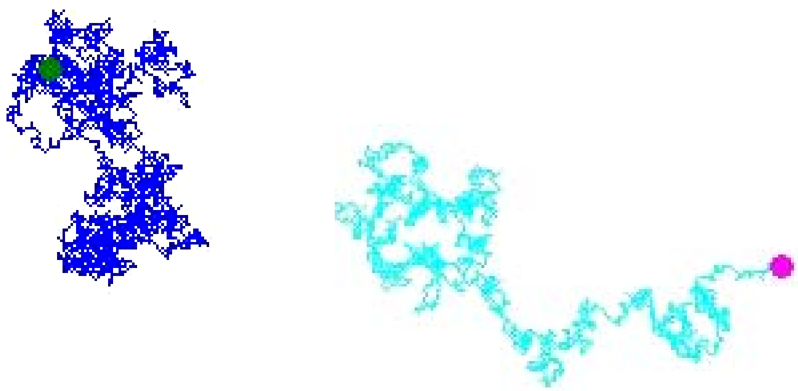
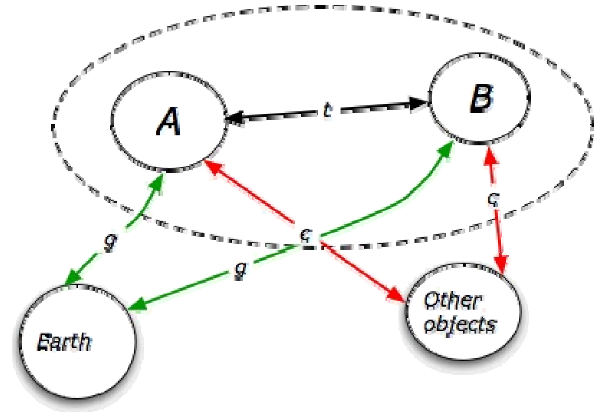
Physics 131- Fundamentals of Physics for Biologists I

Professor: Arpita Upadhyaya

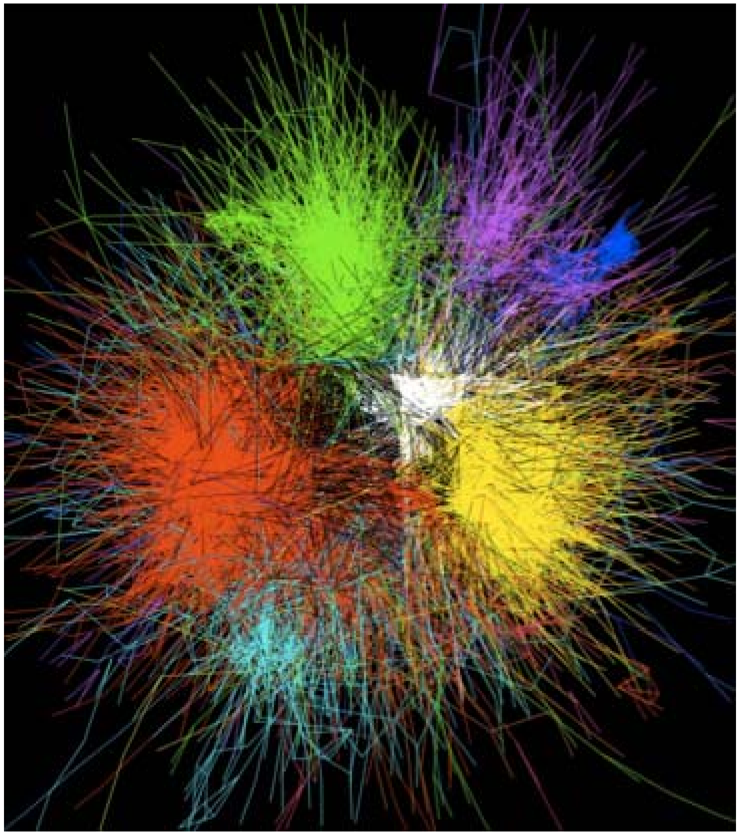
- Quiz 7
- Random Motion
- Diffusion



- So far we have studied about 1-5 objects.



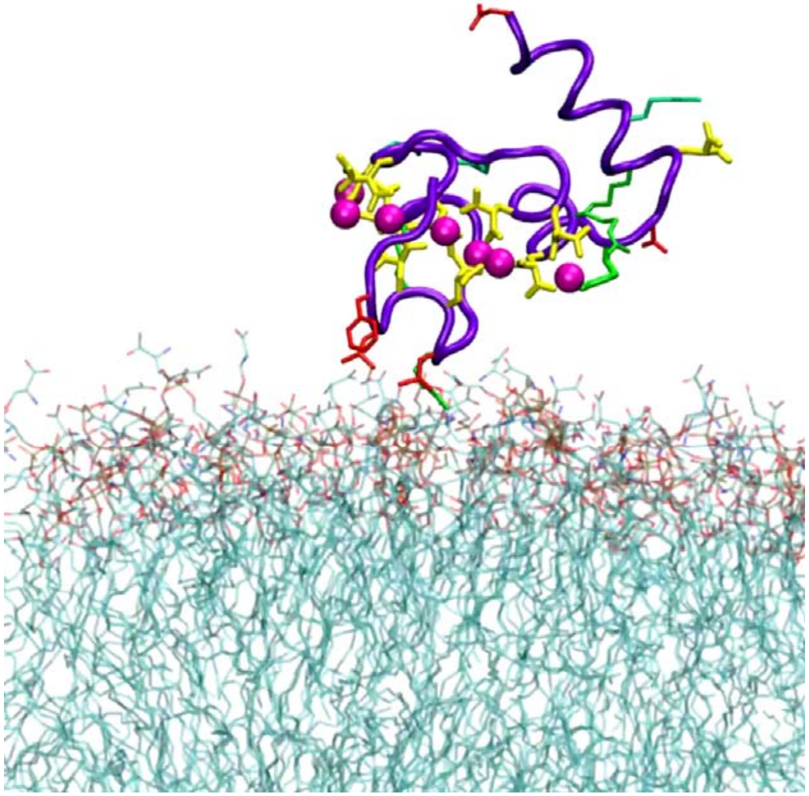
- to study cells, fluids,etc
  - LOTS of objects
  - MANY interactions



Predictions for membrane proteins

- Even a complex system such as a membrane and protein follow Newton's laws.
- However, its impossible to predict motion of atoms/molecules accurately after multiple interactions (and interactions are very frequent!)

What could we potentially predict for the motion of the membrane protein?



