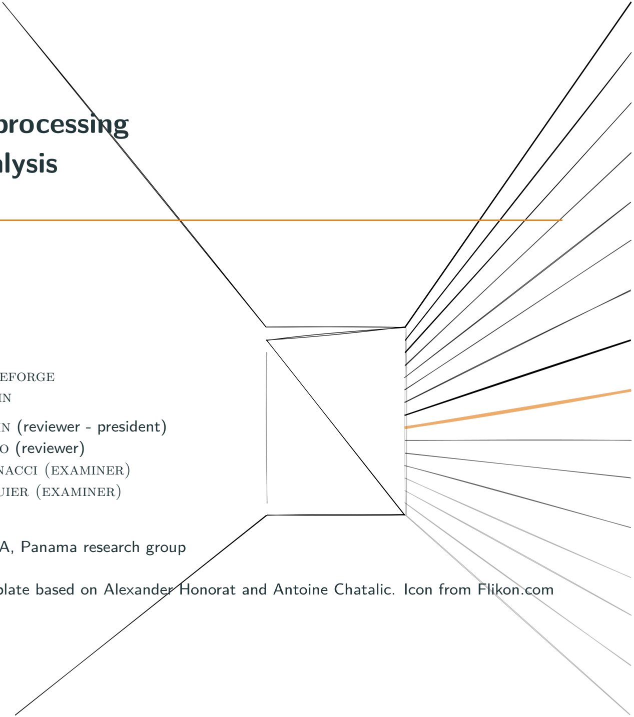
Echo-aware signal processing for audio scene analysis



Diego Di Carlo

November 29, 2020

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Jury members:	Laurent Girin (reviewer - president) Simon Doclo (reviewer) Fabio Antonacci (examiner) Renaud Seguier (examiner)

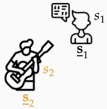
Université de Rennes 1, IRISA/INRIA, Panama research group

Colophon: Metropolis Beamer Template based on Alexander Honorat and Antoine Chatalic. Icon from Flikon.com

Introduction

Echo-aware signal processing for audio scene analysis

Current Scenario

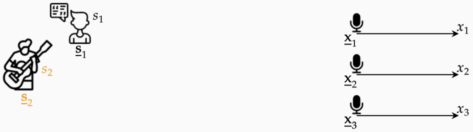


Sound

- produced by sources

Echo-aware signal processing for audio scene analysis

Current Scenario


s_1
$\underline{\mathbf{s}}_1$
s_2
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$\underline{\mathbf{x}}_1$
x_1
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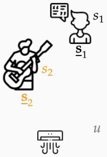
x_2
$\underline{\mathbf{x}}_3$
x_3

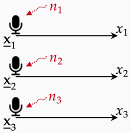
Sound

- produced by sources
- recorded by (array of) microphones

Echo-aware signal processing for audio scene analysis

Current Scenario




n_1
$\underline{\mathbf{x}}_1$
x_1
n_2
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x_2
n_3
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x_3

Sound

- produced by sources
- recorded by (array of) microphones
- corrupted by noise

Echo-aware signal processing for audio scene analysis

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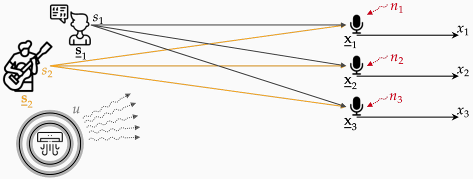
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x_1
x_2
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Sound

- produced by sources
- recorded by (array of) microphones
- corrupted by noise
- propagates in the space

Echo-aware signal processing for audio scene analysis

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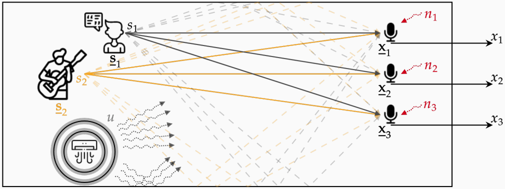
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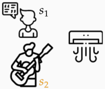
x_1
x_2
x_3

Sound

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

Echo-aware signal processing for audio scene analysis

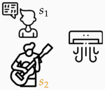
Semantic information



on nature and content

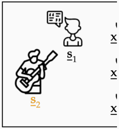
Echo-aware signal processing for audio scene analysis

Semantic information



on nature and content

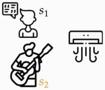
Spatial information



on position and geometry

Echo-aware signal processing for audio scene analysis

Semantic information



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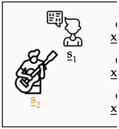
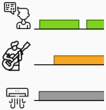


on position and geometry

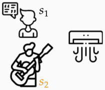
Temporal information



on events activity

Echo-aware signal processing for audio scene analysis

Semantic information



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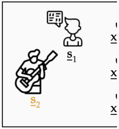
Spatial information



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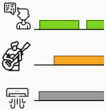
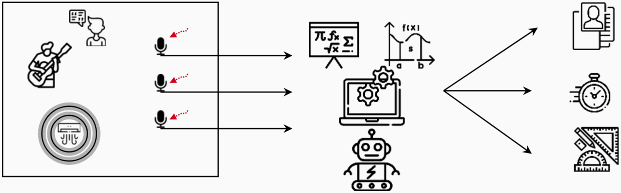


on events activity

Audio Scene Analysis

Extraction and organization of all the information in the sound



Echo-aware signal processing for audio scene analysis

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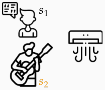

