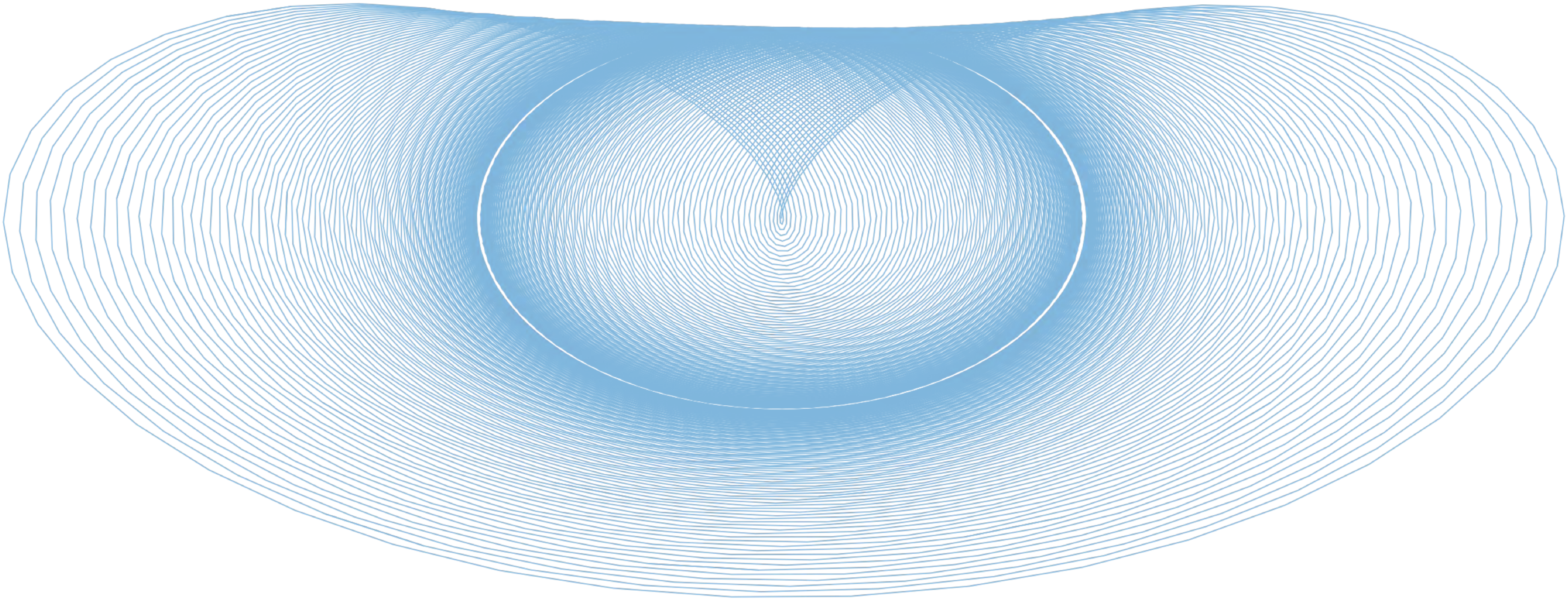
PHYS 1420 (F19)
Physics with Applications to Life Sciences



2019.11.08

Relevant reading:
Kesten & Tauck ch. N/A

Christopher Bergevin
York University, Dept. of Physics & Astronomy
Office: Petrie 240   Lab: Farq 103
cberge@yorku.ca

Ref. (re images):
Wolfson (2007), Knight (2017), Kesten & Tauck (2012)

Announcements & Key Concepts (re Today)

→ Written HW #2: Posted and due Friday 11/15 in class

→ Midterm exams: Grades posted on Moodle and exams to be handed back

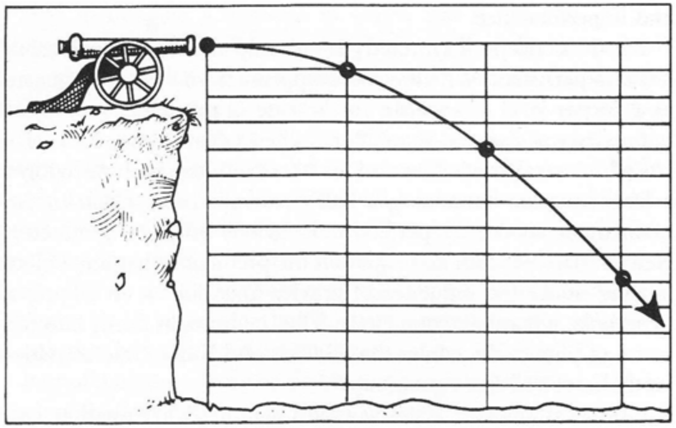
Some relevant underlying concepts of the day…

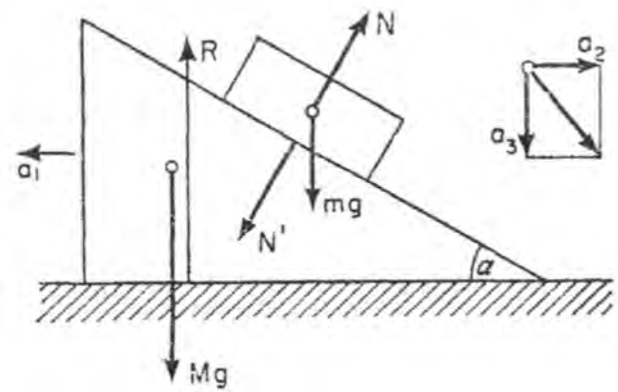
- Movement of "stuff"
- Diffusion
- Random walkers
- Multivariable functions

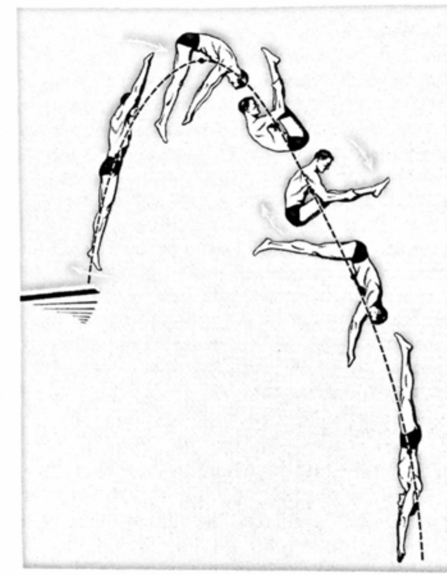
Moving things...

→ We have spent a lot of time thus far examining how things move...

(or don't move as is sometimes the case)







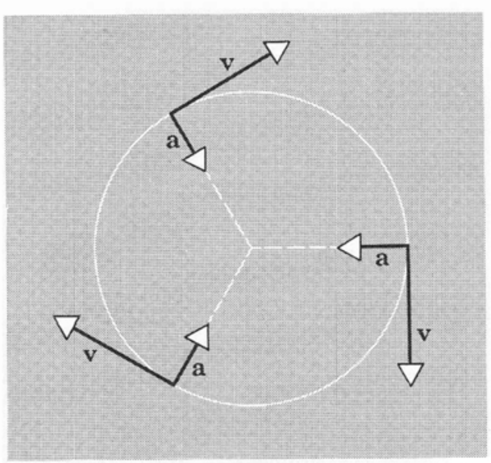
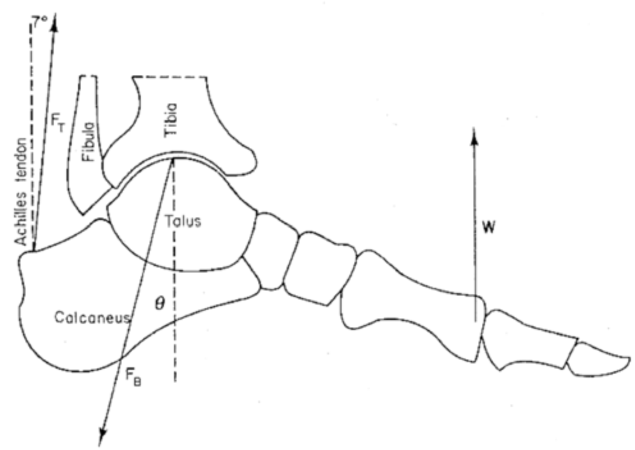
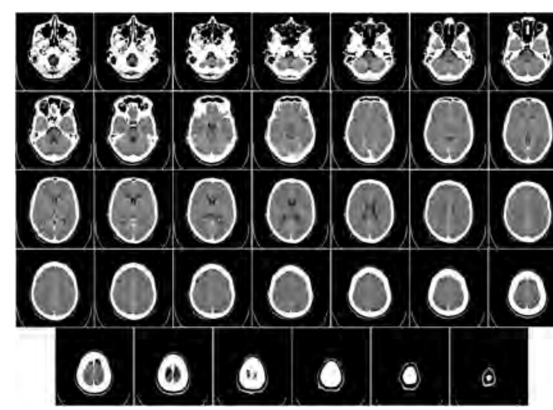
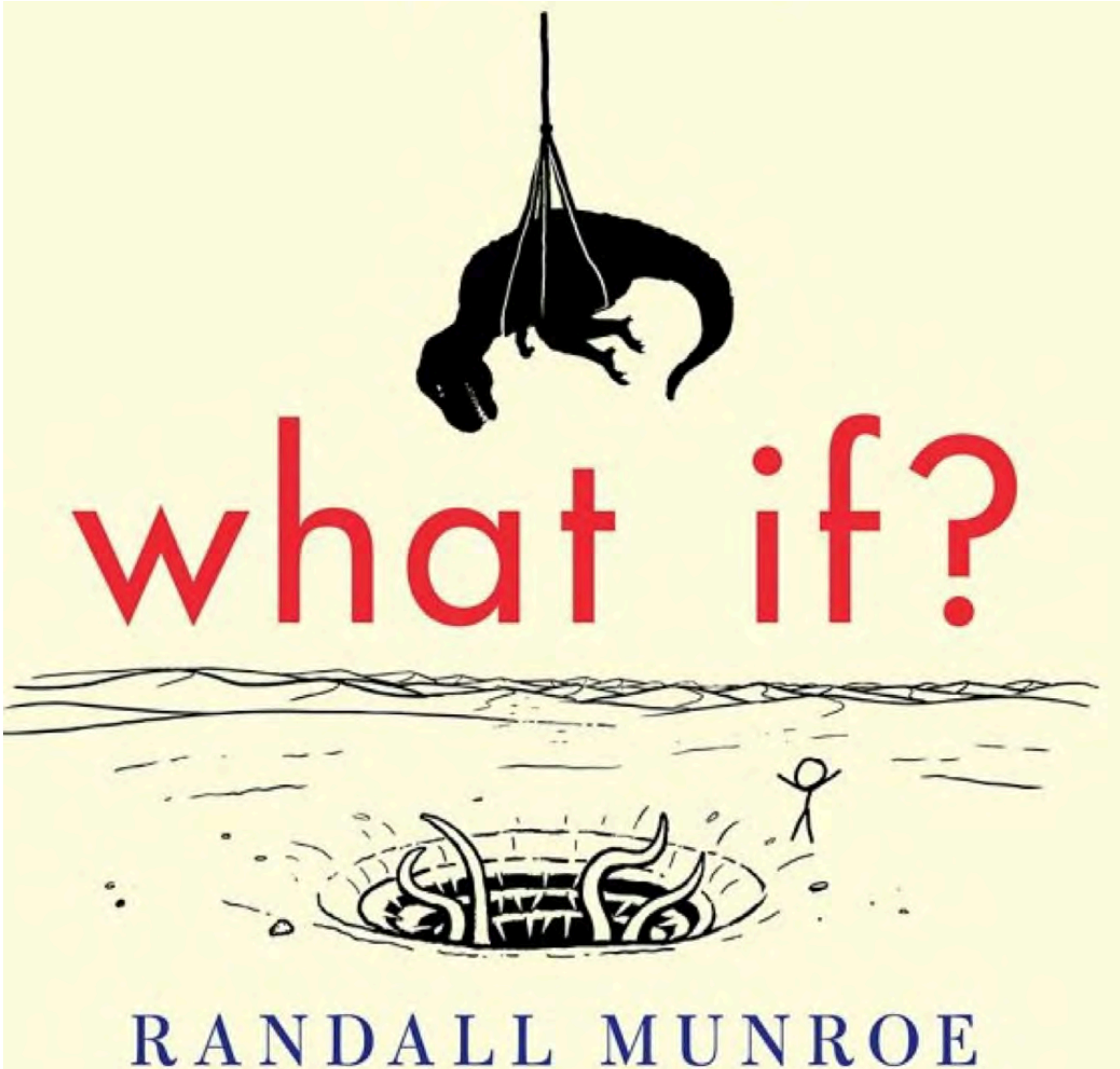


Fig. 4–6 In uniform circular motion the acceleration **a** is always directed toward the center of the circle and hence is perpendicular to **v**.