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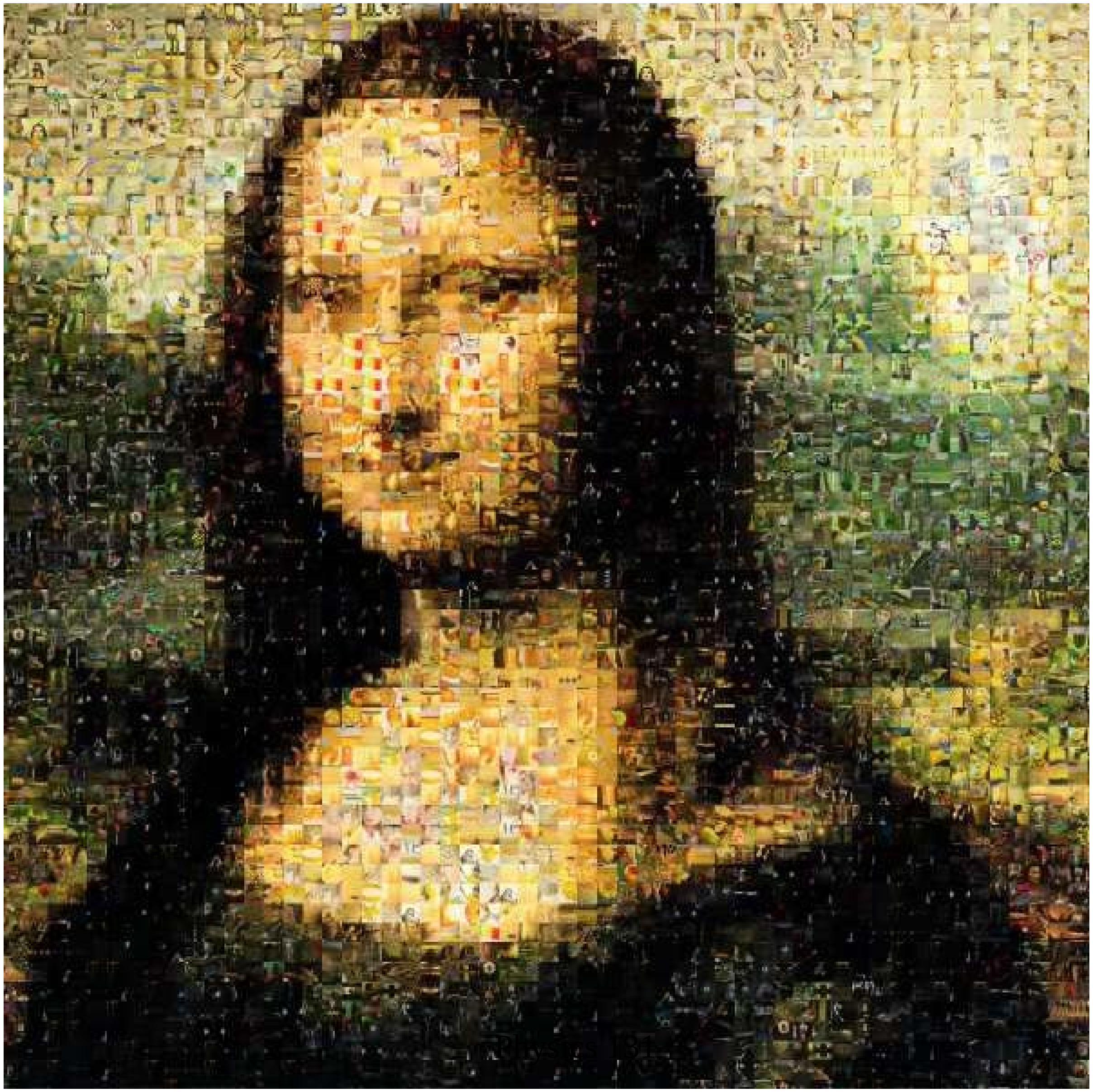
Emergent Properties

The question: Can the properties of a system can be explained in terms of the properties of its component parts (so, biology can be explained by chemistry, chemistry by physics)?

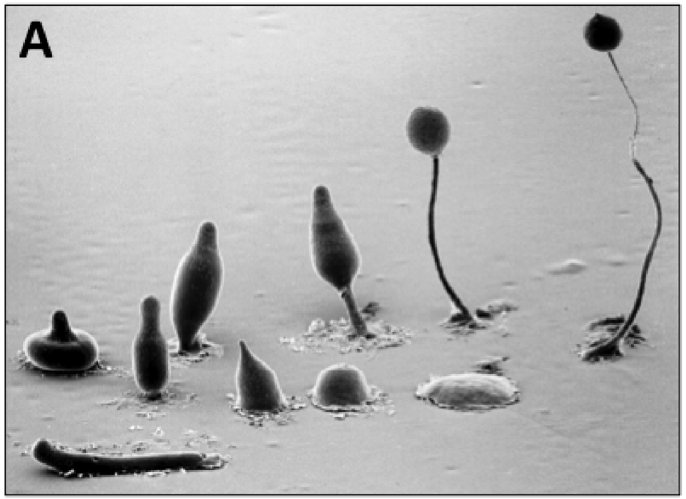
Emergence – some phenomena are undetectable when looked at "in the small". They emerge only when looking at the system as a whole rather than its parts.

