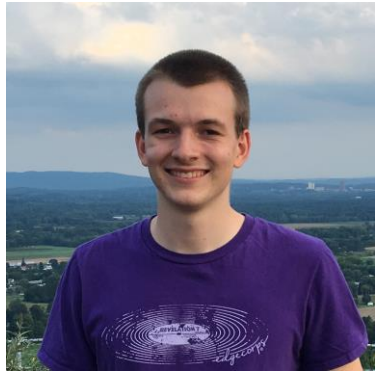
Ear Beamer

Aaron Lucia, Niket Gupta, Matteo Puzella, Nathan Dunn

The Team



Aaron Lucia
CSE

Niket Gupta
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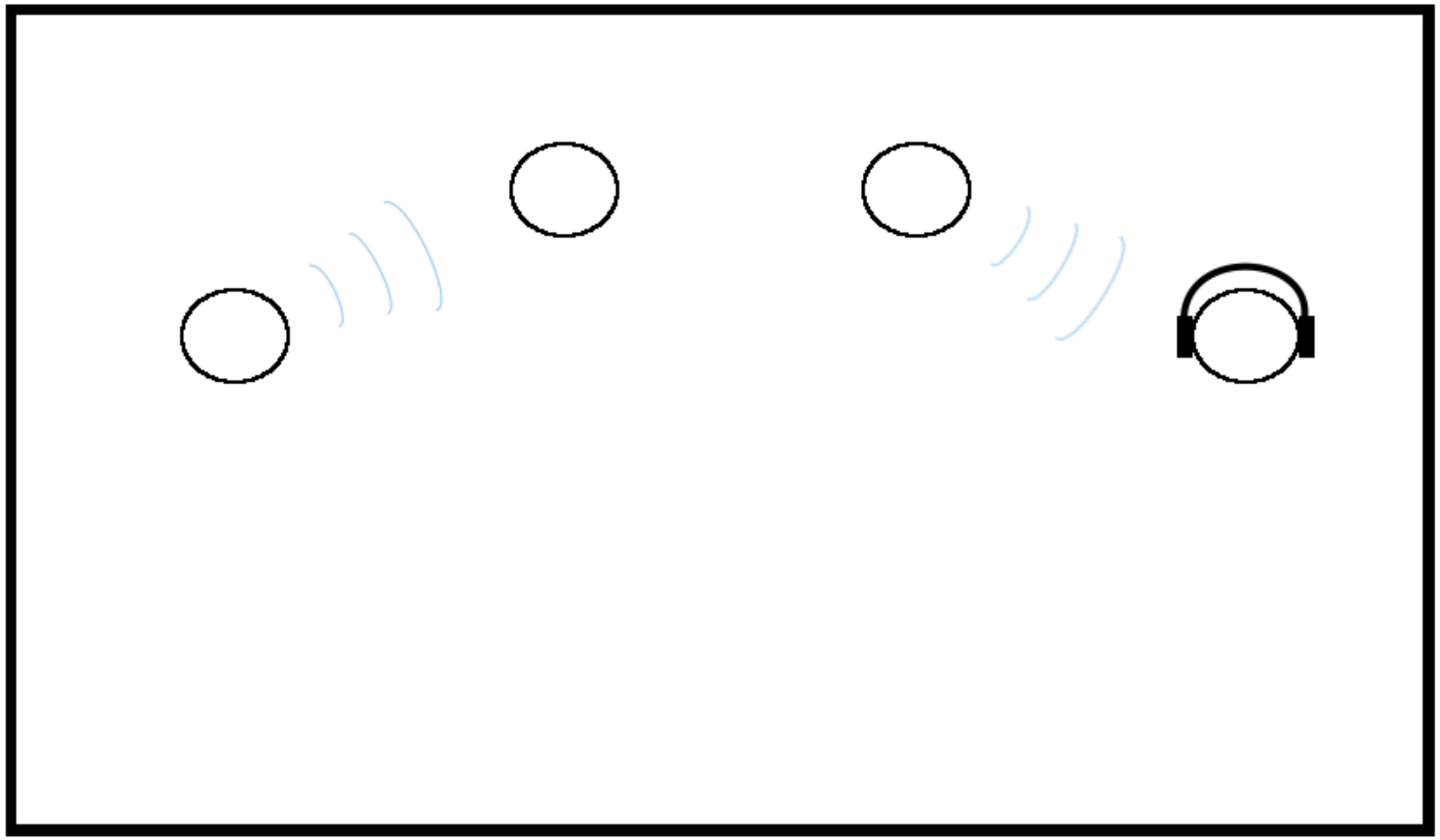
Matteo Puzella
EE

Nathan Dunn
CSE

Advisor: Prof. Mario Parente

A Familiar Scenario

Outlining the System



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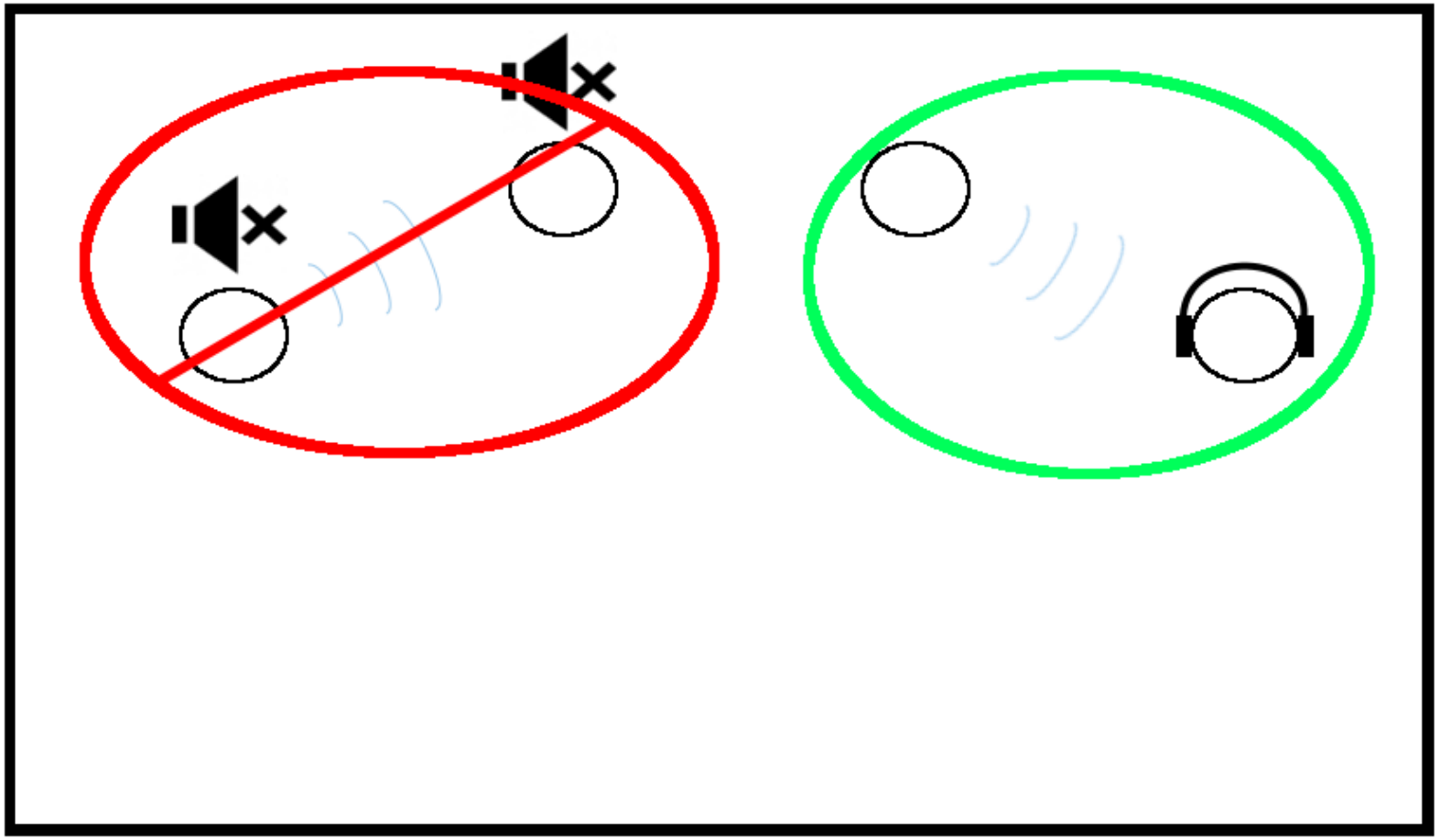


A Goal to Solve the Problem

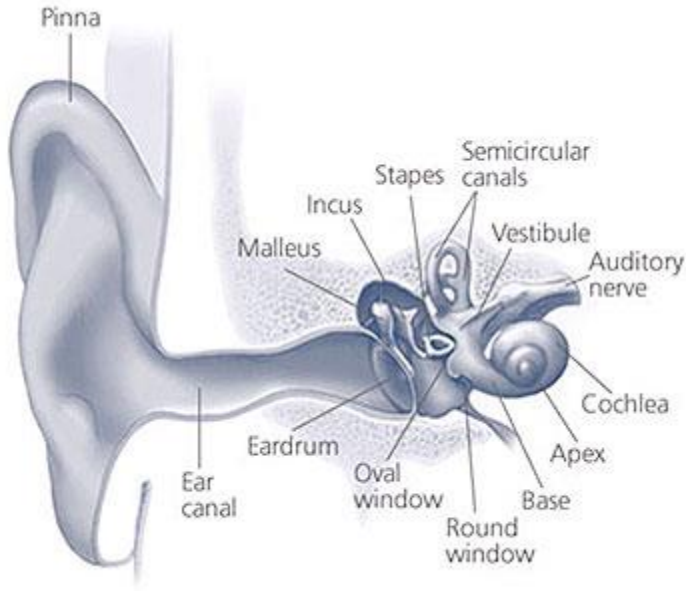
- The Problem: People with moderate to severe hearing loss have difficulty listening to a specific conversation within a noisy environment

