

# Biophysics I (BPHS 4080)

Instructors: Prof. Christopher Bergevin (cberge@yorku.ca)

Website: <http://www.yorku.ca/cberge/4080W2018.html>

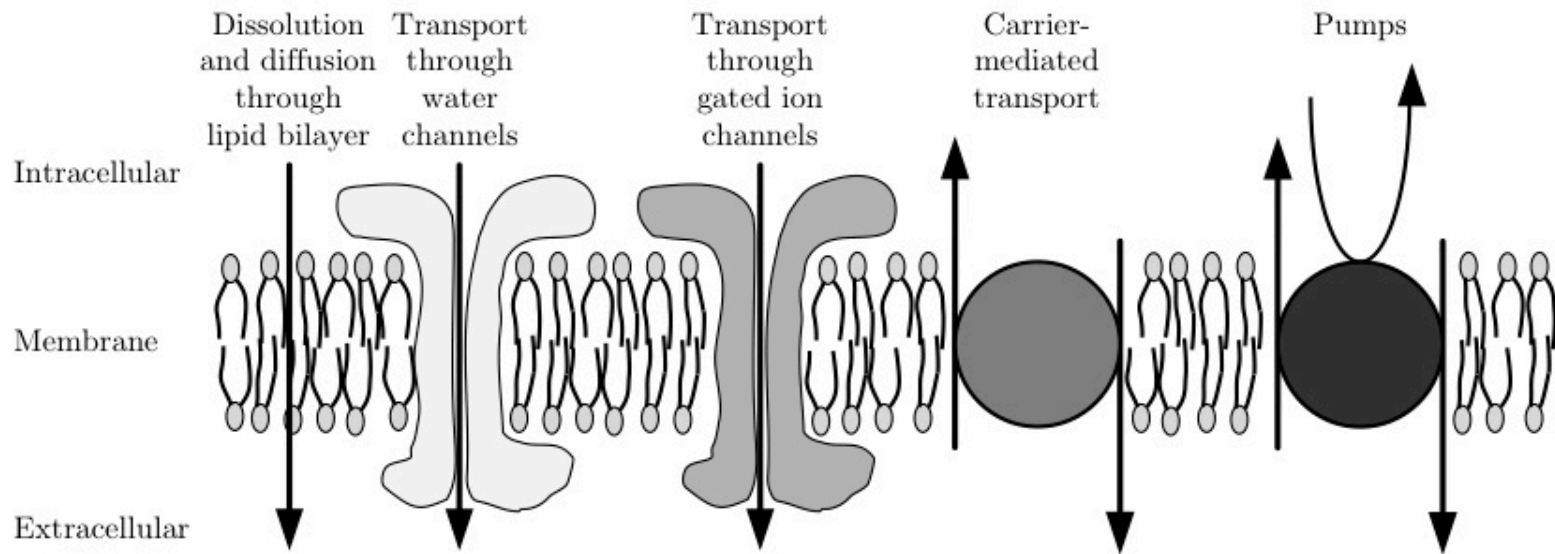


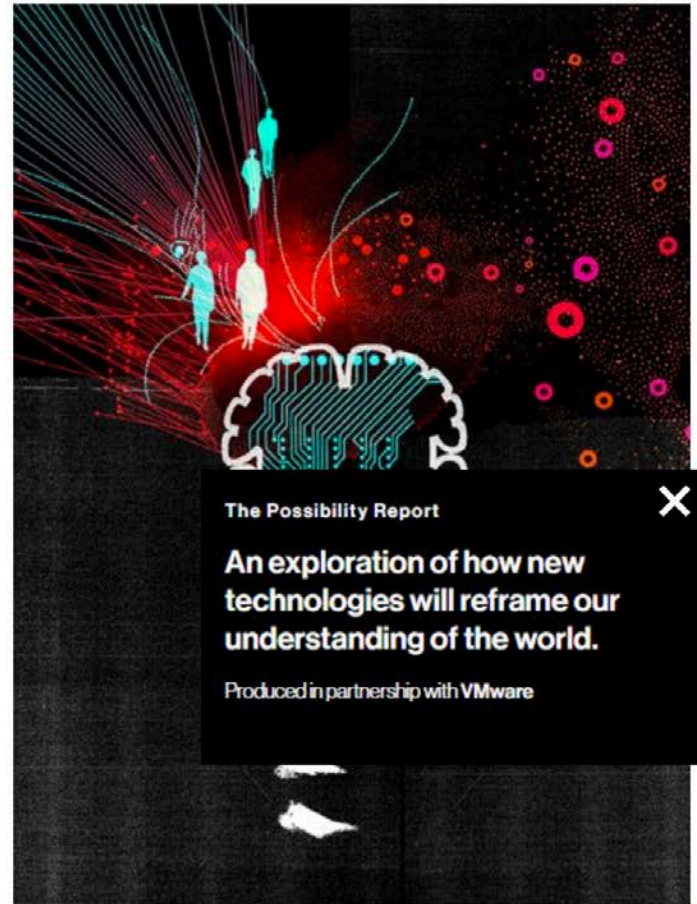
Figure 2.19



10 Breakthrough Technologies The List+ Years+

**Deep Learning**  
With massive amounts of computational power, machines can now recognize objects and translate speech in real time. Artificial intelligence is finally getting smart.

by Robert D. Hof



# A Primer On Deep Learning



## Forbes Agency Council

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POST WRITTEN BY

## Jeremy Fain

Jeremy Fain is the CEO and co-founder of [Cognitiv](#), the first neural network technology.



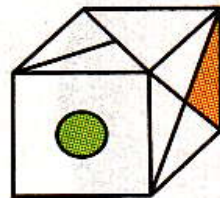
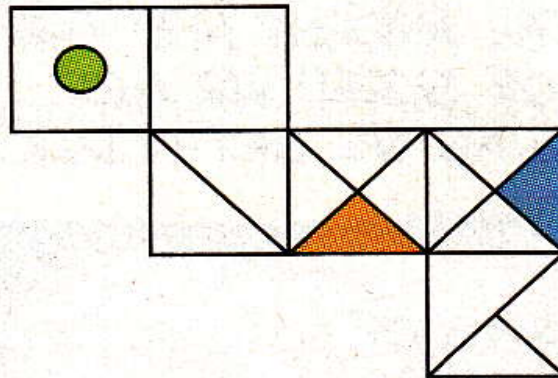
The term “artificial intelligence” (AI) has been around since the 1950s, but there has long existed a yawning gap between what people thought AI to be and what was actually possible. Since the 1960s, much of what has been considered to be AI has been a form of machine learning. However, despite the leaps and bounds in technology since the term was first introduced, the accomplishments of machine learning have often fallen short of public expectations (think the robots in *The Jetsons*).

Fortunately, after a half-century of research, that gap between our expectations and reality is finally closing, thanks to deep learning, a more advanced type of machine learning that's capable of generating human-like insight. Here, I will give an introduction to deep learning and explore the potential of this groundbreaking new field.

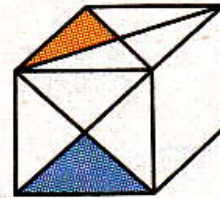




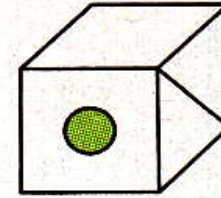
Which of the six boxes below cannot be made from this unfolded box?  
 (There may be more than one.)



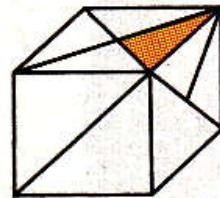
**A**



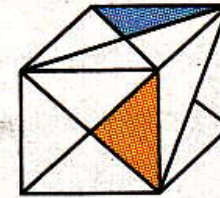
**B**



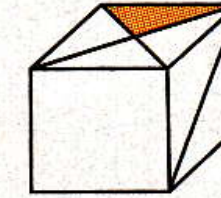
**C**



**D**



**E**



**F**



- What helps prevent disaster here? What sort of ‘signals’ convey the relevant info?
- What are the basic biological mechanisms at work here?
- What are the basic physical mechanisms at work here?

