Virtual Soundscapes & the AudioDome

Center for Brain and Mind: Methods Lunch
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Nima Zargarnezhad
nzargarn@uwo.ca

AudioDome

Acknowledgements

Derek Quinlan

Karsten Babin

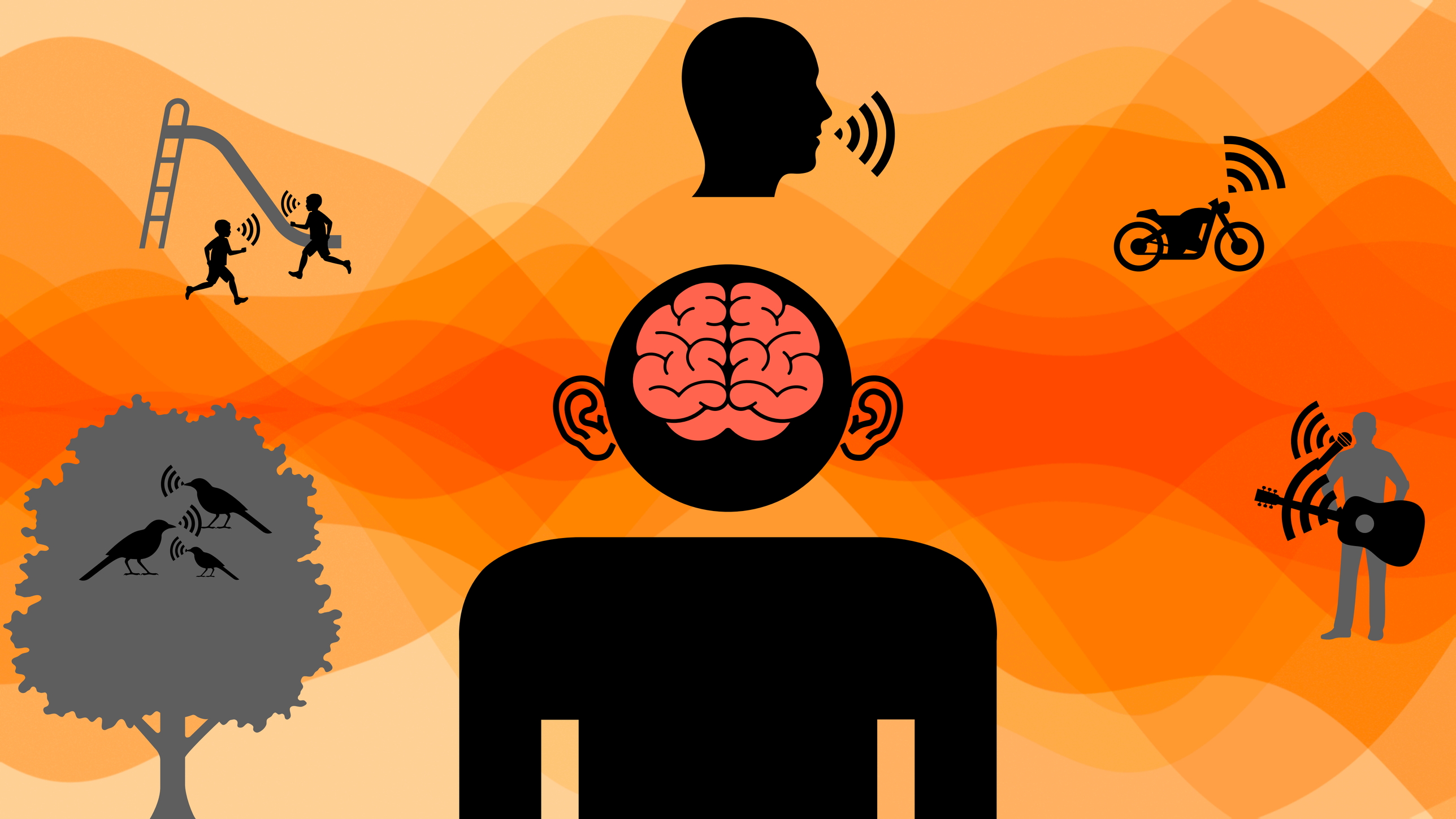
Ewan Macpherson

Ingrid Johnsrude

Bruno Mesquita

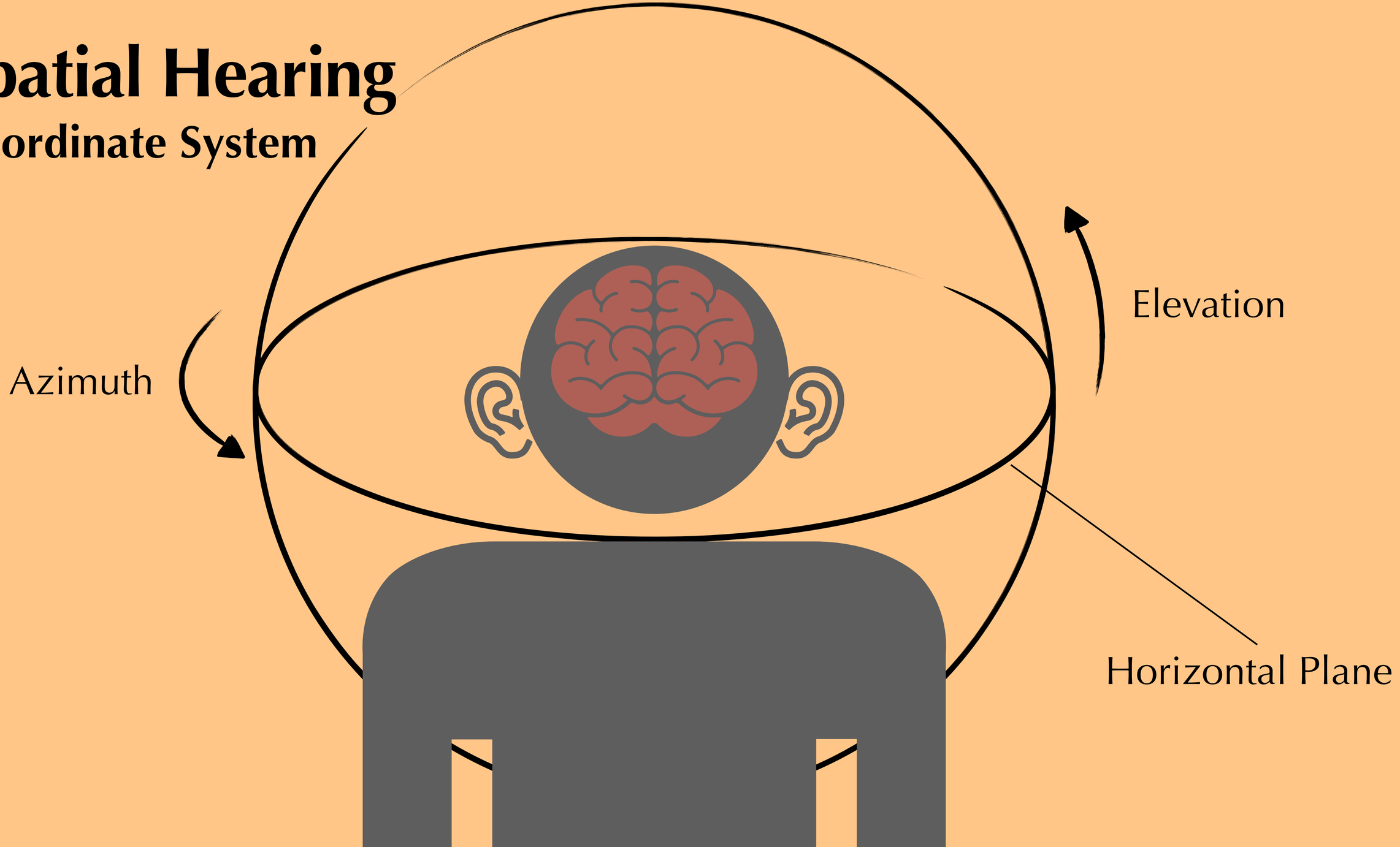
Part I: Fundamentals

What exactly is the AudioDome capable of?



