



Univerzita Hradec Králové
Filozofická fakulta

E-learningový kurz

Modern quantitative methods
and shape analysis in archaeology



EVROPSKÁ UNIE
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání



MINISTERSTVO ŠKOLSTVÍ,
MLÁDEŽE A TĚLOVÝCHOVY

Tento materiál vznikl v rámci realizace projektu
Strategický rozvoj Univerzity Hradec Králové,
reg. č. CZ.02.2.69/0.0/0.0/16_015/0002427.

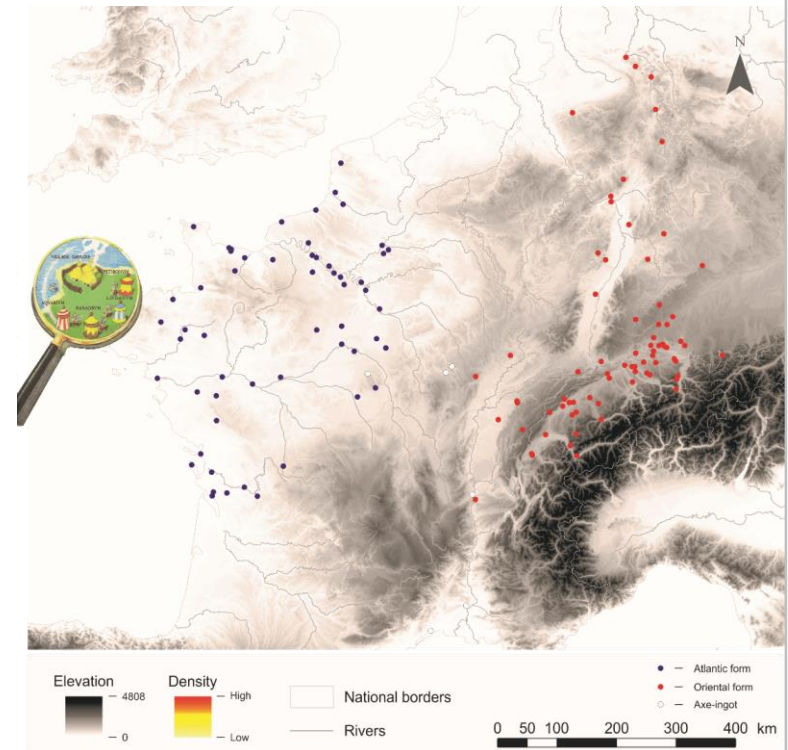
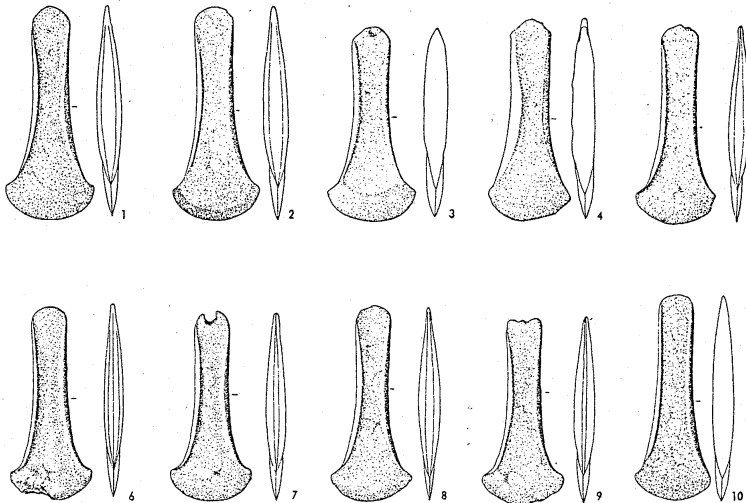
Outline analyses

Practice



EVROPSKÁ UNIE
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání

Middle Bronze Age axes (1650-1350 BC)



Quantitative comparison of Flanged Axes

Questions:

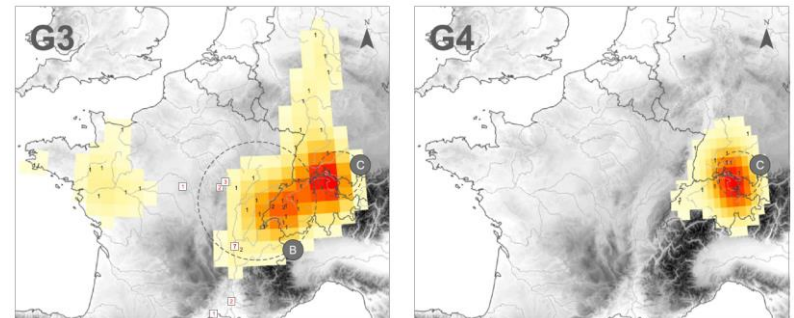
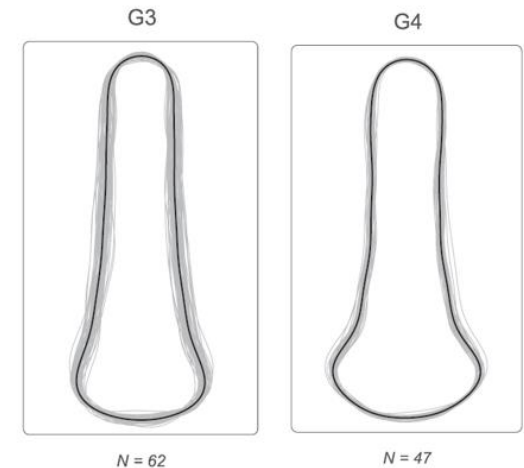
- Are two groups of axes obtained by using GM and GMM different?

Dataset

- 30 axes (out of 62) of group G3
- 30 axes (out of 47) of group G4

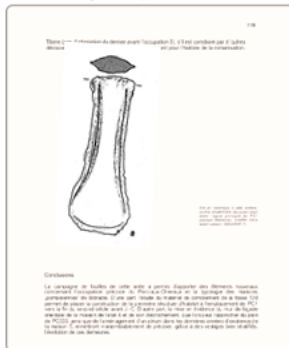
Procedure

- Digitize outlines
- Perform Elliptic Fourier Analysis (EFA)
- Perform Principal Component Analysis (PCA)
- Perform Linear Discriminant Analysis (LDA)
- Perform MANOVA



Original procedure

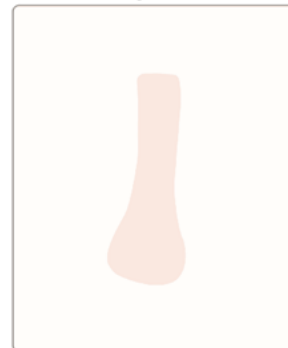
Original publication



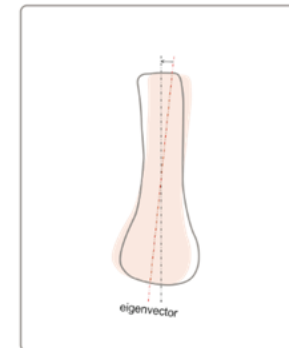
Retracing and scanning at 300 dpi



Extracting of silhoulett



Vertical orientation



Sampling 200 points



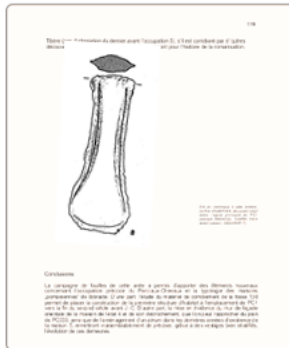
EFA

$$x(t) = a_0 + \sum_{j=1}^k a_j \cos\left(\frac{2j\pi t}{T}\right) + \sum_{j=1}^k b_j \sin\left(\frac{2j\pi t}{T}\right)$$

$$y(t) = c_0 + \sum_{j=1}^k a_j \cos\left(\frac{2j\pi t}{T}\right) + \sum_{j=1}^k d_j \sin\left(\frac{2j\pi t}{T}\right)$$

