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Facial Modelling for Forensic Facial Reconstruction and Identification

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Archeological Face Reconstruction

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Manual CFR

Fig. 1. Example manual craniofacial reconstruction, using the morphometric technique performed by the FFI department of the Belgium federal Police (Ben Claes)

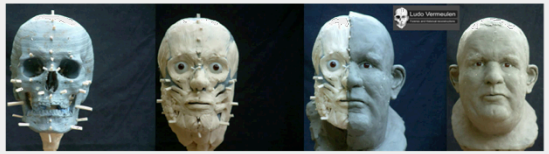

Fig. 2. Example manual craniofacial reconstruction, using the combined morphoscopic and morphometric technique performed by Ludo Vermeulen (Belgium)

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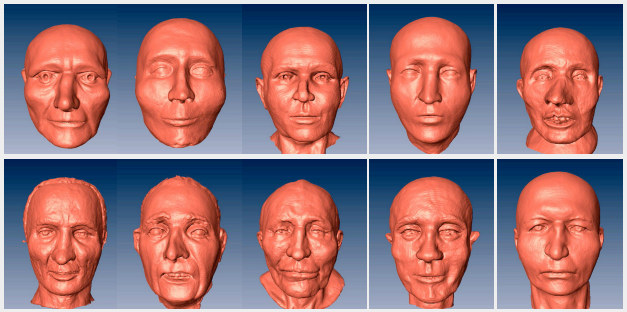
Reconstruction Variability



Courtesy P. Bongartz et al.

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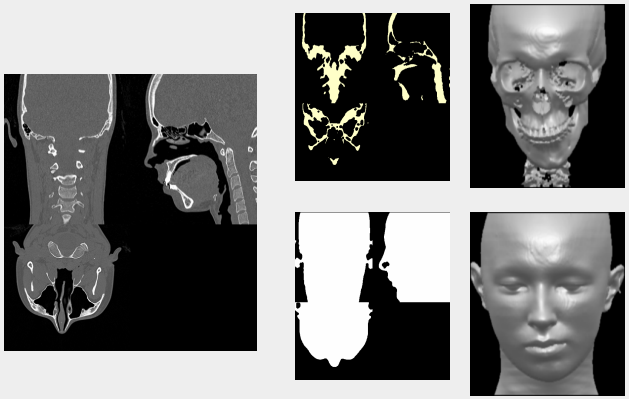
Statement:
Craniofacial Reconstruction is a missing-data problem



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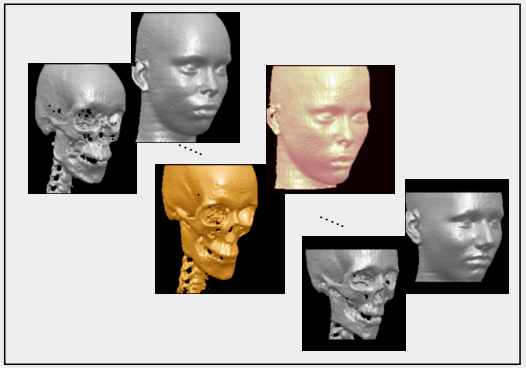
Infer relationship from database of exemplars



Template database

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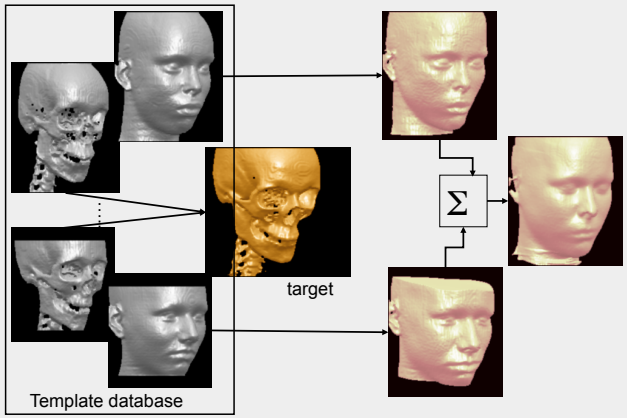
Apply inferred relationship to target



