Using Differential Geometric Methods and Machine Learning to Improve Zooarchaeological Methods for Classifying Fragmented Faunal Remains

•••

Katrina Yezzi-Woodley, Jeff Calder, Peter Olver, Martha Tappen, Reed Coil, Cheri Shakiban, Pedro Angulo-Umaña, Riley O'Neill, Bo Hessburg

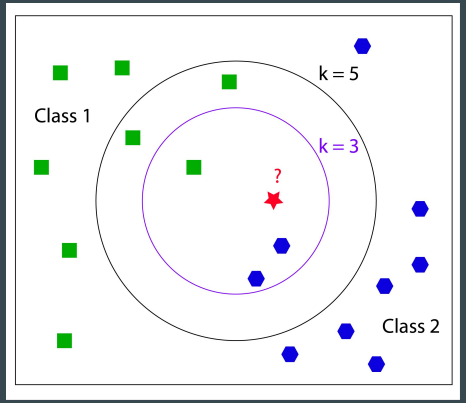
Machine Learning

“Machine learning is a method of data analysis that automates analytical model building. Using algorithms that iteratively learn from data, machine learning allows computers to find hidden insights without being explicitly programmed where to look.” (Rajesh Dey, www.quora.com)

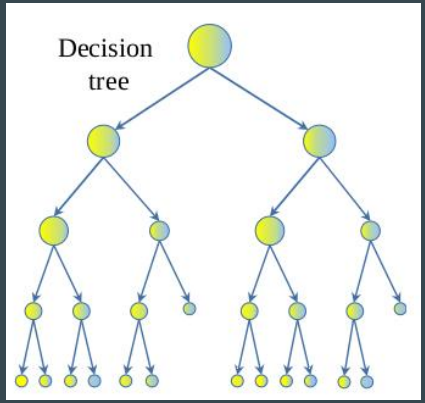
“Machine learning algorithms are an evolution over normal algorithms. They make your programs ‘smarter’, by allowing them to automatically learn from the data you provide.” (Pararth Shah, www.quora.com).

Some Approaches

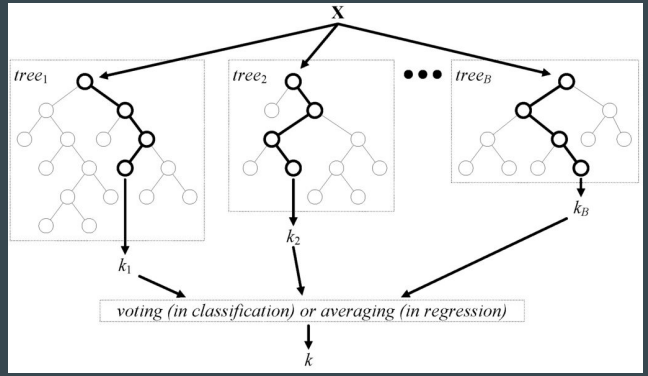
- K-nearest neighbors
- Decision Tree
- Random Forest
- Neural Networks