Original procedure

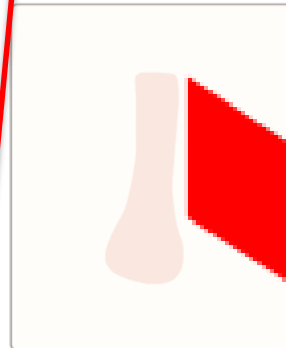
Original publication



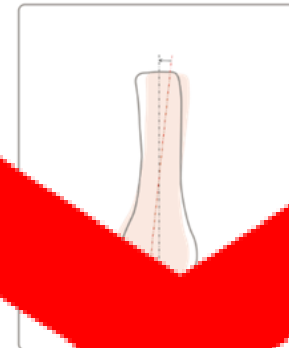
Retracing and scanning at 300 dpi



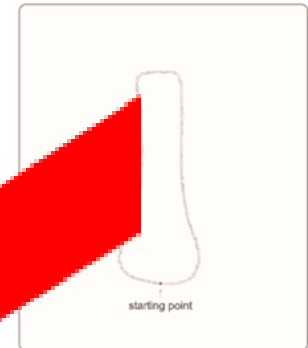
Extracting of silhoulett



Vertical orientation



Sampling 200 points



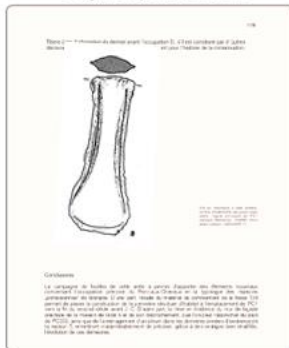
EFA

$$x(t) = a_0 + \sum_{j=1}^k a_j \cos\left(\frac{2j\pi t}{T}\right) + \sum_{j=1}^k b_j \sin\left(\frac{2j\pi t}{T}\right)$$

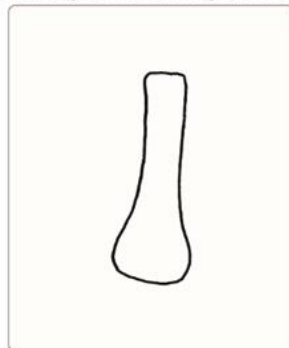
$$y(t) = c_0 + \sum_{j=1}^k a_j \cos\left(\frac{2j\pi t}{T}\right) + \sum_{j=1}^k d_j \sin\left(\frac{2j\pi t}{T}\right)$$

Original procedure

Original publication



Retracing and scanning at 300 dpi



ALT.tif



BEG.tif



BOH6.tif



BRO.tif



CAE1.tif



CHO1.tif



CSF.tif



FUL.tif



HID1.tif



HID2.tif



HID3.tif



KAS.tif



KIR.tif



LUC.tif



MDS4.tif



MOR.tif



NUS.tif



REG.tif



RHE.tif



SAL.tif



SEN22.tif



SEN23.tif



SEN25.tif



SPF.tif



TRM.tif



UNT2.tif



VIN1.tif



VUM1.tif



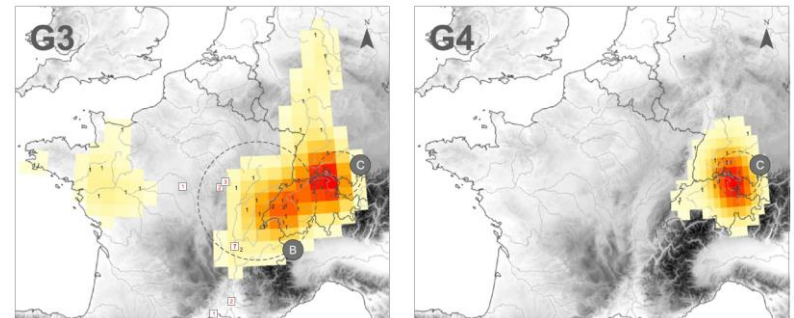
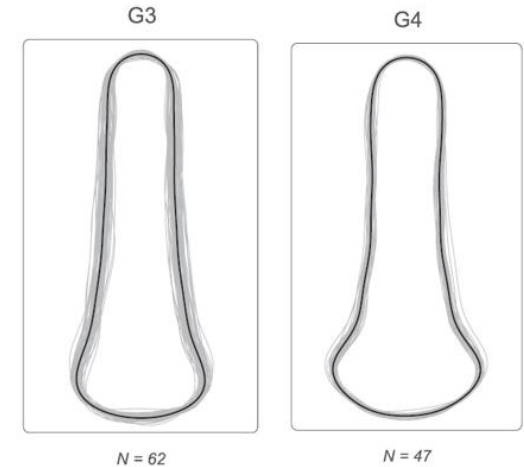
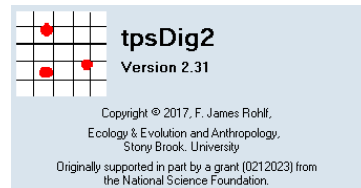
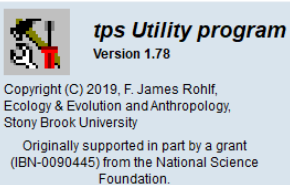
VUM2.tif



WID.tif

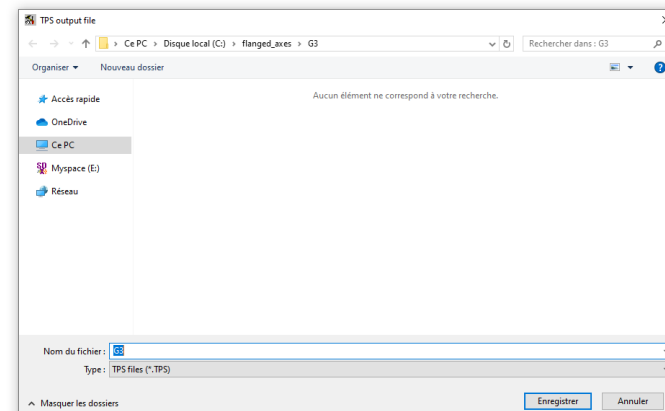
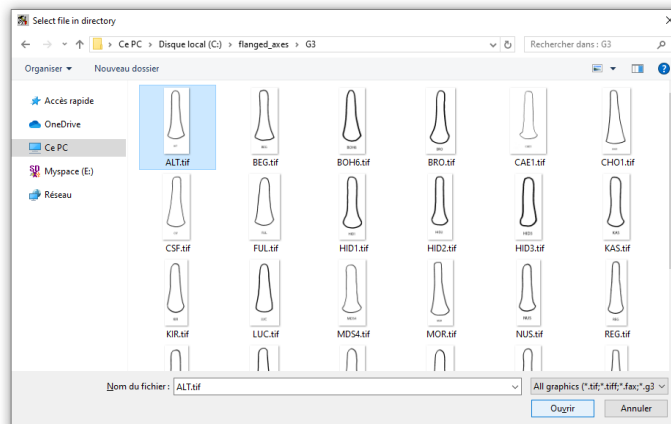
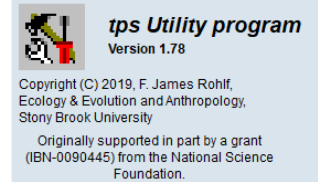
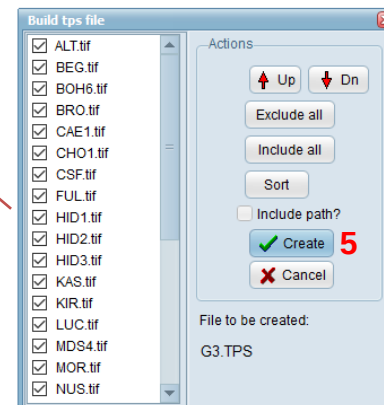
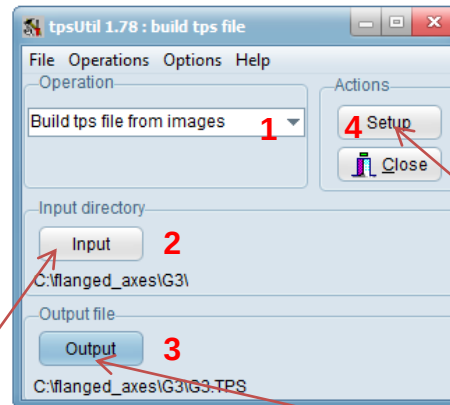
Software

