■ **Theme Music:** **Elvis Presley**

All Shook Up
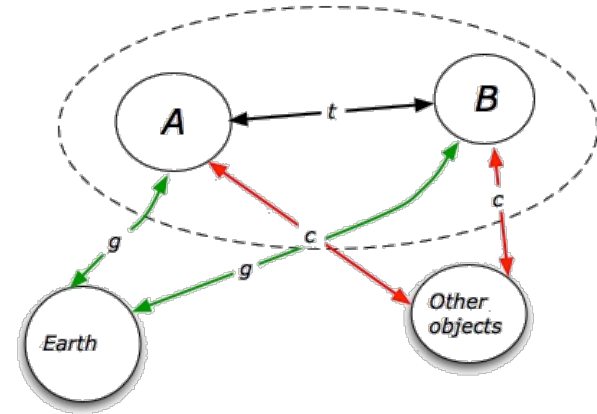
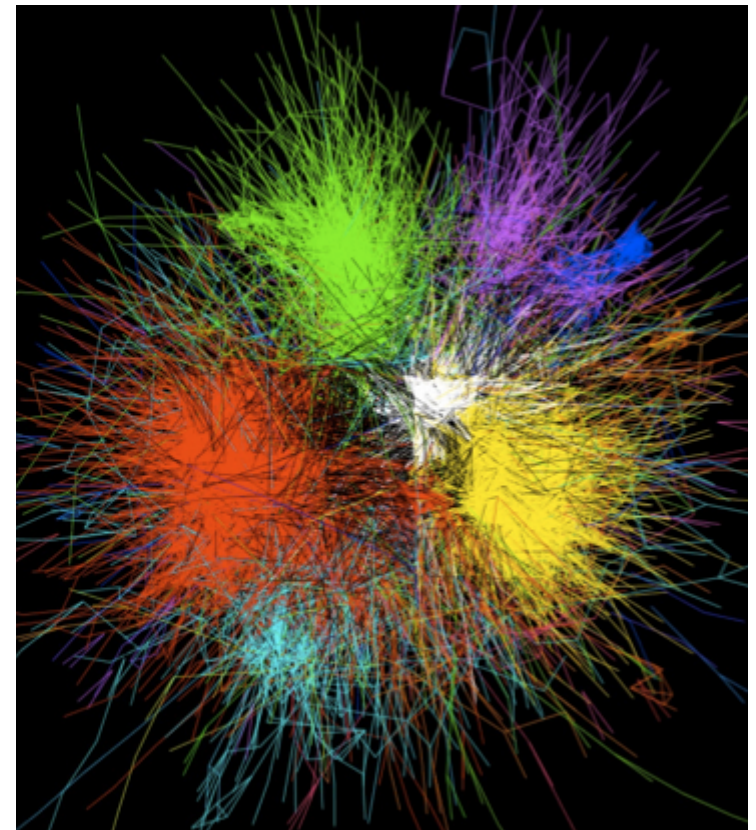■ **Cartoon:** **Scott & Borgman**

Zits

Outline

■ Quiz 6

■ Emergent phenomenon

■ Randomness

■ Diffusion

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

- To study cells, fluids, etc
  - we have LOTS of objects
  - MANY interactions
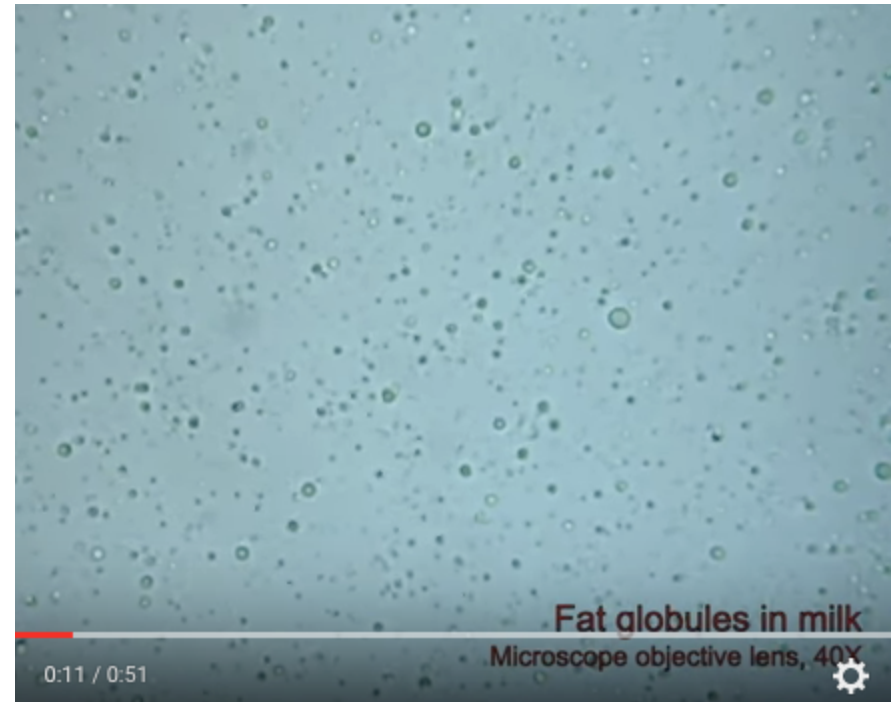- And – they are near the basic molecular scale.

