Exploring the Multidimensional Representation of Unidimensional Speech Acoustic Parameters Extracted by Deep Unsupervised Models

Journée commune AFIA-TLH / AFCP

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Décembre 2023

1. Introduction
2. Analysis & Results
   - Multidimensional representation of acoustic features
   - Interpretation of the learnt dimensions
   - Universal vs. speaker-specific variations
   - Control of the acoustic parameters
3. Conclusion
4. References

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What is a Vocoder ?

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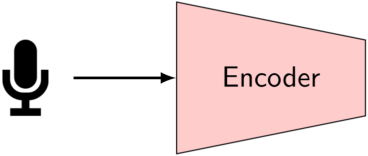

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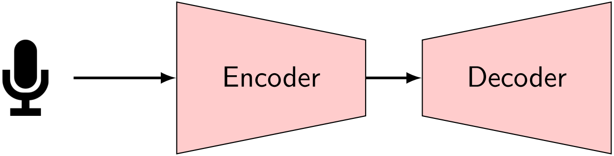

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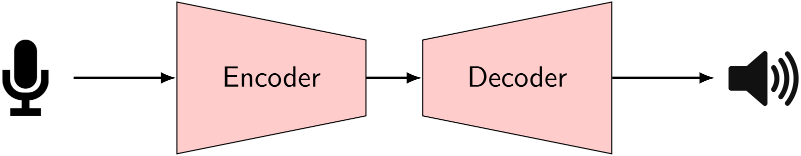
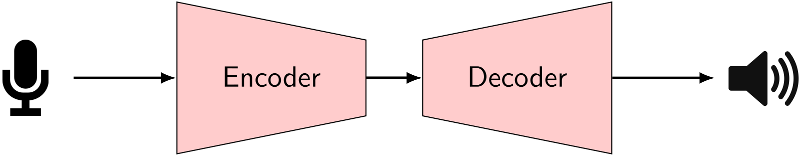
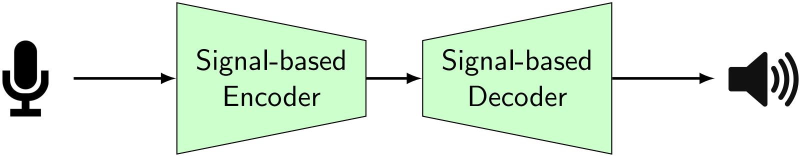


What is a Vocoder ?

Dimensionality reduction



Signal-based Vocoder



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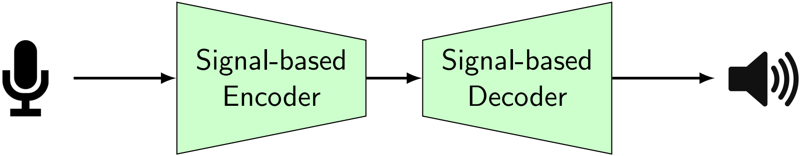

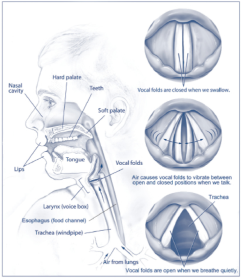

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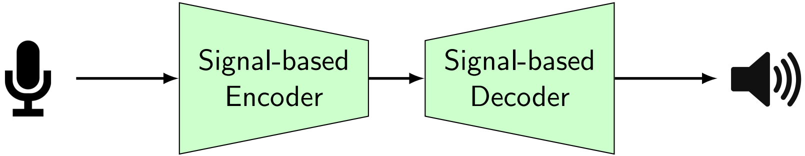
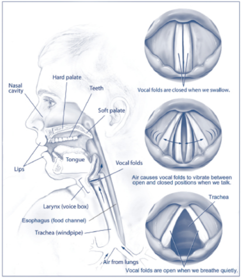
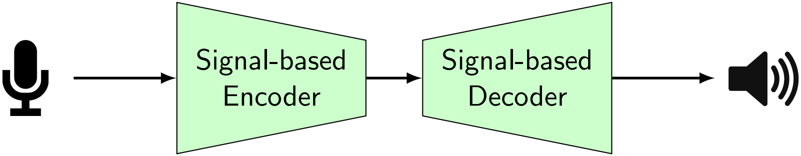
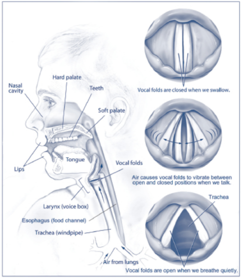




- Fundamental frequency (f_0)
- Formants frequency ($F_{1,2,3}$)

