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Technology Transition Workshop| *Dr. Ann H. Ross*

# *Fundamentals of Traditional Craniometrics and Geometric Morphometrics*

# Traditional Craniometric Methods

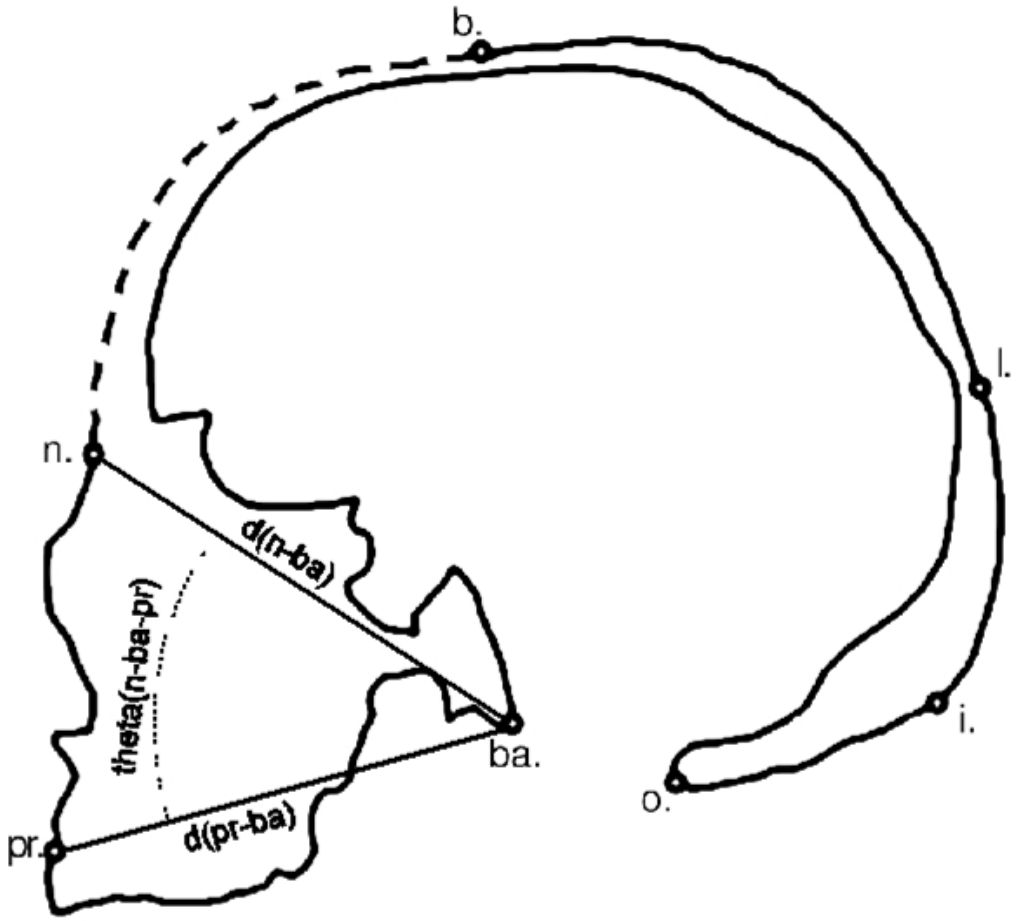


Image from: Slice, D. E.; Ross, A. *3D-ID: Geometric Morphometric Classification of Crania for Forensic Scientists*. Version 03DEC2009. http://www.3d-id.org (accessed Jun 30, 2011).

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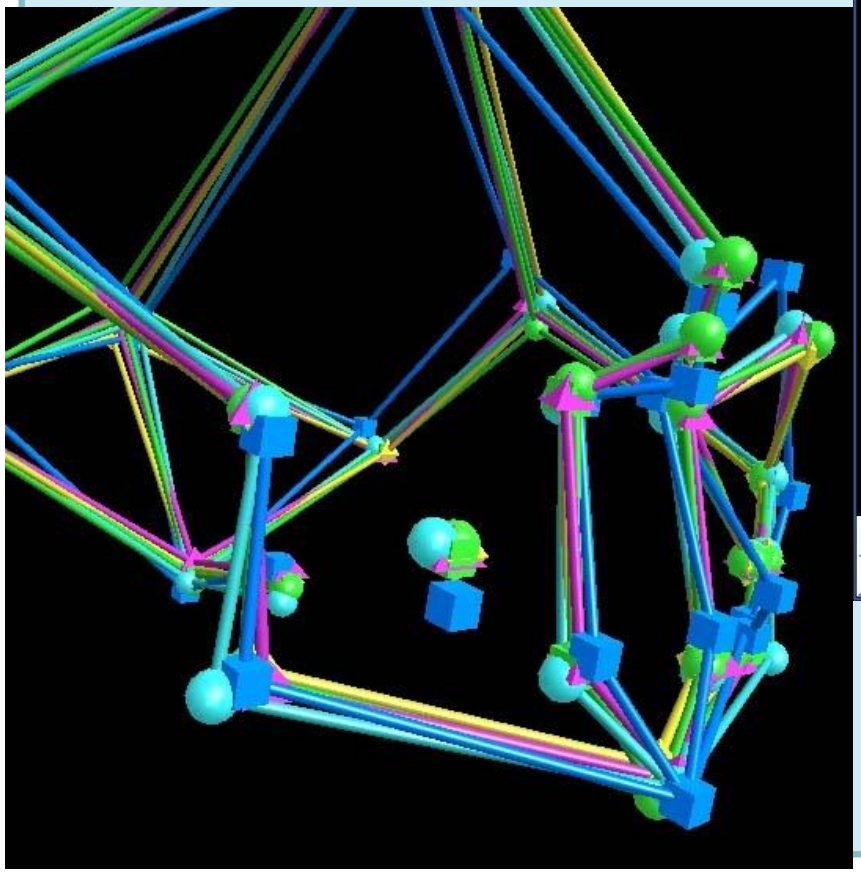
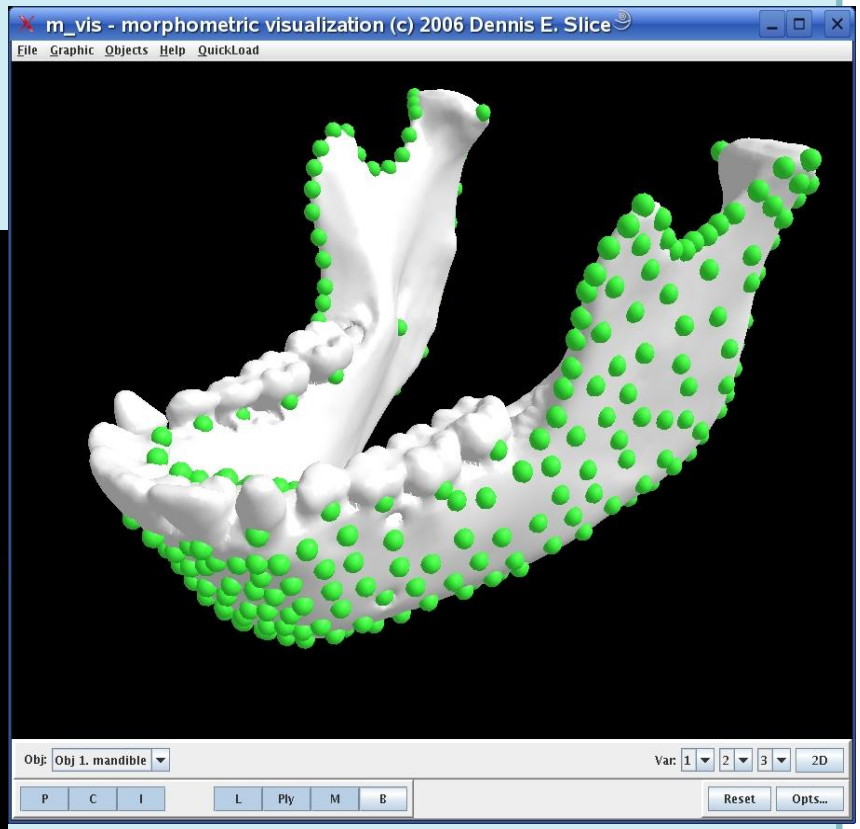
# Geometric Morphometrics






Images courtesy of Dennis E. Slice

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# *Definitions*

- **Shape - the geometric properties of an object that are invariant to location, scale, and orientation**
- **Shape variable - any geometric measure of an object that is invariant to the location, scale, and orientation of the object**

From Slice (2005)

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# *Definitions - Cont'd*

- **Size measure - any positive, real-valued measure of an object that scales as a positive power of the geometric scale of the form**
- **Form - data containing only size and shape**
- **Geometric morphometrics - collection of methods for the acquisition, processing and analysis of shape variables that retain *all* of the geometric information contained within the data**

From Slice (2005)

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# *Definitions – Streamlined*

- ***Morphometrics:*** the study of shape, shape variation, and covariation of shape with extrinsic factors
- ***Shape:*** the geometric properties of a specimen's invariant location, orientation, and scale
- ***Form:*** shape + size
- ***Geometric Morphometrics:*** morphometric methods that retain maximum geometric information throughout an analysis

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# *Resources*

- Slice, D.E. Modern Morphometrics in Physical Anthropology; Kluwer Academic, Plenum: New York, 2005.
- http://life.bio.sunysb.edu/morph/ (accessed Jun 27, 2011).
- http://www.morphometrics.org/morphmet.html (accessed Jun 27, 2011).