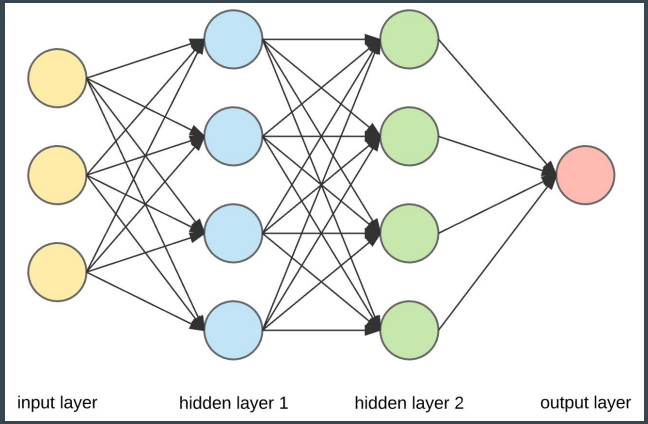
http://www.coxdocs.org



Ignatov, D., & Ignatov, A. (2017) *IEEE*



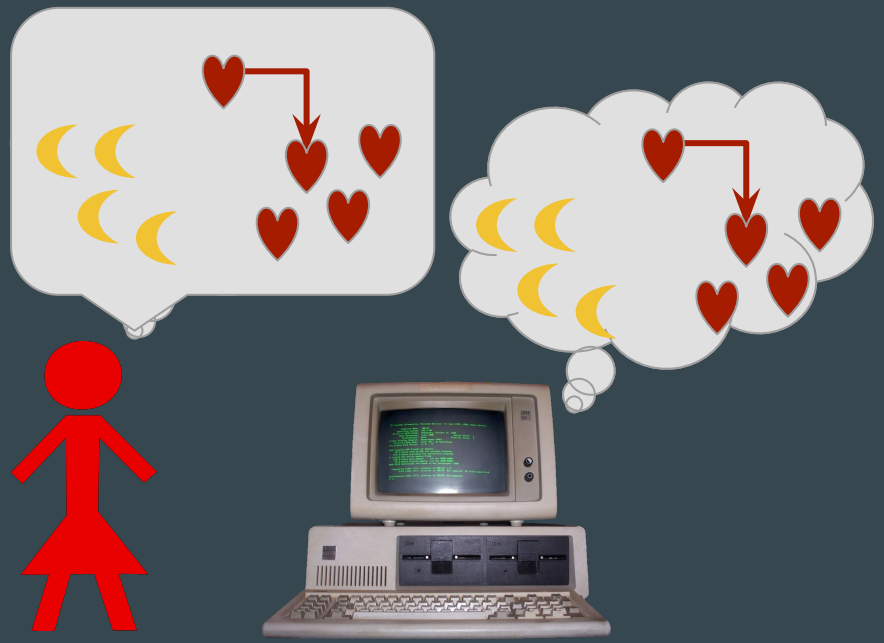
Verikas, A., et al. (2016) *Sensors*



https://towardsdatascience.com

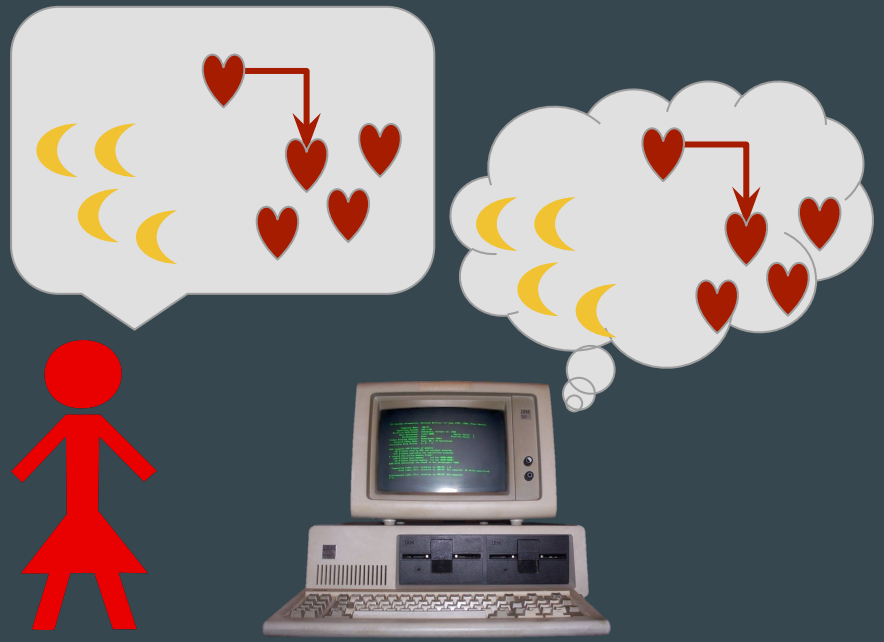
Two Phases

Phase I: Training



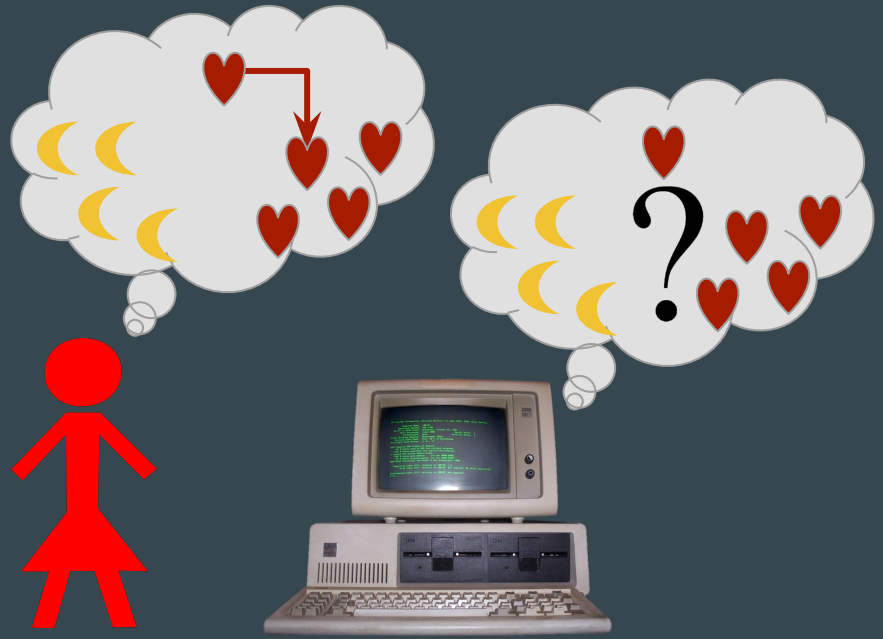
Two Phases

Phase I: Training



Tell the computer

Phase II: Testing



Don’t tell the computer

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]

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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

Published: March 30, 2016 • https://doi.org/10.1371/journal.pone.0151090

SCIENTIFIC REPORTS

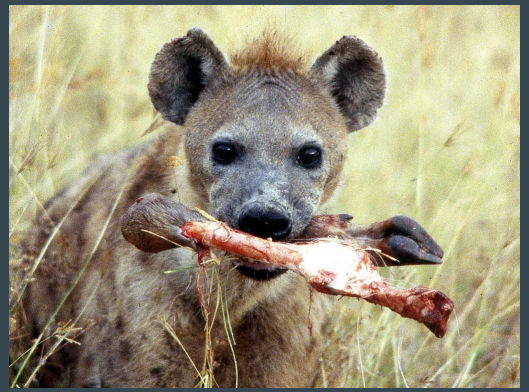
OPEN

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

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

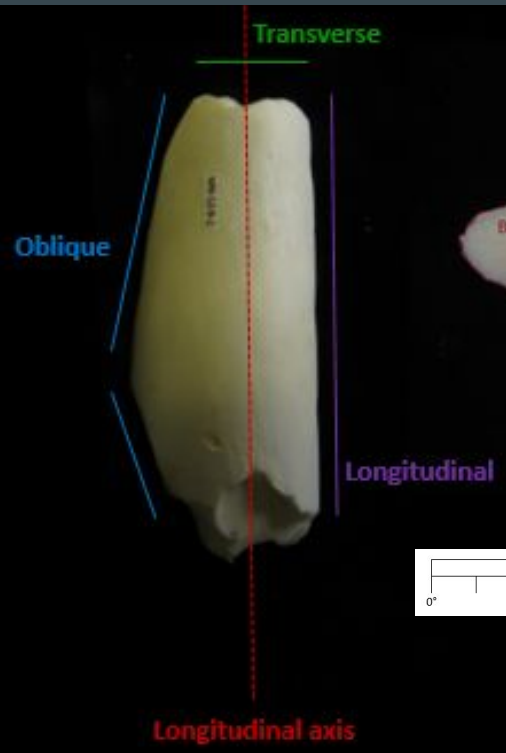
Received: 20 November 2017
Accepted: 19 March 2018

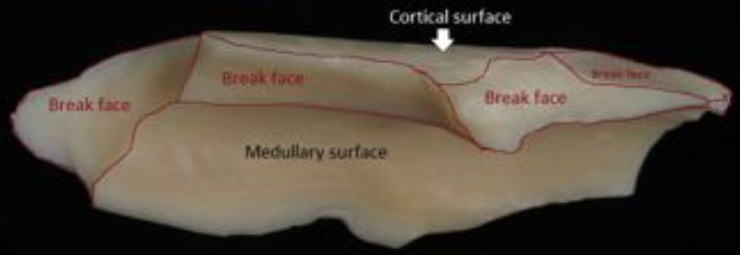
- Social structures
- Food sharing
- Home bases/central places
- Carcass transport
- Localized activity areas
- Scavenging vs. hunting
- Cooperative behavior
- Butchering behavior

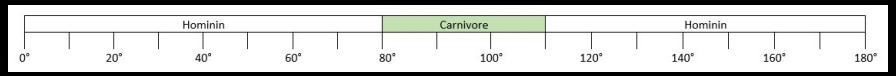


OR
?

