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IRSN
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DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Toward quantitative assessment of the morphological similarity of organs‘ voxel model using geometric and Zernike 3D moments.

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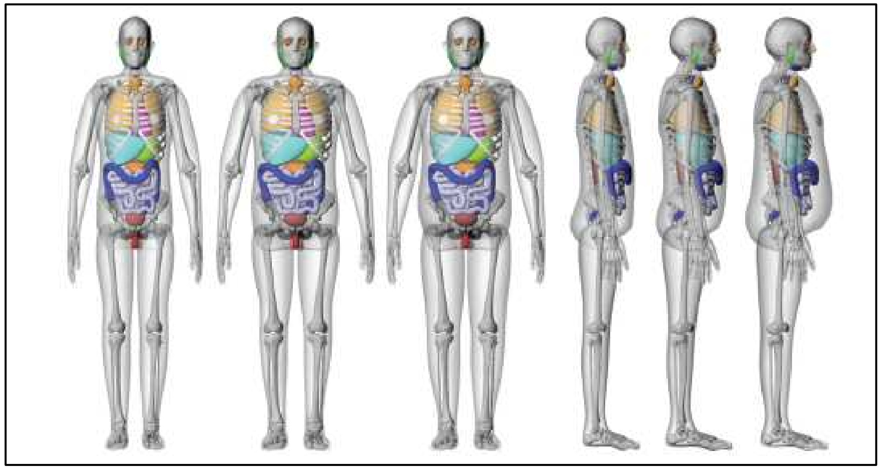
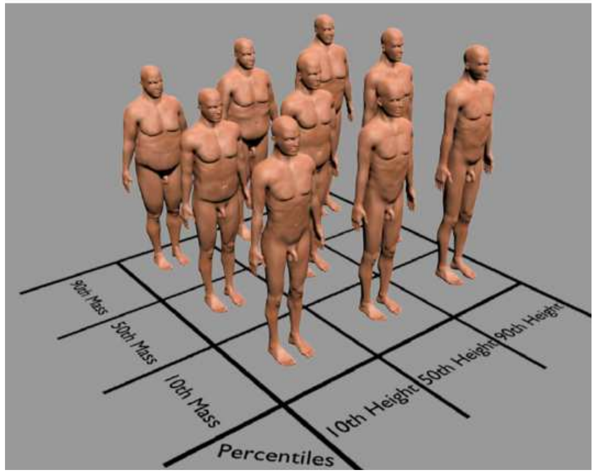
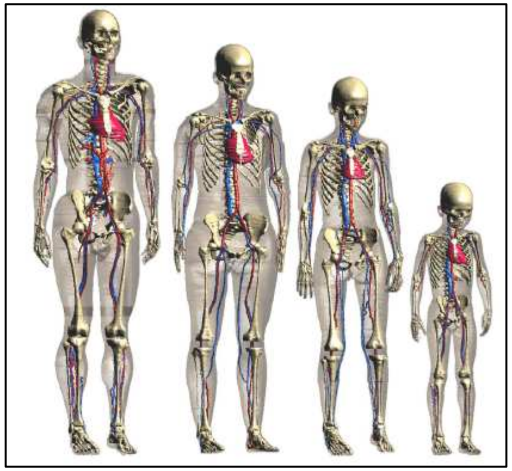
1. **Radiological protection, medical physics : there is an increasing number of human computational models**
   - ➢ How can we assess their morphological similarity ?



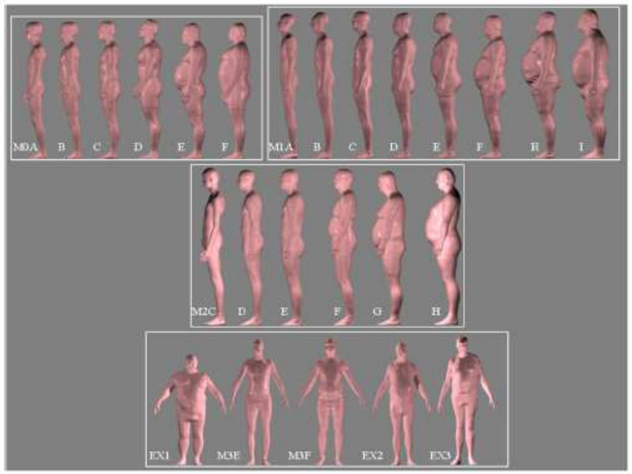
Johnson *et al.* ***2009***, *Phys. Med. Biol.* **54**:3613–3629



Cassola *et al.* ***2011***, *Phys. Med. Biol.* **56**:3749–3772



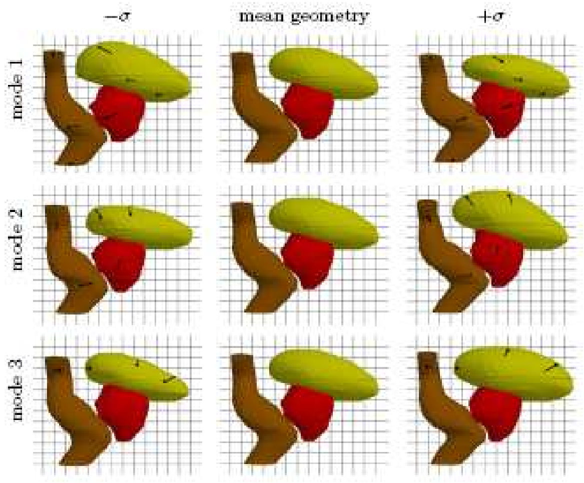
Christ *et al.* ***2010***, Phys. Med. Biol. **55**:N23–N38