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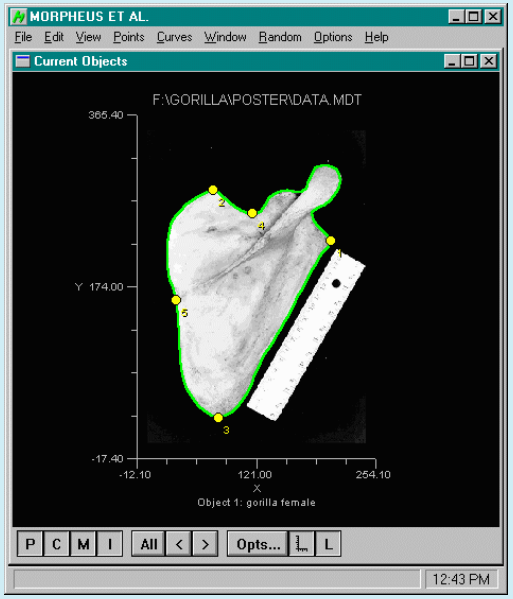
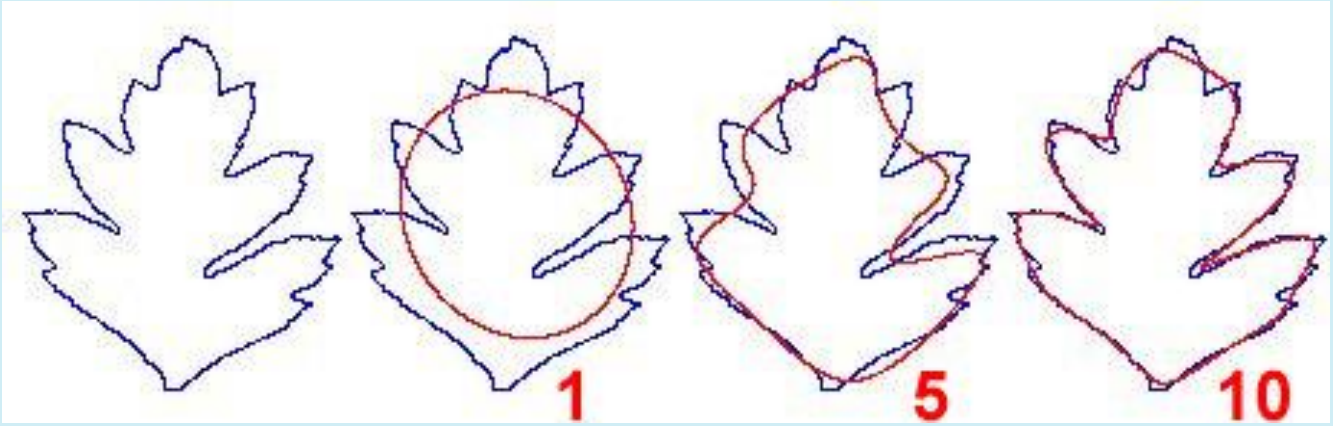
# Morphometric Data

- **Linear distances**
- **Outlines**

  **EFA**




Images courtesy of Dennis E. Slice

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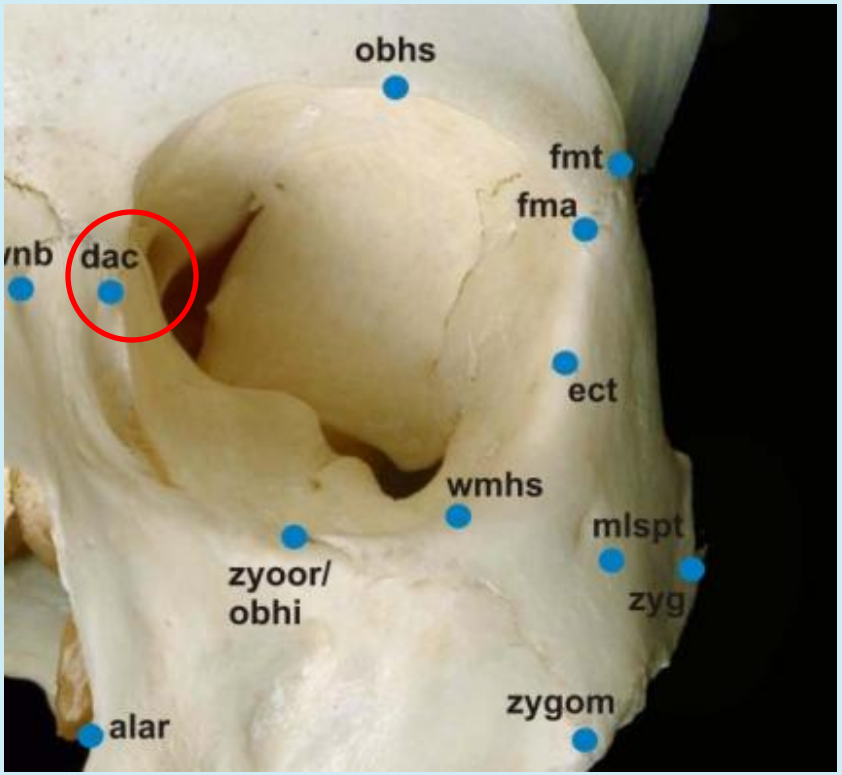
# *Type 1 Landmarks*

- **Bookstein (1991) "orange book"**
- **Discrete juxtapositions of tissues**
  - **e.g., triple points of suture intersections**




e.g. dacryon

Image from: Slice, D. E.; Ross, A. *3D-ID: Geometric Morphometric Classification of Crania for Forensic Scientists*. Version 03DEC2009. http://www.3d-id.org (accessed Jun 30, 2011).

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# *Type 2 Landmarks*

- **Curvature maxima associated with local structures such as bony processes for muscle attachments that have biomechanical implications (e.g., ectoconchion, prosthion)**
- **Bookstein (1991)**

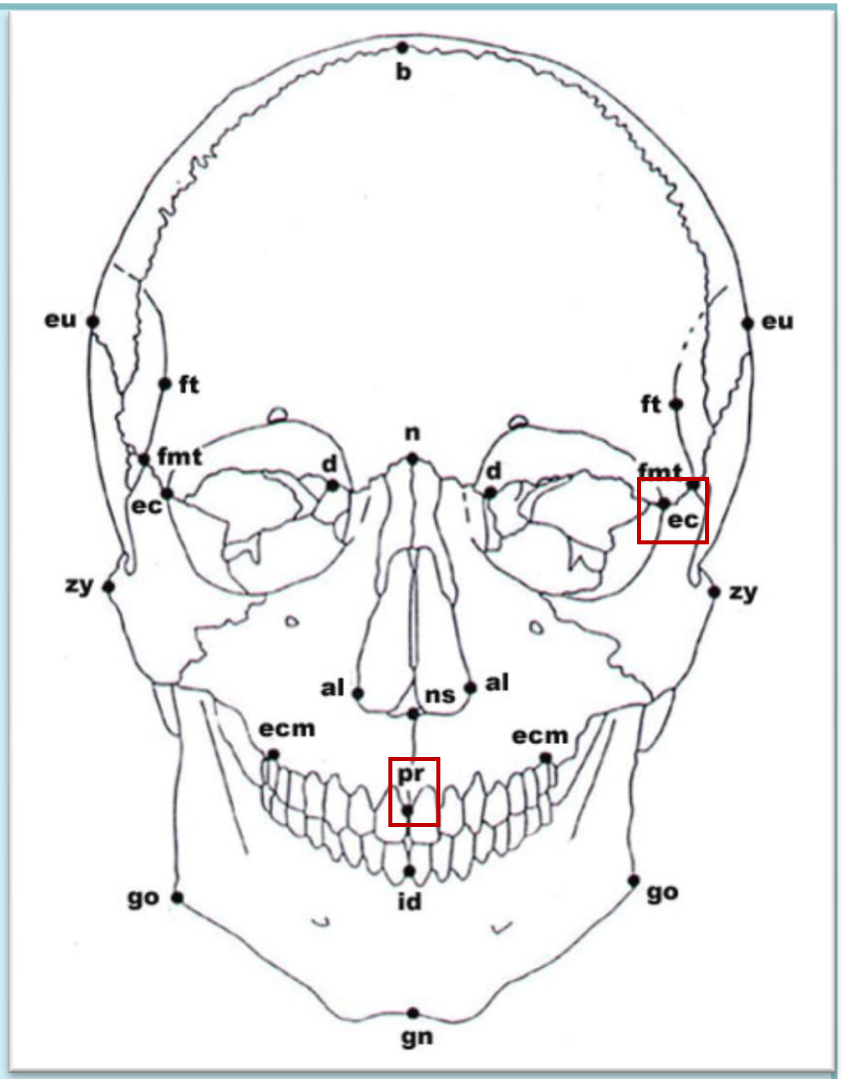


Image from http://www.redwoods.edu/instruct/agarwin/anth_6_measurements.htm
(Accessed June 30, 2011)

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# *Type 3 Landmarks*

- **Extremal points defined with respect to some distant structure**
  - **Like endpoints of maximum breadth or length (e.g., euryon)**
- **Bookstein (1991)**

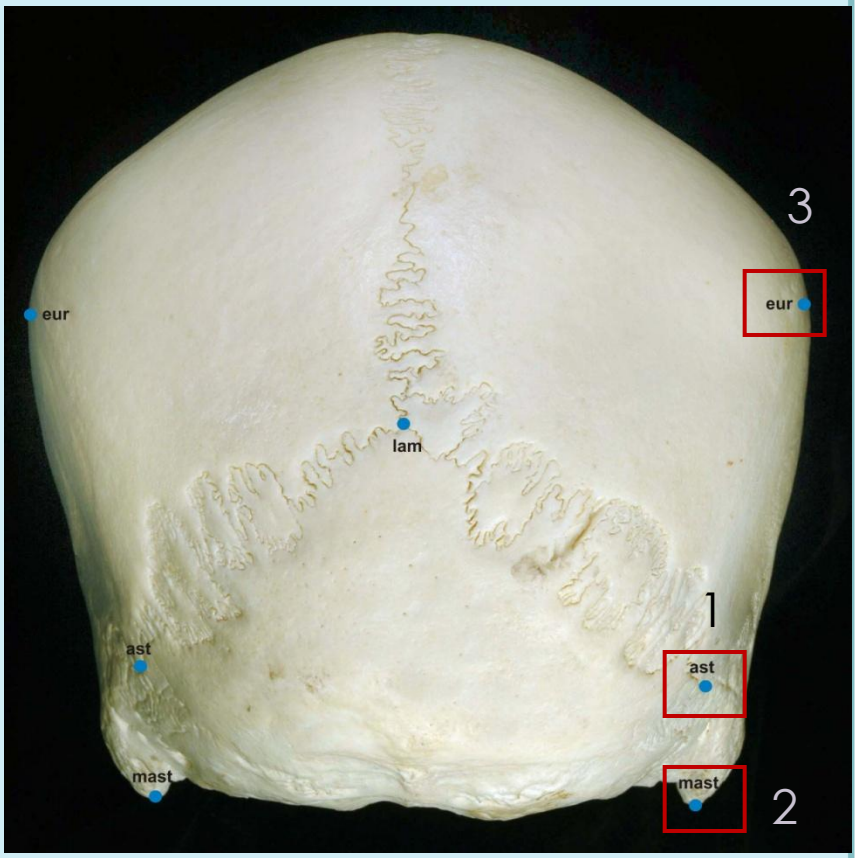


Image from: Slice, D. E.; Ross, A. *3D-ID: Geometric Morphometric Classification of Crania for Forensic Scientists*. Version 03DEC2009. http://www.3d-id.org (accessed Jun 30, 2011).

