Improving Zooarchaeological Methods for Classifying Fragmented Faunal Remains using Differential Geometry and Machine Learning

Katrina Yezzi-Woodley, Jeff Calder, Peter Olver, Martha Tappen, Reed Coil

University of Minnesota Driven to Discover®

Nazarbayev University

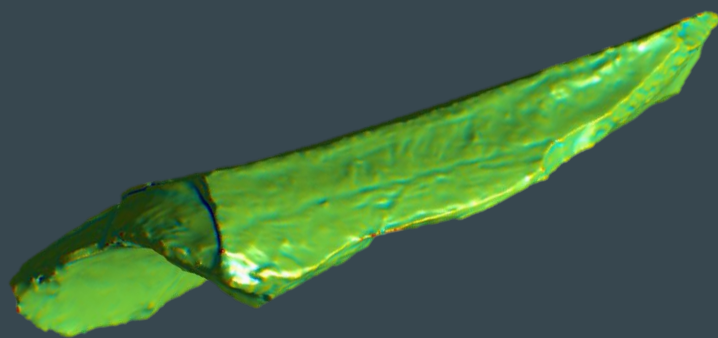
Archaeological importance of fragmentary bone

- Social structures
- Food sharing
- Home bases/central places
- Carcass transport
- Localized activity areas
- Scavenging vs. hunting
- Cooperative behavior
- Butchering behavior

OR
?

Question 1: Does bone fragment shape tell us anything about the actor responsible for fragmentation?

Question 2: If so, can we distinguish hominin damage from carnivore damage? And, can we identify different types of hominin damage?



&

Machine Learning

ELSEVIER
Quaternary Science Reviews
Volume 139, 1 May 2016, Pages 43-52

When felids and hominins ruled at Olduvai Gorge: A machine learning analysis of the skeletal profiles of the non-anthropogenic Bed I sites

Mari Carmen Arriaza [a, b], Manuel Domínguez-Rodrigo [b, c]

ELSEVIER
Palaeogeography, Palaeoclimatology, Palaeoecology
Volume 488, 15 December 2017, Pages 103-112

On applications of micro-photogrammetry and geometric morphometrics to studies of tooth mark morphology: The modern Olduvai Carnivore Site (Tanzania)

Mari Carmen Arriaza [a, b], José Yravedra [b, c], Manuel Domínguez-Rodrigo [b, c, d], Miguel Ángel Mate-González [e, f], Elena García Vargas [c], Juan Francisco Palomeque-González [c], Julia Aramendi [b, c], Diego González-Aguilera [f], Enrique Baquedano [b, g]

Journal of Computational Science 32 (2019) 36–43

Contents lists available at ScienceDirect

ELSEVIER
Journal of Computational Science

journal homepage: www.elsevier.com/locate/jocs

Automated identification and deep classification of cut marks on bones and its paleoanthropological implications

Wonmin Byeon [a,f,1], Manuel Domínguez-Rodrigo [b,c,d,*,1], Georgios Arampatzis [a,e,1], Enrique Baquedano [b], José Yravedra [b,d], Miguel Angel Maté-González [g], Petros Koumoutsakos [a,e]

Archaeological and Anthropological Sciences
https://doi.org/10.1007/s12520-019-00815-6

ORIGINAL PAPER

Classifying agency in bone breakage: an experimental analysis of fracture planes to differentiate between hominin and carnivore dynamic and static loading using machine learning (ML) algorithms

Abel Moclán [1,2,3] • Manuel Domínguez-Rodrigo [3,4] • José Yravedra [4]

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RESEARCH ARTICLE

Where to Dig for Fossils: Combining Climate-Envelope, Taphonomy and Discovery Models

Sebastián Block, Frédérik Saltré, Marta Rodríguez-Rey, Damien A. Fordham, Ingmar Unkel, Corey J. A. Bradshaw

SCIENTIFIC REPORTS

OPEN

Distinguishing butchery cut marks from crocodile bite marks through machine learning methods