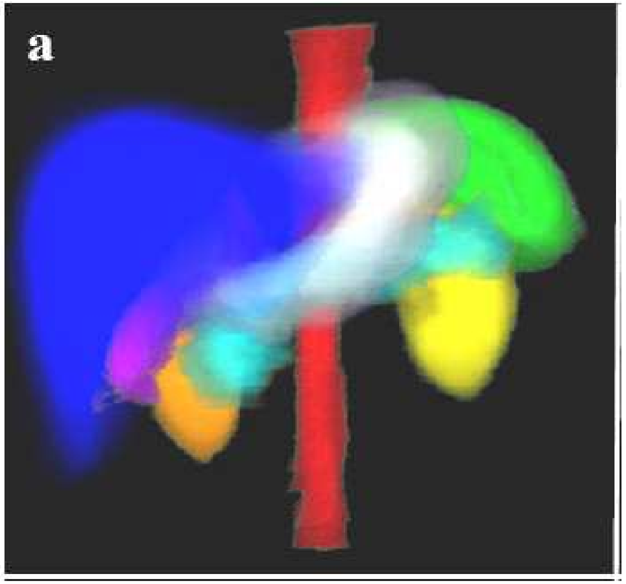
Broggio *et al.* ***2011***, *Phys. Med. Biol.* **56**:7659–7692

2. Medical physics : the study of organs' shape variation regains interest

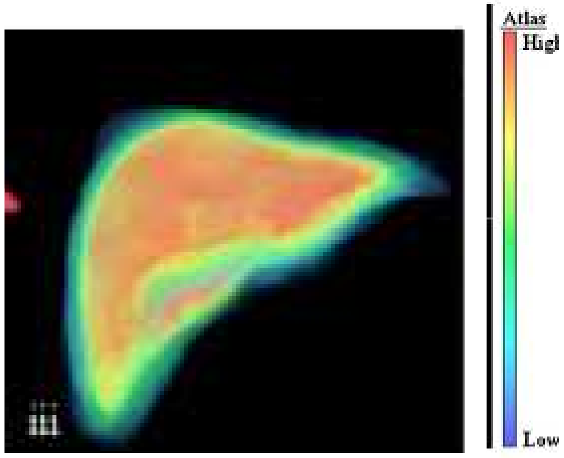
- ➢ How can we define an average shape ?
- ➢ How can we assign properly a probability to an organ's shape ?
- ➢ Simulation of organ's motion.



Söhn *et al.* **2005** *Phys. Med. Biol.* **50:**5893–5908



Reyes *et al.* **2009**
Proc IEEE Int Symp Biomed Imaging 682–685.



Linguraru *et al.* **2010** *Med. Phys.* ***37:***771–783.

1. **Geometric and Zernike 3D moments**
   - Definition
   - Associated tools

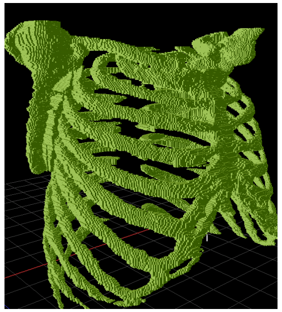
2. **Shape similarity between organs**
   - Study with livers
   - Study with hearts

3. **Construction of organs' shapes with Zernike moments**
   - Methods
   - Preliminary results

1. Geometric and Zernike 3D moments

Geometric and Zernike moments associate a voxel model with a unique set of numbers (i.e. a discrete spectrum).

$f = \begin{cases} 1 \text{ inside} \\ 0 \text{ outside} \end{cases}$

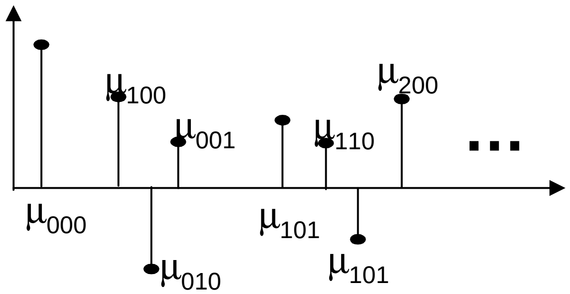


Geometric moments : $\mu_{pqr} = \iiint_D f(x,y,z)\, x^p y^q z^r \, dV$

- Extension of 1st order (gravity center) and 2nd order (inertia tensor) moments.

- Easy to calculate.

- Very bad reconstruction properties.



Zernike moments : $\Omega_{nl}^{m} = \iiint_{\|X\|<1} f(X) Z_{nl}^{m}(X)\, dV = \iiint f(r,\theta,\phi) Y_l^m(\theta,\phi) R_{nl}(r)\, dV$

- Coordinate of the object on the basis of Zernike 3D polynomials (orthogonal basis on the unit sphere).

- Complex number (because of spherical harmonics).

- Less easy to calculate.

- Very good reconstruction properties.

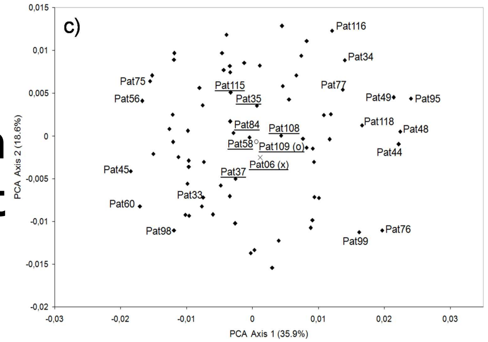
We use the scale independent version of these moments to disregard the volume.

Associated tools

Distance calculation

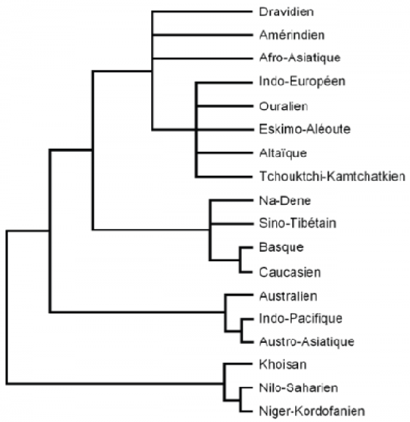
The Euclidean distance between the spectra is the distance between the 3D models.

