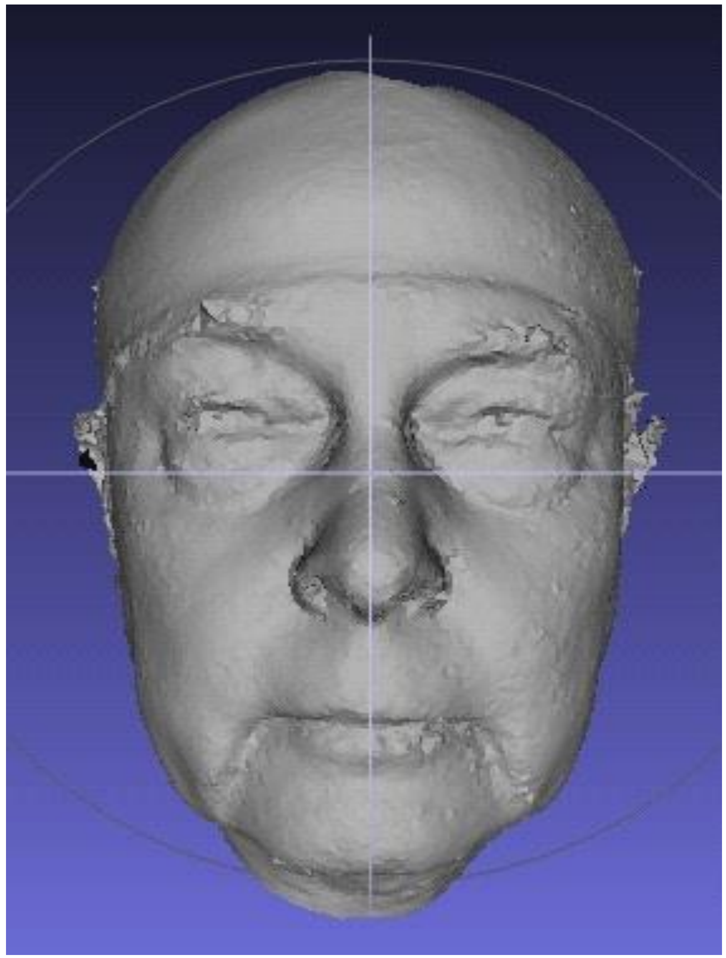
3D Mesh Data for Face and Head Analysis



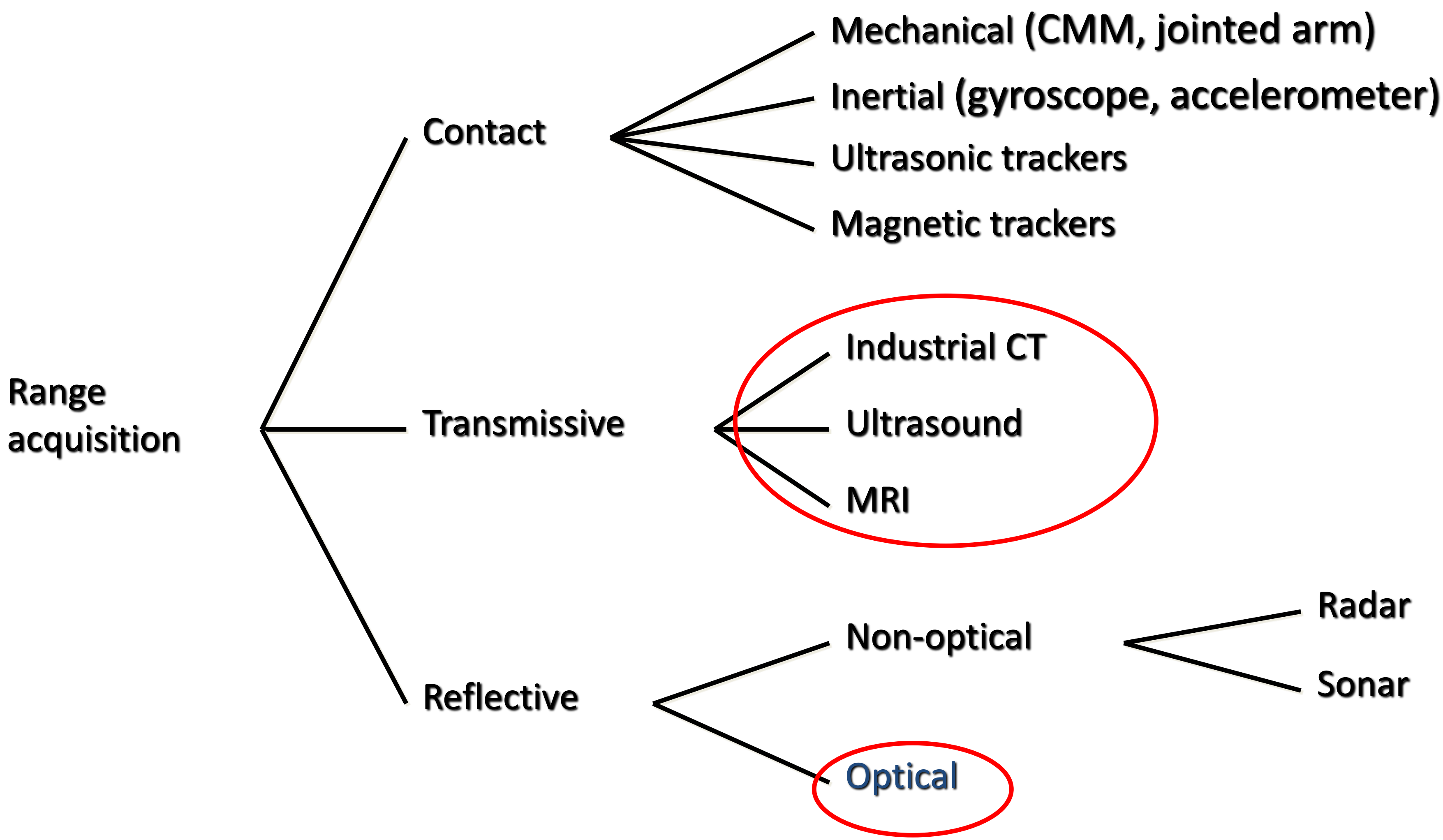
3D Head Mesh Data

- Stereo Vision
- Active Stereo
- 3D Reconstruction
- 3dMD System

Data Types

- Volumetric Data
  - Voxel grids
  - Occupancy
  - Density
- Surface Data
  - Point clouds
  - Range images (range maps)

Range Acquisition Taxonomy



Range Acquisition Taxonomy

- Optical methods
  - Passive
    - Shape from X:
      - stereo
      - motion
      - shading
      - texture
      - focus
      - defocus
  - Active
    - Active variants of passive methods
      - Stereo w. projected texture
      - Active depth from defocus
      - Photometric stereo
    - Time of flight
    - Triangulation

Optical Range Scanning Methods

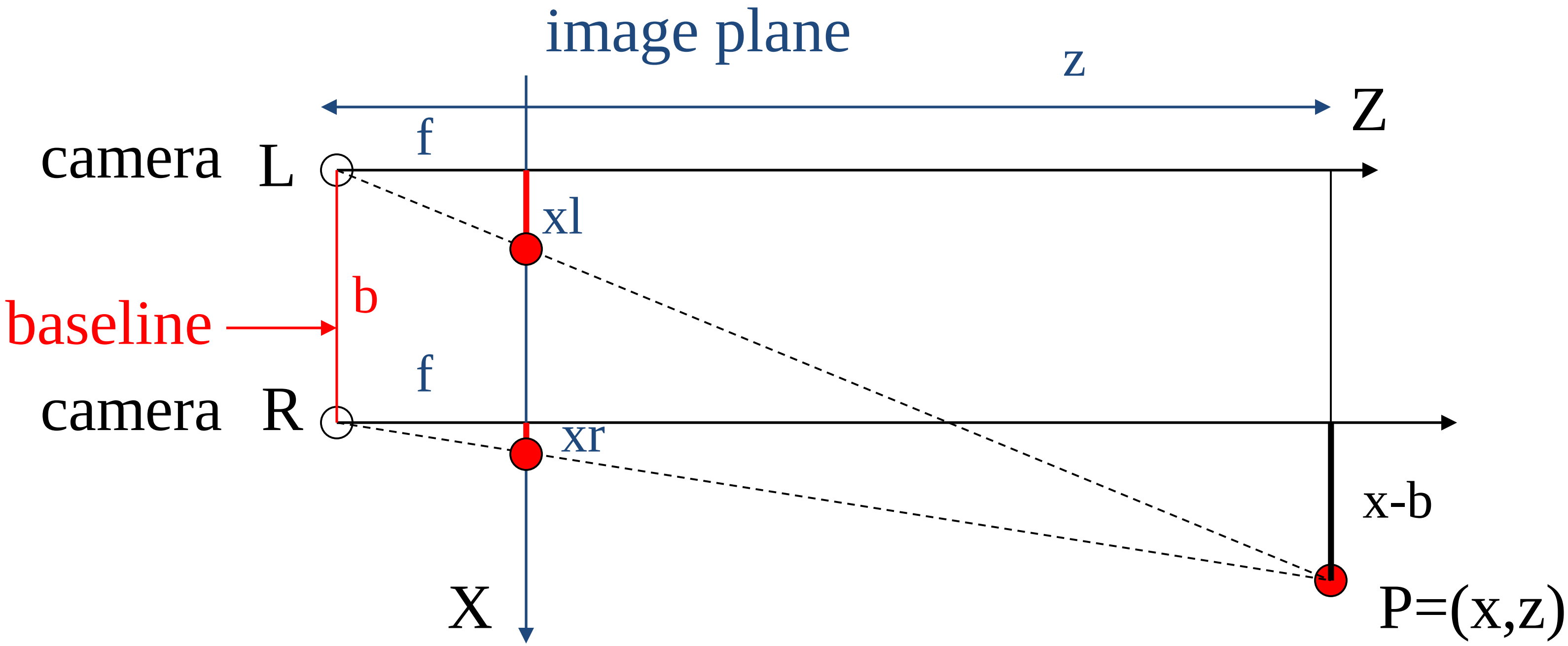
- Advantages:
  - Non-contact
  - Safe
  - Usually inexpensive
  - Usually fast
- Disadvantages:
  - Sensitive to transparency
  - Confused by specularity and interreflection
  - Texture (helps some methods, hurts others)

Stereo

- Find feature in one image, search along epipole in other image for correspondence

Depth Perception from Stereo

Simple Model: Parallel Optic Axes



$$\frac{z}{f} = \frac{x}{xl}$$

$$\frac{z}{f} = \frac{x-b}{xr}$$

$$\frac{z}{f} = \frac{y}{yl} = \frac{y}{yr}$$

y-axis is perpendicular to the page.

Resultant Depth Calculation

For stereo cameras with parallel optical axes, focal length f, baseline b, corresponding image points (xl,yl) and (xr,yr) with disparity d:

$$z = f*b / (xl - xr) = f*b/d$$

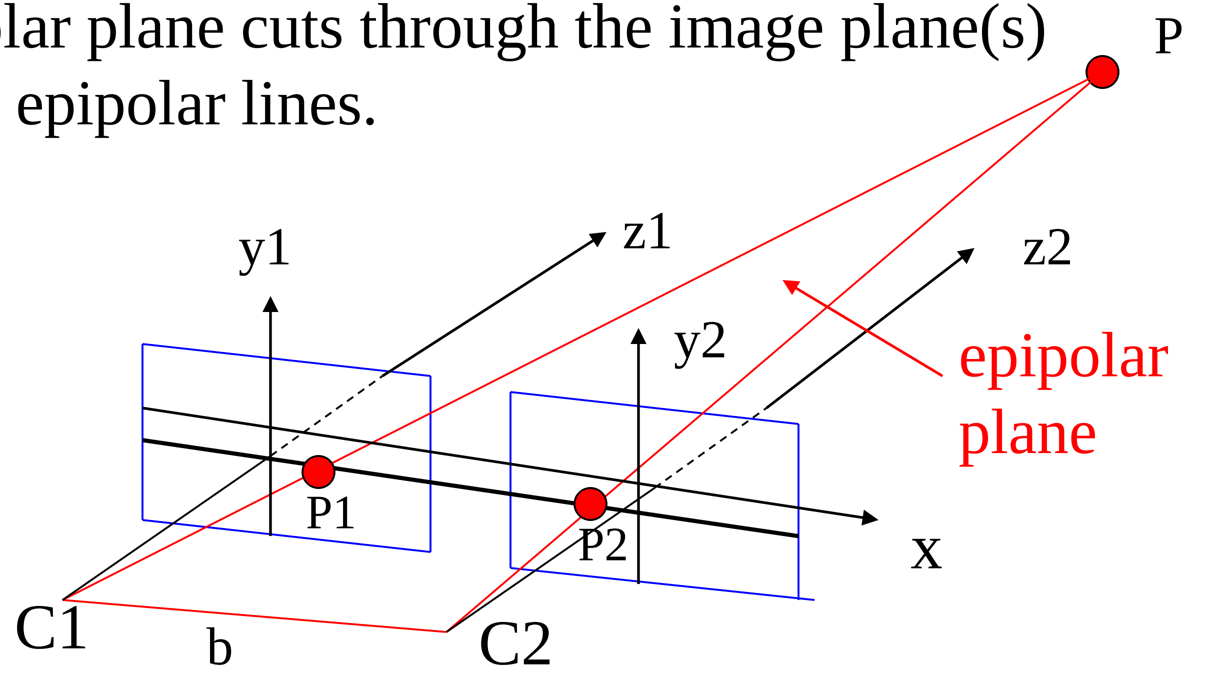
$$x = xl*z/f \quad \text{or} \quad b + xr*z/f$$

$$y = yl*z/f \quad \text{or} \quad yr*z/f$$

This method of determining depth from disparity is called **triangulation**.

