From Azimuth's cocktail party to accident prevention

Binaural Sound Localization

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Outline

Importance

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- cocktail party processing becomes more relevant

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- understand the physical cues

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- understand the physical cues
- human safety and survival system
    - prevent traffic accidents

Background and Approach

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- Lord Rayleigh's duplex theory (1876)
  - binaural and spectral cues
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  - in-cabin warning system
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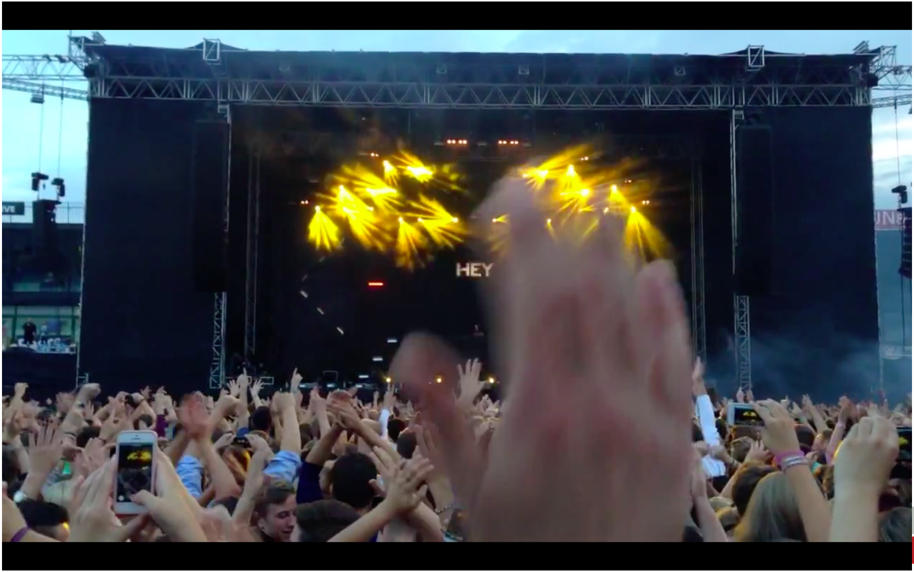
    - in-cabin warning system
    - UK emergency services
- Uniform linear microphone array by Carter and Abraham (1980)

Example

https://www.youtube.com/watch?v=b0lrGXF2Y3w

AVICII live @ HockeyPark Mönchengladbach

Example



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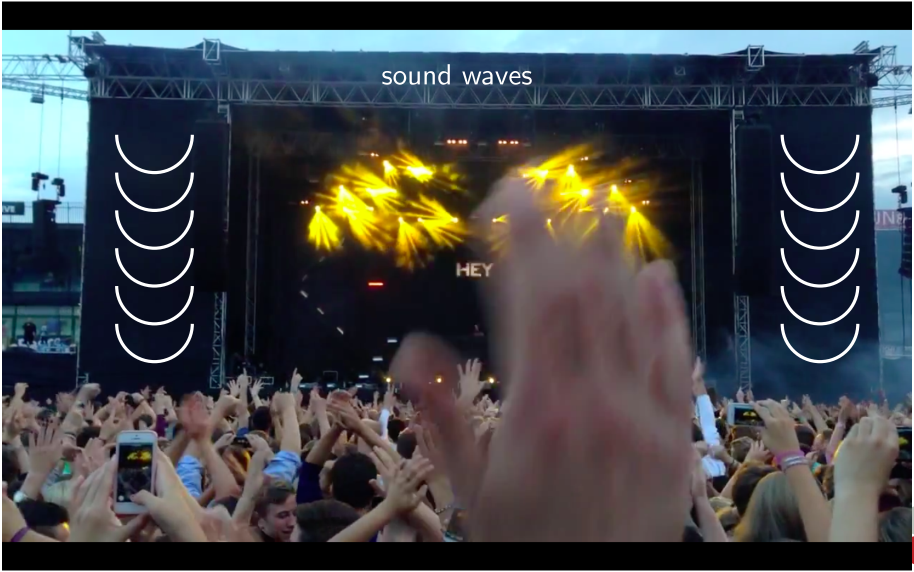

