Fossils, Physics and Fast Computers

Unlocking a Virtual Past

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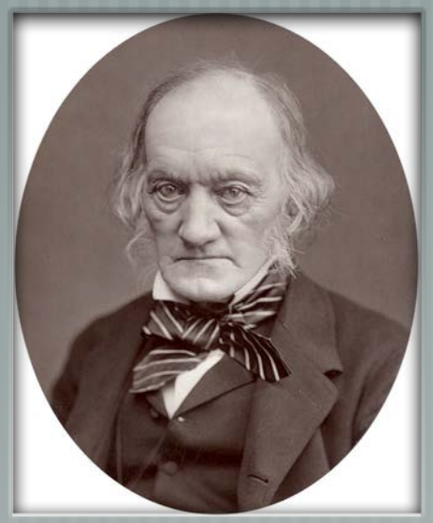
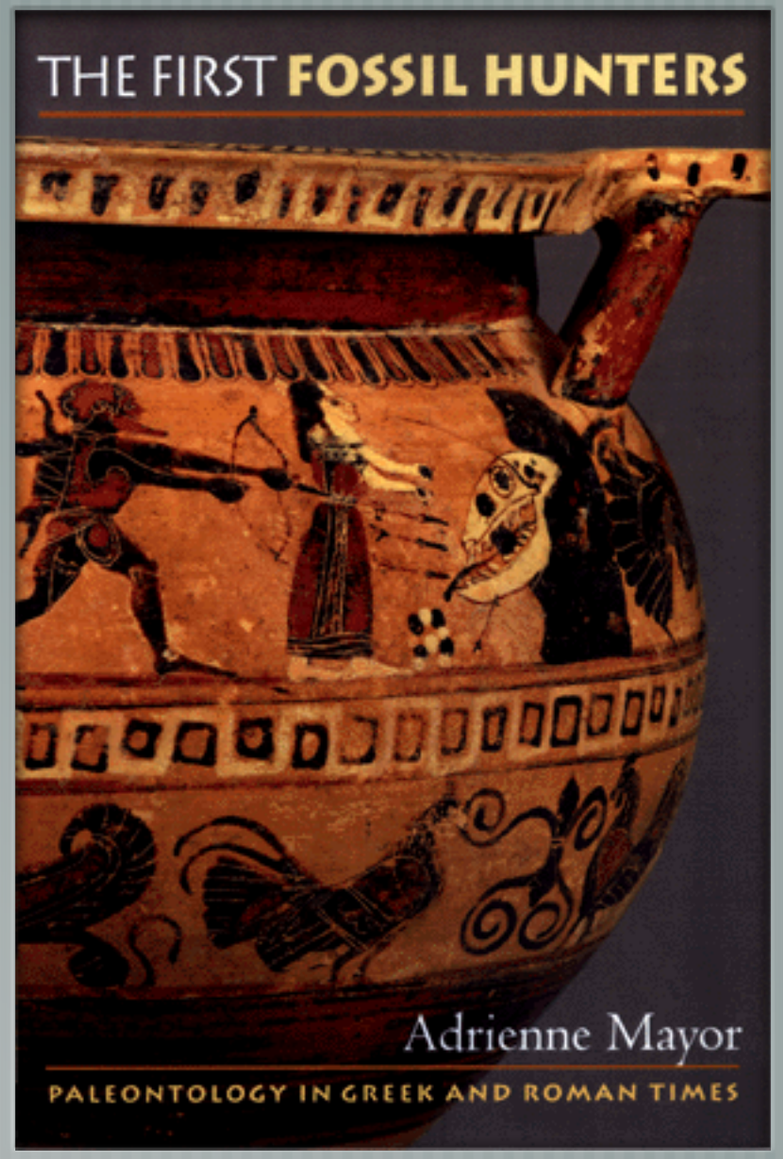
Fascination with Fossils

- Dinosaurs were ‘invented’ by Richard Owen in 1842



- However interest in fossils dates back to antiquity



Jurassic Park (1993): Possibly the most famous fossil locomotor reconstruction.
But did dinosaurs really move like this? And how do we know?

19th Century Horses

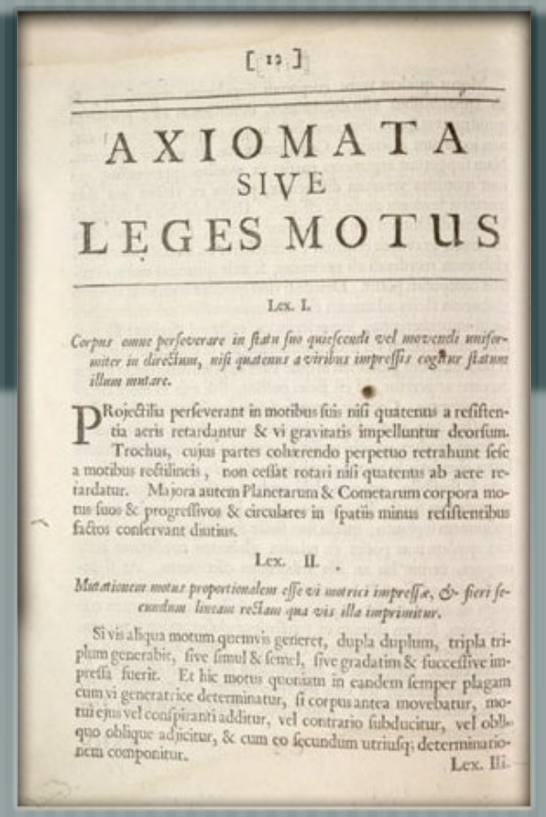
Edward Muybridge 1887

John Herring 1839

Ostrich ≠ Tyrannosaurus

Cannot just use a modern analogue

Physics


[12]

AXIOMATA
SIVE
LEGES MOTUS

Lex. I.

Corpus omne perseverare in statu suo quiescendi vel movendi uniformiter in directum, nisi quatenus a viribus impressis cogitur statum illum mutare.

Projectilia perseverant in motibus suis nisi quatenus a resistentia aeris retardantur & vi gravitatis impelluntur deorsum. Trochus, cujus partes cohærendo perpetuo retrahunt sese a motibus rectilineis, non cessat rotari nisi quatenus ab aere retardatur. Majora autem Planetarum & Cometarum corpora motus suos & progressivos & circulares in spatiis minus resistentibus factos conservant diutius.

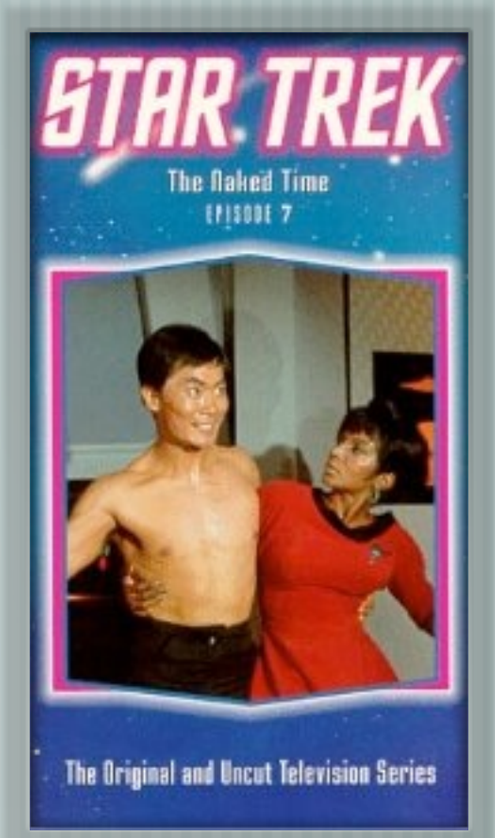
Lex. II.

Mutationem motus proportionalem esse vi motrici impressæ, & fieri secundum lineam rectam qua vis illa imprimitur.

Si vis aliqua motum quemvis generet, dupla duplum, tripla triplum generabit, sive simul & semel, sive gradatim & successive impressa fuerit. Et hic motus quoniam in eandem semper plagam cum vi generatrice determinatur, si corpus antea movebatur, motui ejus vel conspiranti additur, vel contrario subducitur, vel obliquo obliquæ adjicitur, & cum eo secundum utriusq; determinationem componitur.

Lex. III.

Isaac Newton (1687) Principia Mathematica:
Force applied to a mass produces a proportional acceleration
(rough translation from Latin)



Montgomery Scott (1966) The Naked Time
I cannae change the laws of physics!

How do you measure the living mass of a fossil?