Foothold principles: Randomness

■ Matter is made of of molecules in constant motion and interaction. This motion moves stuff around.

■ A large molecule, small organelle, or even a bit of dust or pollen in the air is continually bombarded from all sides by moving molecules of water or air.

■ On the average, they are hit equally from all sides – but since they are not that much bigger than the bombarding molecules sometimes more hit them from one side than the other. The values fluctuate around the averages and these fluctuating imbalances produce a jiggling motion ("Brownian motion")

Brownian Motion

https://www.youtube.com/watch?v=R5t-oA796to

0:14 / 0:28

Fat globules in milk
Microscope objective lens, 40X

0:11 / 0:51
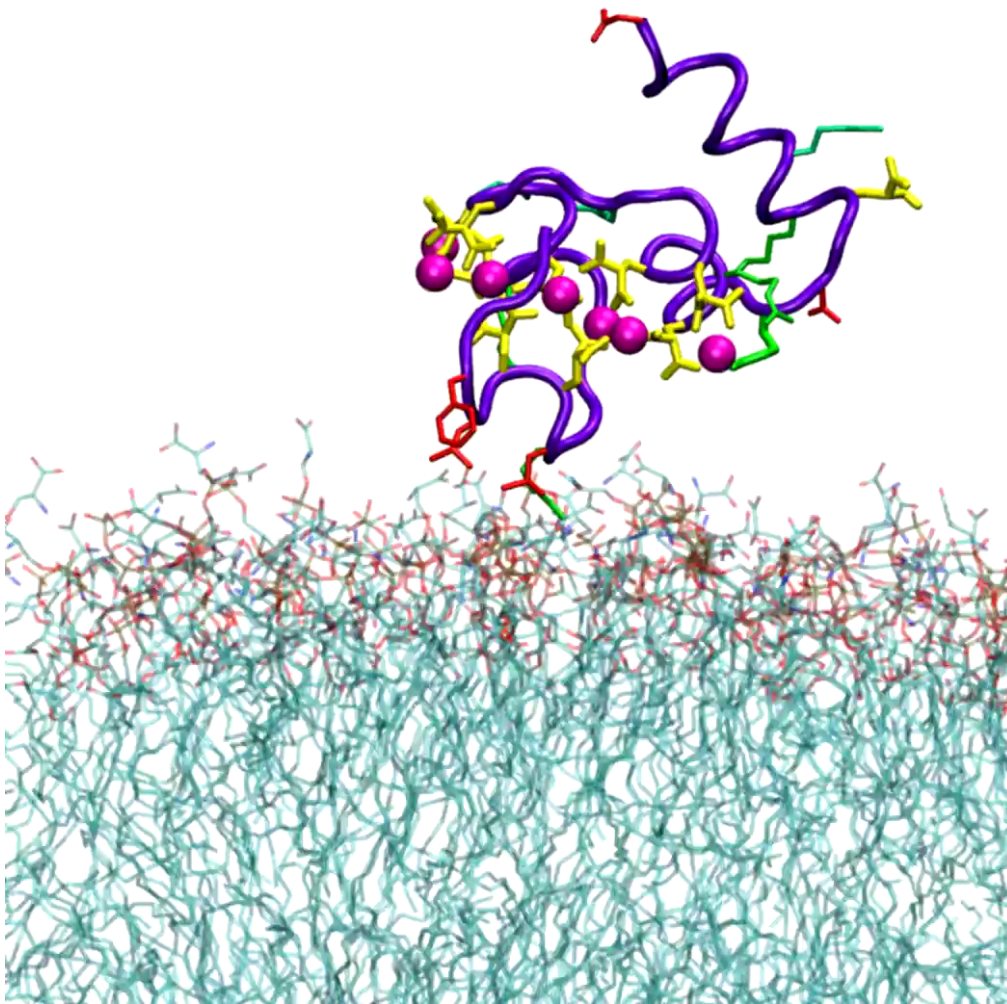
https://www.youtube.com/watch?v=f4mp4TWYfBs

