Extrapolation of Missing Craniofacial Skeletal Structure via Statistical Shape Models

Project #1 Checkpoint Presentation

EN.600.646 Spring 2014

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ERC | CISST

Collabortive Laboratory For
BIGSS
Biomechanical- and Image-guided
Surgical Systems

LABORATORY FOR
Computational
Sensing + Robotics
THE JOHNS HOPKINS UNIVERSITY

Project Overview

- *Project Goal:* Design and implement a method for extrapolating missing anatomical craniofacial skeletal structure with the use of a statistical shape model of the human cranium.
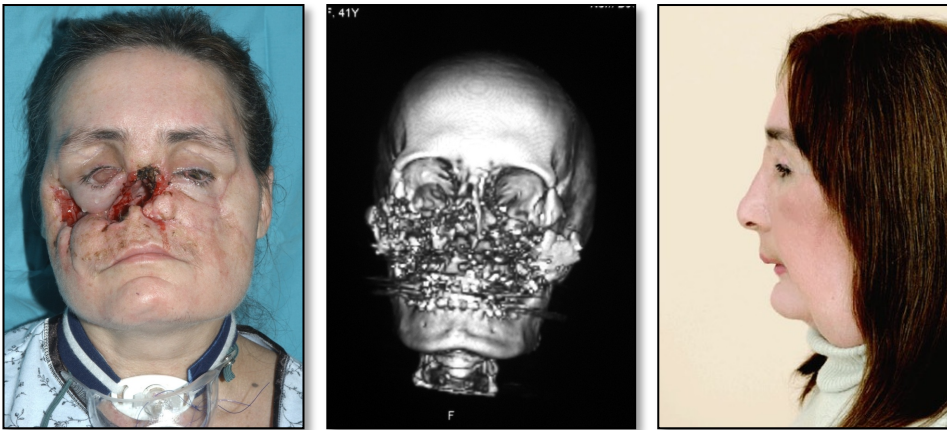
Courtesy of Dr. Chad Gordon
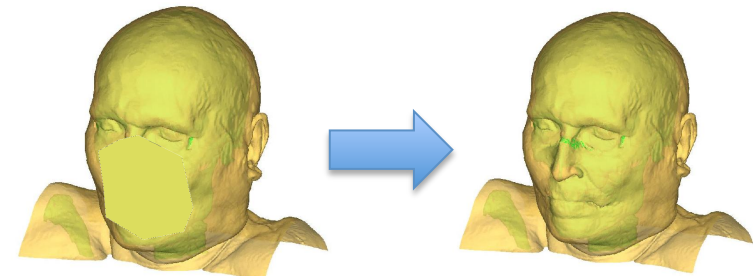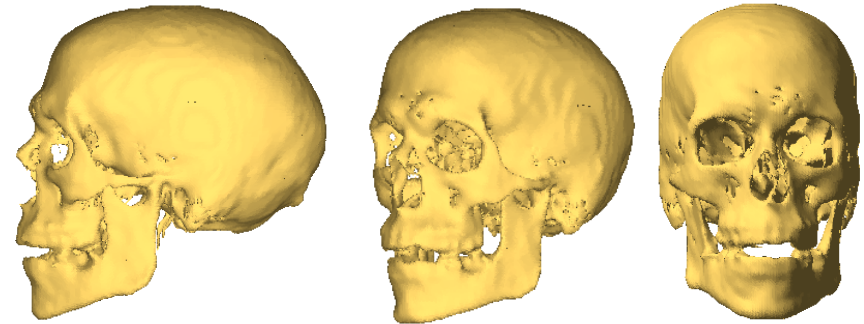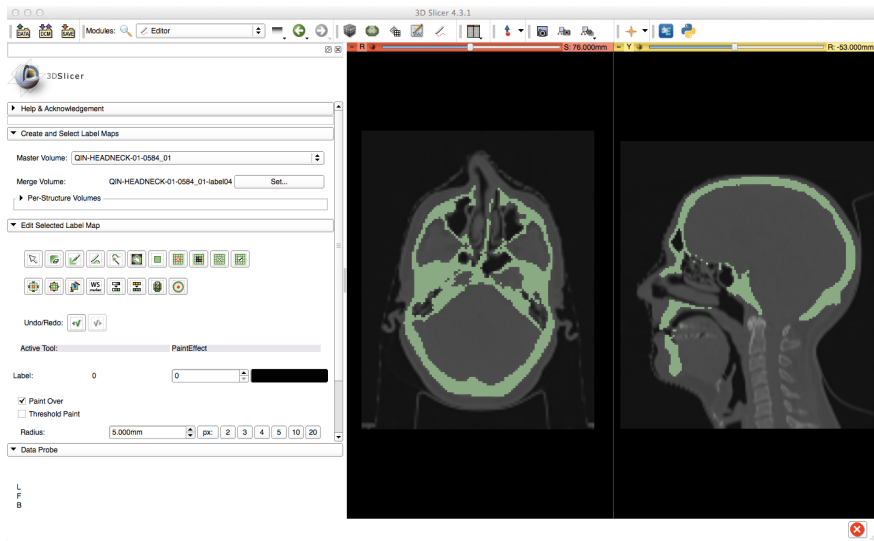

Courtesy of Dr. Otake

All Dependencies Met

- **Obtaining the Cranial CT Data** ✔
  - Data obtained from The Cancer Imaging Archive (TCIA) is sufficient
- **Access to Mentors** ✔
  - Scheduled and ad hoc meetings have been sufficient
- **Access to Fast Computer** ✔
  - Permission granted by Dr. Armand to use the new BIGSS lab server

Original Deliverables

- **Minimum**
  - Segmentation mask of the skeletal regions in the cranial CT images
  - Deformable registration of each CT image (or mesh) to a chosen template
  - Atlas creation and evaluation
  - Development and evaluation of anatomical extrapolation method

- **Expected**
  - Creation and evaluation of an atlas via a bootstrapping technique
  - Development and evaluation of a patient/donor similarity metric