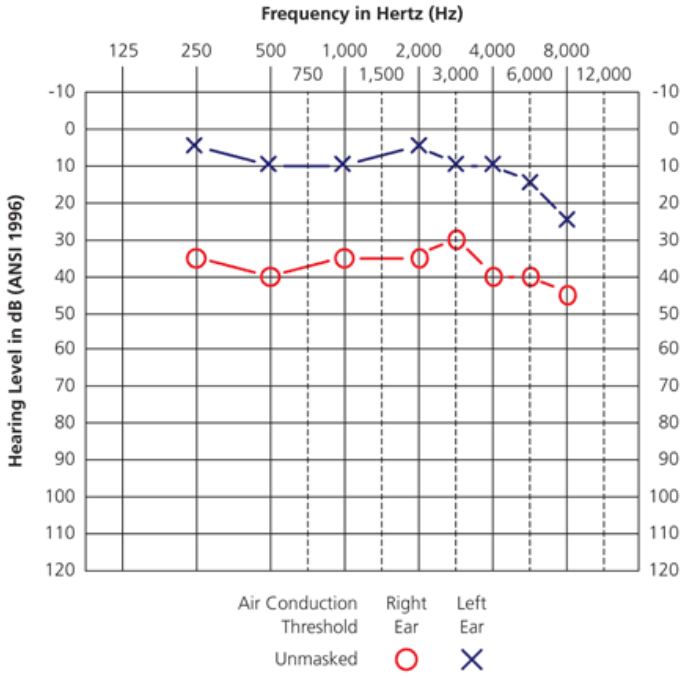
- The Goal: Develop a hearing aid system that gives user ability to individually amplify multiple targets of his/her choice and attenuate unwanted targets, independent of body or head position of the user

Causes of Hearing Loss

- Presbycusis - Age related hearing loss
  - Affects 1 in 3 Americans over age of 65
  - 1 in 2 over 75[1]

- Noise Induced Hearing Loss
  - 15% of Americans aged 20 - 69 have symptoms of NIHL[1]





[1]National Institute on Deafness and other Communication Disorders

A Concerning Problem

- Hearing Loss in adults is associated with increased risk of Major Depressive Disorder
  - In a study of 2,304 adults with hearing loss, those without hearing aids were 50% more likely to suffer from sadness, depression[1]

- Hearing Loss is associated with an increased rates of dementia, cognitive decline
  - Hearing impaired performance declined 30 – 40% faster than healthy population

1. Myers, David. "Silently Suffering From Hearing Loss Negatively Affects Quality of Life." *American Psychological Association*. APA, 7 Aug. 2015. Web. 16 Oct. 2016.

2. Lin FR, Yaffe K, Xia J, Xue Q, Harris TB, Purchase-Helzner E, Satterfield S, Ayonayon HN, Ferrucci L, Simonsick EM, Health ABC Study Group FT. Hearing Loss and Cognitive Decline in Older Adults. *JAMA Intern Med.* 2013;173(4):293-299. doi:10.1001/jamainternmed.2013.1868

Current State of Hearing Aid Market

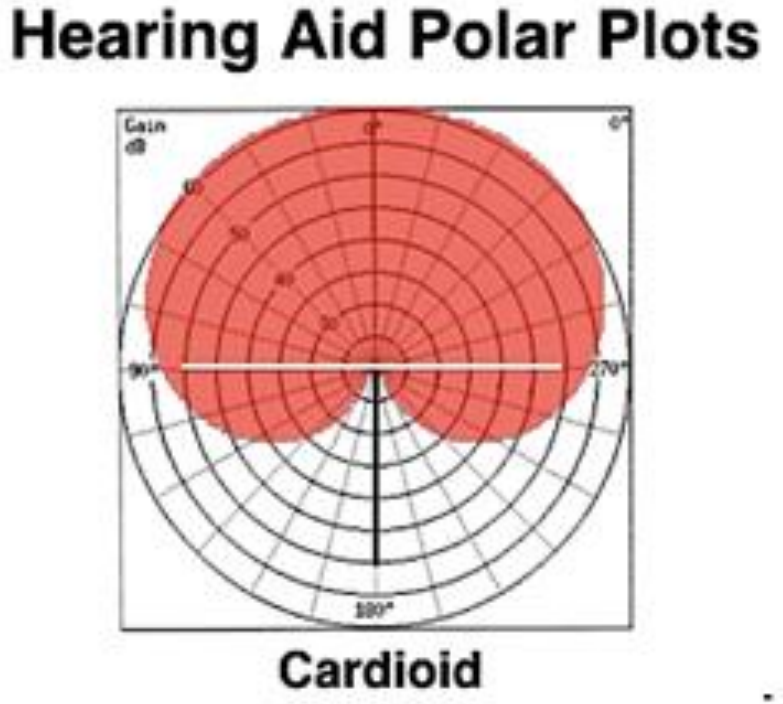
Current hearing aids have been developed to hear speech in a noisy environment

- Directional Microphone Hearing Aids
  - Amplifies sounds coming from the front of the user, and attenuates background noise

- Beam Forming Array Hearing Aids
  - Use of omnidirectional microphones to selectively tune into sounds in front of user

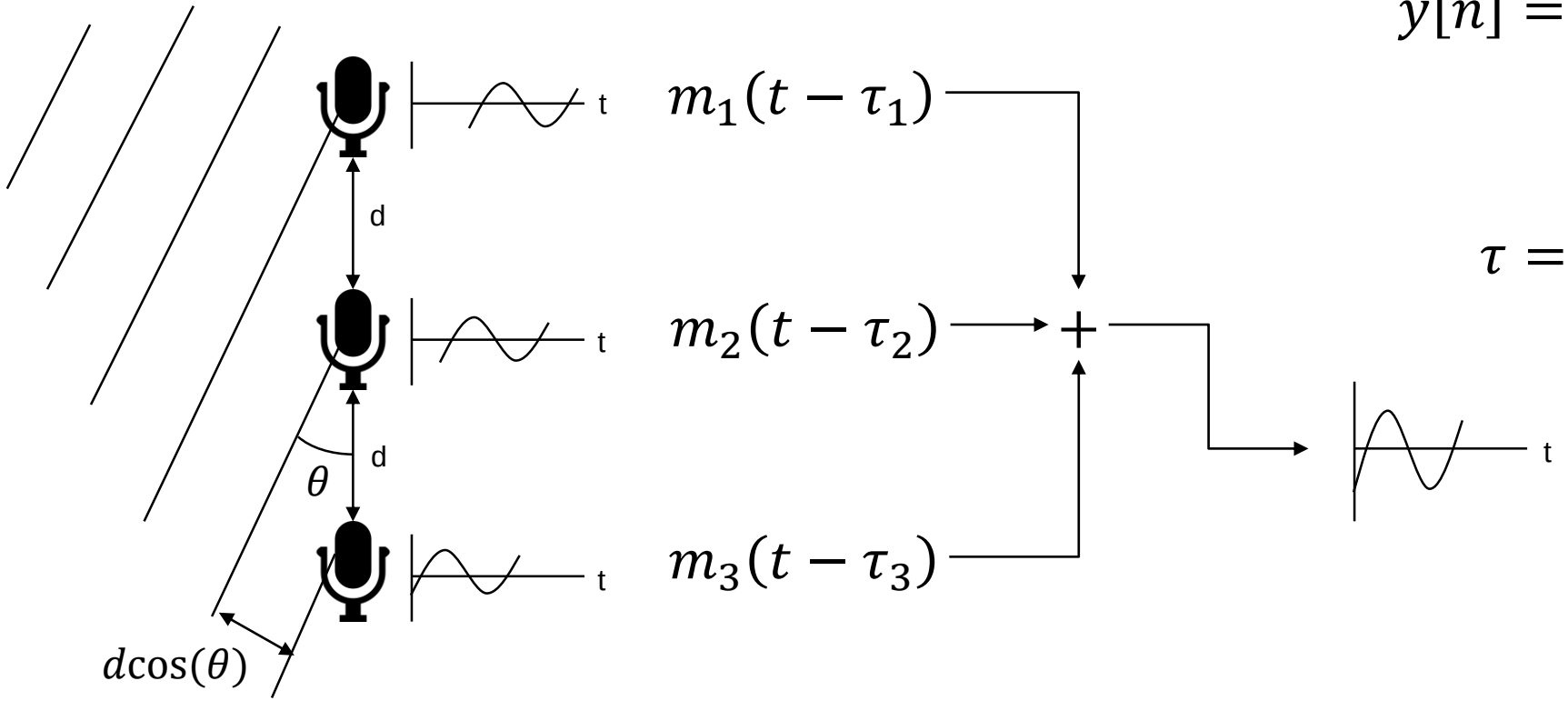
No selection and must be front of target to hear

"Types of Hearing Aids, Sizes & Prices | Exposing Hearing Aids." *Exposing Hearing Aids*. N.p., n.d. Web. 14 Oct. 2016.