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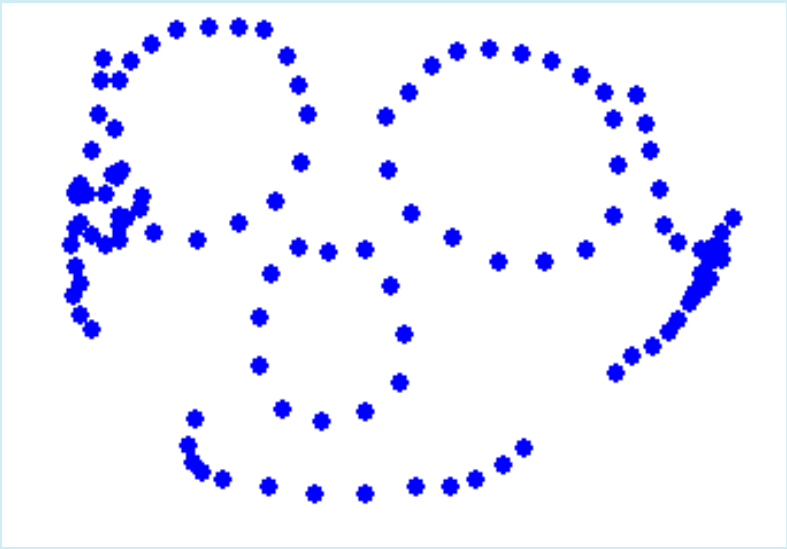
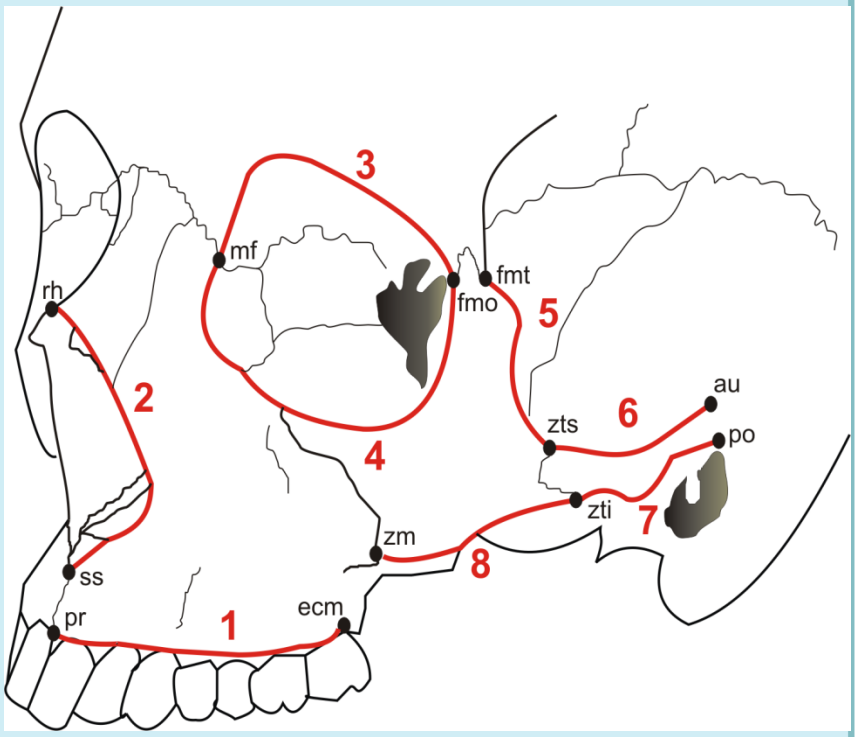
# Semilandmarks






Images from Williams (2008), UF, Dissertation

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# *Landmark Types – Continued*

- **Constructed points**
  - **geometric combinations of other existing landmarks or lines erected at specified angles to "construct" a new landmark**

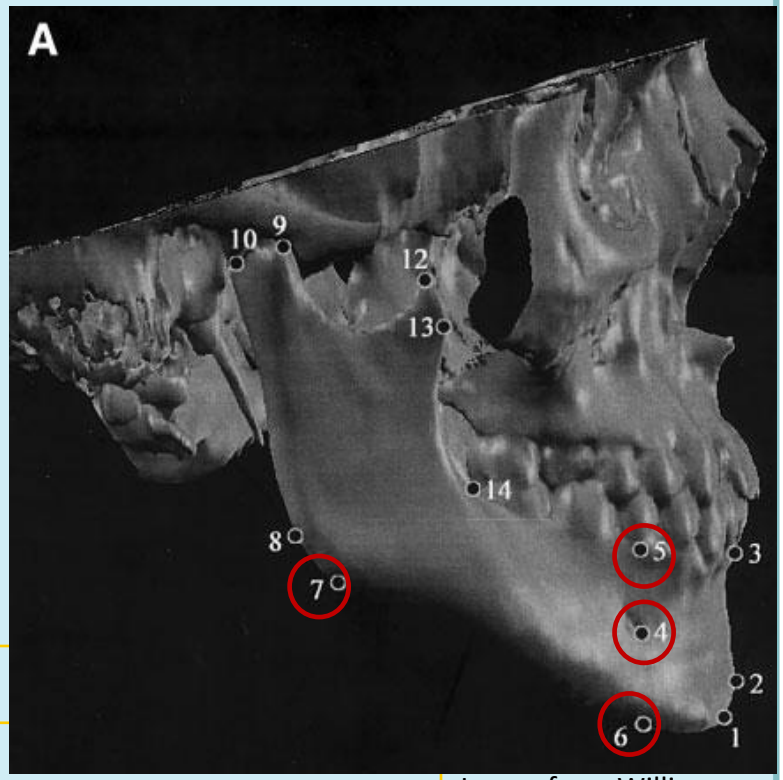


Image from Williams and Richtsmeier (2003)

| Landmark | # | Description |
|---|---|---|
| Mental Foramen | 4 | Anteromedial edge |
| Alveolar border of body | 5 | Directly above mental foramen |
| Inferior border of body | 6 | Directly below mental foramen |
| Gonion | 7 | Junction of ramus and inferior border of body |

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# *Landmark Types – Continued*

- **Fuzzy Landmarks**
  - **represent position of a biological structure that is precisely delineated, but occupies an area that is larger than a single point in space**
  - **ex.= frontal boss**

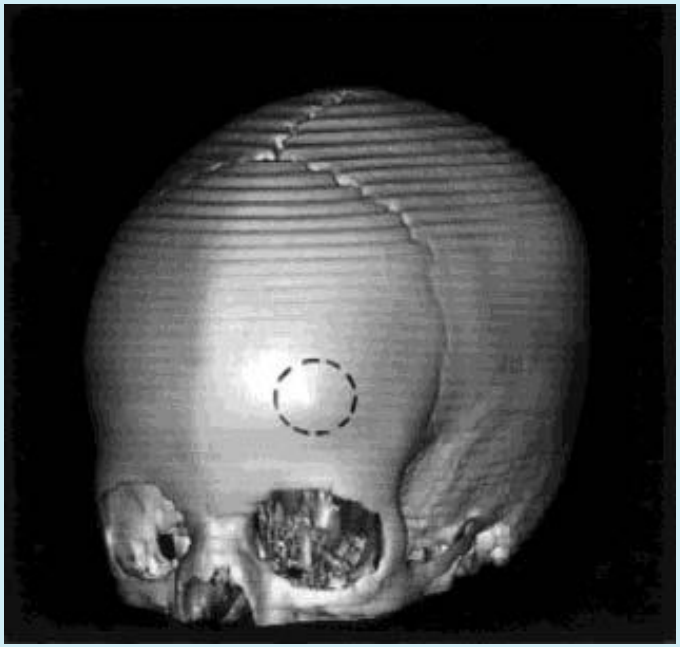

Image from Valeri et al. (1998)

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# *Reliability of Landmarks*

- **BEST**
  - **Biological Landmarks**
    - **Type I – most confidence**
    - **Type II – intermediate**
    - **Type III – least confidence**
- **WORST**
  - **Fuzzy and constructed landmarks**

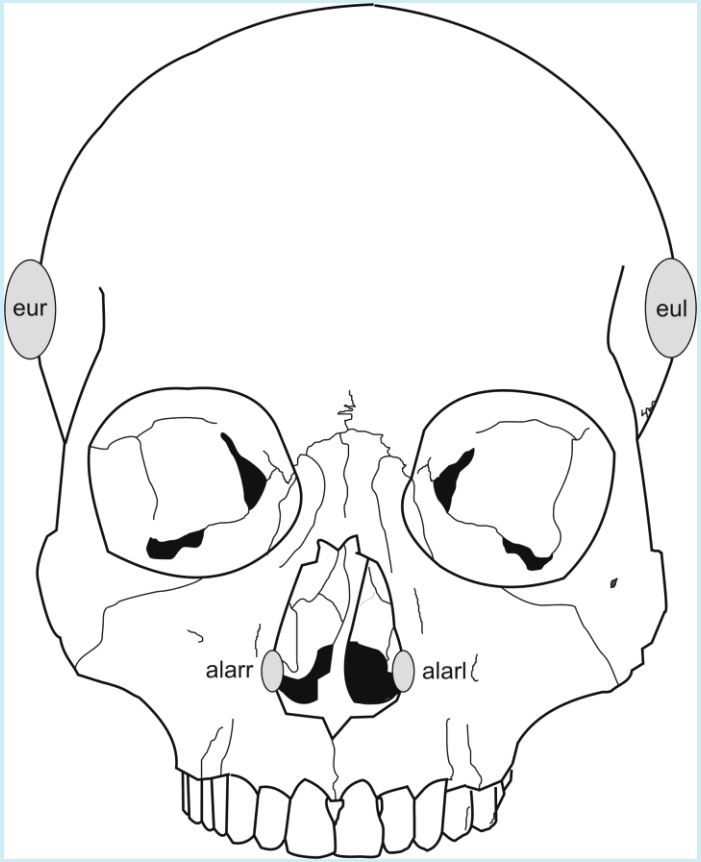


Image from Ross and Williams (2008)