- **Maximum**
  - Design of a method to use the estimated surface of the patient to assist in surgical planning
  - Create a system architecture for the future use of this system
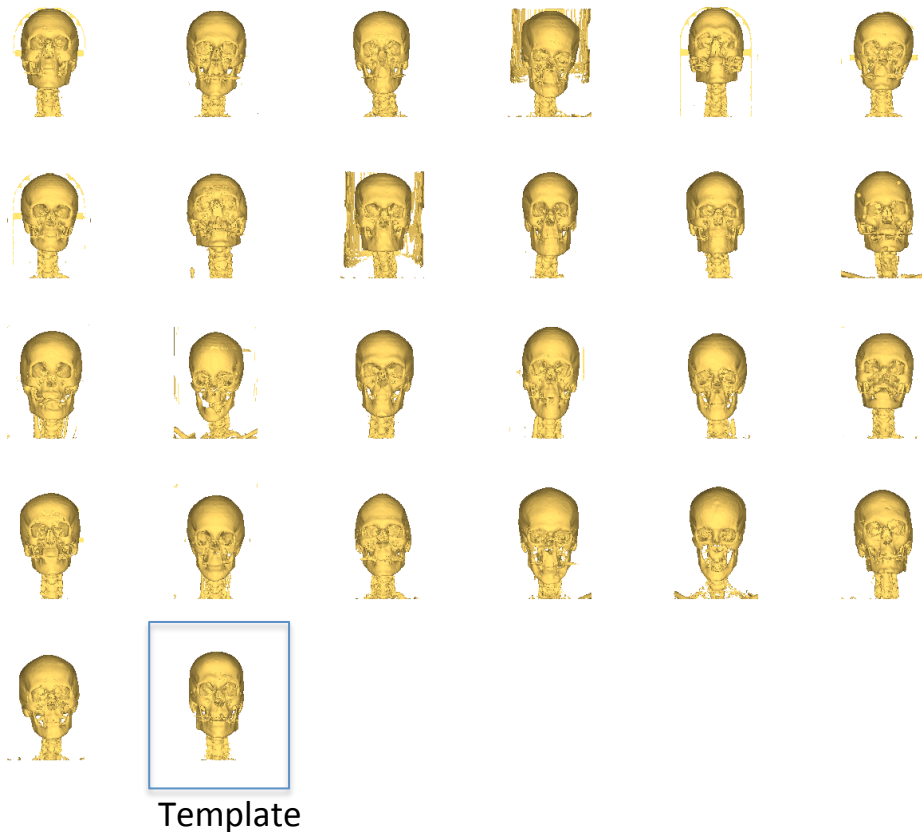
Minimum Deliverable: Manually Segmented Skulls

- Manual segmentation of template CT with 3D Slicer
- Rely on deformable registration to obtain topologically consistent meshes for other images

- Use basic thresholding for surface distance computation between original mesh and deformed mesh and label overlap metric
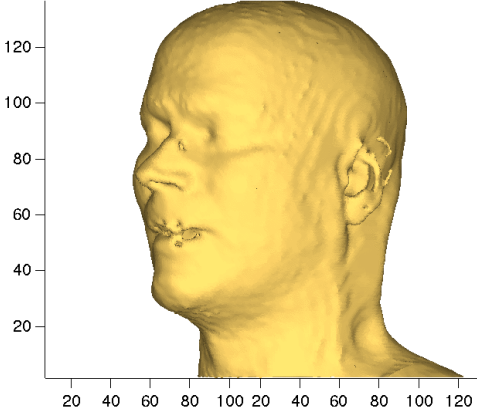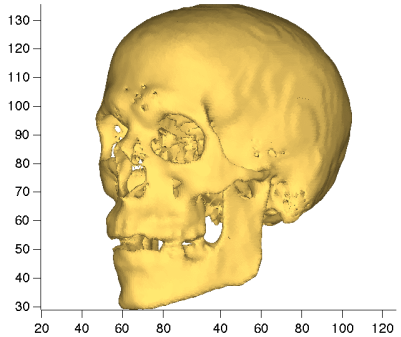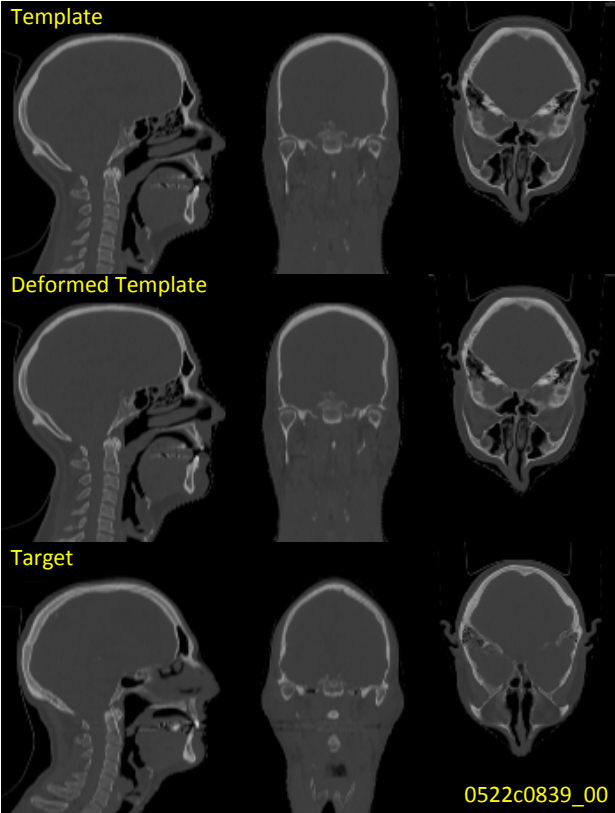

Template

CT Image Source: The Cancer Imaging Archive

Original Deliverables

- **Minimum**
  - Segmentation mask of the skeletal regions in the cranial CT images ✔
  - Deformable registration of each CT image (or mesh) to a chosen template
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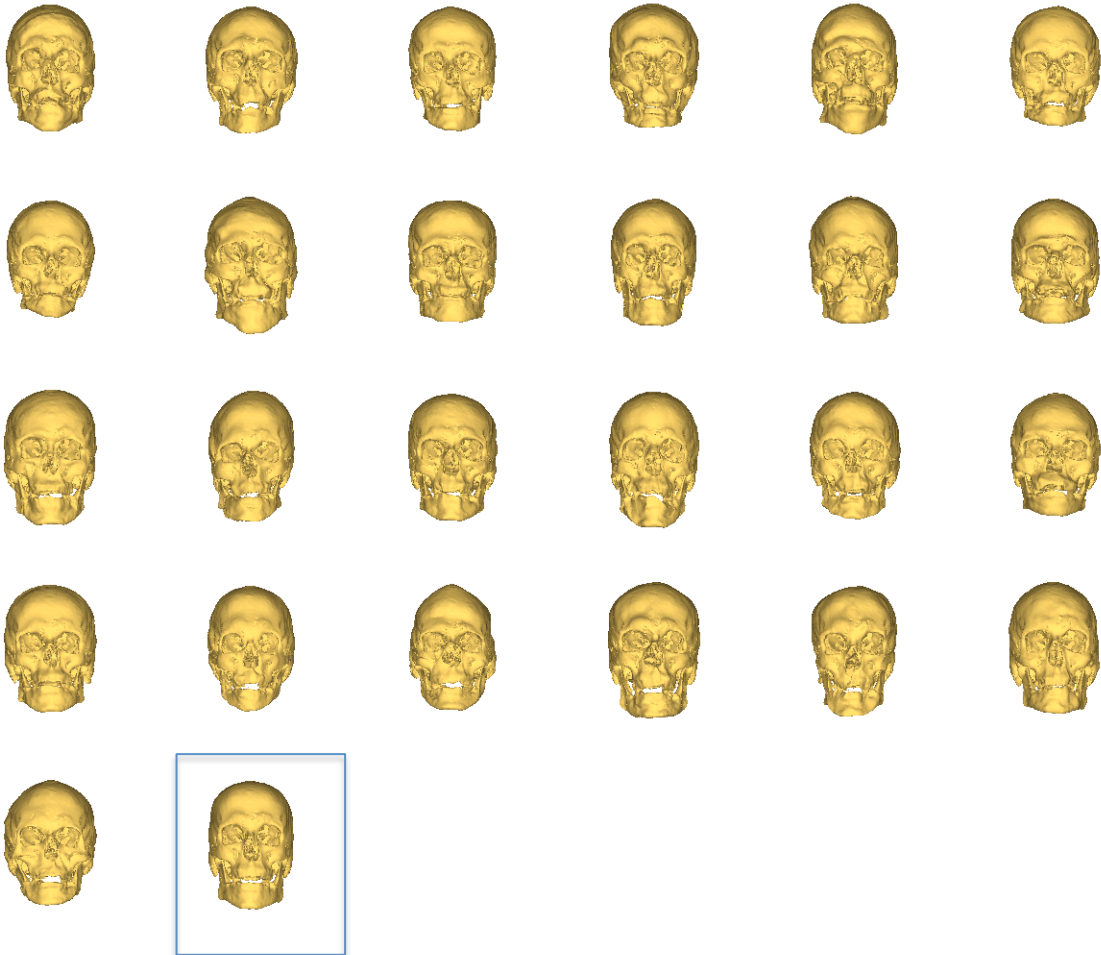# Minimum Deliverable: Deformable Registration Results