Hearing Health Matters

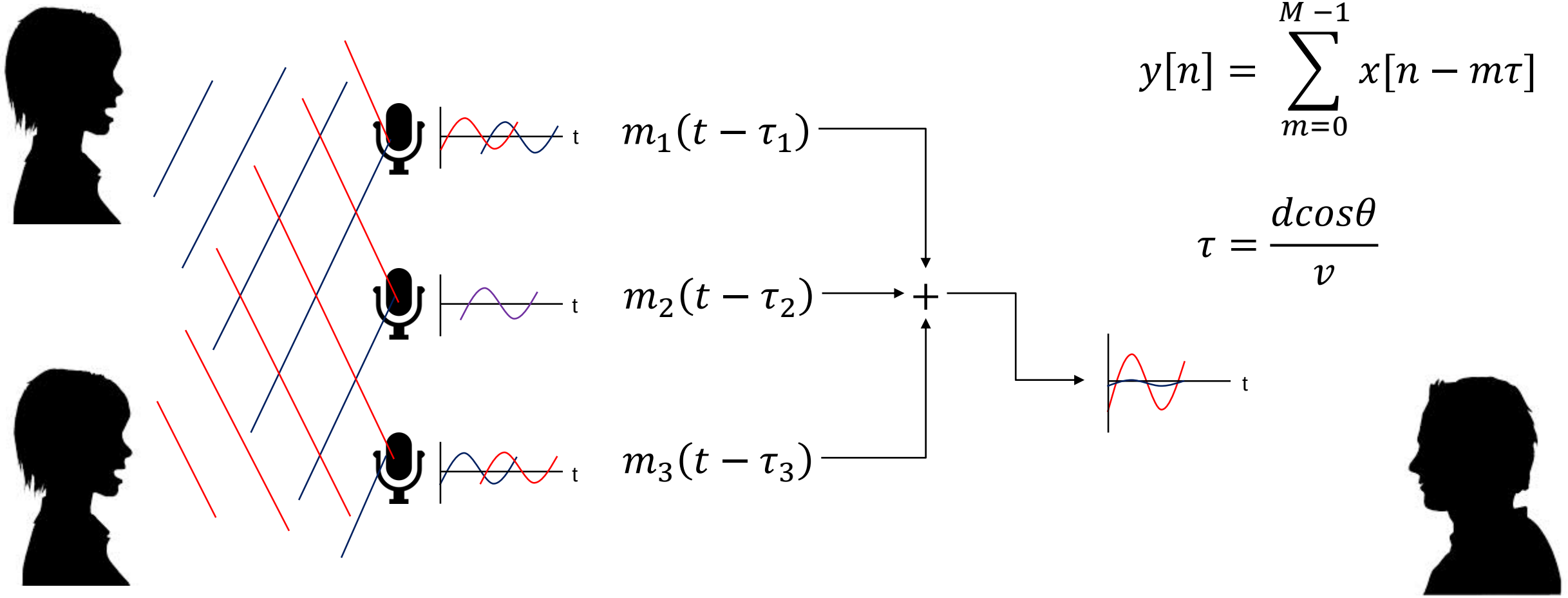
Beamforming



$$y[n] = \sum_{m=0}^{M-1} x[n - m\tau]$$

$$\tau = \frac{d\cos\theta}{v}$$

Beamforming



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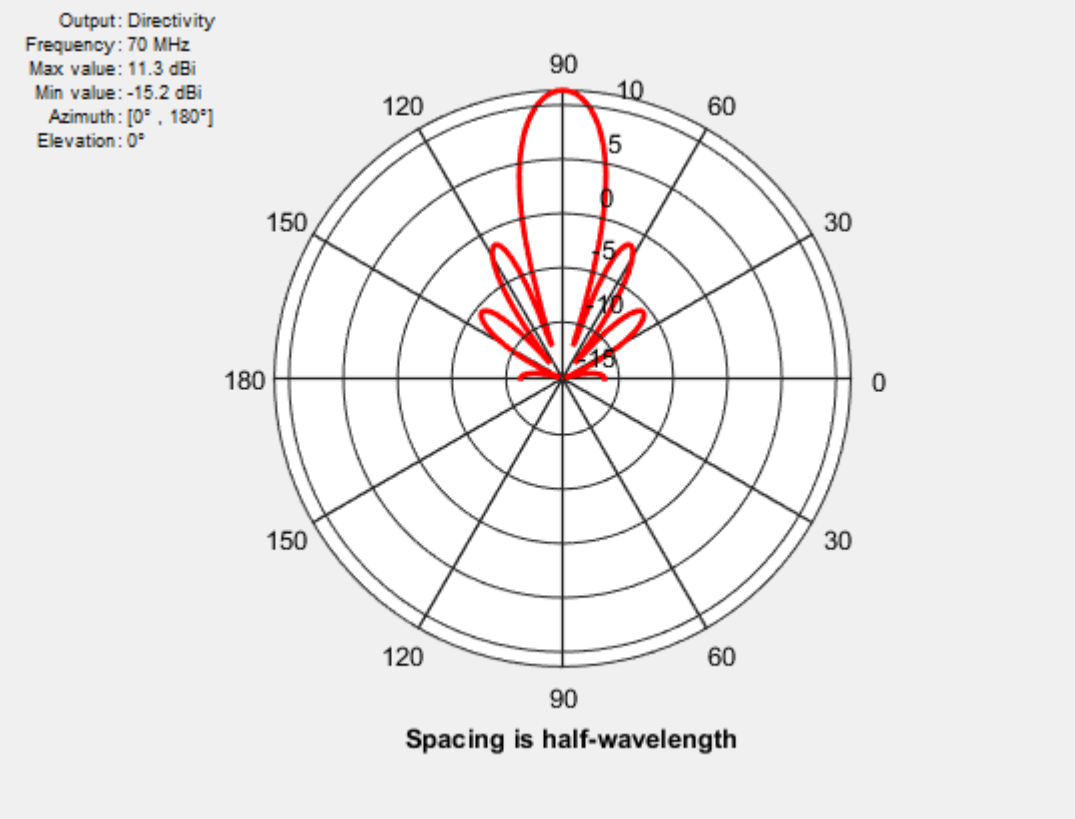
Polar Plot



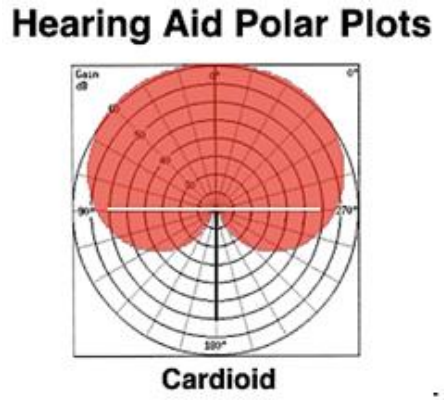


Image Credit: Matlab,"Grating Lobes", Web

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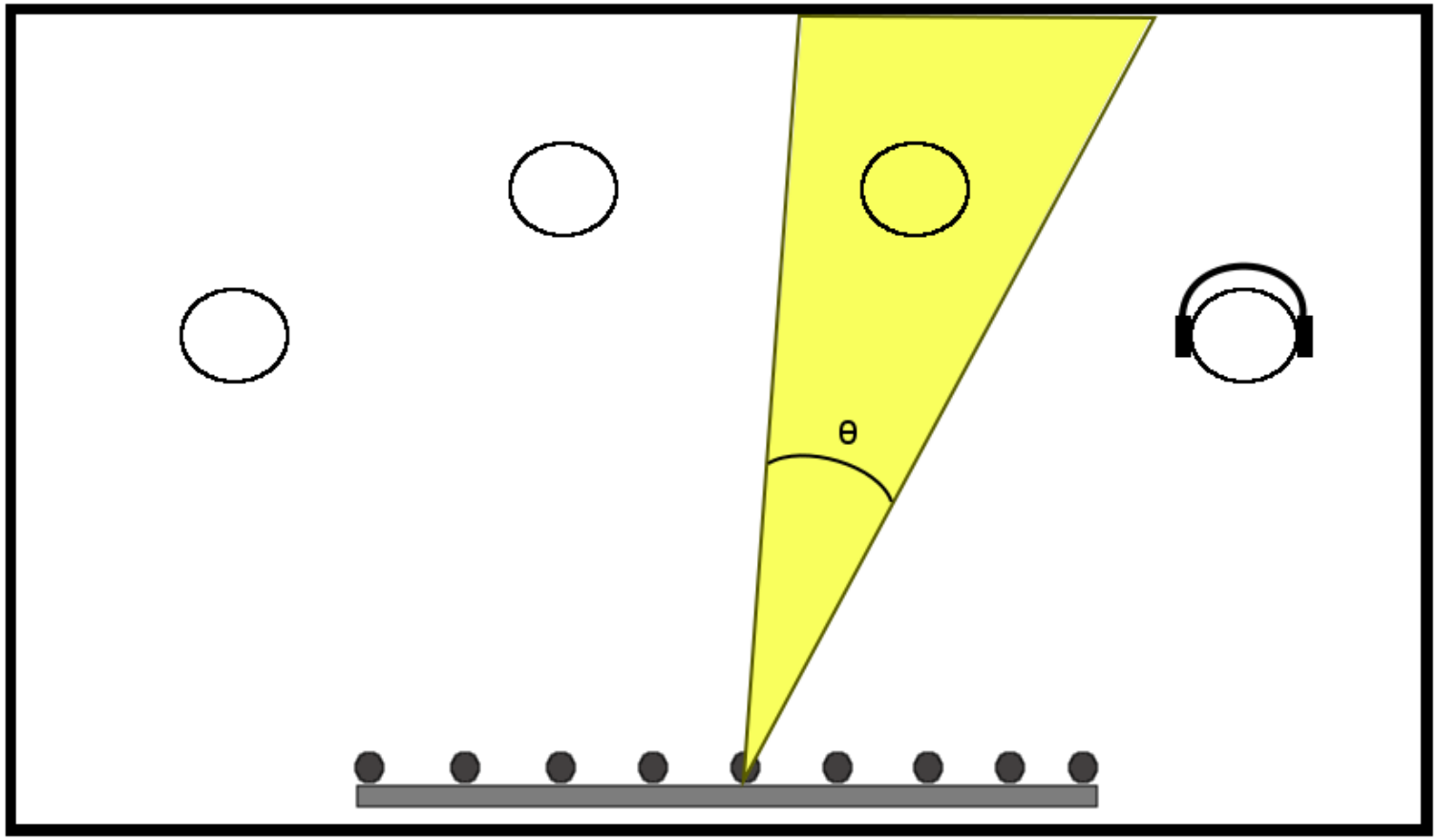

