Introduction:

You all have probably seen Steven Spielberg's movie *Jurassic Park* (1997), which depicts dinosaurs such as the *velociraptor* as fast moving, very efficient predators. Spielberg's movie reflects some of the latest knowledge about dinosaur (even though most of the species appearing in *Jurassic Park* are actually a couple million years younger and did not exist until the Cretaceous). Compare this to Walt Disney's *Fantasia* (1940), where dinosaurs are portrayed as mostly sluggish, half-aquatic (to support their large body size) creatures and you might wonder, how we know so many details about dinosaurs when all we have left is a bunch of bones and footprints. In this lab we will estimate the walking speed of dinosaurs to answer the question: Could you outrun a dinosaur?

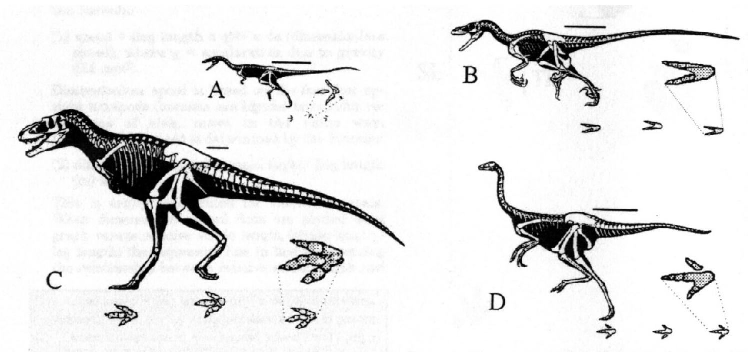

Figure 1. Bipedal carnivorous dinosaurs (theropods) and representative trackways attributed to similar species. Scale bar is 0.5 m. A – coelurosaur *Coelophysis* (from Paul, 1987) and unnamed trackway (from Thulborn, 1990). B – raptor *Velociraptor* (from Paul, 1987) and conjectural trackway. C – carnosaur *Albertosaurus* (from Czerkas and Czerkas, 1991) and unnamed trackway (from Thulborn, 1990). D – ornithomimid *Struthiomimus* (from Wade, 1989) and *Ornithomimipus* (ichnogenus; from Thulborn, 1990).

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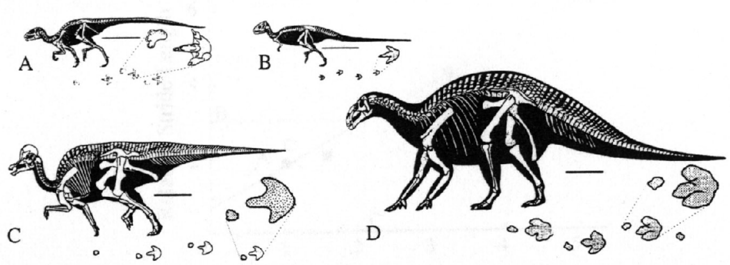


Figure 2. Bipedal and quadrupedal herbivorous ornithopod dinosaurs and representative trackways attributed to similar species. Scale bar is 1.0 m. A – ornithischian *Erikosaurus* (from Paul, 1987) and *Moyenisaurgous* (ichnogenus attributed to ornithopod; from Thulborn, 1990). B – pachycephalosaur *Homocephale* (from Paul, 1987) and *Anomeopus* (ichnogenus attributed to small ornithopod; from Thulborn, 1990). C – crested hadrosaur *Hypacrosaurus* (from Paul, 1987) and *Gypsichnites* (ichnogenus; from Thulborn, 1990) with additional conjectural manus prints. D – iguanodont *Iguanodon* (from Czerkas and Czerkas, 1991) and *Caririchnium* (ichnogenus; from Thulborn, 1990).