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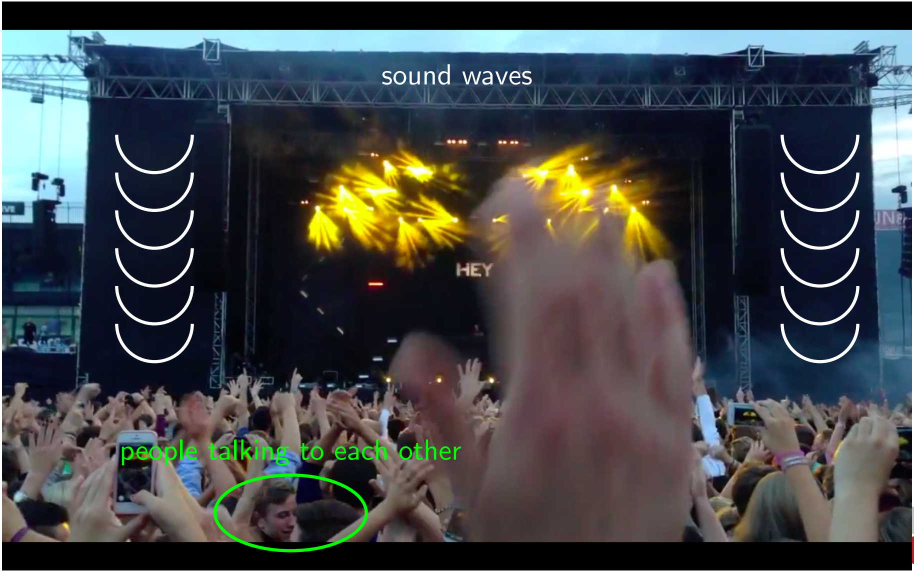

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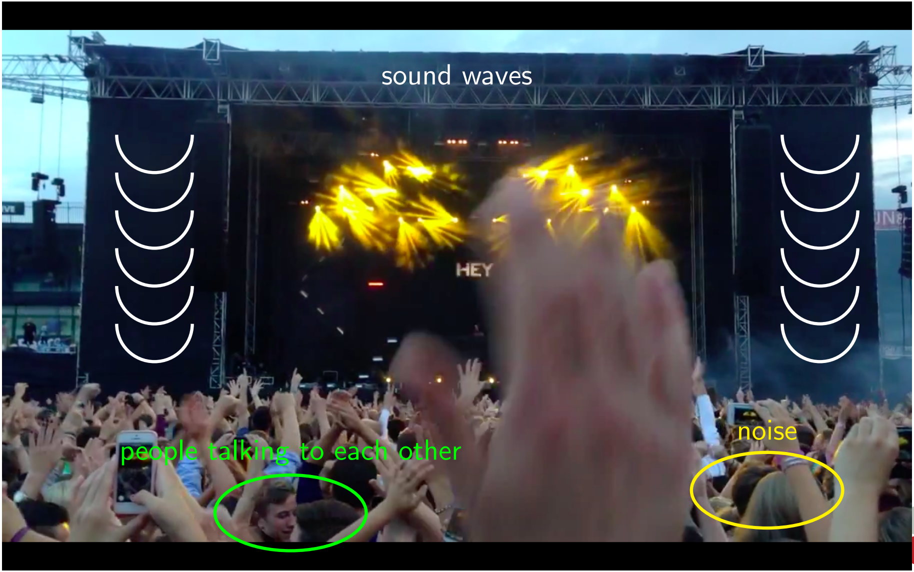
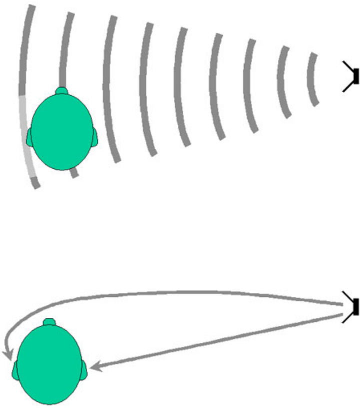


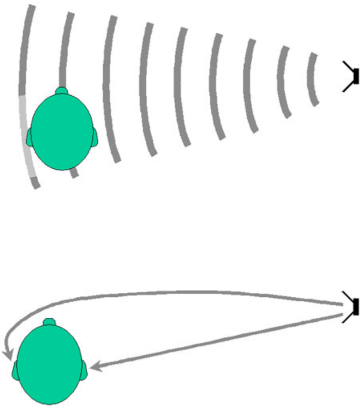
Lord Rayleigh's duplex theory



Duplex Theory [5]

Lord Rayleigh's duplex theory

- sound arrives earlier at the ear closer to the source
- this sound has higher intensity than at the other ear
- only for simple single sound sources in free field



