How to build an average model when samples are variably incomplete? Application to fossil data

Jean Dumoncel[1], Gérard Subsol[2], Stanley Durrleman[3],
Jean-Pierre Jessel[4], Amélie Beaudet[5], José Braga[1]

7th International Workshop on Biomedical Image Registration
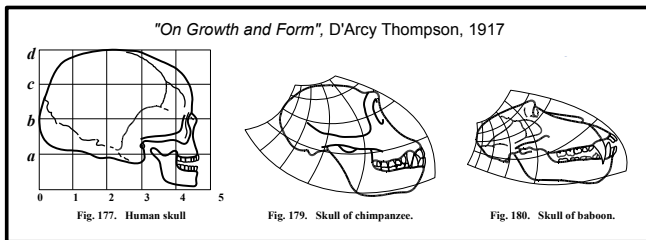
CVPR 2016 Las Vegas, Nevada, USA

INTRODUCTION

Paleontology :

- ▸ Study of morphology and morphometry.
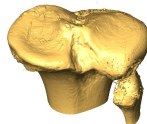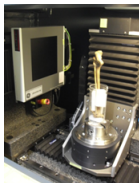
3D reconstruction of a bone by tomographic acquisition

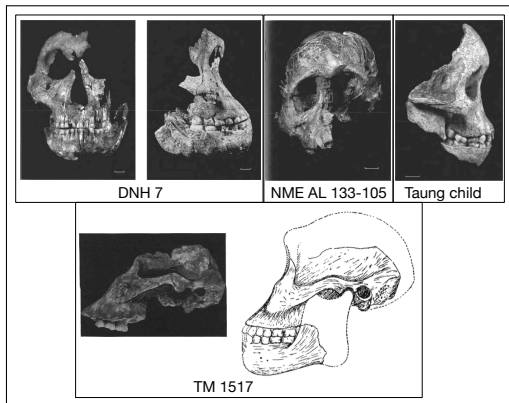- ▸ Taxonomy: naming and classifying organisms.

"On Growth and Form", D'Arcy Thompson, 1917

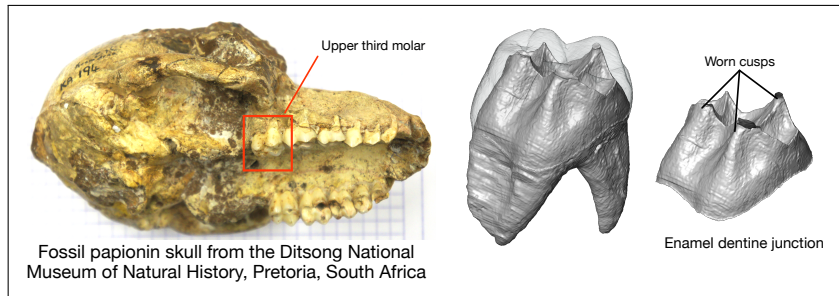Fig. 177. Human skull   Fig. 179. Skull of chimpanzee.   Fig. 180. Skull of baboon.

INTRODUCTION

- Alteration of the geometry of the samples by biological modifications or post-mortem taphonomic processes.
- How to deal with **missing parts** ?


Broom et al. 1938, Schwartz et al. 2011

INTRODUCTION

An example of missing data

- ► Material : enamel-dentine junction of fossil teeth (≈ 2 million years) to be compared to living baboon teeth.
- ► Analysis of the enamel dentine junction which characterizes the tooth shape.
- ► Problem of enamel and dentine loss due to dental wear => **Missing parts** problem.

Upper third molar

Worn cusps

Fossil papionin skull from the Ditsong National Museum of Natural History, Pretoria, South Africa

Enamel dentine junction

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OOOOOOOO

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MORPHOMETRIC METHODS

- Geometric Morphometrics based on a limited set of landmark positions.

