Automatic segmentation of 3D high-resolution images by deformable models

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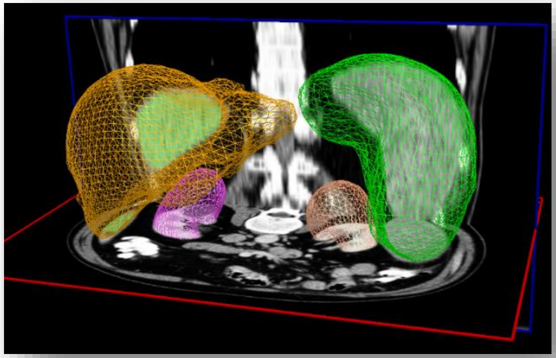
Motivations



Segmentation (e.g. delineating a Region of Interest) is a **major challenge** in 3D image processing.

- Manual method: delineate slice after slice
  - Tedious task (especially for huge data as µ-CT);
  - Operator-dependent.

- Automatic methods:
  - Often based on low-level processing (e.g. thresholding);
  - But becomes very complex when:
    - poor contrast;
    - fuzzy boundaries (artefact, fractured parts…)

→ **Idea: use some knowledge on the shape** to guide segmentation:

- Shape regularity (e.g. smooth);
- Shape characterization;
- Shape + variability characterization.

→ 3D deformable model

Principle of 3D deformable models

- Take a **reference 3D mesh** of the structure;
- Define :
  - **External** constraints: “attraction” by **features** in the 3D image (e.g. image discontinuities);
  - **Internal** constraints: keeping the shape **regular** or **close** to a specific shape (up to some specific variability).
- **Deform** iteratively **the 3D mesh in the 3D image** w.r.t. **both constraints**.

[C. Xu, D. L. Pham, and J. L. Prince, "Medical Image Segmentation Using Deformable Models," Handbook of Medical Imaging -- Volume 2: Medical Image Processing and Analysis, pp. 129-174, edited by J.M. Fitzpatrick and M. Sonka, SPIE Press, May 2000]

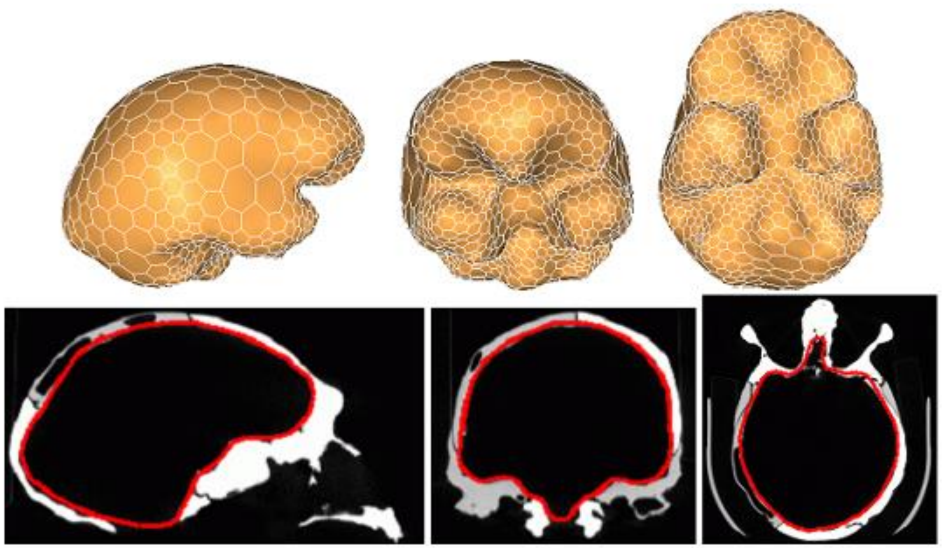
→ 2 examples with different implementations

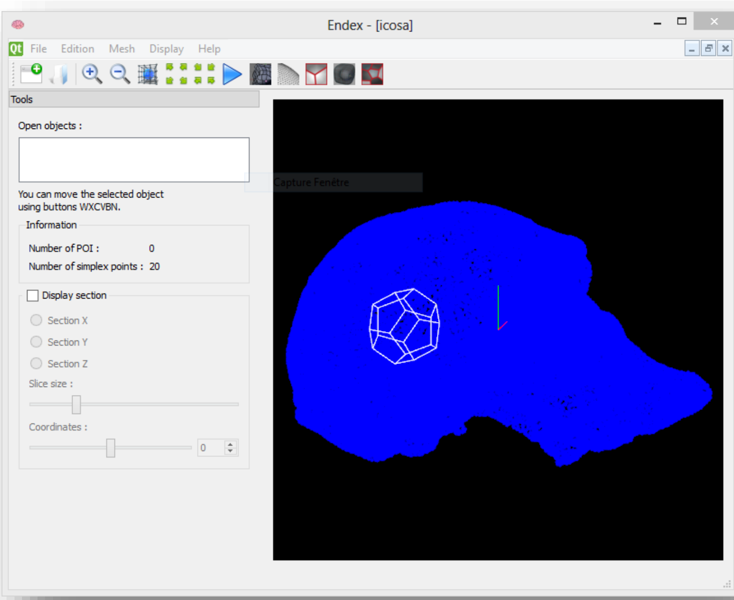
[T. McInerney T, D. Terzopoulos. "Deformable models in medical image analysis: a survey". Med Image Anal. 1996 Jun;1(2):91-108]

Example 1 : segmenting endocranium in CT images

- Endocranium = inner part of the skull:
  - → Gives a 3D rough representation of the brain shape;
  - → Great interest, in particular in paleo-anthropology.

- Skull in CT image: good contrast…. but non-closed structure
  - → *boundaries are non always defined*.

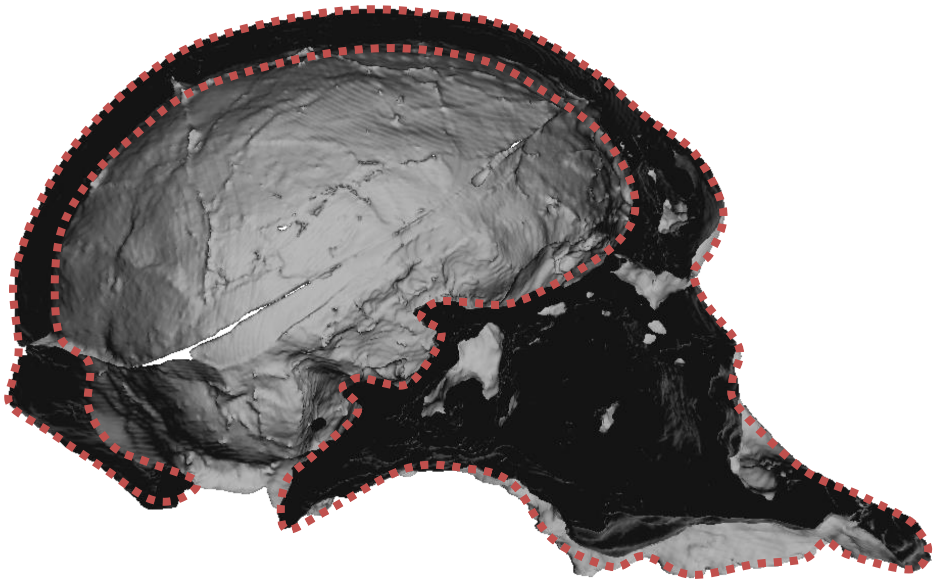




http://www.lsis.org/endex/

Principle of the method

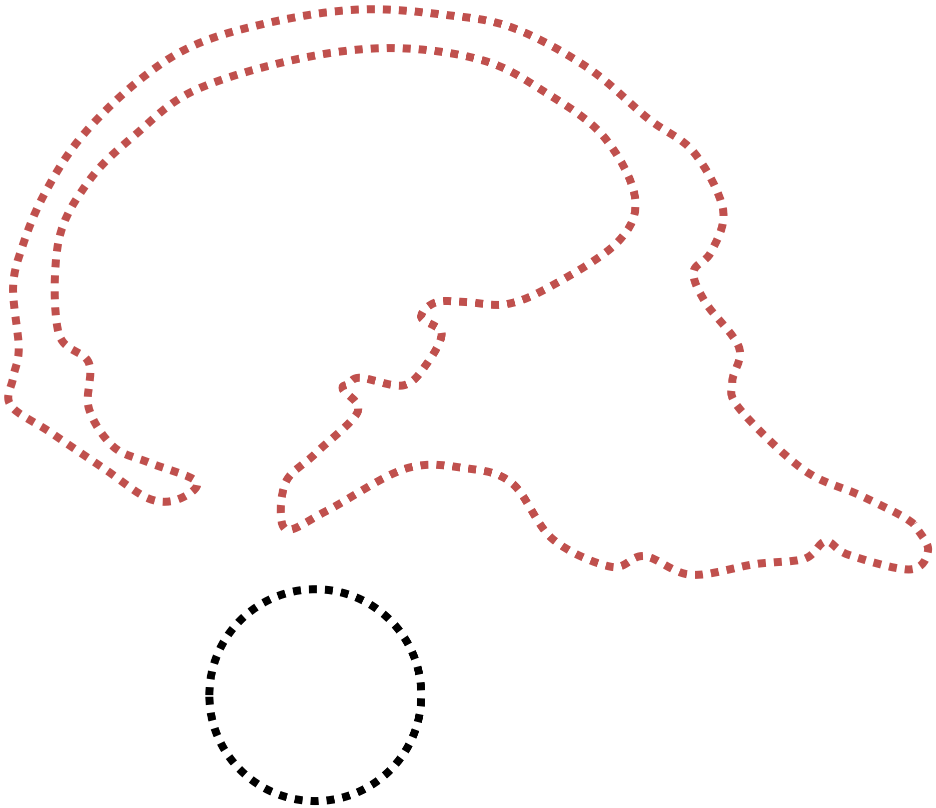
- Features = skull surface (e.g. by thresholding)