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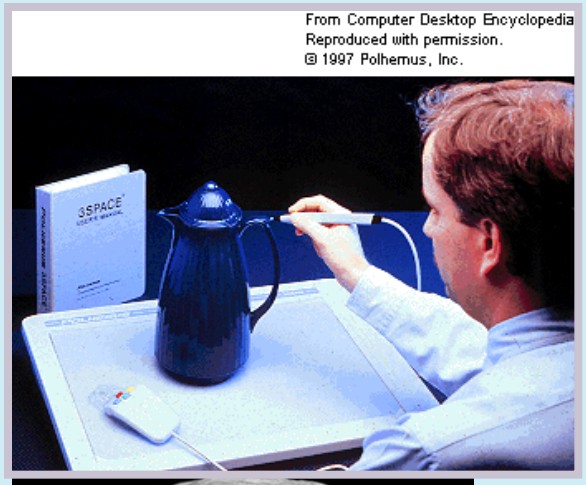
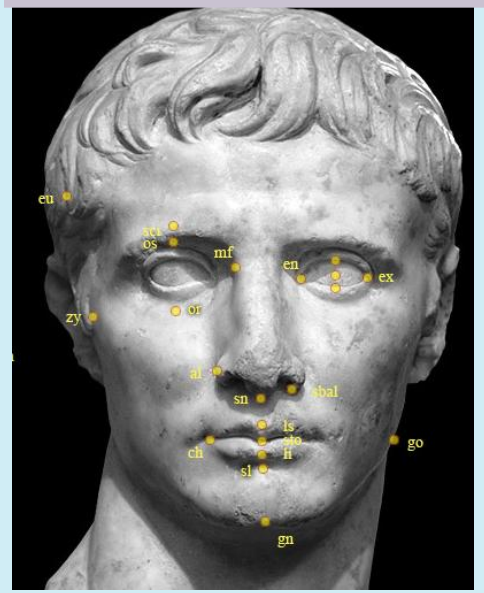
# Data Acquisition Devices




Images from http://images.yourdictionary.com/3-d-digitizer and http://www.rome101.com/Topics/Portraiture/Anthropometry/ (accessed June 30, 2011).

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# *Digitizers*

- http://www.polhemus.com/ **(Accessed Jul 21, 2011)**
- http://www.3d-microscribe.com/ **(Accessed Jul 21, 2011)**

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- **You've collected your data, now what?**

© Microsoft

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# *Methods Available for Assessing Landmark Error*

1. **Superimposition of landmark configurations**
2. **Euclidean distances**
3. **Maintaining constant orientation**
4. **Partial superimposition of landmark configurations**

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# *Generalized Procrustes Analysis (GPA)*

- **Select specimen to approximate mean**
- **Fit entire sample to that specimen using OPA (Ordinary Procrustes Analysis)**
- **Recompute the mean as the simple average of fitted coordinates**
- **Fit entire sample to new estimate**
- **Repeat last two steps until convergence**

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# 1. Superimposition Techniques

- **Generalized Procrustes Analysis (GPA)**
  - **Orientation of the specimens between data acquisition does not need to be maintained**
  - **Optimally translates, scales, and rotates the data into a common coordinate system**

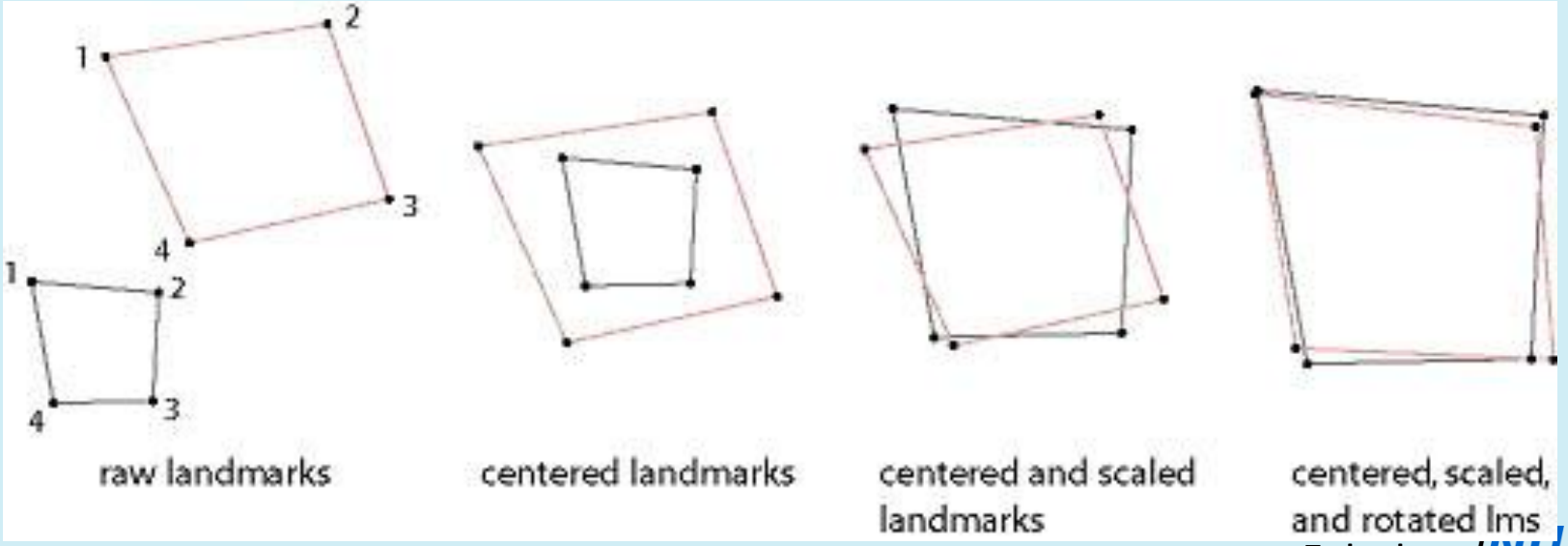


Image from http://www.springerimages.com/Images/LifeSciences/1-10.1007_s11692-009-9055-x-2 (Accessed Jun 30, 2011)

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# 2. Euclidean Distance Methods

- Euclidean Distance = straight line distance between objects
- Euclidean Distance Matrix Analysis (EDMA)
  - Coordinate data rewritten as matrix of interlandmark distances
  - Coordinate system invariance
    - distances remain the same regardless of specimen position or orientation
  - Assesses error contained within all 3 axes simultaneously

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# *Software (Shareware)*

- http://life.bio.sunysb.edu/morph/ **(Accessed Jul 21, 2011)**
- **Morphologika**
- **PAST**
- **Morphometrika for Macs**
- **Morpheus et al.**

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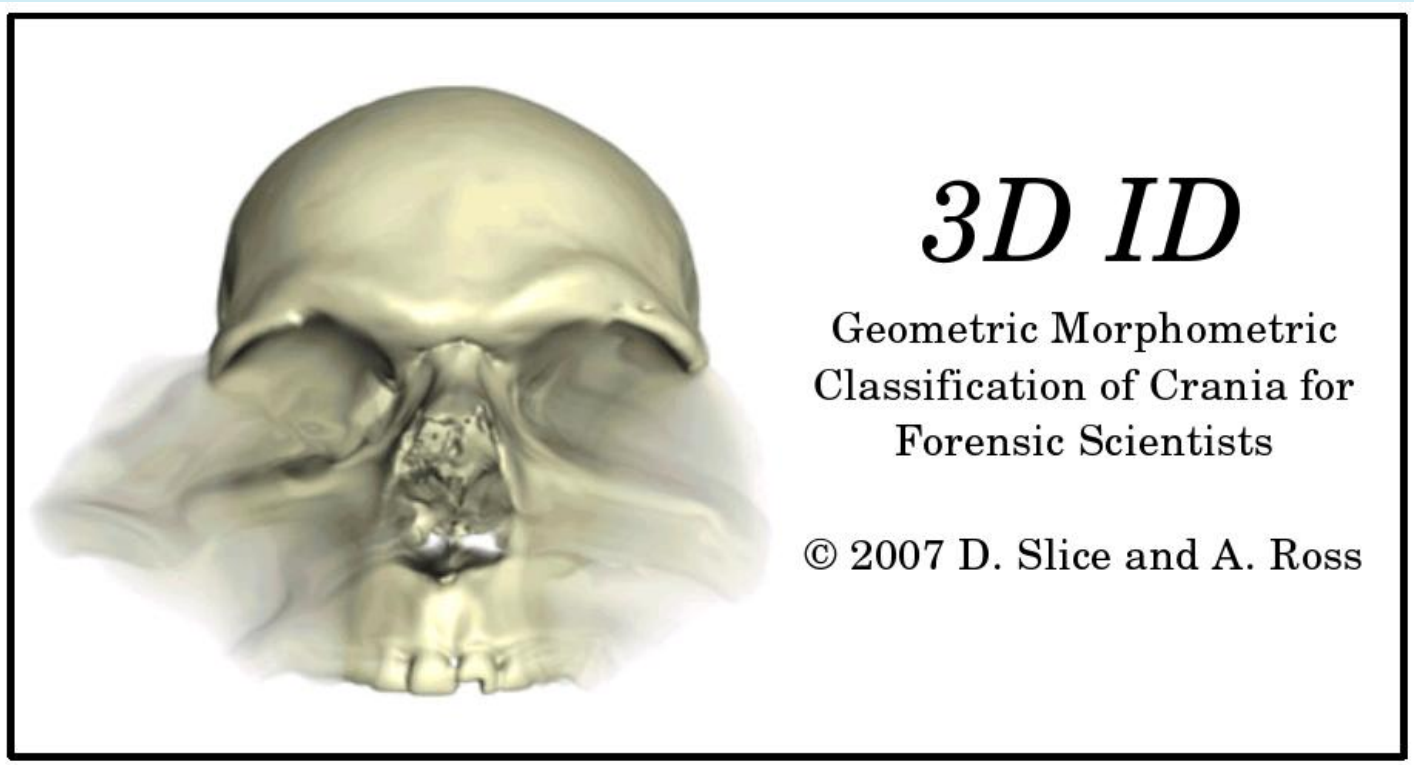


Slice, D. E.; Ross, A. *3D-ID: Geometric Morphometric Classification of Crania for Forensic Scientists*. Version 03DEC2009. http://www.3d-id.org (accessed Jun 30, 2011).

