3D computer assisted craniofacial reconstruction:
a brief (and non-exhaustive) overview

Image from http://www.csm.ornl.gov/viz/
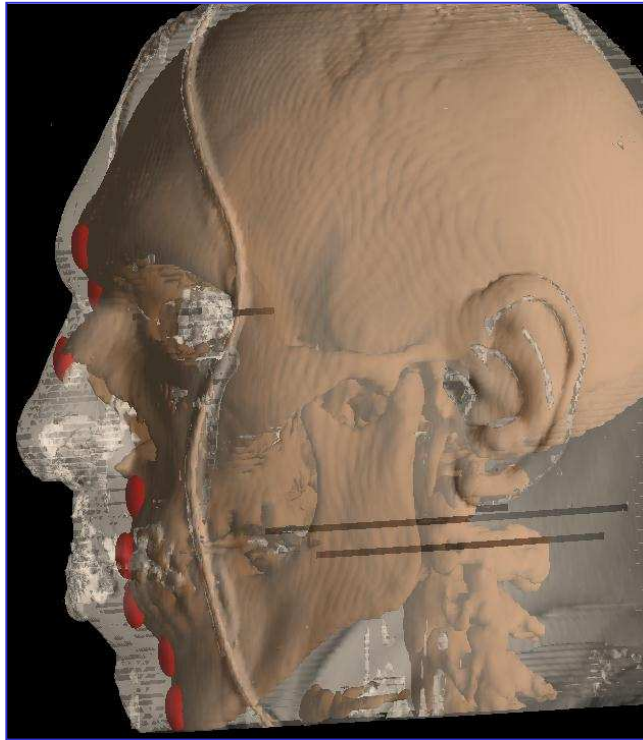
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(part of this work was done at INRIA, Sophia Antipolis - France)

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The emergence of 3D computer assisted methods

• New devices allow to obtain **3D images** of a dry skull, a face surface or of a whole head non-invasively:

	Dry skull	Face surface	Whole head (skull & face)	Comments
CT-Scan	+++	++	+++	+ resolution up to 100μm - artifacts (metallic items) - radiation dose
MRI		++	++ face +/- skull	+ resolution up to 1mm - artifacts (chemical shift)
Laser scanning	++	+++		+ acquisition of texture - occlusions due to holes
3D US			++	+ useful for measurements

