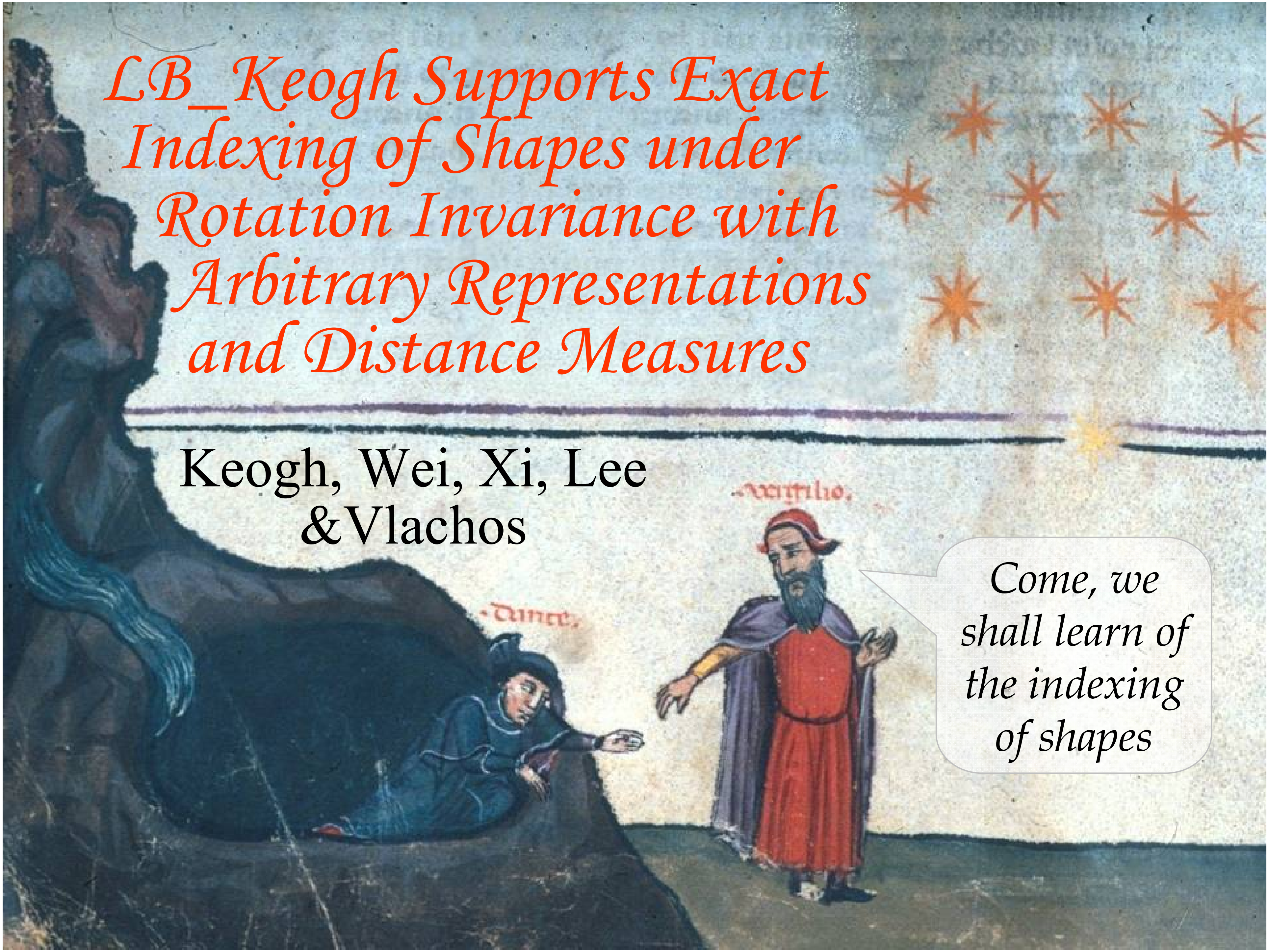
LB_Keogh Supports Exact Indexing of Shapes under Rotation Invariance with Arbitrary Representations and Distance Measures

Keogh, Wei, Xi, Lee &Vlachos



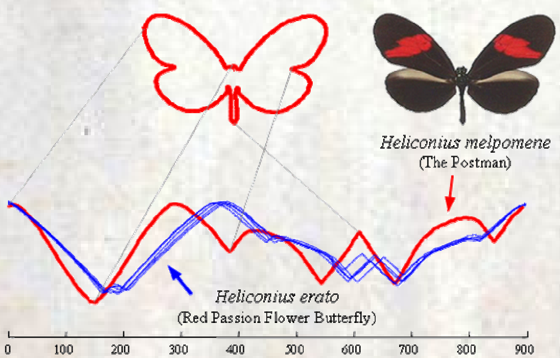
*Set forth these figures as I have conceived their shape…**

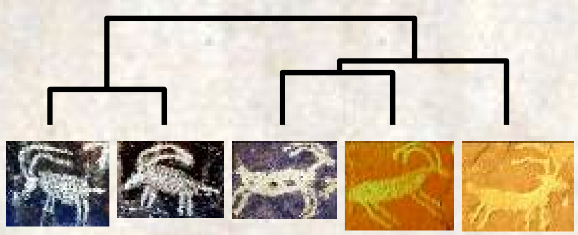
Outline of Talk

- The utility of shape matching
- Shape representations
- Shape distance measures
- Lower bounding rotation invariant measures with the LB_Keogh
- Accuracy experiments
- Efficiency experiments
- Conclusions

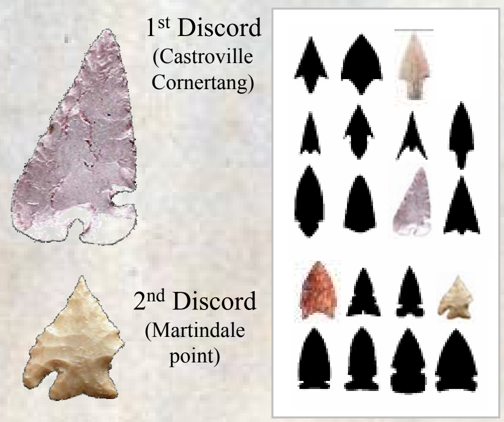
***Paradiso Canto XVIII 85**

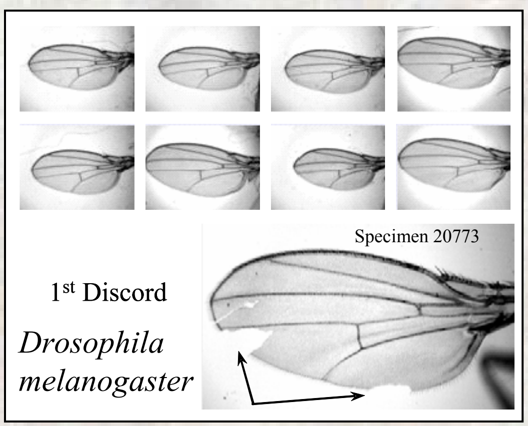
The Utility of Shape Matching I



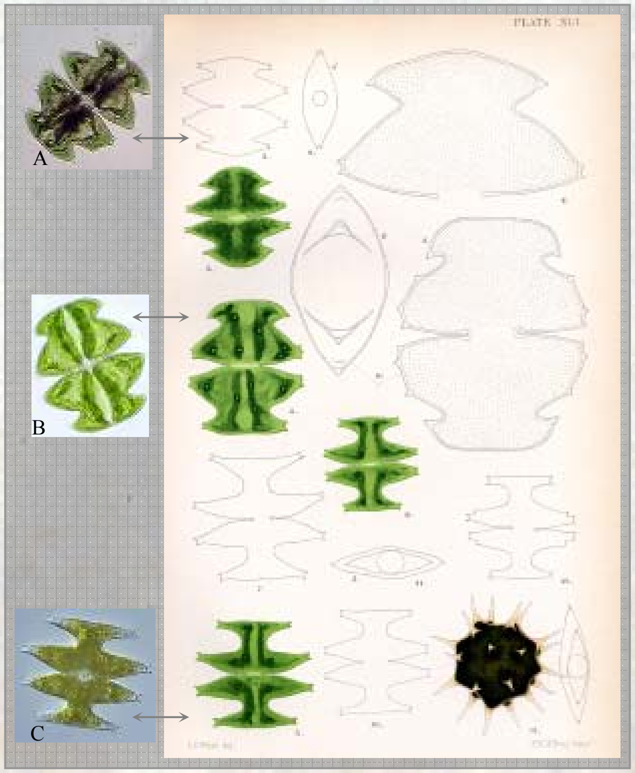


…discovering insect mimicry, clustering petroglyphs, finding unusual arrowheads, tracking fish migration, finding anomalous fruit fly wings…

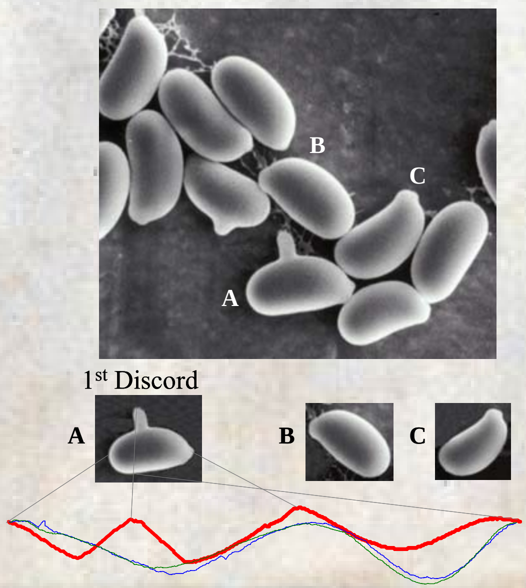


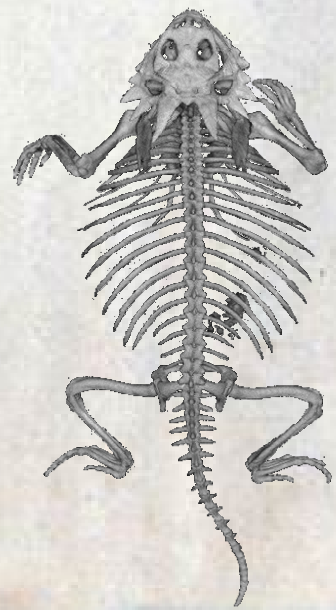


The Utility of Shape Matching II



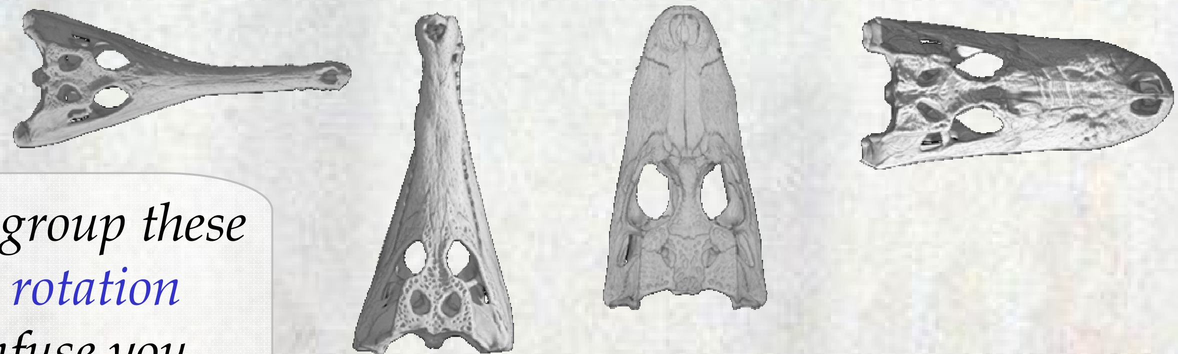
…automatically annotating old manuscripts, mining medical images, biometrics, spatial mining of horned lizards, indexing nematodes…



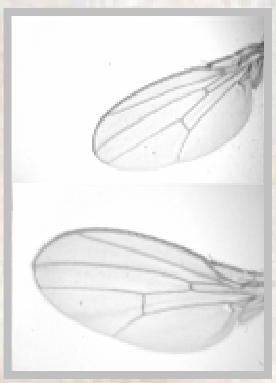


Shape Representations I

*For virtually all shape matching problems, rotation is **the** problem*



If I asked you to group these reptile skulls, rotation would not confuse you



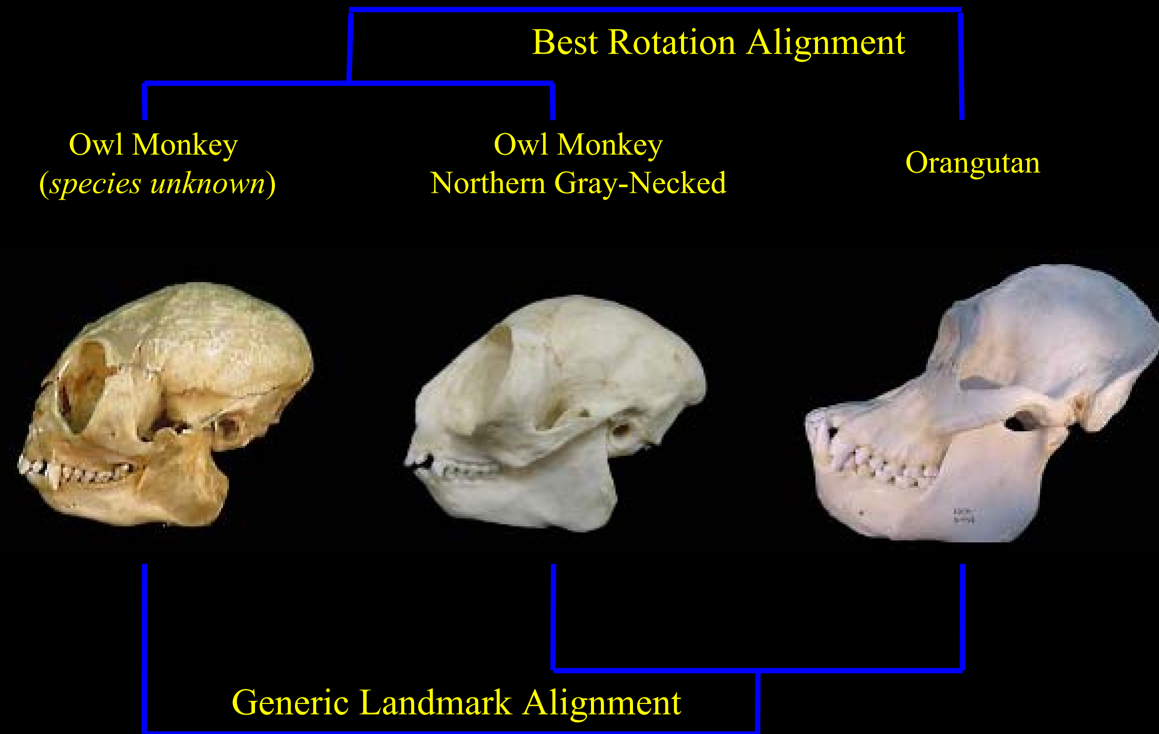
There are two ways to be rotation invariant

