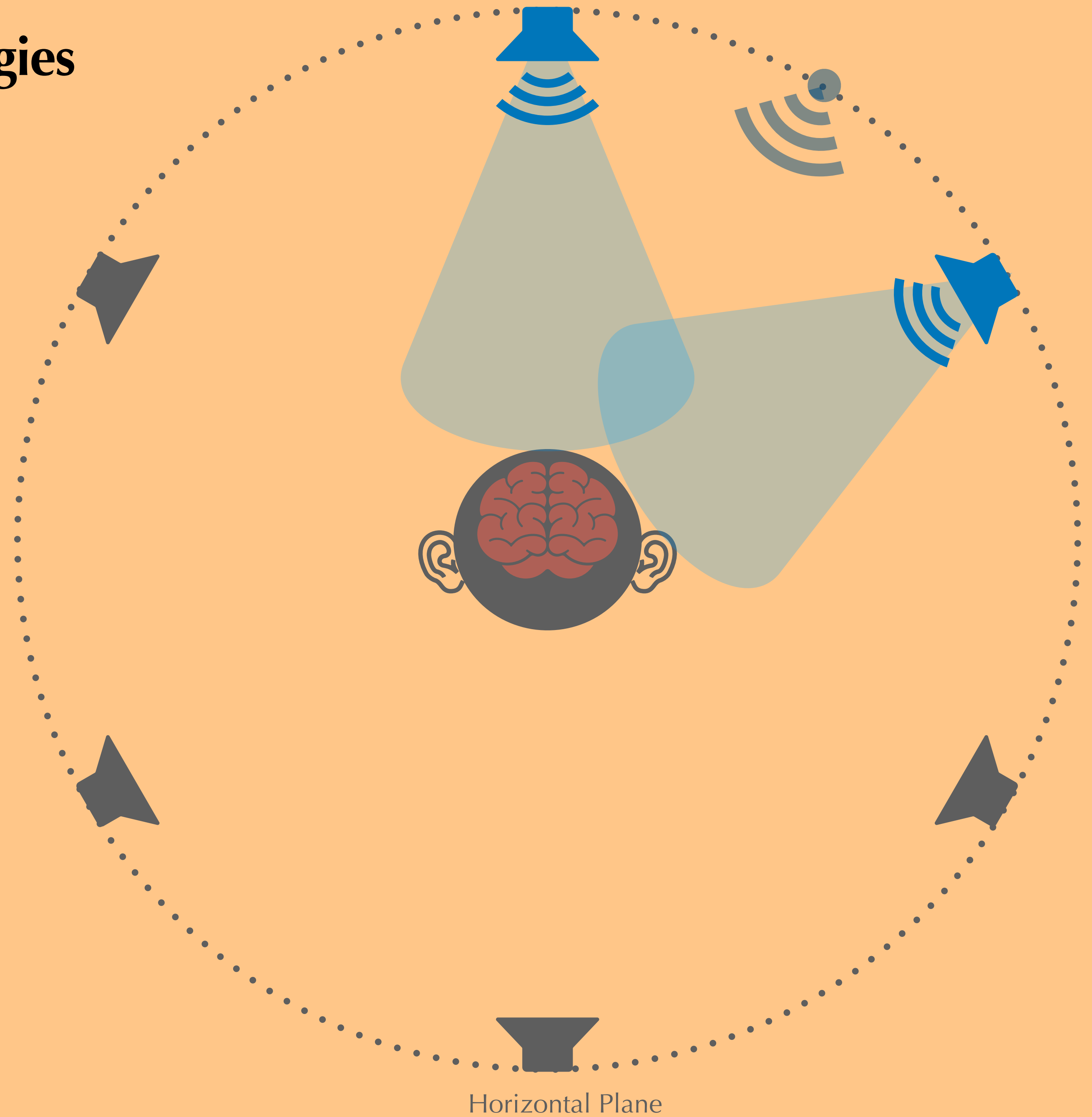
Horizontal Plane

Virtual Auditory Environment Technologies

Vector-Based Amplitude Panning (VBAP)

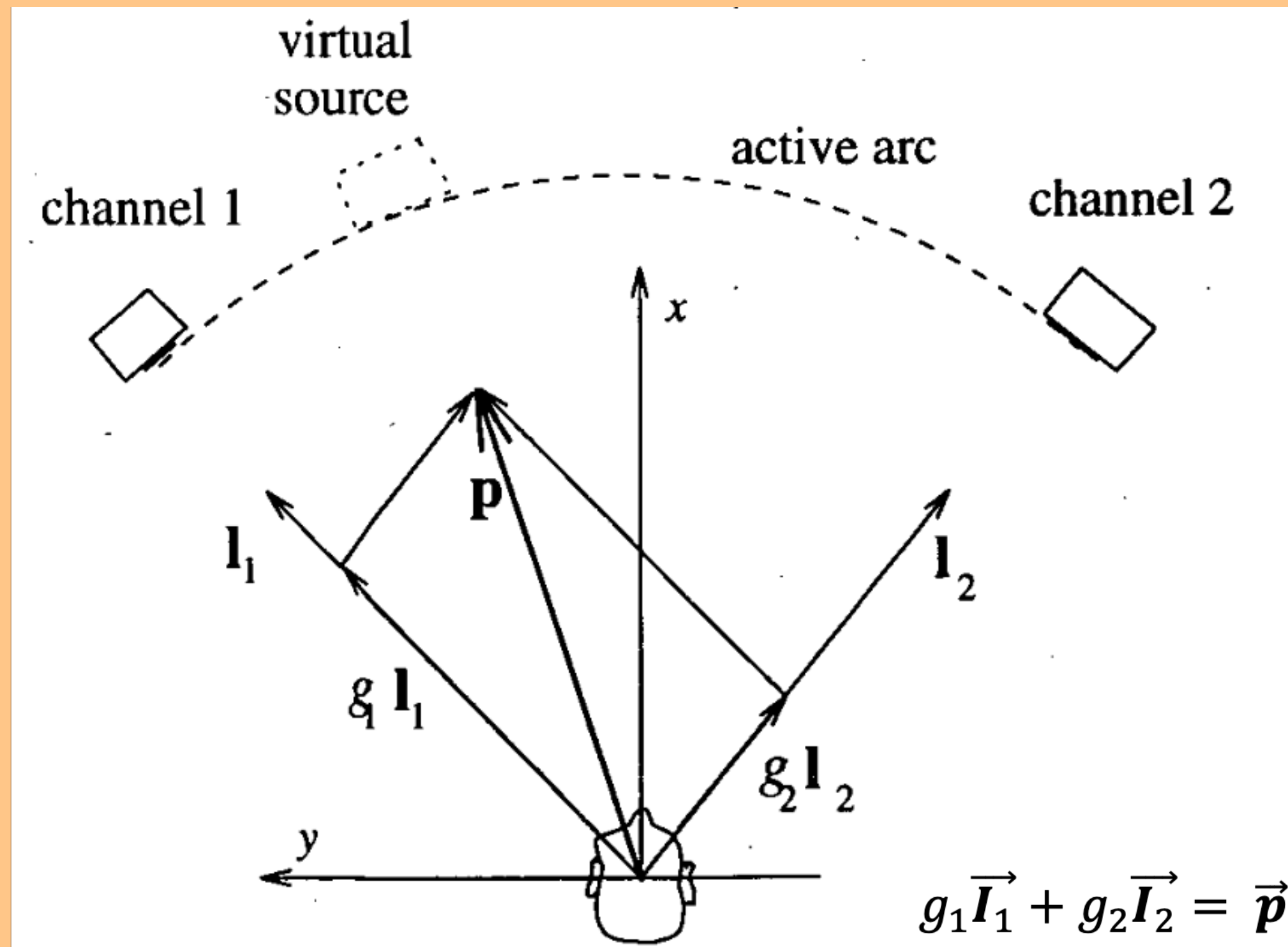


(Pulkki, 1997)

