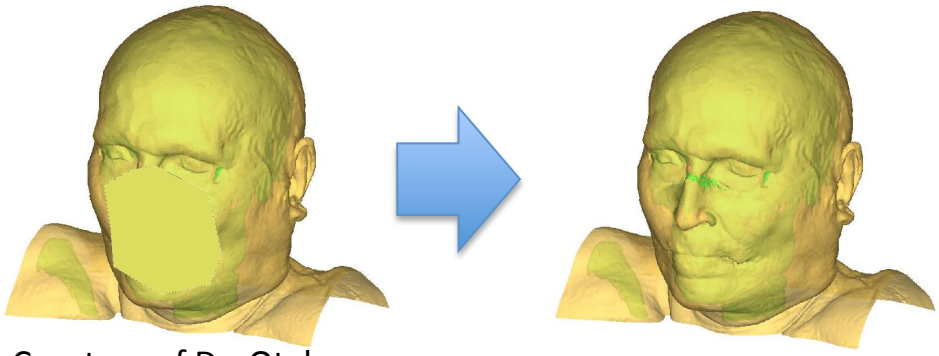
Extrapolation of Missing Craniofacial Skeletal Structure via Statistical Shape Models



Courtesy of Dr. Otake

Robert Grupp

Hsin-Hong Chiang

Dr. Yoshito Otake (Mentor)

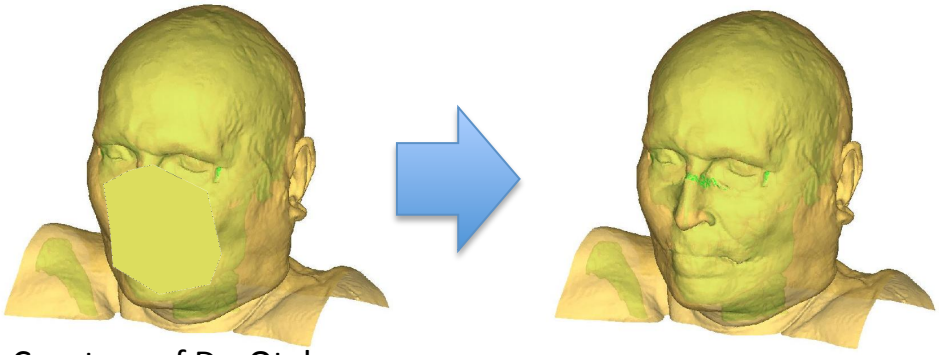
Dr. Russell Taylor (Mentor)

Dr. Mehran Armand (Mentor)

Ryan Murphy (Mentor)

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.