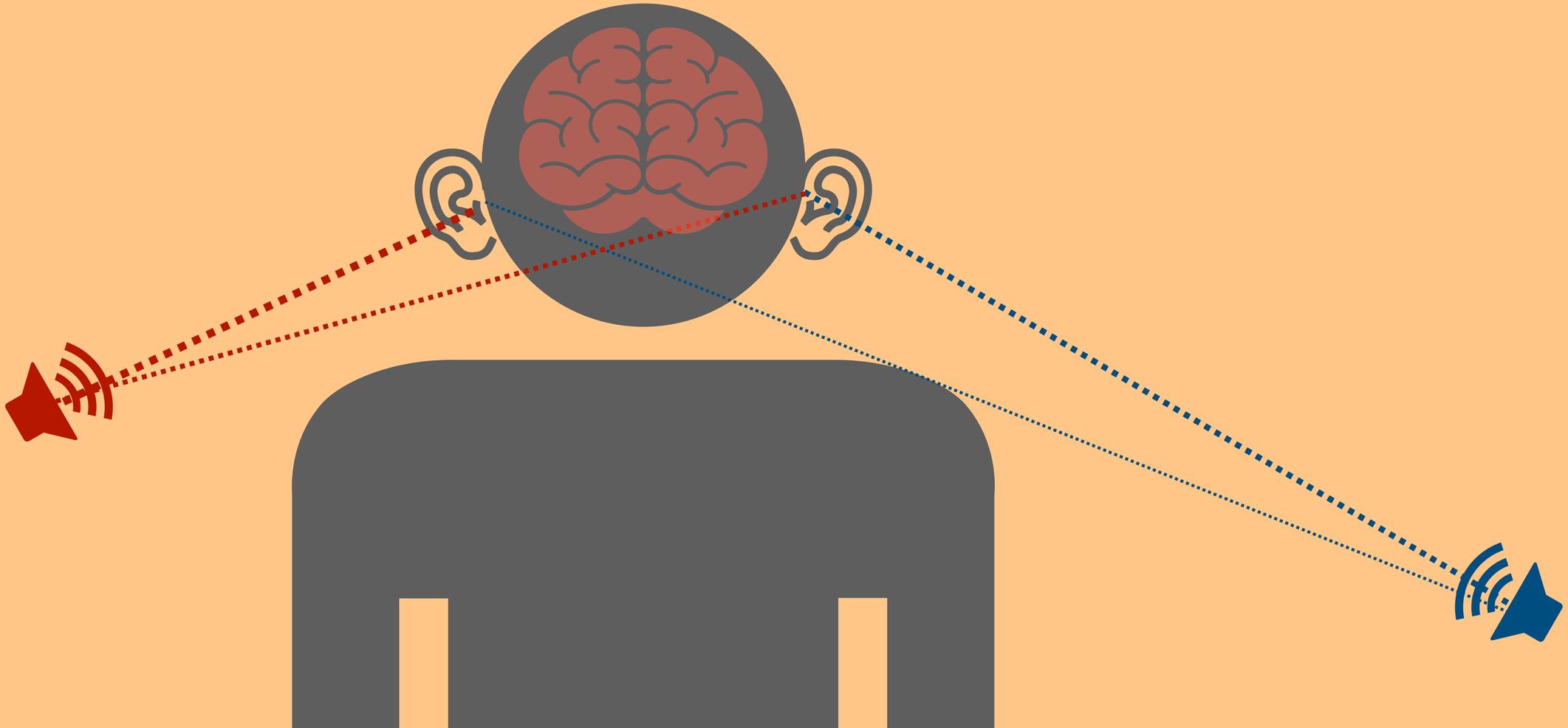
Spatial Hearing

Coordinate System



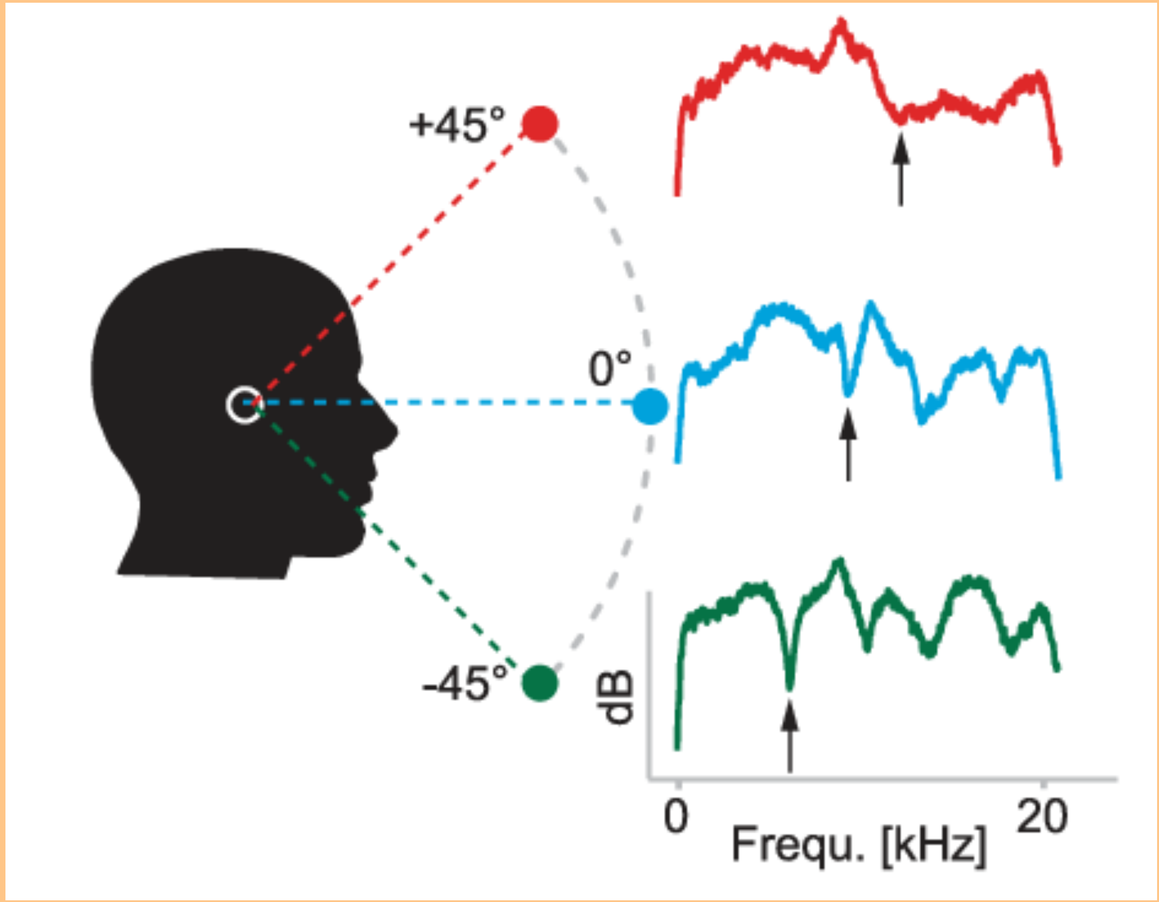
Spatial Hearing

Binaural Localization Cues



Spatial Hearing

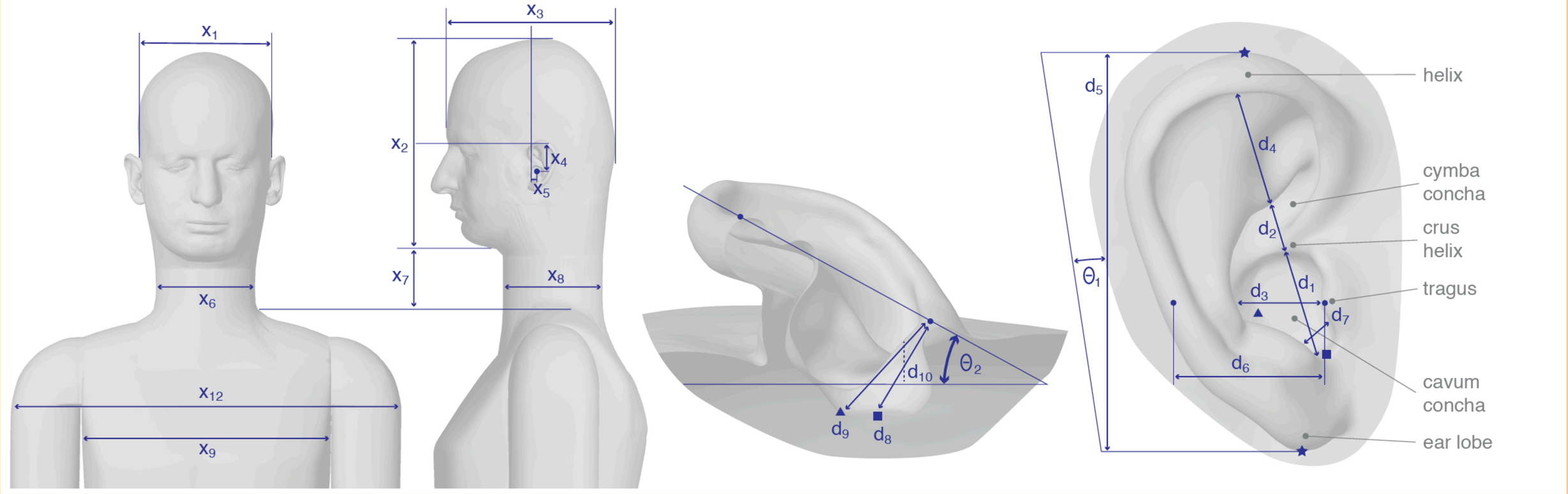
Spectral Cues



(Grothe et al., 2010)

Spatial Hearing

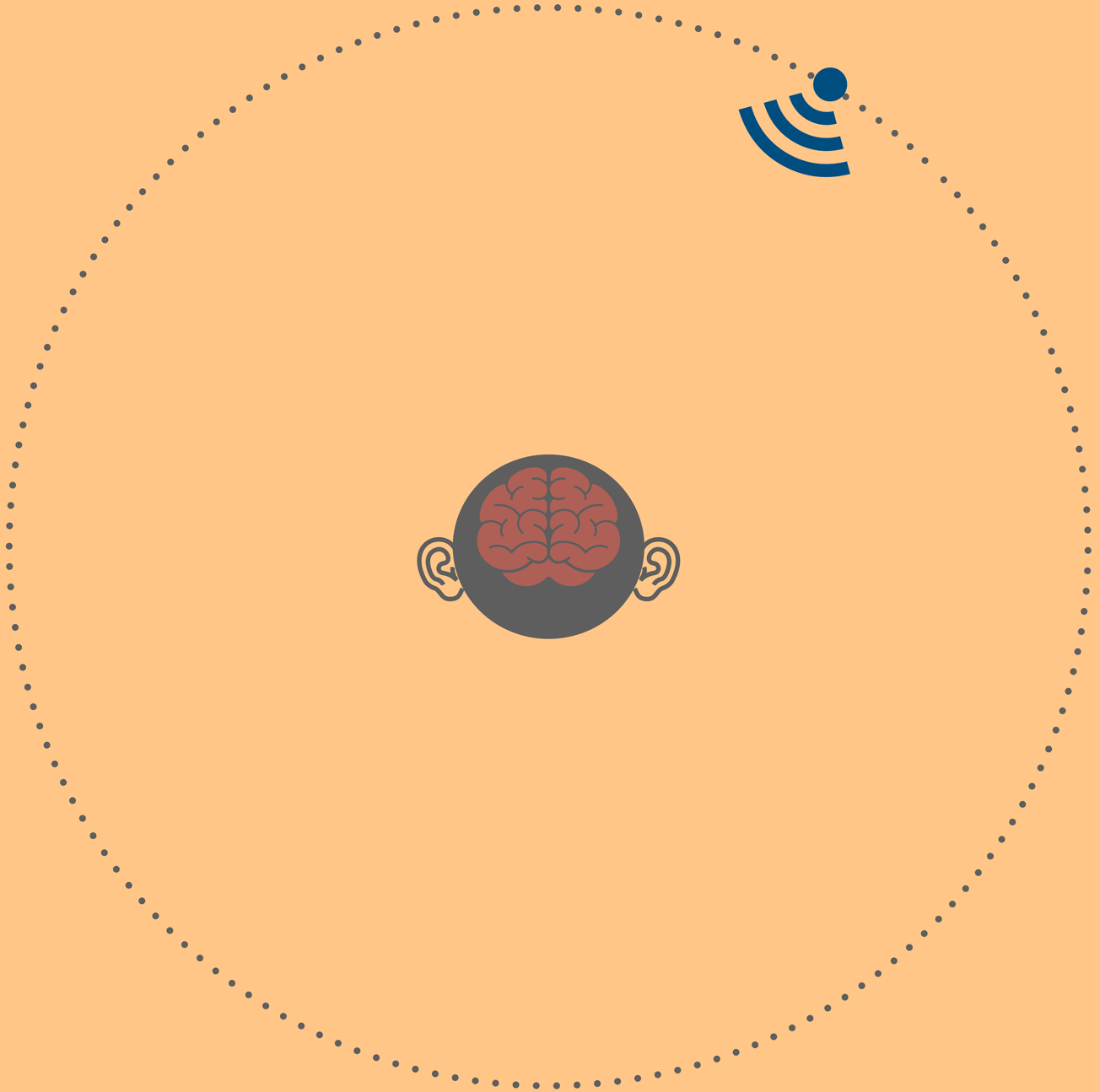
Head-Related Transfer Function and Individual Variability



(Fabian et al., 2019)