An example of something more complex:

Can we apply Newton's laws to predict the motion of the protein?
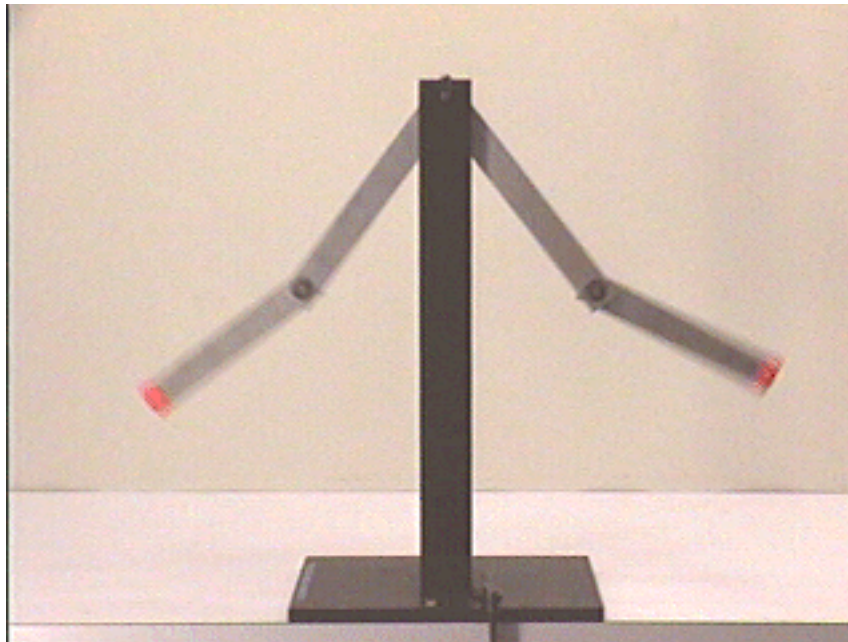
1. No
2. Yes
3. Depends

Blood clotting protein sitting on membrane

6

How well can we predict motion
when the system gets more complicated?

Example: Double pendulum

Physics 131

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Predictions for molecular motions inside a cell

