GENERATING A MORPHABLE MODEL OF EARS

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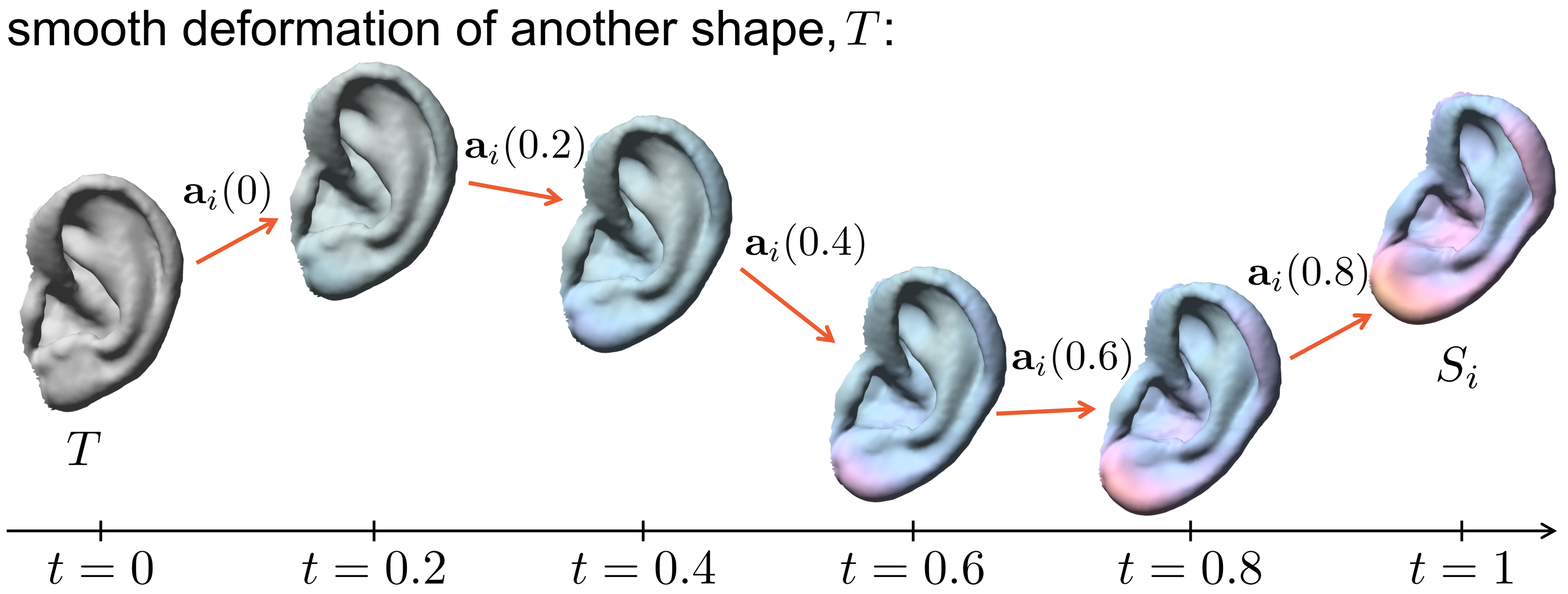
1. INTRODUCTION

Our objective is to assist research into the prediction of individualized 3D audio filters for listeners based on the shape of their ears. Modelling ear shapes with a few dozen parameters aids establishing the link between ear morphology and the corresponding acoustic characteristics (HRIR filters).

2. SHAPE ANALYSIS USING LDDMM

Large deformation diffeomorphic mapping (LDDMM) is a mathematical framework that can be employed for the registration and morphing of 3D shapes. In this framework a shape, S_i, can be represented as a smooth deformation of another shape, T:



At any point in time the transformation is characterized by the momentum vectors, $\mathbf{a}_i(t)$. Because the transformation follows a geodesic path, it is entirely described by the initial momentums, $\mathbf{a}_i(0)$.