Fracture Angles







Alcantara-García et al. (2006).

Fracture Angles

- Not fully tested
  - Limited experimental studies
  - Different taxa tested in each
    - Different results related to taxon and element
    - No independent testing of the same taxon

TRABAJOS DE PREHISTORIA
63, N° 1, Enero-Junio 2006, pp. 37-45. ISSN 0082-5638

DETERMINACIÓN DE PROCESOS DE FRACTURA SOBRE HUESOS FRESCOS: UN SISTEMA DE ANÁLISIS DE LOS ÁNGULOS DE LOS PLANOS DE FRACTURACIÓN COMO DISCRIMINADOR DE AGENTES BIÓTICOS

DETERMINATION OF THE FRACTURE PROCESSES OF FRESH BONE: AN ANALYTICAL SYSTEM OF THE ANGLES OF FRACTURE PLANES AS AN INDICATOR OF BIOTIC AGENTS

VIRGINIA ALC¡NTARA GARCÔA, REBECA BARBA EGIDO, JOS… MARÔA BARRAL DEL PINO, ANA BEL…N CRESPO RUIZ, ARCO IRIS EIRIZ VIDAL, ¡LVARO FALQUINA APARICIO, SILVIA HERRERO CALLEJA, ANA IBARRA JIM…NEZ, MARTA MEGÔAS GONZ¡LEZ, MAITE P…REZ GIL, VICTORIA P…REZ TELLO, JORGE ROLLAND CALVÒ, JOS… YRAVEDRA S¡INZ DE LOS TERREROS, AIXA VIDAL Y MANUEL DOMÔNGUEZ-RODRIGO (*)

archaeometry

Archaeometry 53, 5 (2011) 996–1011 doi: 10.1111/j.1475-4754.2010.00576.x

TESTING ANALOGICAL TAPHONOMIC SIGNATURES IN BONE BREAKING: A COMPARISON BETWEEN HAMMERSTONE-BROKEN EQUID AND BOVID BONES*

S. DE JUANA and M. DOMÍNGUEZ-RODRIGO†

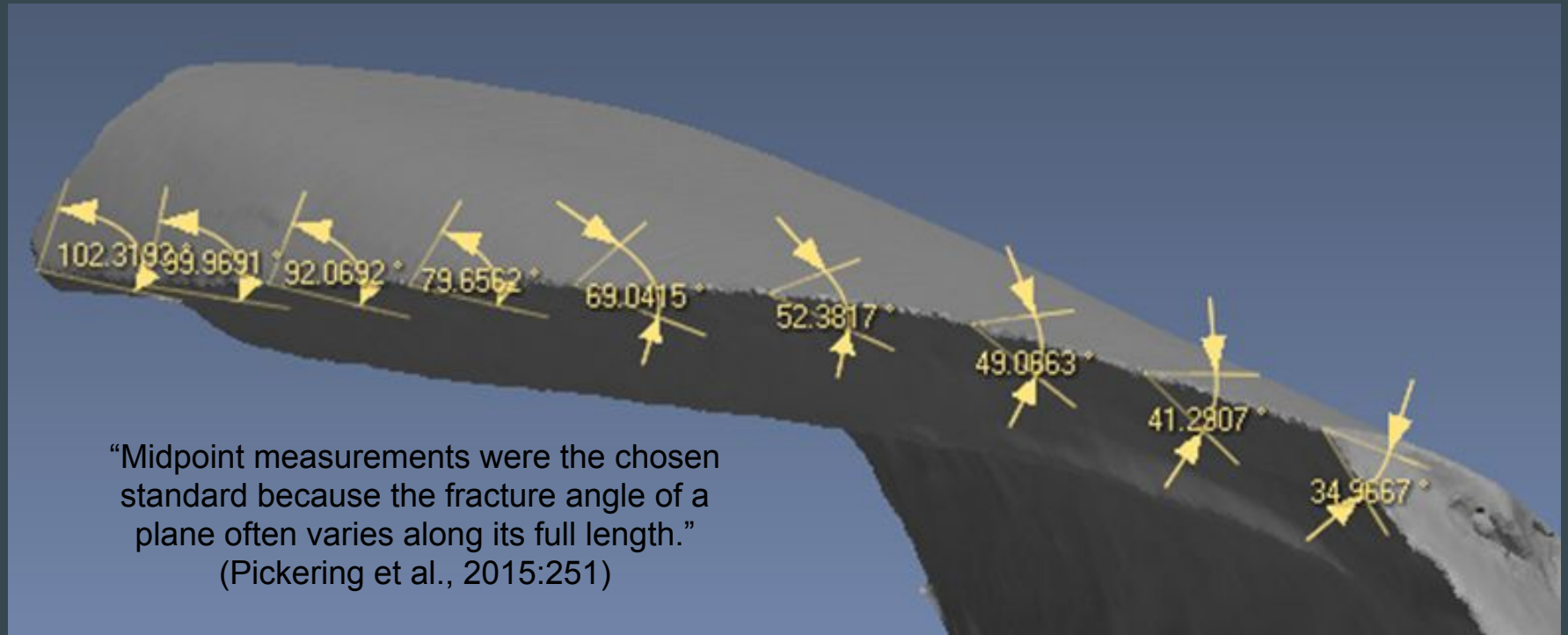
archaeometry

Archaeometry ••, •• (2017) ••–•• doi: 10.1111/arcm.12285

NEW ANALYTICAL METHODS FOR COMPARING BONE FRACTURE ANGLES: A CONTROLLED STUDY OF HAMMERSTONE AND HYENA (*Crocuta crocuta*) LONG BONE BREAKAGE*