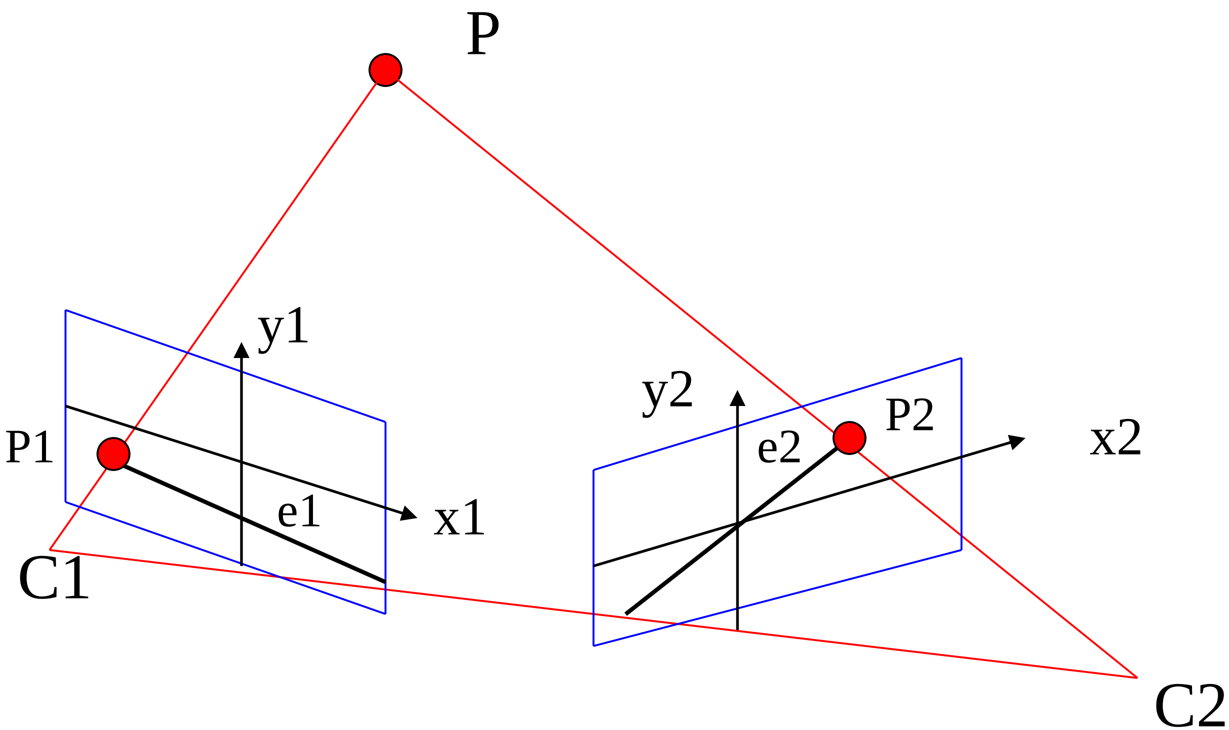
Epipolar Geometry Constraint:
1. Normal Pair of Images

The epipolar plane cuts through the image plane(s) forming 2 epipolar lines.



The match for P1 (or P2) in the other image, must lie on the same epipolar line.

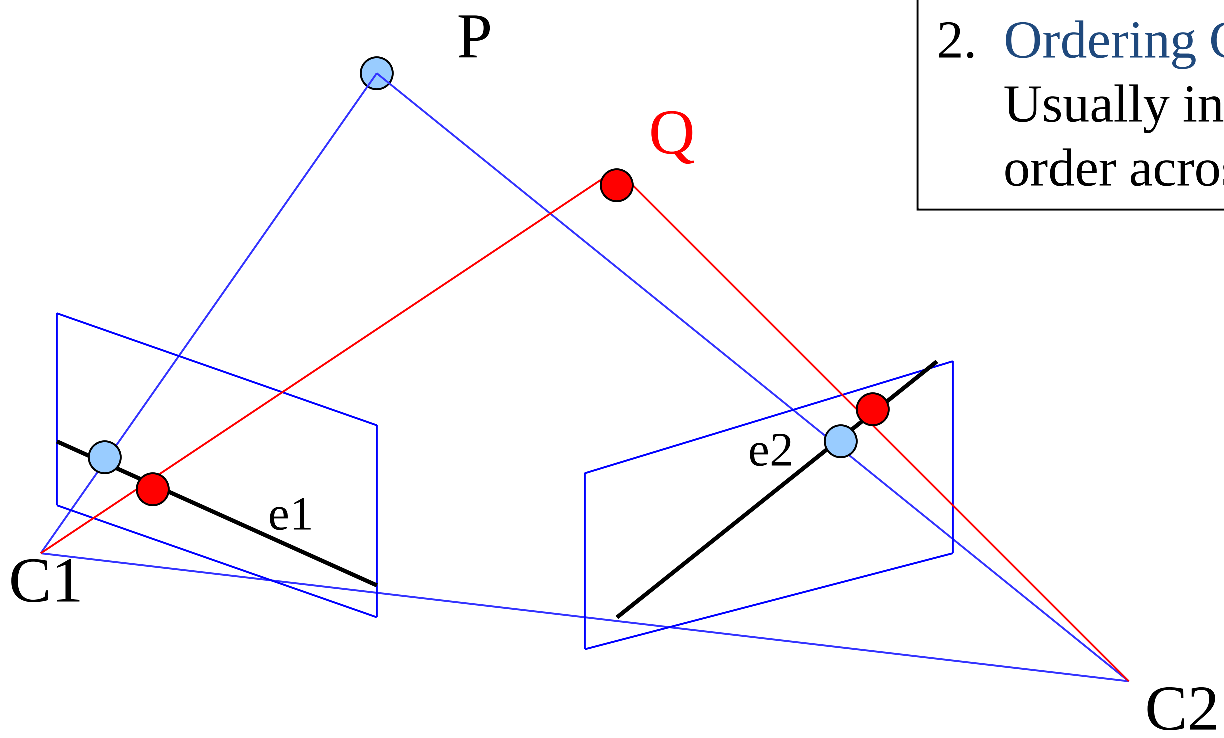
Epipolar Geometry: General Case



Constraints

1. Epipolar Constraint: Matching points lie on corresponding epipolar lines.

2. Ordering Constraint: Usually in the same order across the lines.



Finding Correspondences

- If the correspondence is correct, triangulation works **VERY** well.
- But correspondence finding is not perfectly solved.
- For some very specific applications, it can be solved for those specific kind of images, e.g. windshield of a car where the opening shows up as a clear horizontal line.
- General passive stereo matching is not precise enough for the head meshes used at Children's Research Institute.

Shape from Motion

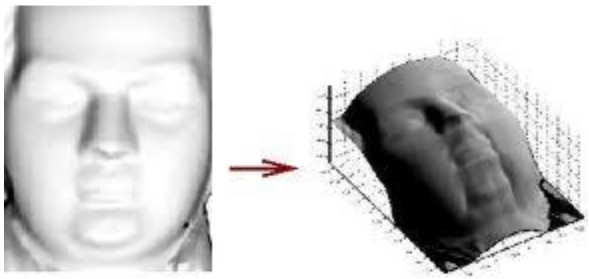
- Track a feature in a video sequence
- For n frames and f features, have $2 \cdot n \cdot f$ knowns, $6 \cdot n + 3 \cdot f$ unknowns
- Solve for the 3D parameters

Shape from Motion

- Advantages:
  - Feature tracking easier than correspondence in far-away views
  - Mathematically more stable (large baseline)
- Disadvantages:
  - Does not accommodate object motion
  - Still problems in areas of low texture, in non-diffuse regions, and around silhouettes

Shape from Shading

- Given: image of surface with known, constant reflectance under known point light
- Estimate normals, integrate to find surface



a) Image

b) 3D surface reconstructed from the single image a)

- Problems: most real images don't satisfy the assumptions; there is ambiguity in the process

Shape from Shading

- Advantages:
  - Single image
  - No correspondences
  - Analogue in human vision
- Disadvantages:
  - Mathematically unstable
  - Can’t have texture
- Not really practical
  - But see photometric stereo

Active Optical Methods

- Advantages:
  - Usually can get dense data
  - Usually much more robust and accurate than passive techniques
- Disadvantages:
  - Introduces light into scene (distracting, etc.)
  - Not motivated by human vision

Active Variants of Passive Techniques

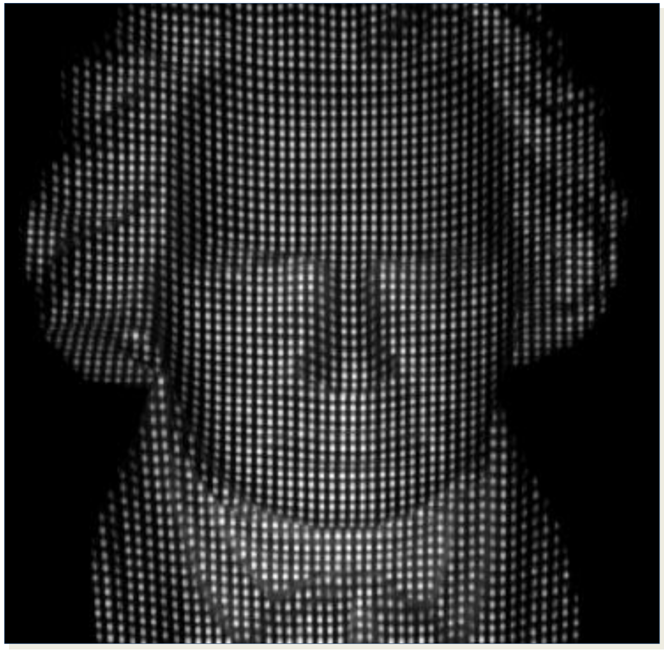
- Active depth from defocus
  - Known pattern helps to estimate defocus
- Photometric stereo
  - Shape from shading with multiple known lights
- Regular stereo with projected texture
  - Provides features for correspondence

What Kinds of Patterns

- Most common: light stripes
- Variation: colored light stripes
- Variation: grids of light stripes
- Variation: point patterns

Multiple Stripes

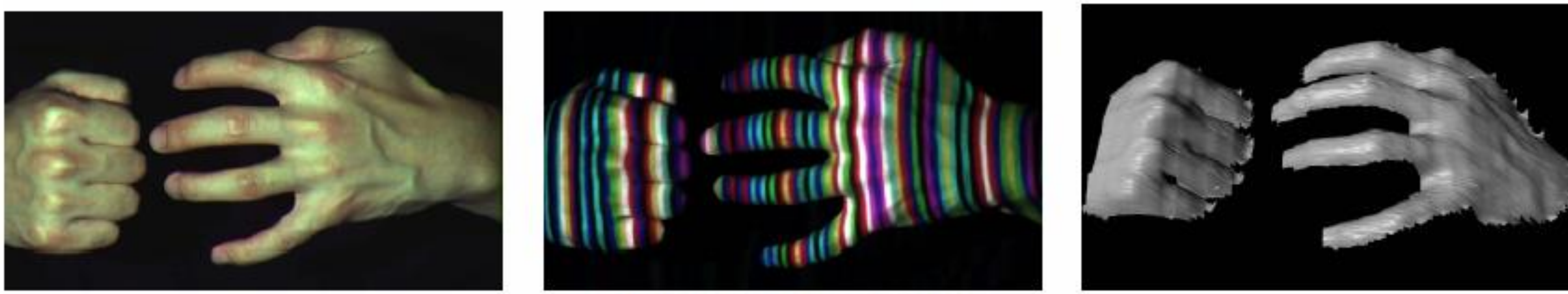
- Project multiple stripes
- But which stripe is which?
- Answer #1: assume surface continuity