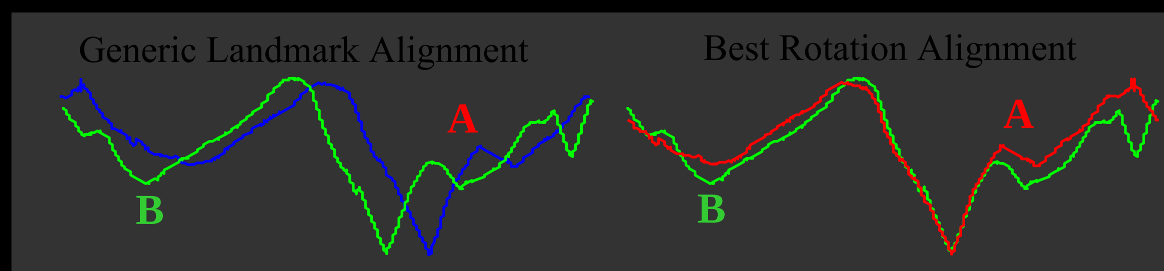
1) Landmarking: Find the one "true" rotation
2) Rotation invariant features

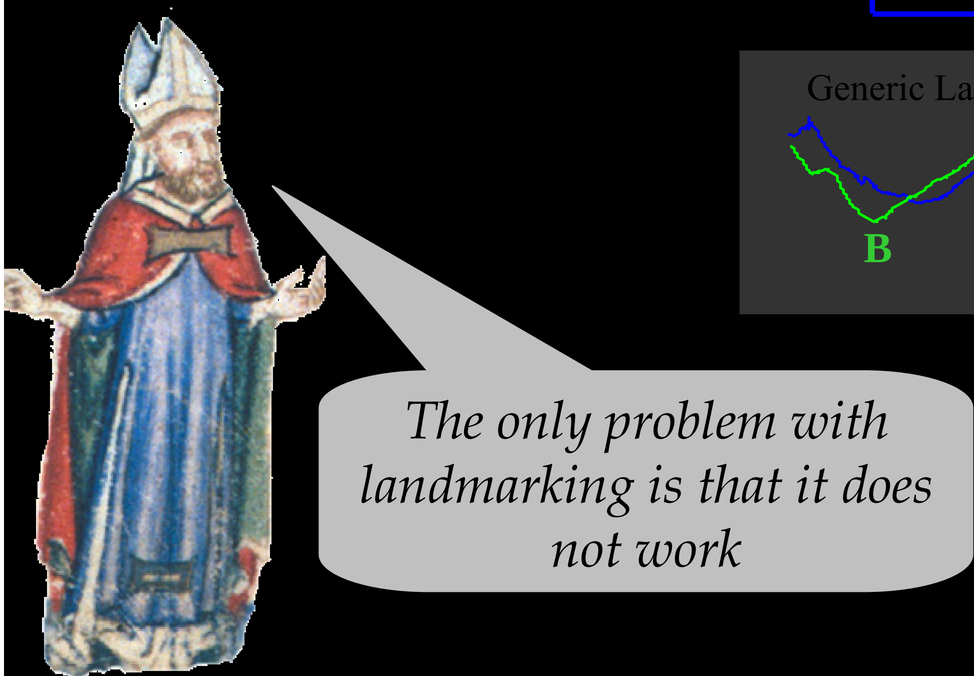
Landmarking

- **Domain Specific Landmarking**
Find some fixed point in your domain, eg. the nose on a face, the stem of leaf, the tail of a fish …

- **Generic Landmarking**
Find the major axis of the shape and use that as the canonical alignment

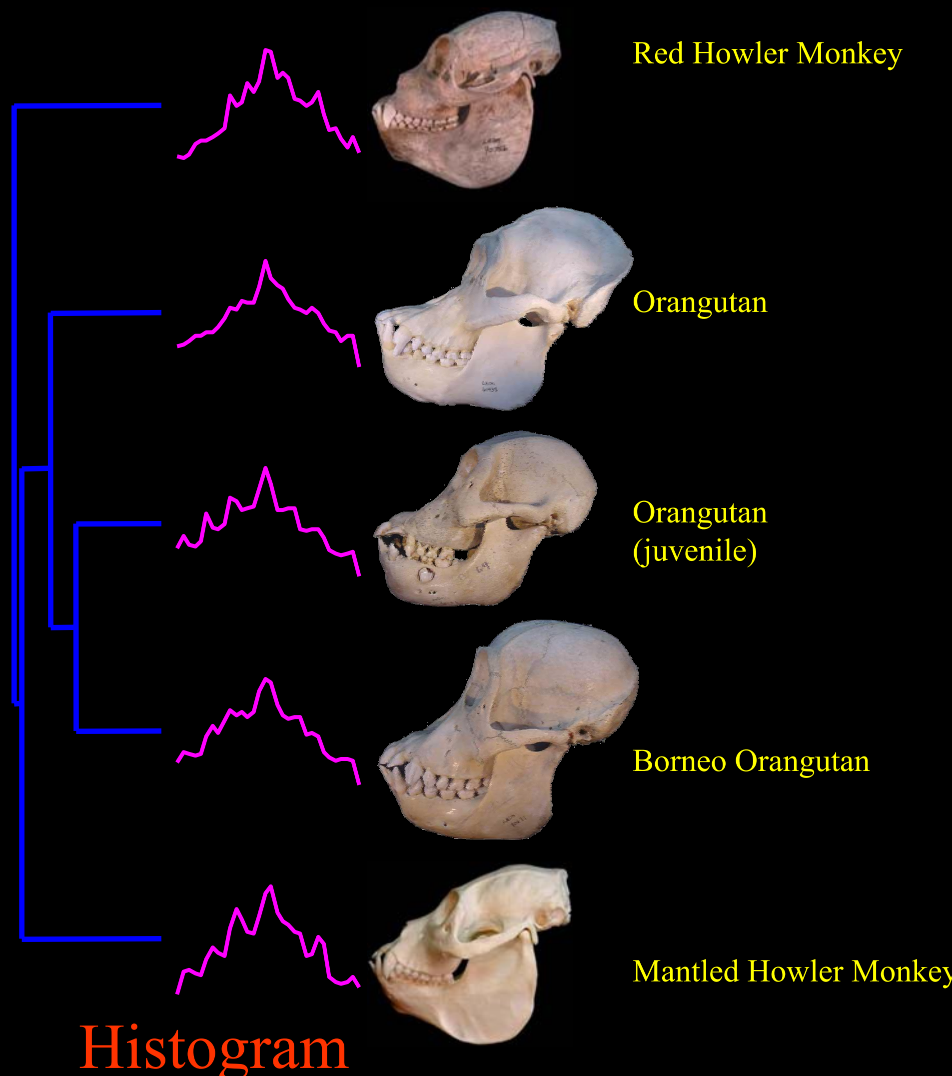






Rotation invariant features

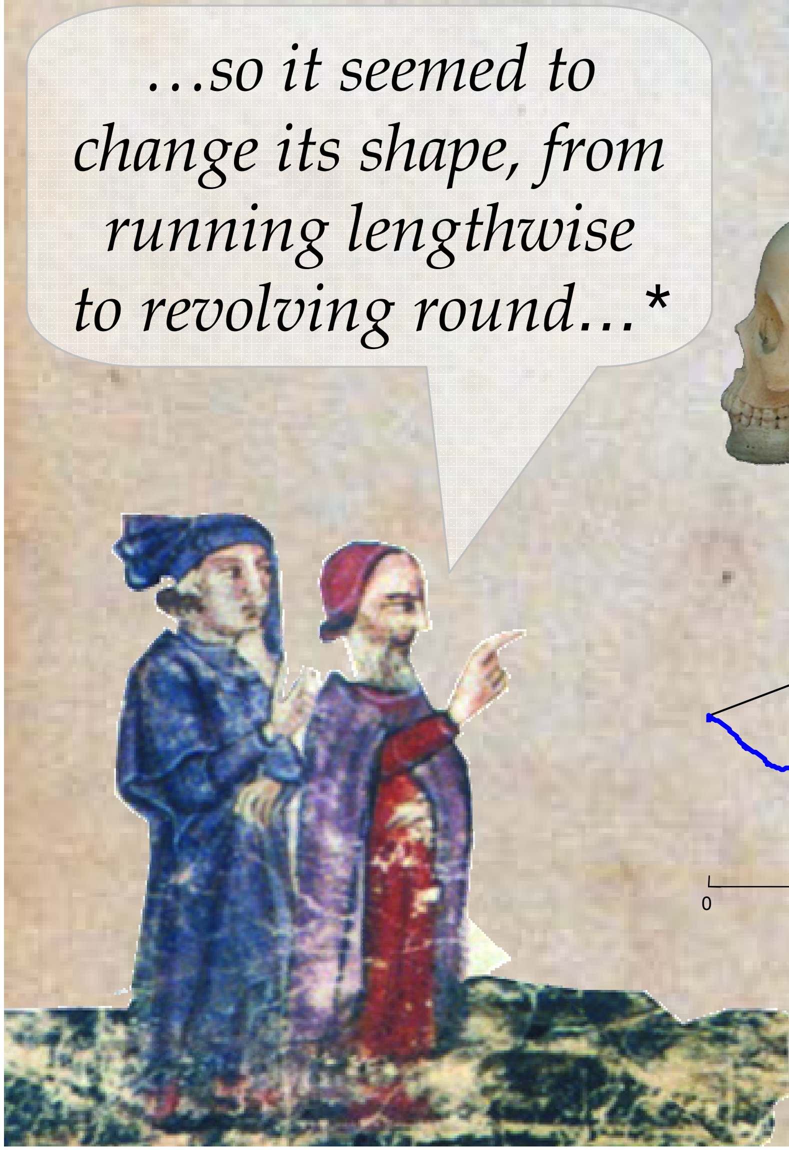
Possibilities include:
Ratio of perimeter to area, fractal measures, elongatedness, circularity, min/max/mean curvature, entropy, perimeter of convex hull and histograms

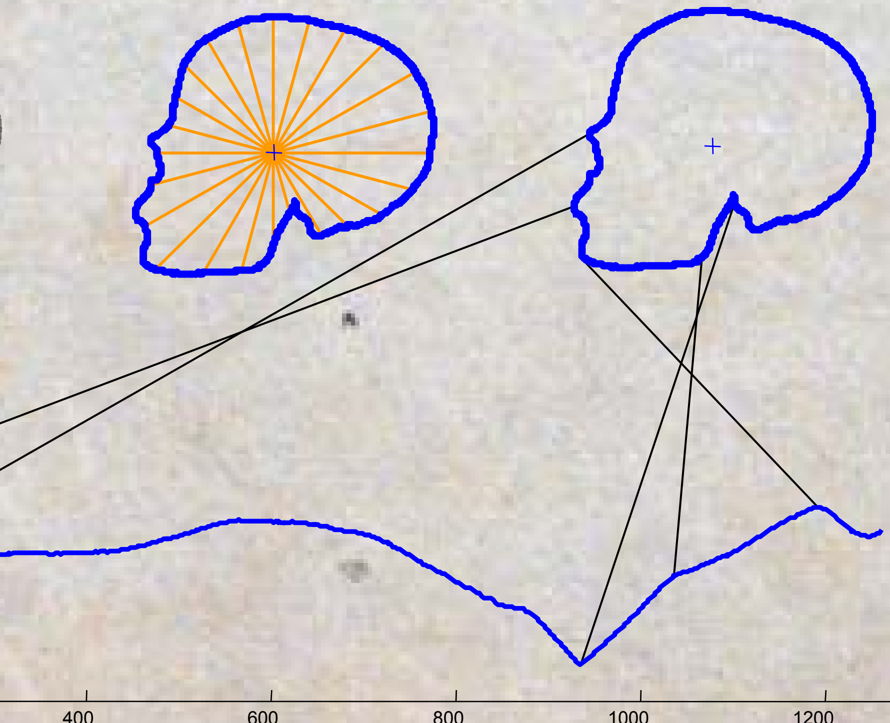


The only problem with rotation invariant features is that in throwing away rotation information, you must invariably throw away useful information

We can convert shapes into a 1D signal. Thus can we remove information about *scale* and *offset*.