Principle of the method

- Features = skull surface (e.g. by thresholding)

- Let a simple closed surface mesh composed of 3D vertices Pi (e.g. a sphere)



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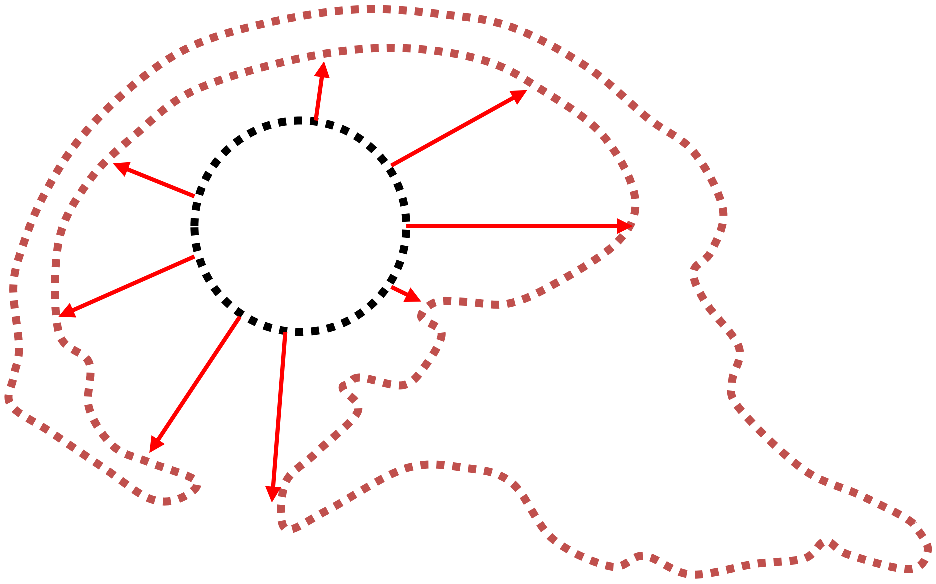

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- Let a simple closed surface mesh composed of 3D vertices Pi (e.g. a sphere)

- The surface mesh is initially positioned "in the middle" of the data

- This surface will deform under the influence of:

  - an external force Fext which attracts the vertices Pi towards the data
  - an internal force Fint which tends to keep the surface smooth (e.g. curvature continuity)

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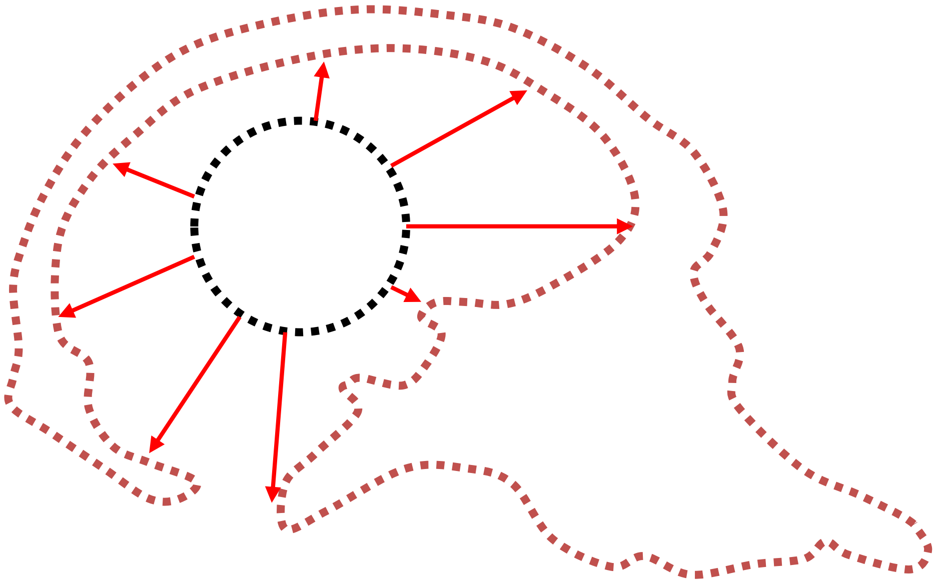

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- At time t, all the vertices Pi follow the evolution law:

$$P_i^{t+1} = P_i^t + (1-\gamma)(P_i^t - P_i^{t-1}) + \alpha_i \mathbf{F}_{int} + \beta_i \mathbf{F}_{ext}$$

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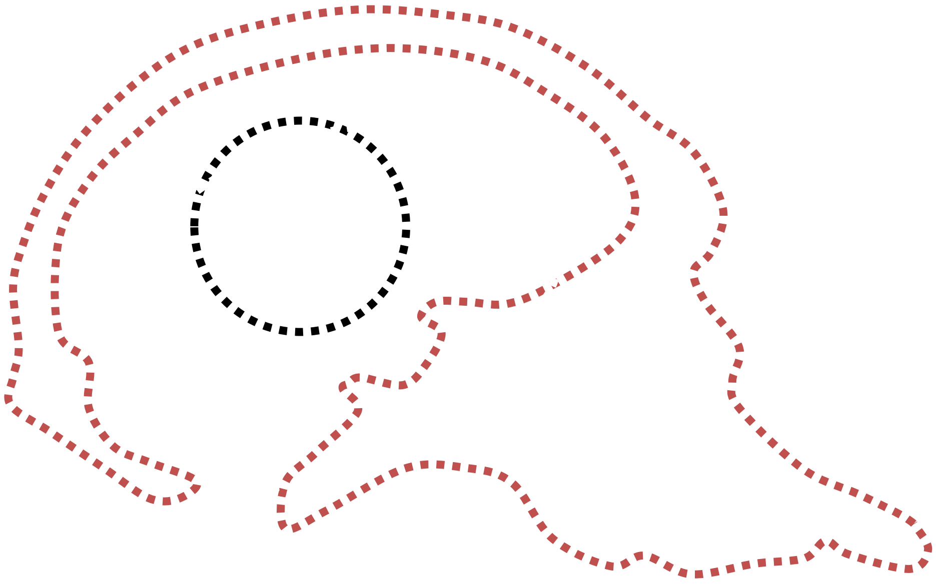

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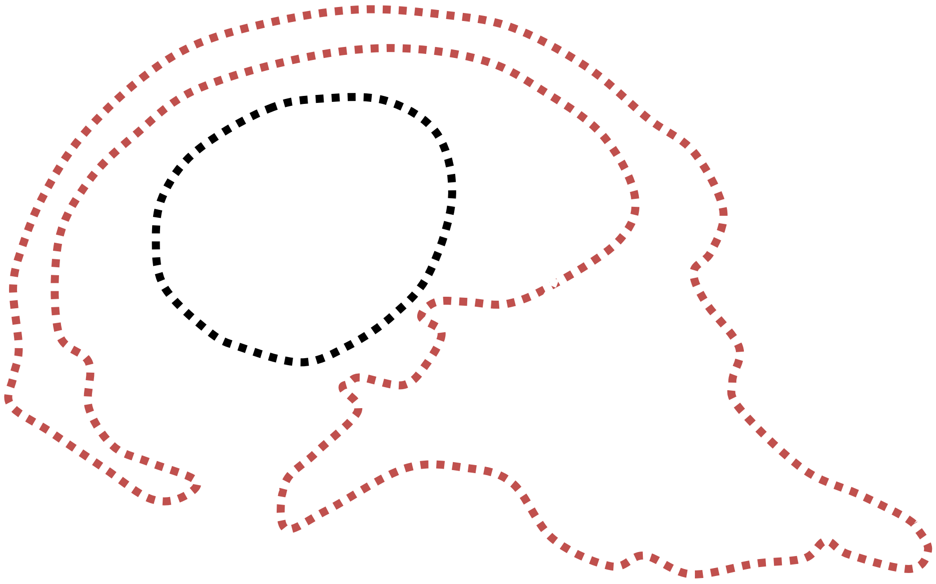