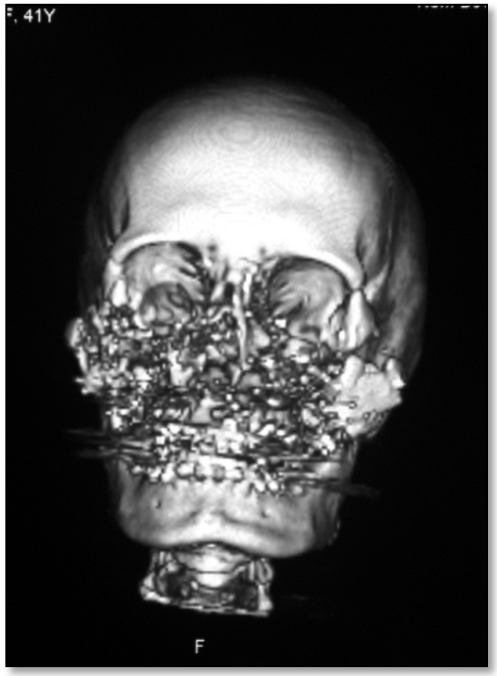


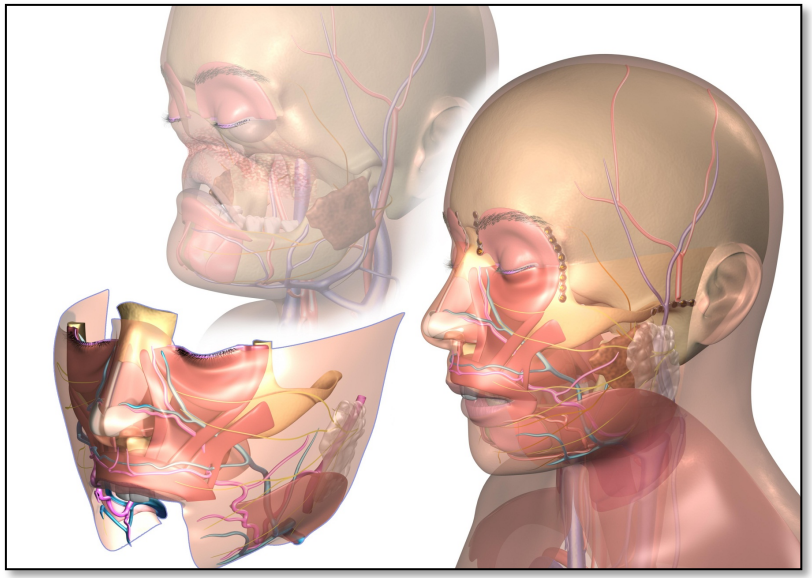
Courtesy of Dr. Otake

Project Relevance: Face Transplant Surgery

- Restore lost functionality
- Restore appearance

Courtesy of Dr. Chad Gordon

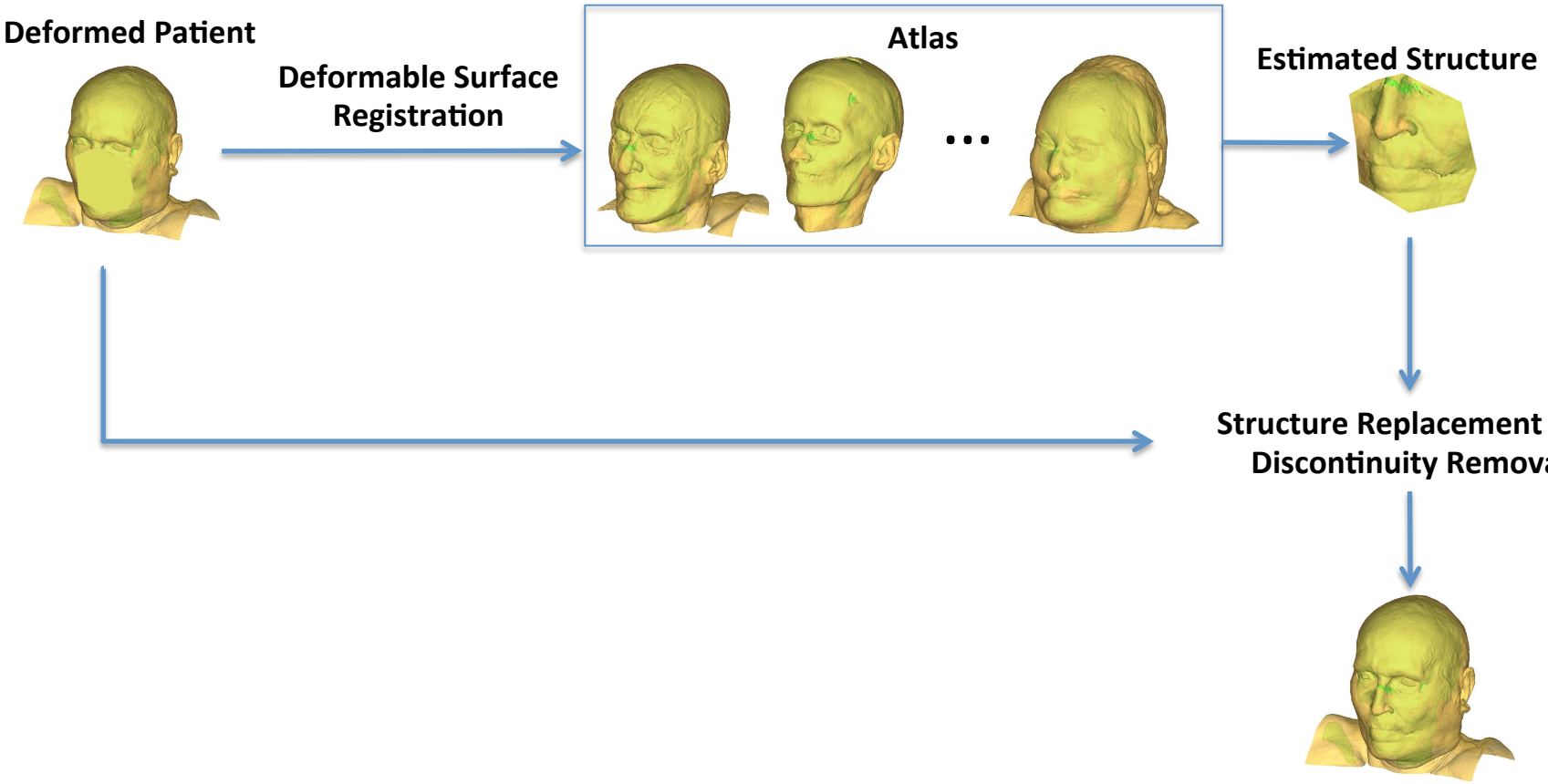




Project Relevance: Face Transplant Surgery (cont.)