# 3D-ID Development Project Goals

- Develop population-specific classification criteria and associated software to aid in identification
- Product to have implications for criminal investigations and mass fatalities incidents
- Have tools incorporate new three-dimensional methods called geometric morphometrics

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# 3D-ID Objectives

- **Compile an extensible population database derived from 3D landmark coordinate data**
- **Develop and validate population-specific procedures for the classification of unknown individuals**
- **Develop cross-platform software for the use in forensic applications of human identification**

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# *Reliability and Precision*
# *Landmarks = 19*

- Alare l/r
- Bregma
- Dacryon l/r
- Euryon l/r
- Lambda
- Metopion
- Occipital subtense
- Opisthocranion
- Parietal subtense
- Radiometer point l/r
- Subspinale
- Zygion l/r
- Zygoorbitale l/r

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# *3D-ID Repeatability Research Design*

- **N = 3 skulls from the C.A. Pound Human ID Lab**
- **2 Observers**
- **3 Digitizing sessions per skull**
- **Each skull was digitized 3 times by each observer for a total of 6 digitizing sessions per skull**
- **Skulls were not "fixed"**

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# *Interlandmark Distances*

- **Distances between all pairs of landmarks or interlandmark distances (ILDs) were calculated using the computer program PAST (PAlaeontological STatistics 2001)**
- **N(N-1)/2 or 19(19-1)/2 = 171**
- **http://www.nhm.uio.no/norlex/past/download.html (Accessed Jul 21, 2011)**

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# *Digitization Error*

- **32% of the ILDs showed digitizing error in excess of 5% or (54/171)**
- **37% of these included euryon**
- **28% of these included alare**
- **Radiometer point and opisthocranion were problematic**

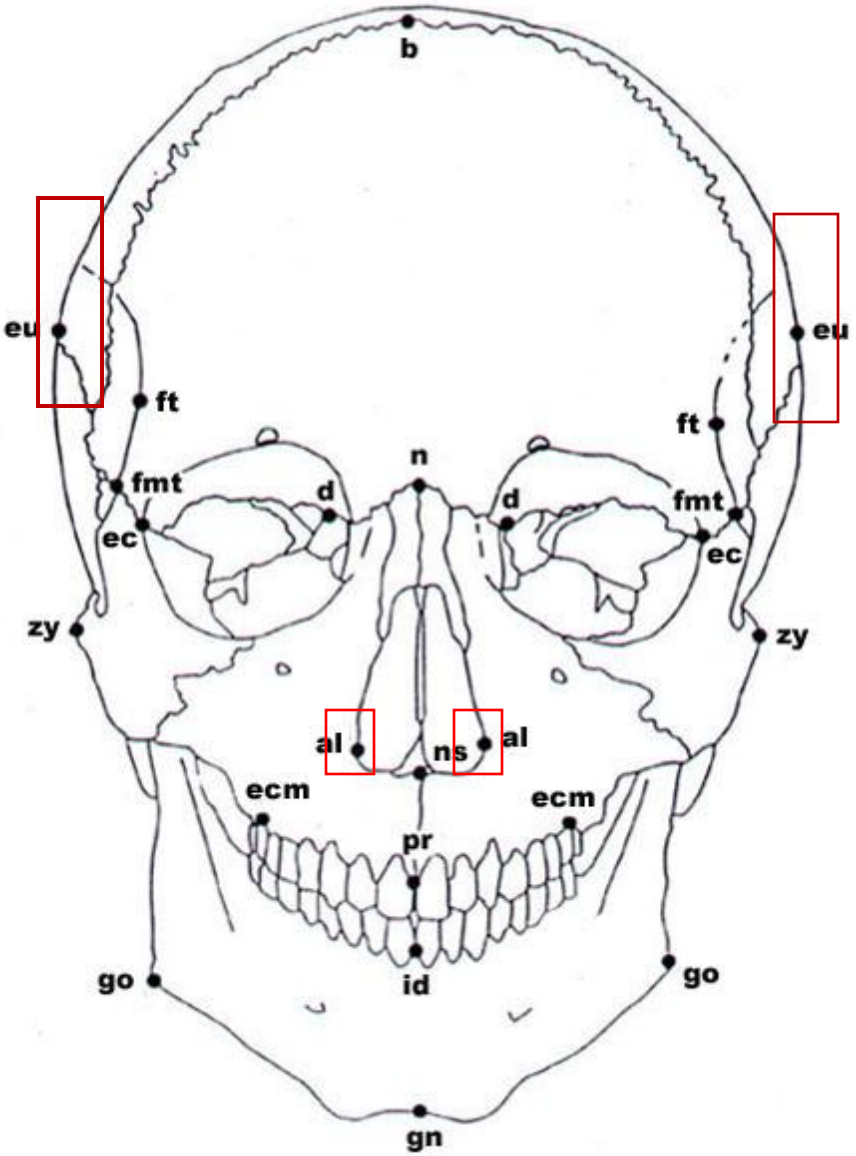


Image from http://www.redwoods.edu/instruct/agarwin/anth_6_measurements.htm (Accessed June 30, 2011)

# Between-Observer Variation

| ILD | DF | Type III SS | MS | F Value | Pr>F |
|---|---|---|---|---|---|
| Alarl-dacr | 1 | 3.89 | 3.89 | 29.98 | 0.03 |
| Alarl-zygr | 1 | 36.38 | 36.38 | 70.85 | 0.01 |
| Alarr-paspt | 1 | 63.13 | 63.13 | 19.39 | 0.05 |
| Brg-radpt | 1 | 13.23 | 13.23 | 27.03 | 0.04 |
| Dacl-rdpt | 1 | 5.05 | 5.05 | 24.24 | 0.04 |
| Dacl-zygool | 1 | 6.02 | 6.02 | 22.78 | 0.04 |
| Dacr-zygool | 1 | 6.14 | 6.14 | 233.91 | 0.004 |
| Eul-radpt | 1 | 196.67 | 196.67 | 167.09 | 0.006 |
| Eul-lam | 1 | 111.36 | 111.36 | 44.53 | 0.02 |
| Eurr-ocspt | 1 | 700.79 | 700.79 | 36.1 | 0.03 |
| Met-ocspt | 1 | 71.72 | 71.72 | 29.98 | 0.03 |
| Paspt-radptr | 1 | 9.93 | 9.93 | 20.01 | 0.05 |
| Paspt-ssp | 1 | 50.97 | 50.97 | 69.64 | 0.01 |
| Ssp-zygool | 1 | 0.58 | 0.58 | 30.88 | 0.03 |

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# Recommendations

- **Caution against using Type 3 landmarks in geometric morphometrics**
  - **Type 3 landmarks have considerable error associated with them**
- **Recommend only using Type 1 and 2 landmarks**

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# 3D-ID

## *www.3d-id.org*

**Developed to provide a means of applying geometric morphometrics to problems of ancestry and sex determination to forensic scientists.**

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# Project Landmarks

- Originally – 75 landmarks
- Accuracy and repeatability – Type III = poor performance
- Continue to collect 75 landmarks for future analysis, but...
- 3D-ID reference data uses 34/5 landmarks for classification (inferior nasal border)
- Definitions from Howells (1973) and Moore-Jansen, Ousley and Jantz (1994)

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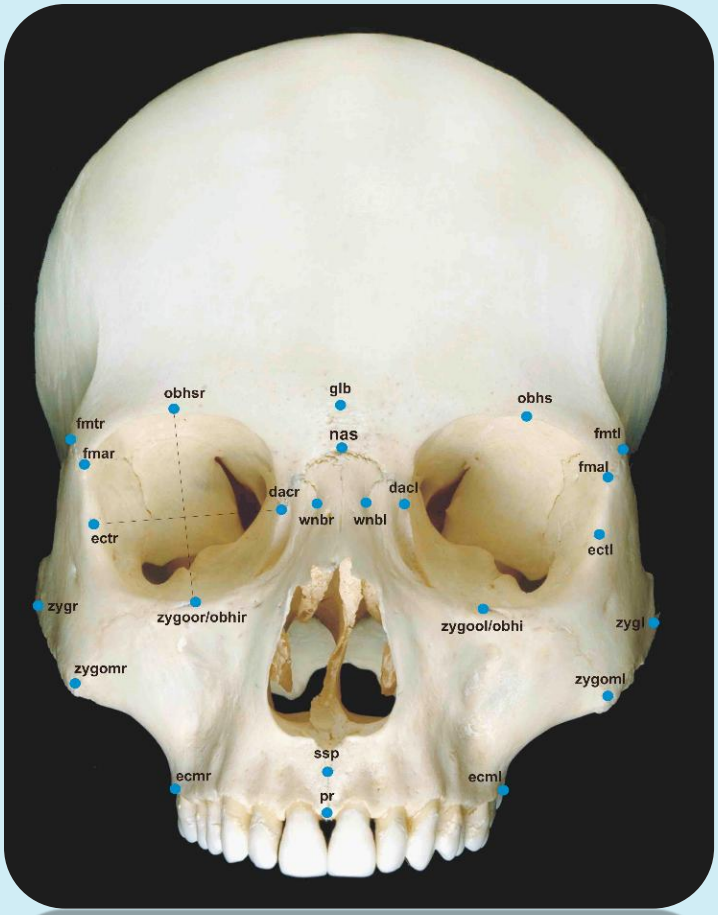


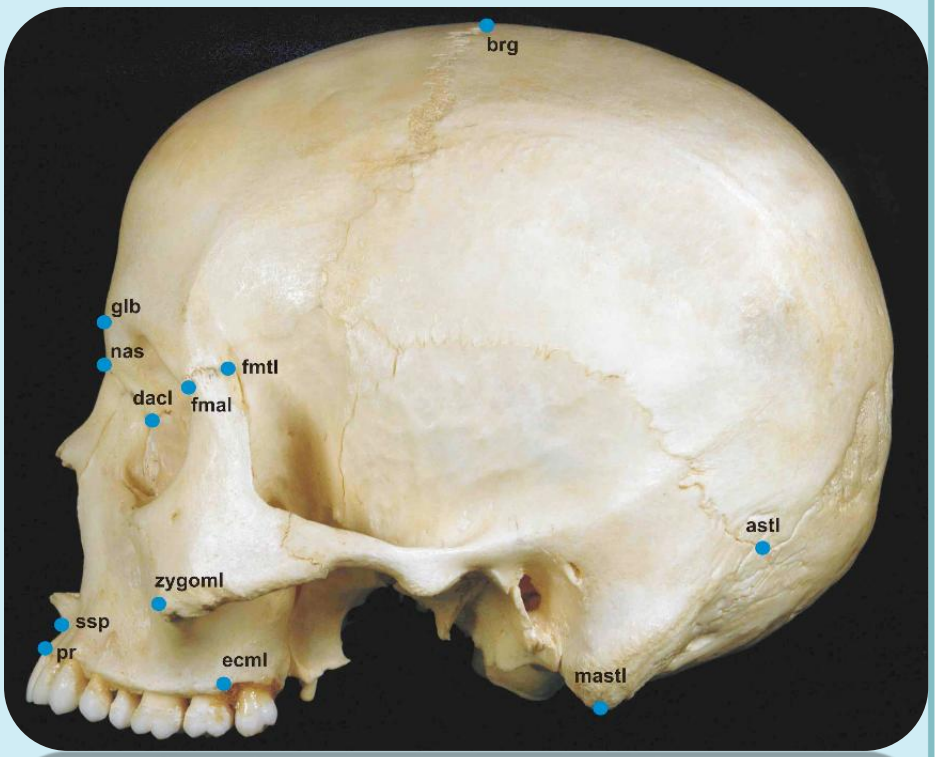


Images from Slice and Ross (2009)