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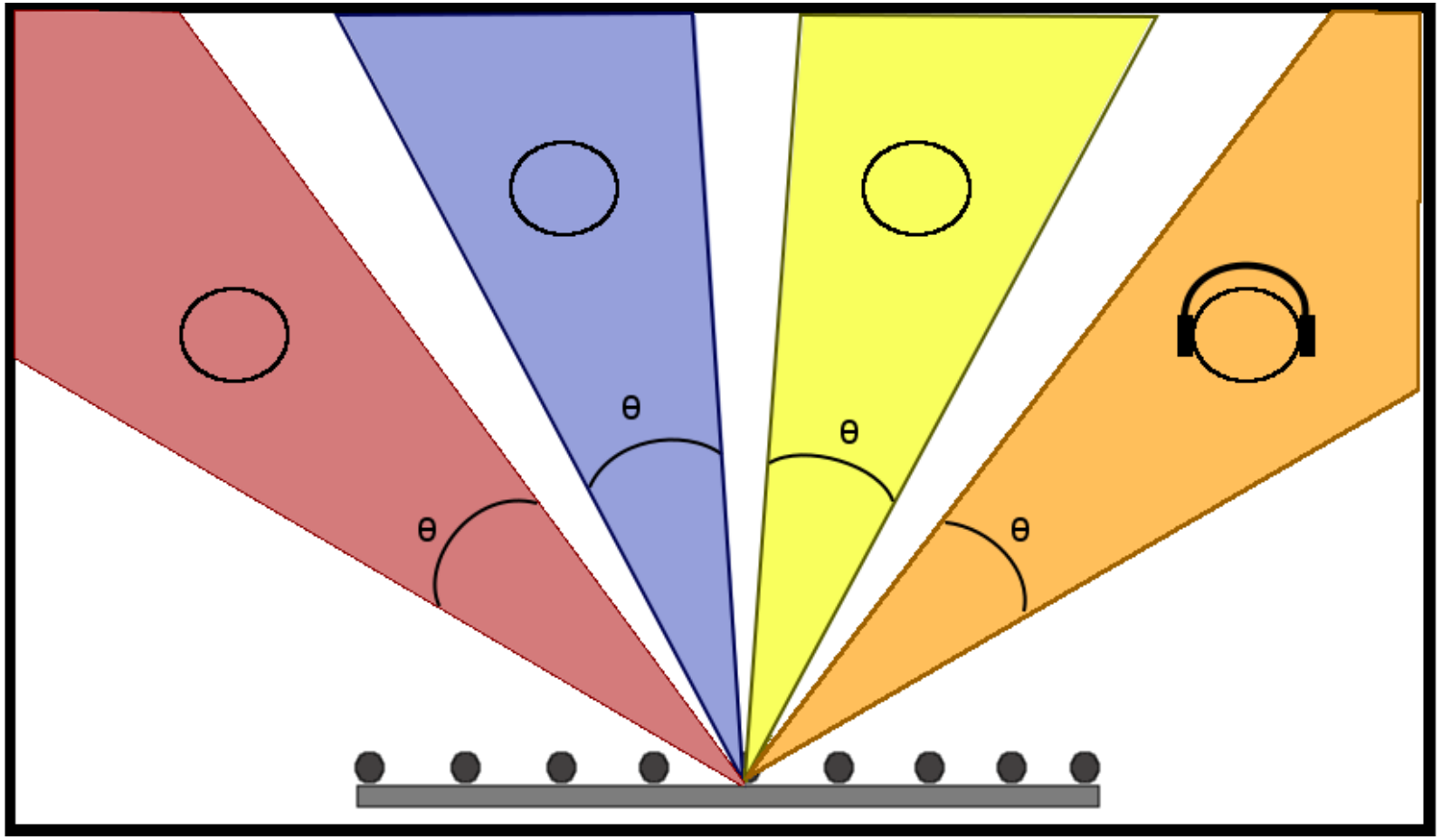

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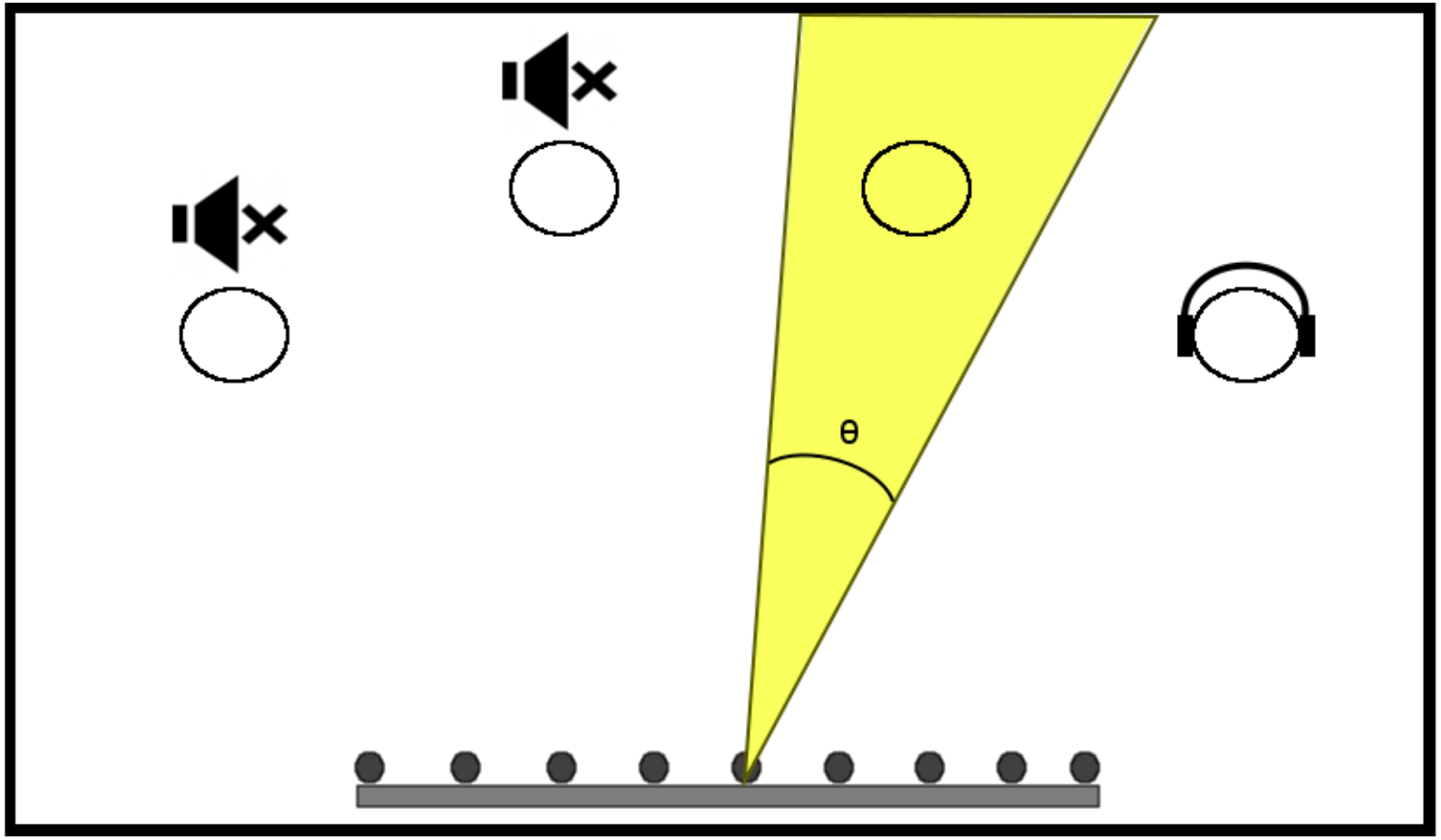
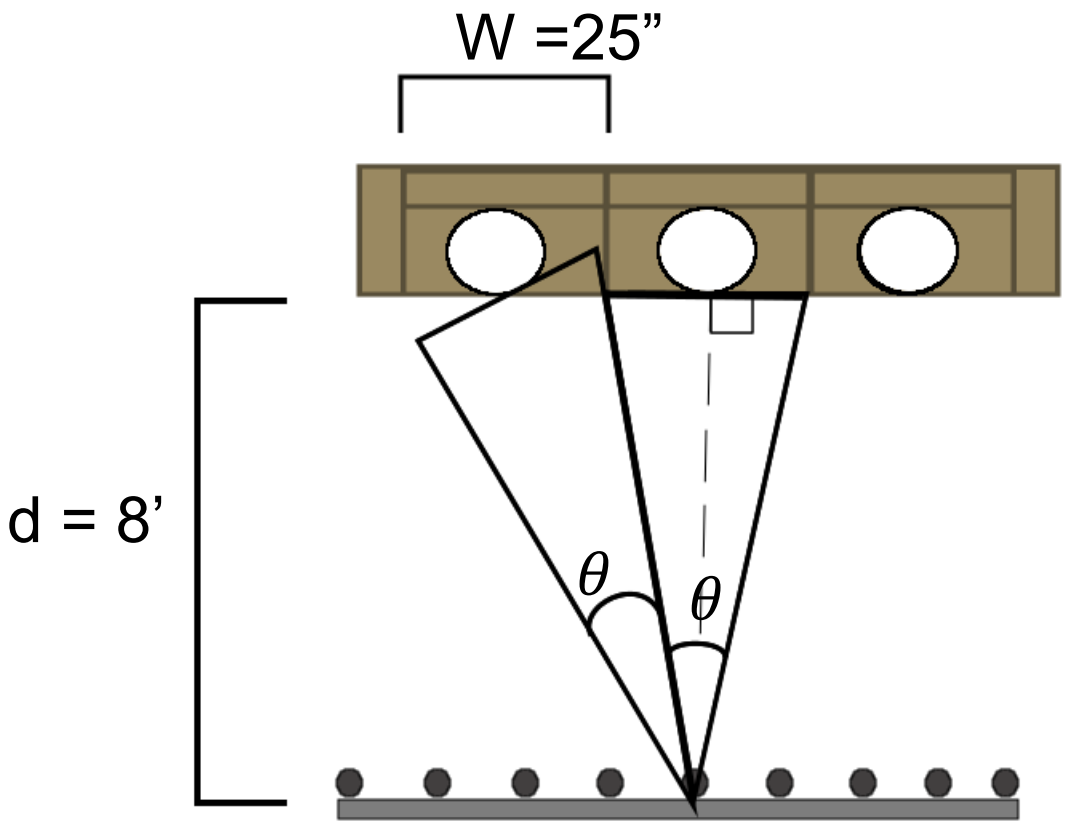


