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Genetic Algorithms and Fuzzy Logic in Forensic Identification

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Outline

- Forensic identification by craniofacial superimposition
- Image registration
- Image registration, uncertainty and forensic identification = soft computing
- First stage: 3D skull model reconstruction using evolutionary algorithms
- Second stage: Skull-face overlay using evolutionary algorithms and fuzzy logic
- Concluding Remarks

OVERVIEW

- Human identification (of alive or dead people) is one of the most outstanding tasks in forensic medicine

Skeleton-based human identification (forensic anthropology)

Previous task to the selection of the candidates sample

- If anthropologists get enough information other techniques might be applied: fingerprint, autopsy, DNA
- Otherwise

Forensic identification (II)

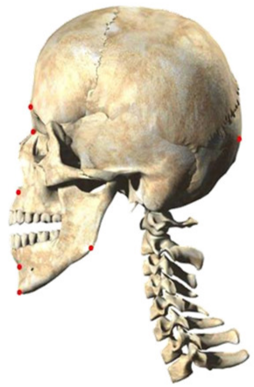
CSI:
crime scene investigation

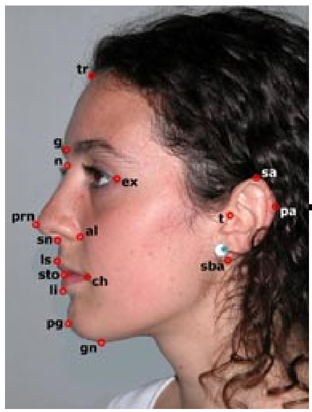
BONES

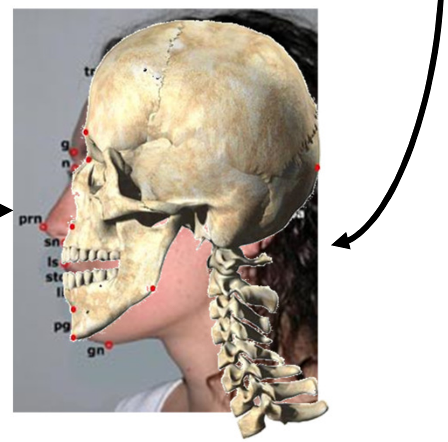
OVERVIEW

- Craniofacial superimposition is a forensic process where photographs or video shots of a missing person are compared with "a model" of a skull that is found

- Projecting one above the other (skull-face overlay) the anthropologist can try to determine whether that is the same person

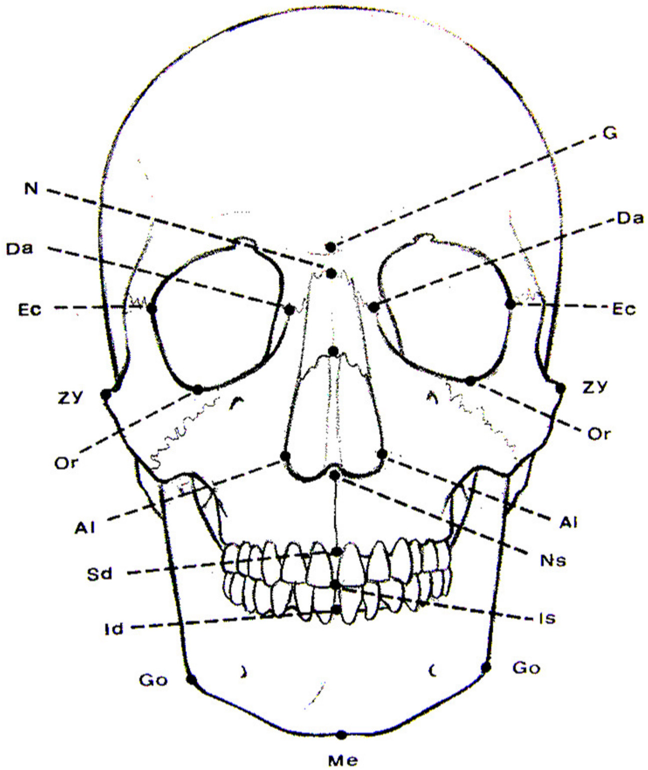




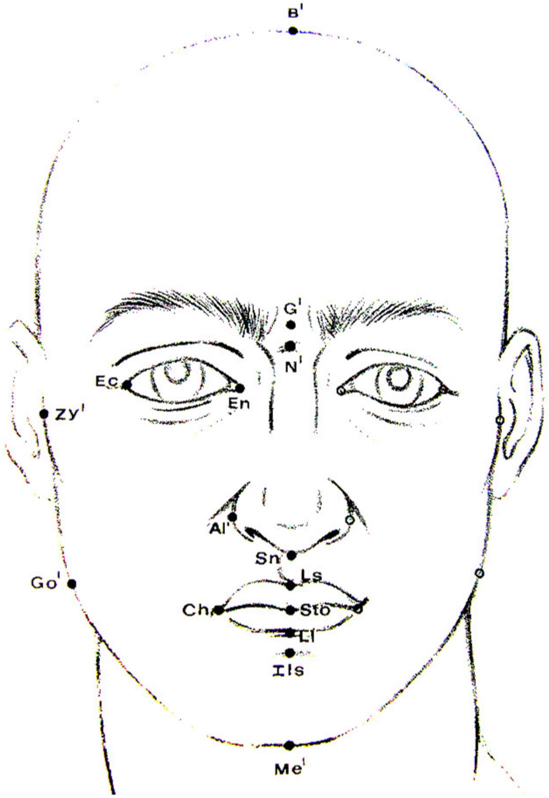


Cranial and facial landmarks

OVERVIEW



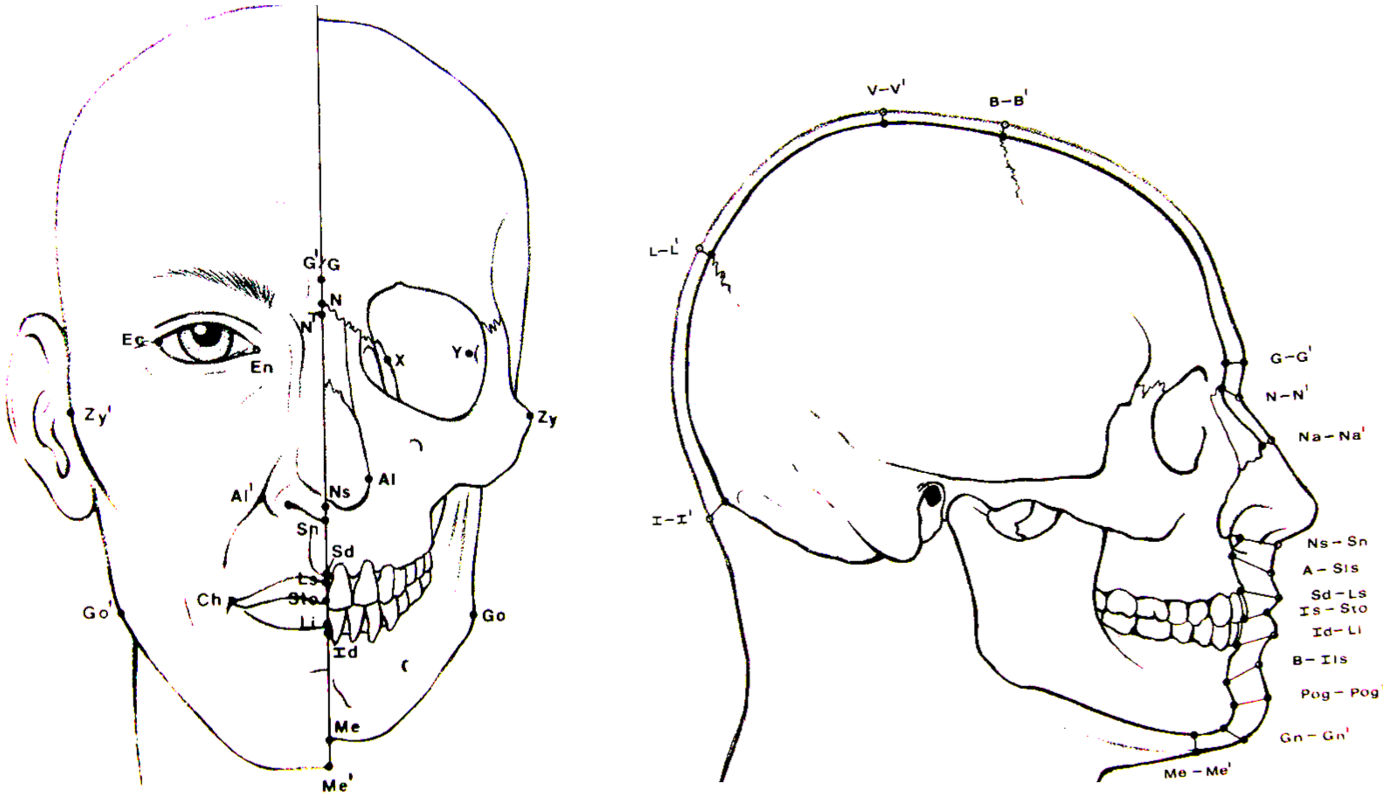
Craniometric landmarks



Cephalometric landmarks

Landmarks matching

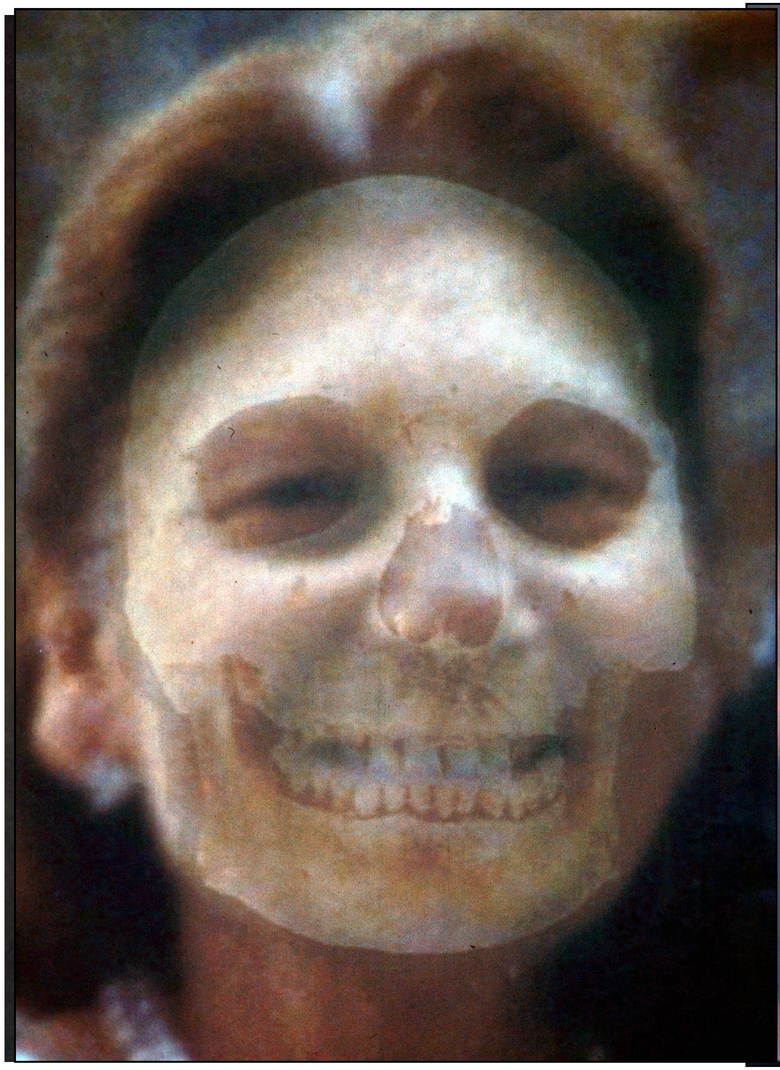
OVERVIEW

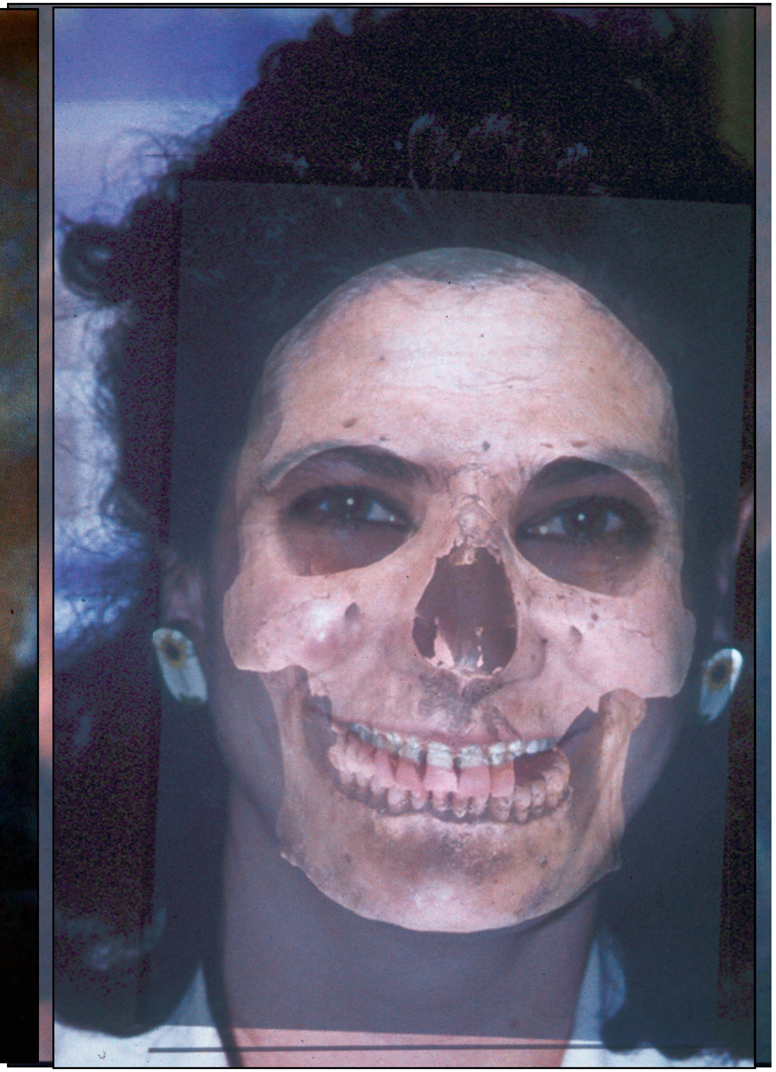


Landmarks correlation

1. Forensic identification by craniofacial superimposition
Real case example

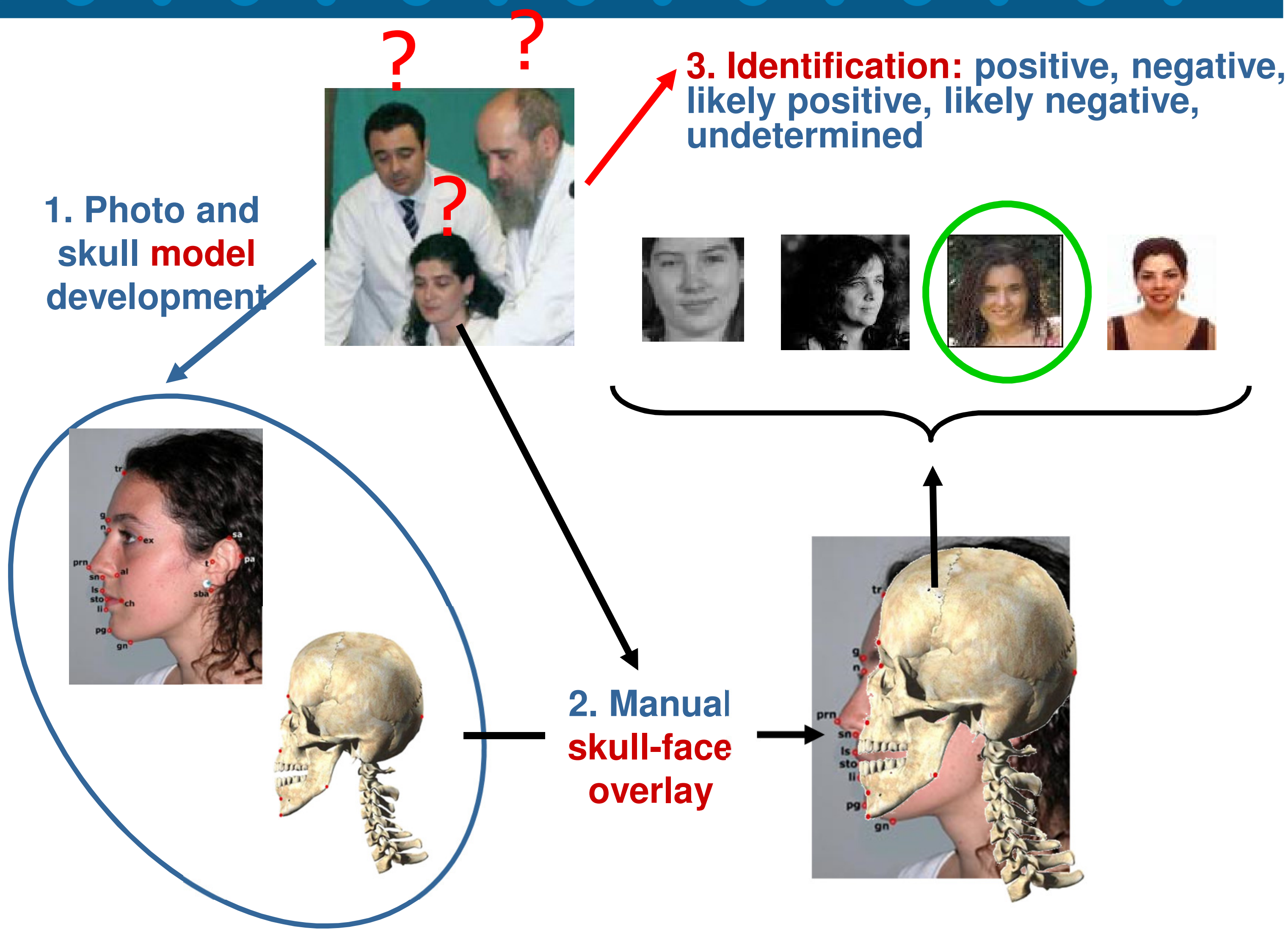
OVERVIEW





Methodology

OVERVIEW



OVERVIEW

1. Forensic identification (FI) by craniofacial superimposition

2. Image Registration (IR)

3. IR, Uncertainty and FI = Soft Computing

4. First stage: 3D skull model reconstruction

5. Second stage: Skull-face overlay

6. Conclusions

- Methodological basis: Broca's skull-face correspondence (1875), Bertillon's accused physiognomic data collection (1986), and Martin and Saller's anthropological measurements studies (1966) studies
- First documented case in 1880: identification of the skeletal remains of the poet Dante Alighieri
- The first identifications were based on photos: superimposition of the skull and face negatives and developing of the positive of the picture
- The next stage was the use of video superimposition, one of the most extended approaches nowadays
- Digital image processing has boomed the technique
- Recently used to identify the Indian tsunami victims and in terrorism. Other successful case studies: Josef Mengele and "Ivan the Terrible"

Critical review

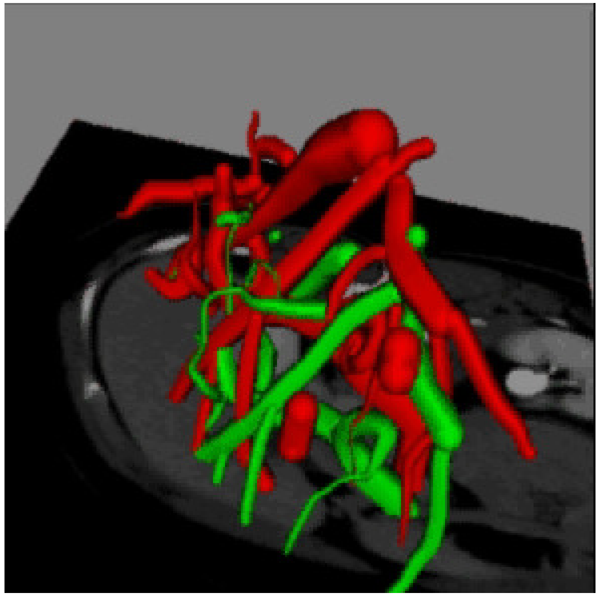
OVERVIEW

- There is not a systematic method: every scientist applies his/her own one from the available information

- Although the technique is sound, there are no methodological criteria to determine an accurate reliability

- By now, it is only used as excluding evidence in crime investigation (never as a charge evidence)

- Image registration (IR) aims to superimpose an image on a similar one considering the same coordinate system



PROBLEM ?

