Evolved Virtual Creatures with Soft-Body Muscles: On a Bio-Mimetic Path to Meaningful Morphological Complexity

Dan Lessin
ITU Copenhagen
Copenhagen, Denmark
dles@itu.dk

Sebastian Risi
ITU Copenhagen
Copenhagen, Denmark
sebr@itu.dk

ABSTRACT

In the past, evolved virtual creatures (EVCs) have been developed with rigid, segmented bodies, and with soft bodies, but never before with a combination of the two. In nature, however, creatures combining a rigid skeleton and non-rigid muscles are some of the most complex and successful examples of life on earth. Now, for the first time, creatures with fully evolved rigid-body skeletons and soft-body muscles can be developed in the virtual world, as well. By exploiting and re-purposing the capabilities of existing soft-body simulation systems, we can evolve complex and effective simulated muscles, able to drive a rigid-body skeleton. In this way, we can begin to bridge the gap between articulated and soft-bodied EVCs, and take the next step on a nature-inspired path to meaningful morphological complexity for evolved virtual creatures.

Categories and Subject Descriptors

I.6.8 [**Simulation and Modeling**]: Types of Simulation—*animation*

Keywords

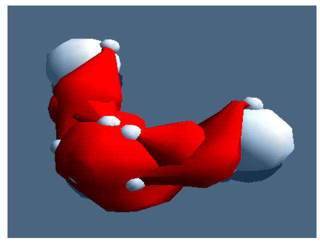
evolved virtual creatures; morphological complexity; muscles

1. INTRODUCTION

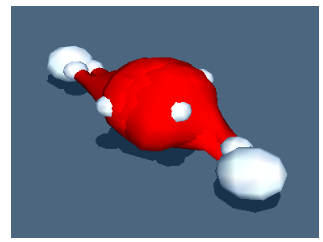
Since evolved virtual creatures (EVCs) were first introduced [3], the standard implementation has employed a rigid-segmented skeleton-like body, with only minor variations. There have been some investigations into rigid-segmented bodies with more complex segment forms [1], and recently, soft-bodied creatures have produced compelling results [2], but no attempt has yet been made to combine the two approaches. Evolution in the natural world has employed such a combination to produce a great variety of highly complex and successful creatures. What might emerge when this method of embodiment is taken from life-as-we-know-it in the real world to life-as-it-could-be in the virtual world?

GECCO '15 July 11-15, 2015, Madrid, Spain

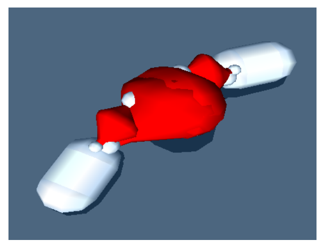
ACM ISBN 978-1-4503-3488-4/15/07.
DOI: http://dx.doi.org/10.1145/2739482.2764897



(a) Evolved Creature 1: Crawler.



(b) Evolved Creature 2: Inchworm.



(c) Evolved Creature 3: Shuffler.

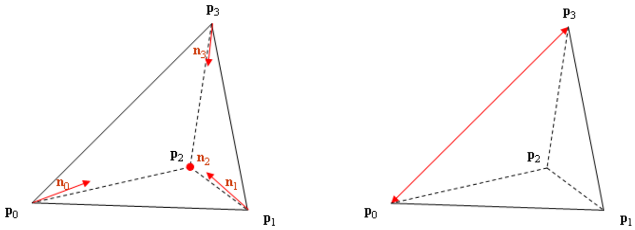
Figure 1: Soft-body-muscled creatures evolved with the system described here. To see these results in motion, please visit https://youtu.be/dSlHoIBDdlc .

To begin this pursuit, appropriate simulated muscles are required. Here, a new approach is introduced in which an existing soft-body simulation system is re-purposed and exploited to produce realistic muscles with many desirable properties for the development of complex and capable EVC bodies.

2. IMPLEMENTATION

The presented soft-body EVC musculature has a number of desired characteristics, each one obtained by employing or re-purposing existing capabilities available in an off-the-shelf physical simulation system: NVIDIA PhysX. In this system, soft bodies are simulated as tetrahedral meshes, with vertices treated as particles, and additional constraints applied per tetrahedron to produce the useful effects described below.

One desired characteristic of soft body muscles is the preservation of volume, which produces a familiar squash-and-stretch behavior as muscles decrease and increase in length.