Duplex Theory [5]

Binaural cues

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Interaural Differences

- **ITD** = *Interaural Time Difference*
- **ILD** = *Interaural Level Difference (aka IID = Intensity Difference)*
- **IPD** = *Interaural Phase Difference*

Binaural cues

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- ITD
  - it takes longer for the sound to arrive at the farer ear
  - maximum is about $600\mu s$
  - depends on the speed of sound, geometry of head and ears
  - not effective at high frequencies

Binaural cues

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- ILD
  - shadowing effect of the head as consequence of absorption and reflection
  - maximum above approximately 1.5kHz
  - may not exhibit a relationship to azimuth
  - not effective at low frequencies

Binaural cues

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- IPD
  - depends on the frequency and the ITD
  - underlies localization performance with low frequency sounds
  - intensity differences responsible for performance

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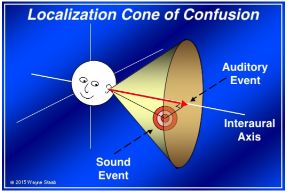
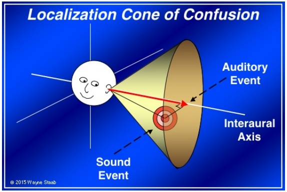
- differences specify a cone of directions
- similar differences (front from back or up from down)

Cone of confusion



Cone Of Confusion [6]

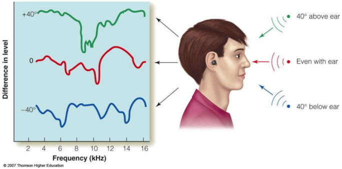
Cone of confusion



Cone Of Confusion [6]

- sound localization along a cone of confusion
- higher frequencies appear higher in elevation
- static sound sources spectral cues stay fixed over duration of the sound
- outside of the free field cues evolve as echoes and reverberation

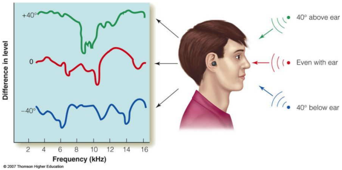
Spatial Localization



HRTF [8]

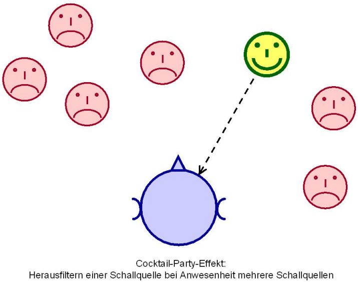
Spatial Localization

- higher complexity of locating moving sounds
- *Head related transfer function* (**HRTF**):
  frequency response as function of azimuth and elevation
- *Precedence effect*:
  sound is reflected from various surfaces before reaching the ears
- *Azimuth*:
  head and ear related coordinate system



HRTF [8]

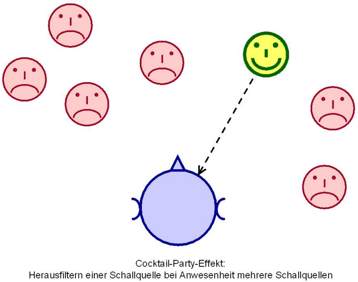
Cocktail Party Processing (CPP)



CPP example [10]

Cocktail Party Processing (CPP)

- phenomenon of selective attention
- separate single voice on a cocktail party
- other example: someone calls your name → focus on this talk



CPP example [10]

Human safety and survival system

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- approaching vehicles can be estimated from an analysis of sound sources
- prevent traffic accidents
- saving humans (civilians, lifesaver and victims) life

Example

https://www.youtube.com/watch?v=ubwmKF7-8Og

Einsatzfahrt RTW

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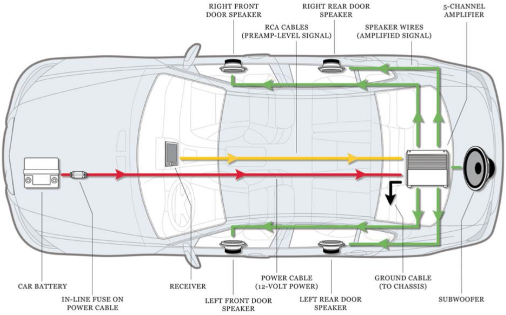
- when siren is heard, looking around trying to determine the direction

First Proposal - In-Cabin Warning System



Car loudspeaker system [7]