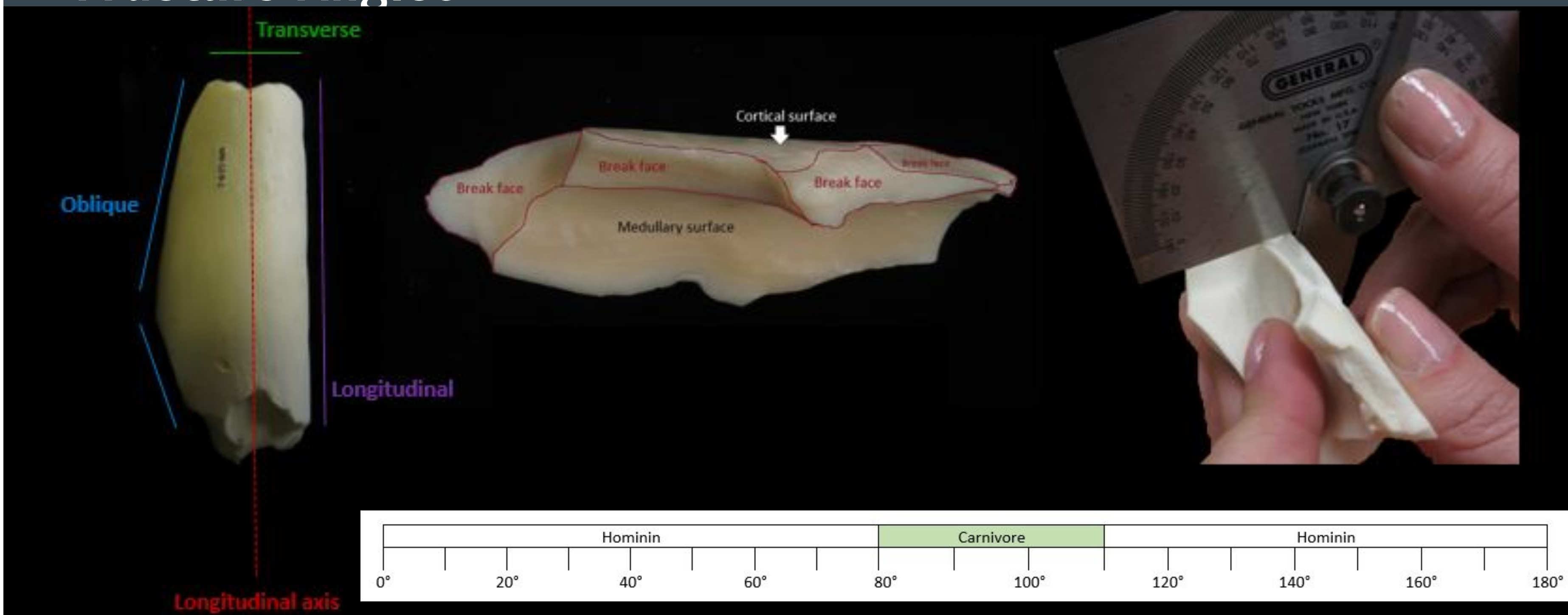
Received: 20 November 2017
Accepted: 19 March 2018

Manuel Domínguez-Rodrigo [1,2] & Enrique Baquedano [1,3]

Studies on bone breakage

- Fracture Outline
- Fracture Plane
- Quality of Fracture Edge
- Remaining Circumference
- Fracture Freshness Index (FFI)
- Fragment Length, width, breadth-to-length ratio
- Notch dimensions
- Fracture Angle

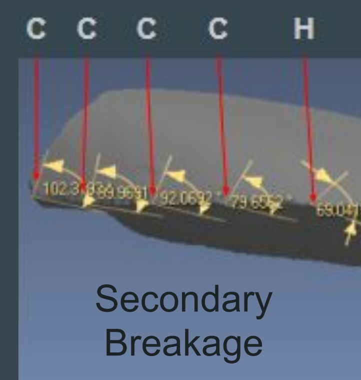
Fracture Angles



Alcantara-García et al. (2006).

Mixed results

< 80° = hominin
80° and 110° = carnivore
> 110° = hominin



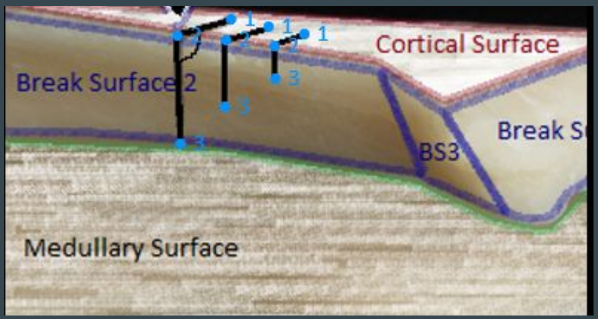
Average = 49° (hom)
Min = 35° (hom)
Max = 102° (carn)
Center = 69° (hom)

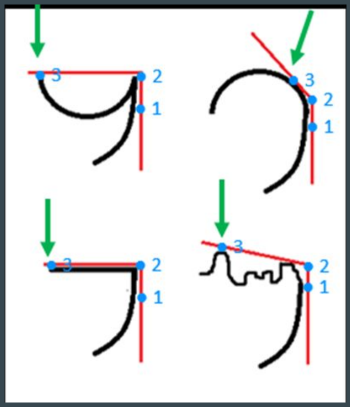
Average = 49° (hom)
Min = 35° (hom)
Max = 69° (hom)
Center = 49° (hom)

