Combination of shape-constrained and inflation deformable models, applied on the segmentation of the Left Atrial Appendage

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Goal

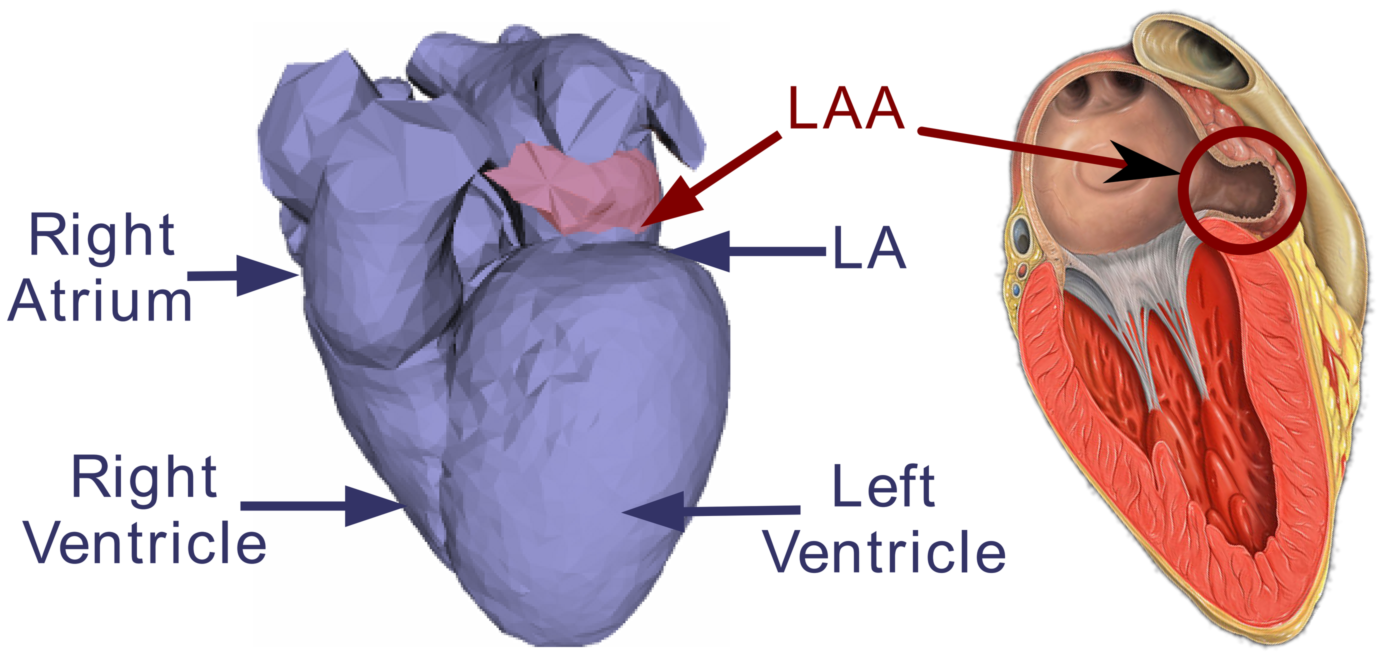
Develop an **automatic model-based method** to segment **highly deformable structures** like the Left Atrial Appendage (LAA).

Conclusion

Model-based algorithm combining two energies:
- one *external*, to make the mesh to inflate,
- one *internal*, to preserve shape.

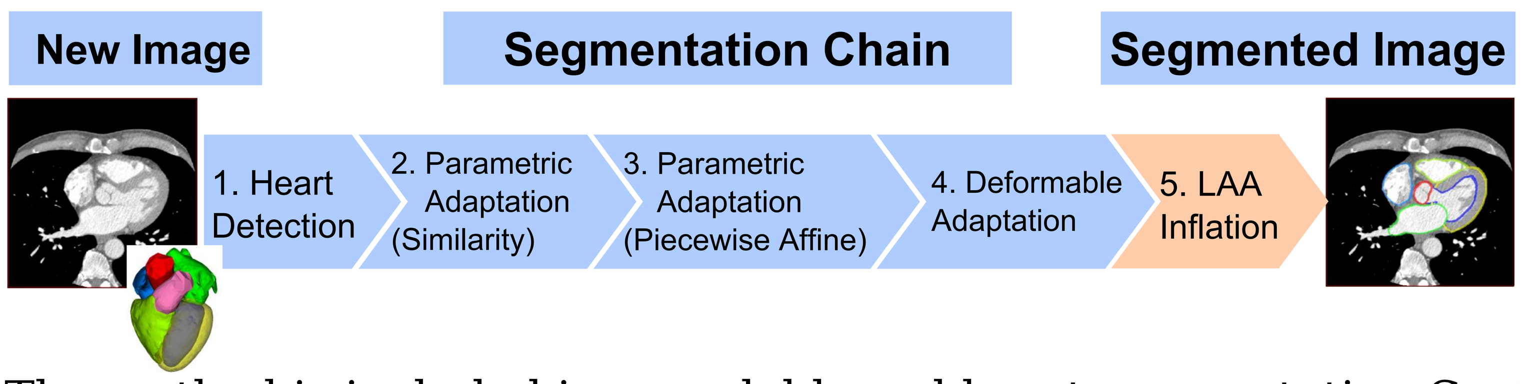
The mesh sometimes doesn't reach extreme borders of the LAA but presents very few segmentation errors.
This could be applied to **other complex structures.**

