For the love of biodiversity

New experiments with the *Gene Pool* simulation achieve species co-existence

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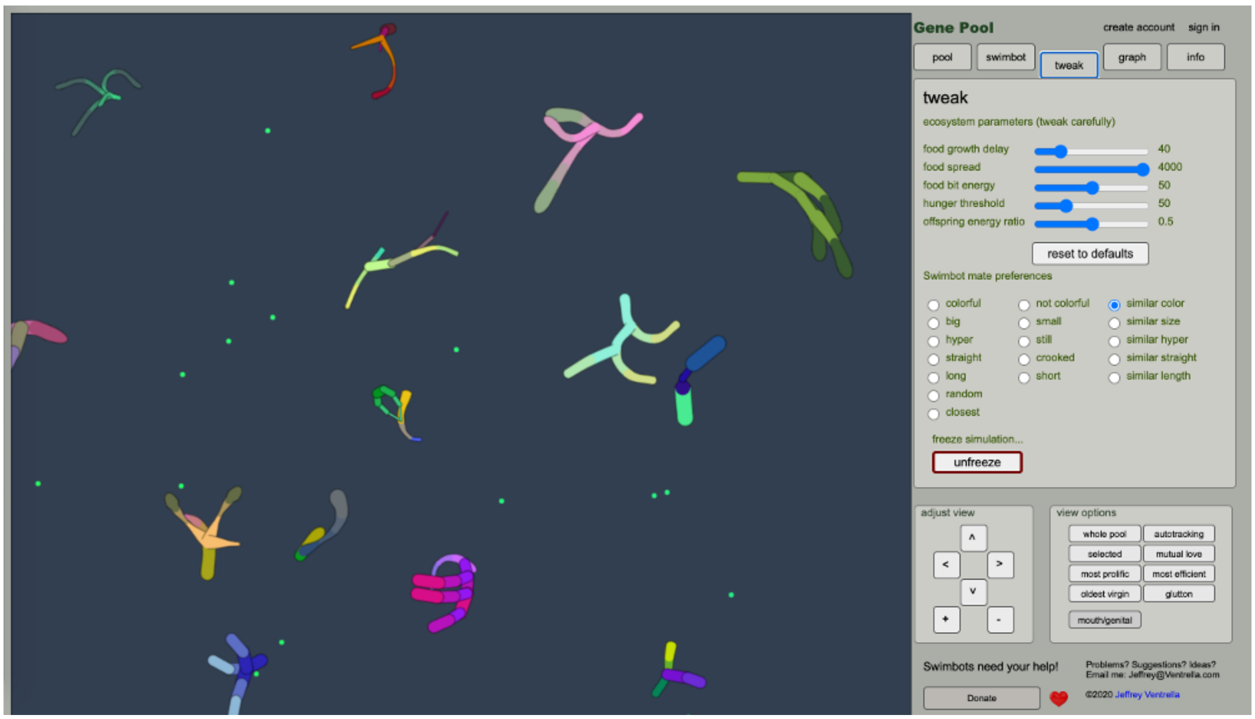
It only takes is a little bit of time engaged with nature—and some high school biology—to understand that biodiversity is important for the health of the planet, and for human bodies and societies. Our individual human bodies contain hundreds of species of microorganisms, many of which are important for good health. Human love for biodiversity is no accident. Biodiversity has always been a necessary component of evolution, and this is why so many scientists feel strongly that we need to avoid species extinctions—at all ecosystem levels—from parasites to gorillas.

In our recent collaboration, we do not hesitate to speak in terms of beauty. When we watch multiple species of virtual organisms swimming among each other over extended time, it’s not just that our experiment is working; it’s also wonderful to watch. Visual engagement has always been important in the design and subsequent upgrades to the Gene Pool simulation.