Beaudet 2015

- Surface-based morphometrics which implies to find automatically the correspondences all over the surface.
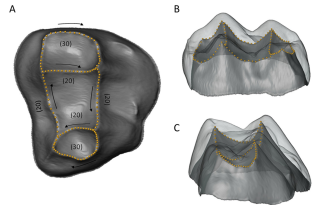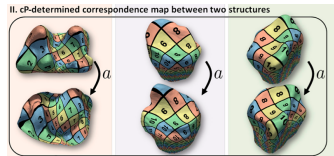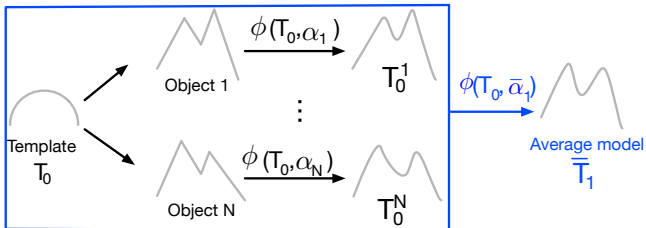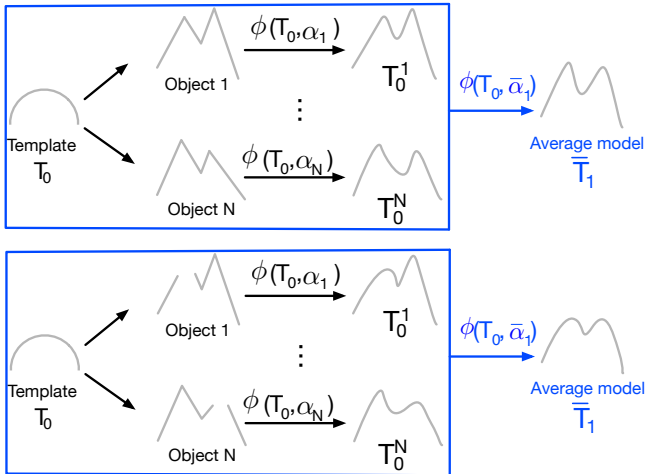

Boyer et al. 2011

REGISTRATION METHODOLOGY

Based on Deformetrica (http://www.deformetrica.org),
Durrleman et al. 2014.

(Registration)

1. STANDARD AVERAGE

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1. STANDARD AVERAGE

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ooooooooo

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1. STANDARD AVERAGE

$$\phi(T_0, \alpha_1)$$

Object 1 $\qquad$ T_0^1

$\phi(T_0, \bar{\alpha}_1)$

$\phi(T_0, \alpha_N)$

Object N $\qquad$ T_0^N

Template T_0

Average model $\overline{\overline{T}}_1$

$\phi(T_0, \alpha_1)$

Object 1 $\qquad$ T_0^1

$\phi(T_0, \bar{\alpha}_1)$

$\phi(T_0, \alpha_N)$

Object N $\qquad$ T_0^N

Template T_0

Average model $\overline{\overline{T}}_1$
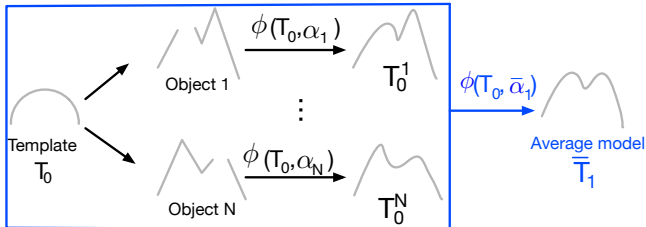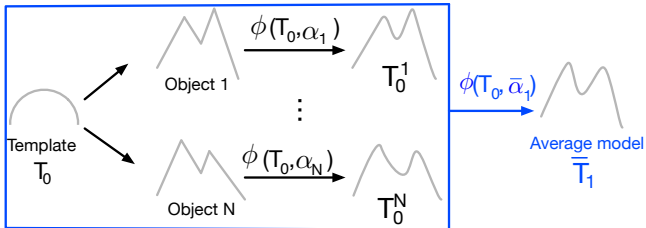
How can the optimum average be evaluated when
samples present missing parts ?

[Duci et al. "Region matching with missing parts". Image and Vision Computing, 2006.]