- Deformation fields and deformed meshes

Template

Deformed Template

Target

0522c0839_00

CT Image Source: The Cancer Imaging Archive

Template

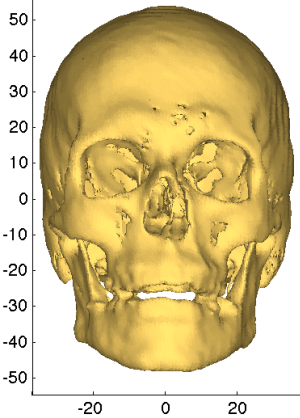CT Image Source: The Cancer Imaging Archive

Original Deliverables

- **Minimum**
  - Segmentation mask of the skeletal regions in the cranial CT images ✔
  - Deformable registration of each CT image (or mesh) to a chosen template ✔
  - Atlas creation and evaluation
  - Development and evaluation of anatomical extrapolation method

- **Expected**
  - Creation and evaluation of an atlas via a bootstrapping technique
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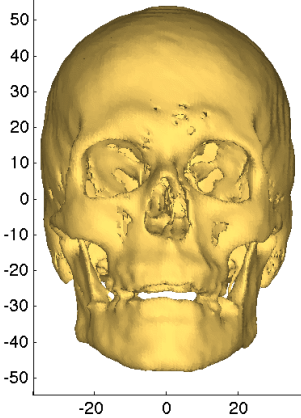
Minimum Deliverable: Atlas

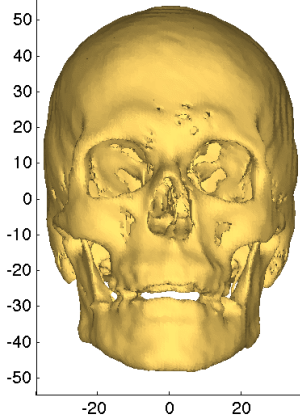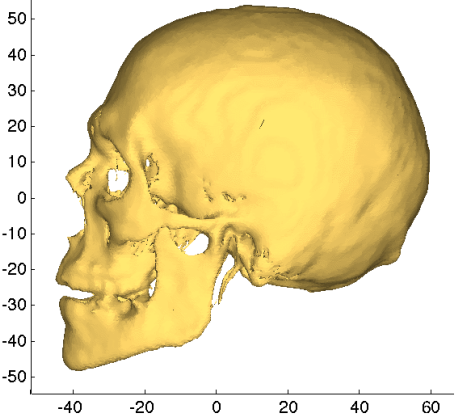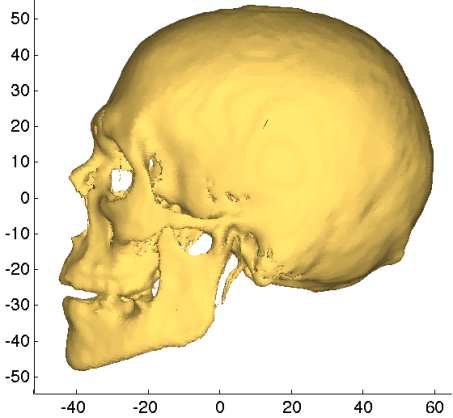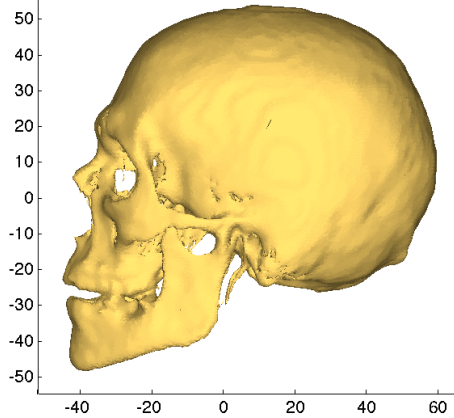| Mode 1	Mode 2	Mode 3
mean +0.00 std. dev.	mean +0.00 std. dev.	mean +0.00 std. dev.
mean +0.00 std. dev.	mean +0.00 std. dev.	mean +0.00 std. dev.

Show in Slideshow mode for Animations

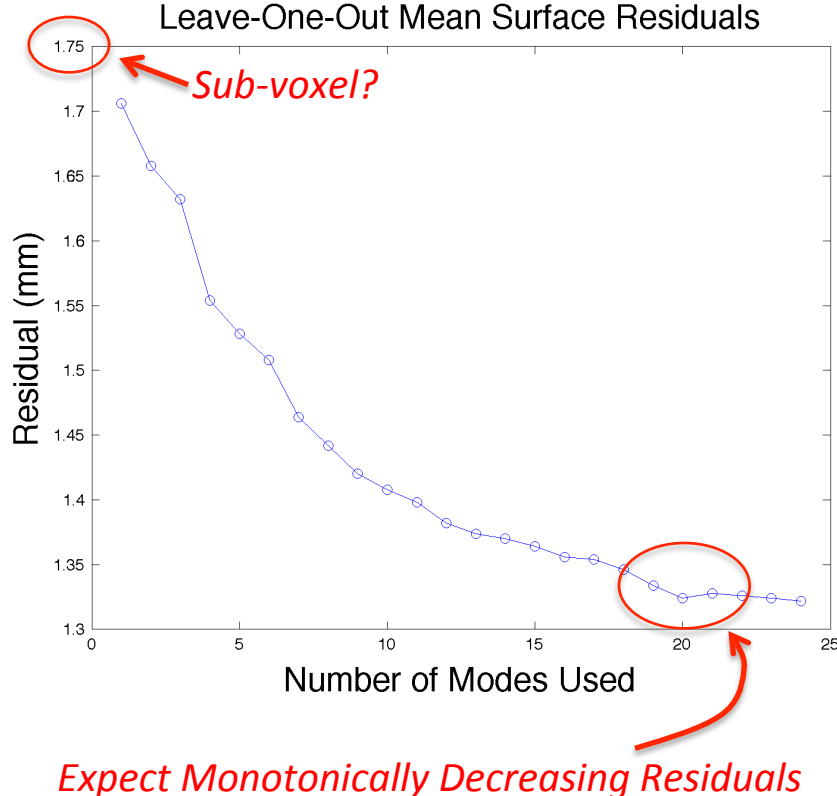CT Image Source: The Cancer Imaging Archive

Minimum Deliverable: Atlas (cont.)