⬇

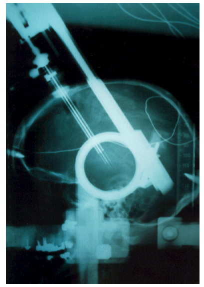
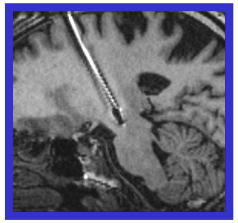
Images acquired in different coordinate systems

⬇

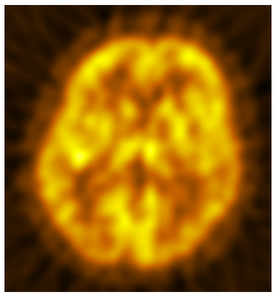
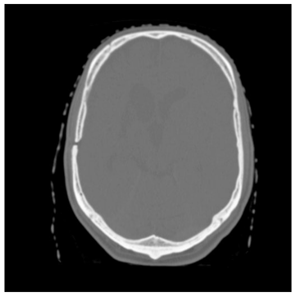
Unknown matching relationship between them

- Surgery planning

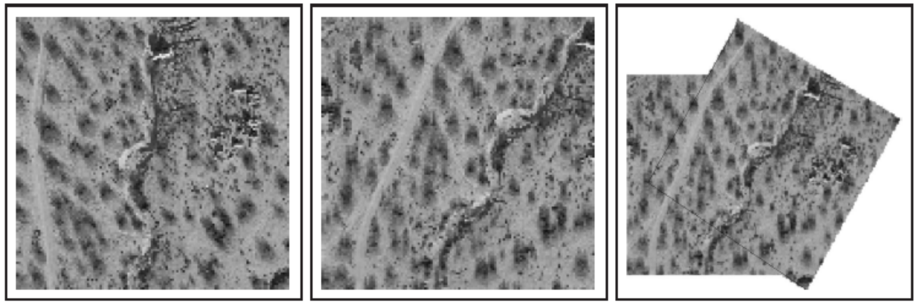


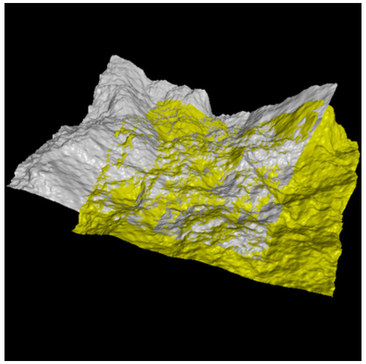



- Image integration: multimodality, 3D/2D, etc.

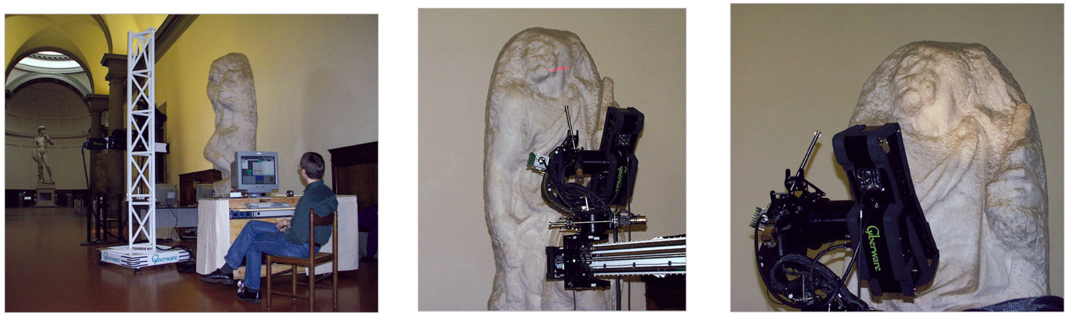





- Remote sensing





- 3D model reconstruction: CAD, archeology, forensic anthropology, etc.



- IR aims to superimpose an image on a similar one considering the same coordinate system

- IR Components:
  - Scene ($I_s \subset R^2/R^3$) and model ($I_m \subset R^2/R^3$) images
  - Transformation ($f: R^2/R^3 \rightarrow R^2/R^3$)
  - Similarity metric (F)
  - Optimizer (search for the optimal f)

2. Image registration
Problem statement (II)

OVERVIEW

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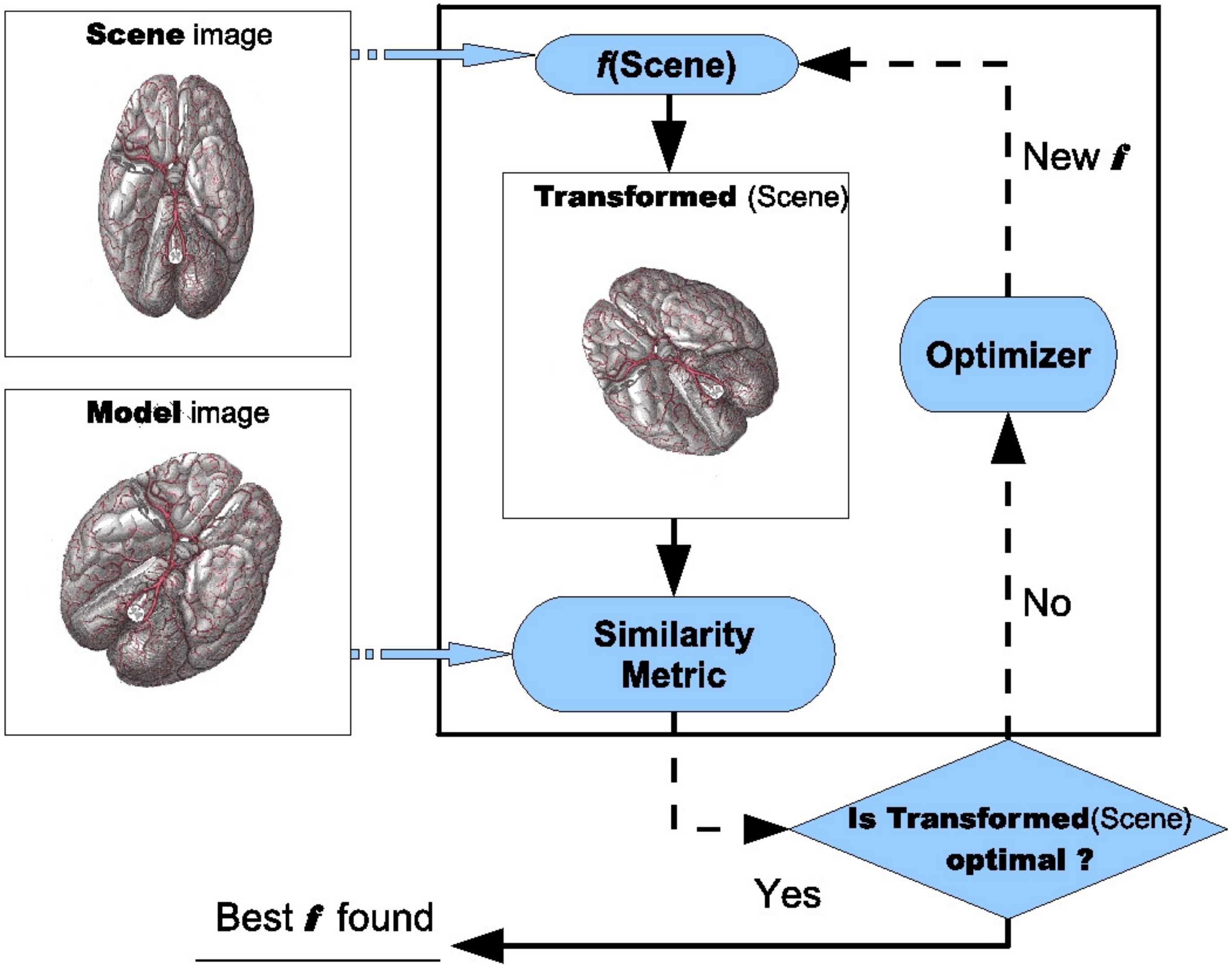


- The problem statement is analogous to some other optimization problems which aim to find the best configuration among a set of choices

$$f^* = \arg\min / _f \ \max F(I_s, I_m; f) \quad s.t. \quad f^*(I_s) = I_m$$

- Taxonomy of algorithms:
  - Exact: find the optimal solution (NP-hard)
  - Approximate: achieve solutions close to the optimal one in reasonable time
- Classical IR methods ➡ stuck in local optima
- **Evolutionary Algorithms (EAs) have successfully tackled these situations**

2. Image registration
Problem statement (IV)

OVERVIEW

Search for the best f parameters (Optimization method)

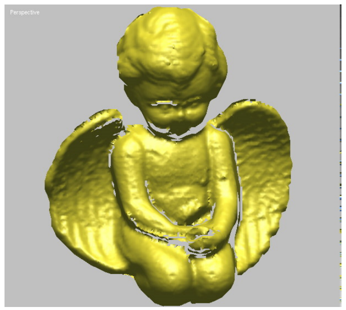
Registration Error

$f' \cong f^*$

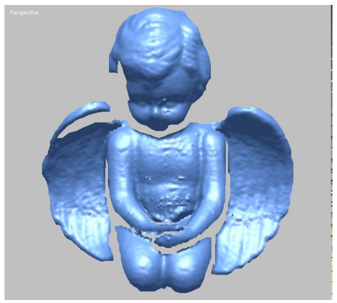
f ′ Evaluation

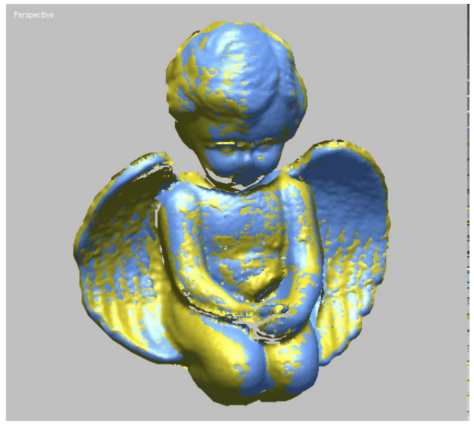
Rotation = {5°, 25°, 0°}
Translation = {2, 0, 1}

For each model point, determine the closest point in the scene



f ′

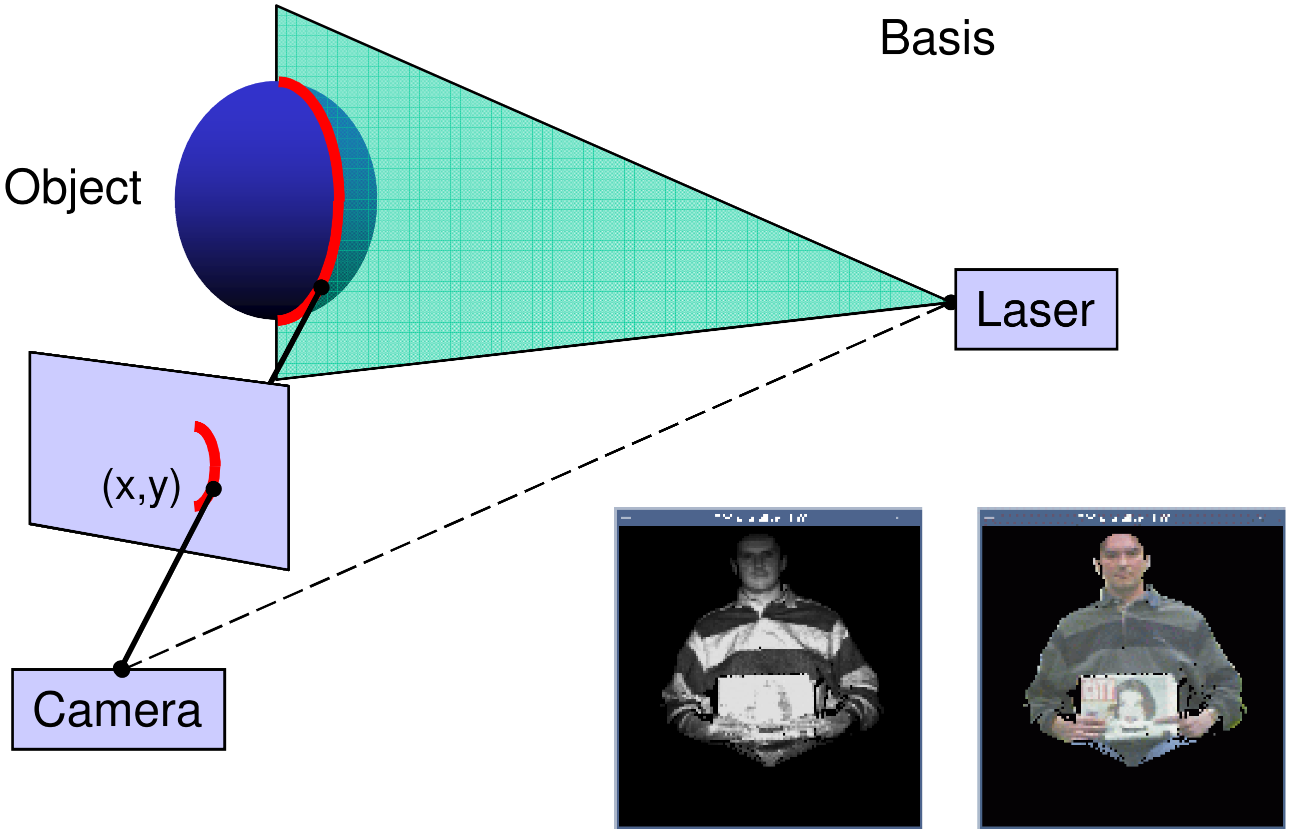




3D model reconstruction from partial views (I)

OVERVIEW

- Range Image registration (RIR) aims to achieve 3D models of real objects using several images (views) from a range scanner



OVERVIEW

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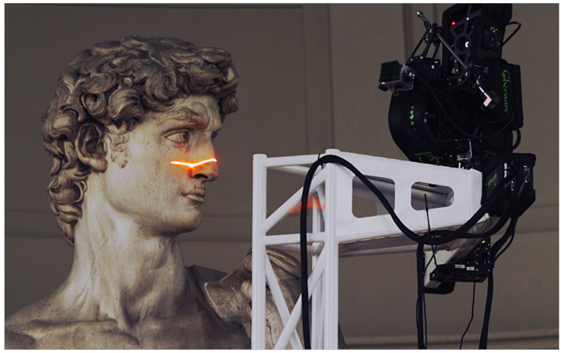
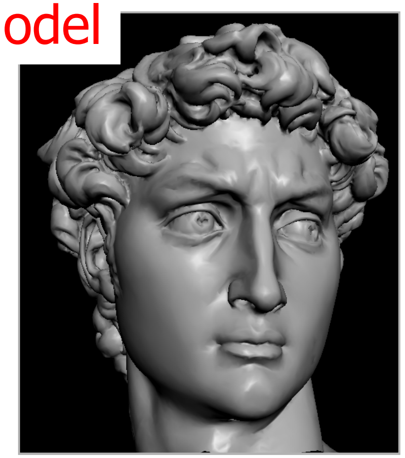
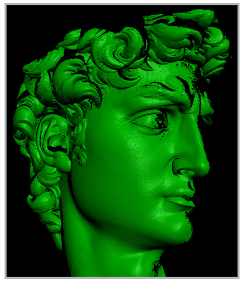


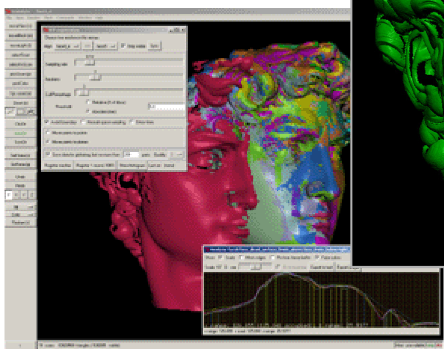
Scanning of multiple object views

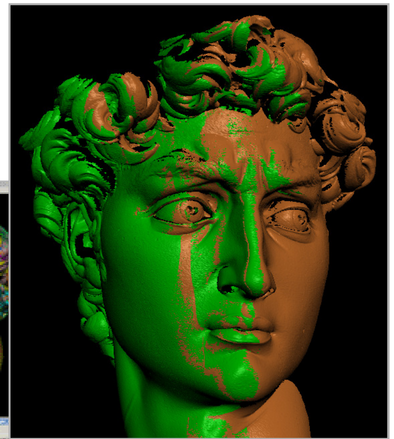
3D Model





Prealignment





Refinement

Image registration and craniofacial superimposition (I)

OVERVIEW

- Many forensic tasks require a 3D model of forensic objects (skulls, bones, corpses, etc.) that could be acquired using a 3D range scanner
- The most advanced forensic labs use a 3D skull models to tackle the craniofacial superimposition technique

3. IR, uncertainty and forensic identification = soft computing
Image registration and craniofacial superimposition (II)

OVERVIEW

1. Forensic identification (FI) by craniofacial superimposition
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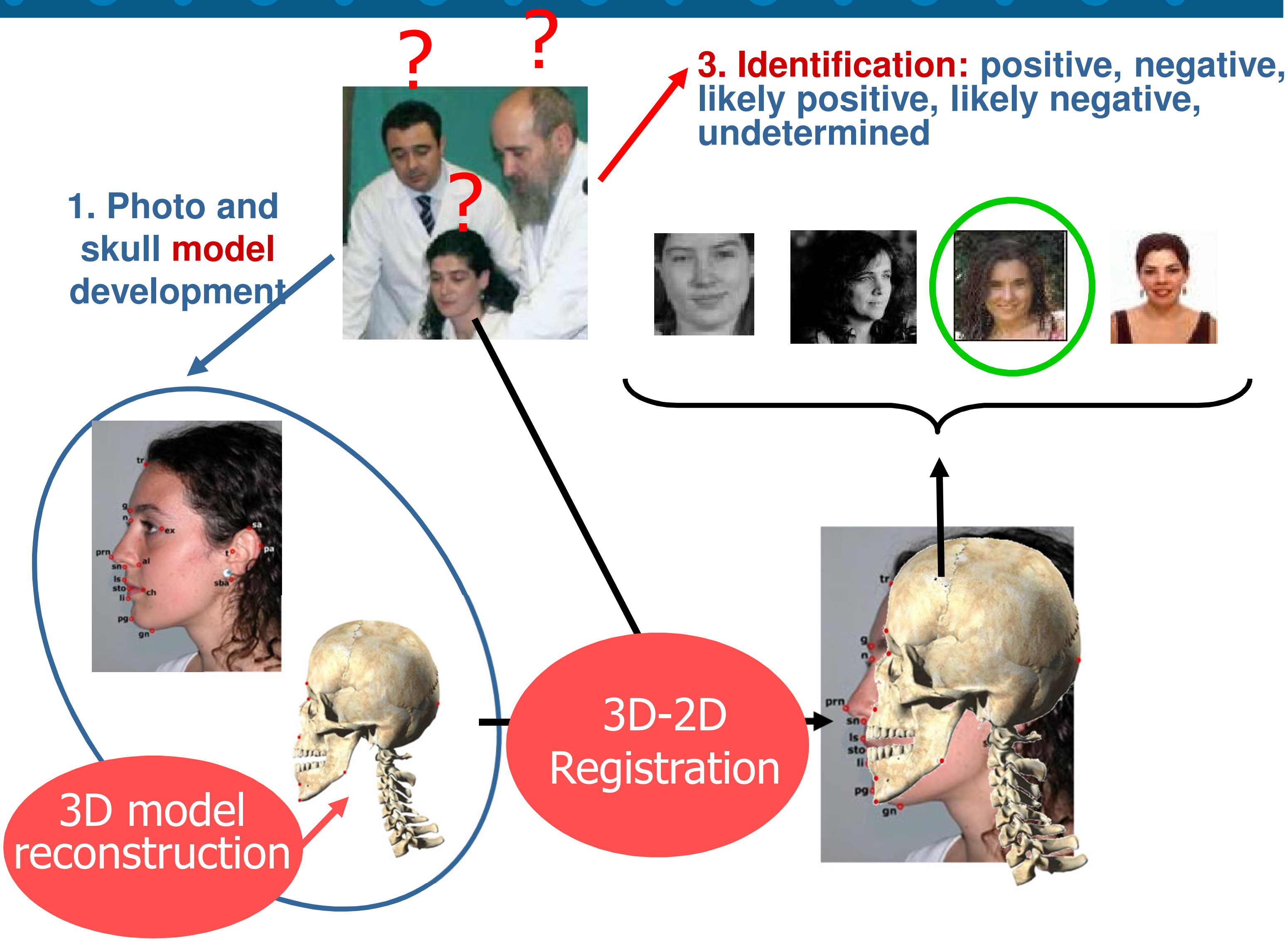
6. Conclusions



Computer-based craniofacial superimposition (I)

OVERVIEW

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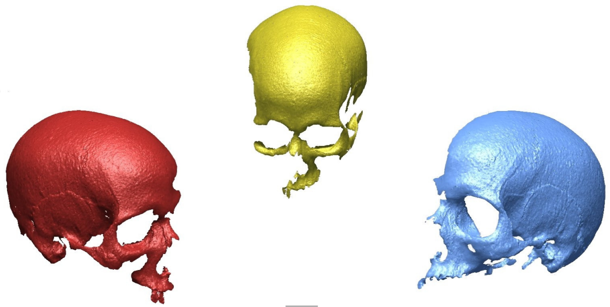
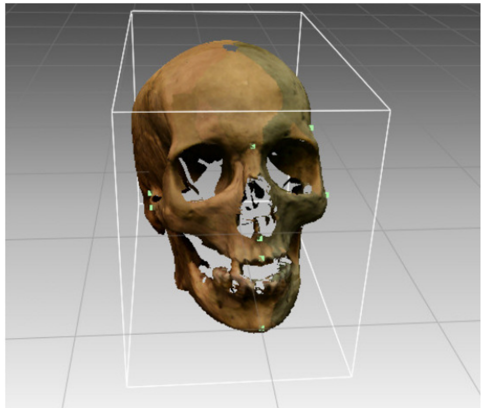
3D partial views