2. Not taking into account the missing parts
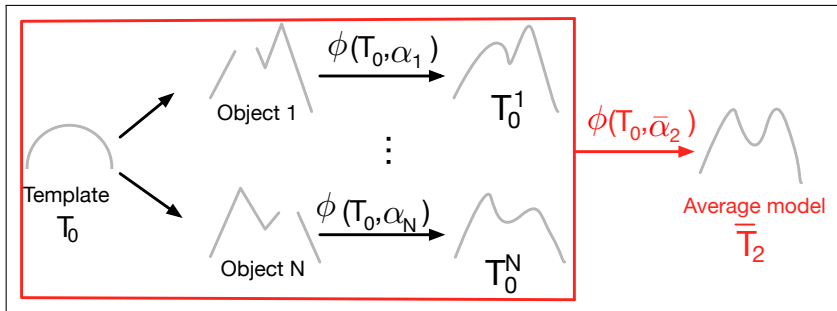
2. NOT TAKING INTO ACCOUNT THE MISSING PARTS
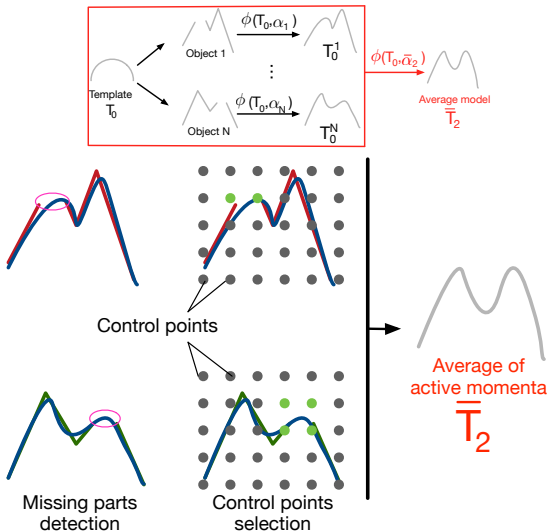
3. COMMON PARTS ONLY

3. COMMON PARTS ONLY

Object 1
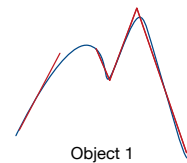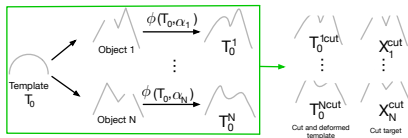

Object N
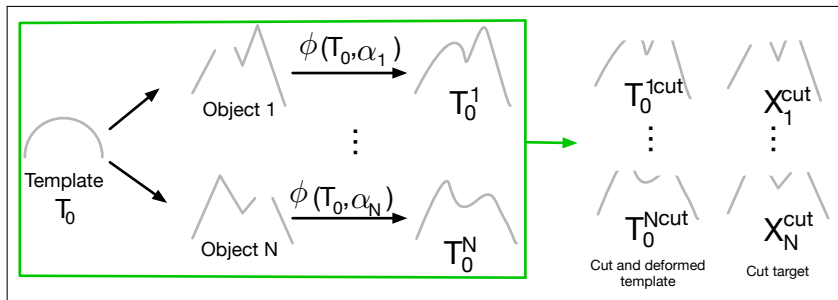
Registration
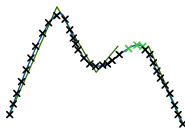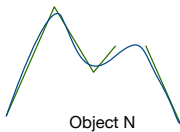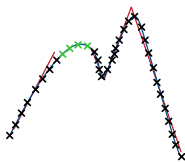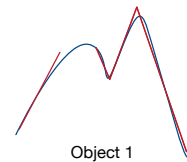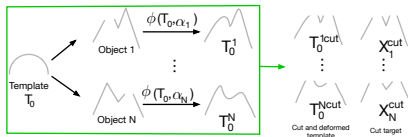
3. COMMON PARTS ONLY