# Neurons

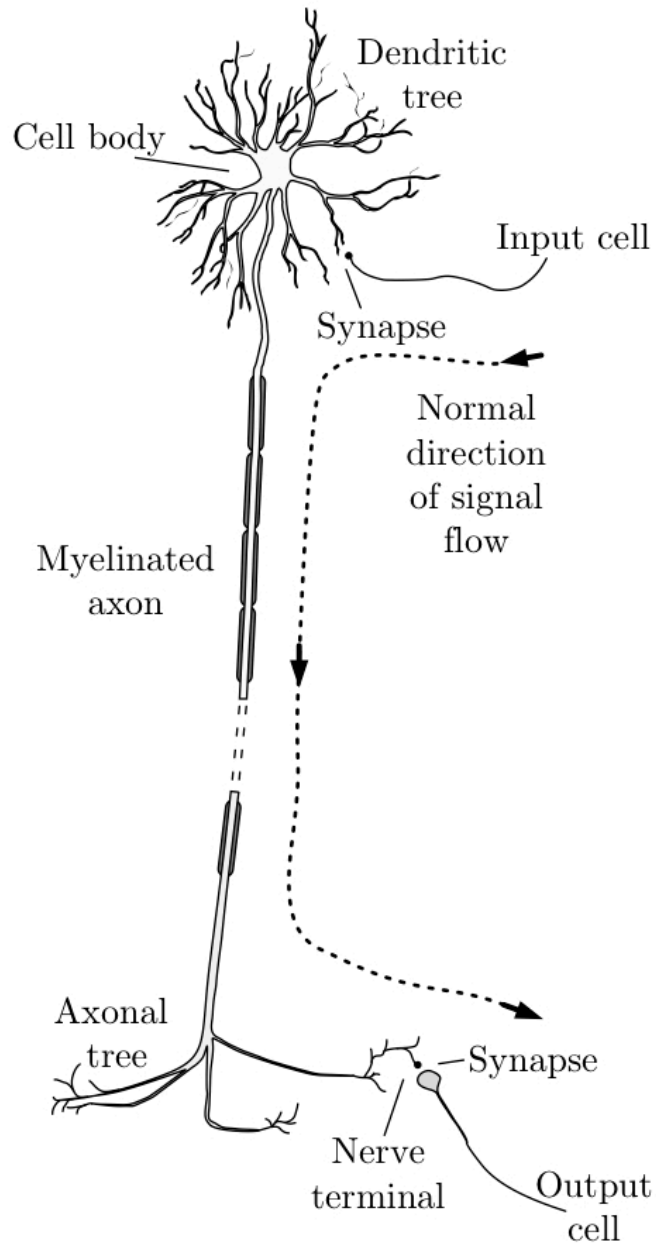


Figure 1.22





# BIOPHYSICS @ YORK



UNIVERSITÉ  
UNIVERSITY

*redefine* **THE POSSIBLE.**

York University  
BPHS 4080: Biophysics I (3 credits)  
Winter 2018

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**Time & Location**

Lecture: MWF 1:30-2:30 (CC 335)

**Instructor:** Christopher Bergevin

Office: Petrie 240

Email: cberge@yorku.ca

Office Hours: Check course website (or email for appt.)

**Course Website:**

<http://www.yorku.ca/cberge/4080W2018.html>

**Textbook:**

*Cellular Biophysics*, vol. I & II, TF Weiss (MIT Press)\*.

**Prerequisites:** SC/BPHS 2090 2.00; SC/PHYS 2020 3.00; SC/PHYS 2060 3.00

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|                             |                                  |
|-----------------------------|----------------------------------|
| First Day of Class .....    | Jan. 5                           |
| Add Deadline .....          | Jan. 31                          |
| <b>*Midterm Exam*</b> ..... | Feb. 9                           |
| Winter Reading Week .....   | Feb. 19–23 ( <b>no classes</b> ) |
| Drop Deadline .....         | Mar. 9                           |
| Good Friday .....           | Mar. 30 ( <b>no class</b> )      |
| Last Day of Class .....     | Apr. 6                           |
| <b>*Final Exam*</b> .....   | TBD                              |

**Course Theme/Topics:** This course will generally focus on the topic of cellular transport to examine the interplay between physics and the life sciences. Topics will include (but are not limited to):

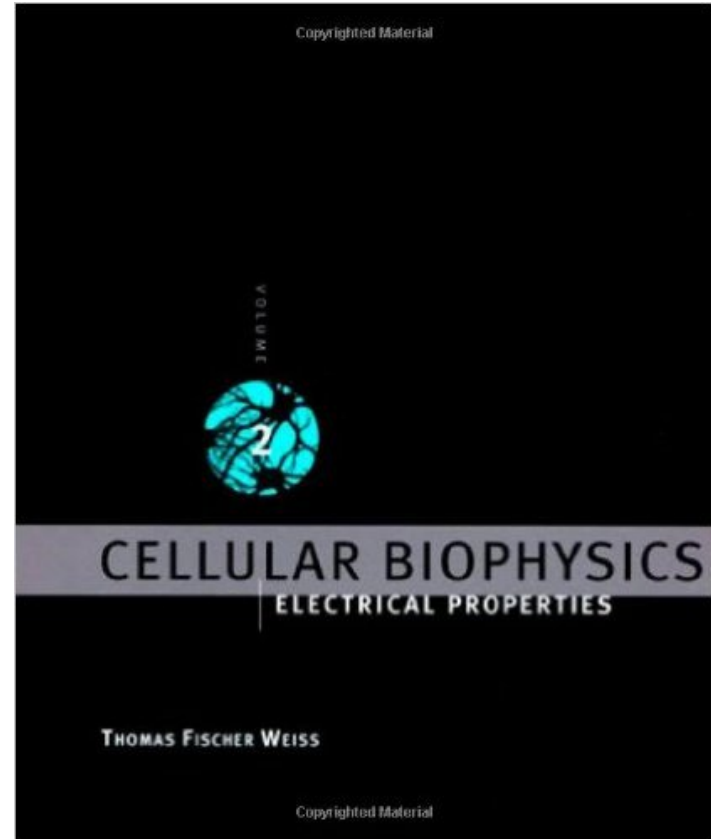
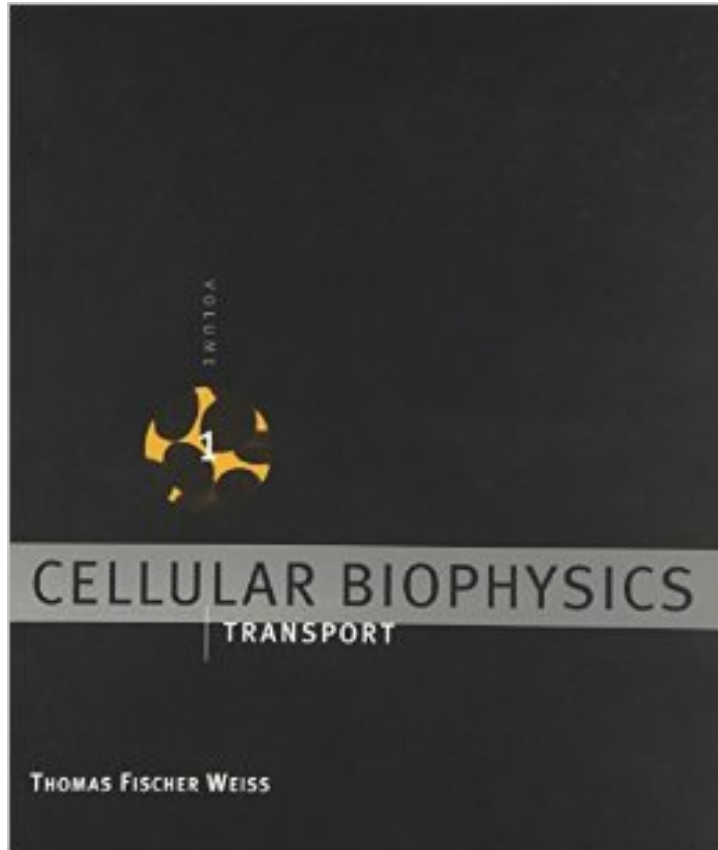
- Diffusion
- Osmosis
- Carrier-mediated transport
- Ion channels
- Modeling cell membranes using electric circuit analogs
- Action potentials (e.g., Hodgkin Huxley model)
- Nonlinear dynamics
- Synapses, Neural systems

<http://www.yorku.ca/cberge/4080W2018.html>

→ This is the course website and will be the main “go to” place for all course-related info (e.g., syllabus, slides, chapters for reading, exam info, etc...)