Virtual Auditory Environments

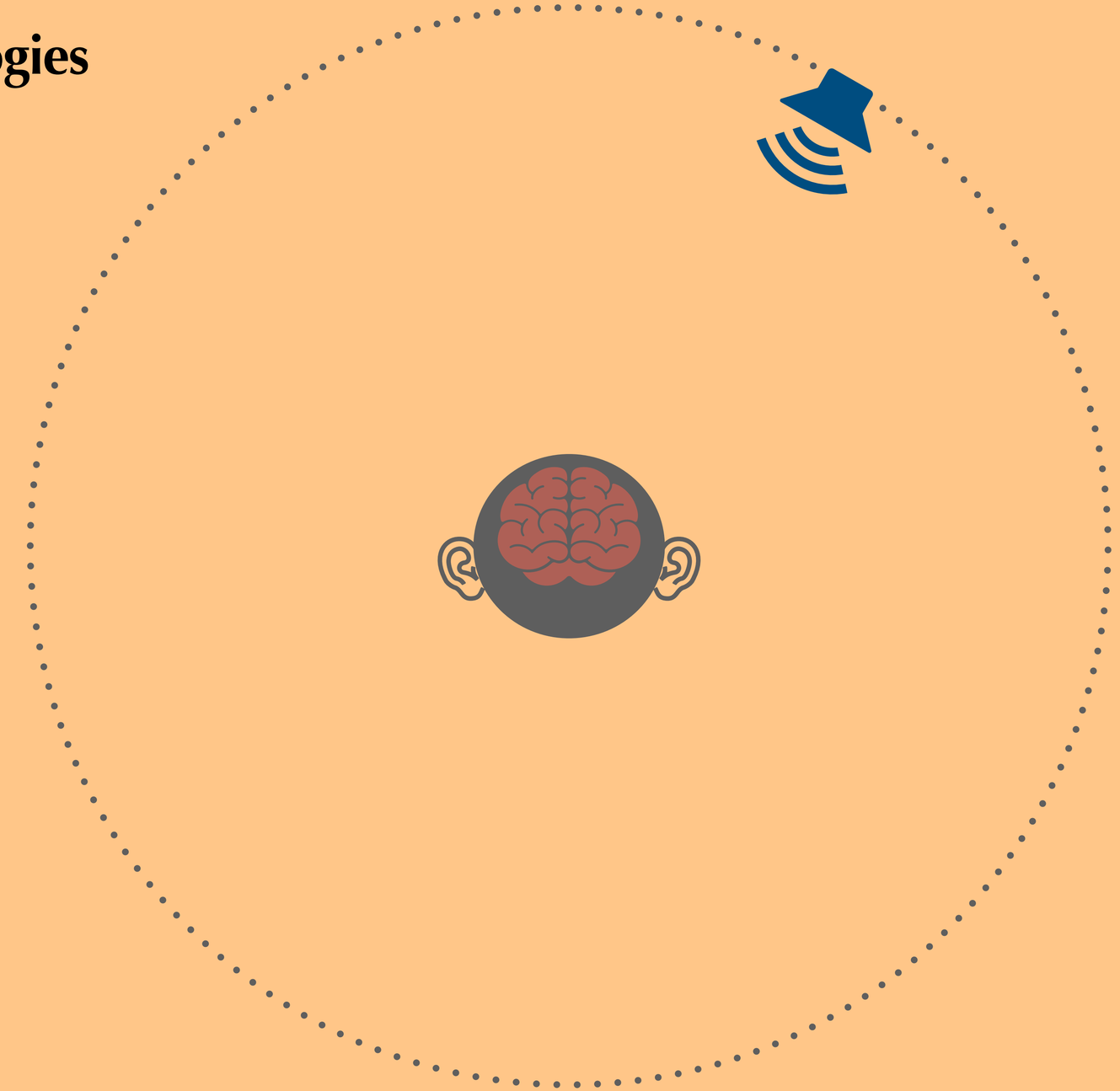
A Virtual Sound Source



Horizontal Plane

Virtual Auditory Environment Technologies

Single-Channel (SC) Presentation

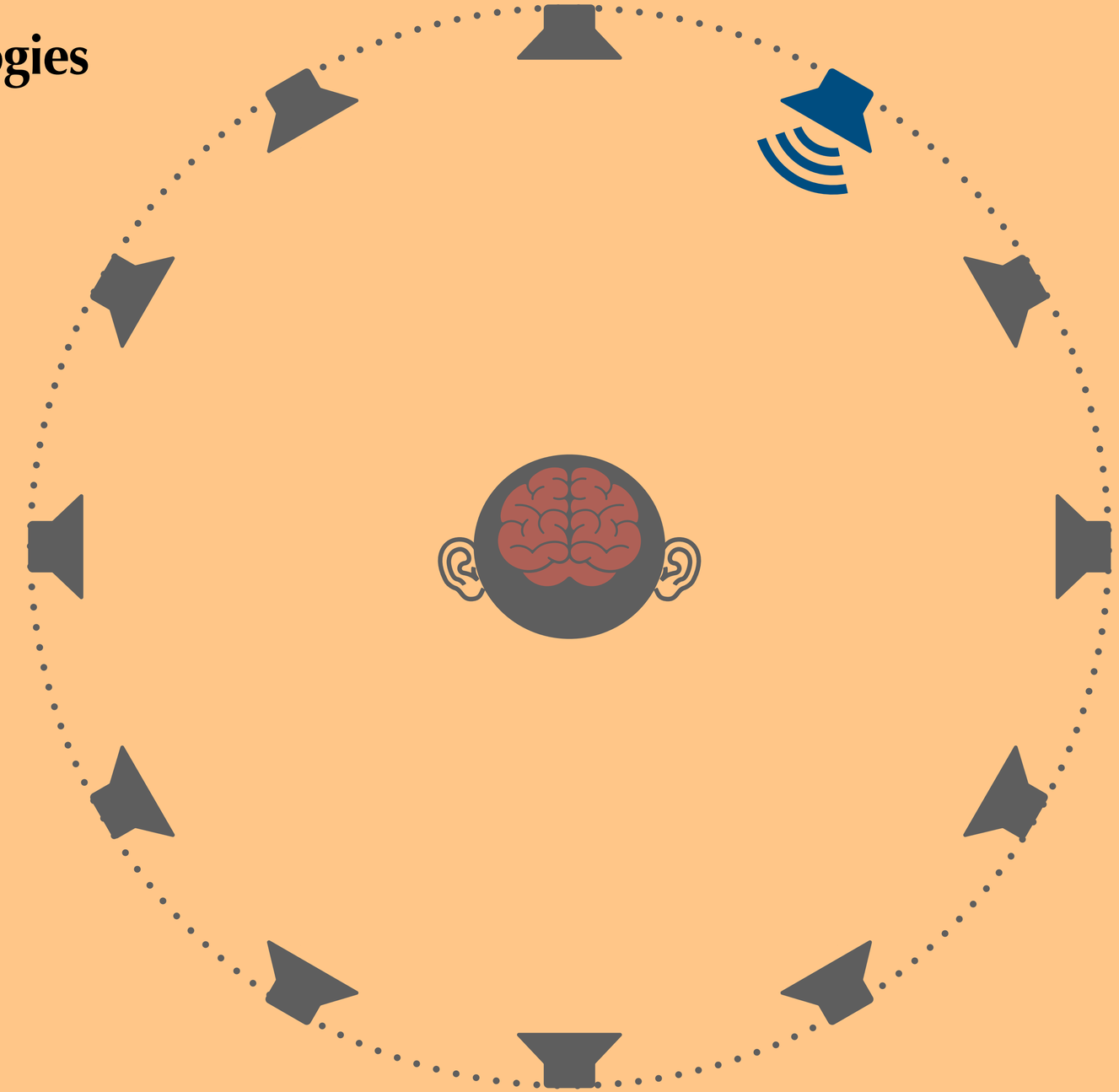


Horizontal Plane

Virtual Auditory Environment Technologies

Single-Channel (SC) Presentation

✔ Precisely focal sound sources



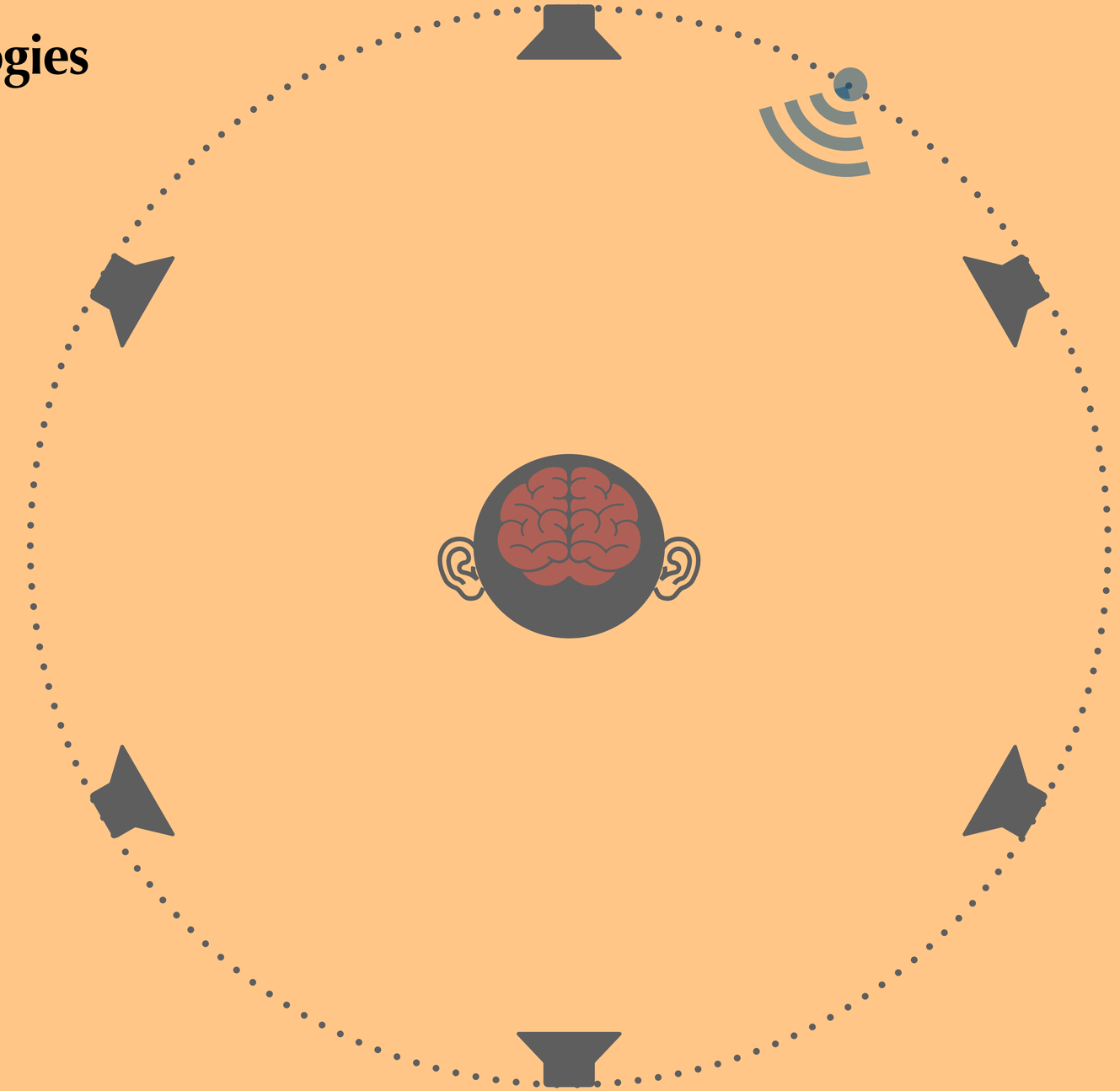
Horizontal Plane

Virtual Auditory Environment Technologies

Single-Channel (SC) Presentation

✓ Precisely focal sound sources

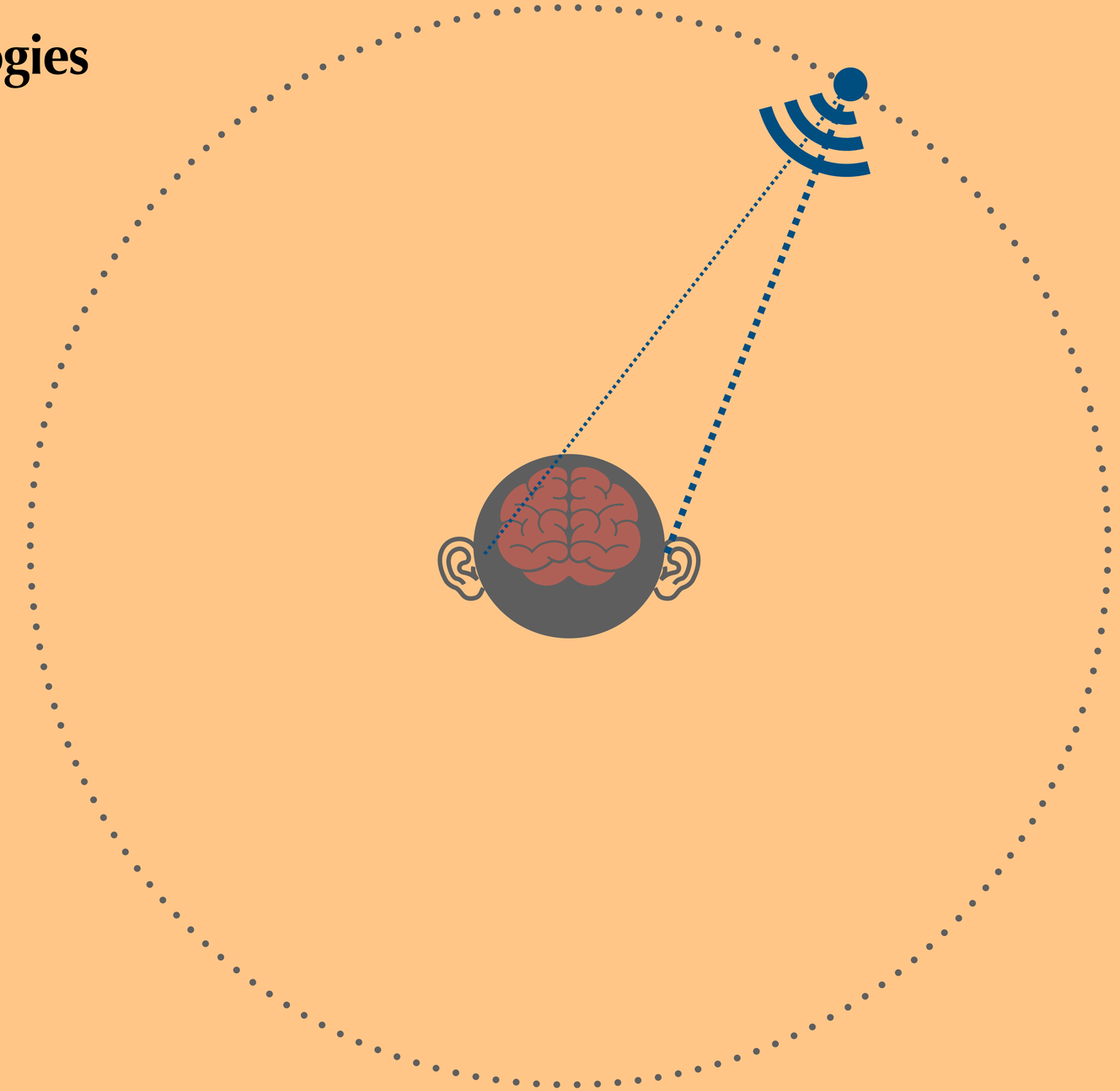
✗ Resolution limited to the location and number of channels