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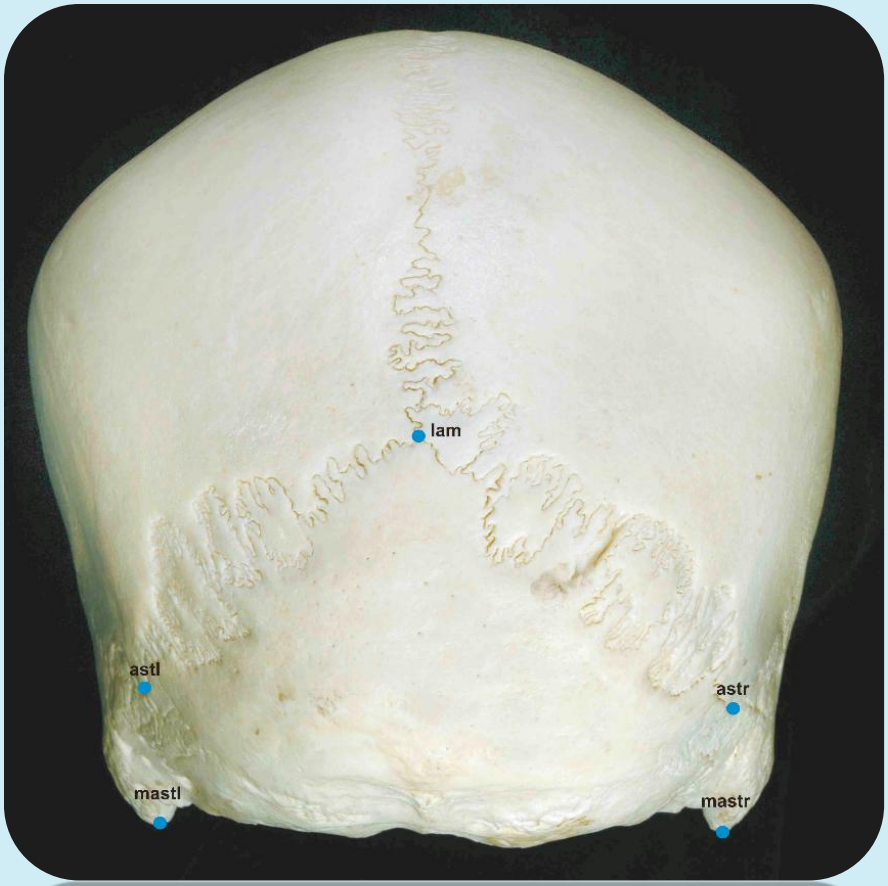


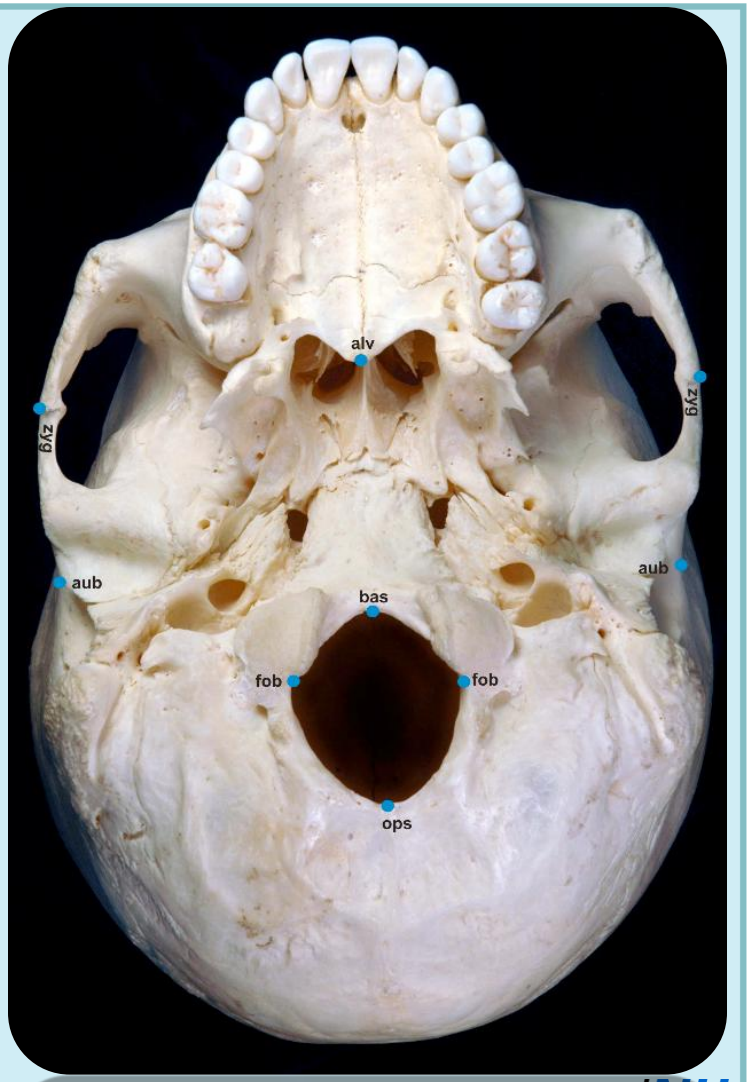


Images from Slice and Ross (2009)