(1) Find a dinosaur

Badlands (Hell Creek Formation), South Dakota, USA: 65 mya

(2) Excavate it

Working on a hadrosaur femur (2011)

(3) Get it back to the lab

Carrying the field jacket - approx. 100kg

(4) Reconstruct the skeleton

- All these stages require a great deal of skill
- For large fossils they are hard work
- But because of these efforts we do know what these animals looked like

Welding up a T. rex mount

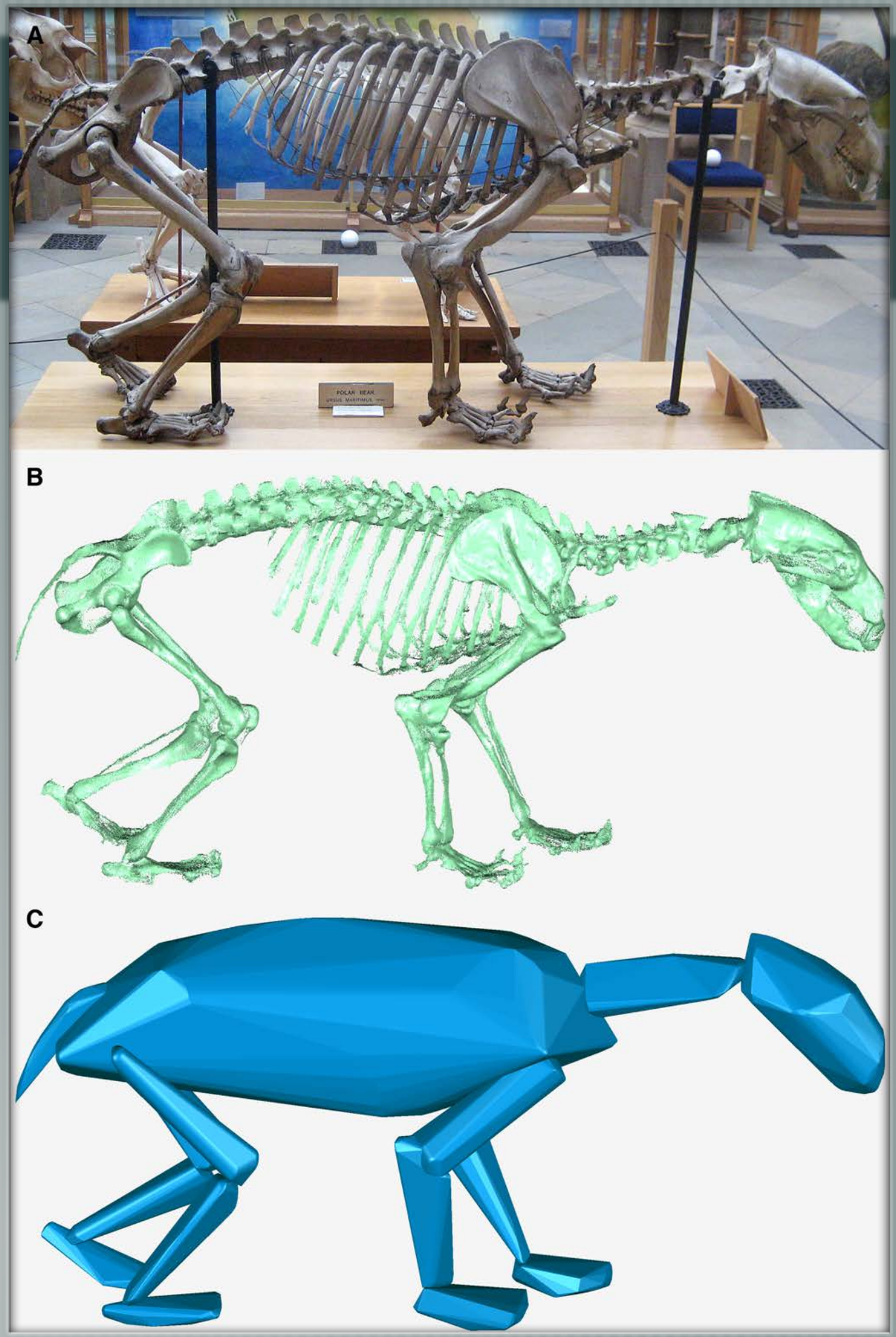
How do you weigh a dinosaur?

Argentinosaurus, 37m long, Museo Municipal Carmen Funes

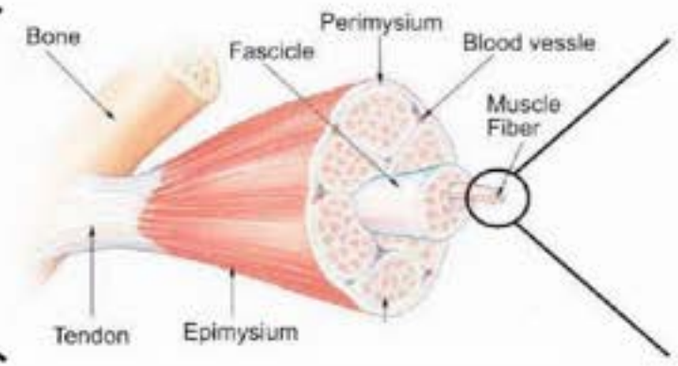
LiDAR scanning a range of living vertebrates at the Oxford University Museum of Natural History

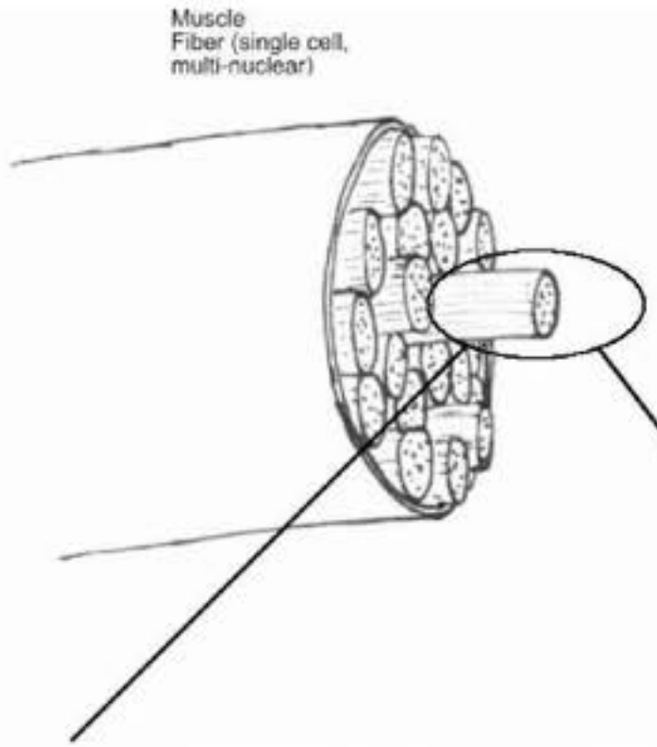
Convex Hulling

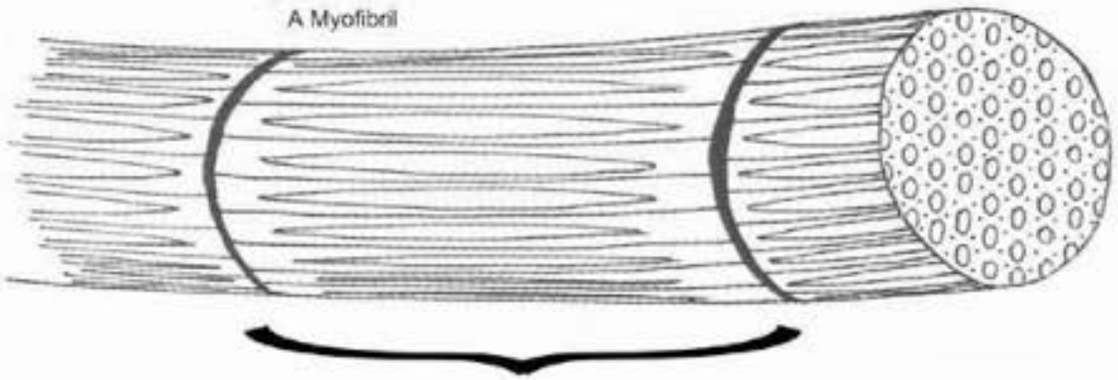
- The LiDAR scan produces a point cloud model in the computer
- We calculate the Convex Hull (the smallest convex shape that encloses all the points) for the major body segments
- Using estimated body density we calculate the convex hull volume