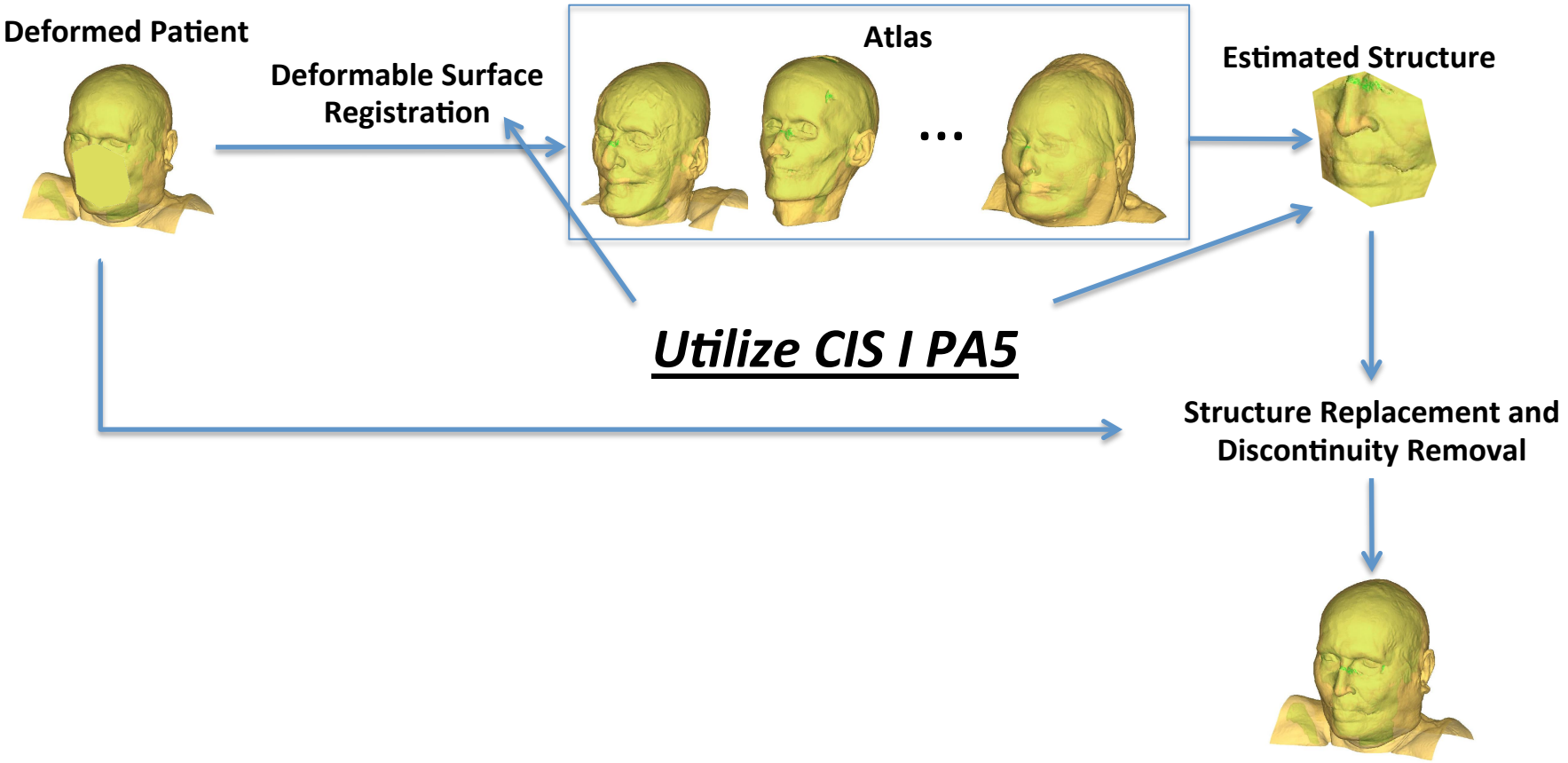
Courtesy of Dr. Chad Gordon

Extrapolation Overview



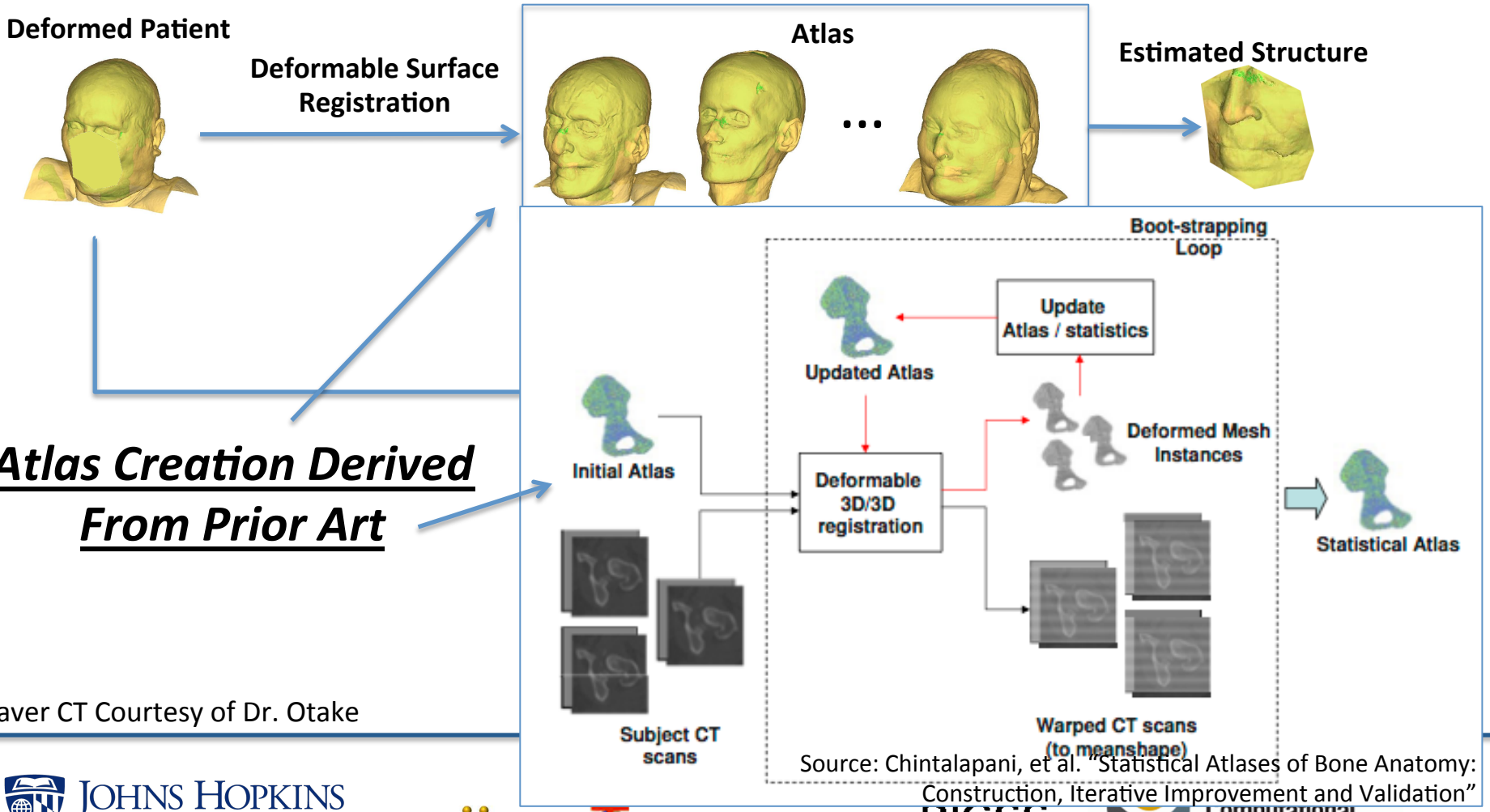
Cadaver CT Courtesy of Dr. Otake

Extrapolation Overview (cont.)



Cadaver CT Courtesy of Dr. Otake

Extrapolation Overview (cont.)