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# *Reference Populations*

## *N=1089*

**American Museum of Natural History**

**C.A. Pound Human Identification Laboratory**

**Georgia Bureau of Investigation**

**Juan Munizaga Collection, Universidad de Chile**

**Luis Lopes Collection, Bocage Museum, Lisbon, Portugal**

**Maxwell Museum**

**Morgue Judicial, Republic of Panama**

**North Carolina Office of the Chief Medical Examiner**

**Oloriz Collection in Spain**

**Samuel Morton Collection**

**Terry Collection**

**The Donated Collection, University of Tennessee**

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# 3D-ID – Data Pane

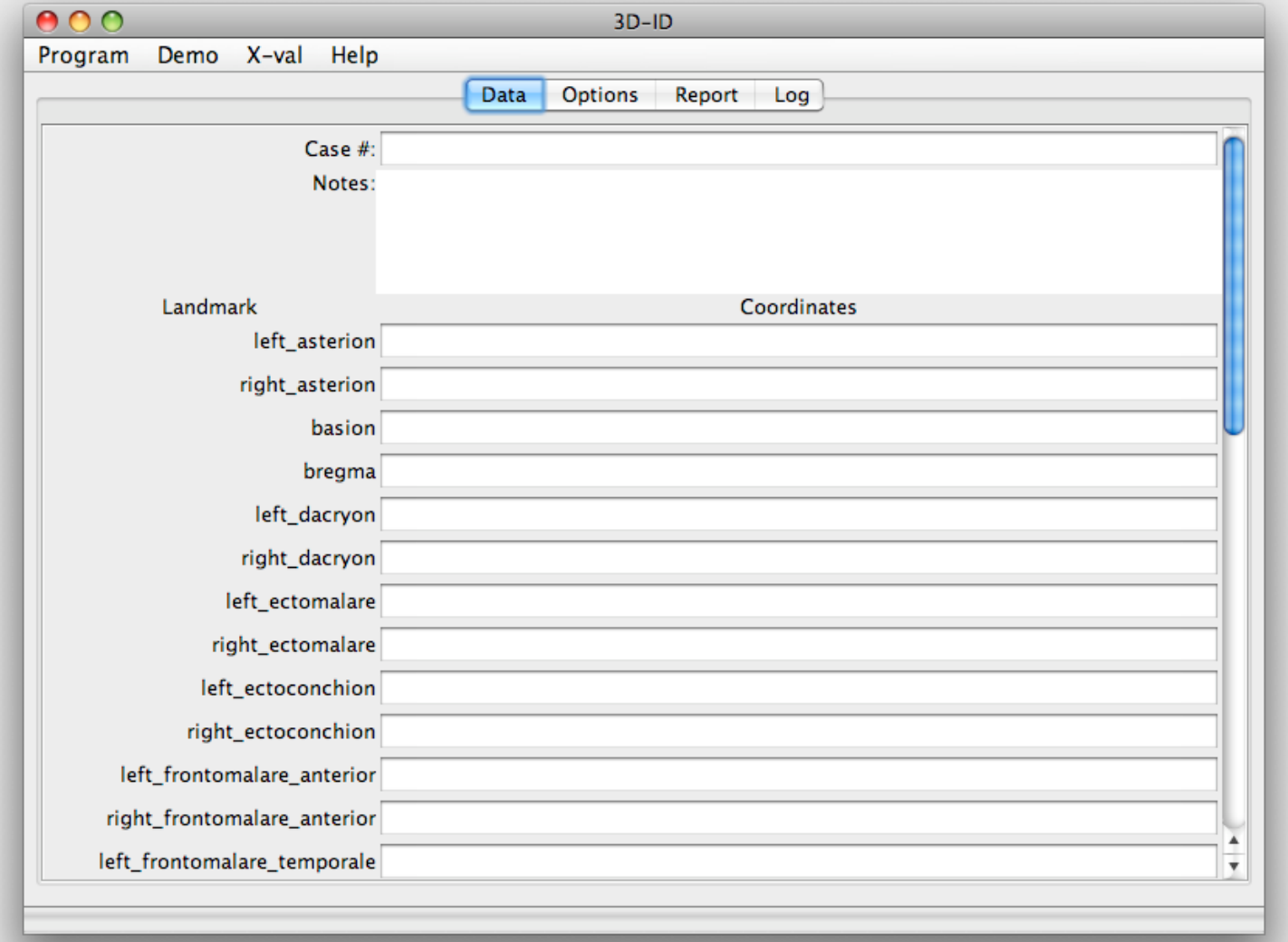



Image courtesy of Dr. Ann H. Ross

# 3D-ID – Options Pane

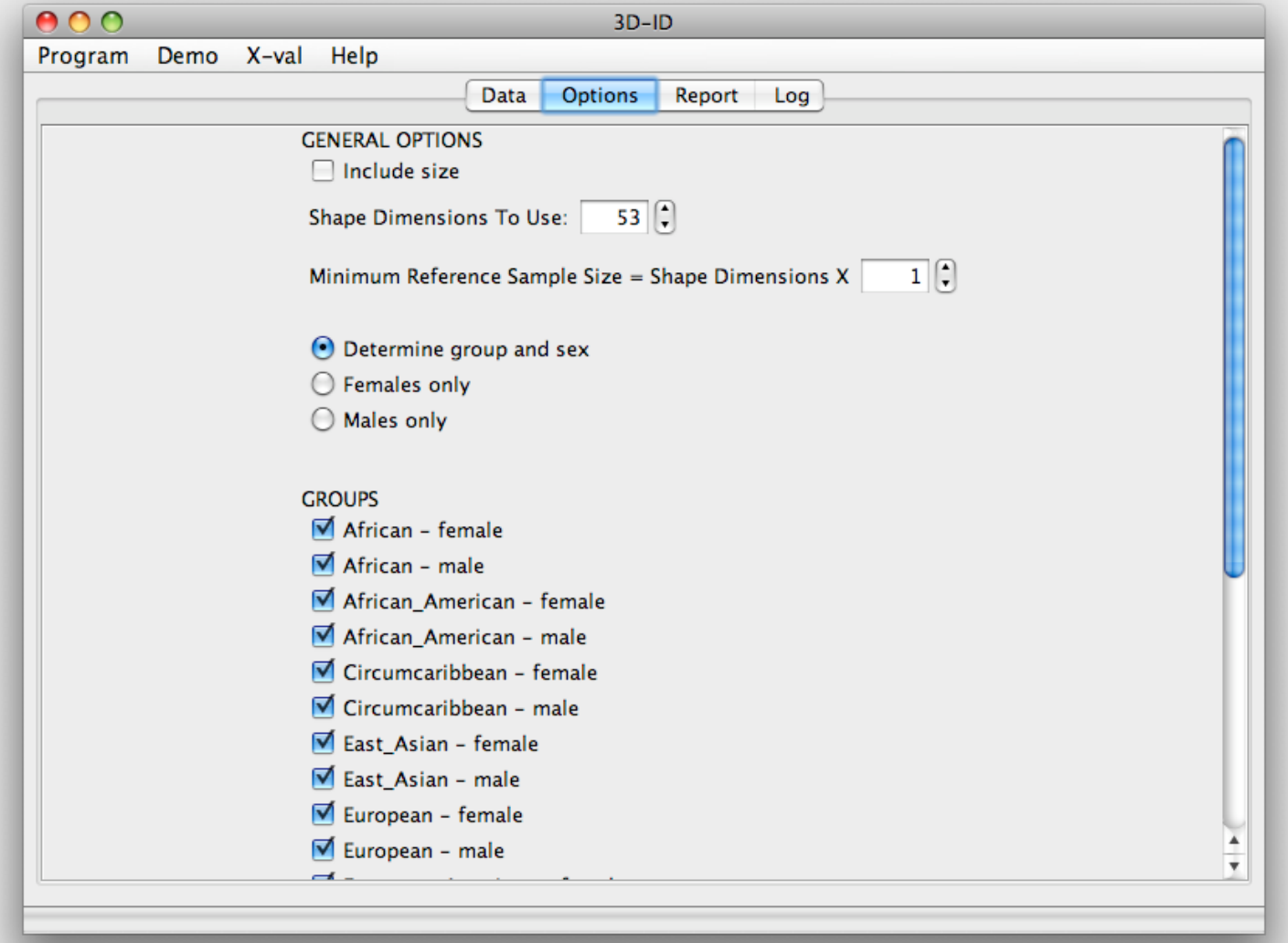



Image courtesy of Dr. Ann H. Ross

# 3D-ID – Process

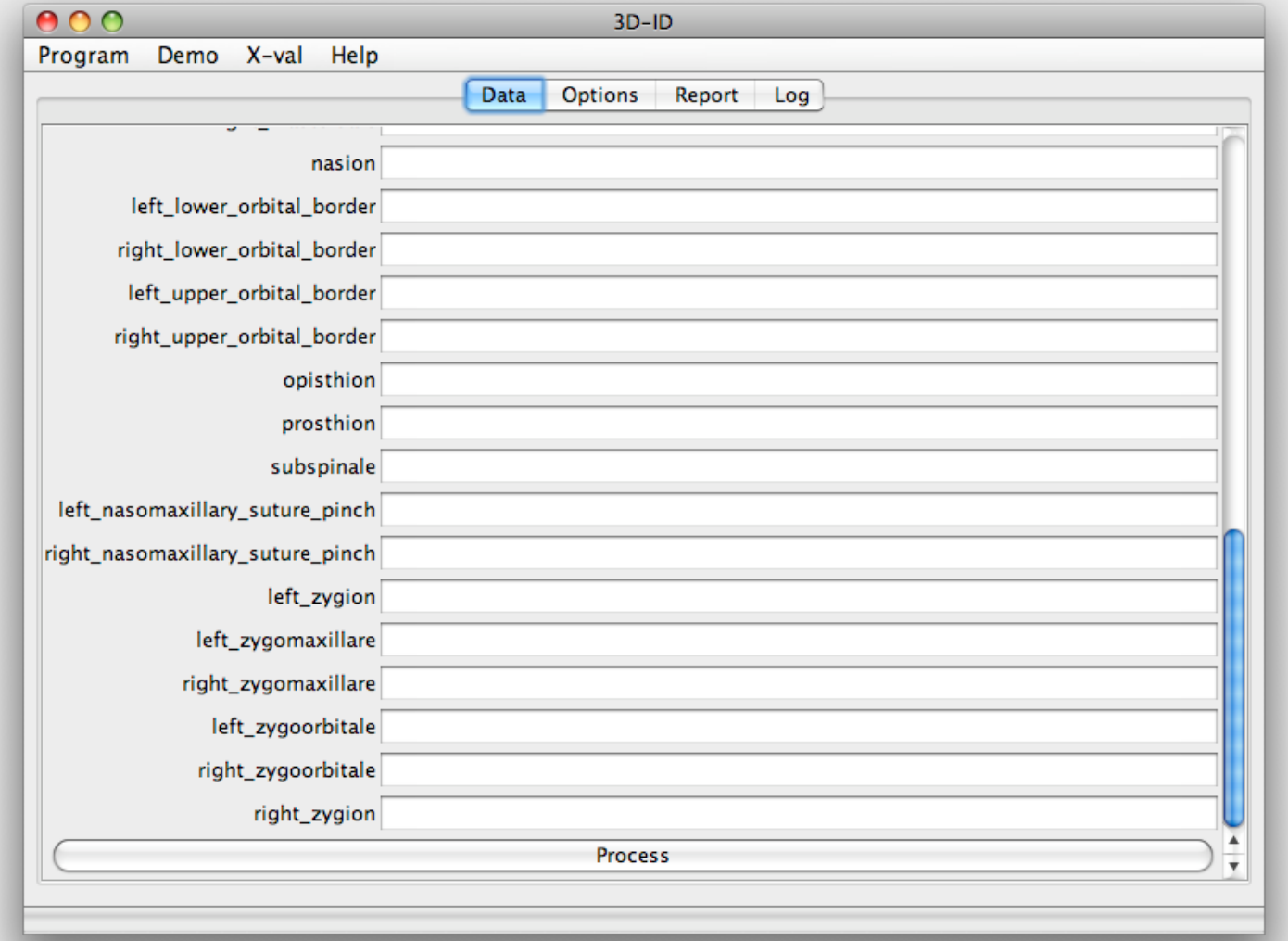
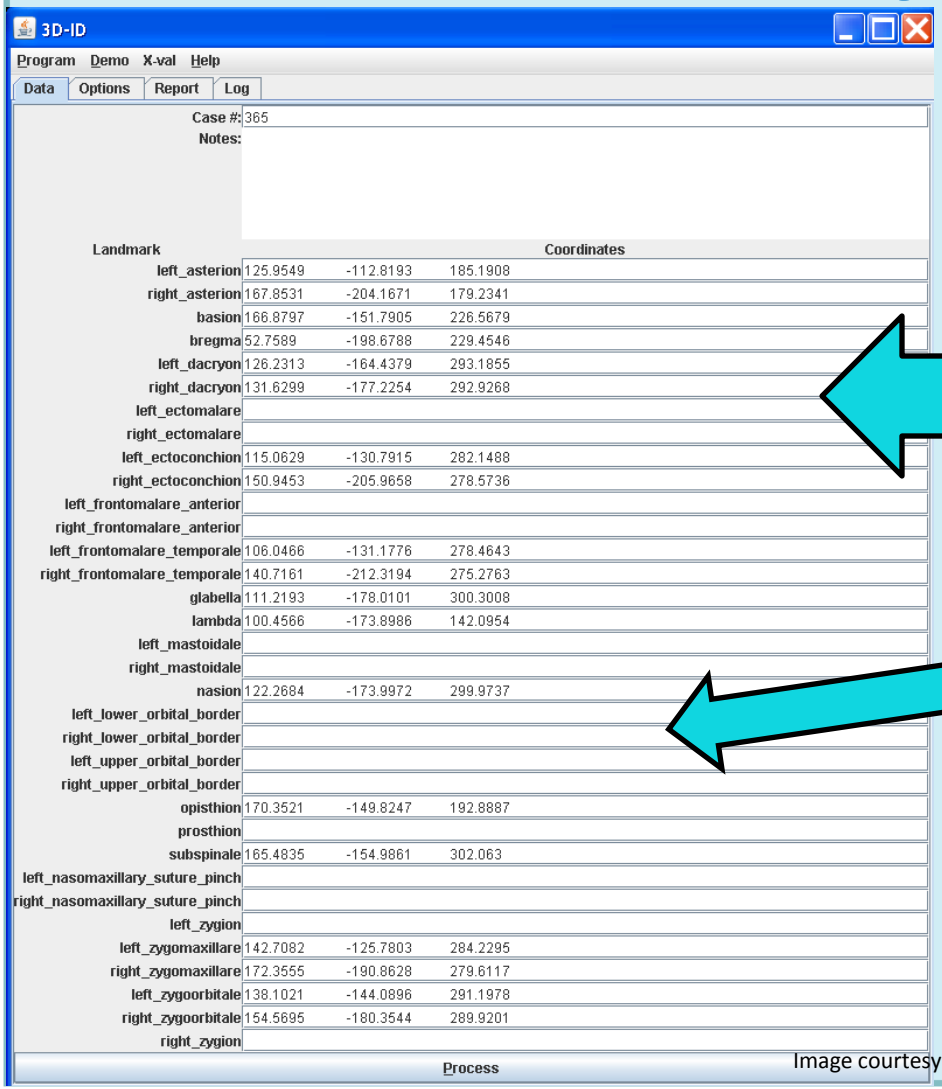