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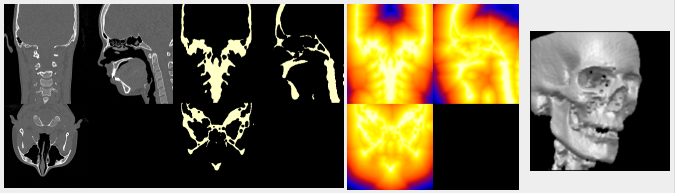
Relationship assumes a model

- Representation of dependent (facial surface) and independent data (skull surface and skull attributes (age, gender, ancestry)



Original image data or implicit representation (Vandermeulen et al. 2006)

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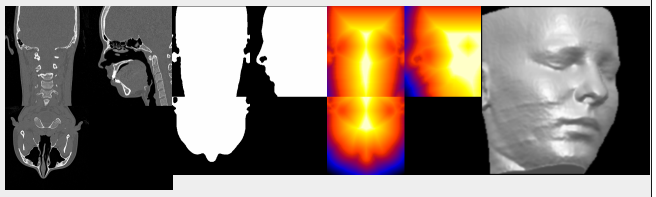
Relationship assumes a model

- Representation of dependent (facial surface) and independent data (skull surface and skull attributes (age, gender, ancestry)



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Relationship assumes a model

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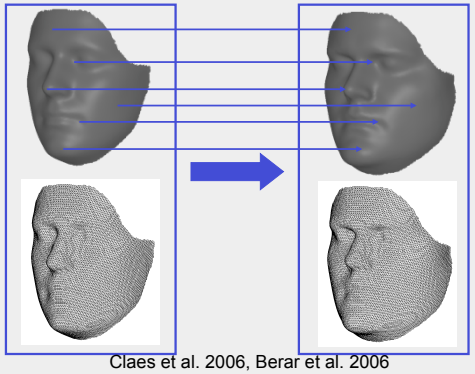

Claes et al. 2006, Berar et al. 2006

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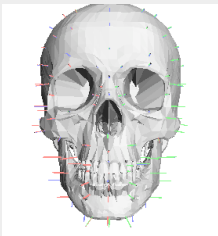
Relationship assumes a model

- Representation of relationship between dependent and independent data
  - Soft tissue thicknesses at a sparse set of "anatomical landmarks"
  - Set of explicit rules ("algorithm") for reconstructing interleaved anatomy

Courtesy B. Claes

Courtesy L. Vermeulen



Archer 1997
Vanezis 1989

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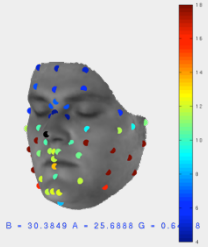
Relationship assumes a model

Representation of relationship between dependent and independent data
- Soft tissue thicknesses at a sparse set of "anatomical landmarks"
- Co-ordinated with facial surface points



Claes et al. 2006

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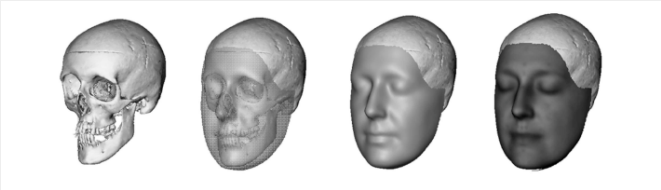
Relationship assumes a model

- Representation of relationship between dependent and independent data
  - Relative position of facial surface points vs. skull points



(Quatrehomme 1997, Nelson et al. 1998, Attardi et al. 1999, Tu et al. 2004, Vandermeulen et al. 2006, Berar et al. 2006)

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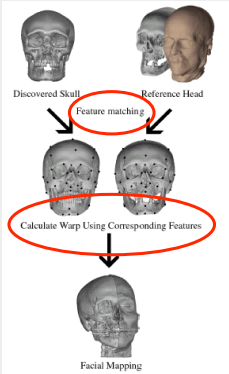
Relationship assumes a model

Representation of relationship between subjects: REGISTRATION based

- Indication of corresponding anatomical landmarks on the skull
  - Manually
  - automatically
- Warping (geometric transformation/ deformation) that maps points on skull surface of subject X onto corresponding skull surface points of subject Y
- Apply warping to facial surface points