R. COIL,[1,2]† M. TAPPEN [2] and K. YEZZI-WOODLEY[2]

Fracture Angles: Methods

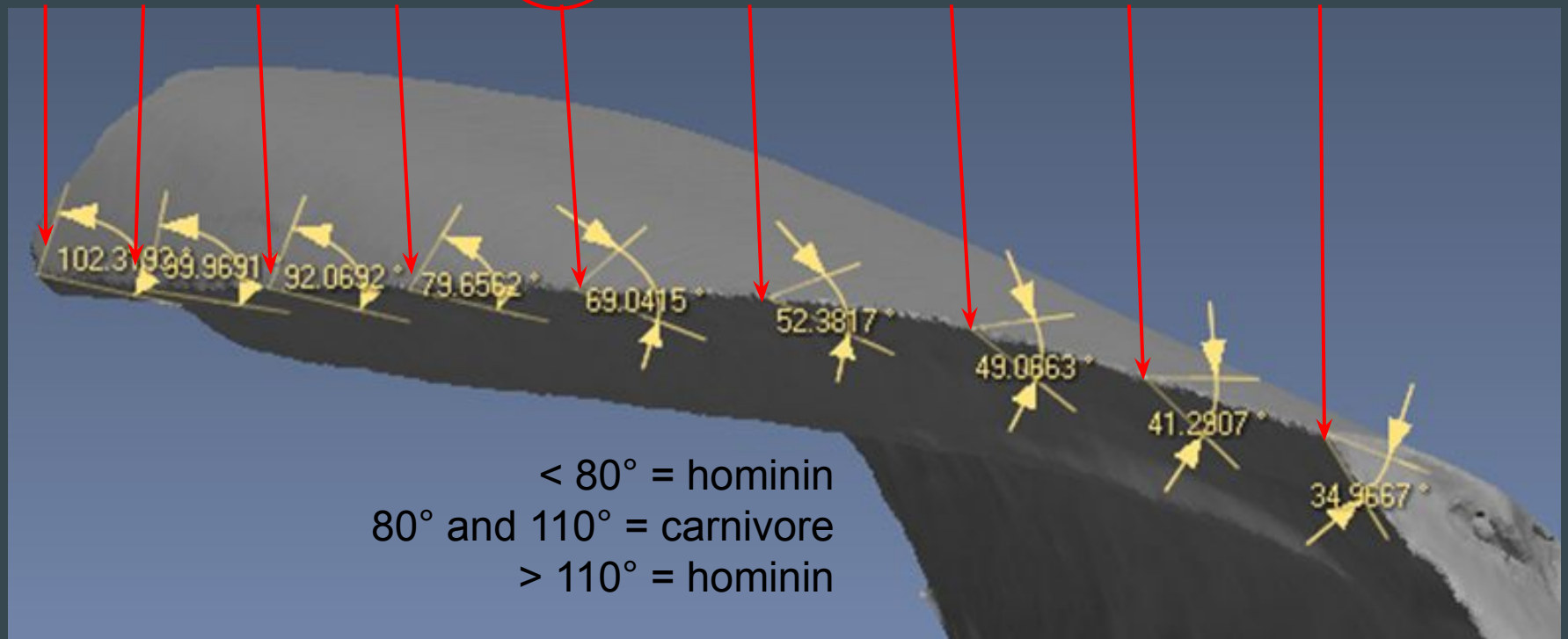


"Midpoint measurements were the chosen standard because the fracture angle of a plane often varies along its full length."
(Pickering et al., 2015:251)

Carnivore Created Fragment

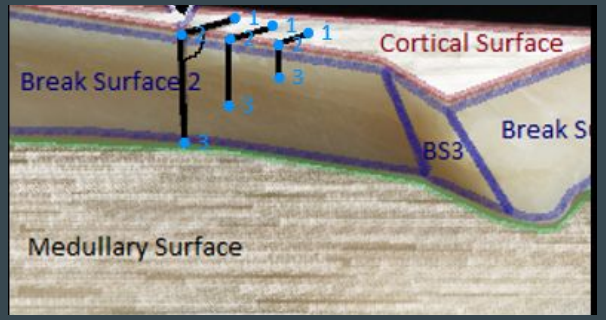
Average = 66°

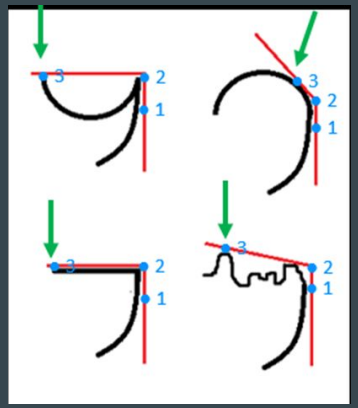
C C C C H H H H H

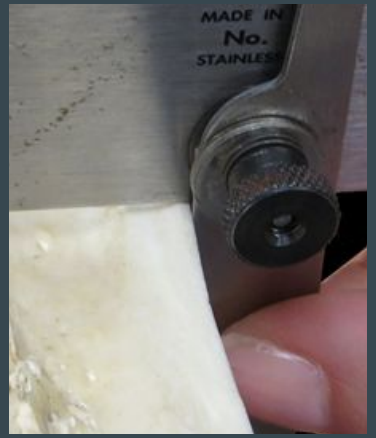


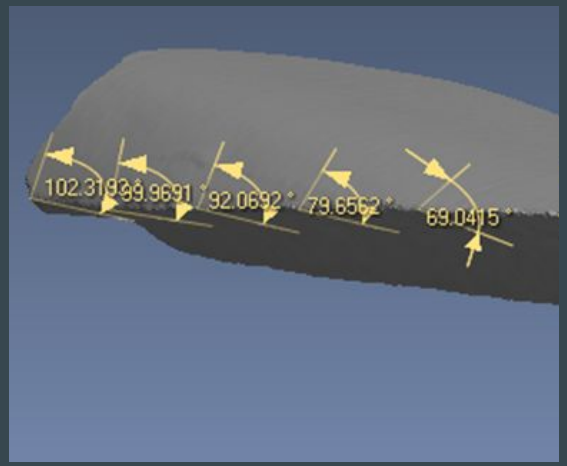
< 80° = hominin
80° and 110° = carnivore
> 110° = hominin