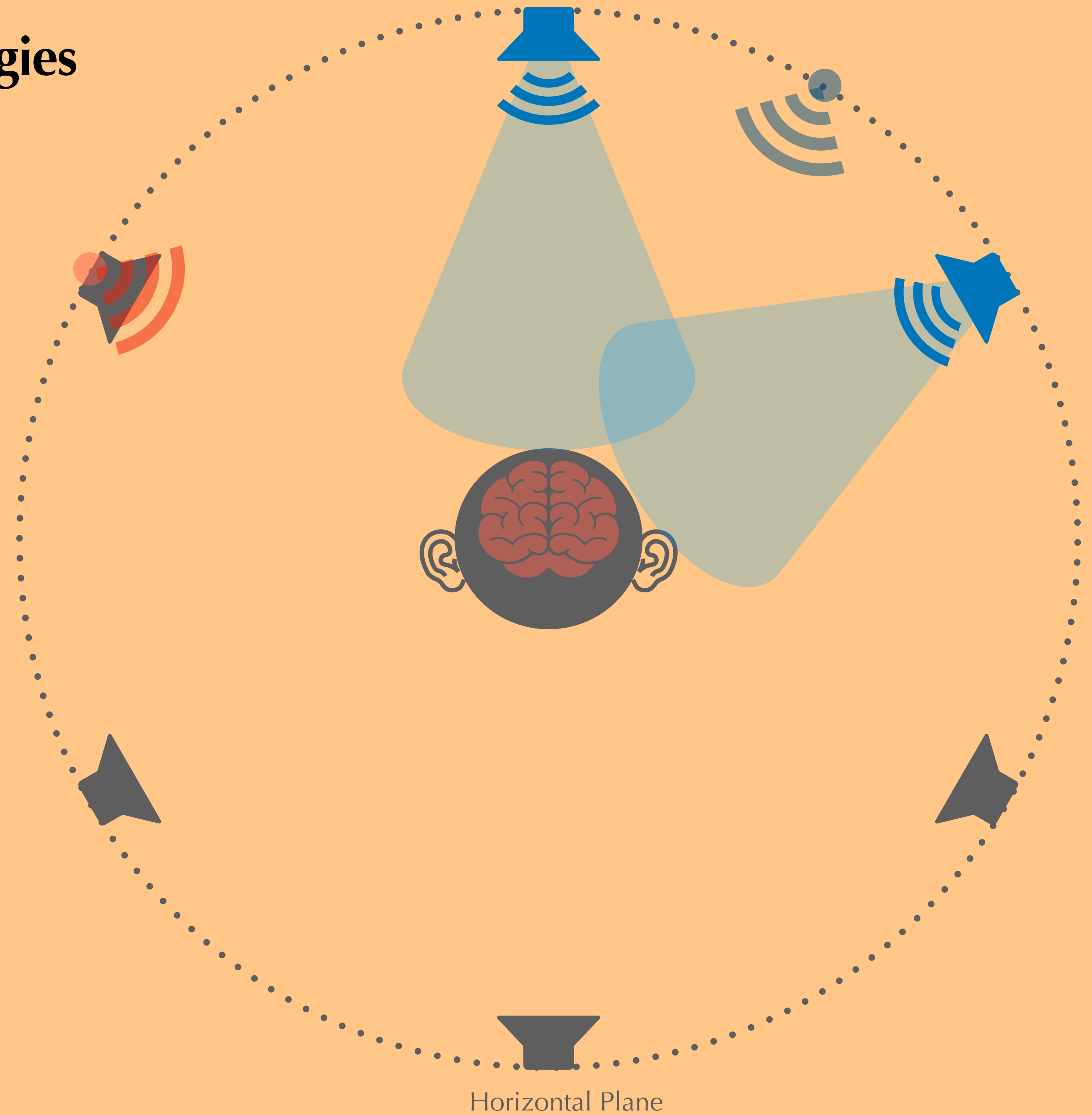


Virtual Auditory Environment Technologies

Vector-Based Amplitude Panning (VBAP)

