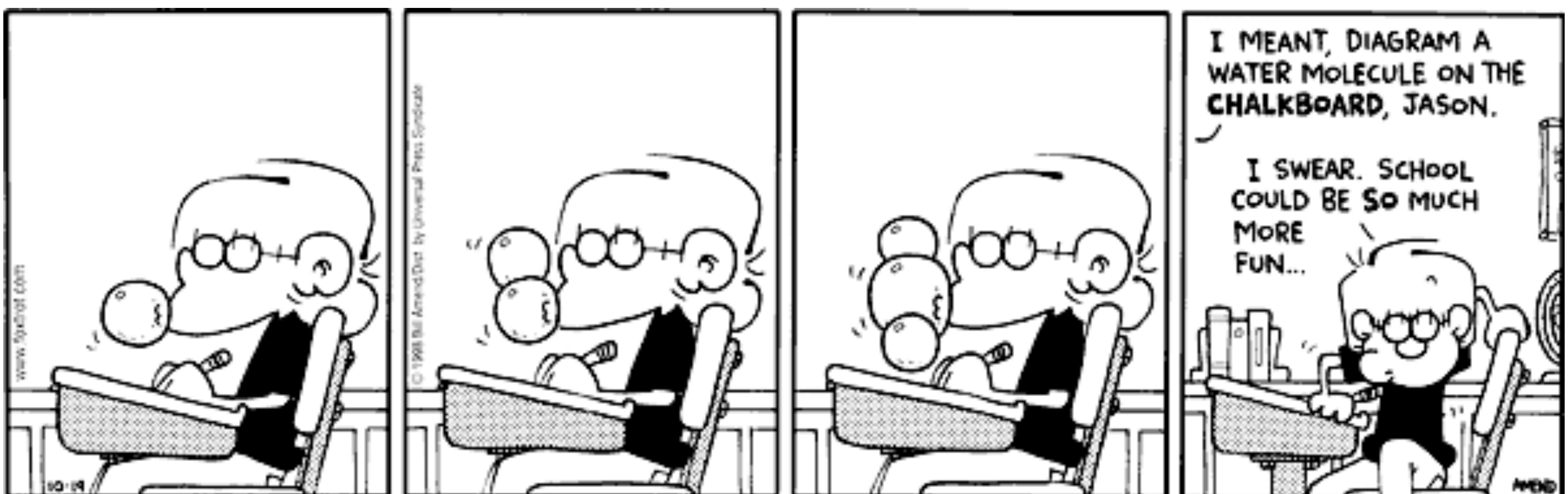
- **Theme Music:** **Kenny Rogers**

  The Gambler

- **Cartoon: Bill Amend**

  FoxTrot



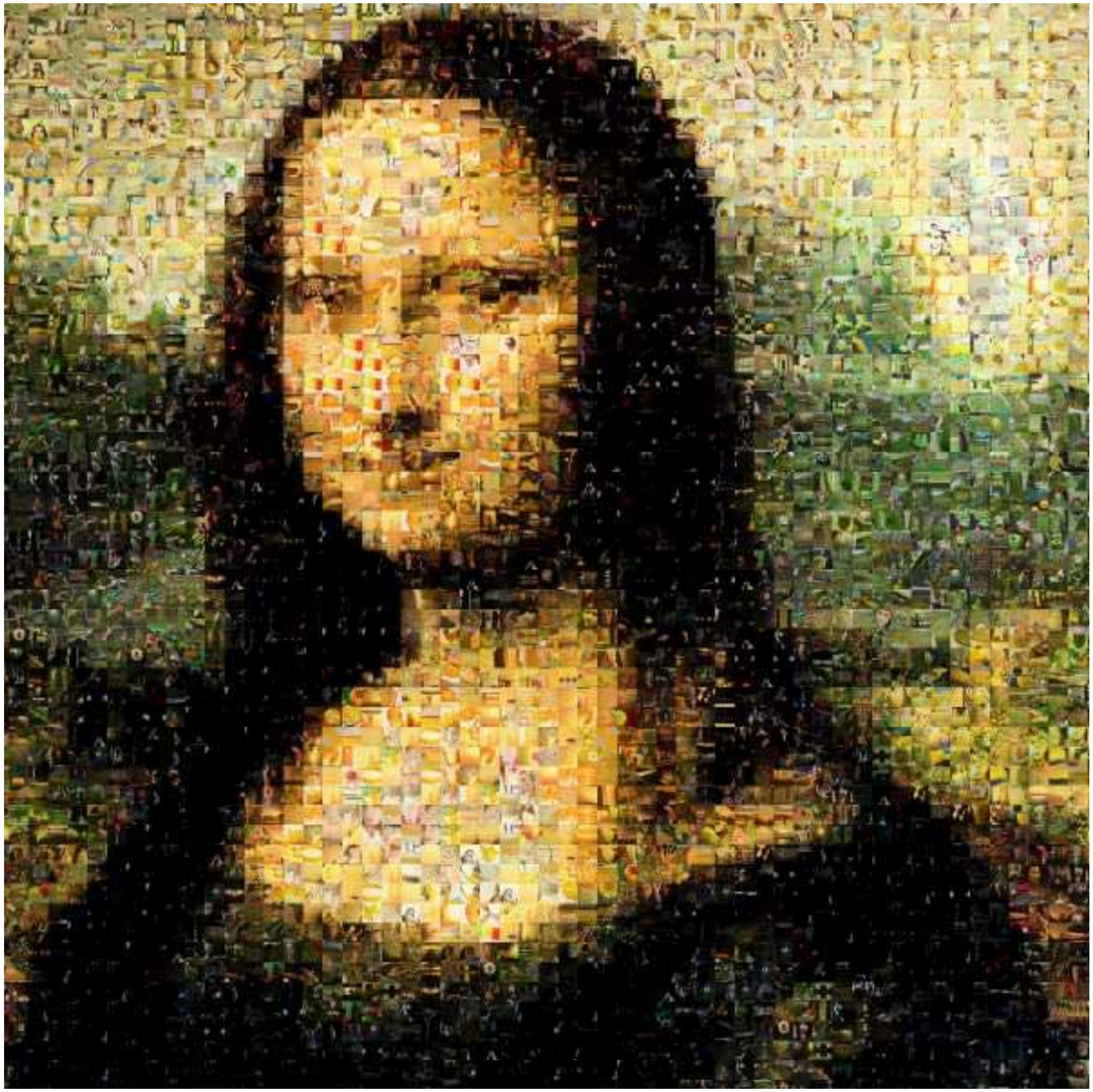
Relating Levels

- *Reductionism* – the belief that 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).
- *Holism* – the belief that the properties of a complex system cannot be explained solely in terms of the properties of its component parts.
- *Emergence* – A way of bringing them together.

Emergence

- Emergence means that a phenomenon that is essentially invisible or indetectable when looked at "in the small" builds up in a coherent fashion as the system you look at gets larger.
- At the large scale, the result is of great (even dominant) importance.

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 millenia, 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*