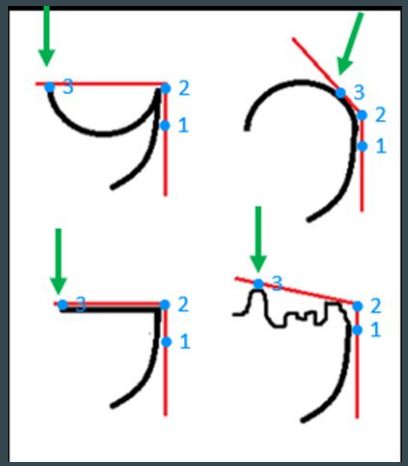
Fracture Angles: Methods








102.3193°
93.9691°
92.0692°
79.6562°
69.0415°


3
2
1
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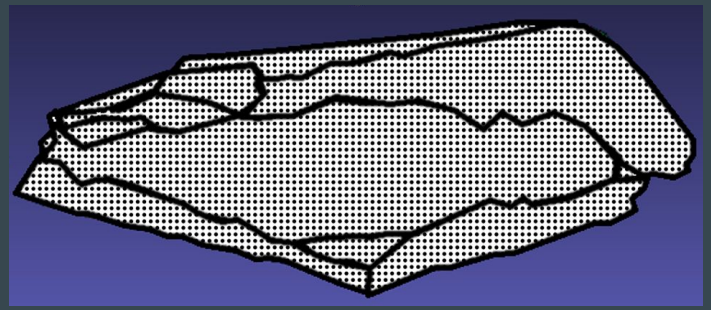
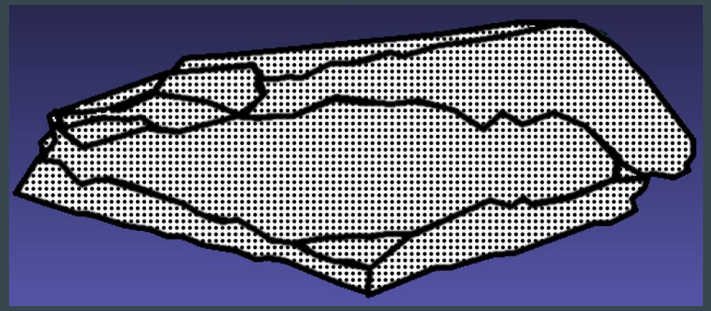
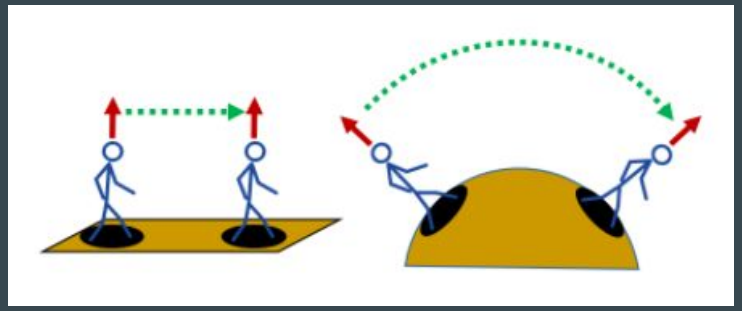
1
3
2
1