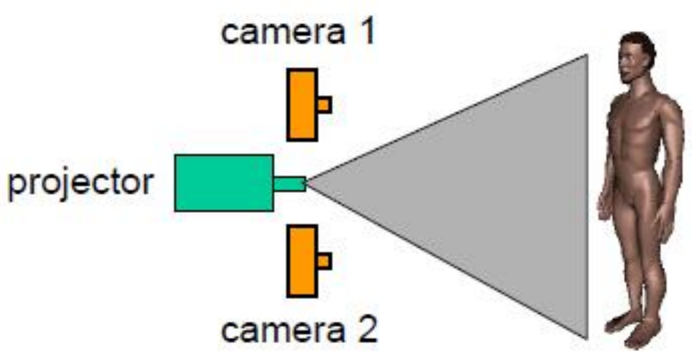
Colored Multiple Stripes

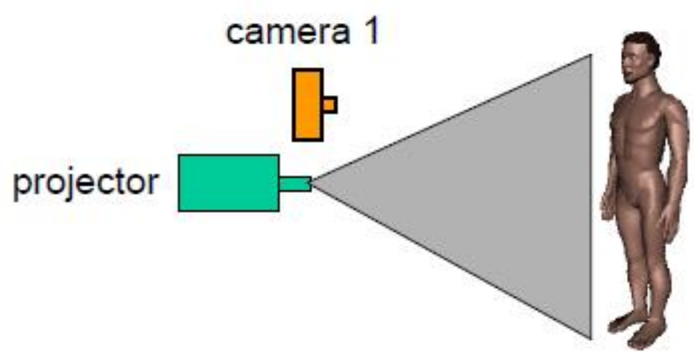
- To go faster, project multiple stripes
- But which stripe is which?
- Answer #2: colored stripes (or dots)

Active stereo with structured light



Li Zhang's one-shot stereo



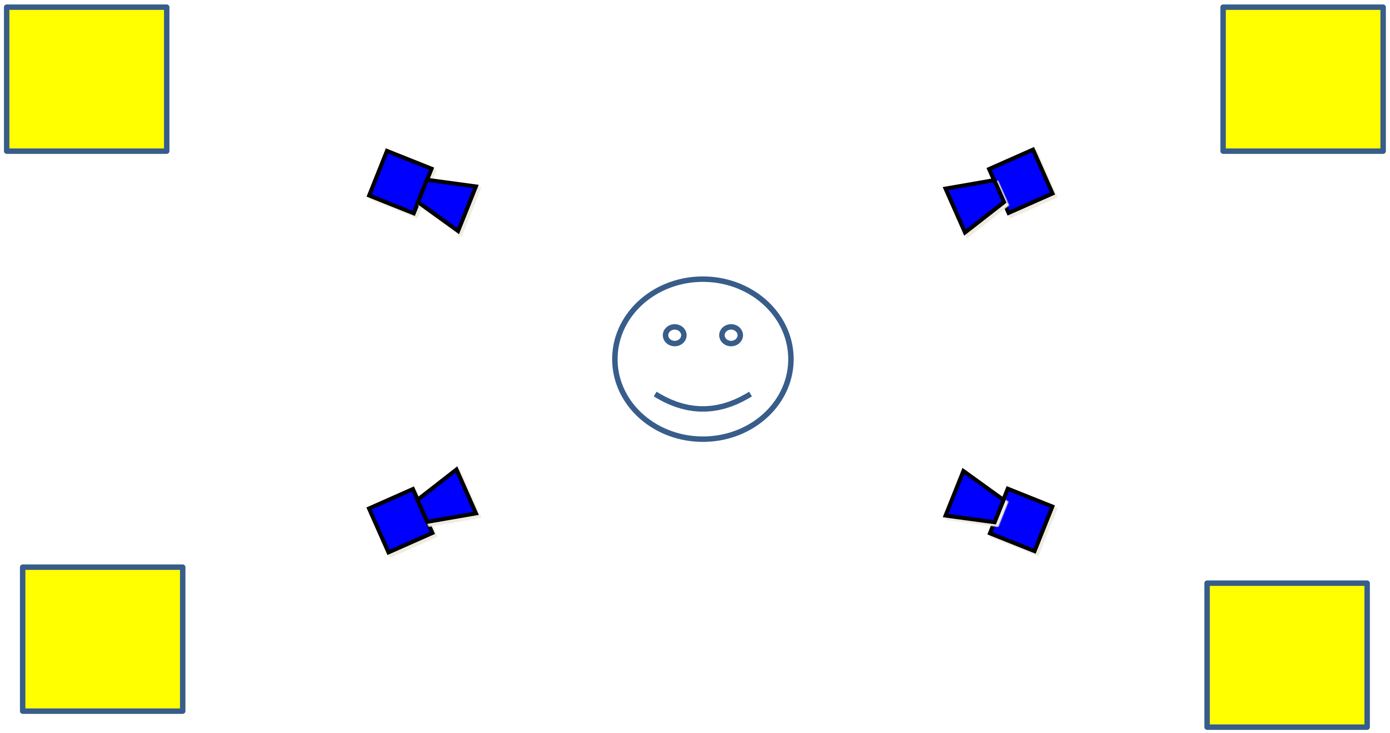


Project "structured" light patterns onto the object

- simplifies the correspondence problem

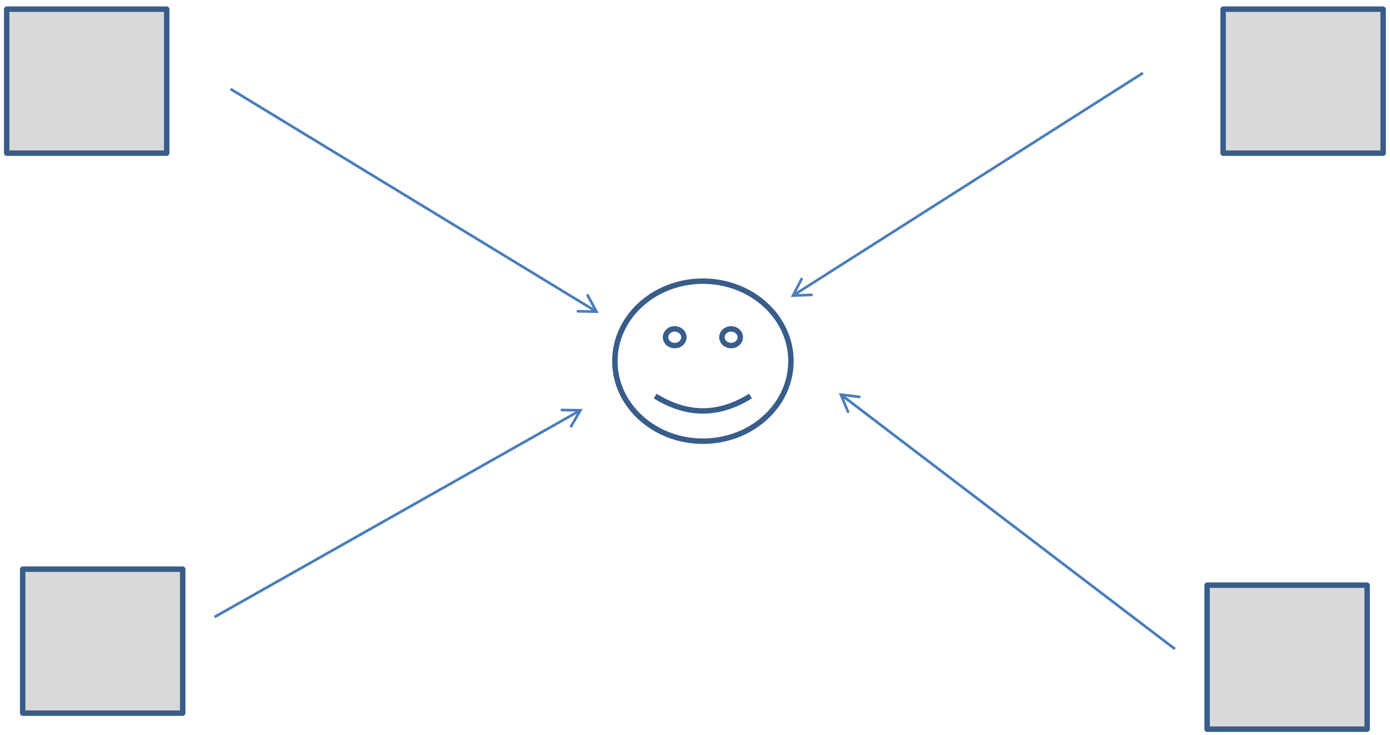
Reconstructing Faces

3D Reconstruction
Color Images



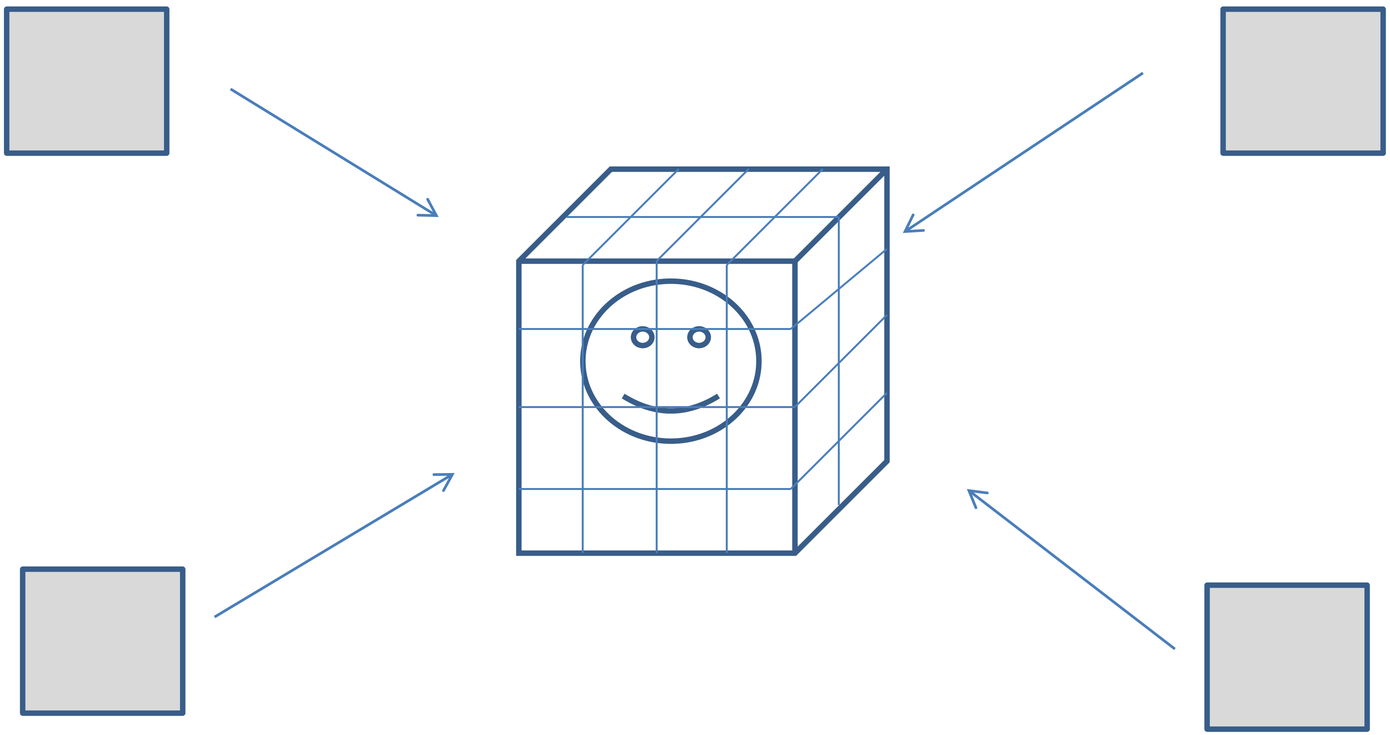
Perform point matching; obtain depth images.

Depth Images



Use the depth, plus the direction from which each image was taken to carve out 3D space to find the object.

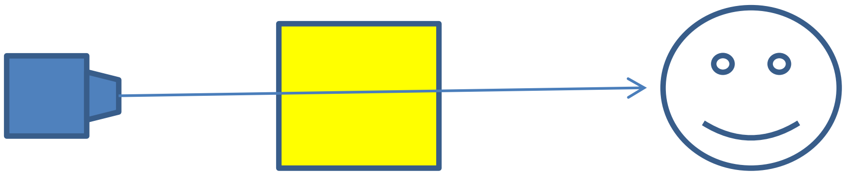
Space Carving



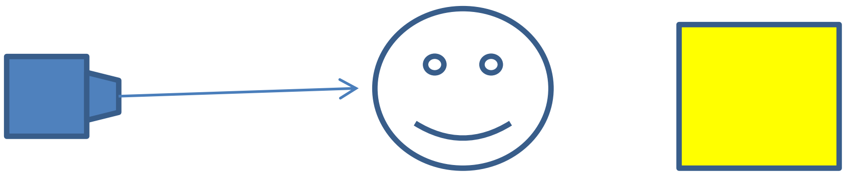
All of 3D space is made up of cubes. Use the known location of each cubes and known depth values in each image of the object to decide if the cube is behind, in front of, or part of the object.