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\*The York U library has a copy. Another text that may be a useful reference for the course (though not necessarily recommended to purchase) is *Intermediate Physics for Medicine and Biology*, 4th Ed., R. Hobbie & B. Roth (Springer). This book can be downloaded for free as a pdf via the York University library (ask course instructor for details)



- Diffusion
- Cell membranes
- Osmosis
- Carrier-mediated transport
- Electrical responses of cells
- Resonance
- Electro-diffusion, Resting potential
- Ion pumps
- Core-conductor model

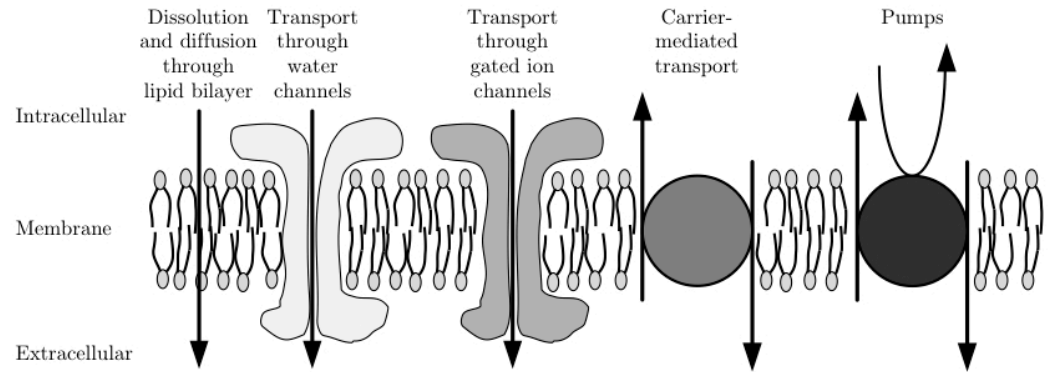


Figure 2.19

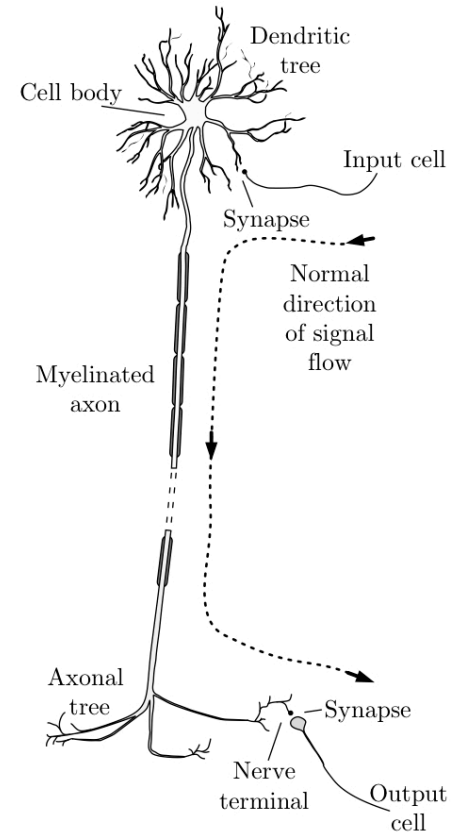


Figure 1.22

- Cable model
- Hodgkin-Huxley
- Myelination, saltatory conduction
- Ion channels

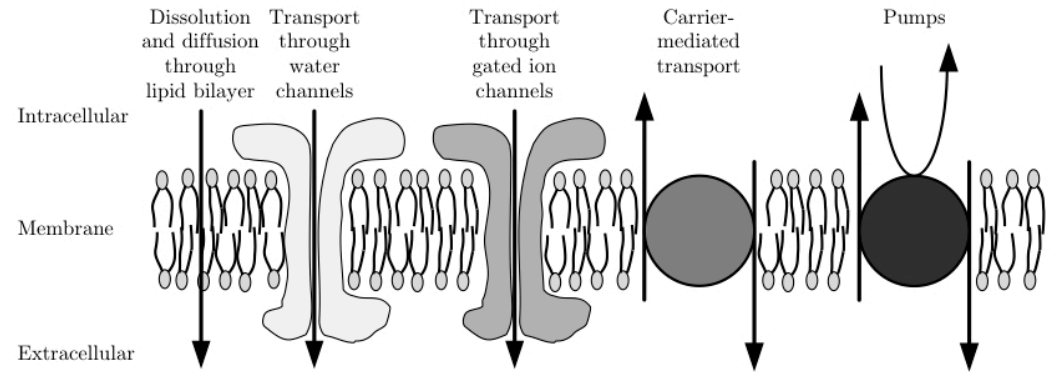


Figure 2.19

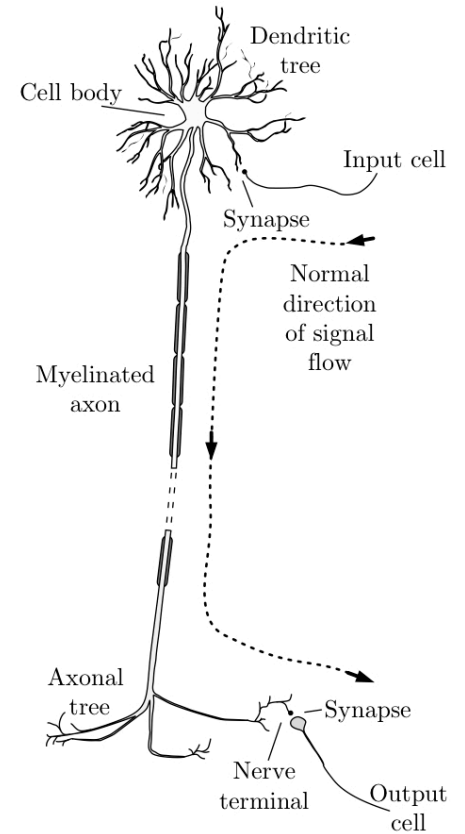


Figure 1.22

## 4080 Summary: Hodgkin-Huxley Equations

$$\frac{1}{2\pi a(r_o + r_i)} \frac{\partial^2 V_m}{\partial z^2} = C_m \frac{\partial V_m}{\partial t} + G_K(V_m, t) (V_m - V_K) + G_{Na}(V_m, t) (V_m - V_{Na}) + G_L(V_m - V_L)$$

$$G_K(V_m, t) = \bar{G}_K n^4(V_m, t)$$

$$G_{Na}(V_m, t) = \bar{G}_{Na} m^3(V_m, t) h(V_m, t)$$

$$n(V_m, t) + \tau_n(V_m) \frac{dn(V_m, t)}{dt} = n_\infty(V_m)$$

$$m(V_m, t) + \tau_m(V_m) \frac{dm(V_m, t)}{dt} = m_\infty(V_m)$$

$$h(V_m, t) + \tau_h(V_m) \frac{dh(V_m, t)}{dt} = h_\infty(V_m)$$

Nernst Equilibrium Potential

$$V_n = \frac{RT}{z_n F} \ln \frac{c_n(d)}{c_n(0)} = \frac{RT}{z_n F} \ln \frac{c_n^o}{c_n^i}$$

$$G_n = \frac{1}{\int_0^d \frac{dx}{u_n z_n^2 F^2 c_n(x)}} \geq 0$$

$$\tau_x \frac{dx}{dt} + x = x_\infty \quad \frac{dx}{dt} = \alpha_x(1-x) - \beta_x x$$

$$x_\infty = \alpha_x / (\alpha_x + \beta_x) \text{ and } \tau_x = 1 / (\alpha_x + \beta_x)$$