■ Even a complex system such as a membrane protein or an ion going through a membrane channel 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 or the ion?
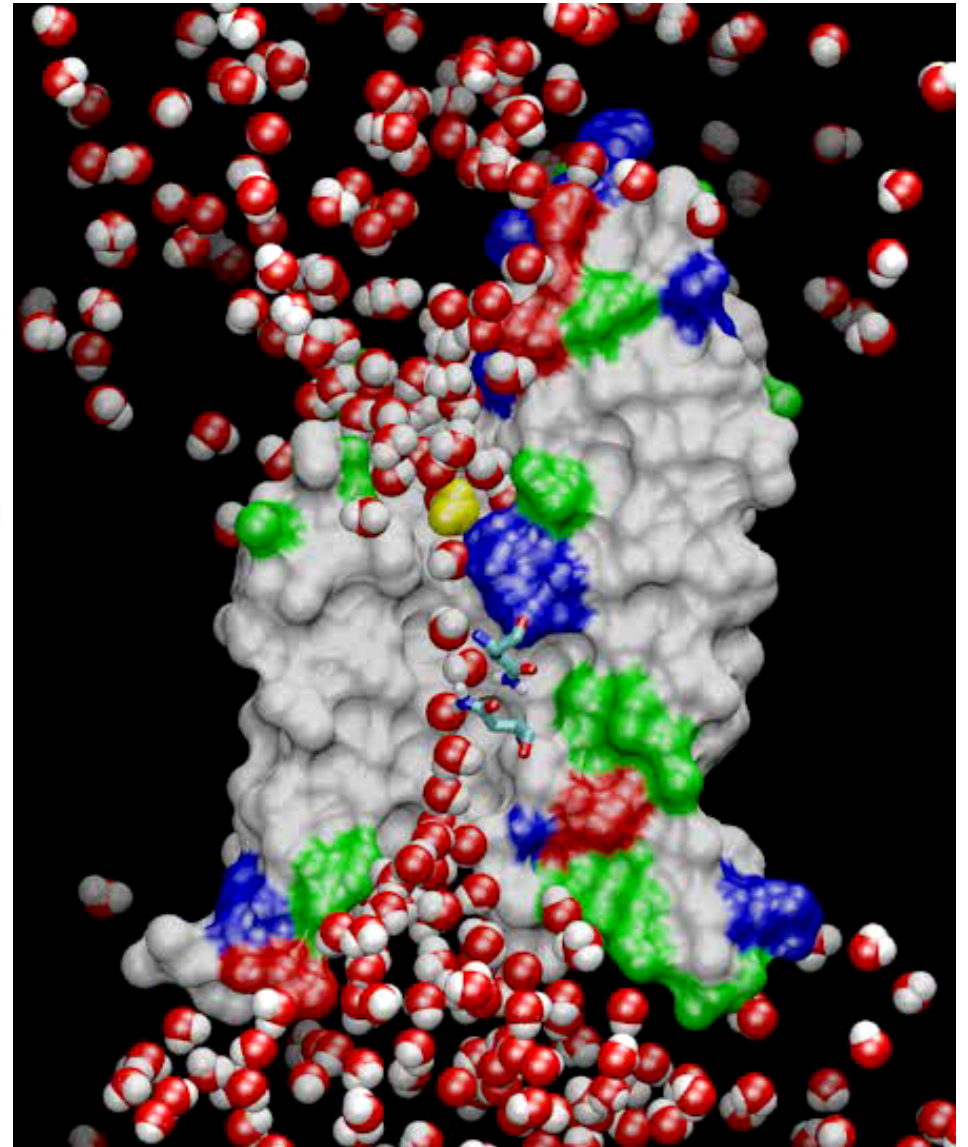
Emergent Properties

The question: Even though detailed properties can't be predicted, can some "average" properties – either local or at a larger scale – be predicted from the laws of motion + an assumption of randomness?

The broader 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" and emerge only when looking at the system as a whole rather than its parts.

