

The Growth of meraspid specimens of *T. becki*, using both landmarks and outline information (semilandmarks)

H.D. Sheets, August, 2002. Circulated privately for comments. DO NOT CITE this.

Contact HDS for the proper paper to cite for use of this software, we have an abstract into the Geological Society of America, Fall 2002 National Meeting based on this work.

Introduction

This is a brief, casual document meant as an introduction to the work I have been doing on software to carry out shape analysis using both landmarks and semi-landmarks, which are points placed along a curve, such as an outline or ridge, on the specimen. This ms. is a “proof of concept” study only, a larger more carefully handled data set would be needed to publish this material. The semi-landmark methods were developed by Bookstein and Greene (Bookstein 1996, Greene 1996), this is an implementation of that approach. What I have been working on is a software tool (part of IMP) that will allow researchers to use both landmarks and semilandmarks, placed along one or more open ended or closed curves on the organism. This manuscript describes a description of the beginnings of an analysis of the changes in shape during growth that appear in *T. becki*, using landmarks, one open-ended curve and one closed curve. Specimens of *T. becki* were photographed

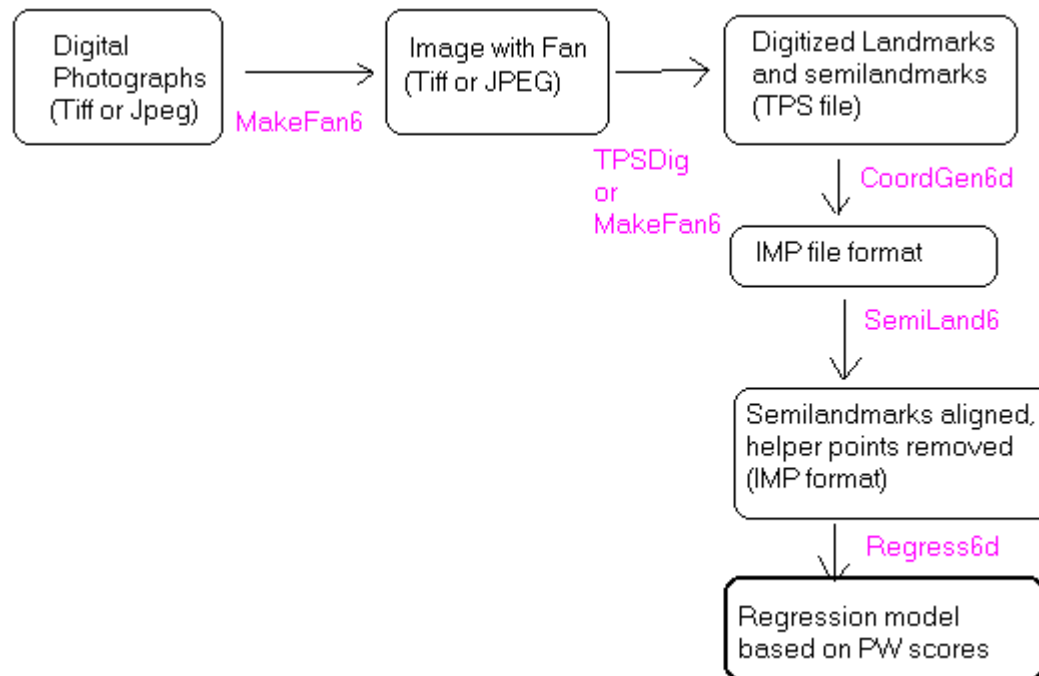
by Dr. Keonho Kim, Dept. of Geology, SUNY at Buffalo, and taken from specimens collected as part of Dr. Kim's dissertation.

Software Used and the Chain of Processing

The diagram below shows how the images of the specimens were processed to carry out the analysis shown below. MakeFan6 is a tool that places alignment “fans” on images to allow for consistent placement of semilandmarks on the image, using a set of guidelines to insure that landmarks are placed at equal angular displacements along a curve.

MakeFan6 is capable of digitizing landmarks, but I recommend use of TPSDig for this step. The tps format file created is then converted to the IMP format in CoordGen6d.

This file is loaded into Semiland6 which processes the semilandmarks to align them along their respective curves. The output of Semiland6 is then be loaded into Regress6d for construction and display of a regression model depicting shape change during the growth of *T. becki*. The output of Semiland6 may be input into other IMP programs, subject to the constraints that the use of semilandmarks places on the statistical methods used (more on that later).