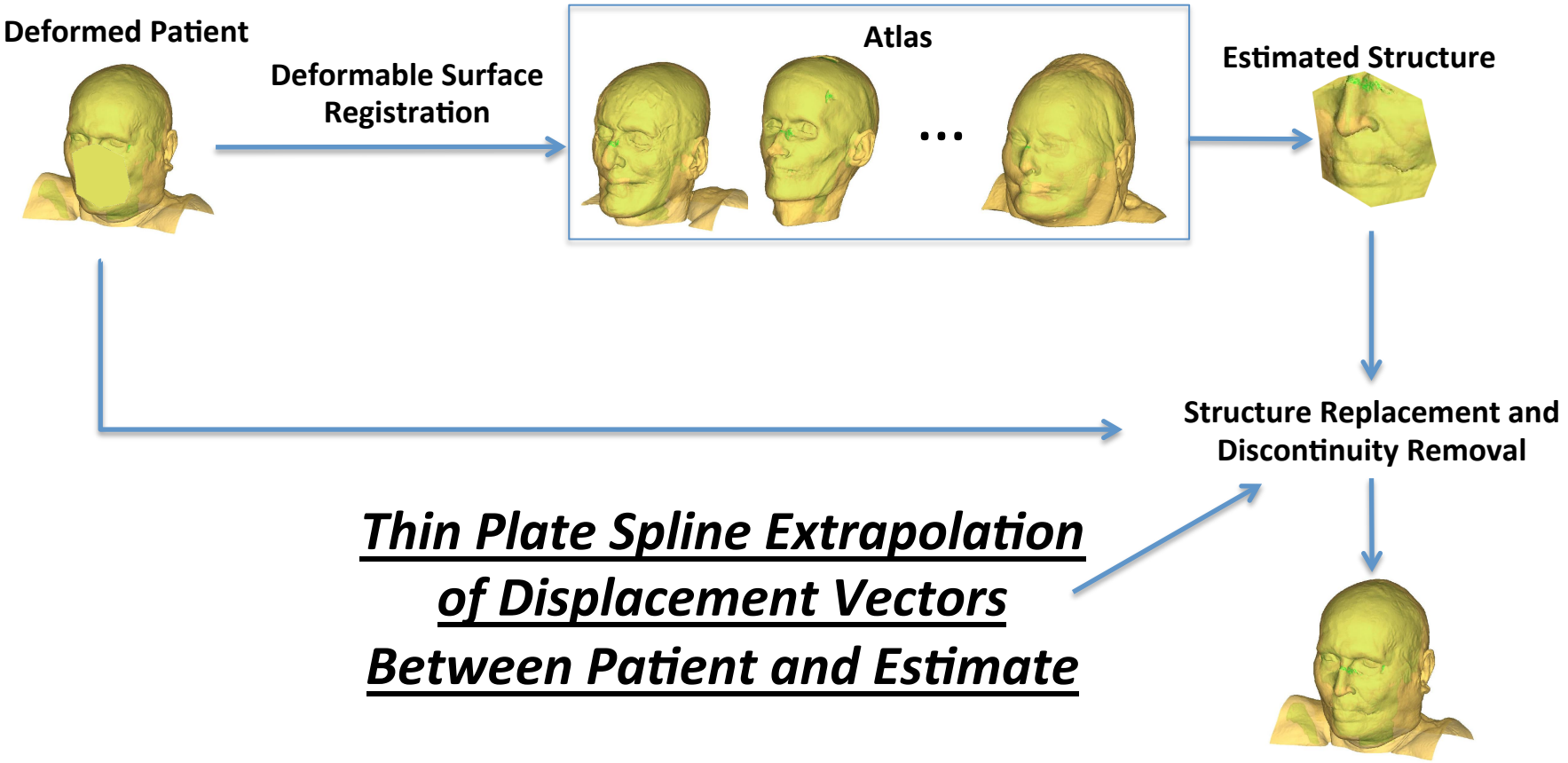


Atlas Creation Derived From Prior Art

Cadaver CT Courtesy of Dr. Otake

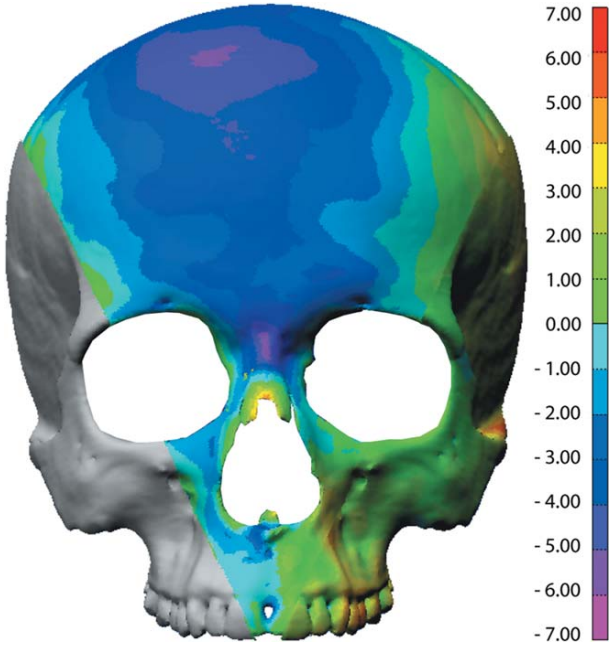
Source: Chintalapani, et al. "Statistical Atlases of Bone Anatomy: Construction, Iterative Improvement and Validation"

Extrapolation Overview (cont.)