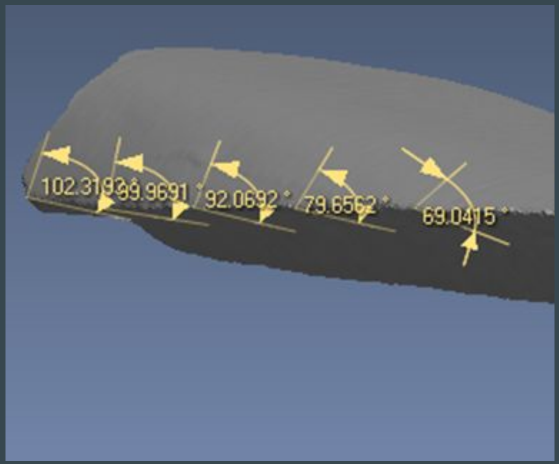
Average = 89° (carn)
Min = 69° (hom)
Max = 102° (carn)
Center = 92° (carn)

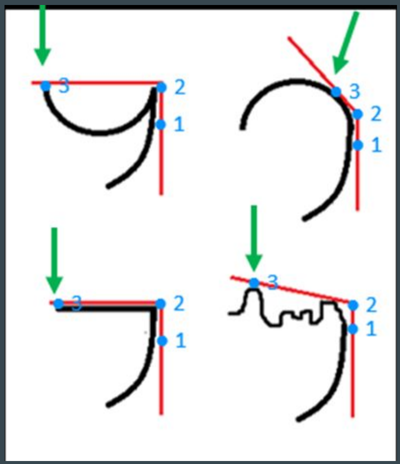
“Midpoint measurements were the chosen standard because the fracture angle of a plane often varies along its full length.”(Pickering et al., 2005:251)

Fracture Angles: Methods






102.3193
99.9691
92.0692
79.6562
69.0415


3
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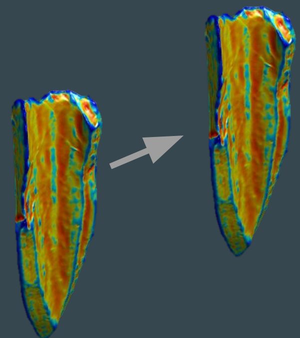
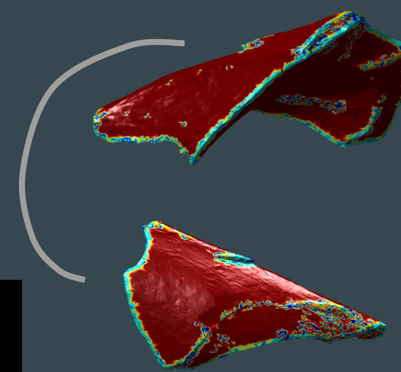
1

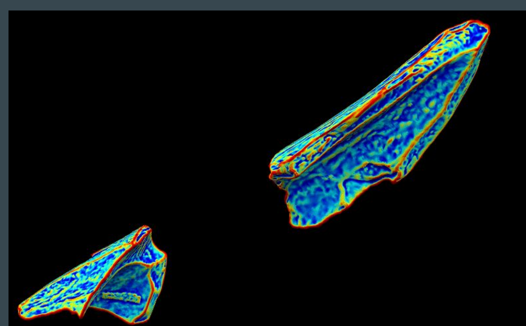

GENERAL TOOLS

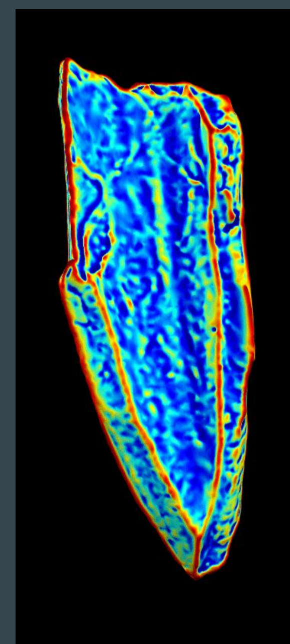
So then, how do we deal with these methodological concerns?