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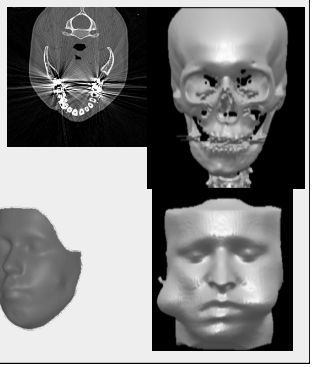
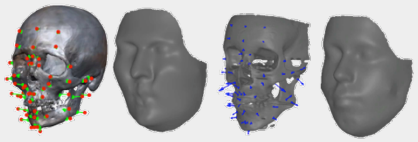
Relationship assumes a model

Representation of relationship between subjects: REGISTRATION based

GENERIC TYPE OF WARPING

Must be robust, is not face-specific





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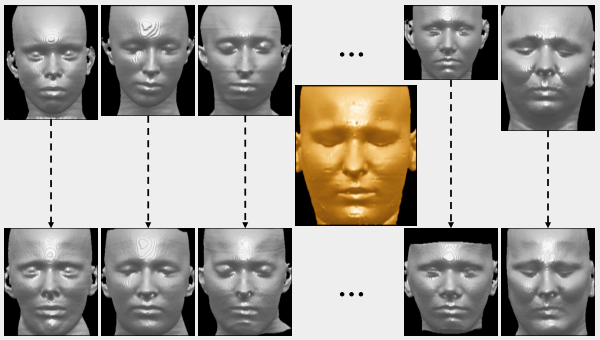
Model Bias



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Modeling Hypothesis

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Objectives:

Model bias due to single template must be avoided

Model-to-target registration should be robust to errors (outliers)

Model should:

incorporate group statistics, hence database required
(Berar et al, Claes et al, Pei et al, Tu et al, Vandermeulen et al)

Model-to-target registration should be face-specific
(Berar et al, Claes et al.)

Data acquisition

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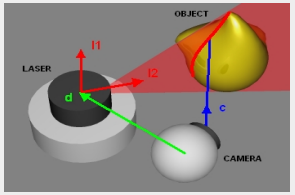
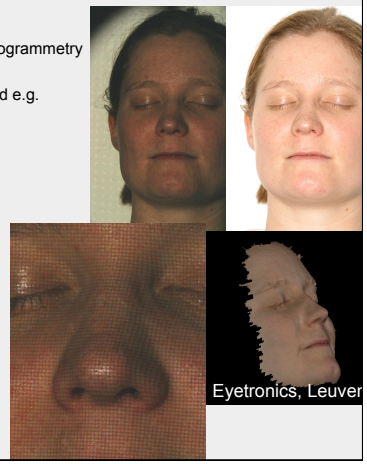
Data acquisition modalities

- Laser scanning or image-based photogrammetry
  - Outer facial surface
  - Sparse Thicknesses : Ultrasound e.g.





Data acquisition

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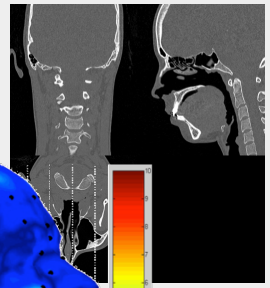
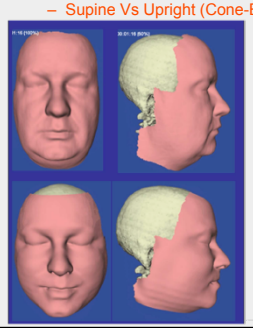
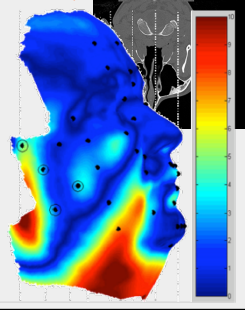
Data acquisition modalities

- CT
  - Skull surface
  - Dens set of thicknesses
  - Irradiation
  - Supine Vs Upright (Cone-Beam CT!)







