Simulating the Green Algae Volvox

Dr. Mannan approached me and explained he was looking for an undergraduate student to do some extended research over the summer. He continued by saying it was about a project he has been working on for quite a while that entails simulating the green algae, Volvox. It immediately sparked my interest because it involves the combination of both my majors, which are mathematics and computer science. The project is mathematical in nature, but it is implemented through coding. Another reason I found this project intriguing was it will give me a sense of what research looks like in graduate school. As I am approaching my final year as an undergraduate, I want to leave my door open for all possibilities next year, one of them being applying to graduate schools.

The idea of the project is to study flagella, a whip-like structure that, in the case of Volvox, allows the organism to swim around in it's environment. Specifically we are trying to understand how the flagella on this organism work together to move the organism in an organized and efficient way. One of the reasons to simulate the green algae, Volvox, compared to others, is the large size and ease of visualization make it an ideal model organism for these studies [3]. Studying flagella on Volvox also provides insight into other biological functions since flagella are present on many types of cells (e.g. the majority of the cells in the human body) and they play an important role in many biological processes. One of the most important roles of flagella is to help clear the airways in the respiratory system [2]. These biological functions often depend on the organized beating of many flagella, and how this synchronization occurs is an active area of research. The specific goal of this project is to look at the synchronization of flagella on the surface of green algae Volvox.

Over the course of the project, I will be building towards simulating the synchronization of flagella across the entire Volvox body by writing code in C/C++ and displaying the images in Python. Each flagellum will be modeled as a single sphere that undergoes a circular orbit. This is the minimal-rotor model proposed in [1, 3]. I will work up to simulating the entire Volvox by first consider each of the following building blocks.

1. I will simulate a single rotor in free space.

2. From there, I will adjust the code to consider the hydrodynamic coupling between two rotors and simulate them in a free space.

3. At this point I can do a sanity check and check my results against published data in [2].

4. Once my results match, it will be time to make a big jump and consider the rotors outside of the Volvox body where fluid can't penetrate. The main difficultly in this step is we must alter the code to change the preferred orbits of the rotors to be in any arbitrary plane in three dimensions. Luckily, I will have the help of existing publicly available code to account for the Volvox body.

5. Finally, I will consider a biological relevant distribution of rotors outside of the sphere. The hope is that the simulation will achieve a steady state that matches what is seen in real-world Volvox.

6. The final goal is to conduct parameter sweeps to fully understand how the parameters controlling each rotor's orbit influences the final collective behavior of all the rotors.

I find this research very intriguing and I believe many others may share a similar interest in it as well. Which is why I want to share my research with as many people as I can. One way I plan to communicate my research to the broader campus community is by presenting at the Celebration of Scholarship in the Fall. Another way Dr. Mannan suggests I could reach a broader audience and present my research is by giving a presentation at the MCS department colloquium in the Fall. Which I believe would be an amazing experience for myself to present at a setting I haven't before. Additionally, if all goes well, it would be an honor to keep extending the research with the intention of submitting it to a journal for publication.

To help reach my final goal in step six, I would like to request $1,200 to support 10 weeks of 10 hours per week of work. I would be very grateful to receive this grant for it will allow me to research into Flagella and the green algae, Volvox, something that piques my interest and involves both of my majors, mathematics and computer science.

References

[1] Douglas R Brumley, Marco Polin, Timothy J Pedley, and Raymond E Goldstein. Hydrodynamic synchronization and metachronal waves on the surface of the colonial alga volvox carteri. *Physical review letters*, 109(26):268102, 2012.

[2] Douglas R Brumley, Marco Polin, Timothy J Pedley, and Raymond E Goldstein. Metachronal waves in the flagellar beating of volvox and their hydrodynamic origin. *Journal of the Royal Society Interface*, 12(108):20141358, 2015.

[3] Thomas Niedermayer, Bruno Eckhardt, and Peter Lenz. Synchronization, phase locking, and metachronal wave formation in ciliary chains. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, 18(3):037128, 2008.