$$\alpha_m = \frac{-0.1(V_m + 35)}{e^{-0.1(V_m + 35)} - 1},$$

$$\beta_m = 4e^{-(V_m + 60)/18},$$

$$\alpha_h = 0.07e^{-0.05(V_m + 60)},$$

$$\beta_h = \frac{1}{1 + e^{-0.1(V_m + 30)}},$$

$$\alpha_n = \frac{-0.01(V_m + 50)}{e^{-0.1(V_m + 50)} - 1},$$

$$\beta_n = 0.125e^{-0.0125(V_m + 60)},$$



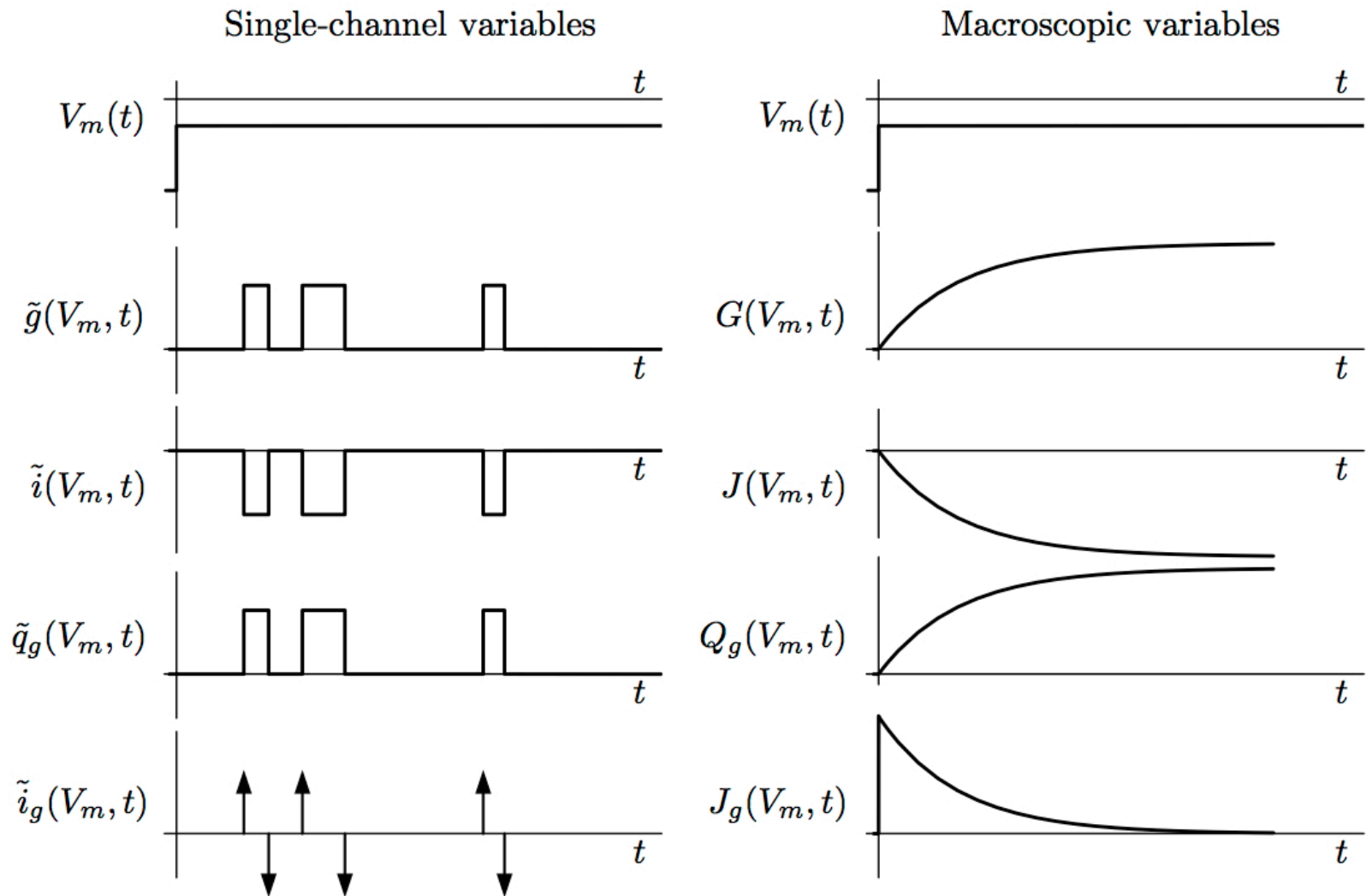
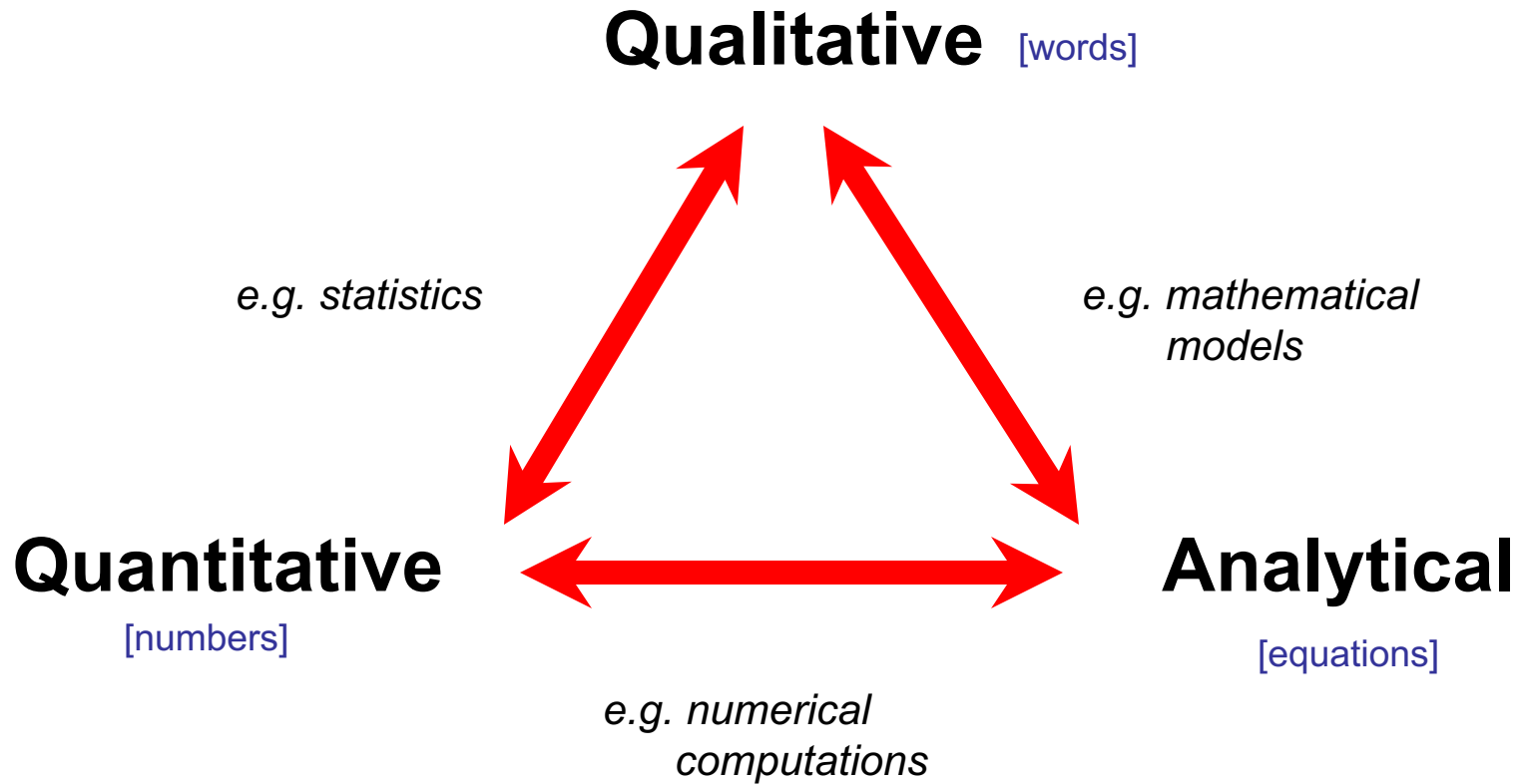


Figure 6.52

Biophysically, this figure encapsulates numerous key ideas....