Database

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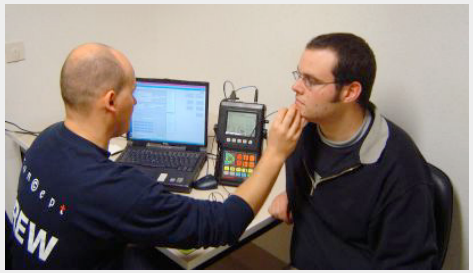
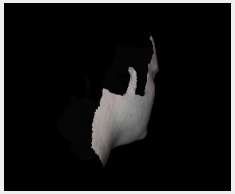
- Soft-tissue thickness acquisition in an upright positioning using non-invasive technology



Ultrasound ⇄ Interface program ⇄ MySQL database

Database

- Facial surface acquisition in an upright positioning using non-invasive technology



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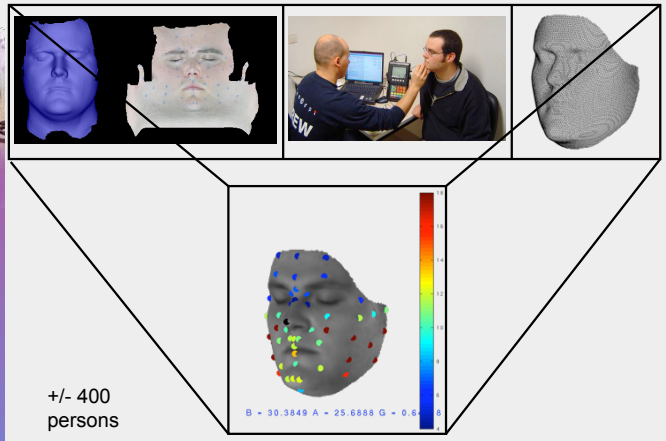
Database



+/- 400 persons

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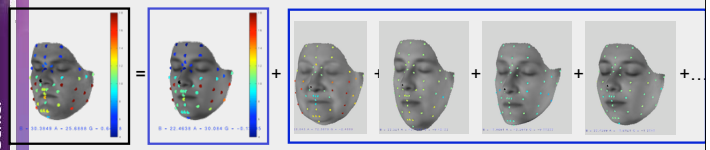
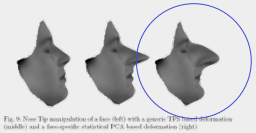
Statistical CFR model

- Principal component analysis
  - Based on inter-subject correspondences in database
  - Geometric averaged face (model template)
  - Principal components (PC)
    - Face-specific deformation model
- Face = average face + Linear (!) combination of principal components





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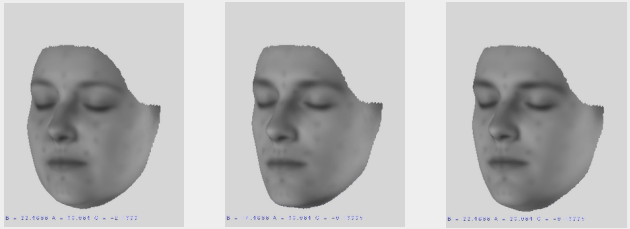
Statistical CFR model

- Facial property normalization
  - To obey given skull properties (Anthropological examination)



Gender bmi Age

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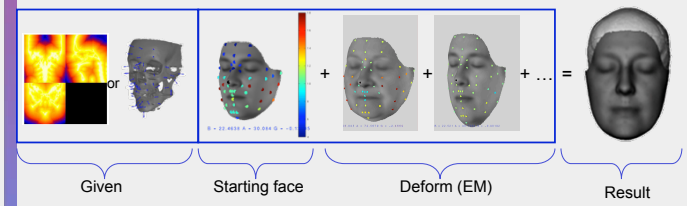
CFR model to skull registration

- Find the most plausible face belonging to the skull substrate
  - Maximum a-posteriori probability: Using the prior knowledge encapsulated in the CFR model, maximize the probability of the facial surface given the skull data.
- Errors in skull representation
  - Expectation-maximization optimization: Detect and neglect errors