Registration   Detection of
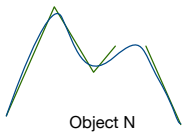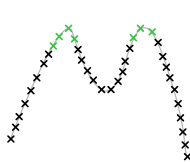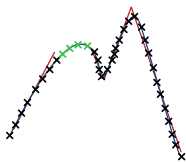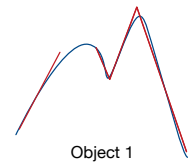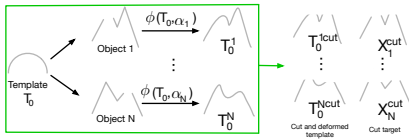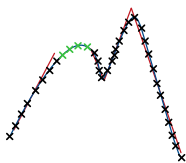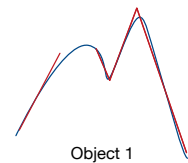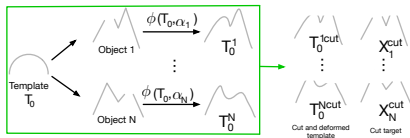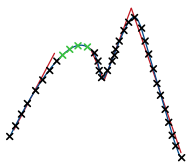   missing parts

3. COMMON PARTS ONLY
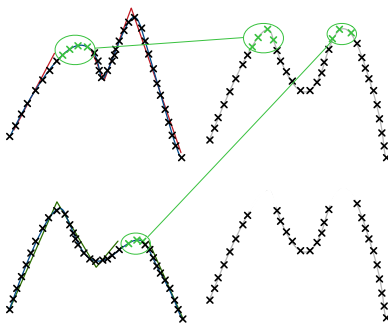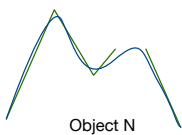
Registration   Detection of missing parts   Average shape
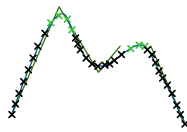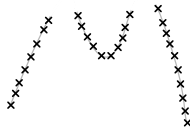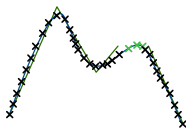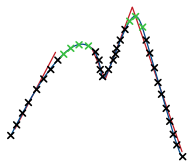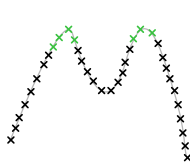
3. COMMON PARTS ONLY

Registration   Detection of missing parts   Average shape
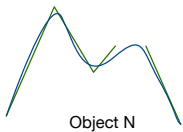
3. COMMON PARTS ONLY

Registration   Detection of missing parts   Average shape
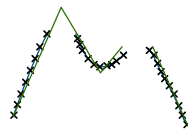
3. COMMON PARTS ONLY
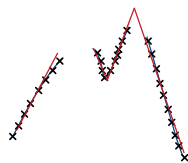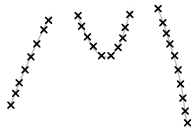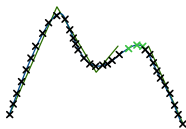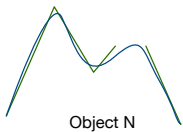