Example of emergence

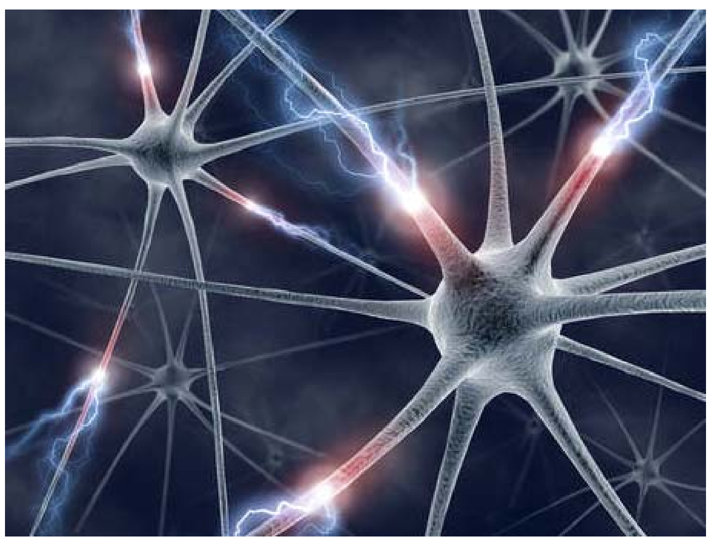


Biological Example of Emergence

Spores

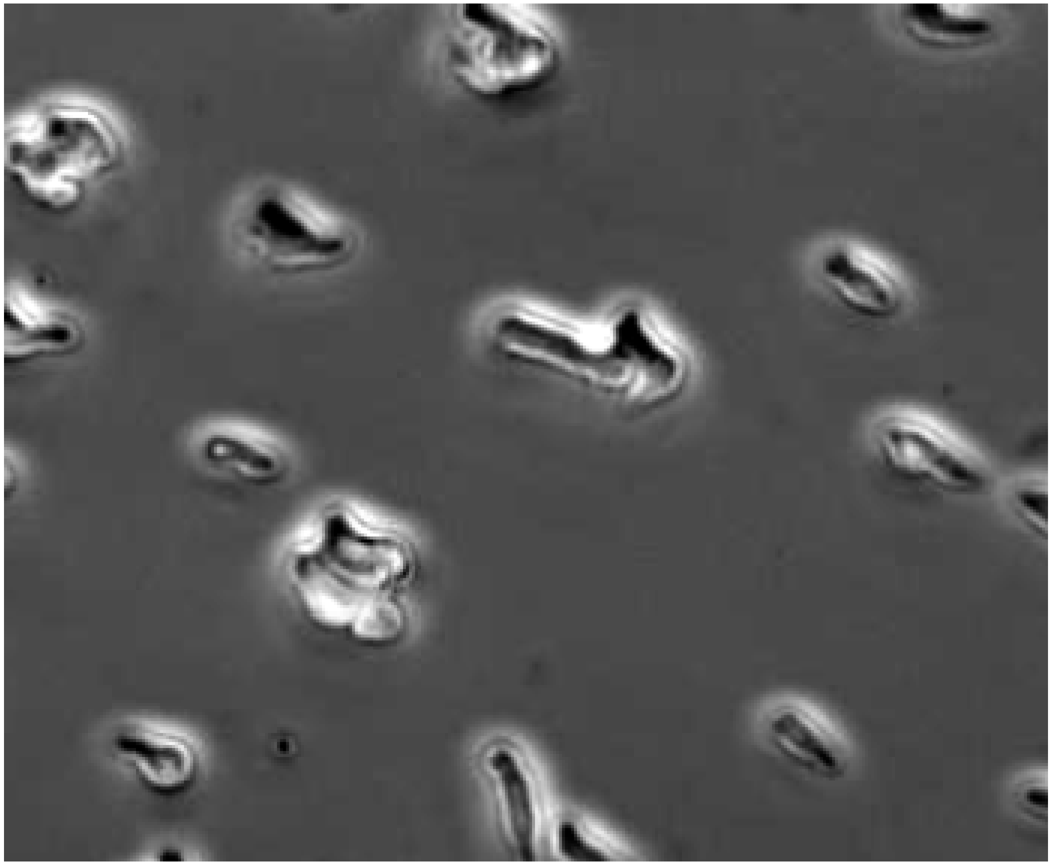


Brain



Biological Example of Emergence

slime mold aggregate by chemotaxis



Biological Example of Emergence

- Evolution
  - If a single species of birds on an isolated island have a range of bill thicknesses, they may all survive and interbreed well under normal circumstances.
  - If the climate shifts so that the birds at the two extremes are more likely to survive than those in the middle – by only a little bit! – after a few decades the population may consist only of birds with only the smallest and largest bills.
  - If the climate now stays shifted, after a few millennia, genetic drift can take the two populations apart so that they can no longer interbreed and would be identified as different species.
  - The shifts are in fact visible over only a few generations.

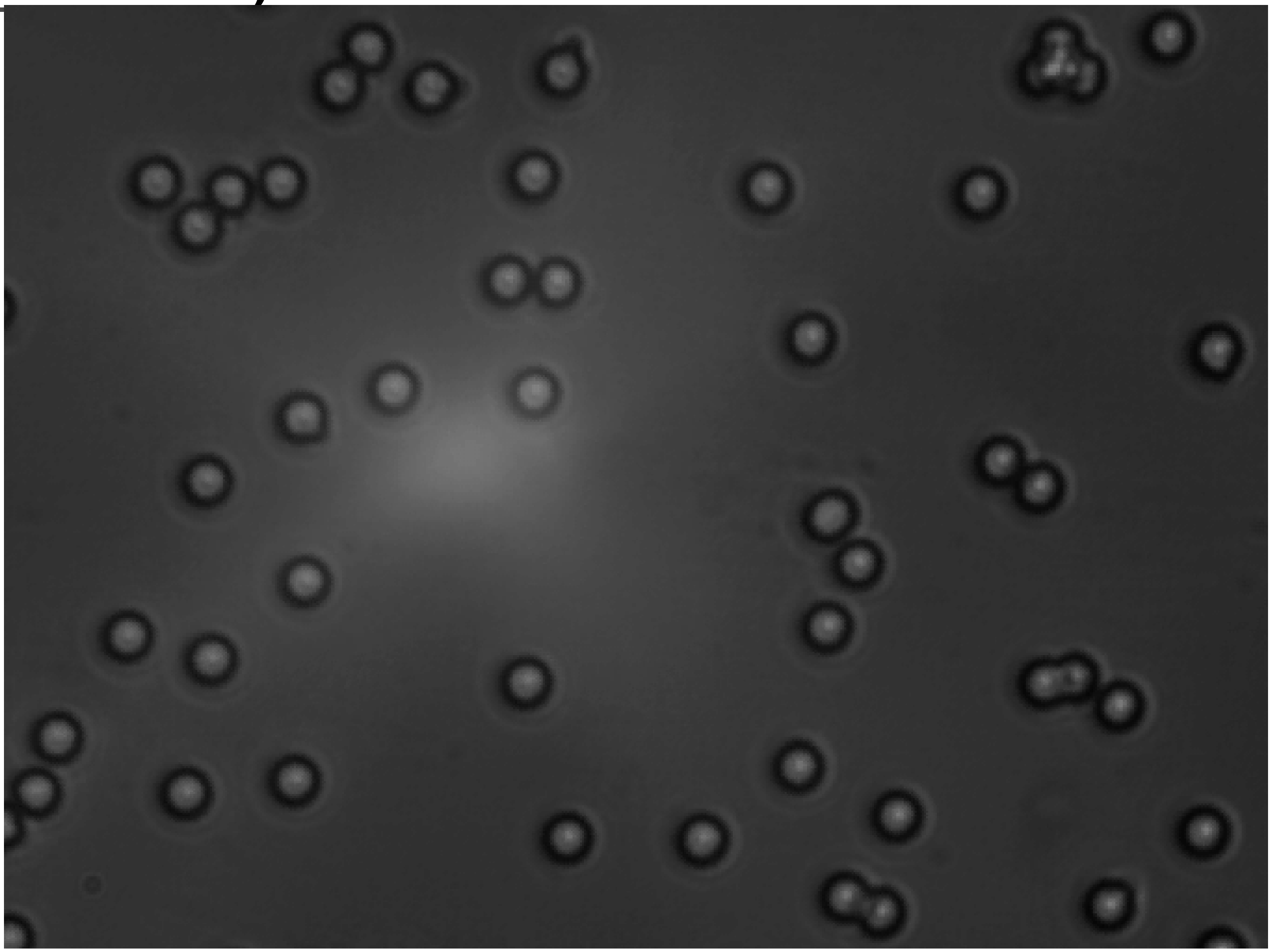
Jonathan Weiner, *The Beak of the Finch*

Foothold principles: Randomness

- Matter is made of of molecules in constant motion and interaction. This motion moves stuff around.
- If the distribution of a chemical is non-uniform, the randomness of molecular motion will tend to result in molecules moving from more dense regions to less.
- This is **not** directed but is an emergent phenomenon arising from the combination of random motion and non-uniform concentration.

