Lecture 1: Speed and velocity

What's important:

- definitions of distance, displacement, speed and velocity

Demonstrations: keratocyte video

Logistics

Textbook: *Physics* by Giancoli

Further reading in biology (just for interest, not needed in this course, don't buy these!)

Molecular Biology of the Cell by Alberts *et al*. (Garland)

Random Walks in Biology by Howard Berg (Princeton)

Grading:	10%	8 assignments	Dates on website
	40%	3 midterm exams (10 - 15 - 15)	
	50%	Final exam	

Useful local websites:

on-line lecture notes *etc*. for this course can be found through

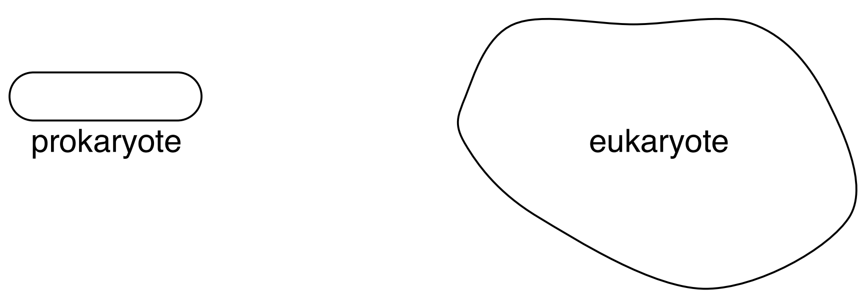
http://physics.sfu.ca or http://www.sfu.ca/~boal

Cells

See Supplement #1 on my PHYS 101 website for details on cell structure and classification. All we want to introduce at this point are the cell dimensions:

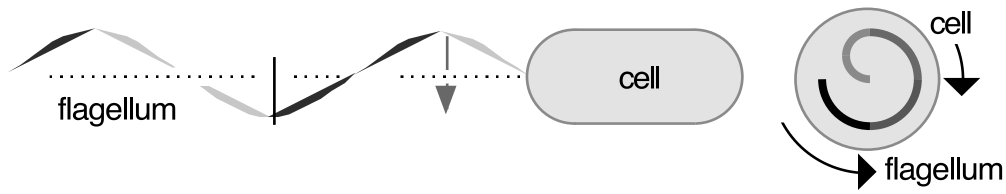
Prokaryotes – cells with no internal structure dating back at least 3.5 billion years on Earth. Modern-day bacteria are prokaryotes. Typical dimensions are a few microns (1 μm = 10^{-6} m); for example, *E. coli* (one cause of gastrointestinal problems) is about 4 μm long and 1 μm across.

Eukaryotes – thought to have appeared about 2 billion years ago, around the time of the rise of atmospheric oxygen. Lots of internal structure, including filaments, networks and internal compartments such as nuclei. Internal compartments are bacterial in size, and the overall cell size is in the 10 μm range. The cells of our bodies are eukaryotes.

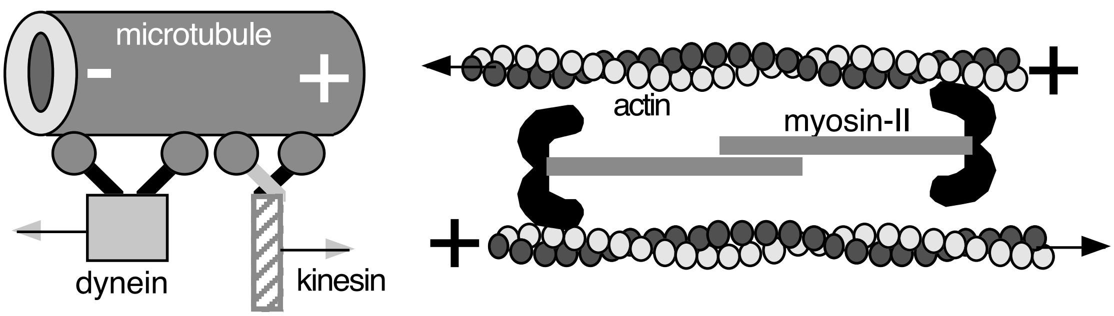


Motion in the cell

Bacteria swim to hunt for food (following a chemical scent); their random motion also makes them more difficult to be caught by bacteria-seeking eukaryotes, such as macrophages, which try to kill bacterial pests in our bodies. One mode by which bacteria swim is through the rotational motion of flagella, long whip-like structures which may be attached to each end of a bacterium.



