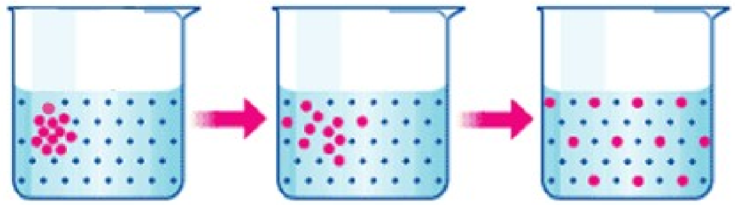
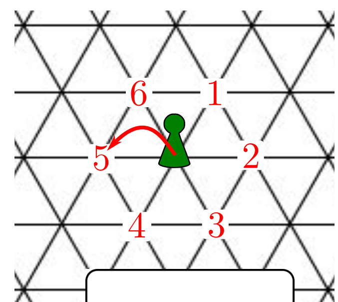
Diffusion: Spreading with Random Walks

All small particles in a fluid jiggle around in a 'random walk' due to being kicked by the surrounding fluid molecules.

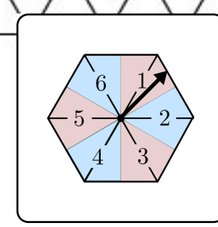


We can use a simulation to understand the behavior of tiny diffusing particles.



1. Every player should place a token on the central red star of the printed triangular network. The "walker", which represents a microscopic particle in water, will step along the network one line segment at a time.

2. Spin the spinner or roll a dice, each time moving the walker in the direction shown. Count your steps



How many steps did it take your walker to step outside the **blue** fence?
(write in your number on the display board)

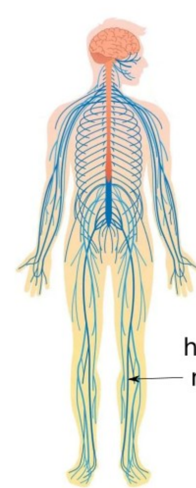
How many steps did it take your walker to step outside the **red** fence?
(write in your number on the display board)

The red fence is twice as far as the blue. On average, how much longer does it take to reach it?

Diffusion is very slow for moving molecules across large distances! Molecules can get across a small distance (like a bacterium) by diffusion alone. But to get across long distances, other ways of transport are needed to move particles around.

E. coli bacterium

$\frac{1}{100}$ second
for sugar molecule
to diffuse across



300 years
for sugar molecule
to diffuse across

Active Transport in the Intracellular World

For delivery over longer distances, cells rely on **active transport** – motors carrying cargo while walking along filaments that serve as highways.

Use hexbugs to simulate active particles moving through a cell.

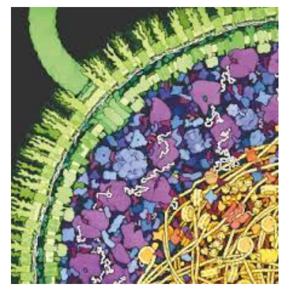
1) Place 2 hex-bugs into a tray, starting in the center facing away from each other.

How much time does it take them to find each other?

(add your measurement to the board)

Effect of crowding:

The inside of a cell is very crowded. Long filaments, sheets of membrane, and blobs of all sizes get in the way of particles that are moving through the cell.



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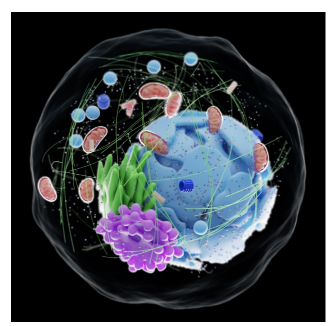
2) To model a more crowded environment for your hexbug, pour a thin layer of rice into the tray.

- How long does it take the active particles to find each other in the crowded medium? (add your measurement to the board)
- How might crowding affect chemical reactions inside of cells?
- What are some strategies a cell might use to speed up the ability of particles to find each other?