Rotation we must deal with in our algorithms…

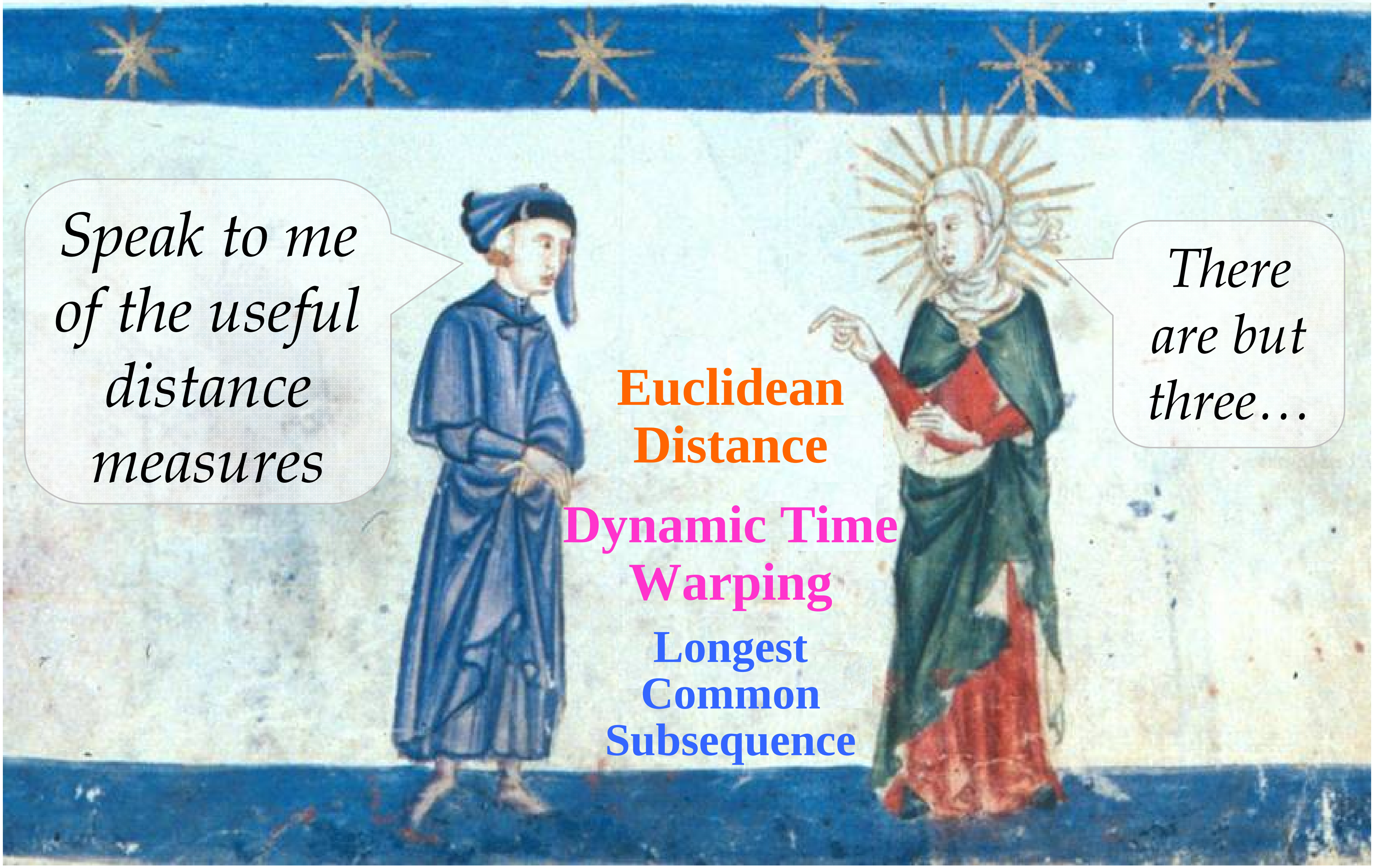


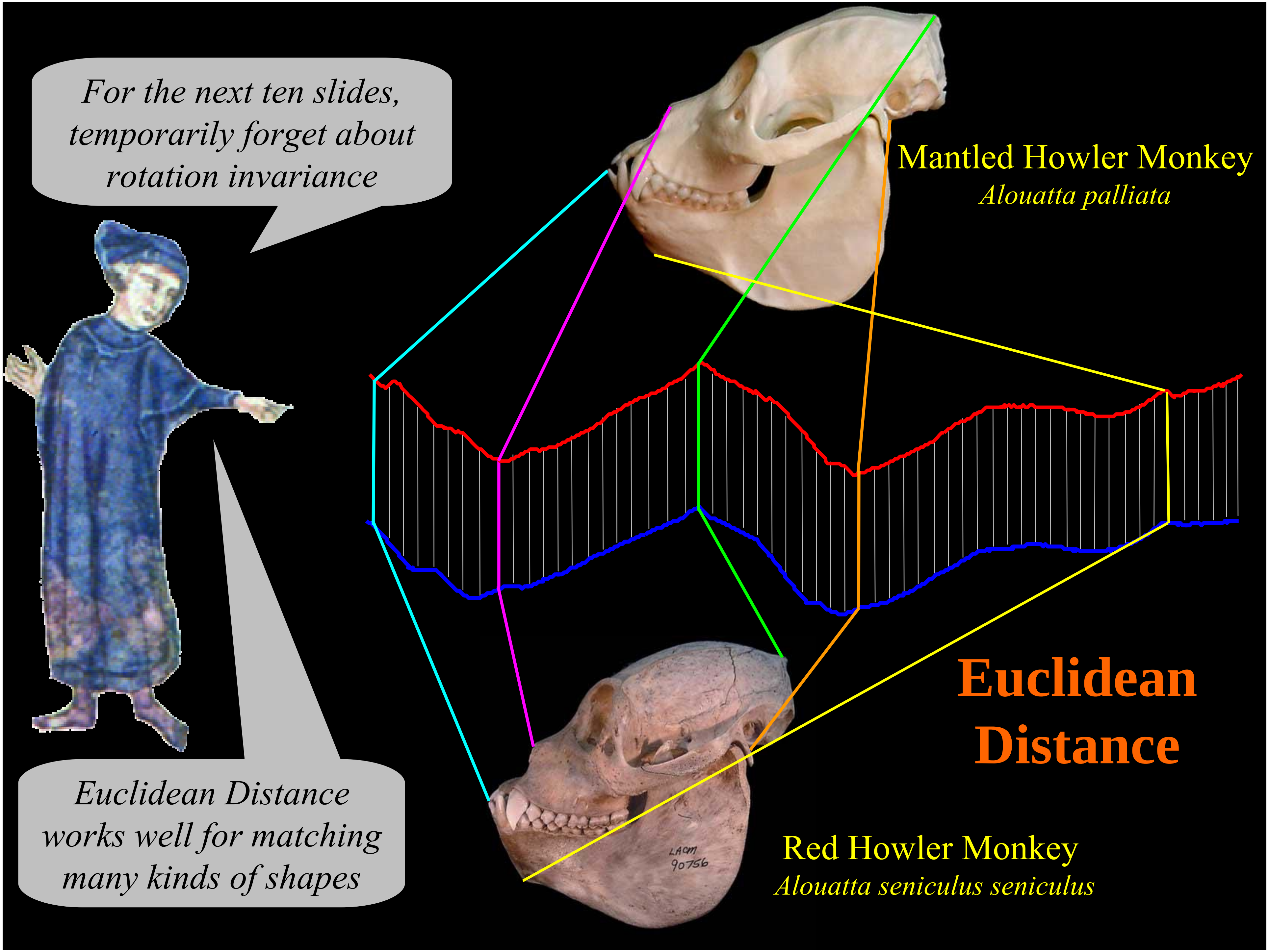


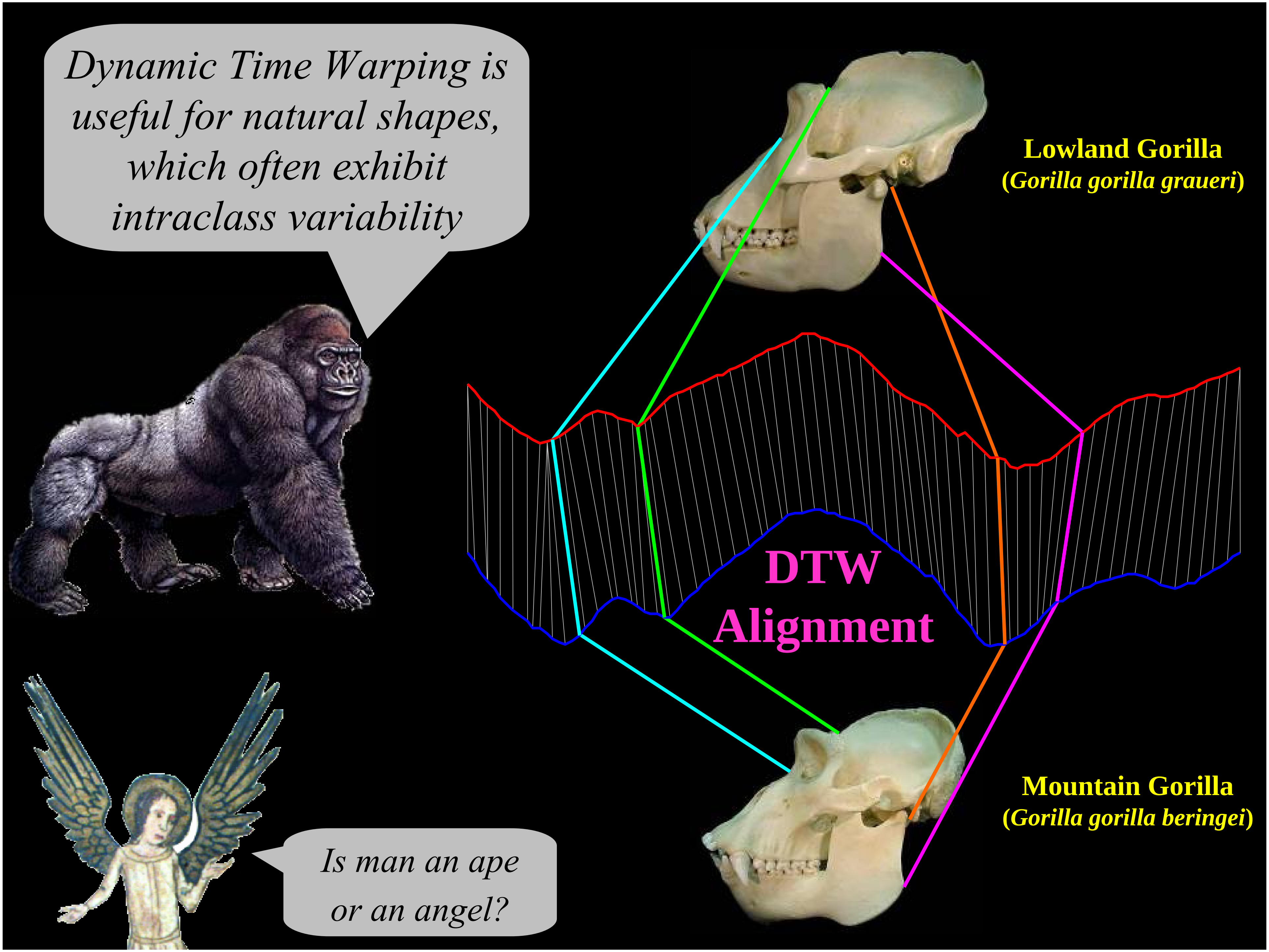
There are many other 1D representations of shape, and our algorithm can work with *any* of them

*Dante Alighieri.The Divine Comedy Paradiso -- Canto XXX, 90.