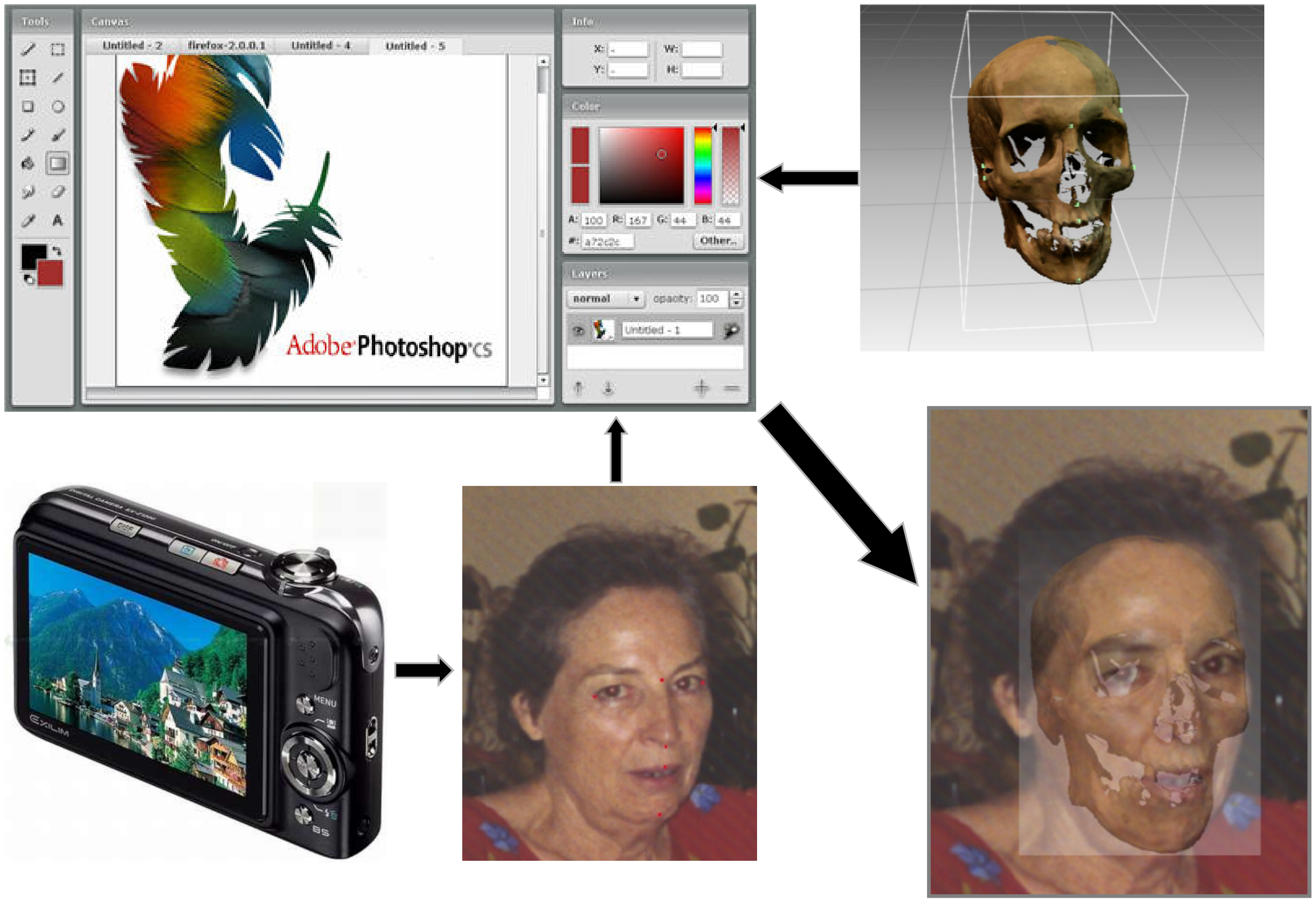




Manual Skull 3D Reconstruction (Pair-wise RIR)

3. IR, uncertainty and forensic identification = soft computing
Computer-based craniofacial superimposition (II)

OVERVIEW



Manual skull-face overlay

Computer-based craniofacial superimposition (III)

OVERVIEW

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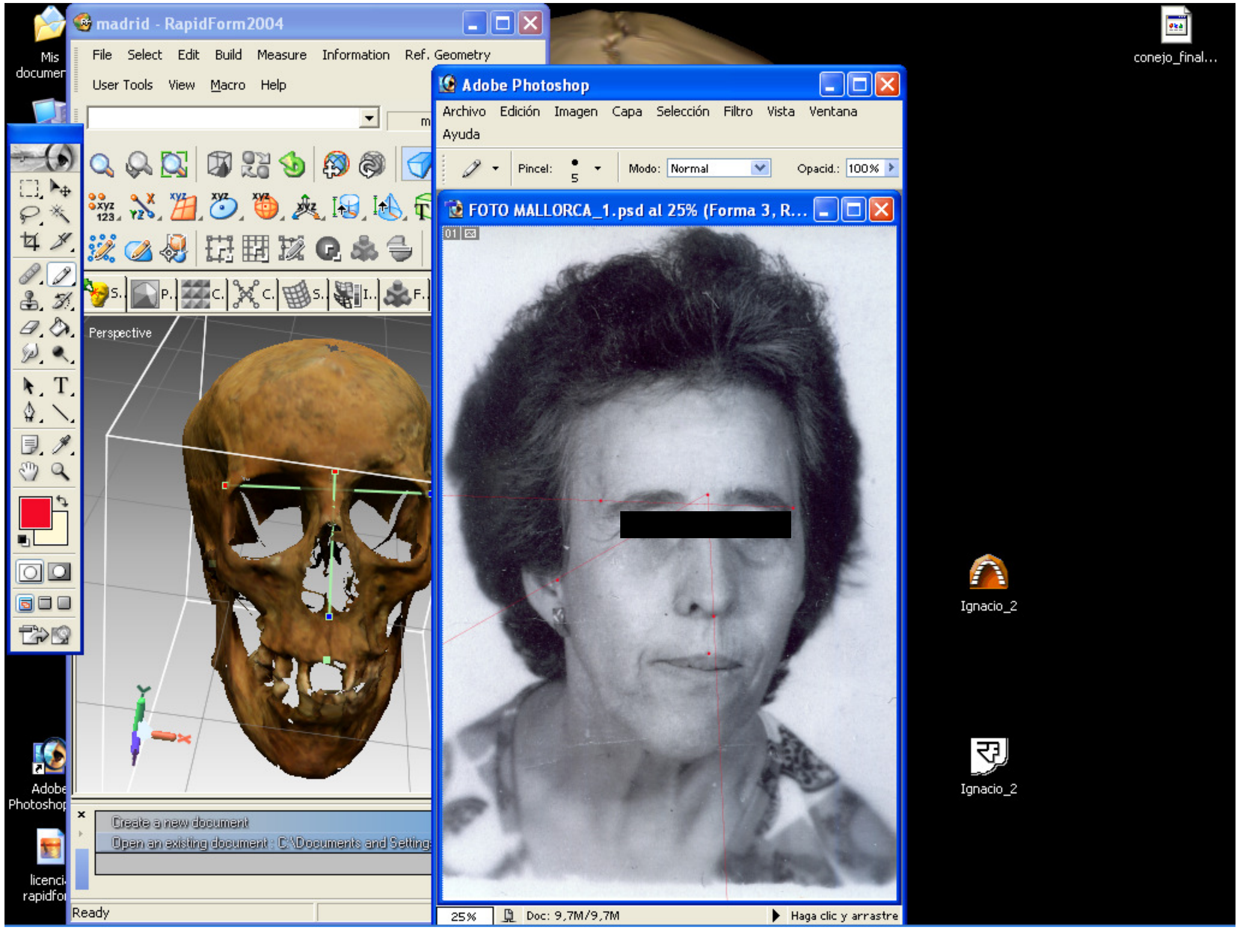
6. Conclusions



Real case of manual craniofacial superimposition

Framework

OVERVIEW

- There is a need of automatic techniques able to deal properly with incomplete information
- No systematic method exists
- The forensic anthropologist is not usually very skillful neither to calibrate the scanner nor to properly match the different views of the skull
- Uncertainty is inherent to landmark location, landmark matching, and to the identification decision
- Clear situation of partial matching: landmarks are located in a different location in the skull and the face, some of them do not have a correspondence, etc.
- The scanner software only determines the correct alignment if a rotary table is available
- Manual craniofacial superimposition is very time consuming
- Degrees of confidence in the identification result

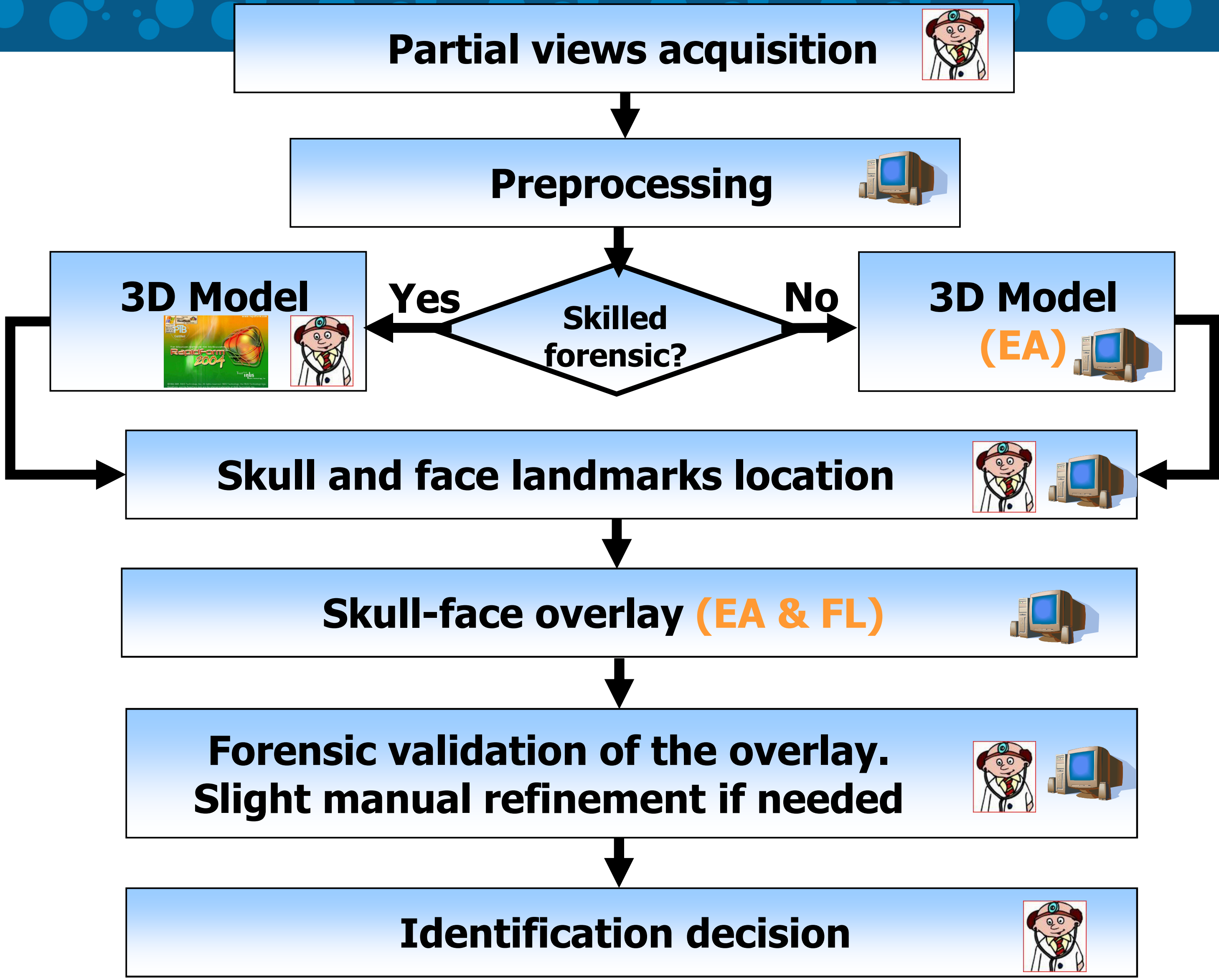
OPPORTUNITY FOR SOFT COMPUTING !

OVERVIEW

- Development of an automatic computer-based procedure to assist the forensic anthropologist in the identification task by craniofacial superimposition:
  - Design of automatic RIR methods to achieve accurate 3D models of forensic objects (using EAs)
  - Design of automatic 3D-2D IR methods to perform the skull-face overlay (using EAs and FL)
- Work supported by two granted projects (national and regional research calls)

3. IR, uncertainty and forensic identification = soft computing
Our computer-based craniofacial superimposition procedure

OVERVIEW



- High complexity of the scenarios:
  - Views acquired every 45º (eight views per skull): small overlapping between adjacent views
  - Symmetries: multimodal search space
  - Huge data set (around 100.000 points in every view)
  - Rather often wrong acquisition of data even with rotary table and, mainly, without it
- It is required an automatic RIR method that is able to deal with these scenarios and to achieve 3D models with a precision of millimeters in reasonable time
- The flexibility of EAs, their good performance in other IR problems, and our previous experience in medical IR led us to consider these techniques

OVERVIEW

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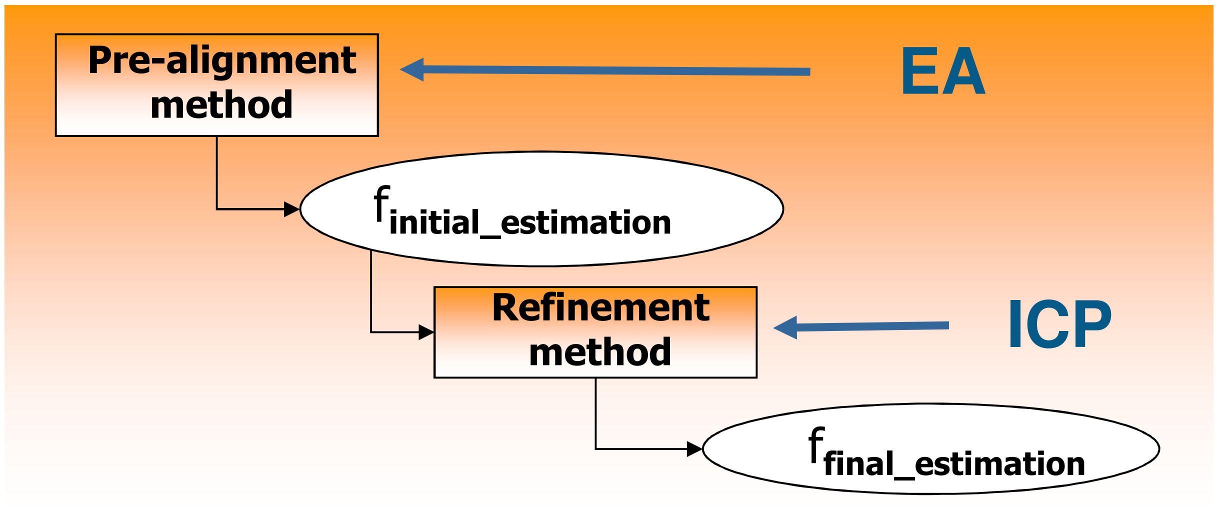
6. Conclusions

- To achieve reasonable results, classical RIR methods are based on the use of a rotary table providing a small misalignment between adjacent views. Otherwise:

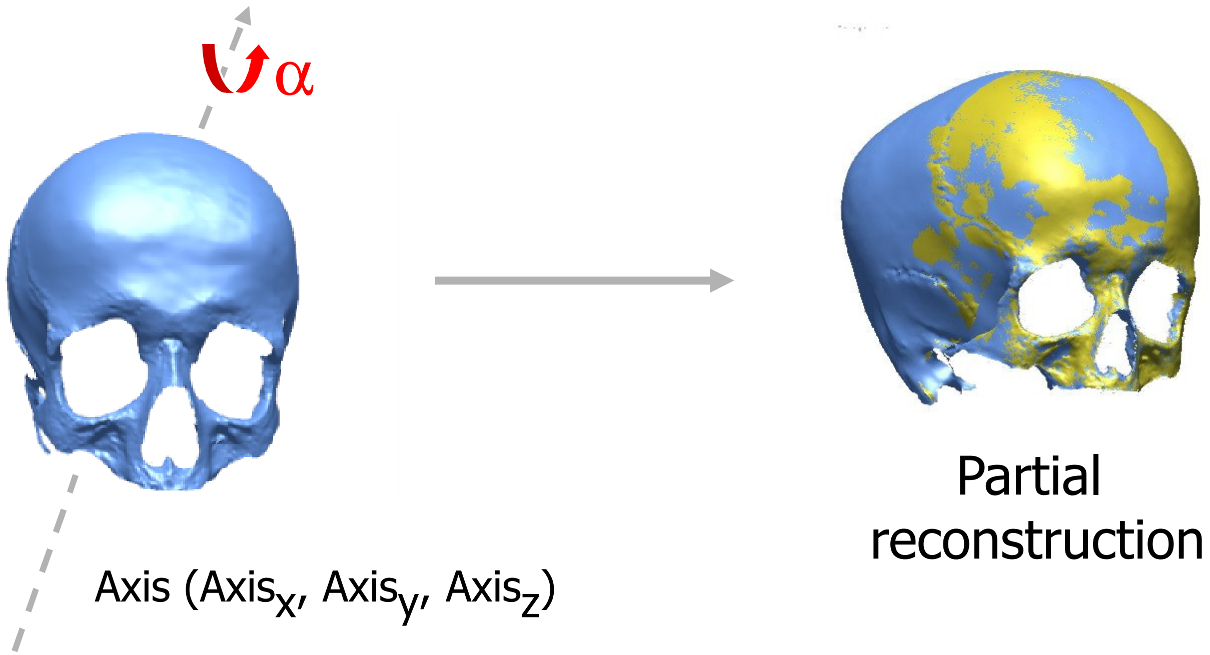
METHOD STACKED IN LOCAL OPTIMA!!