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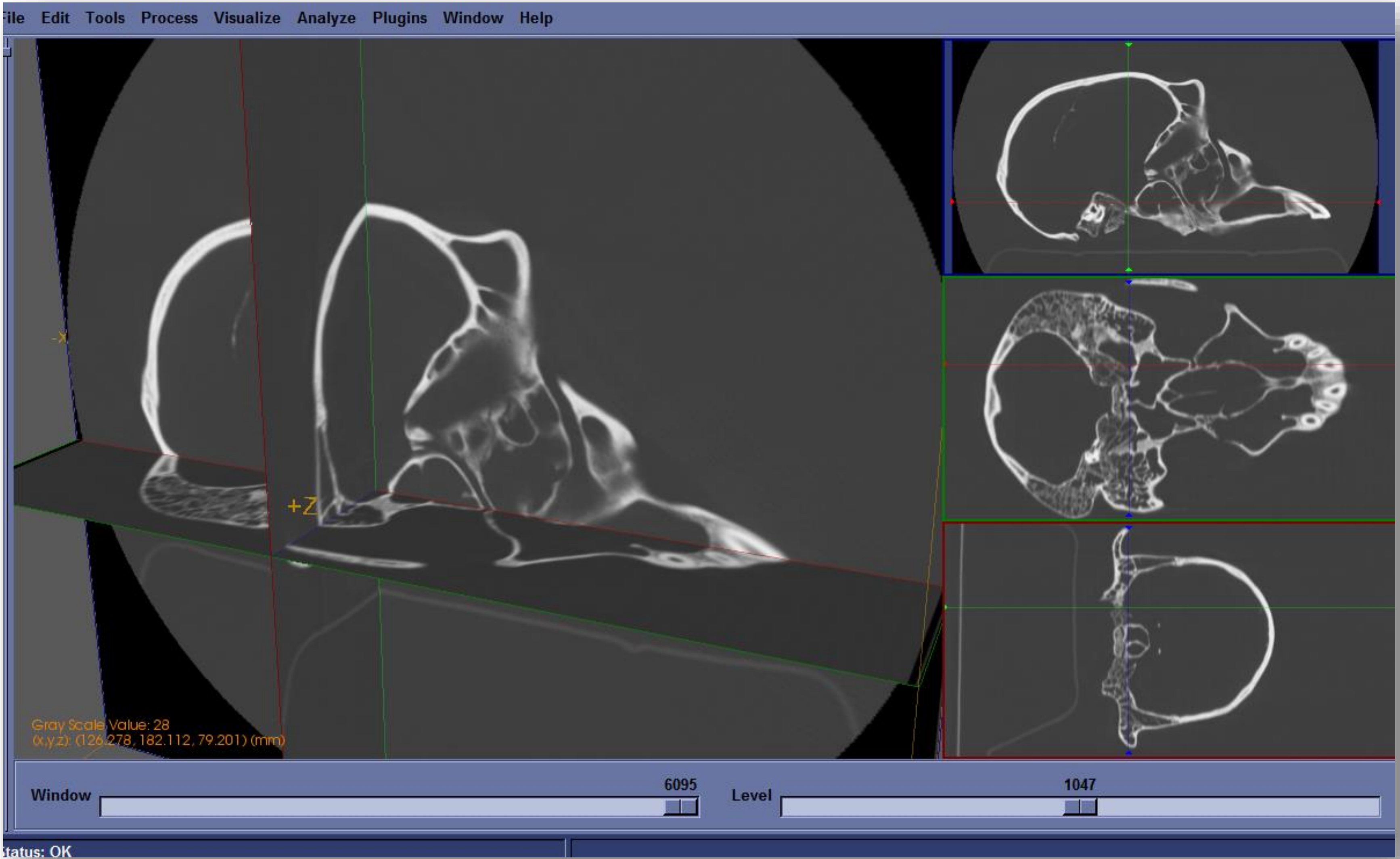
- Iterate the process until the vertices Pi do not move anymore.

- Eventually, add more vertices in the mesh when the distance between the existing vertices becomes too large in order to recover the details.

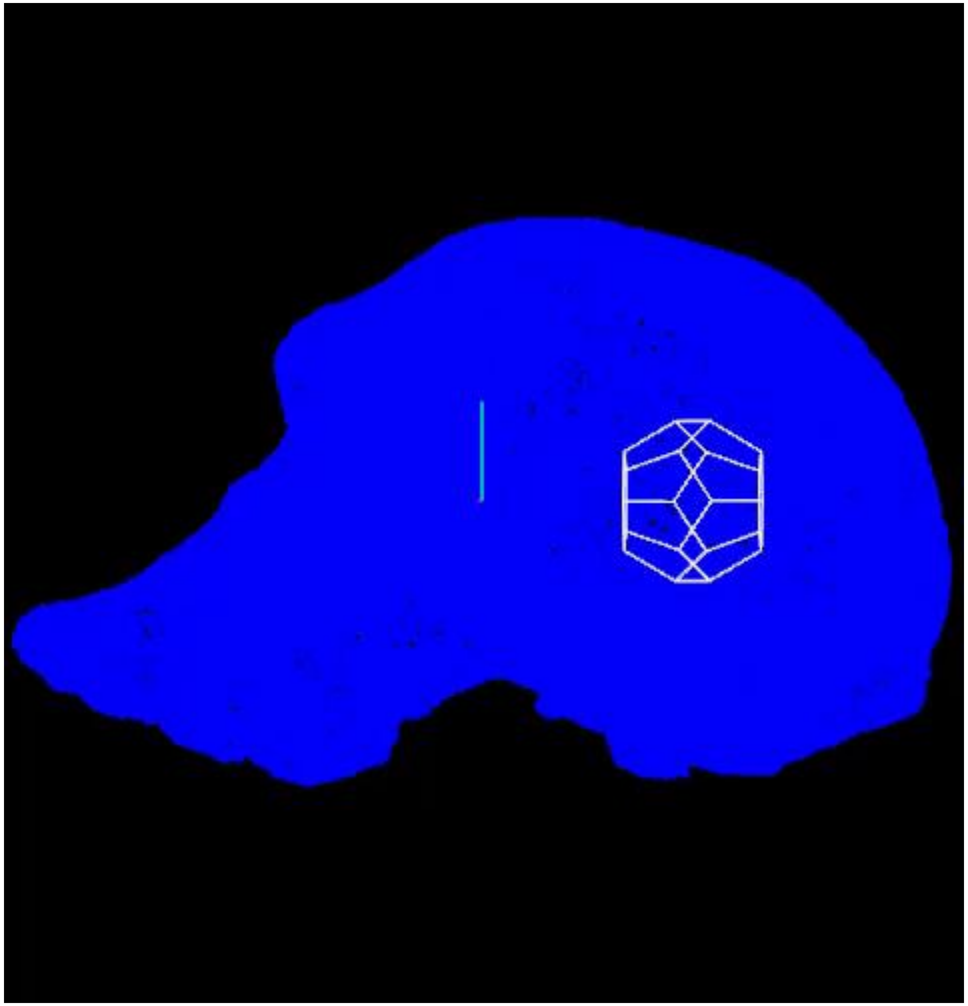
Pan troglodytes

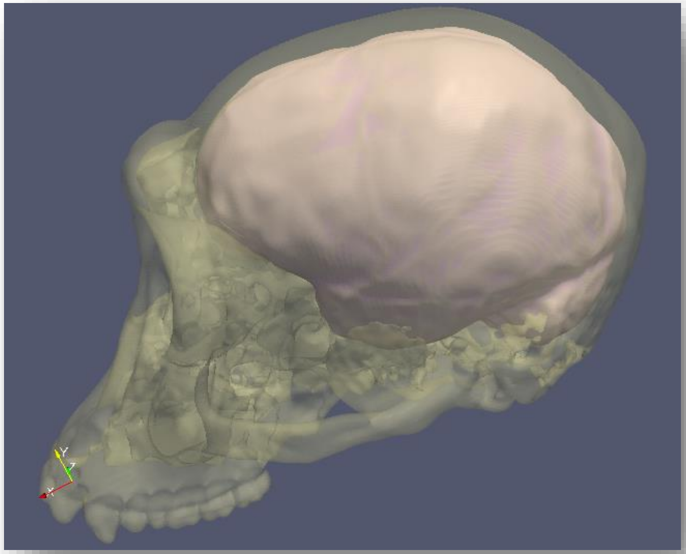
- CT-Scan of a skull: 209 slices of 512 × 512 pixels
- Resolution: 0.461 × 0.461 × 0.600mm

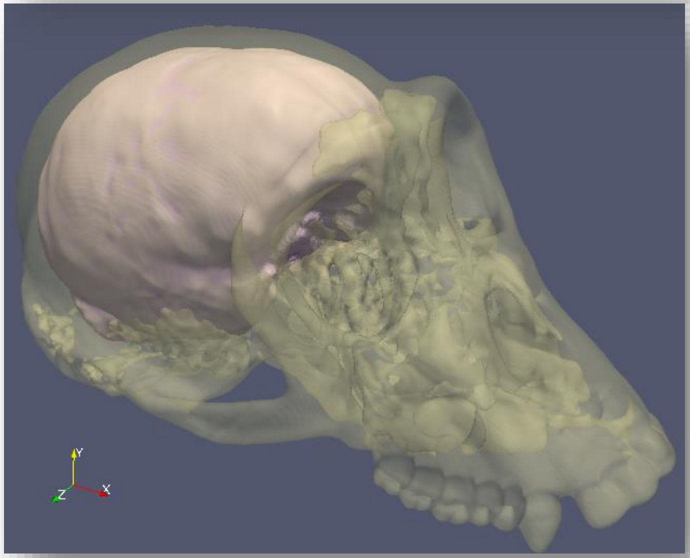


Pan troglodytes

- Manual localization of the initial deformable surface;
- No more user interaction;
- Fast process (real-time video)
- Result mesh: 398,942 vertices / 797,880 faces