1. What is the left atrial appendage ?



Characteristics of the Left Atrial Appendage (LAA):
- linked to the Left Atrium (LA);
- sizes from 1 to 19 cm^3;
- highly variable shape, often tubular and hooked;
- has the function of reservoir.

2. Inclusion in segmentation algorithm



The method is included in a model-based heart-segmentation C++ framework, which combines a **3D black and white image** (the CT scan) and a **3D mesh model** made of triangles.
=> base location of the LAA is known;
=> surroundings substructures are already segmented.

3. External and internal energies combination

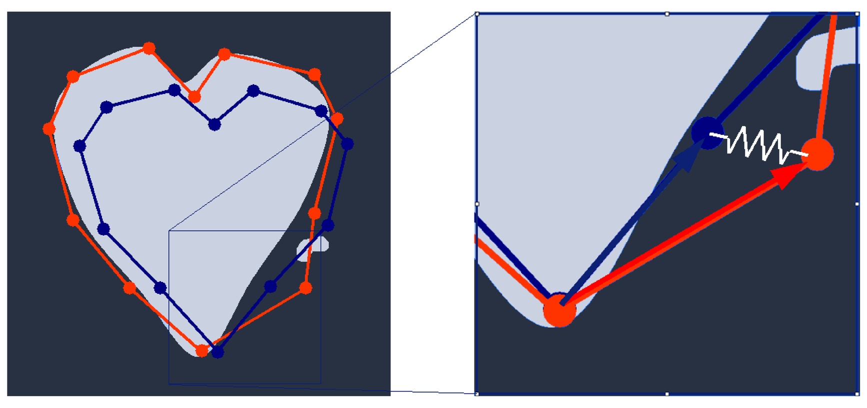
3.1. Combination of two antagonist energies:

$$E_{total} = E_{internal} + \alpha \, E_{external}$$

(with α ponderation factor)

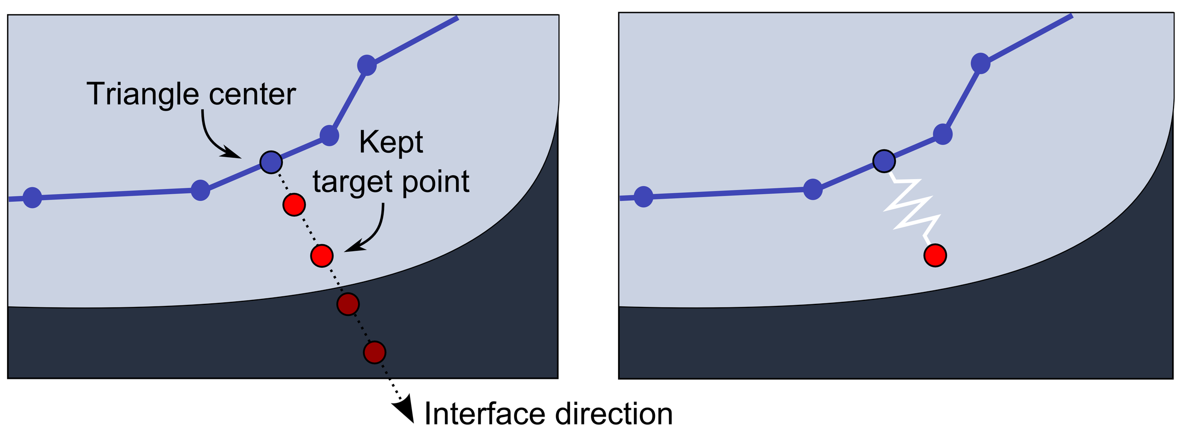
3.2. Internal energy:

At each step, **penalizes all moves** of the triangle vertices.