- The solution is a two-stage method:



- Coding scheme: real-coded vector representing a rigid transformation with seven parameters

$$\underbrace{\boxed{\alpha \mid Axis_x \mid Axis_y \mid Axis_z}}_{\text{Rotation}}\ \underbrace{\boxed{t_x \mid t_y \mid t_z}}_{\text{Translation}}$$



Scatter search + ICP proposal (II)

OVERVIEW

- Coding scheme: real-coded vector representing a rigid transformation with seven parameters

α	$Axis_x$	$Axis_y$	$Axis_z$	t_x	t_y	t_z

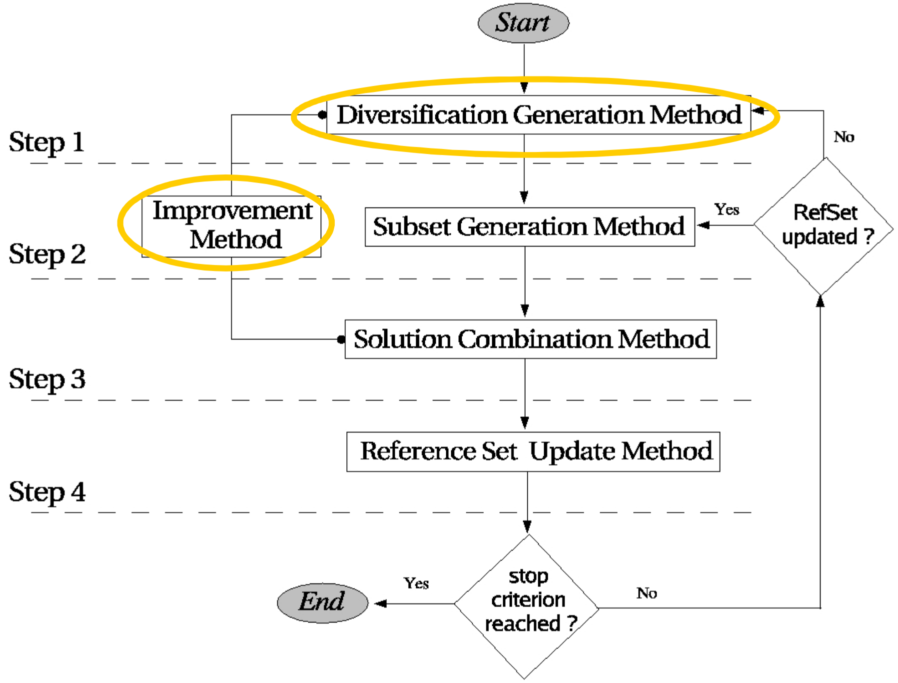
- Fitness function: $F(I_s, \mathrm{I_m}; f) = MIN(M_{edian}\, SE(\mathrm{I_m}, f(Is)))$

MSE is avoided because of the small overlapping between adjacent views

- GCP and KD-Tree data structures are used to speed up the closest point computation

OVERVIEW

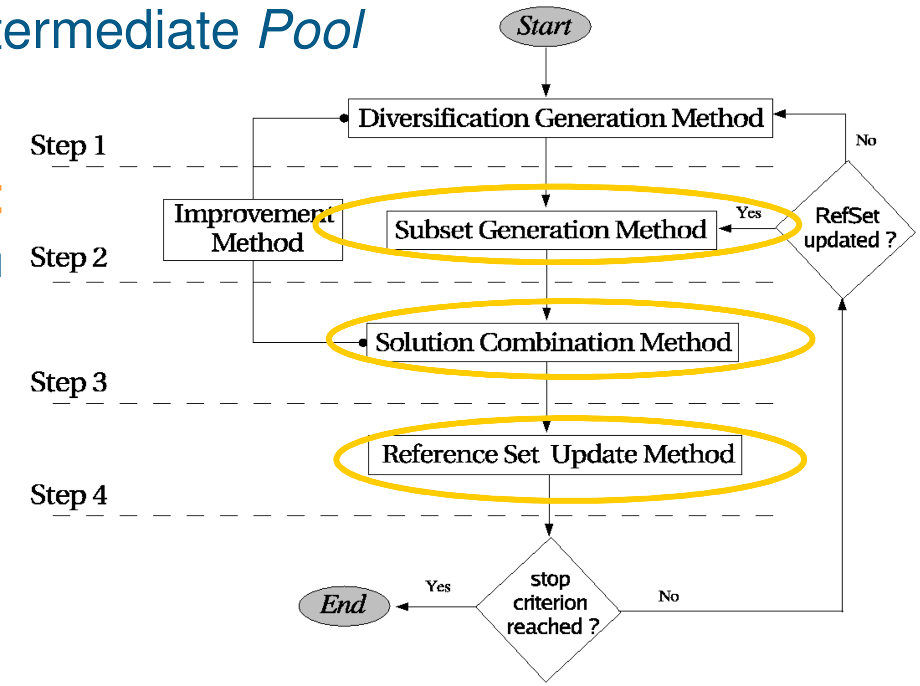
- Scatter search (SS): systematic combination between «elite» solutions taken from a considerably reduced pool named *Reference Set (RefSet)*
- Diversification Generation Method controlled randomization based on a frequency memory to generate the initial set P of diverse solutions
- Improvement Method: local optimizer aiming to improve the quality of the original and combined solutions (Solis-Wets, Powell, …)



Scatter search + ICP proposal (IV)

- Subset Generation Method: it generates a collection of solution subsets from *RefSet* to create new trial solutions. We consider all the possible pairs of solutions
- Solution Combination Method: it uses the BLX-α crossover operator to obtain a trial solution from the two parents which is added to an intermediate *Pool*
- RefSet Update Method: Updates *RefSet* with the best solutions in:

  RefSet U *Pool*

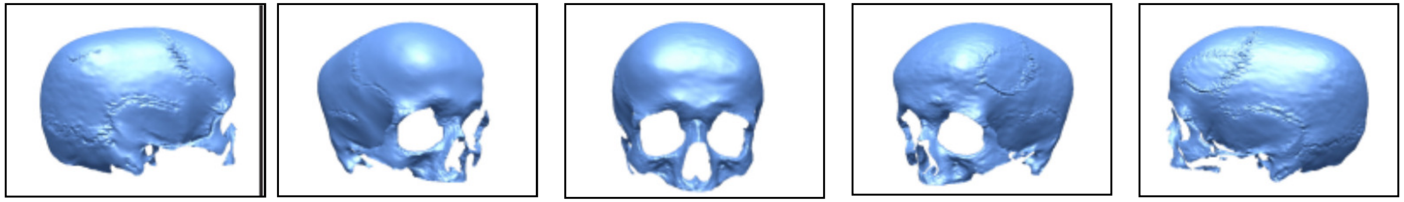


Experiments (I)

OVERVIEW

- RIR of the five frontal views of a skull acquired using the laser range scanner of the Physical Anthropology Lab of the University of Granada (*Konica-Minolta© VI-910*)

- 90º	- 45º	0º	45º	90º



109.936	76.794	68.751	91.590	104.441

- Automatic approach:
  - No image analysis
  - Random sampling of the 15% of points in every view (≈ 12.000 – 15.000 points)

Experiments (II)

OVERVIEW

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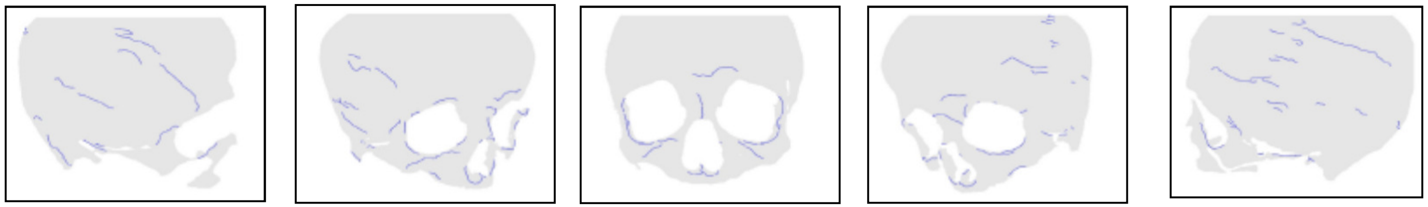
- Semi-automatic approach: image smoothing and crest lines extraction based on the invariant curvature information

- 90º	- 45º	0º	45º	90º



1.380	1.181	986	1.322	1.363

- Laborious image analysis process that also depends on the previous human operator experience!

Experiments (III)

OVERVIEW

- RIR problems: four rigid transformations applied to every pair of adjacent views to simulate the absence of a rotary table
- Stop criterion: 20 seconds for the semi-automatic approach and 100 seconds for the automatic one
- Runs: 15 random initializations to emulate wrong acquisitions made by the forensic anthropologist
- Results validation: MSE of the solution achieved with respect to the ground-truth 3D model from the rotary table

Experiments (IV)

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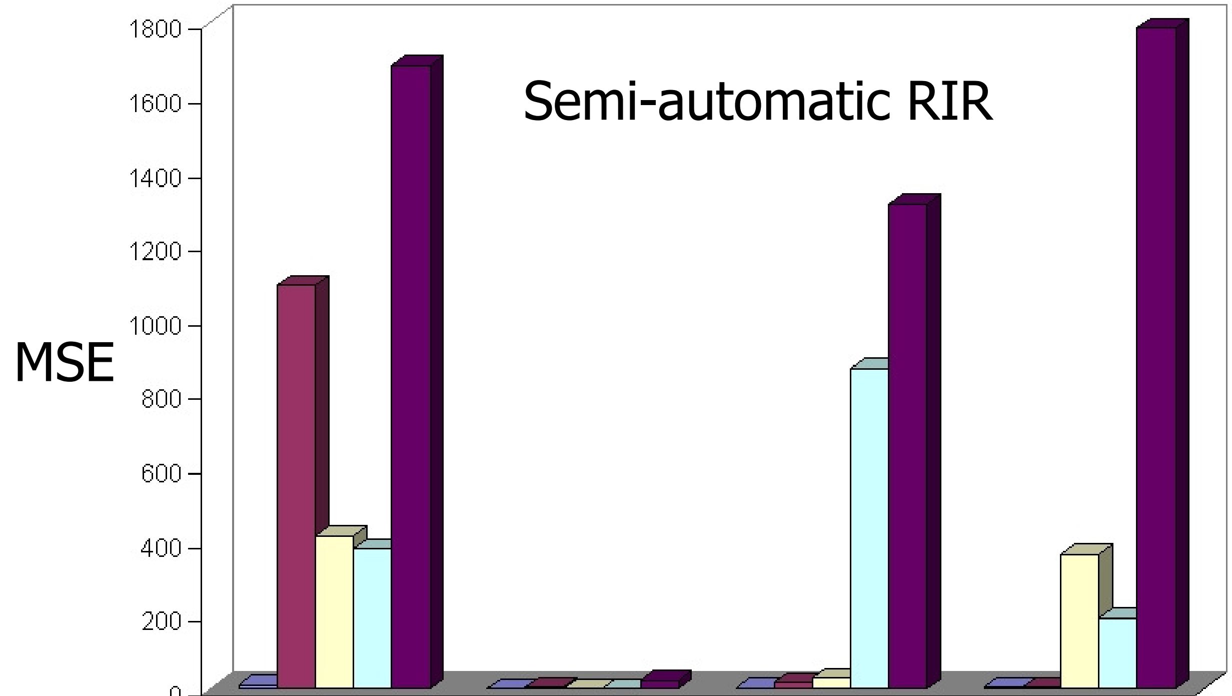

	I0 vs Ti(I45)	I0 vs Ti(I315)	I45 vs Ti(I90)	I315 vs Ti(I270)
SSp	10,455	0,01	1,345	3,465
CHC Real	1089,0425	3,0175	16,0725	3,61
GA He	411,97	0,01	27,4725	362,64
GA Lomosov	378,5025	0,01	866,0075	191,1
GA Chow	1683,4075	21,7675	1308,805	1784,46

scenario

4. 3D skull model reconstruction using evolutionary algorithms
Experiments (V)

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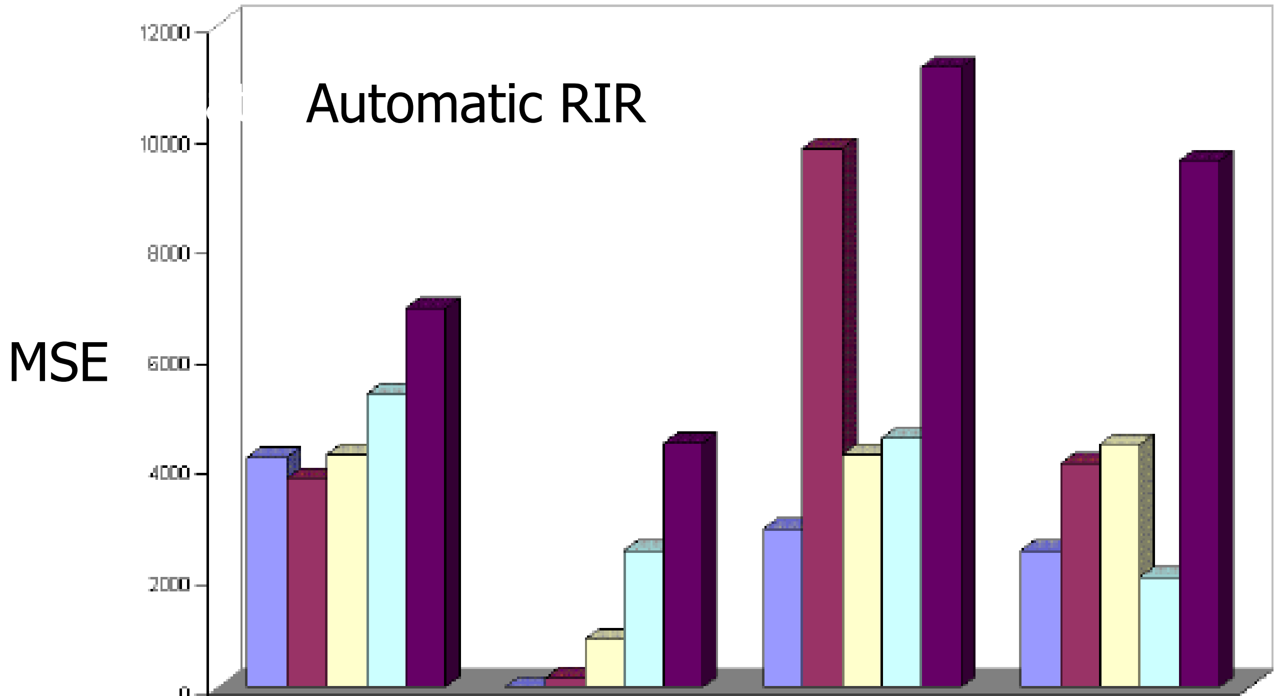

	I0 vs Ti(I45)	I0 vs Ti(I315)	I45 vs Ti(I90)	I315 vs Ti(I270)
SSp	4167.57	0.01	2870.03	2473.96
CHC Real	3787.63	179.28	9770.10	4046.35
GA He	4224.23	858.17	4229.03	4409.30
GA Lomosov	5314.28	2481.92	4501.89	1997.59
GA Chow	6863.61	4442.90	11229.17	9554.22

scenario

4. 3D skull model reconstruction using evolutionary algorithms
Experiments (VI)

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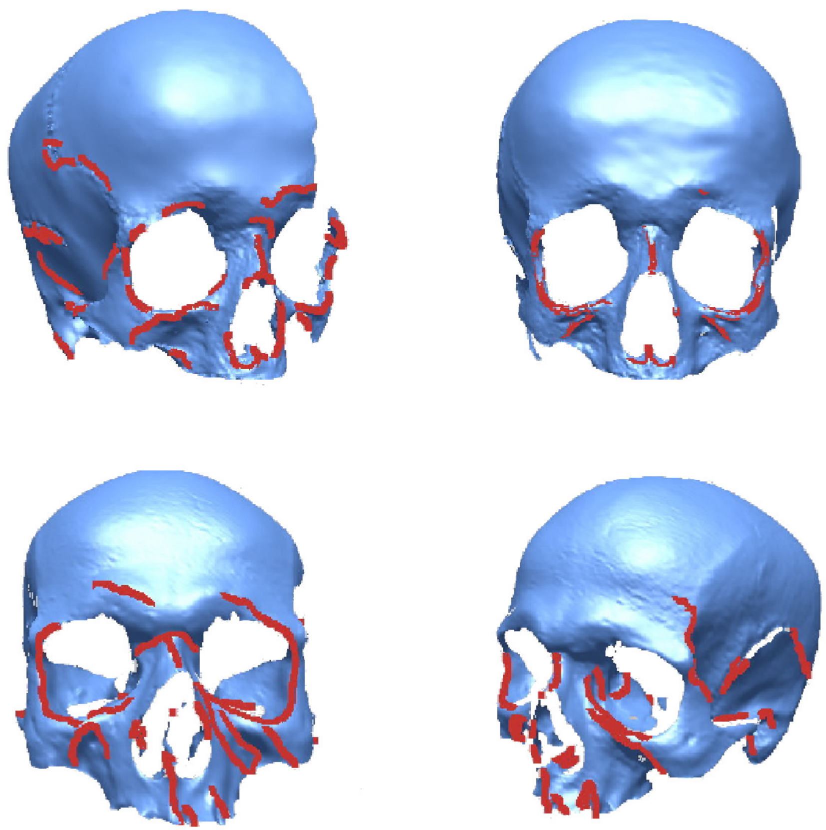
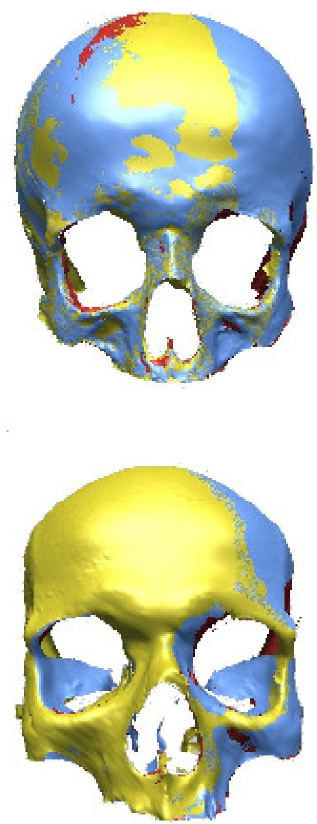
6. Conclusions

3D views: input



Reconstruction

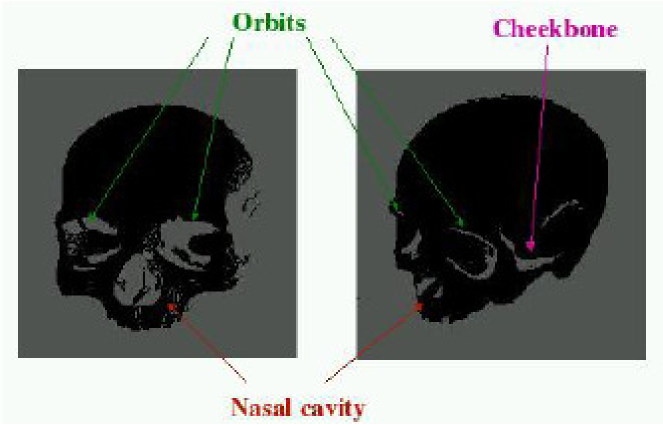


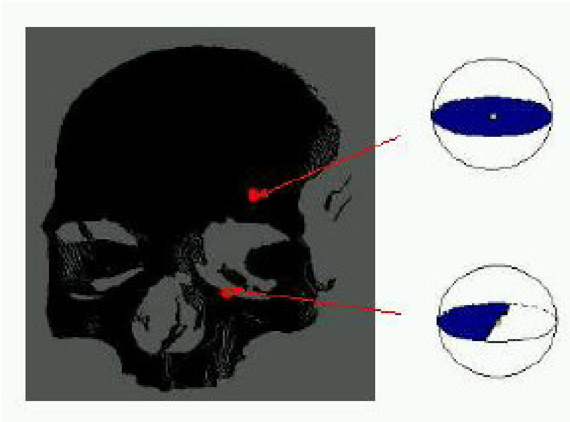
New proposal for automatic feature extraction (I)

- We also proposed a new method for the automatic extraction of relevant skull features
- Those features must be:
  - representative of the skull
  - invariant with respect to rigid transformations
  - the simpler the better (i.e., comprised by the lowest possible number of points)
  - robust to deal with the acquisition of non-uniform point clouds

New proposal for automatic feature extraction (II)

- We concentrated on relevant anatomical regions: eye sockets, nasal cavity, and cheeks
- Those regions surround different cavities in the skull surface:





- We automatically identify them using a density criterion: counting those points inside a spherical neighborhood

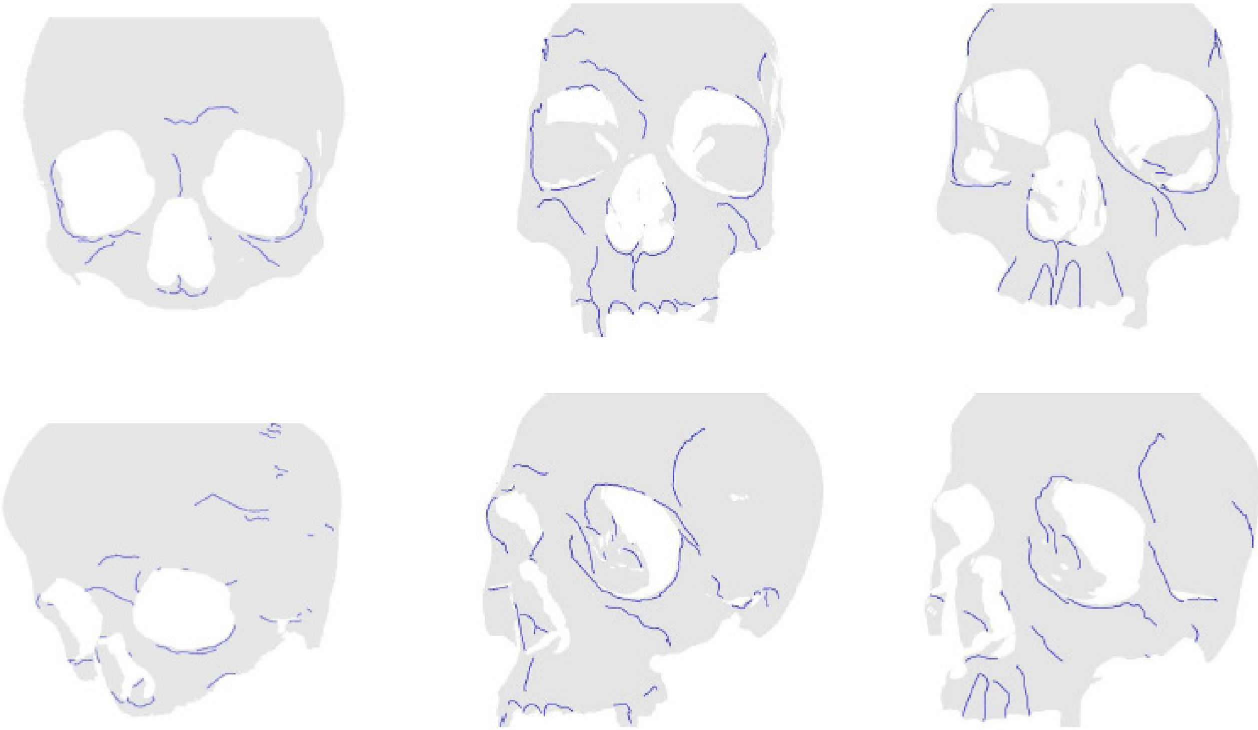
New proposal for automatic feature extraction (III)