First Proposal - In-Cabin Warning System

1. minimize/eliminate spatial ambiguity inherent in existing sirens
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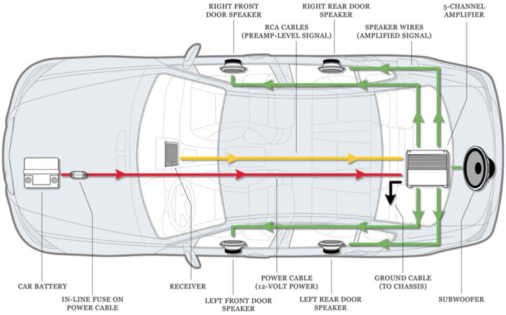

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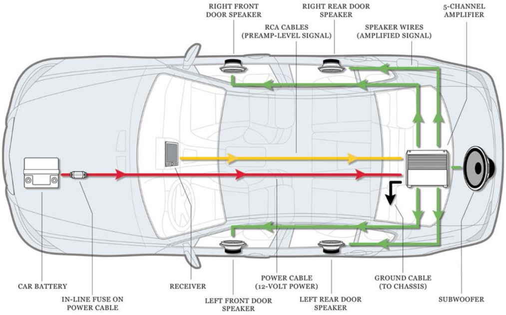
First Proposal - In-Cabin Warning System

1. minimize/eliminate spatial ambiguity inherent in existing sirens
   - patterns contain broadest audible frequency and expand them
2. reduce problems with environmental noise
   - in-cabin auditory as visual warning system
   - relay a warning sound in the same direction as the EV



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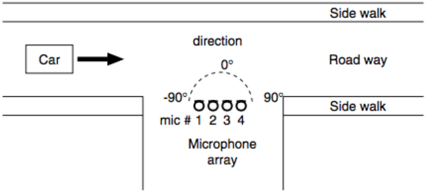
- use microphone array to record sounds of arriving vehicles

Sound recording

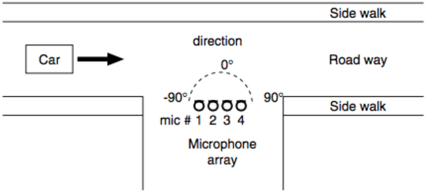


environment [4]

Sound recording

Temperature	15.9 °C
Road condition	Dry
Subject	4 cars
Measurement	5 times
Speed	20, 40, 60 km/h
Weather	Fair
Frequency response	20 - 20kHz
Sampling frequency	44.1kHz

recording conditions [4]



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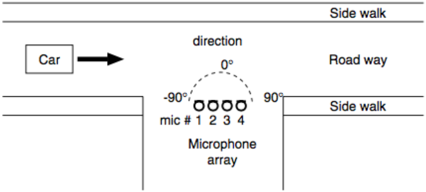
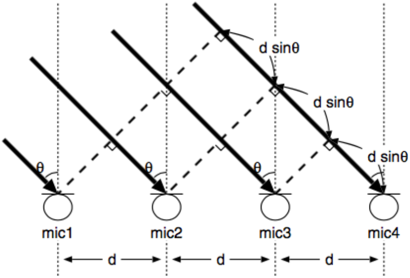


environment [4]

- sounds captured and sampled at 44.1kHz
- vehicle sounds split into
  - frictional sound (between road and tires)
  - engine sound

Sound Localization



microphone array [4]

- $d[m]$ element spacing
- $\theta[rad]$ direction of sound wave
- $dsin\theta$ propagation distance
- time delay[s] $\tau_S = dsin\theta/c$

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- accuracy depends on the bandwith of the input signal
- $\phi(\tau)$ has a clear peak when f_c is significantly large

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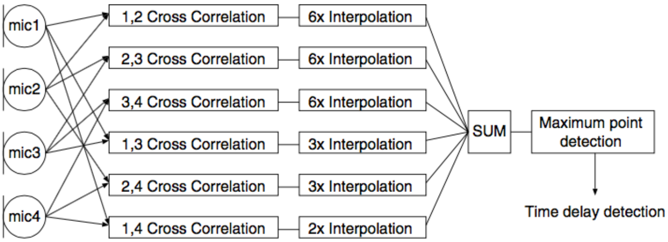

procedure flow [4]

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- cocktail party processing: focus on a talk when someone calls your name
- two systems/methods how drivers can be warned still earlier
  $\Rightarrow$ prevent more accidents and save more lifes

Questions

Thanks for your attention!

References

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