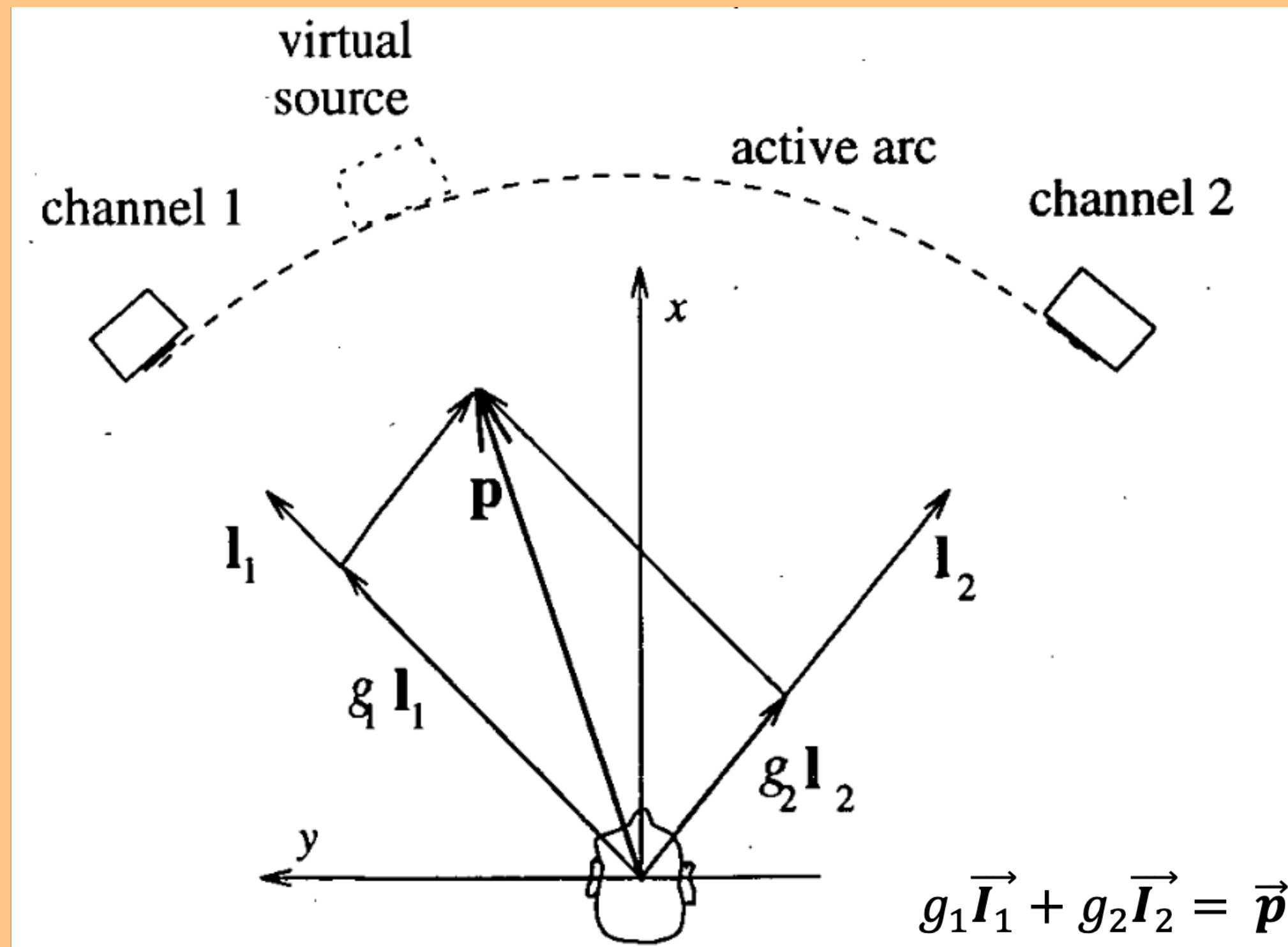


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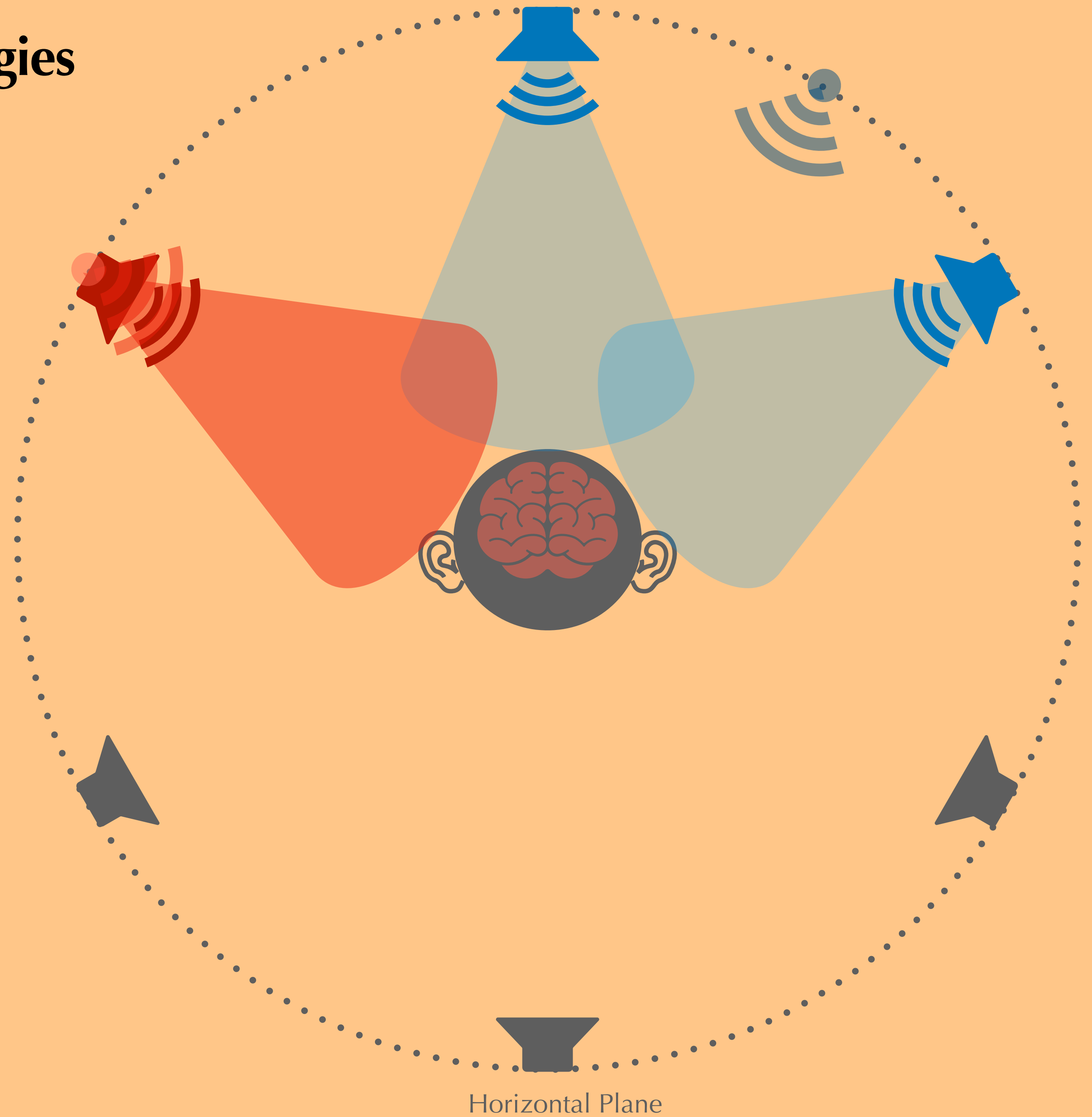


Virtual Auditory Environment Technologies

Vector-Based Amplitude Panning (VBAP)



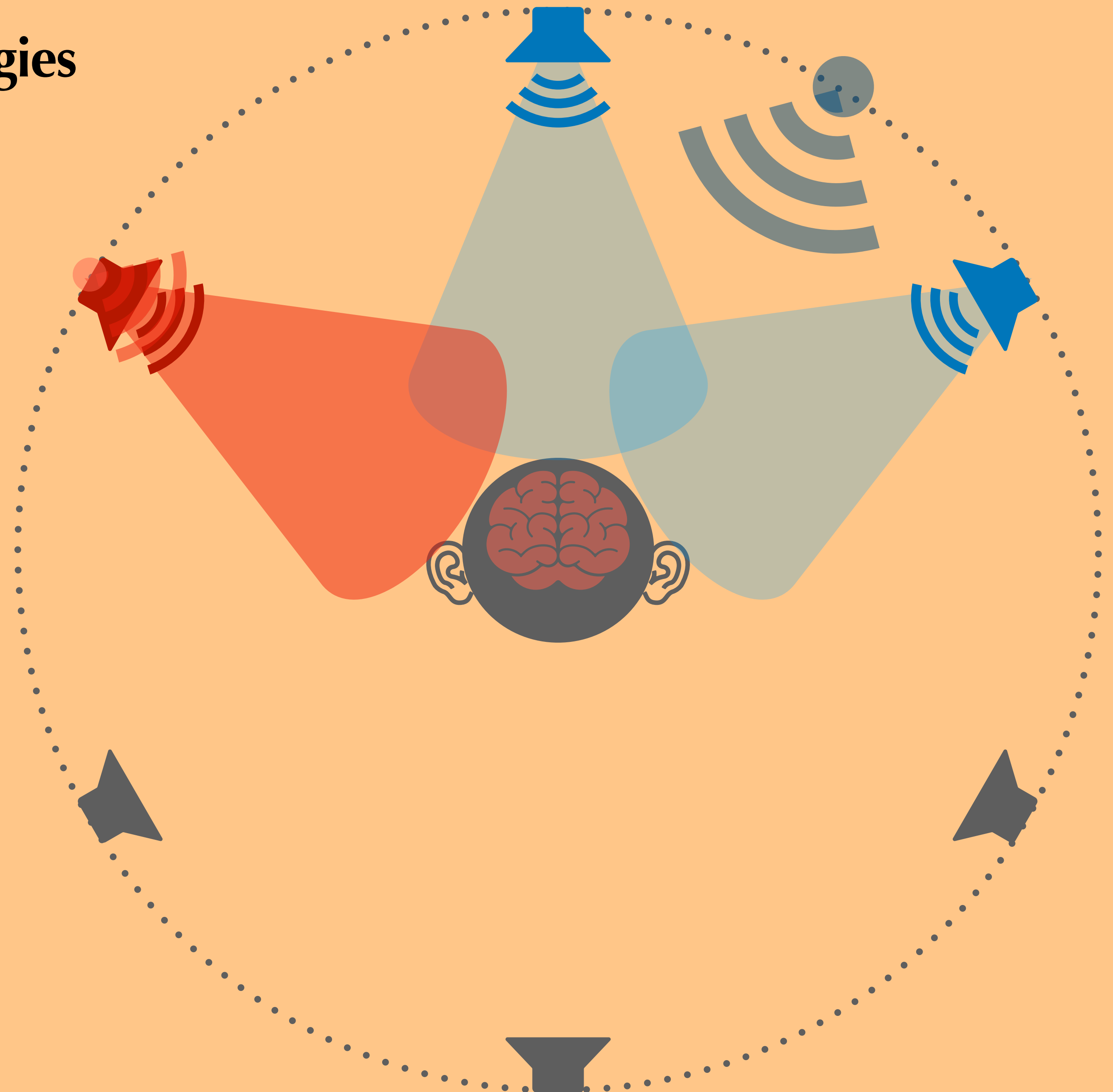
(Pulkki, 1997)



Virtual Auditory Environment Technologies

Vector-Based Amplitude Panning (VBAP)