Space Carving

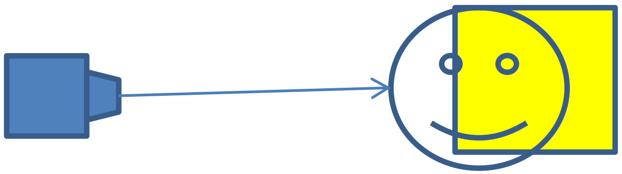
Case 1:
cube in front
of object



Case 2:
cube behind
object



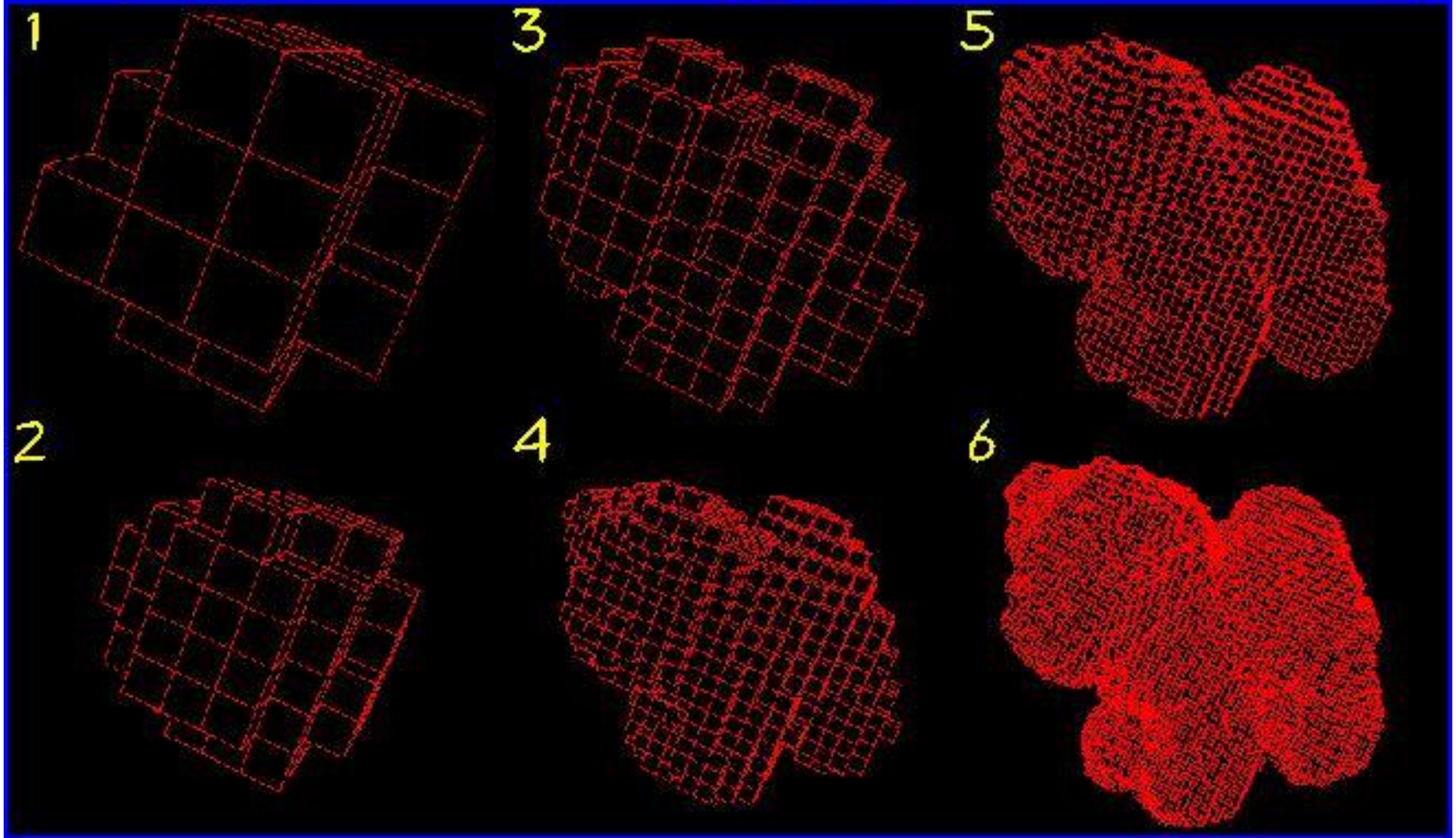
Case 3:
cube on
boundary



Space Carving Algorithm

- for each level of cube resolution from large to small
- for each cube in 3D space at this resolution
  - if the cube lies in front of the object for any camera carve it away
  - if the cube lies behind the object for all cameras make it part of the object
  - else call it on the boundary of the object at this level and go on to the next finer level of resolution

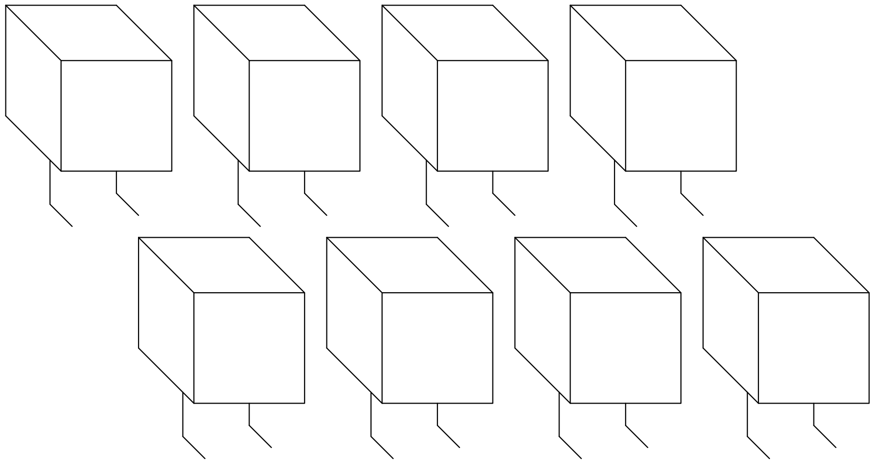
Husky Puppy



From Voxels to 3D Mesh

- Space carving leaves us with a voxel representation.
- Medical imaging modalities also give us a voxel representation.
- We can work with voxels, but it is often more convenient to convert to a 3D triangular mesh as is used in graphics.
- The most common algorithm for producing a mesh from a voxel representation is the Marching Cubes algorithm.

Marching Cubes



Marching Cubes is an algorithm which "creates triangle models of constant density surfaces from 3D medical data."

What does *that* mean?

Medical Data

+ Marching Cubes

~~– Pretty Pictures~~

= Visualization

Visualization Process

1. Medical Data Acquisition
2. Image Processing
3. Surface Construction
4. Display

Medical Data Acquisition

- Computed Tomography (CT)
- Magnetic Resonance (MR)
- Single-Photon Emission Computed Tomography (SPECT)

Each scanning process results in two dimensional “slices” of data.

Surface Construction

- Construction/Reconstruction of scanned surfaces or objects.
- Problem of interpreting/interpolating 2D data into 3D visuals.
- Marching Cubes provides a method of creating 3D surfaces.

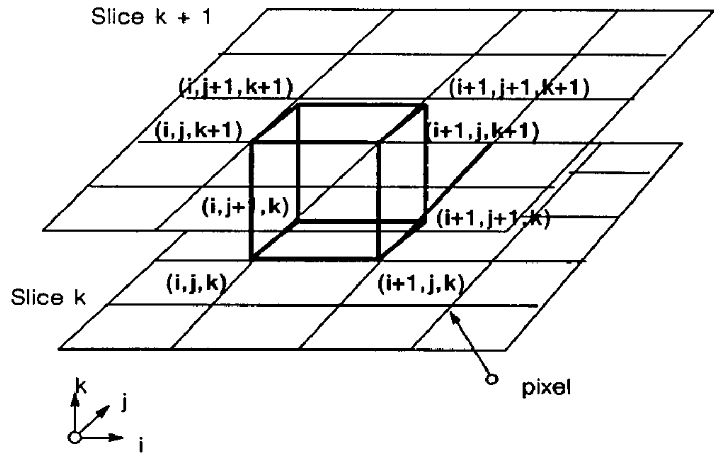
Marching Cubes Explained

- High resolution surface construction algorithm.
- Extracts surfaces from adjacent pairs of data slices using cubes.
- Cubes “march” through the pair of slices until the entire surface of both slices has been examined.

Marching Cubes Overview

1. Load slices.
2. Create a cube from pixels on adjacent slices.
3. Find vertices on the surfaces.
4. Determine the intersection edges.
5. Interpolate the edge intersections.
6. Calculate vertex normals.
7. Output triangles and normals.

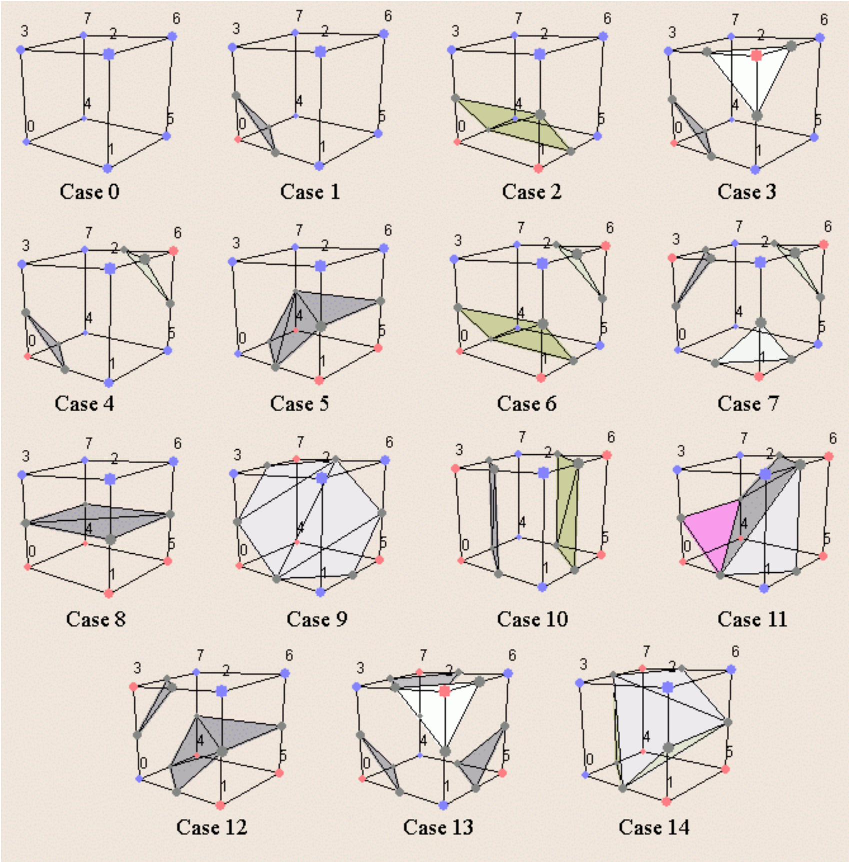
How Are Cubes Constructed



- Uses identical squares of four pixels connected between adjacent slices.
- Each cube vertex is examined to see if it lies on or off of the surface.

How Are The Cubes Used

- Pixels on the slice surfaces determine 3D surfaces.
- 256 surface permutations, but only 14 unique patterns.
- A normal is calculated for each triangle vertex for rendering.



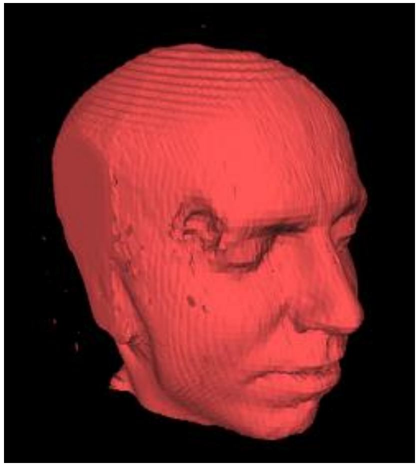
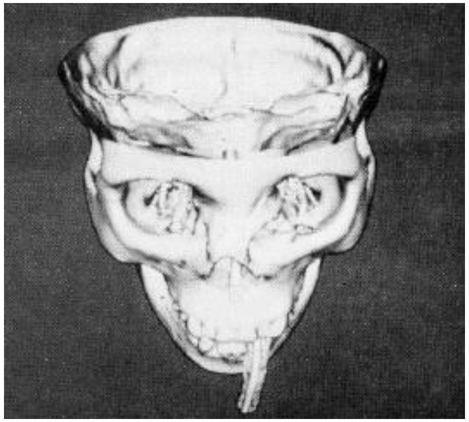
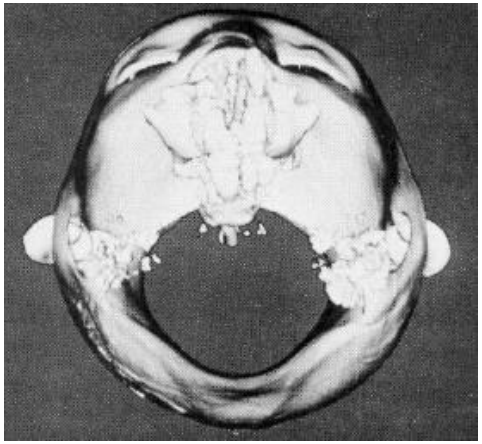
Triangle Creation

1. Determine triangles contained by a cube.
2. Determine which cube edges are intersected.
3. Interpolate intersection point using pixel density.
4. Calculate unit normals for each triangle vertex using the gradient vector.