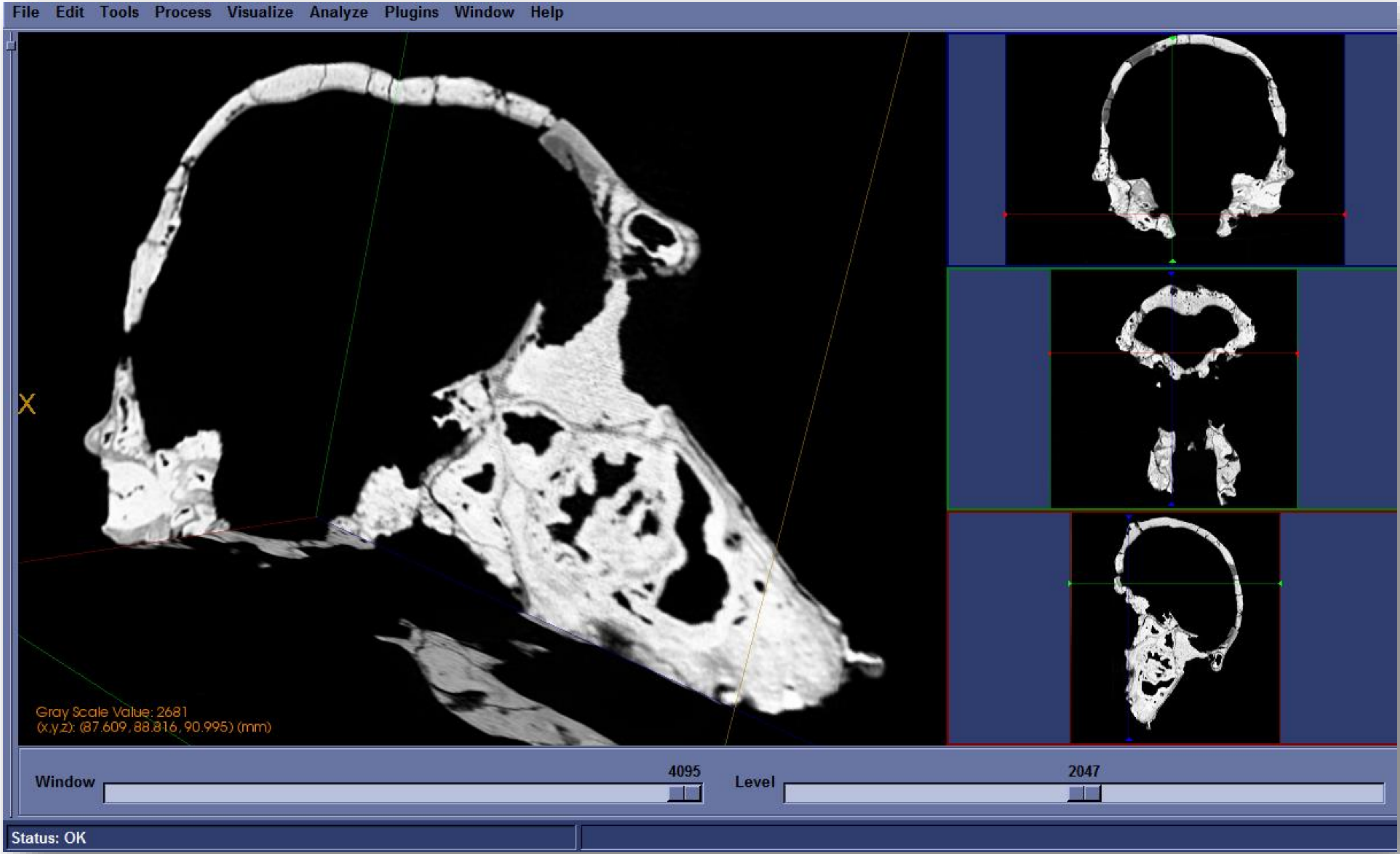




Australopithecus africanus STS5

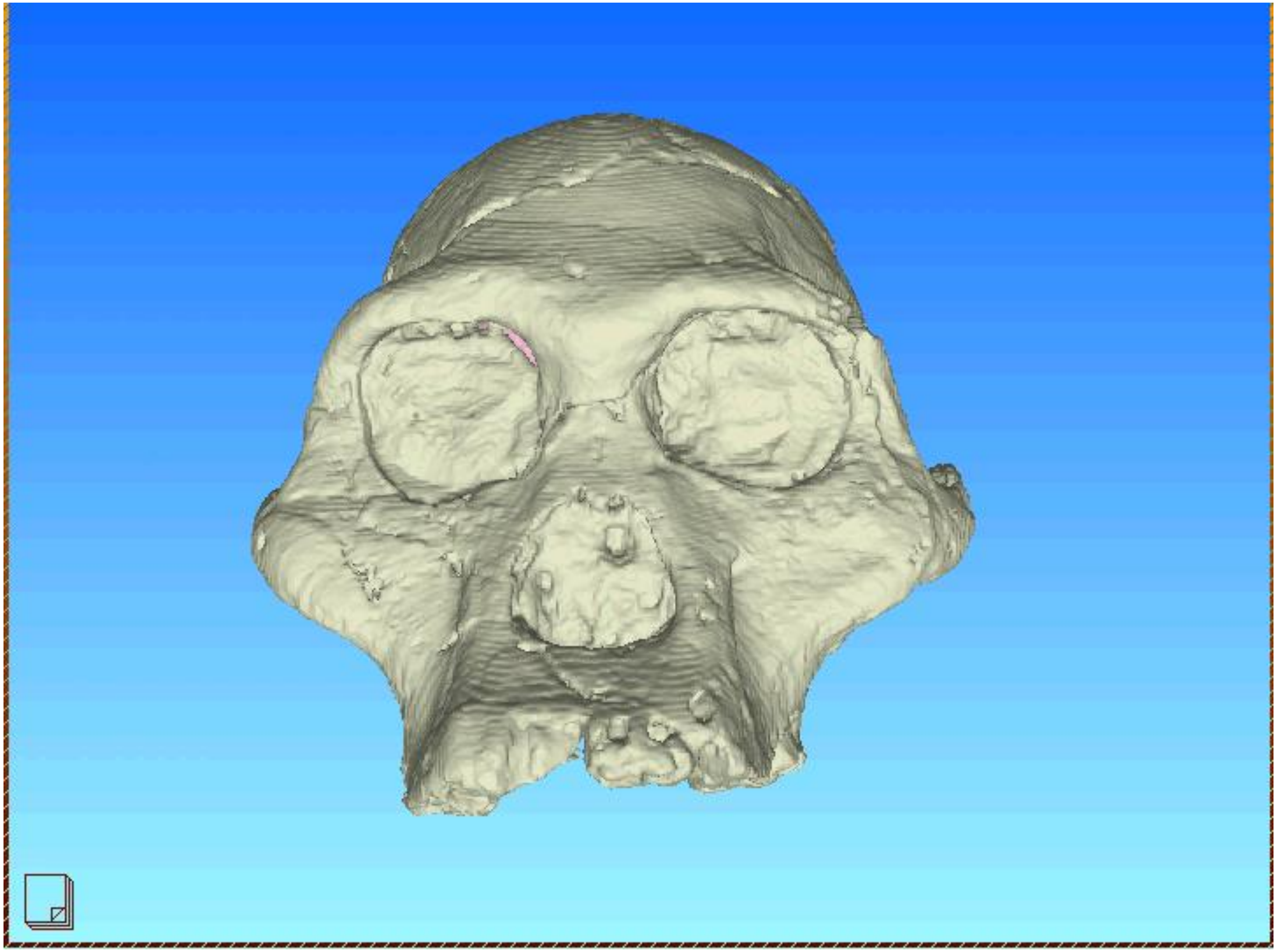
Thanks to S. Potze and Prof. F. Thackeray for providing data.

- CT-Scan of the fossil: 998 slices of 512 × 512 pixels
- Resolution: 0.348 × 0.348 × 0.200 mm