Example of emergence
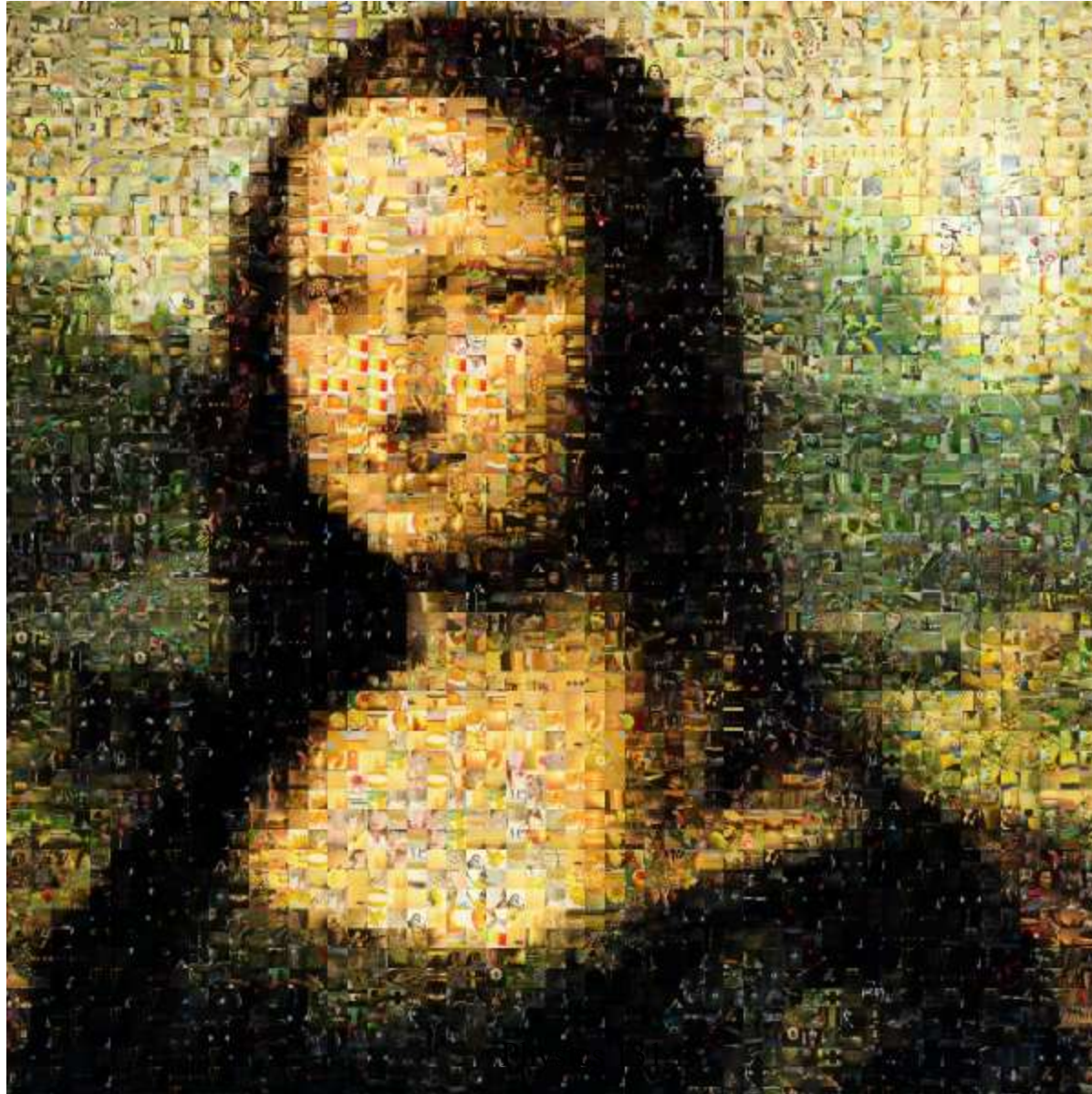
Biological Example of Emergence

■ 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*

Emergence in slime molds

Foothold principles: Diffusion

- If the distribution of a chemical is non-uniform, the fluctuations in how its molecules are being struck by the molecules of the fluid it is in will tend to result in the chemical moving from more dense regions to less.

- This *diffusion* is **not** directed but is an <u>emergent phenomenon</u> arising from the combination of random motion and non-uniform concentration.