Signal-based Vocoder





- Fundamental frequency (f_0)
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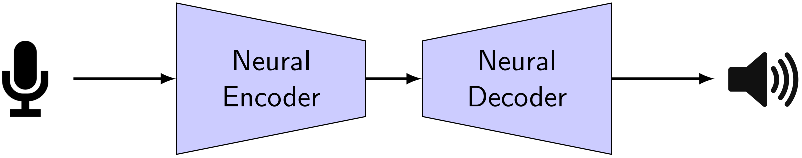
- CELP [1]
- STRAIGHT [2]
- WORLD [3]

[1] Schroeder et al., Code-excited linear prediction(CELP): High-quality speech at very low bit rates, ICASSP, 1985
[2] Kawahara et al., Restructuring speech representations using a pitch-adaptive [...] extraction, Speech communication, 1999
[3] Morise et al., WORLD: A Vocoder-Based High-Quality Speech Synthesis System for Real-Time Applications, IEICE, 2016

Neural Vocoder



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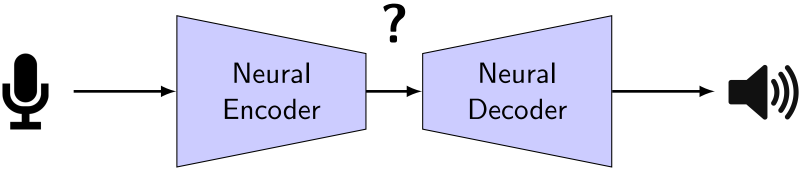

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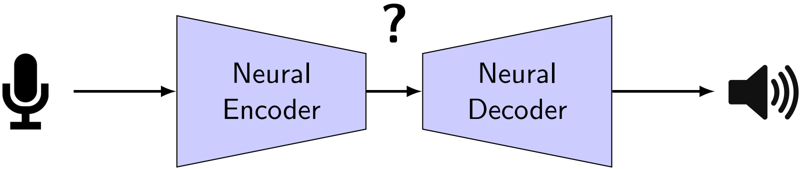
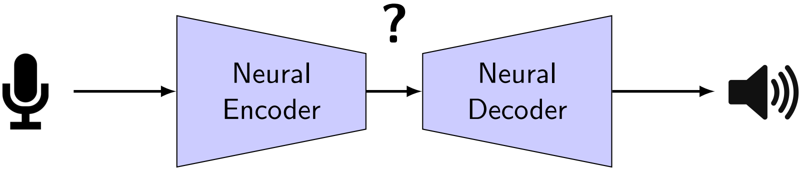


Are acoustic parameters encoded in unsupervised models ?

Neural Vocoder



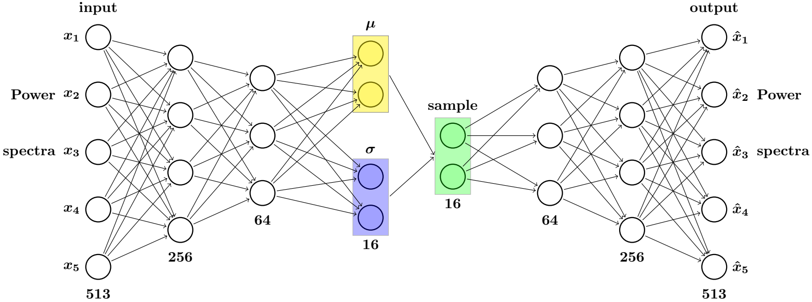
Are acoustic parameters encoded in unsupervised models ?

Sadok et all, *Learning and controlling the source-filter representation of speech with a variational autoencoder*, In Speech Communication, 2023 [4]

Neural Network

Variational autoencoder (VAE)

- Simple but powerful deep generative neural networks [5]



[5] Kingma et al., Auto-Encoding Variational Bayes, ICLR, 2014

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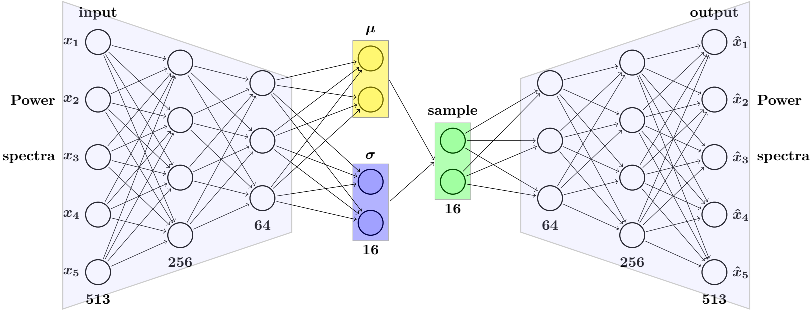

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Why the variation of such one-dimensional feature is often explained by multiple latent dimensions ?