Image from http://www.shef.ac.uk/assem/1/evison.html
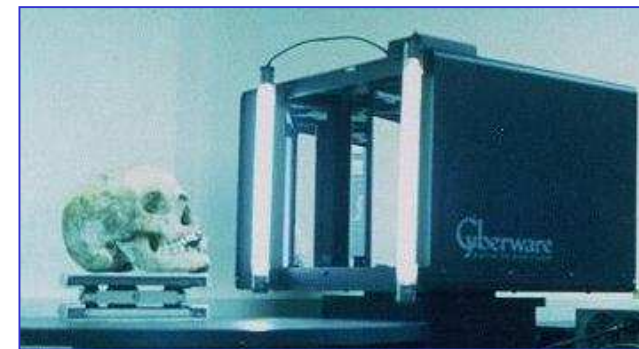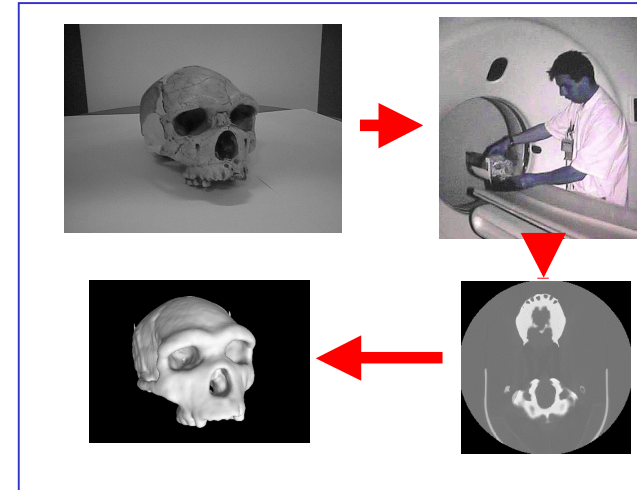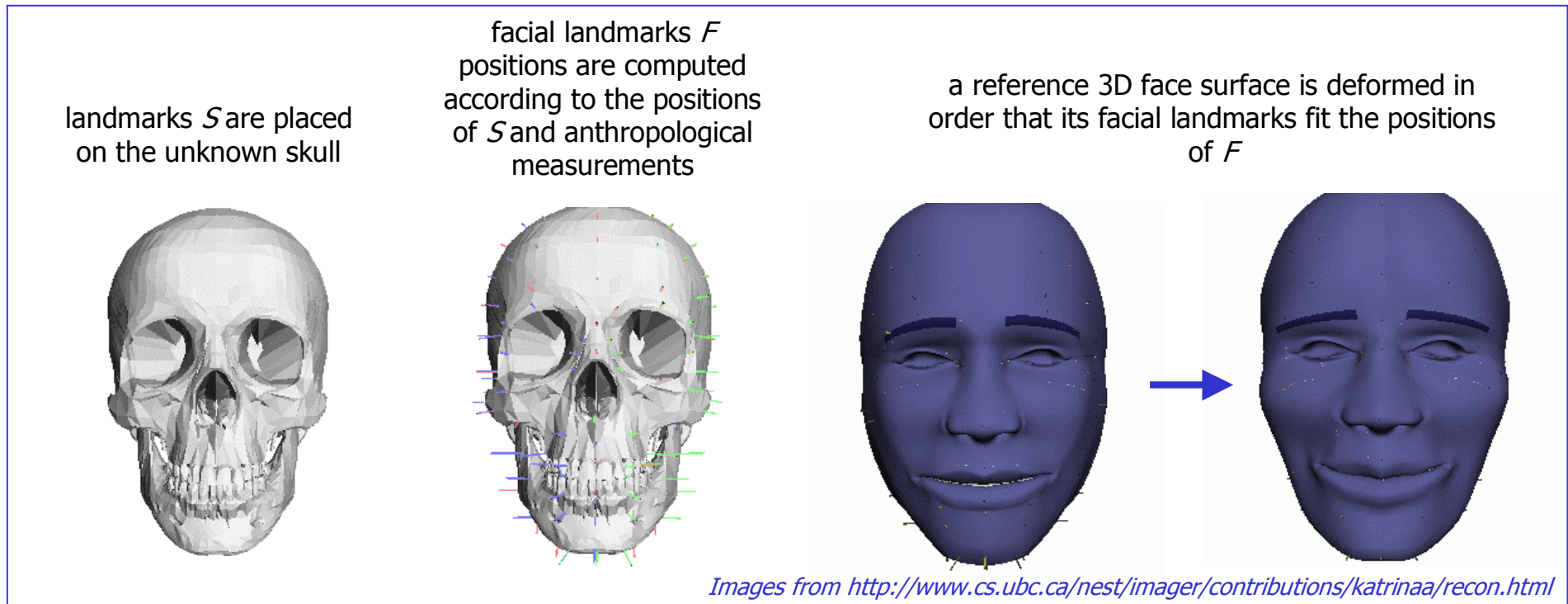
• **Computer Aided Design** and **medical imaging** software, **computer graphics** algorithms and **virtual reality** tools allow to interact with 3D images and surface representations.

• The results can be made available to the scientific community by Internet.

• **University of Glasgow, UK:** [Vanezis P., Blowes R., Linney A., Tan A., Richards R. & Neave R., *Forensic Science International* - 1989]

• **University of Sheffield, UK:** [Tyrrell A., Evison, M., Chamberlain A. & Green M., *Journal of Forensic Sciences* - 1997]

• **Ufa State Aviation Technical University, Russia:** [Ilyasov B., Galiulin R., Mugattarov M. & Tumashinov A., *Int. Workshop on Computer Sciences and Information Technologies* - 2000]

(1) Computerizing the manual method

landmarks S are placed on the unknown skull

facial landmarks F positions are computed according to the positions of S and anthropological measurements

a reference 3D face surface is deformed in order that its facial landmarks fit the positions of F