However, the complete set of distance between objects does not offer a synthetic view.



Principal Coordinate Analysis (PCA) :

The distance between objects is calculated in a high dimensional space. With PCA the best possible 2D plot conserving the distance is obtained.

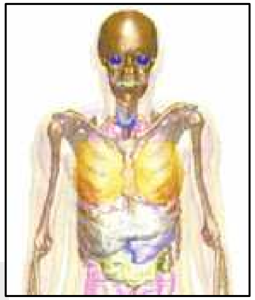


Hierarchical clustering

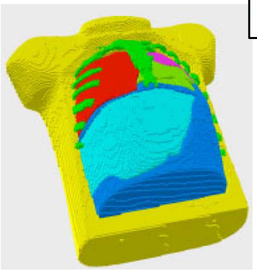
Instead of using PCA, similar objects can be gathered in families and a dentogram is obtained.

2.1 Study with livers (17 cases)

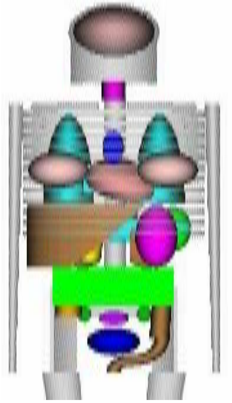
6 female livers + 6 male livers extracted from CT scans



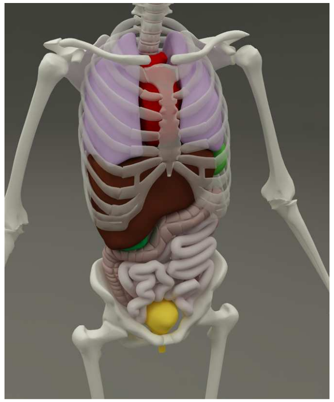
The voxel models of the ICRP male and female livers



The Livermore liver (physical phantom used for calibration)

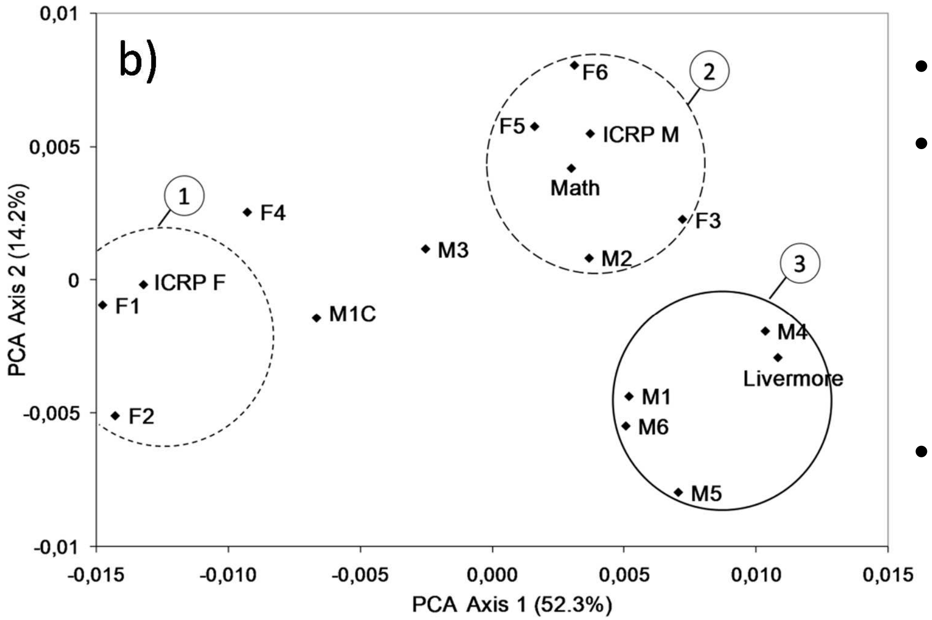


The mathematical liver (ORNL)