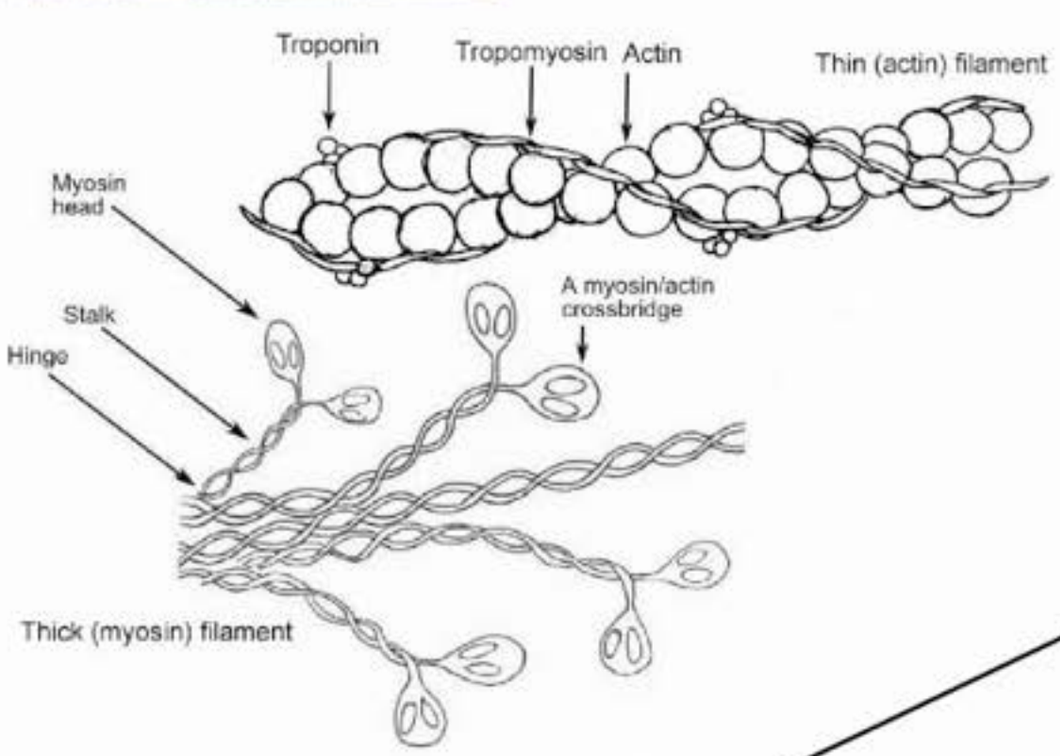


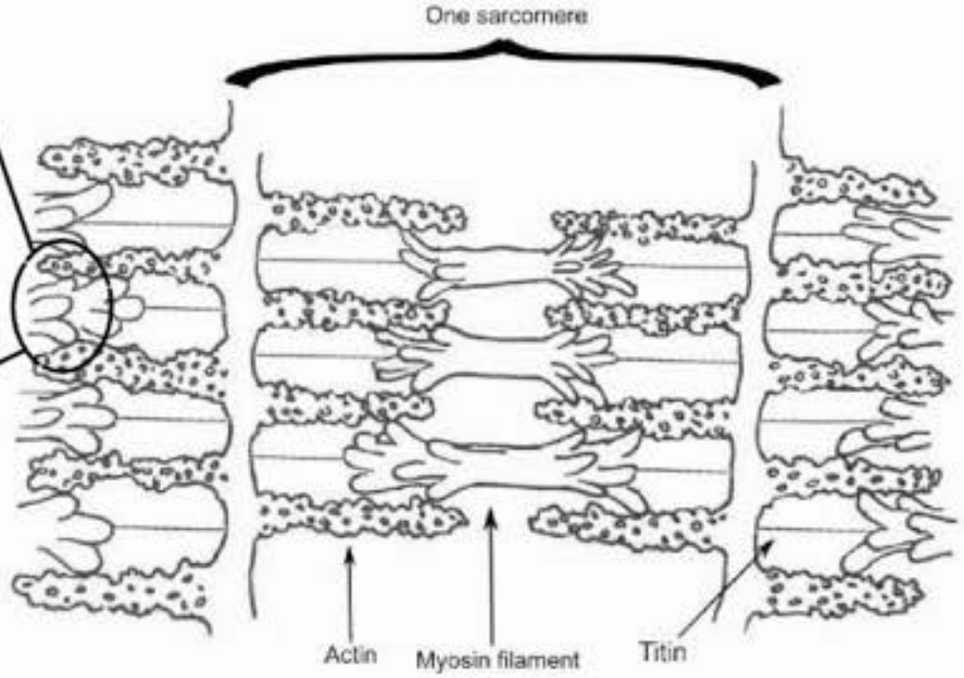
How do you measure the forces in a fossil?


Bone
Fascicle
Perimysium
Blood vessle
Muscle Fiber
Tendon
Epimysium


Muscle Fiber (single cell, multi-nuclear)

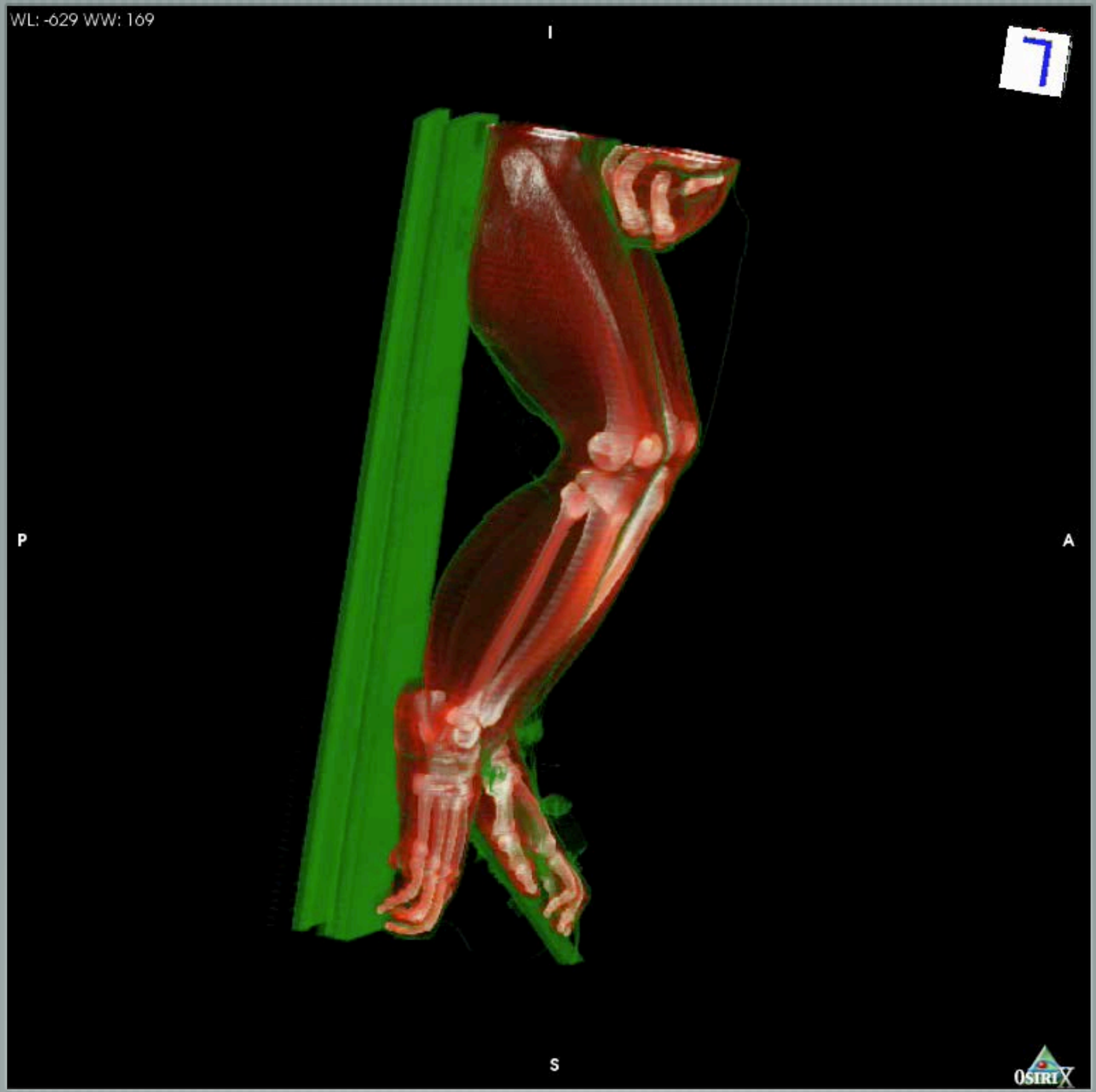

A Myofibril


Troponin
Tropomyosin
Actin
Thin (actin) filament
Myosin head
Stalk
Hinge
A myosin/actin crossbridge
Thick (myosin) filament