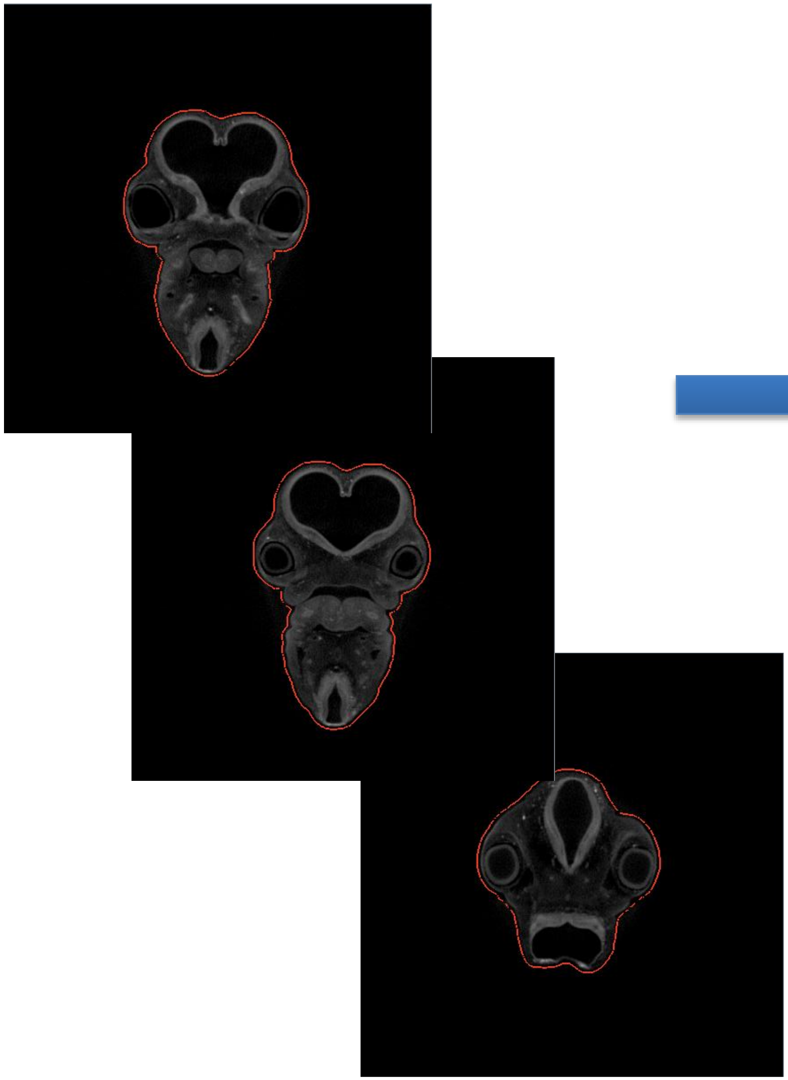
Improvements Over Other Methods

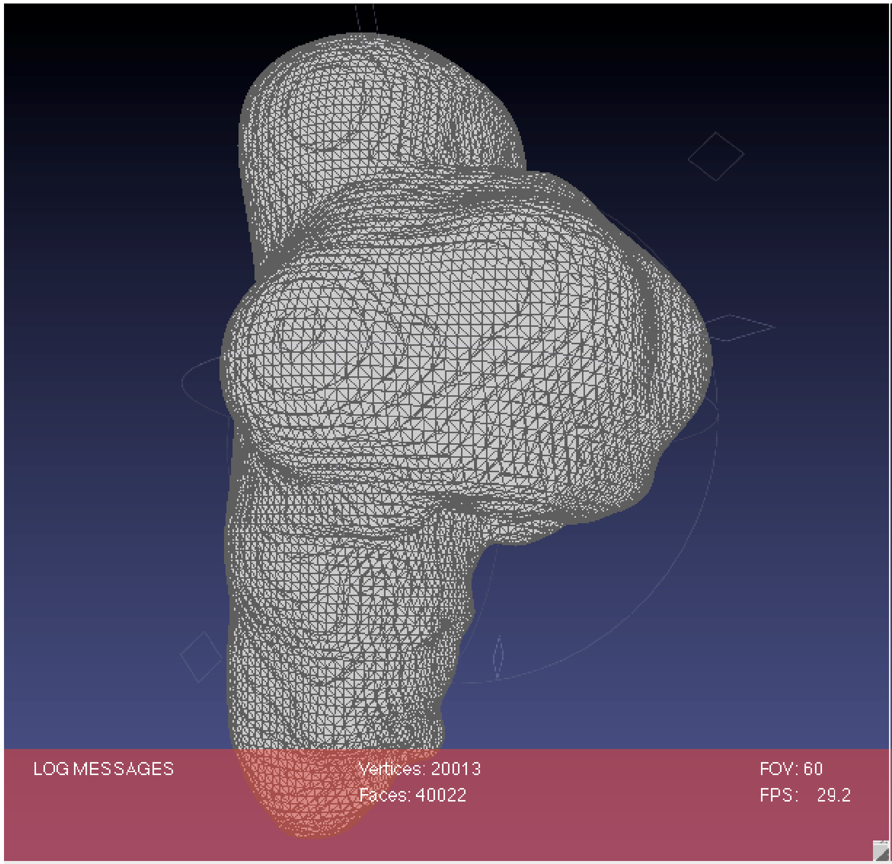
- Utilizes pixel, line and slice coherency to minimize the number of calculations.
- Can provide solid modeling.
- Can use conventional rendering techniques and hardware.
- No user interaction necessary.
- Enables selective displays.
- Can be used with other density values.

