Echo-aware signal processing for audio scene analysis

Diego Di Carlo

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Echo-aware Application

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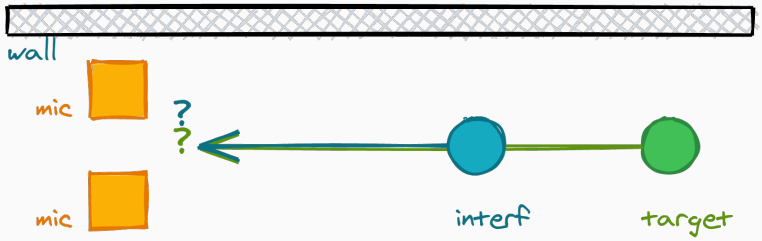
Echoes = same content, different time/direction

Image Source Model
⇔
Image Microphone Mode



Recent literature on echo-aware processing:

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- Sound Source Separation
  [Leglaive et al., 2016]
- Speech Enhancement
  [Flanagan et al., 1993, Dokmanić et al., 2015, **?**]

Where?
Echoes ← image

- Sound Source Localization
  [Ribeiro et al., 2010, Jensen et al., 2019]
- Microphone Calibration
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- Room Geometry Estimation

How?
Echoes ∈ sound propagation

- Blind Channel Estimation
  [Lin et al., 2007, Crocco et al., 2017]
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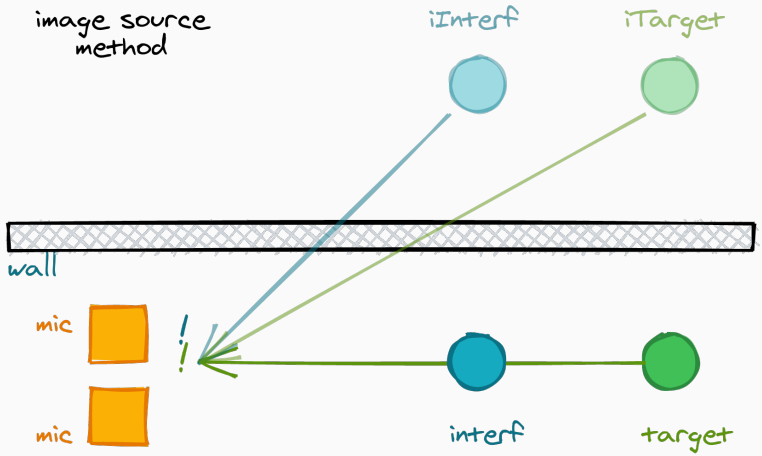

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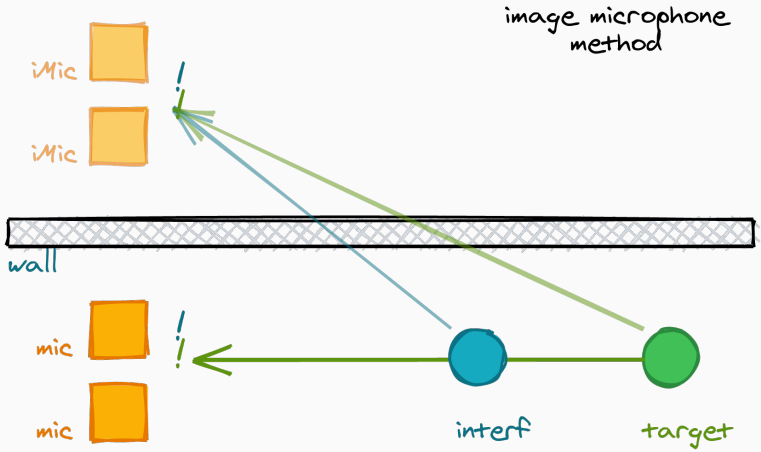