# Making a mathematical model
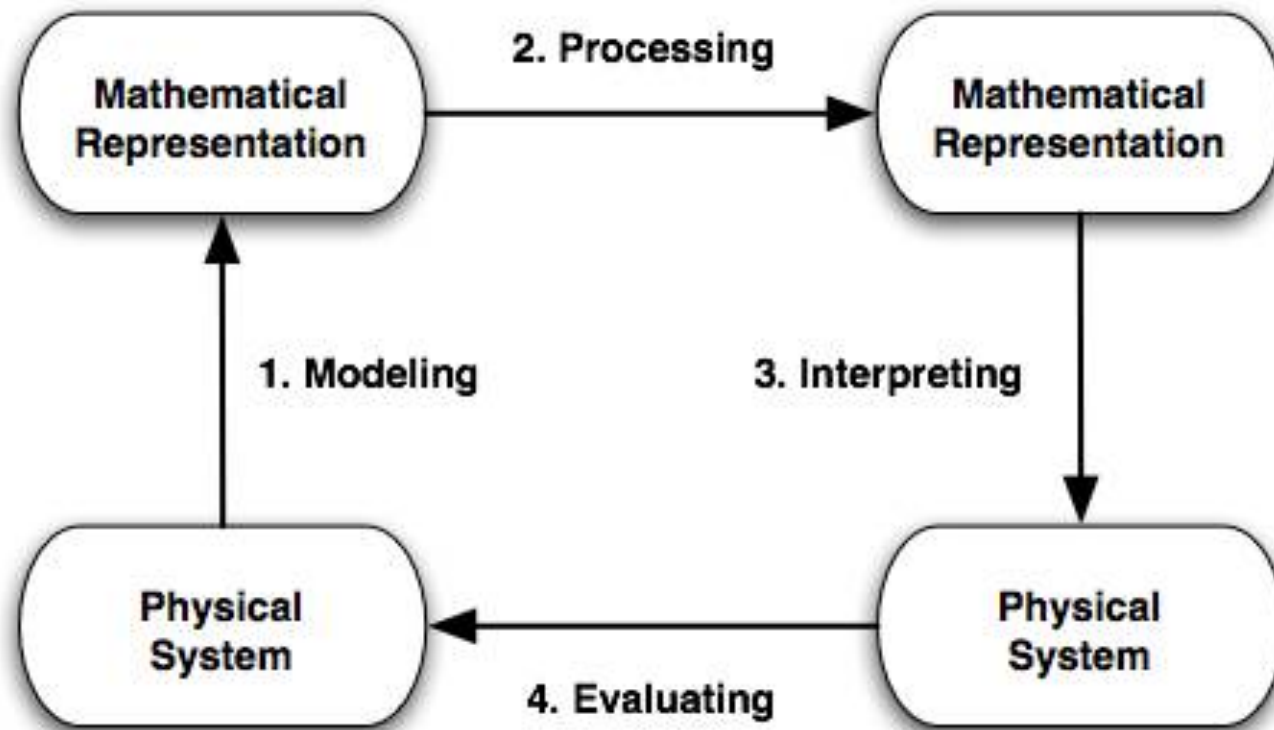
A new start

- 