Assignment #4: Bacterial warfare

Using Python to study the effect of killing on spatial structure in bacterial populations

The next assignment is based upon the paper linked below, a collaboration of multiple GT labs led by William Ratcliff. In this paper, the authors demonstrate how spatial structure among mixed bacterial species can arise from molecular killing machines that each species uses. Please read the paper to get a general sense of the research that was performed so you better understand the goals of this homework assignment.

https://www.nature.com/articles/ncomms14371

This assignment was modified by Tucker J Lancaster

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Killing by Type VI secretion drives genetic phase separation and correlates with increased cooperation

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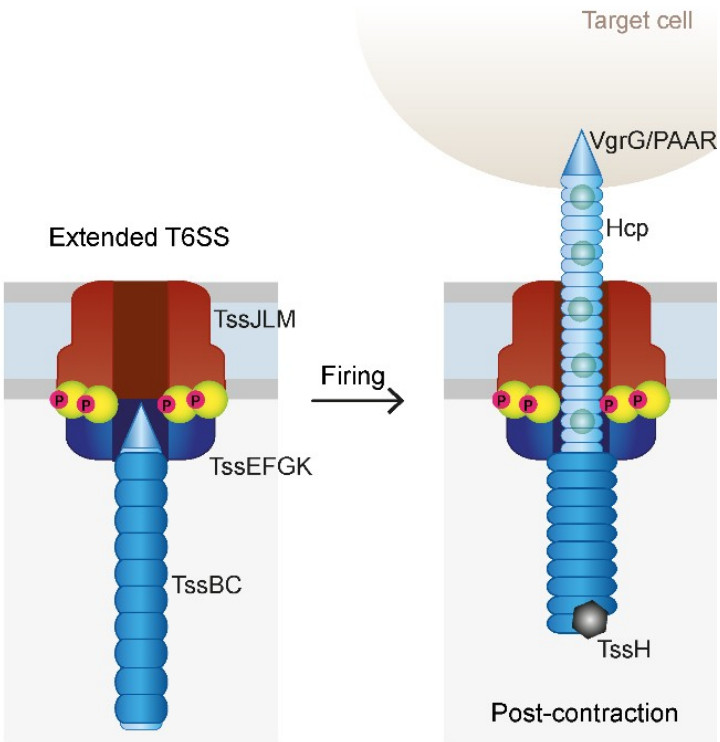
Type 6 secretion systems (T6SS) are protein machine used by a wide range of bacterial species to transport proteins from one cell to another. Typically, they are used to transport a toxin into a 2nd cell, killing it by targeting conserved bacterial proteins or cell wall components. They play an important role in interbacterial warfare. A schematic of how they work is shown below:

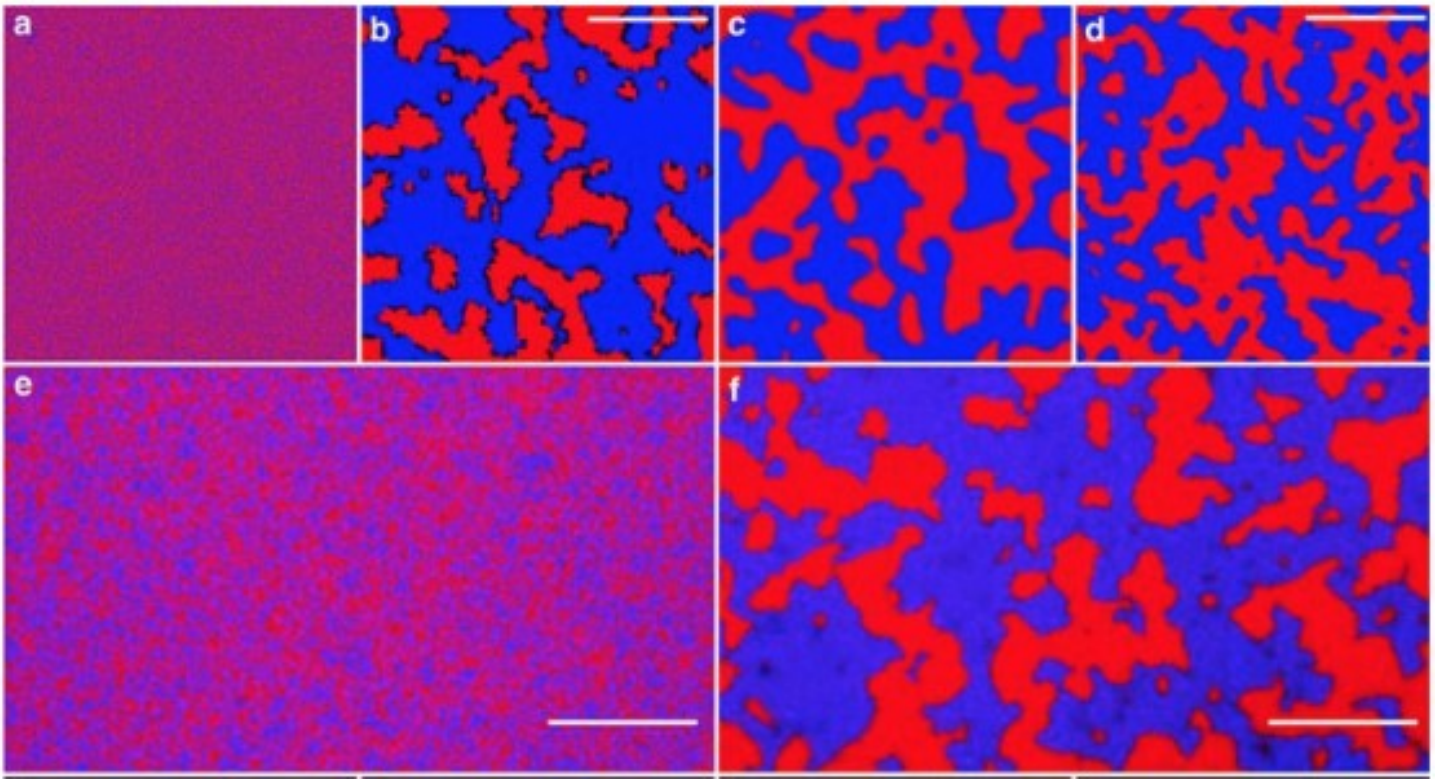


Interestingly, it was found that bacterial cells could not kill their offspring or any closely related cells. This is because cells also express an antidote that counter acts the toxin's effect.

In the paper above, the authors explored how these systems could create spatial structure in populations, allowing cooperative interactions through the local release of enzymes that are necessary for processing food (chitin) to bring it into the cell. The authors use the following system:

"In *Vibrio cholerae,* T6-proficient strains utilize the T6SS to intoxicate T6-deficient eukaryotic predators and diverse proteobacteria, as well as other more closely related *V. cholerae* isolates that lack identical effector immunity pairs[26,27,28,29,30,31,32]. T6-mediated segregation occurs during co-culture of T6-proficient *V. cholerae* with T6-deficient *E. coli*. Segregation was also predicted to occur between two mutually antagonistic T6-proficient strains[33], and recently demonstrated at the single cell level in co-cultures of *V. cholerae* and *Aeromonas hydrophila*[20]."

In other words, each bacterial species, *V. cholerae* and *A. hydrophila*, can kill each other, but not themselves. When you mix these species together, bacterial warfare ensues, where each species tries to kill each other. The authors show that in these situations, phase separation occurs, where each of the two species represents a single phase. A key figure from this paper is reproduced below, showing each species in red or blue:



The authors used a variety of modeling and laboratory experiments to demonstrate this, including a straightforward Python script you should be able to reconstruct based upon what you know already. From the Methods:

"We randomly seeded a 500 × 500 lattice with an equal number of red and blue cells. Every time step, 5% of the cells were randomly chosen to activate their T6SS systems, killing any adjacent (eight cells surrounding the focal cell) cells of the opposite colour. Similarly, 5% of the cells in the landscape were randomly

chosen to attempt to reproduce, filling up to one adjacent unoccupied patch with a cell of its colour. Rates of killing and reproduction were chosen to provide sufficient temporal resolution of population dynamics while still being computationally efficient. Reproduction was aborted if all neighbouring patches were occupied. Within each time step, model updates were propagated sequentially across rows, starting with the first position in the upper left corner. This model was coded in Python and is available upon request."

You may recognize this assignment from the research example in lecture 7. This time, your job is to implement this code using **numpy** and **matplotlib** instead of just using for loops and lists as you did previously in the research example. We have created a starting python file for you to use as a template. We have explicitly defined what type objects should be taken in and what type objects should be output by each function. Make sure your code adheres to these predefined types as the checker script for this assignment will check the types of the outputs from each function.

Assume that the grade you get on the checker will be the grade you get for this assignment. To get any credit beyond the points awarded by the checker will require that you follow the regrade policy outlined in the syllabus -- i.e., you will have to submit a typewritten and well-reasoned explanation of why your answer is correct despite it not passing, including an explanation of how the checker fails to account for your particular solution. In short, they will not be easy points to get back, so **reach out to your TA early if you are having trouble running or understanding the checker script**. Submit your final script as a .py file.

Good luck!