Echo-aware signal processing for audio scene analysis

Diego Di Carlo

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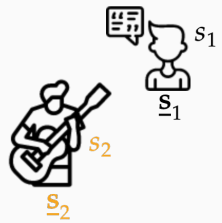
Introduction

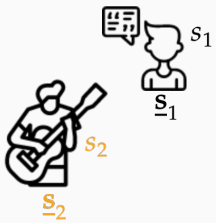
Scenario

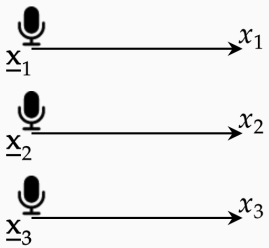


Sound

- produced by sources

Scenario





Sound

- produced by sources
- recorded by microphones

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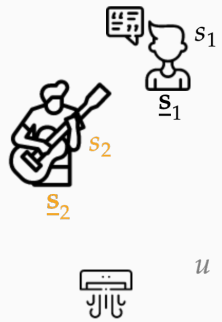

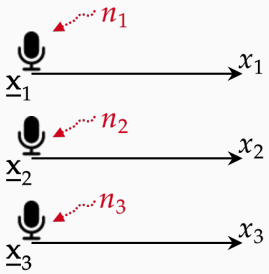

Sound

- produced by sources
- recorded by microphones
- corrupted by noise

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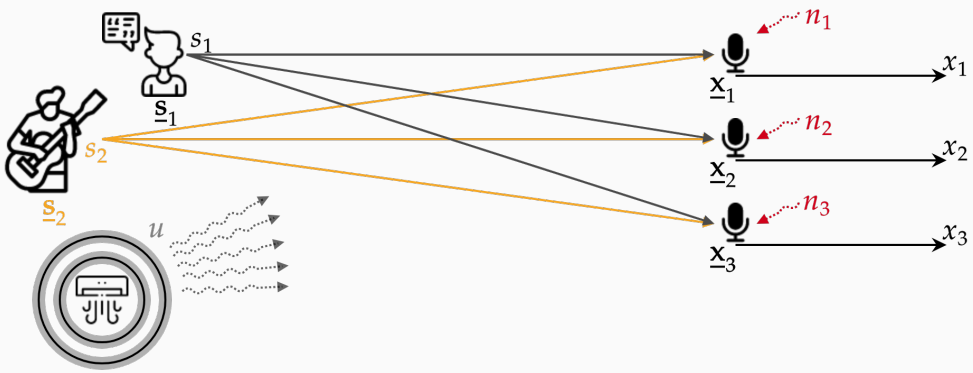

Sound

- produced by sources
- recorded by microphones
- corrupted by noise
- propagates in the space

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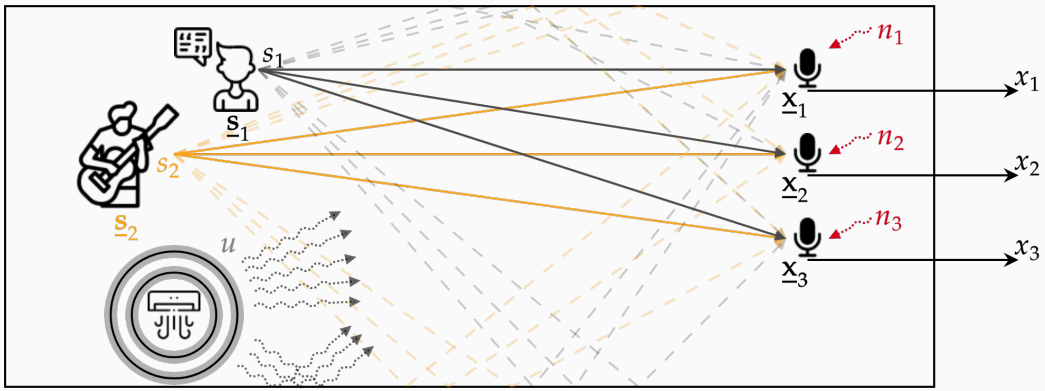