- Leave one out surface distance computed using deformed meshes

Number of Modes Used in Atlas vs Variance Explained

Leave-One-Out Mean Surface Residuals
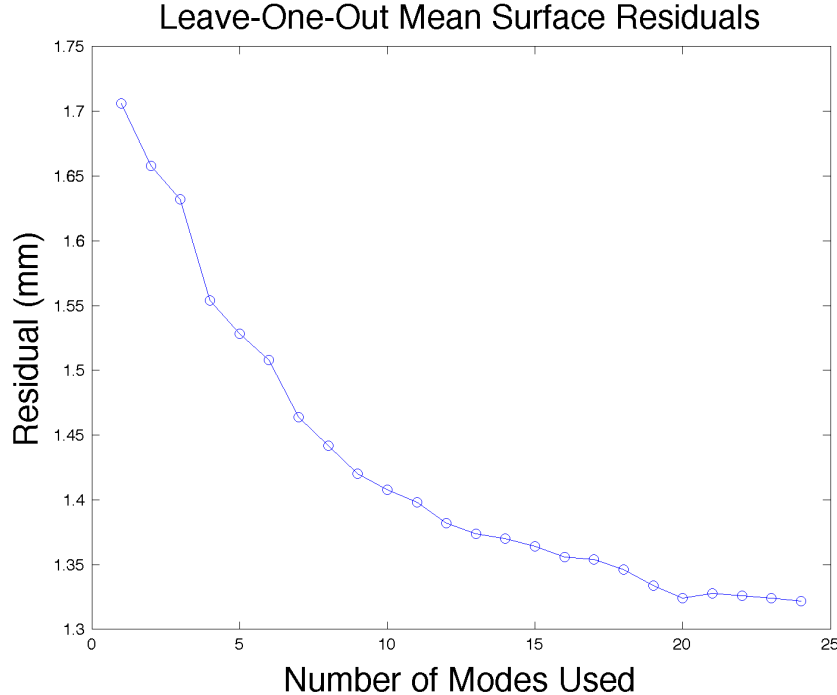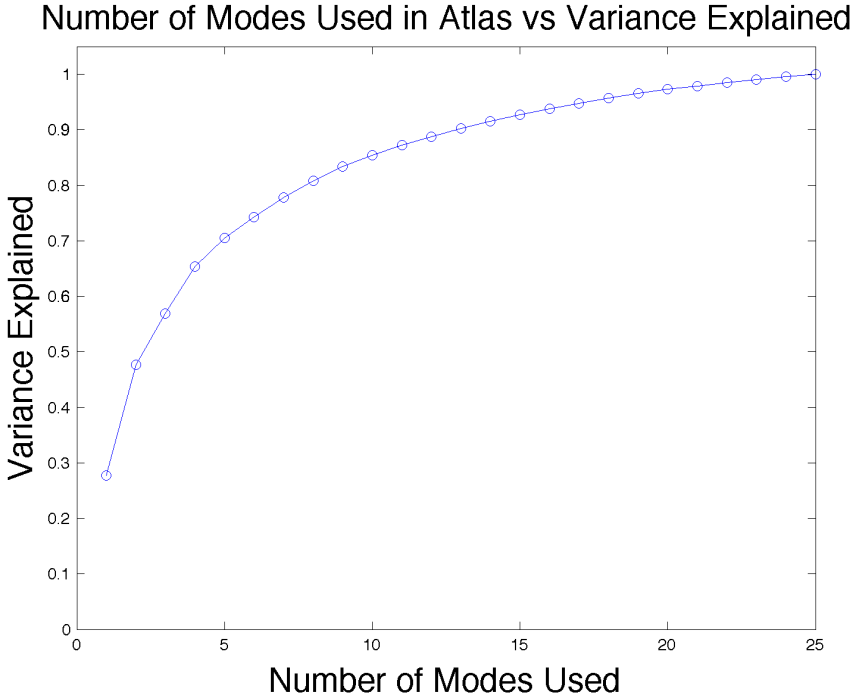
Minimum Deliverable: Atlas (cont.)

- Should also compute surface distance using a mesh derived from manual segmentation (mode matching via PA5)
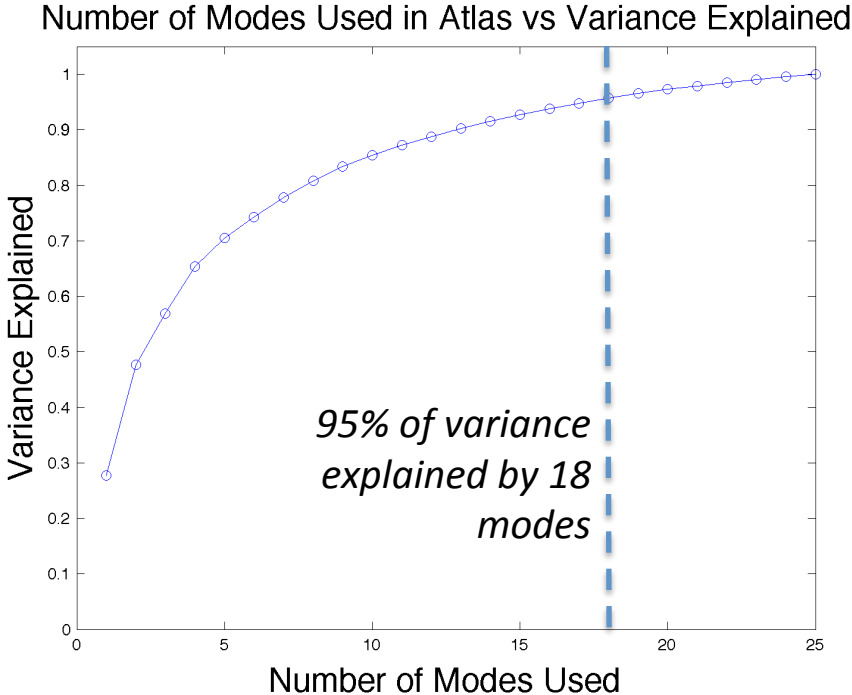
Number of Modes Used in Atlas vs Variance Explained

