Stanford ENGR/BIOE.80 Spring 2020

PSET #1

ASSIGNED: Friday 10 April 2020
DUE: 5:00p Pacific Friday 17 April 2020

NOTES:

- Given the unique circumstance of Spring 2020, we ask you to do your best to maximize your learning. Each problem set is an opportunity to assess your learning, identify gaps, reflect on what you have learned, and determine what you wish to learn next.
- Problem sets must be completed individually unless stated otherwise.
- Please turn in your completed problem sets as an electronic copy via Gradescope. Please make sure to clearly indicate the starting and ending boundaries of your answers to each question on Gradescope.
- Please do not go over any word limits and where appropriate show your work (e.g., calculations with appropriate units).

PSET #1 GOALS:

To help you reflect on the implications and possibilities of engineering living matter. To help you prepare for the quarter by thinking about your individual goals for the class. To introduce or remind you to back-of-the enveloped calculations that enable engineers to quickly frame what might be possible versus what's likely impossible.

(Q1) Who is your bioengineer? (10 pts)

Return to your "Imagine a Bioengineer" exercise from the first day of class. Sketch your imagined bioengineer as best as you can, on a piece of paper or digitally. Describe your bioengineer with three words. Include your sketch and three words in your submission. At the end of the course, you'll have a chance to pick three new words.

(Q2) What do or could bioengineers do? (20 pts)

After the first week of the class, a friend asks you about bioengineering. Your friend is specifically interested in the impact of bioengineering on humanity and civilization to date. Think back and review the three examples provided in the Monday's post-class reading (e.g., polio vaccine).

2.a. Identify on your own another example (similar to the three examples from the reading) of an impact of bioengineering today.

Notes: Keep your answer to one paragraph. Include two to three key references in support of your new example (i.e., newspaper articles, reports, websites). Images are optional.

2.b. Now think about the future. What future do you wish to realize? What roles should bioengineering play in realizing your future? How would you define “success?” Do you have any questions on how to realize this future? What trends, tools, policies, and technologies could help you realize this future? Craft an answer in response to some or all of the preceding questions, as before not more than one paragraph.

Comment: Our aim is to enable you to begin to identify, organize, and communicate the topics that you are excited about. Last year, initial efforts from this question helped guide students in considering possible final project topics.

(Q3) Approximate and rapid numerical estimates (30 pts)

Often, bioengineers encounter a new biological system for which they have no intuition. How can we build intuition such that we have a better understanding of what is physically possible in a new system? As an example, let’s say you wanted to ferment potatoes with wild yeast to make rubbing alcohol. How much alcohol could you make per potato? Or, let’s say you wanted to know how many *E. coli* cells fit on the head of a pin. These problems don’t seem important on their own, but the process of thinking about and answering them makes it easier to tackle the harder problems in bioengineering.

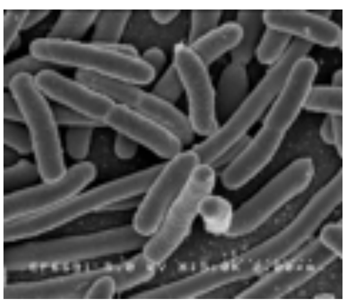
“Fermi problems” are order-of-magnitude estimation puzzles that aim to quickly and approximately answer complicated questions. Engineers do so by using a series of simpler estimations, often using physical principles that are either widely known or easy to guess. For example, before knowing how many bacterial cells might live on the head of a pin, we first need to guess the size of a single cell and the size of the pin head.

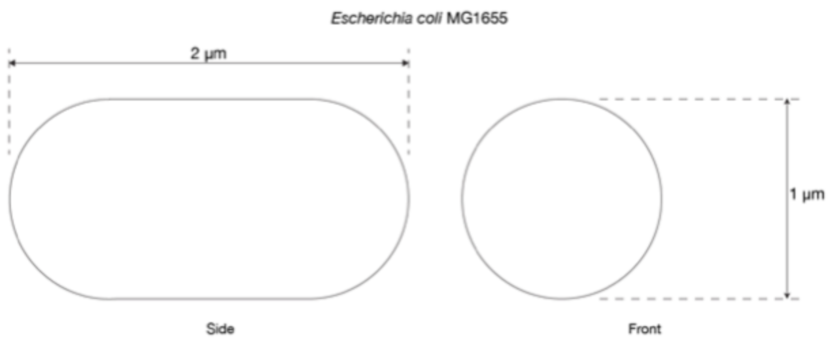
Such an approach the thinking helps build quantitative intuition for new or unintuitive systems. Bioengineers use Fermi problems to determine the feasibility of an idea or better understand a new system. Again, most such estimates are rough: they are designed to give you a quick, order-of-magnitude intuition for what might be possible or what the likely answer could be. Thus, keep in mind that the exactly correct numerical could be different.