- tps: <https://life.bio.sunysb.edu/morph/>
- PAST: <https://folk.uio.no/ohammer/past/>



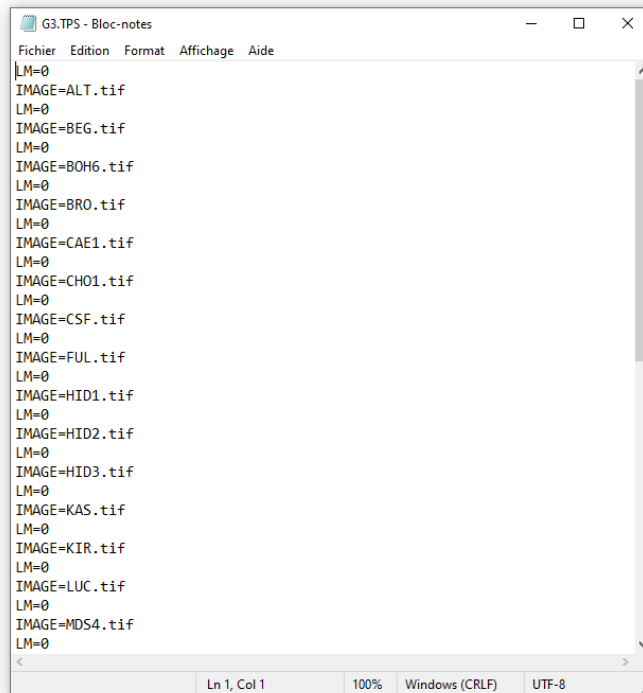
Digitize outlines

- TPS files
- for both groups of axes

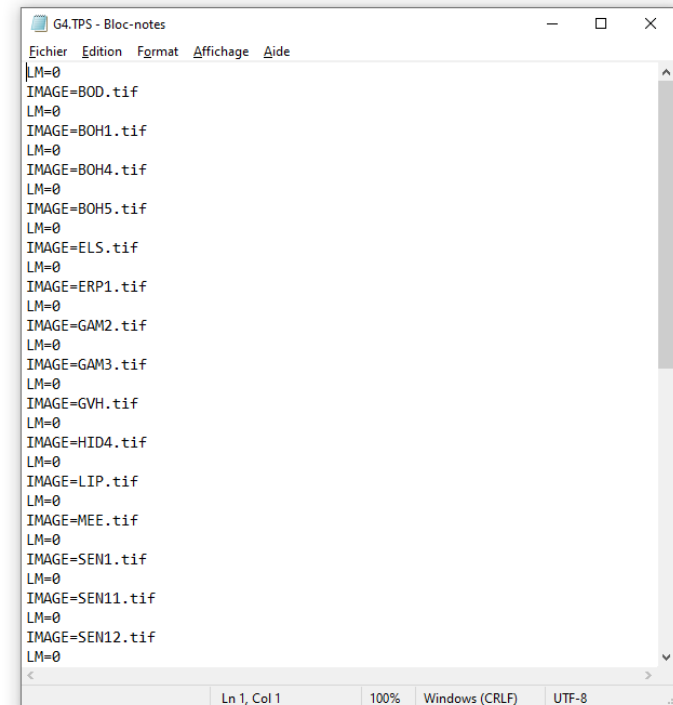


Digitize outlines

- TPS files



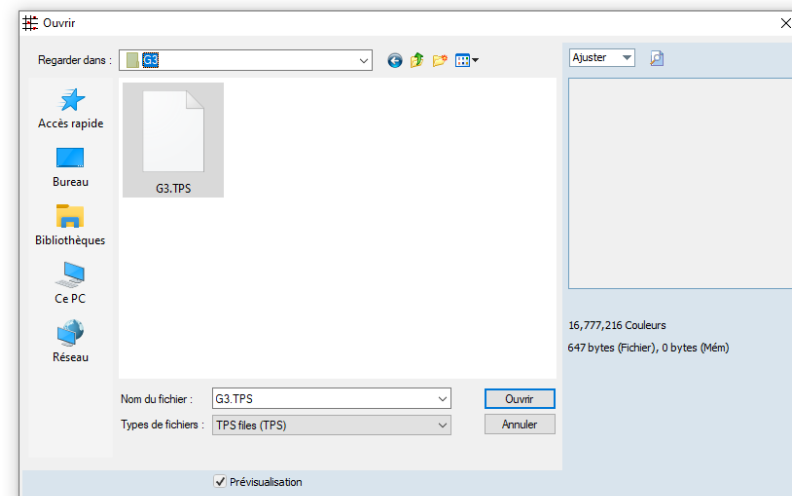
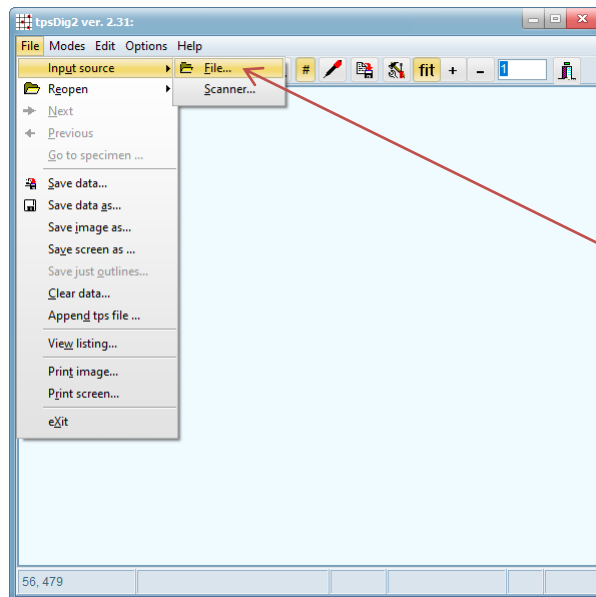
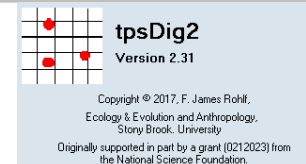
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G3.TPS - Bloc-notes
Fichier Edition Format Affichage Aide
LM=0
IMAGE=ALT.tif
LM=0
IMAGE=BEG.tif
LM=0
IMAGE=BOH6.tif
LM=0
IMAGE=BRO.tif
LM=0
IMAGE=CAE1.tif
LM=0
IMAGE=CHO1.tif
LM=0
IMAGE=CSF.tif
LM=0
IMAGE=FUL.tif
LM=0
IMAGE=HID1.tif
LM=0
IMAGE=HID2.tif
LM=0
IMAGE=HID3.tif
LM=0
IMAGE=KAS.tif
LM=0
IMAGE=KIR.tif
LM=0
IMAGE=LUC.tif
LM=0
IMAGE=MDS4.tif
LM=0
```