Sound

- produced by sources
- recorded by microphones
- corrupted by noise
- propagates in the space
- interacts with the room
  ↪ reverberation

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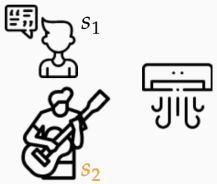
Echo-aware signal processing for audio scene analysis

Semantic information



on nature and content

Echo-aware signal processing for audio scene analysis

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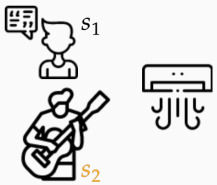

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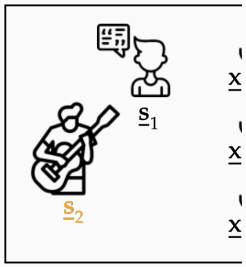
Spatial information



on position and geometry

Echo-aware signal processing for audio scene analysis

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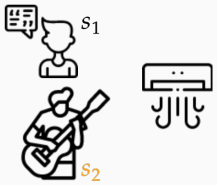

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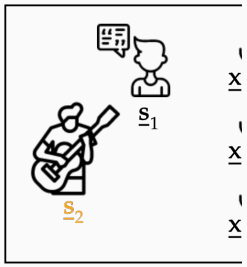

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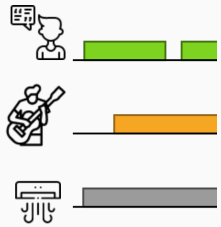
Temporal information



on events activity

Echo-aware signal processing for audio scene analysis

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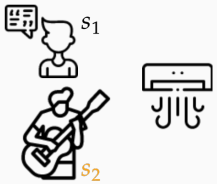

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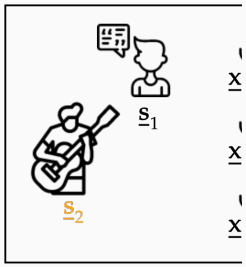

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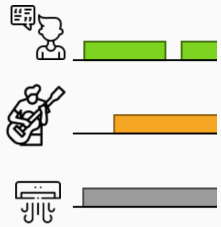

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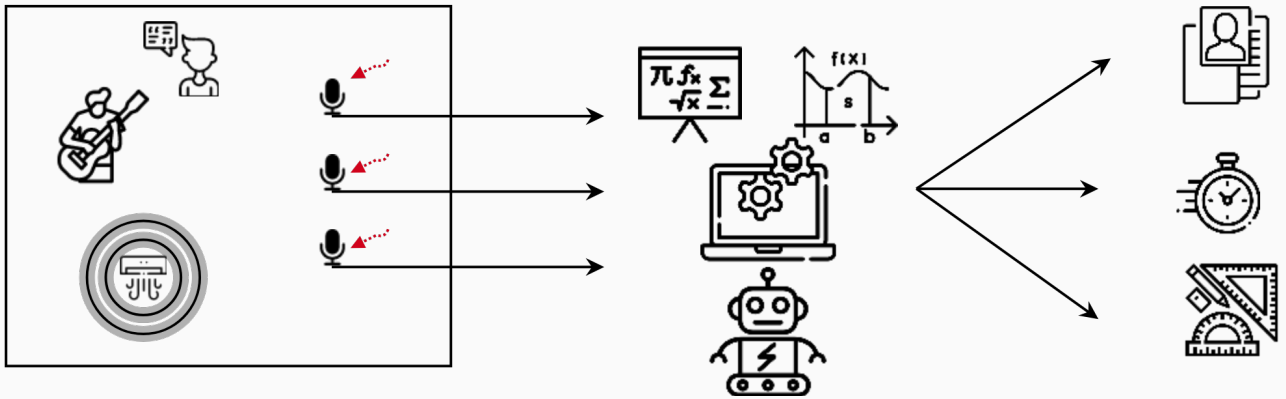
Audio Scene Analysis