Geometric Invariants



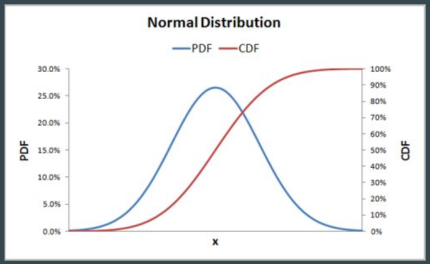




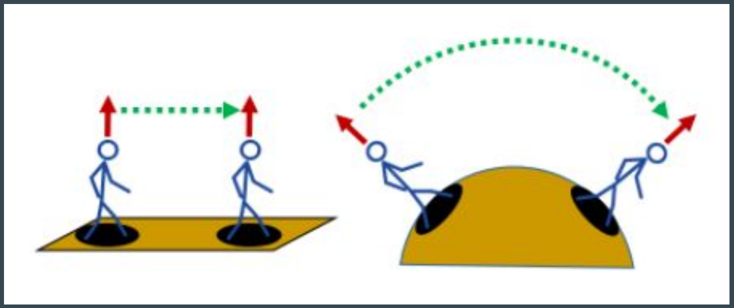


Geometric Invariants

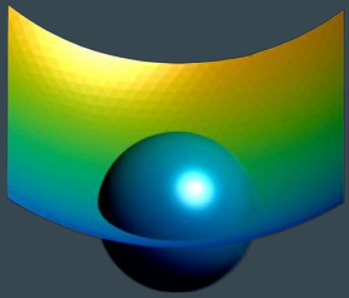
Distance histograms



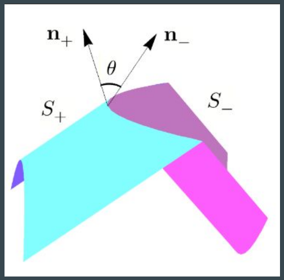
Surface curvature



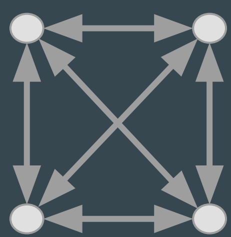
Spherical volume invariant



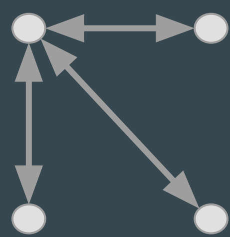
Virtual goniometer



Distance histograms

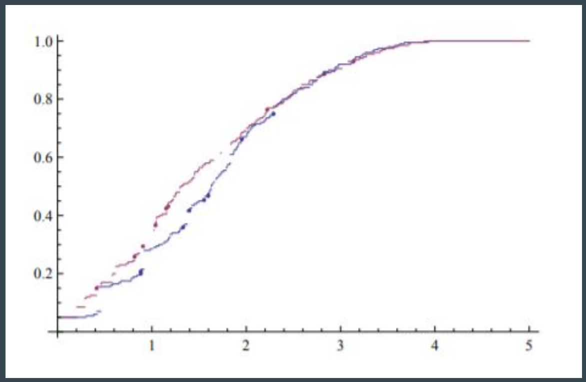


Pairwise

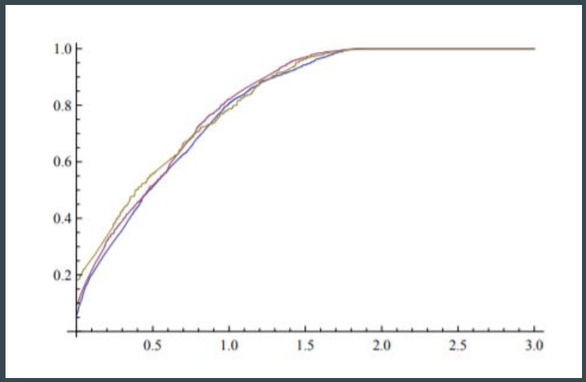


Fixed point

Trapezoid vs. Kite

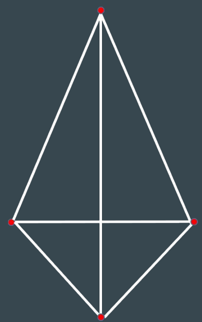


Rectangle vs. Rectangle

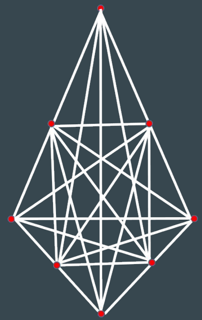


(Brinkman and Olver, 2012)

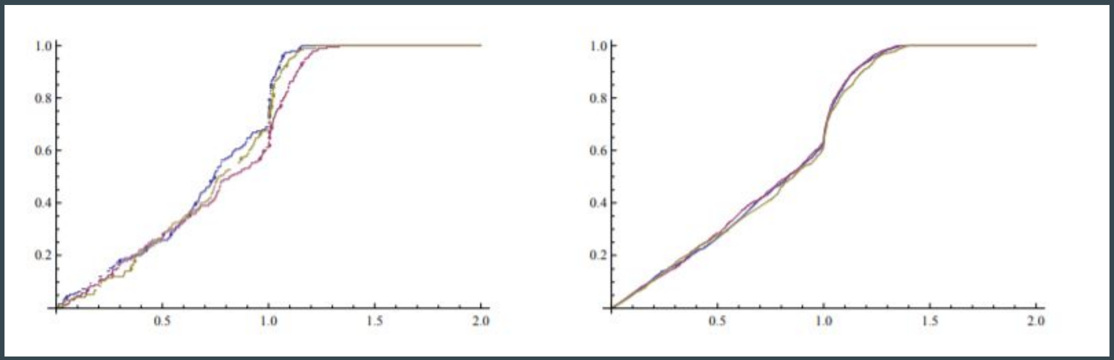
Distance histograms



n = 4



n = 8

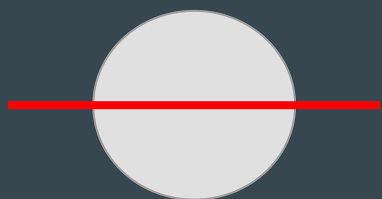


n = 20

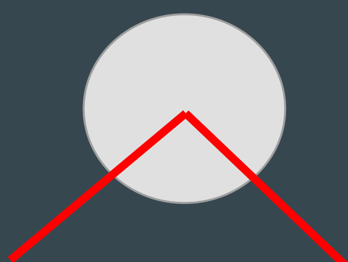
n = 50

(Brinkman and Olver, 2012)

