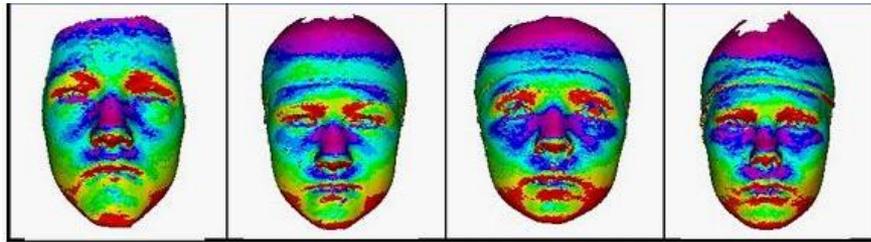




Technology Project: Shape-Based Retrieval of 3D Craniofacial Data



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Harry Hochheiser, Ph.D.

Postdoc: Ravensara Travillian, Ph.D.

RA: Shulin Yang, MS

RA: Jia Wu, MS

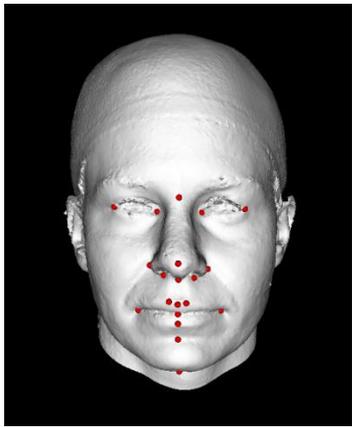
RA: Sara Rolfe, MS

RA: Ezgi Mercan

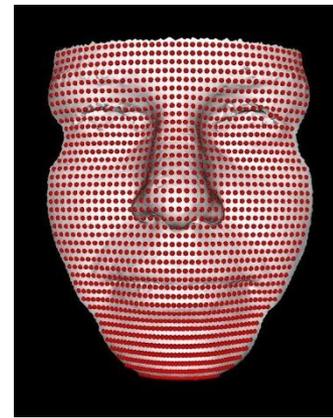


Aims

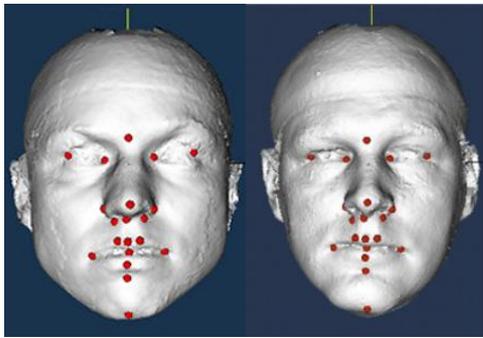
- **Software tools** for craniofacial analysis (we have lots of these; available in CranioGUI)
- **Quantification** of similarity between faces (we use distance measures)
- **Organization** for retrieval (using **Diamond**)
- **Prototype system** for similarity-based retrieval (under development)



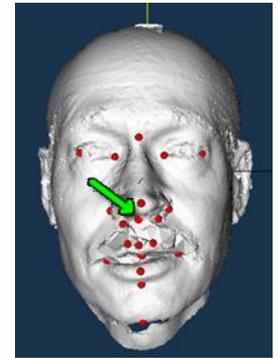
Result 1: Pseudo-Landmarks



- New *fully-automatic* method for computing pseudo-landmarks on 3D meshes
- Experiments run on Seth Weinberg's **Facial Norms Database** comparing gender classification results on
 - Seth's hand-labeled anatomical landmarks
 - our pseudo-landmarks at different resolutions (**automatic**)
 - Hutton/Hammond dense pseudo-landmarks (requires hand labeling and correspondence)
 - Claes pseudo-landmarks (requires hand labeling and correspondence)
- Pseudo-landmarks in general **classified better** than landmarks and our method is **much faster** than the others
- Paper accepted for **IEEE Eng. in Medicine and Biology**