Describing biological/physiological systems



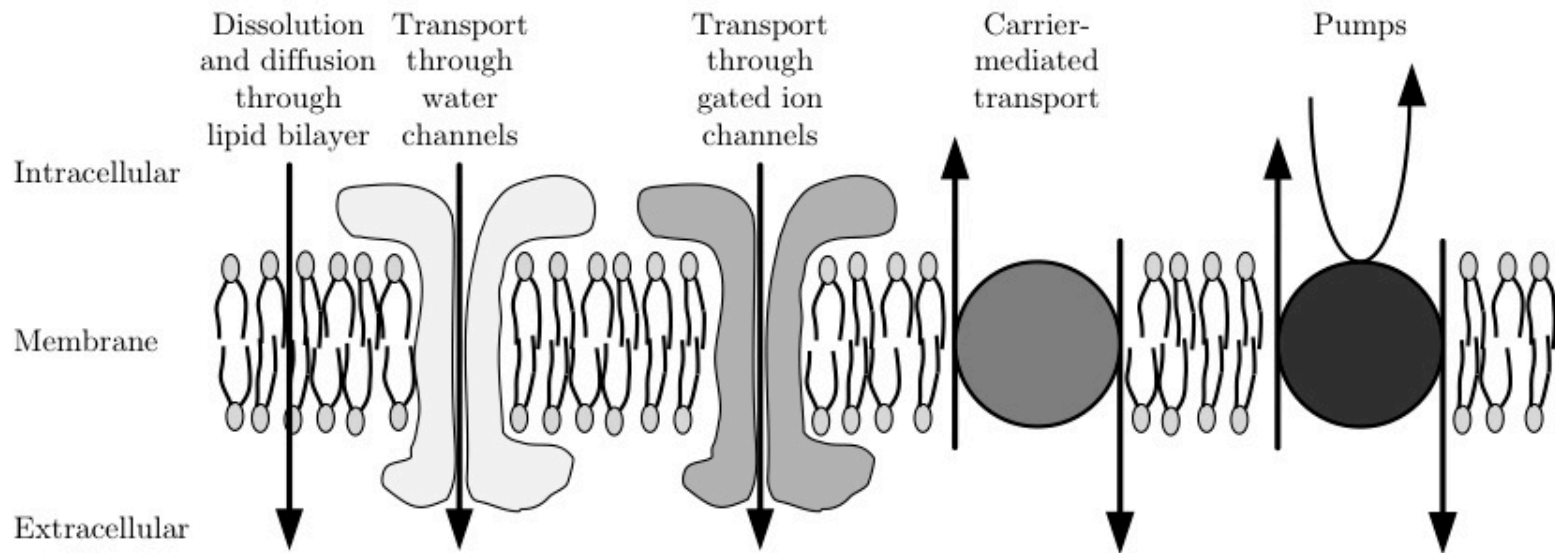
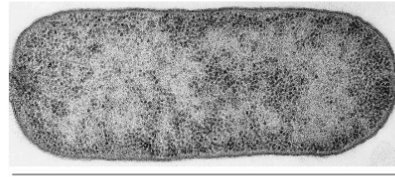


Figure 2.19

# Ex. Eating a potato

*Escherichia Coli (E. Coli)*

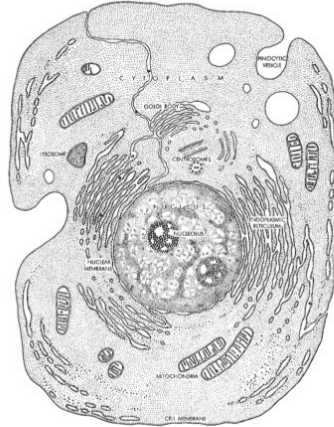


2.5 μm

Culture Medium

|                                  |        |
|----------------------------------|--------|
| NH <sub>4</sub> Cl               | 1.0 g  |
| MgSO <sub>4</sub>                | 0.13 g |
| KH <sub>2</sub> PO <sub>4</sub>  | 3.0 g  |
| Na <sub>2</sub> HPO <sub>4</sub> | 6.0 g  |
| Glucose                          | 4.0 g  |
| Water                            | 1.0 L  |

Generic Eukaryotic Animal Cell



25 μm

Culture Medium

- Essential Amino Acids (a dozen)
- Vitamins (eight)
- Salts (Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Cl<sup>-</sup>, PO<sub>4</sub><sup>3-</sup>, HCO<sub>3</sub><sup>-</sup>)
- Glucose
- Serum

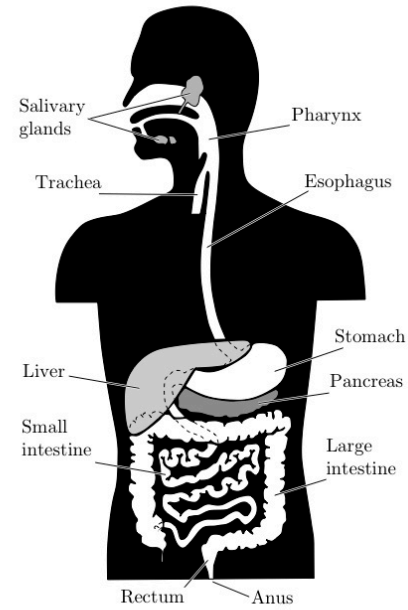
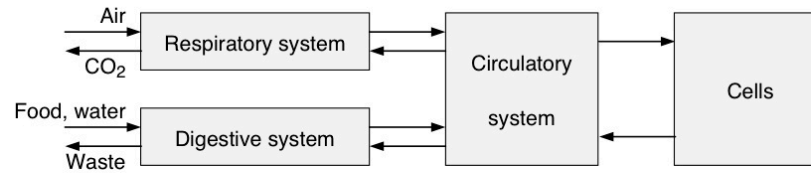


Figure 2.2



Inputs to Organism

- air
- water
- food
  - carbohydrates
  - fats
  - proteins

Inputs to Cells

- oxygen
- water
- ions
- building block molecules
  - sugars
  - lipids
  - amino acids

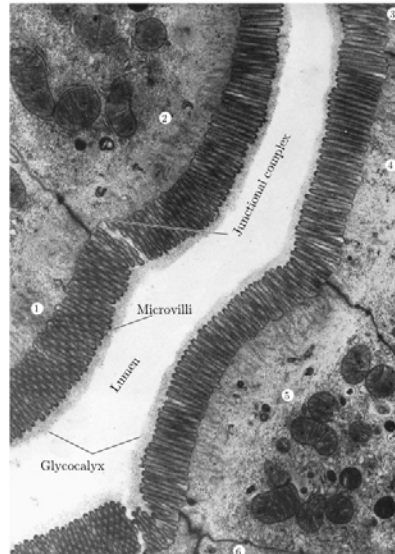


Figure 2.8

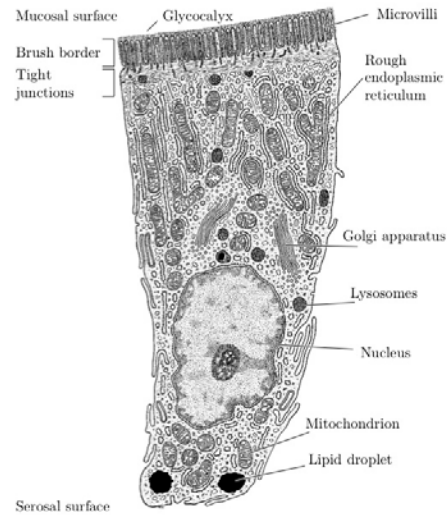


Figure 2.9

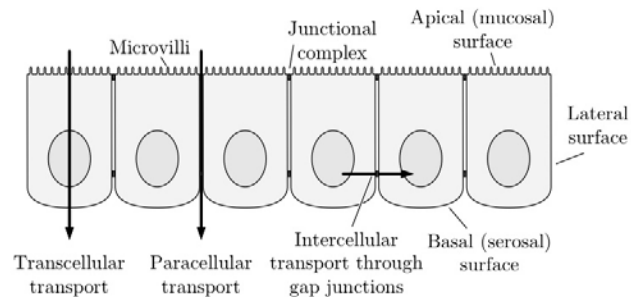


Figure 2.13

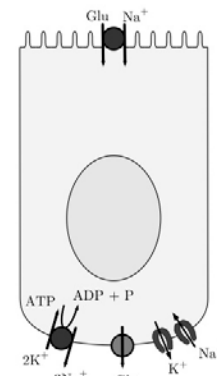


Figure 2.15

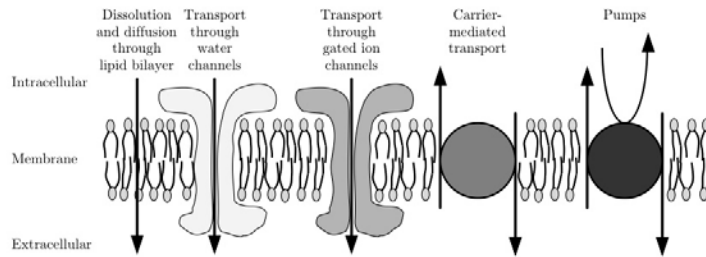


Figure 2.19

## Functions of more than one variable

⇒ will be important for the various types of systems we will be describing analytically in the course