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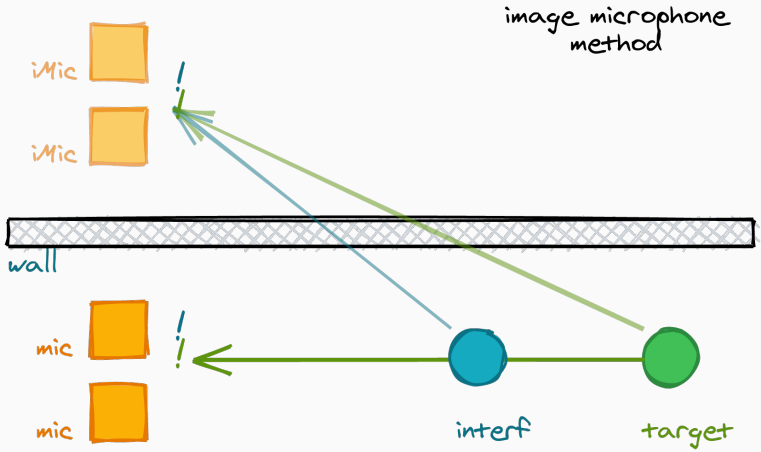

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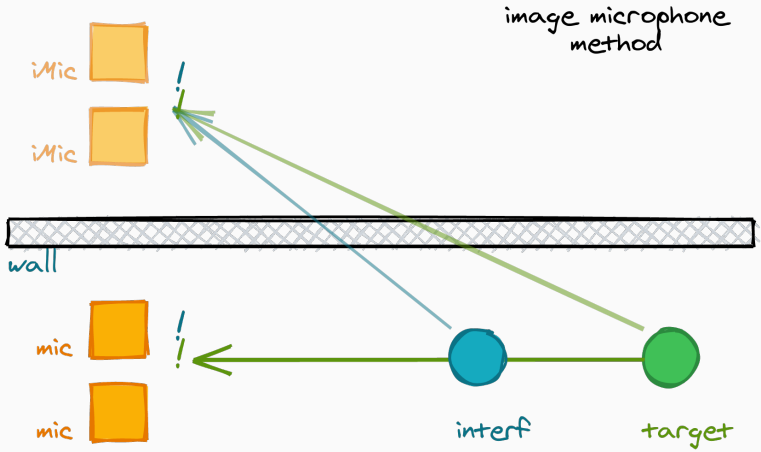

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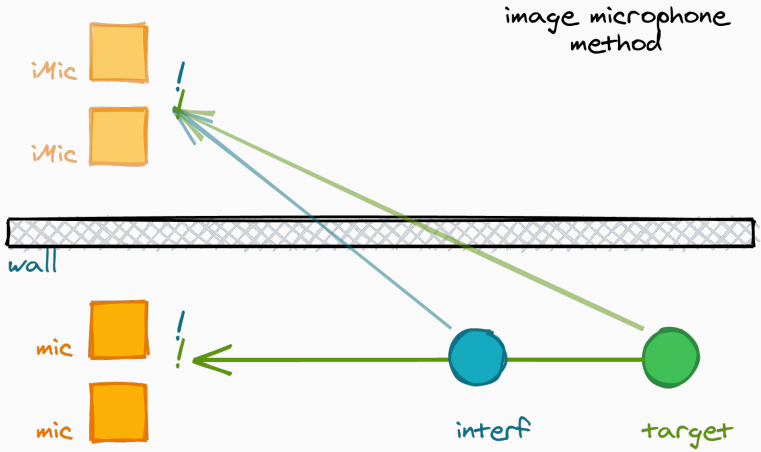

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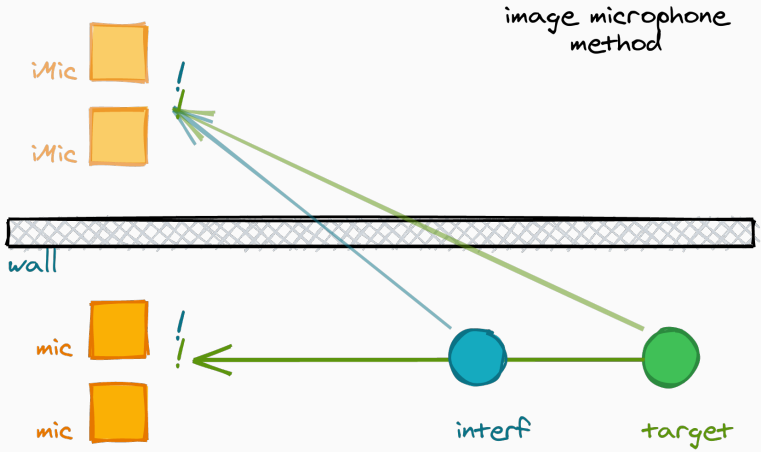