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Results and Validation

- Based on a clinical patient database
  - 12 patients
  - Known skull surface (CT scanner)
  - Known Facial surface (Eyetronics scanner)
- Validation
  - Make reconstruction based on the skull information
  - Compare result with the known facial surface (ground truth)
    - Quantitative: Local surface differences
    - Qualitative: Computer-based recognition algorithm
      - Having 401 candidate faces including the correct face (ground truth)
      - Given the reconstruction, try to recognize (identify) the correct face in the database
  - Compare results with traditional computer-based CFR models
    - Using single template + generic deformation

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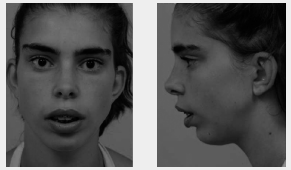
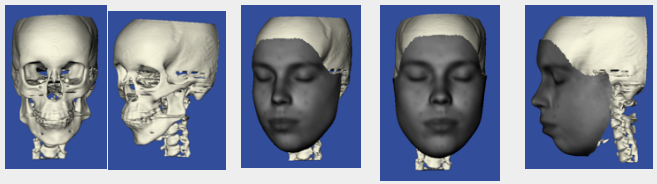
Validation example

- Example
  - Given skull (CT)
  - Known facial outlook
    - High-resolution 2D image
    - 3D surface (eyetronics camera)
  - Combined visualization





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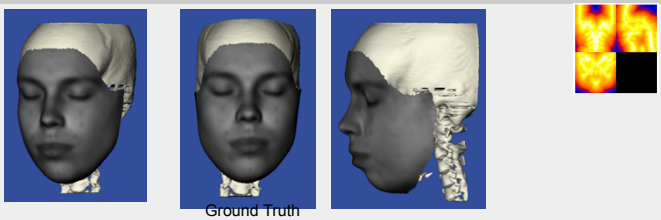
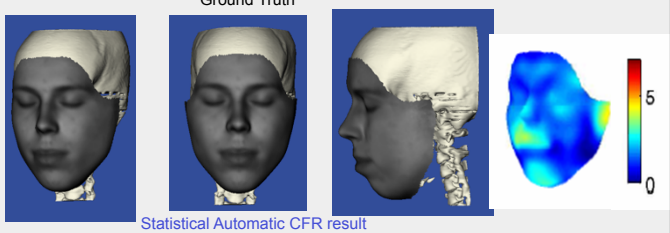
Validation example



Ground Truth



Statistical Automatic CFR result

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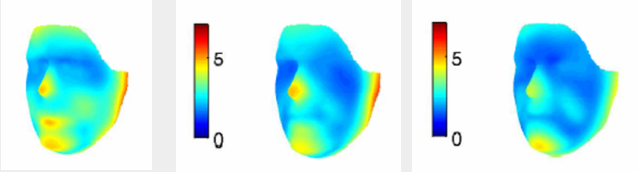
Validation results

- Averaged local surface differences over the 12 patients



Traditional semi-automatic | Statistical semi-Automatic | Statistical automatic

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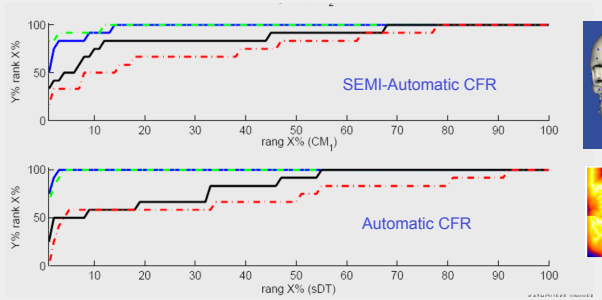
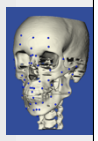
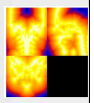
Validation results

- Recognition results over 12 patients
  - Blue and green: Two statistical CFR models
  - Red and black: Traditional (non-statistical) CFR models