Images from http://www.cs.ubc.ca/nest/imager/contributions/katrinaa/recon.html
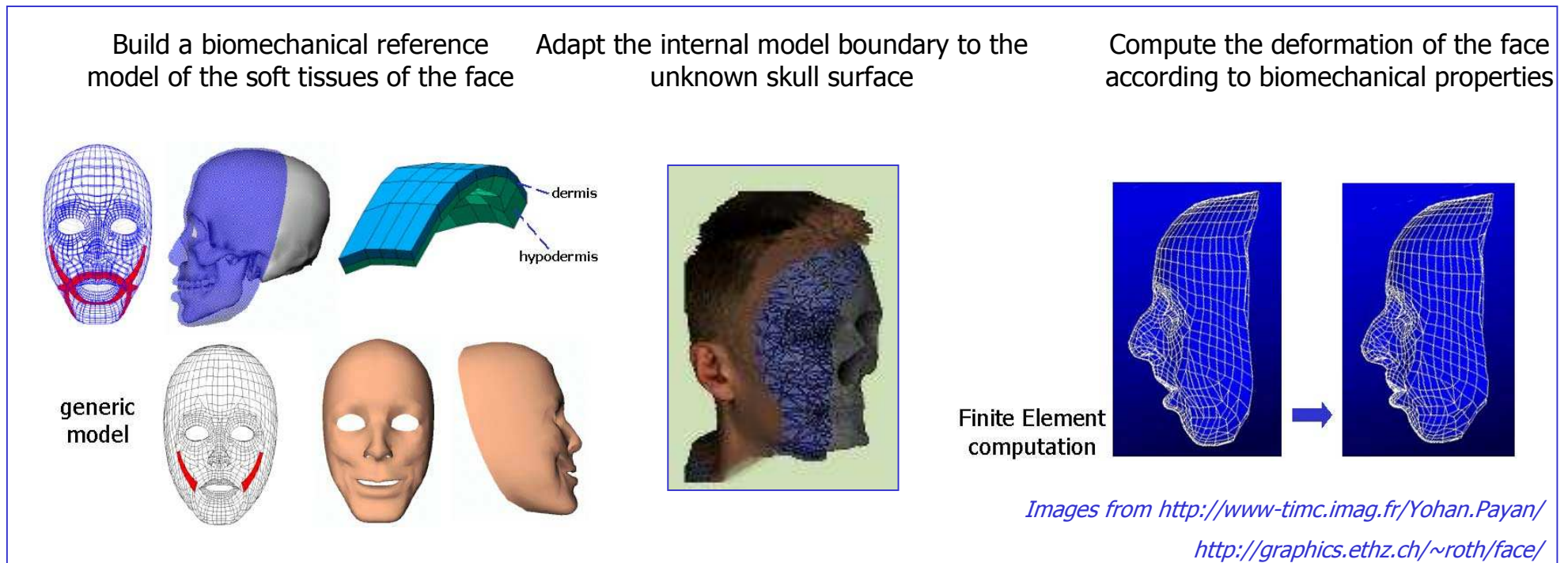
- **University of British Columbia, Canada:** [Archer K., Coughlan K., Forsey D., Struben S., *Graphics Interface* - 1998]

- **Oak Ridge National Laboratory, USA:** [Uberbacher E., Mural R. & Mann R., *Super Computing* - 1999]

- **University of Glasgow, UK:** [Vanezis P., Vanezis M., McCombe G. & Niblett T., *Forensic Science International* - 2000]

- **University of Koblenz-Landau, Germany:** [Petrick M., *Computer Graphics Seminar* - 2001]

- **Polytechnical Institute of Havana, Cuba**: [Plasencia J. - *Int. Conf. in Central Europe on Comp. Graphics, Visualization and Comp. Vision* - 1999]

- **INRIA, Sophia Antipolis, France:** [Delingette H., Subsol G., Cotin S. & Pignon J., *Visualization in Biomedical Computing* - 1994]

$\Rightarrow$ how to interpolate the face shape between the landmarks (bilinear, radial-based functions, B-spline, etc.)?