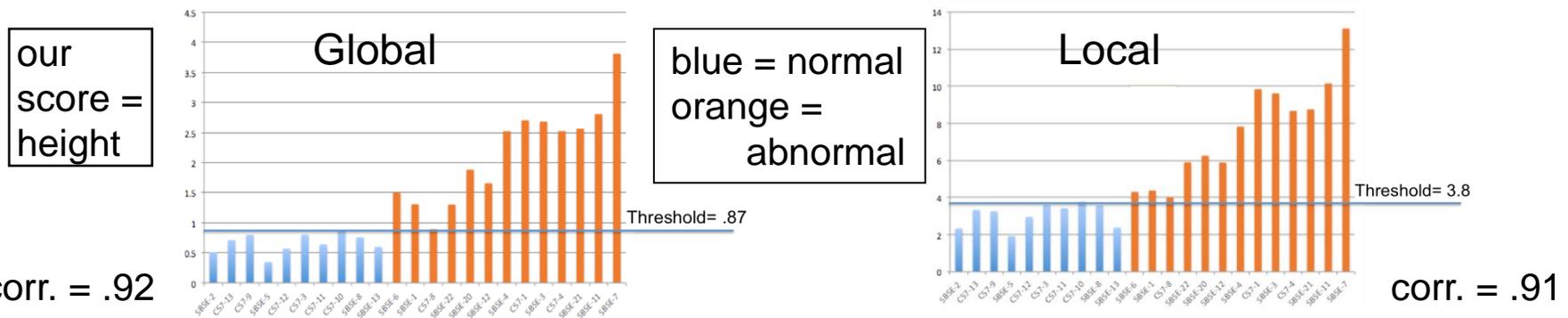
Result 2: Autolandmarking



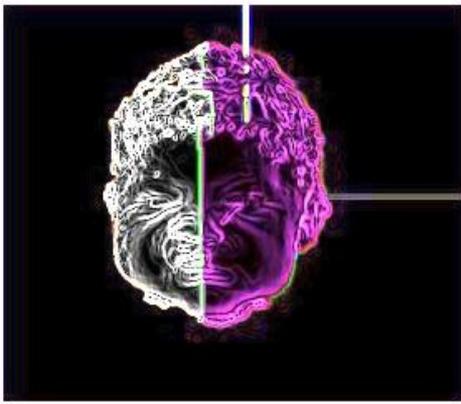
- Method for **automatically detecting** an arbitrary number of **anatomical landmarks** on a 3D face mesh.
 1. **Geometric method** finds an initial set of 17 landmarks on the target mesh.
 2. These are used to **initialize a deformable matching** method from a template mesh to the target mesh.
 3. Using the resultant correspondence, the required landmarks are **transferred** from the template mesh to the target mesh.
- Experiments were run on 115 3D facial meshes of normal adults from Seth Weinberg's Facial Norms Database.
- Our method has an average error of 2.64 mm over the 115 heads and is superior to prior published methods in the literature.
- Paper accepted for **IEEE Eng. in Medicine and Biology**

Result 3: Shape Analysis through Optical Flow Vectors

- New tool for characterizing and quantifying the asymmetry in bilaterally paired structures.
 - Deformable registration produces a dense vector field correspondence
 - Deformation vectors have properties: deformation vector magnitude and the cosine distance between the deformation vector and the surface normal vector.
 - Vectors are clustered to detect regions of asymmetry
- Applied it to the two sides of the mandible of the mouse.
- Asymmetry scores compared to human expert (order=ranking)



- Paper accepted for IEEE Eng. in Medicine and Biology
- Current work on chick embryo images: multiple ages, w/wout cleft



Ongoing: Analysis of Cleft Subjects



- Ongoing cleft study with Dr. Raymond Tse and Dr. Carrie Heike at Seattle Children's Hospital.
- 49 3dMD images (9 bilateral, 35 unilateral, 5 control)
- Ongoing evaluation of our symmetry plane finder (published last year)
- Once plane of symmetry is found, our **grid-patch method** quantifies differences in left and right sides based on **radius, angle and curvature**.
- Initial experiments to classify left vs. right unilateral clefts are 100% accurate.
- Final year's work is on investigating other computable features of clefts.