Determining Ideal Beamwidth



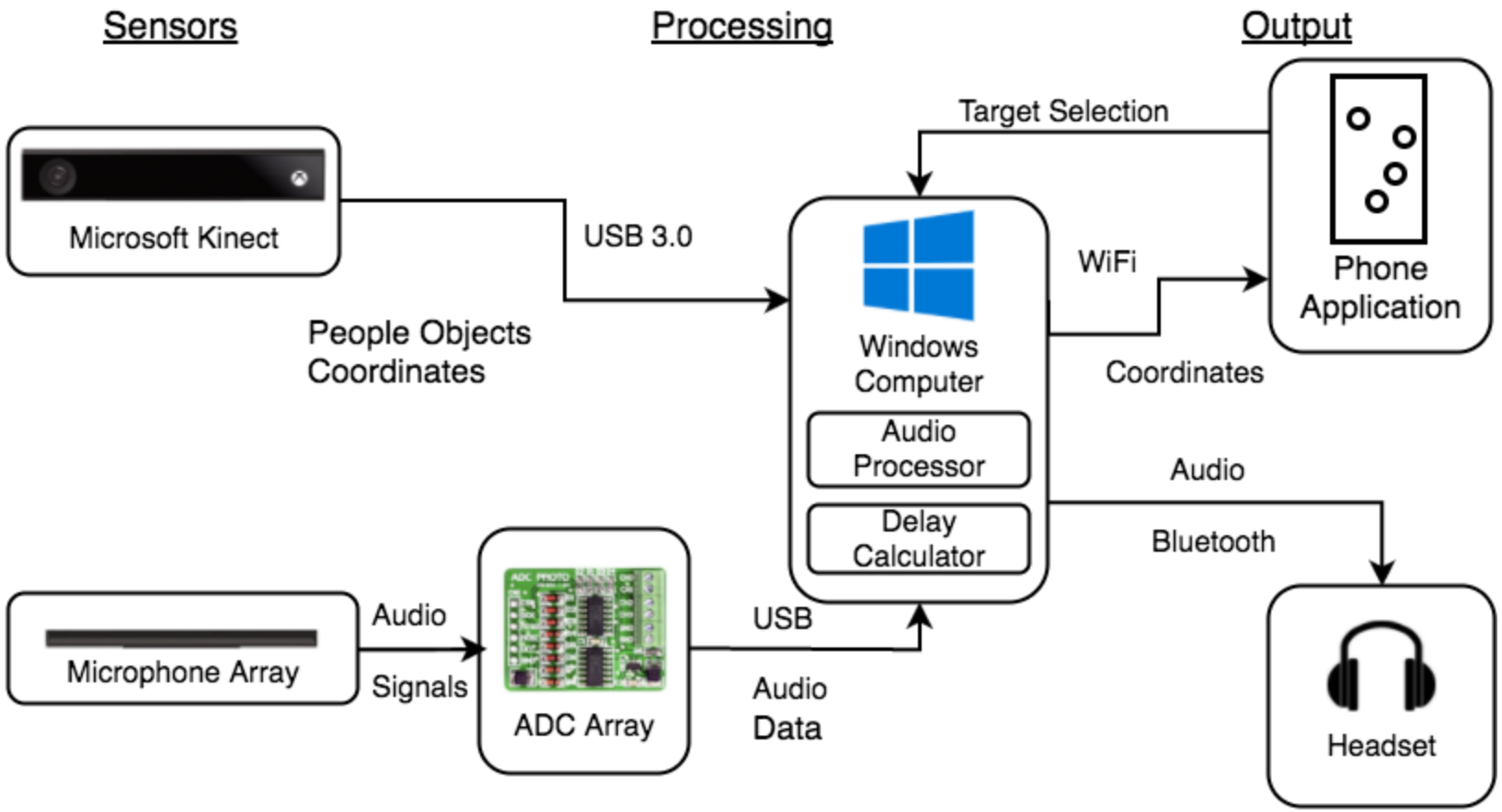
$$\theta = 2\arctan(\frac{w}{2d})$$

$$\theta = 14.83^o \approx 15^o$$

Requirements

- Capture necessary audio signals on the human speech frequency spectrum (500Hz to 3.5kHz)
- If target is within 20 feet, it should appear in the user interface and become selectable
- If target is selected on user interface, the processor should measure azimuth of the target and calculate delays for the beam forming algorithm
- If multiple targets cannot be separated into distinct sectors, the system treats them as one and this is reflected in the user interface
- Delay from Reception of signal to output of hearing aid must be less than 300ms (ITU-T G.177)

Our Solution



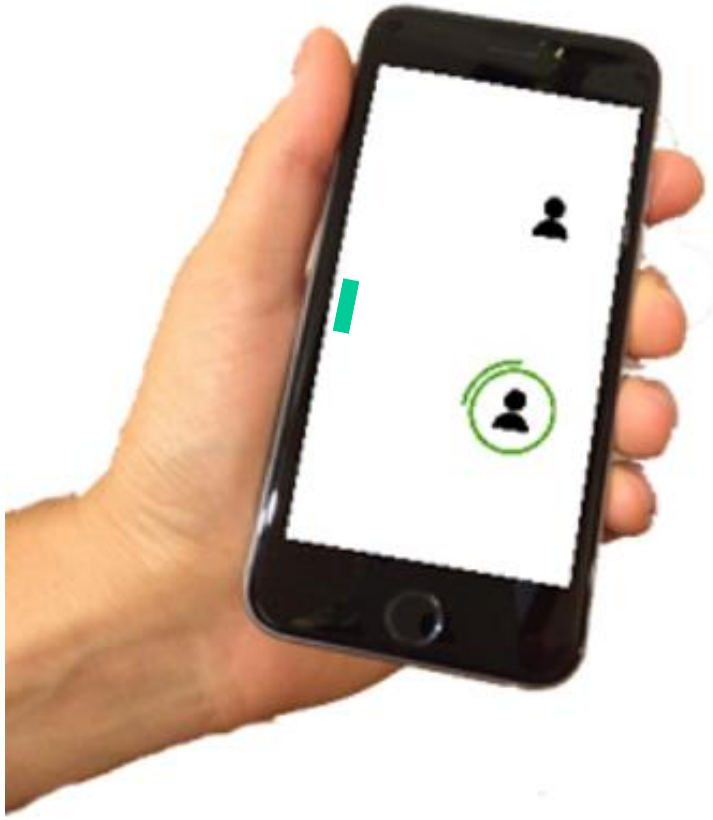
Target Tracking: Kinect

Two main uses for our system:

- Skeleton Tracking API used to identify human targets within frame
  - Returns three dimensional coordinates of joints, with resolution in millimeters
  - Tracks up to six targets
  - New data may be accessed via polling or event-based system
- Infrared depth sensor
  - Depth sensor has effective range of 4.5 meters

User Interface – Mobile Application

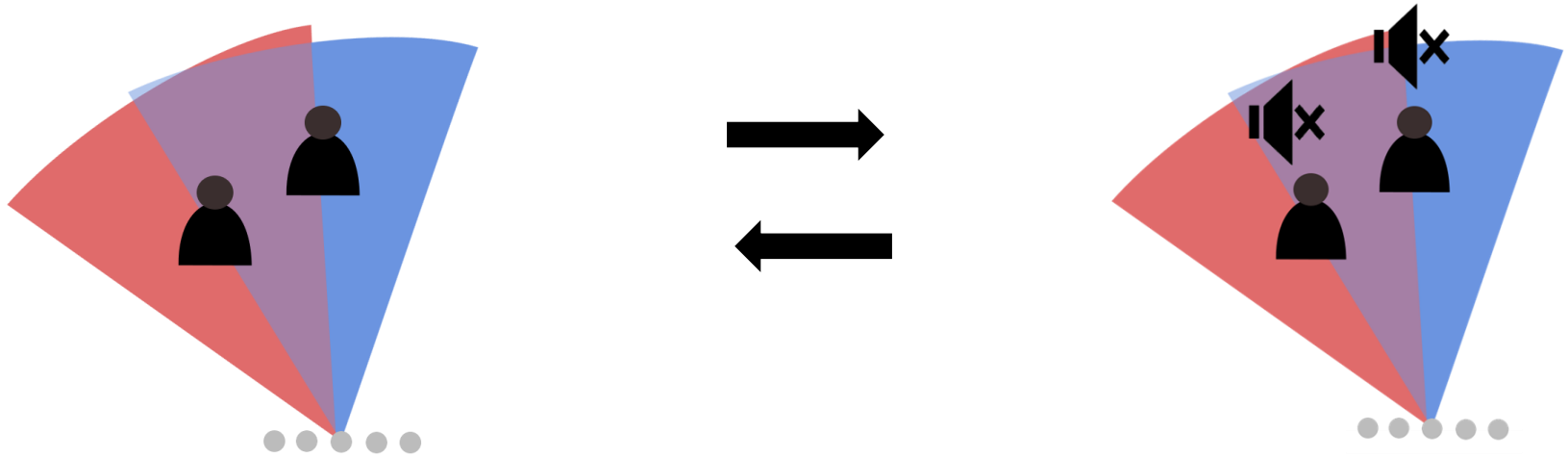
- Simple functionality
  - Top-down view of room
  - Orientation reference
  - Live updates of target position
  - Volume Control
- iOS Development
  - Touch input
  - Polling model from App to Windows Computer
  - Web server model



Beamwidth Considerations

What happens when two targets cannot be isolated within two distinct beams?