95% of variance explained by 18 modes

Leave-One-Out Mean Surface Residuals

Sub-voxel?
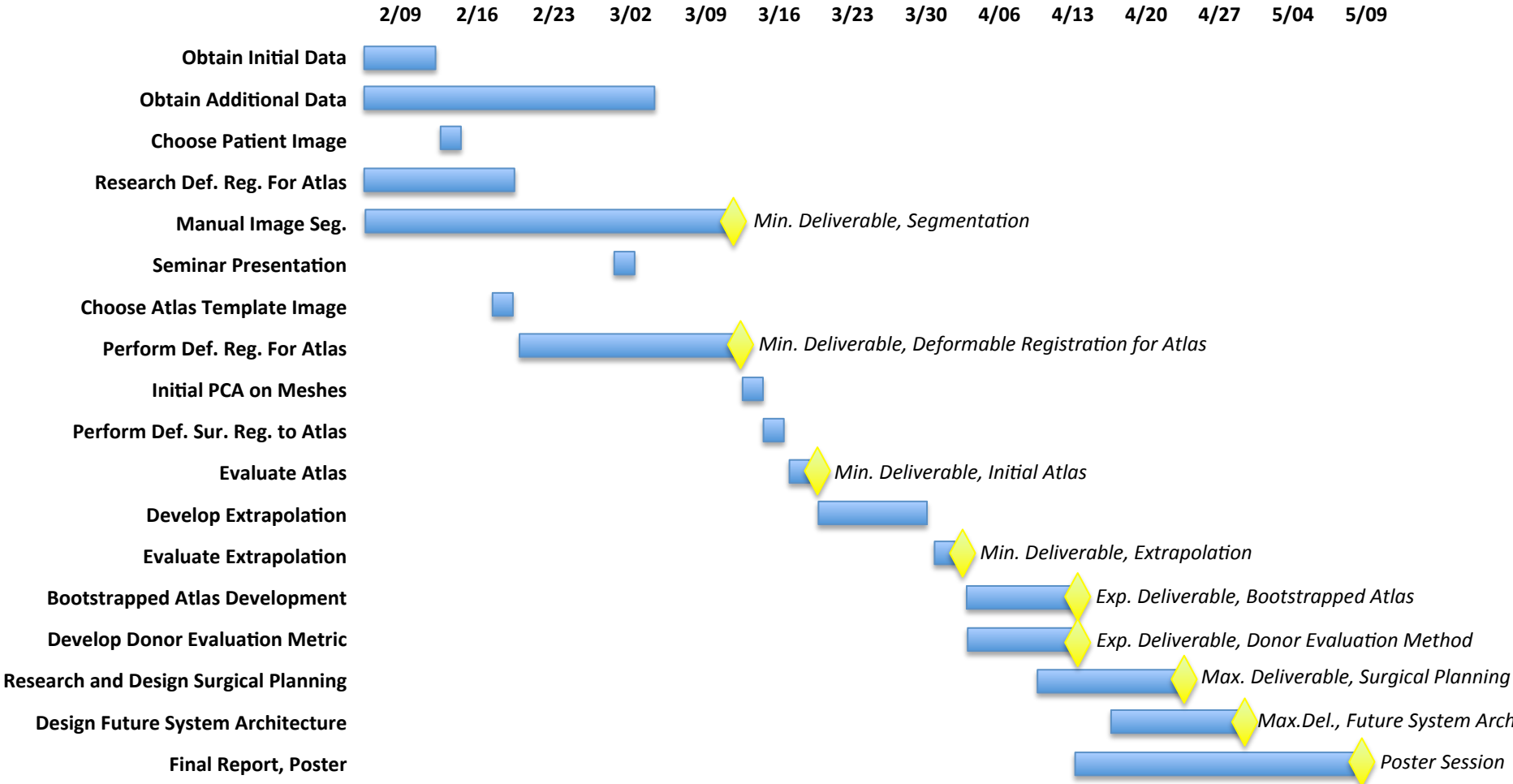
Expect Monotonically Decreasing Residuals

Original Deliverables

- **Minimum**
  - Segmentation mask of the skeletal regions in the cranial CT images ✔
  - Deformable registration of each CT image (or mesh) to a chosen template ✔
  - Atlas creation and evaluation (*near completion*)
  - Development and evaluation of anatomical extrapolation method
- **Expected**
  - Creation and evaluation of an atlas via a bootstrapping technique
  - Development and evaluation of a patient/donor similarity metric
- **Maximum**
  - Design of a method to use the estimated surface of the patient to assist in surgical planning
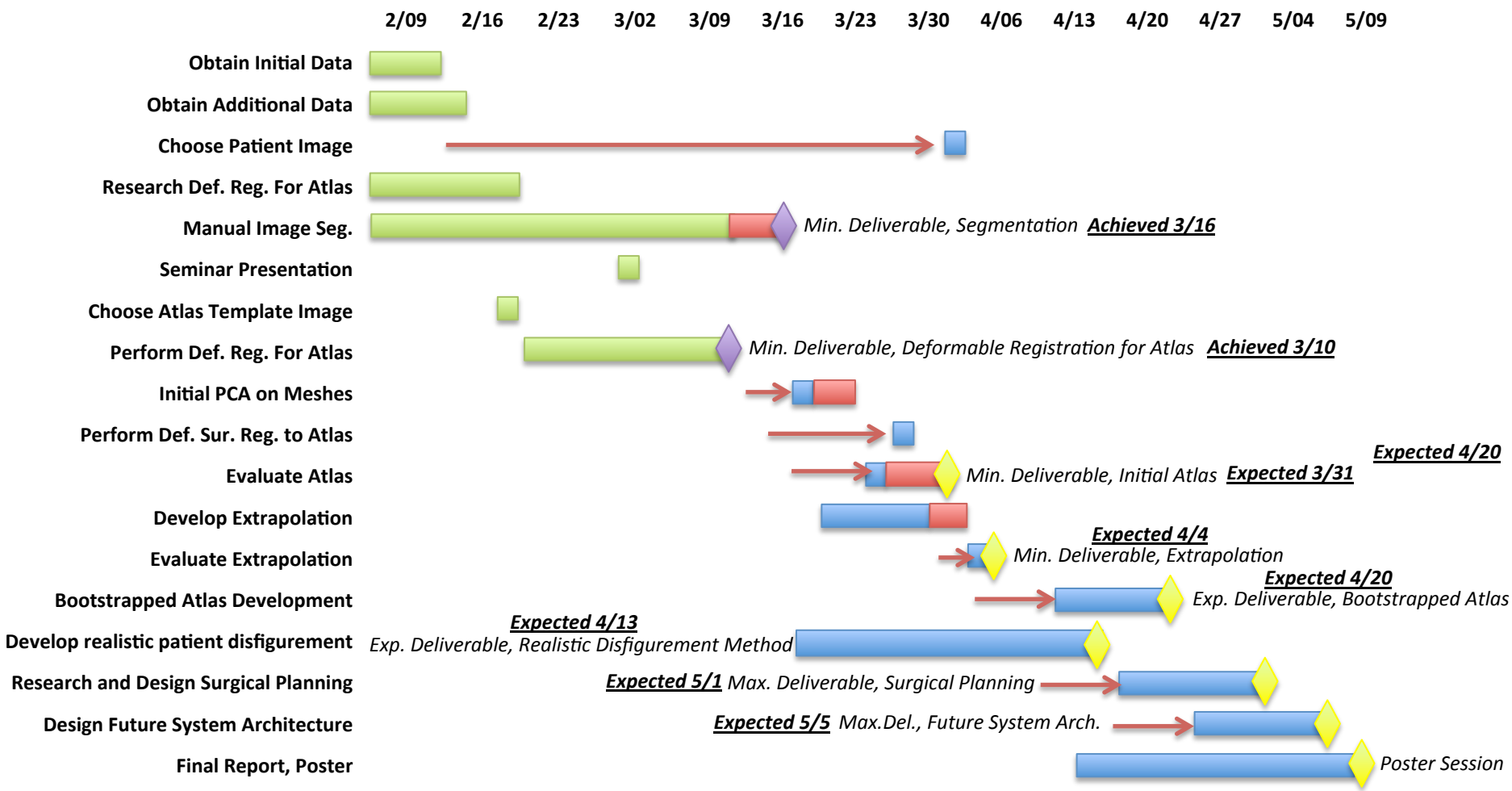 - Create a system architecture for the future use of this system