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Multidimensional representation of acoustic features

Objective

Study the encoding of each acoustic parameter separately

Multidimensional representation of acoustic features

Methodology

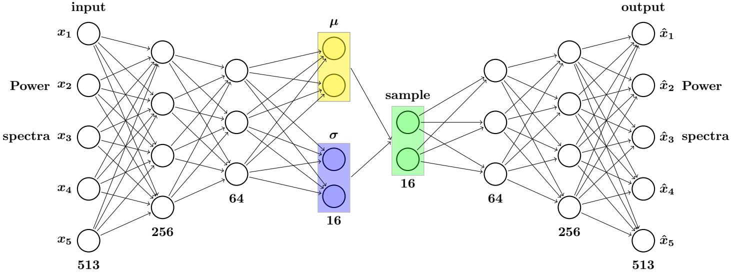
- Training dataset : VCTK [6], multi-speaker dataset, english speakers

[6] Junichi et al., VCTK Corpus: English Multi-speaker Corpus for CSTR Voice Cloning Toolkit, 2019

Multidimensional representation of acoustic features

Methodology

- Training dataset : VCTK [6], multi-speaker dataset, english speakers
- Model based on previous works [4]



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- Training dataset : VCTK [6], multi-speaker dataset, english speakers
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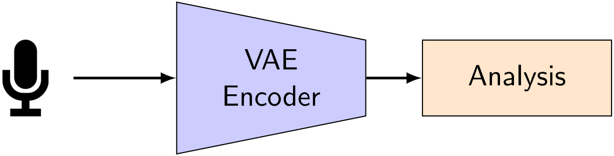
- Linear analysis methods to identify the directions in the latent space that capture the variability for each acoustic parameter



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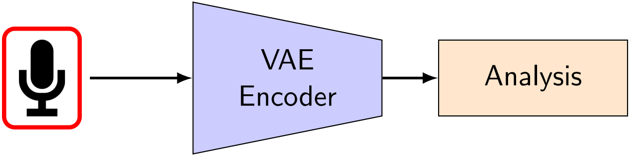
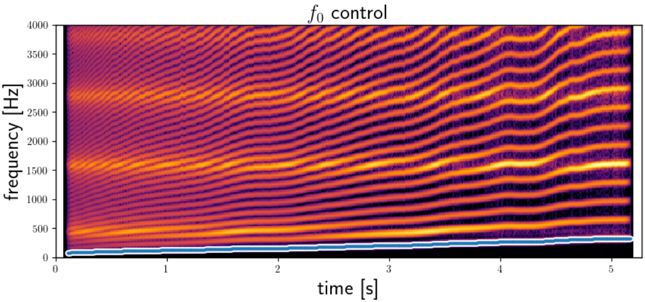


Study the encoding of each acoustic parameter separately

Multidimensional representation of acoustic features

Proposed method

- Soundgen [7] : generate signals with variation of either f_0, F_1, F_2, F_3 while the three other parameters remained constant

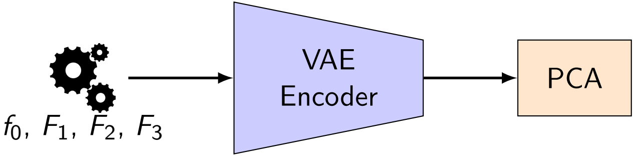


[7] Anikin et al., Soundgen: an open-source tool for synthesizing nonverbal vocalizations, Behavior research methods, 2019

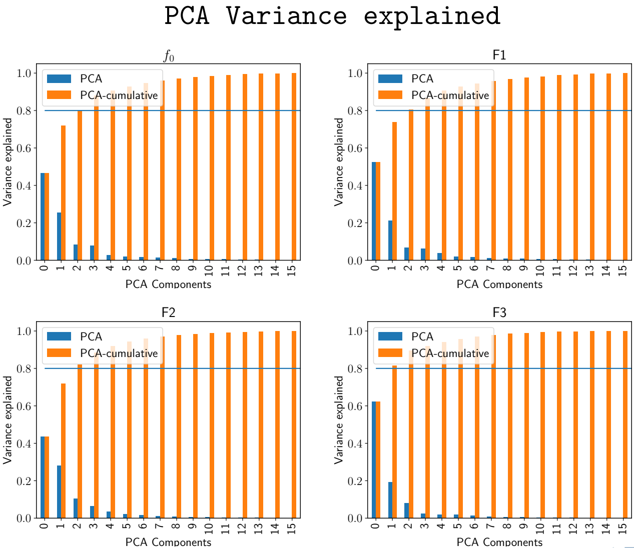
Multidimensional representation of acoustic features

Proposed method

- Soundgen [7] : generate signals with variation of either f_0, F_1, F_2, F_3 while the three other parameters remained constant
- Principal Components Analysis (PCA) : identify the directions that explain the variation of the acoustic parameter