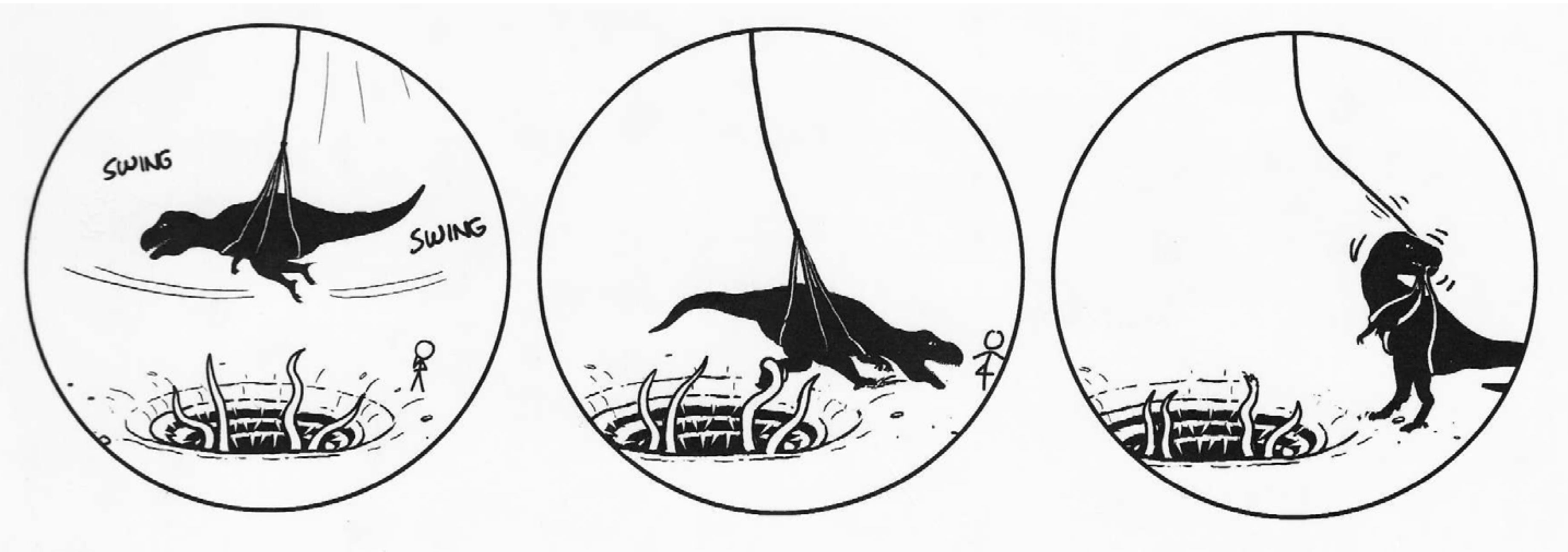




Aside:



Munroe (2014)



Munroe (2014)

Munroe (2014)

Recall: Warmth

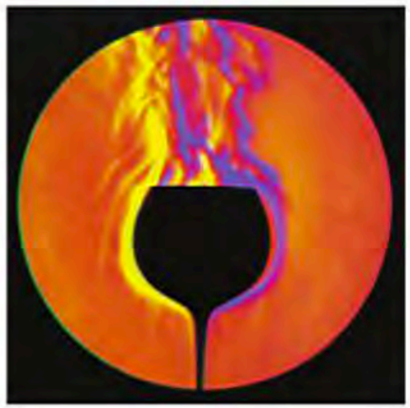
→ How does “warmth" move?

Mechanisms of Energy Transfer

- Four basic mechanisms by which objects exchange heat w/ their surroundings

Heat-transfer mechanisms

When two objects are in direct contact, such as the soldering iron and the circuit board, heat is transferred by *conduction*.



Air currents near a warm glass of water rise, taking thermal energy with them in a process known as *convection*.

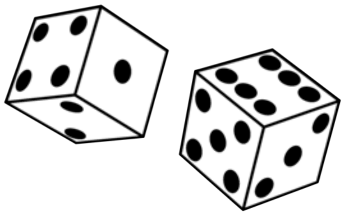
The lamp at the top shines on the lambs huddled below, warming them. The energy is transferred by *radiation*.

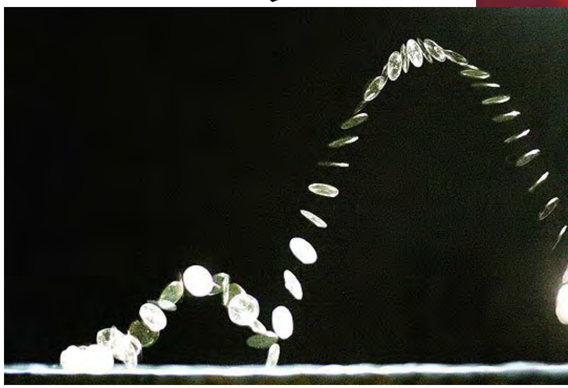
Blowing on a hot cup of tea or coffee cools it by *evaporation*.

Goal now is to build up a theme focusing on one of these in particular....

Knight

Games of chance....





Key connective thread: *Randomness*

(or *stochasticity*)

Aside: Making a Gaussian distribution

EXgaussian1.m

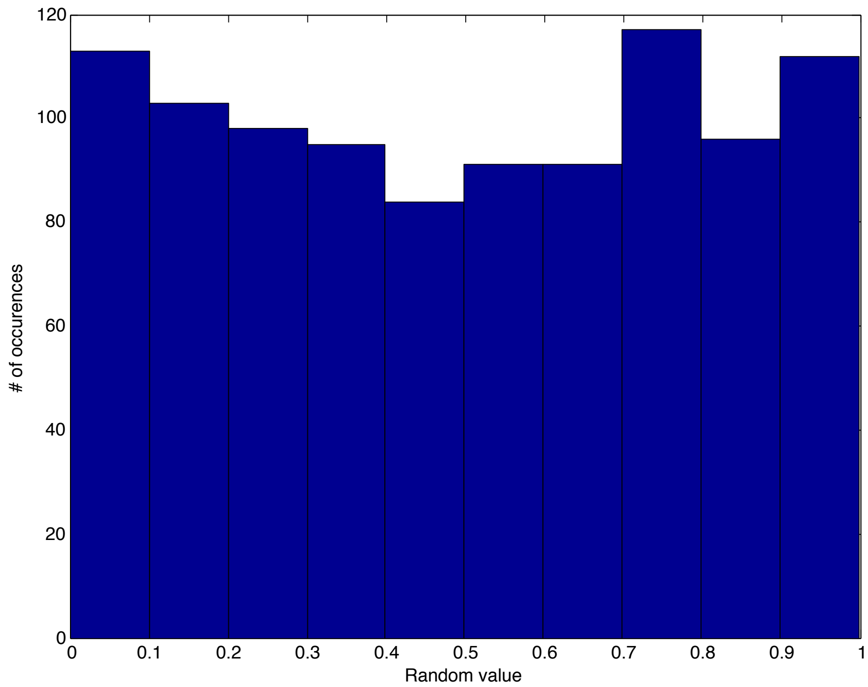
- Simple Matlab code to see if we can 'create' a normal distribution.....

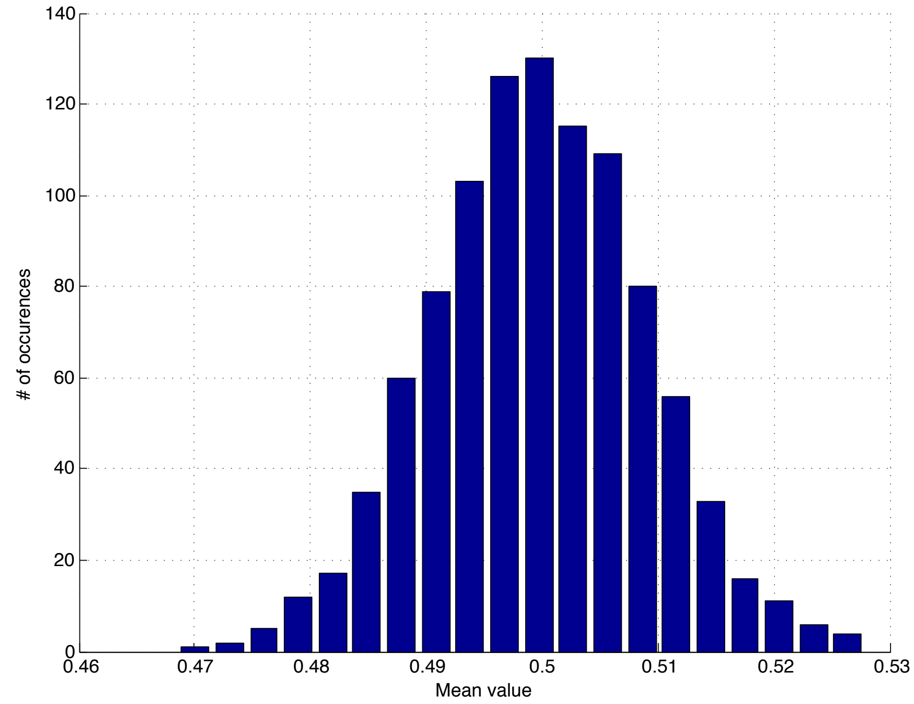
```
%  ### EXgaussian1.m ###
clear
% -----------
M= 1000;        % # of (uniformly distributed) random #s to average
N=1000;         % # of repeats (i.e., how many averages to compute) for histogram
binN= 20;      % # of bins for histogram
% -----------
figure(1); clf; hold on; grid on;
% +++
% loop thru to compute the N averages (each loop deals with the M random #s)
for nn=1:N
    xR= rand(M,1);  % determine array of M random #s
    mu(nn)= mean(xR);   % compute/store mean value
end
% +++
[jj,kk]=hist(mu,binN);   % detrmine histogram distribution
bar(kk,jj);             % plot the histogram (as a bar plot)
```

→ Simply determines a group of uniformly distributed numbers, then averages them. Subsequently, we keep track of the those mean values and plot as a '*histogram*'