Slightly Updated Deliverables

- **Minimum**
  - Segmentation mask of the skeletal regions in the cranial CT images ✓
  - Deformable registration of each CT image (or mesh) to a chosen template ✓
  - Atlas creation and evaluation (*near completion*)
  - Development and evaluation of anatomical extrapolation method

- **Expected**
  - Creation and evaluation of an atlas via a bootstrapping technique
  - ~~Development and evaluation of a patient/donor similarity metric~~
  - Development of a realistic patient "disfigurement"

- **Maximum**
  - Design of a method to use the estimated surface of the patient to assist in surgical planning
  - Create a system architecture for the future use of this system
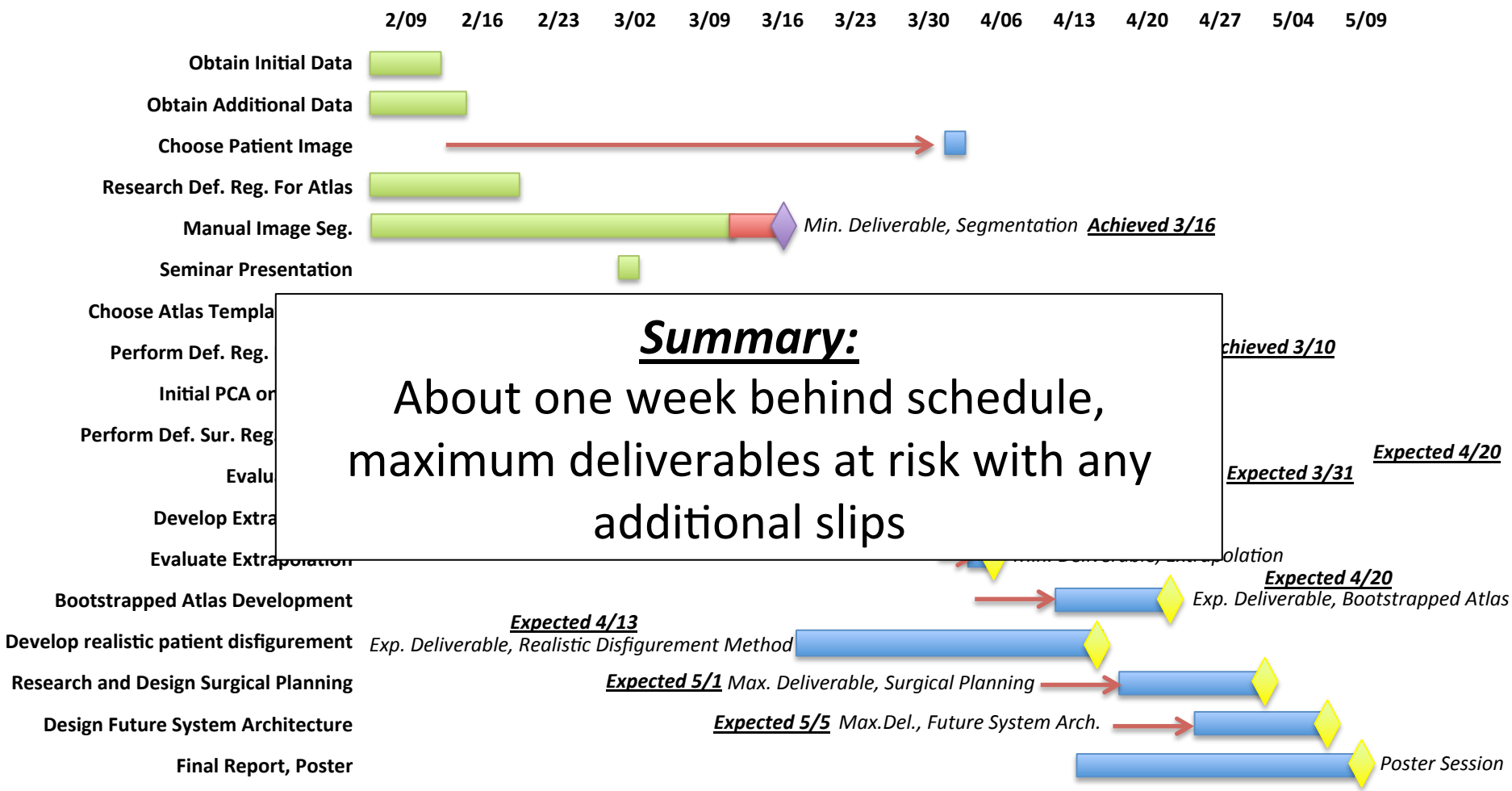
Original Task Schedule

| Task | 2/09 | 2/16 | 2/23 | 3/02 | 3/09 | 3/16 | 3/23 | 3/30 | 4/06 | 4/13 | 4/20 | 4/27 | 5/04 | 5/09 |

- Obtain Initial Data
- Obtain Additional Data
- Choose Patient Image
- Research Def. Reg. For Atlas
- Manual Image Seg. — *Min. Deliverable, Segmentation*
- Seminar Presentation
- Choose Atlas Template Image
- Perform Def. Reg. For Atlas — *Min. Deliverable, Deformable Registration for Atlas*
- Initial PCA on Meshes
- Perform Def. Sur. Reg. to Atlas
- Evaluate Atlas — *Min. Deliverable, Initial Atlas*
- Develop Extrapolation
- Evaluate Extrapolation — *Min. Deliverable, Extrapolation*
- Bootstrapped Atlas Development — *Exp. Deliverable, Bootstrapped Atlas*
- Develop Donor Evaluation Metric — *Exp. Deliverable, Donor Evaluation Method*
- Research and Design Surgical Planning — *Max. Deliverable, Surgical Planning*
- Design Future System Architecture — *Max.Del., Future System Arch.*
- Final Report, Poster — *Poster Session*

Updated Task Schedule

Updated Task Schedule (cont.)

Gantt chart with timeline: 2/09, 2/16, 2/23, 3/02, 3/09, 3/16, 3/23, 3/30, 4/06, 4/13, 4/20, 4/27, 5/04, 5/09

Tasks:
- Obtain Initial Data
- Obtain Additional Data
- Choose Patient Image
- Research Def. Reg. For Atlas
- Manual Image Seg. — *Min. Deliverable, Segmentation* **Achieved 3/16**
- Seminar Presentation
- Choose Atlas Templa...
- Perform Def. Reg. — **Achieved 3/10**
- Initial PCA or...
- Perform Def. Sur. Reg...
- Evalu... — **Expected 3/31**, **Expected 4/20**
- Develop Extra...
- Evaluate Extrapolation — *Min. Deliverable, Extrapolation*
- Bootstrapped Atlas Development — **Expected 4/20**, *Exp. Deliverable, Bootstrapped Atlas*
- Develop realistic patient disfigurement — **Expected 4/13**, *Exp. Deliverable, Realistic Disfigurement Method*
- Research and Design Surgical Planning — **Expected 5/1** *Max. Deliverable, Surgical Planning*
- Design Future System Architecture — **Expected 5/5** *Max.Del., Future System Arch.*
- Final Report, Poster — *Poster Session*

Summary:
About one week behind schedule, maximum deliverables at risk with any additional slips

Questions?