```
G4.TPS - Bloc-notes
Fichier Edition Format Affichage Aide
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LM=0
IMAGE=BOH1.tif
LM=0
IMAGE=BOH4.tif
LM=0
IMAGE=BOH5.tif
LM=0
IMAGE=ELS.tif
LM=0
IMAGE=ERP1.tif
LM=0
IMAGE=GAM2.tif
LM=0
IMAGE=GAM3.tif
LM=0
IMAGE=GVH.tif
LM=0
IMAGE=HID4.tif
LM=0
IMAGE=LIP.tif
LM=0
IMAGE=MEE.tif
LM=0
IMAGE=SEN1.tif
LM=0
IMAGE=SEN11.tif
LM=0
IMAGE=SEN12.tif
LM=0
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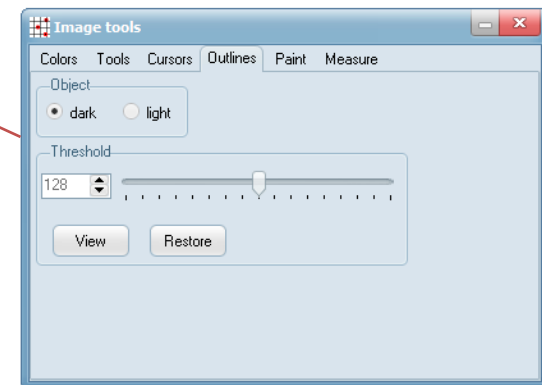
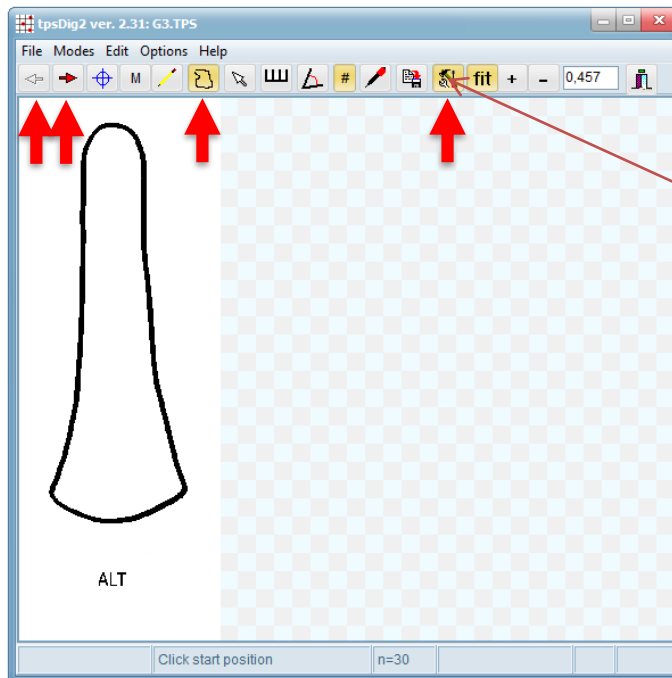
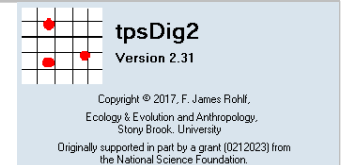
Digitize outlines

- TPS files



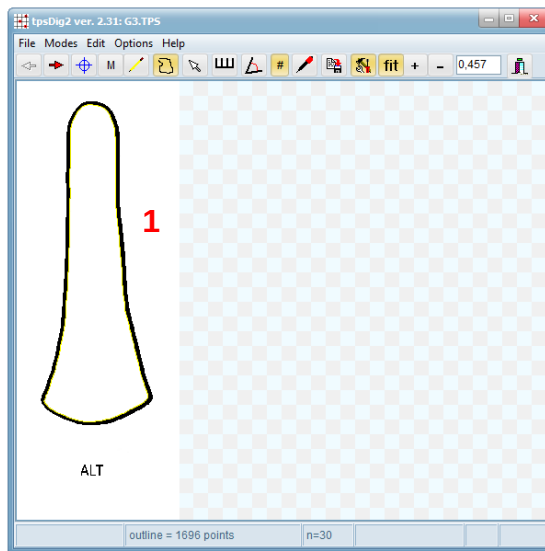
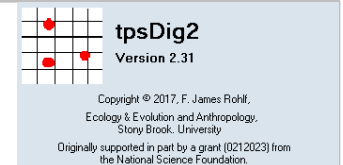
Digitize outlines

- TPS files
- little bit more complicated (when working with photos), fortunately not our case

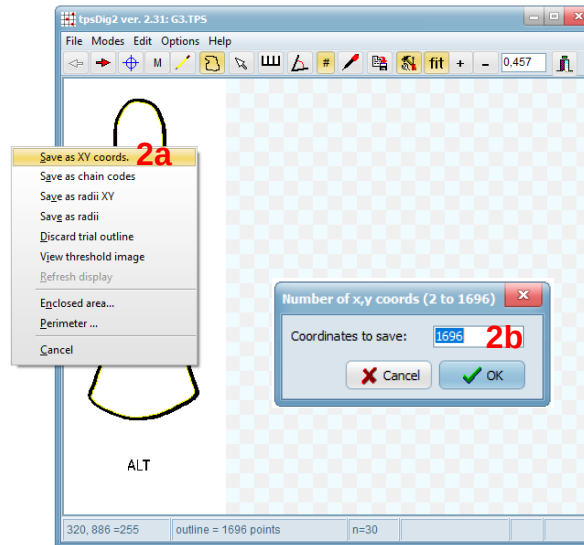


Digitize outlines

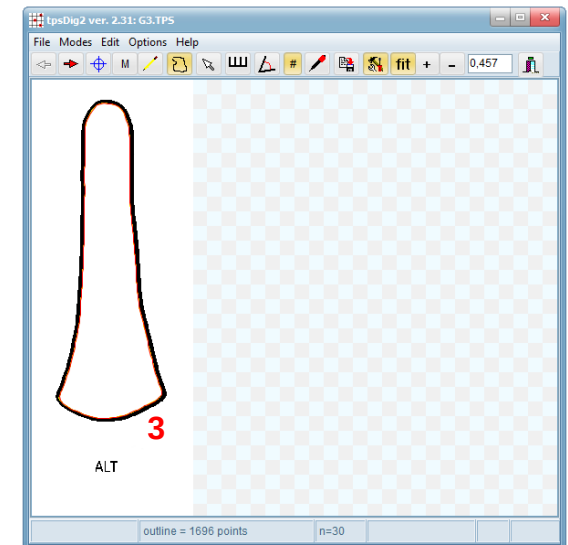
- TPS files
- little bit more complicated then landmarks