Horizontal Plane

Virtual Auditory Environment Technologies

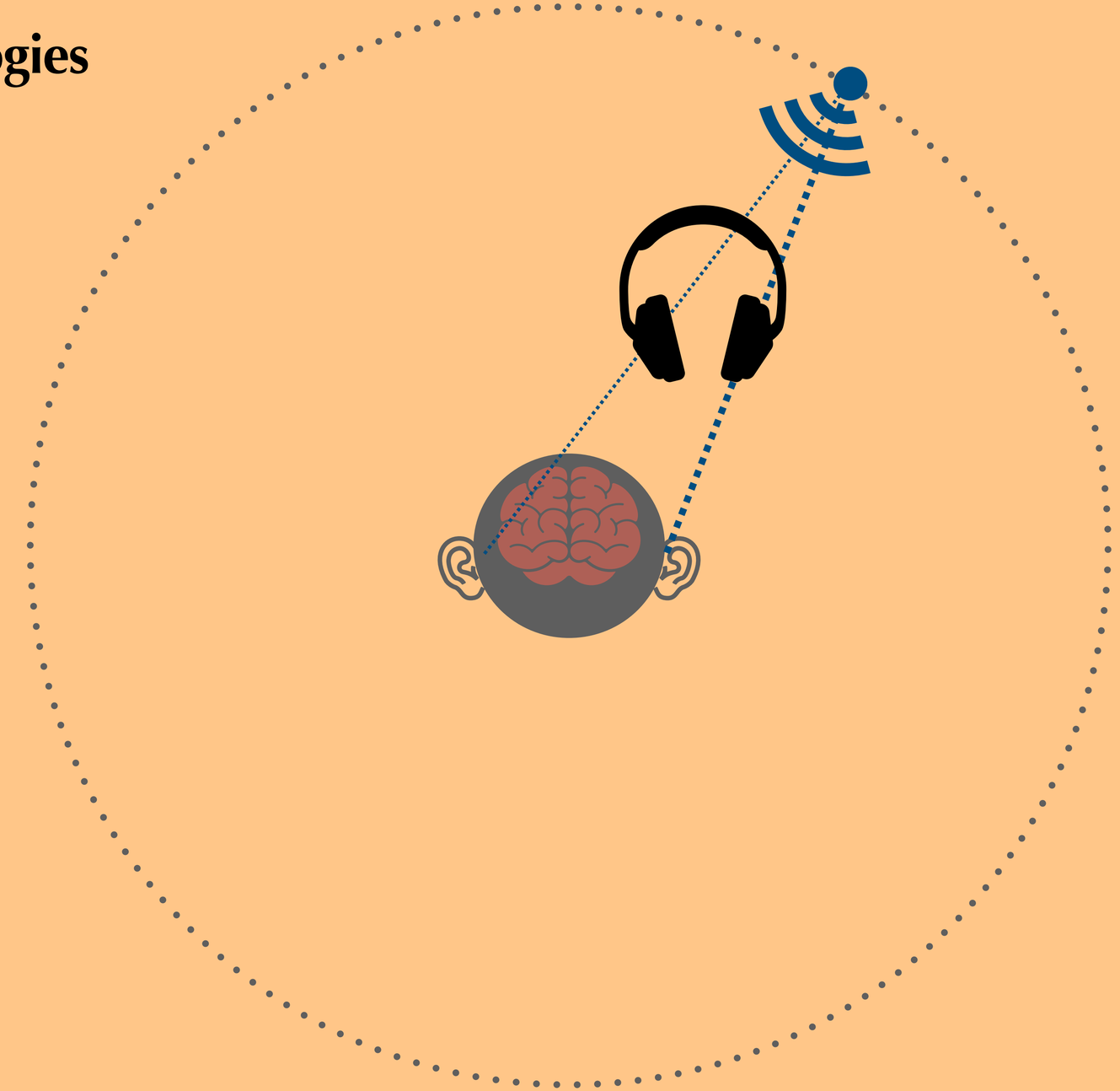
Stereo Headphones



Virtual Auditory Environment Technologies

Stereo Headphones

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

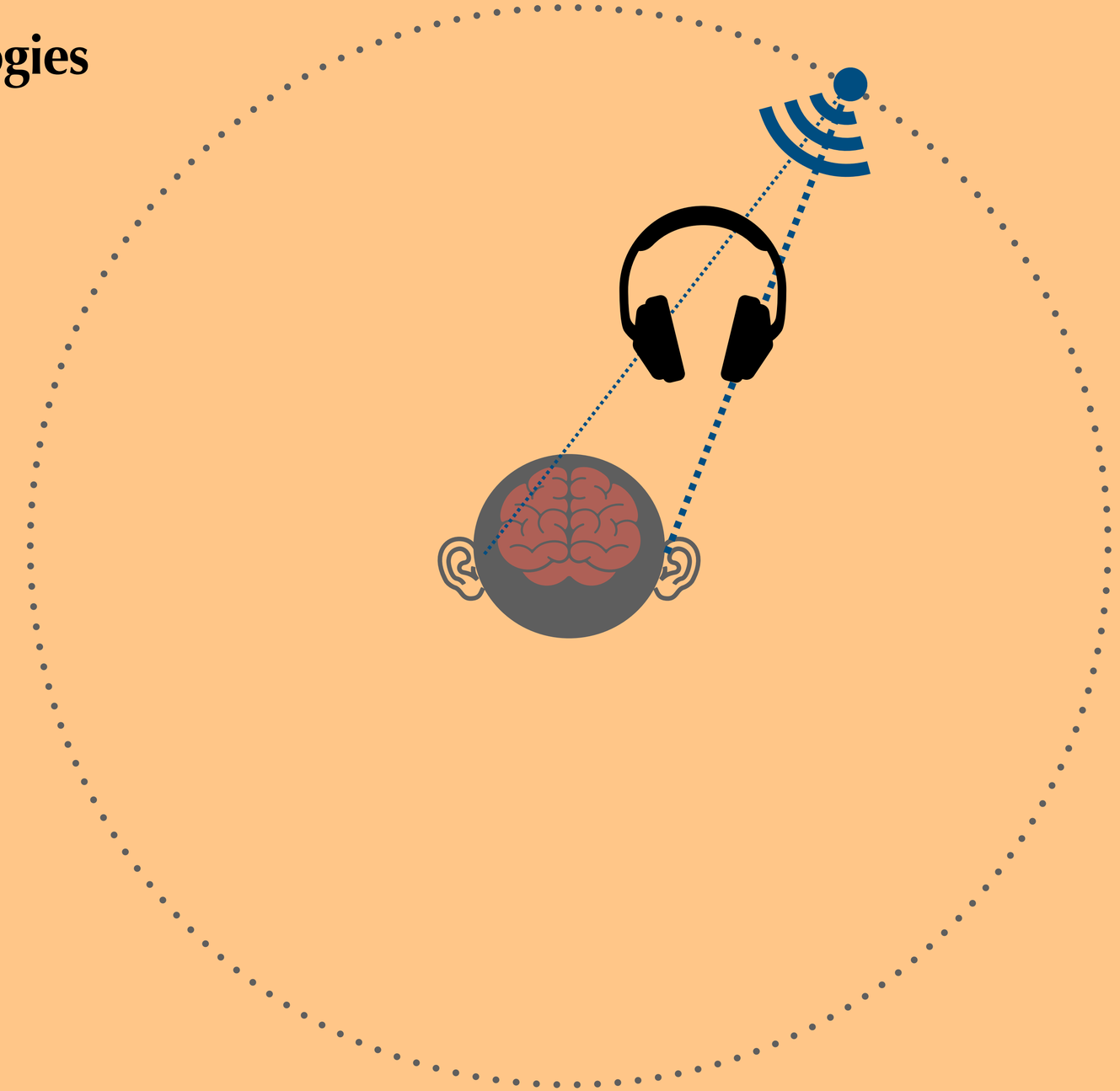


Horizontal Plane

Virtual Auditory Environment Technologies

Stereo Headphones

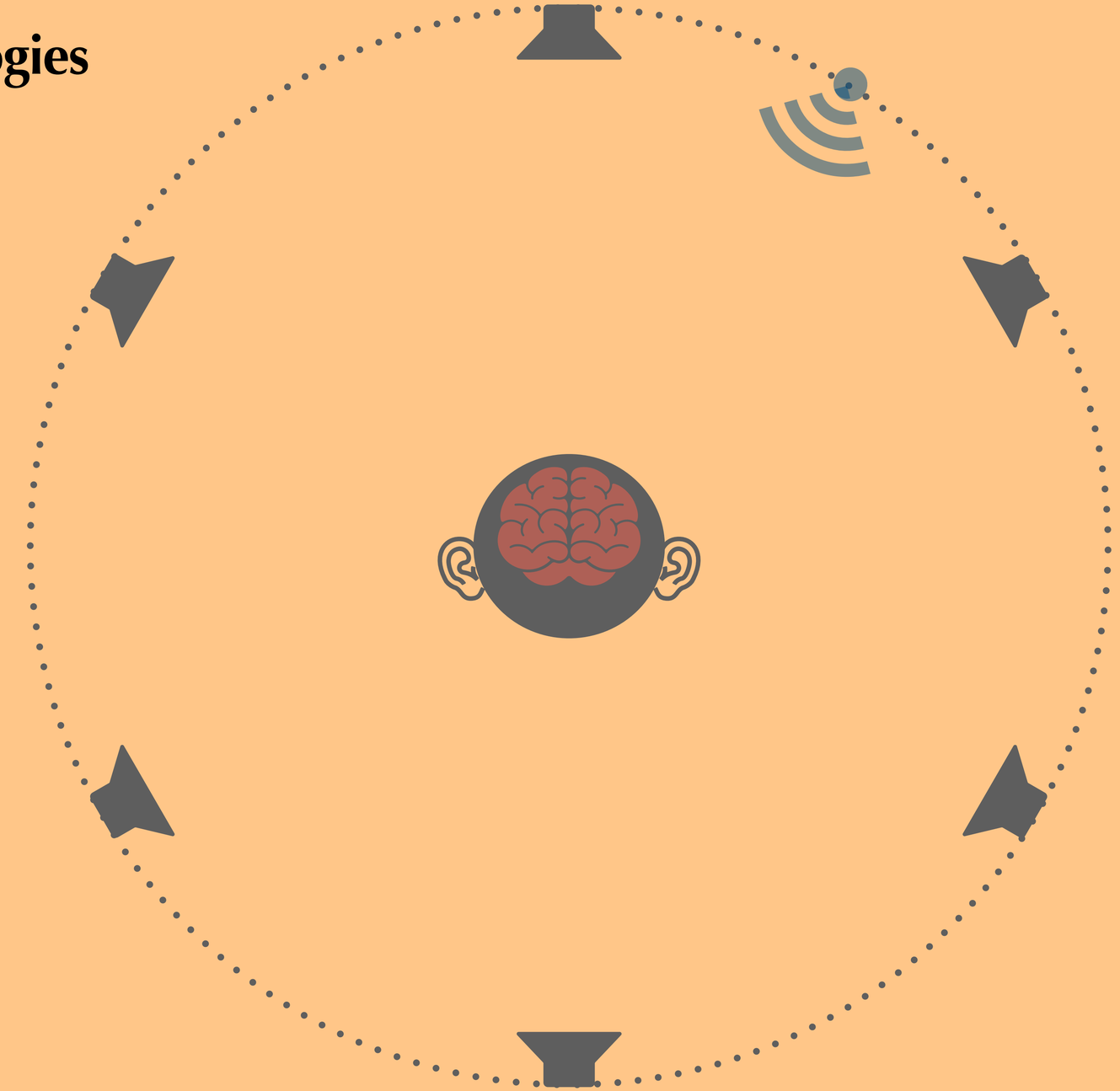
- ✓ Infinite spatial resolution
- ✓ Accessible, affordable, and portable
- ✗ Requires HRTF estimates/models
- ✓ Perfect for fully lateralized scenarios
- ✗ Source location does not update as the listener moves their head



Horizontal Plane

Virtual Auditory Environment Technologies

Vector-Based Amplitude Panning (VBAP)

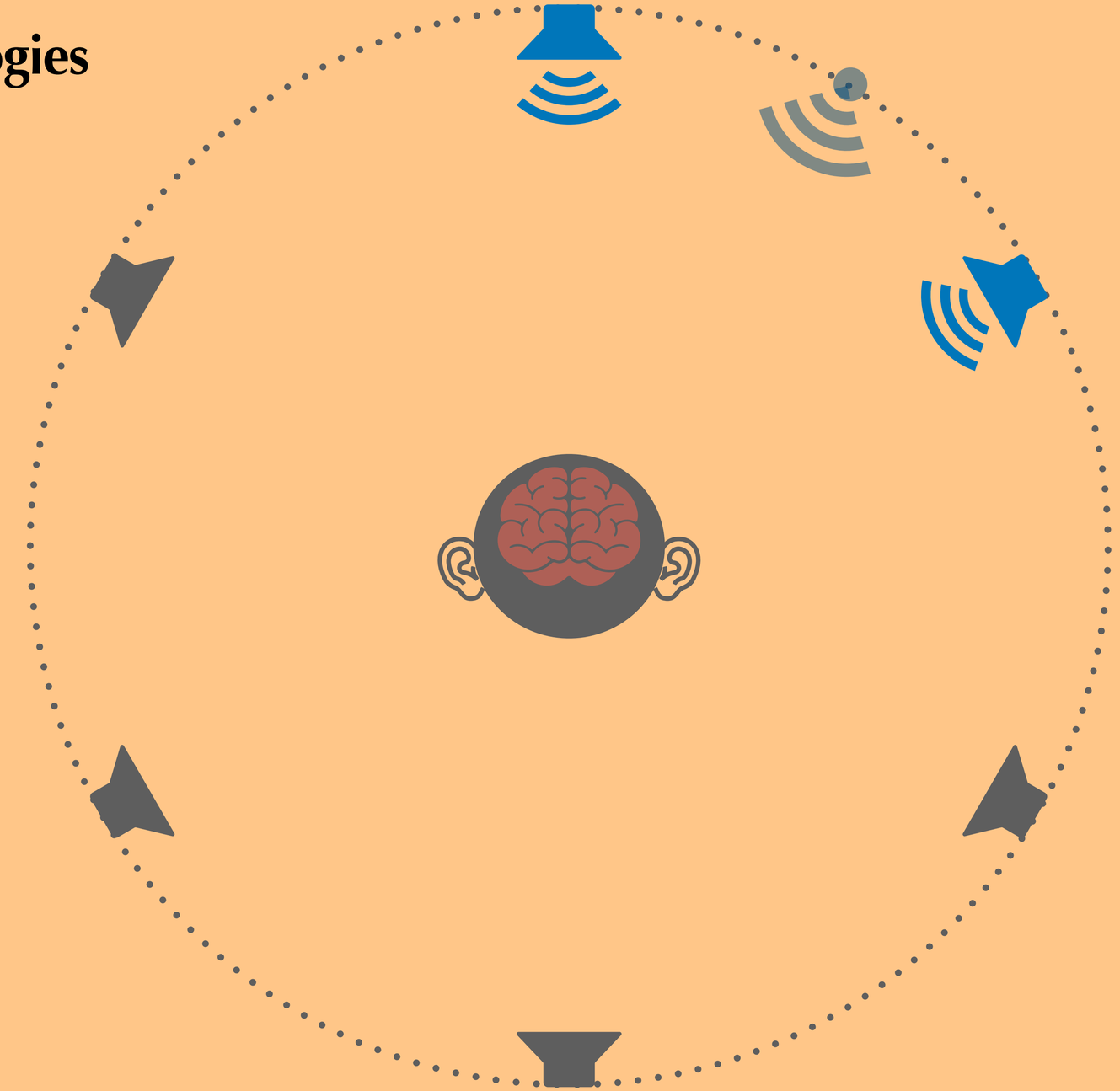


Horizontal Plane

Virtual Auditory Environment Technologies

Vector-Based Amplitude Panning (VBAP)