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Forensic case

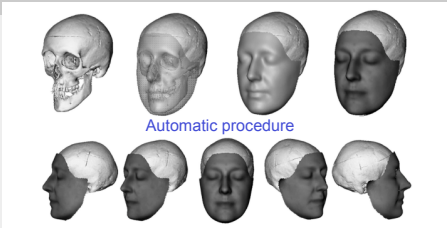

Figure 7.17: Forensic related real reconstruction case of a skull found in Belgium

Property manipulation

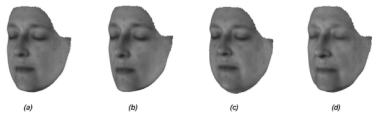

Figure 7.18: Alternative property choices for the forensic case. (a) original from figure 7.17 (b) BMI = 17 (c) BMI = 28 (d) Age = 80

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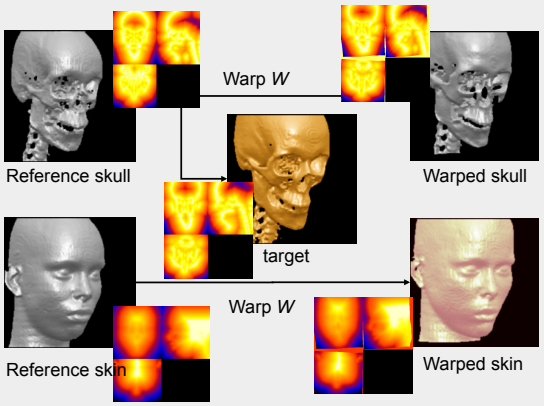
Craniofacial reconstruction: Leuven (Vandermeulen et al.) method



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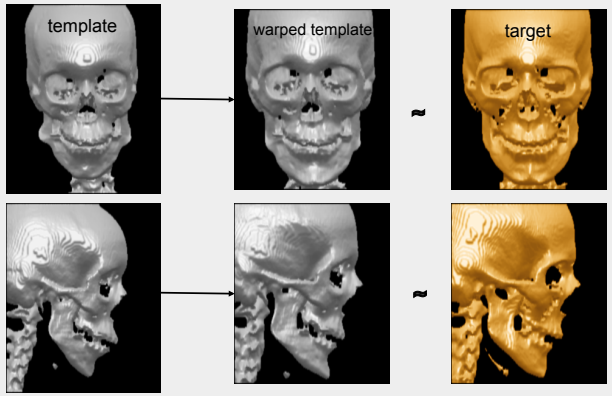
Example: template skull to target skull warping



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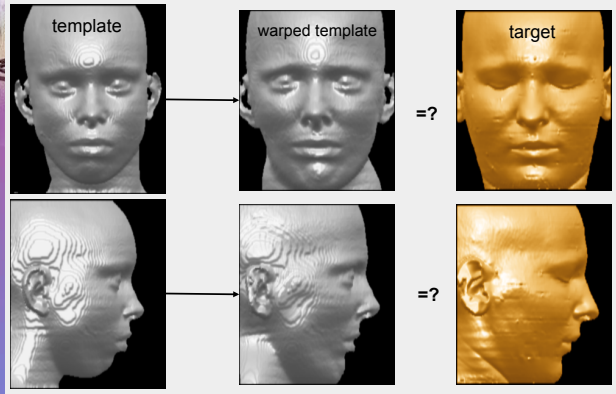
Example: extrapolation to template skin warping



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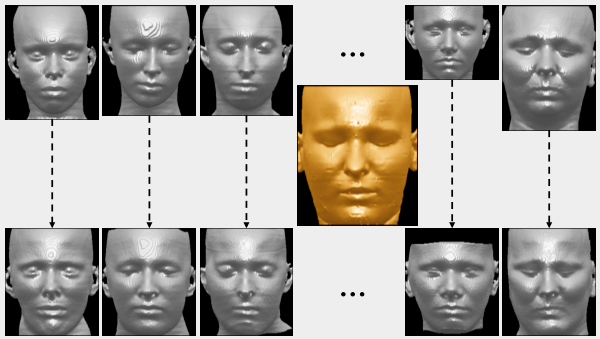
Example: extrapolation to template skin warping