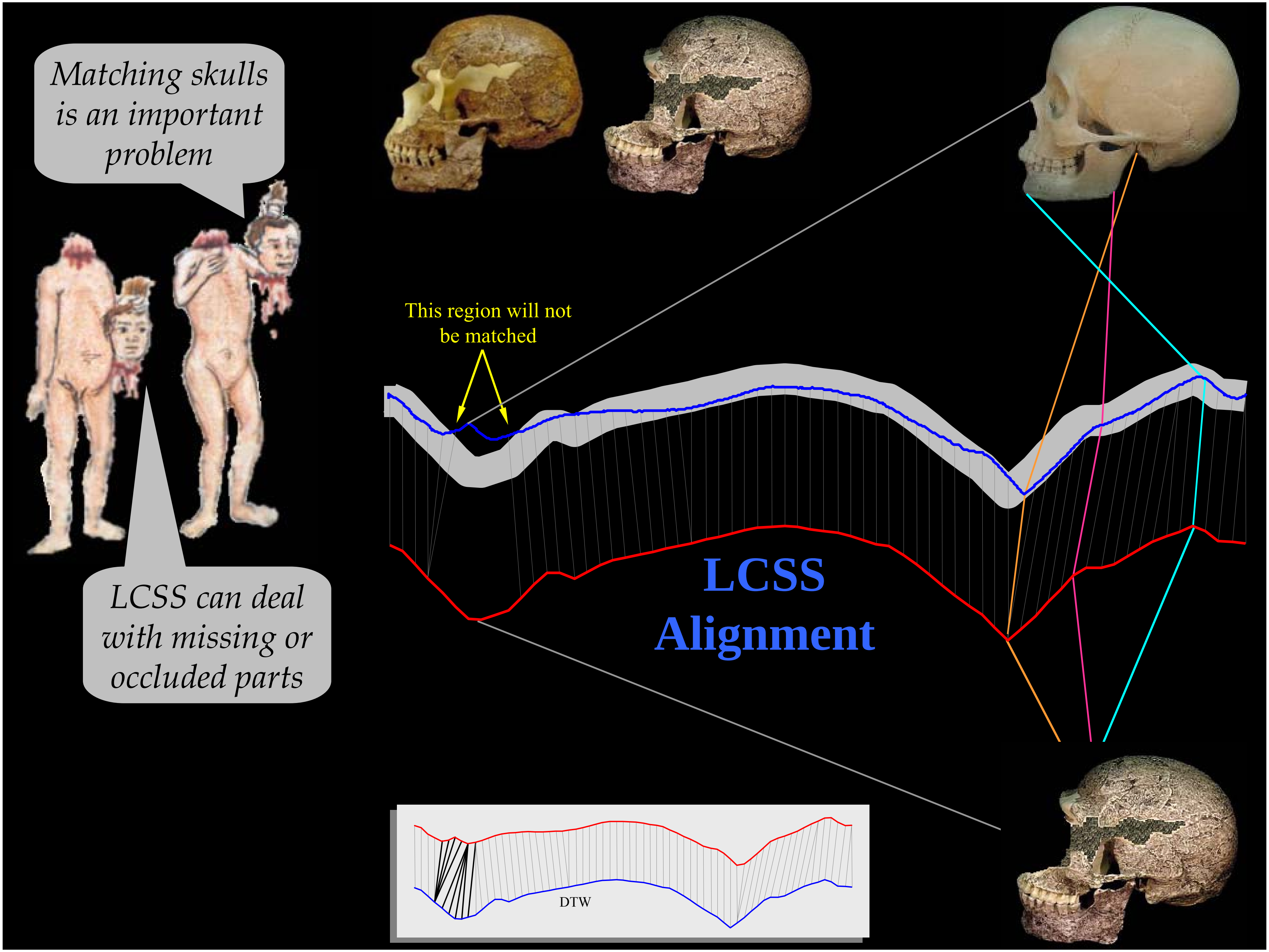
Shape Distance Measures



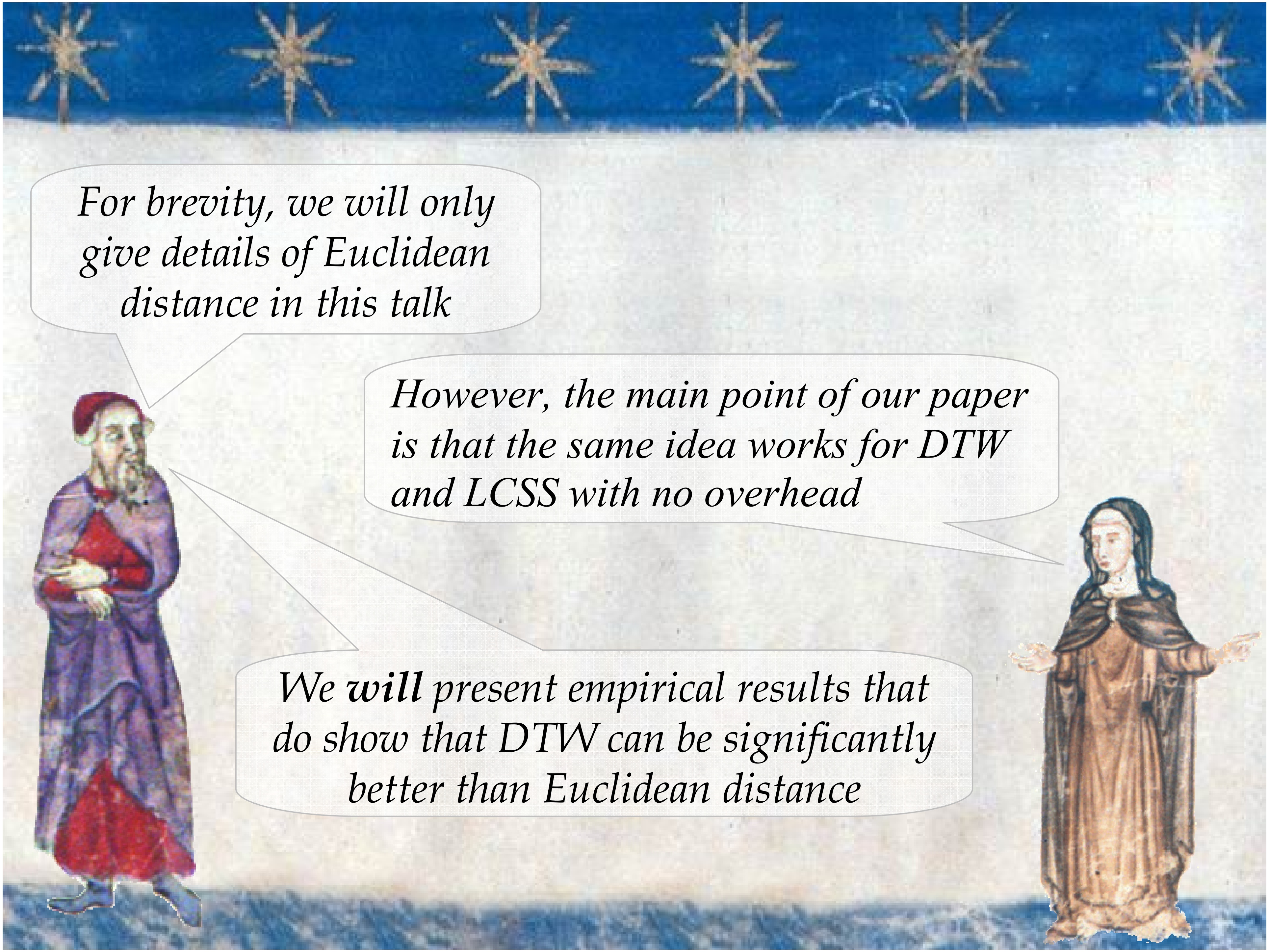

For the next ten slides, temporarily forget about rotation invariance
Mantled Howler Monkey
Alouatta palliata
Euclidean Distance
Euclidean Distance works well for matching many kinds of shapes
LACM
90756
Red Howler Monkey
Alouatta seniculus seniculus



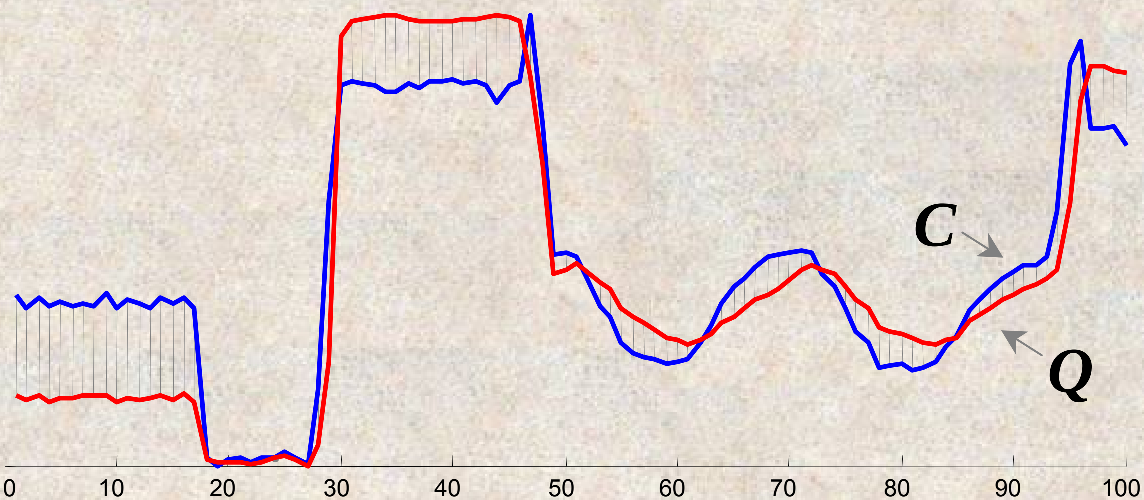
Dynamic Time Warping is useful for natural shapes, which often exhibit intraclass variability
Lowland Gorilla
(Gorilla gorilla graueri)
DTW Alignment
Mountain Gorilla
(Gorilla gorilla beringei)
Is man an ape or an angel?



Matching skulls is an important problem
LCSS can deal with missing or occluded parts
This region will not be matched
LCSS Alignment
DTW


For brevity, we will only give details of Euclidean distance in this talk
However, the main point of our paper is that the same idea works for DTW and LCSS with no overhead
We **will** present empirical results that do show that DTW can be significantly better than Euclidean distance

Euclidean Distance Metric



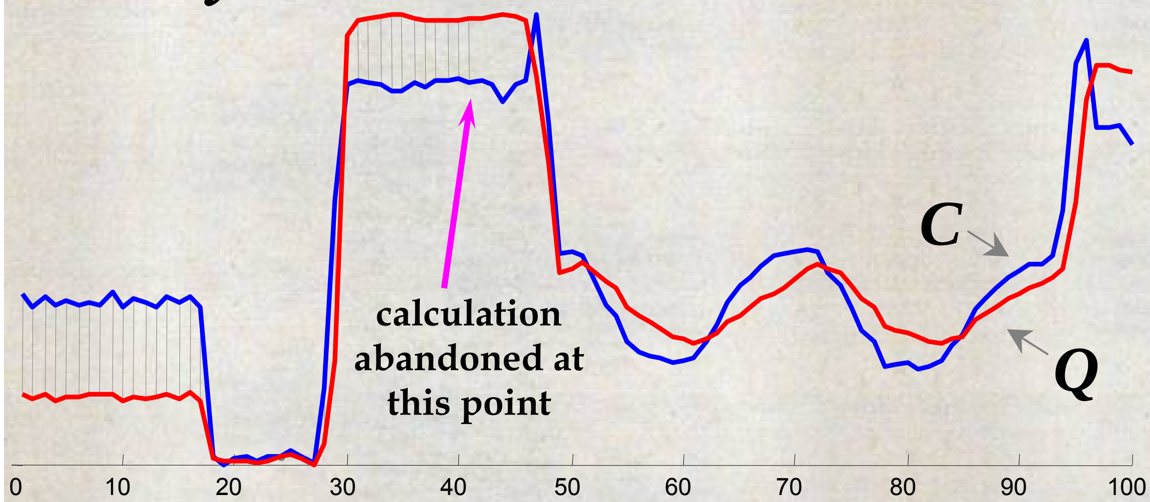
Given two time series $Q = q_1 \ldots q_n$ and $C = c_1 \ldots c_n$, the Euclidean distance between them is defined as:

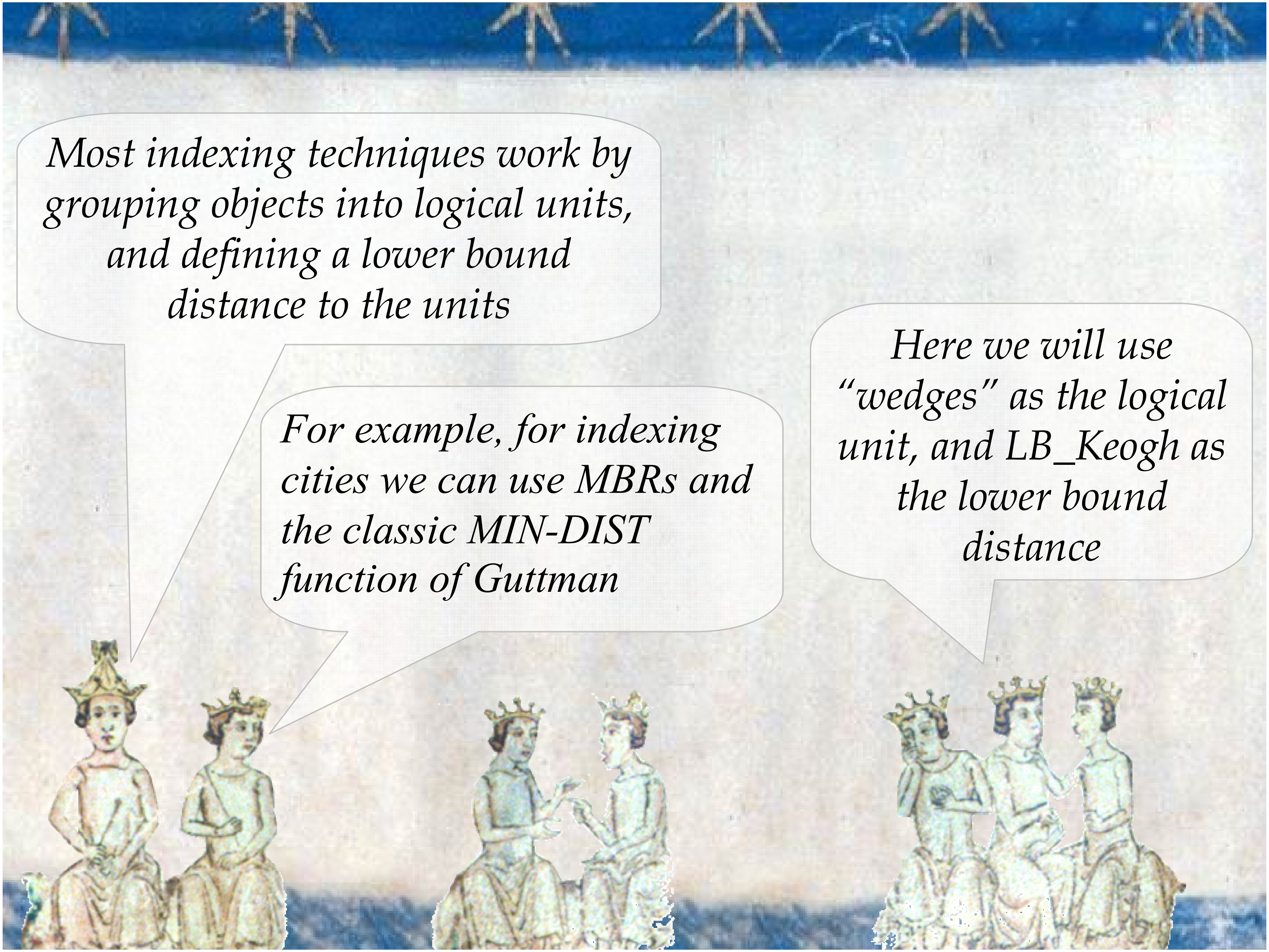
$$D(Q,C) \equiv \sqrt{\sum_{i=1}^{n} (q_i - c_i)^2}$$