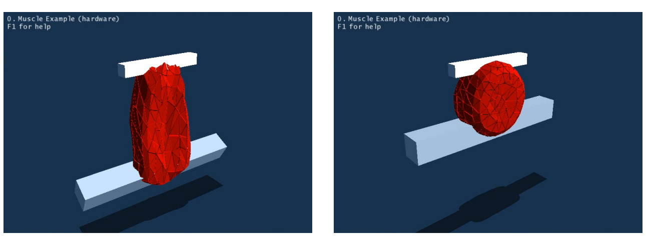
(a) Tetrahedron vertices are moved to preserve volume, when *volume stiffness* is high.

(b) Tetrahedron vertices are moved to preserve edge lengths, when *stretching stiffness* is high.

Figure 2: Physx volume (a) and stretching (b) constraints, used to preserve muscle volume and implement muscle contraction, respectively.

In PhysX, this property (which they call *volume stiffness*) is directly available as an attribute of simulated soft bodies, and is implemented as restorative movements applied to tetrahedral vertices (Figure 2a). This parameter may be varied to produce a range of soft-body styles. For this implementation, it was set to its maximum value: 1.0.

A vital aspect of simulated muscles is the ability to contract in a controllable manner. While PhysX provides no built-in mechanism for this, it does offer the *stretching stiffness* attribute of soft bodies, which can be repurposed to accomplish this goal. This property controls the degree to which a soft body will attempt to retain its original shape (again by changing tetrahedron-vertex positions), as illustrated in Figure 2b. By varying this attribute over time, the muscle's tendency to return to its initial, fully contracted shape is controlled, and it can be made to relax or contract as needed. In figure 3, the ability of this contraction mechanism to lift a rigid-body object is demonstrated.



(a) Low stretching stiffness: muscle relaxed.

(b) High stretching stiffness: muscle contracted.

Figure 3: This figure illustrates the underlying contraction mechanism employed by the soft-body muscles presented here. As stretching stiffness is increased, the simulated muscle changes from its relaxed shape (a) to its original, contracted shape (b), and is able to do useful work, such as lifting the rigid-body segment shown here.

3. RESULTS

Of eight experimental runs, four were successful with respect to fitness score. One of those four succeeded by exploiting a weakness in the fitness definition rather than by producing true locomotion. The remaining three successful runs are presented here as Evolved Creatures 1 through 3. To see these results in motion, please visit https://youtu.be/dSlHoIBDdlc .

In Figure 1a, the first example of a successful result is presented. This creature's rigid skeleton consists of a central sphere attached to spherical limbs by prismatic joints (able to telescope linearly, while maintaining orientation). Each limb is connected to the root segment by three muscles, with varying attachment points and strengths. Its method of locomotion is to move forward (toward its limbs) by quickly extending and retracting its arms in an alternating manner, producing a clawing, crawling gait.

In Figure 1b, the second example of a successful result is presented. Its skeleton consists of a large central sphere, joined to two smaller spheres by spherical (ball-and-socket) joints. The central segment is connected to each of its limbs by two muscles. By aggressively swinging its central segment toward one of the limbs, then more gently returning it towards the other, this creature locomotes along the direction of its body length, producing the fastest result by far among those presented here.

In Figure 1c, the final example of a successful result is presented. This creature's skeleton is composed of a central capsule segment, with capsule limbs extending out and to the back. The limbs are connected with cylindrical joints, which allow both telescoping along the joint's axis and rolling around it, as well. Each limb is connected to the central segment by two muscles. By shifting its weight from side to side, forward (away from the limbs) shuffling locomotion is produced.

4. CONCLUSION

This work has presented a technique for combining rigid articulated skeletons with soft-body muscles in evolved virtual creatures for the first time. This was made possible by a novel combination and re-purposing of a number of existing physical simulation components from an off-the-shelf simulation system. Initial experiments with evolving morphology and control for locomotion were shown, and a number of useful results were presented. This novel bio-mimetic synthesis of two highly successful EVC techniques represents a new step toward matching the morphological complexity of some of the most successful creatures in the natural world.

References

[1] J. E. Auerbach and J. C. Bongard. On the relationship between environmental and morphological complexity in evolved robots. In *Proceedings of the Fourteenth International Conference on Genetic and Evolutionary Computation Conference*, GECCO '12, pages 521–528, New York, NY, USA, 2012. ACM.

[2] N. Cheney, R. MacCurdy, J. Clune, and H. Lipson. Unshackling evolution: Evolving soft robots with multiple materials and a powerful generative encoding. In *Proceeding of the Fifteenth Annual Conference on Genetic and Evolutionary Computation Conference*, GECCO '13, pages 167–174, New York, NY, USA, 2013. ACM.

[3] K. Sims. Evolving virtual creatures. In *Proceedings of the 21st annual conference on Computer graphics and interactive techniques*, SIGGRAPH '94, pages 15–22, New York, NY, USA, 1994. ACM.