Aside: Making a Gaussian distribution

```
M= 1000;         % # of (uniformly distributed) random #s to average
N=1000;          % # of repeats (i.e., how many averages to compute) for histogram
```





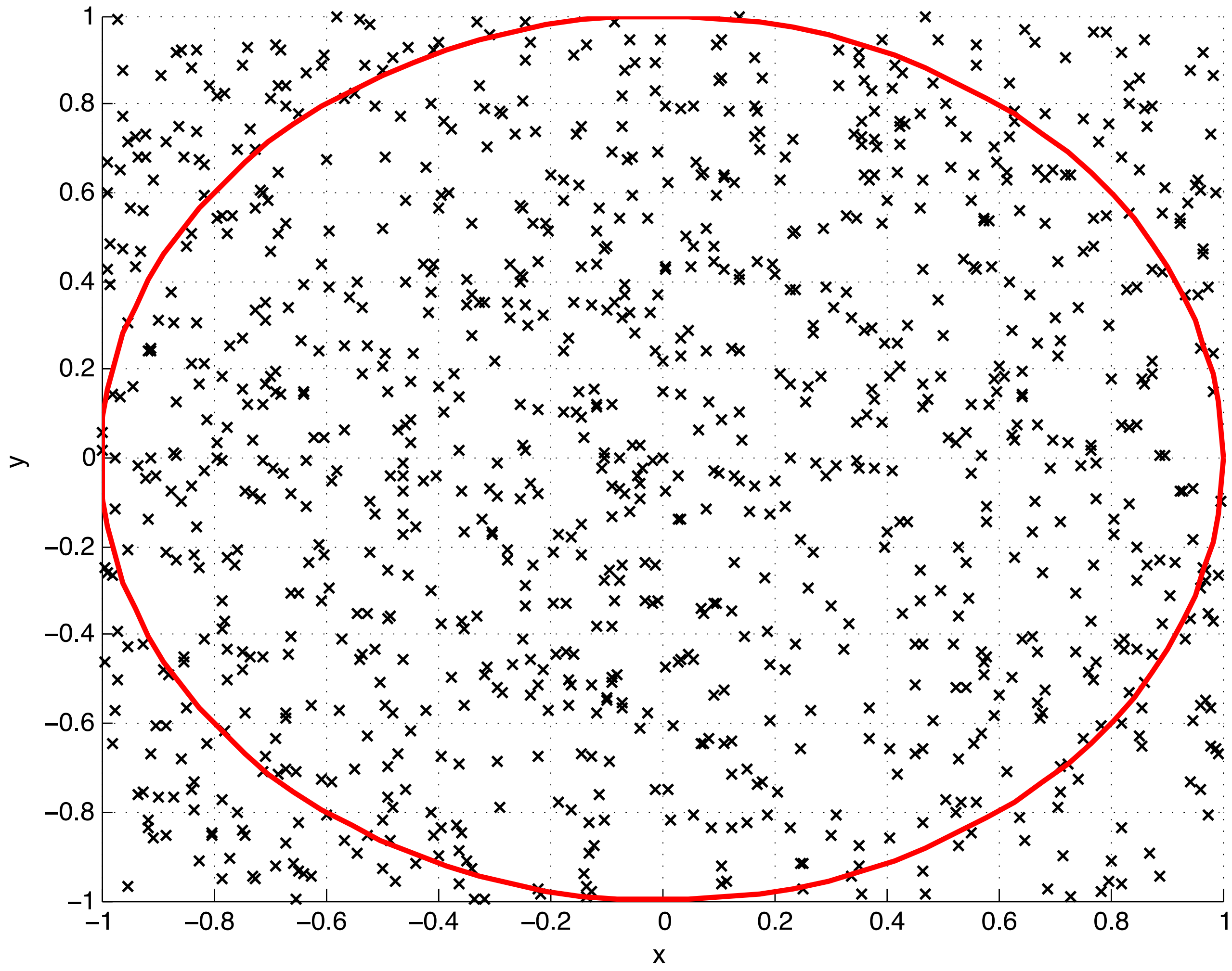
So within a given sample, the `M` points are uniformly distributed...

... but the average value (across `N` repetitions) is normally distributed!

→ This sort of observation demonstrates the notion of a normal distribution and is ultimately telling us something important about the nature of the underlying probability distribution!

Aside: Estimating π (via random #s)

```
N=1000;        % # of points to use
```



→ Simply just using random numbers and ratios of areas

```
estimate for pi = 3.12 (using 1000 points)
```

Random walks

Consider that:

- the drunkard (randomly) stumbles about
- the drunkard may have some sense of where (s)he is going

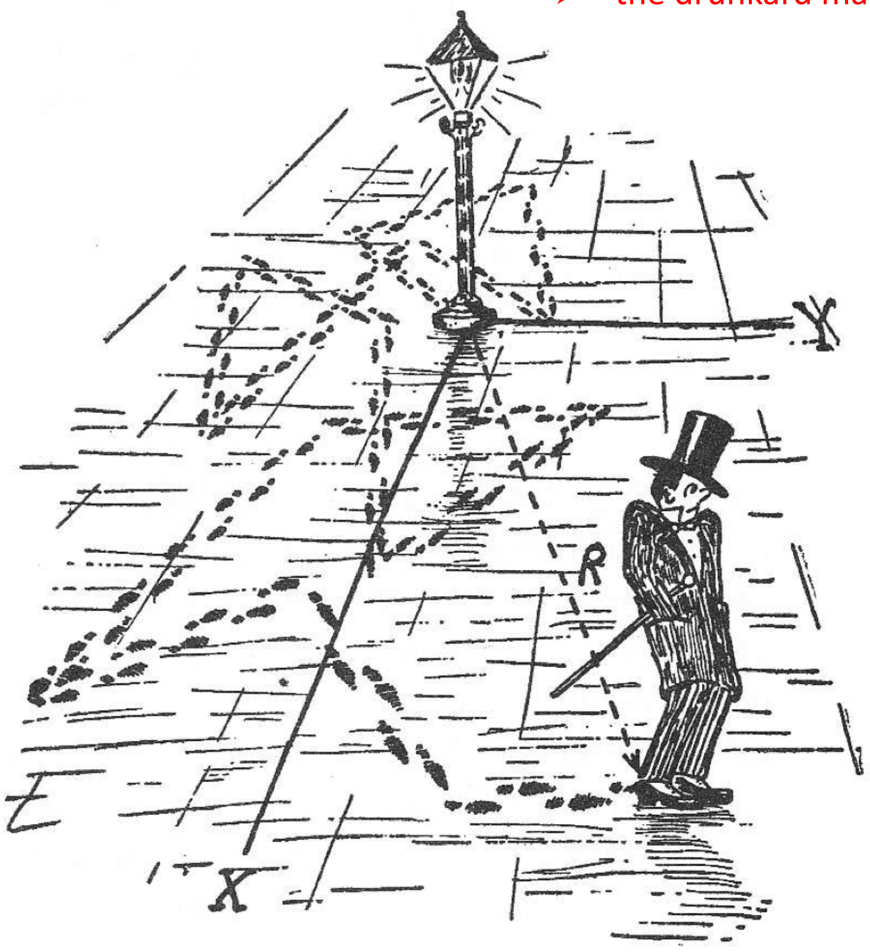


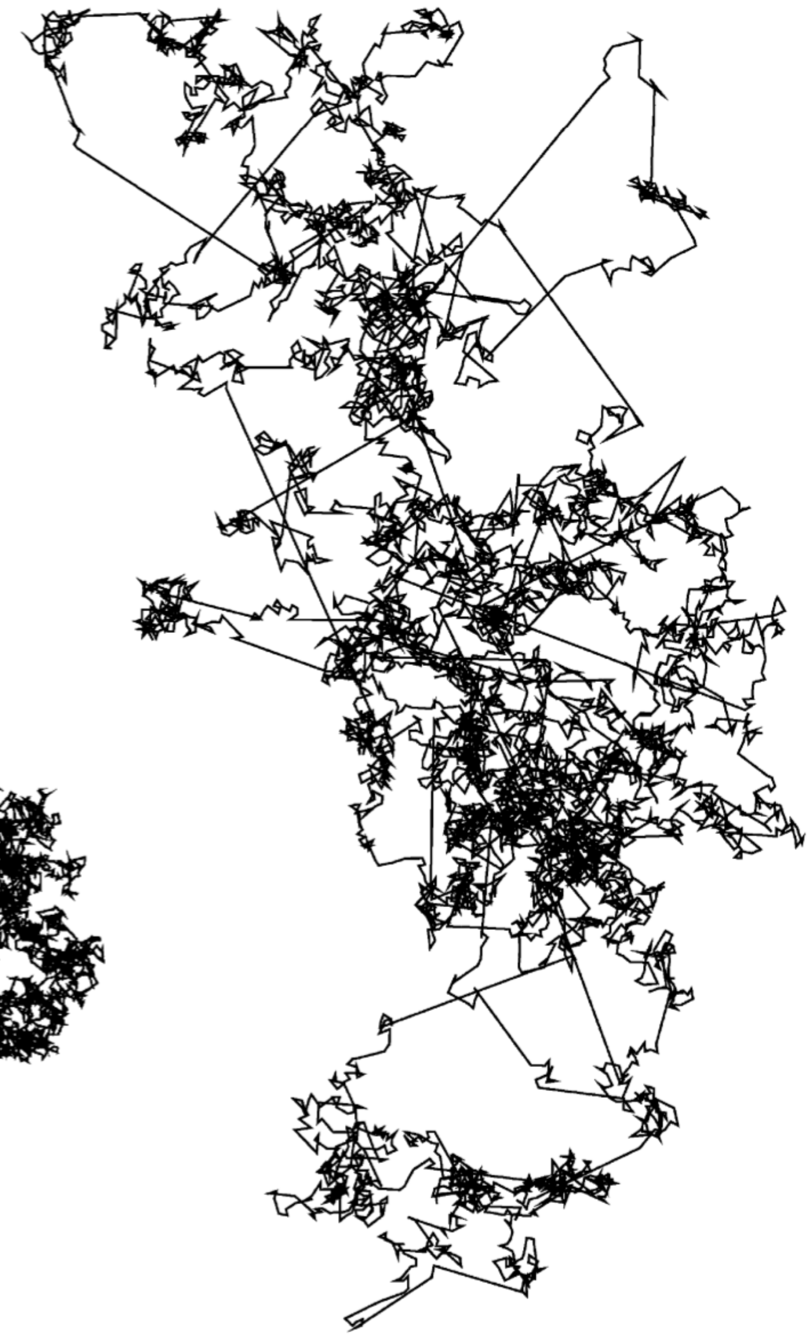
Figure 4.1: (Metaphor.) A random (or "drunkard's") walk. [Cartoon by George Gamow, from Gamow, 1961.]

Nelson (2004)

Quiz

What is different between these two "random" walkers?

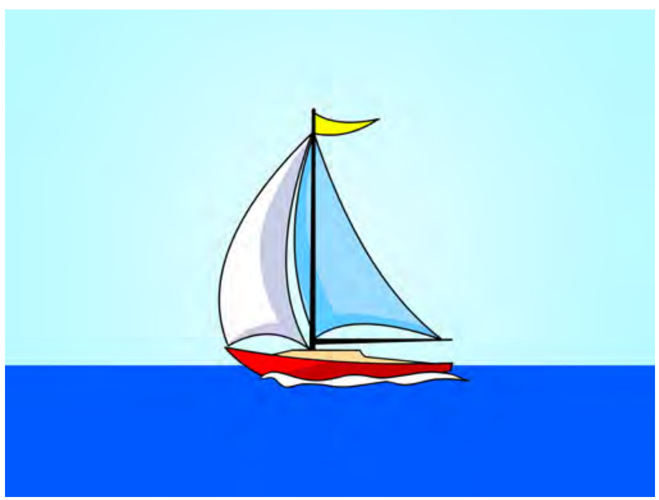
One **passively** gets *jostled* around while the other **actively** *walks* at times...