I notice that you Z-normalized the time series first

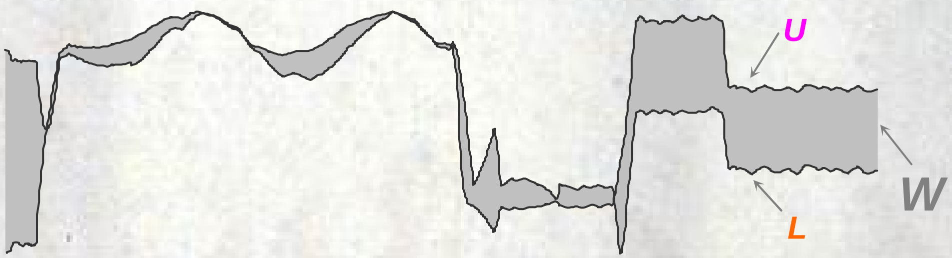
The next slide shows a useful optimization

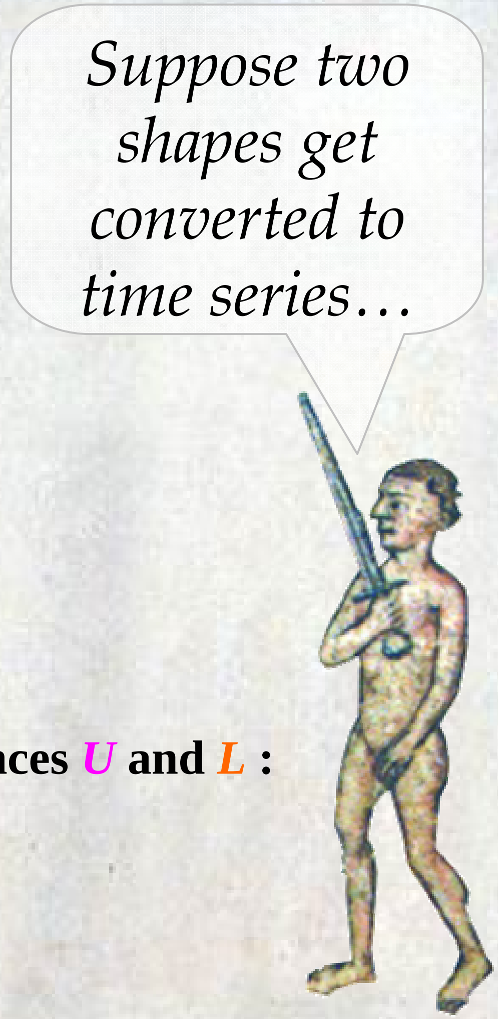
Early Abandon Euclidean Distance




Most indexing techniques work by grouping objects into logical units, and defining a lower bound distance to the units
For example, for indexing cities we can use MBRs and the classic MIN-DIST function of Guttman
Here we will use "wedges" as the logical unit, and LB_Keogh as the lower bound distance

Wedge





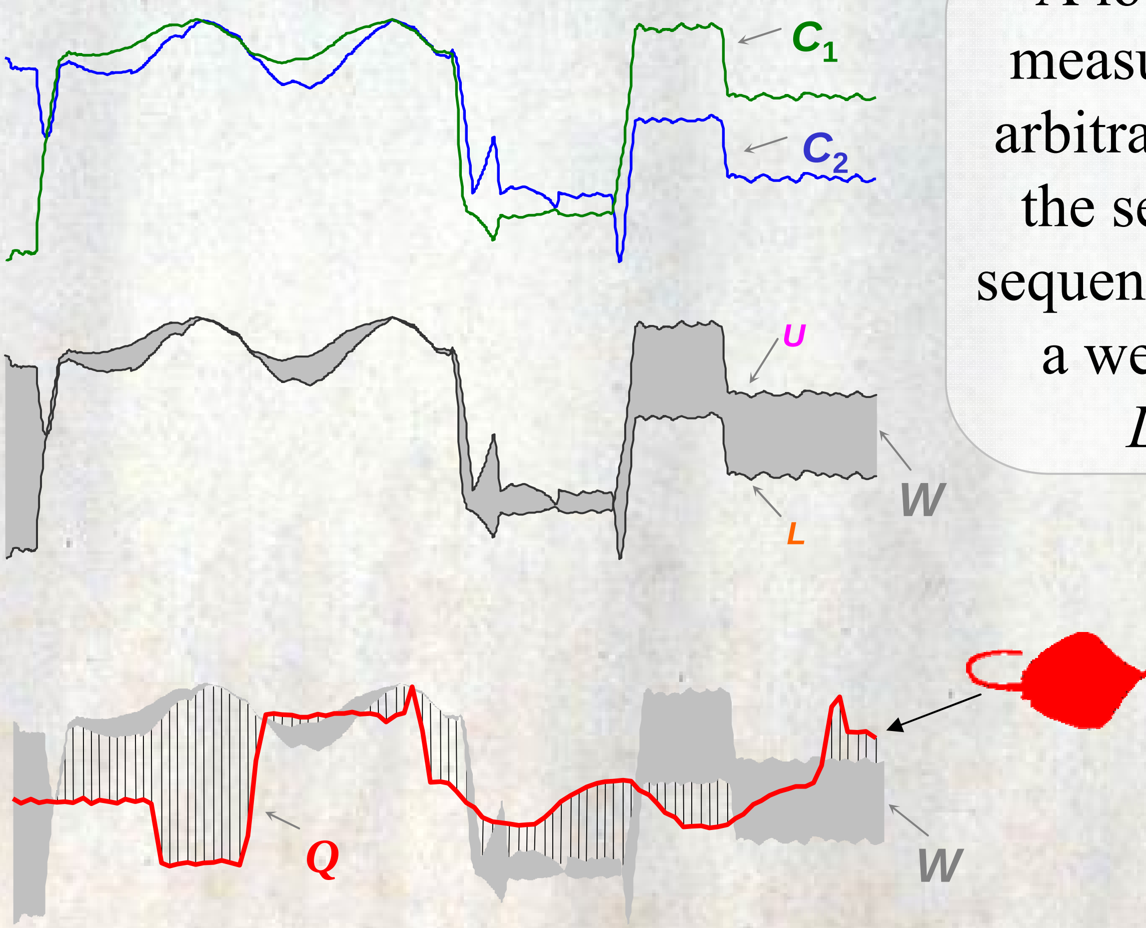
Having candidate sequences C_1, .. , C_k , we can form two new sequences U and L :

$$U_i = \max(C_{1i}, .., C_{ki})$$

$$L_i = \min(C_{1i}, .., C_{ki})$$

They form the smallest possible bounding envelope that encloses sequences $C1$, .. , Ck.

We call the combination of U and L a *wedge*, and denote a wedge as W. $W = \{U, L\}$

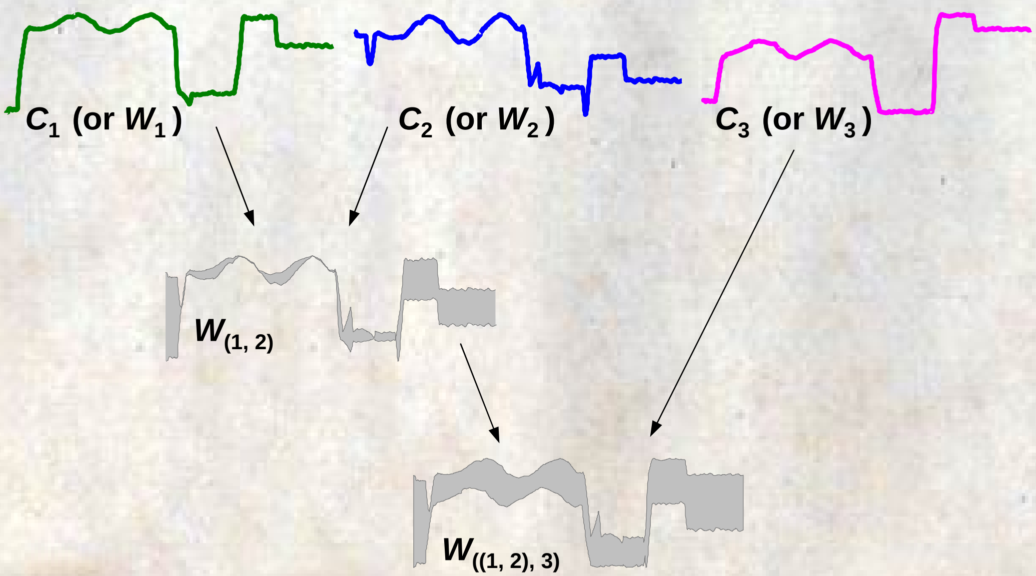


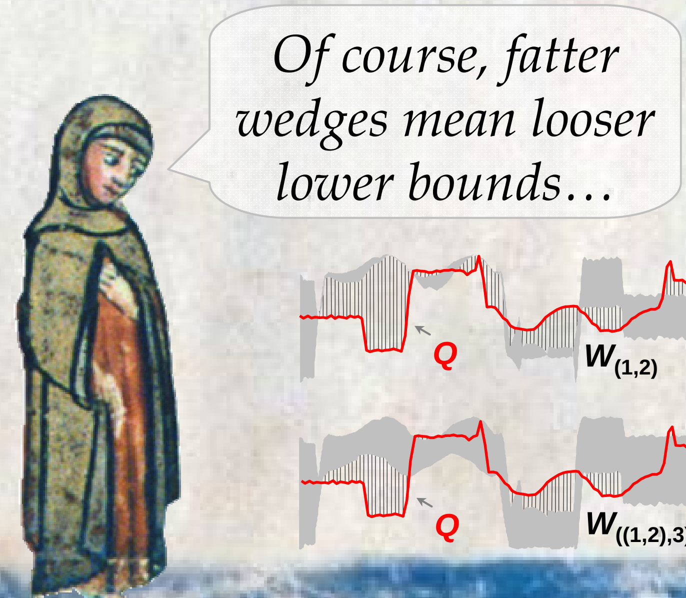
A lower bounding measure between an arbitrary query **Q** and the set of candidate sequences contained in a wedge **W**, is the *LB_Keogh*

$$LB\_Keogh(Q,W) = \sqrt{\sum_{i=1}^{n} \begin{cases} (q_i - U_i)^2 & \text{if } q_i > U_i \\ (q_i - L_i)^2 & \text{if } q_i < L_i \\ 0 & \text{otherwise} \end{cases}}$$

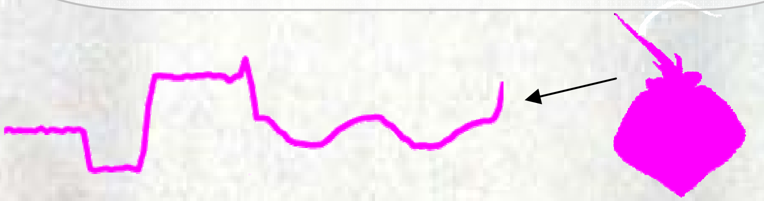
Generalized Wedge

- Use $W_{(1,2)}$ to denote that a wedge is built from sequences C_1 and C_2 .
- Wedges can be hierarchally nested. For example, $W_{((1,2),3)}$ consists of $W_{(1,2)}$ and C_3 .





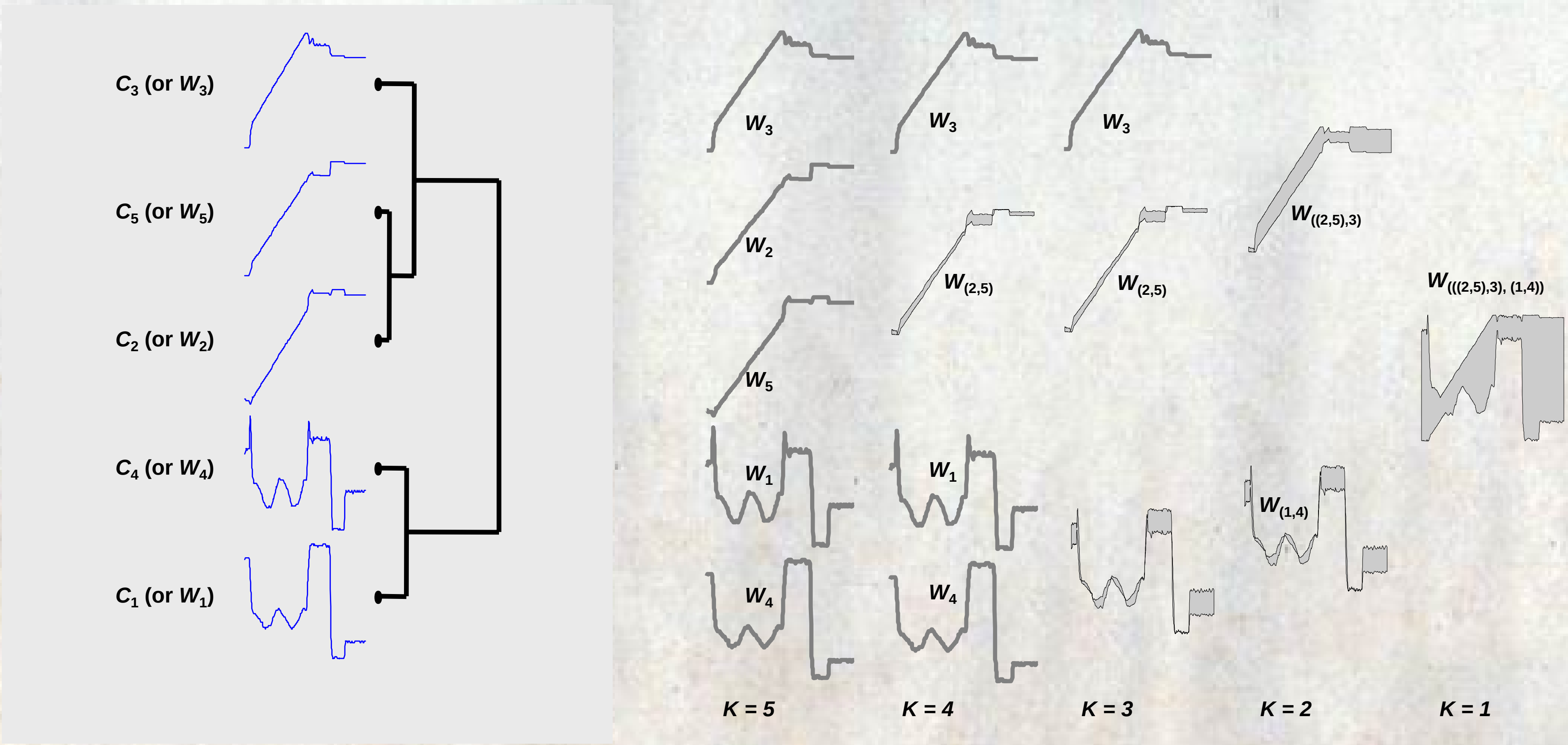
We are finally ready to explain our idea for rotation invariance, an idea we have sidestepped to this point. Suppose we have a shape as before…