OVERVIEW

- Example: original images

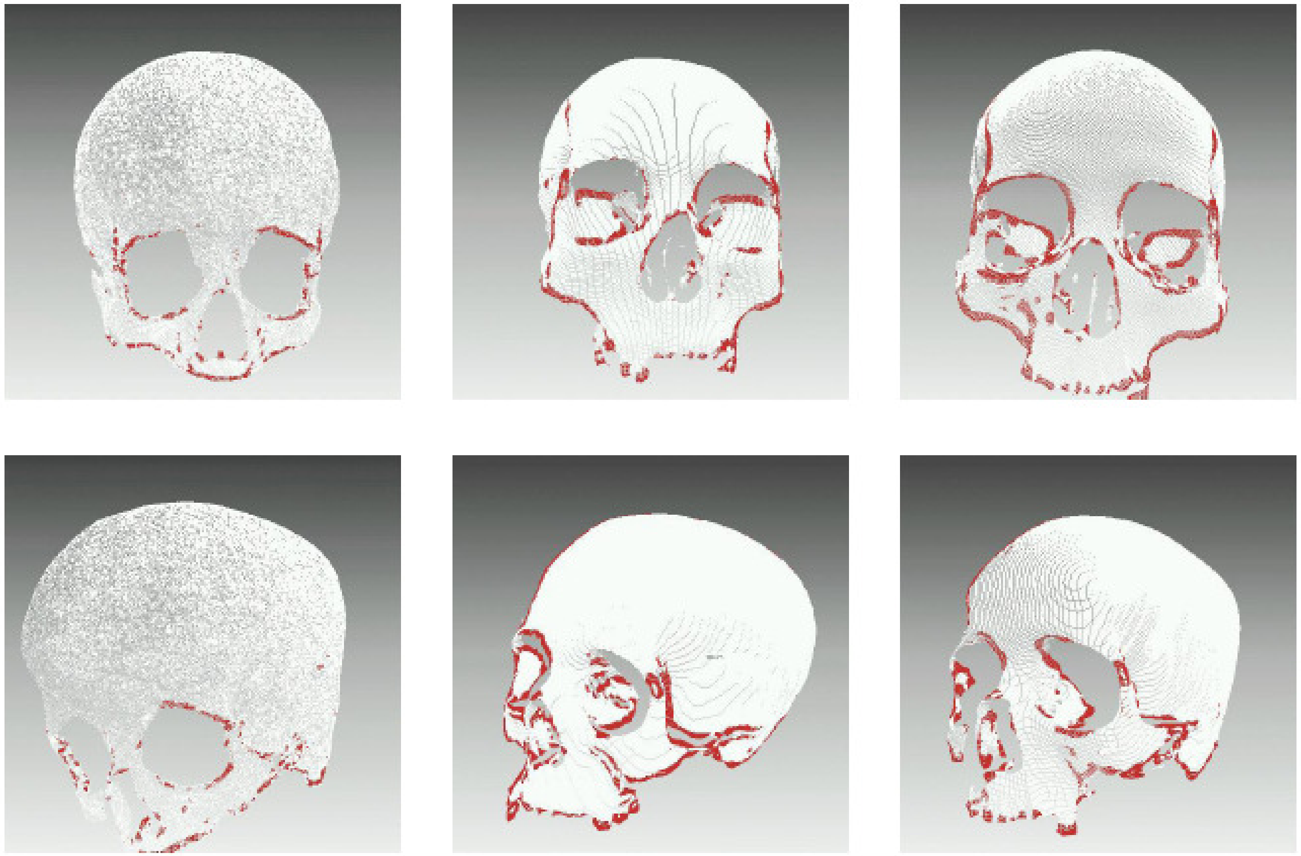
OVERVIEW

- Example: crest line features



OVERVIEW

- Example: density-based feature extraction



OVERVIEW

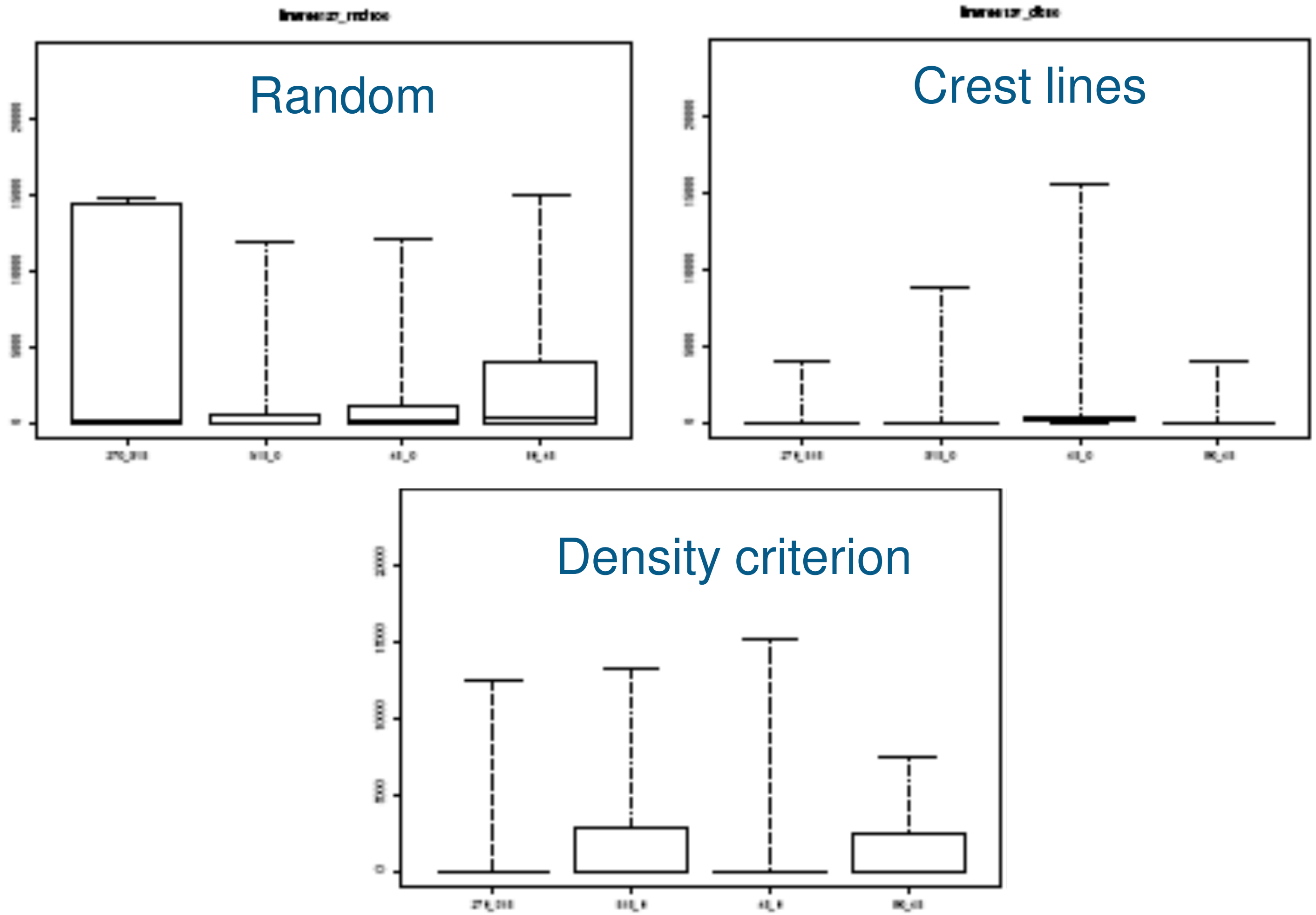
1. Forensic identification (FI) by craniofacial superimposition
2. Image Registration (IR)
3. IR, Uncertainty and FI = Soft Computing
4. **First stage: 3D skull model reconstruction**
5. Second stage: Skull-face overlay
6. Conclusions

- Data simplification (point reduction)

		Views/Images				
		270°	315°	0°	45°	90°
Original	$Skull_1$	109936	76794	68751	91590	104441
	$Skull_2$	121605	116617	98139	118388	128163
	$Skull_3$	116937	107336	88732	111834	123445
	$Skull_4$	129393	124317	102565	125859	137181
	$Skull_5$	110837	102773	83124	101562	110313
Features	$Skull_1$	5199	915	2901	2948	1655
	$Skull_2$	7304	10347	11106	12676	11143
	$Skull_3$	9023	10745	8318	12265	10361
	$Skull_4$	8593	11020	14844	12285	10025
	$Skull_5$	9419	9852	10764	10308	9175

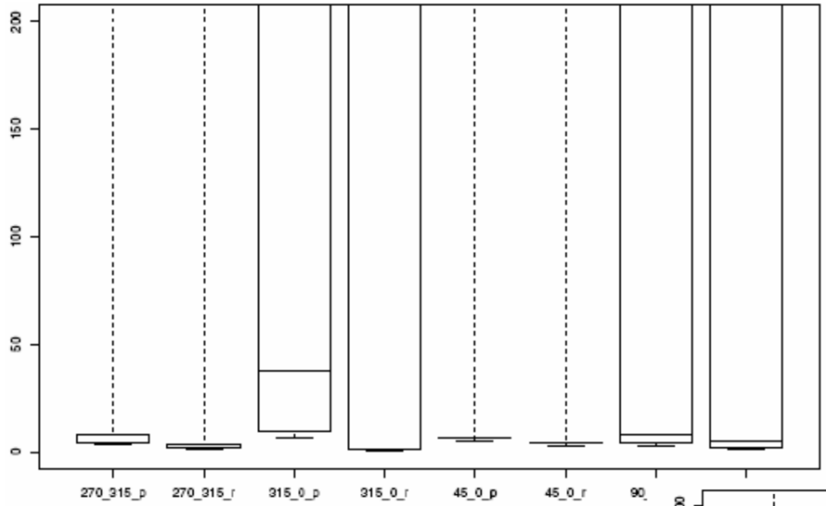
4. 3D skull model reconstruction using evolutionary algorithms
New proposal for automatic feature extraction (VII)

- Experimental results (I): Final 3D reconstruction error



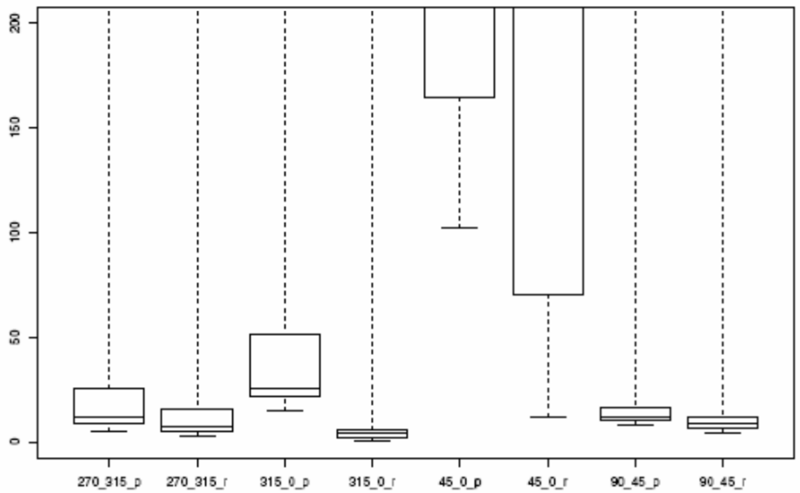
OVERVIEW

Experimental results (II): Final 3D reconstruction error



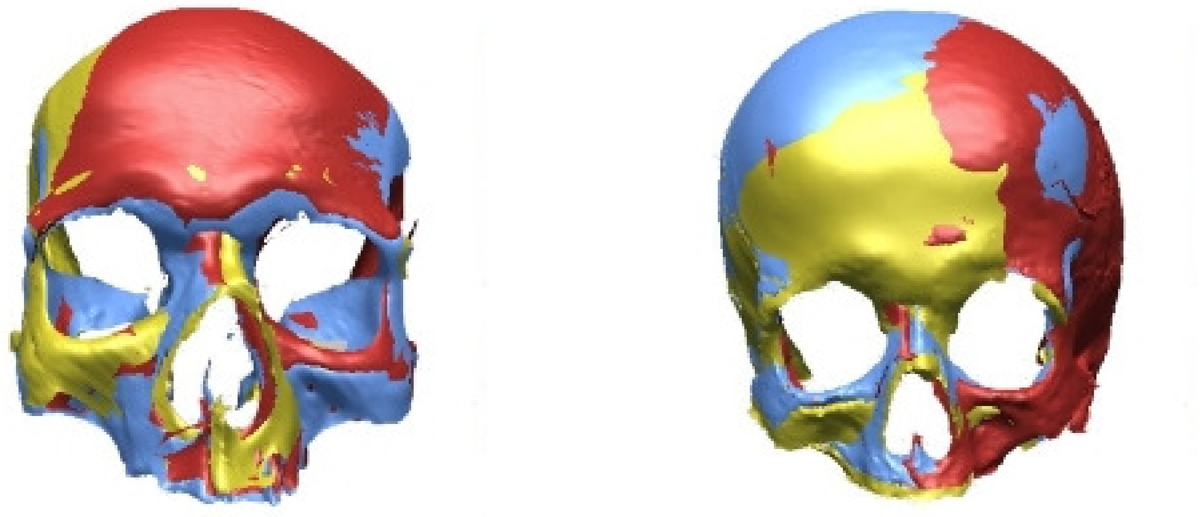
Crest lines

Density criterion



New proposal for automatic feature extraction (IX)

- Analysis of results:



- Mean reconstruction error: less than 1 mm
- 3D reconstruction time: 2 minutes

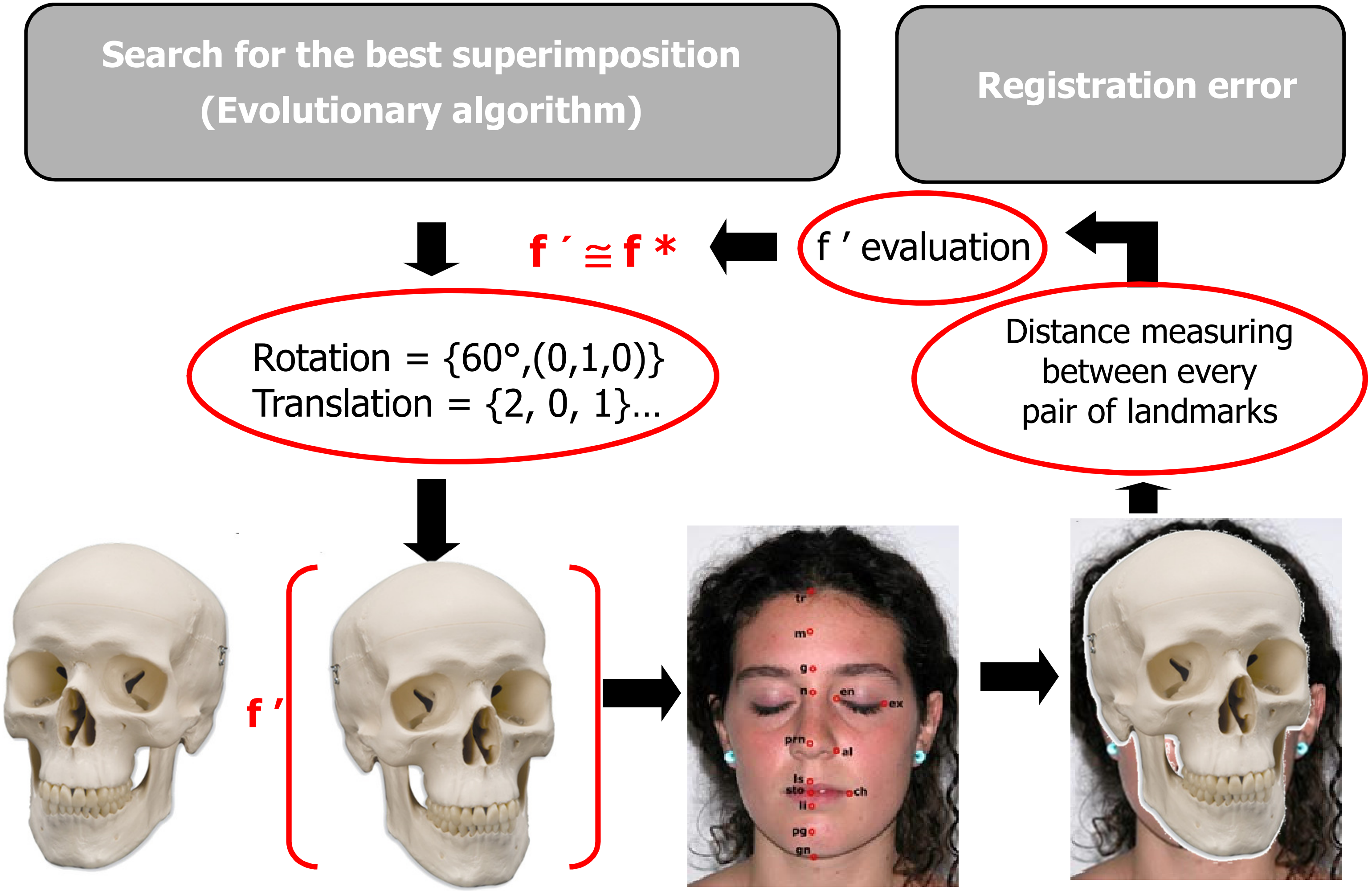
Problem issues, requirements and tools

Again, very complex problem:

- The available photographs are provided by the family:
  - Not always good quality, neither good pose
  - Landmarks may be occluded
  - Camera data are unknown
- Uncertainty is inherent both to the landmark location and matching (the latter due to the flesh lack in the skull)
- Skull-face overlay is a very time consuming trial and error manual procedure
- Need of automatic techniques for skull-face overlay (3D-2D IR) being robust, fast, and able to deal with incomplete information
- We will exploit the suitability of EAs and FL to tackle the IR problem and to deal with the sources of uncertainty, respectively

Considered methodology

OVERVIEW



Existing methods

- Nickerson et al. (Forensic Science International 36 (1991)) did a pioneering work based on genetic algorithms (GAs)

- Binary-coded GA to estimate the superimposition which is defined by a similarity transformation (3D translation, 3D rotation, and uniform scaling) and a perspective projection
- The problem is tackled by only considering four landmarks leading to a set of eight equations in twelve unknowns
- Fitness function: sum of the squared 2D Euclidean distances between the facial landmarks and the projected cranial landmarks
- Bad results when tackling real-world cases

- Improvement of registration transformation: translation, rotation, scaling, and projection. Twelve parameters
- Real-coding scheme, better suited for IR
- Advanced EAs: elitist real-coded GA, binary tournament, BLX- α and SBX crossovers, random mutation. CMA-ES
- Variable number of landmarks according to the photograph and the skull conditions
- Fitness function: mean of the distances between the facial and the projected cranial landmarks (mean error, ME)

New proposal: registration transformation (I)

OVERVIEW

- The final solution to the skull-face overlay problem should be the transformation making the 3D skull model become accurately located in the same pose of the missing person in the photo

- There are two important moments to be considered:

Photograph acquisition

Skull model acquisition

- Replicating the scenario where the photograph was acquired is rather complex because of the number of unknowns involved in the process (even more than camera calibration in CV)

- The registration transformation to be estimated includes a rotation (R), a scaling (S), a translation (T), and a perspective projection (P)
- Given two sets of 2D facial and 3D cranial landmarks:

$$F = \begin{bmatrix} x_{f_1} & y_{f_1} & 1 & 1 \\ x_{f_2} & y_{f_2} & 1 & 1 \\ \vdots & \vdots & \vdots & \vdots \\ x_{f_N} & y_{f_N} & 1 & 1 \end{bmatrix}, \quad C = \begin{bmatrix} x_{c_1} & y_{c_1} & z_{c_1} & 1 \\ x_{c_2} & y_{c_2} & z_{c_2} & 1 \\ \vdots & \vdots & \vdots & \vdots \\ x_{c_N} & y_{c_N} & z_{c_N} & 1 \end{bmatrix}$$