3.3. External energy:

At each step, **pulls** all triangles center to target points.
Points orthogonal to the triangle are looked as candidate points.
The one kept are those with *correct gray value :*
under (resp. *above*) gray value threshold if triangle center is *under* (resp. *above*) gray value threshold.
Among the candidate points in the interface direction, the *farthest of the triangle center* is taken as the target point.



4. Loops : an annoying problem

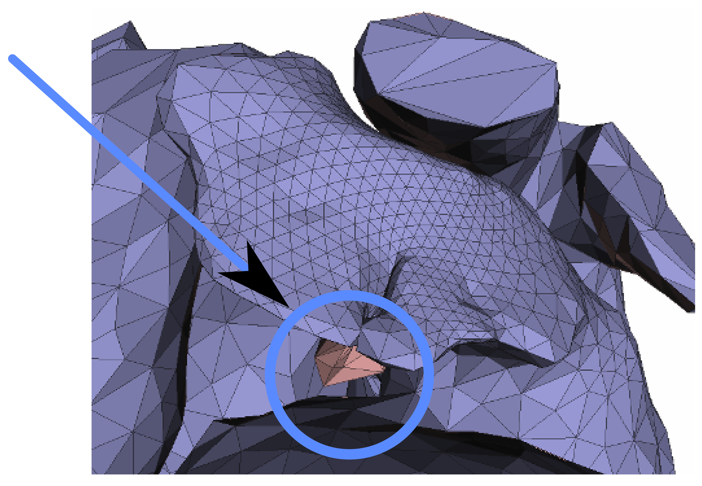


Fig 4.1. Apparition of loop under the mesh

Loops may appear during adaptation.
=> intersecting triangles are **smoothed** with the internal energy