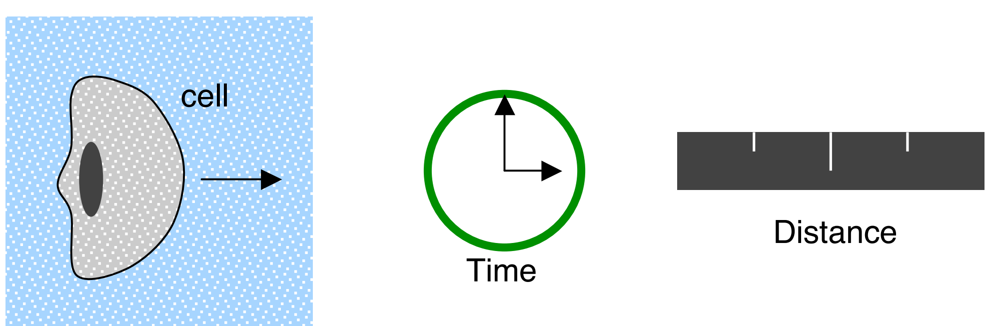
Muscles are primarily composed of filaments of the proteins actin and myosin. Myosin uses its flexible neck to ratchet along an actin filament, which is like a rope composed of individual globs of actin.



Video of keratocyte motion (complex). In the video (from U. North Carolina), a eukaryote slides along a substrate by extending its actin-rich lamellipodium. Speed is a micron/second or less.

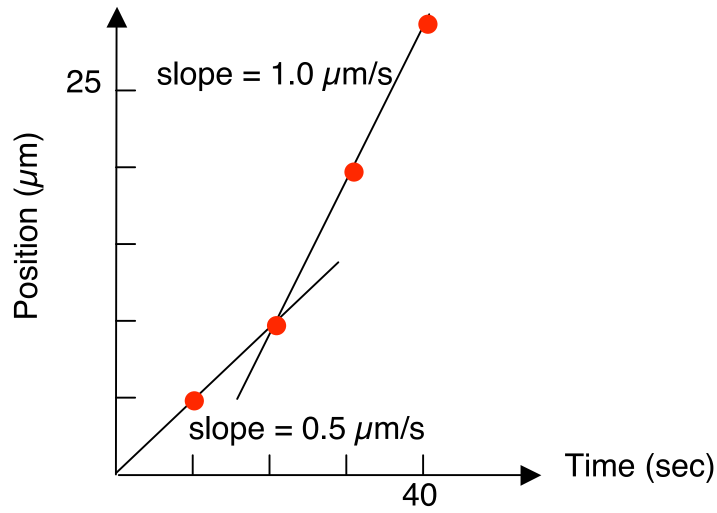
Position and time

Our discussion of kinematics begins with an experiment. Suppose that we perform a series of measurements on a cell's position as a function of time.



Data:

Time (sec)	Position (μm)
0	0
10	5
20	10
30	20
40	30



The position x could have positive or negative values; in general, it has a direction and is mathematically called a vector.

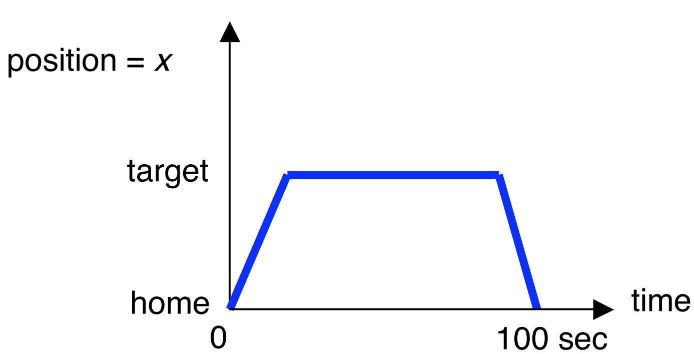
Velocity, speed and distance

In the position *vs*. time graph, we interpolate between the data points and see two straight-line segments. The slope of these segments is related to the rate of change of position, or the velocity. Without making any assumption about the path taken between any two measurements 1 and 2, we can define

$$[\textit{average velocity}] = \bar{\mathbf{v}} = \frac{x_2 - x_1}{t_2 - t_1} \qquad \text{(independent of path).}$$

In our example, the cell moves at 0.5 μm/s initially, then increases to 1 μm/s after 20 seconds. The top speed of a cell is about a micron per second, but most of those cells capable of moving at all, move much more slowly (< 0.1 μm/s).