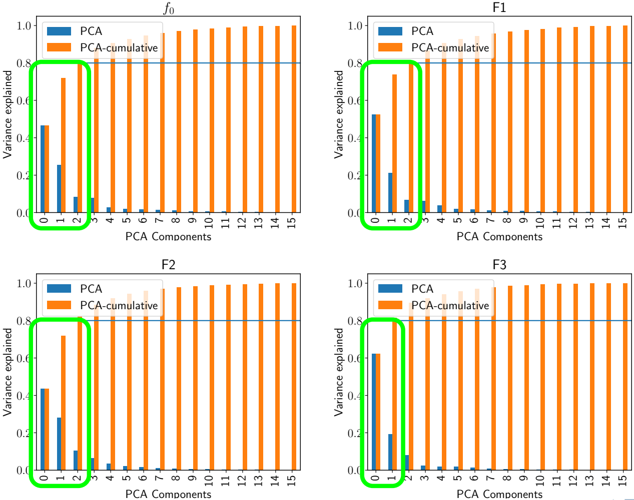


Multidimensional representation of acoustic features

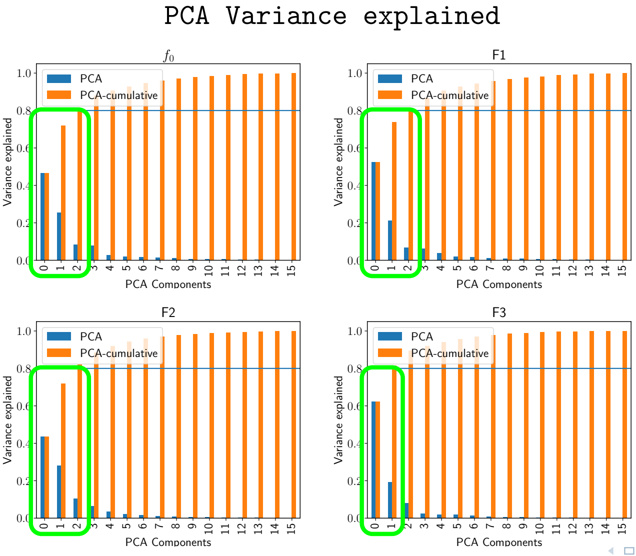


Multidimensional representation of acoustic features

PCA Variance explained

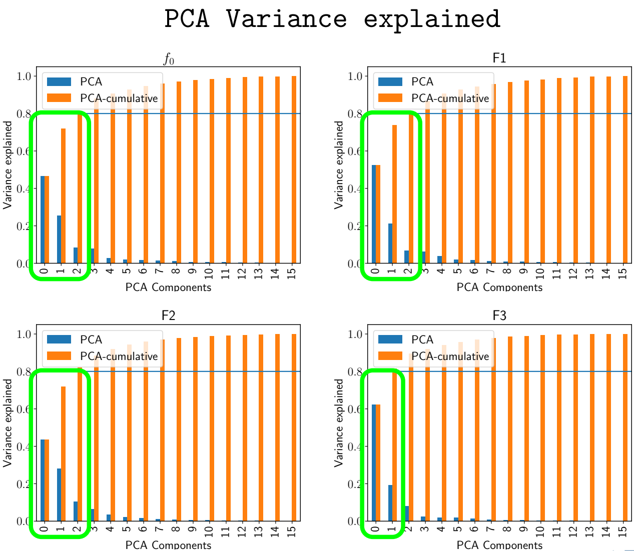


Multidimensional representation of acoustic features



- Each acoustic parameter is encoded by multiple dimensions.

Multidimensional representation of acoustic features



- Each acoustic parameter is encoded by multiple dimensions.
- What kind of information is encoded in each component ?

Interpretation of the learnt dimensions

Objective

Identify the role of these multiple dimensions, through the analysis of natural speech

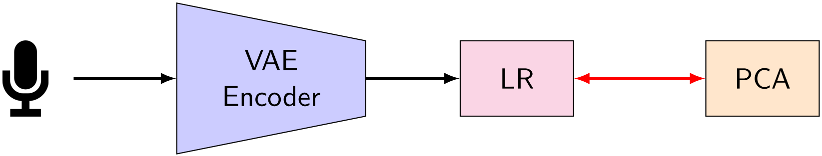
Hypothesis

The different latent dimensions reflect sources of inter- and intra-individual variability of each acoustic parameter

Interpretation of the learnt dimensions

Proposed method

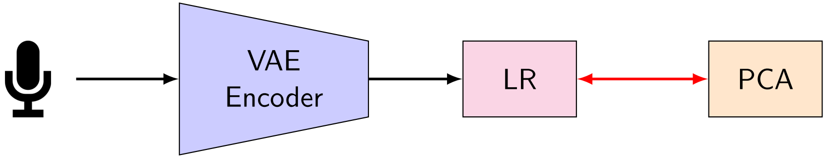
- VCTK [6] : multi-speaker dataset, english speakers not seen during training
- Linear Regression (LR) : analyze the variation of specific acoustic parameters in the natural test set