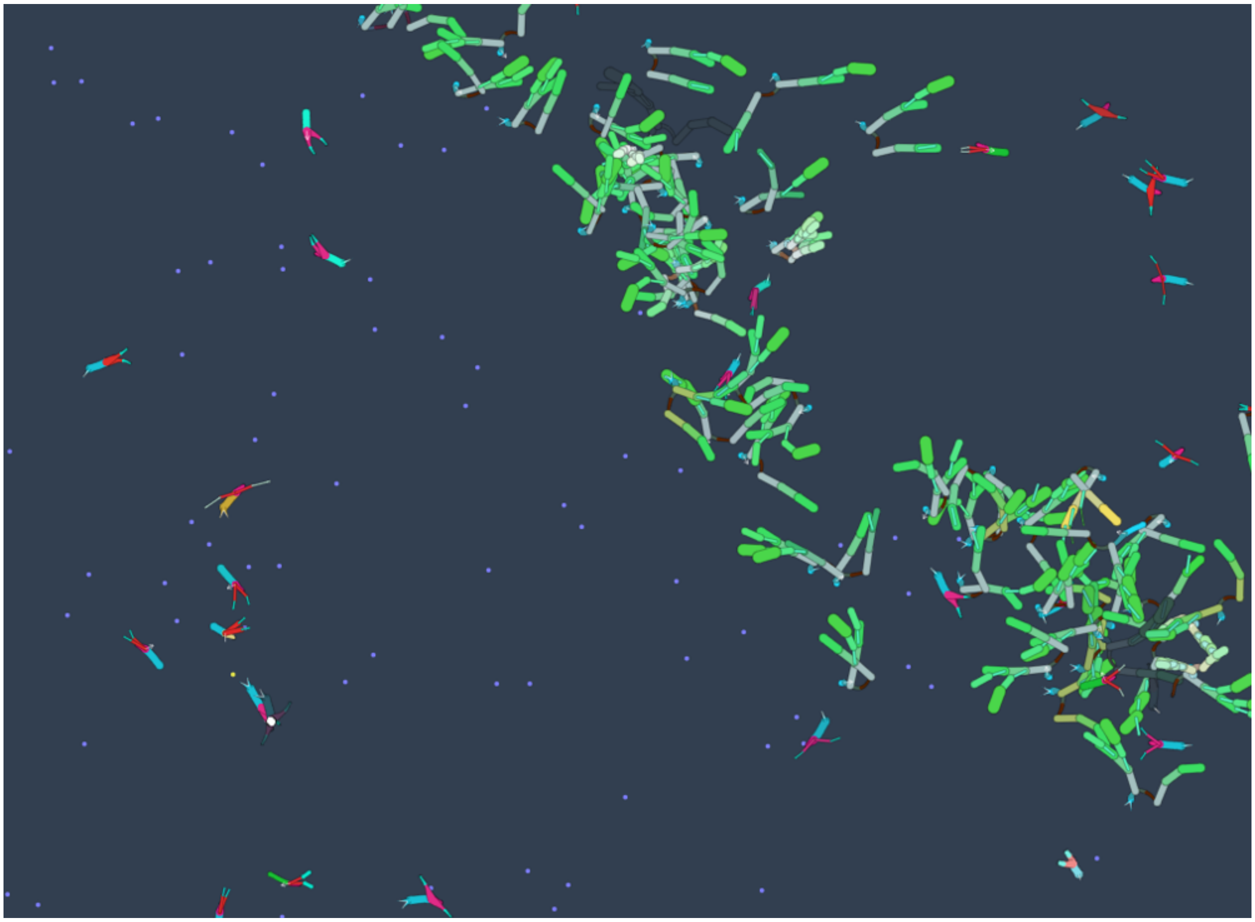
Gene Pool is an animated artificial life simulation in which hundreds of virtual organisms (swimbots) evolve morphology and behavior for better swimming. But “swimming” is never defined. What emerges are various strategies for efficient locomotion, to pursue mates (to reproduce) and food bits (to regain energy burnt-off from moving around). Since swimbots are distributed in space, localized coherent groups of similar swimbots (gene pools) arise, as nearby swimbots mate and cross their genes.

For some background and context, the latest version of Gene Pool can be seen at: http://swimbots.com/genepool/ .



Compatible species

Our experiment takes the simulation up a notch; one small step closer to a natural ecosystem. Species never occur in isolation and are always interacting and coevolving with each other. Gene Pool simulation runs are notorious for evolving into a single dominant “race” of swimbots that out-compete all the others (the winners are always fast and ravenous—eating and mating at such a high rate that other genetic breeds simply cannot compete).



We could say “kudos” to these greedy critters...but anyone who has done their evolution homework knows that there is never really an end-goal. It’s not about winning. Evolution is not just about competition; cooperation and symbiosis are just as important in the struggle for survival, and coexistence is often an emergent property of healthy, sustainable ecosystems.