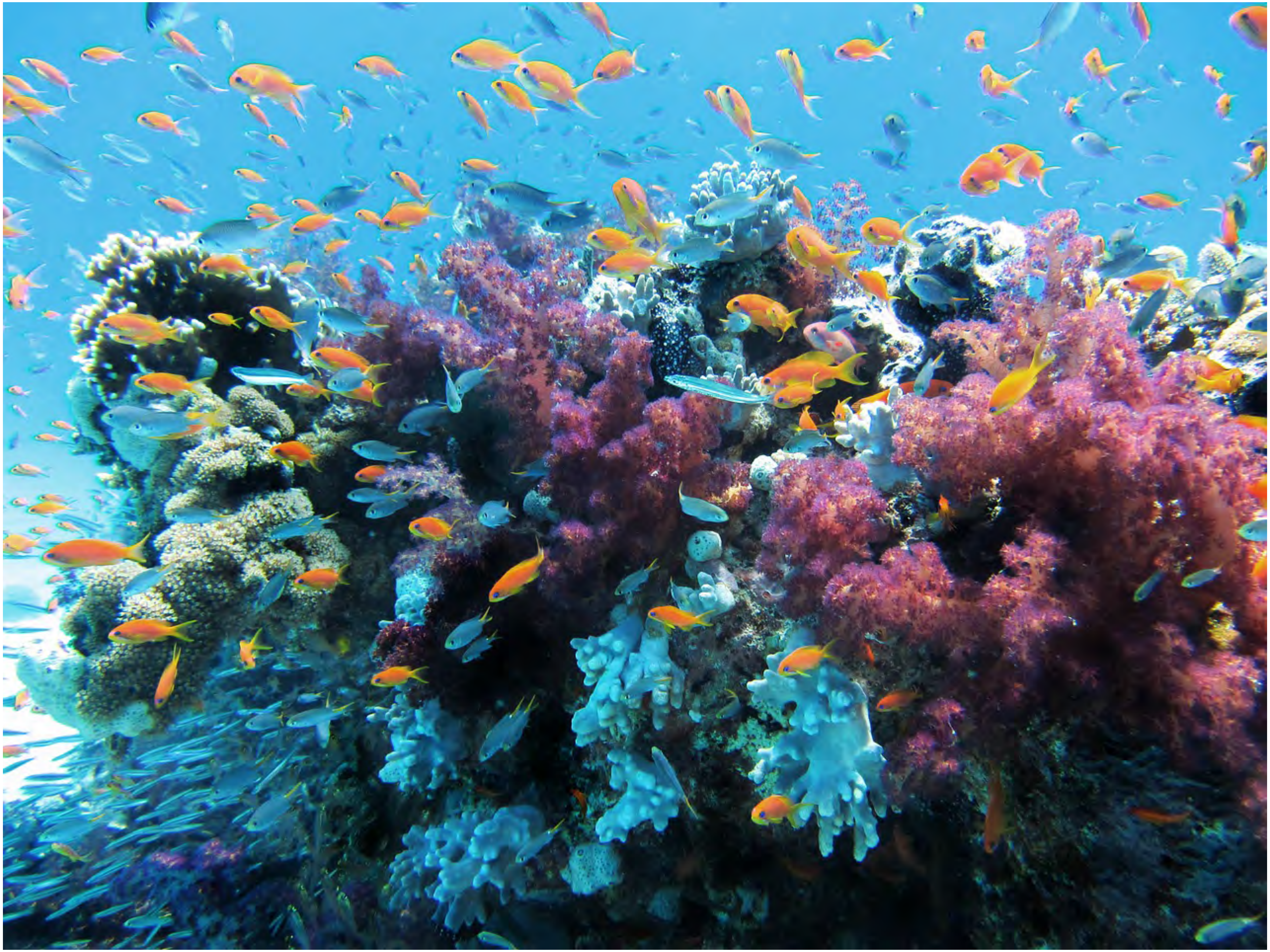


→ There is a fundamental biophysical/biological/evolutionary/etc.... distinction here!

Metzler & Klafter (2000)

Passive versus active movement





Basic physical consideration: Passive vs Active

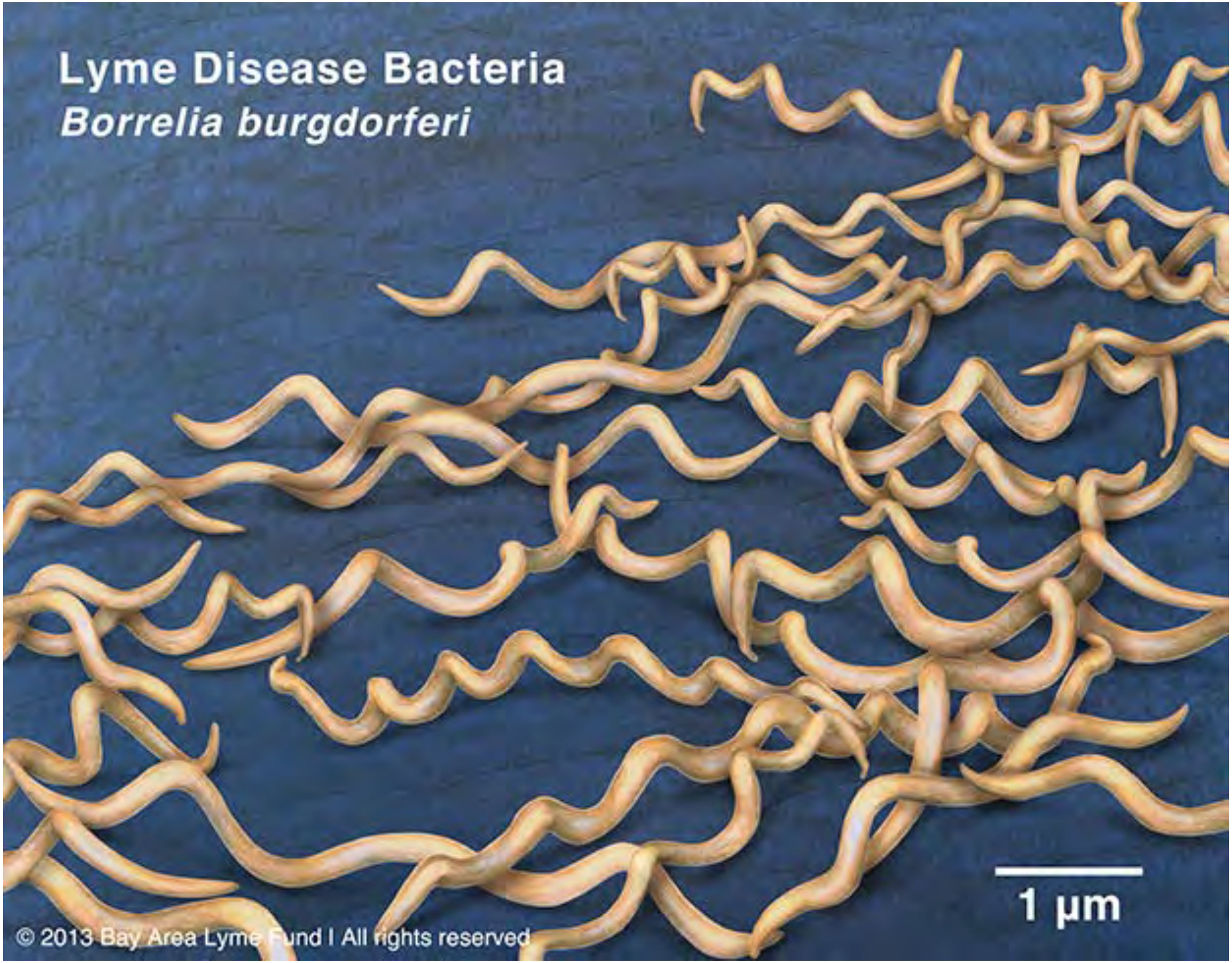
- Passive: movement is subject to the medium you are in moving you around
- Active: you move yourself around (e.g., swim)

MOTILE BEHAVIOR OF BACTERIA

JANUARY 2000 PHYSICS TODAY

E. coli, a self-replicating object only a thousandth of a millimeter in size, can swim 35 diameters a second, taste simple chemicals in its environment, and decide whether life is getting better or worse.

Howard C. Berg


Lyme Disease Bacteria
Borrelia burgdorferi
1 µm
© 2013 Bay Area Lyme Fund I All rights reserved

Bacterial motility

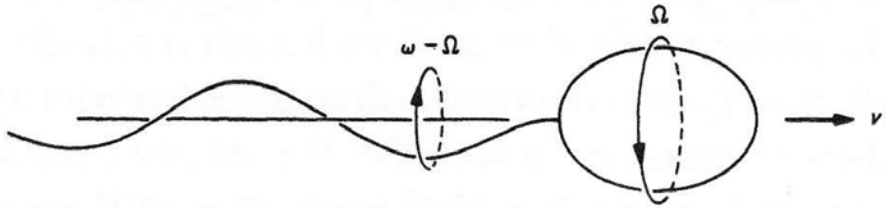


Fig. 6.2. A bacterium swimming to the right at velocity v. A rotary motor at the base of the flagellum turns the helical filament relative to the body of the cell at angular velocity ω. When the cell is viewed from behind, the body turns clockwise at angular velocity Ω, and the filament turns counterclockwise at angular velocity $\omega - \Omega$; ω is larger than Ω. The filament is left-handed; when the helix is viewed end-on, a particle moving along it away from the observer turns counterclockwise.

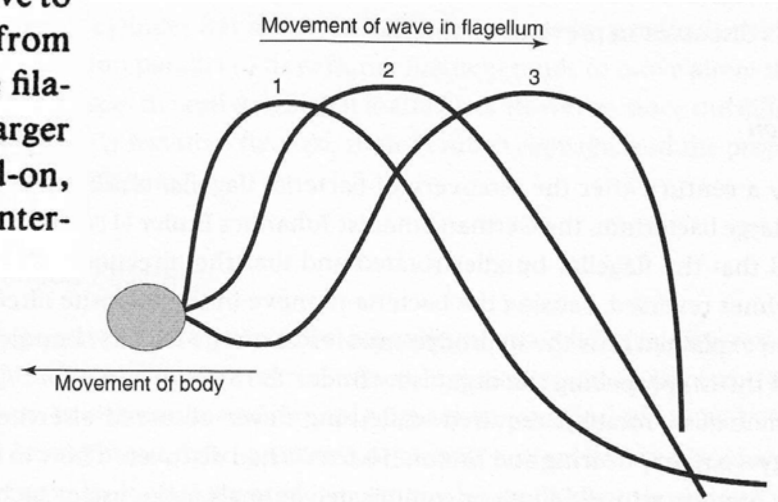


Figure 13.6. Pattern of the beating of a single flagellum. Some eukaryotic microorganisms swim by beating a single flagellum back and forth, with waves of displacement moving down the length of the flagellum. In some organisms, the waves move away from the body, pushing the cell away from the flagellum, while others swim with the flagellum ahead and the waves moving toward the body. In both cases, the cylindrical flagellum moves at an angle to its axis, forcing the surrounding water to move primarily perpendicular to the local axis and parallel to the general axis of the flagellum. With this type of movement, thrust is generated in both phases of the beat. A disadvantage is that the body is rotated back and forth as the flagellum bends at its base.