- Tie the two targets together – when one is muted, the other is muted as well



Analog to Digital Converter

- Convert the analog audio from the microphones into a digital signal that is sent to the audio processor

Sampling Rate and Filtering:

- Low pass filter microphones to 3.5kHz
- Sample at 8kHz to prevent aliasing

- NI ADC for testing and development for MDR, custom solution for FDR

Considering a Microphone Array: Spatial Aliasing

A microphone array samples spatially – analogous to sampling a signal in time

Sampling Rate in Time:
1 Sample / N Seconds

Nyquist Criteria:

Sampling Rate $> 2f_{max}$

Sampling Rate in Space:
1 Sample / N Meters

Nyquist Criteria:
Microphone Distance < $\frac{\lambda_{min}}{2}$

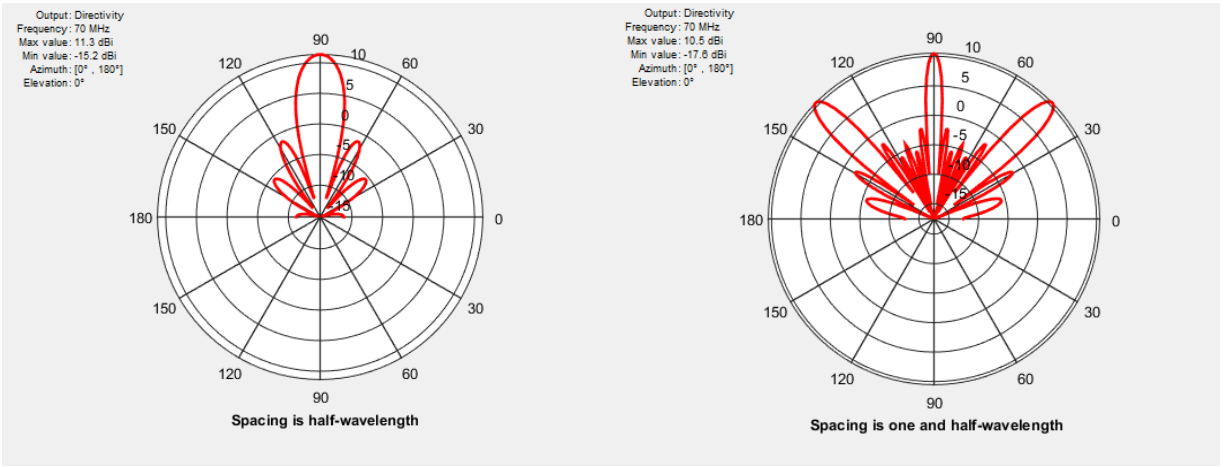


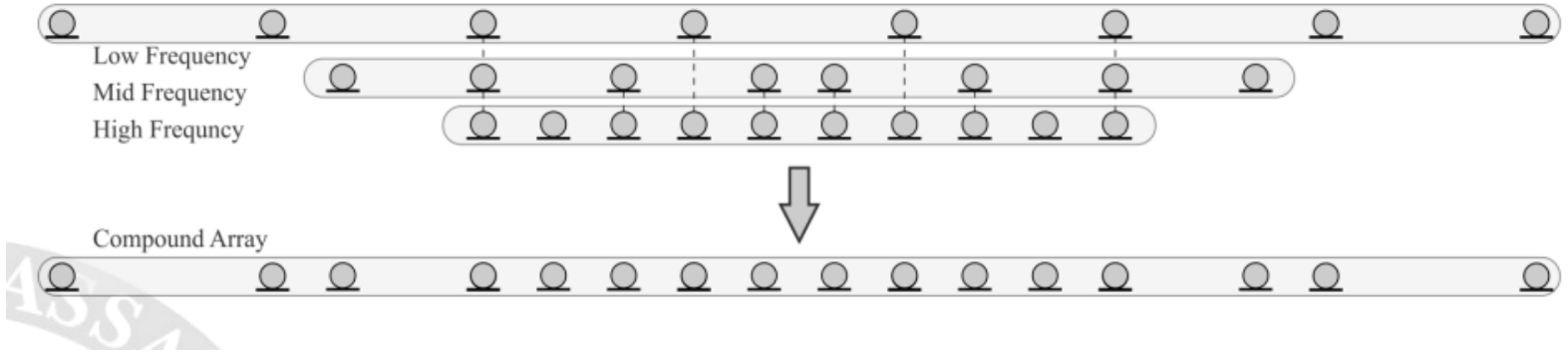
Image Credit: Matlab,"Grating Lobes", Web

Capturing Audio: Microphone Array

Project Sauron: A Harmonic Nested Array

To Avoid Spatial Aliasing, microphone distance *d* must be:

$$d < \frac{\lambda}{2}$$

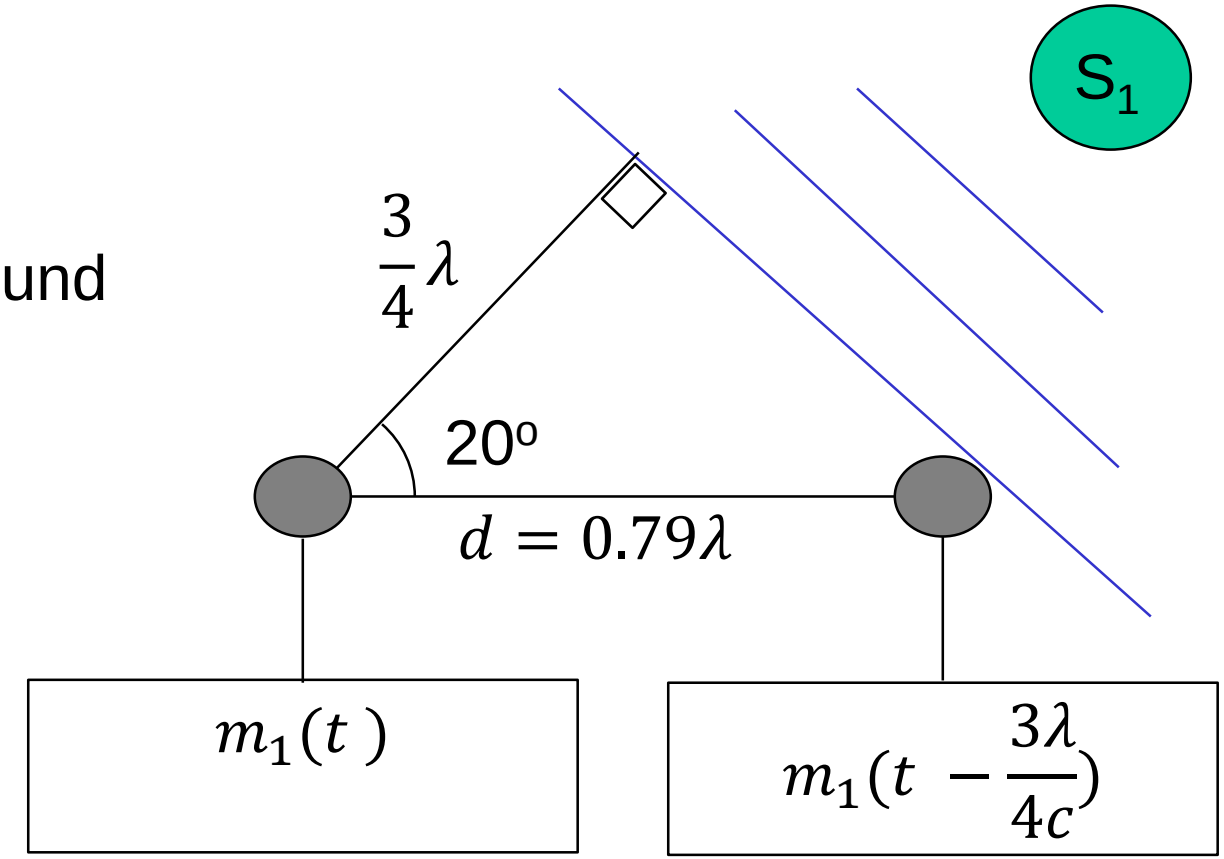


MDR Deliverables

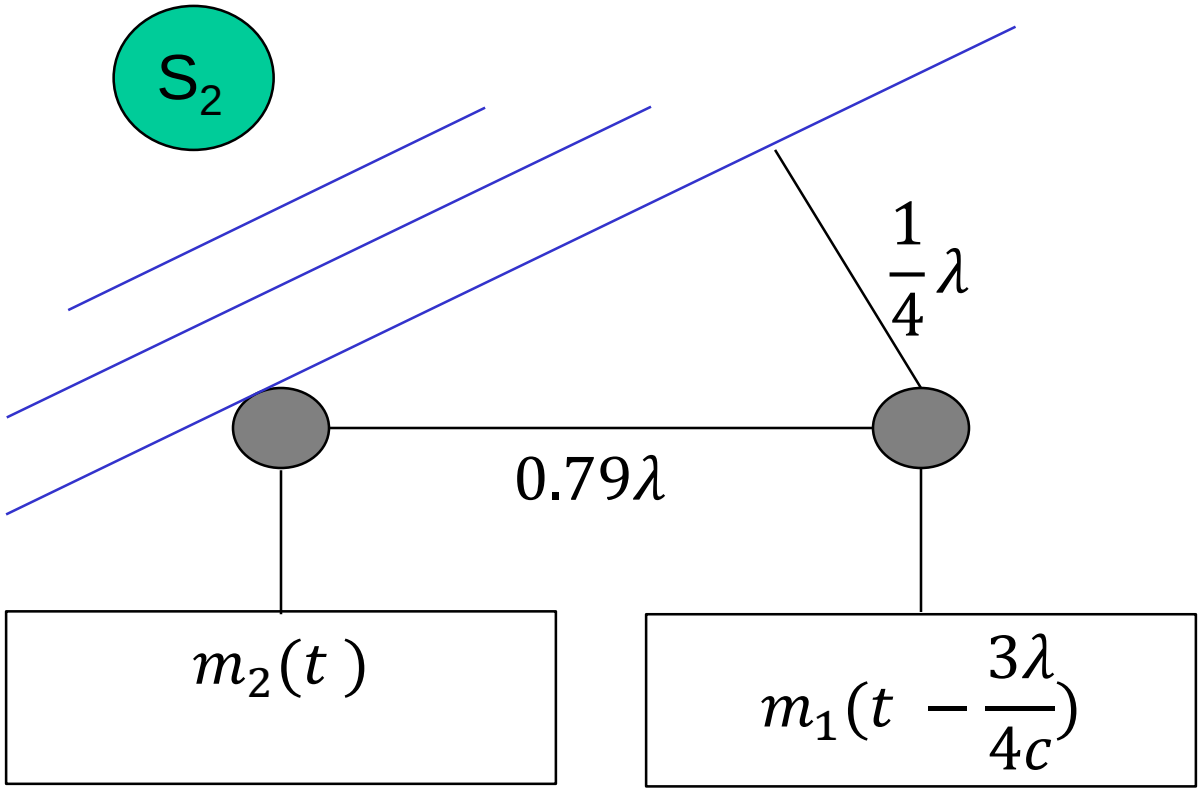
Category	Deliverable	Assignees
Target Identification	Extraction of coordinates of multiple targets from Kinect	Nathan
Mobile Application	Framework for communication between Computer and iOS App	Niket, Aaron
	Display Graphical Representation of targets on screen, using mocked coordinates	
Beamforming	Delay-sum beamforming algorithm implemented with simulated input	Aaron, Nathan
AD/C	Verify that a given reference tone is digitized through a single channel	Matteo
	Obtain verified values from AD/C on computer	
Theory	Identify hardware/signal processing method to narrow beamwidth	All