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.
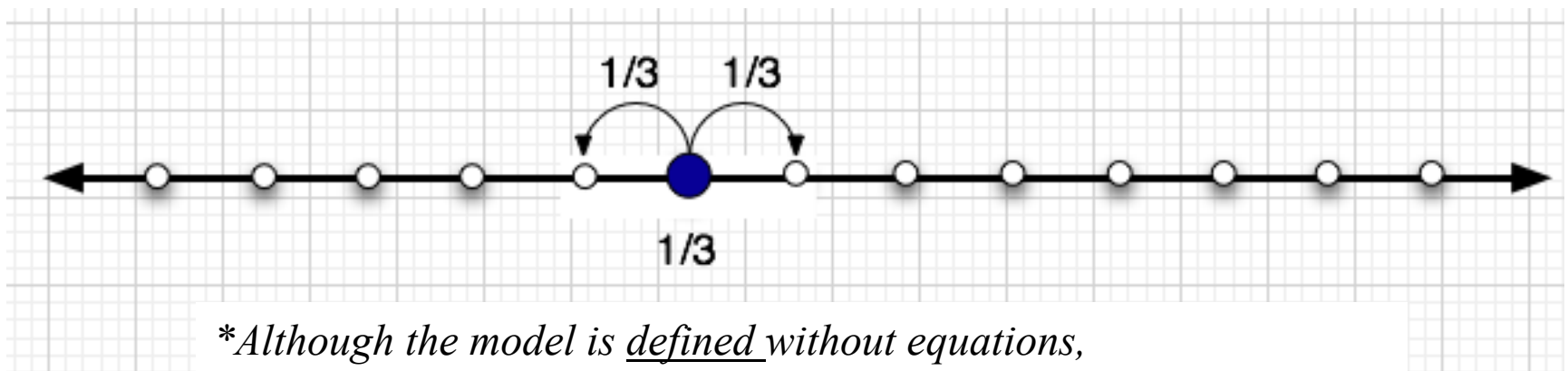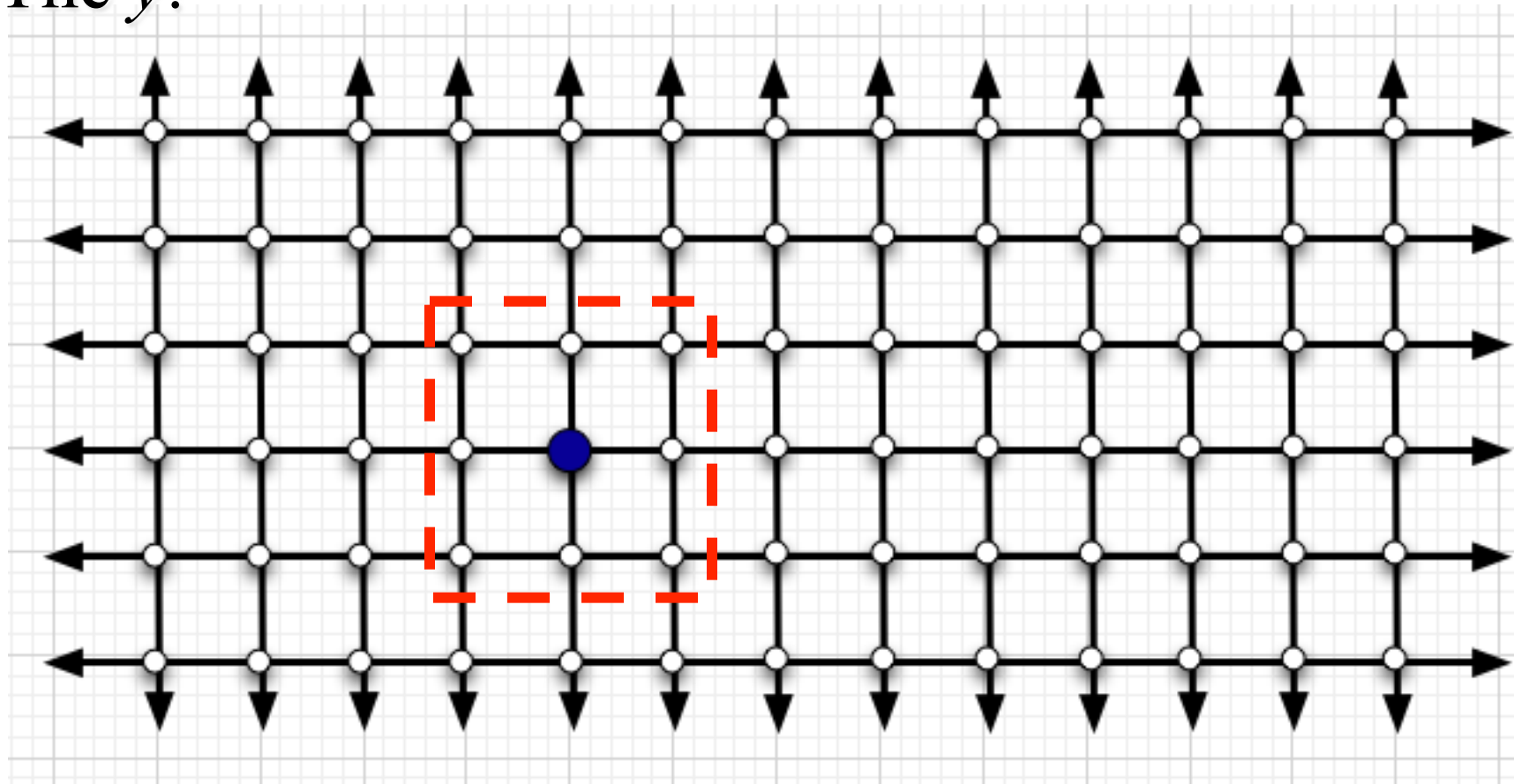