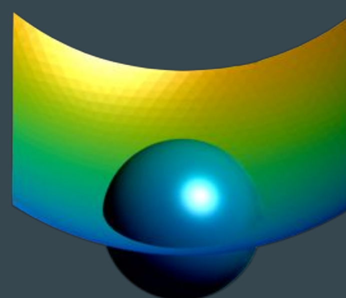
Spherical Volume Invariant (SVI)



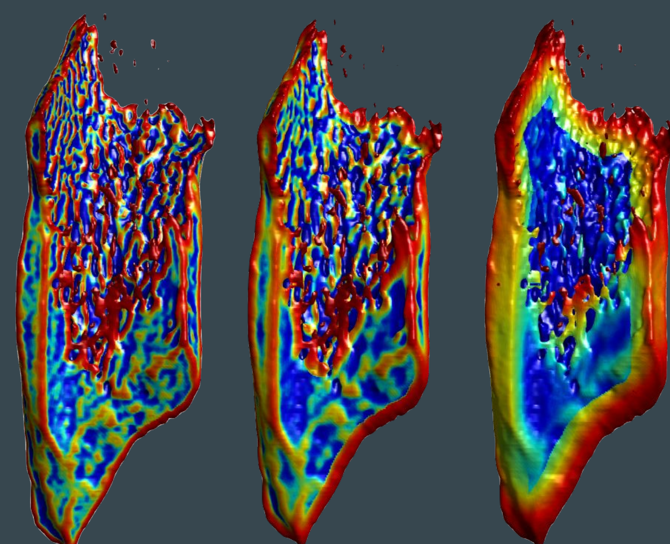
Example A



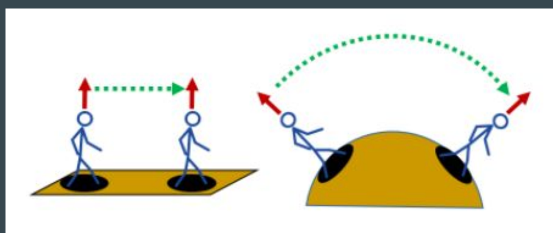
Example B

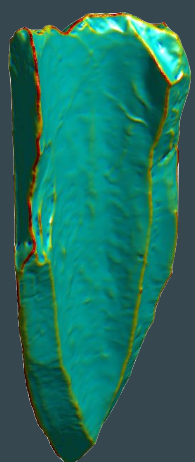


Volume at r = .5, 2, 5   Red = least, blue most (normalized by fragment), shows varying degrees of feature detection