1. Left click on image
(outline gets yellow)
KIR SAL



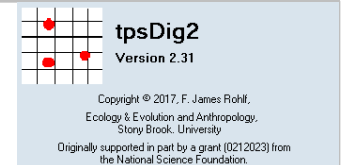
- 2a. Right click on image and select
"Save as XY coords".
- 2b. Specify number of coordinates: 200



3. (if ok, outline gets red)

Digitize outlines

- TPS files



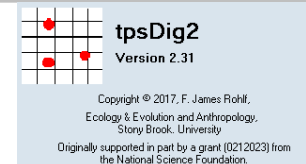
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G3.TPS - Bloc-notes
Fichier Edition Fgmat Affichage Aide
LM=0
OUTLINES=1
POINTS=200
235 891
235 900
235 908
234 917
233 925
232 934
230 942
227 951
224 959
221 968
215 976
208 983
200 987
191 989
183 991
174 992
166 991
157 987
149 980
143 971
138 963
134 954
131 946
129 937
128 929
128 920
Ln 1, Col 1 100% Windows (CRLF) UTF-8
```

```
G4.TPS - Bloc-notes
Fichier Edition Format Affichage Aide
LM=0
OUTLINES=1
POINTS=200
224 638
223 643
222 649
221 654
218 660
213 665
207 670
202 672
196 675
191 677
185 679
180 679
174 677
169 674
164 671
158 666
153 663
148 657
146 652
144 646
142 641
142 635
141 630
141 624
141 619
141 613
Ln 10, Col 8 100% Windows (CRLF) UTF-8
```

Digitize outlines

- TPS files

Attention, be sure that each individual has OUTLINES=1 and this outline is defined by POINTS=200 and not by RADII, RADIIXY, or by CHAIN.



G3.TPS - Bloc-notes

Fichier Edition Format Affichage Aide

LM=0
 OUTLINES=1
 POINTS=200

235 891
 235 900
 235 908
 234 917
 233 925
 232 934
 230 942
 227 951
 224 959
 221 968
 215 976
 208 983
 200 987
 191 989
 183 991
 174 992
 166 991
 157 987
 149 980
 143 971
 138 963
 134 954
 131 946
 129 937
 128 929
 128 920

correct

Ln 1, Col 1 100% Windows (CRLF) UTF-8

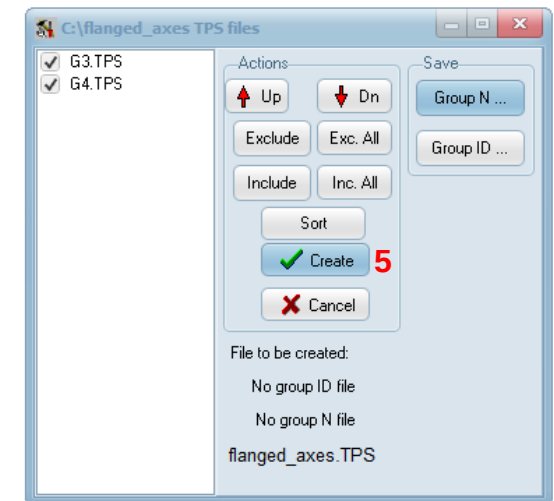
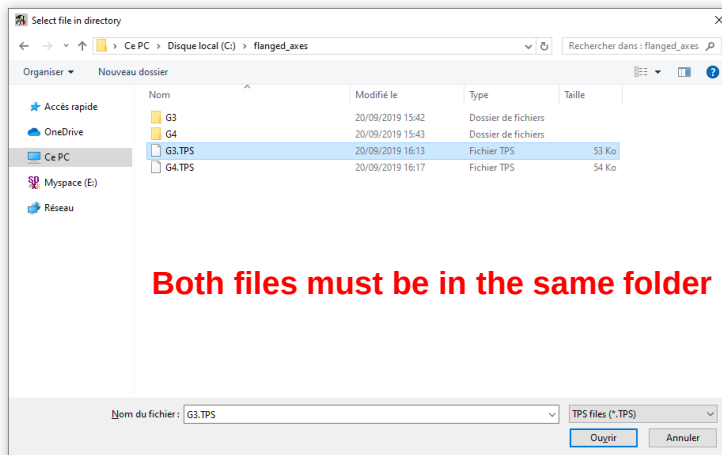
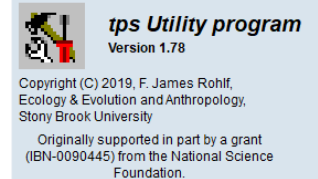
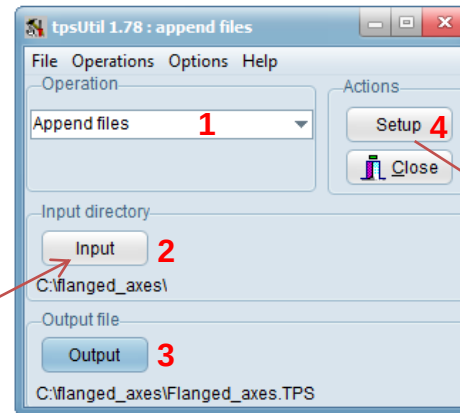
correct

[illegible]

incorrect

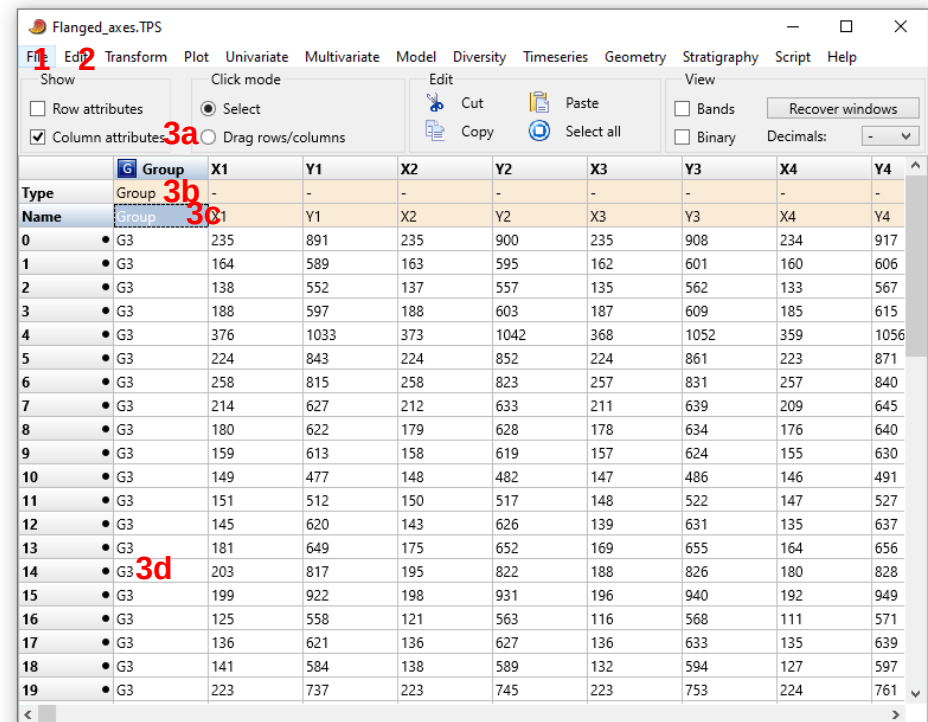
Append both TPS files

- Necessary for further analyses



Data preparation

- 1) Open file:
File >> Open >> Flanged_axes.TPS