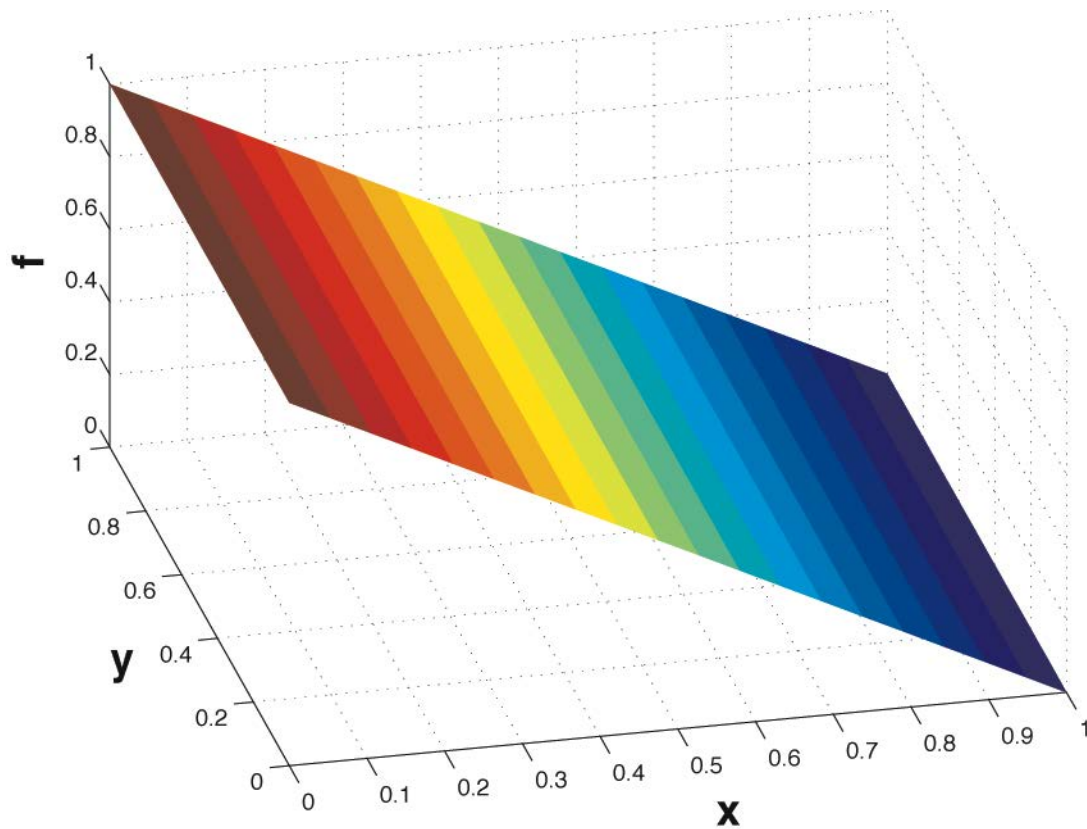
e.g. concentration of a solute in a solution ( $c$ ) depends upon both spatial location ( $x$ ) and time ( $t$ )