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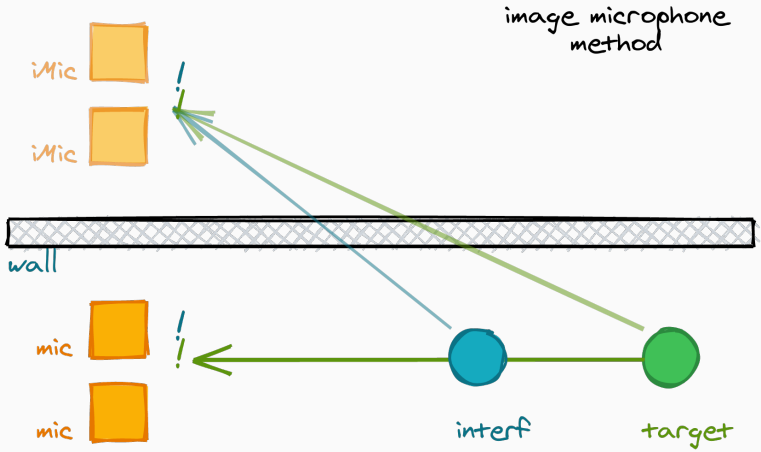

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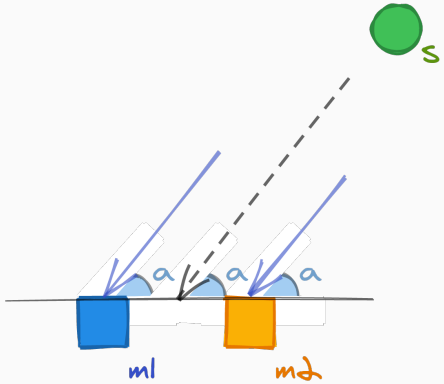
Sound Source Localization (SSL)

(common knowledge)

SSL $\rightarrow$ 3D position of sound source

SSL with 2 microphones

- Only angle of arrival (AOA)
- can be approximated from TDOAusing e.g.GCC-PHAT
  [Knapp and Carter, 1976]
  (known limitation, but good in practice)



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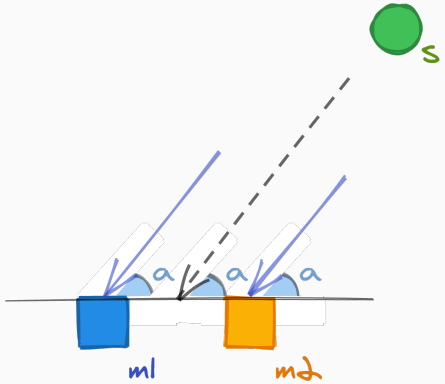
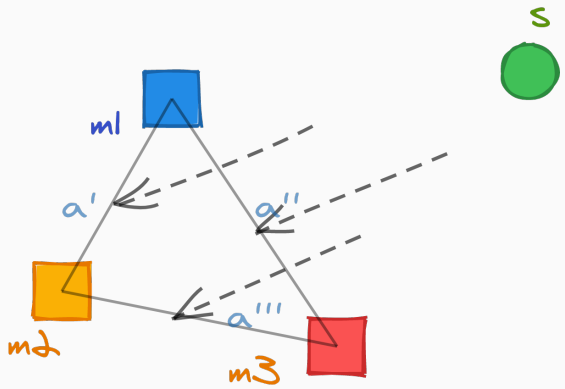


SSL with more microphones

- Only Directon of Arrival (DoA): azimuth (⟷) and elevation (↕)

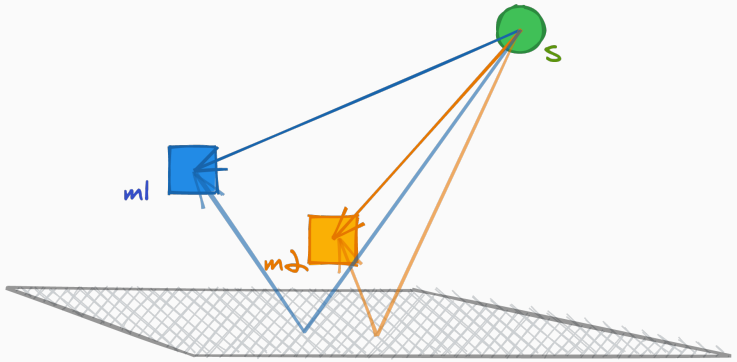
1. AOA for each pair can be "fuse" together (e.g. angular spectra in SRP-PHAT [DiBiase et al., 2001])
   (known limitation, but good in practice)