Extraction and organization of all the information in the sound



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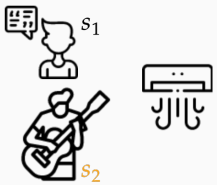

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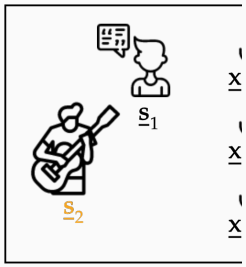

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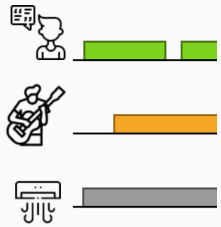

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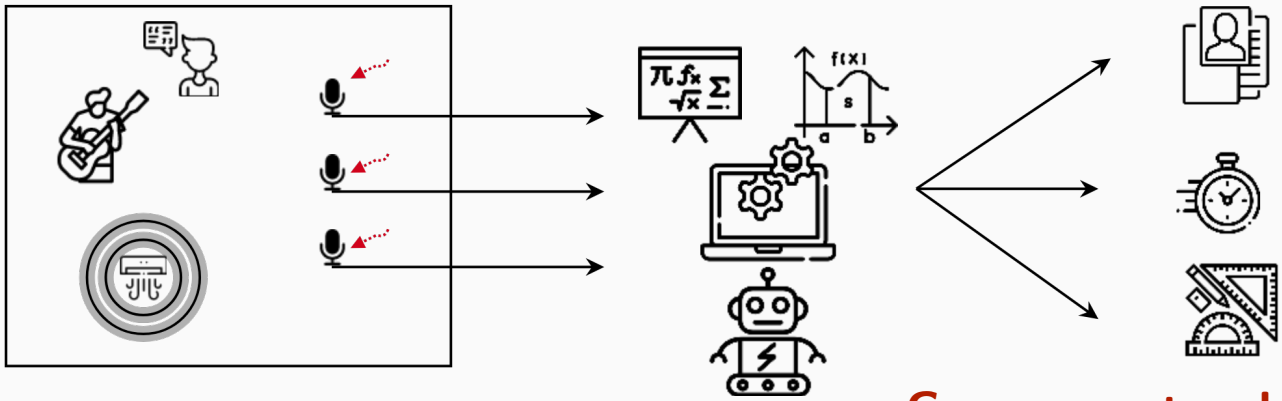
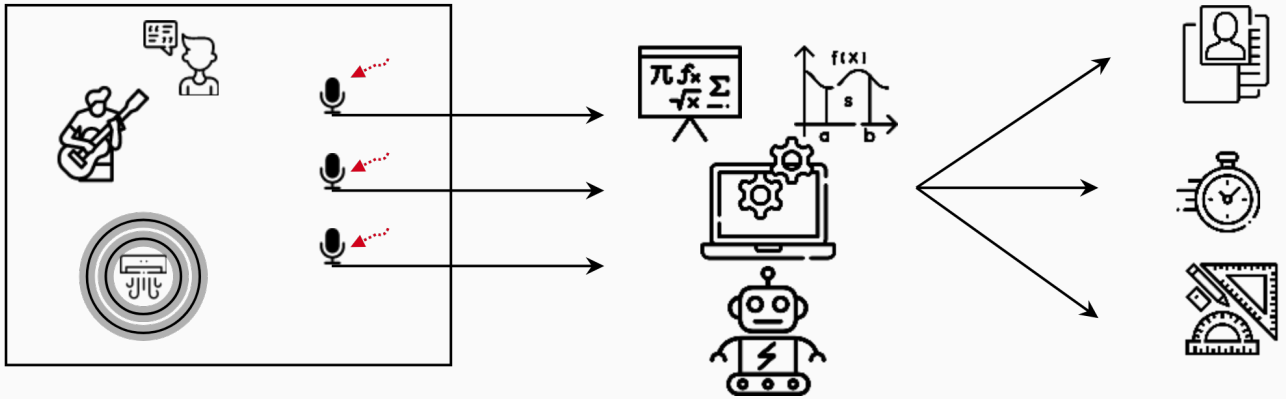


Can computer do it?