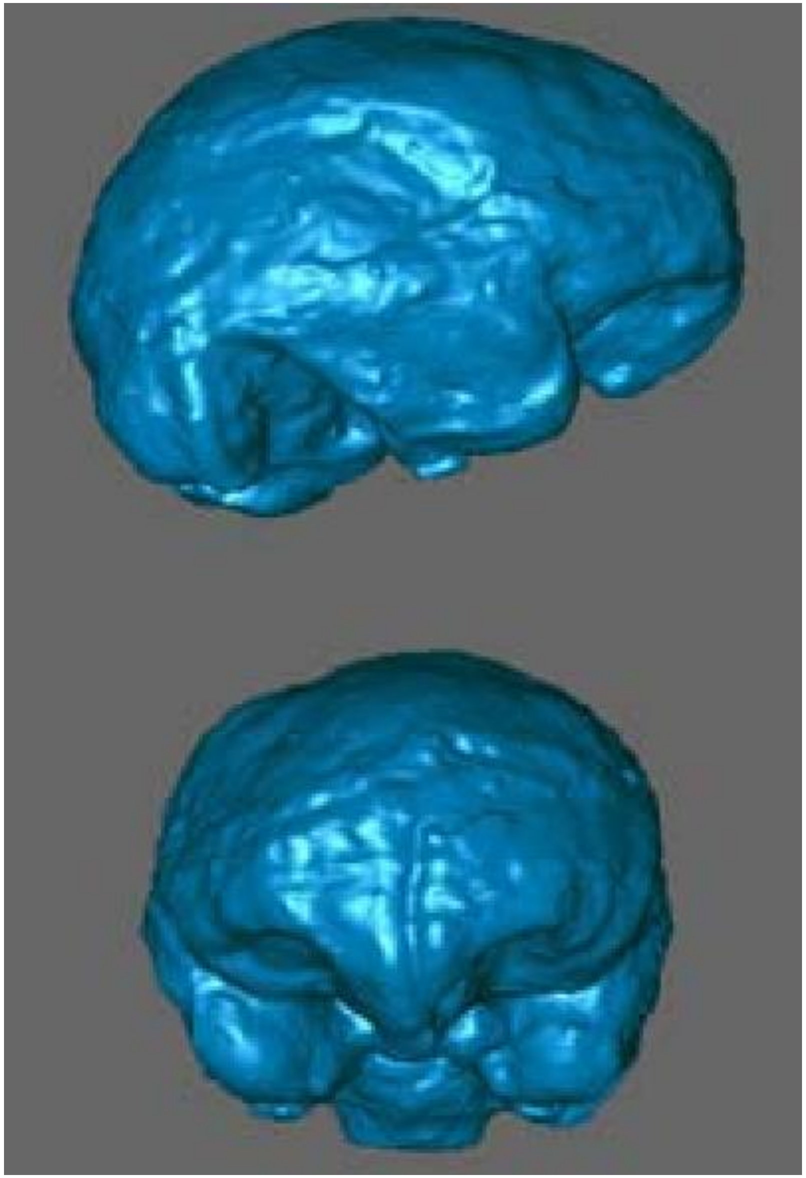


Australopithecus africanus STS5

- Result mesh: 401,960 vertices / 803,916 faces

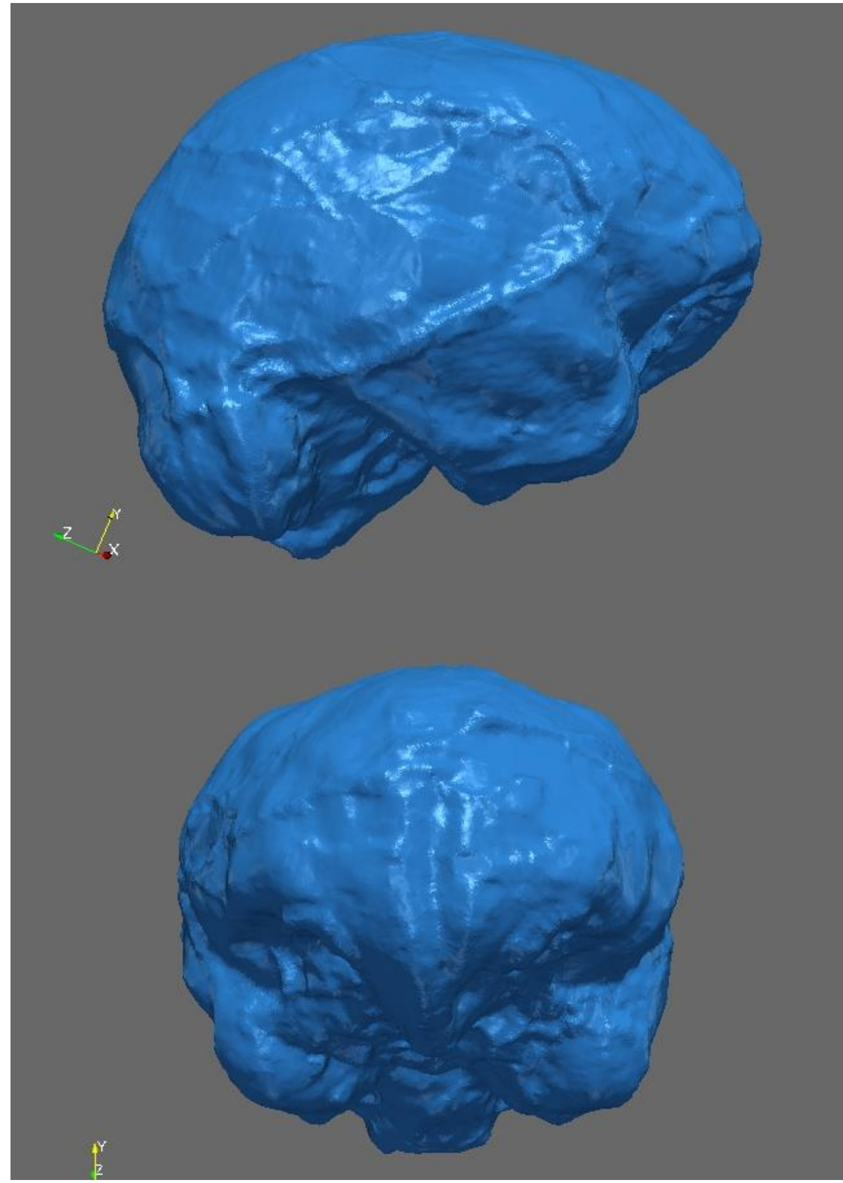


[D. Falk et al. "The Brain of LB1, Homo floresiensis". Science, 308, 242 (2005)] (473 cm3).



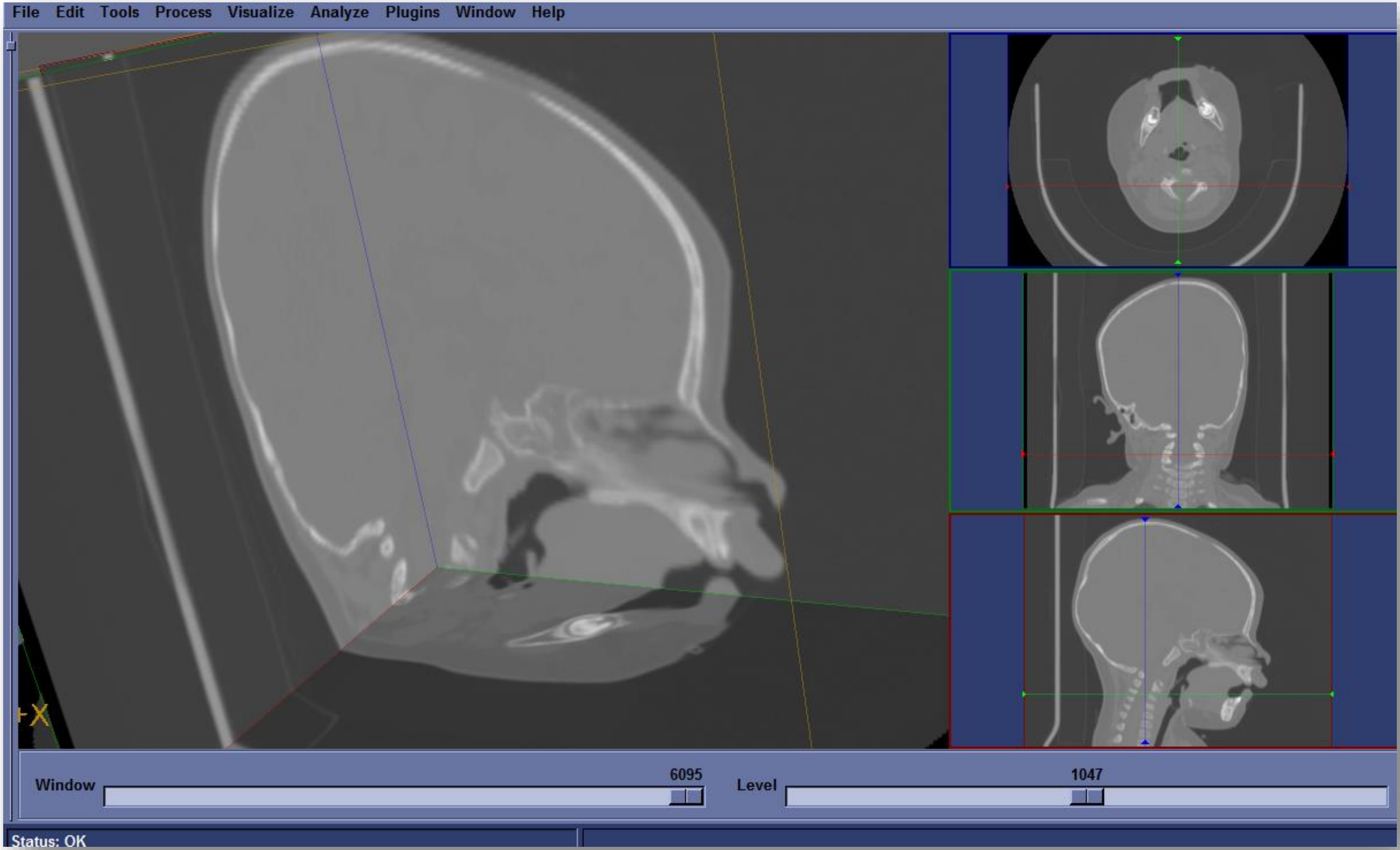
Australopithecus africanus STS5

Our segmentation (476 cm3)



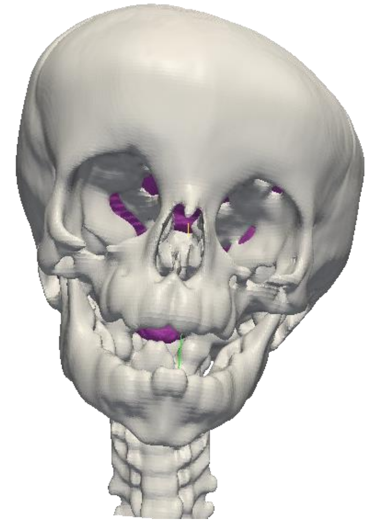
In-vivo data

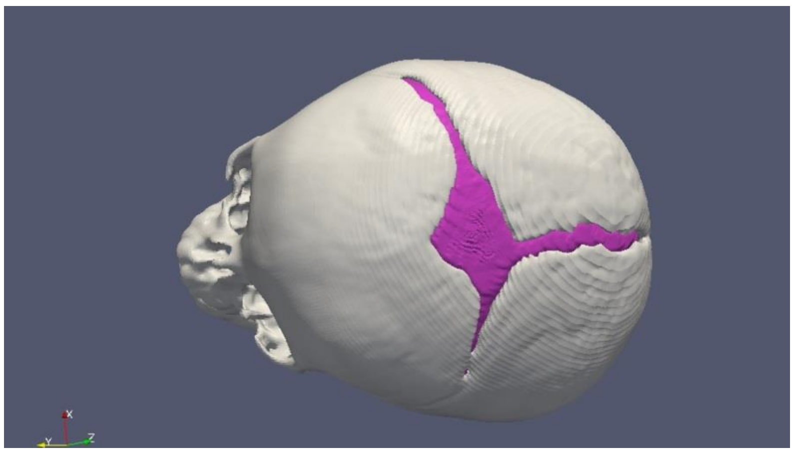
- CT-Scan of the head of a child affected by a plagiocephaly (asymmetrical distortion of the skull): 153 slices of 512×512 pixels
- Resolution: $0.488 \times 0.488 \times 1.250$ mm