Sound Source Localization with Echoes

The Picnic Scenario:

- One source
- Two microphones
  - → passive scenario
  - → generalizable to any array geometry



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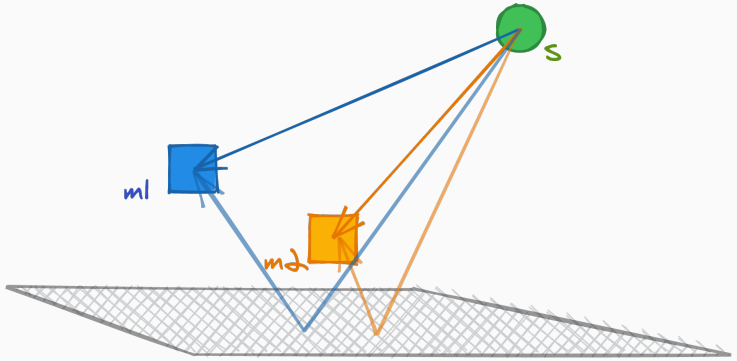
  - → First echo = Strongest echo
  - → α_{picnic} const. $\forall f$
  - → table-top device



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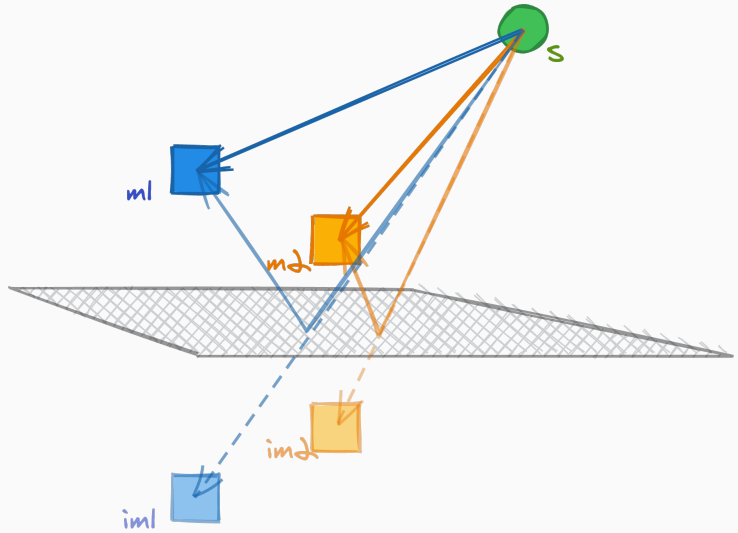
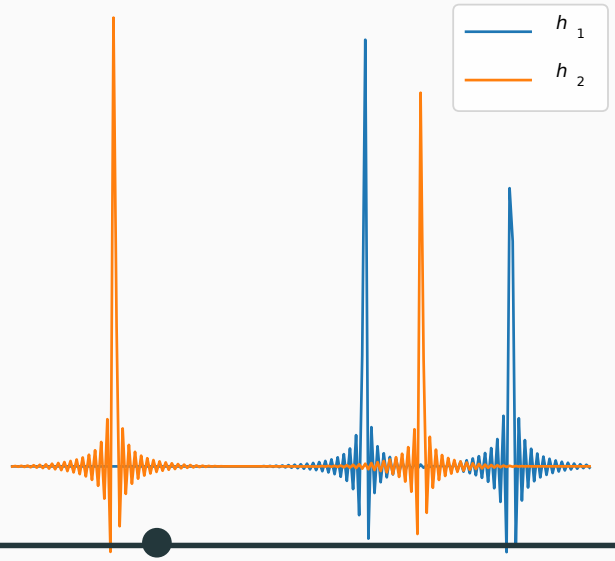


Each pair is augmented with echoes

Mirage Array

(Microphone Array Augmetation with Echoes)

How to access the *image* microphones?