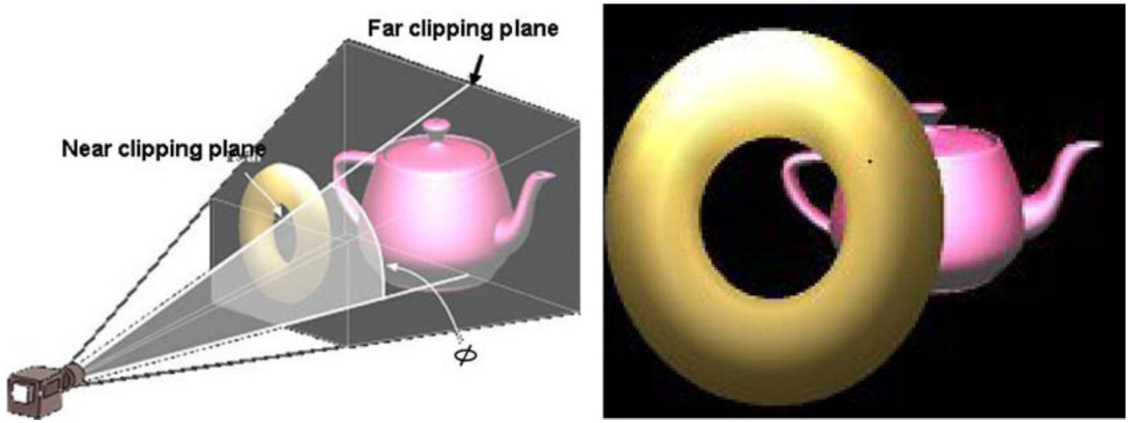
the aim is to solve an over-determined system of equations with 12 unknowns $(r_x, r_y, r_z, d_x, d_y, d_z, \theta, s, t_x, t_y, t_z, \phi)$:

$$F = C \cdot (A \cdot D_1 \cdot D_2 \cdot \theta \cdot D_2^{-1} \cdot D_1^{-1} \cdot A^{-1}) \cdot S \cdot T \cdot P$$

where: $R = (A \cdot D_1 \cdot D_2 \cdot \Theta \cdot D_2^{-1} \cdot D_1^{-1} \cdot A^{-1})$

- Projective transformations are hard to be estimated. Cameras use them to provide a realistic picture of the scene from the observer's viewpoint

- In computer graphics, the pinhole camera is modeled using a frustum given by the near clipping plane (NCP) and the far clipping plane (FCP):



- The frustum determines the visible region

New proposal: registration transformation (IV)

OVERVIEW

- Once the skull is properly rotated, scaled, and translated, the location of the camera with respect to it must be determined

- Hence, the field of view camera parameter, ϕ, must be estimated. The projective transformation is given by:

$$P = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \tan(\phi/2) & \tan(\phi/2) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

- When the camera is properly located and there is no landmark uncertainty, every projection ray coupling a 3D cranial landmark with its corresponding 2D facial landmark converges towards the center of projection

5. Skull-face overlay using EAs and fuzzy logic
New proposal: registration transformation (V)

OVERVIEW

- Thus, our coding scheme is a vector of 12 real values:

$$\underbrace{r_x \;\; r_y \;\; r_z \;\; d_x \;\; d_y \;\; d_z \;\; \theta}_{\text{Rotation}} \;\; \underbrace{s}_{\text{Scaling}} \;\; \underbrace{t_x \;\; t_y \;\; t_z}_{\text{Translation}} \;\; \underbrace{\phi}_{\text{Projection}}$$

ranging in the following intervals:

$$r_i \in [Centroid - radius, Centroid + radius], \quad i \in \{x, y, z\}$$
$$d_i \in [-1, 1], \quad i \in \{x, y, z\}$$
$$\theta \in [0^\circ, 360^\circ]$$
$$s \in [0.25, 2]$$
$$\phi \in [10^\circ, 150^\circ]$$
$$t_x \in [-length_{FB} - (C_x + radius), length_{FB} - (C_x - radius)]$$
$$t_y \in [-length_{FB} - (C_y + radius), length_{FB} - (C_y - radius)]$$
$$t_z \in [NCP - (C_z + radius), FCP - (C_z - radius)]$$

where:

$$radius = \max(\|Centroid - C_j\|)$$

FB is the frustum Base

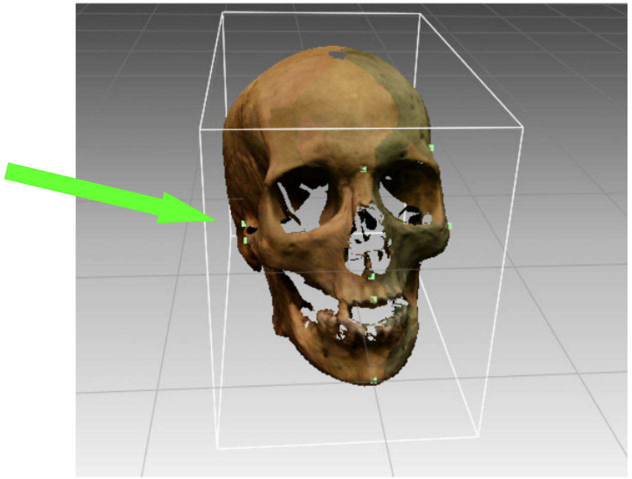
$$length_{FB} = \frac{(\min_{FD} + FCP) * \sin\left(\frac{\phi_{max}}{2}\right)}{\sin\left(90^\circ - \left(\frac{\phi_{max}}{2}\right)\right)}$$

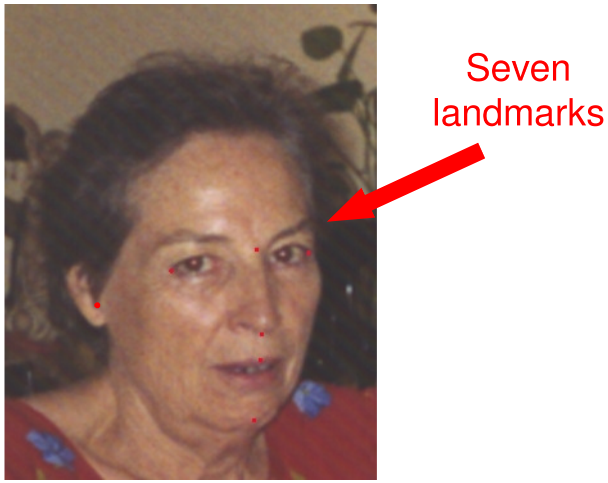
with FD being the Focal Distance and

$$\min_{FD} = \frac{1}{\tan\left(\frac{\phi_{max}}{2}\right)}$$

OVERVIEW

- Real case solved in Málaga (Spain) by the Physical Anthropology Lab at the Univ. of Granada with the scientific police. Pose is not frontal, with hidden landmarks





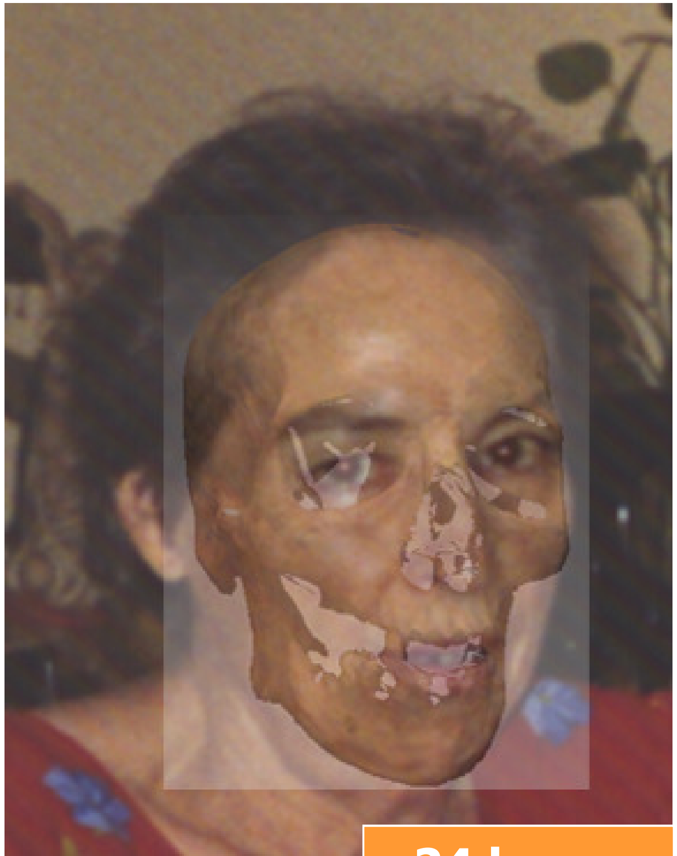
- BinGA, RCGA, CMA-ES. CMA-ES parameters:
  - Termination criterion: 552,000 evaluations
  - μ=15, λ=100, θ =0.01 (mutation step)
  - 30 independent runs

Experiments (II)

OVERVIEW

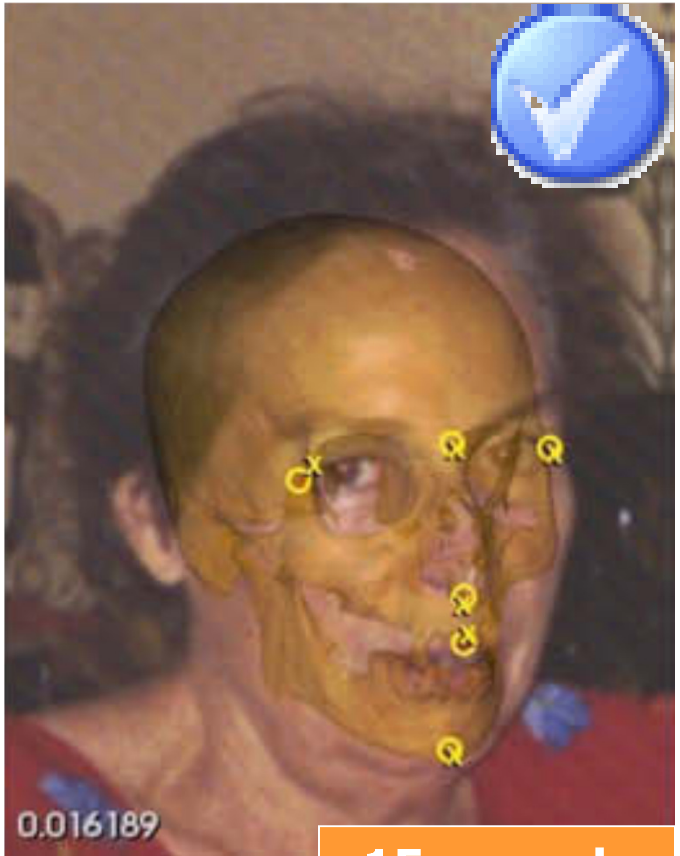
- Manual vs. automatic superimposition comparison

Manual Superimposition



24 hours

RCGA-SBX Superimposition



15 seconds

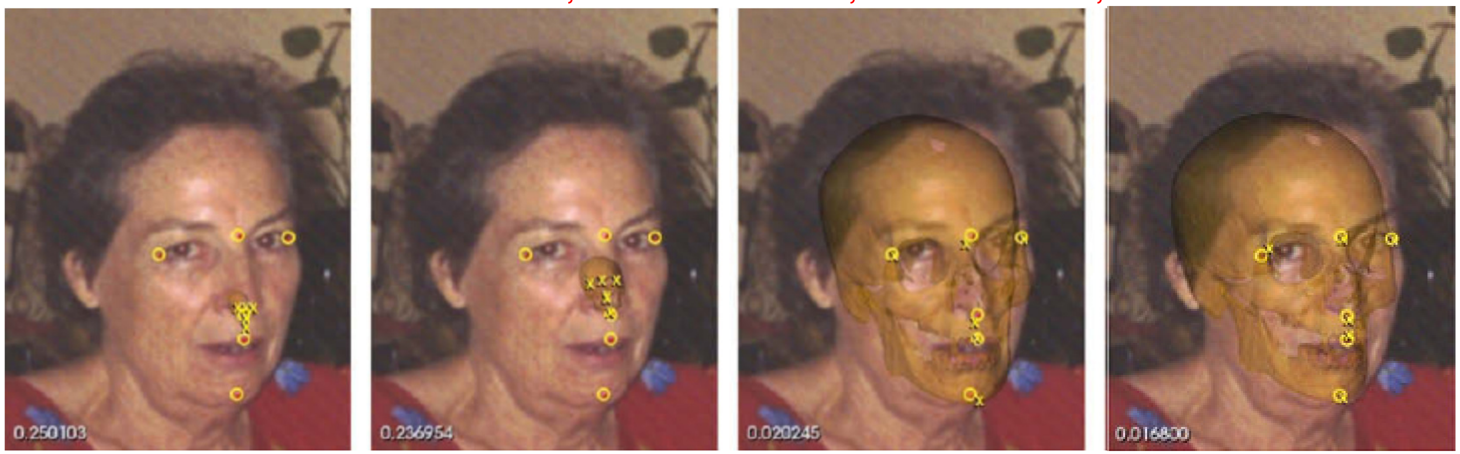
OVERVIEW

1. Forensic identification (FI) by craniofacial superimposition
2. Image Registration (IR)
3. IR, Uncertainty and FI = Soft Computing
4. First stage: 3D skull model reconstruction
5. **Second stage: Skull-face overlay**
6. Conclusions

Comparative study of the methods' robustness

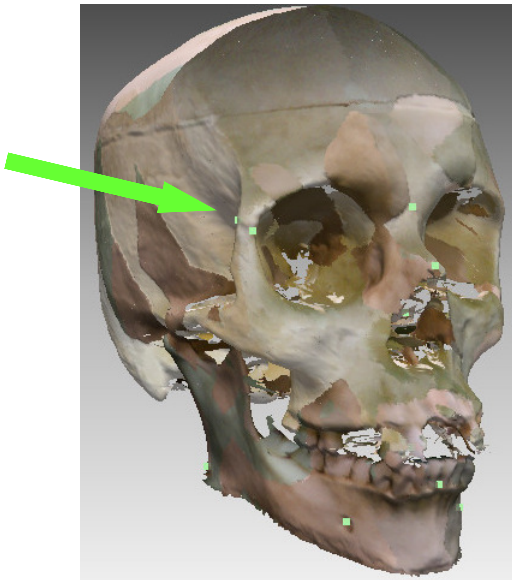
Best result: BinGA, RCGA-BLX-α, RCGA-SBX, CMA-ES

Worst result: BinGA, RCGA-BLX-α, RCGA-SBX, CMA-ES



Experiments: New case (I)

- Another real-world case (Cádiz, Spain) with some photos of higher quality and different poses, making the identification easier:



Pose 1

Pose 2

Pose 3

Pose 4

5. Skull-face overlay using EAs and fuzzy logic
Experiments: New case (II)

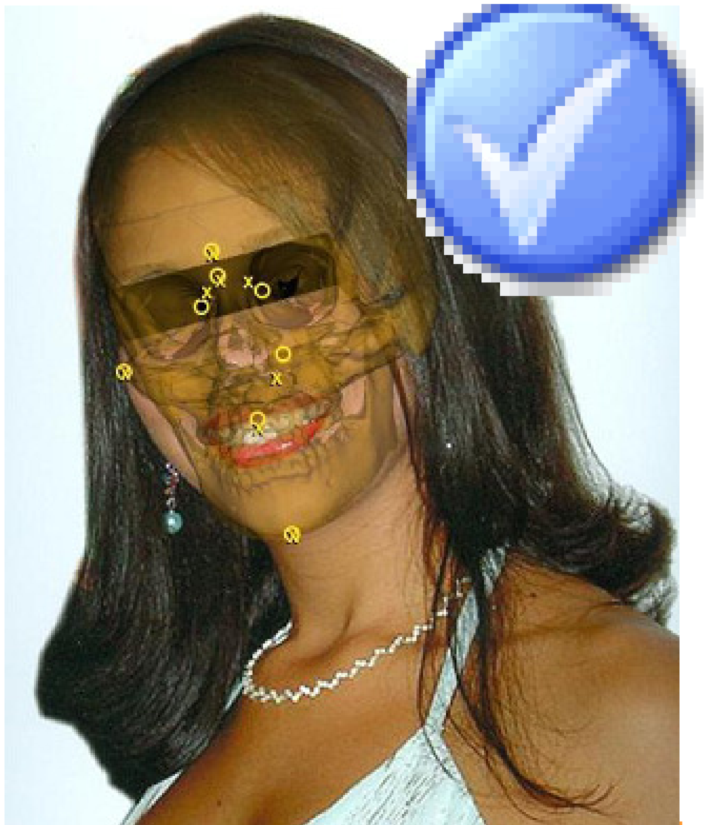
OVERVIEW

- Pose 1: Manual vs. automatic superimposition comparison

Manual superimposition

24 hours

CMA-ES superimposition



18 seconds

Experiments: New case (III)

OVERVIEW

- Comparative study of the methods' robustness

Best result: BinGA, RCGA-BLX-α, RCGA-SBX, CMA-ES

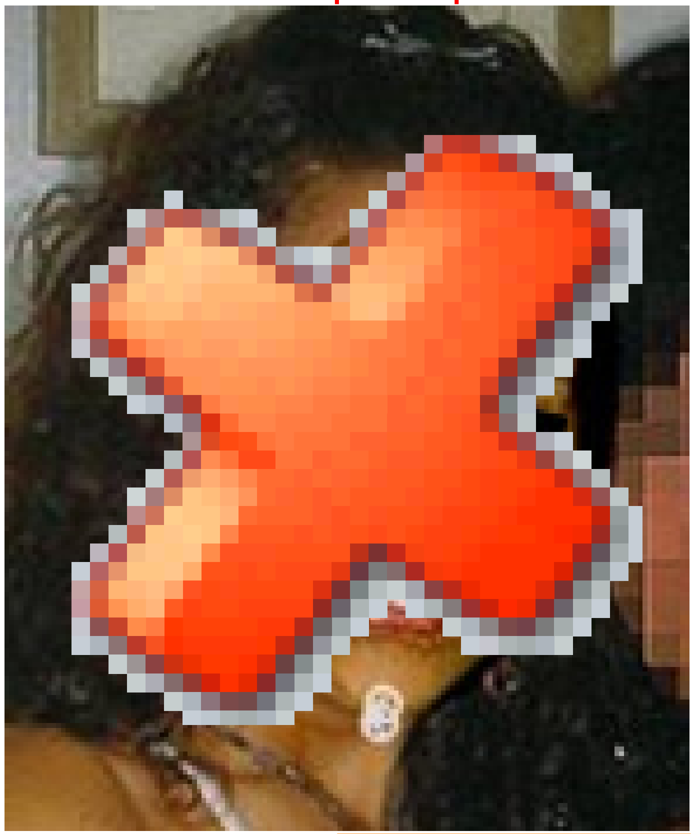
Worst result: BinGA, RCGA-BLX-α, RCGA-SBX, CMA-ES

- Pose 2: Manual vs. automatic superimposition comparison

Manual superimposition

24 hours

CMA-ES superimposition



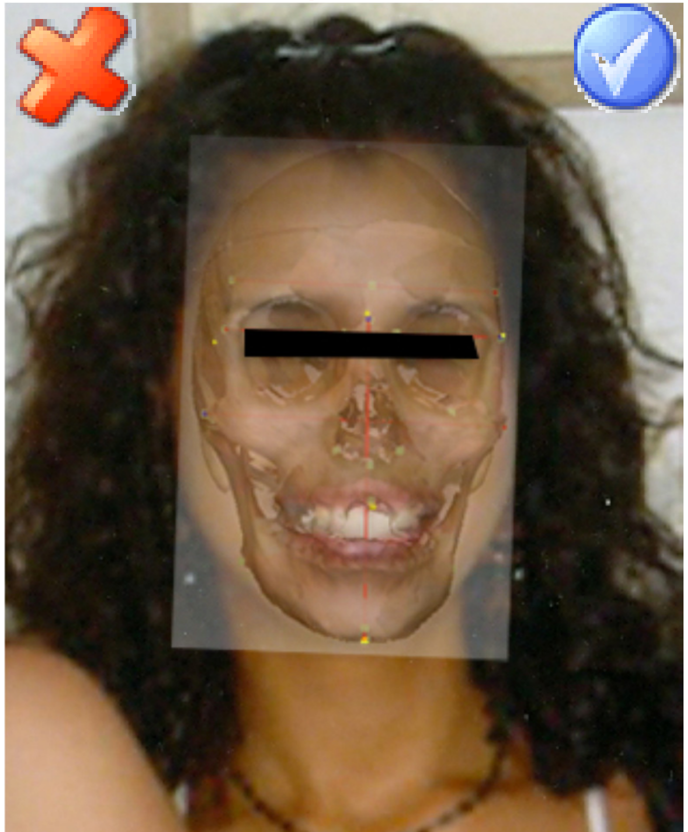
18 seconds

Experiments: New case (V)

OVERVIEW

- Pose 3: Manual vs. automatic superimposition comparison

Manual superimposition



24 hours

CMA-ES superimposition

18 seconds

OVERVIEW

1. Forensic identification (FI) by craniofacial superimposition
2. Image Registration (IR)
3. IR, Uncertainty and FI = Soft Computing
4. First stage: 3D skull model reconstruction
5. **Second stage: Skull-face overlay**
6. Conclusions

- Pose 4: Manual vs. automatic superimposition comparison

Manual superimposition

24 hours

CMA-ES superimposition

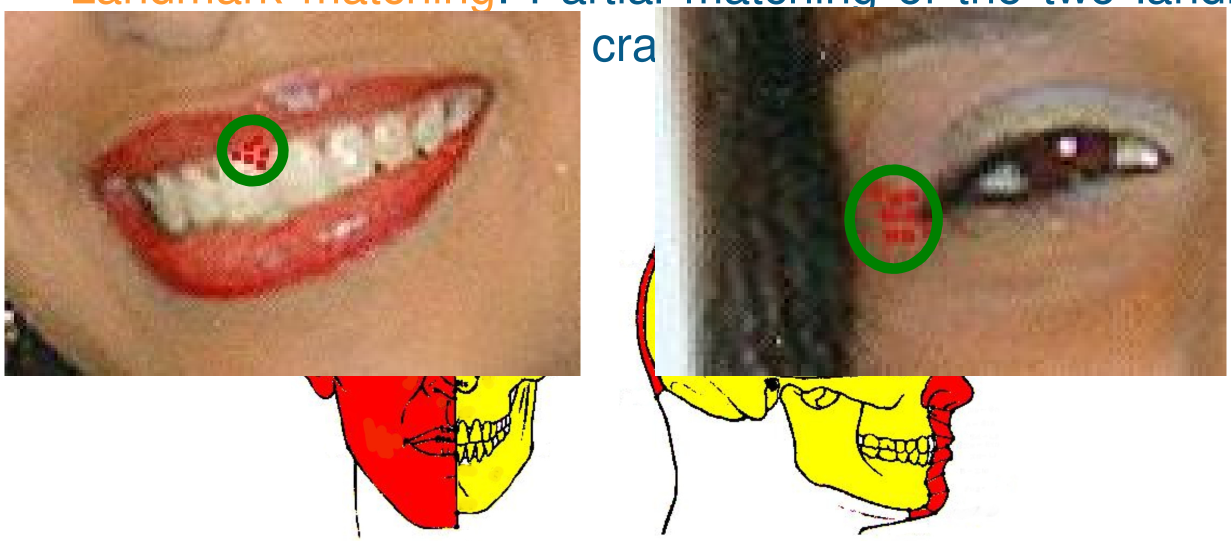
18 seconds

5. Skull-face overlay using EAs and fuzzy logic
Kinds of uncertainty in skull-face overlay (I)

OVERVIEW

Two different sources of uncertainty:

1. Inherent uncertainty associated with the two different objects under study (a skull and a face):
   - Landmark location: Every forensic expert is prone to locate the landmarks in a slightly different place
   - Landmark matching: Partial matching of the two landmark cra



Kinds of uncertainty in skull-face overlay (II)

2. Uncertainty associated with the 3D skull-2D photo overlay process:

- Landmark location: Difficulty to select a good (cephalometric) landmark set due to the photo conditions:
  - face pose, partial occlusions, and poor image quality
  - Forensic anthropologists are prone to locate only those landmarks which can be unquestionably identified!
- Landmark matching: The selected reduced landmark set is usually coplanar or near-coplanar:
  - the equation system becomes undetermined and the 3D-2D IR process gets inaccurate results
  - The preferred photos by the forensic anthropologists are usually those with a frontal pose!