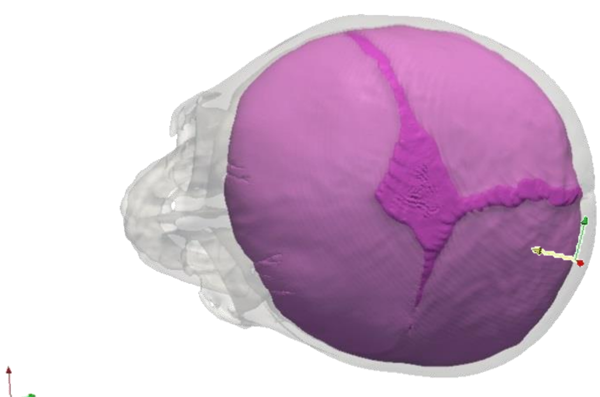


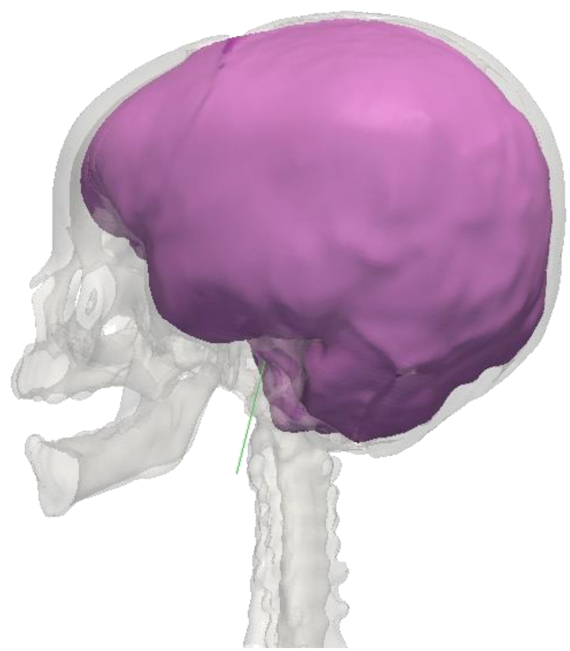
In-vivo data

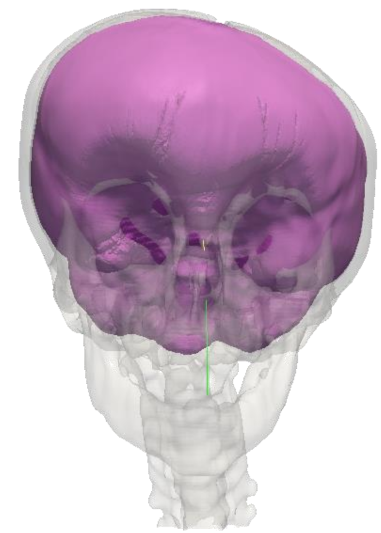
- Manage automatically the fontanels;
- Result mesh: 364,721 vertices / 729,438 faces;
- Could be useful to analyze the 3D deformation of the endocranium and of the skull base.





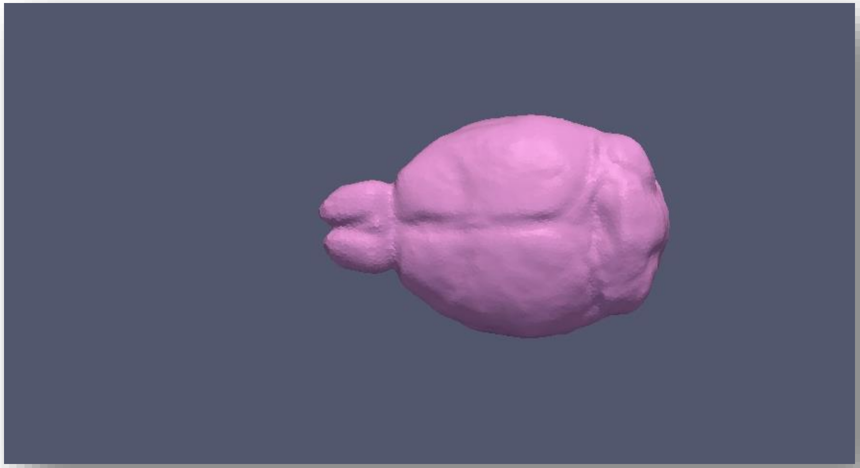


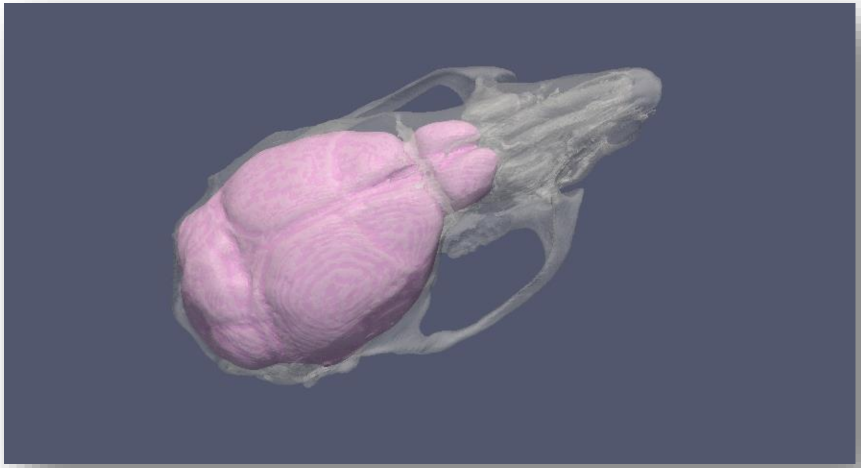


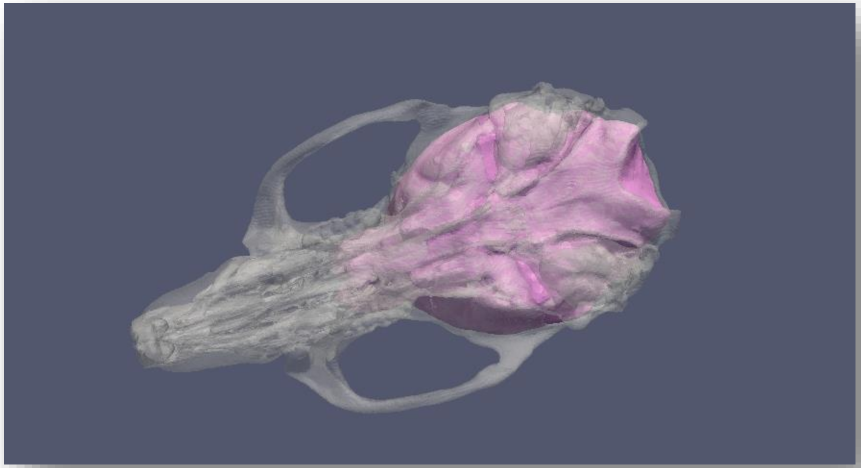


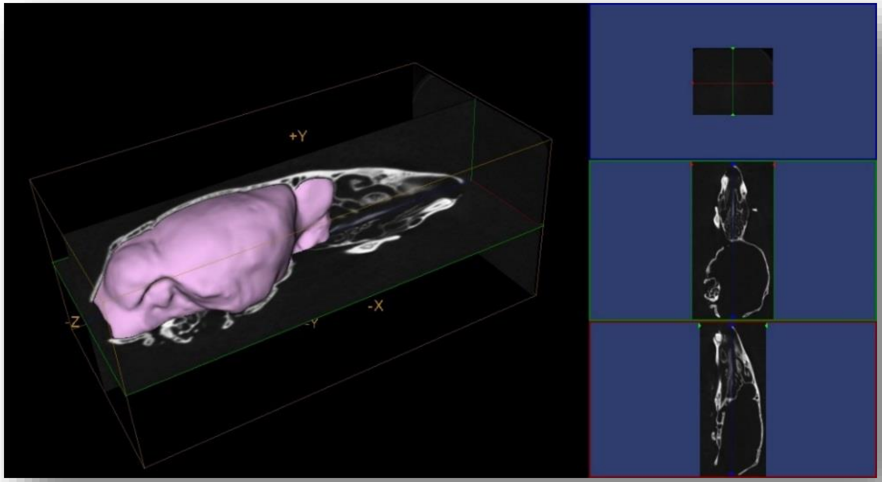
μ-CT data

- μ-CT-Scan of a mouse: 603 slices of 329 × 274 pixels / 0.0386 × 0.0386 × 0.0415 mm
- Application in biomedical research (genetically modified mouse)