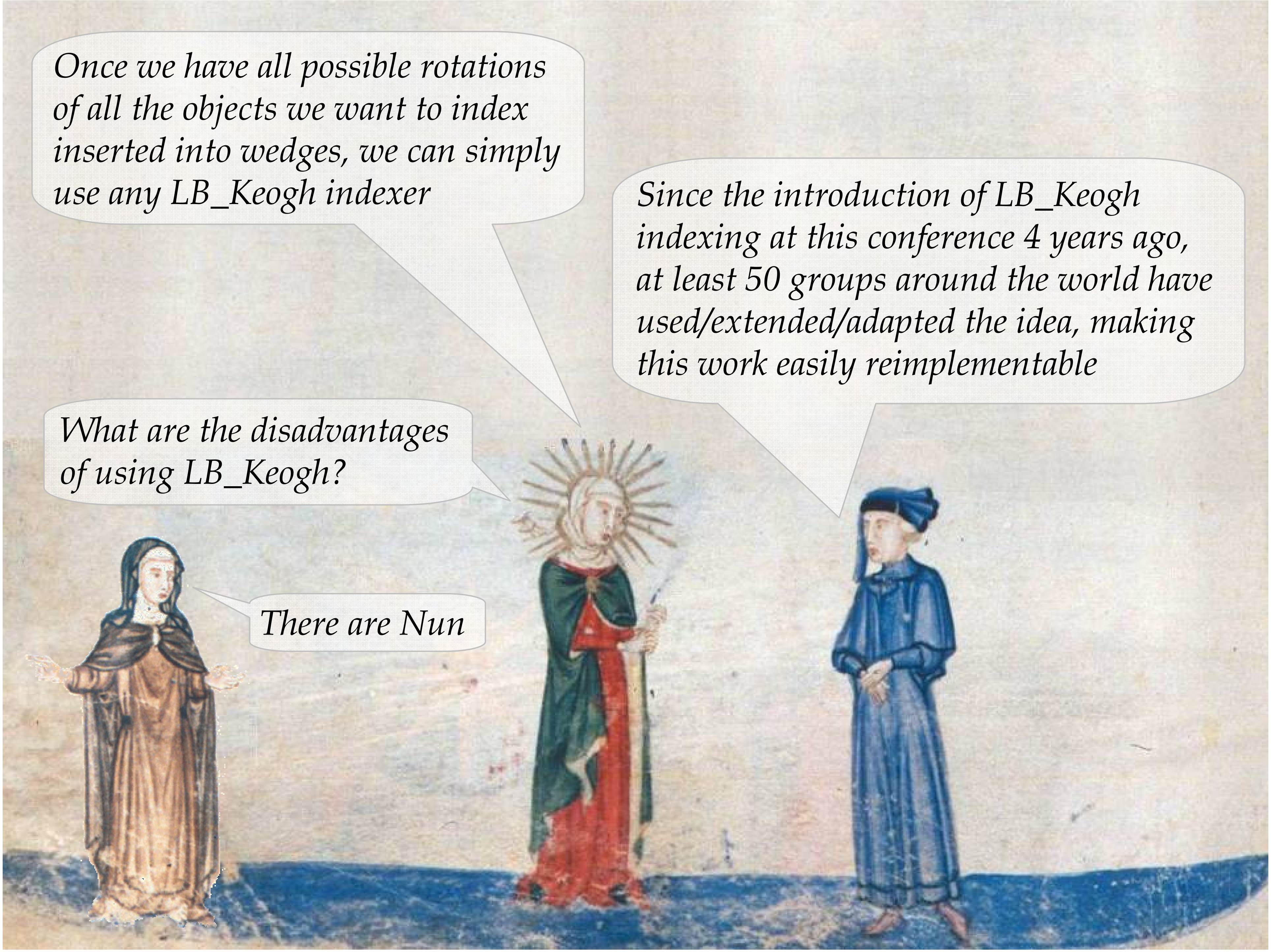
We can create every possible rotation of the shape, by considerer every possible circular shift of the time series, as shown at my left...
But we already know how to index such time series by using wedges!
We just need to figure out the best wedge making policy..

It sucks being a grad student

Hierarchal Clustering



Which wedge set to choose ?


Once we have all possible rotations of all the objects we want to index inserted into wedges, we can simply use any LB_Keogh indexer
Since the introduction of LB_Keogh indexing at this conference 4 years ago, at least 50 groups around the world have used/extended/adapted the idea, making this work easily reimplementable
What are the disadvantages of using LB_Keogh?
There are Nun

"LB_Keogh has provided a convincing lower bound" T. Rath

"LB_Keogh can significantly speed up DTW.". Suzuki

"LB_Keogh is the best…". Zhou & Wong

"LB_Keogh offers the tightest lower bounds". M. Cardle.

"LB_Keogh makes retrieval of time-warped time series feasible even for large data sets". Muller et. al.

"LB_Keogh can be effectively used, resulting in considerably less number of DTW computations." Karydis

"exploiting LB_Keogh, we can guarantee indexability". Bartolini et. al.

"LB_Keogh, the best method to lower bound.." Capitani.

"LB_Keogh is fast, because it cleverly exploits global constraints that appear in dynamic programming" ***Christos Faloutsos****.*

By using the LB_Keogh framework, we can leverage off the wealth of work in the literature

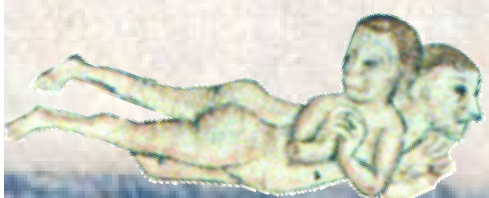
All our Experiments are Reproducible!

www.cs.ucr.edu/~eamonn/shape/

We tested on many diverse datasets

*Purgatorio -- Canto IX 5, ¥Purgatorio -- Canto XXIII, £Purgatorio -- Canto XXVI, ĩParadiso -- Canto XV 88

Name	Classes	Instances	Euclidean Error (%)	DTW Error (%) {R}	Other Techniques
Face	16	2240	3.839	**3.170** {3}	
Swedish Leaves	15	1125	13.33	**10.84** {2}	
Chicken	5	446	19.96	19.96 {1}	20.5 Discrete strings
MixedBag	9	160	4.375	4.375 {1}	Chamfer 6.0, Hausdorff 7.0
OSU Leaves	6	442	33.71	**15.61** {2}	
Diatoms	37	781	27.53	27.53 {1}	26.0 Morphological Curvature Scale Spaces
Plane	7	210	0.95	**0.0** {3}	0.55 Markov Descriptor
Fish	7	350	11.43	**9.71** {1}	36.0 Fourier /Power Cepstrum



Note that DTW is sometimes worth the little extra effort

Implementation details should not matter, for example the results reported should be the same if reimplemented in Ret Hat Linux

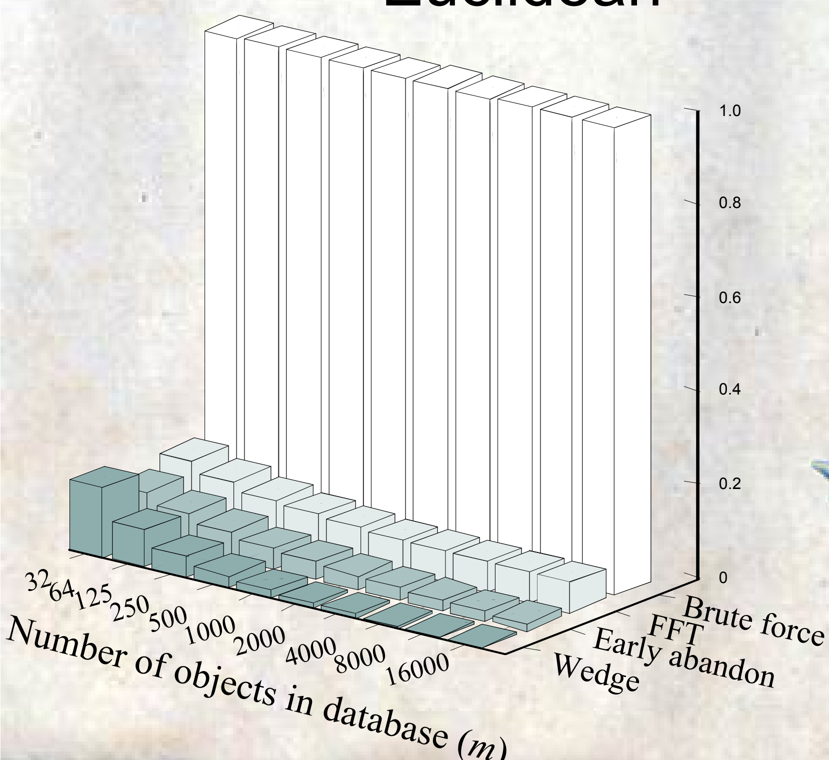
We therefore use a cost model that is independent of hardware/software/buffer size etc. See the paper for details

We compare to brute force, and were possible a Fourier based approach (it can't handle DTW)

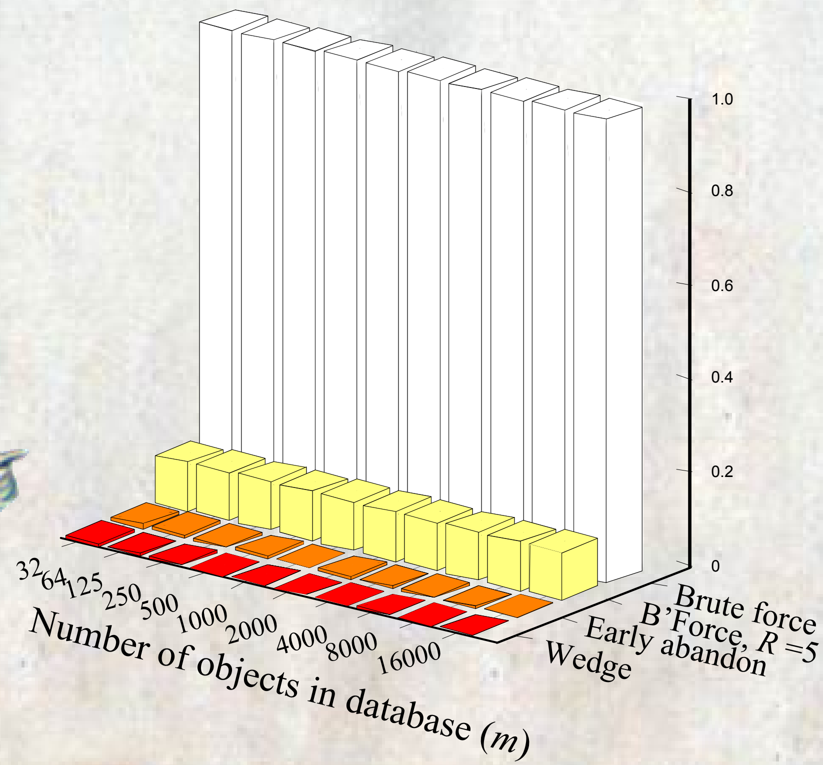
Main Memory Experiments

- Projectile point database
- Increasingly larger datasets
- One-nearest-neighbor queries