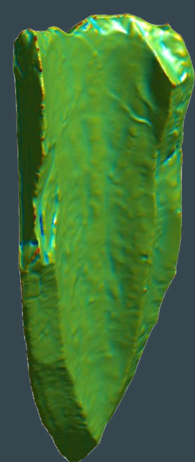
Surface Curvature



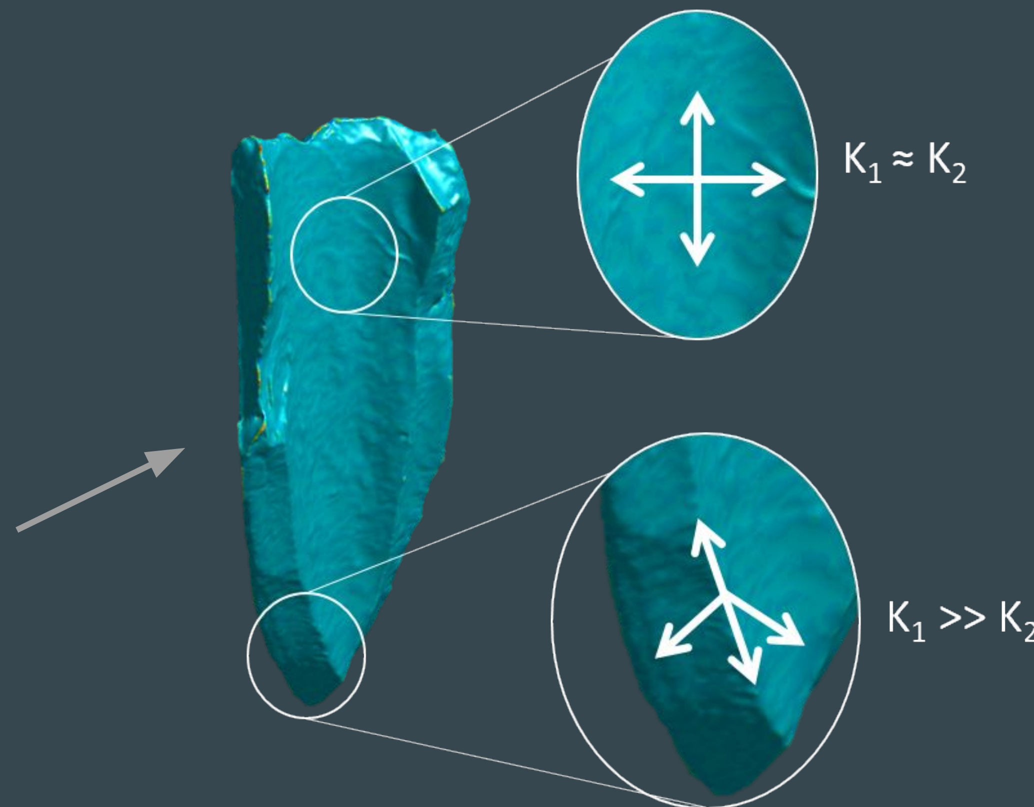


K_1

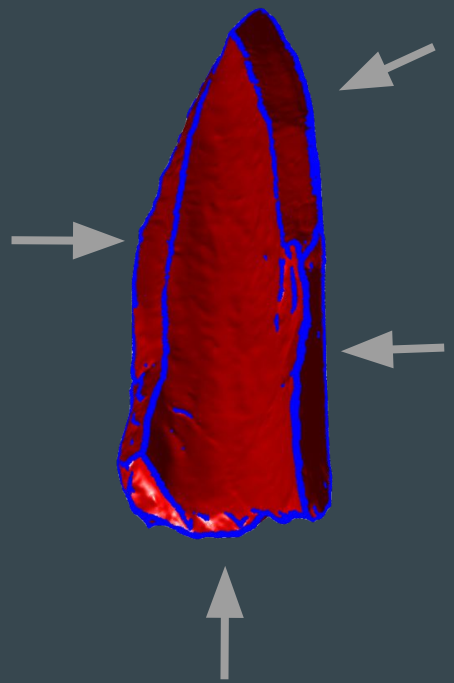
+



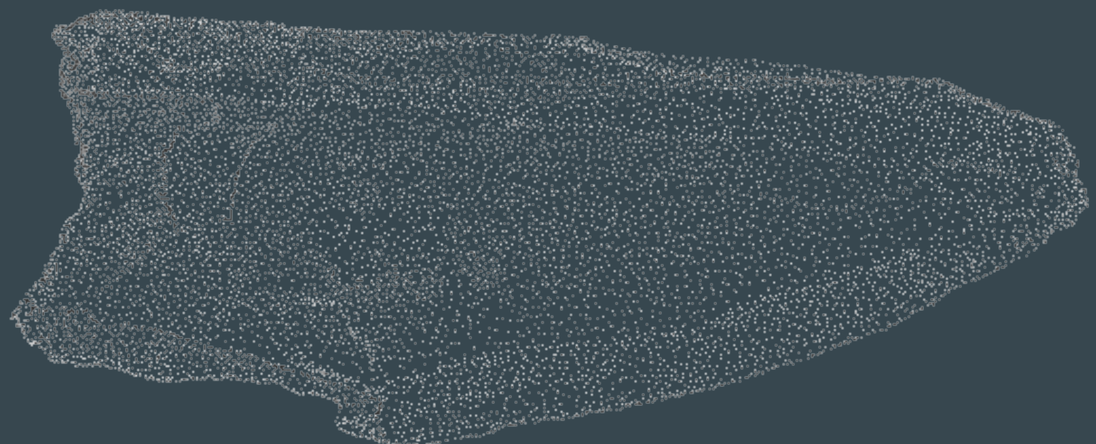
K_2



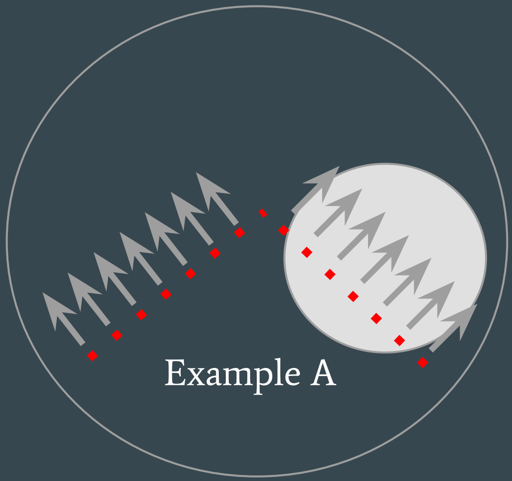
Much Richer Data

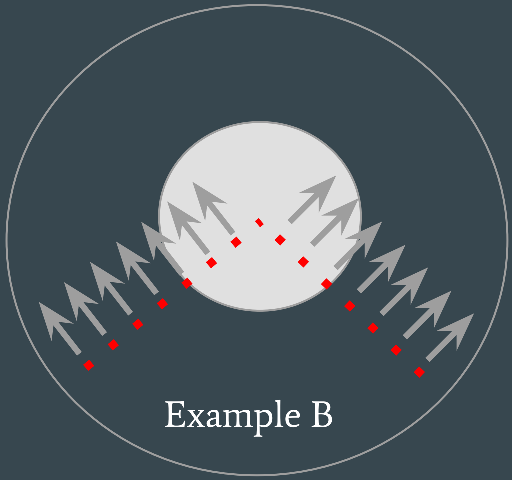


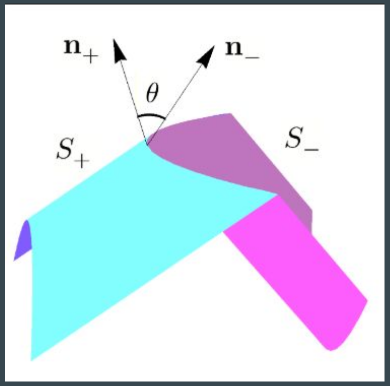
OR

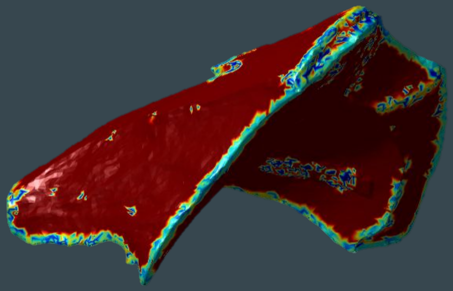


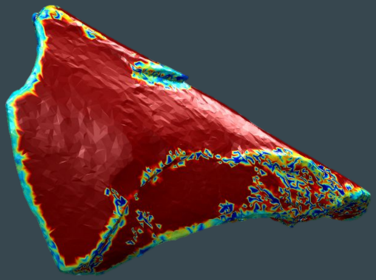
Virtual Goniometer











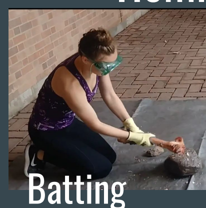
Preliminary results

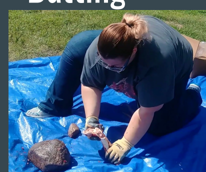
Agents of fragmentation and equifinality

Carnivore