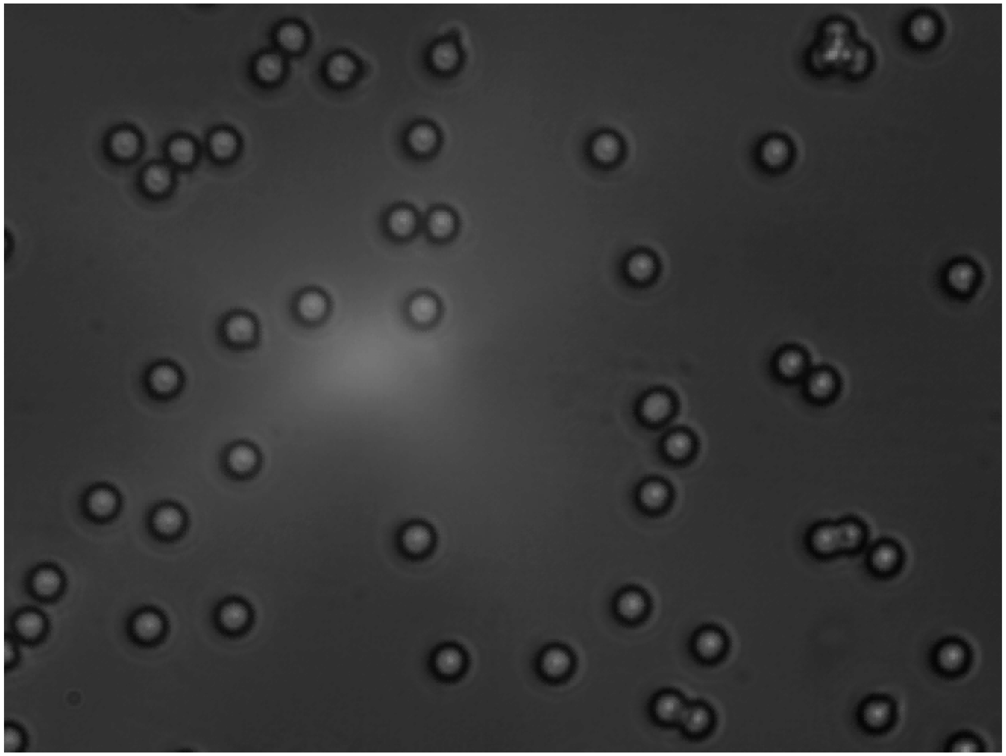
Random Motion

- 5 μm sized beads (analogs for mammalian cells)
- 1 μm sized beads (bacteria analogs)
- (3.2 μm in this video)



Does random motion have emergent properties?

(properties that emerge only when looking at the system as a whole rather than its parts)



1. Yes
2. No
3. The answer has not yet emerged

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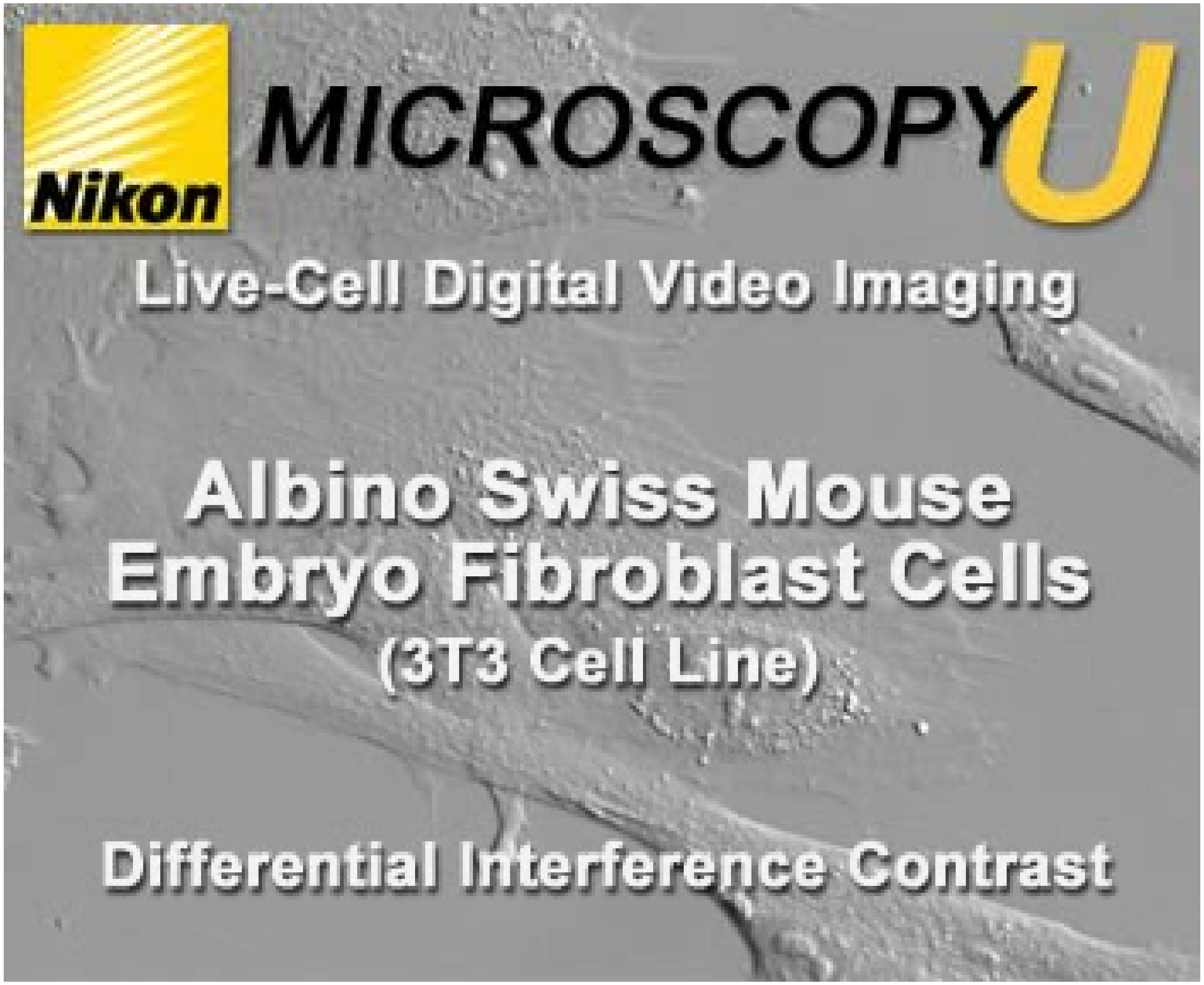
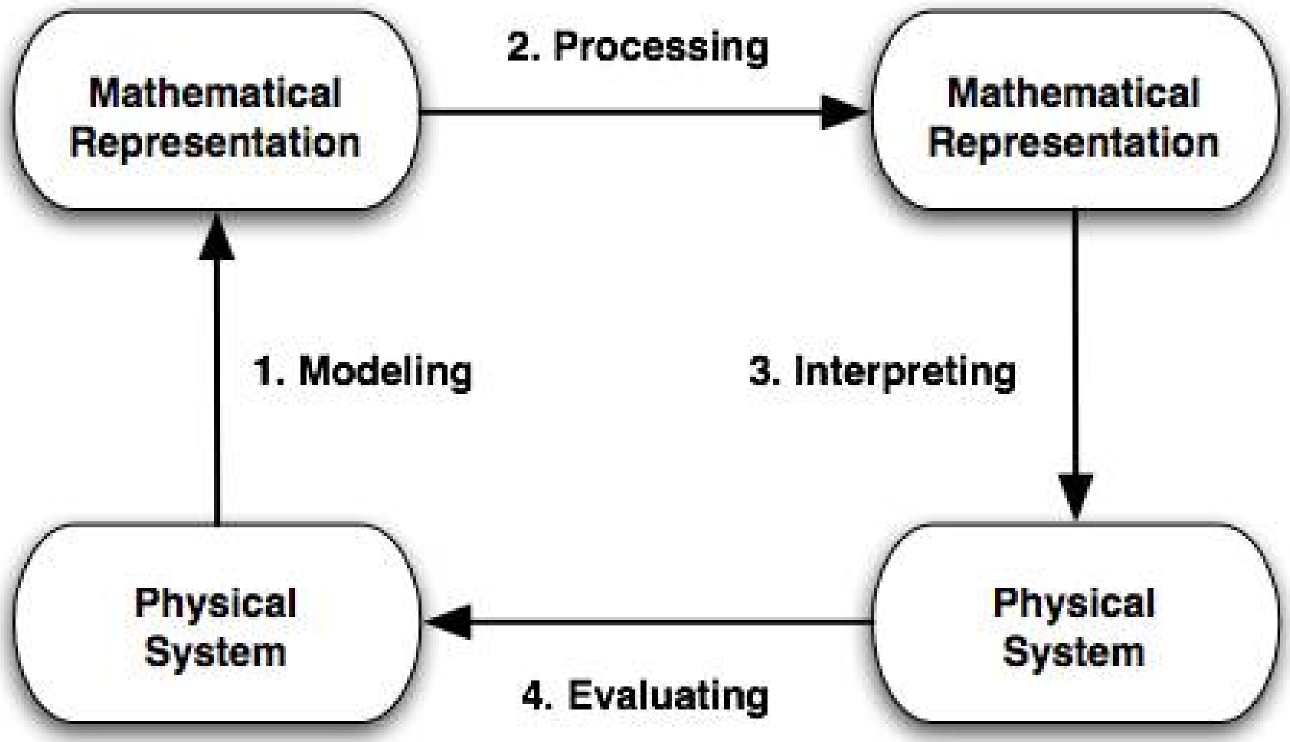
How could we determine whether the observed motion is consistent with random motion?


