## I. Intellectual Merit

Aquatic organisms use a variety of modes of locomotion to effectively swim around their fluid environments [17]. Some modes of locomotion, such as those performed by jellyfish, are known to be much more energy efficient than others [18]. In fact, jellyfish are deemed the most energy-efficiency swimming animal [6], partly due to the low effort necessary to swim near their maximal achievable speeds [11]. However, other animals evolved to implore other modes of locomotion, such as the anguilliform (wave-like) mode like that of fly larvae, worms and eels, and still successfully swim, albeit at higher energetic costs [14, 16, 2]. While computational studies provide a framework to test the efficiency of different locomotive modes, one aspect that is traditionally dismissed upon calculating energetic costs the is the motion of the surrounding fluid. Moreover, different modes of locomotion give produce distinct fluid vortex wake patterns (see Figure 1). Furthermore, even among the same modes of locomotion, some animals are more efficient swimmers than others [2, 11] (see Figure 2).

This suggests an interesting question of what information can be gained from understanding a swimmer's vortex wake topology. That is, given a particular vortex wake, can we predict the efficiency of a swimmer? Some methods have been proposed to extract performance data from vortex wakes [7, 8], but it is a non-trivial endeavor [9]. We propose to use techniques from machine learning, i.e., convolutional neural networks, to help us classify vortex wakes and depict salient features indicative of performance. Others have used neural networks to classify particular wake patterns from oscillating airfoils or fish-like swimmers [5, 10], but have not assessed classification in terms of performance. From my lab's previous locomotion endeavors [12, 3, 2, 11, 1], we have produced over 25,000 fluid dynamics simulations for variety of swimmers, and thus over 25,000 simulations in which we can sample for training data for our neural network model. The **first goal** of this project will be classifying wakes of different modes of locomotion, i.e., jet propsulive (jellyfish-like) or anguilliform (worm-like) modes. The **second goal** will be to classify vortex wakes by energetic metrics (cost of transport) to identify wake topologies and features that lead towards more efficient swimming. We will make use of TCNJ's high-performance computing cluster to train, tune, and run our models [15].

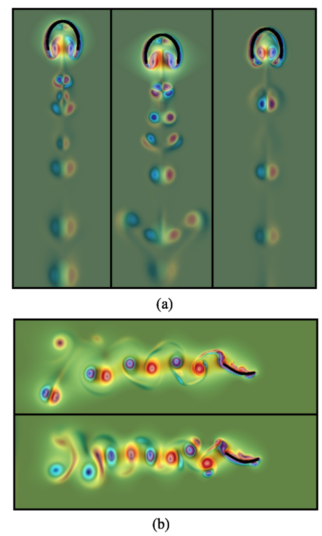


Figure 1: Vortex wakes of (a) jellyfish and (b) anguilliform swimmers

The importance of wake structure and vortex interactions are not limited to solely locomotion processes; a deeper understanding of their governing principles may also be beneficial for inspiring innovative designs for biomimetic devices, such as vertical axis wind turbine (VAWT) farm configurations [19] or flow sensors in aquatic robotics based on vortex induced vibrations [4, 13].

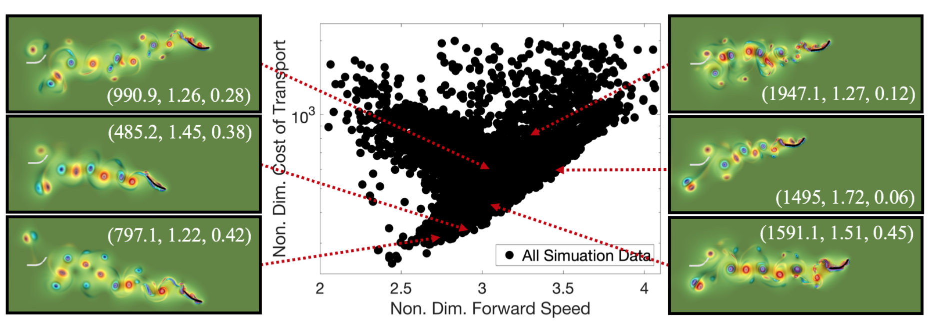


Figure 2: Anguilliform vortex wakes & where they fall within the performance space.