Euclidean

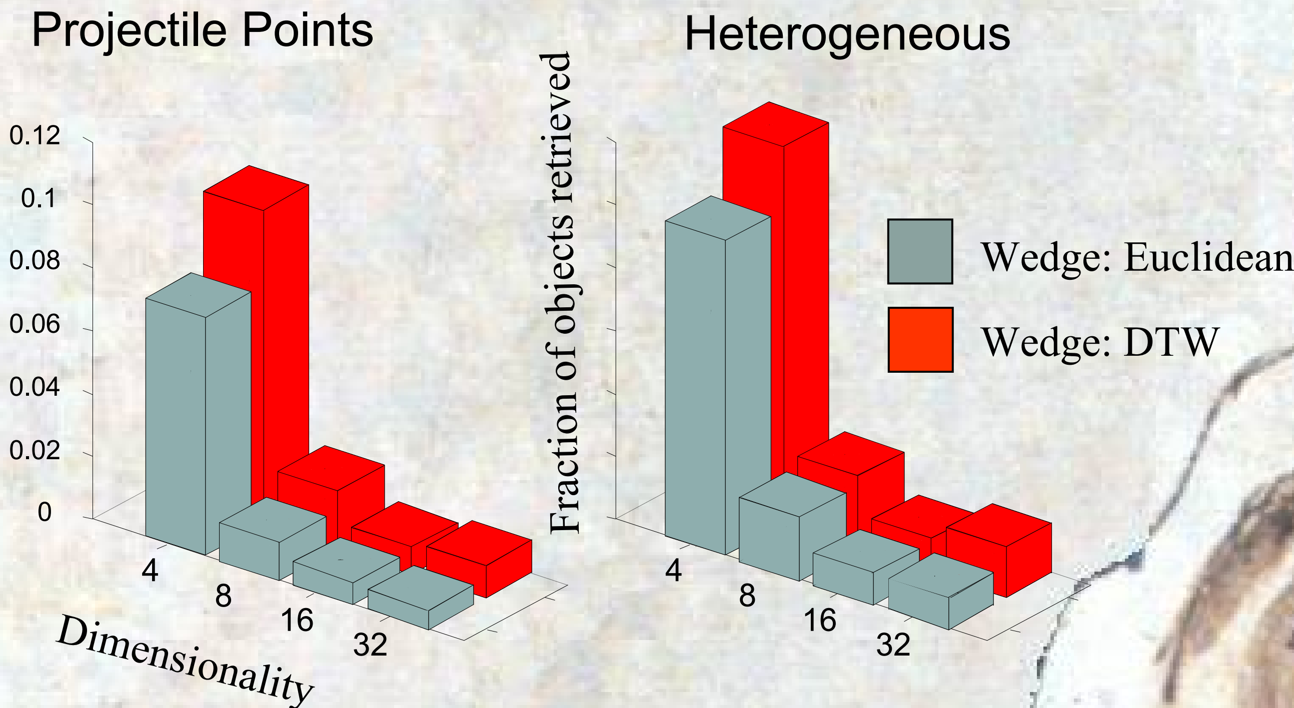


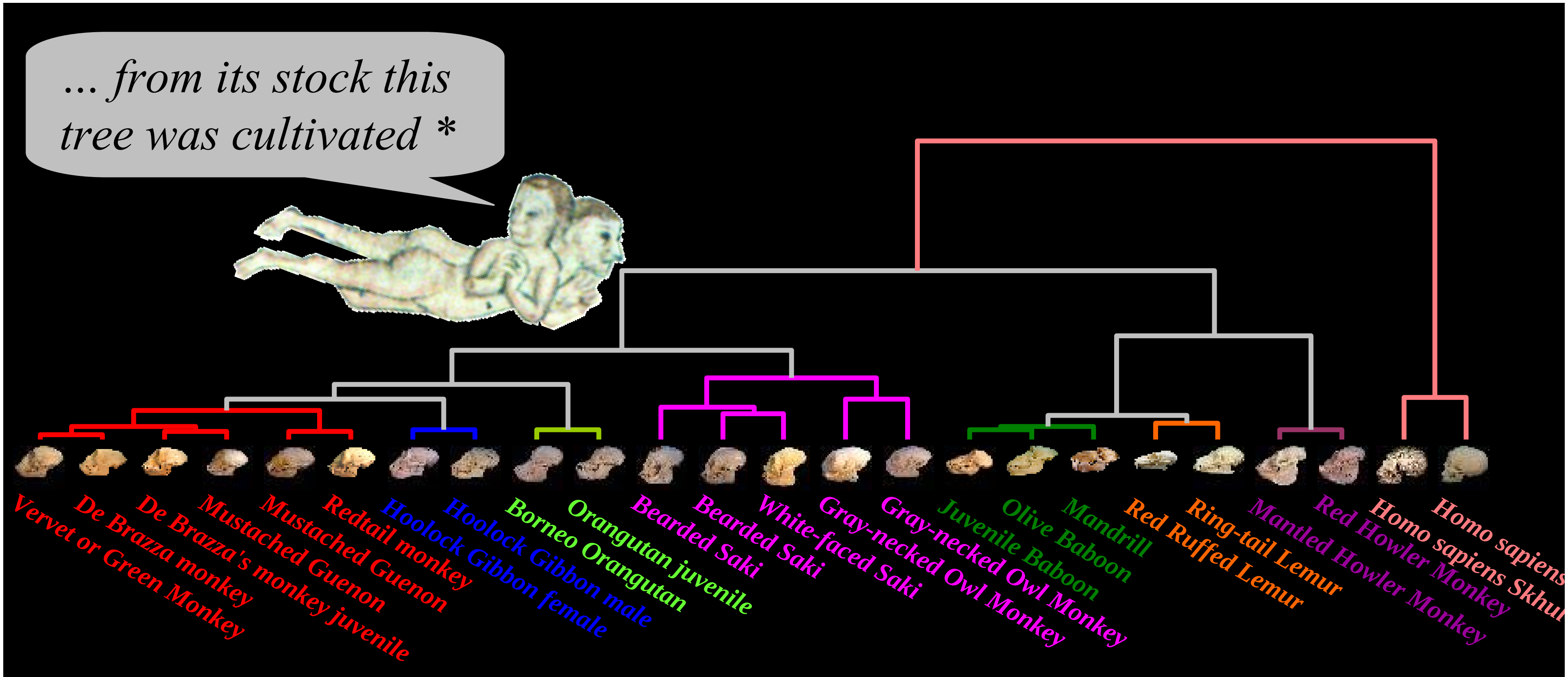
DTW



Indexing Experiments

- Projectile point/Heterogenous databases
- Increasingly large dimensionality
- One-nearest-neighbor queries





All these are in the genus *Cercopithecus*, except for the skull identified as being either a Vervet or Green monkey, both of which belong in the Genus of *Chlorocebus* which is in the same Tribe (***Cercopithecini***) as *Cercopithecus*.

Tribe *Cercopithecini*

Cercopithecus

De Brazza's Monkey, *Cercopithecus neglectus*
Mustached Guenon, *Cercopithecus cephus*
Red-tailed Monkey, *Cercopithecus ascanius*

Chlorocebus

Green Monkey, *Chlorocebus sabaceus*
Vervet Monkey, *Chlorocebus pygerythrus*

These are the same species ***Bunopithecus hooloc*** (Hoolock Gibbon)

These are in the Genus ***Pongo***

All these are in the family ***Cebidae***

Family *Cebidae (New World monkeys)*

Subfamily Aotinae

Aotus trivirgatus

Subfamily Pitheciinae sakis

Black Bearded Saki, Chiropotes satanas
White-nosed Saki, Chiropotes albinasus

All these are in the tribe ***Papionini***

Tribe *Papionini*

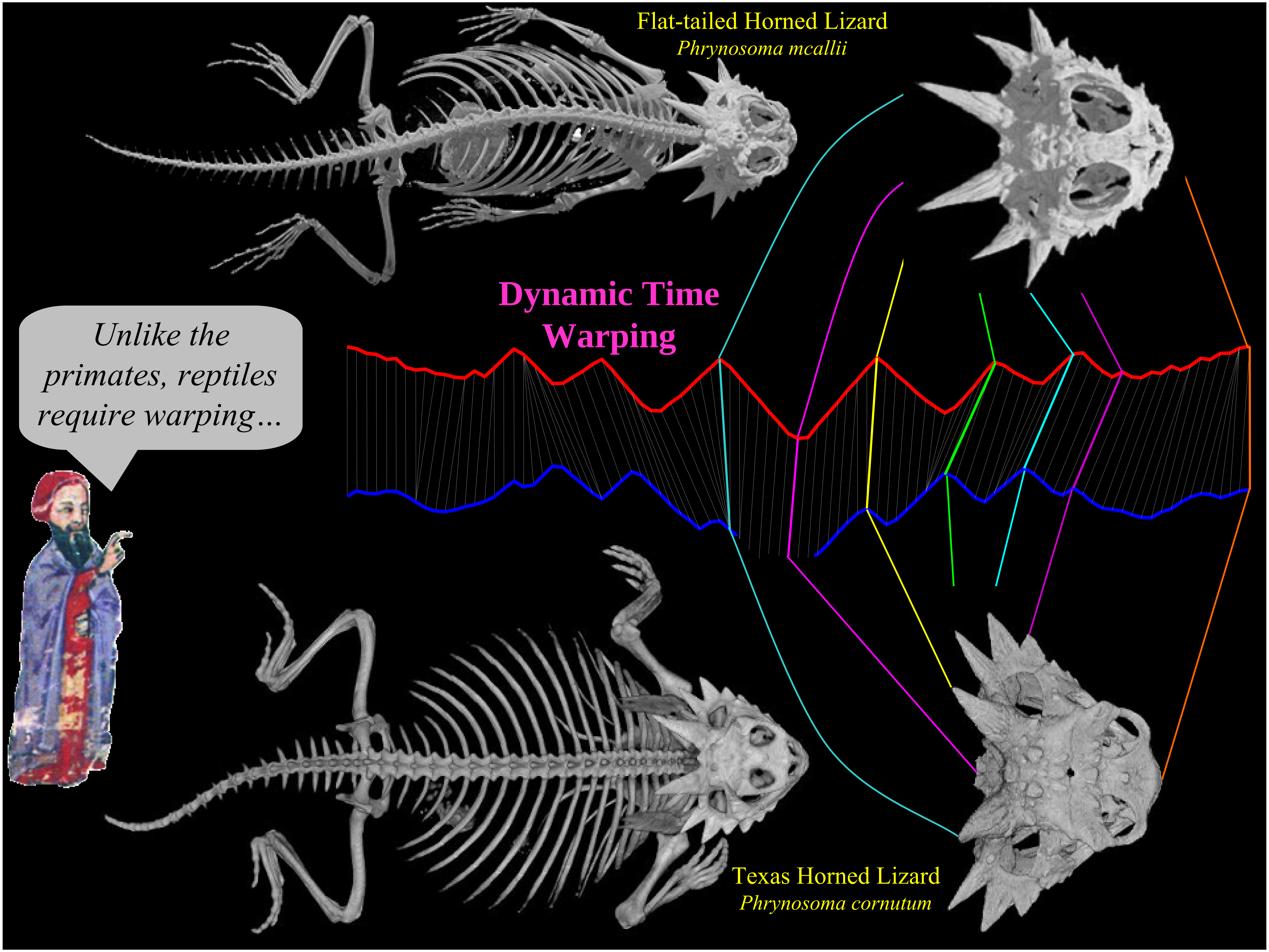
Genus Papio – baboons
Genus Mandrillus- Mandrill

These are in the family ***Lemuridae***

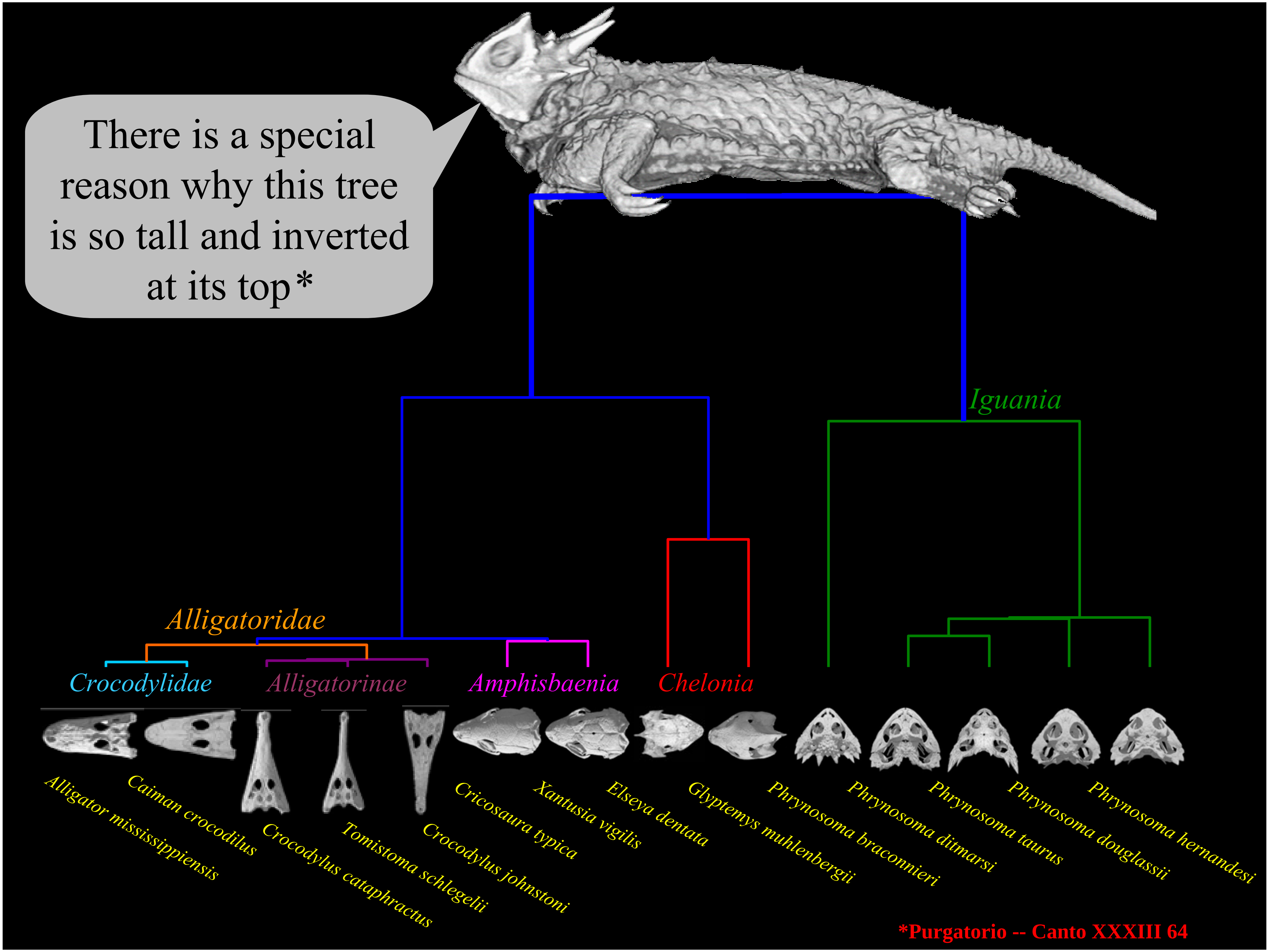
These are in the genus ***Alouatta***

These are in the same species ***Homo sapiens*** (Humans)

