BE/Bi 101: Order-of-Magnitude Biology
Homework 1
Due date: Friday, January 16, 2015

"Satisfaction of one's curiosity is one of the greatest sources of happiness in life."

—Linus Pauling

1. Estimates on biological information.

a) Influenza virus is amazing! There are so many things to admire about these tiny viruses. One of the features that we found particularly intriguing is that each virus carries within it eight distinct RNA molecules and all of them are needed for a viable infection. The 14,000 nucleotide genome is divided amongst these 8 negative-sense RNA molecules within the roughly 100 nm viral particle. How many bits of information are carried in this genome and what is the information density in units of bits/volume? Make an estimate of the information density in a typical computer storage device (such as a thumb drive) and then scale up the biological information storage density of the influenza virus and compare it to our computer technologies.

b) One of the themes we are going to come back to repeatedly is the enormity of sequence space in biology. As a warm up exercise in that regard, in this problem we are going to think about the space of possible proteins. What is the size of a typical protein in amino acid sequence length? Given that characteristic size, how many possible proteins could be made? How big is a typical protein in both radius and volume? Given that size, if you made one copy of each of the possible proteins, what would be the total volume of space you would need for all of these proteins and how does that compare to the size of the known universe?

2. The art of estimation.

In this problem, the goal is actually to make yourself do quick drills to get into the habit of just making guesses about quantities. Do not look up any facts—you can look at the included pictures and just make a quick statement based upon less than 60 seconds of staring. When appropriate, try to use the square root rule that we discussed in class. For each case, give a brief, but thorough description of how you came by your estimates. Don't just quote a single number. Give us some context about how you got your result. These problems are chosen from a wide variety of different biological contexts that will come up during the course and give us the chance to practice our skills at many scales and in many contexts.

a) What is the thickness of the beak of a ground finch (in mm)? Make an estimate of the beak-to-beak variation in beak size between adult ground finches. Use Figure 1 to help in making a rapid estimate.

b) How many starlings are in the flocks seen in Rome? How many kilograms of poop do these birds drop on Rome each day? Figures 2 and 3 can aid you in your thinking.

Figure 1: Ground finch in the Galapagos.

c) When a bacterium is infected by a bacteriophage (a bacterial virus), what is the typical burst size of the viruses (i.e. how many viruses emerge from the cell after it lyses?) Begin by looking at Figure 4 and quickly telling us how big a bacterium is, how big a bacteriophage is. Then for figuring out the burst size, use Figure 4, but don't count. Do quick estimating by picking a lower and upper bound.

d) How many atoms are in a "typical" amino acid? Figure 5 shows the *side chains* of the amino acids and should help you quickly make an estimate. Similarly, give an estimate of the typical mass of amino acids in Dalton units (remember, a Dalton is the mass of one hydrogen atom). How many atoms are in a typical base. Figure 6 shows various representations of bases and DNA. Similarly, give an estimate of the typical mass of nucleotides in Dalton units.

e) Use Figure 7 to estimate the speed of the ocean currents experienced by Rizal Shahputra. Using your estimate from the first part of the problem, give an estimate of the time spent in the ocean by the tortoise shown in Figure 8 in its journey drifting from Aldabra (see Figure 9) to Tanzania!

f) In this part of the problem, you are going to do an integral by eyeballing. Figure 10 shows the spectrum of radiation reaching the earth. By approximating the curve as a rectangle work out a simple statement for the flux of radiation on the earth from the sun in units of W/m^2. Then, using the blue region, figure out the flux 10 m below the surface of the ocean.

g) Every time an electron microscope is used to take an image it corresponds to roughly a $1\mu m \times 1\mu m$ area. The electron microscope is used to explore the structure of the nanometer scale world of cells, for example. Biology is a subject characterized by great naturalist voyages in which figures such as Humboldt, Darwin, Wallace, Huxley and Hooker traveled around the world to try and collect data on biological diversity. The

Figure 2: Starling flock in Rome.

point of this problem is to get a sense of the *microscopic* diversity explored. Make an estimate of the total area looked at in biological samples using electron microscopes in the history of science. How does this correspond to the area of the Earth? What do you conclude about the extent to which we have "explored" the microbial diversity on the planet?

3. A frog drying out in seawater.

In class, we began to discuss a second method for estimating the loss of water from a frog. We invoked the constitutive law

$$j = \alpha \Delta c, \tag{1}$$

where α is a permeability coefficient of order 10^{-4} cm/s. Using that salt water is about 1 M and the salt concentration within the frog is 100 mM (hence $\Delta c \approx 1$ M), work out the time that it will take for all of the water to leave the frog. Please give a full discussion of all of the assumptions that go into your calculation including quantities related to frog geometry.

Figure 3: Consequences of starling flock in Rome.

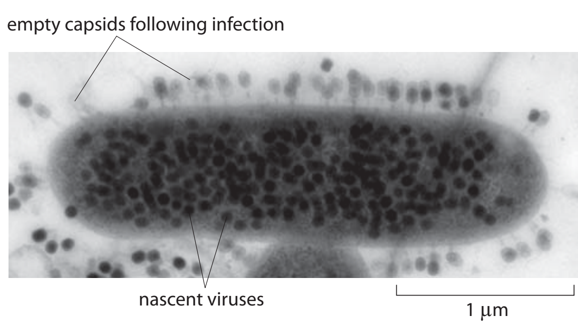

Figure 4: Burst size of an infected bacterium.