One sarcomere
Actin
Myosin filament
Titin

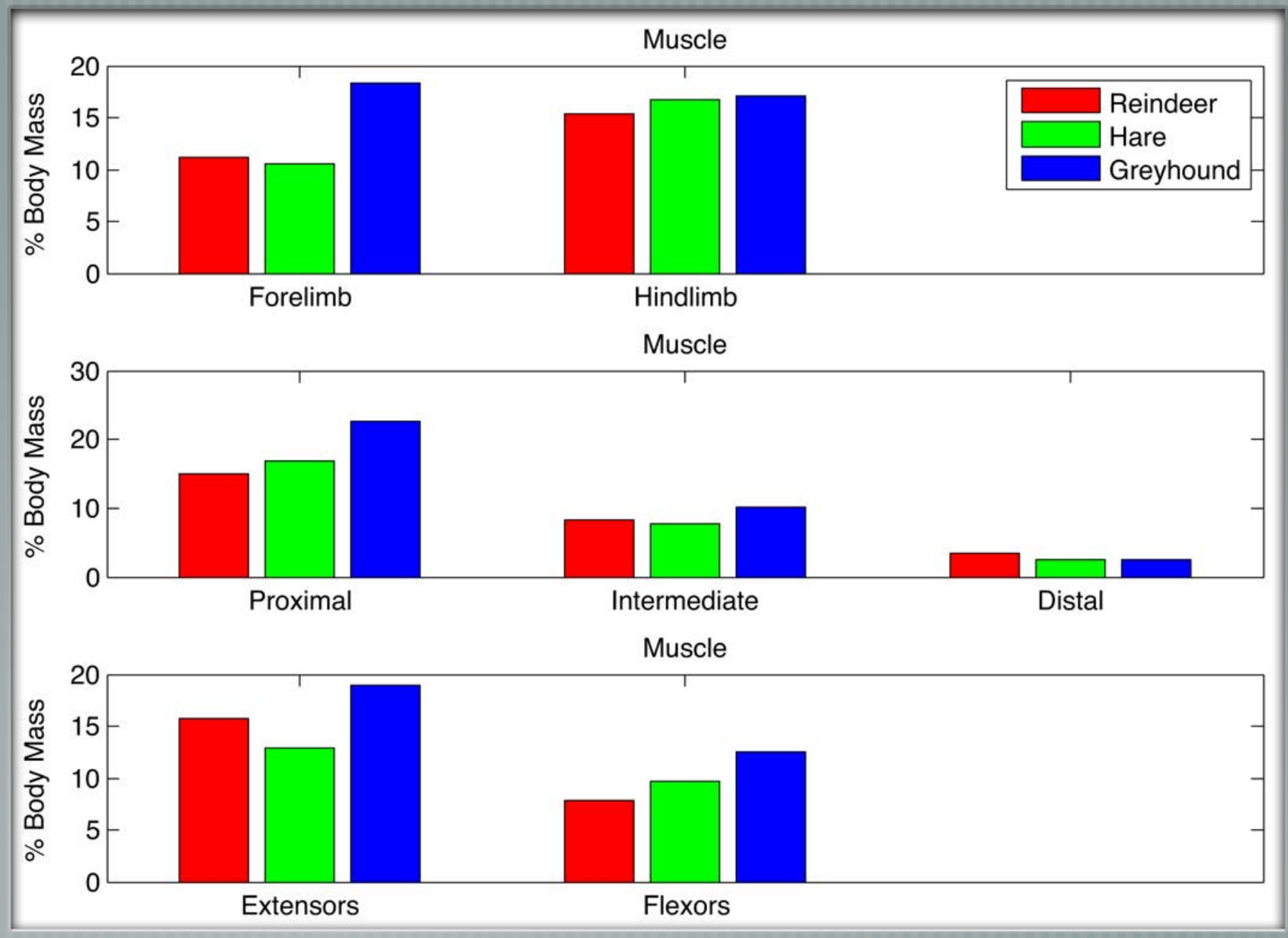

D
1


Medial head.
GASTROC.
REINDEER 1
LHS.
Lateral head
GASTROC.
REINDEER 1
LHS.


WL: -629 WW: 169
I
P
A
S
OSIRIX

Muscle Mass

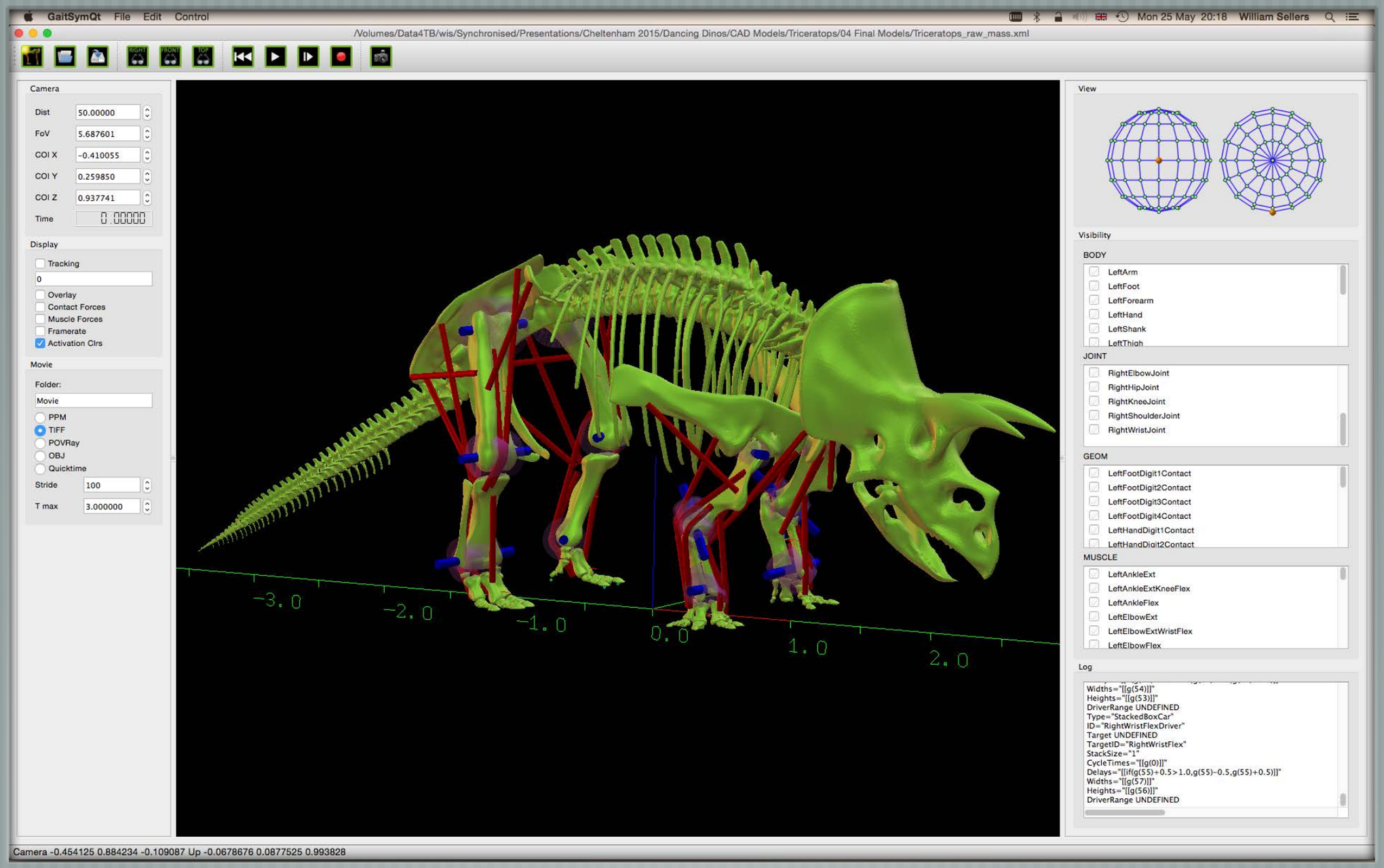
- Muscle distribution seems relatively conserved across mammals
- But currently we don't know very much about non-mammals



Wareing, K., Tickle, P., Stokkan, K., Codd, J. R. & Sellers, W. I. 2011 The musculoskeletal anatomy of the reindeer (Rangifer tarandus): fore- and hindlimb. Polar Biology 10, 1571-1578.

Putting it all together

Multibody Dynamics using GaitSym



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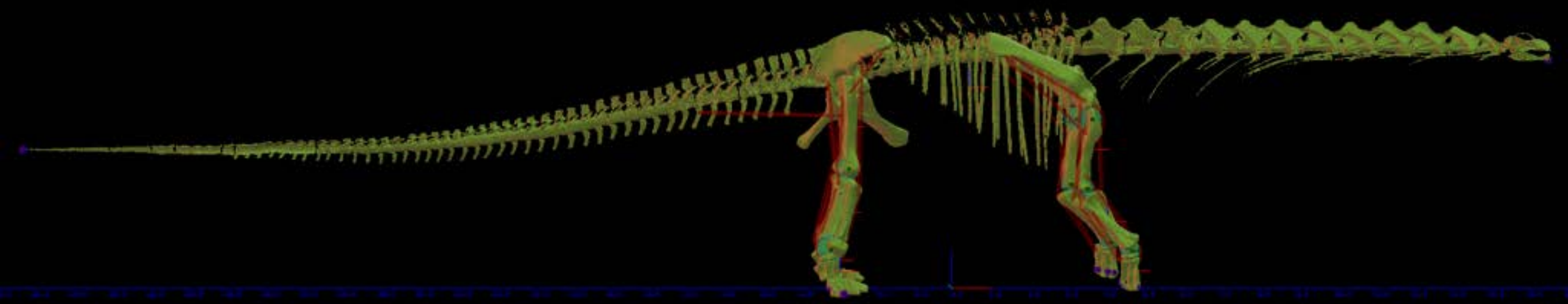
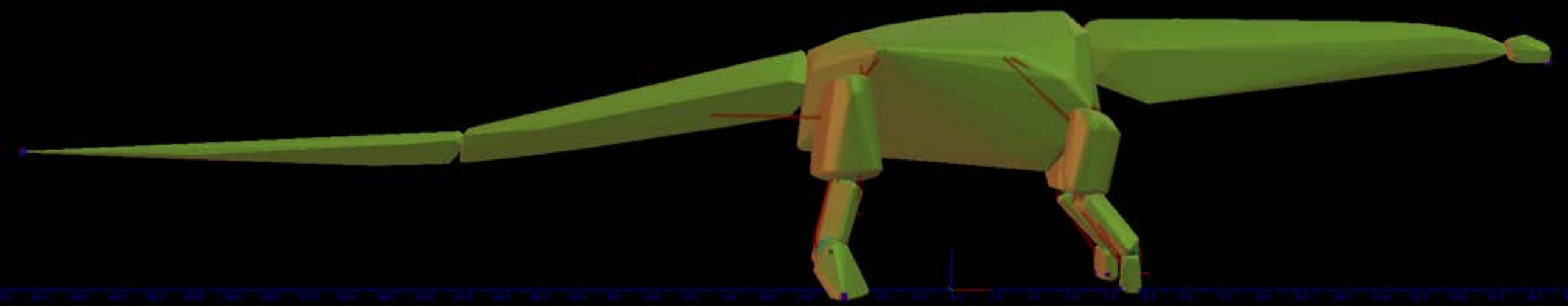
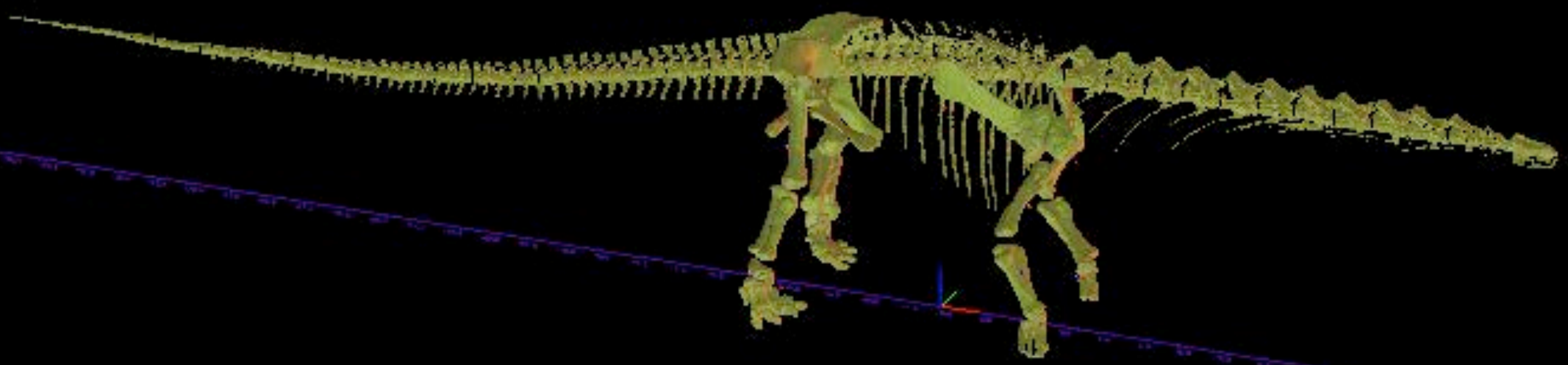
Reconstructing Argentinosaurus