QUESTIONS?

c = speed of sound



M_1's output is in phase with $m_{2!}$



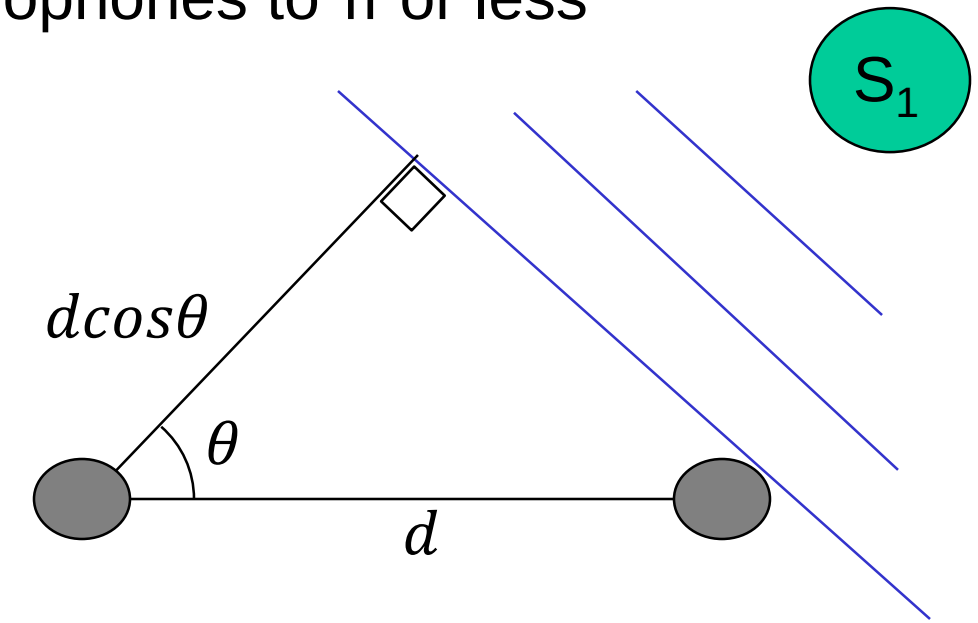
To avoid, limit phase delay between microphones to π or less

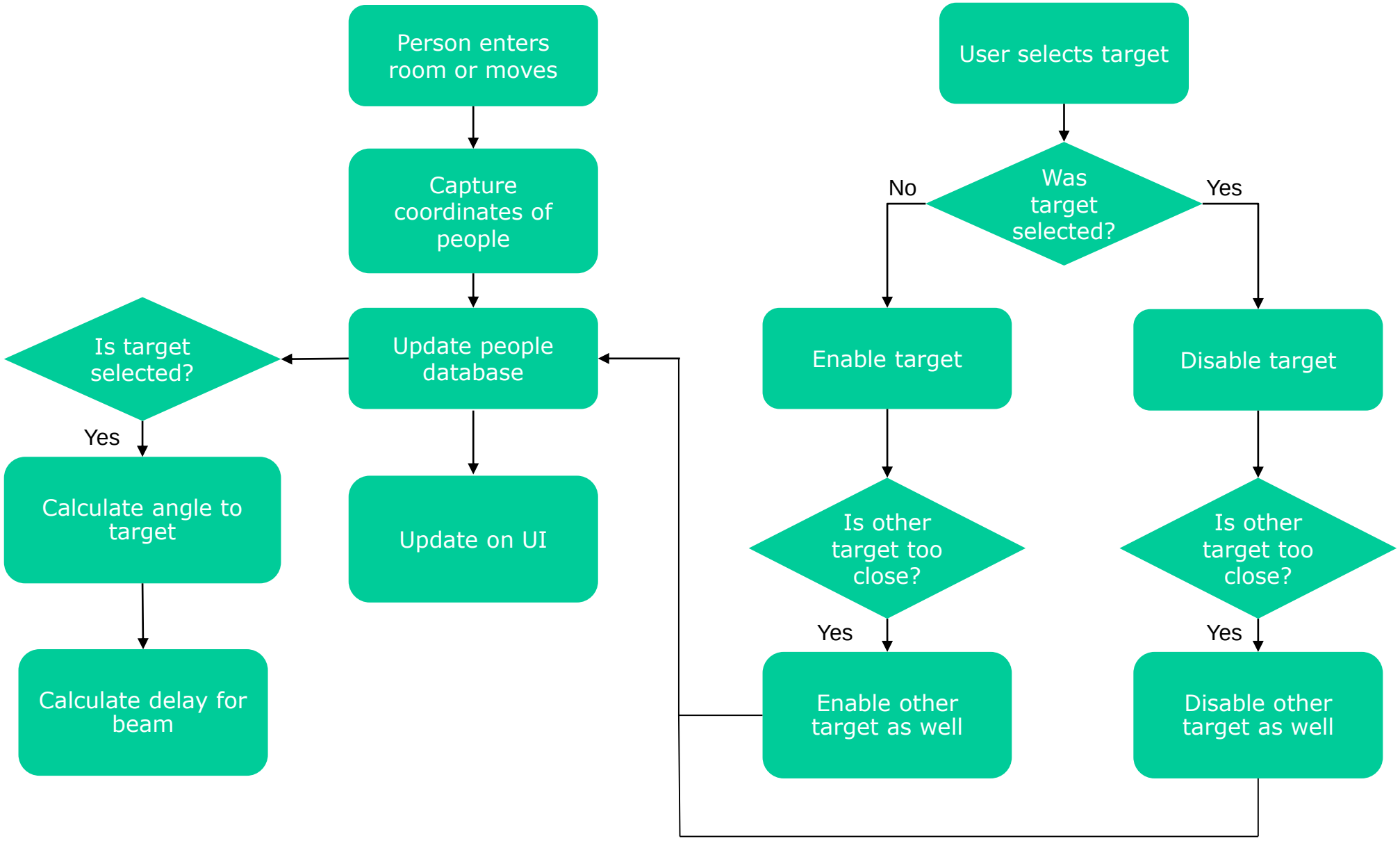
$$2\pi \frac{\tau}{T_{min}} \leq \pi$$

$$2\pi \frac{dcos\theta}{cT_{min}} \leq \pi$$

$$d \leq \frac{cT_{min}}{2cos\theta}$$

$$d \leq \frac{\lambda_{min}}{2}$$

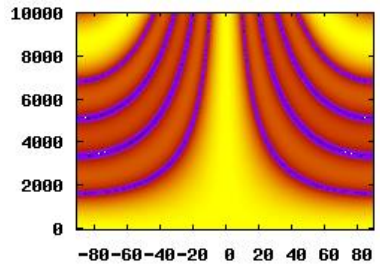



Person enters room or moves
Capture coordinates of people
Update people database
Update on UI
Is target selected?
Yes
Calculate angle to target
Calculate delay for beam
User selects target
Was target selected?
No
Yes
Enable target
Disable target
Is other target too close?
Is other target too close?
Yes
Yes
Enable other target as well
Disable other target as well

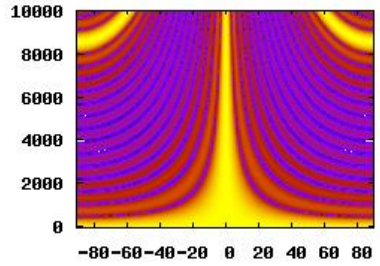
Determining the Microphone Array

More Elements →

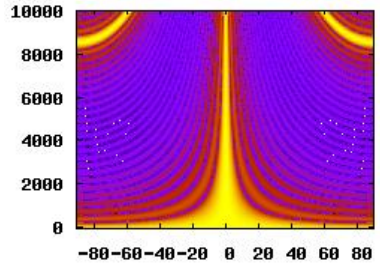
Increased Spacing ↓



5 Elements, 0.04m Spacing, 0.2m Aperture

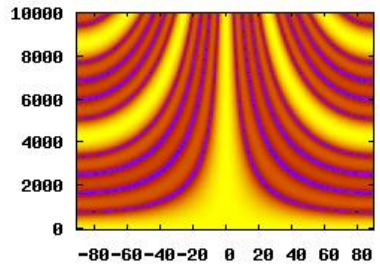


15 Elements, 0.04m Spacing, 0.6m Aperture

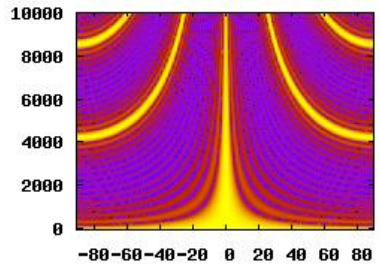


25 Elements, 0.04m Spacing, 1m Aperture

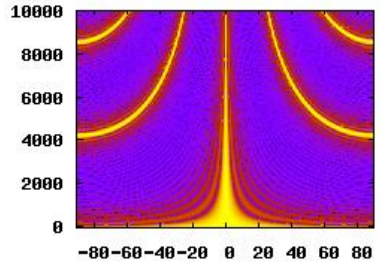
A. Greensted, Delay Sum Beamforming, The lab book Pages An online collection of electronics information, 01-Oct-2012. [Online]. Available: http://www.labbookpages.co.uk/auc /beamforming/delaySum.html