Interpretation of the learnt dimensions

Proposed method

- VCTK [6] : multi-speaker dataset, english speakers not seen during training
- Linear Regression (LR) : analyze the variation of specific acoustic parameters in the natural test set
- Analyse the possible representation of gender-related acoustic parameters



Interpretation of the learnt dimensions

Cosine similarity between LR and PCA

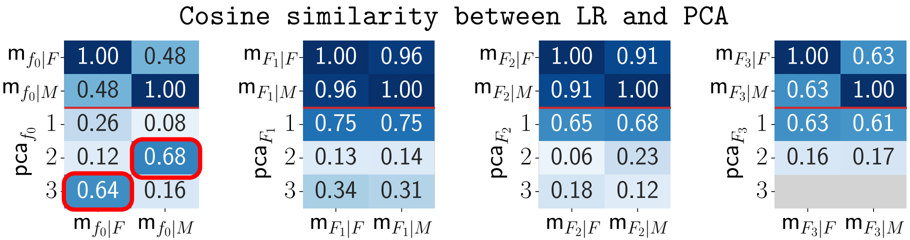
		$m_{f_0\|F}$	$m_{f_0\|M}$
$m_{f_0\|F}$		1.00	0.48
$m_{f_0\|M}$		0.48	1.00
pca_{f_0}	1	0.26	0.08
	2	0.12	0.68
	3	0.64	0.16

		$m_{F_1\|F}$	$m_{F_1\|M}$
$m_{F_1\|F}$		1.00	0.96
$m_{F_1\|M}$		0.96	1.00
pca_{F_1}	1	0.75	0.75
	2	0.13	0.14
	3	0.34	0.31

		$m_{F_2\|F}$	$m_{F_2\|M}$
$m_{F_2\|F}$		1.00	0.91
$m_{F_2\|M}$		0.91	1.00
pca_{F_2}	1	0.65	0.68
	2	0.06	0.23
	3	0.18	0.12

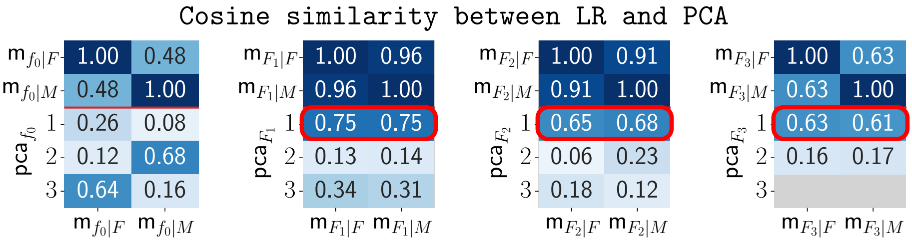
		$m_{F_3\|F}$	$m_{F_3\|M}$
$m_{F_3\|F}$		1.00	0.63
$m_{F_3\|M}$		0.63	1.00
pca_{F_3}	1	0.63	0.61
	2	0.16	0.17
	3		

Interpretation of the learnt dimensions



- For f_0 : each gender is encoded in a distinct component.

Interpretation of the learnt dimensions



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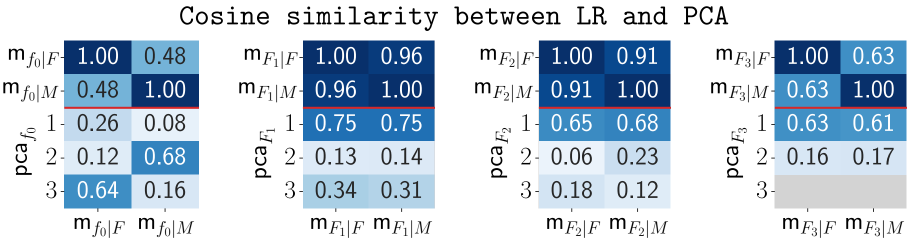
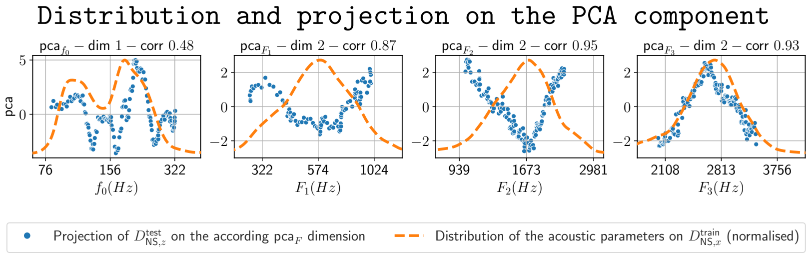
Interpretation of the learnt dimensions



- For f_0 : each gender is encoded in a distinct component.
- For $F_{1,2,3}$: both genders are encoded in the same component.
- Why doesn't the model encode the fundamental frequency and the formants the same way?