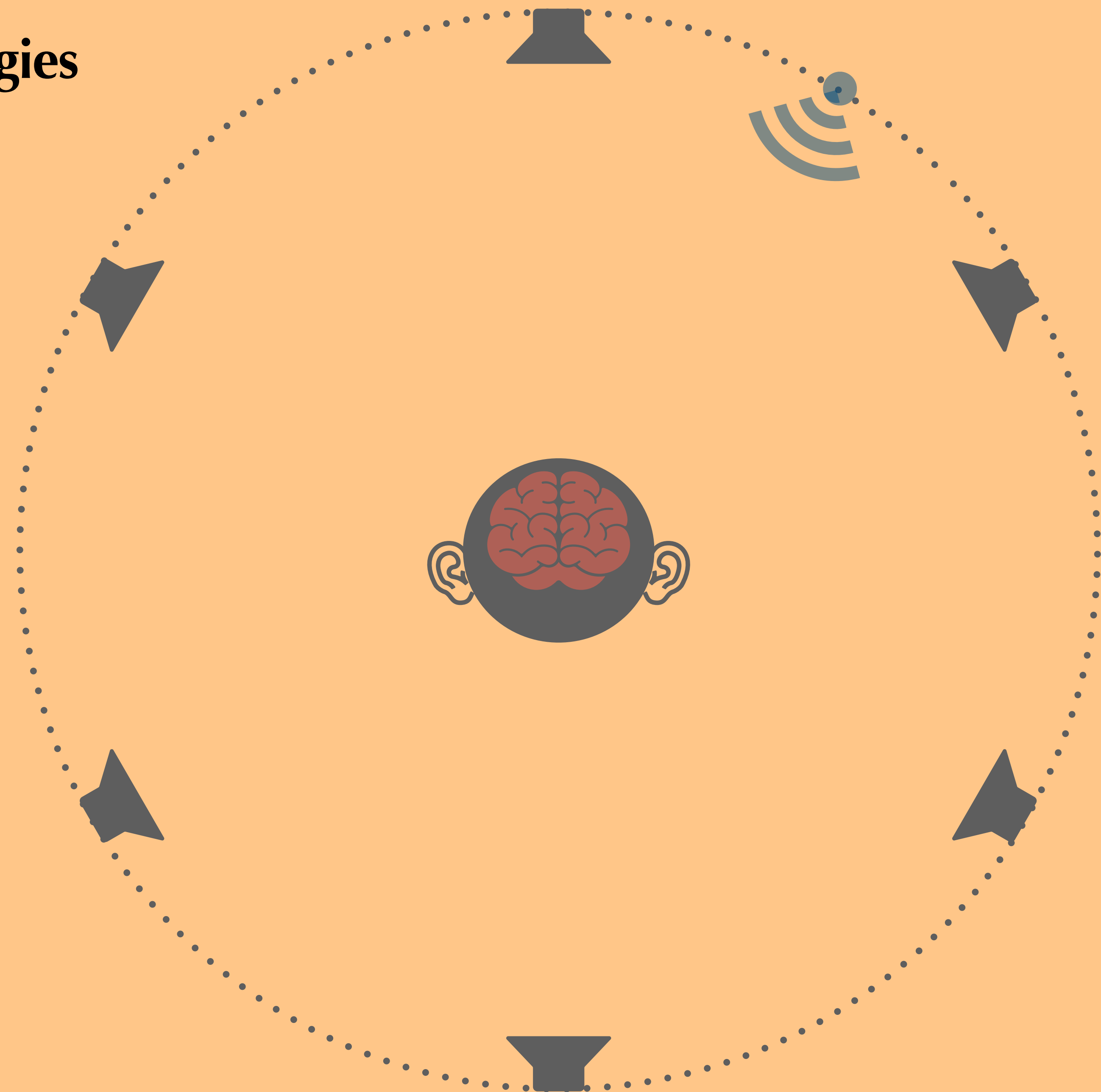
- ✓ No HRTF estimation required; all listeners will hear with their own ears!
- ✗ Virtual sound sources are perceptually blurred
- ✗ Overall blurriness depends on array configuration
- ✗ Blurriness depends on source distance from channels



Horizontal Plane

Virtual Auditory Environment Technologies

Ambisonics

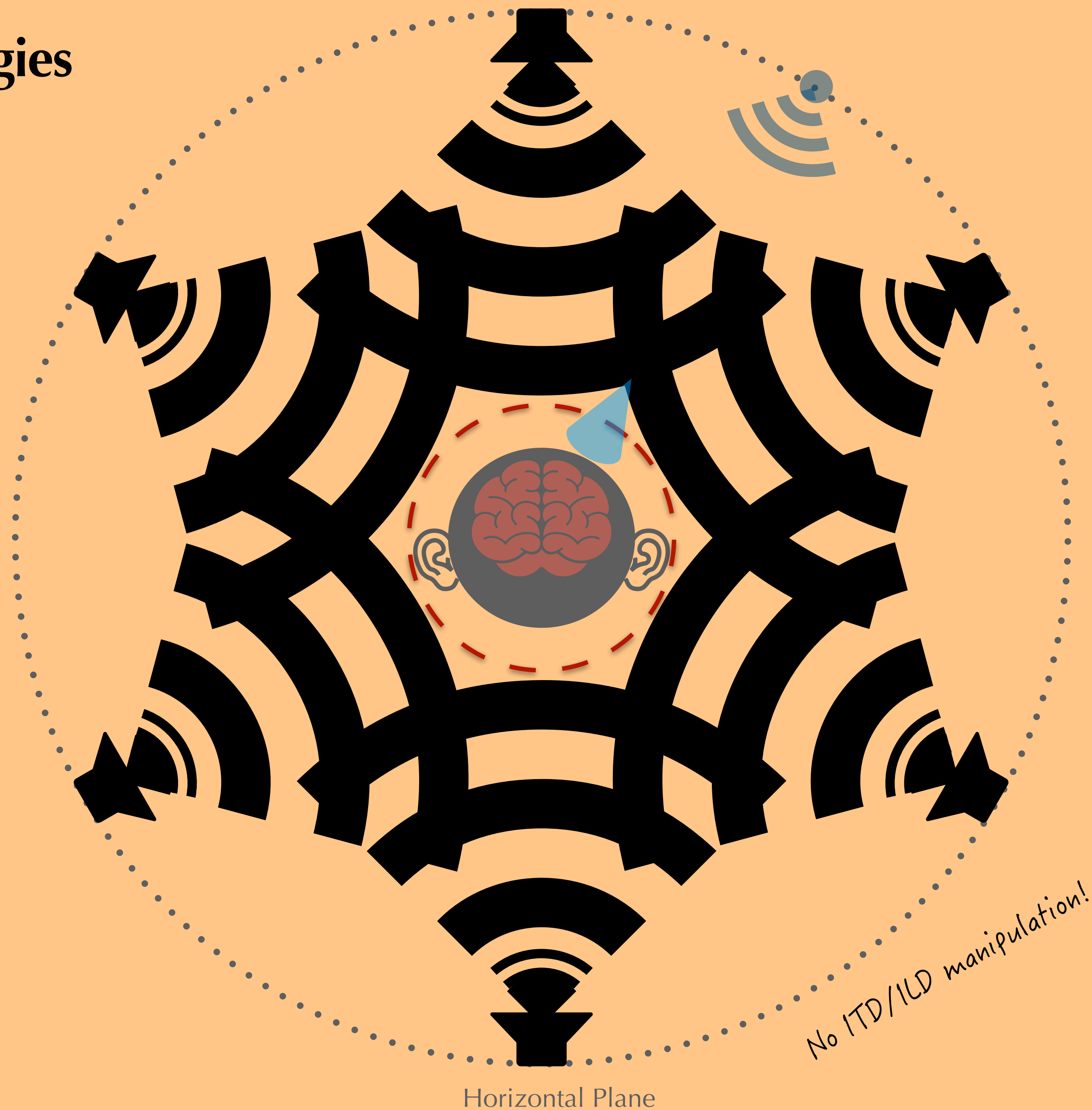


Horizontal Plane

Virtual Auditory Environment Technologies

Ambisonics

- ✓ No HRTF estimation required; all listeners will hear with their own ears!
- ✗ Virtual sound sources are perceptually blurred
- ✓ Blurriness is less than VBAP
- ✓ Blurriness is homogenous, and independent from distance from channels