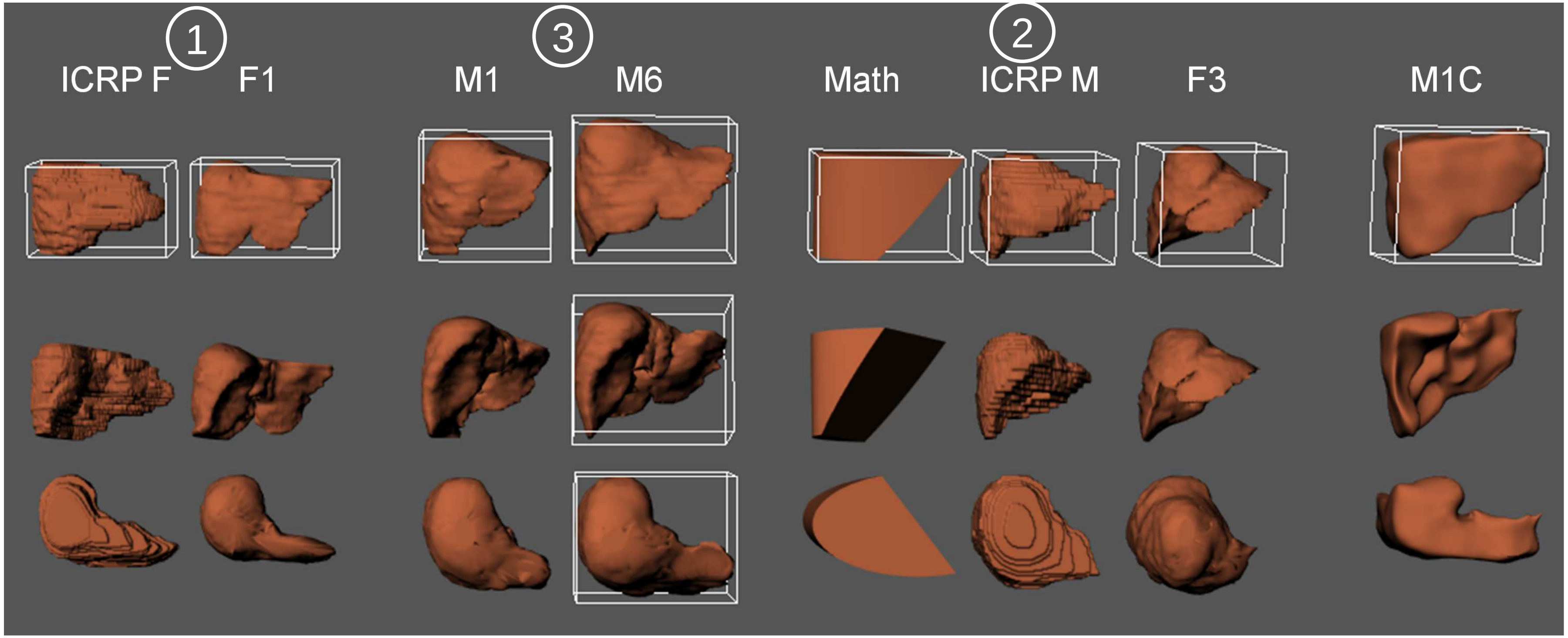


The liver of the M1C model (IRSN full body male library)

2. Shape similarity between organs



- Distance and PCA based on Zernike moments
- Three groups of livers are identified
  1. Large left lobe
  2. Normal liver
  3. Small left lobe, deep intercostal impression
- These groups are known from the litterature.



2.2 Study with Hearts

Retrospective heart dosimetry following radiotherapy is challenging [1-2].

How to define a surrogate heart shape ?

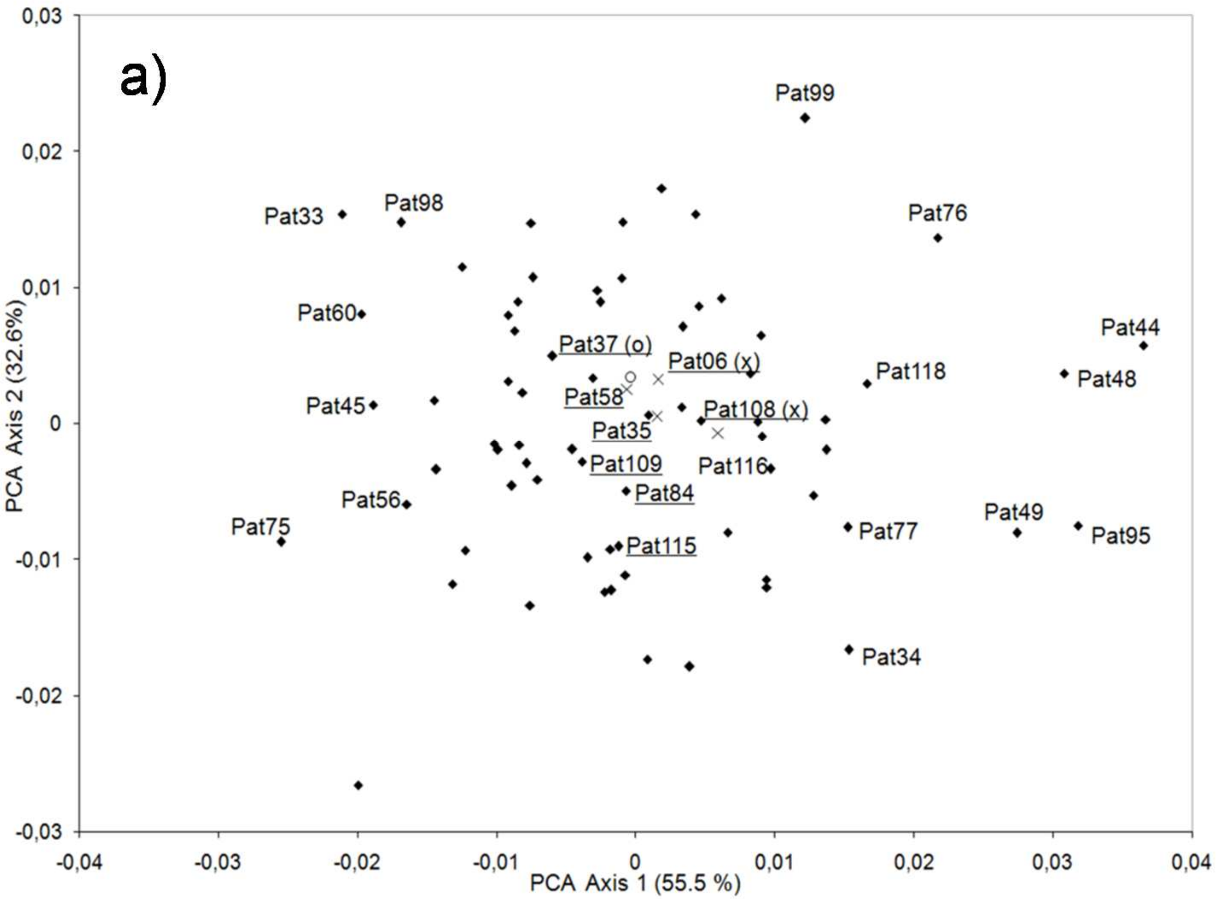
We use 72 heart models, contoured by radiotherapists, in the case of left breast radiotherapy.

We try to identify typical heart shapes.

[1] Aznar M et al. 2011 Evaluation of dose to cardiac structures during breast irradiation *Br. J. Radiol*. 84 743-746.