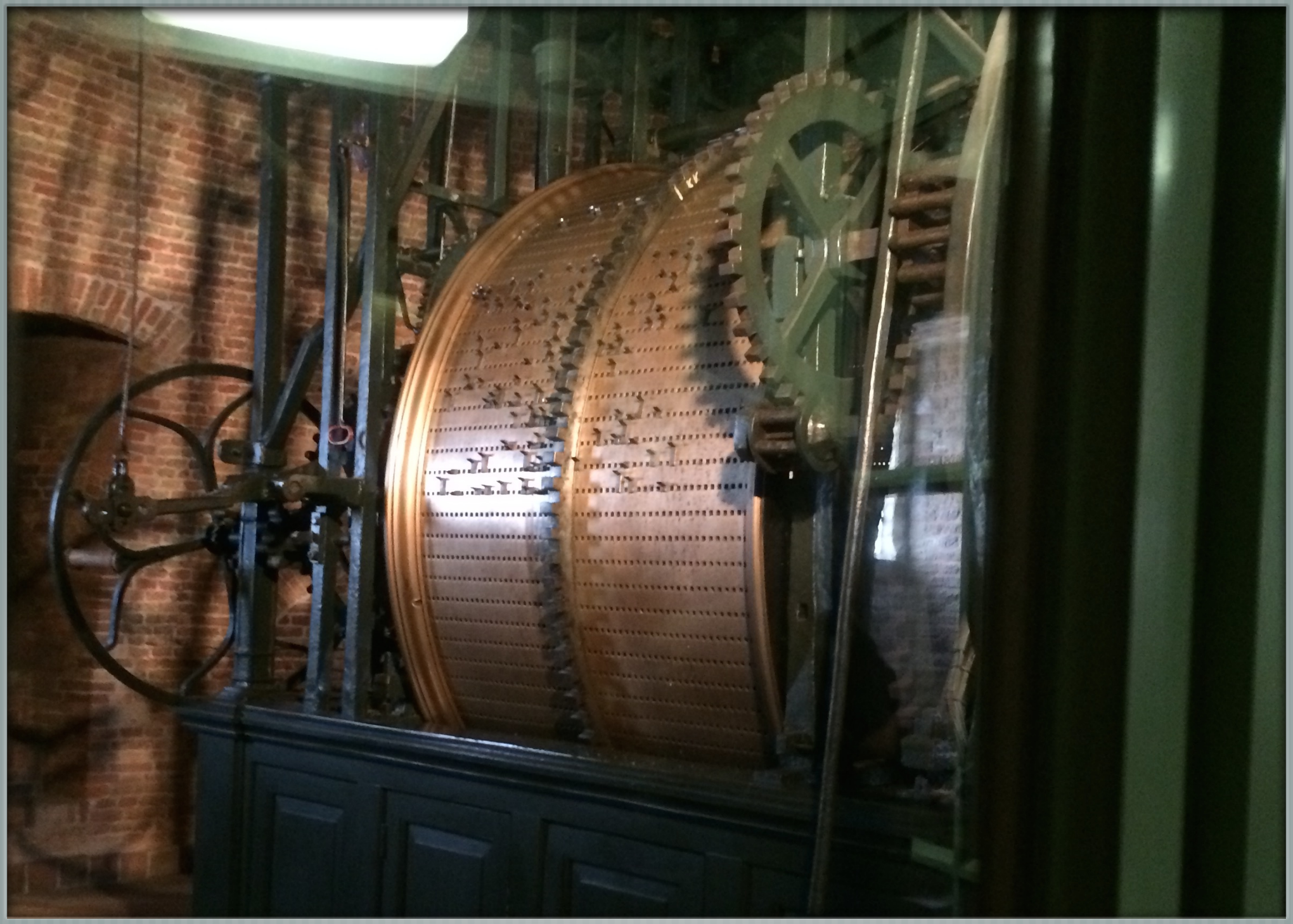
Rig muscles onto the skeleton



Skin the skeleton to calculate the mass (83 tonnes)