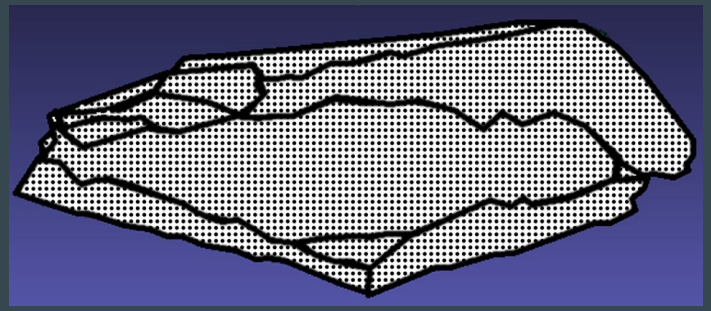
GENERAL TOOLS

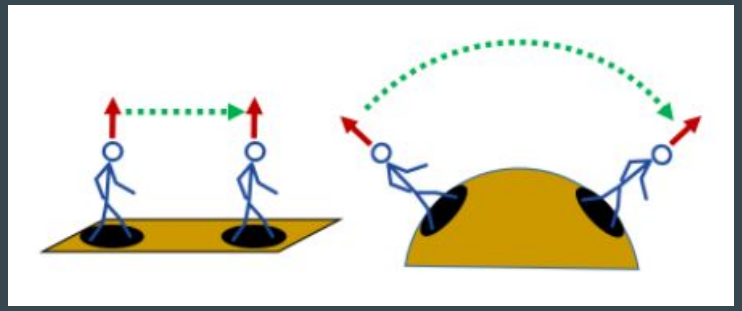
Surface Curvature

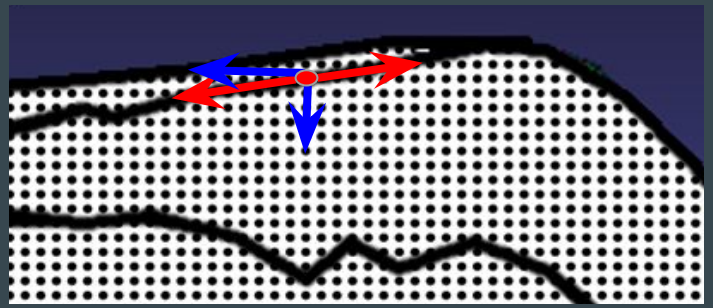


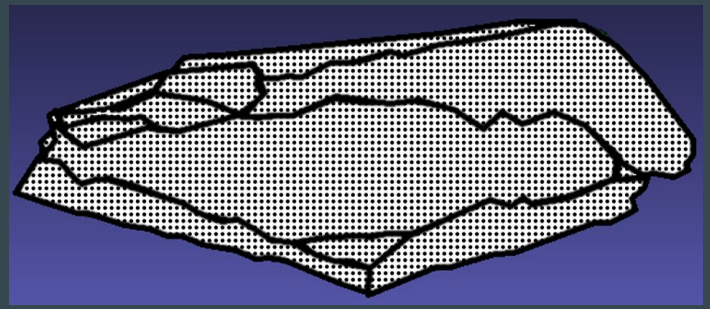


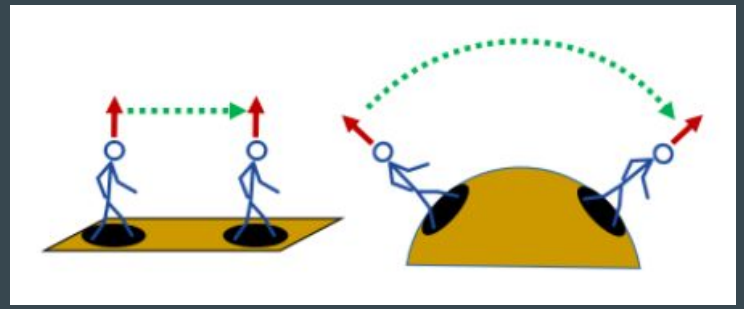


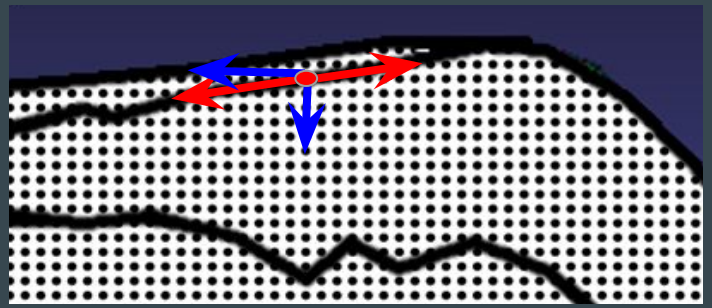


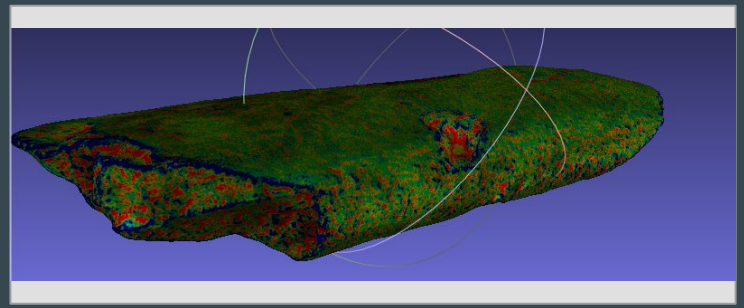




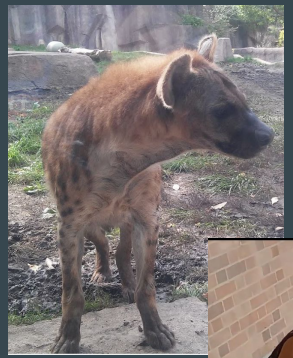








Actor



Taxon

Element

Sample

Carnivore

Crocuta crocuta

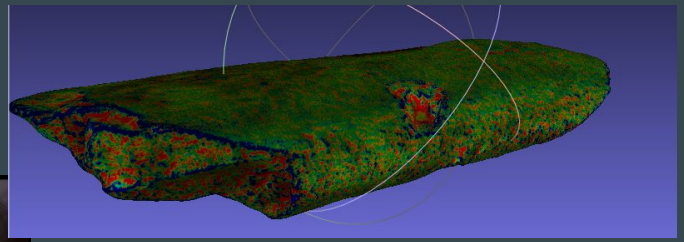
Hominin

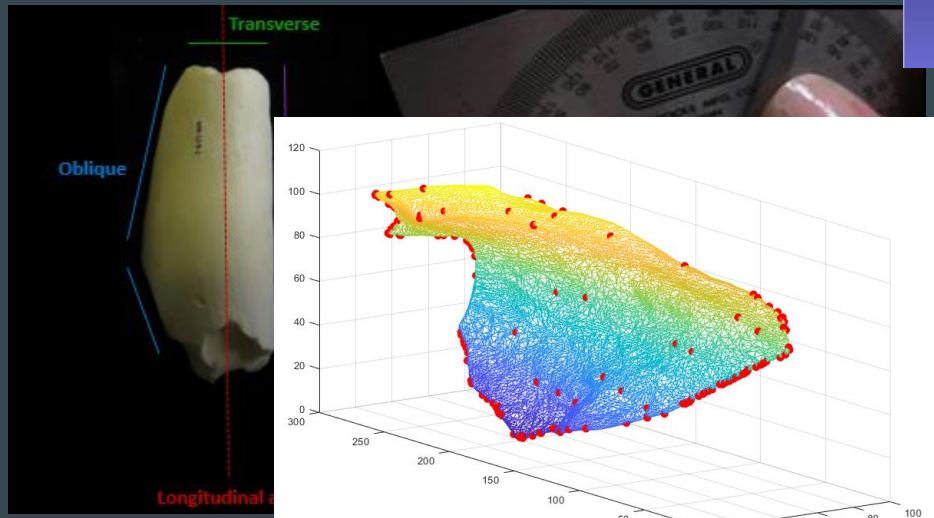
Hammerstone and anvil

Hammerstone only

Geological

Type of data collected





Sample Size (Manual Data)

Number of breaks per element and actor of breakage

	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

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

	Femur	Humerus	Radius-Ulna	Tibia	Total
Crocuta	234 (57%)	32 (27%)	-	13 (20%)	279 (47%)
Hominin	102 (28%)	51 (18%)	64 (22%)	153 (46%)	370 (29%)
Rockfall	-	21 (25%)	31 (30%)	-	52 (27%)
Total	336 (43%)	104 (21%)	95 (24%)	166 (42%)	701 (34%)

Number of breaks per element and method of breakage

	Femur	Humerus	Radius-Ulna	Tibia	Total
Batting	159	144	130	186	619
Crocuta	411	120	-	64	595
Rockfall	-	85	105	-	190
Hammerstone & Anvil	175	137	122	147	581
Hammerstone only	-	10	-	-	10
Hominin mixed method	29	-	35	-	64
Total	774	496	392	397	2059

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

	Femur	Humerus	Radius-Ulna	Tibia	Total
Batting	41 (26%)	29 (20%)	22 (17%)	95 (51%)	187 (30%)
Crocuta	234 (57%)	32 (27%)	-	13 (20%)	279 (47%)
Rockfall	-	21 (25%)	31 (30%)	-	52 (27%)
Hammerstone & Anvil	57 (33%)	19 (14%)	35 (29%)	58 (39%)	169 (29%)
Hammerstone only	-	3 (30%)	-	-	3 (30%)
Hominin mixed method	4 (14%)	-	7 (20%)	-	11 (17%)
Total	336 (43%)	104 (21%)	95 (24%)	166 (42%)	701 (34%)

Sample Size (Digital Data)