Nikon
MICROSCOPY U
Live-Cell Digital Video Imaging
Albino Swiss Mouse
Embryo Fibroblast Cells
(3T3 Cell Line)
Differential Interference Contrast

Reading questions

- How is it that every single object has a net momentum of zero? If molecules move randomly, how does each one have another molecule canceling out its movement?
- I'm a little confused about how random motion isn’t the same thing as coherent motion, because even with random motion aren't all parts of object moving together which is definition of coherent motion?
- When the object (example water balloon) is thrown, is the internal momentum still equal to zero? Or does the internal momentum of the random motion equal to the new total momentum after the object is thrown (some non-zero momentum value?)

Making a mathematical model

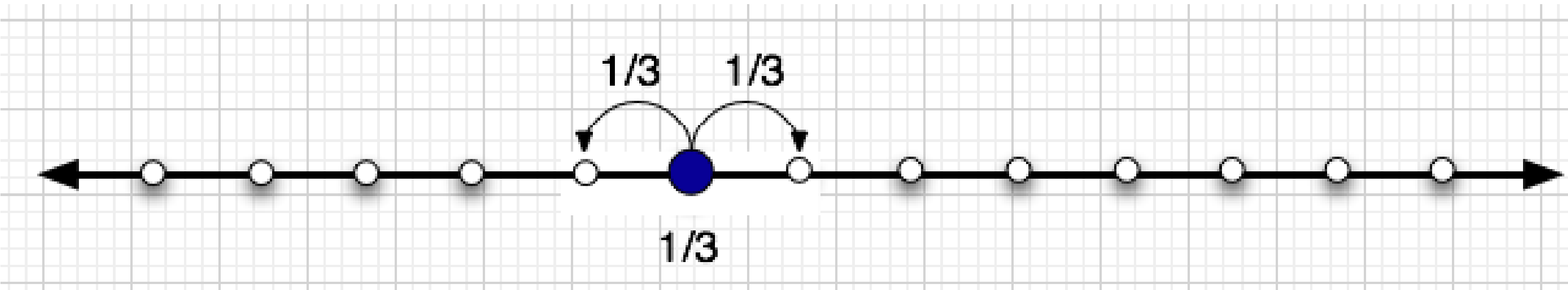


A new start

- Our mathematical model based on identifying position, velocity, and all the forces on an object and then calculating the motion using Newton's second law is too hard for a small particle being hit by many molecules.
- An alternative starting point is to describe the result of all the forces acting on a small object as random motion.
- Average phenomena that emerge from the randomness can still be reliable even though the motion at any given instant can't be predicted.

A mathematical model without equations*

- Describe the position of our object as being on a grid. Run the clock in small time steps, letting the object move to each neighboring point (or stay where it is) with equal probability.



**Although the model is <u>defined</u> without equations,*
lots of equations can be <u>derived</u> about averages and distributions.
See, e.g., H.C. Berg, "Random walks in biology".

If the probability is equal that in the next time step the object moves to any one of the sites in the red box, what is the probability for going to any one particular site?