| Summary Timeline | Week | | | Summary Timeline | Week | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Project Task** | **1** | **2** | **3** | **Project Task** | **3** | **4** | **5** | **6** | **7** | **8** |
| 1. **Learned skills**: familiarity w/ programming environments | | | | 2. **GOAL #1**: Create classification model "who is who"? | | | | | | |
| a. Introduce Jupyter notebooks and/or Google collabs | o | | | a. Train image classifying model on swimming data | o | o | o | | | |
| b. Practice input/output of data | o | | | b. Tune and test model throughly | | o | o | | | |
| c. Learn to use ELSA HPC | o | | | c. Assess accuracy, precision, & confusion matrix | | o | o | | | |
| 2. **Introduce Image Classification Using Resources** | | | | 2. **GOAL #1**: Create classification model for performance | | | | | | |
| a. Run through tutorials | o | o | o | a. Train image classifying model on swimming data | | | o | o | o | |
| b. Produce image classification model | o | o | o | b. Tune and test model throughly | | | | o | o | |
| c. Tune and test model throughly | o | o | o | c. Assess accuracy, precision, & confusion matrix | | | | o | o | |
| d. Assess accuracy, precision, & confusion matrix | o | o | o | 4. **Write-up, documentation, and poster** | | | | | o | o |

## II. Role of Student and Mentor

As a faculty research mentor I believe my primary goal is to ensure a positive, supportive research experience for my students. On that note, I also try to construct a project that is mutually beneficial for my research program as well as ideal for a student to refine or develop new skills for their own career aspirations. In previous conversations with STUDENT, they exhibited interest in furthering their knowledge of machine learning and python programming via an interdisciplinary project. This project will satisfy those desires as well as complement and leverage their existing knowledge as a computer science major.

During Weeks 1 to 3, I will work with them to guide them through the foundational aspects of image classification using neural networks in python. To alleviate the learning curve in this process, we can use resources that I previously contributed to in Google's Applied Machine Learning Intensive program as a guide. During this time we will also discuss ethical implications of such machine learning algorithms as well as how to assess what a successful model, e.g., calculating the confusion matrix to interpret true and false positives and negatives rates and subsequent accuracy and precision metrics. During this time I will also be compiling all of the locomotion images and associated performance data from my lab's previous research endeavors.

In Weeks 4 and 5, they will use these images and data to construct and train their own classification neural network model. This model will be able to distinguish which vortex wakes are produced by a jellyfish or worm-like swimmer. I will provide different training data sets for them to use in order to practice tuning the model and explore its efficacy. After this in Weeks 6 and 7, I will provide two more data sets - one for jellyfish and one for worm-like swimming. Rather than classify who is who, here they will construct a model to assess swimming efficiency. That is, each image will come with a tag of its cost of transport (efficiency), and thus can be classified accordingly.

## III. Broader Impacts

This research will provide new insight into assessing swimming performance via salient flow features. Specifically for the student this opportunity will provide further exploration into machine learning techniques in an interdisciplinary research environment. For me, this will propel my bioinspired research program forward and contribute new tools for future lab members. On that note, my lab has a history of developing popular open-source fluids software for the scientific community and I suspect that this code will also benefit many others, particularly students. I expect that the data collected will translate into at least one peer-reviewed journal article. My target journals are *Physics of Fluids* and *Bioinspiration & Biomimetics*, the latter of which I have previously published in. I also plan to have them present a poster at SACNAS, and myself, present at the Society of Integrative and Comparative Biology in 2022. Furthermore, it will foster increased collaborations between departments at TCNJ, i.e., mathematics and computer science.

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