TPSDig was written by F. James Rohlf (SUNY at Stonybrook,

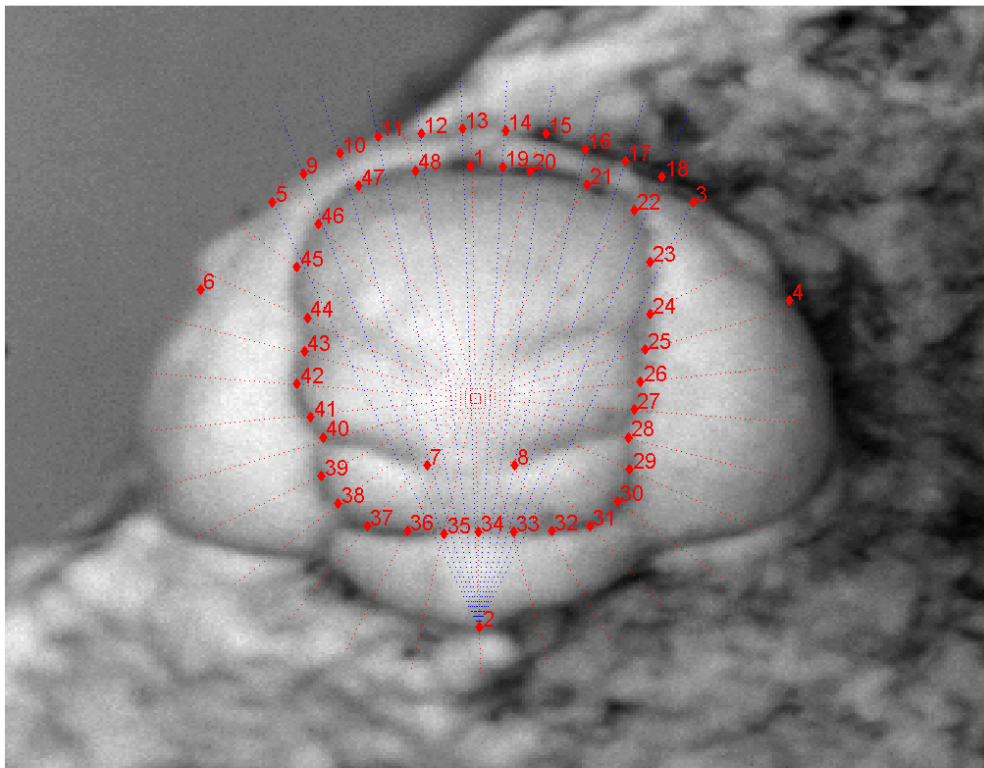
<http://life.bio.sunysb.edu/morph/index.html>), all other software was written by HDS

(<http://www.canisius.edu/~sheets/morphsoft.html>). MakeFan6 and SemiLand6 are not

available for regular distribution as of June 23,2002, contact HDS directly for copies.

Example Regression Analysis

The MakeFan6 tool was used to digitize landmarks and place alignment fans for the semilandmark points on the image. For the meraspid used here, two fans were used, one a triangular fan with 12 lines to align semilandmarks along the front edge of the cephalum (this fan is blue in the picture below), the second (red) fan of 30 lines was used to place semilandmarks along the glabella (hope I got the name right here folks!).

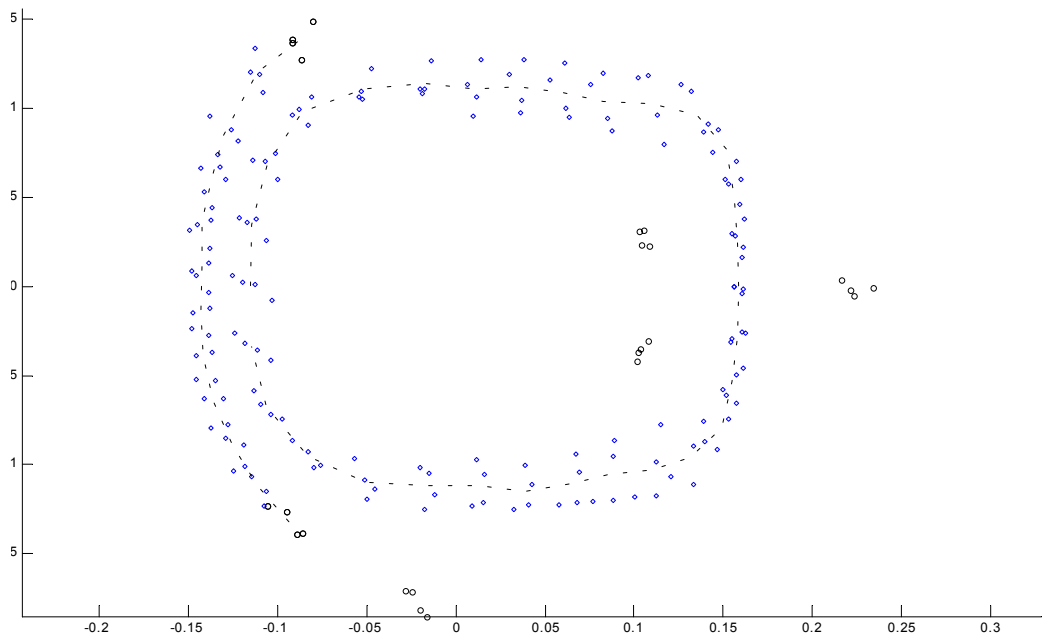


I digitized only four specimens, purely to see if the software was working.