Minimum Deliverable: Manually Segmented Skulls

- Preliminary steps:
  - Resampling to isotropic voxels (2 mm)
  - Cropping of each CT to a uniform ROI
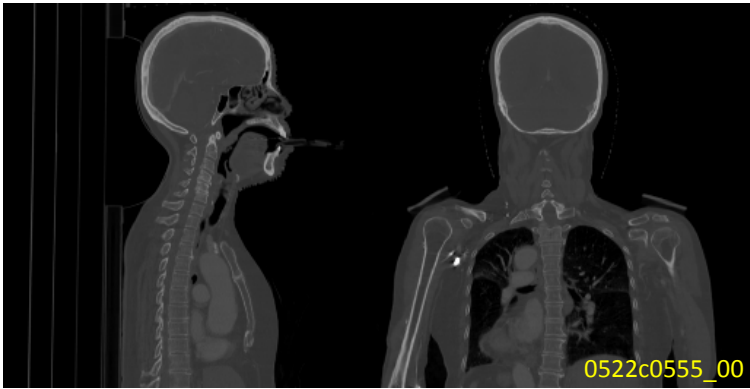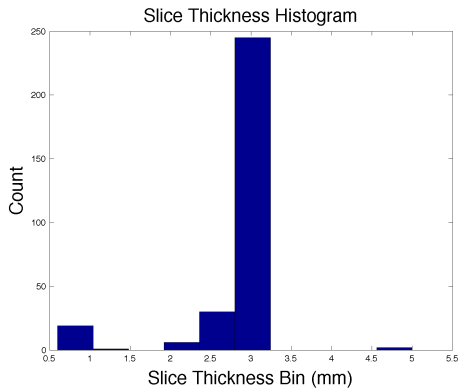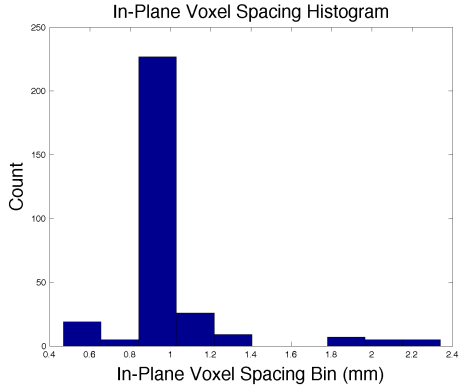
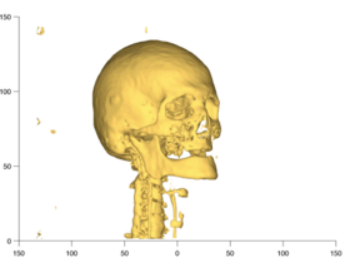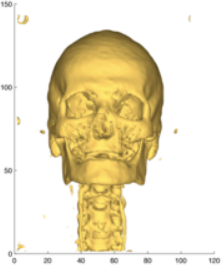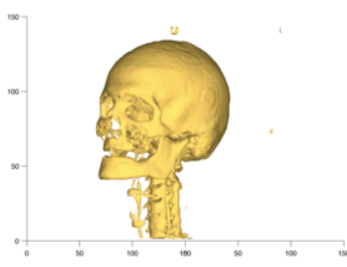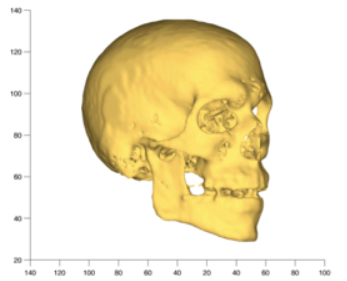CT Image Source: The Cancer Imaging Archive
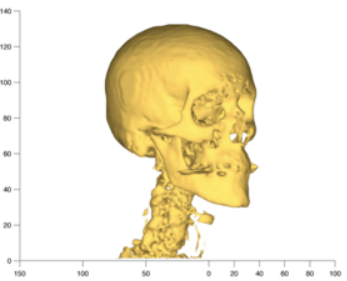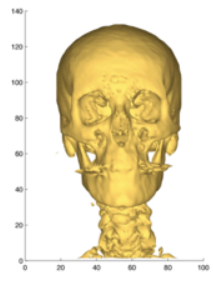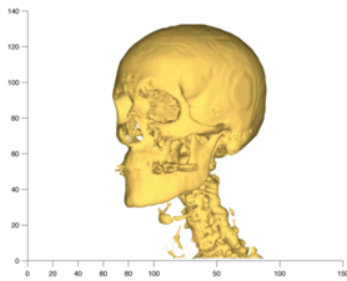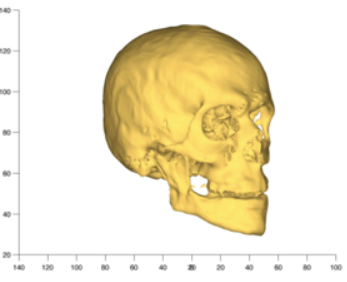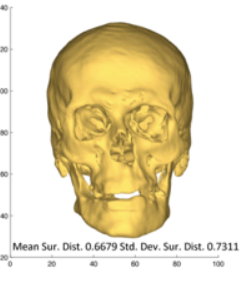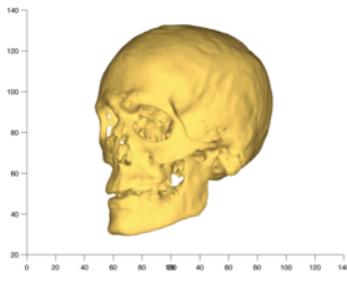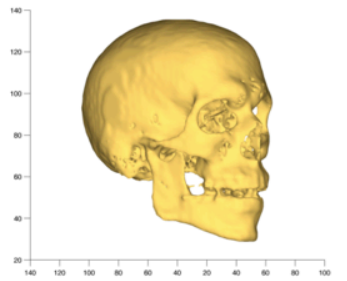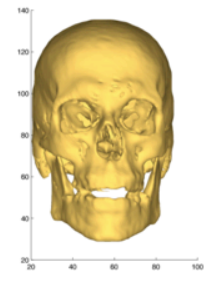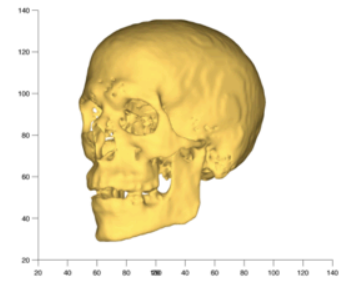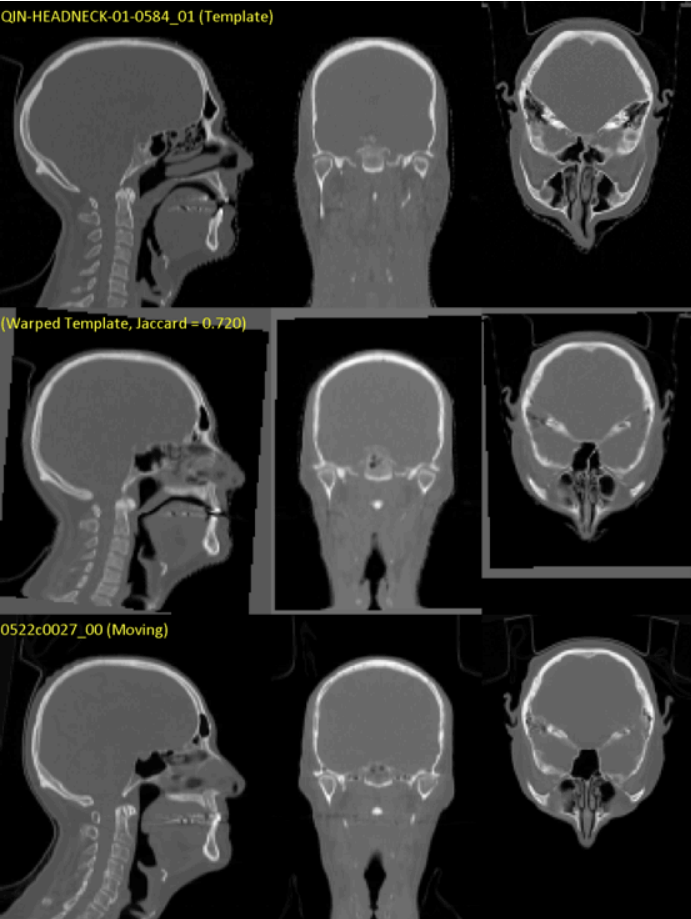
Registration Usable