Delft Carillon


IBM
Blue Gene/P

Evolutionary

Robotics

Fitness Criteria

Genetic Algorithm

Controller

Segments

Muscles

Tendons

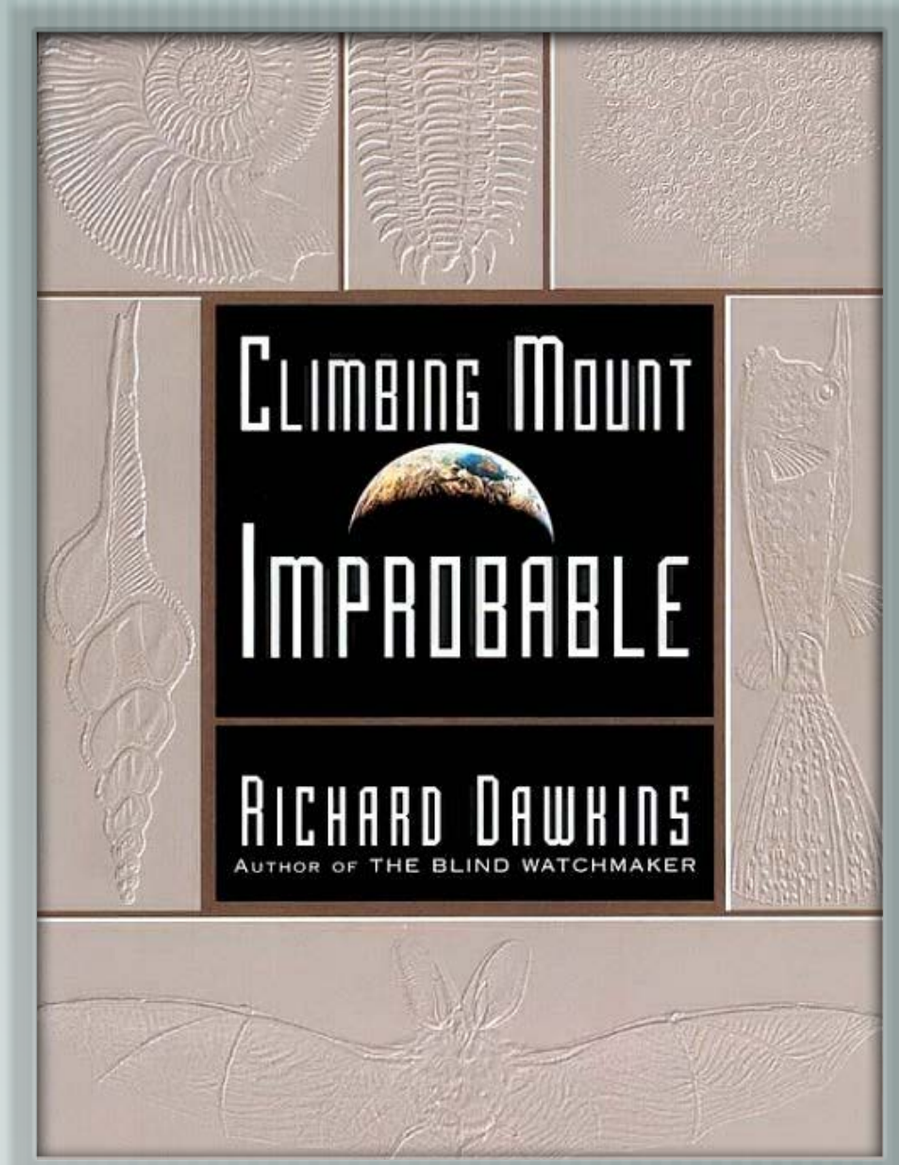
Physics Engine

Joints

Contacts

History of Evolutionary Algorithms

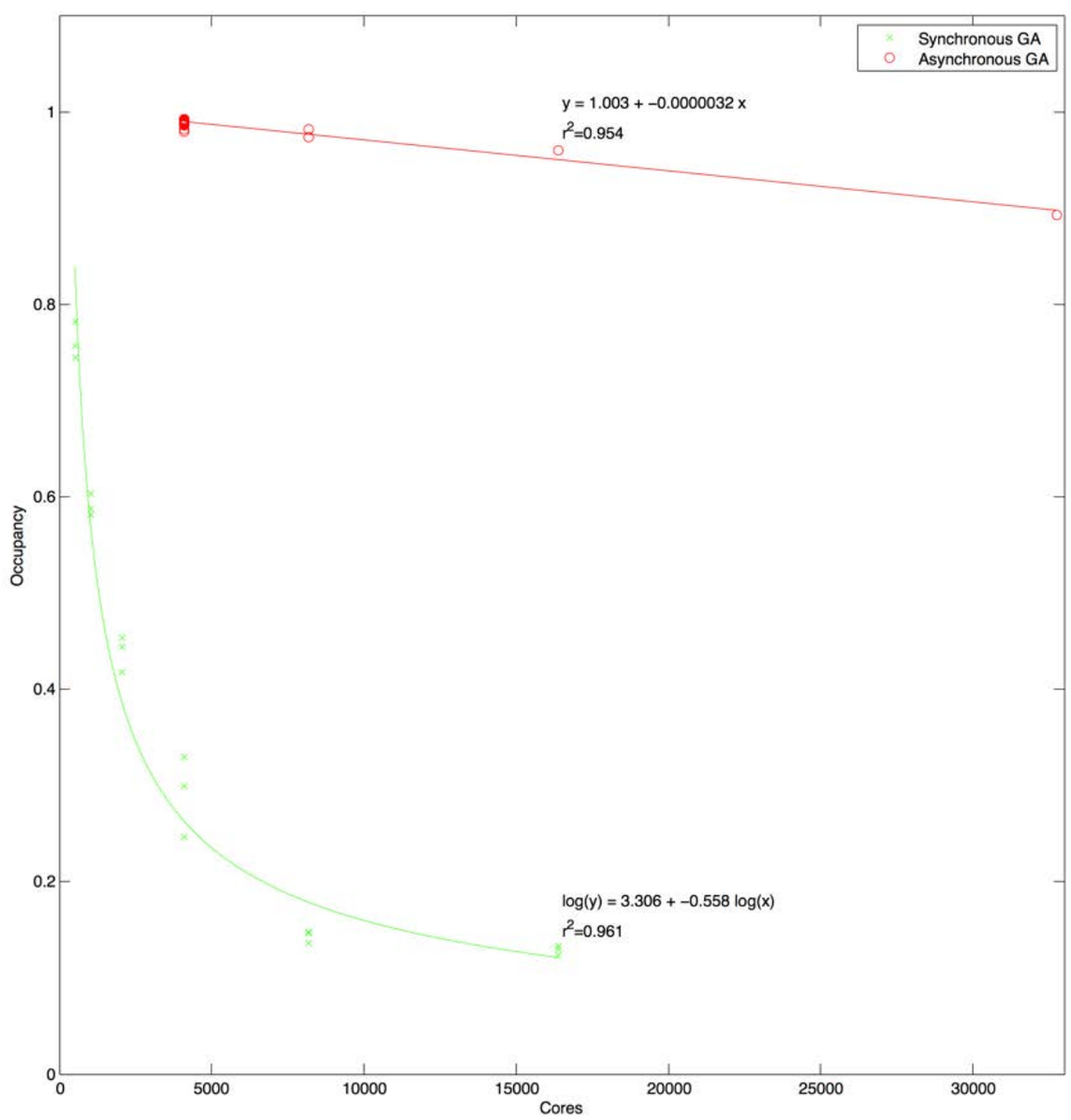
- Evolutionary Search 1960s
- Code problem as genome
- Simulated evolution where fitness is the solution quality
- Fittest genomes represent good solutions