→ How does a bacteria move around?

"Swims" via some sort of motor (e.g., flagellum)

Berg (1993)
Dusenbery (2009)

Bacterial motility

- Some sort of "flagellum" and energy-consuming "motor" is required

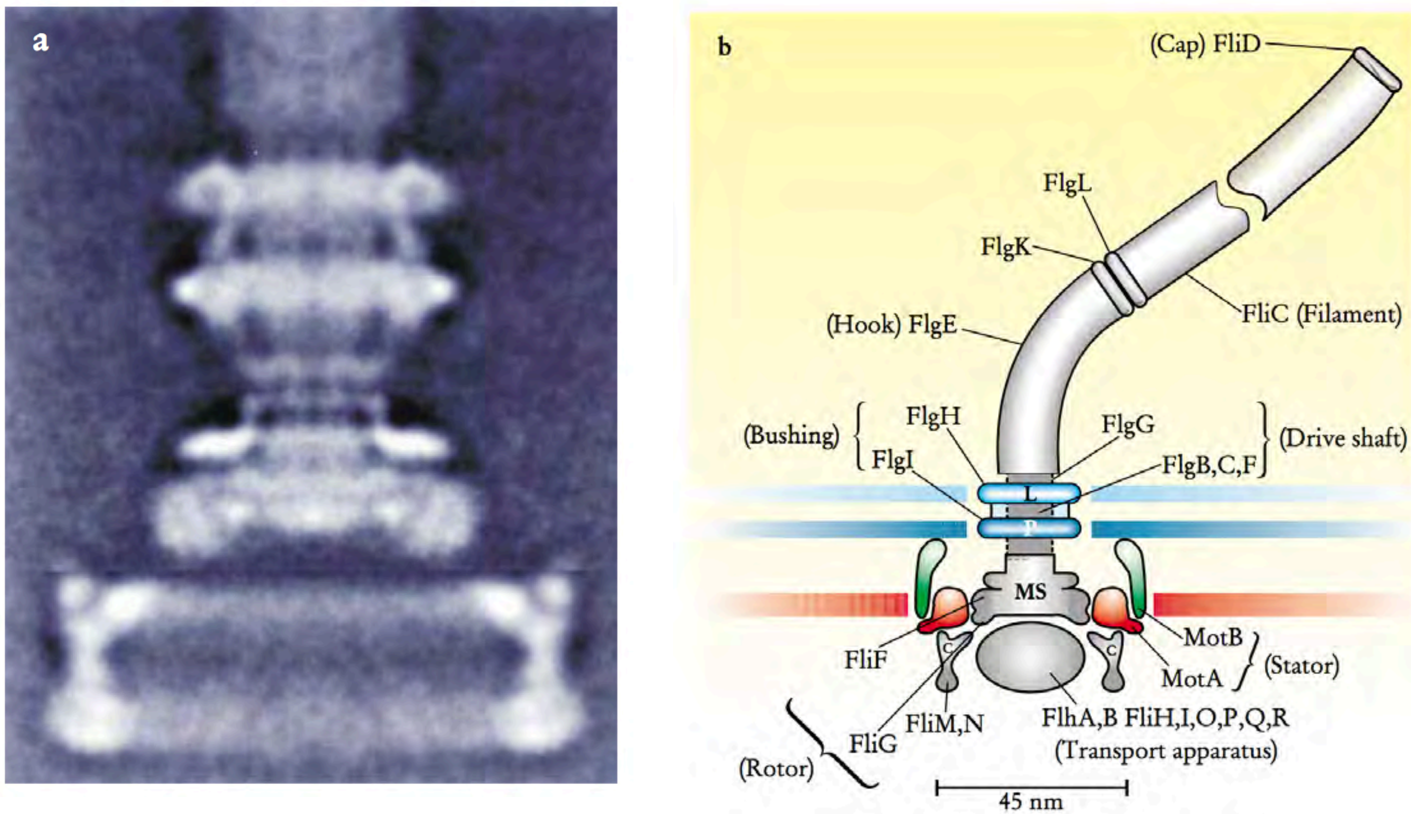
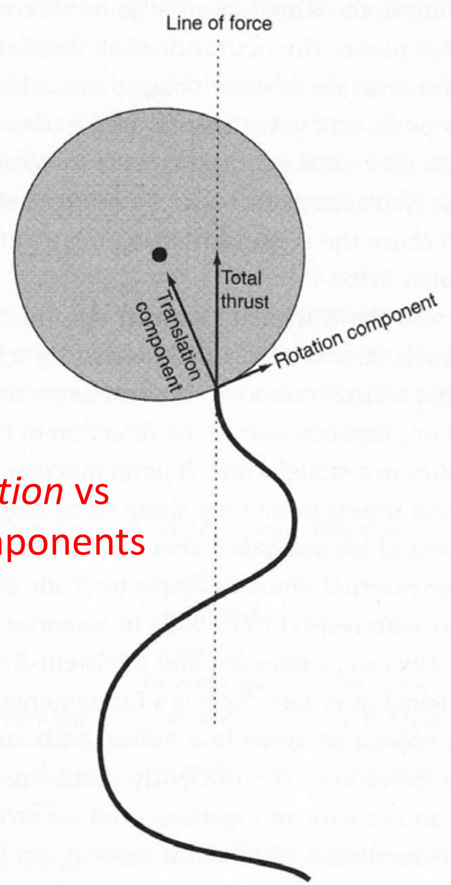


FIGURE 2. BACTERIAL MOTOR AND DRIVE TRAIN. (**a**) Rotationally averaged reconstruction of electron micrographs of purified hook-basal bodies. The rings seen in the image and labeled in the schematic diagram (**b**) are the L ring, P ring, MS ring, and C ring. (Digital print courtesy of David DeRosier, Brandeis University.)

Berg (2000)

Bacterial motility



Note *translation* vs *rotation* components here!

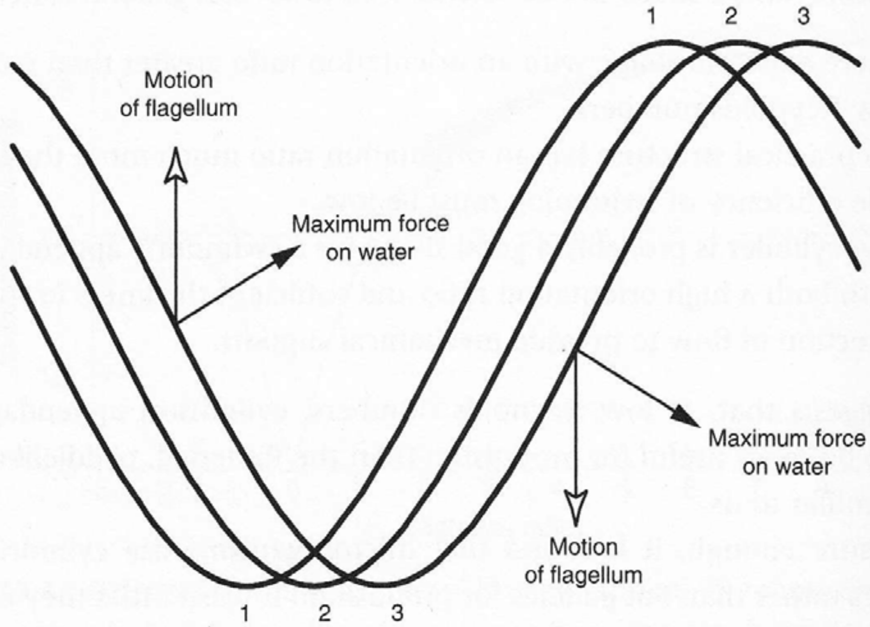


Figure 13.4. The movement and forces generated by an idealized flagellum. The figure represents three snapshots of a length of a flagellum that is propagating bending waves from left to right. Any one section of the flagellum moves predominately up and down (open arrows). But the flagellum alters orientation between the two haves of the cycle, and in both halves the surrounding water is pushed to the right (closed arrows), causing the flagellum to move to the left.

Figure 13.7. Propulsive forces generating helical motion. A swimming microorganism has a center of frictional resistance represented by the black dot. However it generates its propulsive thrust, the thrust is unlikely to be directed perfectly toward this center. The total thrust can then be understood as composed of a component in line with the center (generating pure translation) and a component perpendicular to this line (generating rotation around an axis perpendicular to the line of force). Thus, the body will generally undergo both translation and rotation.

Dusenbery (2009)

