Improving Zooarchaeological Methods for Classifying Fragmented Faunal Remains using Differential Geometry and Machine Learning
• **The Bone Breakage Research Team:** Jeff Calder, Reed Coil, Peter Olver, Cheri Shakiban, Martha Tappen, Anthony Yezzi, Jr., Katrina Yezzi-Woodley

• **Pedro Angulo-Umaña, Jacob Elafandi, Bo Hessburg, Riley O’Neill, Jacob Theis**

• **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,

• **Hyenas:** Milwaukee County Zoo (Scruffy), Irvine Zoo, Wisconsin
Ancient Hominin Sites

- Cradle of Humankind
  - Australopithecus
  - 2.3 Ma
- Olduvai Gorge
  - Homo habilis
  - 1.9 Ma
- Dmanisi, Georgia
  - Homo erectus
  - 1.8 Ma
- ...

...
Research Queries

I. How do the fragments go back together?
II. What broke them?

Fig. 4: the U of M anthropology lab, native habitat of Homo Anthropologis

Fig. 5: The annals of the U of M’s Anthropology Department
Breaking Bones

Carnivore

*Crocuta crocuta* = hyena

Hominin

Batting

Hammerstone and anvil

Hammerstone only

Geological

Rock fall
Working Hypothesis

The geometry of the bone fragments, their identity (taxon and element), and how they are reassembled will tell us the actor of breakage.
Working Hypothesis

The **geometry** of the bone fragments, their identity (taxon and element), and how they are reassembled will tell us the actor of breakage.

🌟 Break edges and break faces 🌟
Segmentation

FIGURE 1: Results of preliminary experiments with face segmentation and edge tracing.
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
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?

Further, can we identify different types of hominin damage?
&

Machine Learning
Could history of humans in North America be rewritten by broken bones?

Smashed mastodon bones show humans arrived over 100,000 years earlier than previously thought say researchers, although other experts are sceptical

Ian Sample Science editor

Wednesday 26 April 2017 13.00 EDT
Busted Mastodon Is Ice Age Roadkill

A mastodon said to be pulverized by Ice Age humans was probably busted up by roadwork

By Brian Switek on April 10, 2019
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

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
New mathematical tools...
Rigid motions
(group theory)
Geometric Invariants

- Distance histograms
- Spherical volume invariant
- Surface curvature
- Virtual goniometer
Distance histograms

Pairwise

Fixed point

Trapezoid vs. Kite

Rectangle vs. Rectangle

(Brinkman and Olver, 2012)
Distance histograms

(Brinkman and Olver, 2012)
Spherical Volume Invariant (SVI)

Volume at $r = \{0.5, 2, 5\}$ Red = least, blue most (normalized by fragment), shows varying degrees of feature detection

Example A

Example B
Surface Curvature

\[ K_1 + K_2 \approx K_2 \]

\[ K_1 \gg K_2 \]
Much Richer Data
Virtual Goniometer

Example A

Example B
Preliminary results
Agents of fragmentation and equifinality

**Carnivore**
- *Crocuta crocuta*

**Hominin**
- Batting
- Hammerstone
- Hammerstone only

**Geological**
- Rockfall

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

**Skeletal Elements**
- Femur
- Tibia
- Humerus
- Radius-ulna
- Metapodials
Sample Size (Digital Data)

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

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

<table>
<thead>
<tr>
<th></th>
<th>Femur</th>
<th>Humerus</th>
<th>Tibia</th>
<th>Radius-Ulna</th>
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</table>
Histogram matching

\[ D = 0.6248 \]

\[ D = 0.3191 \]

\[ D = 0.5962 \]

Guess: Hominin (correct)
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
True negatives: 1.00
False negatives: 0.00
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: 0.034 - 0.051
False negatives: 0.019 - 0.561
False positives: 0.439 - 0.981

Preliminary conclusion: Geometric invariants might perform better than traditional measures.
## hominin vs. hyena (femur) – surface curvature

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## Hominins vs. hyena (femur) – manual data

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<td>Hyena femur</td>
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# Sample Size (Manual Data)

## Number of breaks per element and actor of breakage

<table>
<thead>
<tr>
<th></th>
<th>Femur</th>
<th>Humerus</th>
<th>Radius-Ulna</th>
<th>Tibia</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crocuta</strong></td>
<td>411</td>
<td>120</td>
<td>0</td>
<td>64</td>
<td>595</td>
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<td><strong>Hominin</strong></td>
<td>363</td>
<td>291</td>
<td>287</td>
<td>333</td>
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<tr>
<td><strong>Rockfall</strong></td>
<td>0</td>
<td>85</td>
<td>105</td>
<td>0</td>
<td>190</td>
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<tr>
<td><strong>Total</strong></td>
<td>774</td>
<td>496</td>
<td>392</td>
<td>397</td>
<td>2059</td>
</tr>
</tbody>
</table>

## Number of breaks per element and actor for which no goniometer measurement could be taken

<table>
<thead>
<tr>
<th></th>
<th>Femur</th>
<th>Humerus</th>
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<td><strong>Crocuta</strong></td>
<td>234</td>
<td>32</td>
<td>-</td>
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<td><strong>Hominin</strong></td>
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<td>21</td>
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<td>-</td>
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<td><strong>Total</strong></td>
<td>336</td>
<td>104</td>
<td>95</td>
<td>166</td>
<td>701</td>
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</table>

## Number of breaks per element and method of breakage

<table>
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<td>85</td>
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<td>190</td>
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<tr>
<td><strong>Hammerstone &amp; Anvil</strong></td>
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<td><strong>Hammerstone only</strong></td>
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<td>774</td>
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<td>392</td>
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<td>2059</td>
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</table>

## Number of breaks per element and method for which no goniometer measurement could be taken

<table>
<thead>
<tr>
<th></th>
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<td><strong>Batting</strong></td>
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<td>29</td>
<td>22</td>
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<td>21</td>
<td>31</td>
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<td>52</td>
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<td><strong>Hammerstone &amp; Anvil</strong></td>
<td>57</td>
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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 and apply virtual goniometer
- Incorporate other geometric invariants
- More advanced ML protocols — SVM, KNN, CNN, random forests, etc.
- THE ARCHAEOLOGICAL SAMPLE - Dmanisi
- Also, automated refits (Yezzi-Woodley talk)