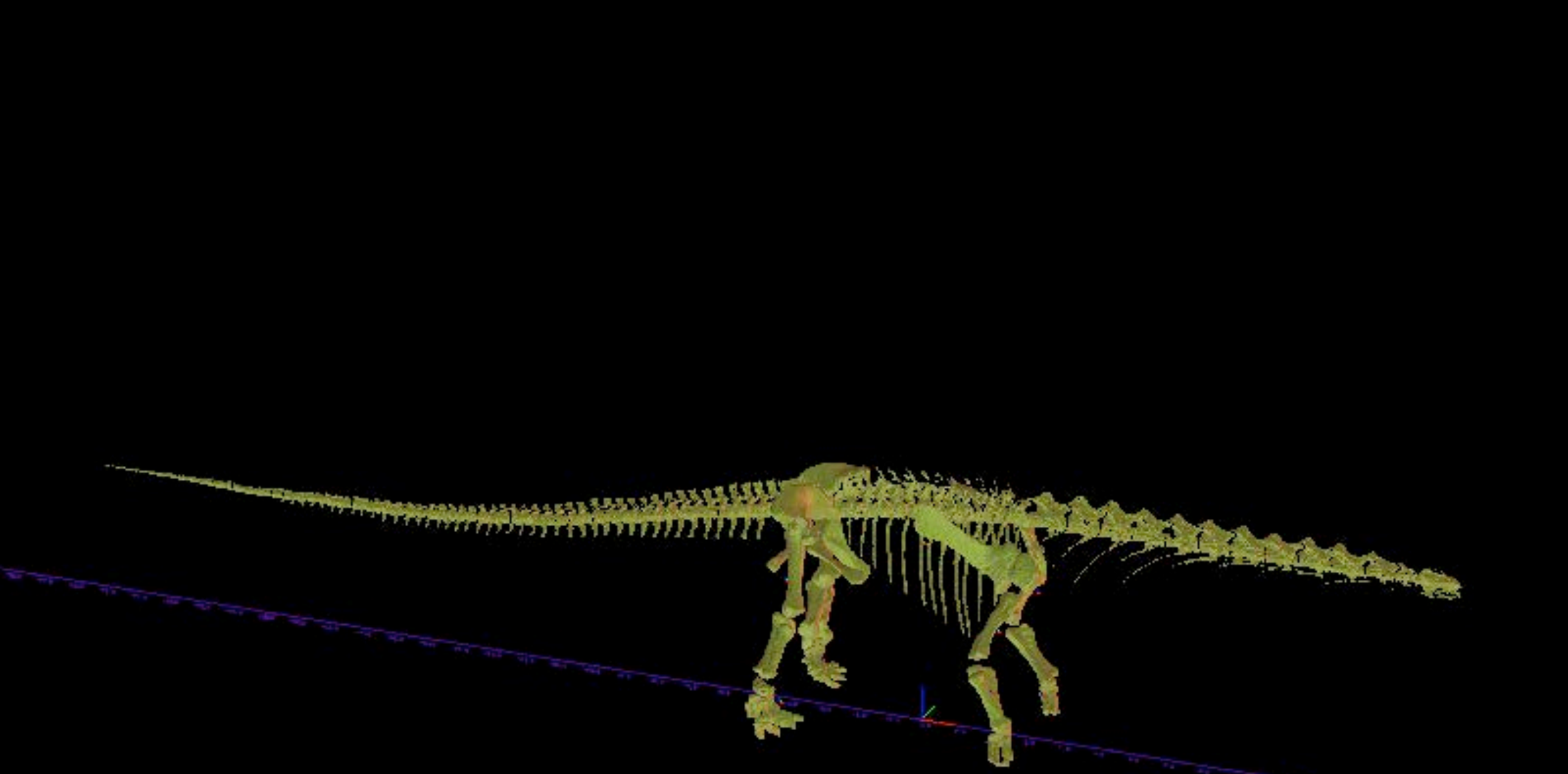


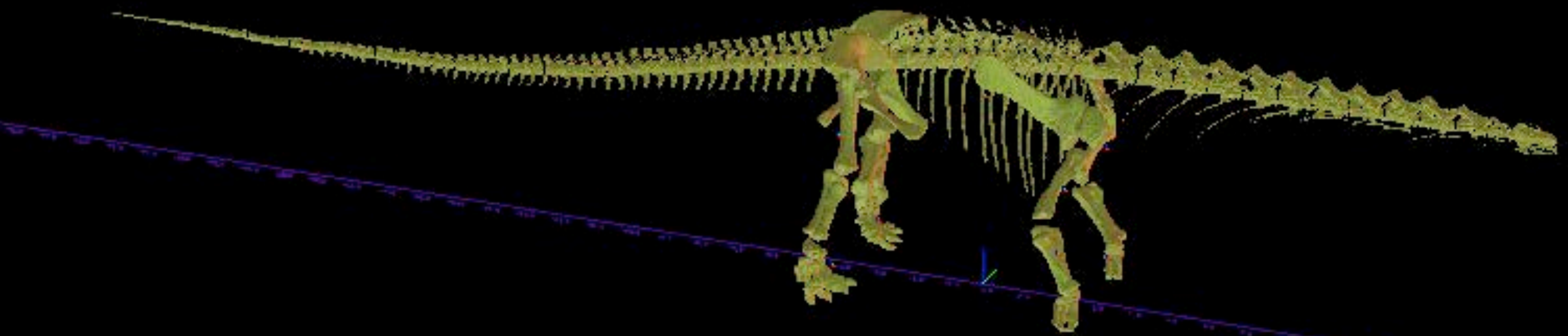
Implementation

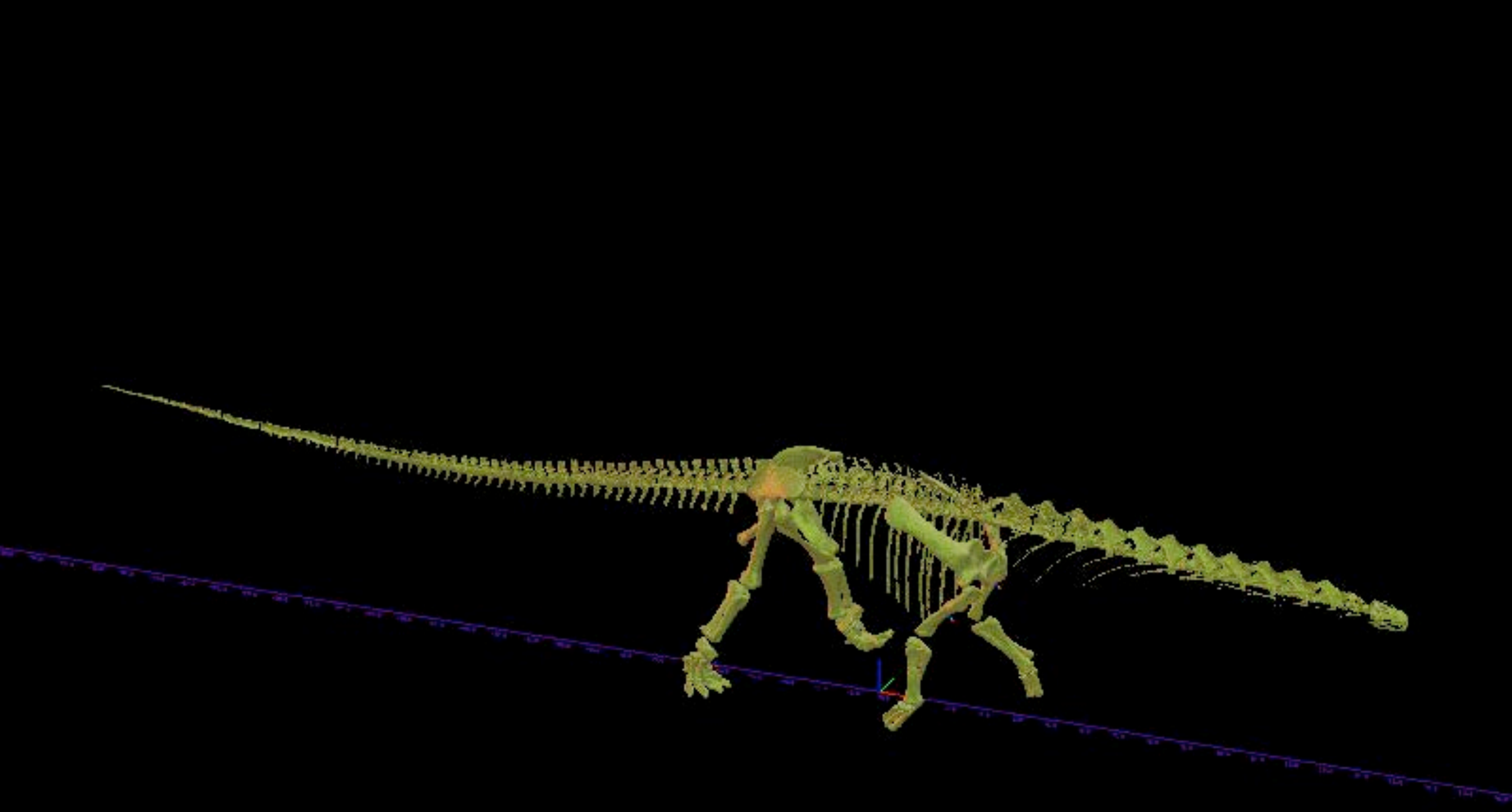
- Asynchronous Genetic Algorithm
- Maintain a single population and allow continuous selection, mutation and crossover
- Uses MPI with population on one node and the fitness assessments (slow) are carried out on individual compute nodes
- Allows the communication load to be spread out

Scaling

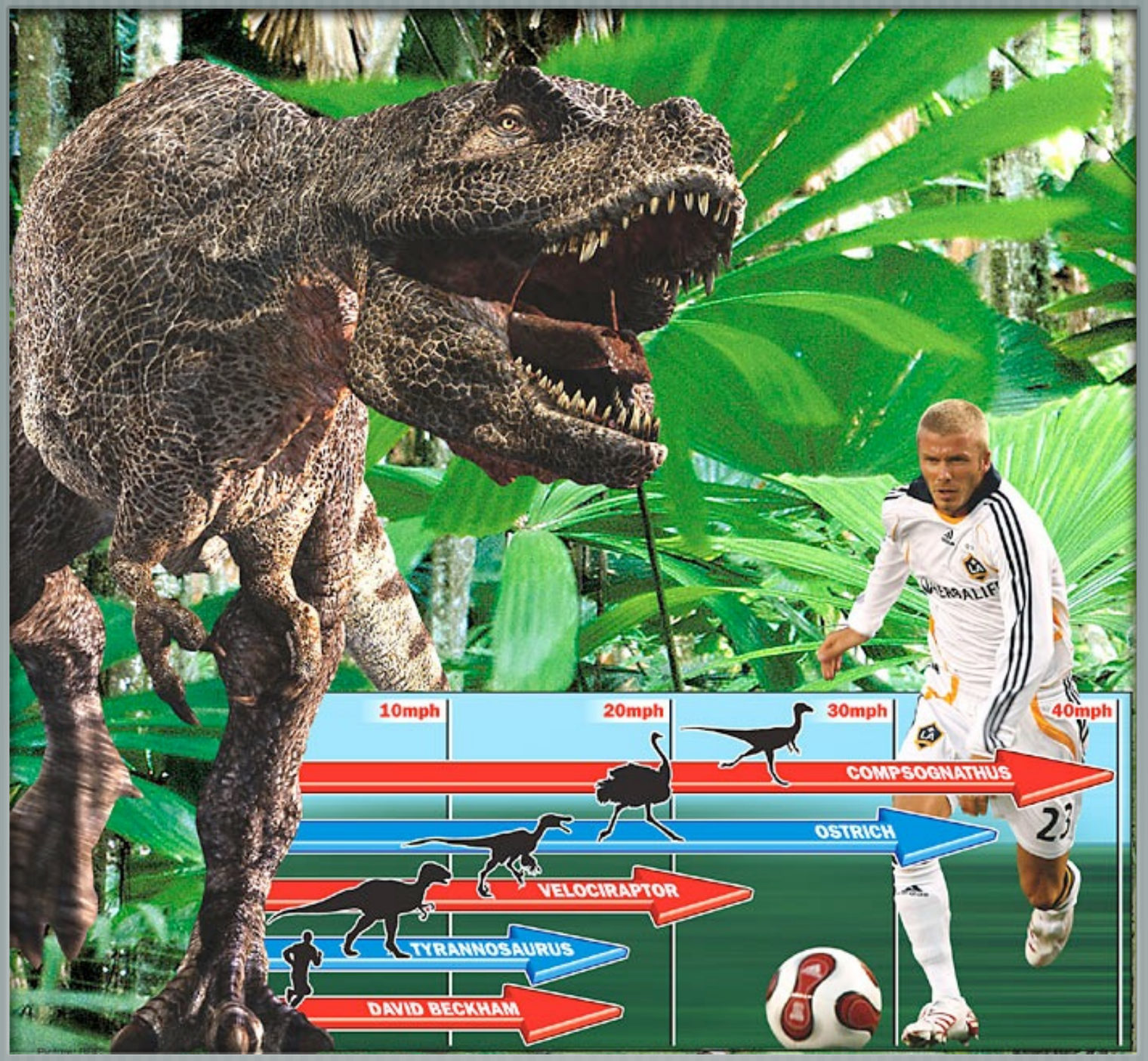

Synchronous GA
Asynchronous GA
y = 1.003 + −0.0000032 x
r²=0.954
log(y) = 3.306 + −0.558 log(x)
r²=0.961
Occupancy
Cores
0
0.2
0.4
0.6
0.8
1
0
5000
10000
15000
20000
25000
30000







T. rex faster than Bex???



Other Animals

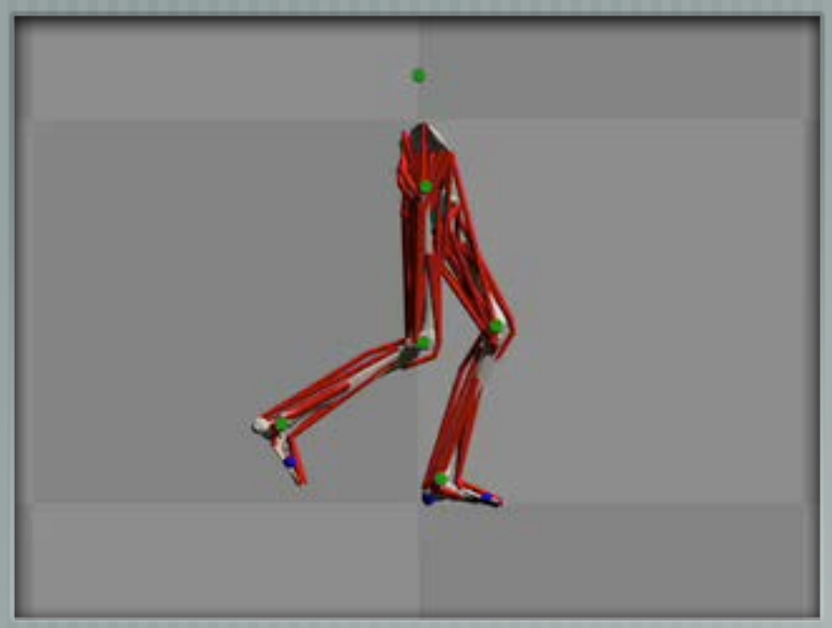
2001 (1968)

Human Bipedalism?