***Purgatorio -- Canto XXIV 117**



Flat-tailed Horned Lizard
Phrynosoma mcallii
Dynamic Time Warping
Unlike the primates, reptiles require warping…
Texas Horned Lizard
Phrynosoma cornutum



There is a special reason why this tree is so tall and inverted at its top*
Iguania
Alligatoridae
Crocodylidae
Alligatorinae
Amphisbaenia
Chelonia
Alligator mississippiensis
Caiman crocodilus
Crocodylus cataphractus
Tomistoma schlegelii
Crocodylus johnstoni
Cricosaura typica
Xantusia vigilis
Elseya dentata
Glyptemys muhlenbergii
Phrynosoma braconnieri
Phrynosoma ditmarsi
Phrynosoma taurus
Phrynosoma douglassii
Phrynosoma hernandesi
*Purgatorio -- Canto XXXIII 64

Petroglyph Mining

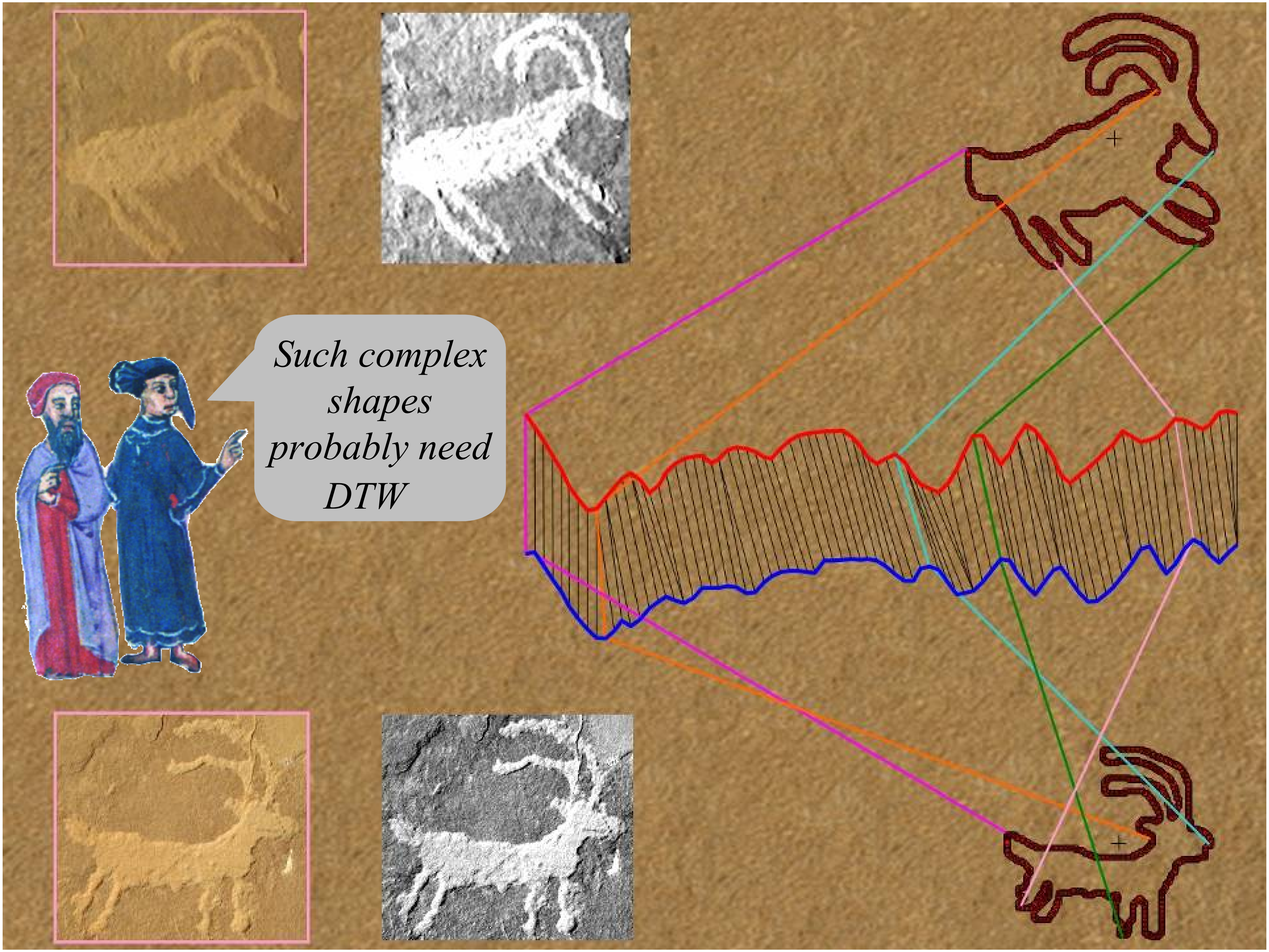
- They appear worldwide
- Over a million in America alone
- Surprisingly little known about them

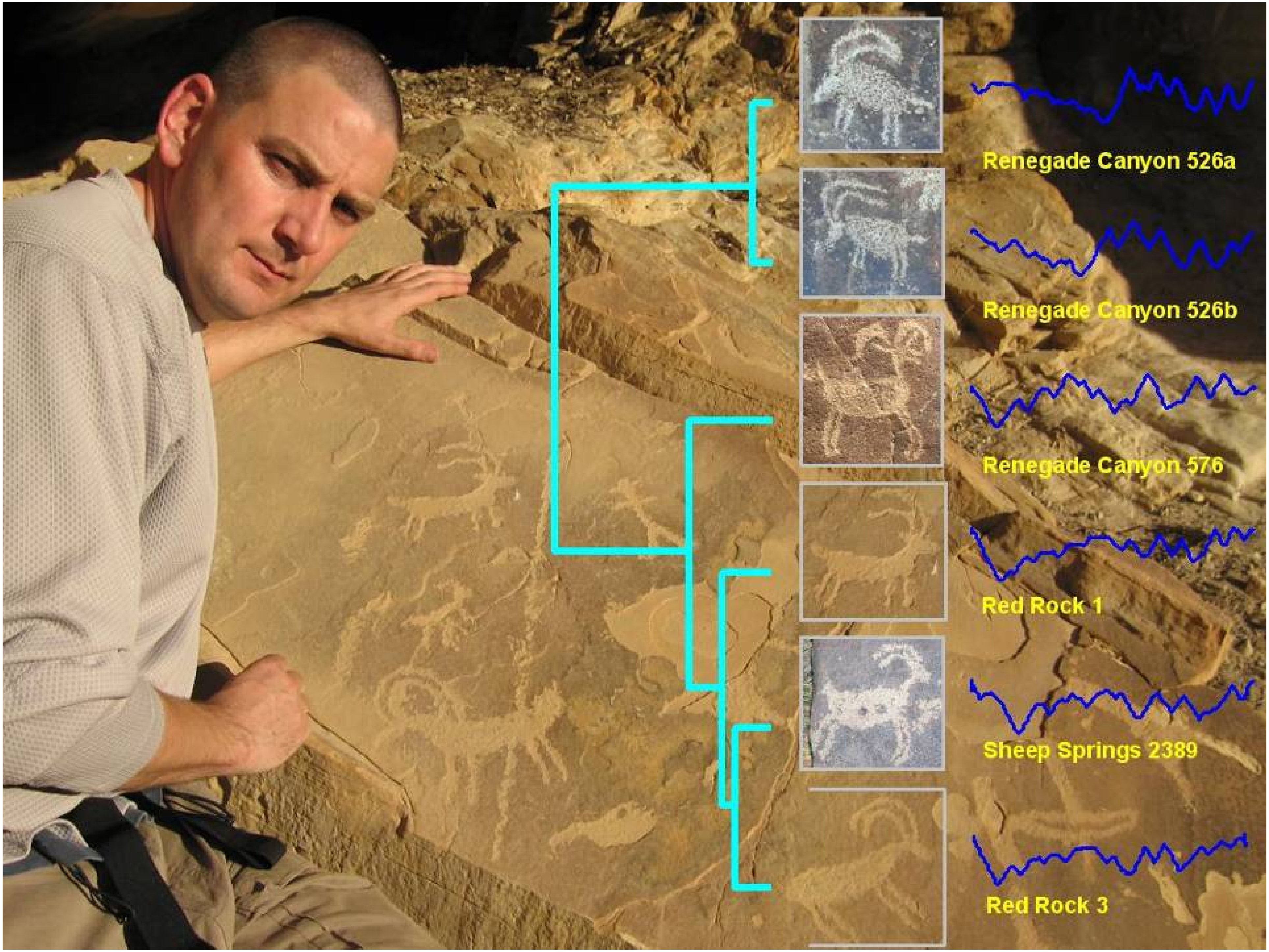
Petroglyphs are images incised in rock, usually by prehistoric, peoples. They were an important form of pre-writing symbols, used in communication from approximately 10,000 B.C.E. to modern times. **Wikipedia**

*who so sketched out the shapes there?**

*.. they would strike the subtlest minds with awe**

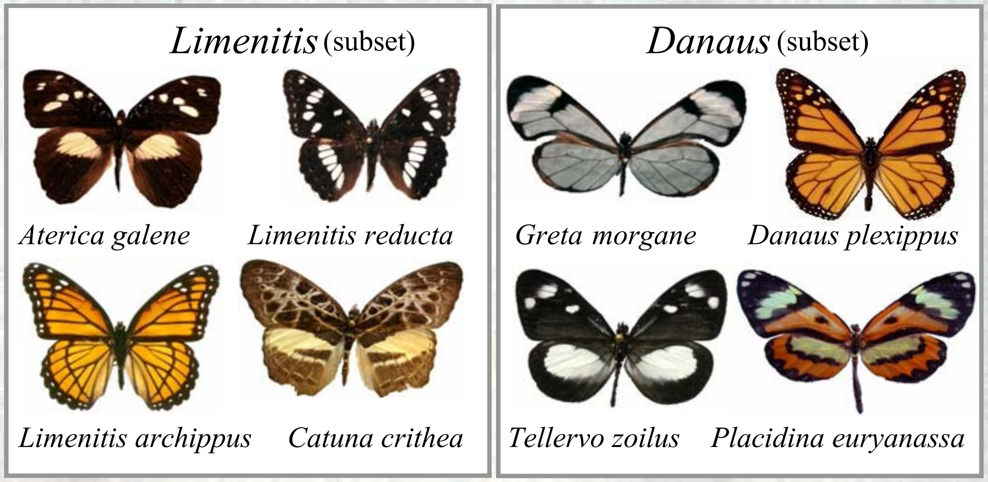
*** Purgatorio -- Canto XII 6**

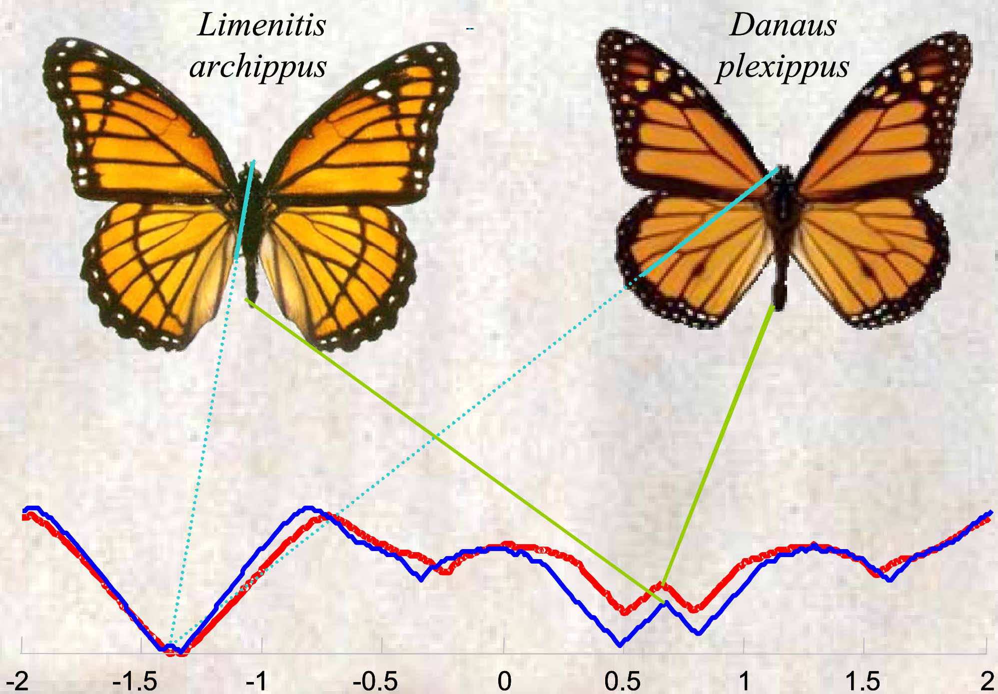

Such complex shapes probably need DTW



Renegade Canyon 526a
Renegade Canyon 526b
Renegade Canyon 576
Red Rock 1
Sheep Springs 2389
Red Rock 3

Future Work: Data Mining





We did not want to work on shape data mining until we could do fast matching, that would have been ass backwards

*.. so similar in act and coloration that I will put them both to one**

* **Inferno -- Canto XXIII 29**

Questions?
Feel free to email us with questions
Eamonn Keogh: Project Leader
eamonn@cs.ucr.edu
Li Wei: Lower Bounding
wli@cs.ucr.edu
Michail Vlachos: Public Nudity and Index Structures
vlachos@us.ibm.com
Sang Hee Lee: Anthropology and Primatology
shlee@ucr.edu
Xiaopeng Xi: Image Processing
xxi@cs.ucr.edu