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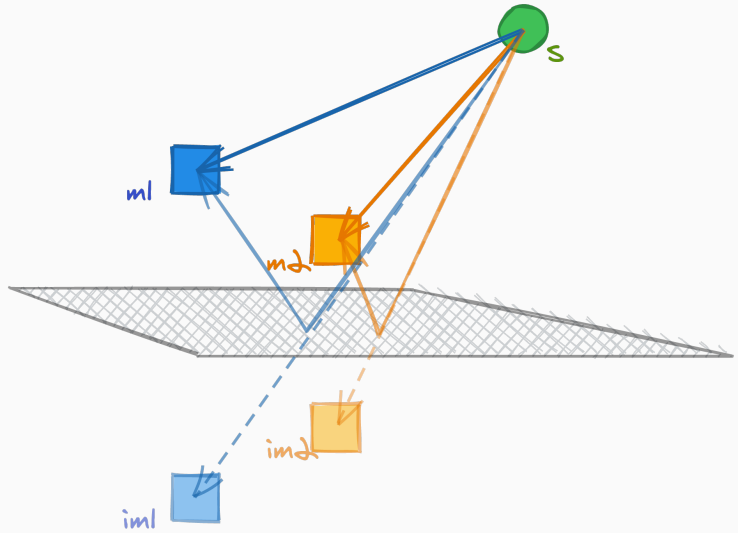

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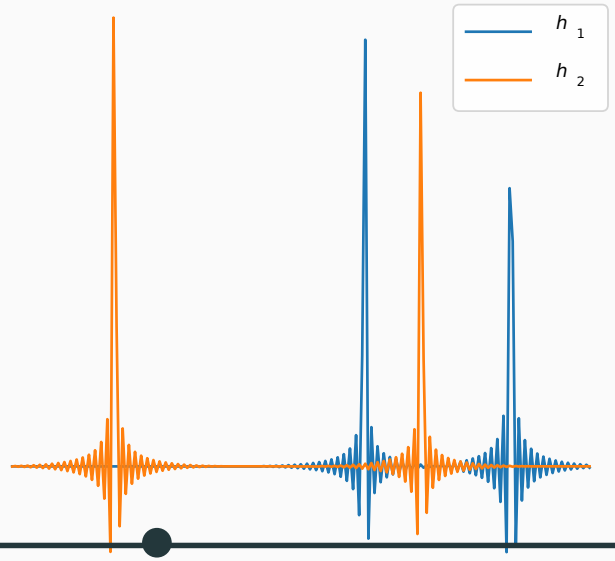

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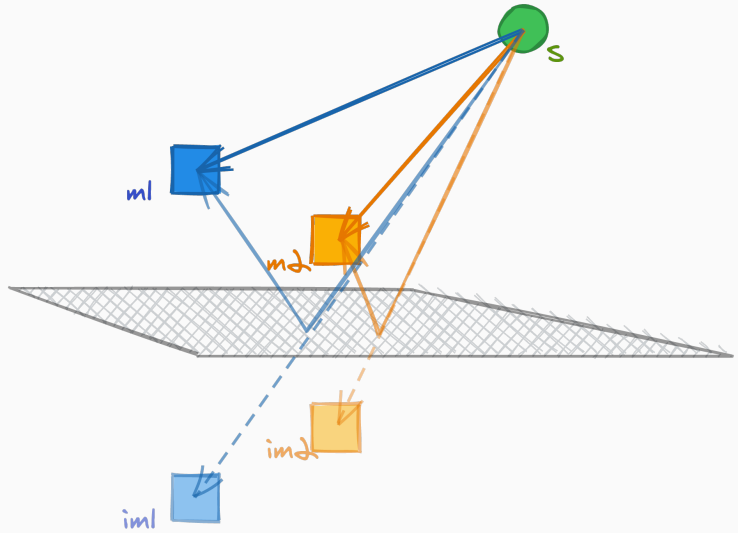

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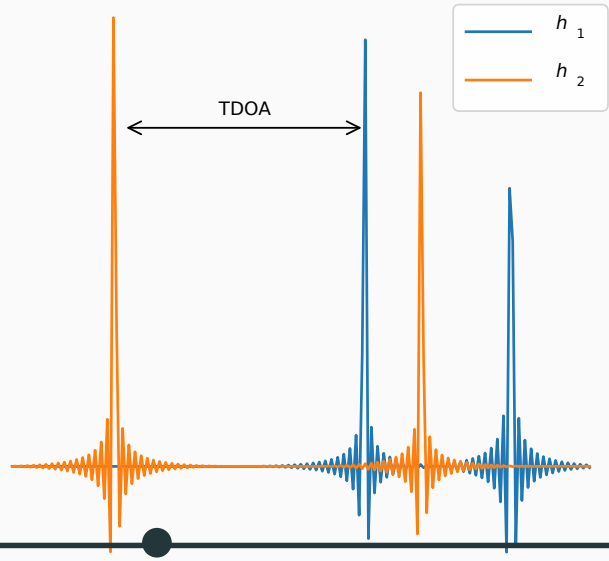