Examples

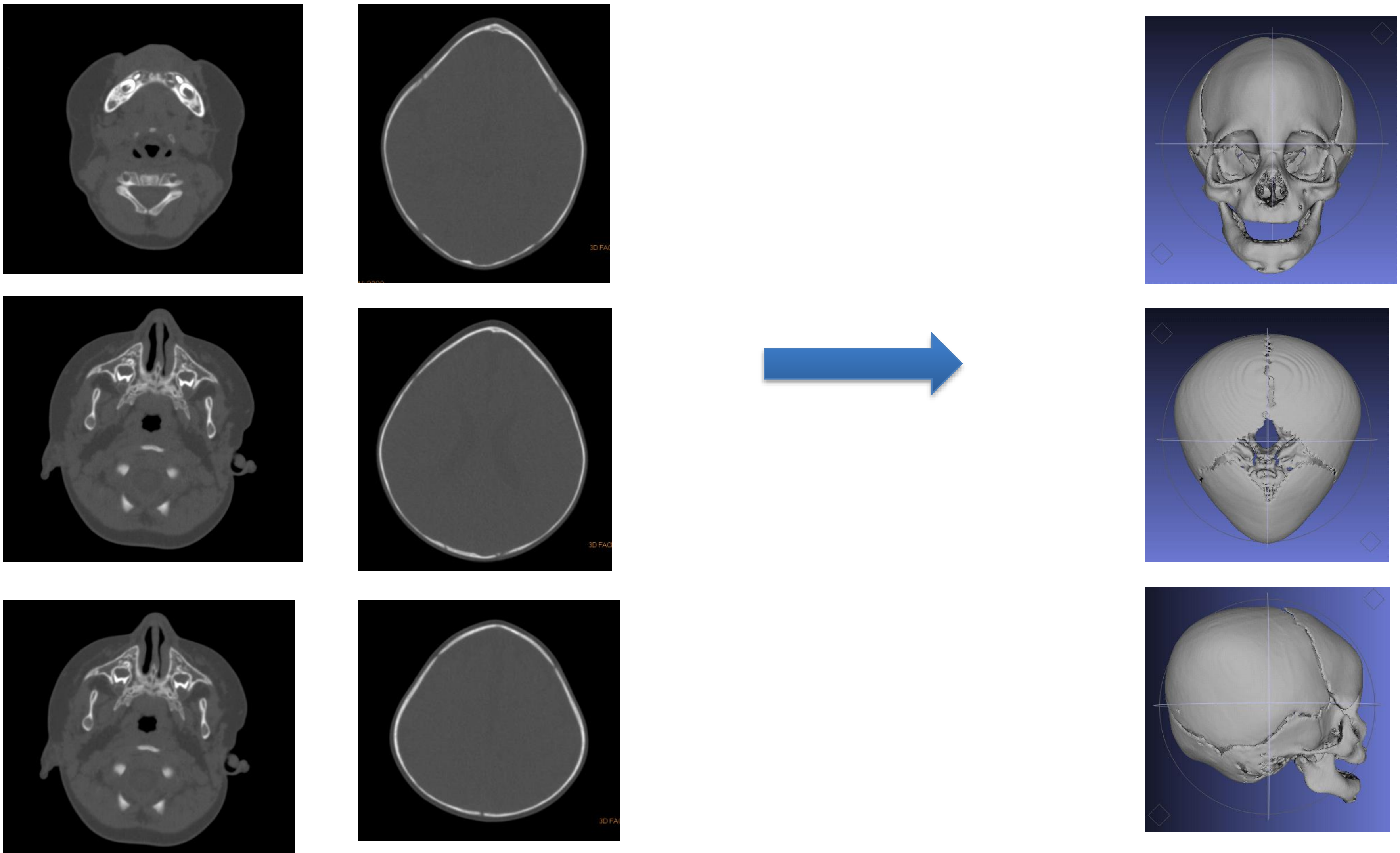





3D Surface from MicroCT Images of a Chicken Embryo





3D Skulls from Human CT Images

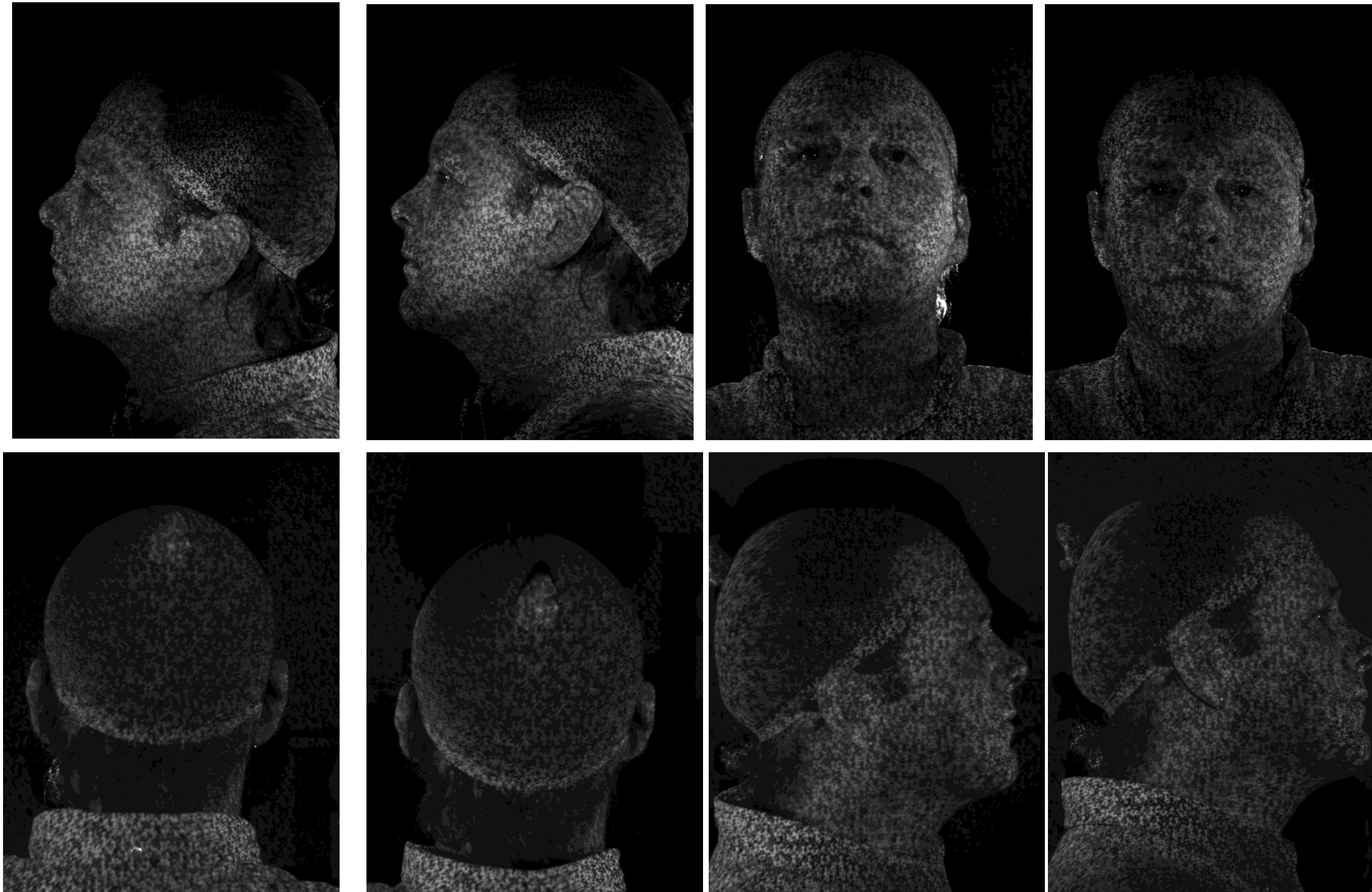


The 3dMD 3D Scanning System

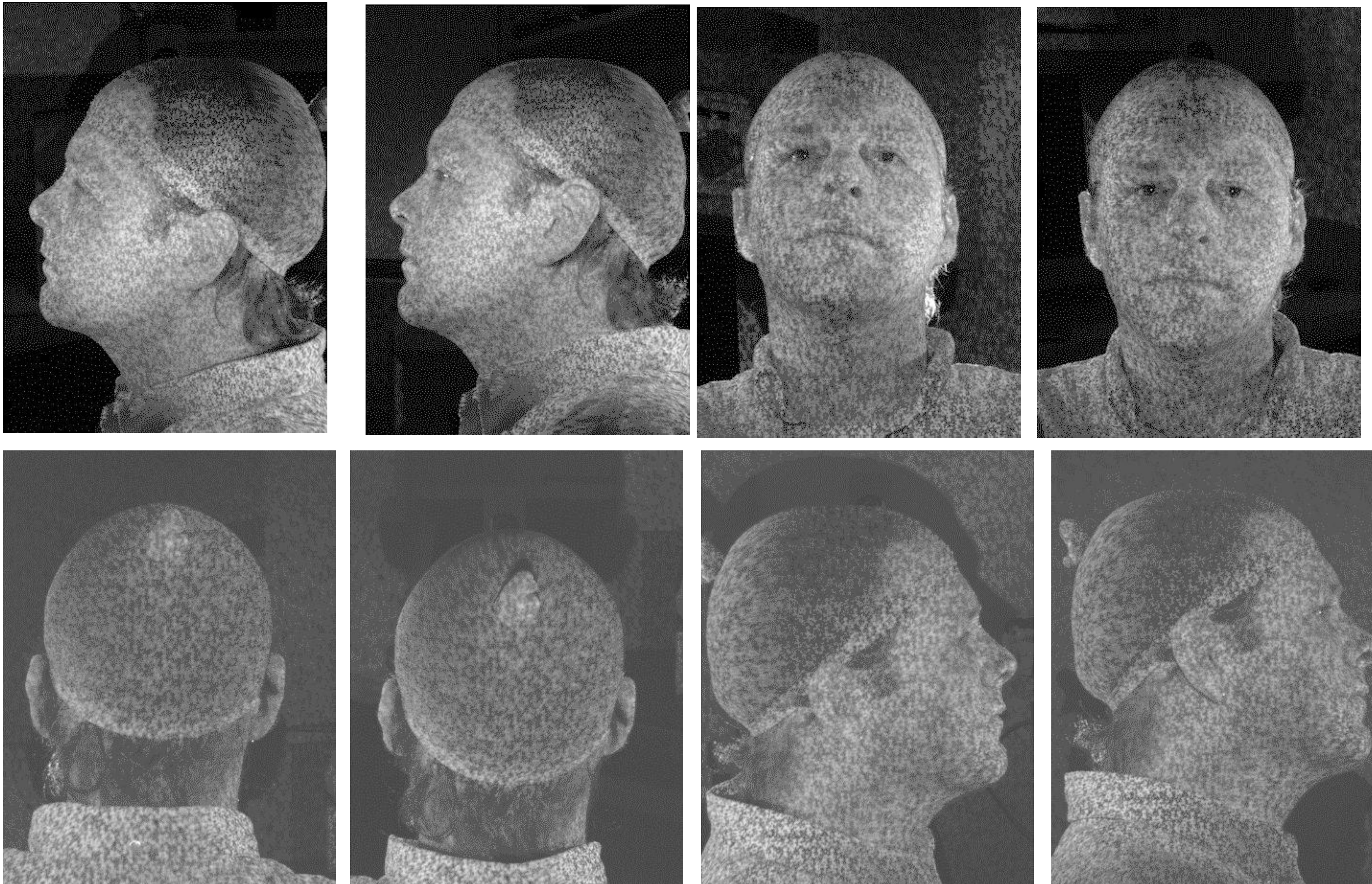
Characteristics

- multiple cameras take color photos
- active stereo using a point pattern for mathing
- rapid image acquisition: 1.5 ms.
- high precision: accurate to within .2mm RMS
- accurate texture mapping of color photos to mesh
- supports multiple file formats
- used in hospitals, clinics, medical research institutes
- used at both Seattle Children’s Hospital and Children’s Research Institute

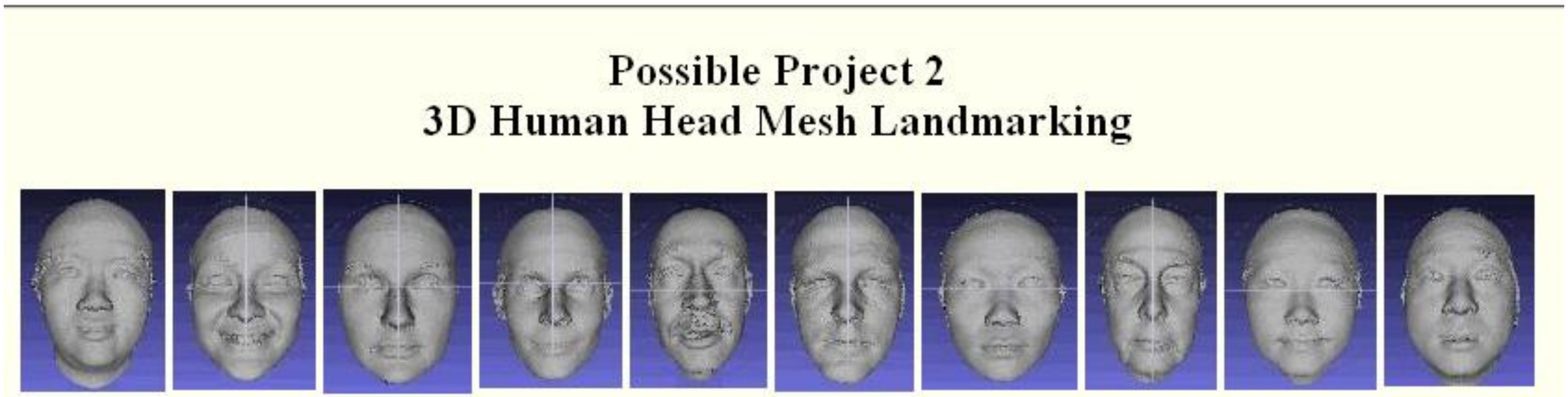
Active Stereo Light Pattern shown on Eric



Active Stereo Light Pattern shown on Eric



The "us" Database



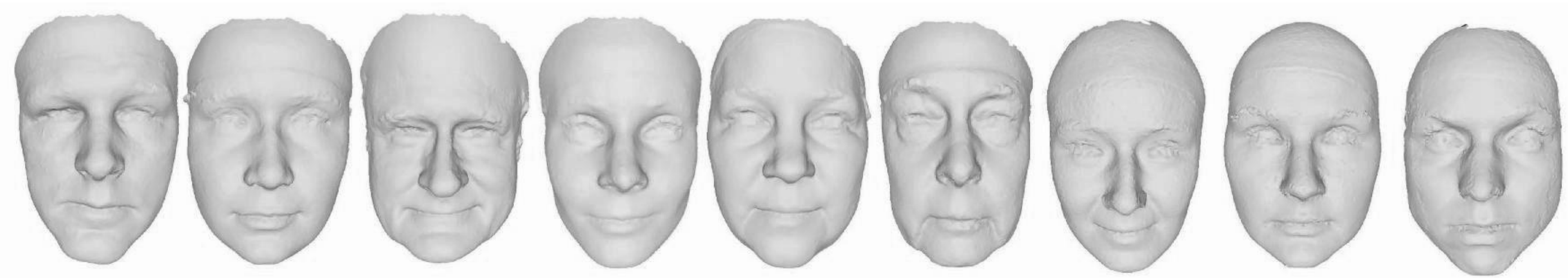
Dingding Indri Kasia Sara Steve **Eric** Jia Linda Shulin Xiang

Seth’s Database

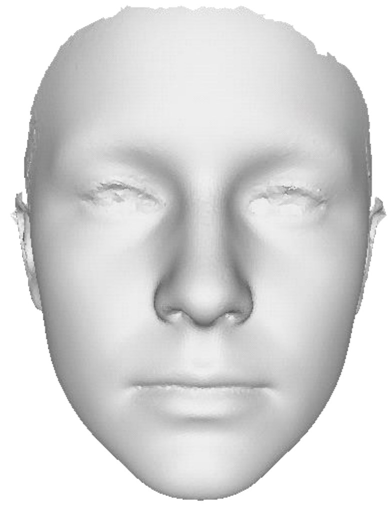
- The 3D Facial Norms Database: Part 1. A Web-Based Craniofacial Anthropometric and Image Repository for the Clinical and Research Community
- Cleft Palate-Craniofacial Journal, Vol. 53, No. 6, November 2016