Virtual Auditory Environment Technologies: Summary



Single-Channel (SC)	Stereo Headphones	Vector-Based Amplitude Panning (VBAP)	Ambisonics
• Precisely focal sound sources • No HRTF estimation required • Sound sources don't move with head movement	• Infinite spatial resolution • Accessible, affordable, and portable • Perfect for fully lateralized scenarios	• No HRTF estimation required • Sound sources don't move with head movement	• No HRTF estimation required • Blurriness is less than VBAP • Sound sources don't move with head movement • Blurriness is homogenous, and independent from distance from channels
• Resolution limited to the location and number of channels	• Requires HRTF estimates/models • Sound sources move with head movement	• Virtual sound sources are perceptually blurred • Blurriness depends on array configuration • Blurriness depends on source distance from channels	• Virtual sound sources are perceptually blurred

Virtual Auditory Environment Technologies

Audio Files

- Single audio recordings/files
- Stereo audio recordings/files
- Multi-channel microphone arrays



The AudioDome

Specs

- 3/4 spheric geodesic array
- 91 channels (loudspeakers) with flat frequency response for frequencies above ~ 90 Hz
- 4 subwoofers to assist with lower frequencies (>150 Hz)
- 7 talkback mics
- 1 camera



The AudioDome

Audio Technologies

- Single-Channel Nearest (nearest)
- Vector-Based Amplitude Panning (vbap)
- 9th-order Ambisonics (ambi)



The AudioDome

Integration and adds-on

- **EEG:** Biosemi
- **VR:** Valve Index and Knuckle Controllers
- **AR/Wearable Monitors:** XReal One
- **Pointing:** Vive Tracker 3.0, Pointing Orthotic
- **Psychophysiology:** Wireless BioPac (ECG, etc.)



The AudioDome

Future Integration and adds-on

- **Motion Tracking:** Optitrack (*to be added this year*)
- **Pupillometry:** Pupil Labs glasses
- **High-end VR head-mounted display:** Varjo XR-4 or similar



The AudioDome

Control & Programming

- SpatialAudioCreator software

Could be controlled with:

- Manually (GUI)

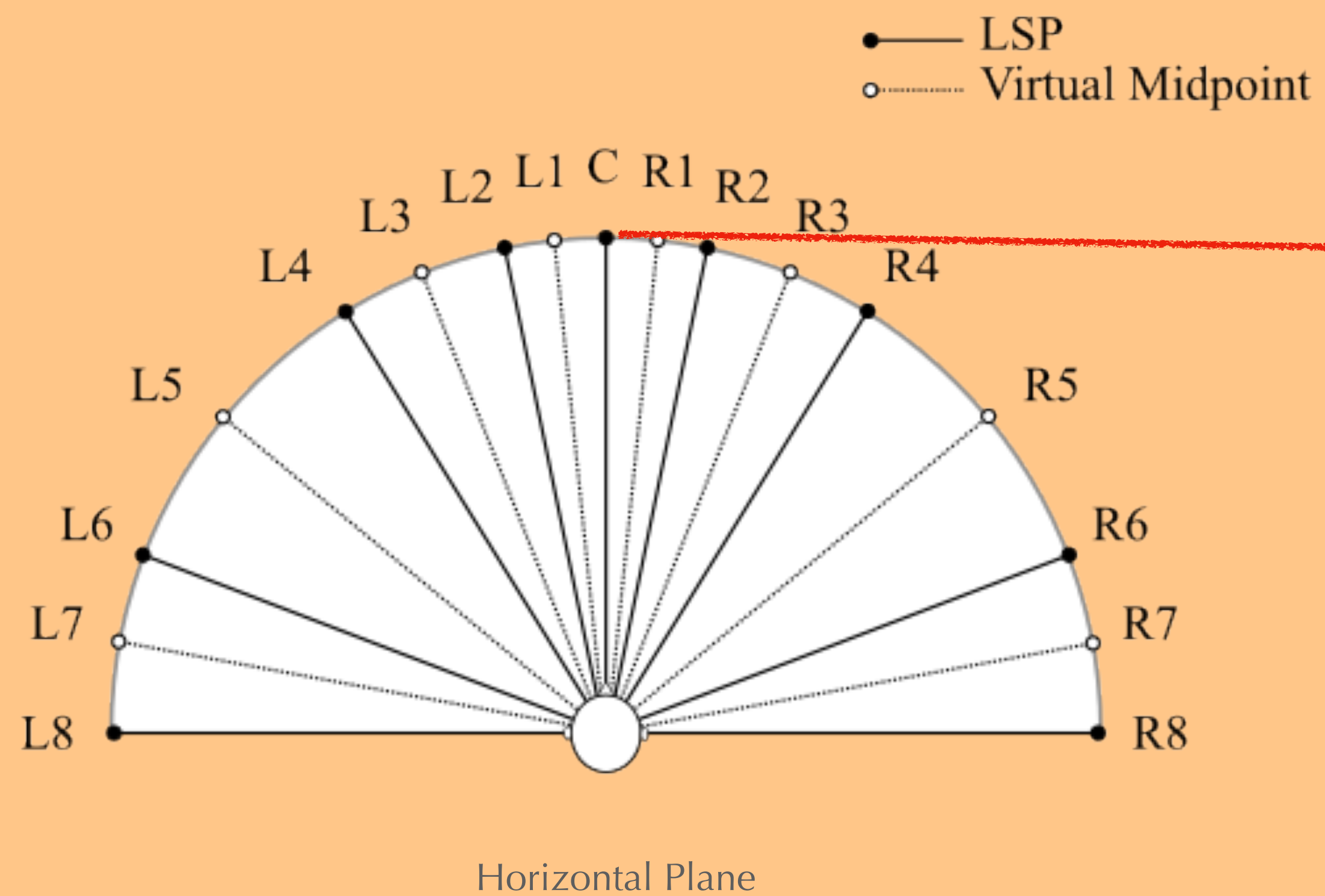
OSC commands could be sent with:

- Python
- MATLAB
- Unity/C#



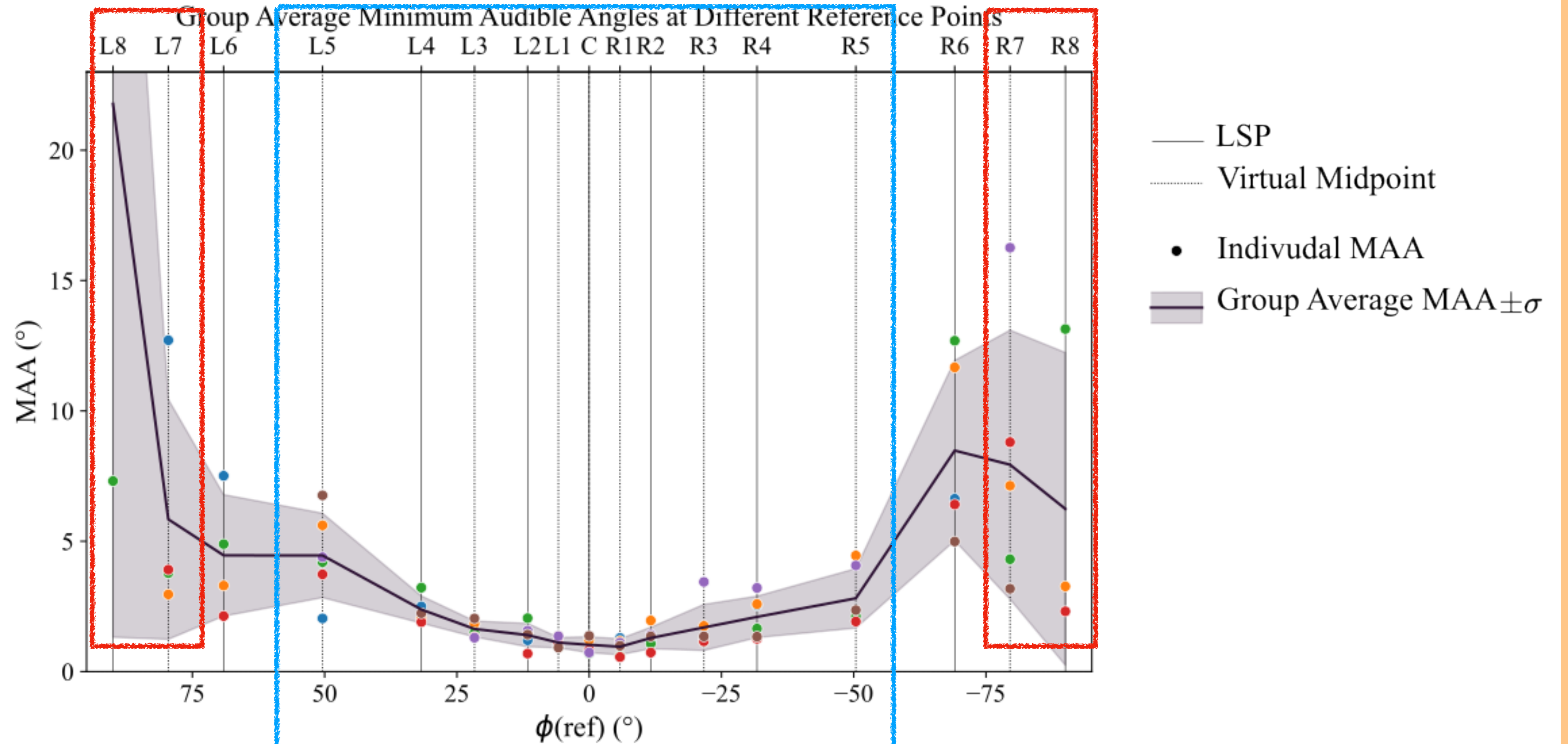
The AudioDome

Findings



The AudioDome

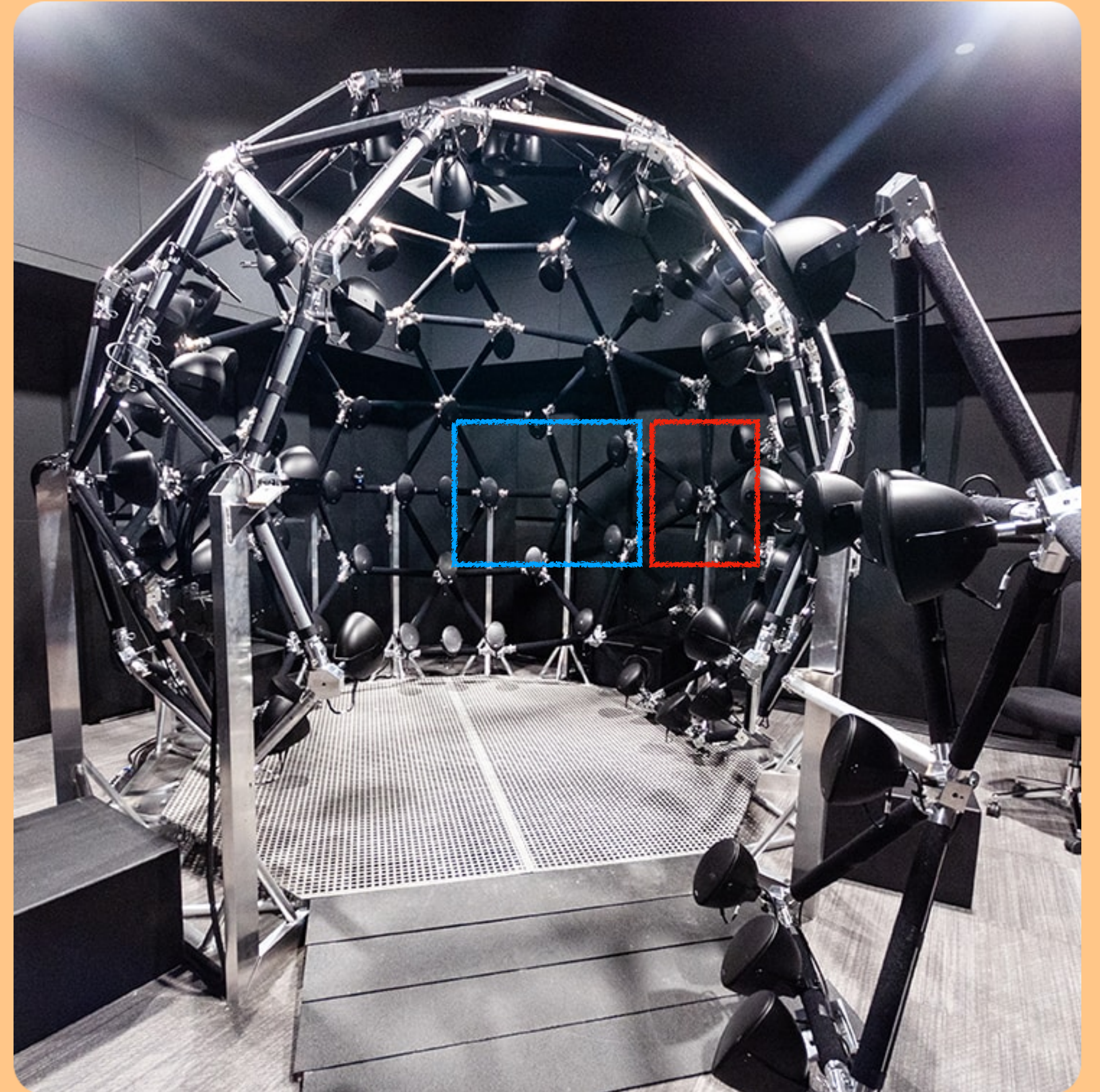
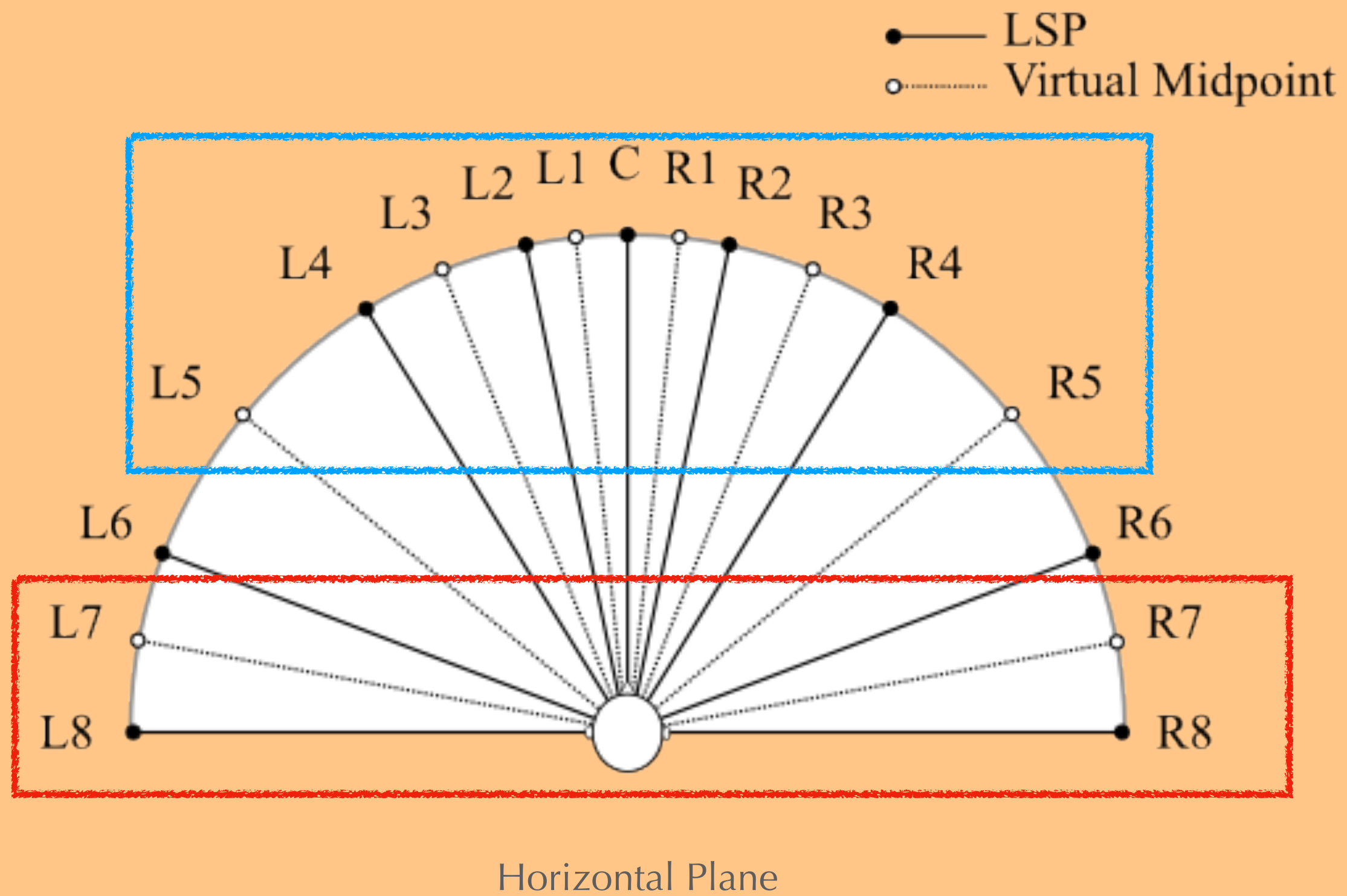
Findings