Bacterial motility

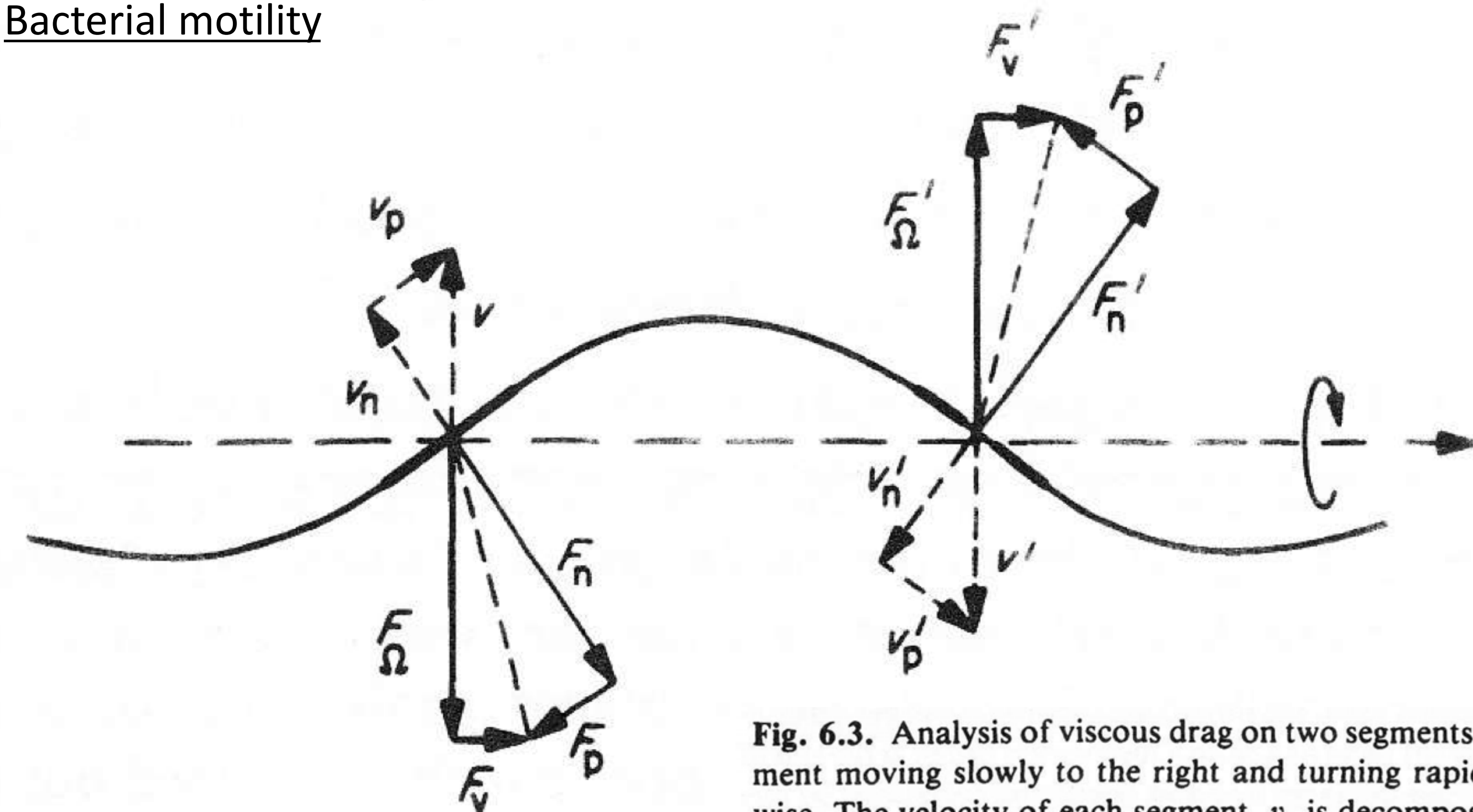


Fig. 6.3. Analysis of viscous drag on two segments of a flagellar filament moving slowly to the right and turning rapidly counterclockwise. The velocity of each segment, v, is decomposed into velocities normal and parallel to the segment, v_n and v_p, respectively. The segment shown on the left is moving upward in front of the plane of the paper; the one shown on the right (denoted by primes) is moving downward behind the plane of the paper. The frictional drags normal and parallel to each segment, F_n and F_p, act in directions opposite to v_n and v_p, respectively. Note that their magnitudes are in the ratios $F_n/F_p \simeq 2v_n/v_p$. F_n and F_p are decomposed into components normal and parallel to the helical axis, F_Ω and F_v, respectively. F_Ω and F_Ω' act in opposite directions and form a couple that contributes to the torque. F_v and F_v' act in the same direction and contribute to the thrust.

→ Looks like *torques* are at play here!

Berg (1993)

Bacterial motility

Note: This is a 3-D plot!
(try crossing your eyes)

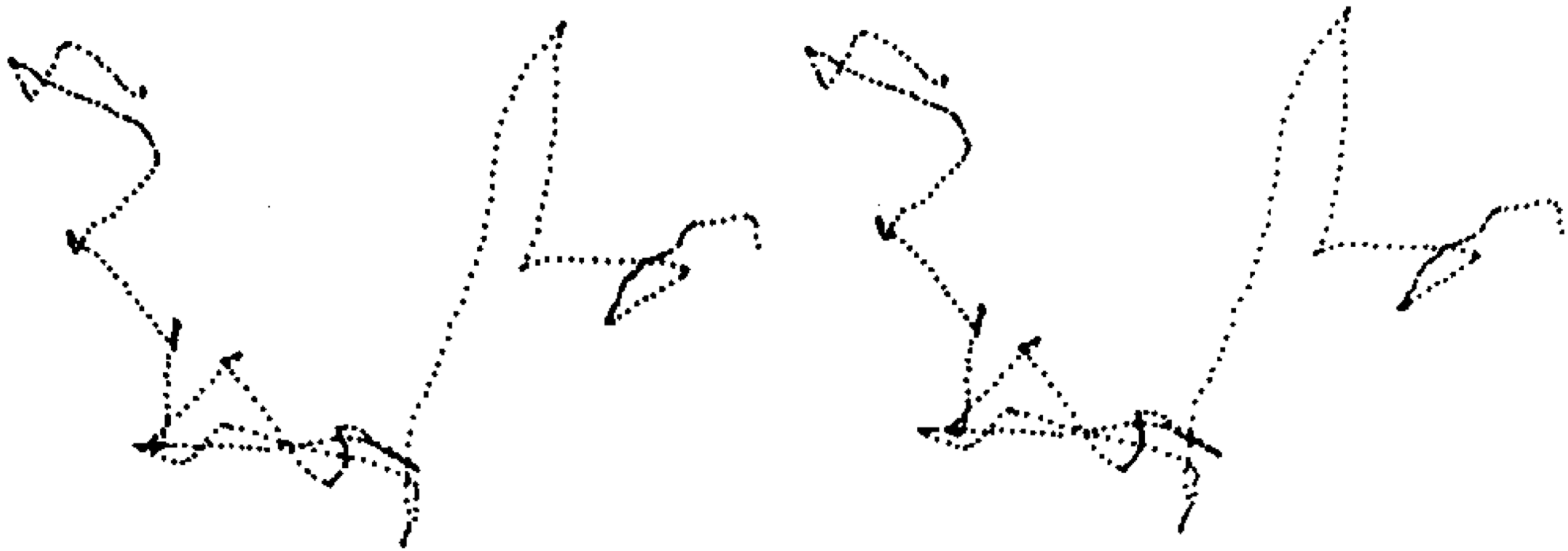
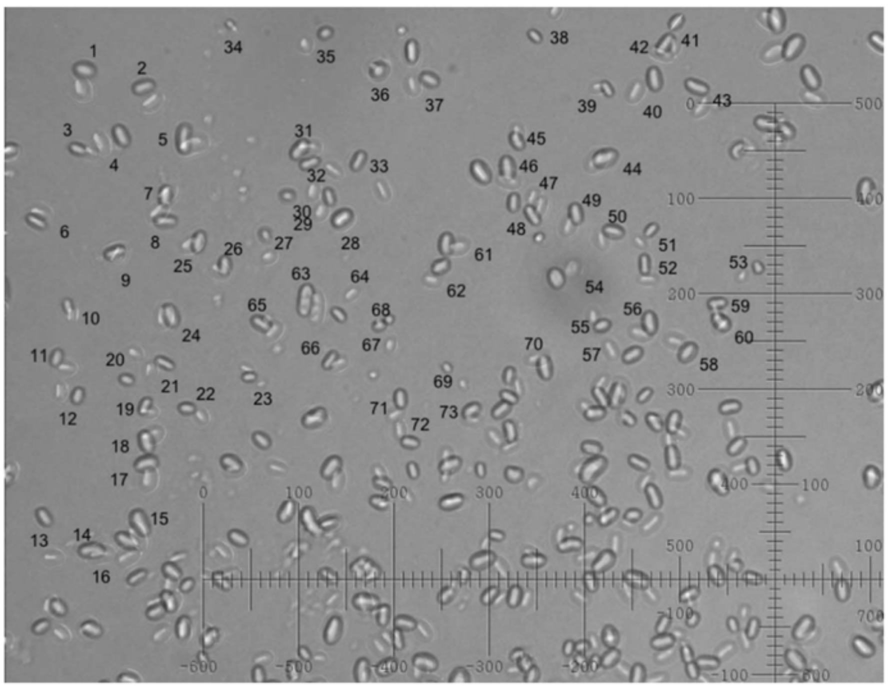


FIGURE 3. MOVEMENT. This stereo plot shows about 30 s in the life of one *Escherichia coli* K-12 bacterium swimming in an isotropic homogenous medium.[18] The track spans about 0.1 mm, left to right. The plot shows 26 runs and tumbles, the longest run (nearly vertical) lasting 3.6 s. The mean speed is about 21 μm/s. To see this plot in three dimensions, look at the left image with your left eye and the right image with your right eye, and relax your eye muscles so that the two images overlap. A stereoscope (pair of lenses) helps.

Berg (2000)

Robert Brown
(1773-1858)



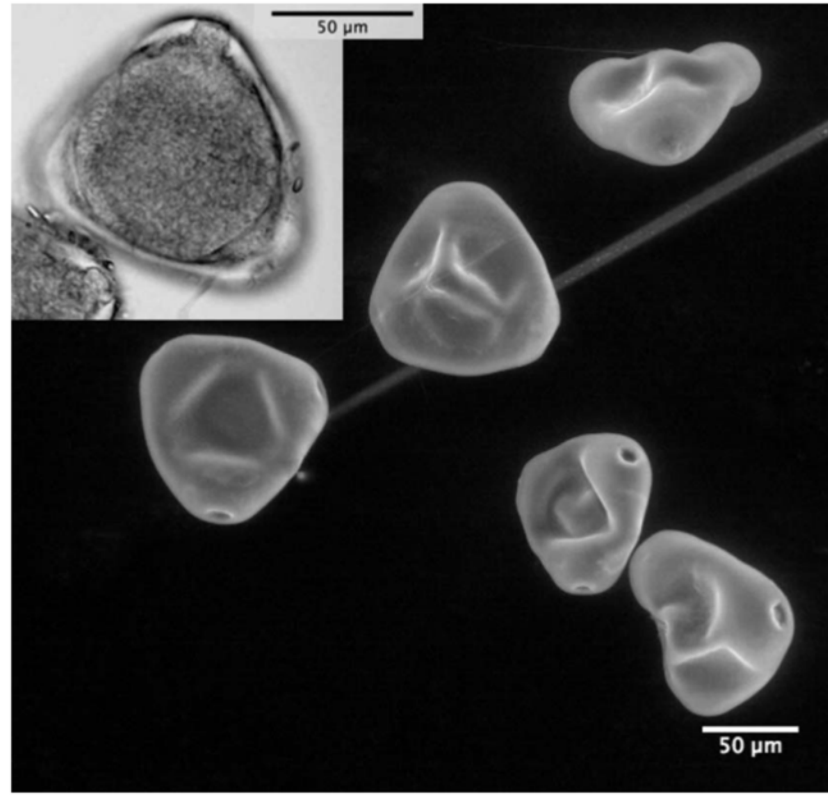


Fig. 1. *Clarkia pulchella* pollen imaged by a microscope (inset) and by an electron microscope.

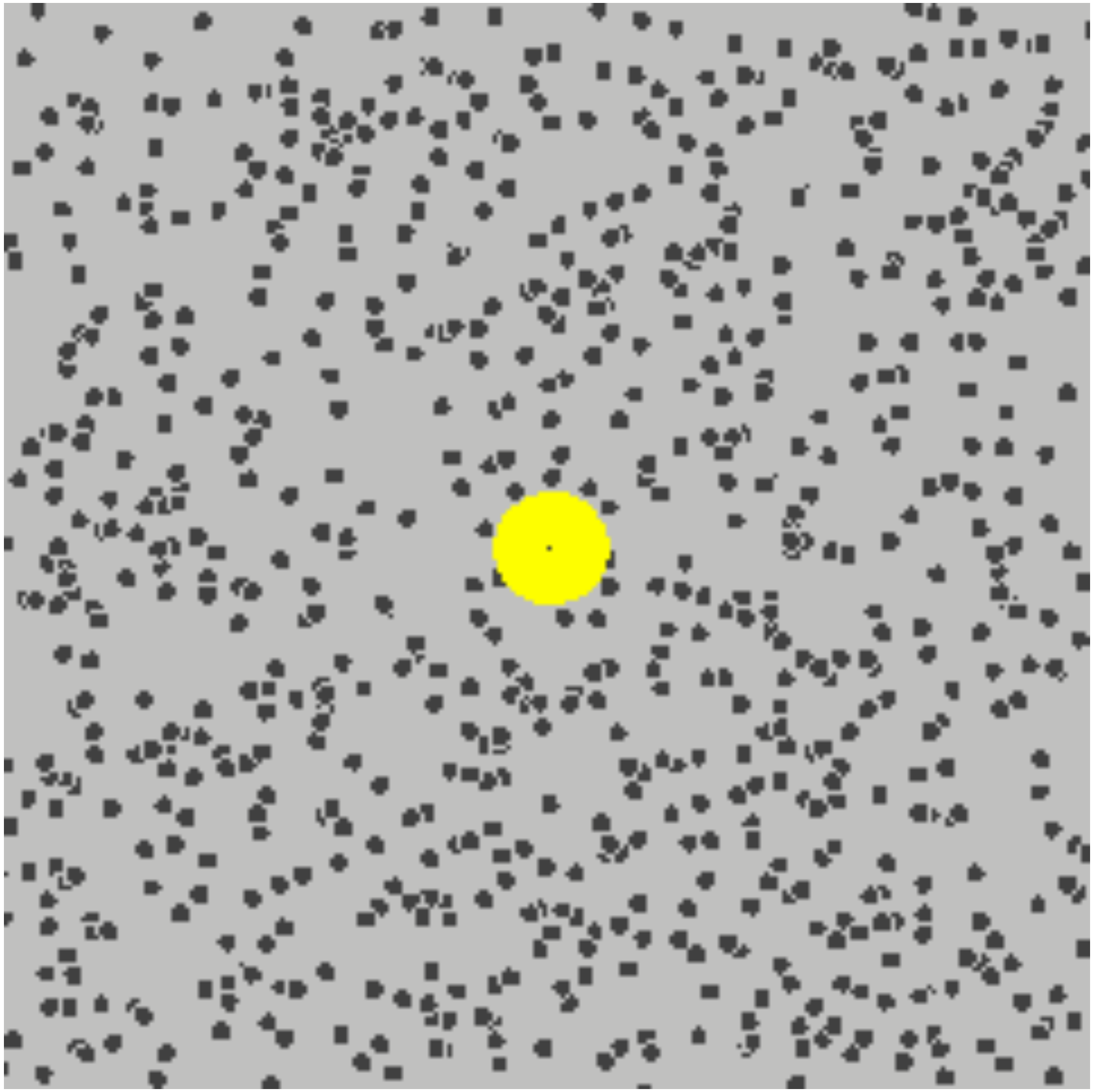
How does a "non-living" thing (e.g., pollen) move around?