3dMD Face Dataset

- 3dMD face scans of our group

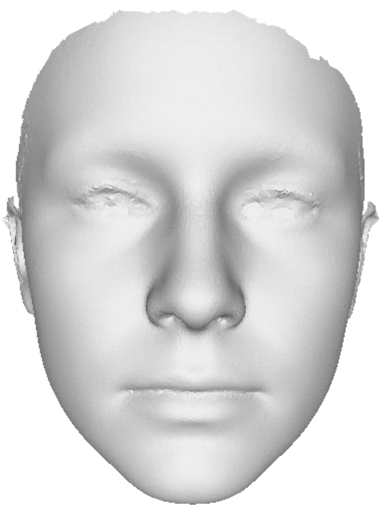


3dMD Face Dataset

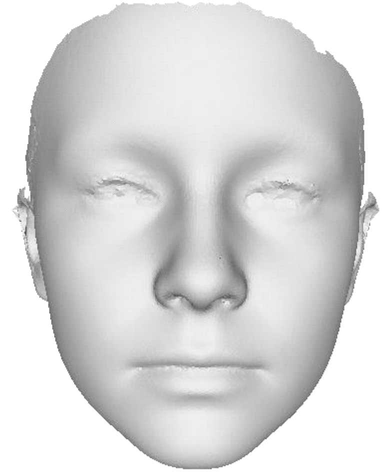


mean shape

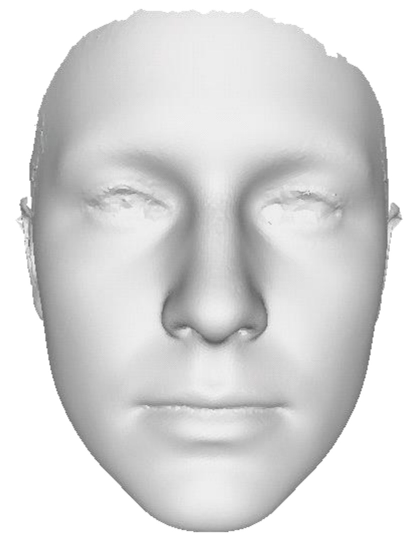
3dMD Face Dataset



mean shape

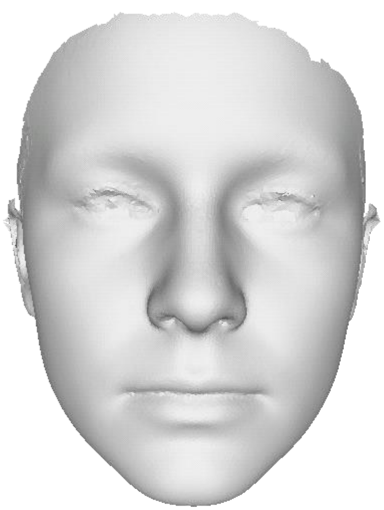


+ 1^{st} PC

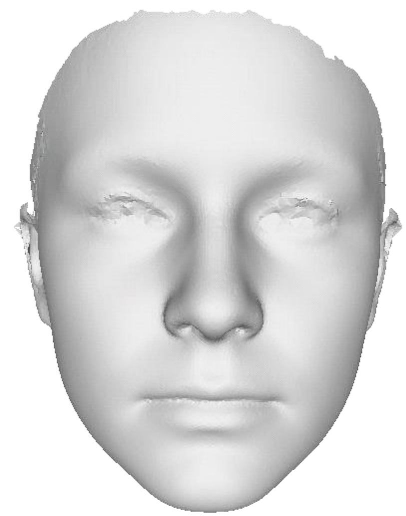


- 1^{st} PC

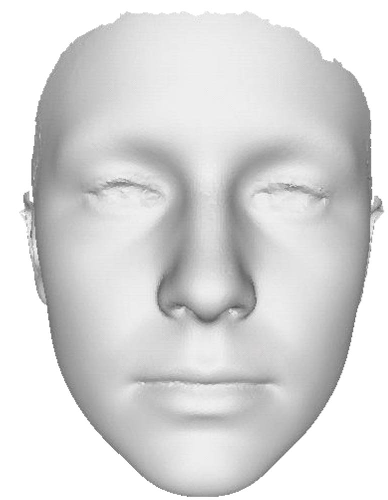
3dMD Face Dataset



mean shape

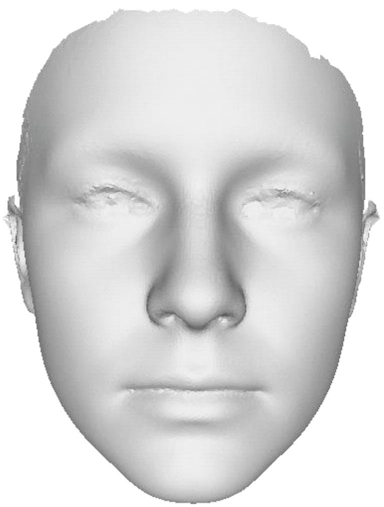


+ 2nd PC

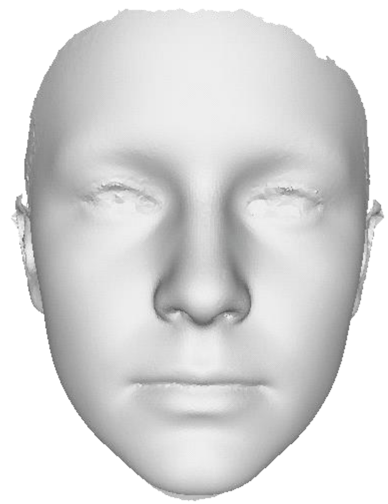


- 1nd PC

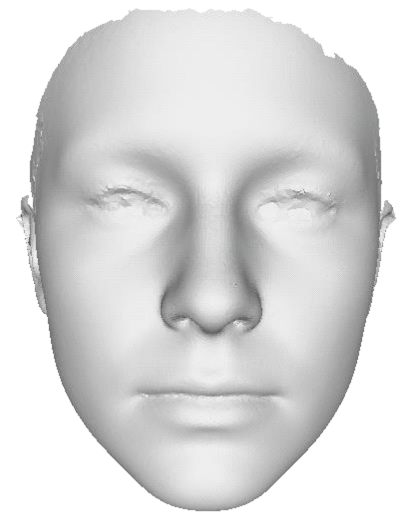
3dMD Face Dataset



mean shape

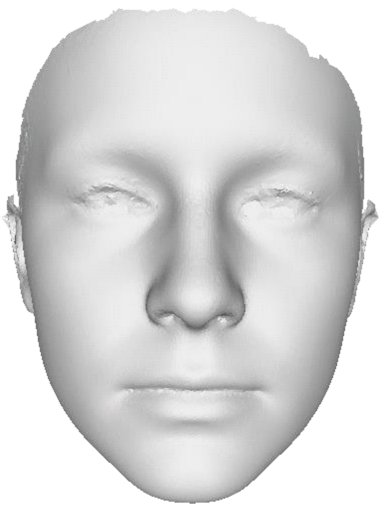


+ 3rd PC

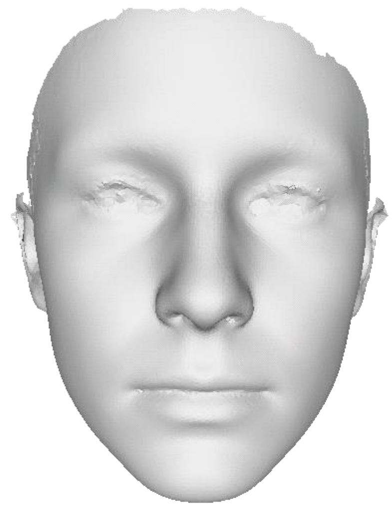


- 3rd PC

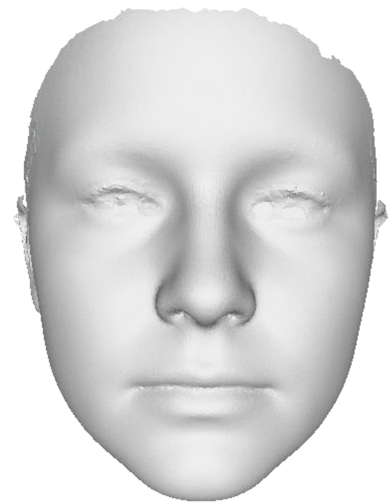
3dMD Face Dataset



mean shape

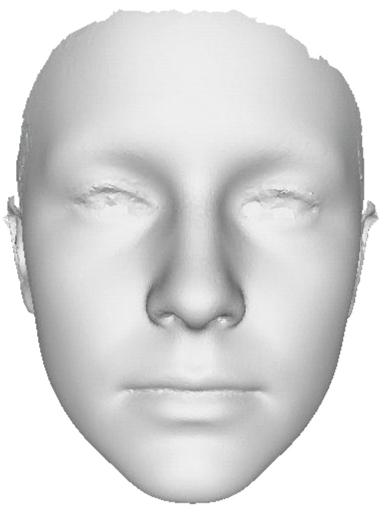


+ 4^{th} PC

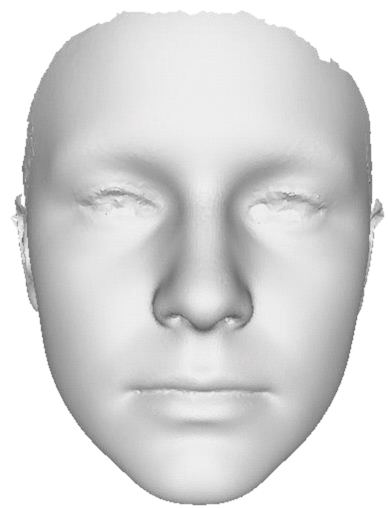


- 4^{th} PC

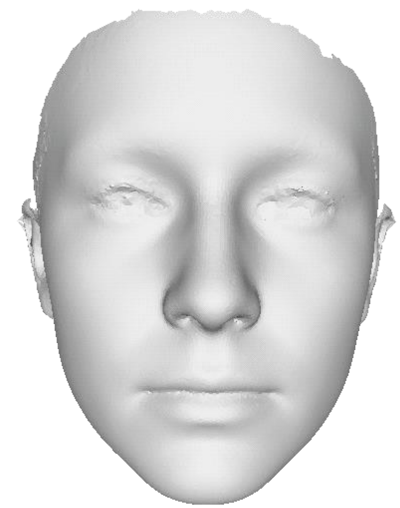
3dMD Face Dataset



mean shape



+ 5^{th} PC

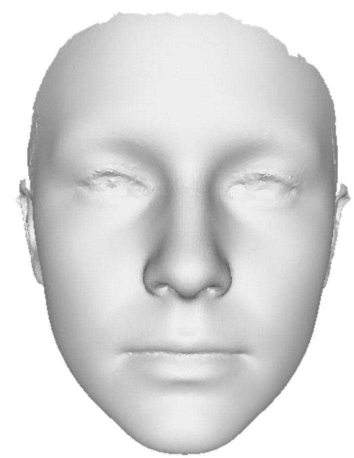


- 5^{th} PC

3D Morphable Model

- Any person's face can be expressed as the linear combination of the PCs

=



$$+\sum_{i=1}^{200} \alpha_i PC_i$$

Projects

- We still have two 3D head/face data sets (and are applying for renewal from FaceBase)

1. The 3D Facial Norms Data Set that was provided to NIDCR by Seth Weinberg at Pitt
2. The African Children Data Set that was provided to NICDR by Richard Spritz at U of Colorado

- These are 3D meshes in OBJ format and can be operated on by most packages for working with mesh data. We used VTK, which was C++ but now has Python wrappers.

Ideas

- Features of the mouth, eyes, nose
- Comparison of features of the two data sets
- You name it.
- NOTE: these are normal people

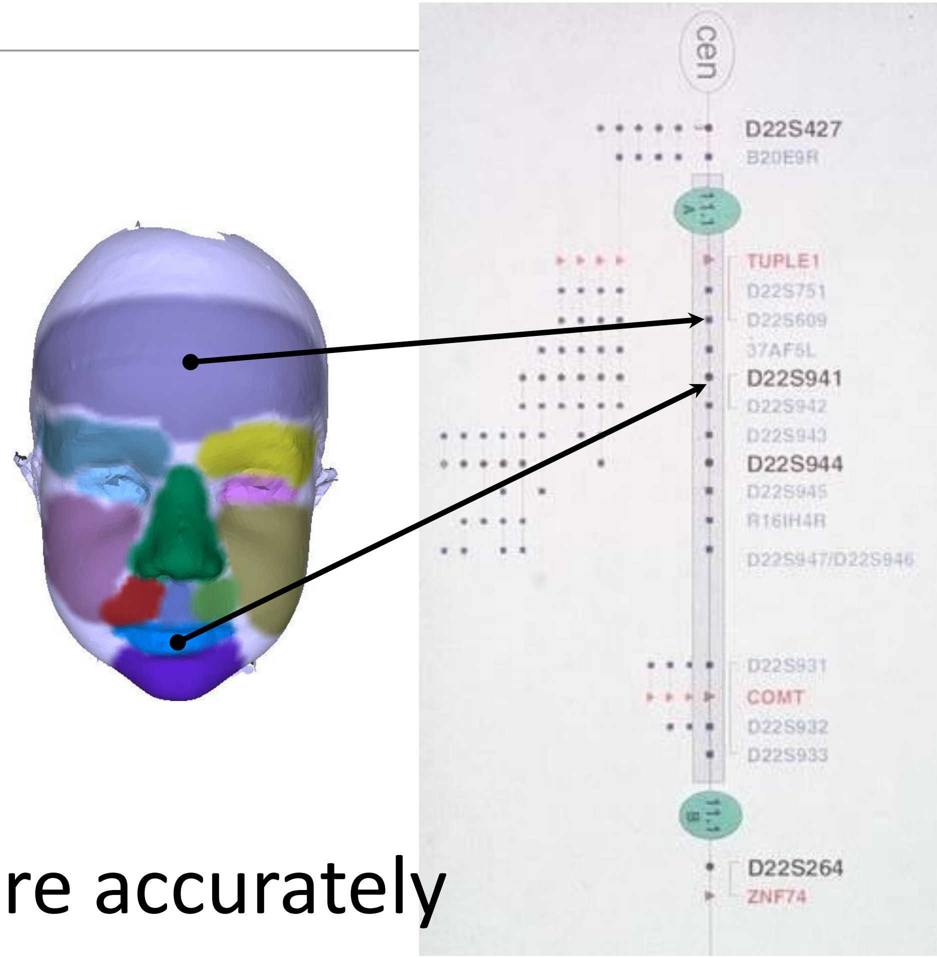
Shape-based Quantification of 3D Face Data for Craniofacial Research

Katarzyna Wilamowska

General Exam
Department of Computer Science & Engineering
University of Washington
2008