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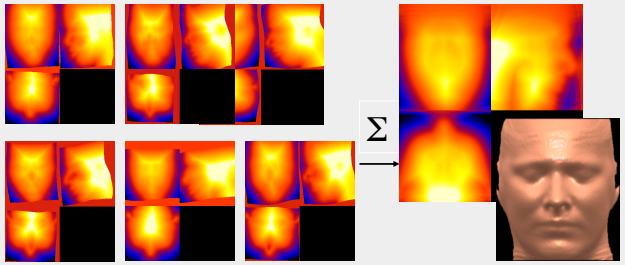
Skin Surface Reconstruction

- Construct (weighted) average of warped skin sDT's



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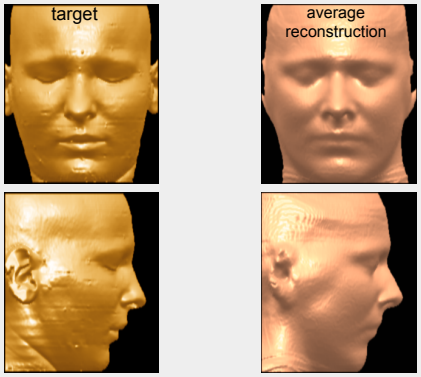
Example



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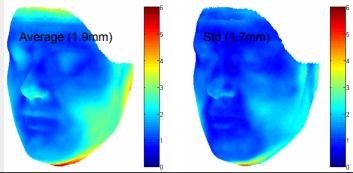
Quantitative Validation

- Given only small-sized database (N=20), how to separate into test and validation subsets?
- N-fold Cross-Validation or Leave-one-out CV:
  - For i=1:NrSubjects
    - Reconstruct Subject i from all other subjects in Database
    - Compare Result to ground truth of i
    - Evaluate Reconstruction Error
      - Average: 1.9mm
      - Std: 1.7mm
    - Evaluate Classification Error
      - Rank 1 correct: 70%
      - Rank 2 correct: 80%



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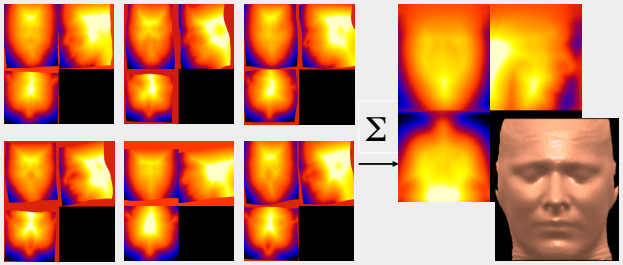
Attribute-modulated reconstruction

- All reconstructions so far made with all data in the database, irrespective of gender, age and BMI!



$sDT = \Sigma_i w_i sDT_i$, $w_i = 1/N$

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Example of Attribute-weighted interpolation

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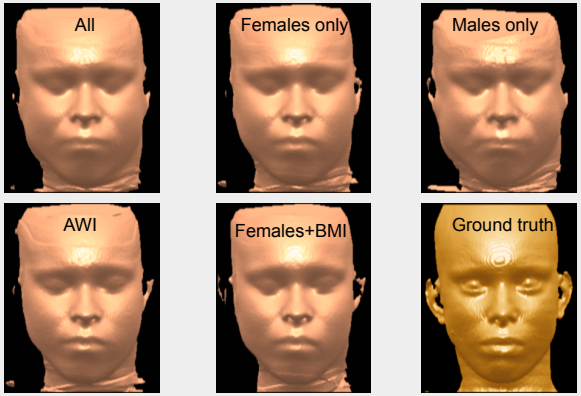
Example



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Conclusions and Expectations

- Computer-based Craniofacial reconstruction has matured enough to be taken seriously!
- Maybe not as a full substitute for manual (even computer-assisted) procedures, but at least as an adjunct
- Extension to larger CT-databases
  - Protocols running at Leuven for post-mortem acquisition of full-body multi-(64)-slice spiral CT with high-resolution in the head region
- Extension to other ethnic groups
  - Acquisition protocol (using US) readily available, including hardware
  - Collection of CT-databases of different ethnic groups (over gender, age, and other properties)
- We need real case studies to fine tune and further validate!

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