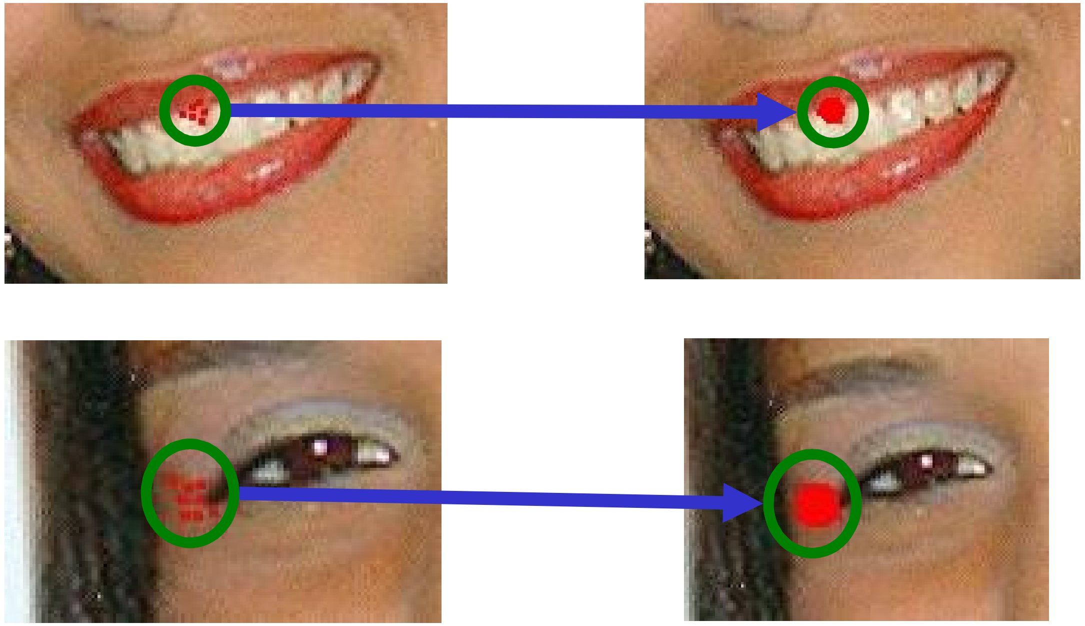
Fuzzy landmarks to jointly tackle location and coplanarity problems (I)

OVERVIEW

- Each cephalometric landmark is a fuzzy point defined by a bi-dimensional fuzzy set. The higher the uncertainty related to a landmark → the broader the fuzzy region
- Solution for the two landmark location problems:
  - The inherent difficulty to locate the landmark in the right place
  - The complexity of locating a significant and unquestionable number of landmarks in a photo
- Thanks to the flexibility given to the forensic expert, (s)he is able to mark a larger number of landmarks located in different planes, thus also solving the coplanarity problem

Fuzzy landmarks to jointly tackle location and coplanarity problems (II)

OVERVIEW

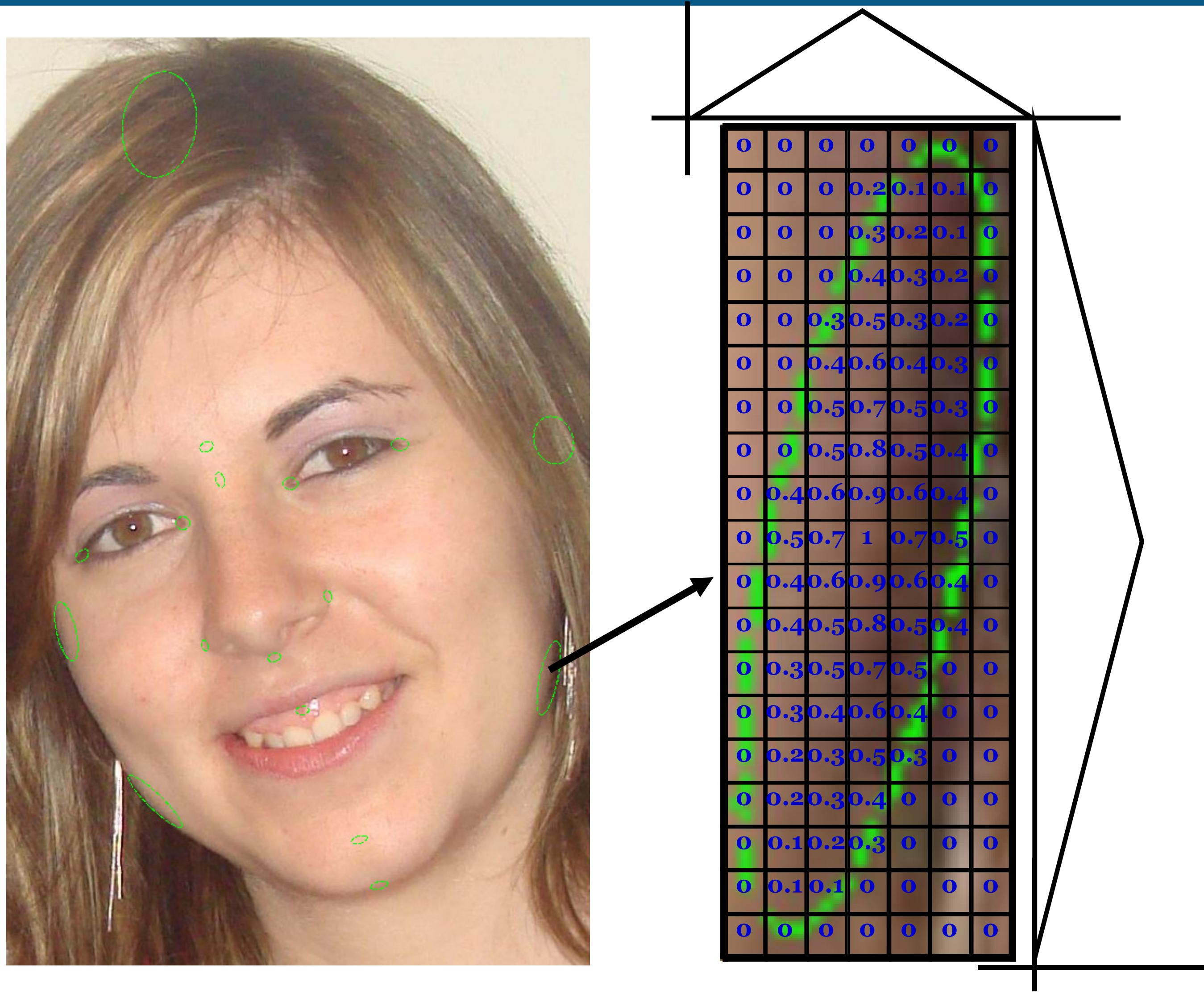


- There is a mask with the membership degree of each pixel to the fuzzy point associated to every landmark

- Need of a new fitness function considering a distance between crisp and fuzzy points

Fuzzy landmarks to jointly tackle location and coplanarity problems (III)

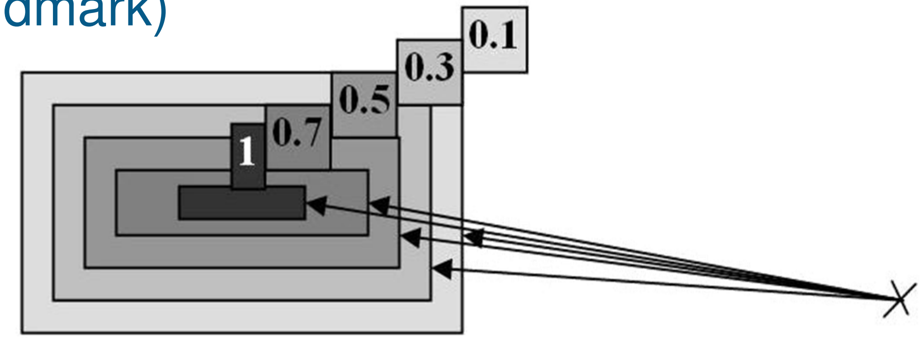
OVERVIEW



Fuzzy landmarks to jointly tackle location and coplanarity problems (IV)

OVERVIEW

- α-cuts to calculate the distance from a crisp point (projected craniometric landmark) to a fuzzy point (cephalometric landmark)



- Crisp-fuzzy distance and new fitness function:

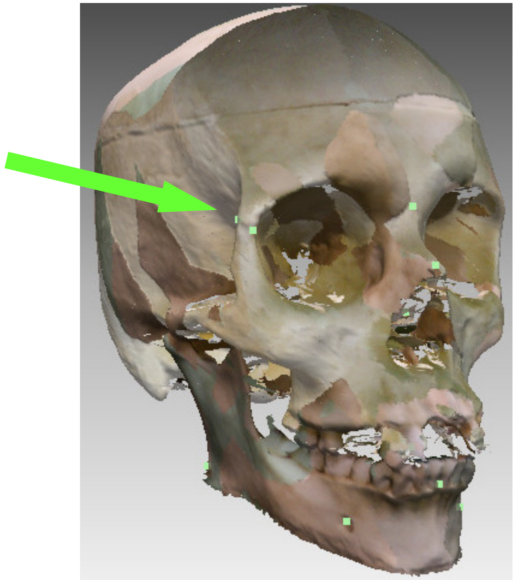
$$d^*(x, \widetilde{F}) = \frac{\sum_{i=1}^{m} d_i \cdot \alpha_i}{\sum_{i=1}^{m} \alpha_i}$$

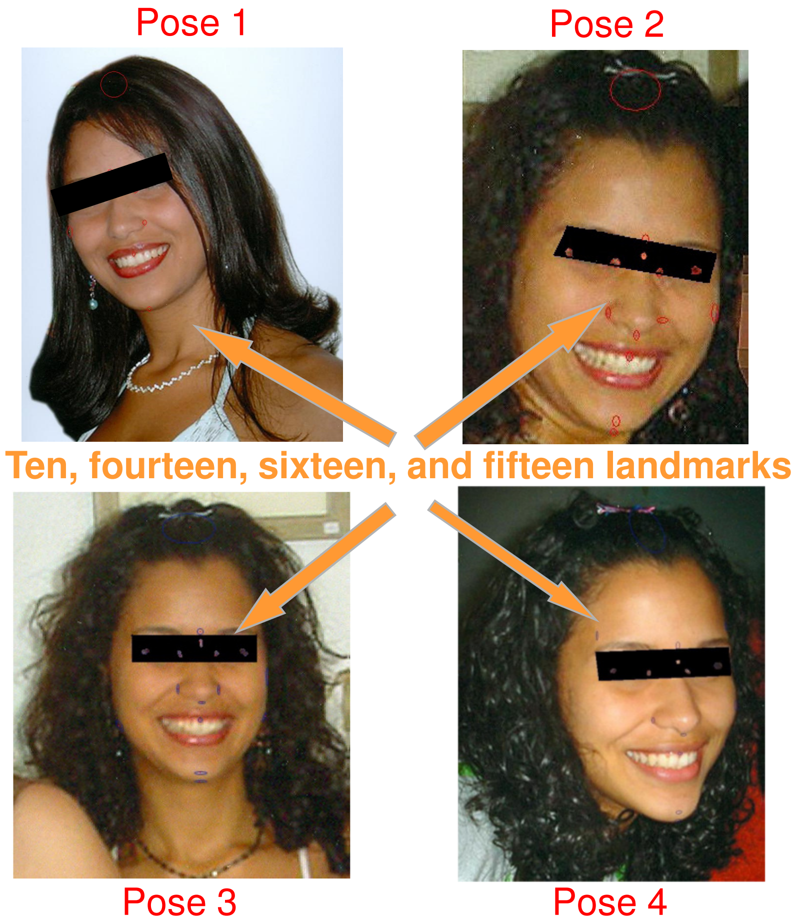
$$fuzzy\ ME = \frac{\sum_{i=1}^{N} d^*(f(cl^i), \widetilde{F}^i)}{N}$$

Fuzzy landmarks experiments (I)

OVERVIEW

- Thanks to the uncertainty treatment, the forensic expert is now able to locate a higher number of landmarks:





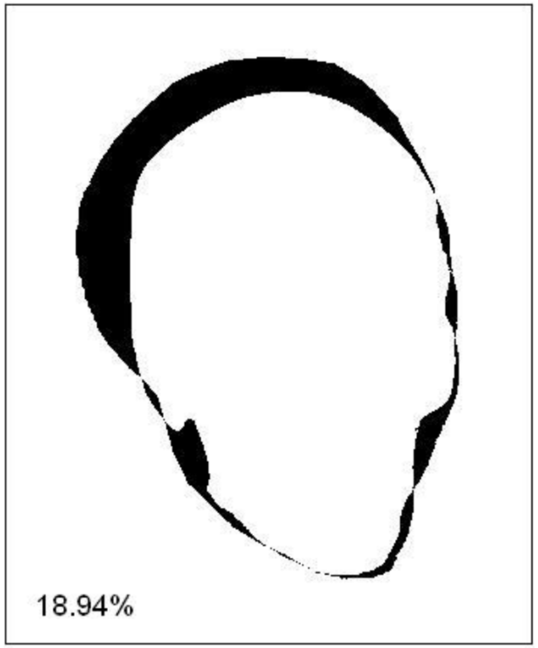
Experimental design:

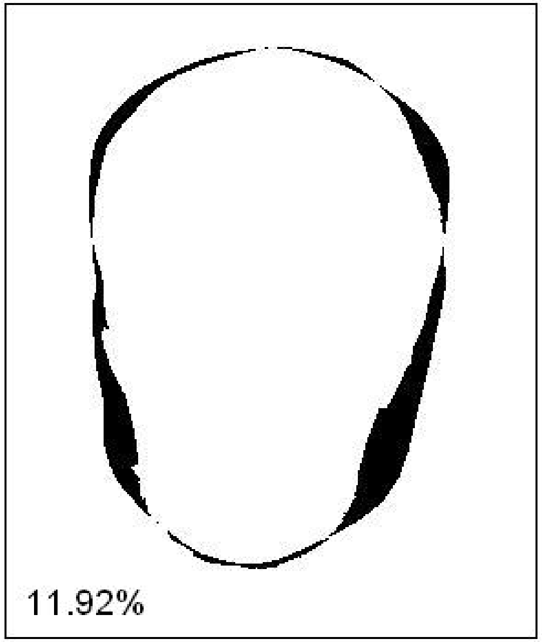
- Target: compare skull-face overlay results using near-coplanar crisp vs. fuzzy cephalometric landmarks
- ME is not valid (two different landmark sets)!
- Qualitative analysis → visually comparing the overlay results from the original set of crisp landmarks and the new fuzzy landmark set
- Quantitative analysis → percentage of the head boundary not covered by the projected skull boundary (manually defined by the forensic anthropologists)

Fuzzy landmarks experiments (III)

OVERVIEW

Area Deviation Error:





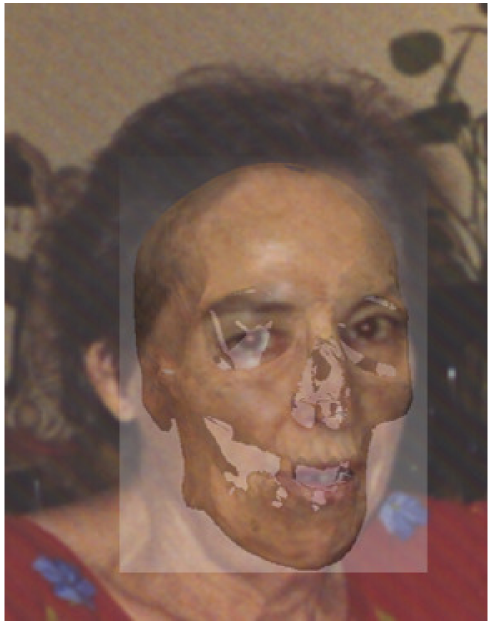
It is not a perfect measure (no information on accuracy of the inner skull parts fitting) but at least it is objective (and complementary)!

