“Xenobots in Space”

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Background & Significance

Computer designed organisms, commonly known as Xenobots, are “living robots” designed and programmed by AI to perform a pre-specified task and built from the ground up using biological cells. Unlike traditional robots made of rigid materials such as metals and plastics, they possess unique characteristics due to their biological origin that make them promising candidates for various space exploration tasks. For example, CDOs are biodegradable, self-healing, and autonomous making them particularly suitable for sample-acquisition tasks on extraterrestrial bodies. Another potential use for CDOs is as a personalized, targeted drug delivery system that could better allow astronauts to combat spaceborne diseases such as radiation poisoning. Although there is tremendous potential, such applications are far from realization as CDO research is still in the early stages. My aim is to improve the AI systems used to design and program CDOs for the development of increasingly complex and functional biological machines.

Project Goal

In previous work, Xenobots were designed by an AI that is given two types of cells as building blocks: cardiac cells which beat providing a means for movement and skin cells which provide structure. It then generates candidate designs by arranging these cells in various configurations. The designs are judged on a particular task and the AI continually improves upon the design. The best design is then constructed out of cells to assess whether it successfully transferred to real life and completes the simulation-to-reality (sim2real) pipeline. This construction process is tedious and time consuming as layers of cells must be meticulously pieced together. Another method for a biological robot (biobot) to gain motion without the use of multiple cell types is via cilia, organelles that protrude from the cell body and beat to propel the organism forward. It is unknown, however, how the organism controls cilia and thus how a pattern of the cilia translates into a predictable behavior. I am developing a “real2sim” pipeline to bring biobots from real life into simulation so allowing for the rapid testing of hypotheses about mechanisms by which cilia create motion.

Summary of Key Findings

Main findings of this work include establishing a preliminary pipeline in which a biological robot is instantiated *in silico* and placed into a physical simulation to observe behavior under various conditions (Fig. 1). The pipeline begins with a ciliated biological robot that has been stained to identify specific parts of the body. Of particular interest is the stain that shows where the cilia are located on the biobot. The other stains identify the morphology of the biobot. A stack of 2-dimensional images of the bot can be used to produce a reconstructed 3-dimensional image (Fig. 1A). The cilia pixel data can be separated from the rest of the body, both of which can then be exported as 3-dimensional meshes (Fig. 1B,C). These meshes are then converted into two 3D binary matrices: the first identifying the body and the second identifying the cilia. A series of post-processing filters are applied to these matrices which reduce noise, smooth the surface of the bot, and remove detached cells. The matrices are combined to produce a single matrix defining both the body and cilia. This matrix is then downscaled to a size that was determined to have the best trade-off between error in the cilia location and size of biobot as smaller objects can be simulated more efficiently in voxcraft, the simulation software. The resulting matrix (Fig. 1D) is placed in a virtual world which approximates that of the *in vivo* biobot. Next steps include evaluating behavior *in silico* under a variety of cilia control mechanisms. Those conditions that produce behaviors that match their *in vivo* counterparts may provide insights into the biological mechanisms controlling the real-life bots. Such a pipeline can be used as a tool for a wide variety of future work on computer designed organisms to help investigate other characteristics of biological robots that might become a designable feature in the future.

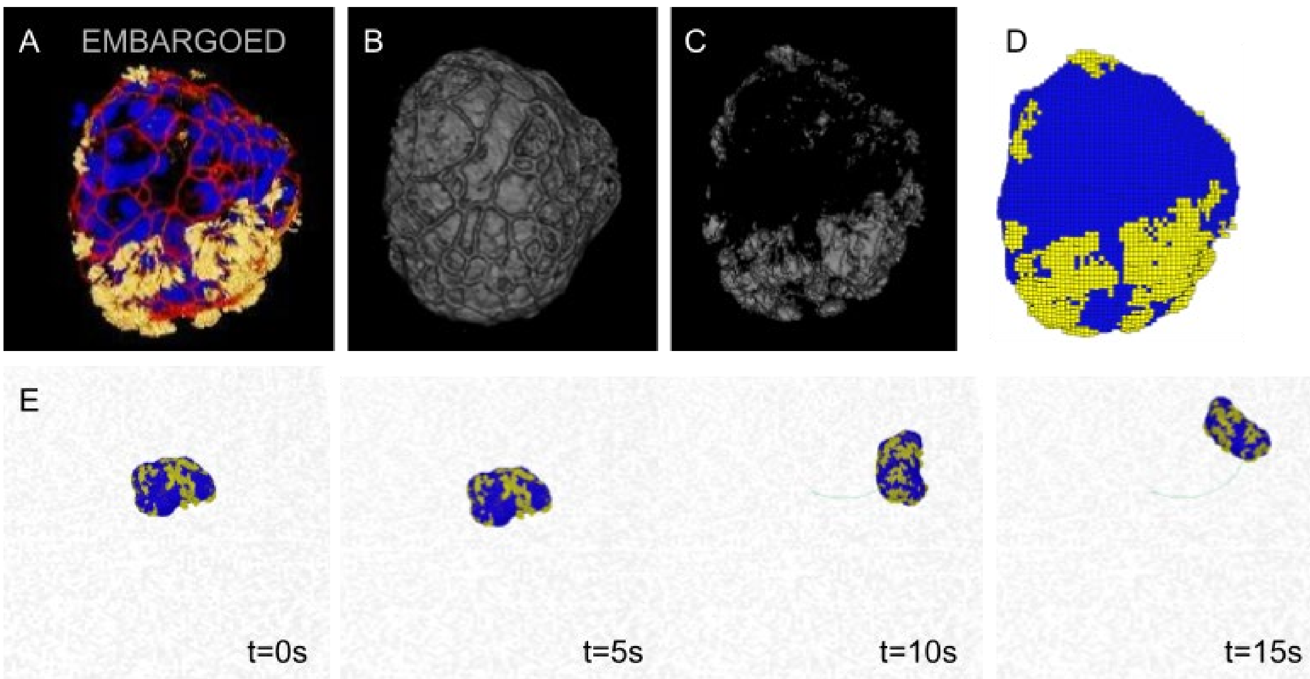

Figure 1. Top panel: Real2Sim pipeline. (A) Reconstructed 3D image. Yellow denotes cilia, blue and red define the body of the biobot. (B,C) 3D meshes of the body and cilia, respectively. (D) Combined body and cilia matrix. Yellow denotes cilia, blue denotes the body of the biobot. Bottom panel: Time-lapse of a biobot in voxcraft.