Echo-aware signal processing for audio scene analysis



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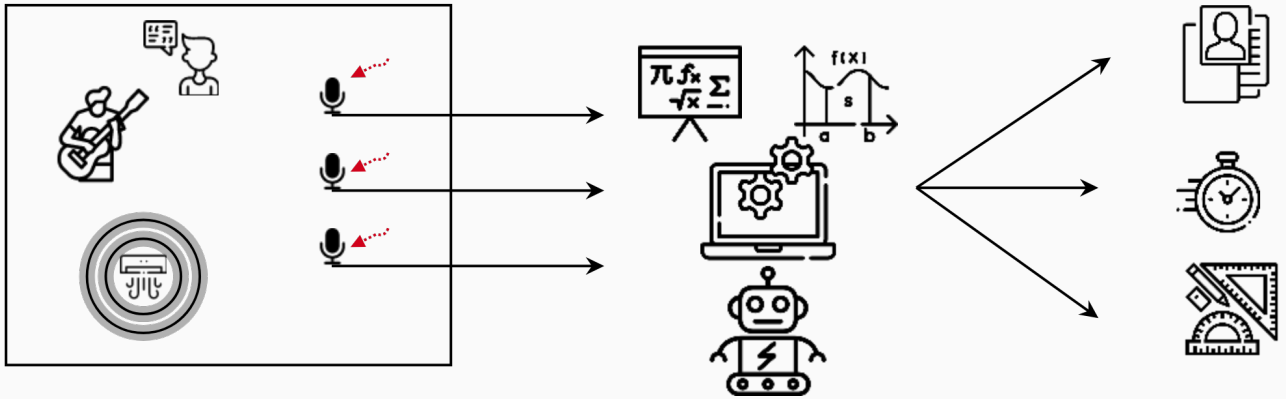
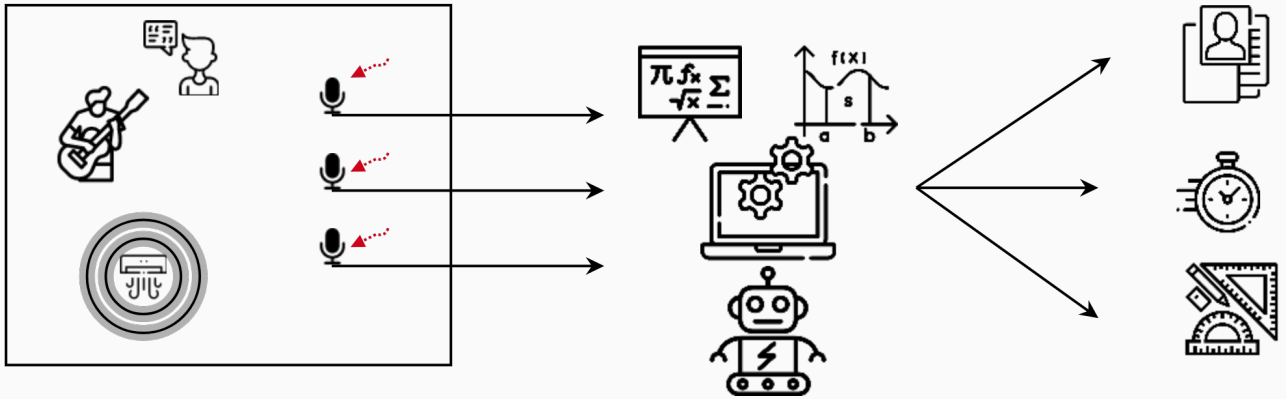