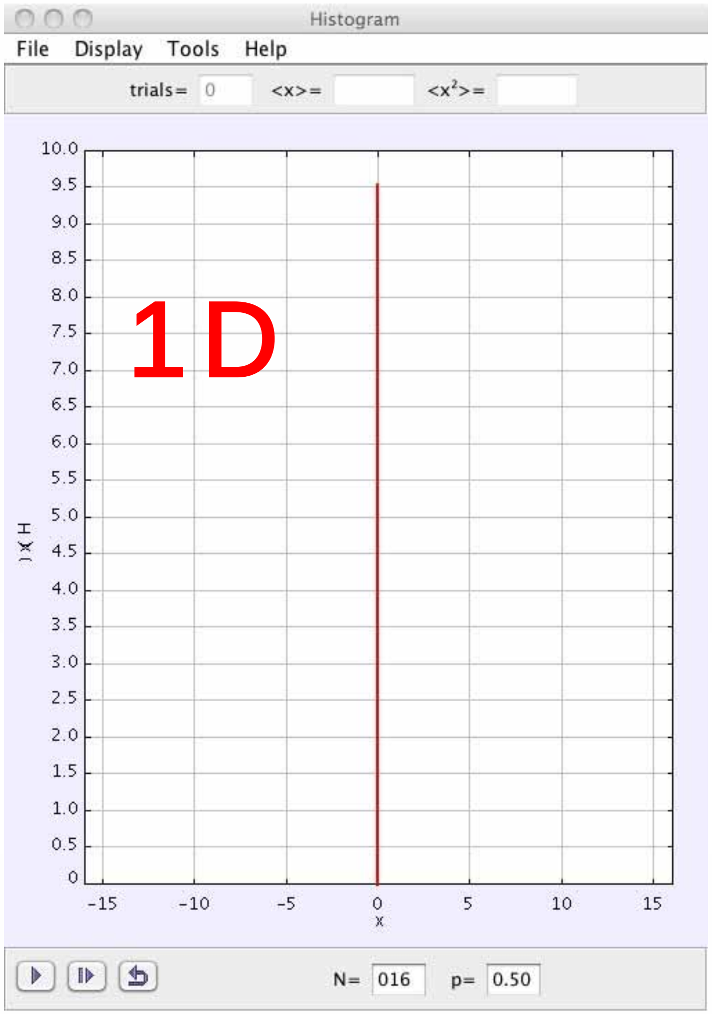
Foothold principles: Randomness

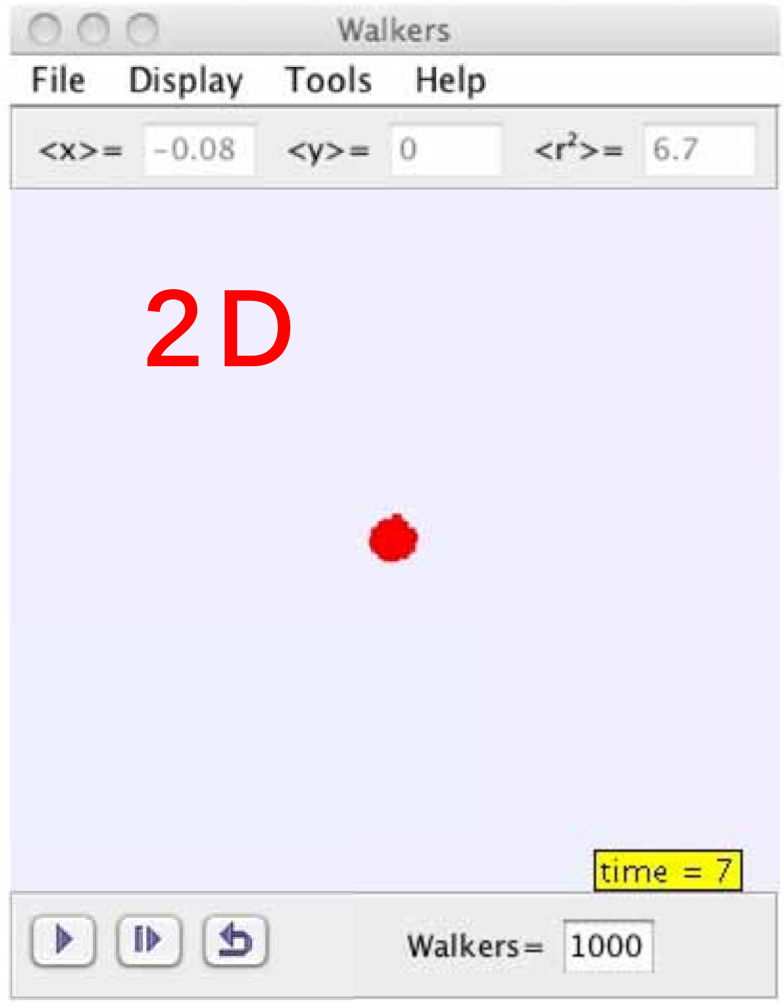
- Matter is made of of molecules in constant motion and interaction. This motion moves stuff around.
- If the distribution of a chemical is non-uniform, the randomness of molecular motion will tend to result in molecules moving from more dense regions to less.
- This is **not** directed but is an emergent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

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 isnt 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?)

What happens when there are a lot of particles?



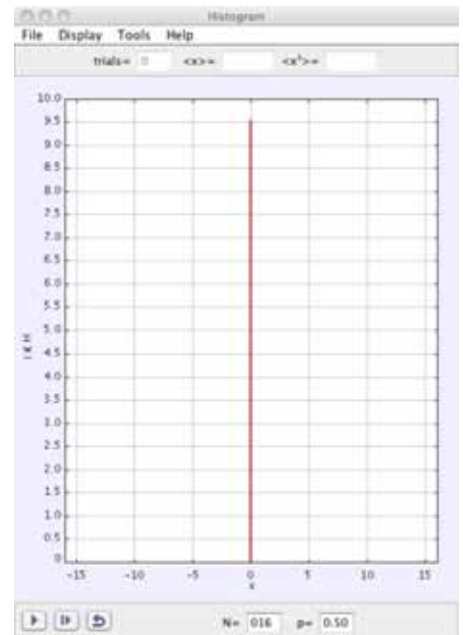


Stp_RandomWalk1D.jar

Stp_RandomWalk2D.jar

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.