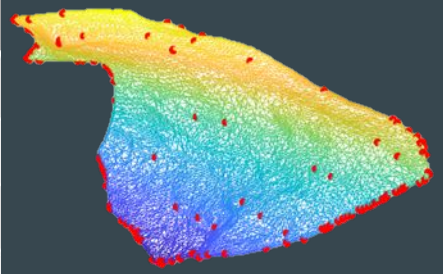
Manual Data

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

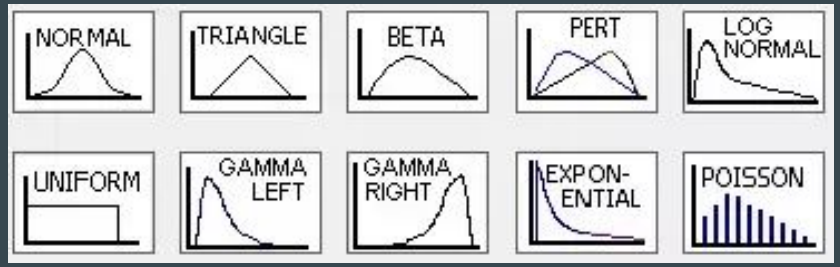
Digital Data

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

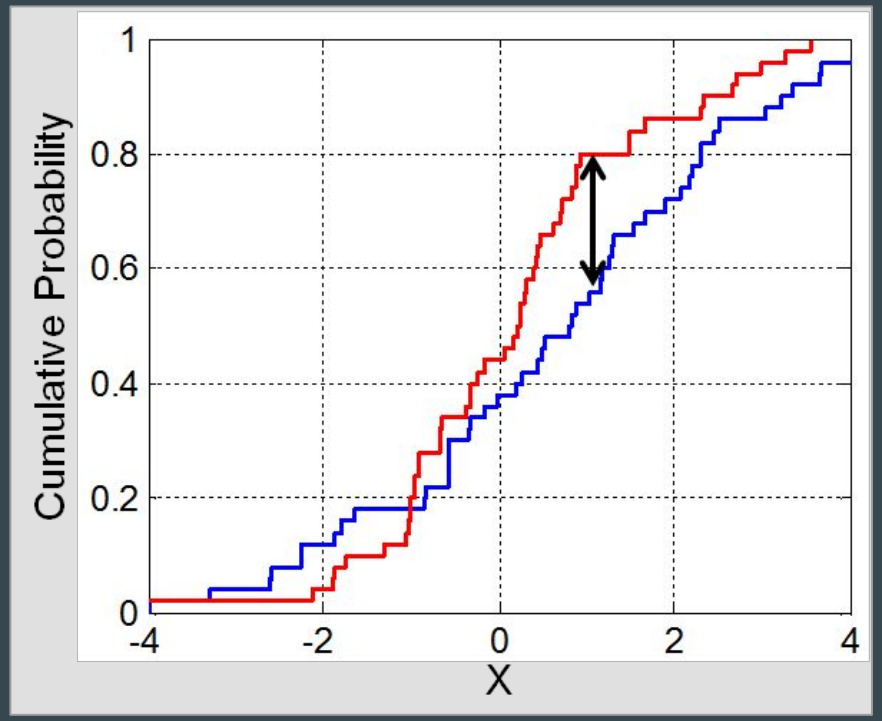
	Femur	Humerus	Tibia	Radius-Ulna	Total
Batting	1,758	606	1,878	1,531	5,773
Crocuta	1,824	780	-	-	2,604
Hammerstone & Anvil	1,485	1,003	1,291	1,613	5,392
Total	5,067	2,389	3,169	3,144	13,769



First Stages



www.quora.com



Hominins vs. hyena (femur) – surface curvature

Yes category	yes Size	No category	no Size	Training percentage	Training Size	Sensitivity	Specificity	Precision	Negative Predictive Rate	Miss Rate	Fall out
hominin (femur)	3243	hyena (femur)	1824	75	811	0.942	1	1	0.94518	0.058	0
hyena (femur)	1824	hominin (femur)	3243	75	456	0.95	1	1	0.95238	0.05	0
hominin (femur)	3243	hyena (femur)	1824	65	1136	0.947	1	1	0.94967	0.053	0
hyena (femur)	1824	hominin (femur)	3243	65	639	0.939	1	1	0.94251	0.061	0
hominin (femur)	3243	hyena (femur)	1824	50	1622	0.949	1	1	0.95147	0.051	0
hyena (femur)	1824	hominin (femur)	3243	50	912	0.946	1	1	0.94877	0.054	0
hominin (femur)	3243	hyena (femur)	1824	40	1824	0.946	1	1	0.94877	0.054	0
hyena (femur)	1824	hominin (femur)	3243	40	1095	0.938	1	1	0.94162	0.062	0

Hominins vs. hyena (humerus) – surface curvature

Yes category	yes Size	No category	no Size	Training percentage	Training Size	Sensitivity	Specificity	Precision	Negative Predictive Rate	Miss Rate	Fall out
hominin (humerus)	1609	hyena (humerus)	780	75	403	0.954	1	1	0.95602	0.046	0
hyena (humerus)	780	hominin (humerus)	1609	75	195	0.941	1	1	0.94429	0.059	0
hominin (humerus)	1609	hyena (humerus)	780	65	564	0.947	1	1	0.94967	0.053	0
hyena (humerus)	780	hominin (humerus)	1609	65	273	0.933	1	1	0.93721	0.067	0
hominin (humerus)	1609	hyena (humerus)	780	50	780	0.96	1	1	0.96154	0.04	0
hyena (humerus)	780	hominin (humerus)	1609	50	390	0.95	1	1	0.95238	0.05	0
hominin (humerus)	1609	hyena (humerus)	780	40	780	0.95	1	1	0.95238	0.05	0
hyena (humerus)	780	hominin (humerus)	1609	40	468	0.949	1	1	0.95147	0.051	0

HS & Anv vs. batting (femur) – surface curvature

Yes category	yes Size	No category	no Size	Training percentage	Training Size	Sensitivity	Specificity	Precision	Negative Predictive Rate	Miss Rate	Fall out
Batting femur	1758	HS & Anv femur	1485	75	440	0.951	1	1	0.95329	0.049	0
HS & Anv femur	1485	Batting femur	1758	75	372	0.956	1	1	0.95785	0.044	0
Batting femur	1758	HS & Anv femur	1485	65	616	0.938	1	1	0.94162	0.062	0
HS & Anv femur	1485	Batting femur	1758	65	520	0.948	1	1	0.95057	0.052	0
Batting femur	1758	HS & Anv femur	1485	50	879	0.942	1	1	0.94518	0.058	0
HS & Anv femur	1485	Batting femur	1758	50	743	0.957	1	1	0.95877	0.043	0
Batting femur	1758	HS & Anv femur	1485	40	1055	0.954	1	1	0.95602	0.046	0
HS & Anv femur	1485	Batting femur	1758	40	891	0.951	1	1	0.95329	0.049	0