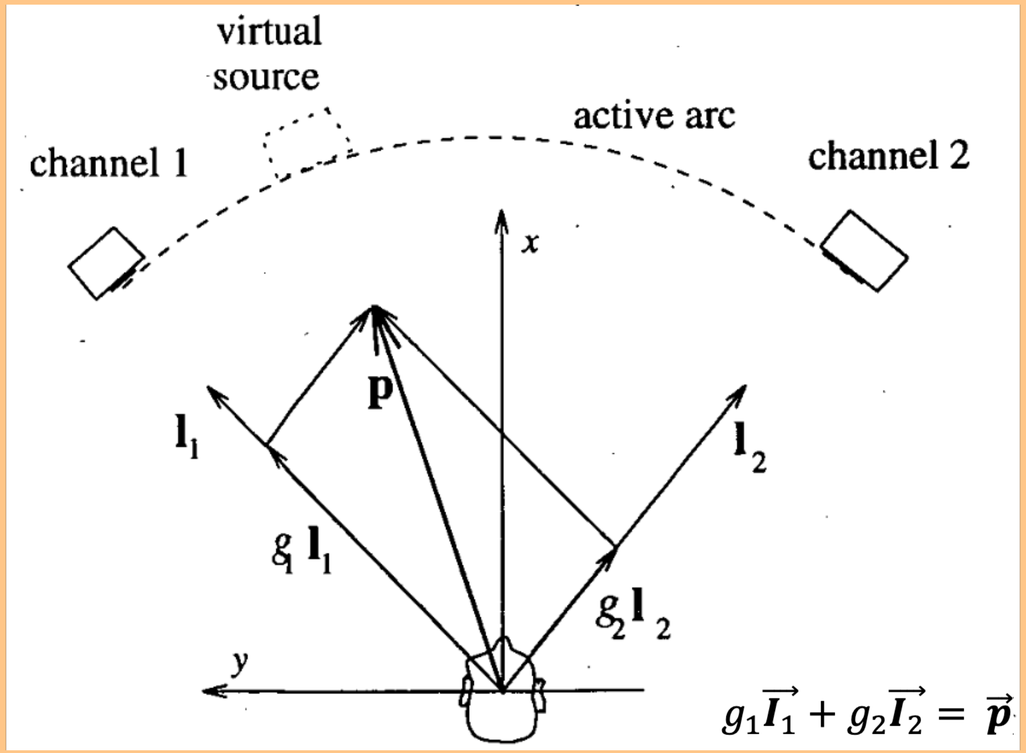
✓ No HRTF estimation required; all listeners will hear with their own ears!



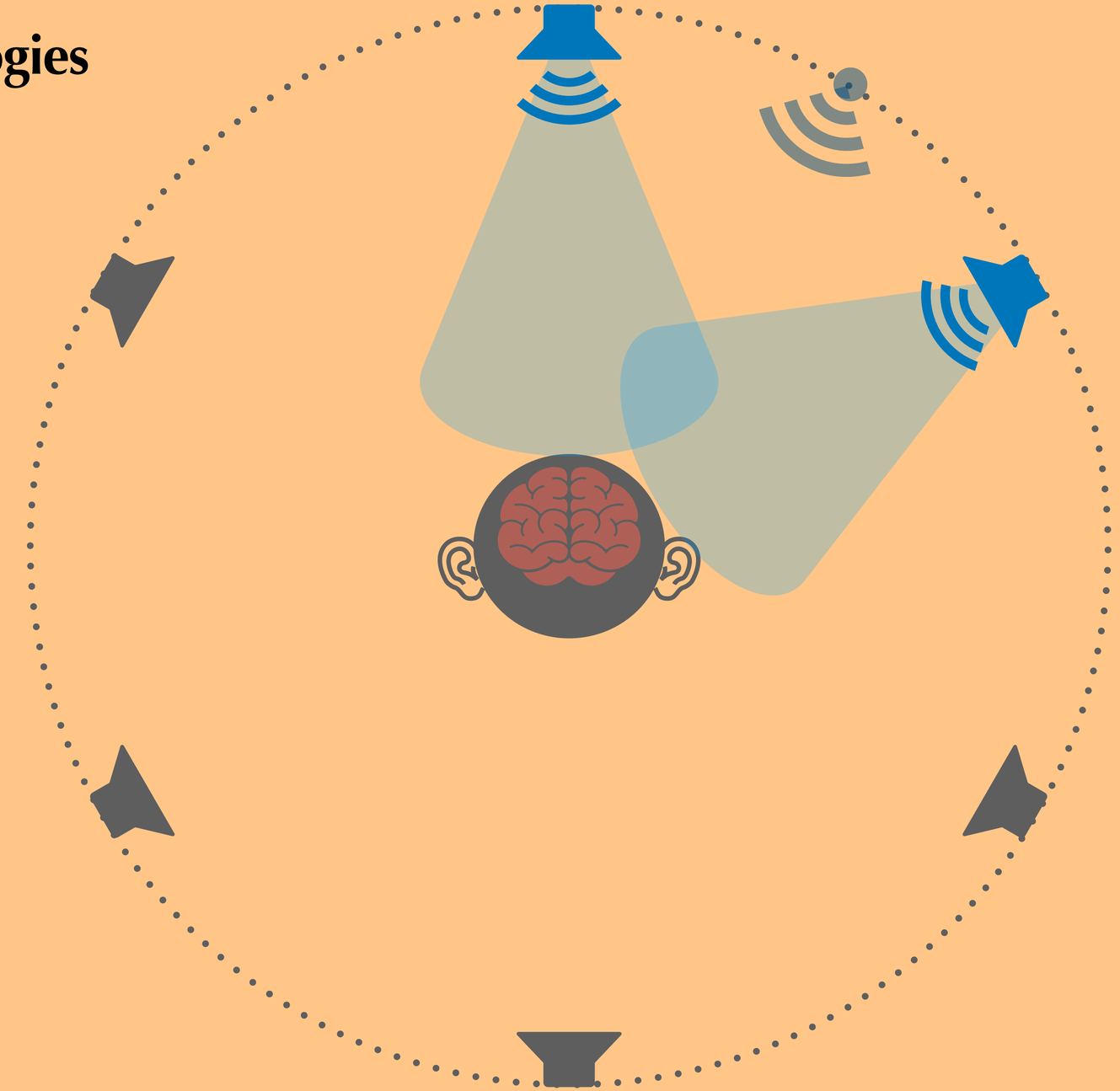
Horizontal Plane

Virtual Auditory Environment Technologies

Vector-Based Amplitude Panning (VBAP)



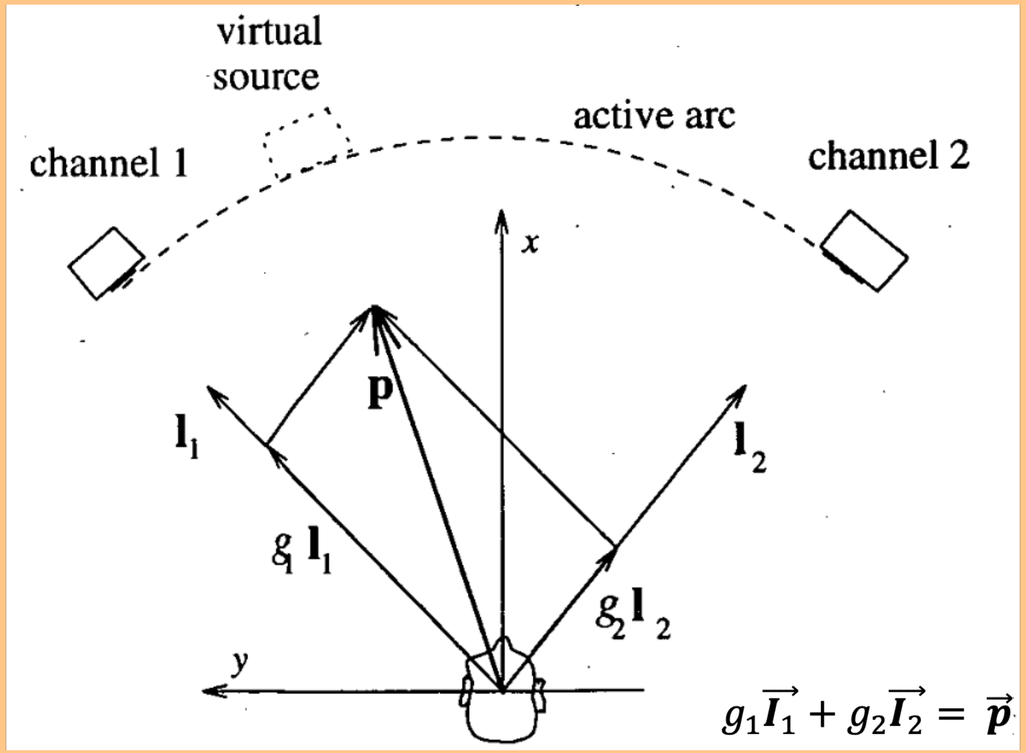
(Pulkki, 1997)



Horizontal Plane

Virtual Auditory Environment Technologies

Vector-Based Amplitude Panning (VBAP)



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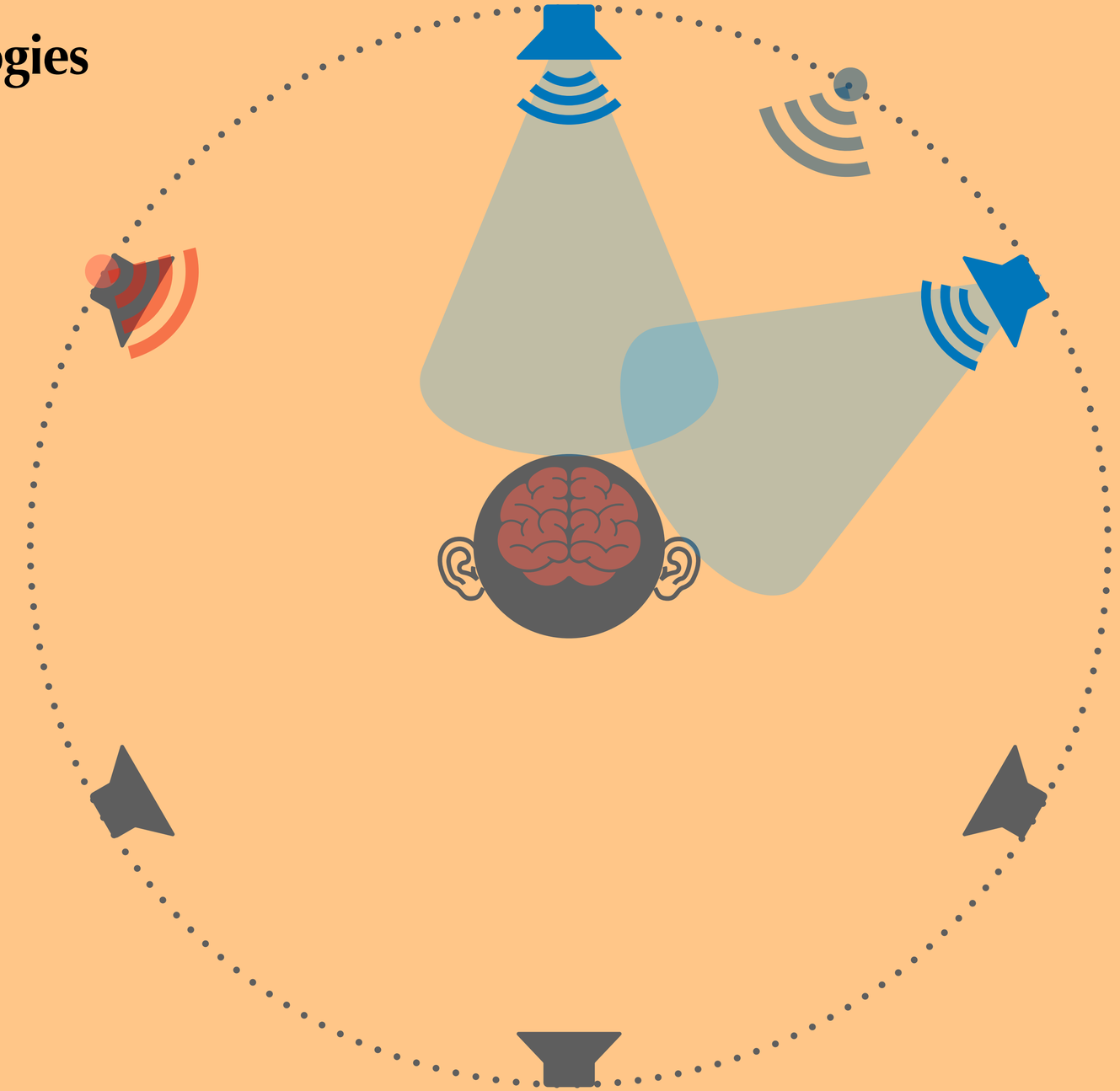
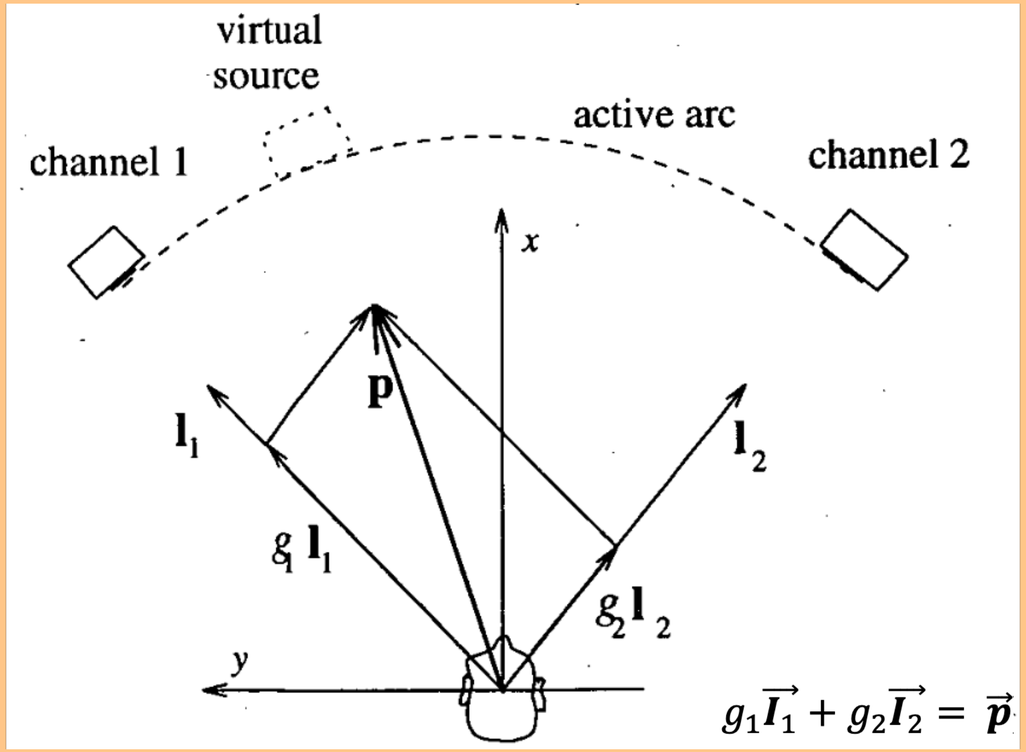