Crocuta crocuta

Hominin





Hammerstone and anvil

Hammerstone only

Geological

Taxa

- Cervus canadensis
- Odocoileus virginianus
- Capra hircus
- Ovis aries
- Bos taurus
- Equus caballus

Skeletal Elements

- Femur
- Tibia
- Humerus
- Radius-ulna
- Metapodials

Bones: >300
Fragments: ~3,212

Sample Size (Digital Data)

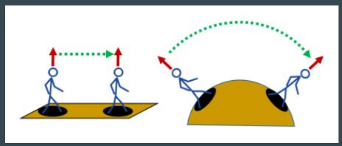
	Femur	Humerus	Radius-Ulna	Tibia	Total
Crocuta	411	120	0	64	595
Hominin	363	291	287	333	1274
Rockfall	0	85	105	0	190
Total	774	496	392	397	2059

Manual Data

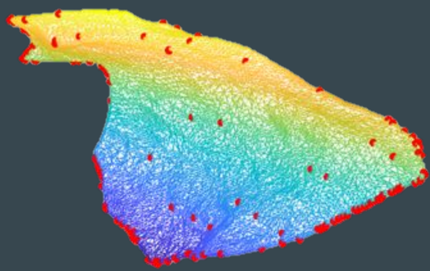
- 457 fragments
- 2,059 breaks
- 1,358 measurements