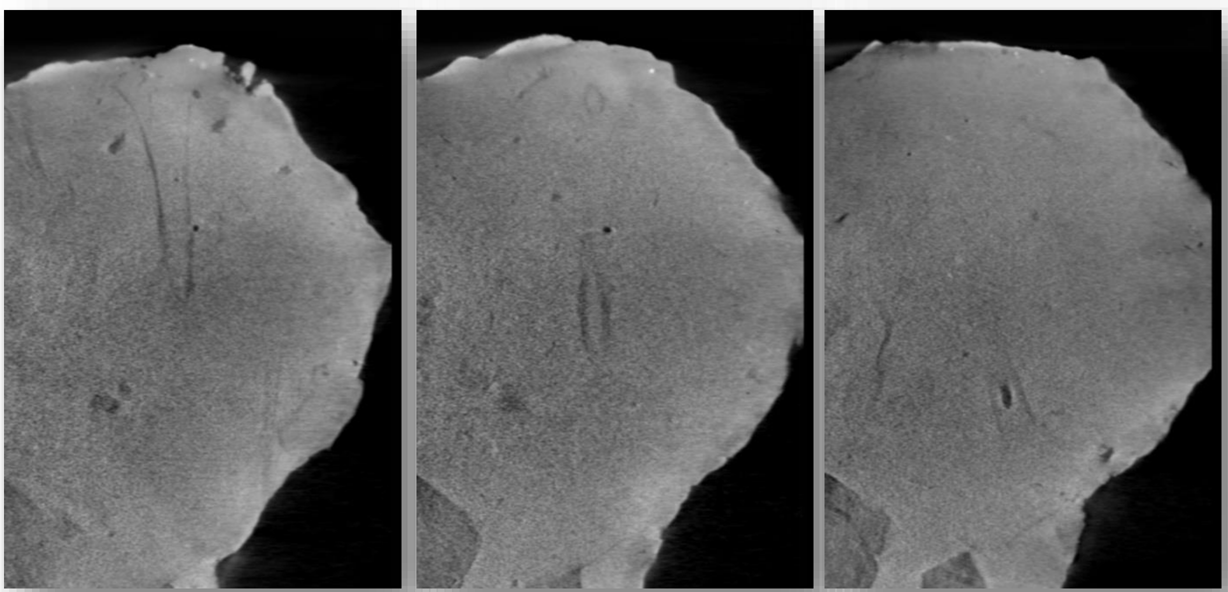
Example 2: computer-aided recognition

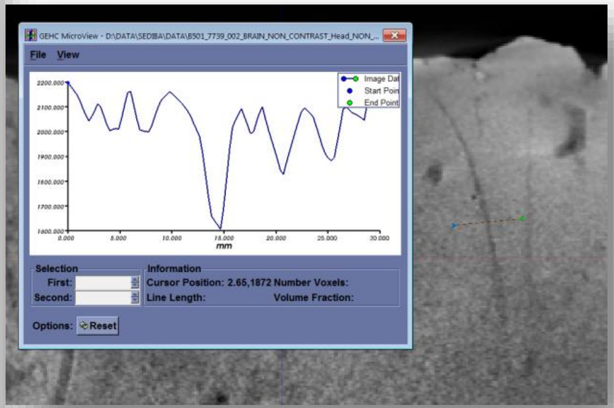
CT-Scan of a potential fossil-bearing block (512×512×1,139 voxels, 0.9766×0.9766×0.5 mm)..

Poor contrasted CT image with many artefacts → *unclear boundaries*

Thanks to Prof. Lee Burger for providing data.

See also "Virtual preparation of fossil bones from Cave deposit in the Cradle of Humankind" presented by Aurore Val yesterday.

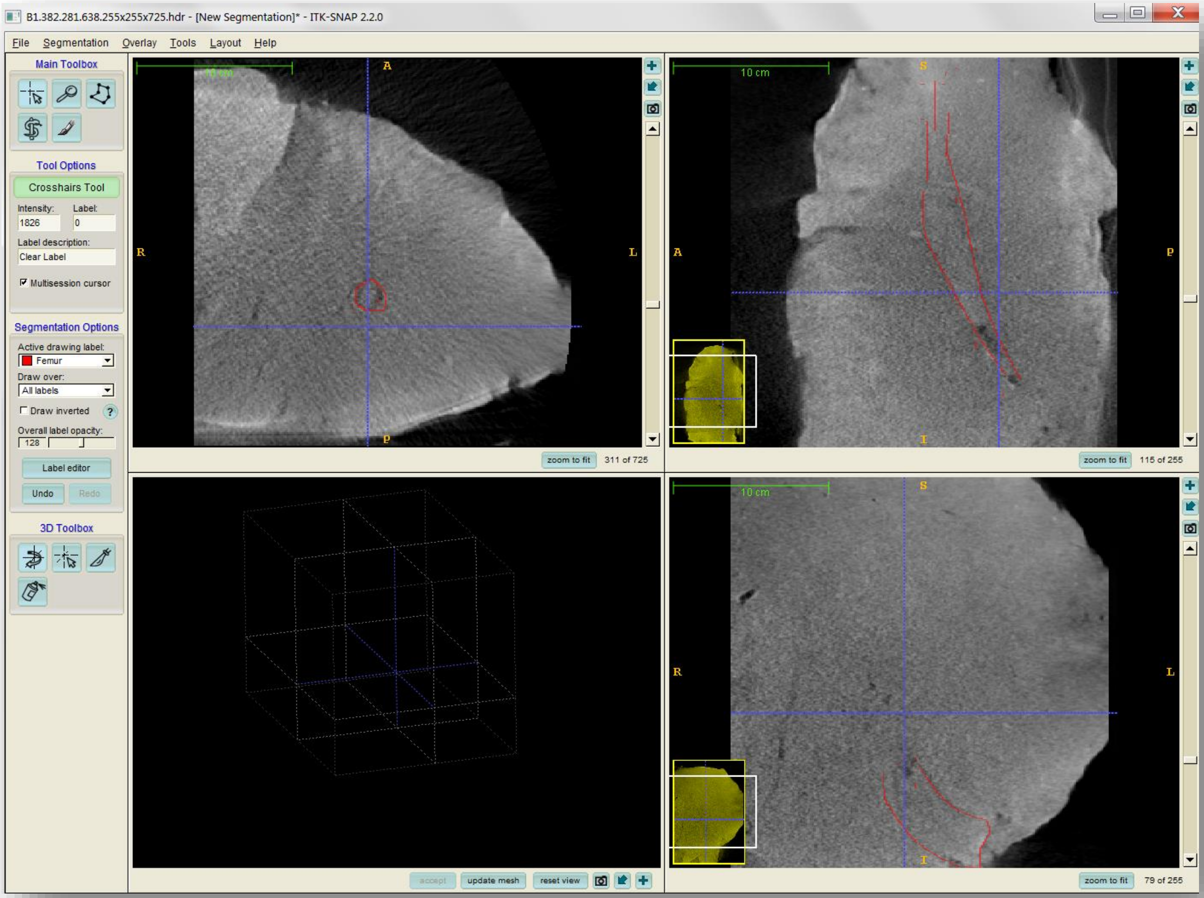


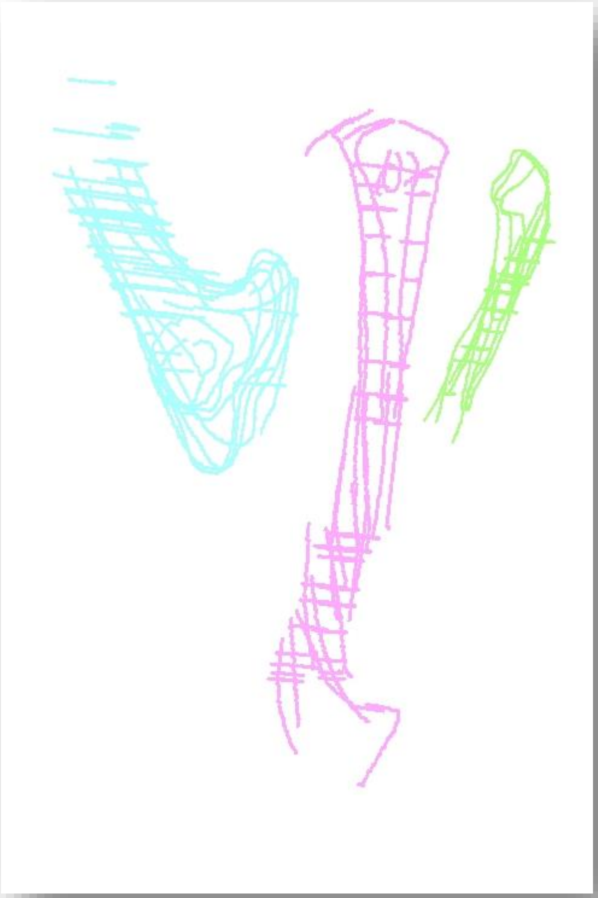


Example 2: computer-aided recognition

→ **Try to identify the bone**:

- ➢ Define manually some features in the 3D image (<5 mn);

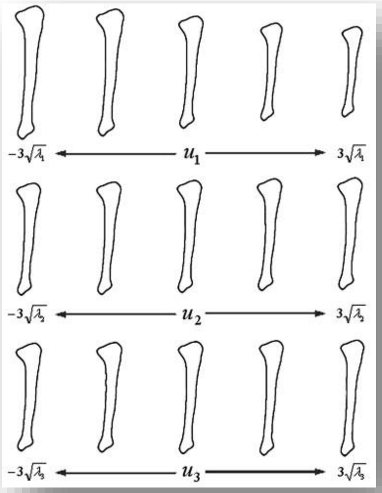




Example 2: computer-aided recognition

➢ **Use a 3D deformable surface of a given anatomical structure** to fit features;

Shape characterization will be too limited in this case → **Shape + variability** characterization.