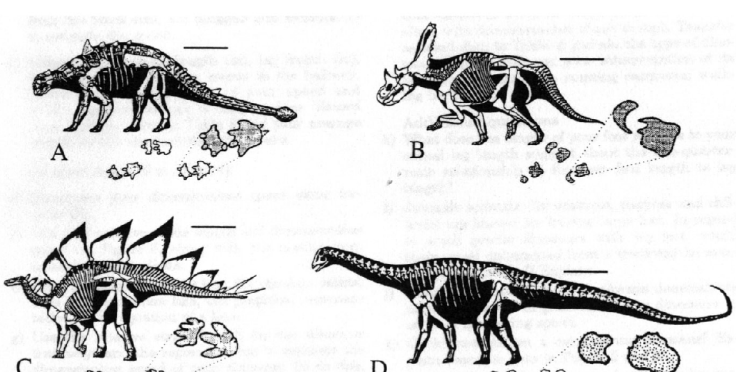


Figure 3. Quadrupedal herbivorous dinosaurs and representative trackways. Scale bar is 1.0 m. A – ankylosaur *Euoplocephalus* (from Czerkas and Czerkas, 1991) and *Tetrapodosaurus* (ichnogenus; from Thulborn, 1990). B – ceratopsian *Chasmosaurus* (from Paul, 1987) and unnamed trackway (from Thulborn, 1990). C – stegosauran *Stegosaurus* (from Paul, 1987) and conjectural trackway (from Thulborn, 1990). D – sauropod *Titanosaurus* (from Czerkas and Czerkas, 1991) and *Brontopodus* (ichnogenus; from Thulborn, 1990).

1. The Size of Dinosaurs

Getting at the size of dinosaurs seems to be pretty straightforward: just measure the fossilized skeletons ... Well, in this exercise today you won't see a single fossilized bone, but our size reconstructions are based on the measurements of footprints, or tracks.

The basic idea is that nature repeats

[1]This lab exercise is based on two articles by Over (1995) and Renshaw et al., (2000) as well as a laboratory handout by D. Czeck, (2001)

itself, and some basic features of some vertebrates are remarkably similar (due to the fact that we all came off the same evolutionary tree). One such ratio that is relatively constant for many species (including ourselves) is the ration between leg length and foot length, or in mathematical terms:

$$\frac{L}{F} = c \qquad \text{(eq. 1)}$$

where L is the length between your foot and your hip or *leg-length*, and F is the length of your foot or *foot length* (or later the size of your footprint). Based on your leg-length and some anatonomical knowledge you can estimate your body size. For humans the body size would be close to twice the leg size, probably a bit less. Today's first exercise will deal with the size of dinosaurs, and we will calculate the ratio L/F for humans before we attempt to reconstruct dinosaur sizes based on the size of their footprints.

Figures 1 - 3 show you several dinosaur reconstructions and their tracks. Note that the size of every dinosaur is given by a scalebar, representing 0.5 m or 1.0 m respectively. You notice that dinosaurs come in a variety of sizes and we will have to find a method that fits them all (or at least most of them).

2. How Fast Could They Run?

In the 1960's R.M. Alexander analyzed the tracks and walking/running speeds of many different animals (birds, mammals, etc...) and realized that walking or running speed is roughly proportional to leg length and stride length. We will test this assumption first on the species must accessible to us (humans) and will then try to reconstruct the walking speeds of dinosaurs based on the dinosaur tracks found in front of and inside the Life sciences Building.

We will first explore the connection between stride length (S) and walking speed (s). You can convince yourself rather easily that your stride length increases as you walk (or run) faster. We will quantify this relationship in exercise 3.

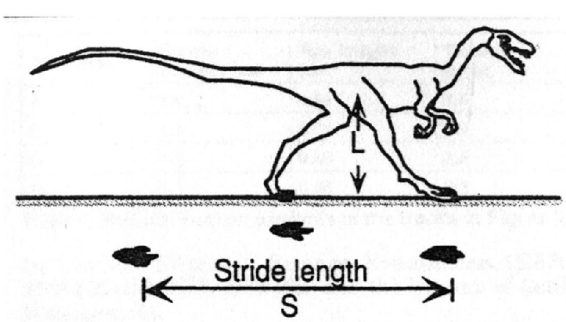


Figure 4. Dinosaur schematic demonstrating the leg (L) and stride (S) lengths. After Alexander (1991).