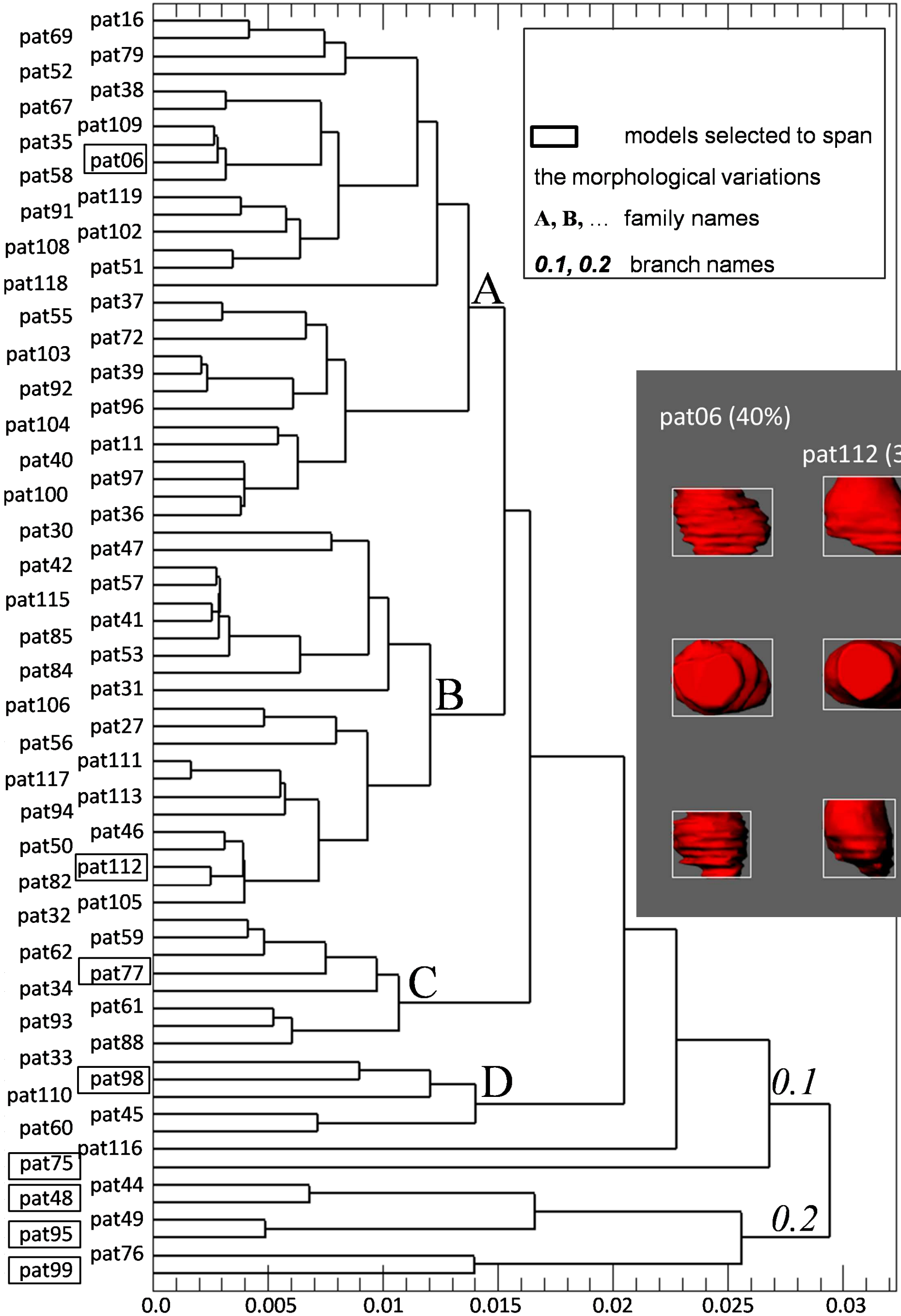
[2] Moignier A et al. 2012 Potential of Hybrid Computational Phantoms for Retrospective Heart Dosimetry After Breast Radiation Therapy: A Feasibility Study *International Journal of Radiation Oncology Biology Physics* (Article in press. doi:10.1016/j.ijrobp.2012.03.037).

2. Shape similarity between organs



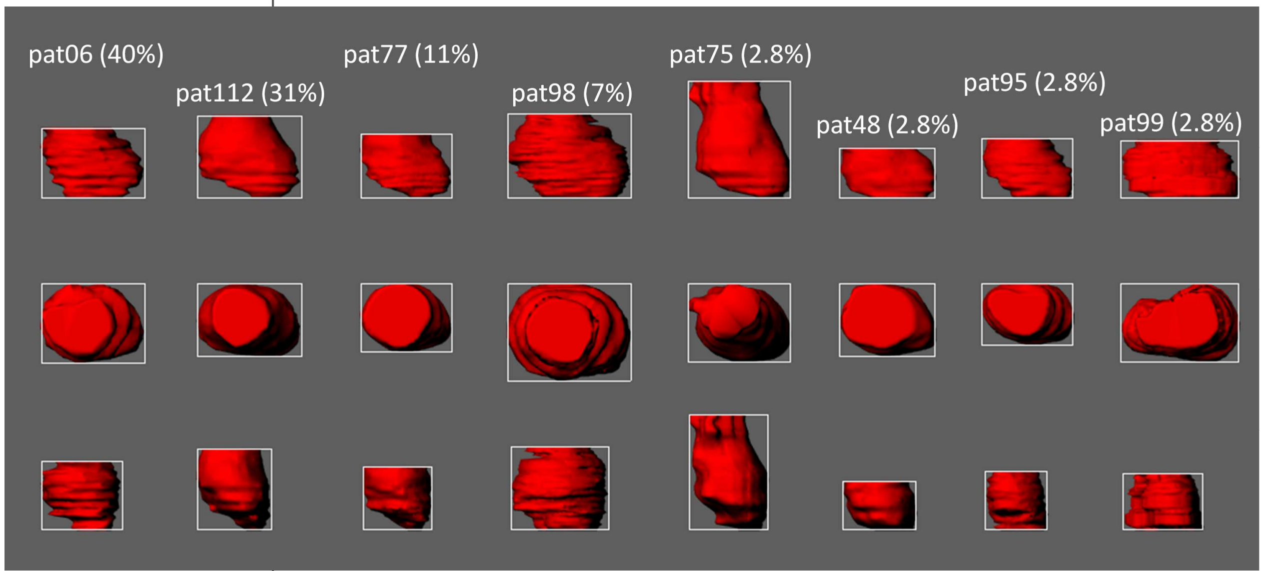
PCA based on geometric moments does not reveal groups of similar shapes

2. Shape similarity between organs



But the dentogram enables the classification in families.