Ongoing: Content-Based Image Retrieval

- Developed a [web application](#) for content-based retrieval of 3D face meshes using Satya's [Diamond](#) system from CMU (part of HUB).
- [Adding features](#) to the system (automatic landmarks, pseudo-landmarks) so we can run multiple kinds of retrievals in controlled tests.
- Plans to test features in a [face retrieval task](#) that will involve whole-face and facial-feature similarity, using Seth Weinberg's Facial Norms Database.
- Will have 2 kinds of evaluation
 - [human evaluators](#) (limited due to IRB)
 - [comparison to retrievals using computationally expensive dense correspondence method with Procrustes distance.](#)

Ongoing: CranioGUI

- We developed **CranioGUI** to allow people to try our software without downloading and in an interactive environment.
- It runs on our server in client-server mode; users can upload their own images and download results.
- We've added a page of **source code** in the same tree structure as the CranioGUI modules, so users can take the source code of modules they want (but the VTK library is required; we can help you with that).
- We've added multiple **new modules**
 - some specifically for those of you who wanted **points**
 - some that produce our more advanced features

New Modules

- PLY reader, PLY visualizer, STL-PLY and PLY-STL conversion (needed for some modules)
- Landmarks
 - Automatic landmarks from geometry (finds 17)
 - Deformation (maps target image to a template image using the automatic landmarks)
 - Transfer-Landmarks (transfers 24 landmarks from the template to the target)
 - Pseudo-Landmarks

Autolandmarking and Deformation Modules

The screenshot displays the CranioGUI software interface, which is used for autolandmarking and deformation of 3D meshes. The interface is divided into several sections:

- Left Panel (Tree View):** Lists various modules and options, including Input (Directory Reader, ARFF Reader, MODEL Reader, OBJ Reader, PLY Reader, STL Reader, TXT Reader), Output (MODEL Outputter, STL Outputter, TXT Outputter, ANY Outputter), Visualization (STL Visualizer, STL Visualizer with Local Feat, STL Visualizer with Azimuth E, STL Visualizer with Landmark, PLY Visualizer with Local Feat, TXT Visualizer, ANY Visualizer), Conversion (OBJ to STL, OBJ to PLY, STL to PLY, STL to OBJ, PLY to STL, PLY to OBJ, Skull Extraction), Local Feature Extraction, 2D Azimuth-Elevation Histogram, Landmark Analysis (Auto-Landmarks, Deformation, Transfer Landmarks, Pseudo-Landmarks), and Symmetry Analysis.
- Workflow Diagram:** A central workspace showing a sequence of modules connected by arrows. The flow starts with two 'PLY Reader' modules (one with path '\SampleData\Sh', the other with 'Data\Carrie.ply'). These feed into two 'Auto-Landmarks' modules, which then feed into two 'PLY to STL' modules. The output of these 'PLY to STL' modules feeds into a 'Deformation' module. The 'Deformation' module has inputs for 'Source Mesh' (PLY), 'Source Landmarks' (TXT), and 'Target Landmarks' (TXT), and produces a 'Target Mesh' (PLY). The output of the 'Deformation' module feeds into a final 'PLY to STL' module, which produces an 'STL' file.
- Visualization Windows:** Three windows at the bottom show the results of the process:
 - STL Visualizer with Landmarks:** Displays a 3D model of a face labeled 'Template: Lynn' with red dots indicating landmarks. A 'TXT' file is shown as an output.
 - STL Visualizer with Landmarks:** Displays a 3D model of a face labeled 'Target: Carrie' with red dots indicating landmarks. A 'TXT' file is shown as an output.
 - STL Visualizer:** Displays a 3D model of a face labeled 'Deformation', showing the result of mapping the 'Carrie pts' to the 'Lynn points'. A yellow text overlay reads 'Carrie pts mapped to Lynn points'.