$\Rightarrow$ the small number and the sparseness of landmarks limits the accuracy of the reconstruction

$\Rightarrow$ requires to locate precisely manually some anatomical landmarks

Other methods have been investigated

(2) Introduction of a biomechanical model

Build a biomechanical reference model of the soft tissues of the face

Adapt the internal model boundary to the unknown skull surface

Compute the deformation of the face according to biomechanical properties

generic model

dermis

hypodermis

Finite Element computation

Images from http://www-timc.imag.fr/Yohan.Payan/

http://graphics.ethz.ch/~roth/face/

Research in craniofacial surgery:

• **Federal Inst. of Tech. Zürich, Switzerland:** [Koch R., Gross M., Carls, F., von Büren D., Fankhauser G. & Parish Y, *SIGGRAPH - 1996]*

• **Faculty of Medicine of Grenoble, France:** [Chabanas M. & Payan Y., *Medical Image Computing and Computer-Assisted Intervention - 2000]*

Is it possible to use such a model to reconstruct the face from an unknown skull?

⇒ extremely difficult to build a realistic biomechanical model for the whole face: several structures (muscles, epidermis, dermis, hypodermis) with physical behaviors that are not well defined

⇒ how to fit the model to the unknown skull (i.e. to find the structure locations and to adapt their material parameters)?

⇒ numerical resolution (e.g. Finite Element Method) can be highly time consuming

(3) Volume deformation of a reference model
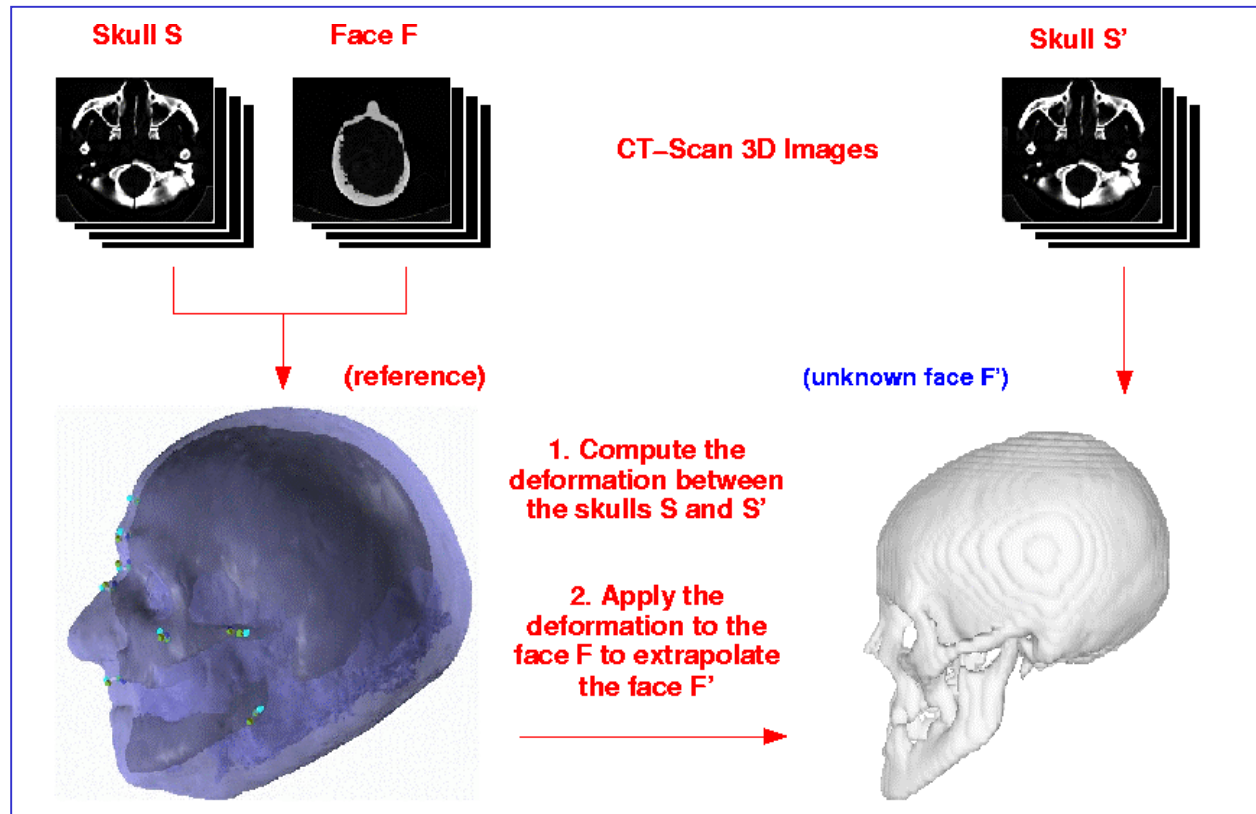
- **University of Nice & INRIA Sophia Antipolis, France:** [Quatrehomme G., Cotin S., Subsol G., Delingette H., Garidel Y., Grevin G., Fidrich M., Bailet P. & Ollier A., *Journal of Forensic Sciences* - 1997]