$$f = f(x, y)$$

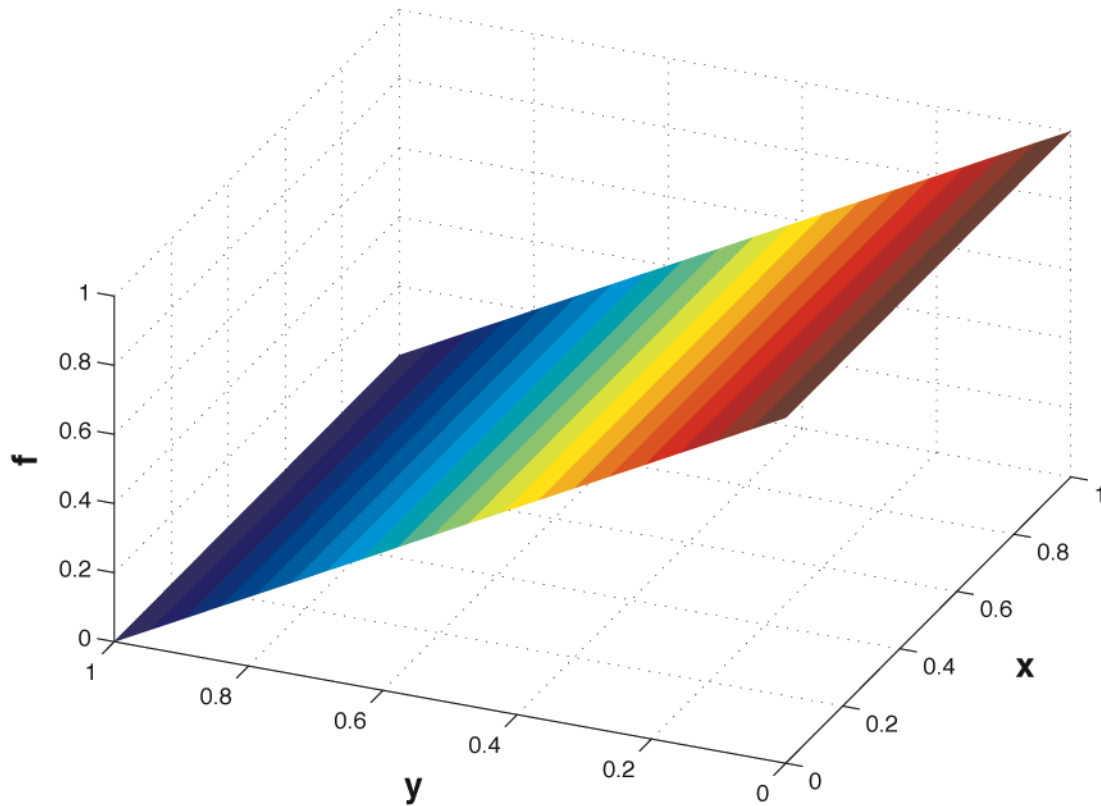
$f$  - dependent variable

$x, y$  - independent variables





$$f(x, y) = (1 - x) = f(x)$$

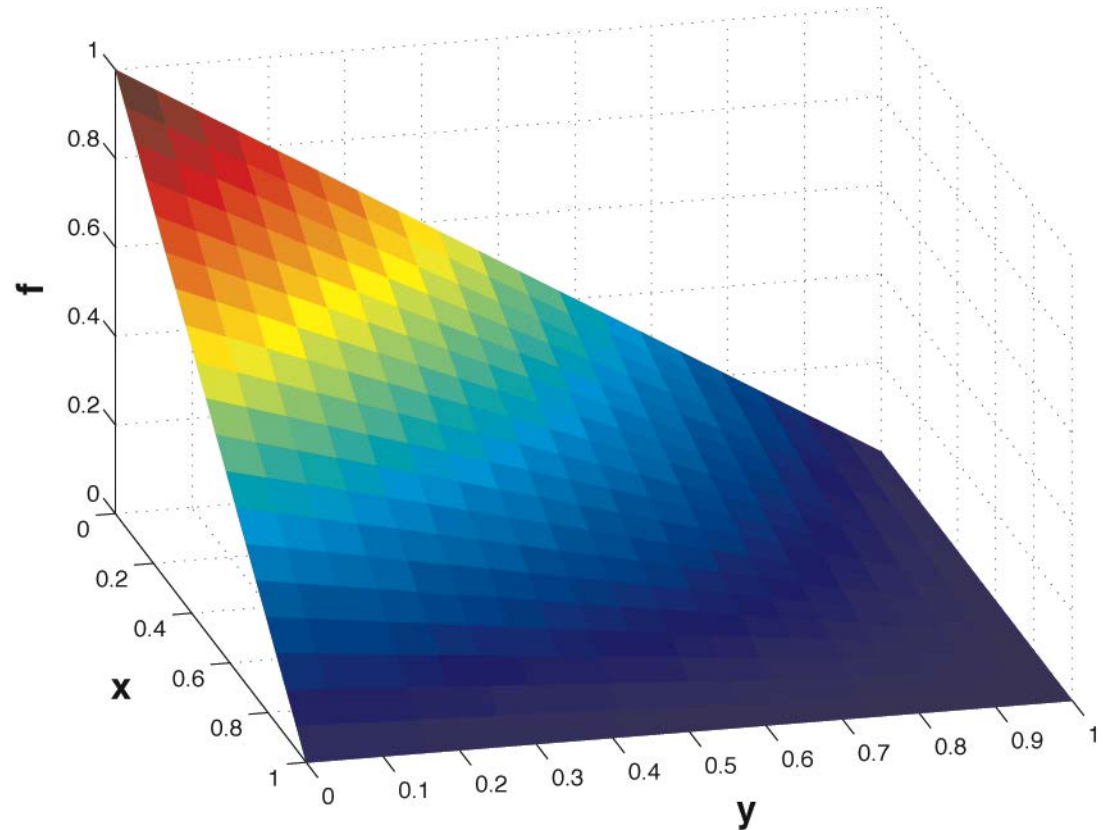


$$f(x, y) = (1 - y) = f(y)$$

## Biological Context

$f$  - reaction rate [ $mol/s$ ]

$x, y$  - concentration  
of inhibitor agents [ $mol$ ]

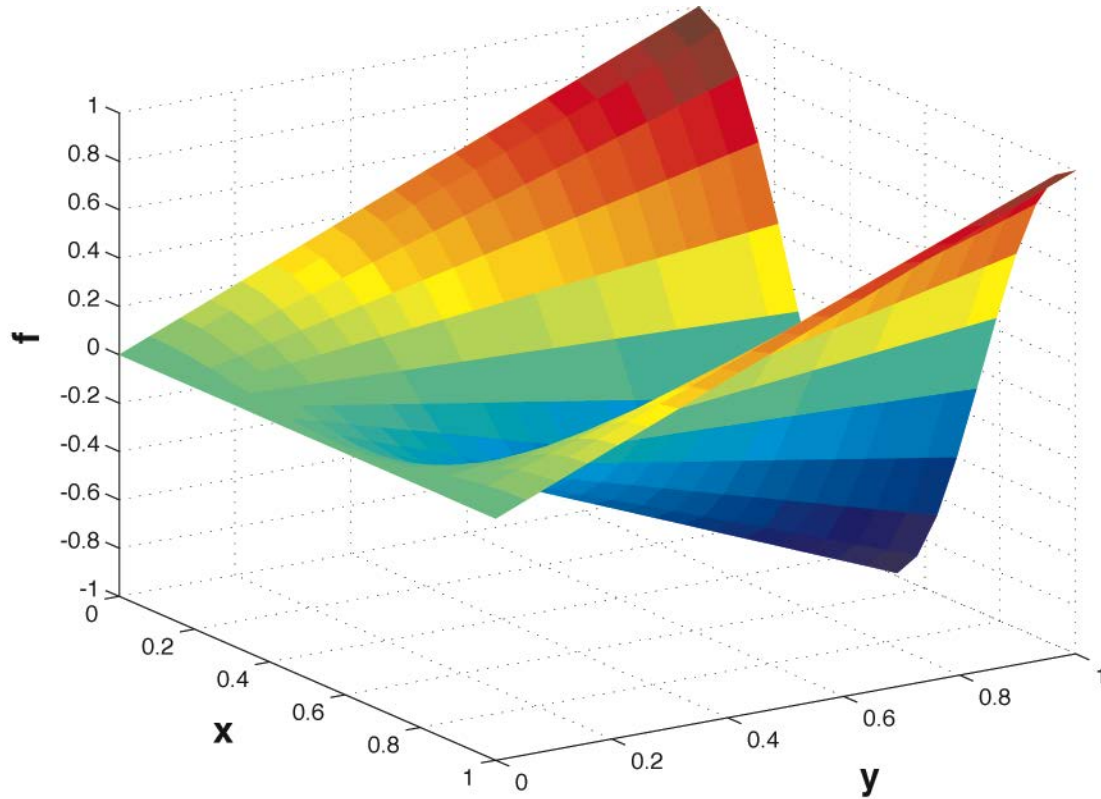


$$\del f(x, y) = (1 - y)(1 - x)$$

don't forget  
about units!

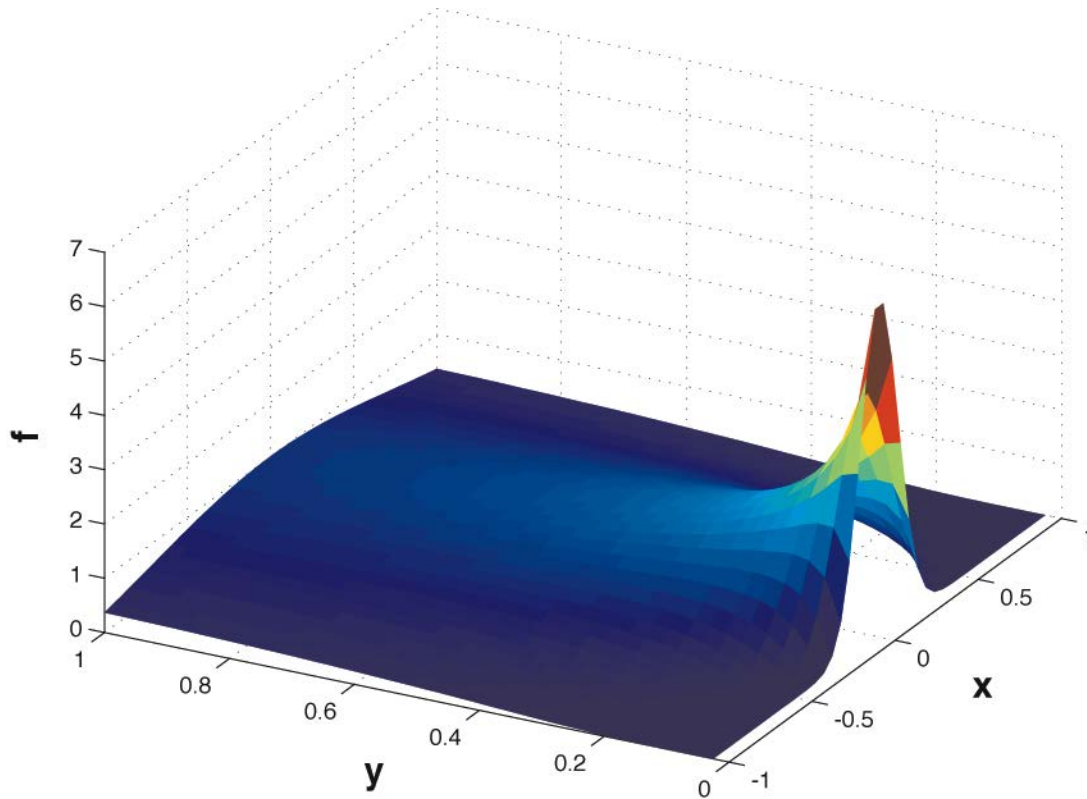
$$f(x, y) = k(1 - x)(1 - y)$$

$$[k] = \frac{1}{mol \cdot s}$$



$$f(x, y) = y \cos(2\pi x)$$

can you think of an example  
of what the various variables  
might represent?



$$f(x, y) = \frac{1}{\sqrt{y}} e^{-x^2/y}$$

solution to  
diffusion equation  
(or *heat eqn.*)