5. Skull-face overlay using EAs and fuzzy logic
Fuzzy landmarks experiments (IV)

OVERVIEW

- Malaga case study: Overlays comparison

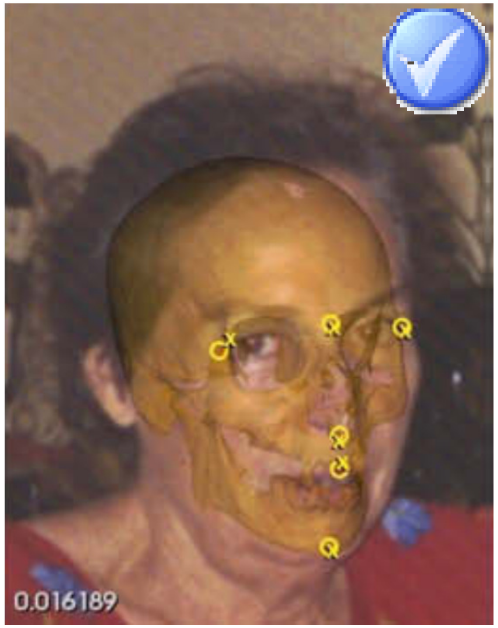
Manual



Area deviation error: 34.70%

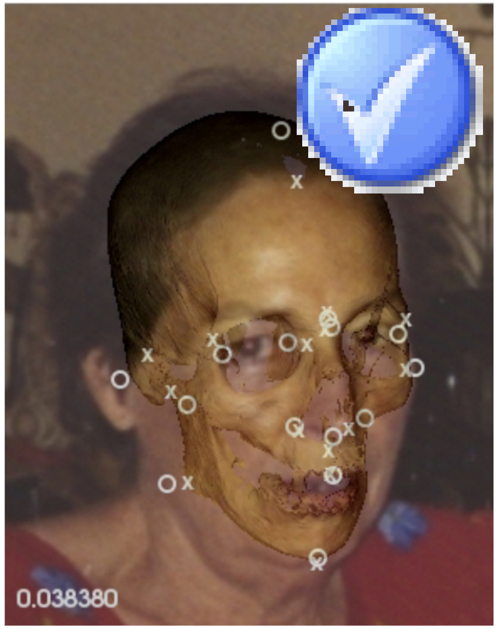
24 hours

RCGA-SBX



15 seconds

Fuzzy CMA-ES



Area deviation error: 13.23%

2-4 minutes

OVERVIEW

- Cádiz case study, pose 1: Overlays comparison

Manual

Area deviation error: 32.64%

24 hours

CMA-ES

18 seconds

Fuzzy CMA-ES

Area deviation error: 15.84%

2-4 minutes

Fuzzy landmarks experiments (VI)

OVERVIEW

- Cádiz case study, pose 2: Overlays comparison

Manual

Area deviation error: 31.58%

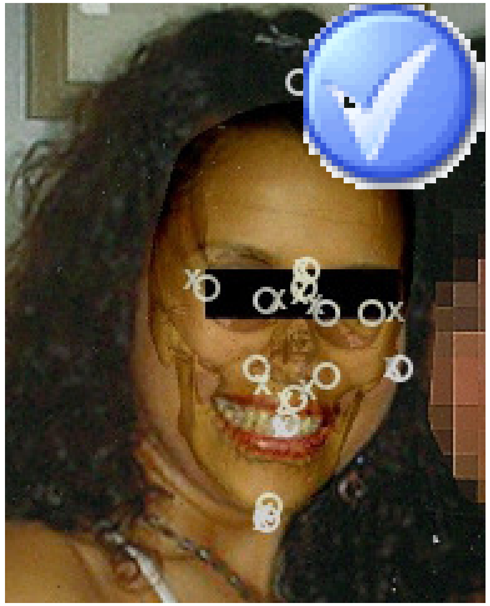
24 hours

CMA-ES

Area deviation error: 50.28%

18 seconds

Fuzzy CMA-ES



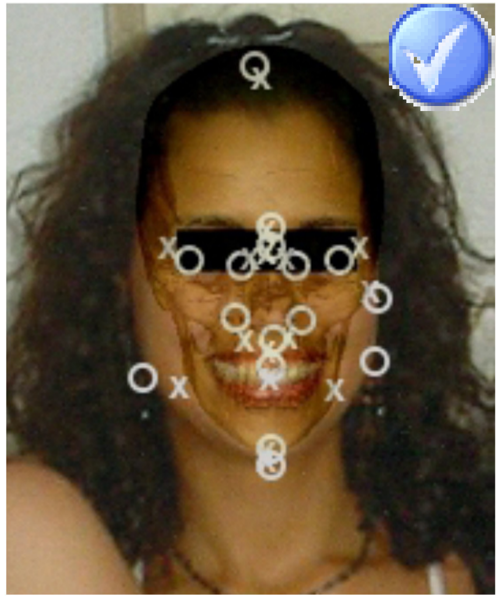
Area deviation error: 27.96%

2-4 minutes

Fuzzy landmarks experiments (VII)

OVERVIEW

- Cádiz case study, pose 3: Overlays comparison

Manual	CMA-ES	Fuzzy CMA-ES
		
Area deviation error: 31.84%	Area deviation error: 42.84%	Area deviation error: 21.26%
24 hours	**18 seconds**	**2-4 minutes**

5. Skull-face overlay using EAs and fuzzy logic
Fuzzy landmarks experiments (VIII)

OVERVIEW

1. Forensic identification (FI) by craniofacial superimposition
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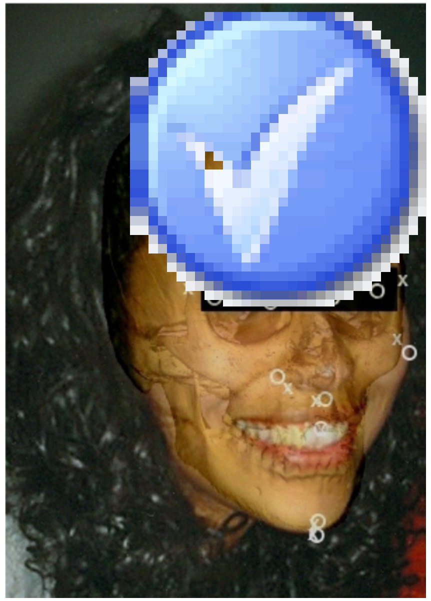
3. IR, Uncertainty and FI = Soft Computing
4. First stage: 3D skull model reconstruction
5. **Second stage: Skull-face overlay**
6. Conclusions

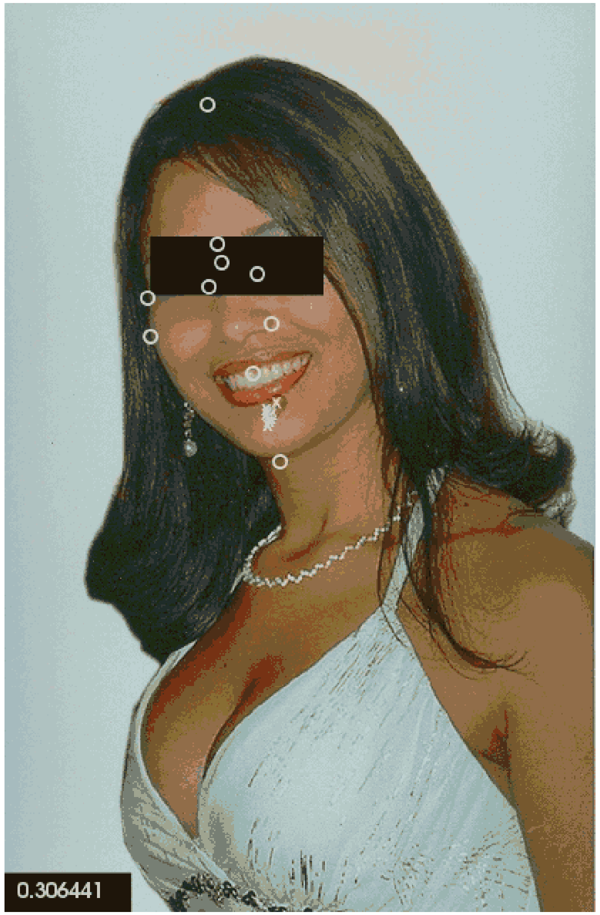
- Cádiz case study, pose 4: Overlays comparison

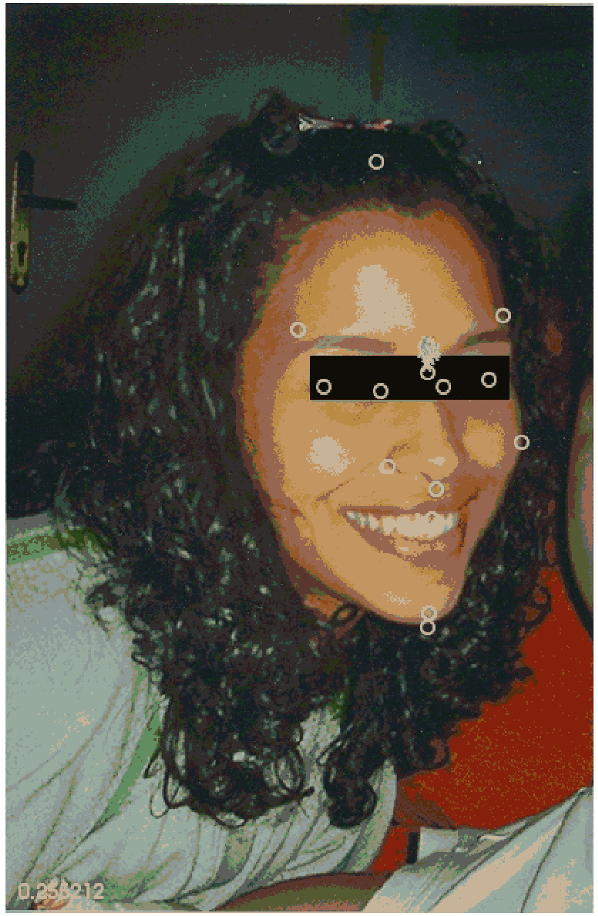
Manual	CMA-ES	Fuzzy CMA-ES
		
Area deviation error: 38.22%	Area deviation error: 53.85%	Area deviation error: 18.95%
24 hours	**18 seconds**	**2-4 minutes**

Fuzzy landmarks experiments (IX)

OVERVIEW

Fuzzy CMA-ES example runs:





5. Skull-face overlay using EAs and fuzzy logic
Fuzzy landmarks experiments (X)

OVERVIEW

1. Forensic identification (FI) by craniofacial superimposition

2. Image Registration (IR)

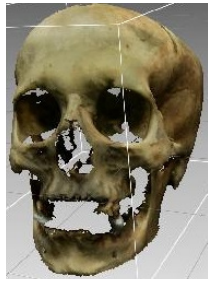
3. IR, Uncertainty and FI = Soft Computing

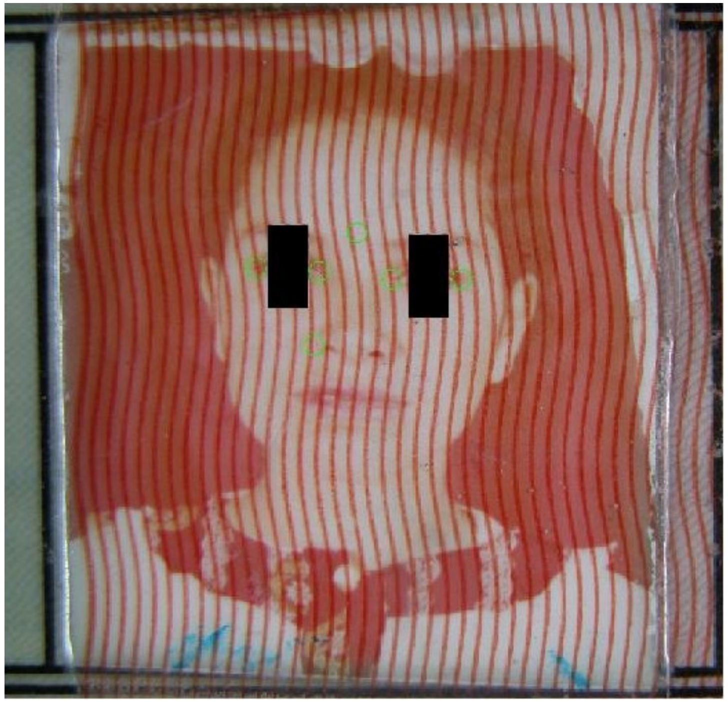
4. First stage: 3D skull model reconstruction

5. Second stage: Skull-face overlay

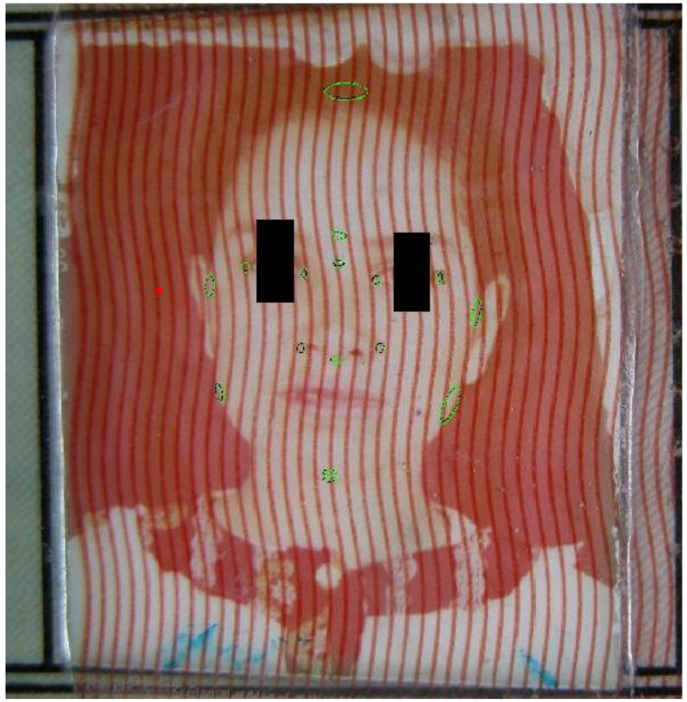
6. Conclusions

- Very complex real case. Cádiz (Spain). Single, low quality, passport photo:





6 crisp landmarks



16 fuzzy landmarks

Fuzzy landmarks experiments (XI)

OVERVIEW

Morocco case study: Overlays comparison

Manual

Area deviation error: 31.73%

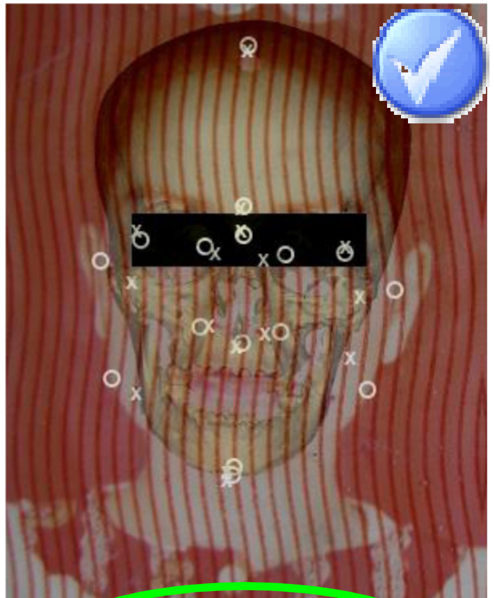
24 hours

CMA-ES

Area deviation error: 32.63%

15 seconds

Fuzzy CMA-ES



Area deviation error: 11.92%

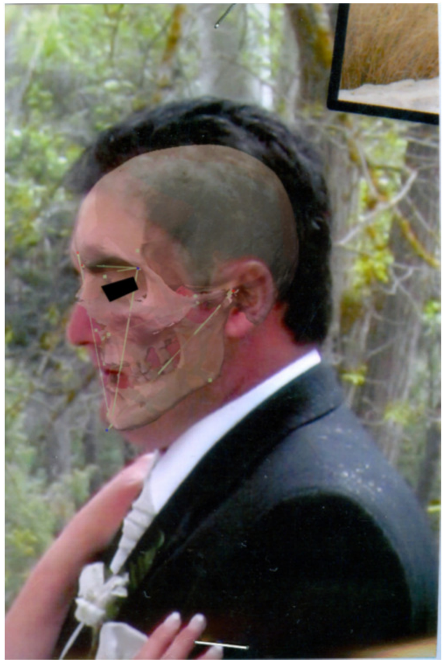
2-4 minutes

OVERVIEW

1. Forensic identification (FI) by craniofacial superimposition
2. Image Registration (IR)
3. IR, Uncertainty and FI = Soft Computing
4. First stage: 3D skull model reconstruction
5. **Second stage: Skull-face overlay**
6. Conclusions

- Another real case (Granada, Spain):

Manual superimposition



Area deviation error: 13.81%

24 hours

Fuzzy CMA-ES superimposition

Area deviation error: 4.73%

2-4 minutes

Fuzzy landmarks experiments (XIII)

- Last real case (Alhambra surroundings, Granada, Spain):

Manual superimposition

Area deviation error: 28.26%

24 hours

Fuzzy CMA-ES superimposition

Area deviation error: 21.79%

2-4 minutes

5. Skull-face overlay using EAs and fuzzy logic
Fuzzy landmarks experiments (XIV)

OVERVIEW

- Last real case (second photograph):

Manual superimposition

Area deviation error: 37.54%

24 hours

Fuzzy CMA-ES superimposition

Area deviation error: 21.04%

2-4 minutes

6. Conclusions

OVERVIEW

- We have tackled the automation of the forensic identification by craniofacial superimposition in order to assist the forensic anthropologist
- Soft computing is really suitable for this task given the intrinsic characteristics of this identification technique
- Future works:
  - a web-based poll is being developed with forensic experts to estimate the landmark location variability
  - we will tackle the uncertainty in landmark matching shortly

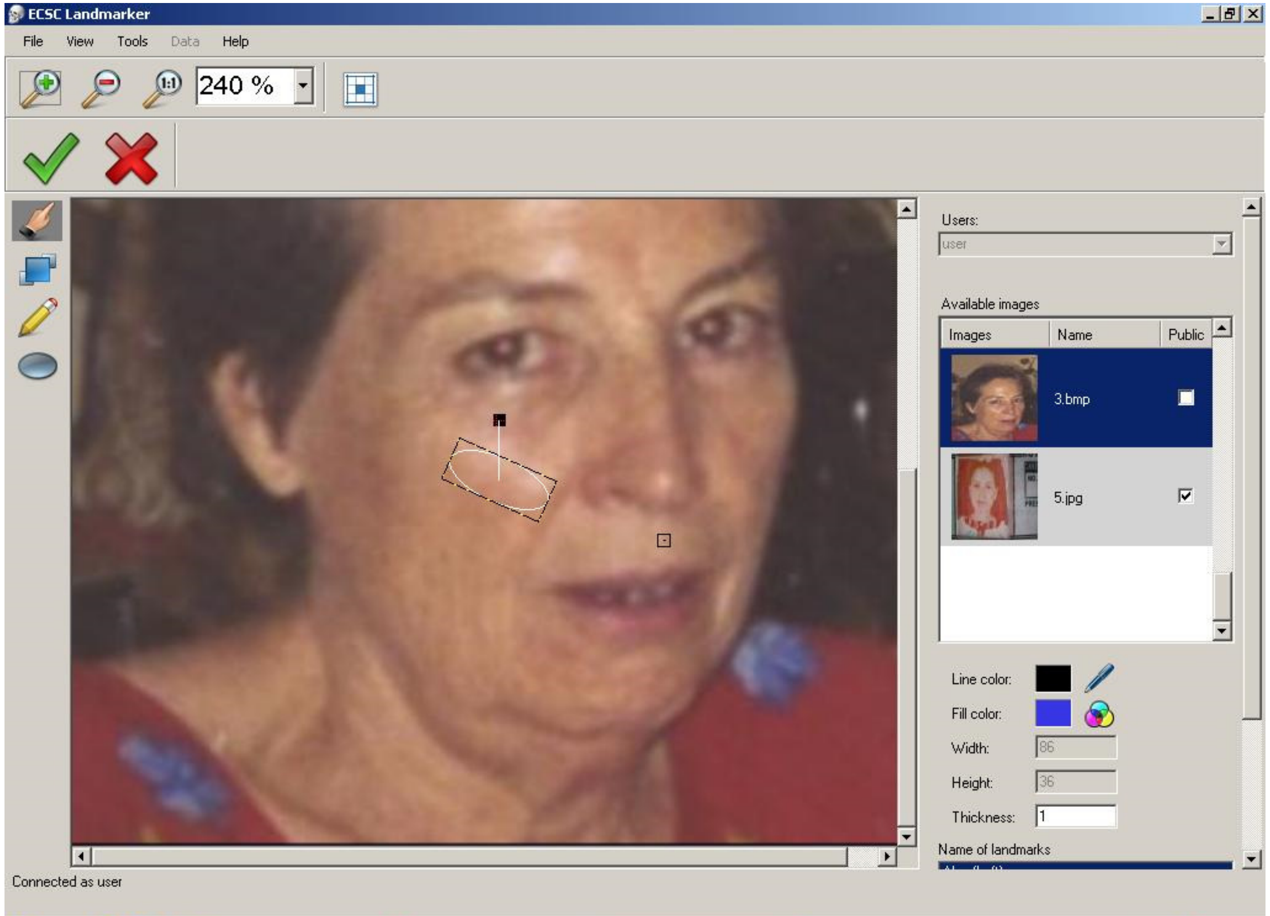
OVERVIEW

- Our techniques have been already used in the identification of a real-world case
- We aim to properly model old-fashioned cameras to tackle identification cases related to the Spain's civil war
- A web site has been developed for the project: www.softcomputing.es/socovifi
- A patent was submitted to the Spanish Agency in July, 2009

6. Conclusions
Software package

OVERVIEW

1. Forensic identification (FI) by craniofacial superimposition
2. Image Registration (IR)
3. IR, Uncertainty and FI = Soft Computing
4. First stage: 3D skull model reconstruction
5. Second stage: Skull-face overlay
6. **Conclusions**



Main publications

- S. Damas, O. Cordón, O. Ibáñez, J. Santamaría, I. Alemán, MC. Botella, F. Navarro. Forensic identification by computer-aided craniofacial superimposition: A survey. ACM Journal on Computing (2010), to appear. IF 2008: 9.920. Category: Computer Science, Theory & Methods. Order: 1/84.

- O. Ibáñez, L. Ballerini, O. Cordón, S. Damas, and J. Santamaría (2009). An experimental study on the applicability of evolutionary algorithms to craniofacial superimposition in forensic identification. Information Sciences 179, 3998–4028. IF 2008: 3.095. Category: Computer Science, Information Systems. Order: 8/99.

- J. Santamaría, O. Cordón, S. Damas, and O. Ibáñez (2009). Tackling the coplanarity problem in 3D camera calibration by means of fuzzy landmarks: a performance study in forensic craniofacial superimposition. In IEEE International Conference on Computer Vision, 3DIM, Kyoto, Japan, pp. 1686–1693.

- J. Santamaría, O. Cordón, S. Damas, J.M. García-Torres, A. Quirin. Performance Evaluation of Memetic Approaches in 3D Reconstruction of Forensic Objects. Soft Computing 13: 8-9 (2009) 883-904. IF 2008: 0.984.

- J. Santamaría, O. Cordón, S. Damas, I. Alemán, M. Botella. A Scatter Search-based Technique for Pair-Wise 3D Image Registration in Forensic Anthropology. Soft Computing 11:9 (2007) 819-828. IF: 0. 607.

6. Conclusions
Research team

OVERVIEW

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Thank you for your attention

Questions ?