Interpretation of the learnt dimensions



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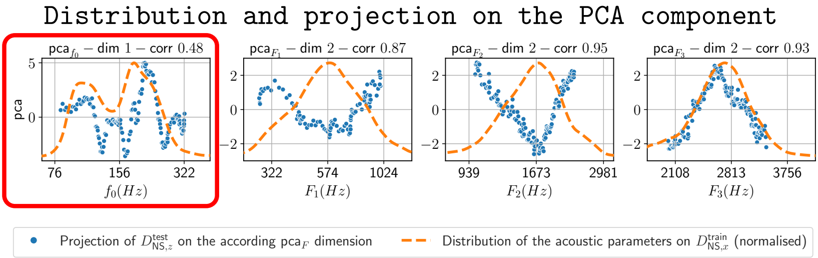
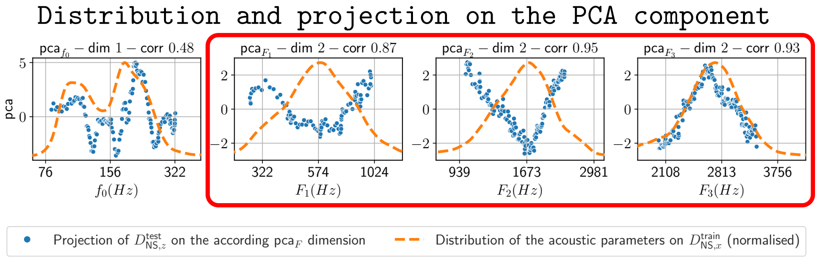


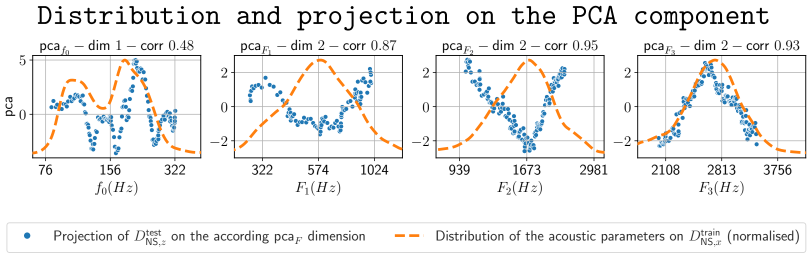
- For f_0 : the bimodal distribution is the most correlated with the first component

Interpretation of the learnt dimensions



- For f_0 : the bimodal distribution is the most correlated with the first component
- For $F_{1,2,3}$: the unimodal distribution is the most correlated with the second component.

Interpretation of the learnt dimensions



- For f_0 : the bimodal distribution is the most correlated with the first component
- For $F_{1,2,3}$: the unimodal distribution is the most correlated with the second component.
- The multidimensional representation of a single acoustic parameter is closely related to the multimodality of the parameter distribution.

Interpretation of the learnt dimensions

Objective

Identify a disentangled representation of inter- and intra-individual variability in the latent space

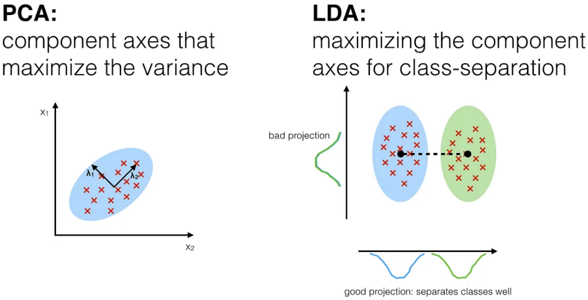
Hypothesis

A linear combination of latent dimensions that best discriminates the speakers, should display an inter-gender direction on its first component, and thus an intra-gender direction on remaining components

Universal vs. speaker-specific variations

Proposed method

- VCTK [6] : multi-speaker dataset, english speakers not seen during training
- Linear Discriminant Analysis (LDA) : underline the model's ability to disentangle inter- and intra-individual variability



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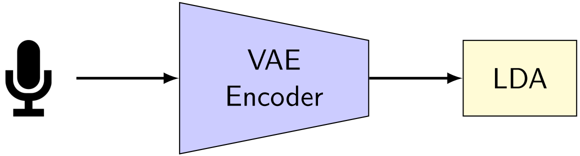

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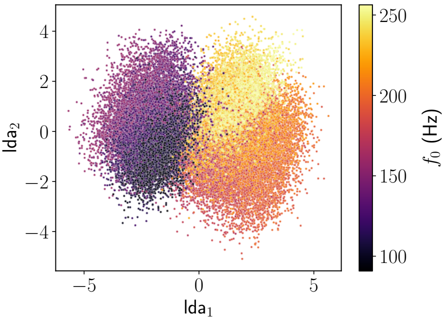