| Registration | Detection of missing parts | Average shape | Cut objects |

DATABASE

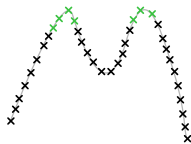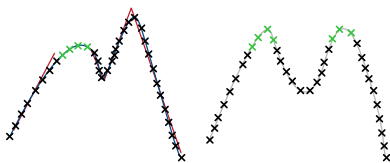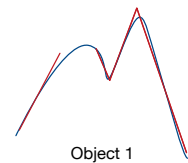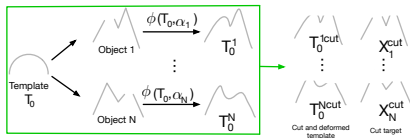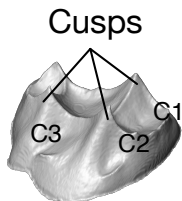- μ-CT acquisitions performed at Necsa (South Africa) and CIRIMAT (France).
- Resolution: $\simeq 70\mu$m.
- Study of the missing part influence on 3 cusps.
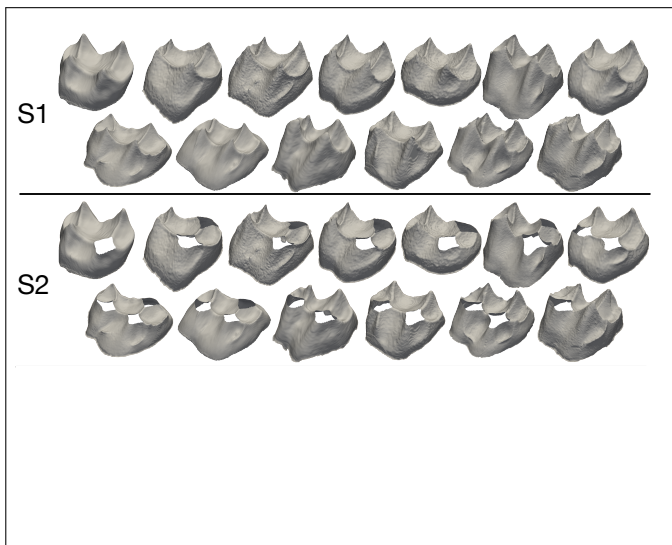
(EDJ segmentation)
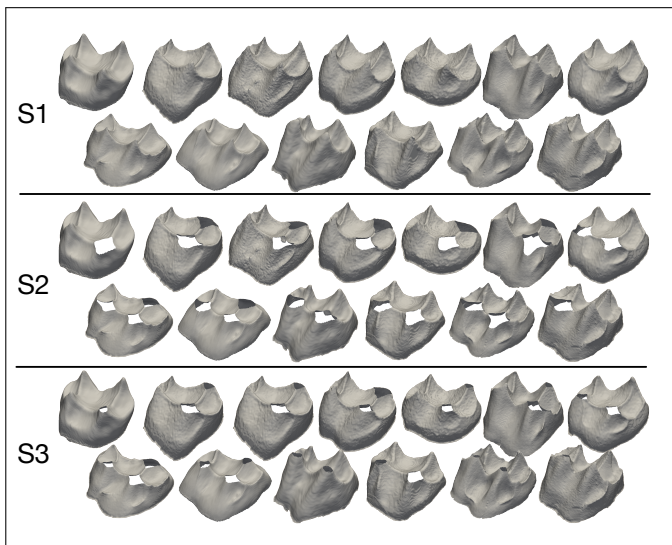
Cusps

DATABASE

First sample : 13 complete surfaces

DATABASE

Second sample : 13 manually cut surfaces

DATABASE

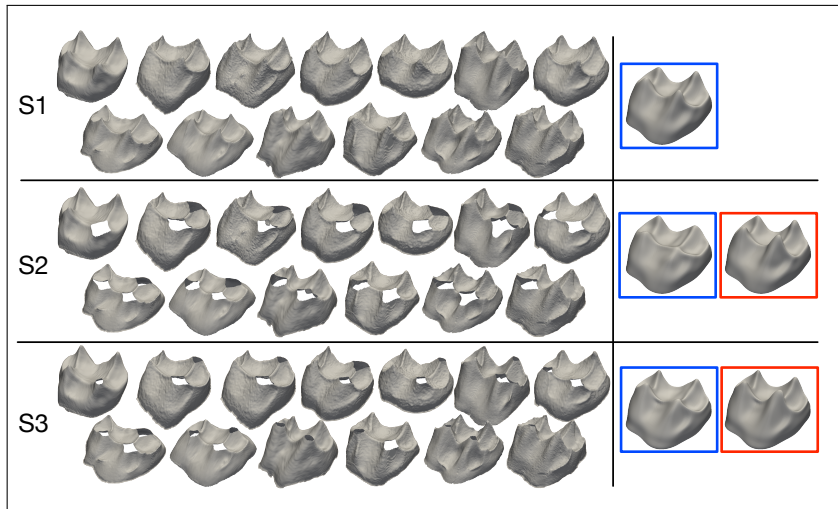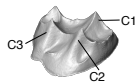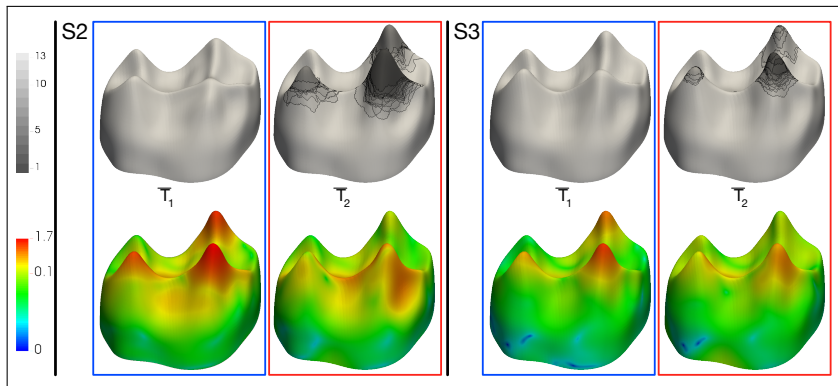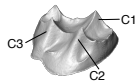Third sample : 13 manually cut surfaces