Image courtesy of Dr. Ann H. Ross

# Individual Analysis: 3D-ID




- **Three dimensions for 34 Type I and II cranial landmarks available for entry**
- **Capable of handling missing landmarks**

Image courtesy of Dr. Ann H. Ross

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# 3D-ID - Report

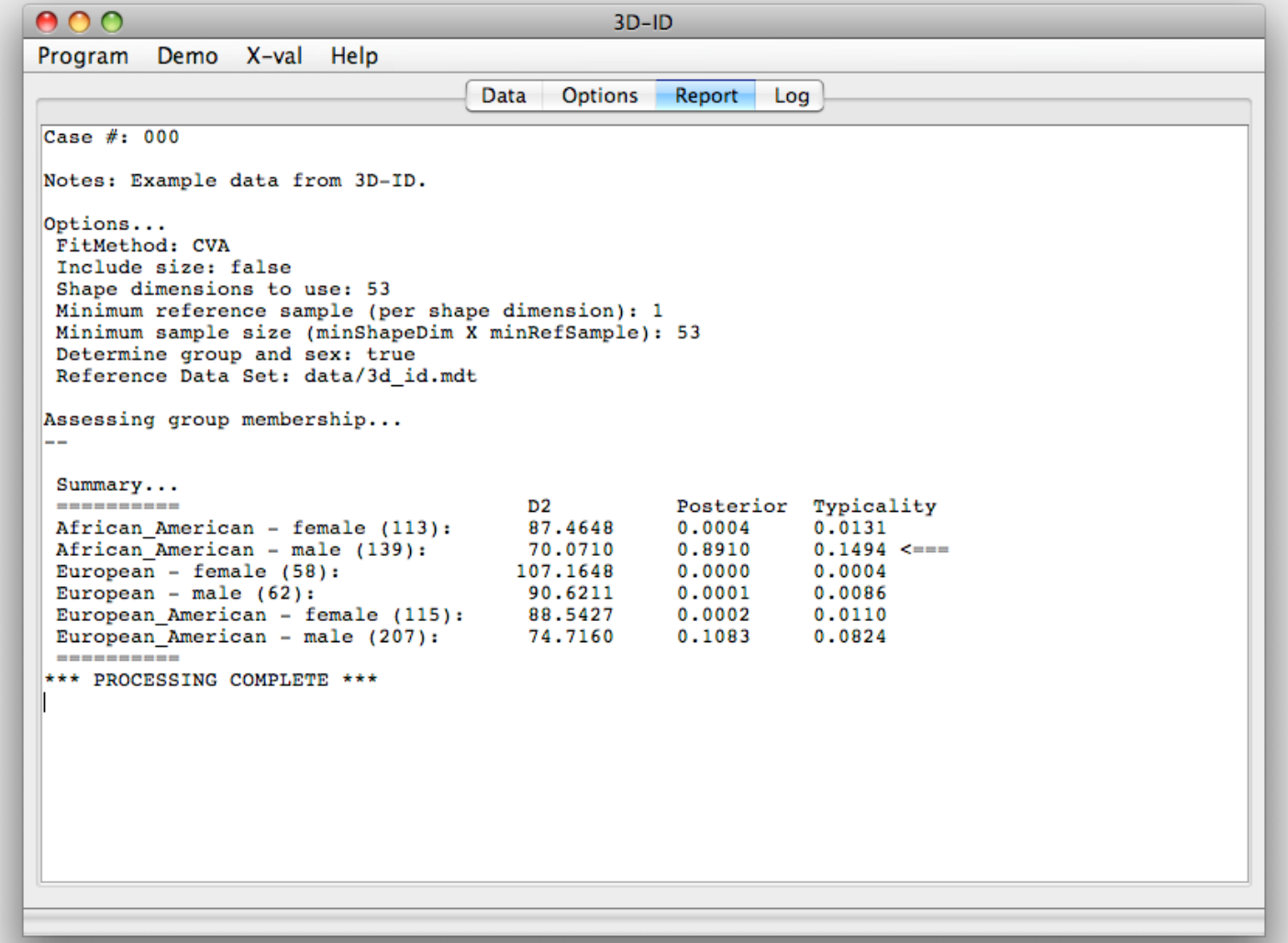


Image courtesy of Dr. Ann H. Ross

# Applications

- **Positively identified case = Euro-American male**
  - **3D-ID: European-American male**

    **posterior probability = 0.6565**

    **typicality = 0.332**
  - **FORDISC: White Male**

    **posterior probability = 0.775**

    **typicality = 0.362**
- **Subadults = 10, 11-16yo Portuguese**
  - **10 = European, European-American**
  - **90% (9/10) correctly classified to sex**

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# 3D-ID Summary

- Available, solid, works well
- Lots of potential as platform for new, enhanced methods
  - Proper CVA
  - Alternative fitting procedures
  - Generalized classifiers
  - Age-adjusted classification
  - User programmable interface

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# Future Applications- Subadults

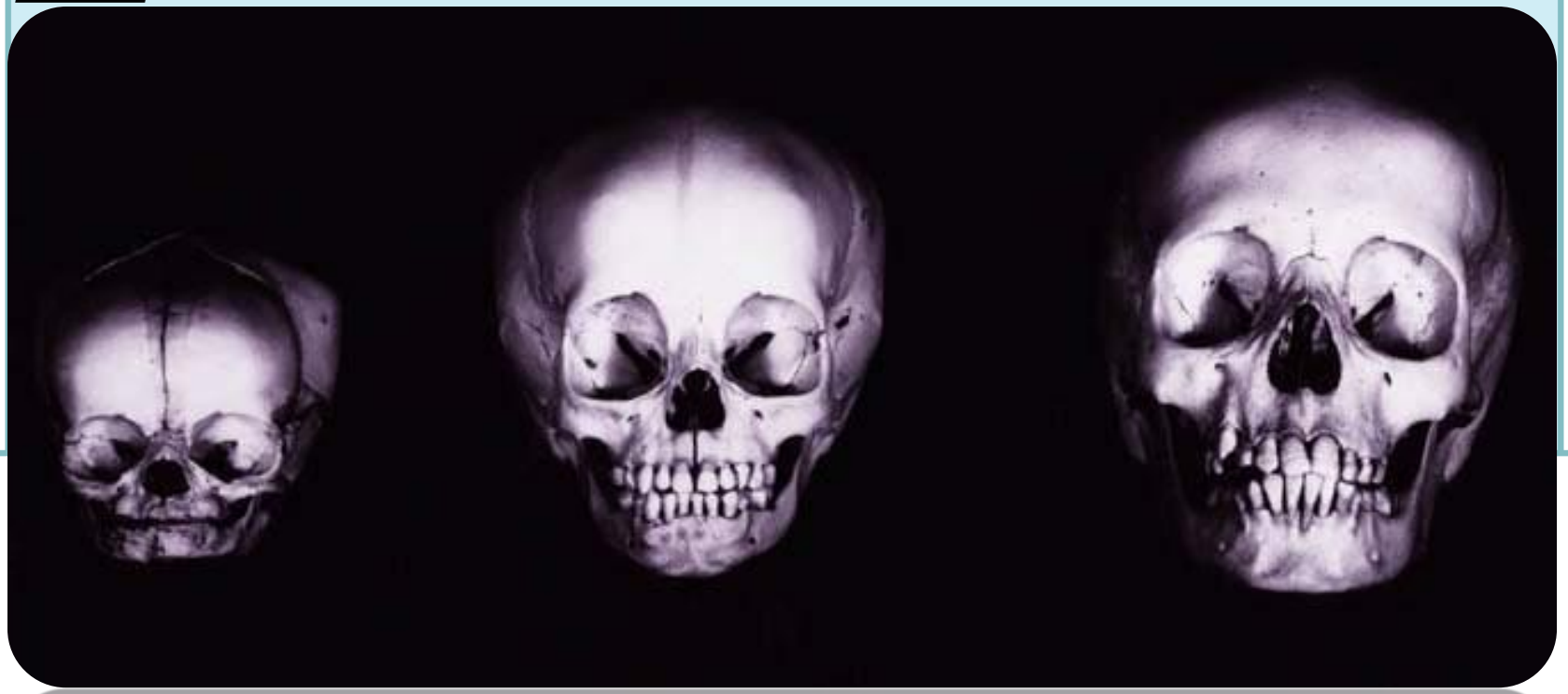

Image of pediatric skulls from the Bosma Collection from Shapiro and Richtsmeier (1997)

**Following data compiled by:**
**Shanna E. Williams, Ph.D – University of Florida**
**Ann H. Ross, Ph.D – North Carolina State University**

# *Group Analysis: Discriminant Function Analysis Cross Validation Results*

## Percentage Classified into Group (PCs 1-9)

| | Cuban | Historic African Slave | African-American | Portuguese Adult | Portuguese Subadult |
|---|---|---|---|---|---|
| **Cuban** | 33.3% | 0% | 9.5% | 52.4% | 4.75% |
| **Historic African Slave** | 0% | 35.7% | 35.7% | 21.3% | 7.14% |
| **African-American** | 2.1% | 0% | 97.9% | 0% | 0% |
| **Portuguese Adult** | 26.4% | 1.9% | 5.7% | 64.2% | 1.9% |
| **Portuguese Subadult** | 0% | 0% | 0% | 50% | 50% |

# *Conclusions and Implications*

- **GM techniques capable of correctly characterizing ancestry in subadult crania**
- **Study highlights value of incorporating GM techniques, such as 3D-ID, into standard forensic practices**
  - **Particularly when dealing with unknown subadult skeletal material**


Image courtesy of Dr. Ann H. Ross

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# Acknowledgements

**Eugenio Aspillaga (Universidad de Chile), Greg Berg, Hugo Cardoso (Bocage Museum, Portugal), María Dolores Garralda (Universidad Complutense, Spain), Richard Jantz, Erin Kimmerle, Antonio Martinez, Janet Monge, Jose Vicente Pachar (Director General, Instituto de Medicina Legal y Ciencias Forenses, Panama), Juan Carlos Prados (Departamento de Anatomía e Embrología Humana, Spain), José Luis Prieto (Instituto Anatómico Forense, Spain), Rick Snow, Kate Spradley, Doug Ubelaker, Danny Wescott, Shanna Williams, American Museum of Natural History, C.A. Pound Human Identification Lab, Georgia Bureau of Investigation, North Carolina Office of the Chief Medical Examiner**

**and**

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# *Cited Scientific References*


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# *Questions?*

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