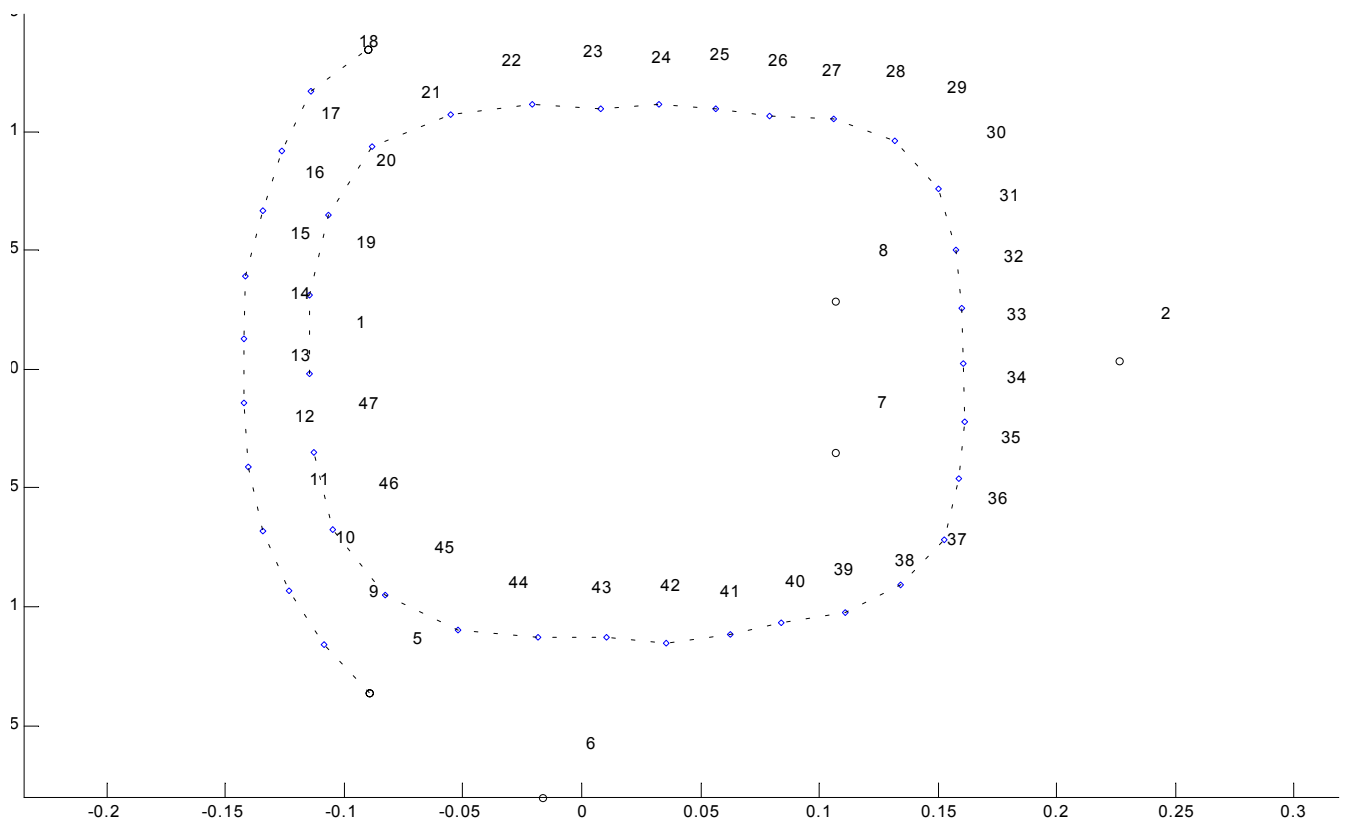
After creation of the .tps file using MakeFan (or alternatively, TPSDig), the file is converted into the x1y1..CS format used throughout IMP and loaded into the program SemiLand6. Semiland6 is a tool that carries out the minimization of distances between semi-landmarks by sliding them along the curves to minimize the bending energy between them. This is a parsimonious approach to selecting points along the curves, but there are some serious concerns about homology (be careful!).

This is a picture of the aligned specimens produced by Semiland6. The blue points are semi-landmarks, and the black points are landmarks. The curves are drawn connecting the points along the curves on the mean specimen.