Digital Data

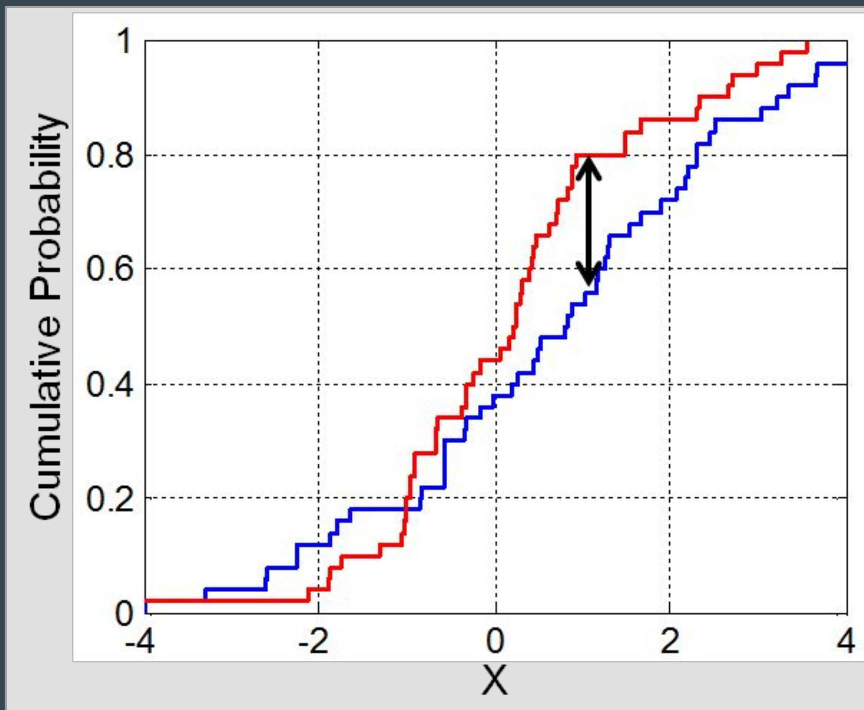
- 82 fragments
- 1,376,900 measurements
- 1% = 13,769



	Femur	Humerus	Tibia	Radius-Ulna	Total
Batting	1,758	606	1,878	1,531	5,773
Crocuta	1,824	780	-	-	2,604
Hammerstone & Anvil	1,485	1,003	1,291	1,613	5,392
Total	5,067	2,389	3,169	3,144	13,769



First Stages



Training set

(Hyena)

~~Test set~~

~~(Hominin)~~

NO

Test set

(Hyena)

YES

Results

Curvature Test Results

Tests: >50
Test sets: 40% - 75% (152 - 1824 curvature extractions)
Trials per test: 1,000
True positives: 0.938 - 0.965
False negatives: 1.00
False positives: 0.035 - 0.062

Manual Test Results

Tests: 15
Test sets: 40% - 75% (22 - 157 fracture angles)
Trials per test: 1,000
True positives: 0.949 - 0.966
True negatives: 0.019 - 0.561
False negatives: 0.034 - 0.051
False positives: 0.439 - 0.981

Preliminary conclusion: Geometric invariants might perform better than traditional measures.

Moving Forward

- Continue to develop scanning and post-processing methods that are useful for large assemblages.
- Complete the experimental breakage
  - Adding in the additional taxa
  - Adding in the additional methods of breakage including rockfall
- Continue to take manual measurements
- Incorporate the other invariants described here
- SVM, KNN, CNN, Random forests, etc.
- THE ARCHAEOLOGICAL SAMPLE - Dmanisi
- Also, automated refits

Acknowledgments

- **The Entire Bone Breakage Research Team:** Pedro Angulo-Umaña, Cora Brown, Dr. Jeff Calder, Dr. Reed Coil, Jacob Elafandi, Bo Hessburg, Dr. Peter Olver, Riley O'Neill, Dr. Cheri Shakiban, Dr. Martha Tappen, Jacob Theis, Dr. Anthony Yezzi, Jr.

- **Committee:** Dr. Martha Tappen (Adviser), Dr. Kieran McNulty (Chair), Dr. Peter Olver, Dr. Ray Rogers, Dr. Gilliane Monnier

- **Anthropology Laboratory Manager:** Matt Edling

- **Scanning:** Advanced Imaging Service for Objects and Spaces (AISOS) (Sam Porter and Colin McFadden), Center for Magnetic Resonance Research, Department of Radiology (CMRR) (Todd Kes and Cassandra Koldenhoven), Anthropology Computer Laboratory, anthropology undergraduate interns and volunteers

- **Funding Entities:** University of Minnesota Graduate Research Partnership Program (GRPP), Anthropology Department block grants, NSF Grant DMS-1816917

- **Bone suppliers:** Elk Marketing Council, Crescent Meats

- **Volunteers (bone breaking):** Matt Edling, Ivy Faulkner, Theodore Wilson, Irena Wilson, Erin Crowley, TJ Paulli, Ranae Paulli, Brisa Yezzi-Woodley, Kilee Johnson, Kyra Johnson, Kameron Dropps, Riley O'Neill, Pedro Angulo-Umaña, Bo Hessburg, all the paleopicnic participants, Milwaukee County Zoo, Irvine Zoo, Wisconsin

- **General Support:** Dr. Kristy Golubiewski-Davis, Sam Porter, Dr. Jason Massey, Dr. Ivy Faulkner, Risa Luther, Ela Heaton, Dr. Kirsten Jenkins, Samantha Gogol, Erin Crowley