Saved workspace to deformation.cranio

Transfer of Anatomical Landmarks: Template to Target

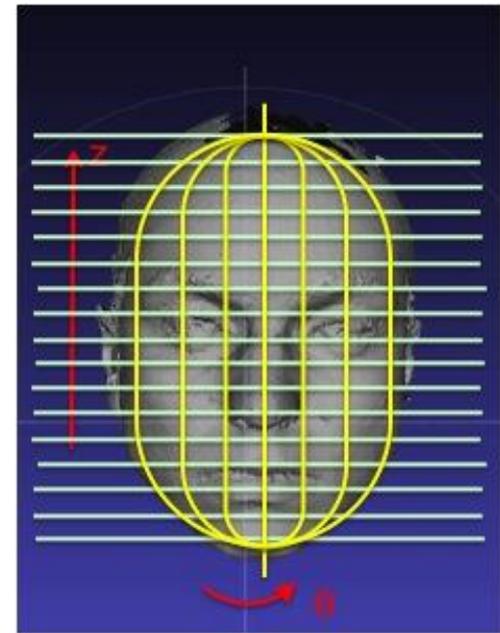
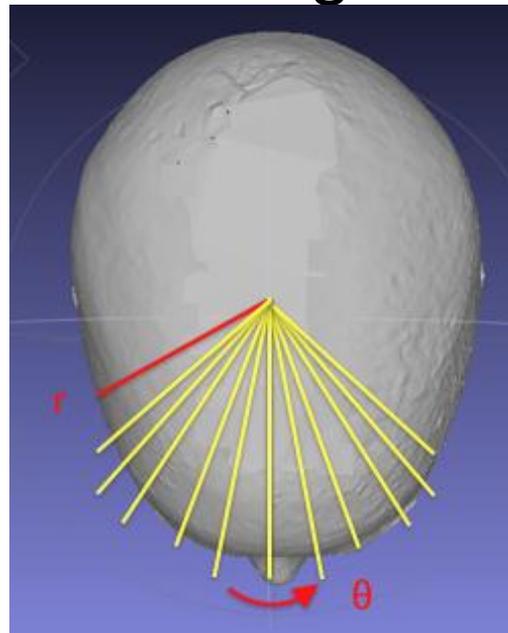
The screenshot displays the CranioGUI software interface, which is used for processing craniofacial data. The interface is organized into several main sections:

- Left Panel (Navigation):** A tree view showing the software's structure, including categories like Input, Output, Visualization, Conversion, Local Feature Extraction, 2D Azimuth-Elevation Histogram, Landmark Analysis, and Symmetry Analysis. Under Landmark Analysis, options include Auto-Landmarks, Deformation, Transfer Landmarks, Pseudo-Landmarks, and Symmetry Analysis.
- Workflow Diagram:** A central workspace showing a sequence of processing steps connected by arrows:
 - PLY Reader:** Reads source data (e.g., eData\Shulin.ply).
 - Auto-Landmarks:** Processes the source mesh to extract landmarks.
 - Deformation:** Aligns the source mesh with a target mesh (e.g., Target Mesh).
 - Transfer Landmarks:** Transfers landmarks from the source to the target mesh.
 - PLY to STL:** Converts the processed data into STL format.
 - STL Visualizer with Landmarks:** Displays the final result, showing a 3D model of a face with red dots representing landmarks. The text "Target: Carrie" and "with all landmarks" is overlaid on the visualization.
- Right Panel (Visualization):** A window titled "STL Visualizer with Landmarks" showing a 3D model of a human face with red dots representing anatomical landmarks. The text "Target: Carrie" and "with all landmarks" is overlaid on the visualization.

The bottom of the screen shows the Windows taskbar with the Start button, various application icons, and the system tray displaying the date and time (9:50 PM, 4/2/2013).