22q11.2 Deletion Syndrome

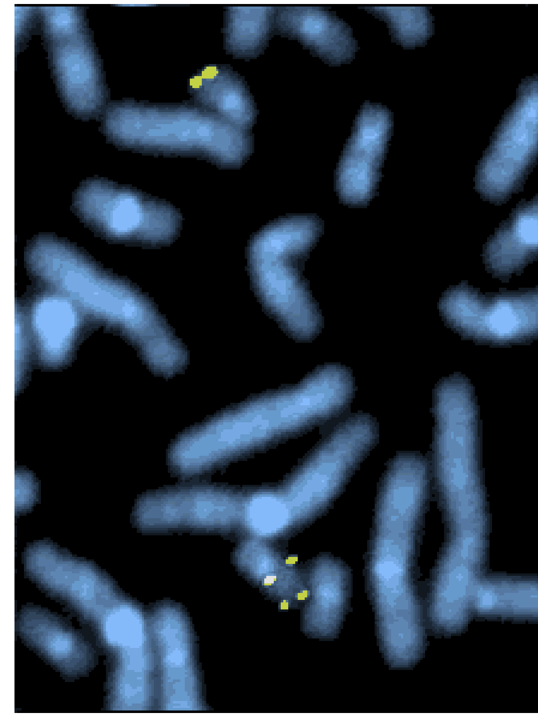
Motivation



- Help detect disease more accurately
- Describe useful features

22q11.2 Deletion Syndrome (22q11.2DS)

- aka Velo-cardio-facial syndrome (VCFS)
- affects approximately 1 in 4000 individuals in the US
- early detection is important
  - cardiac anomalies
  - mild to moderate immune deficiencies
  - learning disabilities



genetic test for 22q11.2DS

22q11.2 Deletion Syndrome has Subtle Facial Features

VELO-CARDIO-FACIAL SYNDROME
Specialist Fact Sheet

Velo-cardio-facial syndrome (VCFS), also known as ***Shprintzen syndrome, DiGeorge sequence or syndrome***, and ***22q11 deletion syndrome***, is caused by a deletion of a small segment of the long arm of chromosome 22. It is one of the most common genetic disorders in humans. The following list shows the anomalies that have bee findings have a 100% frequency, but all occur with sufficient frequency to warrant assessme check the web site of **The Velo-Cardio-Facial Syndrome Educational Foundation, Inc.** a

Craniofacial/Oral Findings

1. Overt, submucous or occult submucous cleft palate
2. Retrognathia (retruded lower jaw)
3. Platybasia (flat skull base)
4. Asymmetric crying facies in infancy
5. Structurally asymmetric face
6. Functionally asymmetric face
7. Vertical maxillary excess (long face)
8. Straight facial profile
9. Congenitally missing teeth
10. Small teeth (in primary dentition)
11. Enamel hypoplasia
12. Hypotonic, flaccid facies
13. Downturned oral commissures
14. Cleft lip (uncommon)
15. Microcephaly
16. Small posterior cranial fossa

50. Tetralogy of Fallot
51. Right sided aorta
52. Truncus arteriosus
53. PDA (patent ductus
54. Interrupted aortic ar
55. Coarctation of the a
56. Aortic valve anomal
57. Aberrant subclavian
58. Vascular ring
59. Anomalous origin of carotid artery
60. Transposition of the great vessels

Eye Findings

17. Tortuous retinal vessels
18. Suborbital congestion ("allergic
19. Strabismus
20. Narrow palpebral fissures
21. Posterior embryotoxon
22. Small optic disk
23. Prominent corneal nerves
24. Cataract
25. Iris nodules
26. Iris coloboma (uncommon)
27. Retinal coloboma (uncommon)
28. Small eyes
29. Mild orbital hypertelorism
30. Mild vertical orbital dystopia
31. Puffy or hooded upper eyelids

Ear/Hearing Findings

32. Overfolded helix
33. Attached lobules
34. Protuberant, cup-shaped ears
35. Small ears
36. Mildly asymmetric ears
37. Frequent otitis media

Nasal Findings

42. Prominent nasal bridge
43. Bulbous nasal tip
44. Mildly separated nasal domes (tip appears bifid)
45. Pinched alar base, narrow nostrils
46. Narrow nasal passages

Problems in Infancy

115. Feeding difficulty, Failure-to-thrive
116. Gastroesophageal reflux (GER/GERD)
117. Nasal regurgitation
118. Irritability
119. Chronic constipation

74. Small cerebellar vermis
75. Cerebellar hypoplasia/dysgenesis
76. White matter hyperintensities
77. Generalized hypotonia
78. Cerebellar ataxia
79. Seizures
80. Strokes
81. Spina bifida/meningomyelocele
82. Mild developmental delay
83. Enlarged Sylvian fissure
84. Cavum septum pellucidum
85. Variations in size of various brain segments.

Abdominal/Kidney

99. Hypoplastic/aplastic kidney
100. Cystic kidneys
101. Inguinal hernias
102. Umbilical Hernias

Immunologic

157. Frequent upper respiratory infections
158. Frequent lower airway disease (pneumonia, bronchitis)
159. Reduced T cell populations
160. Reduced thymic hormone

Problems in Infancy

-to-thrive
iER/GERD)

148. Impulsiveness
149. Flat affect
150. Dysthymia, Cyclothymia
151. Social Immaturity
152. Obsessive compulsive disorder

163. Hypothyroidism
164. Auto-immune thyroiditis
165. Mild growth deficiency, relative small stature (childhood)
166. Absent, hypoplastic thymus
167. Small pituitary gland (rare)

Skeletal/Muscle/Orthopedic

168. Scoliosis
169. Osteopenia
170. Sprengel's anomaly, scapular deformation
171. Talipes equinovarus
172. Small skeletal muscles
173. Joint dislocations
174. Chronic leg pains

Psychiatric/Psychological

141. Bipolar affective disorder
142. Manic depressive illness and psychosis
143. Schizophrenia
144. Rapid or ultrarapid cycling of mood disorder
145. Mood disorder, depression
146. Autism spectrum disorder
147. Schizoaffective disorder

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ve disorder
ive illness and psychosis
apid cycling of mood disorder
, depression
m disorder
e disorder

Most common syndrome of cleft palate
Most common microdeletion syndrome in humans
Most common syndrome expressing conotruncal heart anomalies

Experts Looking at Photos

Becker et al. 2004

- 14 affected, 10 control
- one photo at infancy & one beyond 2 years old

Profession	#	Sensitivity	Specificity
Geneticist	9	0.72	0.51
Speech Pathologist	13	0.72	0.52
Surgeon	10	0.64	0.50

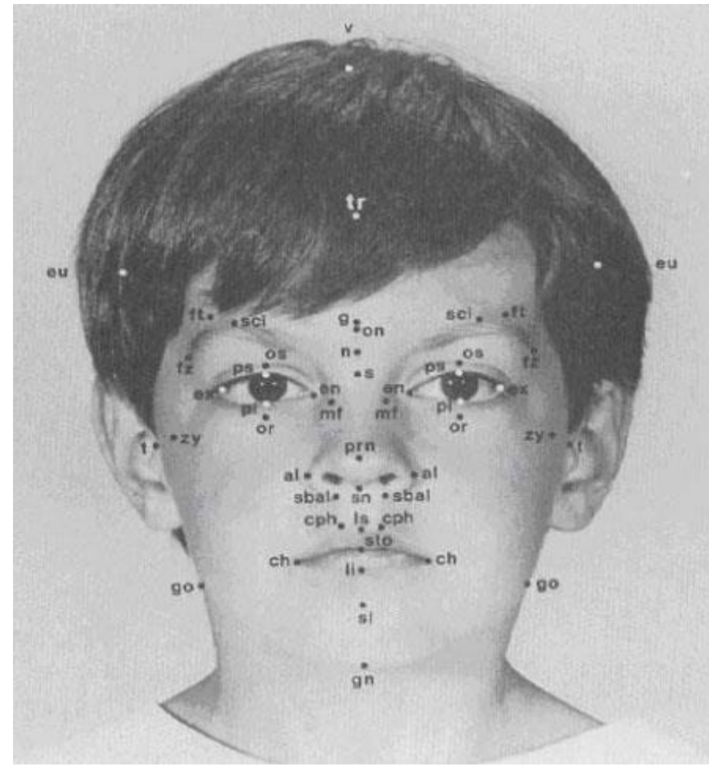
- Improve accuracy of genetic testing referrals

Research Objective

- Develop a successful methodology to
  - classify 22q11.2 deletion syndrome affected individuals
  - quantify the degree of dysmorphology in facial features
- Design consideration
  - Minimal human involvement

Related Literature

- Medical Craniofacial Assessment
  – calipers, manual landmarks
  – CT, MRI, Ultra Sound, Stereoscopic imaging
- Time consuming human involvement



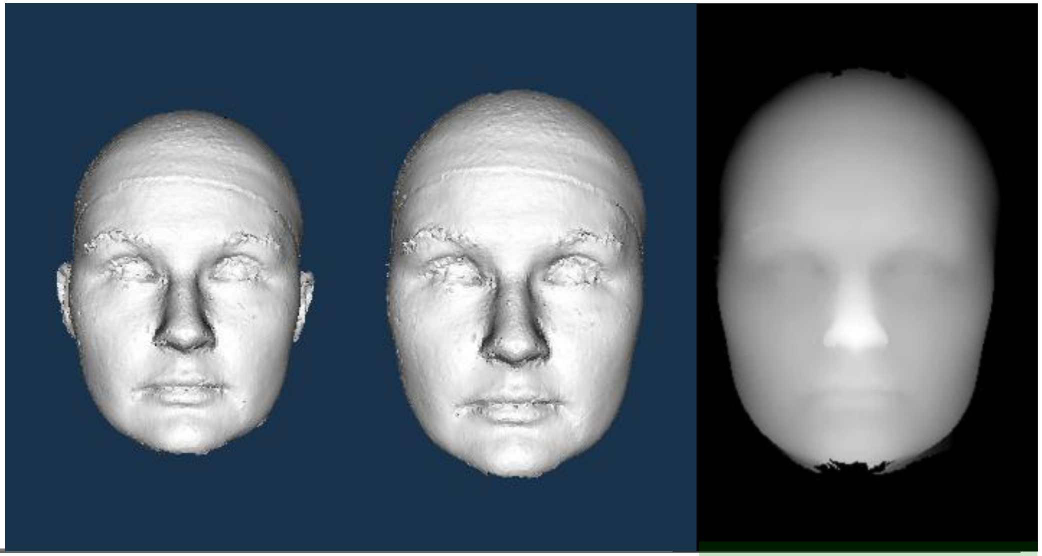
Related Literature

- Computer Vision Craniofacial Analysis
  - 1D waveforms
  - 2D images, landmarks
  - 3D morphable models, new representations, landmarks
  - hybrid 2D/3D systems
- Focus: biometric authentication and recognition

Data Representation

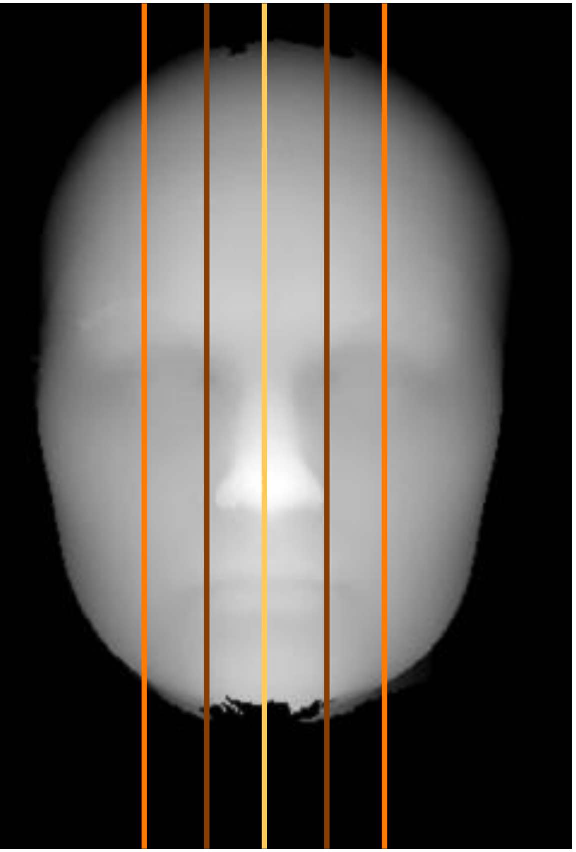
- 3D snapshot
- 2.5D depth image
- Curved lines

Results: 3D snapshot vs. 2.5D



Data Set	3Dsnp	3Dsnp cut	2.5D
F-measure	0.71±0.18	0.68±0.20	0.72±0.20
Precision	0.88±0.18	0.82±0.20	0.80±0.20
Recall	0.63±0.22	0.62±0.24	0.69±0.22
Accuracy	0.76±0.14	0.74±0.13	0.75±0.16

Results: Curved Lines



Data Set	2.5D	Vertical Lines 1	3	5	7
F-measure	0.72	0.71	0.76	0.78	0.67
Precision	0.80	0.81	0.88	0.88	0.79
Recall	0.69	0.68	0.70	0.73	0.62
Accuracy	0.75	0.75	0.79	0.82	0.72