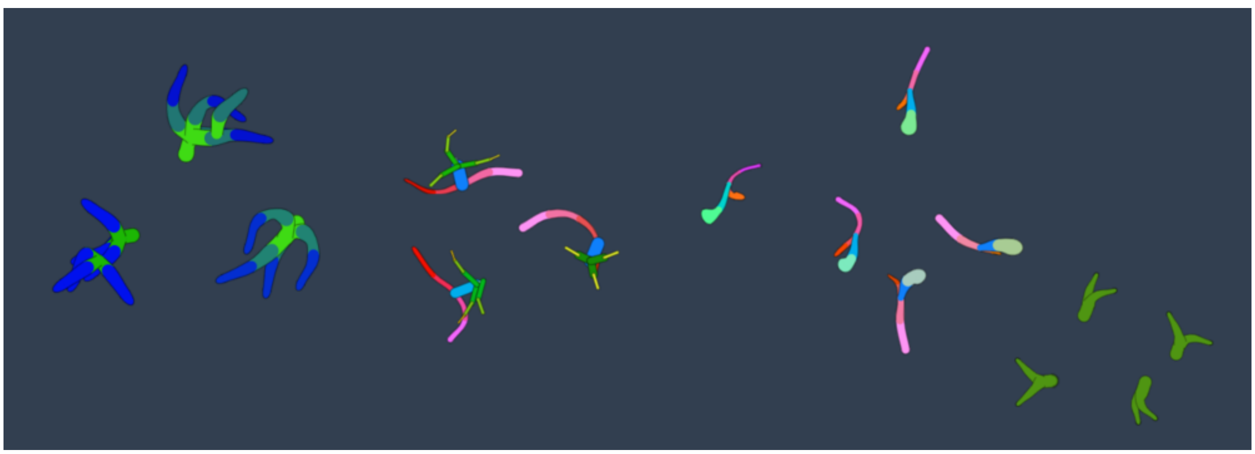
Any simulation model that achieves genuine species coexistence is a worthy cause, and may support some theories on how coexistence works in the natural world. We now have some exciting preliminary results. They will be added to the website soon. Also, we hope to have something worth publishing in the new year. What follows is a brief explanation of our motivation and design approach.

Background research on co-existence

In 2000, Dr. Peter Chesson (now of University of Arizona) published a review describing how mechanisms that lead to species coexistence tend to fall in two general categories (Chesson, 2000): (1) *equalizing,* and (2) *stabilizing* mechanisms. So we took on the challenge of seeing how well these mechanisms can be used to reach diversity and co-existence in Gene Pool. Can applying this to Gene Pool also teach us something about real-world species co-existence?

Establishing a swimbot taxonomy

Our first task was to replace this vague idea of a swimbot “race” with something more precise. Previously we had been referring to “races” because swimbots always had the ability to interbreed, no matter how vastly different they were. To establish a cleaner definition of biological entities and diversity in Gene Pool, we took that extra step in allowing swimbots to eventually become incompatible after they diverge genetically beyond a certain threshold.



In a subsequent publication we will go into the process and mechanisms behind this, but for now we can begin to describe Gene Pool evolution in terms of speciation (the evolution of new species).

We can now embark on our experiment: to test Chesson’s mechanisms. These mechanisms are explained below:

1. *Equalizing co-existence*

Grocery store analogy: Imagine a small town with many small shops. There are several grocery stores. They are all about the same size, have similar prices, and put up a healthy competitive fight with each other. We have a diversity of stores and shops in our imaginary town because no one store is substantially better than the other. Maybe one store opens up an organic section so many new people start shopping there. It's not long before other stores follow suit with their own organic sections. Coexistence occurs because stores are approximately equal in their "fitness" compared to one another, so no one store can totally win out. That is…assuming nothing gets perturbed.

Applying this to Gene Pool: In Gene Pool (as in biology), swimbot fitness is measured in terms of the number of offspring each swimbot has. If several different swimbot species in one pool all have a similar fitness, then it would be difficult for any one swimbot species population to rise above all the rest—or at least it would take a long time. So, one way to prevent one species from quickly rising to the top would be to impose some rules or limitations on how prolific any one race can become relative to the rest. This is tricky if we are striving to follow a key ethos in artificial life: modeling an environment with as little top-down design as possible. Nonetheless, we know that physics and chemistry impose real limits on our own world, and so designing an artificial life simulation ultimately requires setting certain constraints. Here are a few that we have explored:

1. Making it impossible for "eels" to evolve (the swimbot eel morphology/movement type is the "Walmart" of grocery stores). There is a degree of unavoidable top-down design in the implementation of a swimbot phenotype, as an expression of its genotype. A small, unobtrusive adjustment to this design creates a handicap for the eels.

2. Imposing tradeoffs in swimbot biology: *So you swim faster? Well, you probably expend more energy than average, and so you spend more of your life foraging for food to keep your energy up, which means you spend less time mating…and*

producing offspring. (This feature of Gene Pool has always existed).

3. "Calming" evolution by reducing mutation rate: this might give more of the initial random swimbot races an opportunity to reach a healthy population size.