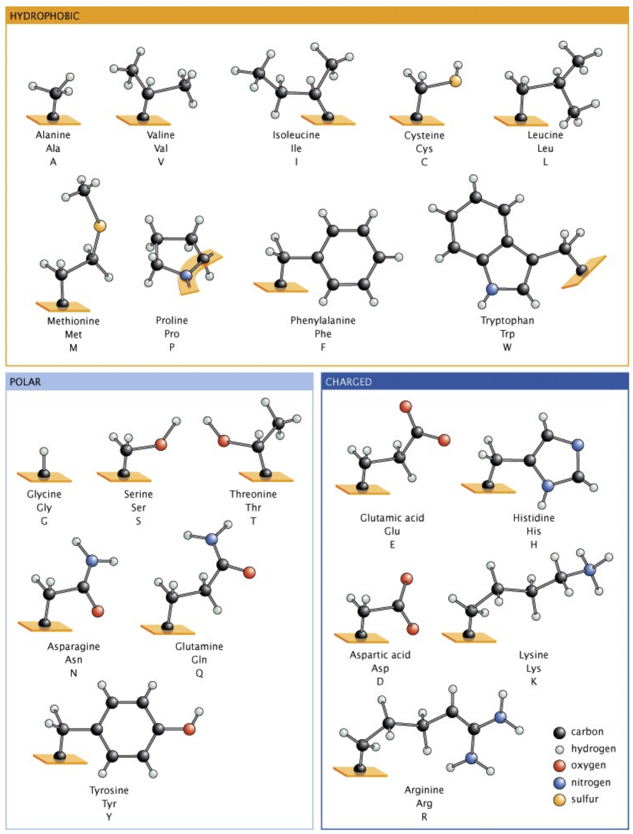

Figure 5: Amino acid side chains.

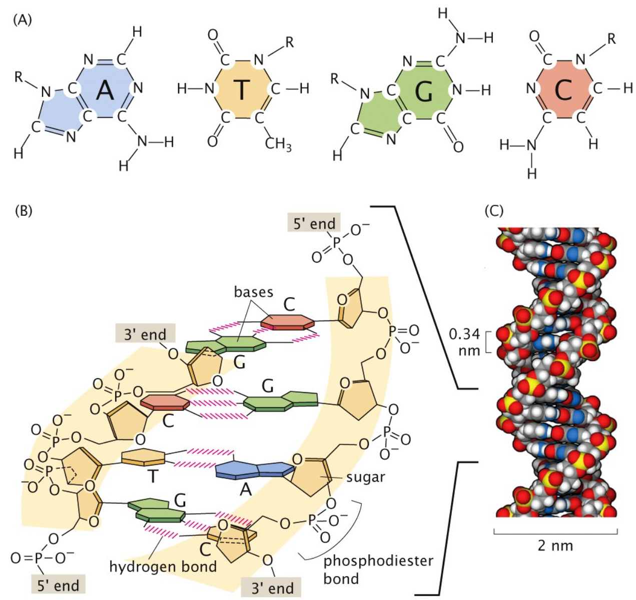

Figure 6: Structure of DNA.

Tsunami man survives week at sea

An Indonesian man has been found floating on tree branches in the Indian Ocean, eight days after a devastating tsunami struck the region.

Rizal waved to a passing cargo ship

Rizal Shahputra, 23, said he was initially swept out to sea with other survivors and family members, but that one by one they drowned.

He was rescued on Monday by a passing container vessel.

He was taken to Malaysia where officials said he was in good condition - he survived eating floating coconuts.

Rizal said he was cleaning a mosque in Banda Aceh on the northern tip of Sumatra on 26 December when the tsunami struck. Children ran in to warn him, but he was swept out to sea, along with several other people.

"At first, there were some friends with me," Rizal told reporters. "After a few days, they were gone... I saw bodies left and right."

He drank rainwater, and ate coconuts, which he reportedly cracked open with a doorknob.

Rizal said at least one ship sailed by without noticing him before the MV Durban Bridge spotted him, 160km (100 miles) from Banda Aceh.

Figure 7: Article about tsunami survivor after Boxer Day earthquake in Indonesia in 2004.

Figure 1. The Aldabra tortoise at Kimbiji, shortly after its discovery in December 2004. Photograph: C. Muir.

Figure 8: Tortoise found in Tanzania after traveling across the ocean. Notice the barnacles that have attached to the tortoise.

Figure 9: Map showing the position of the Aldabra Atoll in the Indian Ocean.

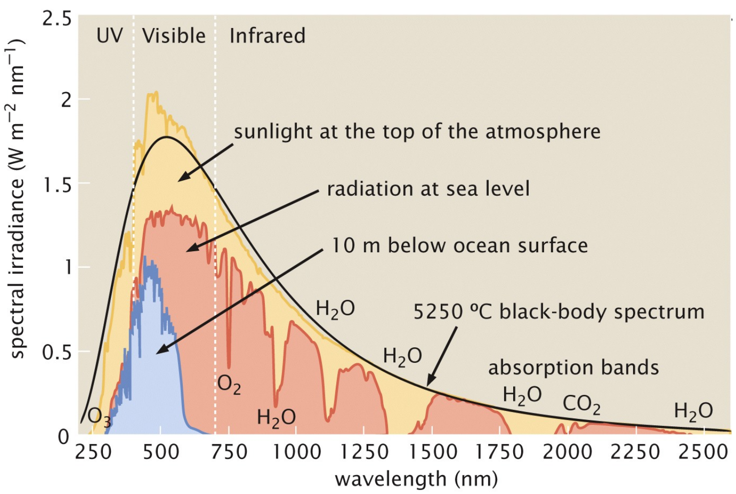

Figure 10: Spectrum of solar radiation reaching the Earth.