(Zargarnezhad et al., in press)

The AudioDome

Findings



The AudioDome

Findings Summary

Focality of sound source placement by higher (9th) order ambisonics and perceptual effects of spectral reproduction errors

 Nima Zargarnezhad,  Bruno Mesquita,  Ewan A Macpherson,  Ingrid Johnsrude

doi: <https://doi.org/10.1101/2024.08.07.606870>

- Horizontal resolution with ambisonics captures human spatial acuity within 50 degrees off the midline.
- Spatial blurriness with ambisonics is homogenous and independent from sound source distance to loudspeakers.
- ITD cues are practically reconstructed fine with ambisonics and VBAP, but low frequency ILDs are misleading in VBAP while they are fine with ambisonics.
- High-frequency content (>4 kHz) are reconstructed with spectral notches that alter the perceived elevation on the sides. The frequency limit was predicted theoretically!

The AudioDome

Technical Notes

- Loudspeakers' frequency response is flat and reliable for 90 Hz-20 kHz.
- Audio files need to be preloaded to the server. Dynamic/adaptive stimuli need careful design.
- Unless a prerecorded file is provided Doppler's effect could not be reproduced for studies involving moving sound sources.
- Trigger communication is limited and needs consideration when integrating with other devices.
- There is a communication lag between the control system and the server that should be managed. (Especially if there are moving objects in the design)
- There is a memory limit (100 files) for each sound source. (-unless you don't use programming and control the device manually)

Part II: Technicalities

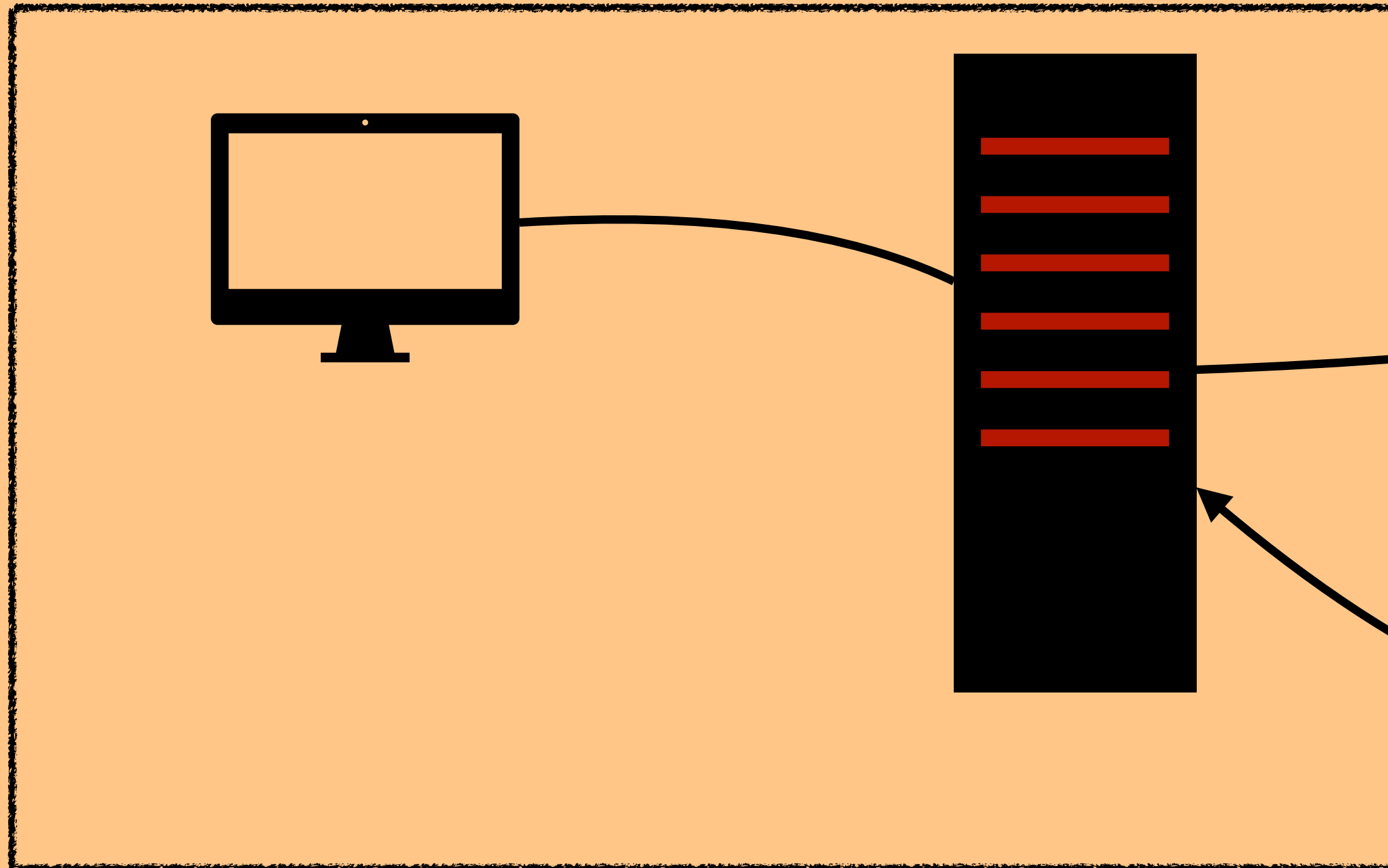
How to run the AudioDome?