Cadaver CT Courtesy of Dr. Otake

Prior Work From Forensics Community



Source: Senck, Sascha, et al., Virtual Reconstruction of Very Large Skull Defects Featuring Partly and Completely Missing Midsagittal Planes

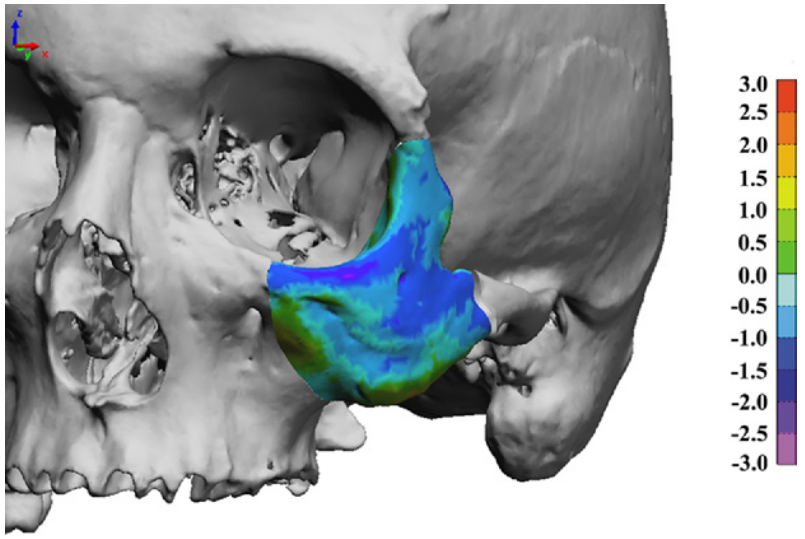
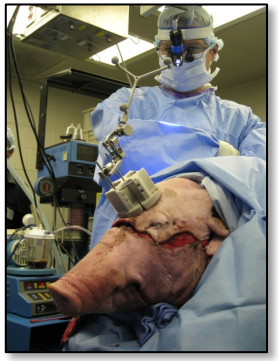


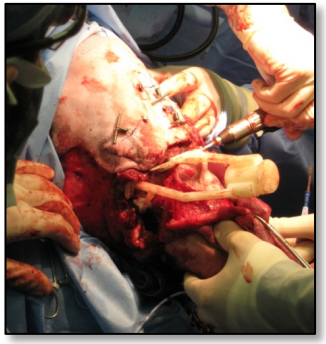
FIGURE 5. Skull H14, anterolateral view. Reconstruction using method 1. Color map illustrating distance between reconstruction and original model (in millimeters).

Benazzi and Senck. 3D Virtual Methods for Craniomaxillofacial Reconstruction. J Oral Maxillofac Surg 2011.

Additional Work

- Development of a method to incorporate this structure estimation into surgical planning
  - Integration into APL Face Surgery?
- Design of a future system architecture
  - For example, enabling the automatic identification of a potential donor



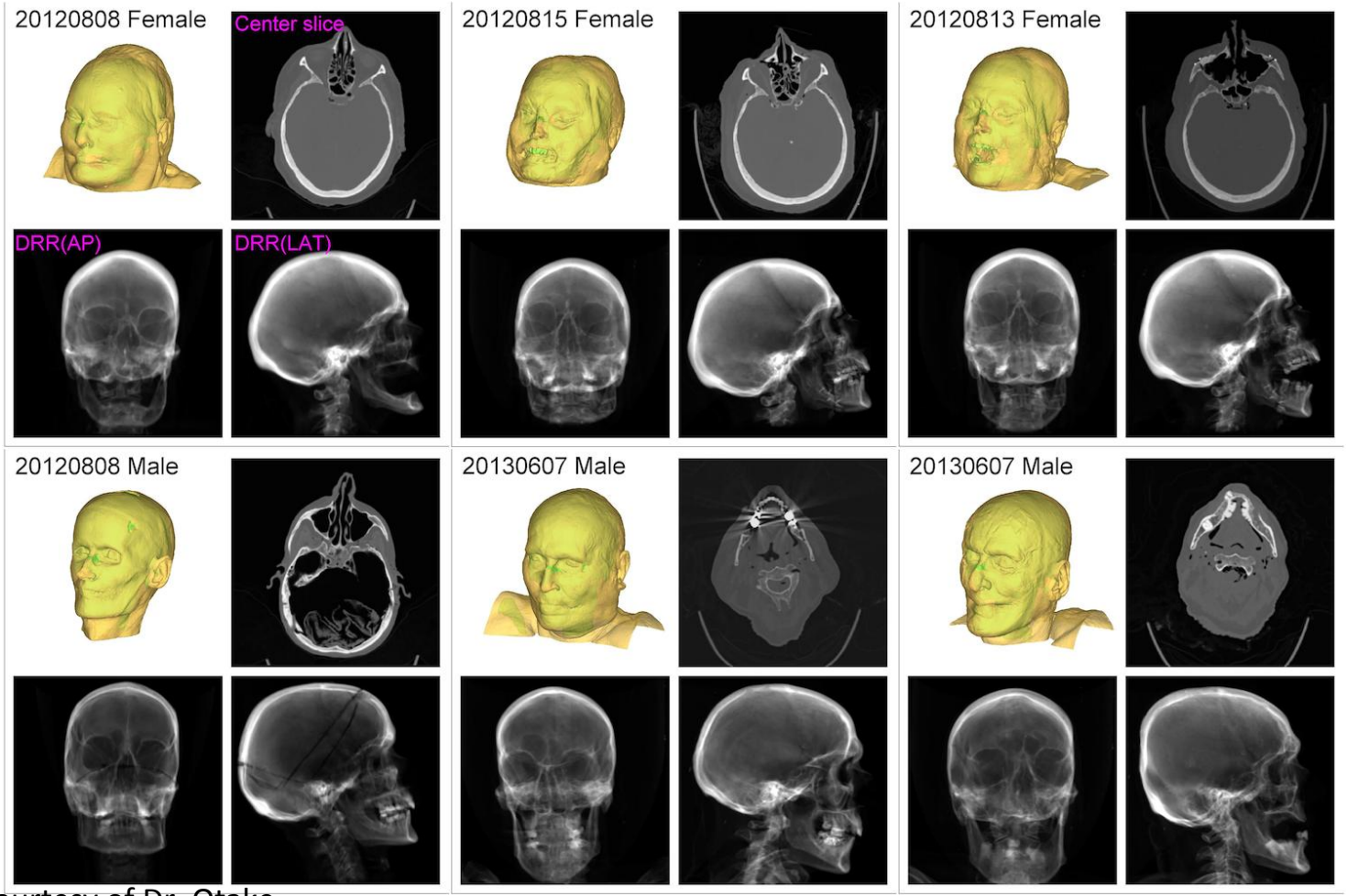


Intra-operative strategy

- Navigation with optical tracker performed concurrently on both donor and recipient
- Hard tissue navigation involving tracking guides and lines of osteotomy
- Soft tissue navigation via mapping vessels and nerves
- 3D visualization of the surgical progress
- Intra-operative plan updates and biomechanical assessment during the surgery