- **ZGDV Darmstadt, Germany:** [Hildebrand A. & Seibert F., *Computer Graphics topics* - 1997]

- **University of Wales Swansea, UK:** [Nelson L. & Michael S., *Forensic Science International* - 1998]

- **University of Pisa, Italy:** [Attardi G., Betrò M., Forte M., Gori R., Guidazzoli A., Imboden S. & Mallegni F., *SIGGRAPH* - 1999]

- **GE Corporate R&D Center, USA:** [Tu P., Hartley R., Lorensen W., Allyassin M., Gupta R. & Heier L., *Scientific Meeting of the International Association for Craniofacial Identification* - 2000]

$\Rightarrow$ what type of mathematical function to take to obtain a smooth and accurate deformation?

$\Rightarrow$ how to compute the deformation? Landmarks points are sparse. **3D image registration algorithms** allow to find automatically correspondences between the two skull images

A requirement: creating a significant reference model

The three presented methods require a database of measurements or of reference models to deal with the large intra-human variability.

- **INRIA, Sophia Antipolis, France:** [Subsol G., *Ph.D. thesis* - 1995]

- **University of Pennsylvania, USA:** [DeCarlo D., Metaxas D. & Stone M., *SIGGRAPH* - 1998]

- **Case Western Reserve University, USA:** [Dean D., Bookstein F., Koneru S., Kamath J., Luce E., Hans M., Goldberg J. & Cutting C., J*ournal of Craniofacial Surgery* - 1998]

- **GE Corporate R&D Center, USA:** [Tu P., Hartley R., Lorensen W., Allyassin M., Gupta R. & Heier L., *Scientific Meeting of the Int. Assoc. for Craniofacial Identification* - 2000]

- **University of Sheffield, UK:** [Evison M., *Forensic Science Communications* - 2001]

"mean" skull
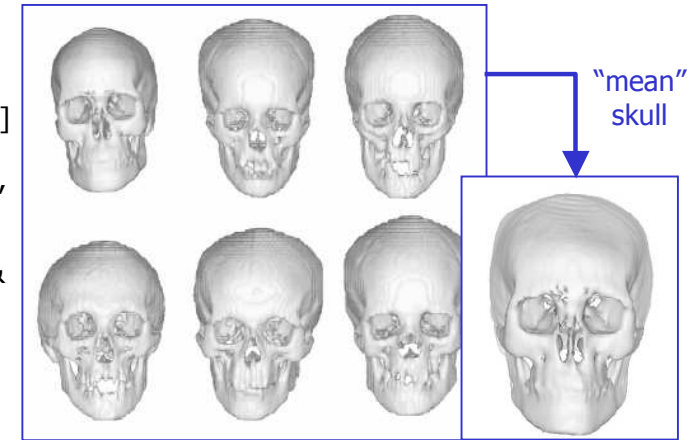
3D image processing and computer graphics tools allow:

⇒ to take 3D measurements all over the face in-vivo

⇒ to build an average model from a database of cases

⇒ to quantify and synthesize the variability ("principal warps Principal Component Analysis, etc.)