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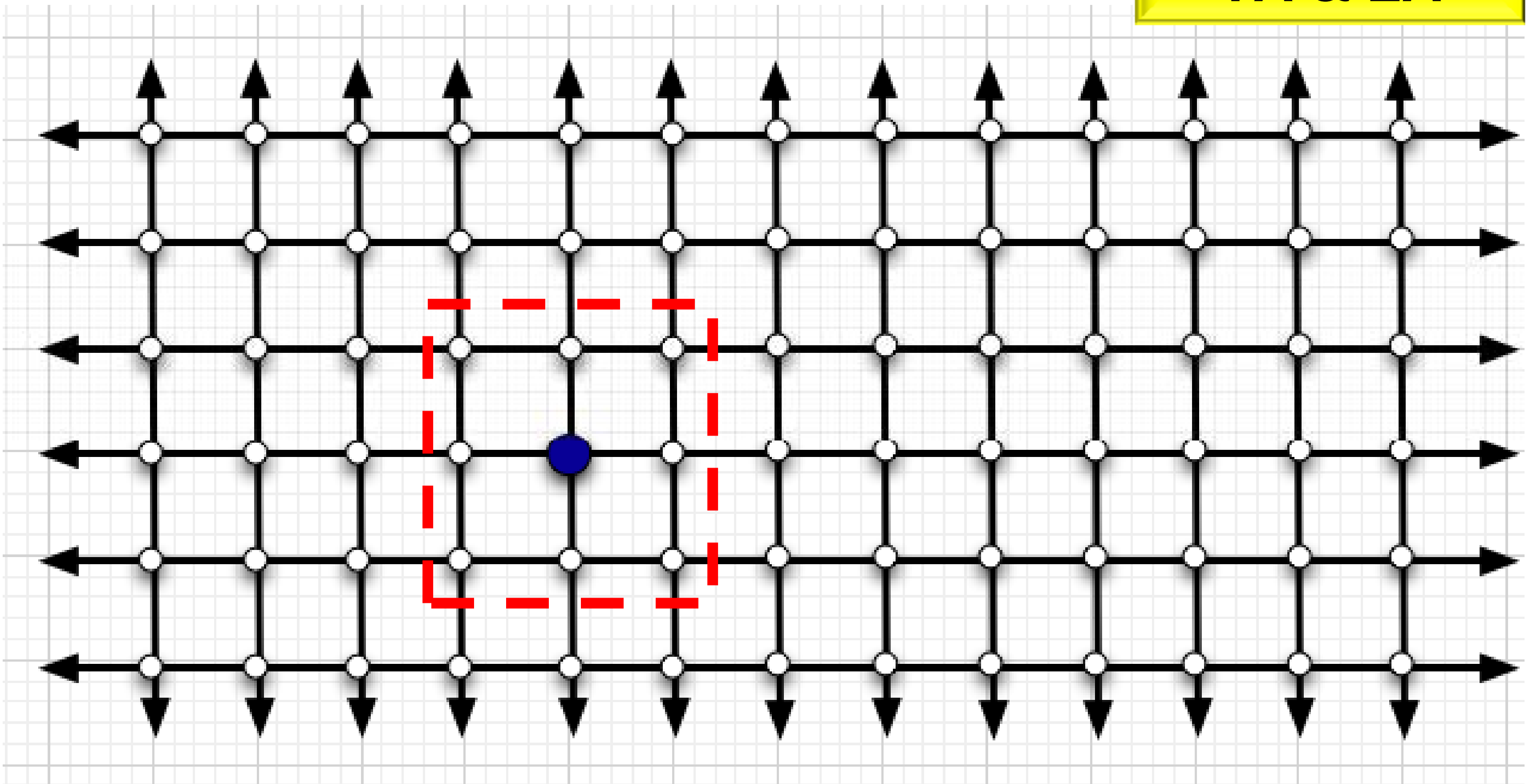
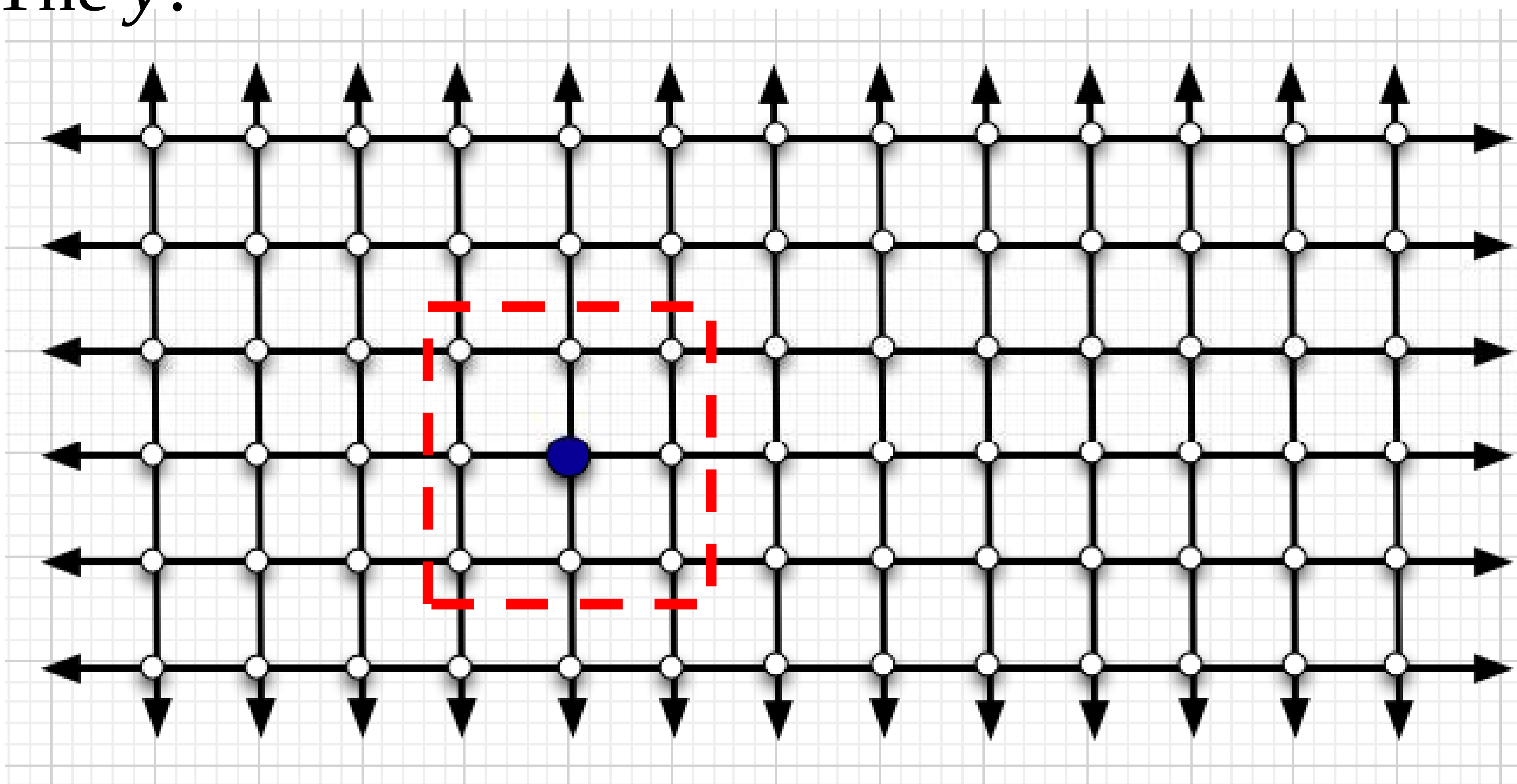
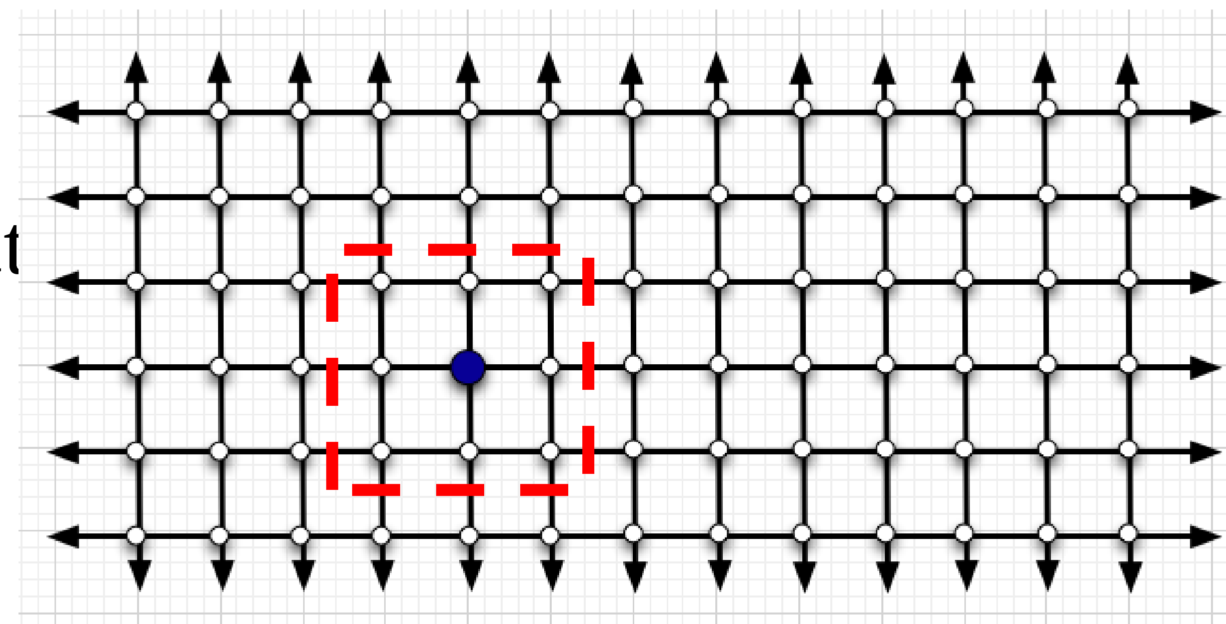