There are two fundamental operations in LDDMM:

- **Mapping** is the operation of calculating the deformation from shape T to shape S_i:

$$\mathbf{a}_i(0) = \mathscr{M}(T, S_i)$$

  This is done by minimizing a functional J given by:

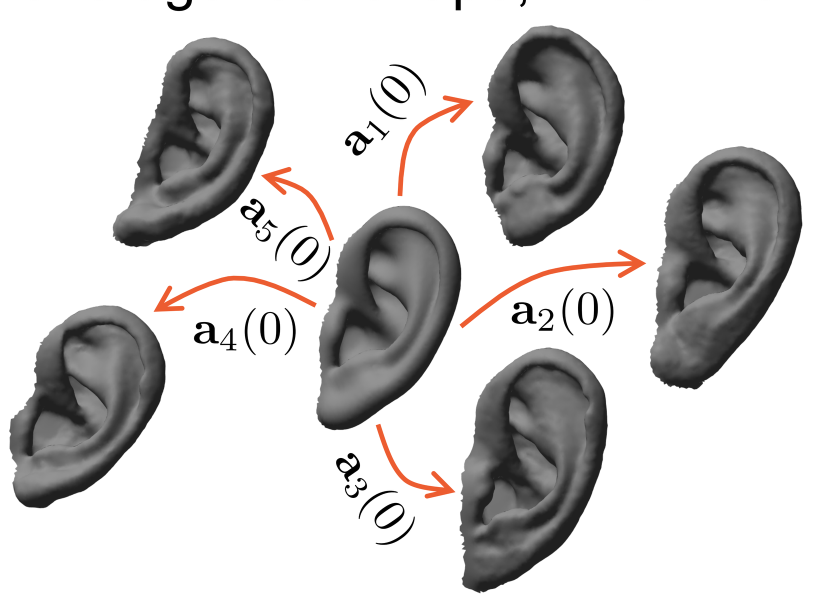
$$J(\mathbf{a}_i(t)) = \underbrace{f(\mathbf{a}_i(t))}_{\text{Length of the transformation}} + \underbrace{g(T, S_i, \mathbf{a}_i(t))}_{\text{Mismatch between } S_i \text{ and the morphed } T}$$

- **Shooting** is the operation of morphing T into an approximation of S_i, $\hat{S}_i$, given the initial momentum vectors $\mathbf{a}_i(0)$:

$$\hat{S}_i = \mathscr{S}(T, \mathbf{a}_i(0))$$

3. KERNEL PCA

The first step in building our morphable model consists is representing every ear in the considered population as a transformation from an "average" ear shape, which we refer to as the template, T.



We then form a matrix $\mathbf{A}$ containing the initial momentums for every shape in the population:

$$\mathbf{A} = [\hat{\mathbf{a}}_1, \hat{\mathbf{a}}_2, \ldots, \hat{\mathbf{a}}_L]$$

where $\hat{\mathbf{a}}_i$ is the vector of the centred momentums for shape S_i:

$$\hat{\mathbf{a}}_i = \mathbf{a}_i(0) - \bar{\mathbf{a}} \quad \text{with} \quad \bar{\mathbf{a}} = \frac{1}{L}\sum_{i=1}^{L} \mathbf{a}_i(0)$$

In order to extract orthonormal basis vectors from this data, we apply a kernel-based principal component analysis (K-PCA). We first calculate the correlation between the different shapes in the Hilbert space of deformations. The correlation matrix, $\mathbf{C}$, is given by:

$$\mathbf{C} = \mathbf{A}^{\mathsf{T}} \mathbf{K} \, \mathbf{A}$$

where $\mathbf{K}$ is the kernel matrix corresponding to: (i) the kernel associated with the space of deformations and (ii) the template vertices.

A singular value decomposition (SVD) is then applied to $\mathbf{C}$:

$$\mathbf{C} = \mathbf{V}\mathbf{D}\mathbf{V}^{\mathsf{T}}$$

Lastly, the matrix of the principal components (PC), $\mathbf{U}$, is given by:

$$\mathbf{U} = \mathbf{A}\mathbf{V}\mathbf{D}^{-\frac{1}{2}}$$

Note that the PCs are orthonormal in the kernel space, i.e.: $\mathbf{U}^{\mathsf{T}}\mathbf{K}\mathbf{U} = \mathbf{I}$

4. MORPHABLE MODEL OF EARS

The model **parameters** for a new (unseen) ear S_p are calculated by:

- **Mapping** the template T to S_p:

$$\mathbf{a}_p(0) = \mathscr{M}(T, S_p)$$

- **Projecting** the centred initial momentum vectors onto the principal components:

$$\tilde{\mathbf{v}}_p = \mathbf{U}^{\mathsf{T}}\mathbf{K}(\mathbf{a}_p(0) - \bar{\mathbf{a}})$$

The shape can then be **reconstructed** using the model by:

- **Summing** the contribution of the principal components:

$$\tilde{\mathbf{a}}_p(0) = \bar{\mathbf{a}} + \mathbf{U}\tilde{\mathbf{v}}_p$$

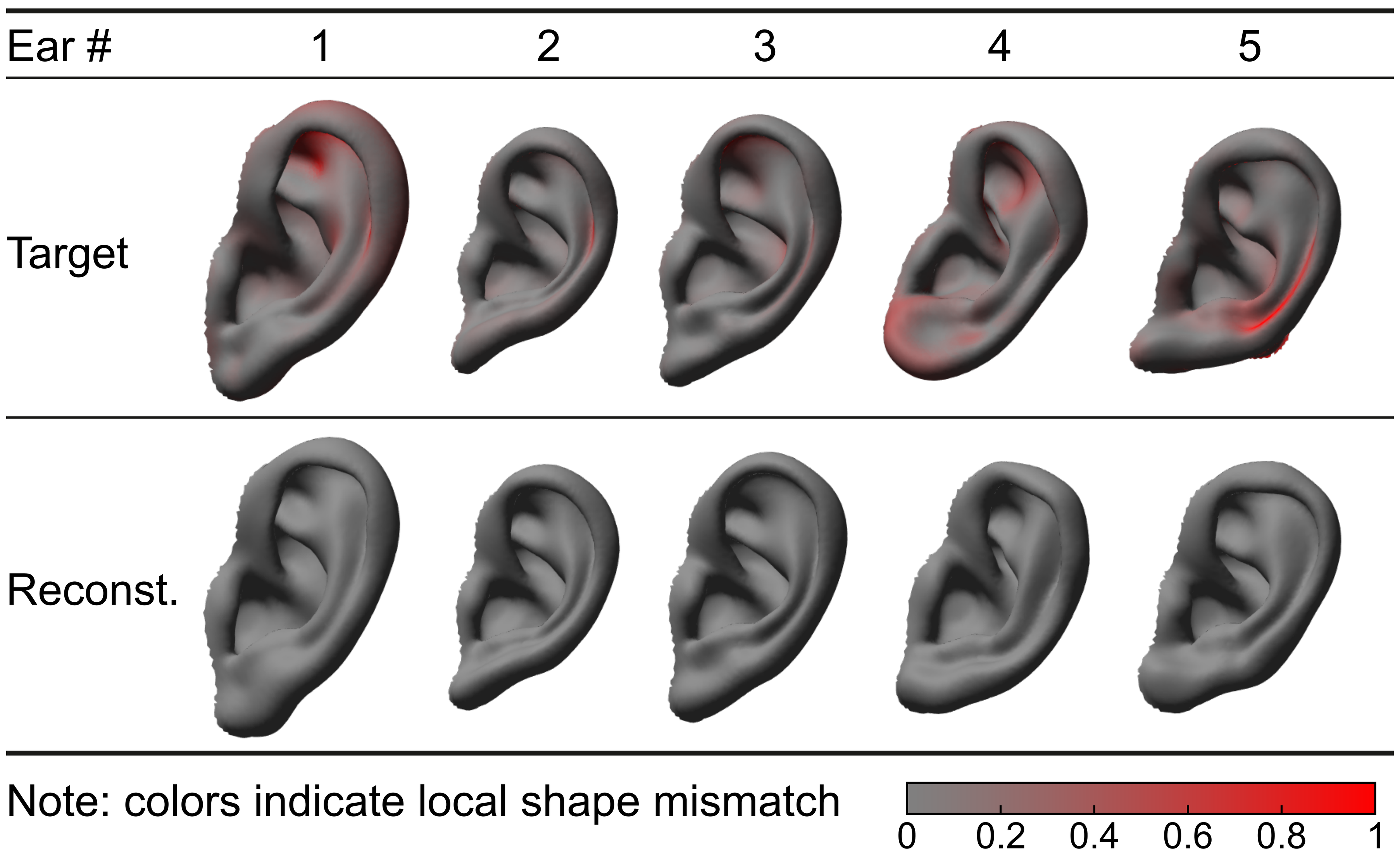
- **Shooting** from the template using the obtained momentum vectors:

$$\tilde{S}_p = \mathscr{S}(T, \tilde{\mathbf{a}}_p(0))$$

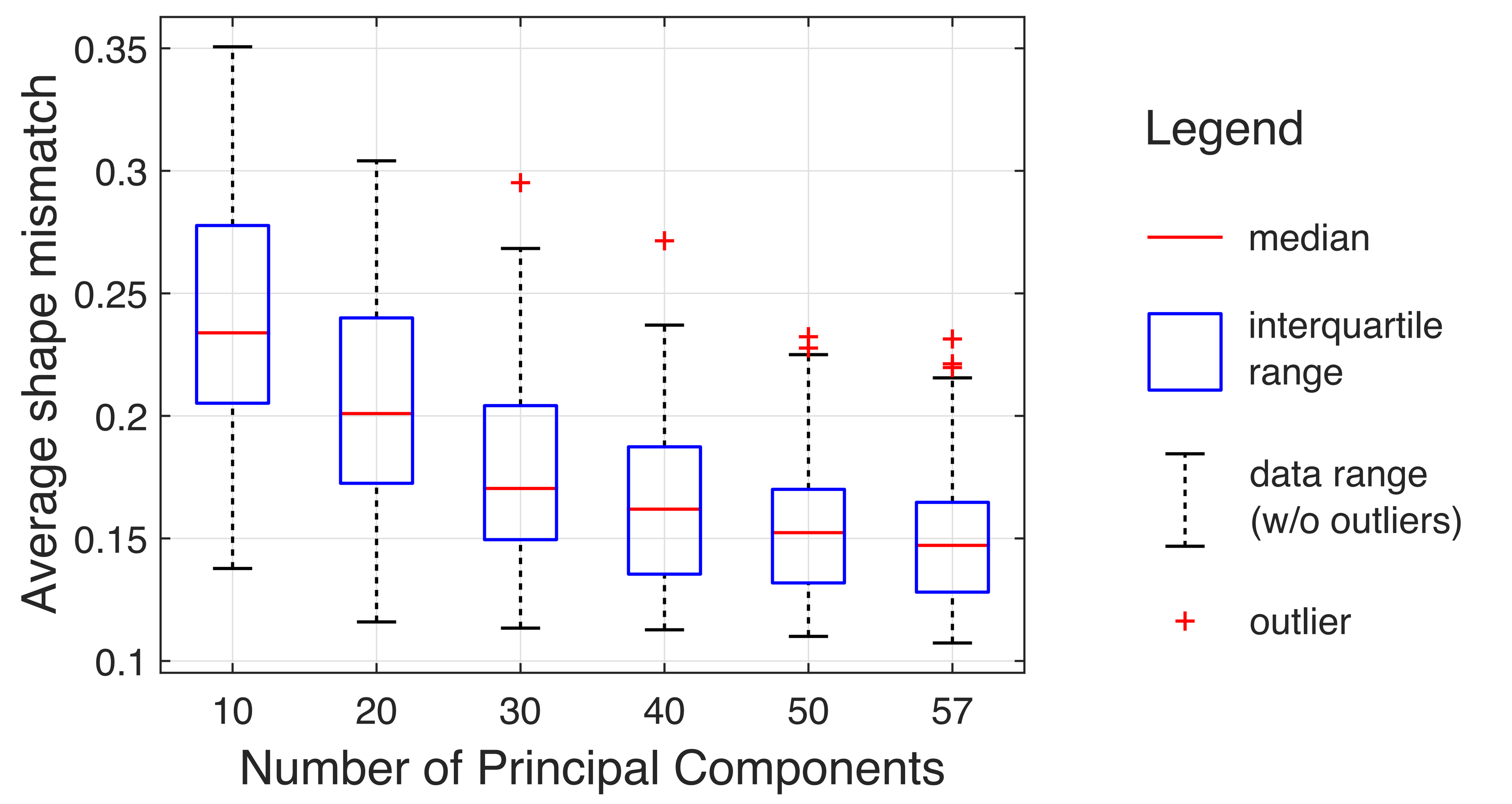
5. RESULTS

We examined the ability of a KPCA model to reconstruct an ear that was left out of the population used to create the model. This study was conducted using a population of 58 ears from the **SYMARE** database.

- Examples of ears reconstructed using 50 principal components:



- Influence of the number of principal components on ear shape reconstruction accuracy:



5. CONCLUSIONS

- The K-PCA approach is promising.
- The fact that some ear shapes cannot be reconstructed accurately indicates that a larger and more diverse population of ears is required to generate a model that can morph into any ear shape.
- It is as yet unclear how many parameters would be required to morph the template ear into any ear shape with sufficient accuracy.

http://sydney.edu.au/engineering/electrical/carlab/index.htm