New Modules

- Symmetry
 - Mirror symmetry plane
 - Symmetry score from points
 - Symmetry score from grid cells
 - Radius
 - Angle
(between surface normal vectors)
 - Curvature



Symmetry Plane and Symmetry Score from Points

CranioGUI

File Workspace Help

Craniocfacial

- Input
- Output
- Visualization
 - STL Visualizer
 - STL Visualizer with Local Featu
 - STL Visualizer with Azimuth El
 - STL Visualizer with Landmark
 - PLY Visualizer with Local Featu
 - TXT Visualizer**
 - ANY Visualizer
- Conversion
- Local Feature Extraction
- 2D Azimuth-Elevation Histogram
- Landmark Analysis
- Symmetry Analysis

PLY Reader

t/Carrie.ply

Browse

PLY

Mirror Symmetry Plane

Plane Center and Normal

Visualize Plane

PLY

TXT

TXT

PLY Visualizer with Local Features

Local Feature File

PLY

Carrie plane

PLY Visualizer with Local Features

Local Feature File

PLY

point symmetry

TXT

TXT

TXT Visualizer

-0.102282,8.829183,-3.684973,0.999991,0.00323

TXT

Symmetry Score (Point)

Source Mesh

Average Point Distance

PLY

Symmetry Plane

Visualizer Input

PLY

Visualize Point Distance

TXT

TXT

TXT Visualizer

mean Distance is 5.795924

score 5.8 mm (average)

Finished flow

Symmetry Plane and Symmetry Score from Points

The screenshot displays the CranioGUI software interface with a workflow for calculating a symmetry plane and score from a point cloud. The workflow consists of several interconnected components:

- PLY Reader:** Reads the input file 'a/Linda.ply'.
- Mirror Symmetry Plane:** Calculates the plane center and normal, outputting a PLY file and a TXT file.
- PLY Visualizer with Local Features (Linda plane):** Visualizes the point cloud with a vertical symmetry plane, showing the left side in blue and the right side in red.
- PLY Visualizer with Local Features (point symmetry):** Visualizes the point cloud with a color map representing local features.
- Symmetry Score (Point):** Calculates the average point distance from the symmetry plane, outputting a PLY file and a TXT file.
- TXT Visualizer:** Displays the calculated symmetry score: mean Distance is 4.628268.

The workflow is completed, as indicated by the 'Finished flow' message at the bottom left.

score 4.6 mm
less asymmetry

Symmetry Plane and Symmetry Score from Grid Cells

CranioGUI

File Workspace Help

Craniocfacial

- Input
 - Directory Reader
 - ARFF Reader
 - MODEL Reader
 - OBJ Reader
 - PLY Reader
 - STL Reader
 - TXT Reader
- Output
- Visualization
 - STL Visualizer
 - STL Visualizer with Local Featu
 - STL Visualizer with Azimuth El
 - STL Visualizer with Landmark
 - PLY Visualizer with Local Featu
 - TXT Visualizer
 - ANY Visualizer
- Conversion
- Local Feature Extraction
- 2D Azimuth-Elevation Histogram
- Landmark Analysis
- Symmetry Analysis
 - Mirror Symmetry Plane
 - Symmetry Score (Point)
 - Symmetry Score (Grid)

PLY Reader

1/Carrie.ply

Mirror Symmetry Plane

Plane Center and Normal

Symmetry Score (Grid)

Source Mesh

Average Scores

Symmetry Plane

Visualizer Input

Grid Number

Visualize Angle Distance

Theta Range

Visualize Curvature Distance

Theta Number

Visualize Radius Distance

PLY Visualizer with Local Features

Local Feature File

Carrie angle dist.

PLY Visualizer with Local Features

PLY Visualizer with Local Features

Local Feature File

Local Feature File

Carrie curv. dist.

Carrie radius dist.