*Although the model is <u>defined</u> without equations, lots of equations can be <u>derived</u> about averages and distributions. See, e.g., H.C. Berg, "Random walks in biology".
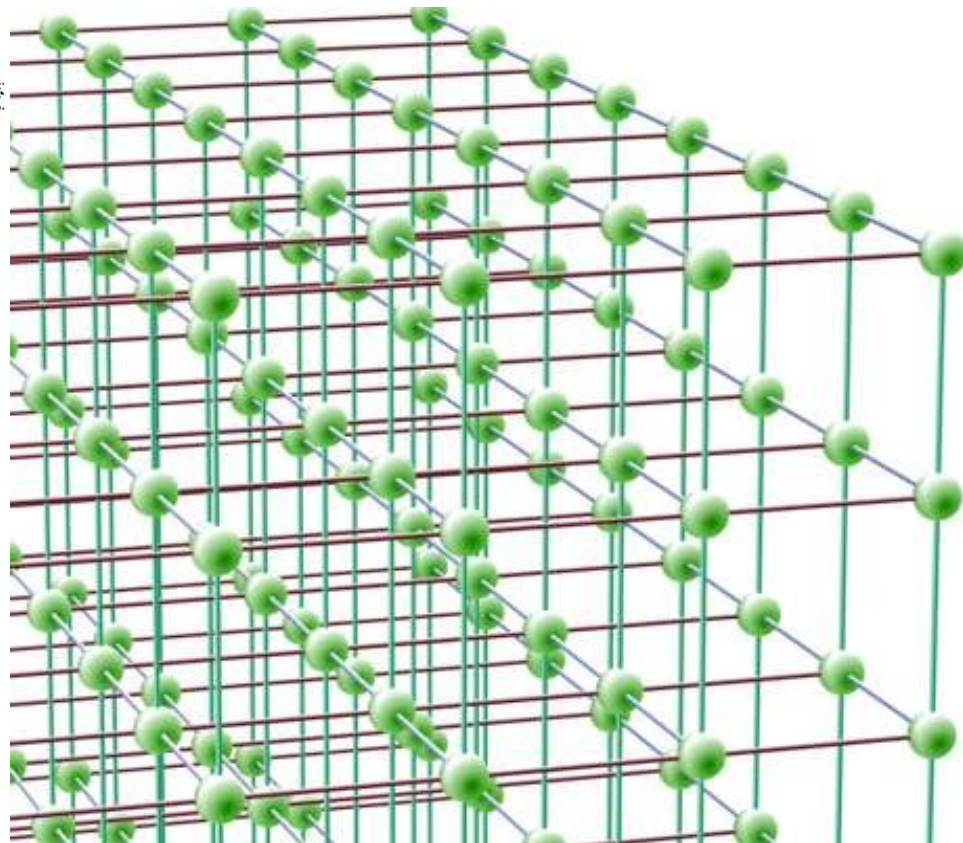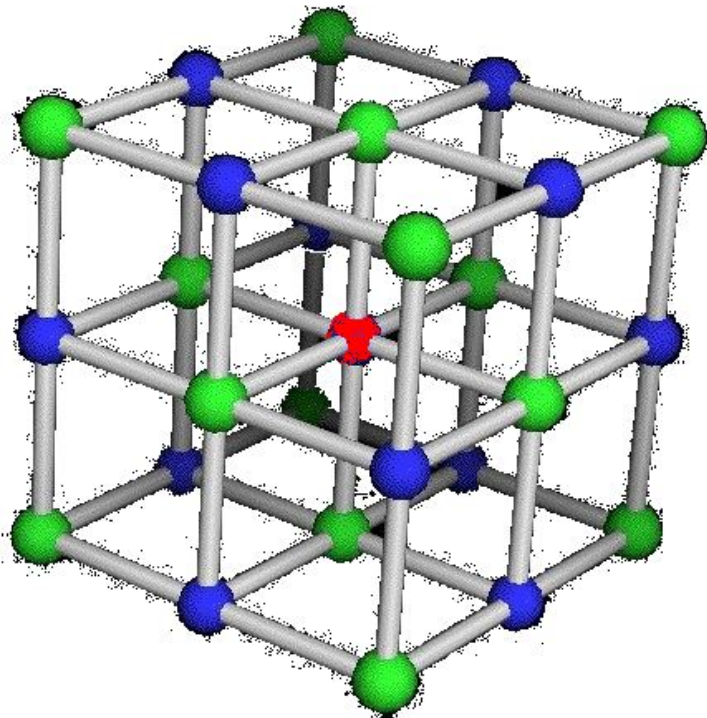
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If the probability is equal that, in the next time step, the object moves to any one of the sites in the red box, what is the probability for the *x*-coordinate to change by: +1, 0, or -1? The *y*?

For 3D we use a lattice model. The molecules we are considering step randomly from lattice site to lattice site as a result of being bombarded from all sides by the molecules of the fluid they are imbedded in.

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*? To wind up at any particular site in this cube?

A. 1/2
B. 1/4
C. 1/8
D. 1/3
E. 1/9
F. 1/27