- 2) Add grouping column for coin type:
Edit >> Insert more columns
- 3) Specify variable type of grouping column and fill it:
 - a) Check Column attributes in Show panel
 - b) Specify Type to Group
 - c) Specify Name of Variable (Optionally)
 - d) Fill group for each coin: 30 x G3, 30 x G4

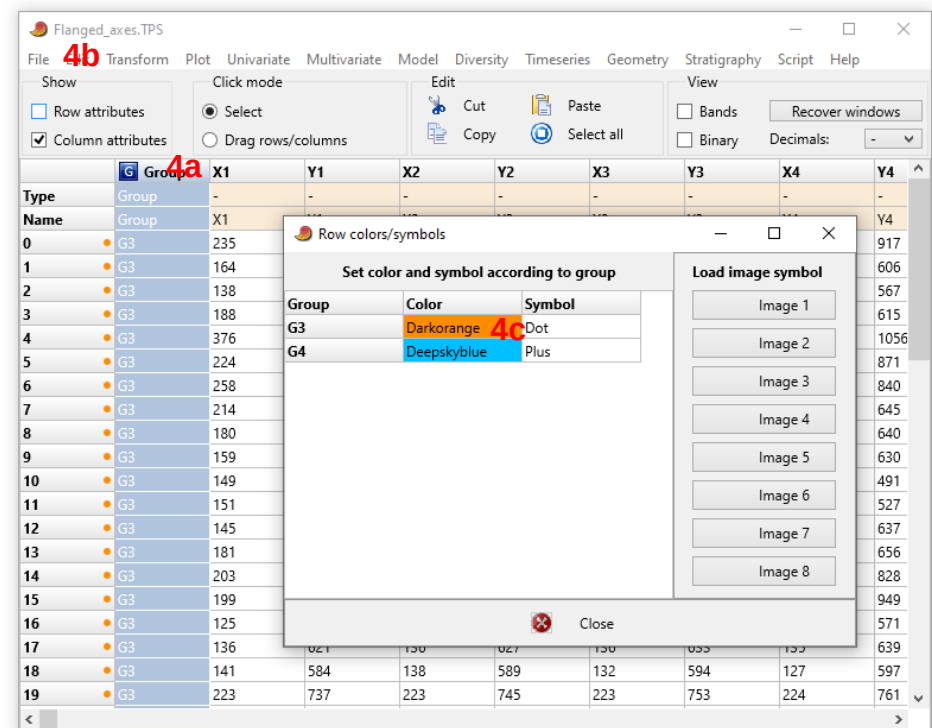


	Group	X1	Y1	X2	Y2	X3	Y3	X4	Y4
0	G3	235	891	235	900	235	908	234	917
1	G3	164	589	163	595	162	601	160	606
2	G3	138	552	137	557	135	562	133	567
3	G3	188	597	188	603	187	609	185	615
4	G3	376	1033	373	1042	368	1052	359	1056
5	G3	224	843	224	852	224	861	223	871
6	G3	258	815	258	823	257	831	257	840
7	G3	214	627	212	633	211	639	209	645
8	G3	180	622	179	628	178	634	176	640
9	G3	159	613	158	619	157	624	155	630
10	G3	149	477	148	482	147	486	146	491
11	G3	151	512	150	517	148	522	147	527
12	G3	145	620	143	626	139	631	135	637
13	G3	181	649	175	652	169	655	164	656
14	G3	203	817	195	822	188	826	180	828
15	G3	199	922	198	931	196	940	192	949
16	G3	125	558	121	563	116	568	111	571
17	G3	136	621	136	627	136	633	135	639
18	G3	141	584	138	589	132	594	127	597
19	G3	223	737	223	745	223	753	224	761

Data preparation



- 1) Open file:
File >> Open >> Flanged_axes.TPS
- 2) Add grouping column for coin type:
Edit >> Insert more columns
- 3) Specify variable type of grouping column and fill it:
 - a) Check Column attributes in Show panel
 - b) Specify Type to Group
 - c) Specify Name of Variable (Optionally)
 - d) Fill group for each coin: 30 x G3, 30 x G4
- 4) Specify colours for coins based on grouping column
 - a) Select grouping column
 - b) Edit >> Row colors/symbols
 - c) Adjust as you wish



Flanged_axes.TPS

File 4b Transform Plot Univariate Multivariate Model Diversity Timeseries Geometry Stratigraphy Script Help

Show Click mode

☐ Row attributes ☒ Select ☐ Drag rows/columns

☒ Column attributes

Edit Cut Paste Copy Select all

View ☐ Bands ☐ Binary Decimals: -

Recover windows

4a