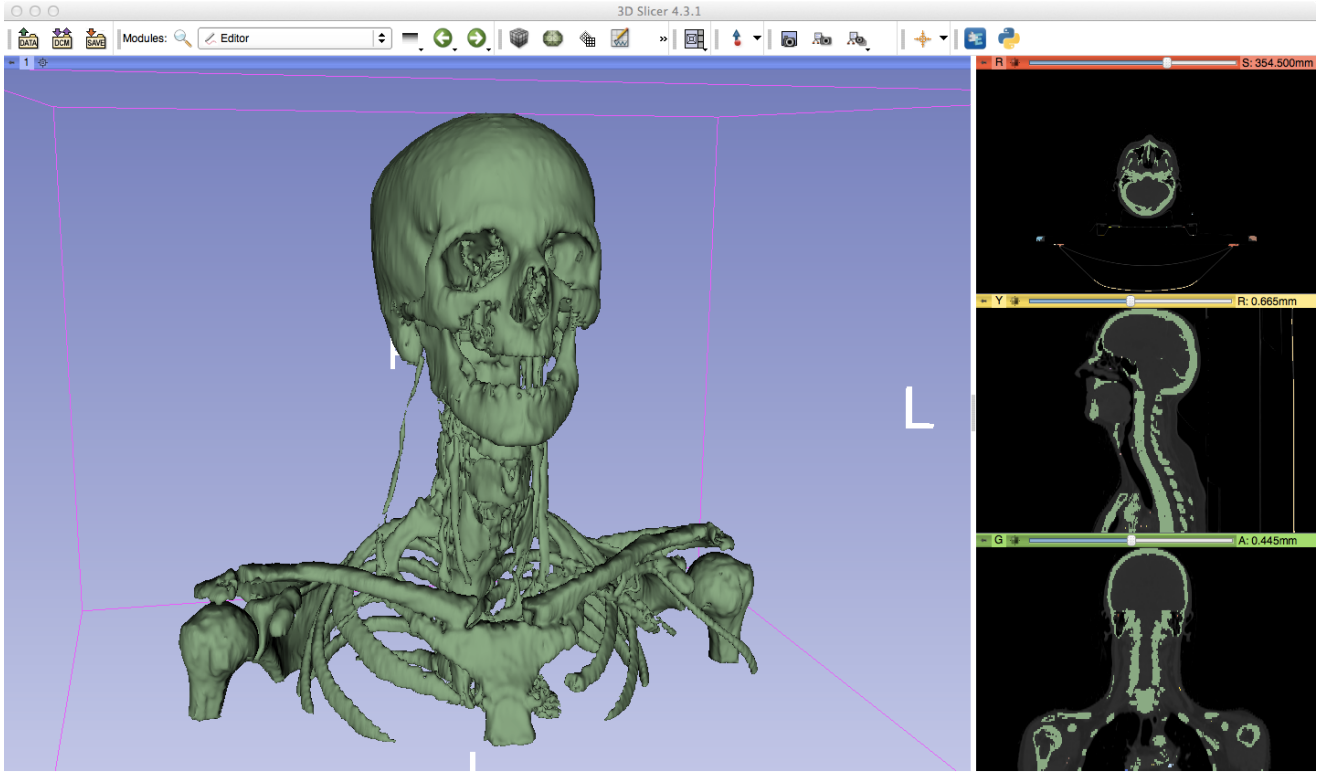
Figures Courtesy of Ryan Murphy, JHU APL

Initial Set of Six Cadaver Heads



Cadaver CT Courtesy of Dr. Otake

- *Disclaimer:* 2 minute segmentation & model
  - Simple threshold, connected components, Marching Cubes



Data Source: https://wiki.cancerimagingarchive.net/display/Public/Head-Neck+Cetuximab

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

Dependencies

- **Obtaining the Cranial CT Data**
  - We have an initial set of 6 cadaver head CT images from Dr. Otake
  - The Cancer Imaging Archive (TCIA) has two datasets with head CT images of 77 and 91 patients, respectively; the data is freely available with no usage restrictions
  - If TCIA data is insufficient, then we can request additional data from Dr. Armand, however it may require IRB approval.
  - If neither of these plans work, then the fallback would be to use existing pelvis CT data.
- **Access to Mentors**
  - A recurring weekly meeting with Dr. Otake has been scheduled
  - Schedule meetings with Dr. Taylor, Dr. Armand, and Ryan Murphy as needed
- **Access to Fast Computer**
  - Ask Dr. Armand for permission to use the new BIGSS lab computer
  - Fallback is to use personal computers