Signal Processing

Mathematical models, frameworks and tools to tackle and solve such problems

Echo-aware signal processing for audio scene analysis



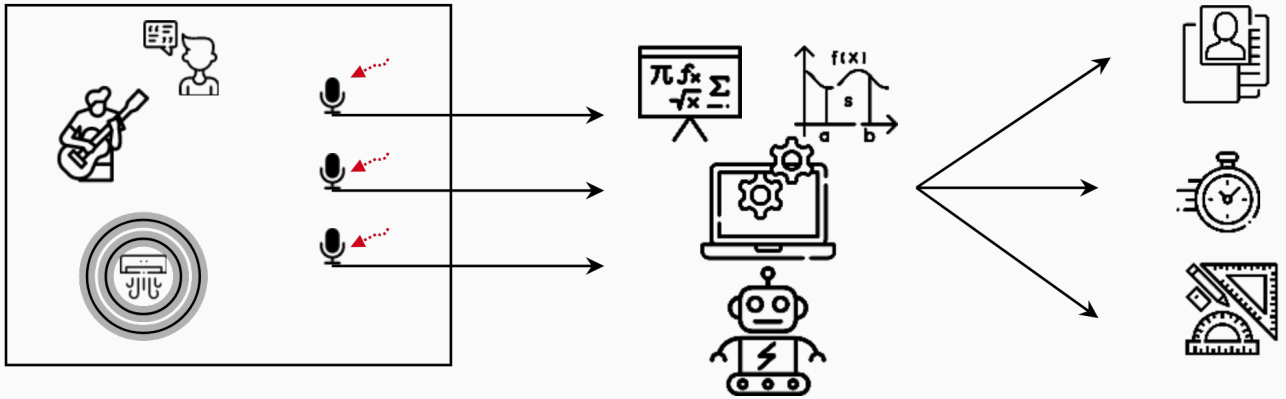
Signal Processing

Mathematical models, frameworks and tools to tackle and solve such problems

Some (inverse) problems

- Speaker Identification
- Sound Source Separation (SSS)
- Speech Enhancement (SE)
- Automatic Speech Recognition (ASR)
- Voice Activity Detection
- Diarization
- RT_{60} estimation
- Acoustic Channel Estimation
- Wall Absorption Estimation

Echo-aware signal processing for audio scene analysis



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Echo-aware signal processing for audio scene analysis

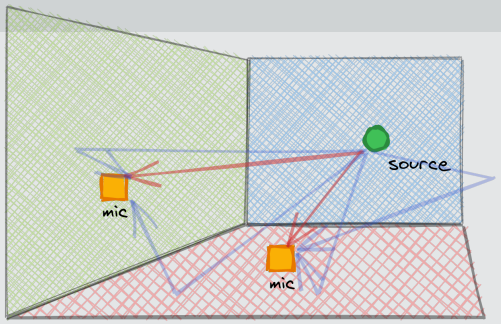
Sound interacts with environment

it is reflected (specularly and diffusely)
+ it is diffracted
+ it is absorbed and transmitted
+ other physical interaction

} = all sound propagation

Acoustic Echoes

- **Elements** of **reverberation**
- **Standing out** for time and strength
- **Repetition** of a sound but **after**
  - time $\Leftrightarrow$ distance
  - same content



Everyday examples:

Echo points Bat Dolphins Room coloration

Typically sound propagation is

- ignored $\Longrightarrow$ simple processing

but reverberation = noise

Echo-aware methods

Outline and contributions

Thesis title:

Audio Scene Analysis

↓

context and problems

Outline and contributions

Thesis title:

Audio Scene Analysis ↓ context and problems

Signal Processing ↓ models and frameworks

Outline and contributions

Thesis title:

Audio Scene Analysis	Signal Processing	Echo-aware
↓	↓	↓
context and problems	models and frameworks	better processing

Outline and contributions

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Thesis content

How to estimate them?

- Analytical method
- Learning-based method

How to use them?

- Source Separation
- Source Localization
- Speech Enhancement
- Room Geometry Estimation

Where to find them?