Running the AudioDome

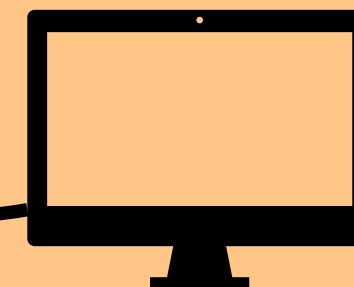
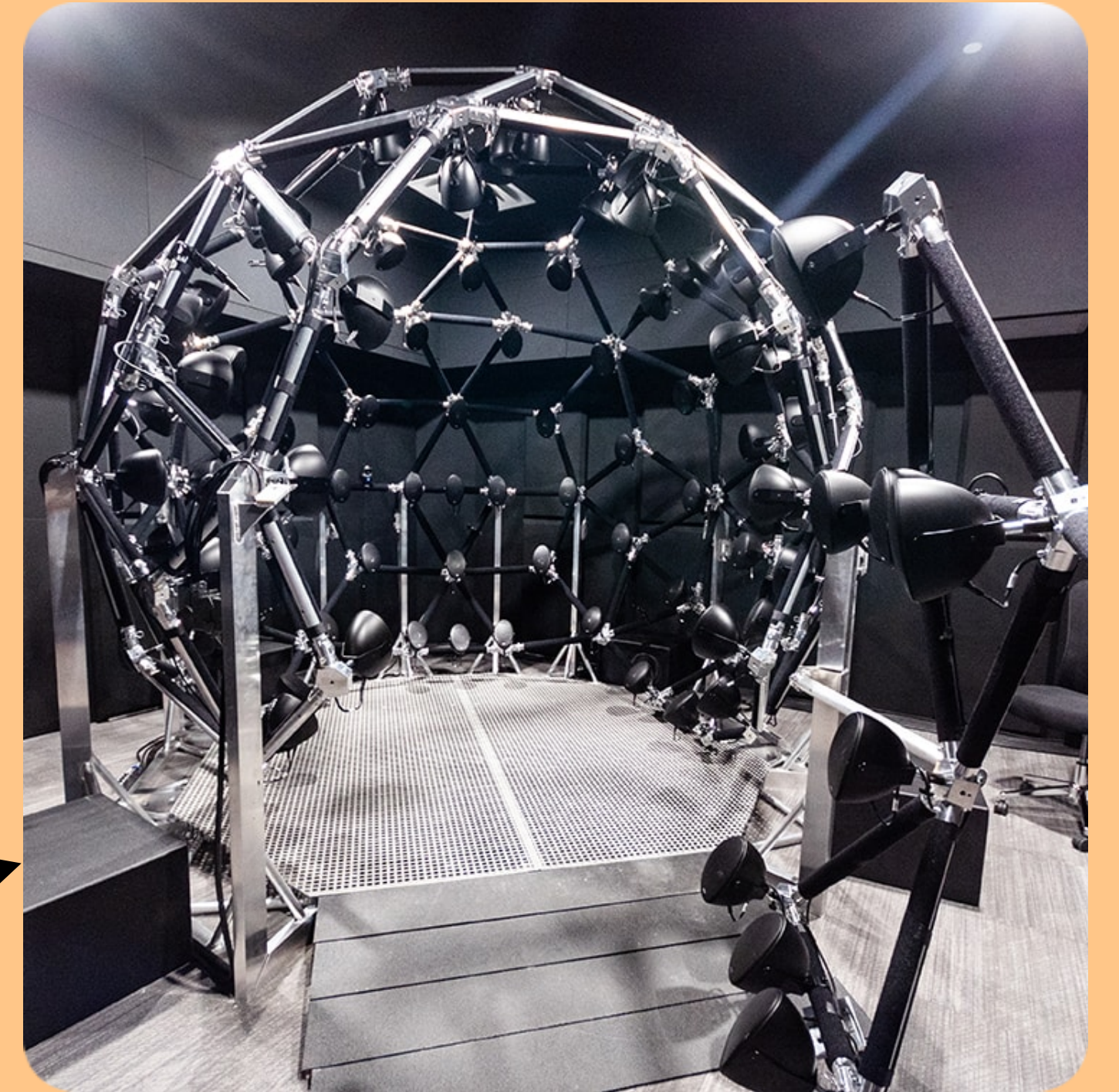
Resources

- **Getting Started:** Notion Page (ask Karsten for access)
- **Technical Details:** Sonible Manual (available on the Notion page)
- **Python Module:** github.com/NimaZN/AudioDome_Module

Running the AudioDome Structure



Control Room



Sound Attenuating Chamber

Objects

ID

Name

Playback

Spatialization

Room Settings

add object

1	Speech	play stop 0.0 dB loop		ambi -37.0° -22.0° 0.30 0.50 delete
3	Transients	play stop 0.0 dB loop		ambi 31.0° 32.0° 0.30 0.50 delete
4	Noise	play stop 0.0 dB loop		ambi -105.0° 34.0° 0.30 0.50 delete
5	Masker	play stop 0.0 dB loop		ambi 126.0° 14.0° 0.30 0.50 delete
2	Masker 2	play stop 0.0 dB loop		ambi 75.0° -33.0° 0.30 0.50 delete

Atmo

1

Trainstation

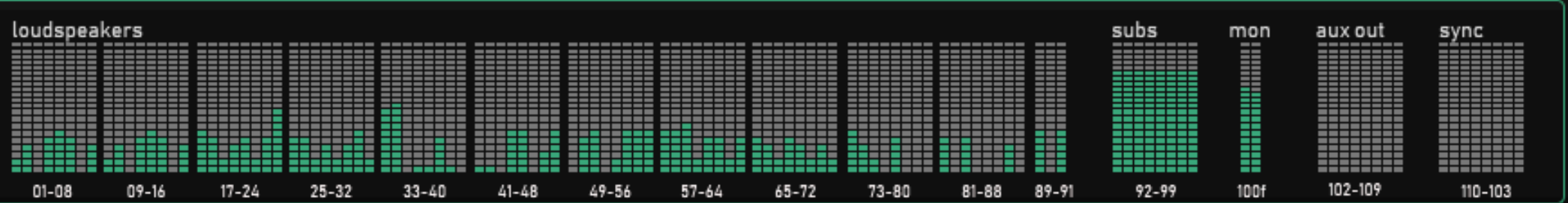
play stop

0.0 dB

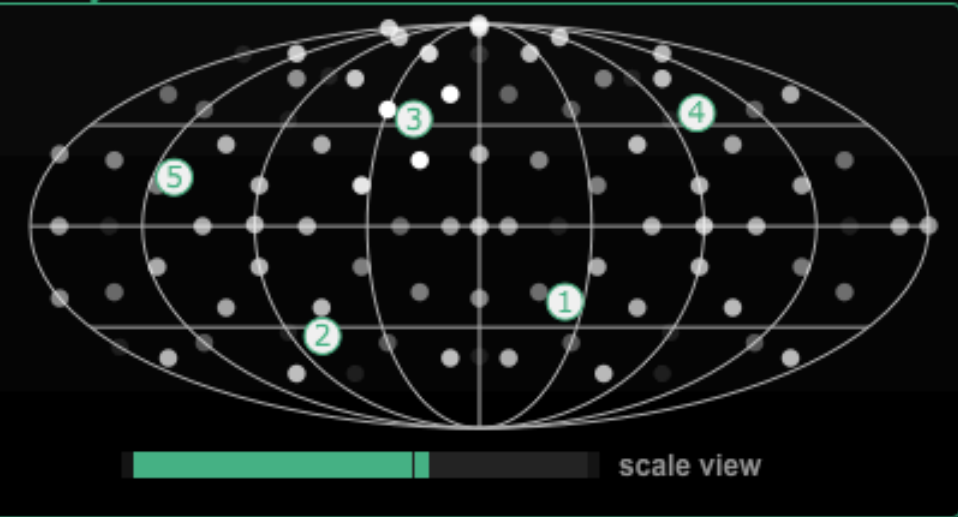
loop

delete

Level Meter



Array Overview



Gains

Main

live room on

0.00

level

live on

subs on

Monitor

binaural

0.00

level

output

Talkback

0.00

on

from live room

0.00

on

to live room

Bass Management

0.0

level

mono

pan mode

omni

directivity

Object Settings

3

Transients

add cue

Set ID	Filename	Playback	
1	drums002.wav	play stop	delete 0.0 dB
2	drums003.wav		
3	drums004.wav		
4	drums005.wav		
5	drums006.wav		
6	drums007.wav		
7	drums008.wav	play stop	delete 0.0 dB
8	drums009.wav	play stop	delete 0.0 dB
9	drums010.wav	play stop	delete 0.0 dB
10	bongos001inv.wav	play stop	delete 0.0 dB
11	drums001.wav	play stop	delete 0.0 dB

Playback / Routing

play stop

0.0 dB

loop on

ambi

rendering method

distance

room size

room on

Panning

front

left

right

31°

azimuth

32°

elevation

channel #

Movement

disabled

start direction

0

azimuth

0

elevation

stop direction

0

azimuth

0

elevation

speed

10

azimuth

10

elevation

mode

stop

Aux Out

off

aux output channel (overrides panning)

none

pulse output channel

Experiment Workflow

1. Prepare audio files
2. Preload audio with the predefined indices to the SAC software
3. Initiate the controller program with the same parameters as SAC
4. For each trial, prepare an entire scene (set the objects locations, gains, select cues, etc.) then play the scene

Programming

Stimuli Preparation and Preloading

- You need to manually make your scenes, objects, and preload your cue and atmo audio files.
 - It should be done in **one seating** as saving does not overwrite properly
- Each scene can have only 1 atmo file
- Each object can have up to 100 cues

Programming

Trigger Communication

- There are 4 channels of sync pulse channels (2 verified to be functional and accurate that send a pulse when an object is played)

Python Module

github.com/NimaZN/AudioDome_Module