RESULTS

☐ Result with standard average
☐ Result with our average procedure

COMPARISON WITH THE GROUND-TRUTH COMPLETE DATASET

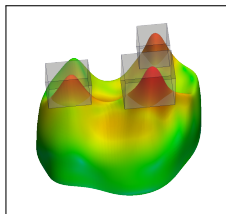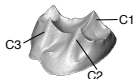□ Result with standard average
□ Result with our average procedure

Top: Number of samples used to compute the average shape.
Bottom: distance maps between the ground-truth shape and the average shapes with incomplete samples.

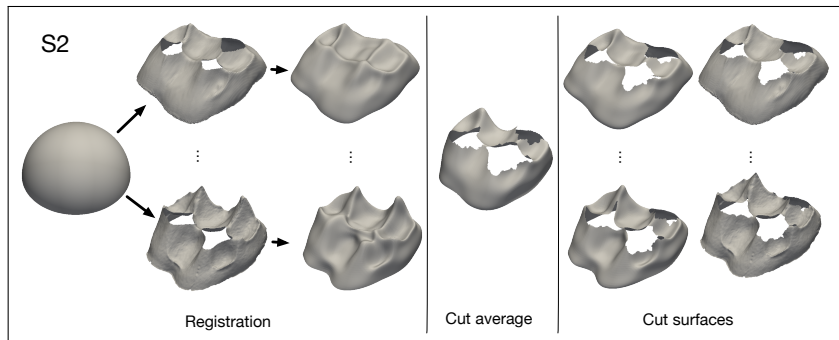# COMPARISON WITH THE GROUND-TRUTH COMPLETE DATASET

□ Result with standard average
□ Result with our average procedure

		All	Cusp 1	Cusp 2	Cusp 3
S2	□	0.11 (0.21)	0.47 (0.18)	0.81 (0.38)	0.58 (0.23)
	□	0.10 (0.13)	0.18 (0.09)	0.42 (0.17)	0.06 (0.03)
S3	□	0.05 (0.10)	0.15 (0.07)	0.40 (0.22)	0.25 (0.11)
	□	0.05 (0.07)	0.15 (0.08)	0.24 (0.12)	0.05 (0.02)

The mean (and standard deviation) of the distances between the average shape of S1 and the average shapes of S2 and S3

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ELIMINATION OF NON-COMMON PARTS

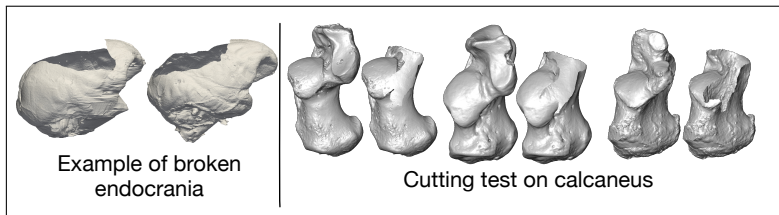Registration   Cut average   Cut surfaces

CONCLUSION

Our method contributes to:

- ▸ the inclusion of damaged specimens in morphometrical analyses.
- ▸ a more accurate evaluation of the paleobiodiversity.

Perspectives:

- ▸ anatomical variant.
- ▸ influence of the parameters.
- ▸ application on endocrania and bones (calcaneus).

Example of broken endocrania   Cutting test on calcaneus

THANK YOU FOR YOUR ATTENTION!