We prefer not to depend on too many of these kinds of rules and limitations. It feels like we are trying to prop-up something that has a tendency to "tip over". That's not surprising: Chesson describes equalizing mechanisms of coexistence as "unstable", meaning that *eventually* one species does win out: given enough time one grocery store or swimbot race still rises to the top. Here's an analogy: if you balance a seesaw just right, it will stay flat. But given the inevitable breeze (or alighting butterfly), it will eventually fall to one side.

In my hometown, a big box chain supermarket has taken center stage. Perhaps this was inevitable. However, the local legislature prevents large store signs. This simple act allows for the small family owned grocery store to have a sign just as big as its big-box counterpart, leading to a slightly closer to equal fitness advantage for both stores. Oh, and they also blocked Walmart from coming to town. Turns out my hometown knew something about "equalizing co-existence"! But this is not the only reason there are still several surviving grocery stores in town.

2. Stabilizing co-existence

Back to the grocery store analogy: The multiple grocery stores in our imaginary town are also able to survive and co-exist because they each have their own niche of customers they serve. I go to the local food coop when I want to buy good organic produce, I go to the corner shop to get more processed foods and anything else. Oh and there's also a local butcher that has some of the best meat I've ever had. Meanwhile I personally have no interest in shopping at the big box store. Because each store seeks to serve a particular niche, the competition between stores is lessened. The big box store has its own customer base and can be as big as it wants to be, but it will never be able to compete with my need for local organic produce bought from people I trust and love.

Applying this to Gene Pool: The essence here is to give swimbots the opportunity to fill different niches so that different races are not competing with each other in one single *uber-niche*. But how do we define a swimbot niche? The niche of an organism is related to the resources it uses in order to successfully reproduce. In the case of swimbots, their main resource is a continual supply of food bits, and there is currently only one type of food bit (green). This is analogous to having a town where everyone is identical in their food shopping needs. Only one store niche would come to exist; all the rest would have to close shop. So, what are some of the ways we can we add extra resource dimensions to Gene Pool?

1. Making more than one type of food bit, and associating food bit preference with genes that code for food preference. This might be as simple as linking food color to a gene that codes for preference. Or it might be as complex as having different food bit sizes (requiring morphological adaptations (beak size?)…for cracking open those tasty food bits.

2. Making different regions of food bit growth that are spatially isolated from each other (two stores side by side would compete more heavily than each being in a separate town). This adds a spatial niche dimension to resource availability.

3. Swimbots also rely on the resource of water-viscosity in order to be able to swim effectively. What if water viscosity (or other physics parameters) varied around the pool to encourage unique and different strategies for reaching food in these regions.

4. Using different sized obstacles could create patches of the pool that only allow small swimbots to enter and pick out food, while the large swimbots would stay in the regions where food is more easily accessible.

5. Food bits could form as “fruits” with a hard shell on the outside and food bits on the inside. Some fruits have small holes and some fruits have larger holes,

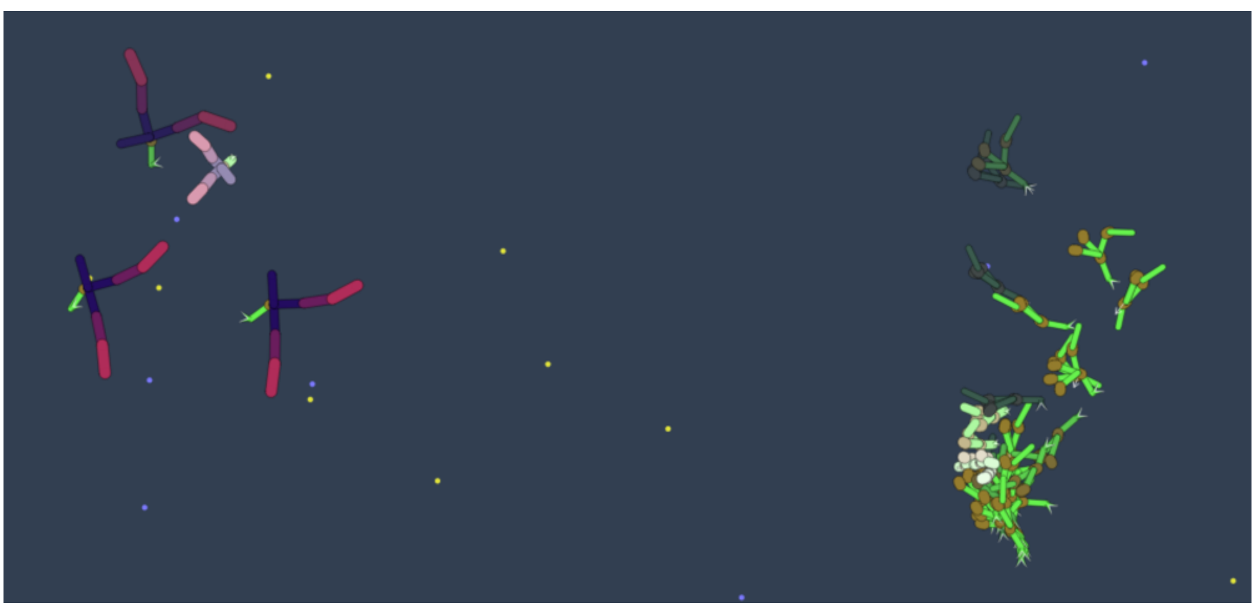
allowing swimbots to evolve different body size niches.