Surrogate models can be extracted for each family.



About 90% of heart shapes can be represented by 4 heart models.

3. Construction of organs' shapes with Zernike moments

3.1 Shape construction from Zernike moments

3.2 Interpolation between two shapes

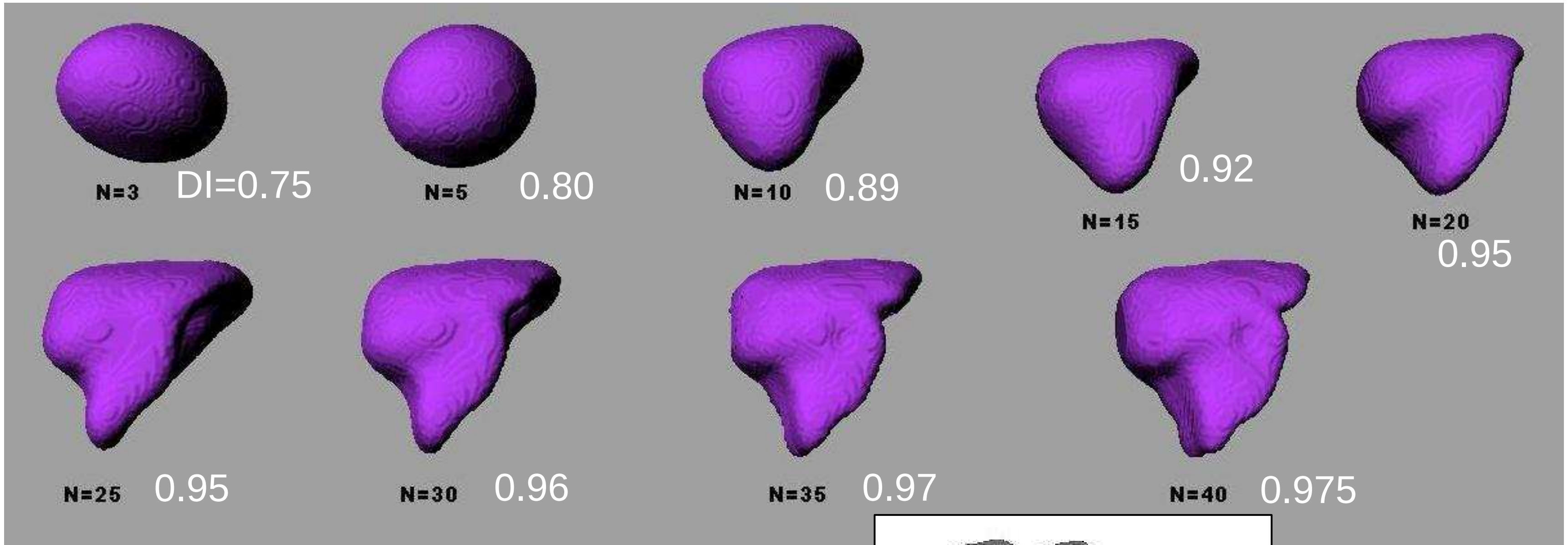
3.3 Construction of statistical shapes by the dominant eigenmodes method

3. Construction of organs' shapes with Zernike moments

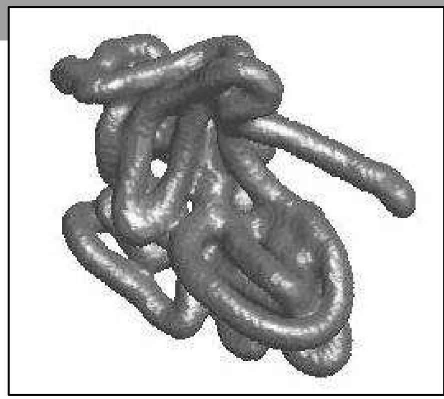
3.1 Shape construction from Zernike moments

$$\hat{f}(\mathbf{x}) = \sum_{n}\sum_{l}\sum_{m} \Omega_{nl}^{m} \cdot Z_{nl}^{m}(\mathbf{x}).$$

➢The quality of reconstruction can be measured using the Dice Index (~percent of agreement between original and reconstructed objects)