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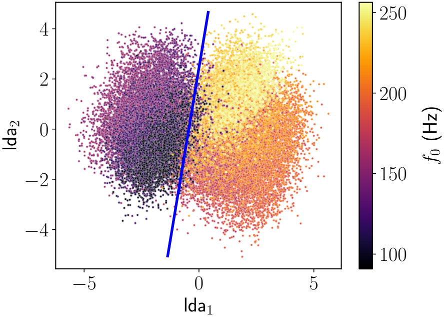

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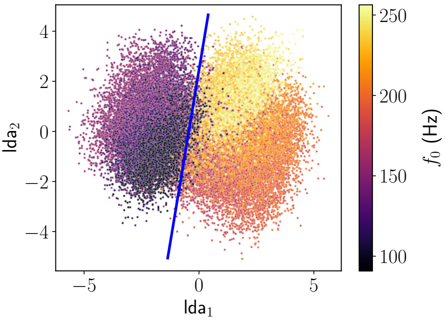
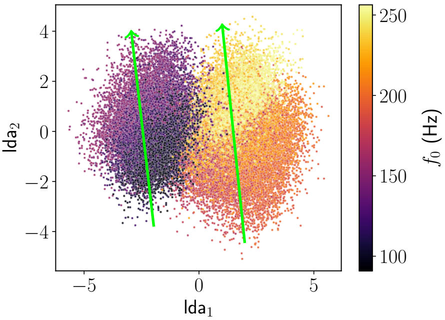


- The first component models the inter-gender variation of f_0.

Universal vs. speaker-specific variations



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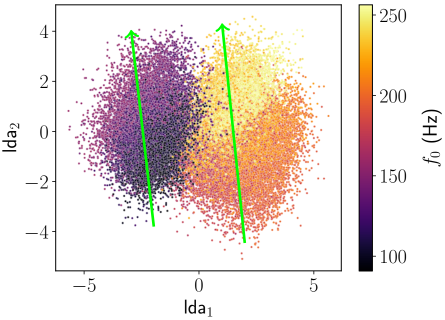

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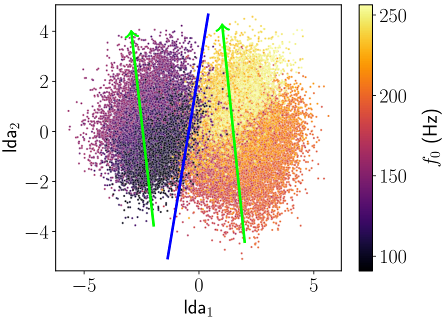

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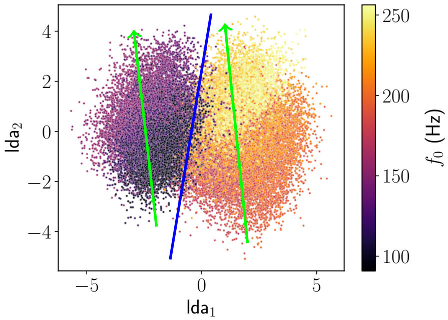
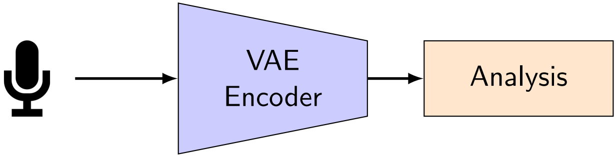


- The first component models the inter-gender variation of f_0.
- The second component models the intra-gender variation of f_0.
- The model is able to disentangle inter- and intra-gender variations along two distinct directions.

Control of the acoustic parameters



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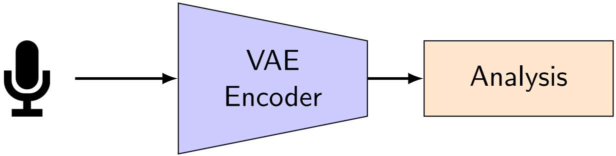
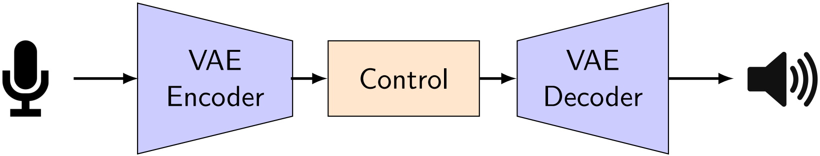


Can we use those methods to control the acoustic parameters values ?