If the probability is equal that, in the next time step, the object moves to any one of the sites in the red box, what is the probability for the *x*-coordinate to change by: +1, 0, or -1?
The *y*?

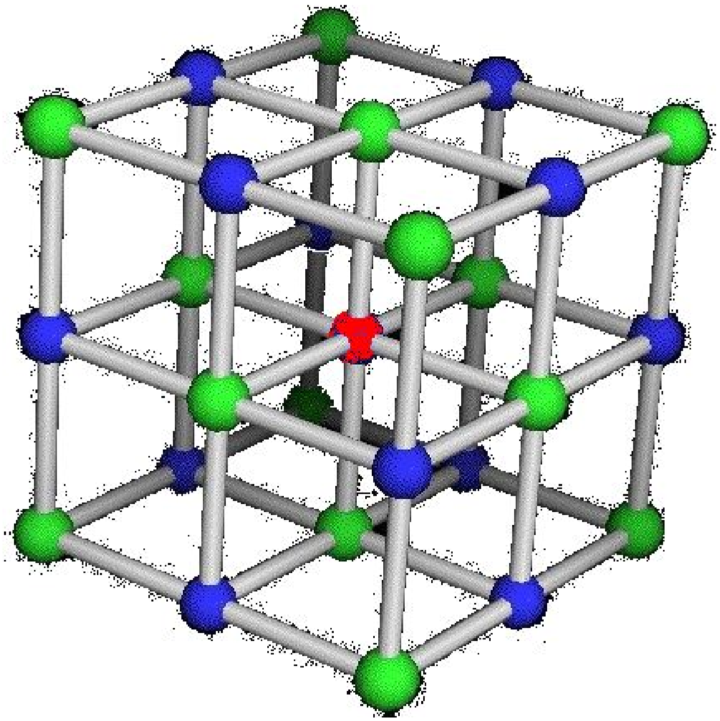


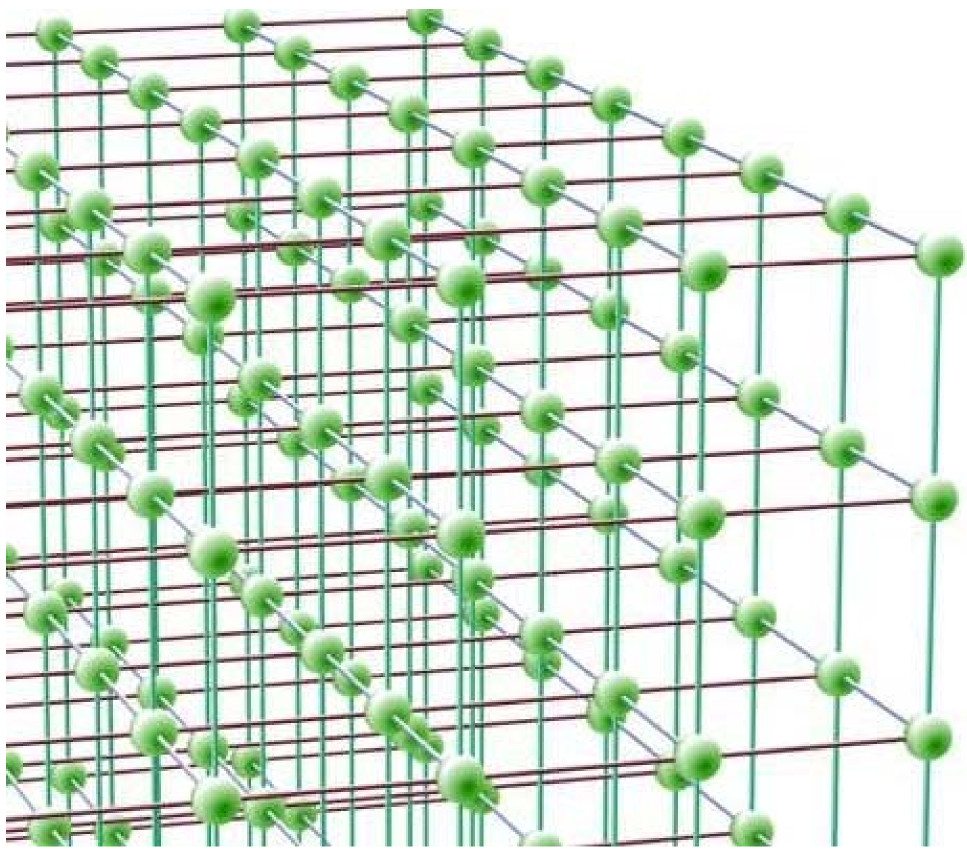
If the probability is equal that, in the next time step, the object moves to any one of the sites in the red box, what is the probability for the *x*-coordinate to change by: +1, 0, or -1? (or the *y*, for that matter!)

