Evolving swimming soft-bodied creatures

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Introduction Robotic and fluid dynamics studies suggest that flexibility can be advantageous for organisms living in water [Alben et al., 2002, Bergmann et al., 2014, Shelley and Zhang, 2011, Giorgio-Serchi et al., 2016, Giorgio-Serchi and Weymouth, 2016], which would partly explain the abundance of soft-bodied creatures produced by natural evolution in this environment. A new setup is introduced that allows further investigations on this issue from an evolutionary perspective. The effects of a fluid environment on the evolution of soft morphologies will be investigated. Other efforts will be directed to studying the evolutionary transitions water↔land, and how these affect the evolution of successful morphologies and behaviors.

Fluid model Soft creatures are simulated in the VoxCAD simulator [Hiller and Lipson, 2014], empowered with a mesh-based fluid drag model. A local drag force is computed for each facet of the deformable mesh, and added up as an additional force experienced by the underlying voxel (Fig. 1). The total drag force F_{dv} experienced by a voxel v is:

$$\vec{F_{\text{dv}}} = \sum_{i=0}^{N} \vec{F_{\text{dfi}}} \tag{1}$$

where N is the number of facets surrounding the voxel and F_{dfi} is the drag force experienced by the i-th facet:

$$\vec{F_{\text{dfi}}} = -\frac{1}{2}\,\rho_f\,C_d\,A_f\,\vec{v_f}^{\,2} \tag{2}$$

- ρ_f is the fluid density
- C_d is the facet's drag coefficient
- A_f is the facet's area
- $\vec{v_f}$ is the facet's normal speed

Neutral buoyancy is assumed. Complex phenomena such as turbulences are overlooked by this model, which might limit the range of life-like locomotion strategies that can be simulated.

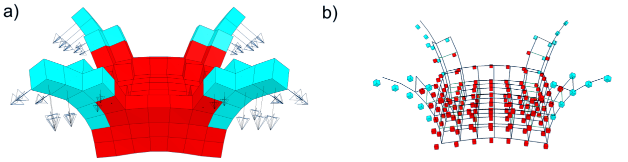

Figure 1: a) The deformable mesh (drag forces are plotted) b) The underlying voxel-based model.

Evolution Robots are evolved using a multi-objective implementation of CPPN-NEAT [Corucci et al., 2016, Cheney et al., 2015]. Two CPPNs are evolved: the first one (CPPN1) determines the morphology of the robot, the second one (CPPN2) determines its control. Queried at each voxel of a cubic workspace, they both take as inputs the 3D location of the voxel (x, y, z), the polar radius (d), and a bias (b). CPPN1 has two outputs, determining whether a voxel should be full or empty, actuated (red) or passive (cyan). The outputs of CPPN2 dictate the frequency and phase offset of the sinusoidal actuation. The task consists in locomotion, and four objectives are defined:

1. Maximize the traveled distance
2. Minimize the actuation energy (% of actuated voxels)
3. Minimize the number of voxels
4. Minimize the age of each individual [Schmidt and Lipson, 2011]

In a first experiment robots are evolved in water only. Additional experiments are then performed by starting evolution in water, then switching to land halfway (and viceversa).

Results A sample of the evolved morphologies can be observed in Fig. 2 and in the accompanying video [1]. The system is able to evolve diverse and life-like morphologies and locomotion strategies. Preliminary results also encourage the investigation of the effects of environmental transitions on morphological evolution (Fig. 3).

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[1] https://youtu.be/4ZqdvYrZ3ro

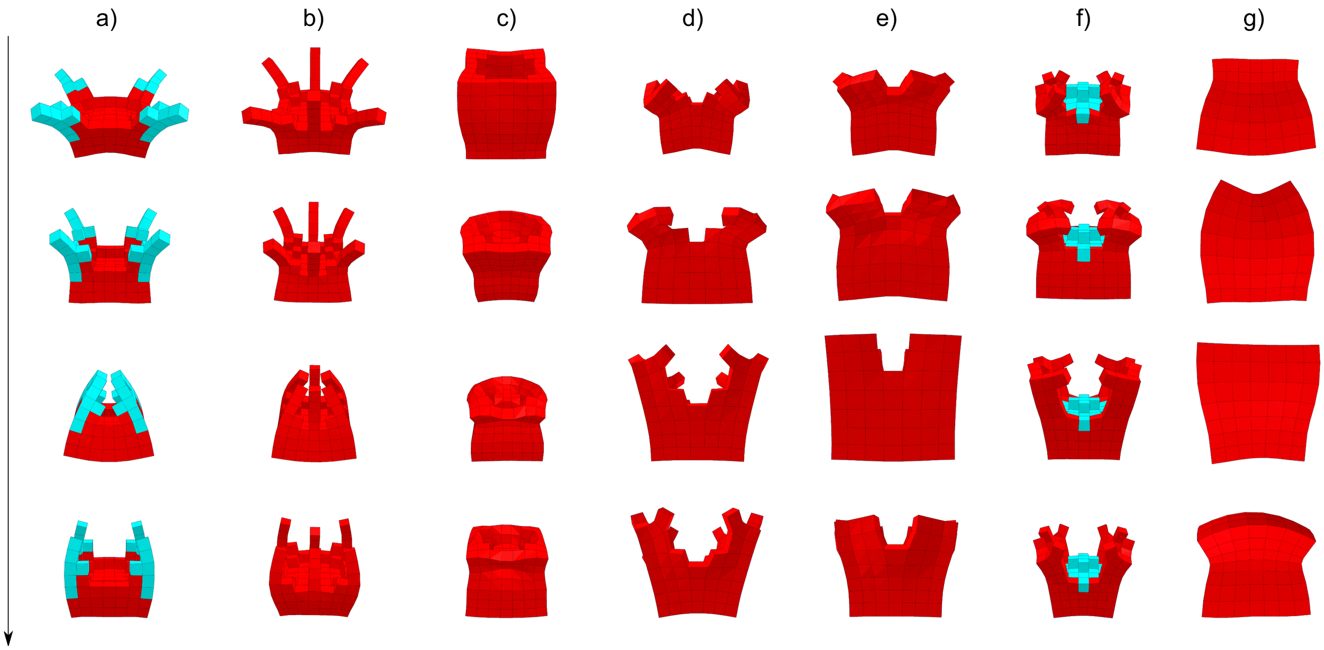

Figure 2: A sample of the evolved swimming creatures.

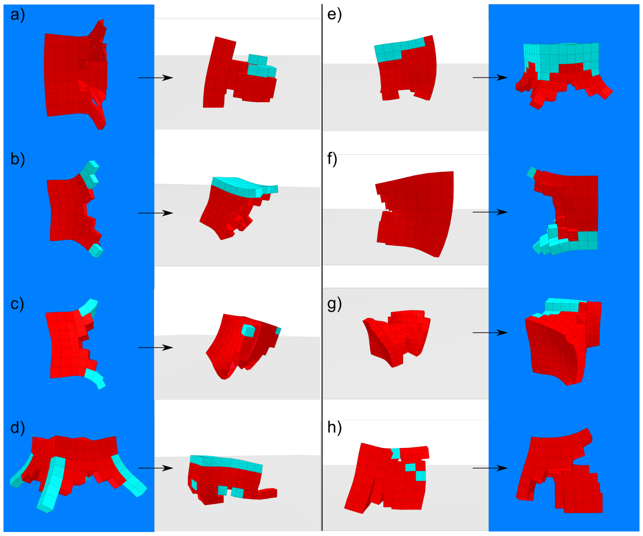

Figure 3: Examples of environmental transitions water ↔ land. Exaptation phenomena can be observed.

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