Echo-aware database for estimation and application

Problem Statement

Signal model

Sound propagation process $\Leftrightarrow$ Source $\rightarrow$ Filter $\rightarrow$ Receiver model

source signal

microphone signal $\tilde{x}_i(t) = (\tilde{h}_i * \tilde{s})(t) + +\tilde{n}(t)$ noise term

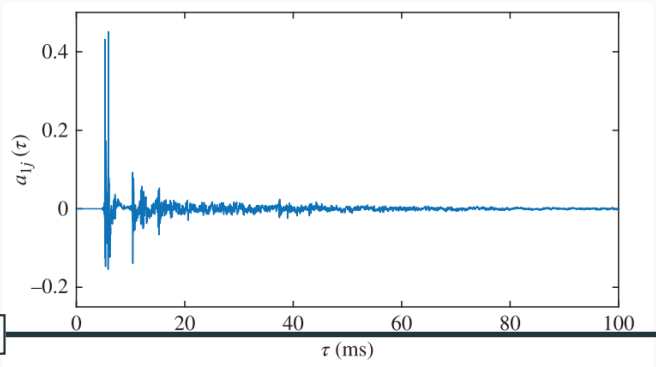
continuous-time convolution

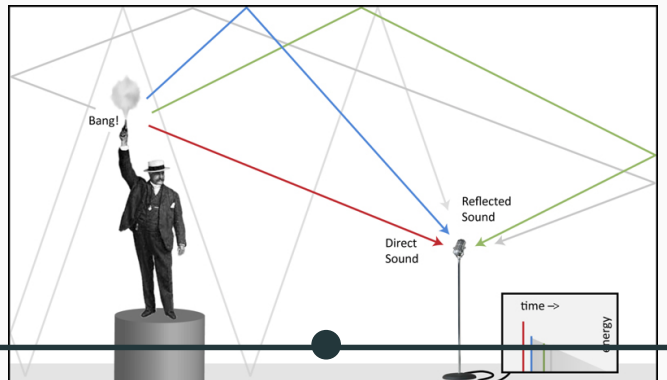
-3mm

⚠ continuous time

Room Impulse Response (RIR)

- linear filtering effect of the sound
- acoustic response of a room to a (prefect) impulsive sound
- depends on spatial properties (room geometry, mic/src position)

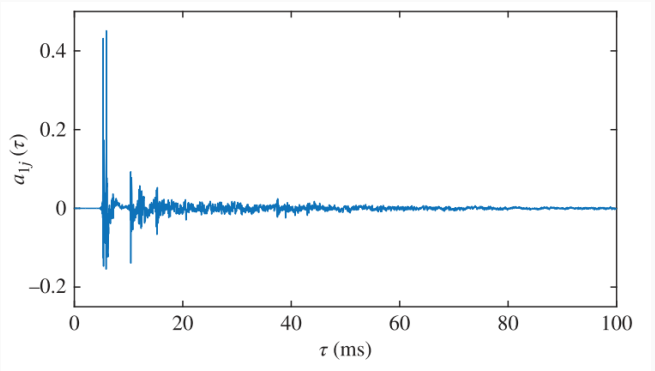




Echoes in the RIR

RIR model

$$\tilde{h}_i(t) = \tilde{h}_i^{\mathsf{d}}(t) + \tilde{h}_i^{\mathsf{e}}(t) + \tilde{h}_i^{\mathsf{lrev}}(t) + \varepsilon_i(t)$$



Echoes can be modeled as sum of Dirac's delta

$$\tilde{h}_i^{\mathsf{echoes}} = \tilde{h}_i^{\mathsf{d}}(t) + \tilde{h}_i^{\mathsf{e}}(t) \approx \sum_{r=0}^{R} \alpha_i^{(r)} \delta(t - \tau_i^{(r)})$$

Goal: estimated the $\tau_{i_{i,r}}$

Challenges:

- α distortion (even if we know it $\implies$ labeling)
- $\alpha \to \alpha(t)$ (sum of diracs $\to$ sum of filters)
- h_l reverberation is included in the noise term
- depends on the scene geometry (room, source and mic position)

References i