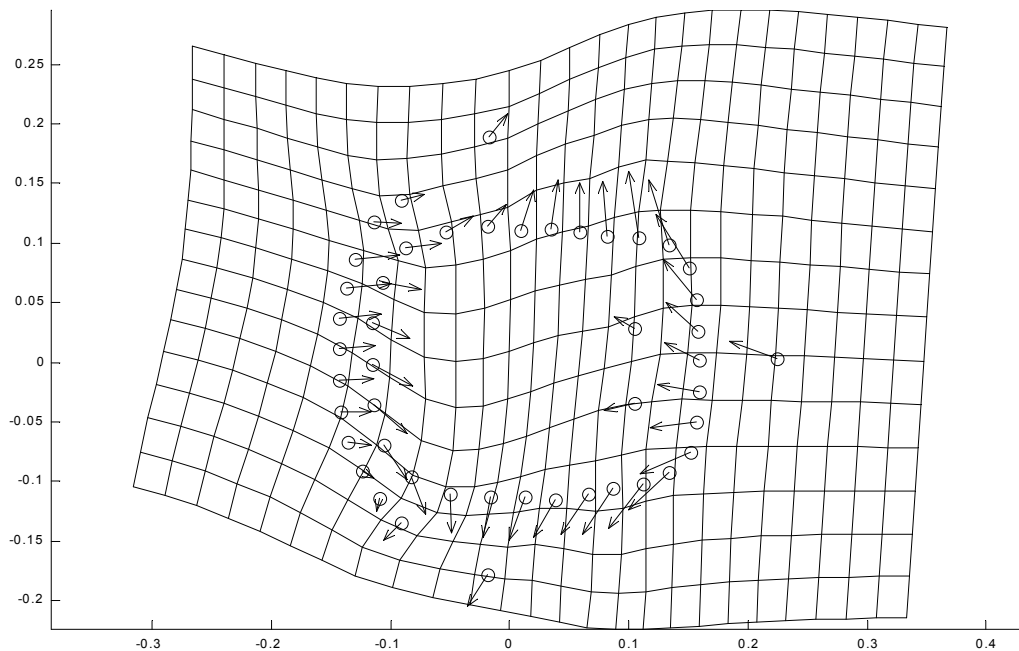
Semiland6 must be provided with a *protocol file* that informs it which points are landmarks, which are semilandmarks and which are *helper points* used only for the purpose of aligning the semi-landmarks correctly along the curve they represent.



This plot shows only the mean specimen with the landmarks and semi-landmarks



The picture obtained for the changes in the relative positions of landmarks and semilandmarks due to changes in log centroid size, as produced by loading all landmark and semi-landmark data into Regress6d. There does appear to be some asymmetry to these results, perhaps due to the small sample size (4) or to careless digitizing on my part. It is also very possible that more points are needed along one or both curves to get smooth superimposition of the semilandmarks during processing.



Concerns about the Use of Semi-landmarks in Shape Analysis

1.) Landmarks each have 2 degrees of freedom, while semilandmarks have only one. All software that computes degrees of freedom based on the number of coordinates in an input file (the way all the IMP software does) will have incorrect calculations of the

degrees of freedom present when evaluating the results of statistical tests. This difficulty may be avoided by using only bootstrap or permutation based tests.

2.) The number of semi-landmarks along a curve (either 12 or 30 in the two curves shown in the example above) is much larger than the number of landmarks typically used in a study (7 in the example above). This means that the semi-landmarks along a single curve may “dominate” an analysis, over-representing if you will the information contained in the curve. One approach is to use “helper points”, which are points arrayed between semi-landmarks along the curve and used to align the semi-landmarks (within Semiland6), but thereafter discarded from the analysis, or at least from the calculations of statistics during the analysis. It is possible to load the same data into Semiland6 using different protocols (to designate variable numbers of points along a curve as helpers rather than semi-landmarks) to study the effect of the choice of the number of semi-landmarks has on an analysis.

3.) The biological homology of the points along the curve is perhaps in doubt. One must be careful to represent biologically homologous curves when setting up the study, and then remember that while the semi-landmarks along the curves are not homologous, they were obtained by carrying out a consistent mathematical operation on homologous curves. This issue needs further debate!

4.) Currently MakeFan spaces semilandmarks along a curve at an equal angular spacing, it may be necessary to develop a tool to produce equal linear spacing along a curve,

rather than equal angular spacing. This type of tool or approach may already exist in the literature on outline based methods.

Literature Cited

Bookstein, F.L. 1996. Landmark methods for forms without landmarks: morphometrics of group differences in outline shape. *Medical Image Analysis* 1(3) pp. 225-243.

Green W.D.K. 1996. The thin-plate spline and images with curving features. In Mardia, K.V, C.A. Gill and I.L. Dryden, eds. *Proceedings in Image Fusion and Shape Variability Techniques*, pp 79-87. Leeds University Press, Leeds.