Fig. 4

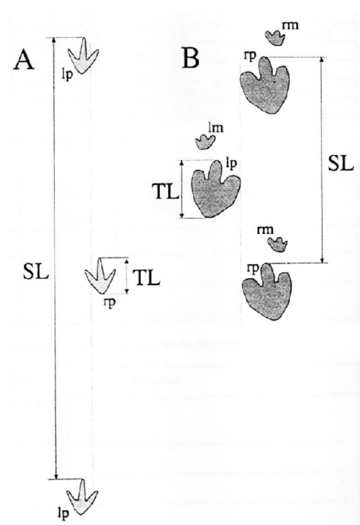


Figure 5. Measurement of track length (TL) and stride length (SL) from a stylized carnivorous dinosaur (theropod) trackway (A) and stylized quadrupedal herbivorous (ornithopod) trackway (B). The tracks are labeled right (r), left (l), manus (front) (m), and pes (hind)

Armed with our experimental data from exercise 3 we could now plot speed versus stride length, but it will become clear that we would need a new graph for each person, because everybody's leg length (and therefore stride length) is different. Remember, the size variations in dinosaurs are much larger than in humans, so we have to accommodate those differences. For this reason we resort to normalized, dimensionless variables:
Instead of plotting stride length S we calculate the ratio S/L, or **relative stride length**.

$$\frac{S}{L} = relative\ stride\ length \qquad \text{(eq. 2)}$$

You noticed that your stride length increases as you run or walk faster, but your maximum stride length is determined by your leg length and the relative stride length S/L compensates for differences in body size. S/L indicates your "**stride efficiency**" or how much of your stride you are using when walking at a certain speed.
Notice, that both S and L have dimensions of *length* (or units of m), while the normalized stride S/L is *dimensionless* (the units cancel out). Dimensionless parameters have the advantage of being independent of the unit of measurement used in the calculation. As long as you use the same units consistently it doesn't matter which unit you use. Normalized stride length, for example, remains the same whether S and L are initially measured in meters, feet, inches etc. Try it out!
A similar argument can be made for a normalized speed parameter. While stride length S is more or less defined by leg length L, speed depends on both leg length L and the Earth's gravity g. To see how gravity affects your ability to walk and run recall the Apollo astronauts and their effortless walks across the lunar surface (in bulky space suits and huge life support backpacks).
However, if we simply use L and g as normalizers for s we get

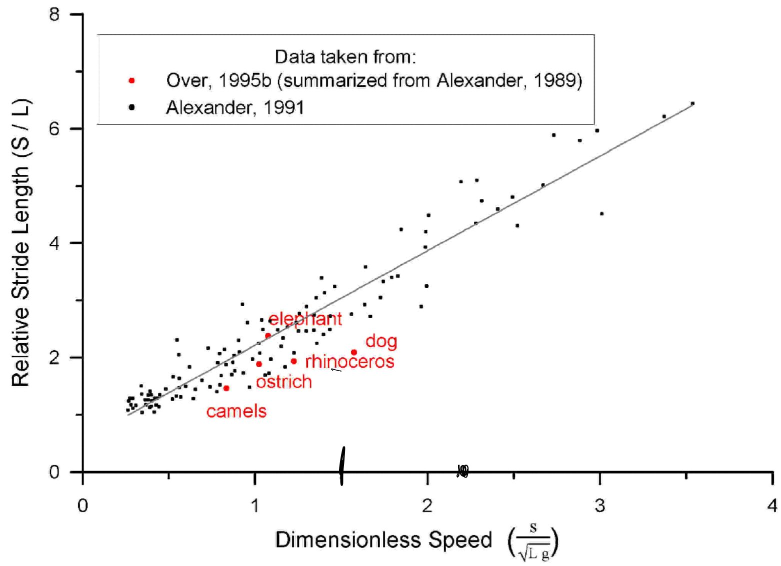
$$s_n = \frac{s}{Lg} \qquad \text{(poorly normalized speed)}$$

The units of s_n do not cancel out and our normalized speed is *not* dimensionless. We can avoid this problem by using the following ratio:

$$s_n = \frac{s}{\sqrt{Lg}} \qquad \text{(dimensionless normalized speed)} \qquad \text{(eq. 3)}$$

which is dimensionless (and also known as the *Froude number* to the guys who study fluid dynamics and similar engineering problems).