Type	Group	X1	Y1	X2	Y2	X3	Y3	X4	Y4
Name	Group	X1							
0	G3	235							
1	G3	164							
2	G3	138							
3	G3	188							
4	G3	376							
5	G3	224							
6	G3	258							
7	G3	214							
8	G3	180							
9	G3	159							
10	G3	149							
11	G3	151							
12	G3	145							
13	G3	181							
14	G3	203							
15	G3	199							
16	G3	125							
17	G3	136							
18	G3	141	584	138	589	132	594	127	597
19	G3	223	737	223	745	223	753	224	761

Row colors/symbols

Set color and symbol according to group

Group	Color	Symbol
G3	Darkorange 4c	Dot
G4	Deepskyblue	Plus

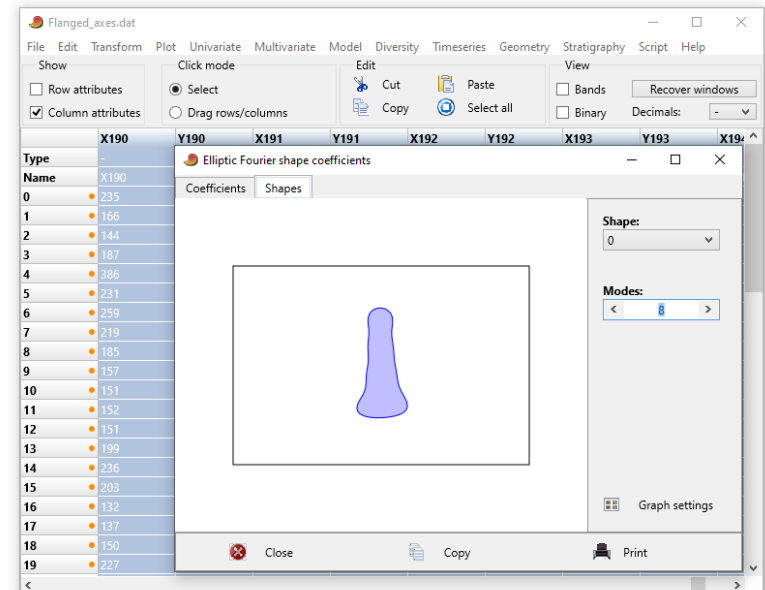
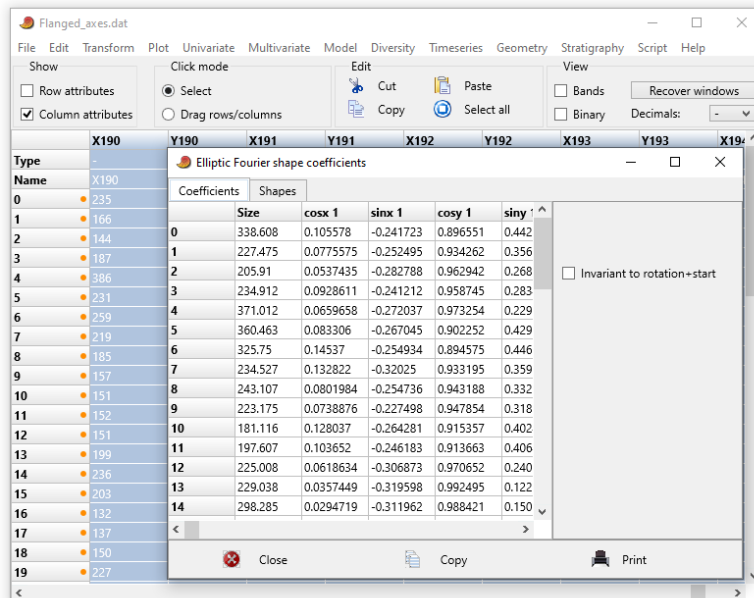
Load image symbol

Image 1
Image 2
Image 3
Image 4
Image 5
Image 6
Image 7
Image 8

Close

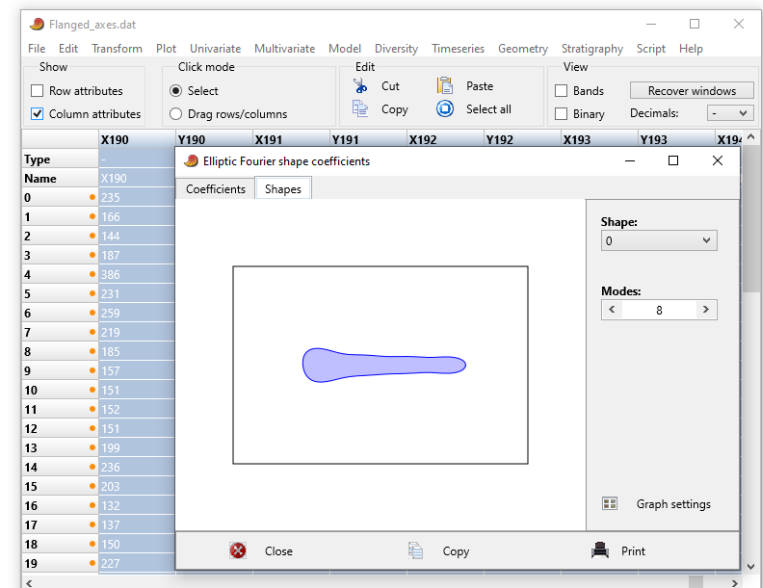
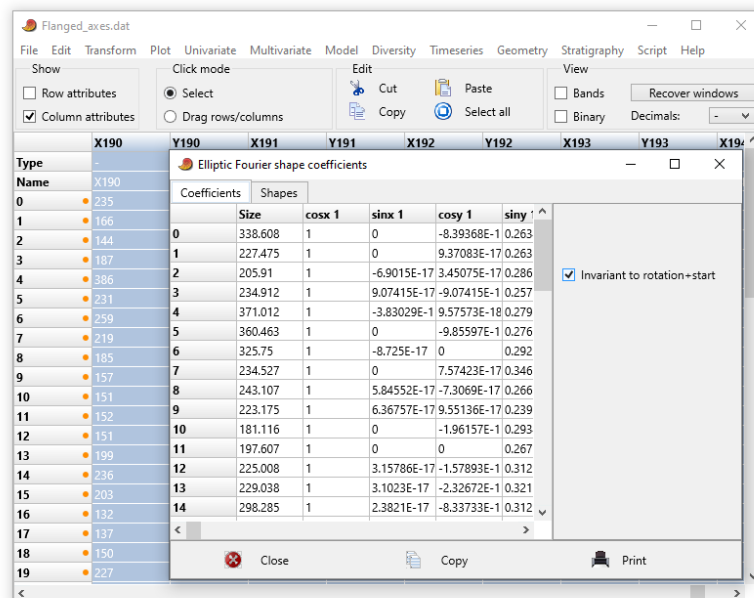
Elliptic Fourier Analysis (EFA)

Geometry >> Elliptic Fourier (2D outlines) >> EFA coefficients



Normalised Elliptic Fourier Analysis (NEFA)

Geometry >> Elliptic Fourier (2D outlines) >> EFA coefficients

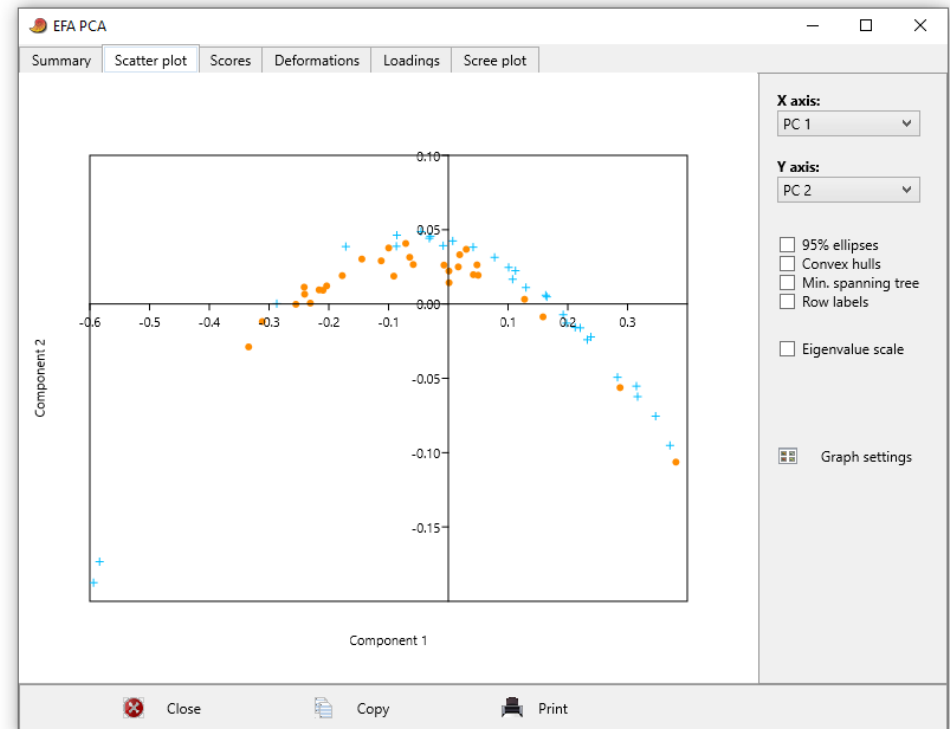
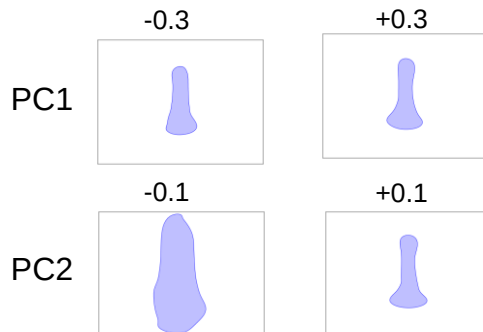


Principal Component Analysis (PCA)

Geometry >> Elliptic Fourier (2D outlines) >> EFA PCA
 specify number of harmonics used (Modes)
 specify **EFA** / NEFA

Description and discussion

- how much information we see in graphics?
- how many components are meaningful?
- **what is represented by the first PC?**
- **horse-shoe**
- are there differences between groups?
- are there outliers? If so, comment.
- ...

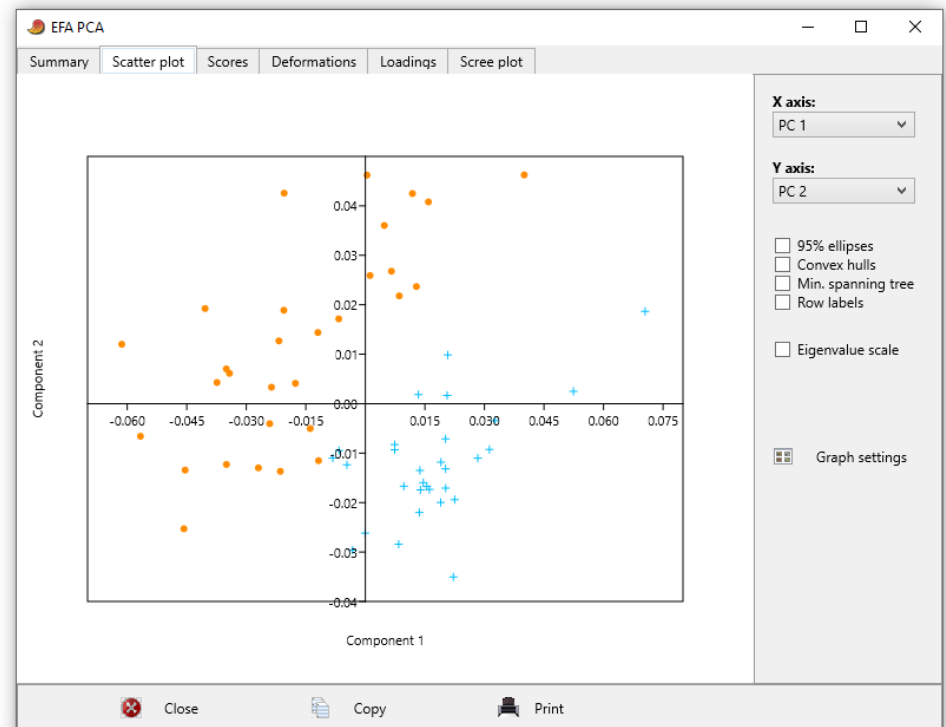
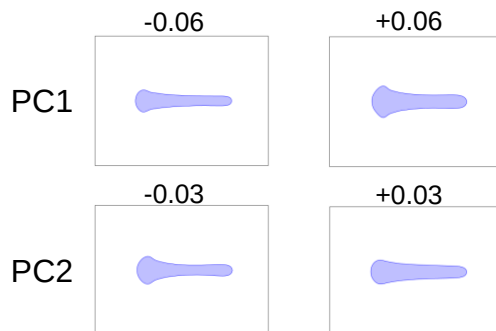


Principal Component Analysis (PCA)

Geometry >> Elliptic Fourier (2D outlines) >> EFA PCA
 specify number of harmonics used (Modes)
 specify EFA / **NEFA**

Description and discussion

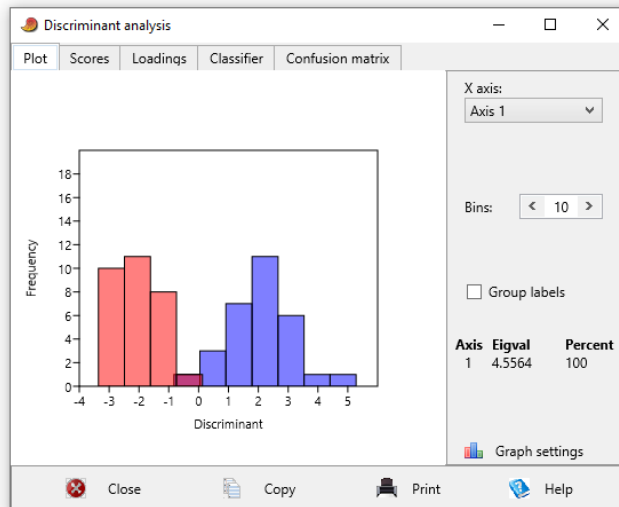
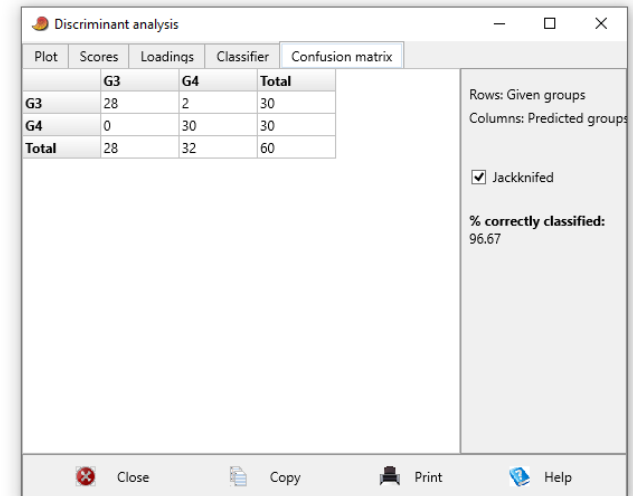
- how much information we see in graphics?
- how many components are meaningful?