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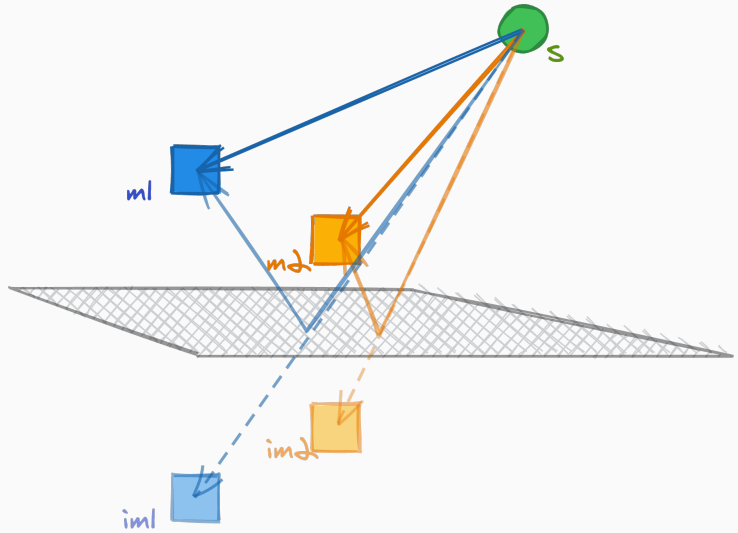

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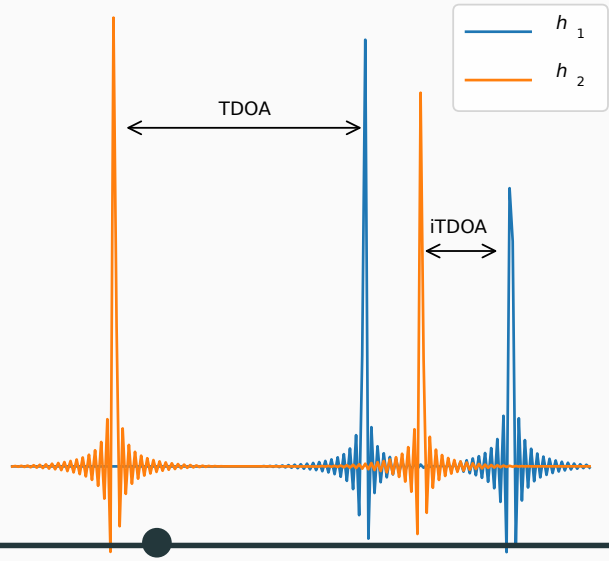

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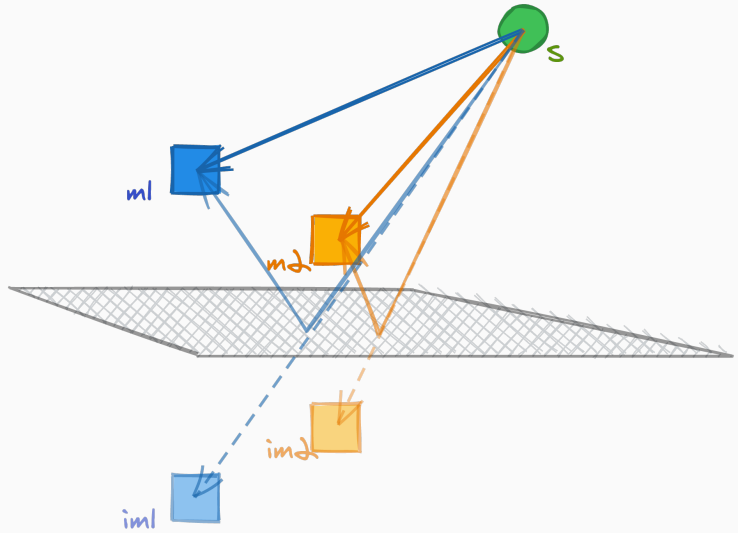