HS & Anv vs. batting (humerus) – surface curvature

Yes category	yes Size	No category	no Size	Training percentage	Training Size	Sensitivity	Specificity	Precision	Negative Predictive Rate	Miss Rate	Fall out
anv humerus	606	hsanv humerus	1003	75	152	0.947	1	1	0.94967	0.053	0
hsanv humerus	1003	anv humerus	606	75	251	0.952	1	1	0.9542	0.048	0
anv humerus	606	hsanv humerus	1003	65	213	0.948	1	1	0.95057	0.052	0
hsanv humerus	1003	anv humerus	606	65	352	0.951	1	1	0.95329	0.049	0
anv humerus	606	hsanv humerus	1003	50	303	0.965	1	1	0.96618	0.035	0
hsanv humerus	1003	anv humerus	606	50	502	0.961	1	1	0.96246	0.039	0
anv humerus	606	hsanv humerus	1003	40	364	0.941	1	1	0.94429	0.059	0
hsanv humerus	1003	anv humerus	606	40	602	0.946	1	1	0.94877	0.054	0

HS & Anv vs. batting (tibia) – surface curvature

Yes category	yes Size	No category	no Size	Training percentage	Training Size	Sensitivity	Specificity	Precision	Negative Predictive Rate	Miss Rate	Fall out
anv tibia	1878	hsanv tibia	1291	75	470	0.945	1	1	0.94787	0.055	0
hsanv tibia	1291	anv tibia	1878	75	323	0.943	1	1	0.94607	0.057	0
anv tibia	1878	hsanv tibia	1291	65	658	0.94	1	1	0.9434	0.06	0
hsanv tibia	1291	anv tibia	1878	65	452	0.954	1	1	0.95602	0.046	0
anv tibia	1878	hsanv tibia	1291	50	939	0.946	1	1	0.94877	0.054	0
hsanv tibia	1291	anv tibia	1878	50	646	0.947	1	1	0.94967	0.053	0
anv tibia	1878	hsanv tibia	1291	40	1127	0.941	1	1	0.94429	0.059	0
hsanv tibia	1291	anv tibia	1878	40	775	0.945	1	1	0.94787	0.055	0

HS & Anv vs. batting (rad-uln) – surface curvature

Yes category	yes Size	No category	no Size	Training percentage	Training Size	Sensitivity	Specificity	Precision	Negative Predictive Rate	Miss Rate	Fall out
Batting raduln	1878	HS & Anv raduln	1291	75	470	0.962	1	1	0.96339	0.038	0
HS & Anv raduln	1291	Batting raduln	1878	75	323	0.957	1	1	0.95877	0.043	0
Batting raduln	1878	HS & Anv raduln	1291	65	658	0.948	1	1	0.95057	0.052	0
HS & Anv raduln	1291	Batting raduln	1878	65	452	0.95	1	1	0.95238	0.05	0
Batting raduln	1878	HS & Anv raduln	1291	50	939	0.954	1	1	0.95602	0.046	0
HS & Anv raduln	1291	Batting raduln	1878	50	646	0.953	1	1	0.95511	0.047	0
Batting raduln	1878	HS & Anv raduln	1291	40	1127	0.946	1	1	0.94877	0.054	0
HS & Anv raduln	1291	Batting raduln	1878	40	775	0.956	1	1	0.95785	0.044	0

Hominins vs. hyena (femur) – manual data

Yes category	yes Size	No category	no Size	Training percentage	Training Size	Sensitivity	Specificity	Precision	Negative Predictive Rate	Miss Rate	Fall out
hominin femur	261	hyena femur	177	75	66	0.956	0.368	0.60202	0.8932	0.044	0.632
hyena femur	177	hominin femur	261	75	45	0.957	0.222	0.55159	0.83774	0.043	0.778
hominin femur	261	hyena femur	177	65	92	0.959	0.502	0.6582	0.92449	0.041	0.498
hyena femur	177	hominin femur	261	65	62	0.966	0.294	0.57775	0.89634	0.034	0.706
hominin femur	261	hyena femur	177	50	131	0.963	0.561	0.68688	0.93813	0.037	0.439
hyena femur	177	hominin femur	261	50	89	0.966	0.299	0.57948	0.8979	0.034	0.701
hominin femur	261	hyena femur	177	40	157	0.949	0.494	0.65223	0.90642	0.051	0.506
hyena femur	177	hominin femur	261	40	107	0.956	0.327	0.58686	0.8814	0.044	0.673

Hominins vs. hyena (humerus) – manual data

Yes category	yes Size	No category	no Size	Training percentage	Training Size	Sensitivity	Specificity	Precision	Negative Predictive Rate	Miss Rate	Fall out
hominin humerus	240	hyena humerus	88	75	60	0.958	0.069	0.50715	0.62162	0.042	0.931
hyena humerus	88	hominin humerus	240	75	22	0.956	0.055	0.50289	0.55556	0.044	0.945
hominin humerus	240	hyena humerus	88	65	84	0.953	0.019	0.49276	0.28788	0.047	0.981
hyena humerus	88	hominin humerus	240	65	31	0.955	0.069	0.50636	0.60526	0.045	0.931
hominin humerus	240	hyena humerus	88	50	88	0.96	0.035	0.4987	0.46667	0.04	0.965
hyena humerus	88	hominin humerus	240	50	44	0.964	0.066	0.5079	0.64706	0.036	0.934
hominin humerus	240	hyena humerus	88	40	88	0.954	0.055	0.50237	0.54455	0.046	0.945
hyena humerus	88	hominin humerus	240	40	53	0.958	0.067	0.50661	0.61468	0.042	0.933

Moving forward

- More taxa
  - *Bos*
  - *Ovis/Capra*
  - *Equus*
- All appendicular long bones
- Archaeological collections
- Factor in rock fall
- More geometric methods
  - Volume, surface areas (total/faces)
  - Mean, variance, PCA
  - Higher moments
  - Digital measures of break angles at break curves using surface normals
  - Break curve geometric invariants: curvature, torsion, etc.
  - Surface curvatures (principal, Gauss, mean, total)

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