Effect of confinement:



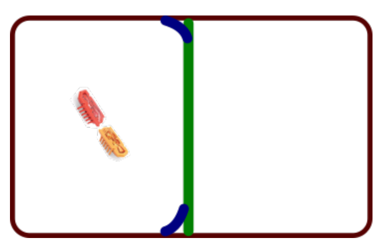
Cells use confinement into compartments called organelles to speed up reaction rates. Molecules packaged into the same organelle can find each other faster.

3) Simulate confinement into subcellular structures by dividing the tray into two sections with modeling clay.

4) Place the two hexbugs in the middle of the same half, facing away from each other.

How long does it take for them to find each other?

(add your measurement to the board)



Transport Through Pressure Gradients

1. Place 6 skittles of assorted colors around the inside boundary of a dish.

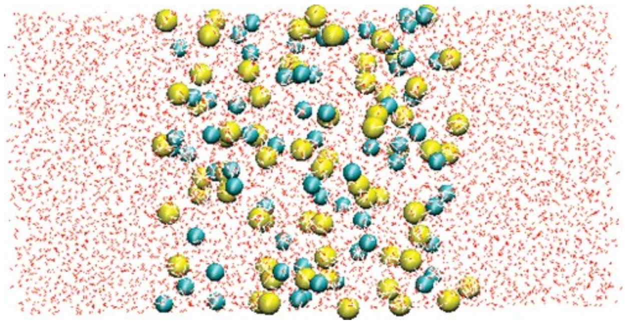
2. Pour enough water into the dish to cover the bottom. Observe for a couple of minutes. Do not touch the dish or shake the table!

What do you see?

What happens when the spreading colors touch each other?

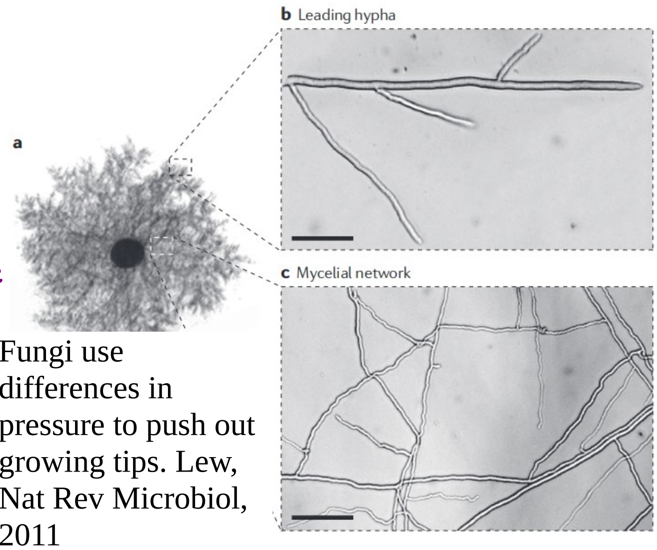
Do you think the color molecules are going on random diffusive walks or is something pushing them out? Why or why not?

Water tends to flow into regions that are more crowded with particles; this is called **osmotic pressure**. As the coating of the candy dissolves, it makes a dense region with lots of sugar. Water flows into this region, pushing out both sugar and colored pigment molecules. This is the fast spreading you see. Once the colors meet each other, the density is the same on both side of the boundary and water stops flowing. From there, the pigment molecules mix by pure random diffusion – which is very slow.



Simulation of osmotic pressure in crowded solution. Luo & Roux, J Phys Chem, 2009

Differences in pressure can help move material inside a cell. These differences can be made by tiny motors squeezing the 'sponge' of filaments that make the cell's skeleton. They can also be made by pumping in extra ions and molecules on one side of a cell. All such mechanisms require active burning of energy to help move particles faster than diffusion!



Fungi use differences in pressure to push out growing tips. Lew, Nat Rev Microbiol, 2011