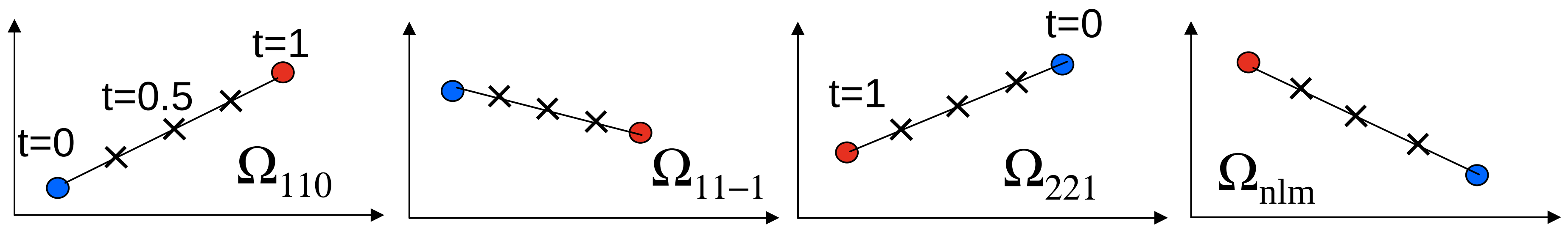


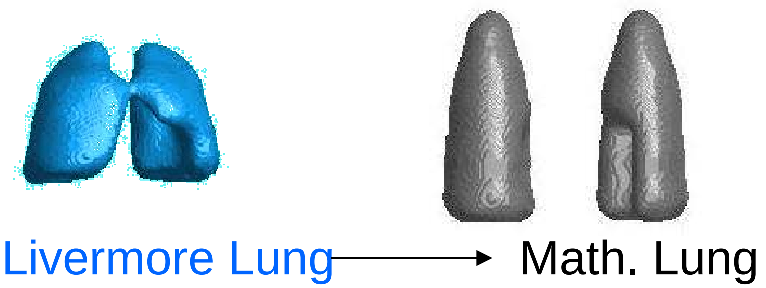
➢It works well, and also for more complex shapes.