Note we now have two equations (eq. 2 and 3) that tell us how much of our stride we use (relative stride length, eq. 2) and how our stride efficiency is linked to walking or running speed (eq. 3). We can measure stride length S based on the spacing of foot prints and estimate the leg length L from eq. 1. The gravitational acceleration g is a constant and the physicists will tell you that $g = 9.8\ m/s^2$. Fig. 4 shows you how stride length relates to the footprints you find in the mud, or rock outcrops.
Fig. 5 shows the relation between normalized stride length and dimensionless speed for a variety of animals. You can see that the relation is not perfect (there is quite a bit of scatter in the data), but the two parameters are clearly related to each other. After measuring S and estimating L you can use Fig. 5 to find the dimensionless speed for any relative stride value.



References:

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Assignments:

Exercise 1:

Working in groups of 3 or 4, determine your foot-length F and leg-length L, using a metric ruler (no inches, please!).

a) Measure leg length from the ground up to your hip bone and foot-length from heel to toe.

b) Enter all the data into a table and find the averages for F and L and calculate the ratio L/F.

c) How accurate is your result? Can you give an error estimate? Make sure you discuss the uncertainty of your measurements in the lab report.

Exercise 2:

a) Determine the approximate scale used for the drawings of *Velociraptor* (Fig. 1b) and *Titanosaurus* (Fig. 3d) by measuring the length of the scalebar with a ruler and converting to common units. For example: the scalebar for *Albertosaurus* (Fig. 1c) is 4mm long and represents 0.5 m. To calculate the scale of the drawing we have to convert both measurements to the same units. With 0.5 m = 500 mm we get a scale of 4 mm / 500 mm = 1/125. Make sure you do the calculations in your notebook and keep them legible!

b) How tall was *Velociraptor*, how long was *Albertosaurus*?

Exercise 3: Determining the dimensionless speed of humans

a) use the measuring tapes to set up a course, 20 m long.

b) each member of your group should cross the course 3 times, the other members of the group measure: how long it takes for the person to finish the course (Δt) and the stride length (S). The stride length is best measured by counting how often the person's left (or right) foot hits the ground while crossing the course.
First cross the course at **walking** speed, then at an easy **jogging** pace, and finally **sprint** it as fast as you can. Summarize your results in a table in your lab notebook.

c) Calculate the relative stride length and dimensionless speed for each run and enter the data onto the enlarged copy of Fig. 6. make sure you draw your results accurately! How well do your results fit with the data shown by Anderson (1991)?

Exercise 4: How fast were the Dinosaurs?

There are two fossilized dinosaur track ways located in front of and inside the life sciences building. Before you start measuring, study the tracks and compare them with the tracks shown in Figs. 1-3.

a) What types of dinosaurs made these tracks? Were they bipedal or quadrupedal? How many different types of tracks can you see?

b) Once your group agreed on a certain basic type measure the foot length for a series of tracks. Report all your measurements in your lab book and find the average track (or foot) length. Note, there are several types of tracks preserved, so you have to make sure that you don't mix up the tracks of the various species. **Use a ratio of L/F = 4 for your calculations.**