CT Image Source: The Cancer Imaging Archive
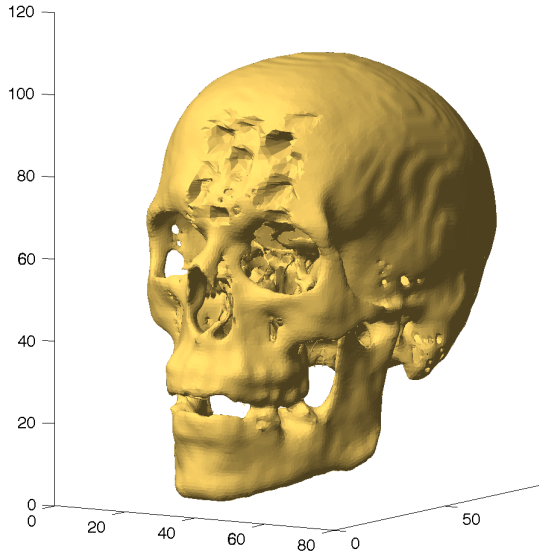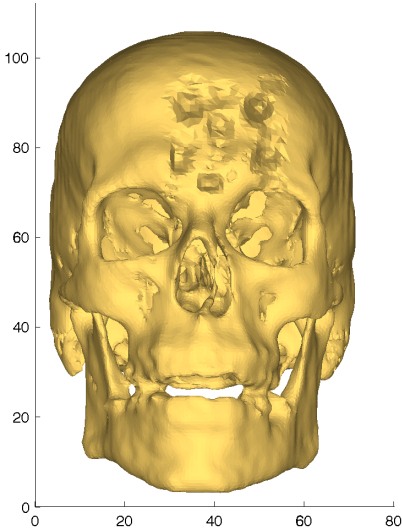
Registration Failed
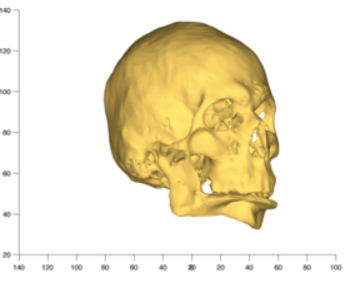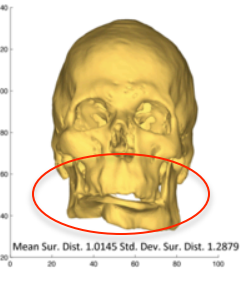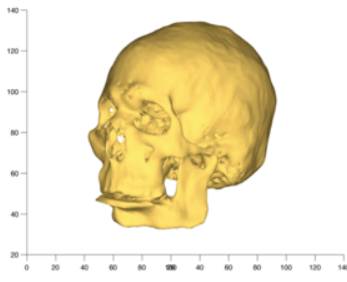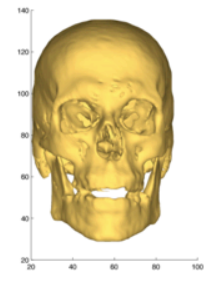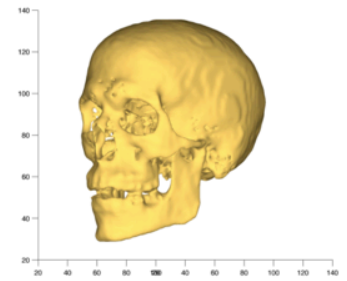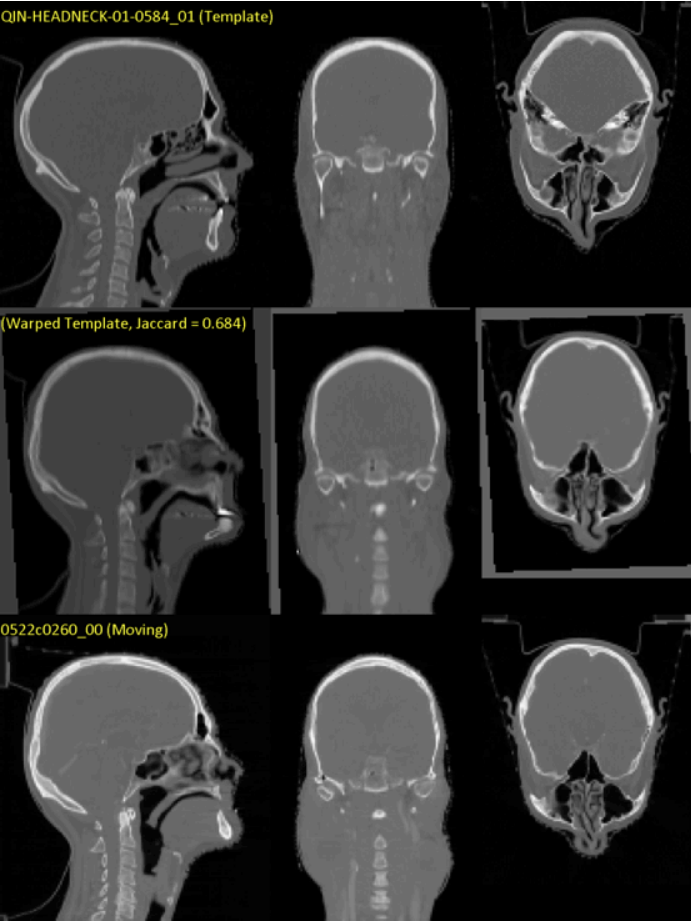
CT Image Source: The Cancer Imaging Archive

"Realistic Disfigurement" Work in Progress

- Additive Gaussian Noise to vertex coordinates in specific region

Courtesy of Dr. Chad Gordon

CT Image Source: The Cancer Imaging Archive