For each calculation below please develop your answers to two significant figures and provide units where appropriate. Show your work. You should only need simple math and arithmetic; a couple of lines of work at most.

Escherichia coli is a well-studied bacteria considered to be representative of how single-cell microbial systems work generally (i.e., a ‘model’ organism). *E. coli* is also easy to grow in the lab and divides rapidly (as fast as 20 mins for one cell to make two cells) . As a result, *E. coli* is frequently used in bioengineering research.

3.a. First, estimate the volume of an *E. coli* cell by approximating the cell as a rectangular box 2 um x 1 um x 1 um. Next, estimate the cell volume by approximating the cell as a spherocylinder, as shown in Figure 1. How different are these two approximations? Go to the following page. How does your estimation compare with the measured values? (Optional practice: convert the volume to liters instead of m^3)





E. coli cells are shaped like rods with rounded ends, which we can approximate as spherocylinders (i.e., cylinder with hemispherical caps). Of historical note, MG1655 is the name for a commonly used lab strain of *E. coli* that was originally derived from a diphtheria patient at the Palo Alto hospital in 1922.

For the rest of question 3 problem, please use your volume estimate arrived at via your rectangular-box approximation.

3.b. The mean diameter of a typical protein is roughly 4 nanometers (1 billionth of a meter, abbreviated as nm). Presuming all proteins are spheres of this average size, what is the upper bound for how many proteins could fit inside a typical *E. coli* cell?

3.c. The mean volume of a DNA base pair is 10^{-27} m^3 (1 over 10 followed by 27 zeros). What is the upper bound on how many DNA base pairs could fit inside a typical *E. coli* cell?

3.d. Take a look at the actual estimated numbers of proteins and DNA in an E. coli cell from Figure 6a of the following link. What is the ratio of your upper bound numbers to the actual estimated numbers? (present your results in a table) Are you surprised by your result (the upper bound vs actual)? Why or why not?

"Cell Biology by the Numbers" is a useful resource for learning estimation problems in biology. You can get a free copy of the draft version here. The authors have recently published an informative SARS-CoV-2 (COVID-19) by the numbers as well.

(Q4) What's Unique About Living Matter? (10 pts)

Revisit the video describing the unique properties of living matter.

4.a. According to the video, what makes living matter unique? (please give two reasons and explain each in 2-3 sentences)

4.b. After watching the video, what did you find most surprising? (2-3 sentences)

(Q5) Reading research papers (30 pts)

Research papers serve as a primary source of information for many fields. One of the goals for BIOE/ENGR.80 is to give you tools (or improve your tools) that enable you to quickly read and learn from the primary research literature.

Briefly read the following paper or preprint: "Enabling community-based metrology for wood-degrading fungi" available from: link

5.a. In your own words, what is the primary claim of the paper? Take a look at the abstract (1-2 sentences)

5.b. In your own words, what is the primary evidence in support of the claim? Take a look at the figures)? (1-2 sentences)

5.c. What did you find as the most interesting idea, fact, conclusion from the abstract of the paper? (From the abstract, figure, or conclusion)

(***) YOUR QUESTIONS

Do you have any unanswered questions or comments from the first week of class that you would like to share with us?

Additional Learning Resources:

You can make and keep track of your own private library of bioengineering research papers. Tools can help. For example here is a link to a free and useful resource: Zotero The takeaway here is to make sure you have a system in place for managing your resources that support your thinking and problem solving.

Biology refresher-1: If you need additional learning materials or refresher for biology you can start by going through the first three chapters (very brief don't worry) of The Machinery of Life by David S. Goodsell. An electronic copy of the book is available from Stanford Library and you should be able to access from here