- what is represented by first components?
- are there differences between groups?
- what shapes characterise groups?
- are there outliers? If so, comment.
- ...



Linear discriminant analysis (LDA)



- 1) Open file: Flanged_axes_efa_pca.dat (contains Scores of PCA calculated before)
- 2) Select 10 PC accounting for 97.2 % of variance
- 3) Perform LDA
Multivariate >> Ordination >> Discriminant analysis (LDA)

	G3	G4	Total
G3	28	2	30
G4	0	30	30
Total	28	32	60

Rows: Given groups
Columns: Predicted groups

☒ Jackknifed

% correctly classified:
96.67

MANOVA and PERMANOVA

- 1) Open file: Flanged_axes_efa_pca.dat (contains Scores of PCA calculated before)
- 2) Select 10 PC accounting for 97.2 % of variance
- 3) Perform Normality test
Multivariate >> Tests >> Multivariate Normality
- 4) Perform MANOVA
Multivariate >> Tests >> MANOVA
- 5) Perform PERMANOVA
Multivariate >> Tests >> PERMANOVA



Multivariate normality tests

Mardia tests				
Parameter	Value	Statistic	df	p (normal)
Skewness:	51.73	517.3	220	5.359E-26
Skewness, small sample corrected:		548.1	220	5.833E-30
Kurtosis:	131.1	2.766		0.005668

Doornik and Hansen omnibus	
Fp	82.79
p (normal):	1.313E-09

☐ Within-groups

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MANOVA

Wilks' lambda:		Pillai trace:		Constraints:	
df1:	10	df1:	10	< 0 >	
df2:	49	df2:	49		
F:	22.33	F:	22.33		
p (same):	5.844E-15	p (same):	5.844E-15		

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One-way PERMANOVA

PERMANOVA	
Permutation N:	9999
Total sum of squares:	2.95
Within-group sum of squares:	2.685
F:	5.716
p (same):	0.0157

Similarity index: Euclidean

Permutation N: 9999

Recompute

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References

- Wilczek, J., Monna, F., Gabillot, M., Navarro, N., Rusch, L., Chateau, C., 2015. Unsupervised model-based clustering for typological classification of Middle Bronze Age flanged axes. J. Archaeol. Sci. - Rep. 3, 381–391.