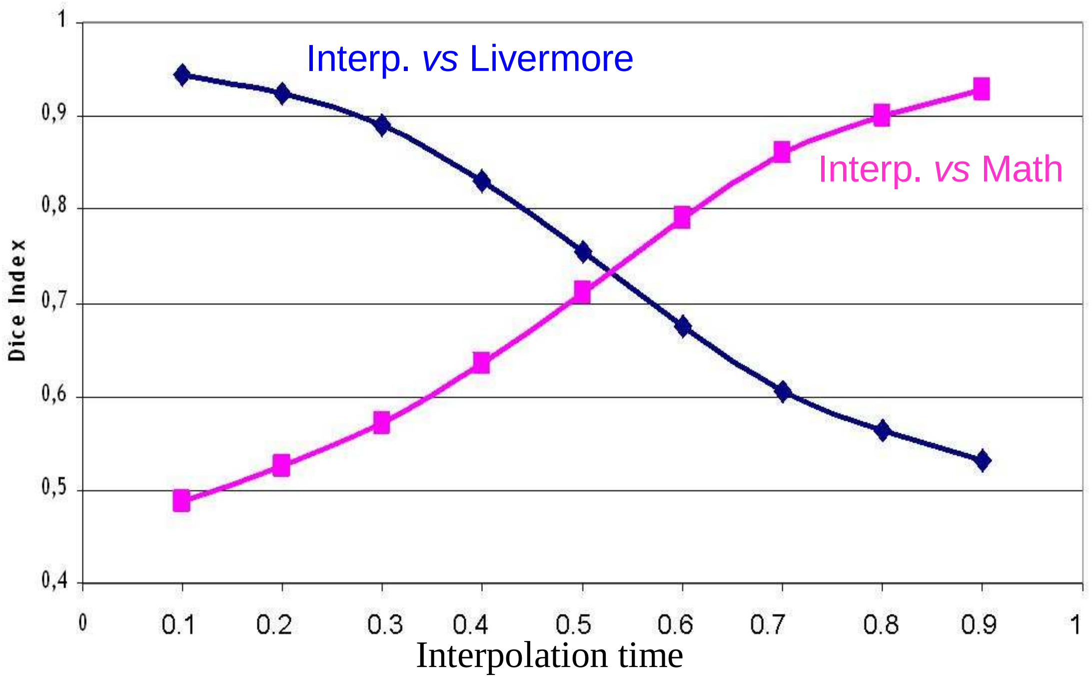


DI=0.90

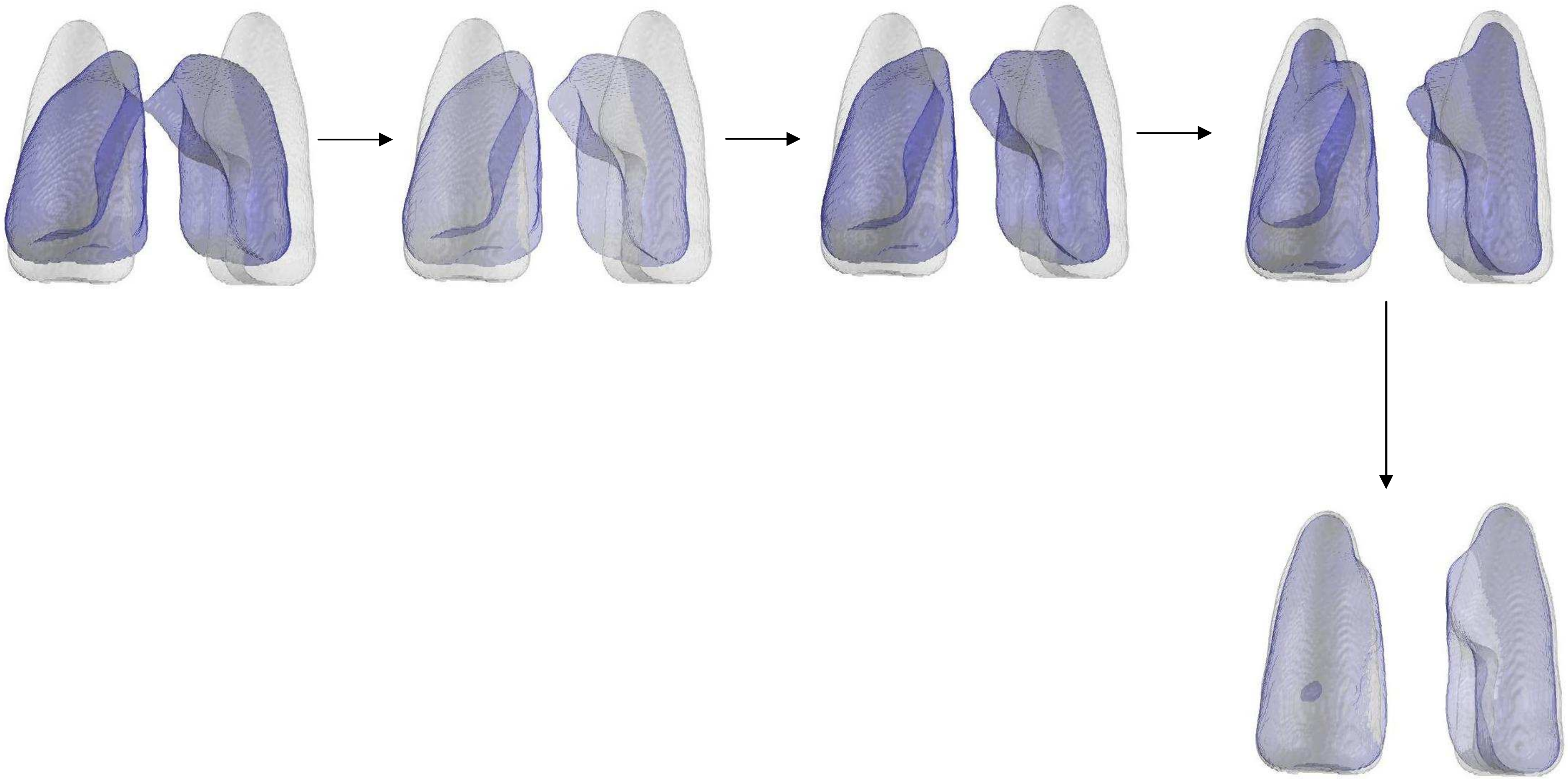
3.2 Interpolation between two shapes







3.2 Interpolation between two shapes



3.3 Construction of statistical shapes by the dominant eigenmodes method

- Take a set of shapes defined by their Zernike Moments (V_i)
- Construct the mean object $\bar{V} = \frac{1}{N}\sum_{i=1}^{N} V_i$
- Construct the covariance matrix $C = \frac{1}{N-1}\sum_{i=1}^{N}(V_i - \bar{V}).(V_i - \bar{V})^t$
- Compute its eigenvalues (λ_j) and eigenvectors ($\vec{v}_j$)
- Build new shapes with the eigenvalues and eigenvectors

$$V = \bar{V} + \sum_j c_j \vec{v}_j$$

A probability can be attributed to the *new shape,* it depends on the λ_j

When complex numbers, like Zernike Moments, are used the method needs some refinements.

It's possible to obtain the Zernike moments from the geometric moments and the method could also be applied to the geometric moments (work in progress).

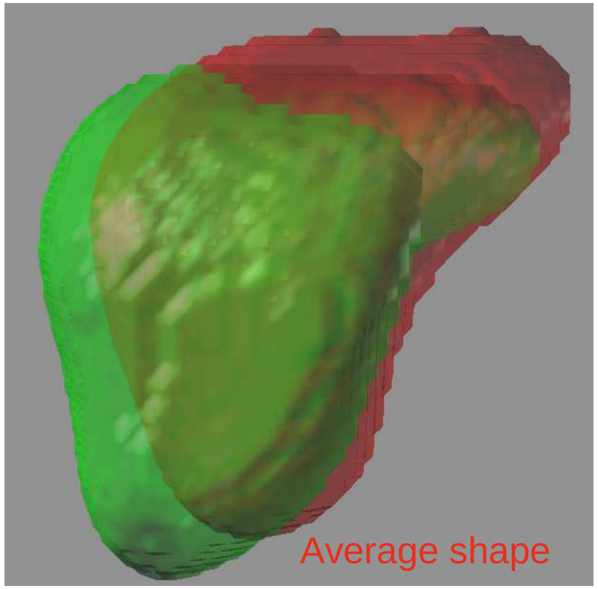
Application.

Starting set: 14 livers (12 CT scan based + ICRP M & F)

We build some liver shapes of the same volume

Results.

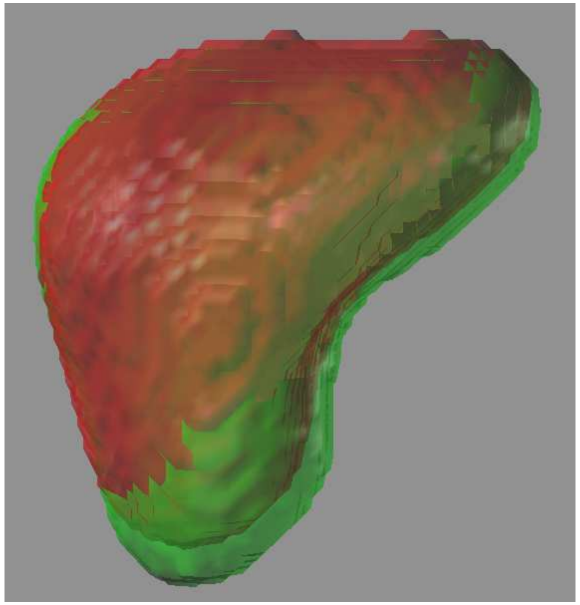
8 eigenvectors provide 95% of the variations



Variation with the 1st eigenvector only ($c_1=2.\lambda_1$)

Gravity centers moves and enlargement

Dice Index = 0.69



Variation with the 3rd eigenvector only ($c_3=-\lambda_3$)

Small mvt. of gravity center, extension at the bottom

Dice Index = 0.91

Conclusion

A lot of mathematical and computationnal details have not been shown.

But, I have tried to focus on the main ideas and possible applications.

To compare organs' shapes and to give a rigorous mathematical meaning to statistical shapes I believe that the most promising way is *to associate a shape with a unique spectrum.*

Further investigations and improvements are needed.

- Several kinds of spectral decomposition can be performed
- Extraction of synthetic and relevant information from spectra.
- For statistical shape construction the choice of the starting set is important.
- Comparing sets of organs might require more development.

Acknowledgements

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