Ape-like Bipedalism

Early Hominin Gait

Bent Hip Bent Knee

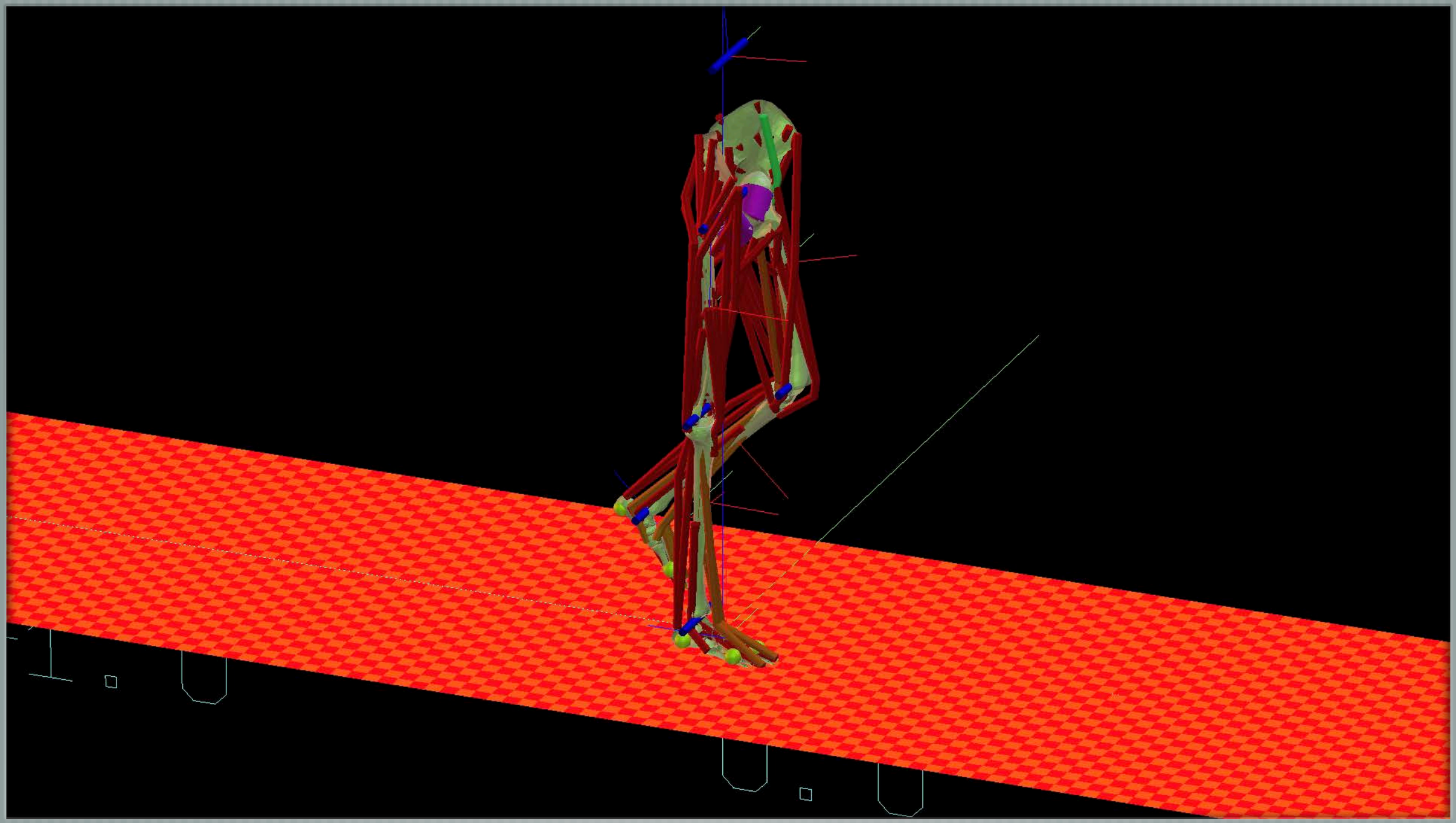


Upright

Laetoli Footprints

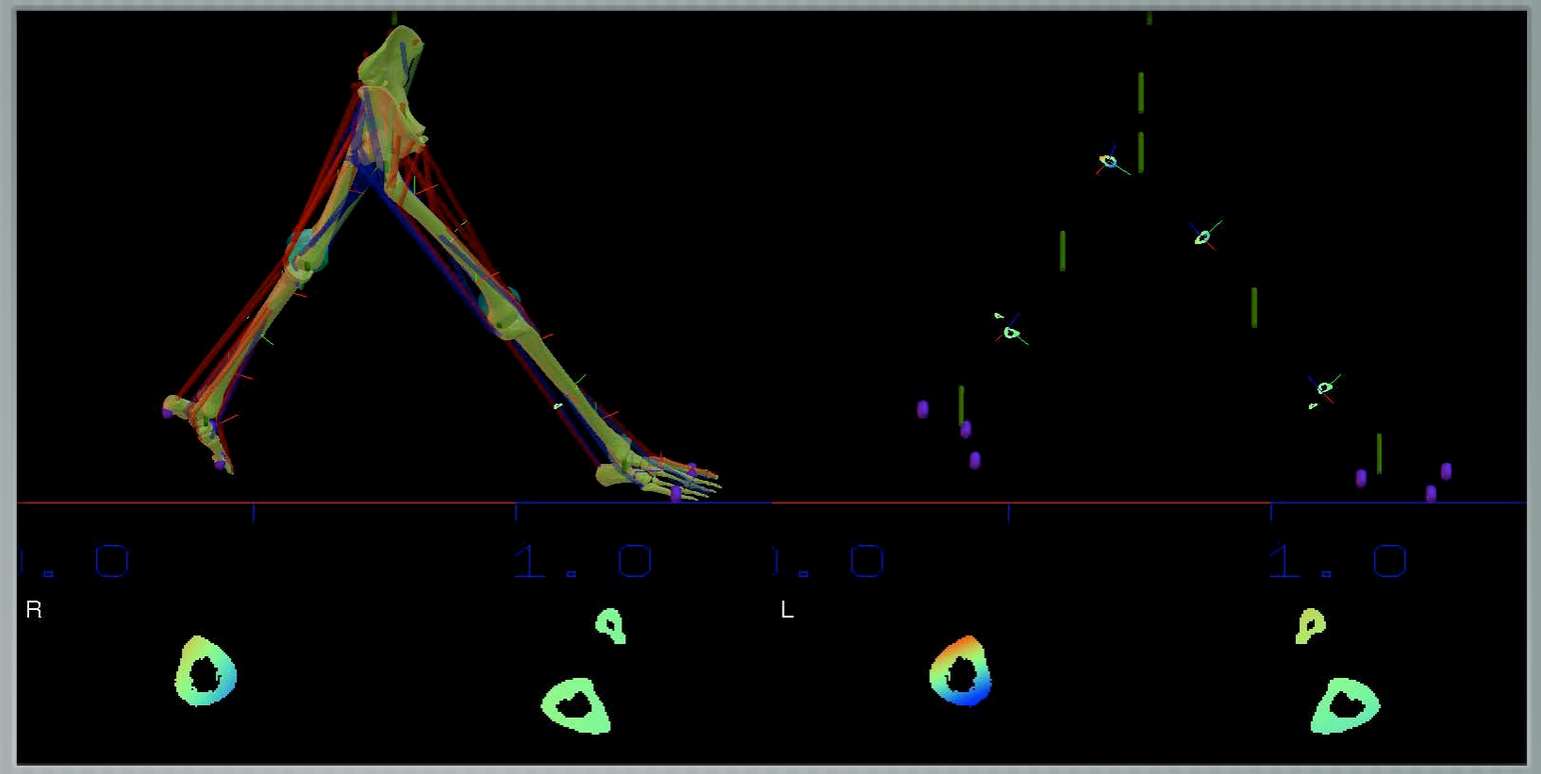
Upright & Groucho Walking

Crompton, R. H., Pataky, T. C., Savage, R., D'Août, K., Bennett, M. R., Day, M. H., Bates, K., Morse, S. & Sellers, W. I. 2012 Human-like external function of the foot, and fully upright gait, confirmed in the 3.66 million year old Laetoli hominin footprints by topographic statistics, experimental footprint-formation and computer simulation. Journal of the Royal Society Interface 9, 707-719.



Future Plans

- Upscale from 10,000 cores to 1,000,000 cores by implementing a multi-population approach (or find a new optimisation strategy - help!)
- Add an FEA solver for dynamic strain calculation
- Non-steady state locomotion



Thanks!

Animal Simulation Laboratory

- Charlotte Brassey, Karl Bates, Victoria Egerton, Peter Falkingham, Jacob Hepworth-Bell - who put in a lot of work
- Phil Manning, Lee Margetts, Paul Mummery - for a lot of technical advice and assistance
- Cliff Addison, Martin Baker, Rudolpho Coria - for HPC access, CT scanning and access to specimens
- NERC, BBSRC, EPSRC, Leverhulme Trust, National Geographic - for money

- Any Questions? Find me in the bar or email wis@mac.com

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