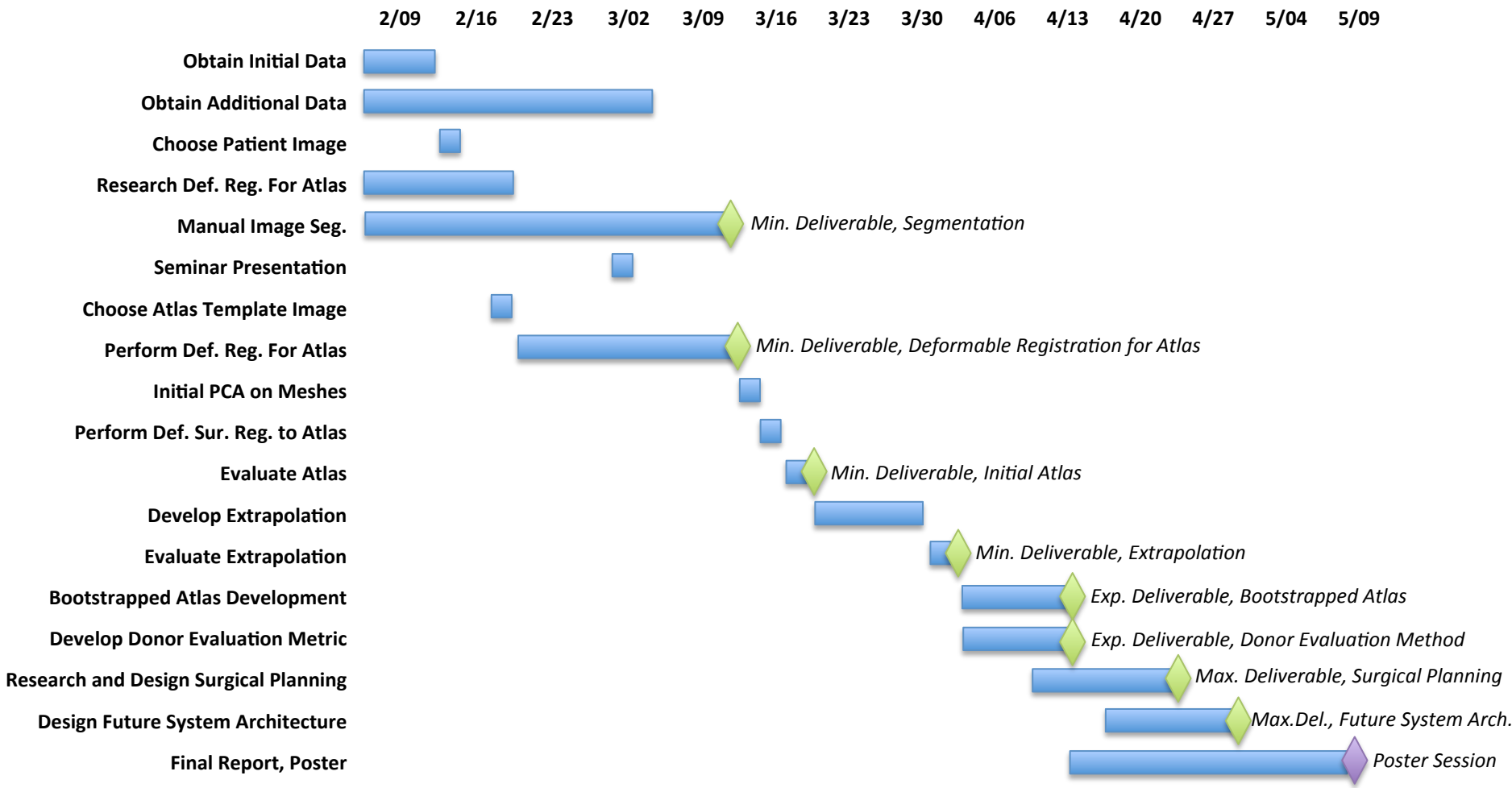
Management Plan: Basics

- Program Manager: Robert Grupp
- Two Weekly Recurring Team Meetings
  - More as needed
- Weekly Recurring Meeting Scheduled with Dr. Otake
  - Meetings with Dr. Taylor, Dr. Armand, and Ryan Murphy as needed
- Source Code and Document Control via LCSR Git Lab

Management Plan: Key Milestones

- **March 2:** All data obtained and pre-processed as needed
- **March 10:** Manual segmentation of all images complete
- **March 12:** Deformable registration for atlas creation complete
- **March 21:** Initial atlas created and evaluated
- **April 2:** Extrapolation algorithm complete and evaluated
  - *Minimum deliverables achieved*
- **April 13:** Bootstrapped atlas created and evaluated
- **April 13:** Compatibility metric between donor and patient complete
  - *Expected deliverables achieved*
- **April 25:** Surgical planning tool design complete
- **May 1:** Future system architecture complete
  - *Maximum deliverables achieved*
- **May 9:** Poster session

Management Plan: Detailed Task Schedule



Reading List

- **Craniofacial Surgery Background**
  - James A. McNamara Jr., A method of cephalometric evaluation, American Journal of Orthodontics, Volume 86, Issue 6, December 1984, Pages 449-469.
  - F. V. Tenti., Cephalometric analysis as a tool for treatment planning and evaluation, Eur J Orthod (1981) 3 (4): 241-245.
  - Cutting, Court M.D., et al., Three-Dimensional Computer-Assisted Design of Craniofacial Surgical Procedures: Optimization and Interaction with Cephalometric and CT-Based Models. Plastic \& Reconstructive Surgery. 77(6):877-885, June 1986.
  - Gordon, Chad R. DO, et al., The Cleveland Clinic FACES Score: A Preliminary Assessment Tool for Identifying the Optimal Face Transplant Candidate. Journal of Craniofacial Surgery. 20(6):1969-1974, November 2009.
  - Chopra, Karan MD, et al., Clinical Application of the FACES Score for Face Transplantation. Journal of Craniofacial Surgery. 25(1): 64-69, January 2014.
  - Gordon, Chad R. DO, et al., The World's Experience With Facial Transplantation: What Have We Learned Thus Far? Annals of Plastic Surgery. 63(5):572-578, November 2009.
  - Gordon, Chad R. DO, et al., Le Fort-Based Maxillofacial Transplantation: Current State of the Art and a Refined Technique Using Orthognathic Applications. Journal of Craniofacial Surgery. 23(1):81-87, January 2012.

Reading List (cont.)