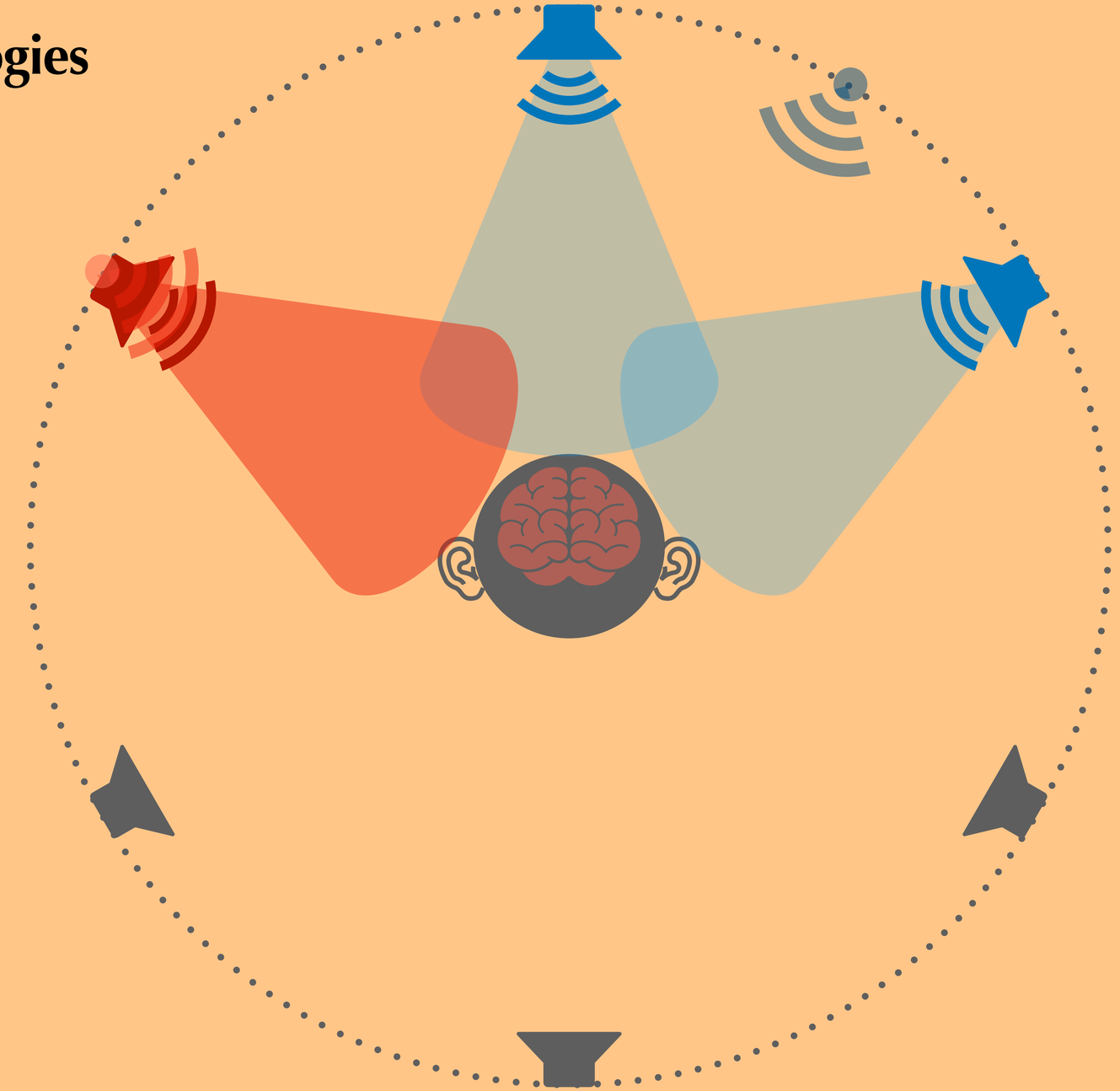
Horizontal Plane

Virtual Auditory Environment Technologies

Vector-Based Amplitude Panning (VBAP)



(Pulkki, 1997)

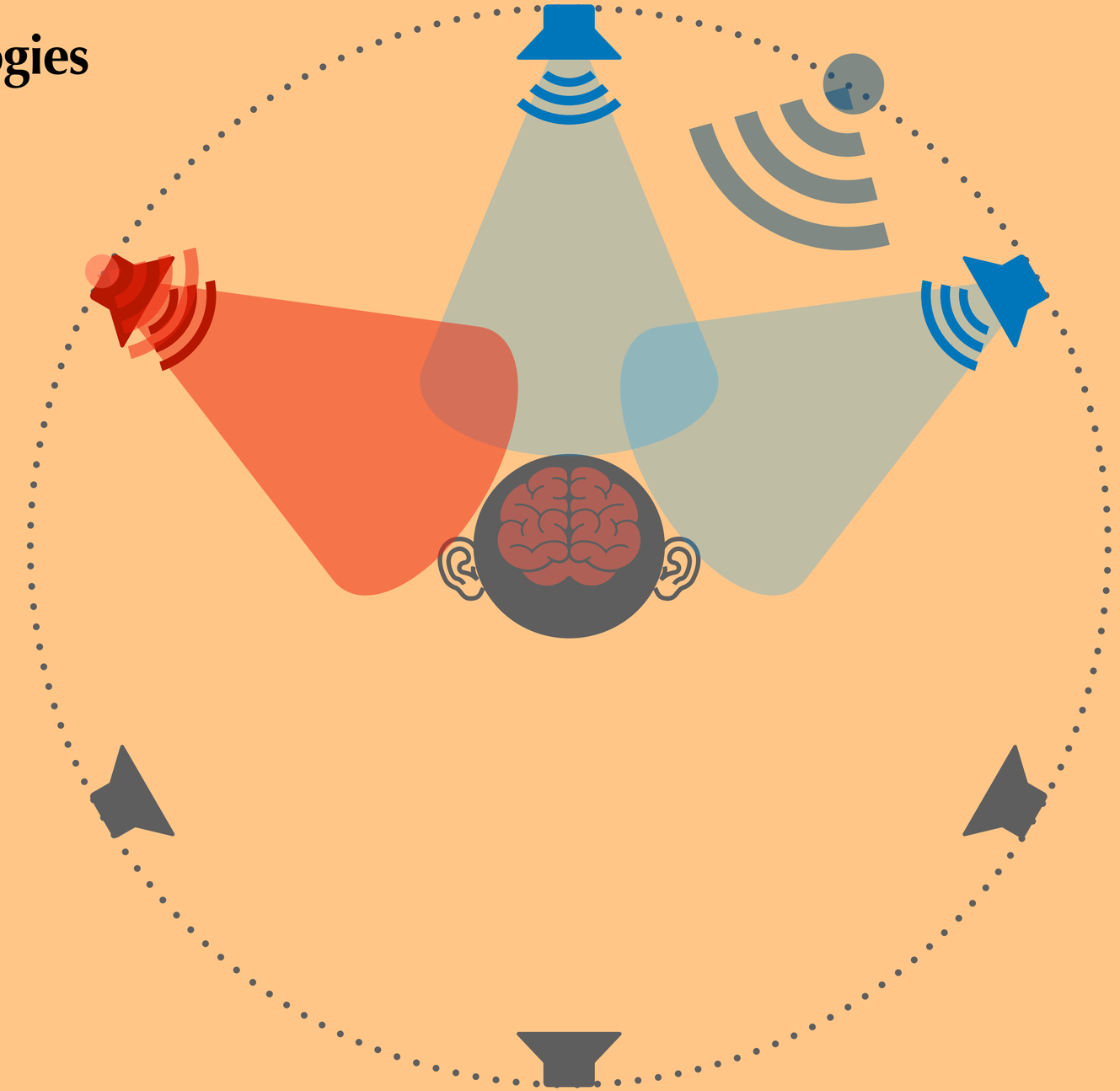


Horizontal Plane

Virtual Auditory Environment Technologies

Vector-Based Amplitude Panning (VBAP)

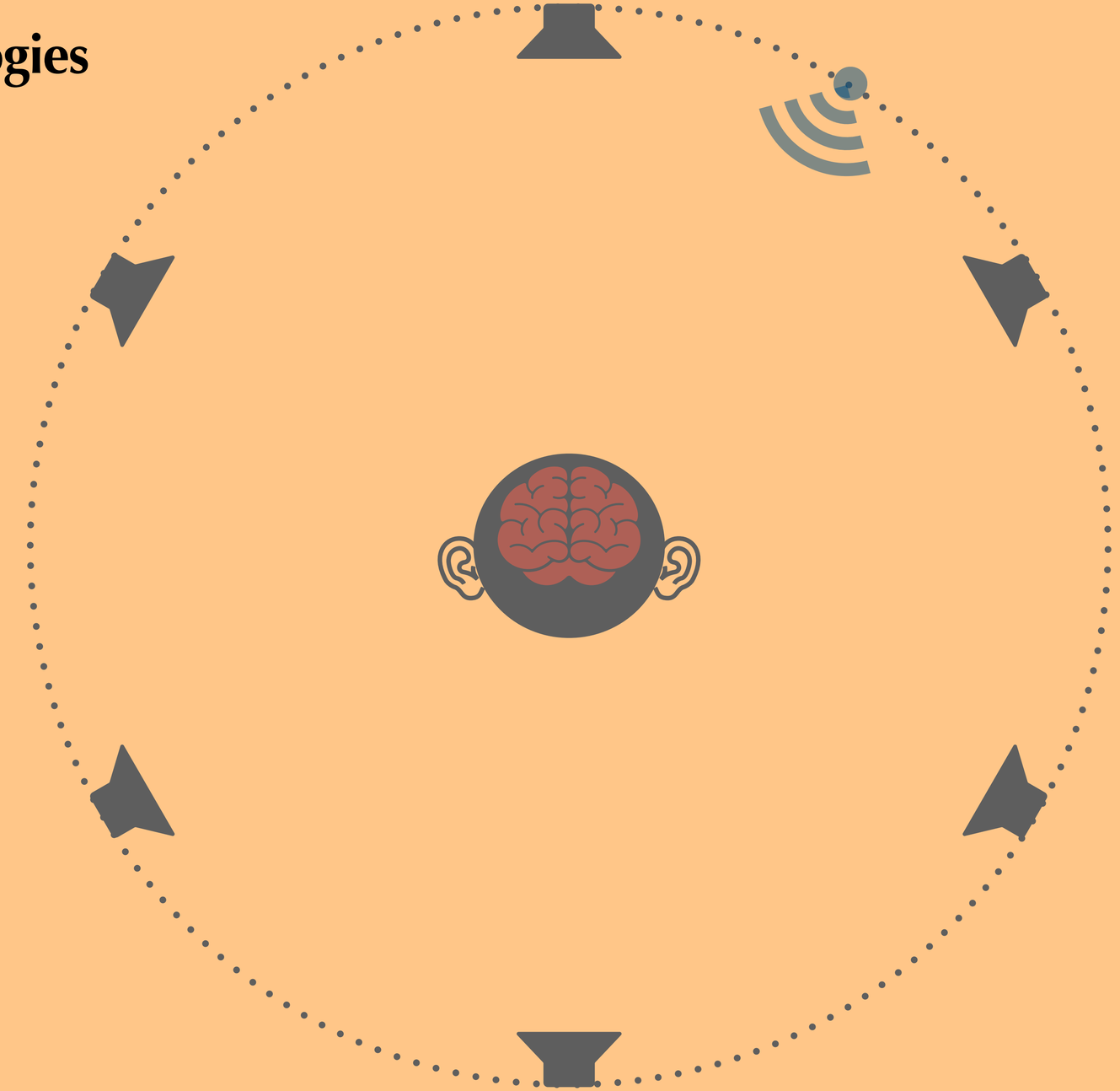
- ✓ No HRTF estimation required; all listeners will hear with their own ears!
- ✗ Virtual sound sources are perceptually blurred
- ✗ Overall blurriness depends on array configuration
- ✗ Blurriness depends on source distance from channels