Control of the acoustic parameters



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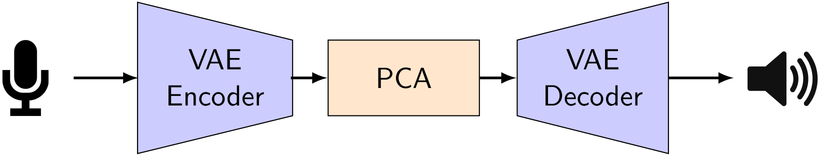
Control intra



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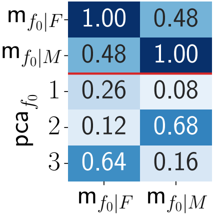

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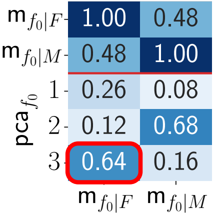
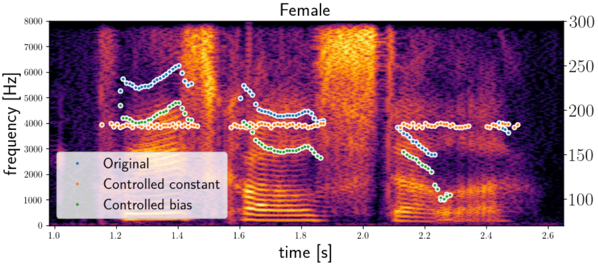
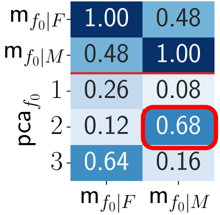
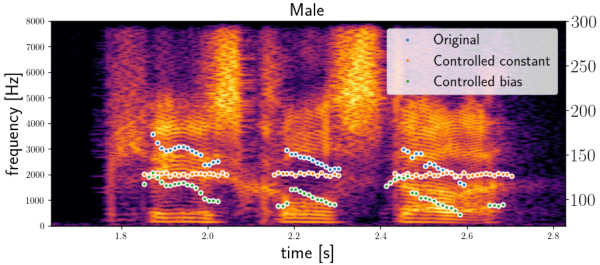


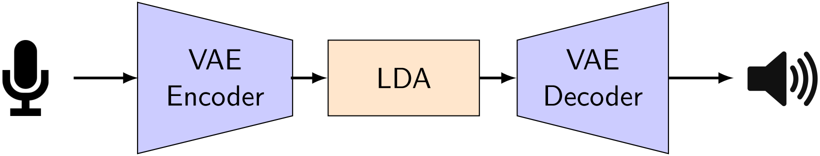


Control intra





Control inter



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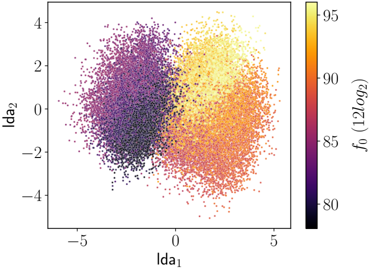

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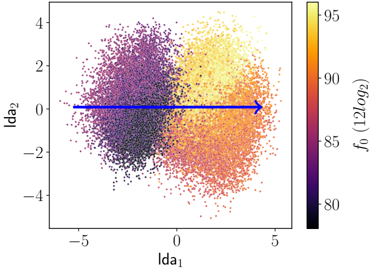

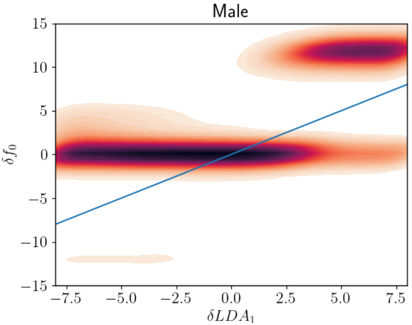

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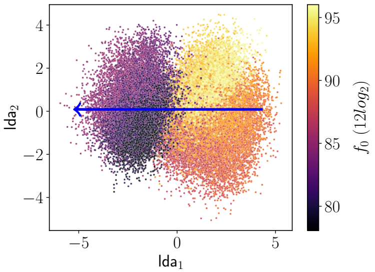

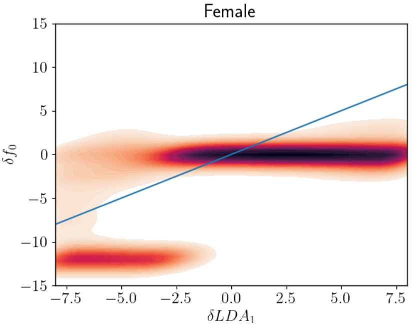

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- We demonstrated that one of these dimensions encodes the global shape of the distribution of each acoustic parameter over the training set.
- We identified the directions in latent space that explain the between-mode and within-mode variation of the acoustic parameter.
- We controlled the variation of fundamental frequency between-mode and within-mode.

Future works

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- Evaluate the effect of a more expressive training dataset on the observed results.
- Apply this method to other types of unsupervised or self-supervised models.

Thank you for your attention

1. Introduction
2. Analysis & Results
   - Multidimensional representation of acoustic features
   - Interpretation of the learnt dimensions
   - Universal vs. speaker-specific variations
   - Control of the acoustic parameters
3. Conclusion
4. References

References I

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