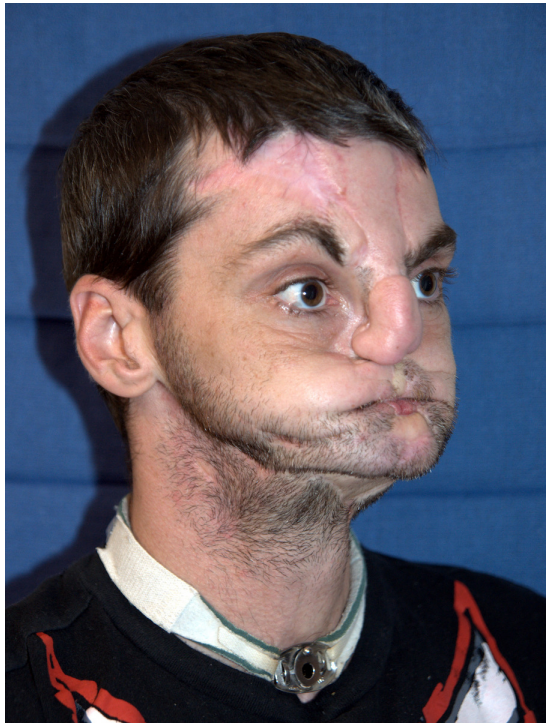
- **Atlas Creation**
  - T.F. Cootes, et al., Active Shape Models-Their Training and Application, Computer Vision and Image Understanding, Volume 61, Issue 1, January 1995, Pages 38-59.
  - Chintalapani, Gouthami, et al., Statistical Atlases of Bone Anatomy: Construction, Iterative Improvement and Validation, Medical Image Computing and Computer-Assisted Intervention – MICCAI 2007, 4791:499-506, 2007.
  - Chintalapani, Gouthami. Statistical Atlases of Bone Anatomy and Their Applications. Thesis (Ph. D.)--Johns Hopkins University, 2010.
  - Sadowsky, O.. Image registration and hybrid volume reconstruction of bone anatomy using a statistical shape atlas. Thesis (Ph. D.)--Johns Hopkins University, 2009.
  - Stefan Zachow, et al., Reconstruction of mandibular dysplasia using a statistical 3D shape model, International Congress Series, Volume 1281, May 2005, Pages 1238-1243.

Reading List (cont.)

- **Deformable Registration (for Atlas Creation)**
  - Sotiras, A., et al., Deformable Medical Image Registration: A Survey, Medical Imaging, IEEE Transactions on , vol.32, no.7, pp.1153,1190, July 2013.
  - Brian B. Avants, et al., A reproducible evaluation of ANTs similarity metric performance in brain image registration, NeuroImage, Volume 54, Issue 3, 1 February 2011, Pages 2033-2044.
- **Surface Interpolation**
  - Bookstein, Fred L., Principal warps: thin-plate splines and the decomposition of deformations, Pattern Analysis and Machine Intelligence, IEEE Transactions on , vol.11, no.6, pp.567,585, Jun 1989.
  - Kazhdan, Michael, et al., Poisson surface reconstruction. In Proceedings of the fourth Eurographics symposium on Geometry processing. 2006.
- **Forensic Anthropology**
  - Stefano Benazzi, et al., A new OH5 reconstruction with an assessment of its uncertainty, Journal of Human Evolution, Volume 61, Issue 1, July 2011, Pages 75-88.
  - Senck, Sascha, et al., Virtual Reconstruction of Very Large Skull Defects Featuring Partly and Completely Missing Midsagittal Planes, The Anatomical Record. 296(5):745-758, May 2013.

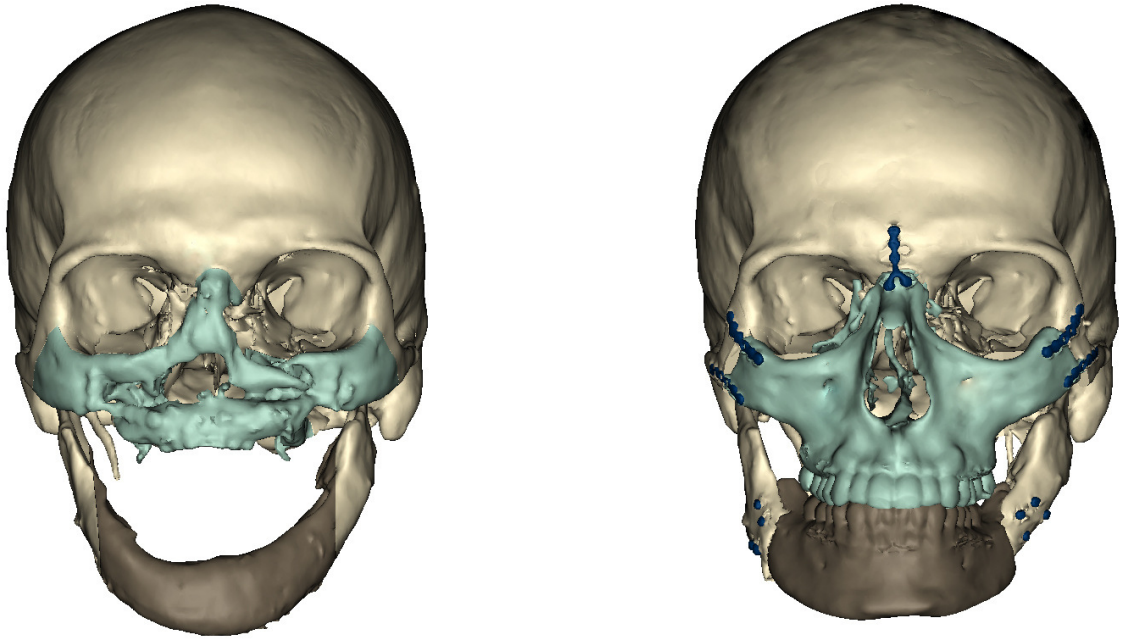
Questions?

Face Transplant Surgery, March 2012


Source: University of Maryland Medical Center (https://umm.edu/programs/face-transplant/media-resources)

Face Transplant Surgery, March 2012 (cont.)



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