5. Example of mesh adaptation

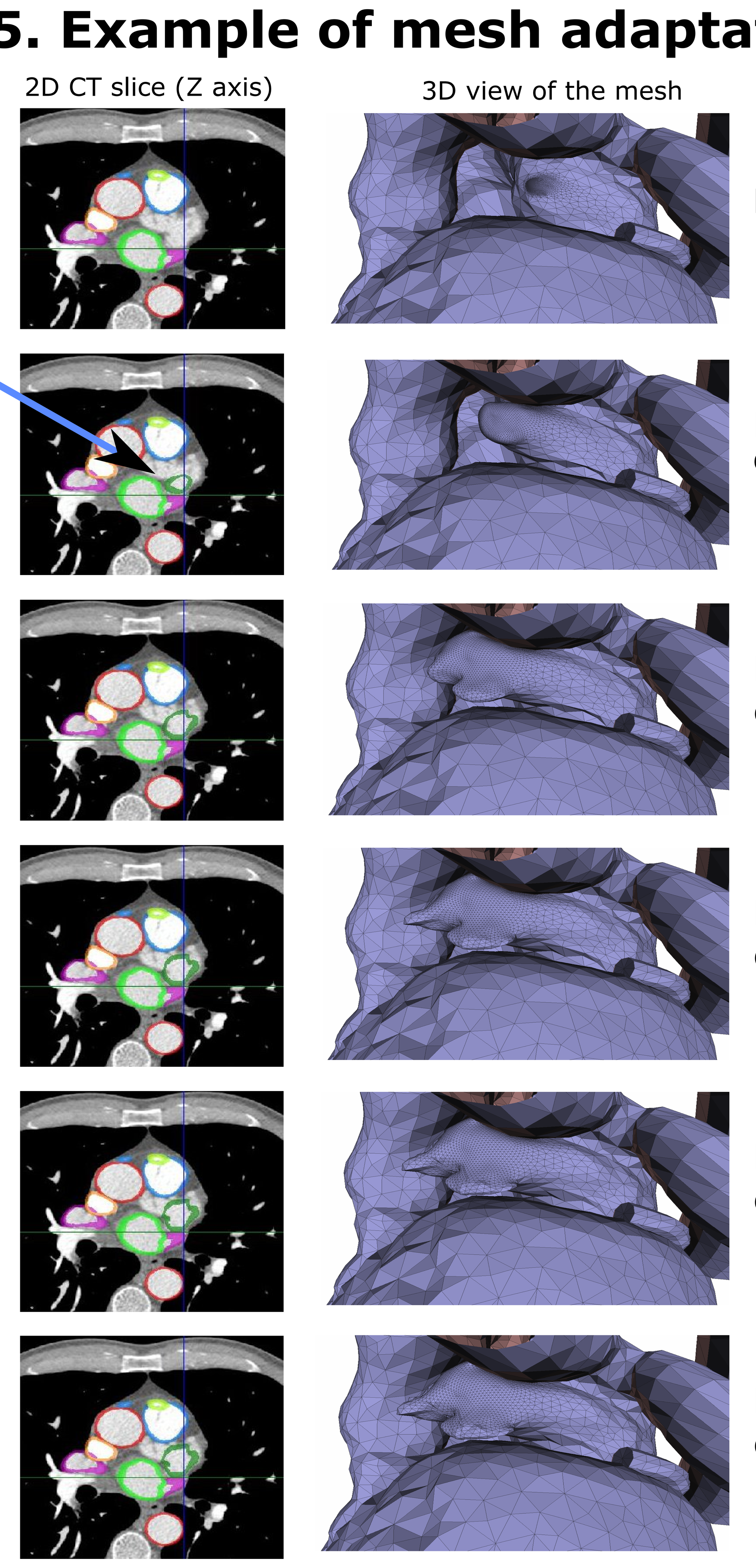


Fig 5.1. Initial state

Fig 5.2. Five iterations further, α = 0.2

Fig 5.3. Five iterations further, α = 1

Fig 5.4. Five iterations further, α = 2

Fig 5.5. Five iterations further, α = 5

Fig 5.6. Five iterations further, α = 10

6. Qualitative and quantitative results

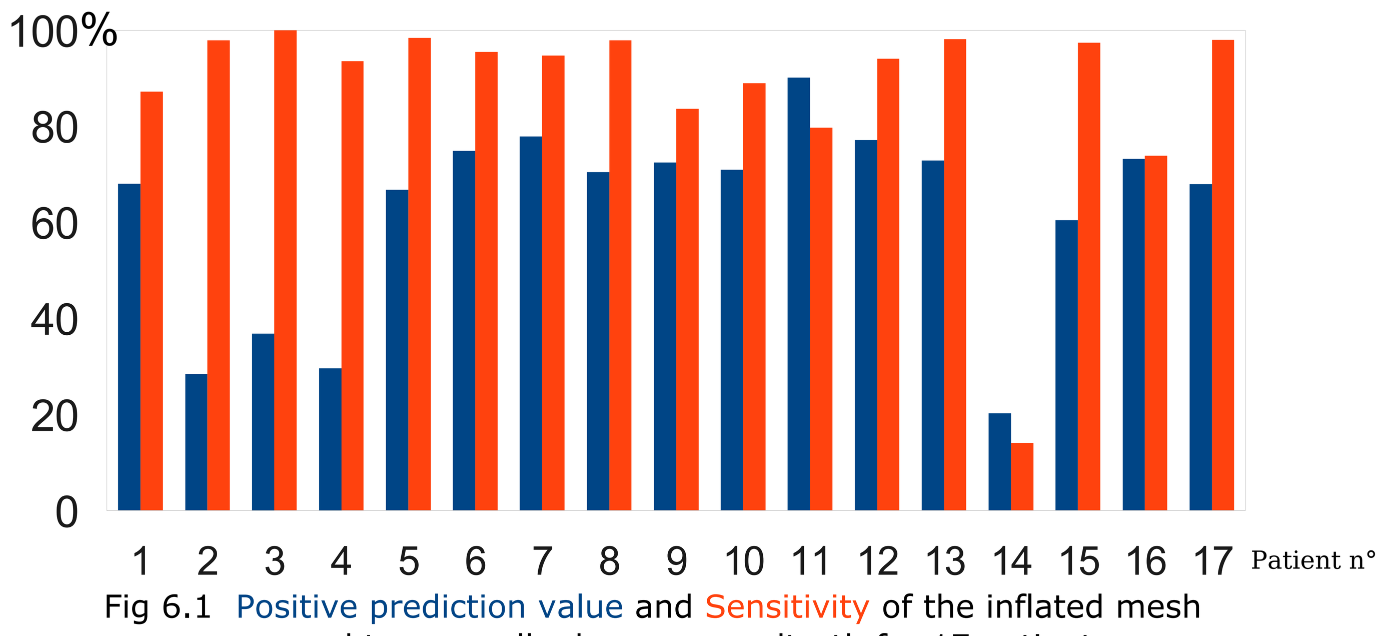


Fig 6.1 Positive prediction value and Sensitivity of the inflated mesh compared to manually drawn groundtruth for 17 patients

$$\text{Sensitivity} = \frac{\textit{true positive}}{\textit{true positive} + \textit{false negative}}$$

$$\text{Positive prediction value} = \frac{\textit{true positive}}{\textit{true positive} + \textit{false positive}}$$

- Difficulties to **reach the tip** of the LAA (low sensitivity);
- **Very few segmentation errors**, with a good adaptation to the shape of the LAA (high positive predictive value);
- Failures (patient 2,3,4, and 14) are mainly due to inaccuracies during the first segmentation phases occurring near the LAA base.

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