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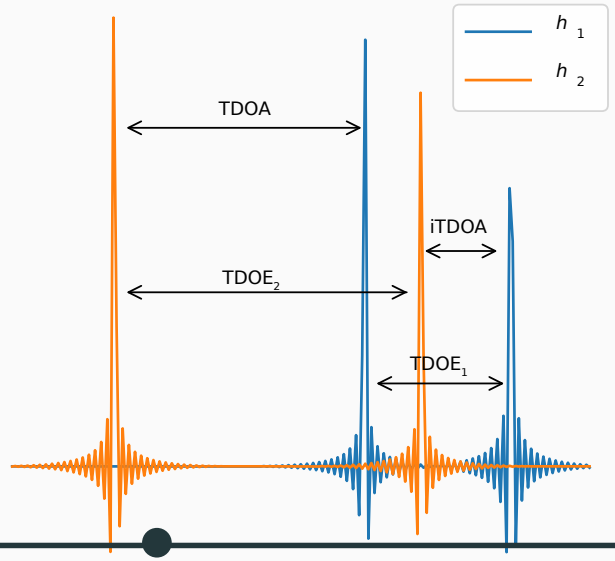

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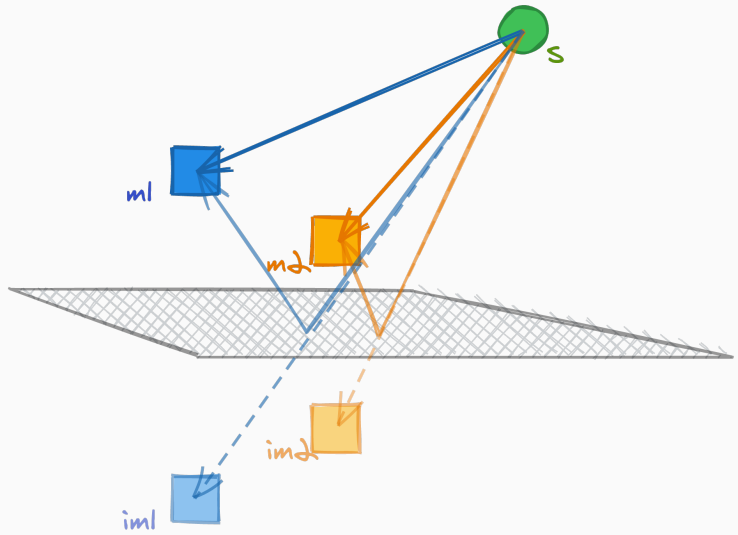
Idea: perform DoA estimate with this.
Recall: these TDOAs are the same of the DNN-based method



Proposed Approach:

- use proposed DNN-based TDOA estimation
- fuse together the estimation ...
  - knowing the position of the microphones;
  - use the error on a validation set as measure of uncertainty.

Baseline: GCC-PHAT on true microphones

Experimental results

Proposed: `MLP` with `Mirage` (mod of SRP-PHAT[1])

Baseline: `GCC PHAT`[2]

Data: virtually generated close dataset as for `Lantern`

Metric: Accuracy (<ang10, <20°) (↰ also error in the manuscript)

AOA estimation

- ✓ Similar when wn
- ✗ Huge drop when noise
- ✗ Huge drop when speech and noise

AOA ⤢	Input	ACCURACY $\alpha < 10°$	ACCURACY $\alpha < 20°$
MIRAGE	wn	77	97
MIRAGE	wn+n	26	54
GCC-PHAT	wn	81	97
GCC-PHAT	wn+n	65	83
MIRAGE	sp	63	82
MIRAGE	sp+n	16	35
GCC-PHAT	sp	82	97
GCC-PHAT	sp+n	19	32

2D SSL estimation
(both Az. and El.)

DoA ✣	Input	ACCURACY $< 10°$ θ↔	ACCURACY $< 10°$ ϕ↕	ACCURACY $< 20°$ θ↔	ACCURACY $< 20°$ ϕ↕
MIRAGE	wn	59	71	79	88
MIRAGE	wn+n	18	26	35	66
MIRAGE	sp	45	59	71	83

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