## Differentiation of functions of more than one variable

Derivative (definition) for a function of a single variable

$$\frac{dg(x)}{dx} = \lim_{\Delta x \rightarrow 0} \frac{g(x + \Delta x) - g(x)}{\Delta x}$$

For multi-variable function, keep one variable constant

$$\frac{\partial f(x, y)}{\partial x} = \lim_{\Delta x \rightarrow 0} \frac{f(x + \Delta x, y) - f(x, y)}{\Delta x}$$

note difference  
in notation

$y$  is effectively held  
constant here



## Differentiation of functions of more than one variable

Can also take partial deriv.  
with respect to partial deriv.

$$\frac{\partial}{\partial y} \left( \frac{\partial f}{\partial x} \right)$$

Simplified notation

$$\frac{\partial}{\partial y} \left( \frac{\partial f}{\partial x} \right) = \frac{\partial}{\partial y} (f_x) = (f_x)_y = f_{xy}$$

## Differentiation of functions of more than one variable

### Examples:

ex.1  $\frac{\partial z}{\partial x}$  for  $z(x, y) = (xy)^{1/2}$

$$\frac{\partial z}{\partial x} = \frac{1}{2} y^{1/2} x^{-1/2}$$

ex.2  $\frac{\partial}{\partial b} \left( \frac{\partial \phi}{\partial a} \right)$  for  $\phi(a, b) = ab^2 + 3a^2 e^b$

Notation:  $\frac{\partial}{\partial b} \left( \frac{\partial \phi}{\partial a} \right) = \frac{\partial}{\partial b} (\phi_a) = (\phi_a)_b = \phi_{ab}$

First find  $\phi_a$  (assume  $b$  is constant):  $\phi_a = b^2 + 6ae^b$

$$\frac{\partial}{\partial b} \left( \frac{\partial \phi}{\partial a} \right) = 2b + 6ae^b$$

Now differentiate with respect to  $b$ :  $\phi_{ab} = \frac{\partial}{\partial b} (\phi_a) = 2b + 6ae^b$

Note: In this case  $\phi_{ab} = \phi_{ba}$  which is true for continuous functions (i.e. order of differentiation doesn't matter)

## Differential equations

ODE ('ordinary'): considers a function of one variable and how it changes with respect to that variable

ex.  $\frac{dc}{dt} = kc$  where  $c = c(t)$  and  $k = \text{const.}$

PDE ('partial'): considers a function of more than one variable and how its various partial derivatives are related

ex.  $\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2}$  where  $c = c(x, t)$  and  $D = \text{const.}$

## ODE review

Solving an ODE: find  $c(t)$  for  $\frac{dc}{dt} = kc$

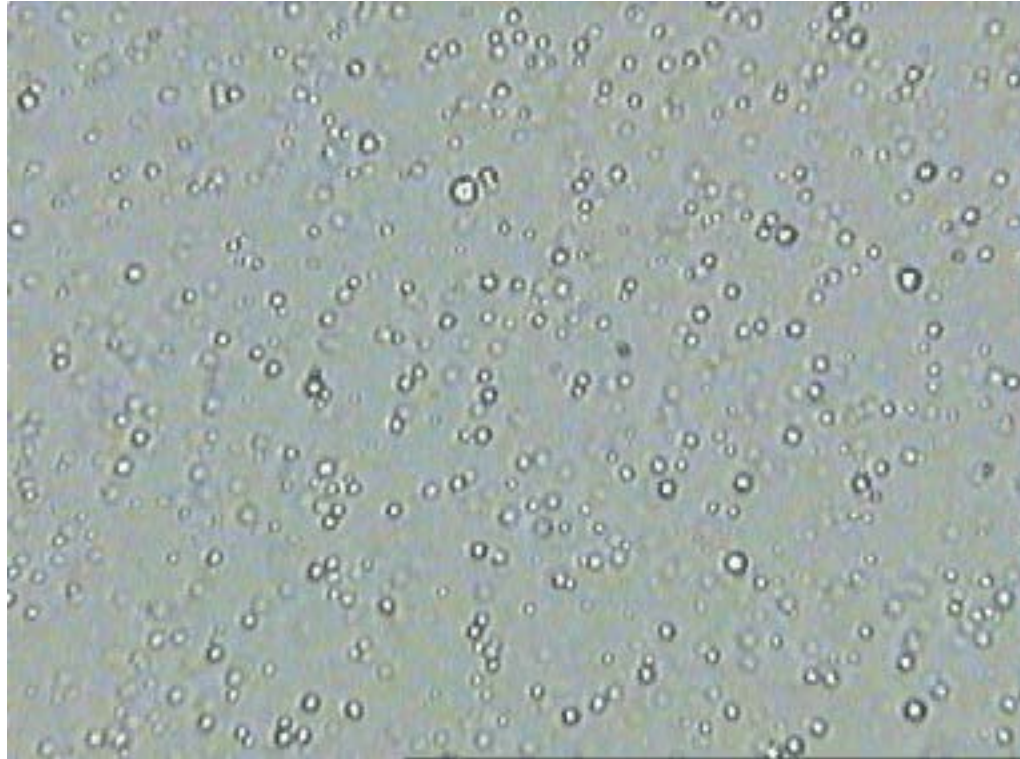
1. Separate variables and integrate  $\int \frac{dc}{c} = \int k dt$

$$\Rightarrow c(t) = Ae^{kt}$$

2. Use an initial condition to find a unique solution. Suppose we have  $c(1/k) = \frac{\ln(e^e)}{3}$

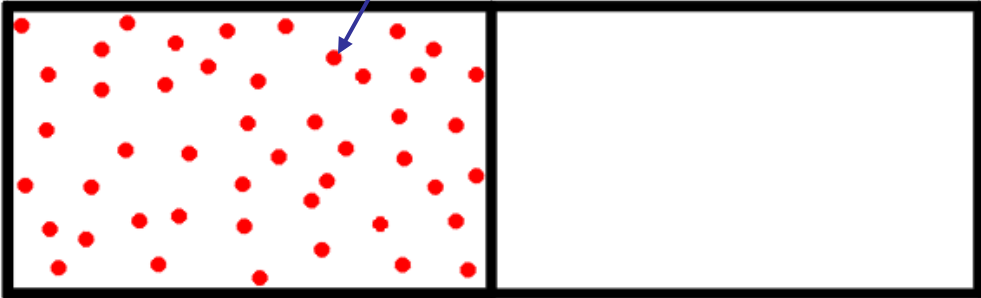
$$c(t) = \frac{e^{kt}}{3}$$

## Brownian motion



Diffusion

each particle undergoes  
Brownian motion

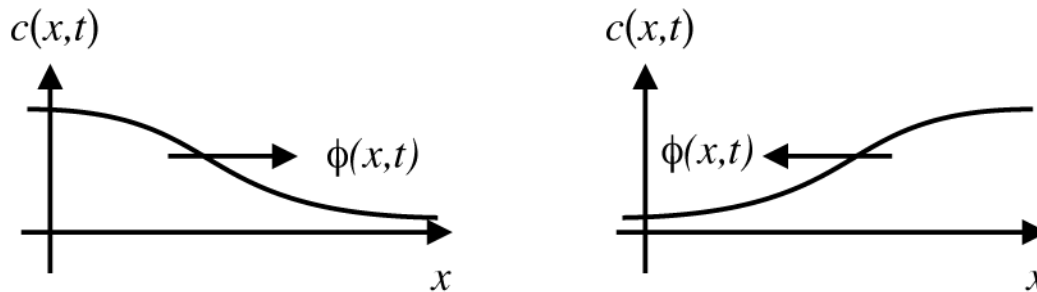




## Diffusion (1-D)

- Thomas Graham (Scottish chemist, ~1828-1833)

[pioneered the concept of dialysis]



- Adolf Fick (German physiologist, ~1855)

[actually was the first to successfully put a contact lens on a person in 1888!]

“ A few years ago, Graham published an extensive investigation on the diffusion of salts in water, in which he more especially compared the diffusibility of different salts. It appears to me a matter of regret, however, that in such an exceedingly valuable and extensive investigation, the development of a fundamental law, for the operation of diffusion in a single element of space, was neglected, and I have therefore endeavoured to supply this omission.”

- A. Fick (1855)

**Qualitative**

**Quantitative**

**Analytical**