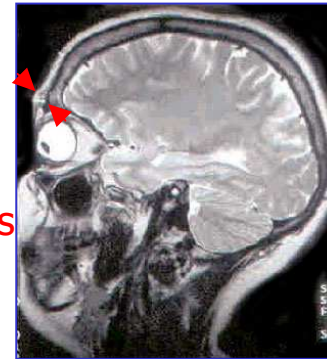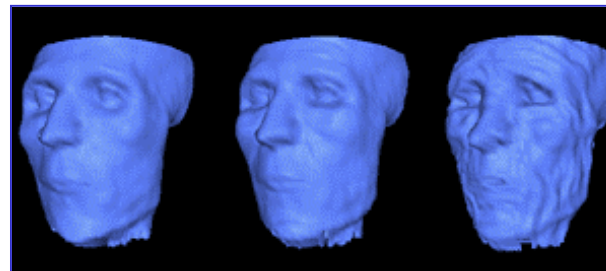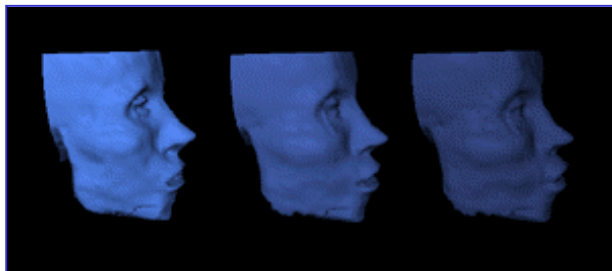⇒ to classify the variability w.r.t. sex, ethnicity or corpulence

Image from http://www.fbi.gov/hq/lab/fsc/backissu/jan2002/sahni.htm

Images from http://forensic.shef.ac.uk/

Image from http://athos.rutgers.edu/~decarlo/
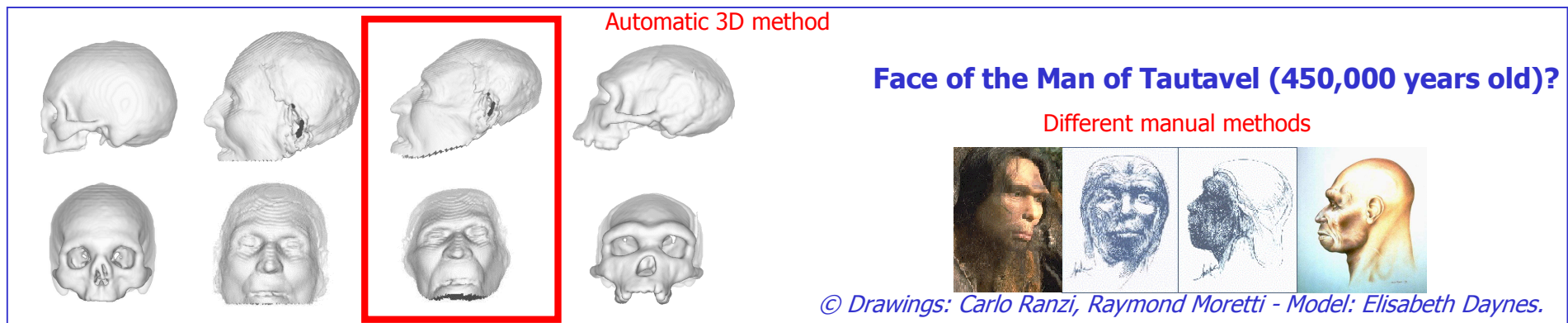
The future of computer assisted 3D facial reconstruction

• **Validation** of the computerized methods

• **Mixing different methods** (e.g. 1+3: finding the correspondences between the points of two skulls in order to propagate a reference 3D face)

> • **University of Wales Swansea, UK:** [Jones M.W., *Modeling and Visualization* - 2001]

• Application in **archeology** and **paleontology** for **museum presentations**

> • **Nagoya University, Japan**: [Yasuda T., Yokoi S., Yoshida S. & Endo M., *Museums and the Web* - 2002]
>
> • **University of Nice & INRIA Sophia Antipolis, France:** [Odin G., Quatrehomme G., Subsol G., Delingette H., Mafart B. & de Lumley M.A. *XIV International Congress of Prehistoric and Protohistoric Science - 2001]*

Automatic 3D method

Face of the Man of Tautavel (450,000 years old)?

Different manual methods

© Drawings: Carlo Ranzi, Raymond Moretti - Model: Elisabeth Daynes.

• Application of these methods to reconstruct **non-human faces** (e.g. prehistoric animals)

> • **National Museum of Natural Sciences, Spain & Liverpool University, UK:**
> [Antón M., García-Perea R. & Turner A., *Zoological Journal of the Linnean Society* - 1998]