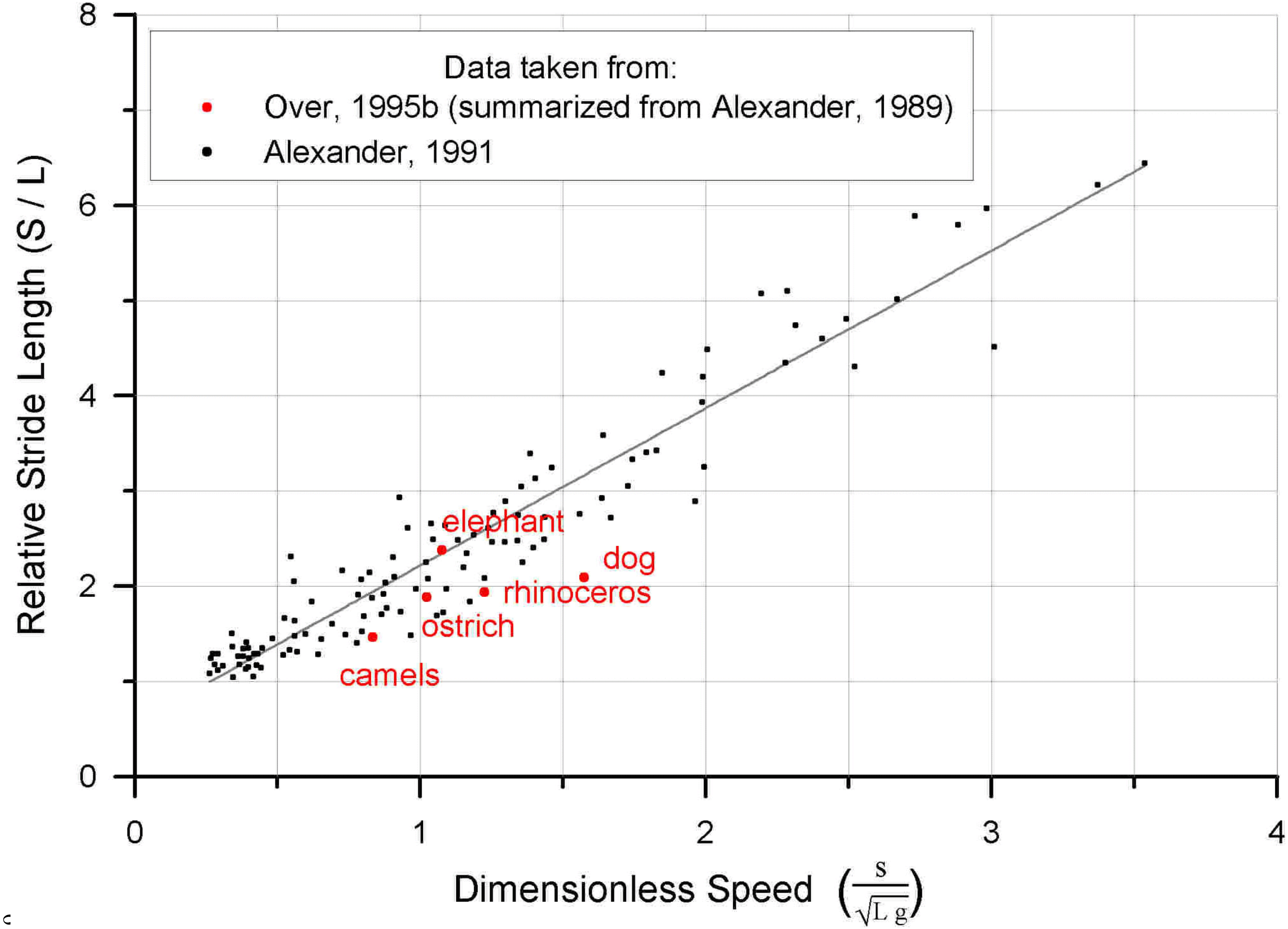
c) Based on the likely body type, estimate the size of the dinosaur using the calculated leg length L and Figs. 1 - 3.

d) Now measure the stride length (see Fig. 4 on how to do this) for both track ways. Again, make sure you measure as many strides as you can find, don't mix up the various species, and report them in your lab book and use an average stride value for your calculation of relative stride length. Reporting your measurements and results in a table is a good idea.

e) Find the dimensionless speed s_n for the various tracks from Fig. 5.

f) Calculate the actual speed s (in meters/second) by solving eq. 3 for s.

g) Now, here comes the hardest part: Sit back and consider all the uncertainties that went into your estimate of dinosaur speed. We had uncertainties creeping in at various places and they all will affect the final result. Could you devise strategies that could improve our estimate? And, finally, could you outrun a dinosaur?


Data taken from:
Over, 1995b (summarized from Alexander, 1989)
Alexander, 1991
elephant
dog
rhinoceros
ostrich
camels
Relative Stride Length (S / L)
Dimensionless Speed $\left(\frac{s}{\sqrt{L g}}\right)$
0
2
4
6
8
0
1
2
3
4