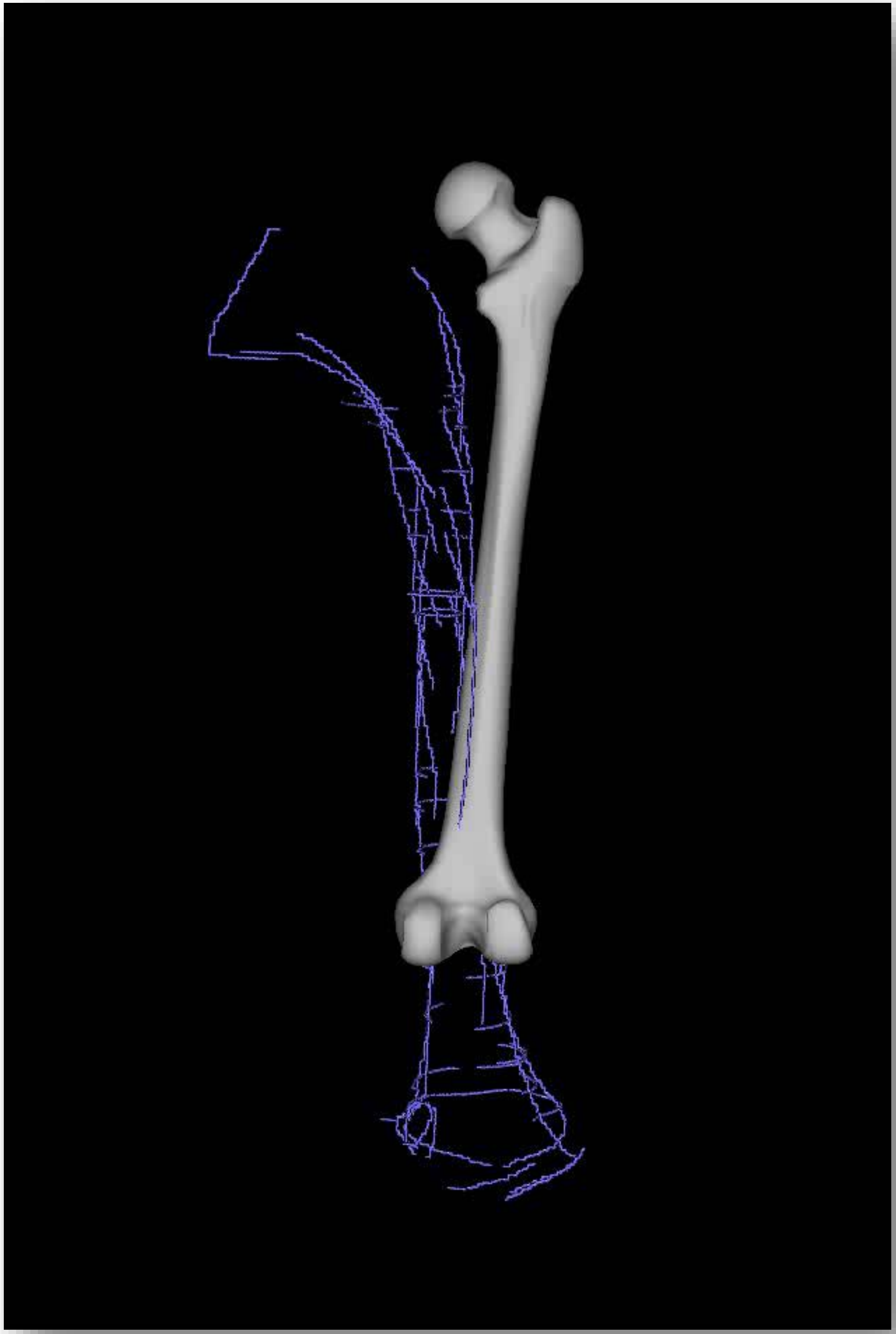
1. Creation of an average + variability model:

- Database of 3D meshes of the given anatomical structure;
- Register all the 3D meshes on a reference one;
- Compute an average 3D mesh by averaging vertex positions;
- Principal Component Analysis of all the differences w.r.t. to the average 3D mesh
  → Principal modes of variation and their variances.

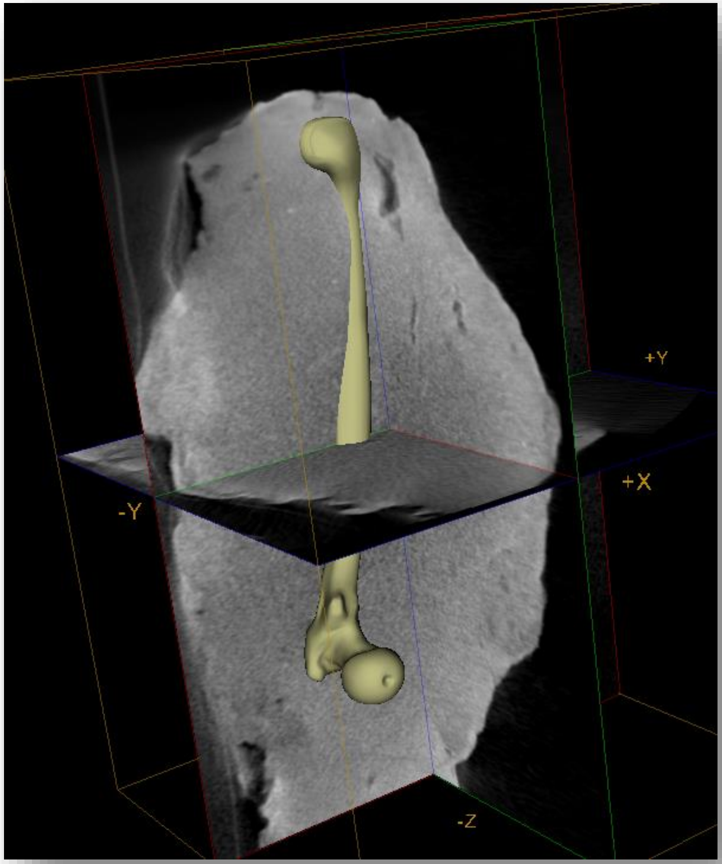
2. Using the deformable surface

- For each vertex of the 3D average mesh, find the closest feature;
- All correspondences → 3D transformation;
- Project this transformation on the *n* first principal modes
  → New transformation which takes into account the variability around the average shape.
- Apply this transformation;
- Increase *n* in order to get a more detailed transformation;
- Iterate until it converges.

B. Gilles, L. Revéret, D.K. Pai. "Creating and animating subject-specific anatomical models", Computer Graphics Forum, 29(8), pp 2340-2351, 2010.

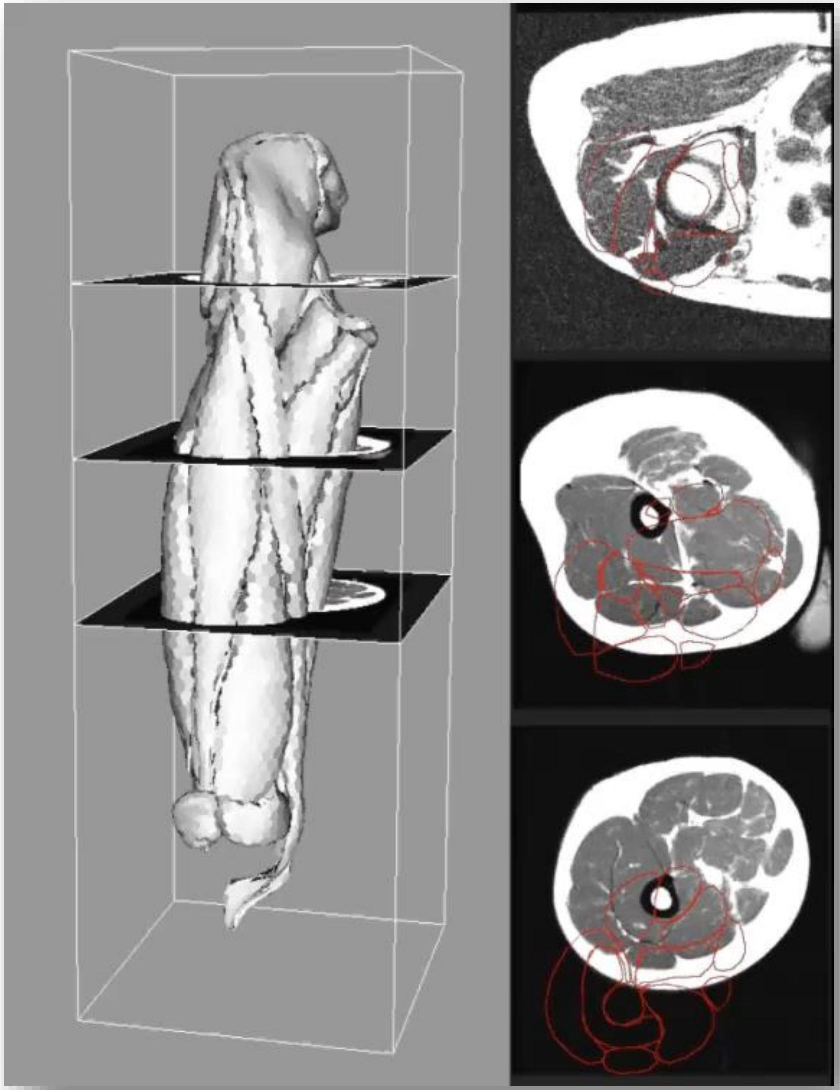


- Assess the result in the 3D image.
- If not, take the model of another anatomical structure.



Conclusions

- Deformable models can be used for segmentation in **many applications** in 3D imaging (e.g. segmentation of thigh muscles in MR images);
- May give good results if the **shape is smooth or can be characterized**;
- Very interested **to collaborate** on this topic (palaeoanthropology, medicine, geology… ?);
- Some software is **freely available** for testing in specific applications (*http://www.lsis.org/endex/).*



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Thank you for your attention.