→ **Does not** move like bacteria (i.e., does not swim around)....

Pearle et al (2010)

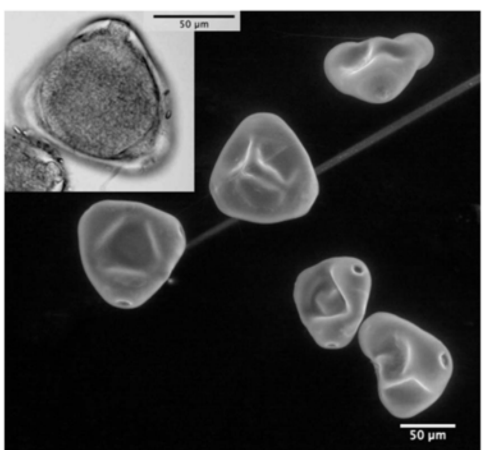
Brownian Motion

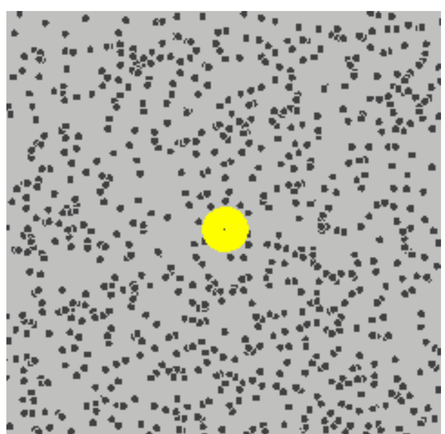
Random motion of large object (yellow circle) due to interaction with many little objects (black circles)

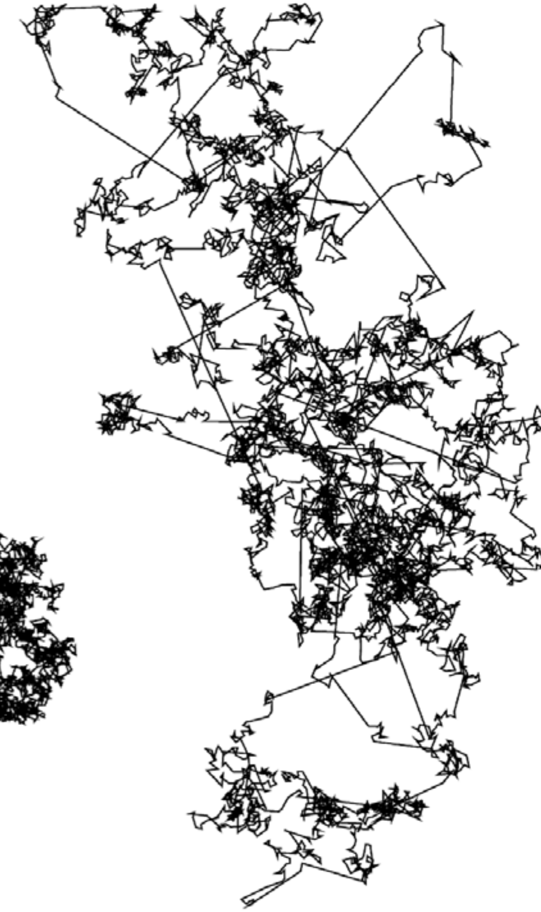


Seems to be "jostled" around...

wikipedia (Brownian motion)





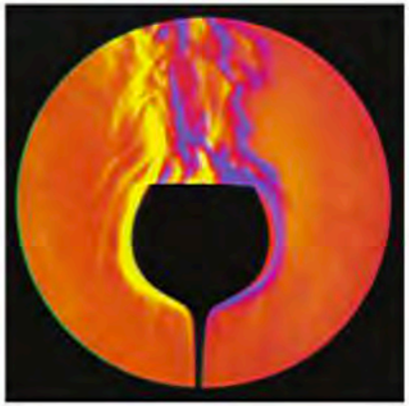


→ So a more general question emerges:

What are the basic mechanisms by which "stuff" moves around?

Heat-transfer mechanisms

When two objects are in direct contact, such as the soldering iron and the circuit board, heat is transferred by *conduction*.



Air currents near a warm glass of water rise, taking thermal energy with them in a process known as *convection*.

The lamp at the top shines on the lambs huddled below, warming them. The energy is transferred by *radiation*.

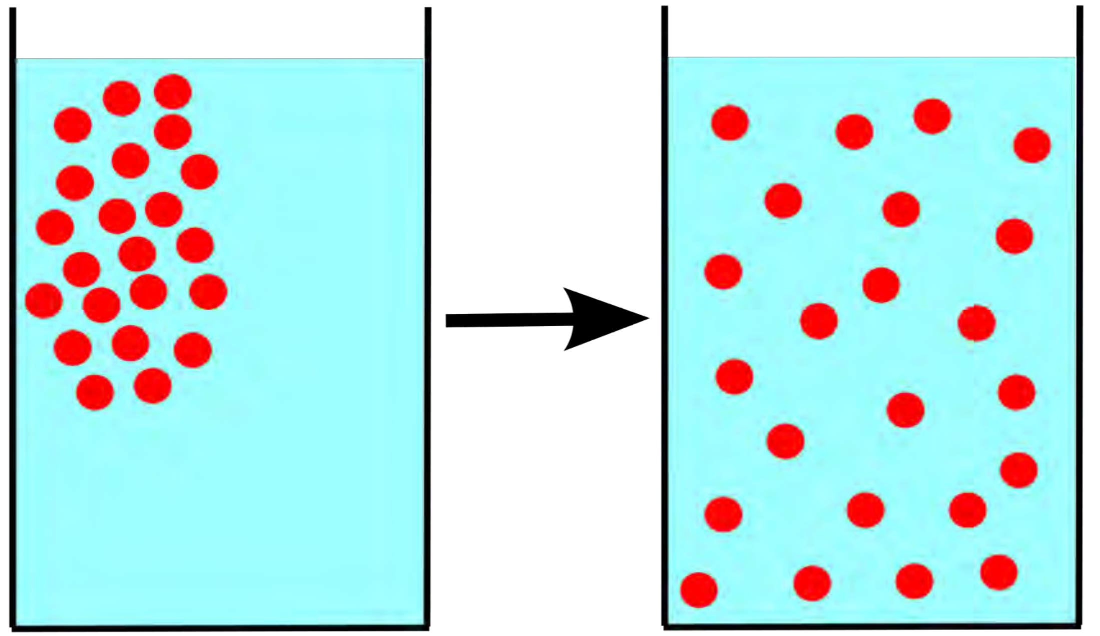
Blowing on a hot cup of tea or coffee cools it by *evaporation*.

Goal now is to build up a theme focusing on one of these in particular....

... and that is a key principle underlying *conduction*

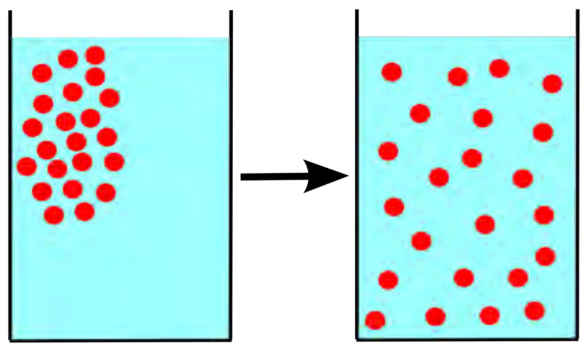
Knight

Diffusion



Diffusion

- According to wikipedia....



- According to the dictionary....

diffusion

[dih-**fyoo**-zhuh *h* n]

Spell Syllables

Examples Word Origin

noun

1. act of diffusing; state of being diffused.

2. prolixity of speech or writing; discursiveness.

3. *Physics.*
   a. Also called **migration**. an intermingling of molecules, ions, etc., resulting from random thermal agitation, as in the dispersion of a vapor in air.
   b. a reflection or refraction of light or other electromagnetic radiation from an irregular surface or an erratic dispersion through a surface; scattering.