TXT Visualizer

R dis is 1.758322
angle dis is 0.111879
curvature dis is 0.008026

A = .112 deg.
C = .008
R = 1.76 mm

Finished flow

Symmetry Plane and Symmetry Score from Grid Cells

CranioGUI

File Workspace Help

Craniofacial

- Input
 - Directory Reader
 - ARFF Reader
 - MODEL Reader
 - OBJ Reader
 - PLY Reader
 - STL Reader
 - TXT Reader
- Output
- Visualization
 - STL Visualizer
 - STL Visualizer with Local Featu
 - STL Visualizer with Azimuth El
 - STL Visualizer with Landmark
 - PLY Visualizer with Local Featu
 - TXT Visualizer
 - ANY Visualizer
- Conversion
- Local Feature Extraction
- 2D Azimuth-Elevation Histogram
- Landmark Analysis
- Symmetry Analysis
 - Mirror Symmetry Plane
 - Symmetry Score (Point)
 - Symmetry Score (Grid)

PLY Reader: a/Linda.ply

Mirror Symmetry Plane: Plane Center and Normal, Visualize Plane

Symmetry Score (Grid): Source Mesh, Symmetry Plane, Grid Number (10), Theta Range (1.5), Theta Number (10), Average Scores, Visualizer Input, Visualize Angle Distance, Visualize Curvature Distance, Visualize Radius Distance

PLY Visualizer with Local Features: Linda angle dist

PLY Visualizer with Local Features: Linda curv. dist.

PLY Visualizer with Local Features: Linda radius dist.

TXT Visualizer: R dis is 1.014846, angle dis is 0.081174, curvature dis is 0.009778

A = .081 deg.
C = .009
R = 1.01 mm

Finished flow

ShapeGUI

- A new GUI to show a separate set of modules for our animal (chicken and mouse) work.
- Data comes from micro-CT scans.
- Current demo is on **mouse mandible data**.
- Has modules from low-level preprocessing and smoothing through registration and comparison through **deformation vector analysis**.

Comparing Left and Right Sides of a Mouse Mandible

The screenshot displays the ShapeGUI software interface with a workflow for comparing the left and right sides of a mouse mandible. The workflow is organized into several panels:

- Input:** Includes HDR Reader (nand_L_036.hdr), MHD Reader (se_13_Field.mhd), and RAW Reader (se_13_Field.raw).
- Output:** Includes HDR Reader (nand_R_036.hdr), IMG Reader (nand_R_036.img), and RAW Reader (se_13_Field.raw).
- Image Pre-processing:** Includes HDR, IMG, and VTK filters.
- Clustering:** Includes Clustering (Number of Clusters: 7) and VTP Visualizer for Clustering (Feature Option: 0).
- Visualization:** Includes VTK Visualizer (flipped, smoothed left side), VTP Visualizer for Clustering (clusters), and Symmetry Calculation Filter (Symmetry Distance: 0.456022).
- Smoothing:** Includes Smooth Image Filter (Smoothing Factor X-dimension: 2, Y-dimension: 2, Z-dimension: 2) and Flip Image Filter.

Annotations in red text highlight key results:

- flipped, smoothed left side** (pointing to the VTK Visualizer)
- smoothed right side** (pointing to the VTP Visualizer for Clustering)
- symmetry distance .46** (pointing to the Symmetry Calculation Filter)

The interface also shows a sidebar with a tree view of the workflow and a bottom status bar indicating "Finished flow".

Supplement: Ontology of Craniofacial Development and Malformation

- OCDCM **use cases** have been extended, re-categorized, and cross-linked for comparison and extraction of common themes. <https://www.facebase.org/ocdm/wiki/use-cases>
- Workflow has been established for creating and exporting OCDCM content. **OWL file** is used for queries. Modules and queries will be covered by Jim Brinkley.
- **Content** on adult human and mouse, developing human and mouse, malformations of human and mouse, and some mappings between them have been created.
- A **web client for visualization** of the OCDCM has been developed and is under continued improvement.
<https://www.facebase.org/content/ocdm>.