Although path-independent quantities, such as the average velocity, are easy to define and evaluate, they have their limitations. Consider the motion of a cell approaching a target:

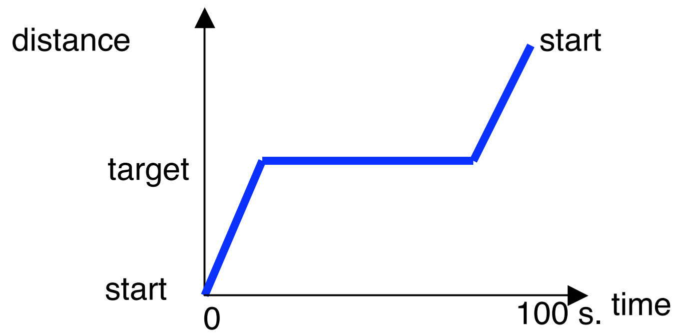


Calculate the average velocity of the cell from 0 to 100 seconds. The change in position is obviously zero:

$$[\textit{average velocity}] = \bar{\mathbf{v}} = \frac{[\textit{change in position}]}{[\textit{change in time}]} = \frac{\Delta \mathbf{x}}{\Delta t} = 0$$

The average velocity does not always tell us what we want to know about the motion.

The position of an object with respect to a reference location is called its **displacement**. A different quantity used to describe the motion is the path length or **distance**, obtained from the position by ignoring the direction of the motion, and summing over the magnitudes of all the individual displacements.



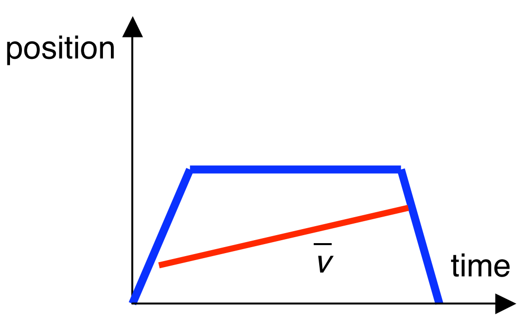
Displacement tells you where you are at a given time, **distance** includes part of the history of how you got there. Displacement is the more fundamental quantity, in that you can find the distance knowing the time history of the displacement, but you can't find the displacement knowing only the time history of the distance.

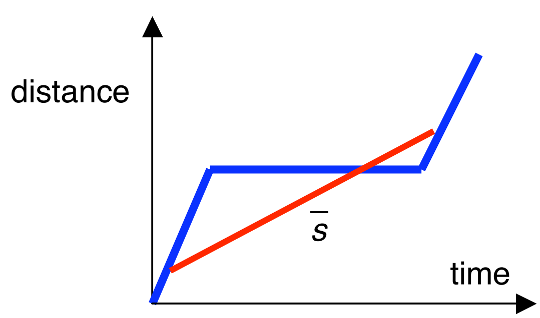
Now, we can use **distance** to define an average **speed** in the same way that we used **displacement** to define an average **velocity**:

$$[\textit{average speed}] = \bar{s} = \frac{[\textit{change in distance}]}{[\textit{change in time}]}$$

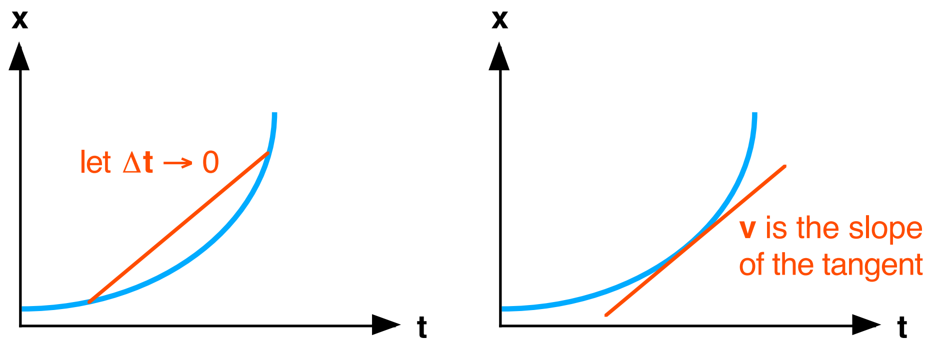
Both average speed and average velocity can be obtained from the slope of the line joining the two ($\mathbf{x}$, t) points:

$$[\textit{slope}] = \frac{\mathbf{x}_2 - \mathbf{x}_1}{t_2 - t_1} = \frac{\Delta \mathbf{x}}{\Delta t}$$





We can define an instantaneous velocity **v** (or instantaneous speed *s*) by finding the slope of the tangent to a point on the curve, so $\mathbf{v} = d\mathbf{x}/dt$:



Note that **v** has a sign (positive or negative), but *s* does not, because the distance never decreases with time. Further, the instantaneous speed is just the absolute value of the instantaneous velocity:

$$s = |\mathbf{v}|.$$

Lastly, what is the reverse process of finding the slope?

slope of an *x vs*. time graph is a rate of change

area under a rate of change *vs.* time graph is the **CHANGE** of *x*

For example, driving a car at a speed of 100 km/hr for two hours gives a distance of 200 km according to

change in distance = [*mean speed*] • [*time*].