Horizontal Plane

Virtual Auditory Environment Technologies

Ambisonics

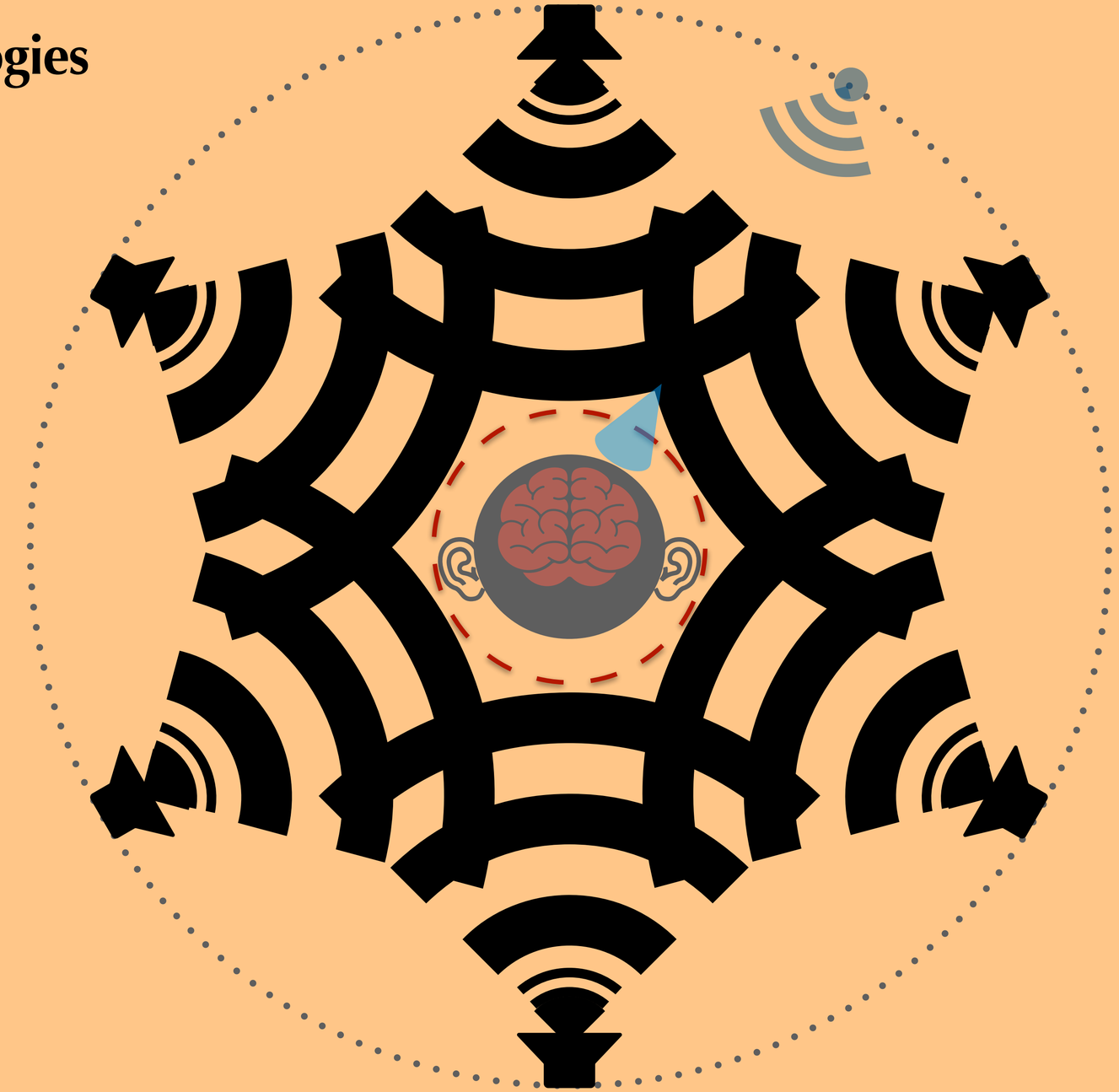


Horizontal Plane

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



Horizontal Plane

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:

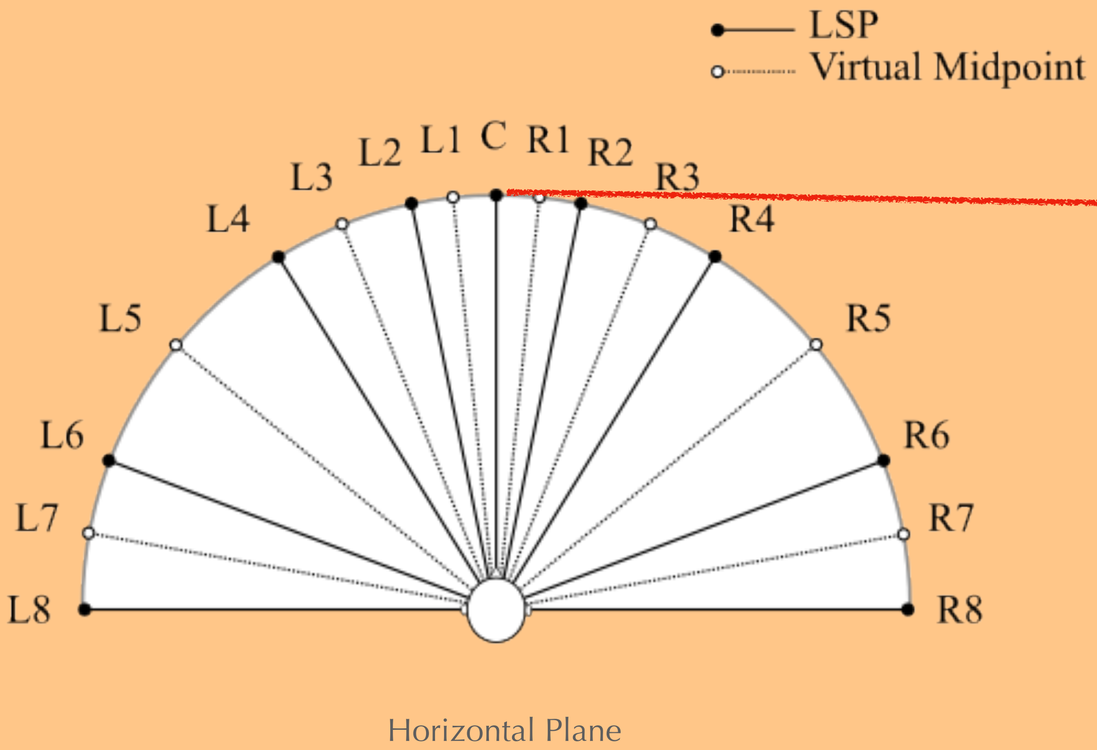
  - Manually (GUI)

    OSC commands could be sent with:

    - Python
    - MATLAB
    - Unity/C#

The AudioDome

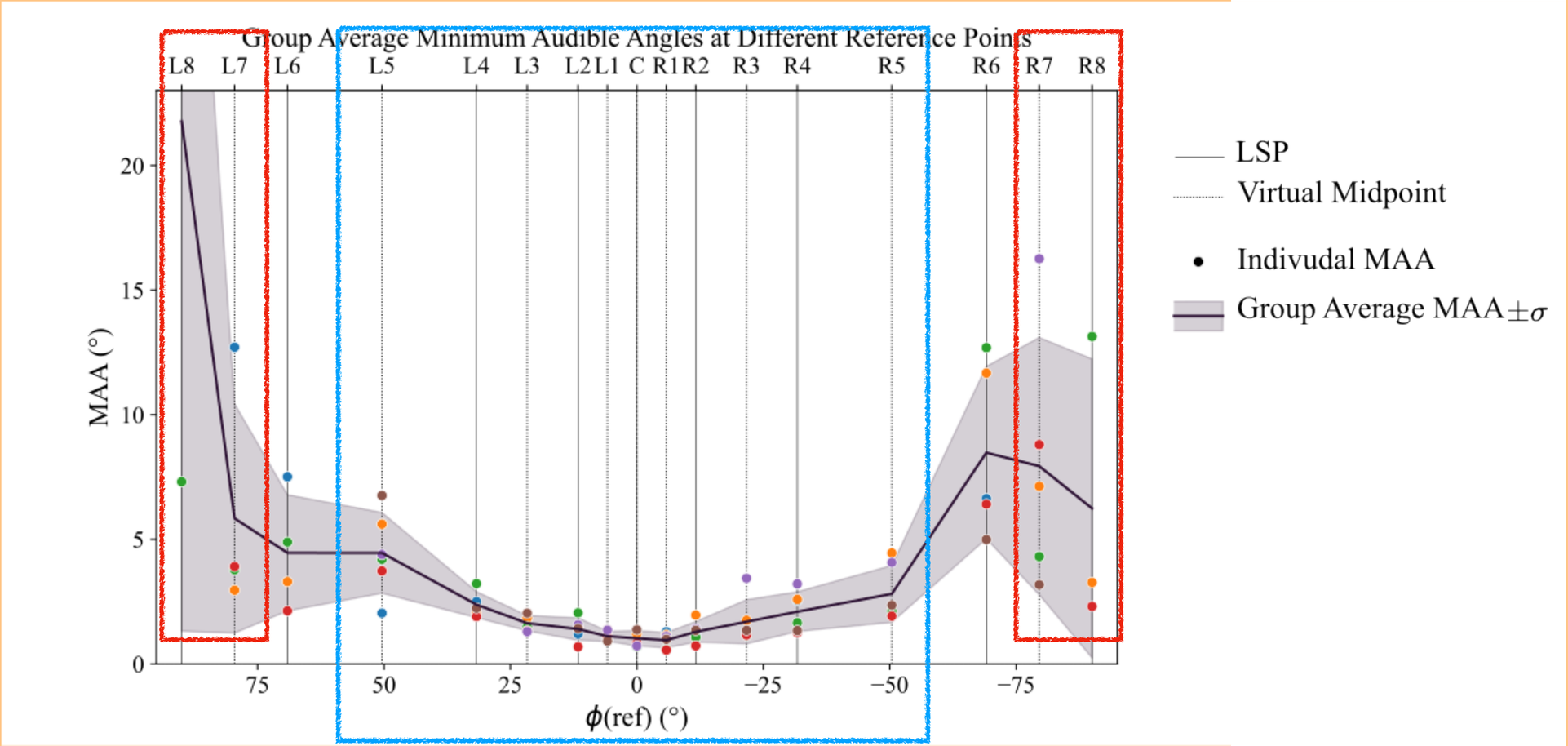
Findings



Horizontal Plane

The AudioDome

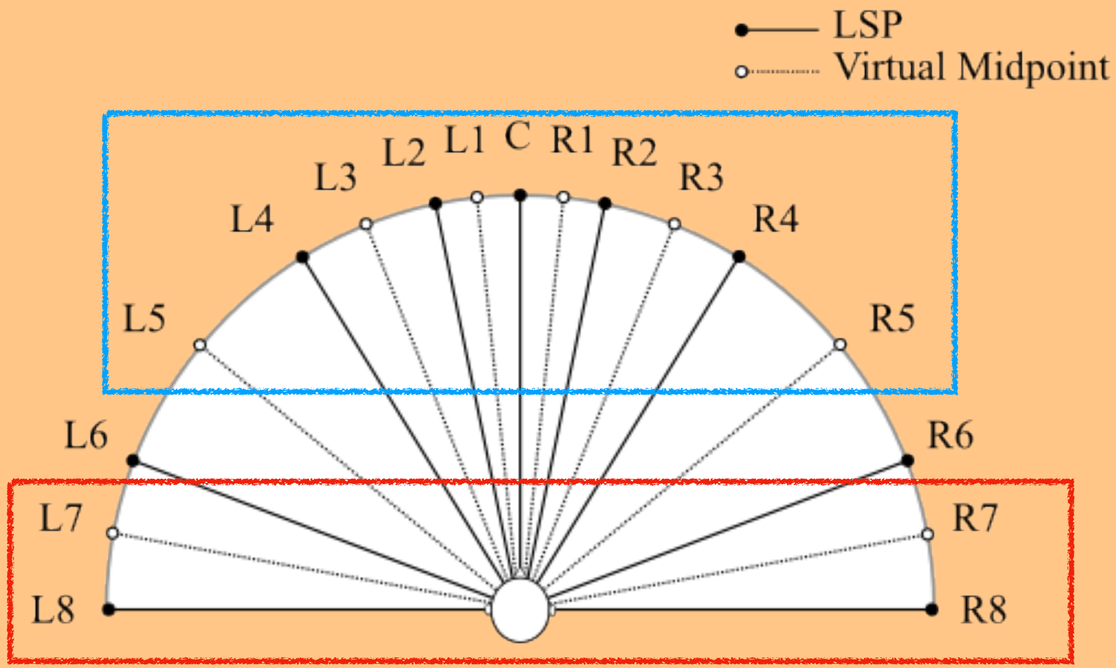
Findings



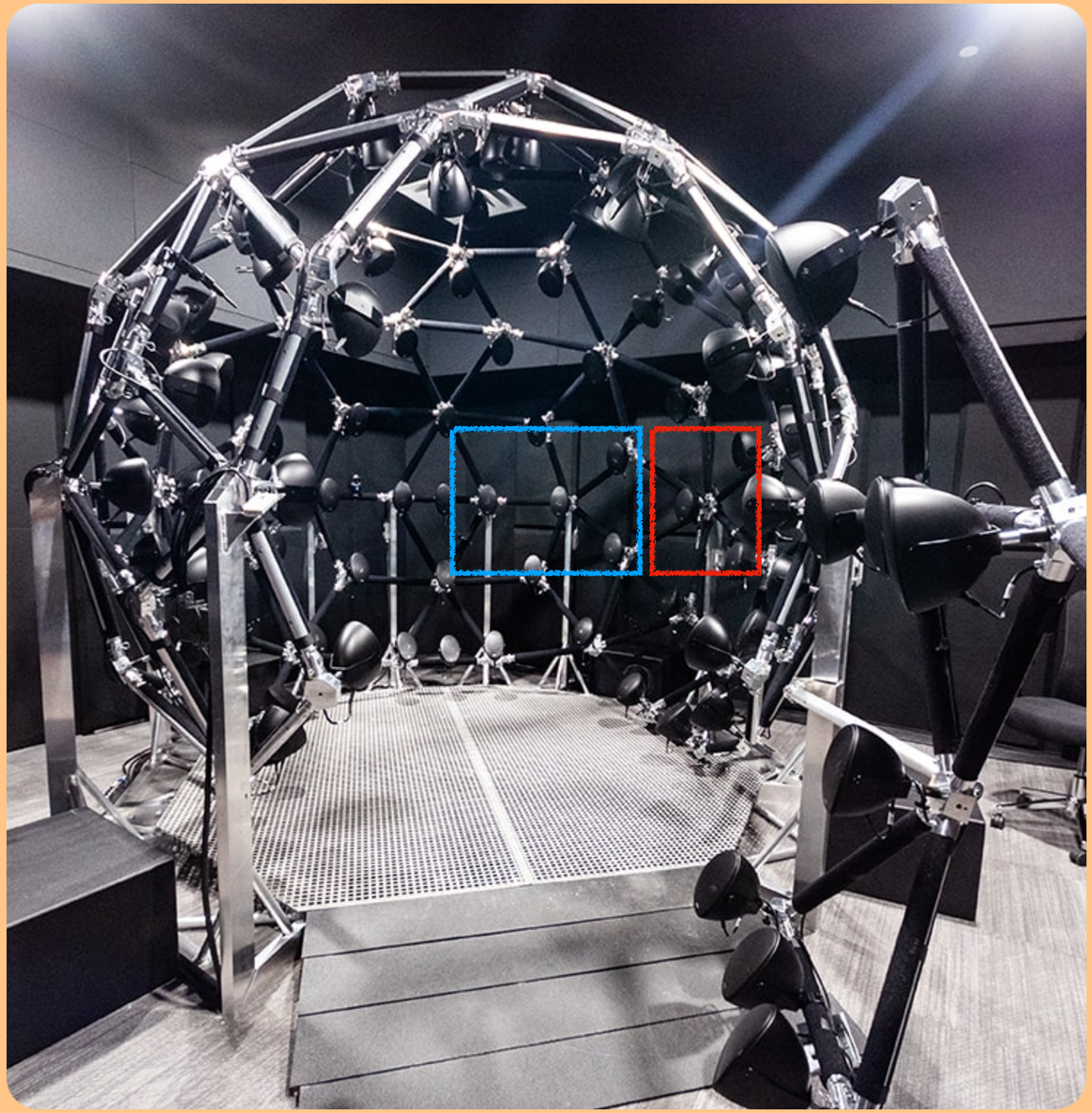
(Zargarnezhad et al., in press)

The AudioDome

Findings



Horizontal Plane



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?

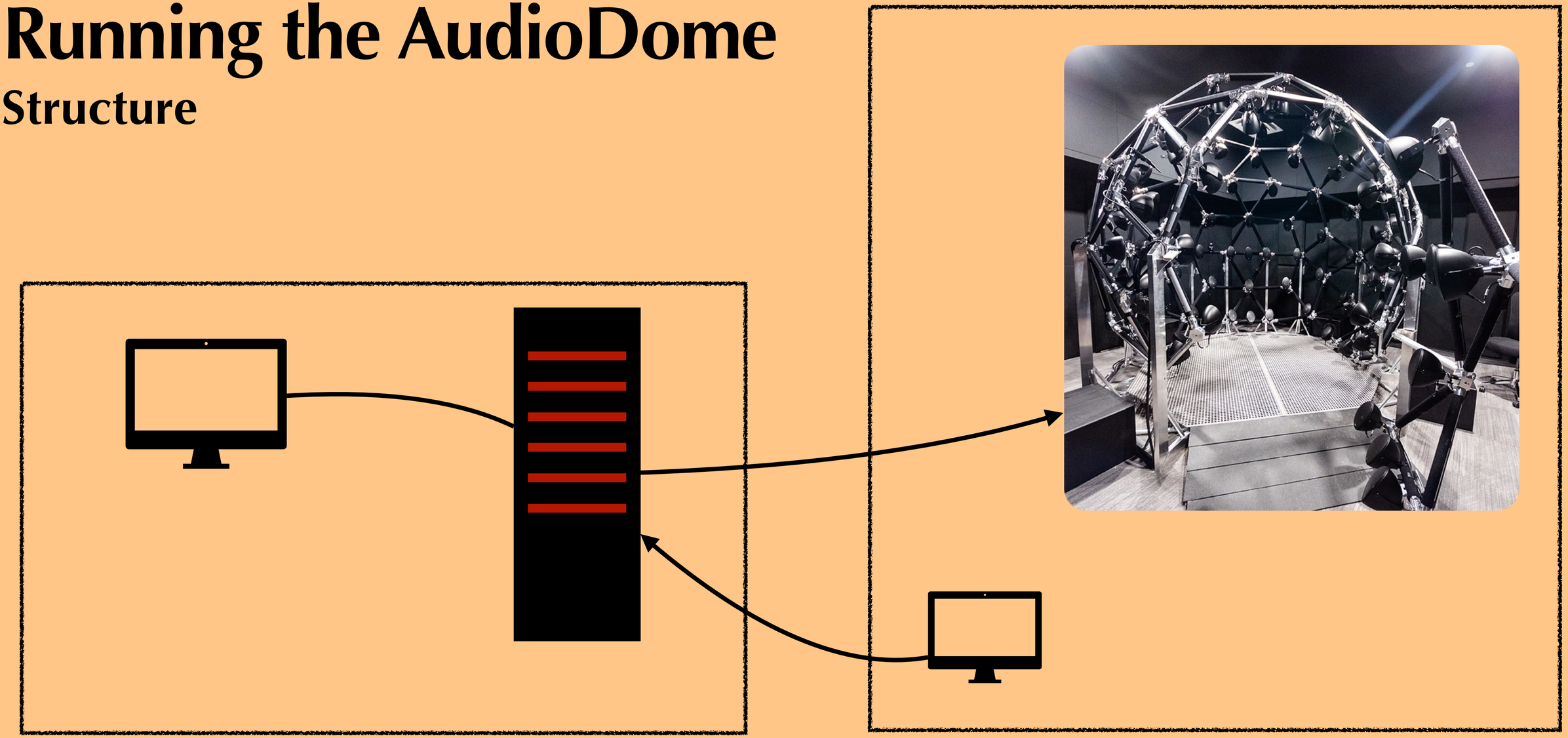
Running the AudioDome

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

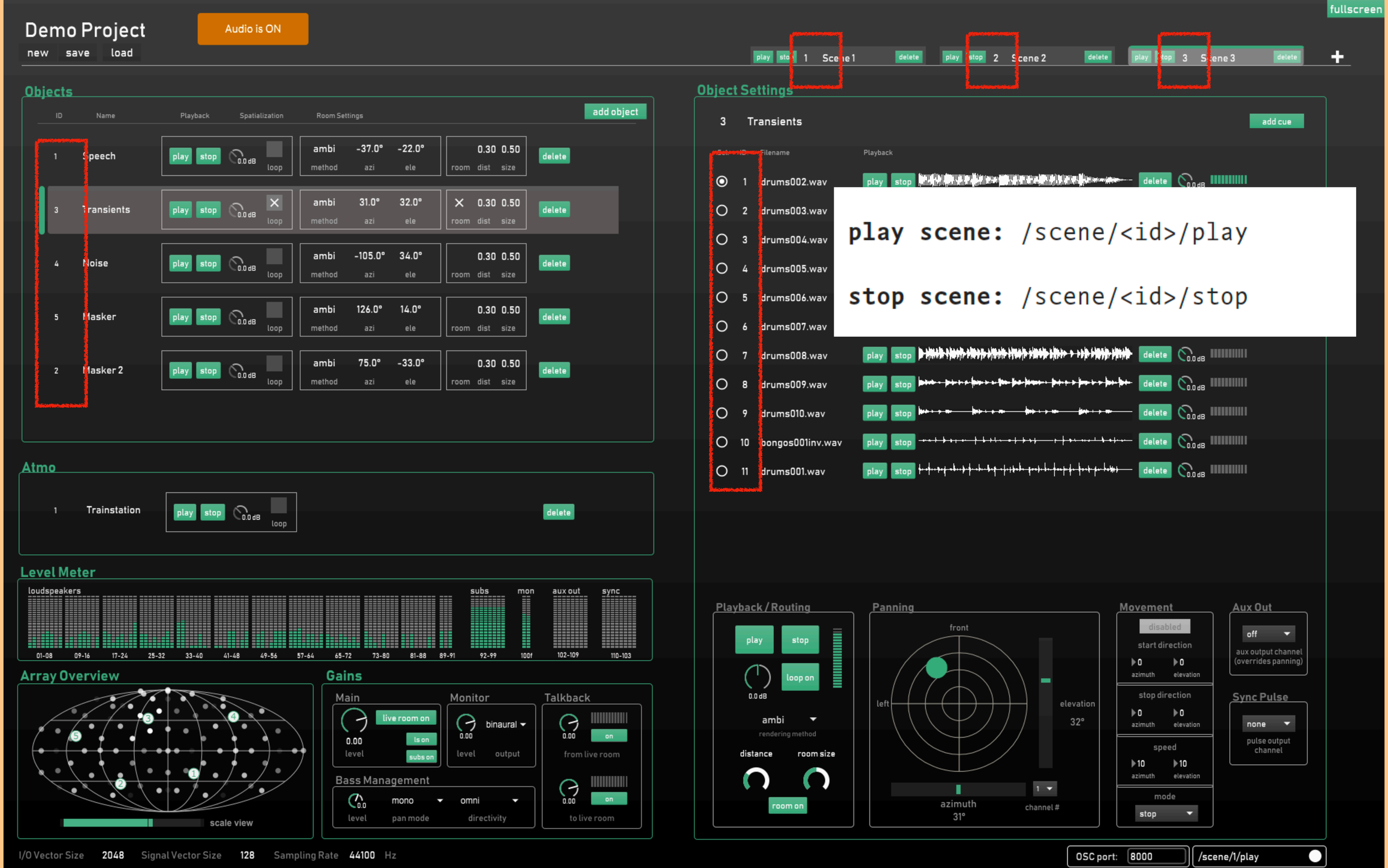
Running the AudioDome

Structure



Control Room

Sound Attenuating Chamber


Demo Project
new
save
load
Audio is ON
fullscreen
play stop 1 Scene 1 delete
play stop 2 Scene 2 delete
play stop 3 Scene 3 delete
Objects
add object
ID Name Playback Spatialization Room Settings
1 Speech play stop 0.0 dB loop ambi -37.0° -22.0° method azi ele 0.30 0.50 room dist size delete
3 Transients play stop 0.0 dB loop ambi 31.0° 32.0° method azi ele 0.30 0.50 room dist size delete
4 Noise play stop 0.0 dB loop ambi -105.0° 34.0° method azi ele 0.30 0.50 room dist size delete
5 Masker play stop 0.0 dB loop ambi 126.0° 14.0° method azi ele 0.30 0.50 room dist size delete
2 Masker 2 play stop 0.0 dB loop ambi 75.0° -33.0° method azi ele 0.30 0.50 room dist size delete
Atmo
1 Trainstation play stop 0.0 dB loop delete
Level Meter
loudspeakers
subs
mon
aux out
sync
01-08 09-16 17-24 25-32 33-40 41-48 49-56 57-64 65-72 73-80 81-88 89-91 92-99 100f 102-109 110-103
Array Overview
scale view
Gains
Main
live room on
ls on
subs on
0.00
level
Monitor
binaural
0.00
level output
Talkback
on
0.00
from live room
Bass Management
0.0
level
mono
pan mode
omni
directivity
on
0.00
to live room
Object Settings
3 Transients
add cue
Sound 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
play scene: /scene/<id>/play
stop scene: /scene/<id>/stop
Playback / Routing
play
stop
loop on
0.0 dB
ambi
rendering method
distance
room size
room on
Panning
front
left
elevation
32°
azimuth
31°
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)
Sync Pulse
none
pulse output channel
I/O Vector Size 2048 Signal Vector Size 128 Sampling Rate 44100 Hz
OSC port: 8000
/scene/1/play

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