A. 1/2
B. 1/3
C. 1/4
D. 1/9
E. Can't predict

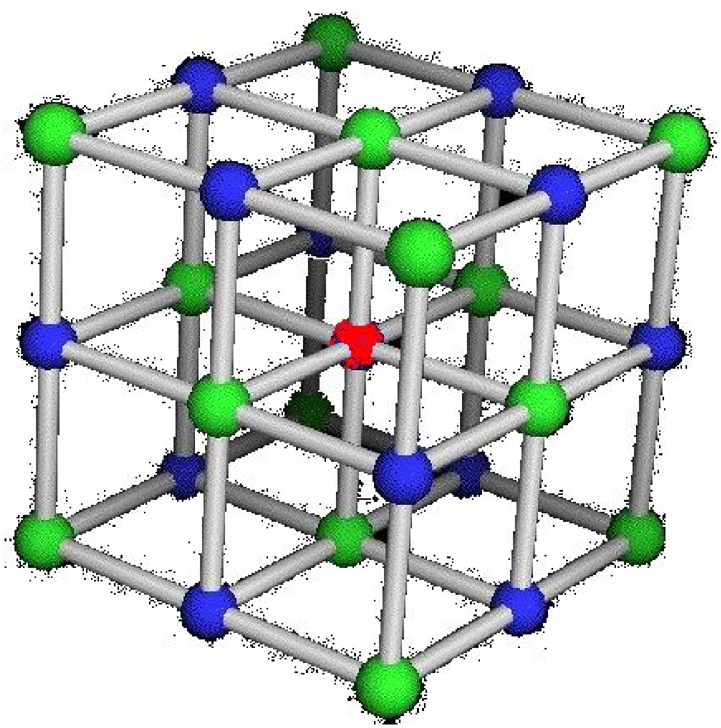


If we use a 3D lattice model, what is the probability to step
to each of the neighboring sites?



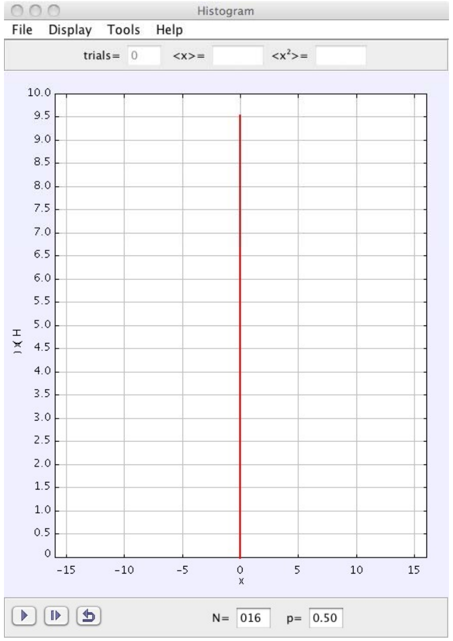


If the probability is equal that, in the next time step, the object moves to any one of the sites in the cube. What is the probability for the *x*-coordinate to change by: +1, 0, or -1? The *y*? The *z*?



In this simulation, a “walker” starts at 0 and steps left and right with equal probability. We will let it take N steps. If we release a lot of walkers from the origin at once, on the average, what will our distribution of particles look like?

1. There will be equal numbers near +N/2 and –N/2
2. They will be mostly near 0 no matter how many steps you take.
3. It will peak at 0 and getting farther will decrease in probability.
4. There will be peaks at + and – values but not at +N/2 and –N/2; 0 will be less likely.



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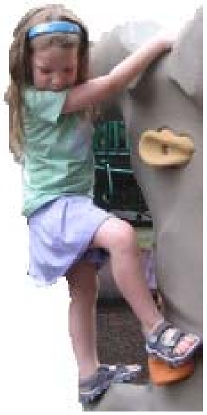
Stp_RandomWalk1D.jar

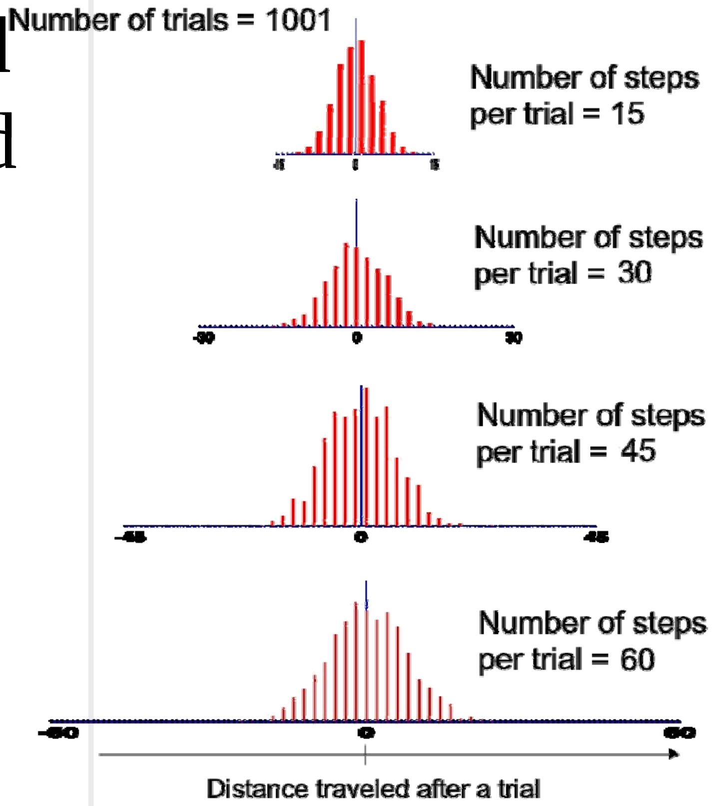
Foothold ideas: Random walk in 1D



- As a result of random motion, an initially localized distribution will spread out, getting wider and wider. This phenomenon is called *diffusion*
- The width of the distribution will grow like

$$\left\langle (\Delta x)^2 \right\rangle = 2Dt$$

- *D* is called *the diffusion constant* and has dimensionality $[D] = L^2/T$



If the average rate at which a 1D particle moves is given by $\left\langle (\Delta x)^2 \right\rangle = 2Dt$ what will be the rate at which it moves in 2D? 3D?

A. $\left\langle (\Delta r)^2 \right\rangle = 2Dt$

B. $\left\langle (\Delta r)^2 \right\rangle = 4Dt$

C. $\left\langle (\Delta r)^2 \right\rangle = 6Dt$

D. Something else

Sodium ions are at different densities on the inside and outside of a cell. Assume each ion moves randomly as a result of collisions with other atoms and molecules.

A small patch of membrane (area A) is shown in yellow. There are more ions are on the left than on the right.

What do you expect is true about the ions on the **left side** of the membrane?

A. More go to the right

B. More go to the left

C. Equal amount goes left and right

D. There is not enough information to tell