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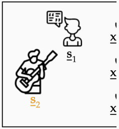

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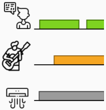
Temporal information



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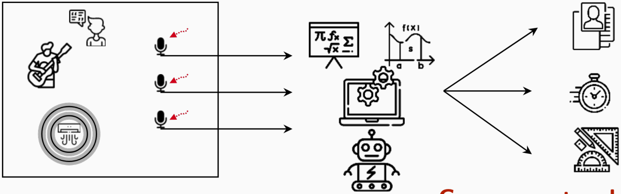
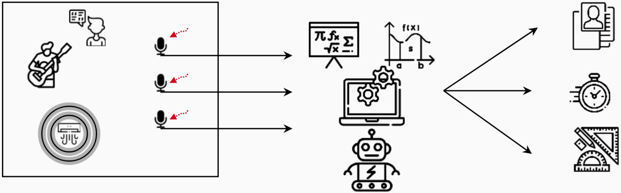
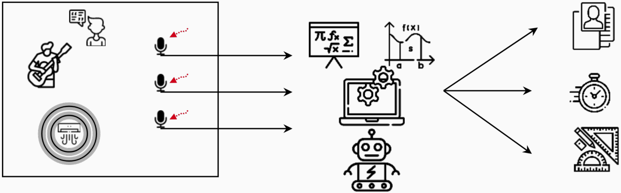


Can computer do it?

Echo-aware signal processing for audio scene analysis



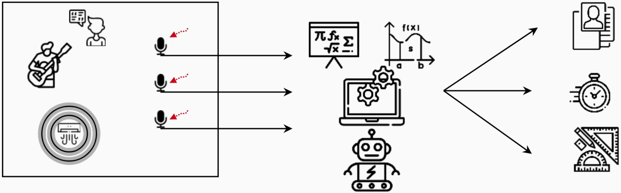
Echo-aware signal processing for audio scene analysis



Signal Processing

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

Echo-aware signal processing for audio scene analysis



Signal Processing

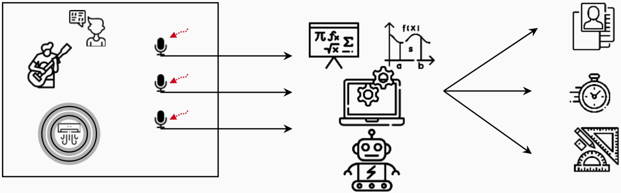
Mathematical models, frameworks and tools to tackle and solve such problems

Some (inverse) problems

- Speaker Identification
- Sound Source Separation (SSS)
- Speech Enhancement (SE)
- Automatic Speech Recognition (ASR)
- Sound Source Localization (SSL)

- 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

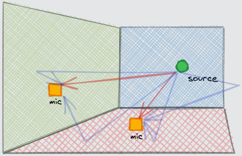
Sound interacts with indoor environment:

it is reflected,
specularly and diffusely
+ it is absorbed,
+ it is transmitted,
+ and other.

= all reverberation

Acoustic Echoes

- Elements of reverberation
- Specular reflection standing out for time and strength
- Repetition of a sound but after
  - same content
  - delay ⇔ distance



4/8

Everyday examples:

Outline and contributions

Thesis title

Audio Scene Analysis

↓

context and problems

Outline and contributions

Thesis title

Audio Scene Analysis	Signal Processing
↓	↓
context and problems	models and frameworks

Outline and contributions

Thesis title

Audio Scene Analysis
↓
context and problems

Signal Processing
↓
models and frameworks

Echo-aware
↓
better processing

Outline and contributions

Thesis title

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

Thesis content:

How to estimate them?

- Analytical method
- Learning-based method

no parameter tuning

no full sound modeling

How to use them?

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

Where to find them?

Echo-aware database for
estimation and application

Problem Statement

Signal model

Sound propagation process ⇔ Source → Filter → Receiver model

source signal

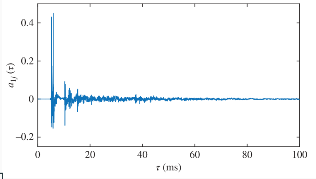
microphone signal ← $\tilde{x}_i(t) = (\tilde{h}_i * \tilde{s})(t) + +\tilde{n}(t)$ → noise term

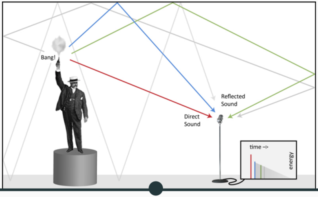
continuous-time convolution

⚠ 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)

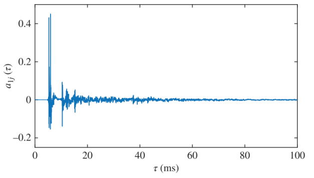




Echoes in the RIR

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 → sum of filters)
- h_l reverberation is included in the noise term
- depends on the scene geometry (room, source and mic position)

References i