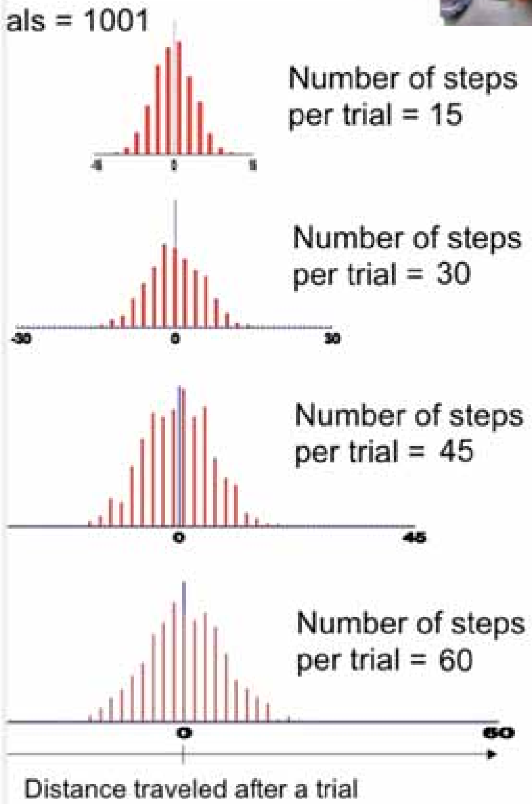
Stp_RandomWalk1D.jar

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

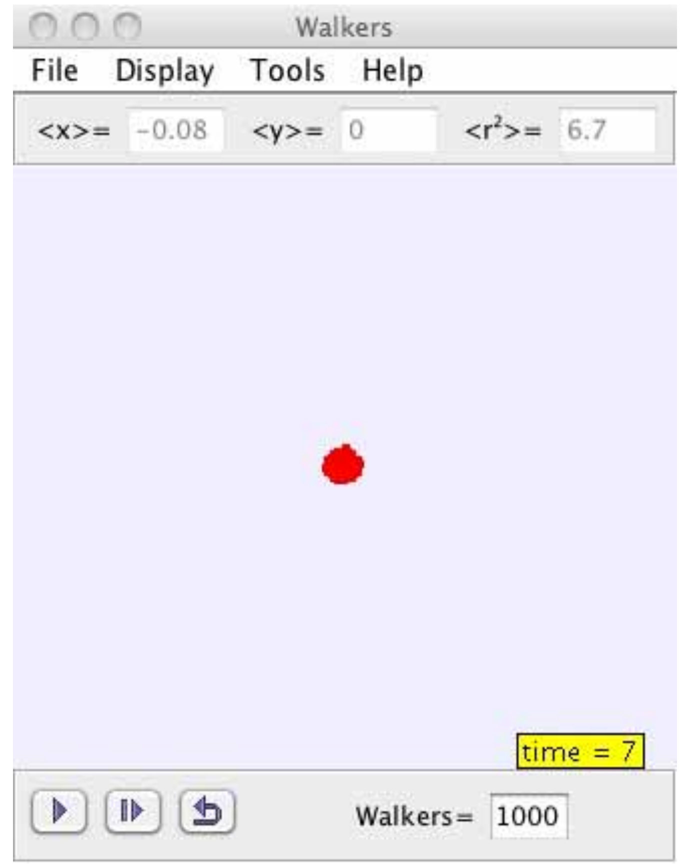
$$\left\langle (\Delta x)^2 \right\rangle = 2Dt$$

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



In this simulation, a lot of “walkers” starts in 2D near 0 and step in a random directions with equal probability. As time grows, what will happen to the distribution of walkers – number as a function of distance??

1. They will form a “wave” – a ragged ring of particles moving outward.
2. They will be mostly stay near 0 no matter how long you wait.
3. It will peak at 0 and getting farther will decrease in probability, the distribution remaining mostly the same.
4. It will peak at 0 and getting farther will decrease in probability, the distribution getting wider with time.



Foothold ideas: Random walk in 2D

- The density of walkers decreases uniformly as you get farther from the source.
- The total number within a given radius peaks – since the area within a radius r decreases to 0 as r gets small. ("phase space")
- The width of the peak grows with the square root of time.