Simulating Random Walks within the Cell

Cells rely on intracellular roadways to transport cargos between different locations in the cell, much like countries depend on real-life roads to transport goods and materials across the country. Trucks play the important role of transporting goods between cities; within your cells, molecular motors are responsible for pulling cargos along roadways called microtubules.

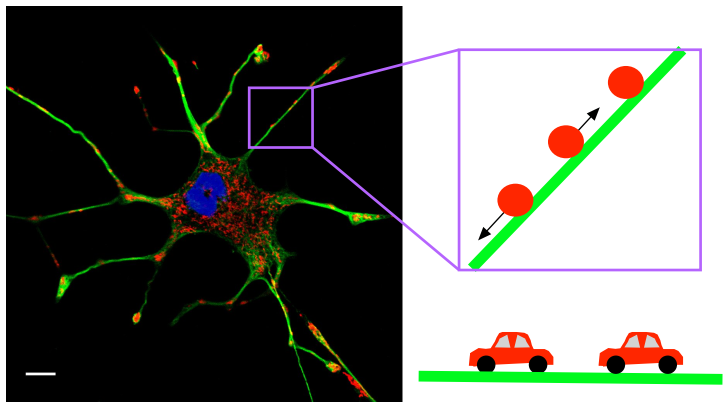
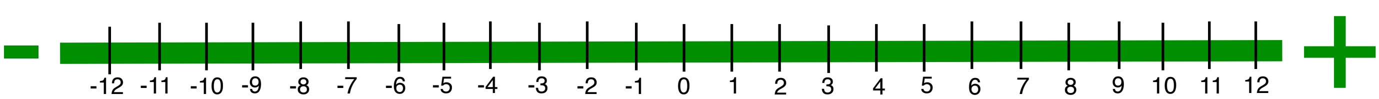


Figure 1: This is a picture of a cell with lime green roadways inside of it. These roadways are responsible for transporting cargos (red) throughout the cell. You can think of cargo travel inside your cells as similar to car travel on roads, but there are two big differences: cargo travel is random and occurs in both directions, not just forward. Image credit: image of cell is by 8x57is [CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)], from Wikimedia Commons.

While trucks drive forward toward their destination, transport inside cells is complex and stochastic. Motors take turns grabbing onto cargos and pulling them in different directions. One type of motor, which we will call the + motor, takes steps in the positive direction toward the plus end of the microtubule, while another motor, which we will call the - motor, attaches to cargos and pulls them toward the – end. Depending on which motor is attached to the cargo, it will move in the positive or negative direction. This creates a random walk, and we are going to use a random walk simulator in Matlab to explore how these two motors impact how far cargos travel within the cell.

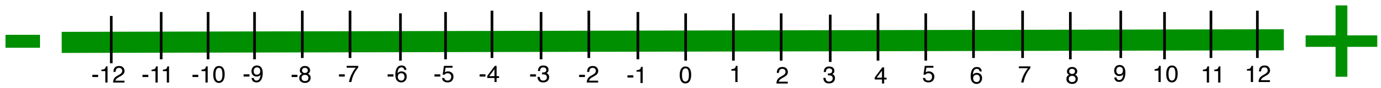
Task 1: First we will assume that for each step, a cargo is equally likely to be attached to a + motor or a - motor. This means that the probability that a cargo takes a step in the positive direction is 50%, and the probability that it takes a step in the minus direction is 50%. This is the same as a coin flip, and we will now use the coin and microtubule number line provided to examine a cargo's random walk. Initially place your pencil tip at x = 0. Your partner will flip a coin: if it lands heads, move your pencil tip one step in the + direction. If it lands tails, move your pencil tip one step in the – direction. Repeat this process 9 more times for a total of 10 coin flips. Where does your cargo end up?



Coordinate of your first cargo: ____

Cargo's final distance from the origin: ________________________________

Now switch with your partner: it's their turn to move the pencil while you flip the coin. Repeat the experiment from before with the microtubule number line on the next page. What does your team get this time?



Coordinate of your second cargo: ________________________________

Cargo's final distance from the origin: ________________________________

What is the average of your two coordinates? To find the average, add the coordinates of your cargo and your partner's cargo and divide by 2:

(________________ + ________________) ÷ 2 =____________________

That was a lot of work! Imagine if the cargo was taking 2000 steps rather than 10. We'd be flipping coins all day!

Task 2: Now we will use computer code instead of coin flips to study transport in cells. You provide the number of steps and the code will return an animation of the cargo's journey in the cell, the final coordinate, and the final distance travelled.

Run this script for 100 steps and write your results below:

Coordinate of your cargo: ____

Cargo's final distance from the origin: ________________________________

Compare your results with a friend and take the average of your two cargos' final coordinates. Does this average match your intuition and your coin flip experiment?

Average final coordinate: ____

So far we have studied unbiased random walks; this means the cargo has the same chance of moving to the right as it does to the left. What if the cargo is more likely to move in the + direction than the – direction on the microtubule? Biologically, this could mean that there are more + motors than - motors in the cell, for example. Suppose the probability of moving to the right is 70% and the probability of moving to the left is 30%.

Task 3: Let's conduct a number of random walks to determine how far a cargo will likely travel in 100 steps if the probability of moving to the right is 70% and the probability of moving to the left is 30%. Using the computer program, conduct 20 random walks. Record the coordinates of the cargo's final position and the cargo's final distance from the origin in Table 1.

Table 1: Cargo Transport Simulation Results

Run number	X coordinate	Distance
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
Average		
Minimum		
Maximum		

Compare your results with another group. Explain your observations.

Task 4: Now we will conduct a mathematical biology experiment. Suppose you are working with a biologist to help determine if a cell has more + or - motors present, but the motors are too difficult to see under a microscope, so they cannot be counted. Instead, only the cargos can be seen. The biologist you are working with gives you the following table of data showing the final distance travelled and location of 20 cargos she observed in her lab for 100 steps each.

Table 2: Cargo Data from the Lab

Observation	X coordinate	Distance
1	-38	38
2	-51	51
3	-39	39
4	-34	34
5	-31	31
6	-38	38
7	-47	47
8	-34	34
9	-49	49
10	-20	20
11	-43	43
12	-35	35
13	-47	47
14	-29	29
15	-38	38
16	-32	32
17	-47	47
18	-43	43
19	-42	42
20	-25	25
Average		

Using this data, can you predict whether there are more + or - motors present in this cell? What is your prediction? To improve your prediction, what would you suggest your biological collaborator do?

In making your prediction, what data was more helpful to know: the final coordinate or the distance travelled by the cargo?