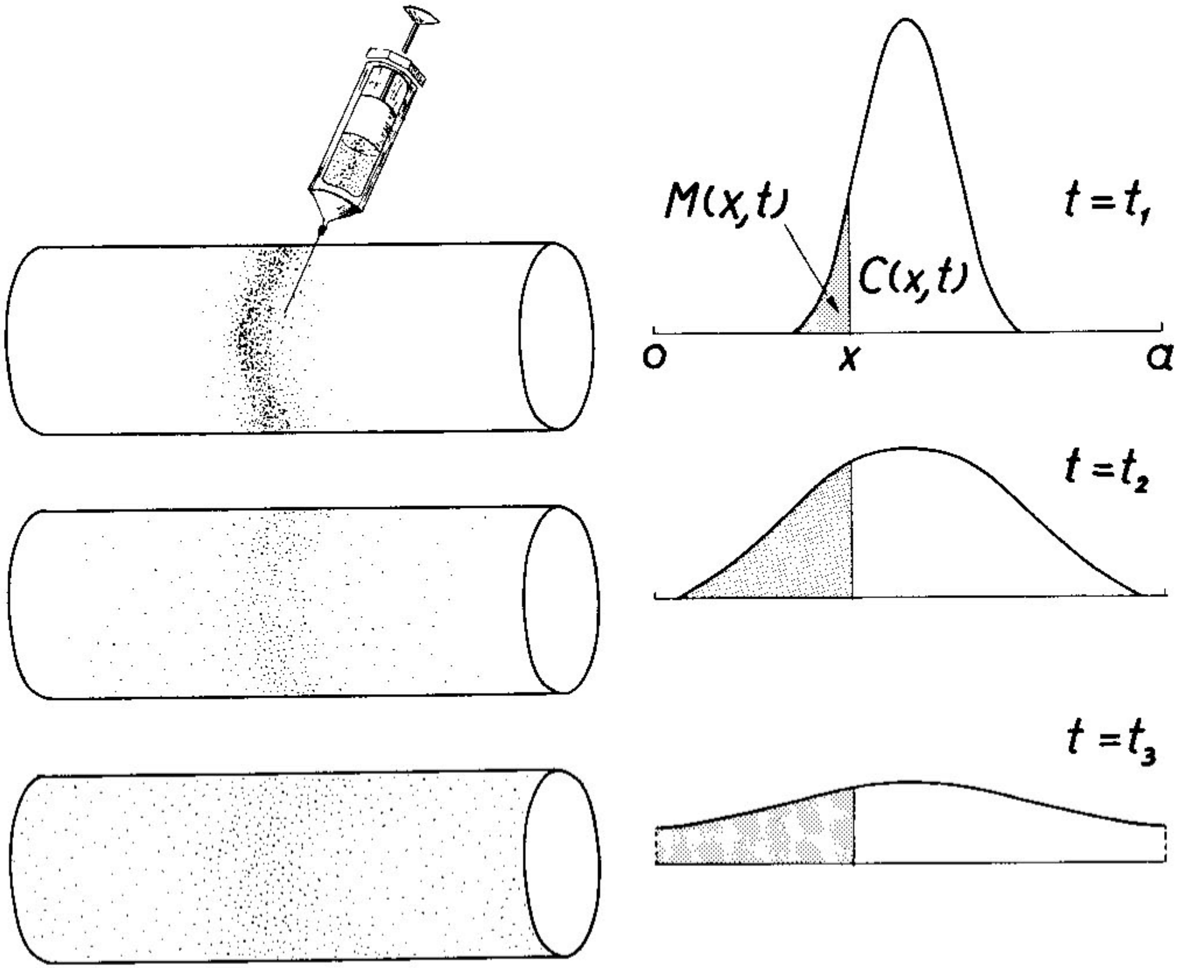
4. *Movies.* a soft-focus effect resulting from placing a gelatin or silk plate in front of a studio light or a camera lens, or through the use of diffusion filters.

5. *Meteorology.* the spreading of atmospheric constituents or properties by turbulent motion as well as molecular motion of the air.

6. *Anthropology, Sociology.* Also called **cultural diffusion**. the transmission of elements or features of one culture to another.

Diffusion Processes

→ You have intuition for this already....

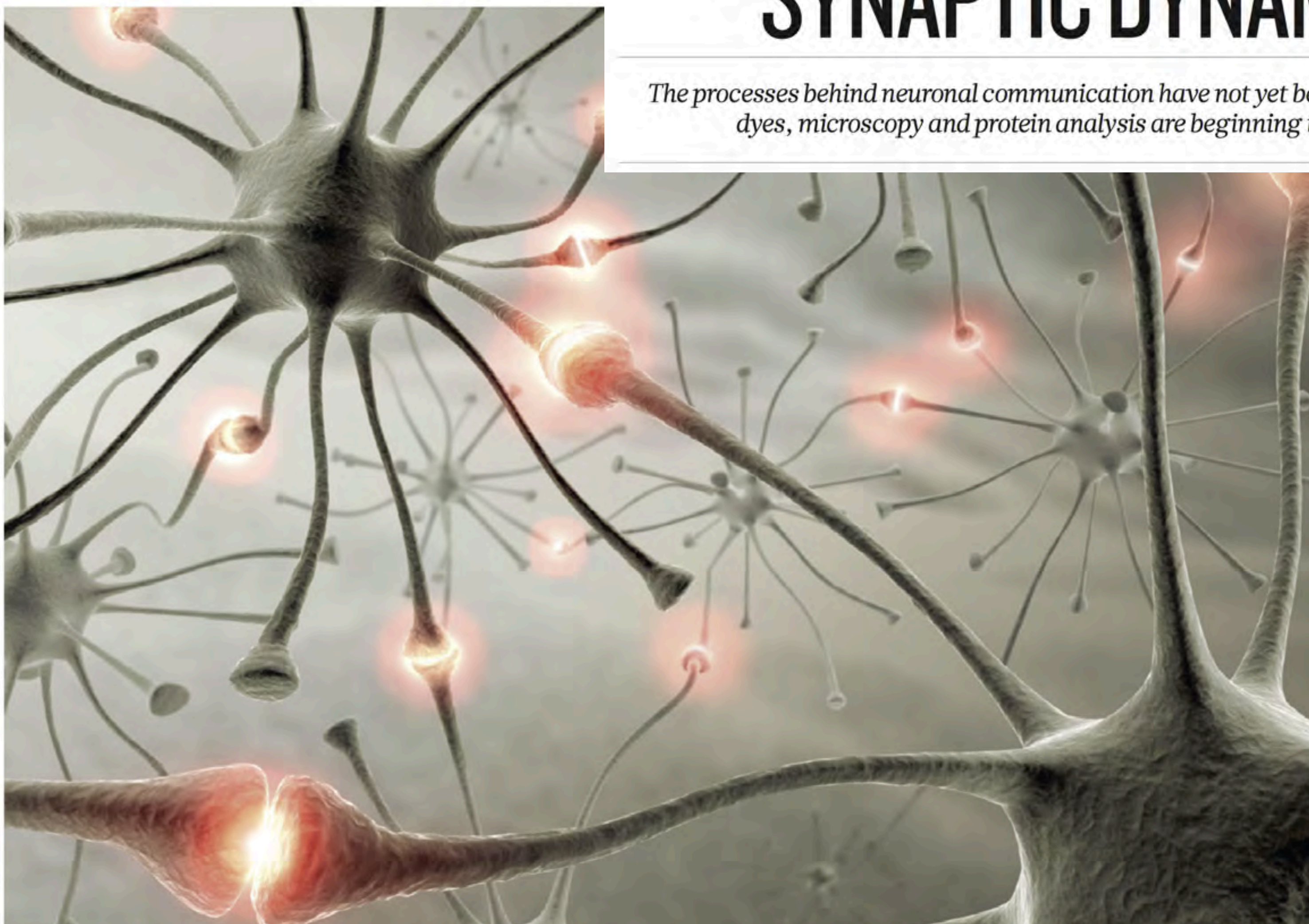


Batschelet Fig.12.5

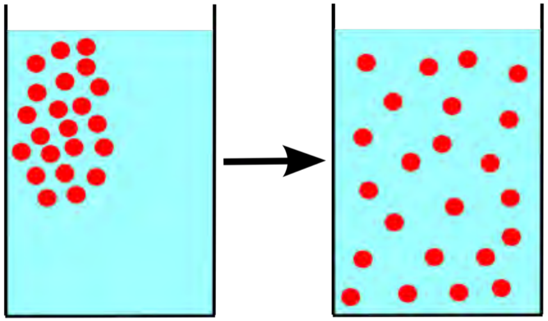
TECHNOLOGY FEATURE

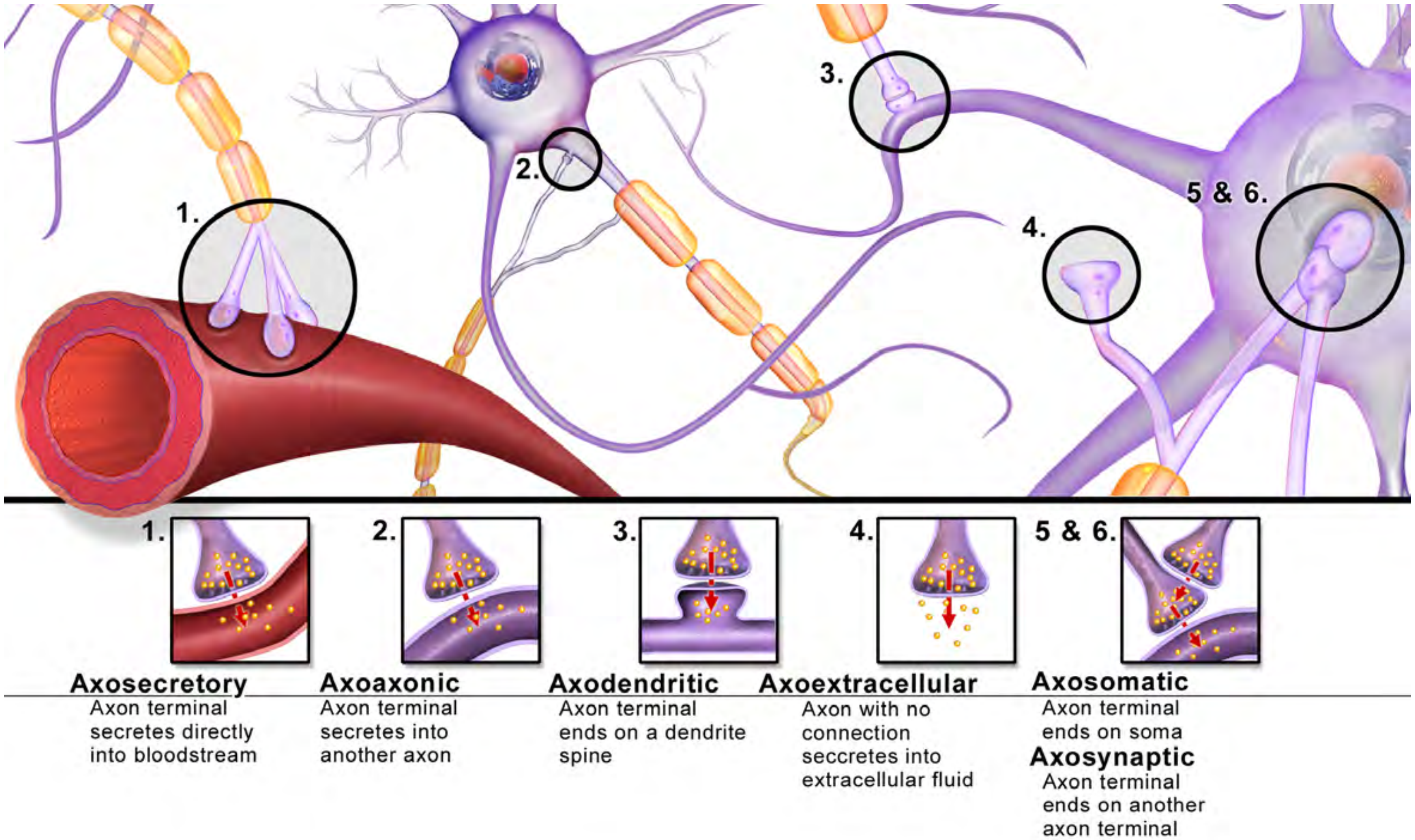
A DEEP LOOK AT SYNAPTIC DYNAMICS

The processes behind neuronal communication have not yet been resolved in detail, but dyes, microscopy and protein analysis are beginning to fill in the gaps.



Synapses are crucial to the communication between neurons, but the events that happen there have been difficult to capture.




1.
2.
3.
4.
5 & 6.
1.
2.
3.
4.
5 & 6.
Axosecretory
Axon terminal secretes directly into bloodstream
Axoaxonic
Axon terminal secretes into another axon
Axodendritic
Axon terminal ends on a dendrite spine
Axoextracellular
Axon with no connection seccretes into extracellular fluid
Axosomatic
Axon terminal ends on soma
Axosynaptic
Axon terminal ends on another axon terminal

Wikipedia