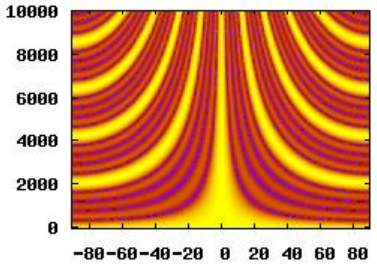
5 Elements, 0.08m Spacing, 0.4m Aperture



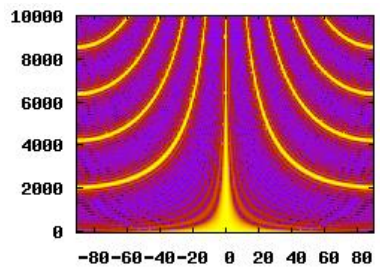
15 Elements, 0.08m Spacing, 1.2m Aperture



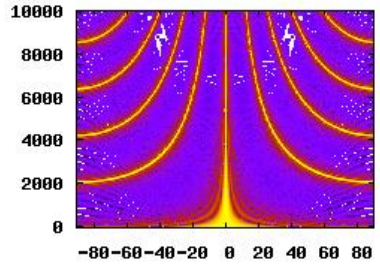
25 Elements, 0.08m Spacing, 2m Aperture



5 Elements, 0.16m Spacing, 0.8m Aperture



15 Elements, 0.16m Spacing, 2.4m Aperture



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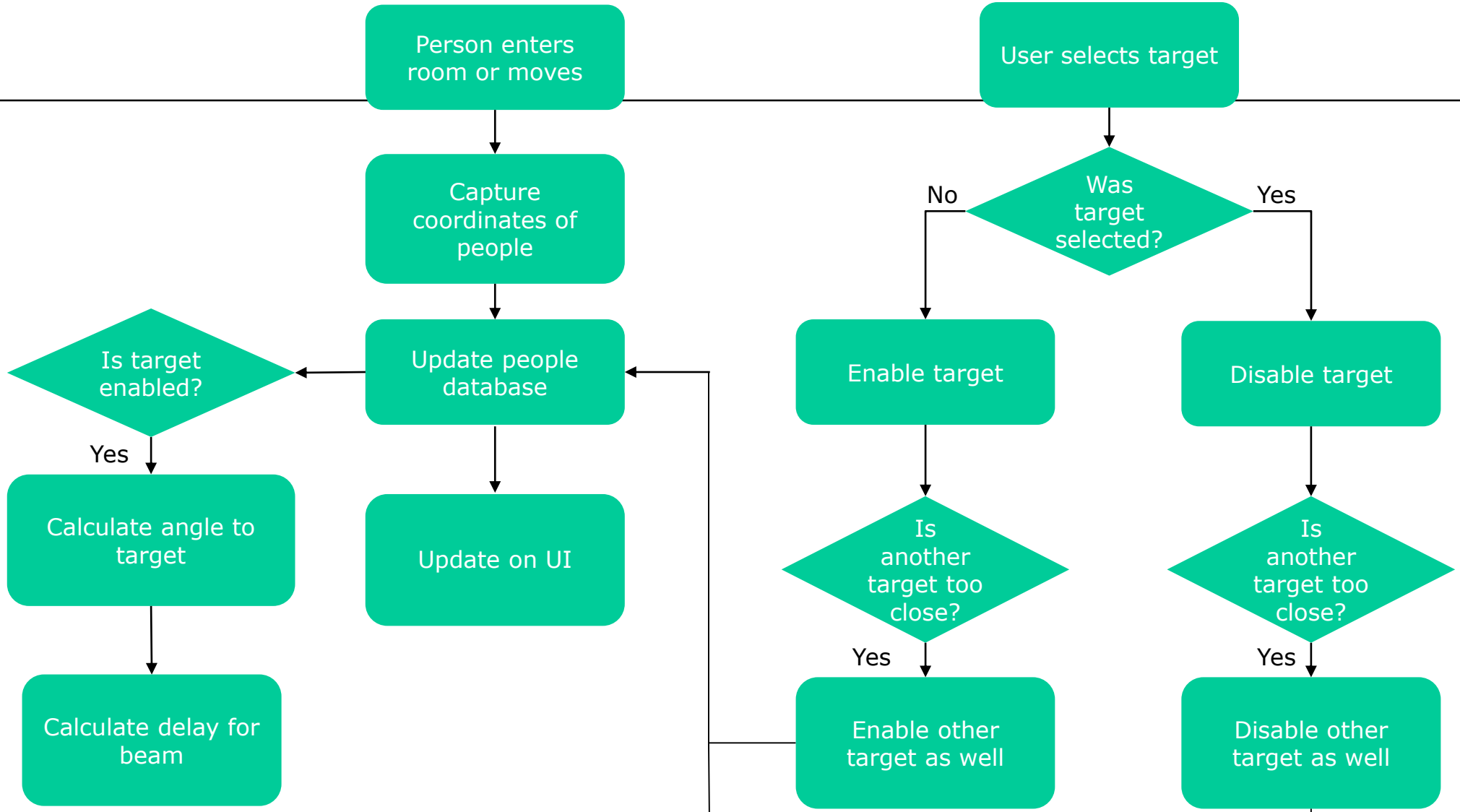
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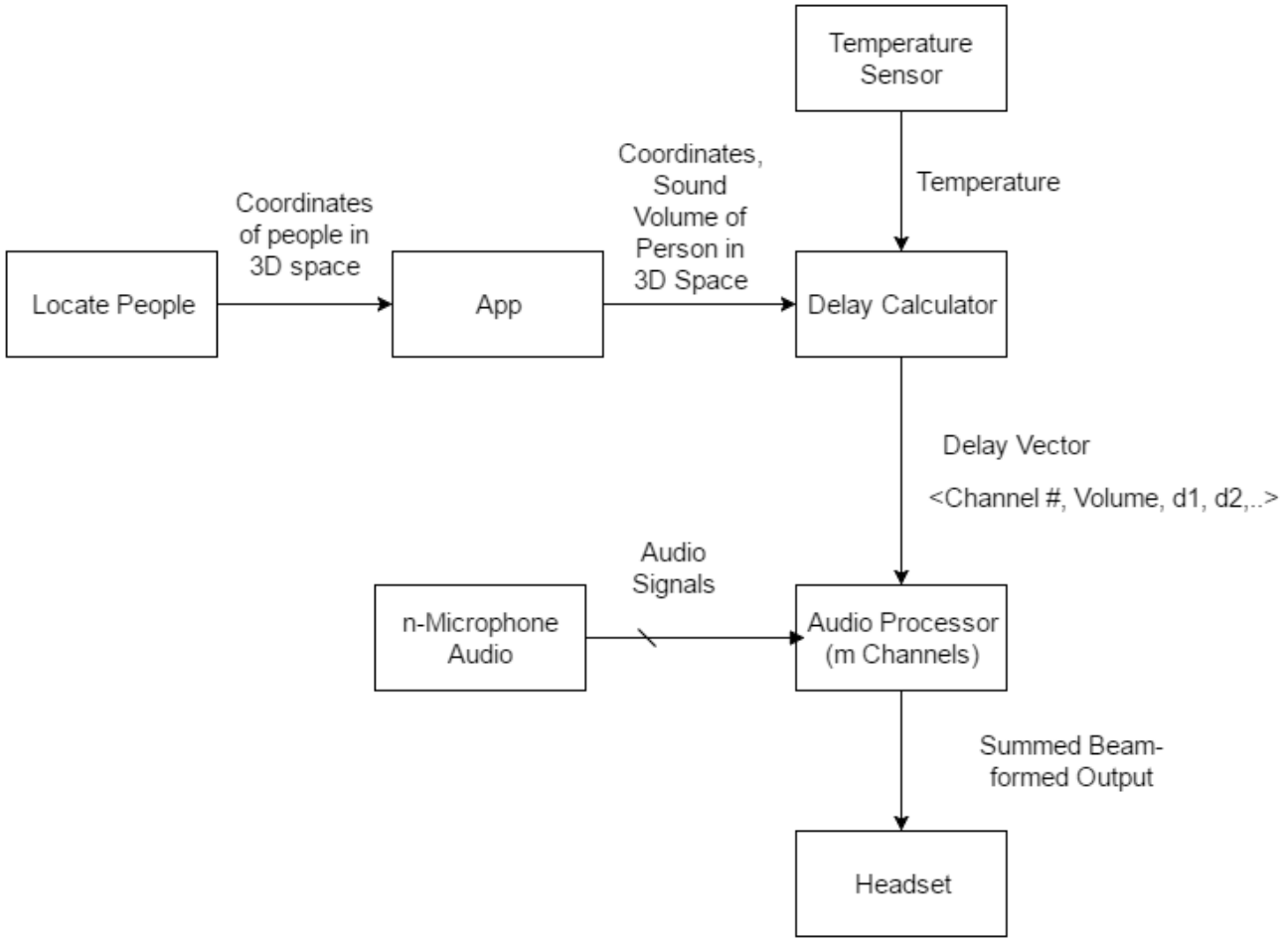
Temperature Sensor
Temperature
Coordinates, Sound Volume of Person in 3D Space
Coordinates of people in 3D space
Locate People
App
Delay Calculator
Delay Vector
<Channel #, Volume, d1, d2,..>
Audio Signals
n-Microphone Audio
Audio Processor (m Channels)
Summed Beam-formed Output
Headset