6. Some food bits could always be on the move (and be hard to get), but they would provide more energy, while other food bits do not move, but provide less energy.

7. Food bits could begin at the top of the pool (surface of the pond?) and slowly fall down to the bottom of the pool, changing energy and nutrient value as they settle to the bottom. This might be some form of combining a spatial niche with differences in how food can be foraged.

In short, there are many ways to try approaching this, but they all reach a similar condition, which is a bit subtle:

Chesson describes stabilizing coexistence as what happens when competition between ***individuals in the same species*** is greater than competition between ***individuals of different species***. In terms of grocery stores, there is less competition between the health-food store and the big box chain than there is between the health-food store and another health-food store. With different types of food, swimbots would be competing more heavily with swimbots that eat the same food type than they would compete with swimbots that eat something different.



It is important to note that both of the mechanisms we have described (*equalizing,* and *stabilizing*) are important for co-existence. Having different niches might not stand a chance against a disproportionate skew in fitness (if Walmart came to town!) And having a perfectly balanced competitive landscape would not stand a chance against time and the inevitability of one organism eventually becoming dominant (a gentle breeze or a butterfly coming to rest). Taken together, equalizing mechanisms would slow down the time it takes for one swimbot species to become dominant, and stabilizing mechanisms would reduce the chance that it ever happens.

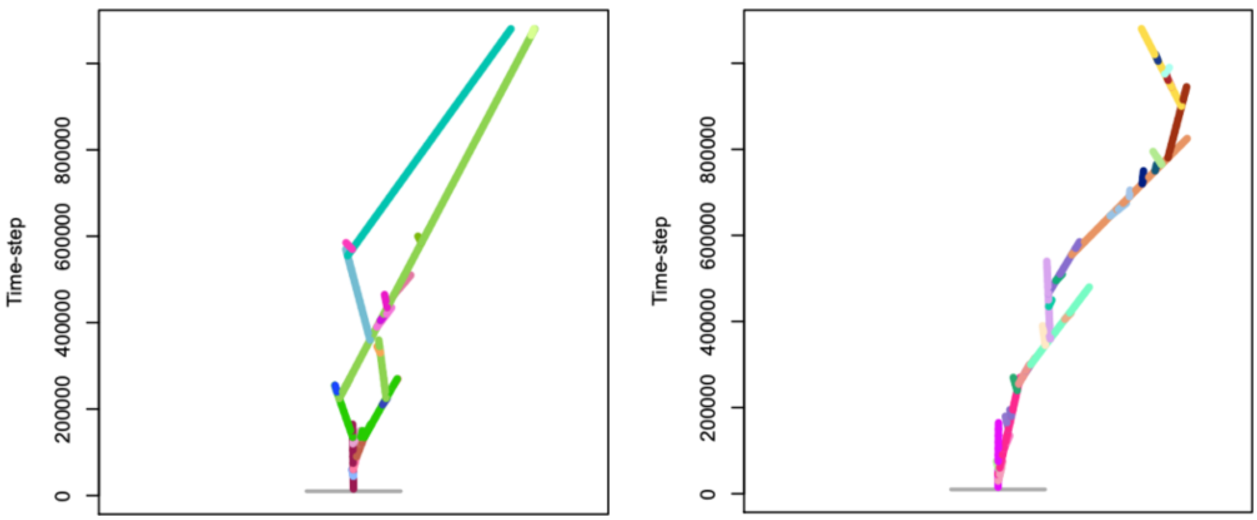
With all of our suggestions and hypotheses above, we can begin to tweak certain parameters in the pool (like adding more than one type of foodbit), but how do we actually end up testing whether these tweaks lead to successful coexistence? For that we bring in a new tool designed specifically for conducting experiments with Gene Pool.

Gene Pool Laboratory

We are now developing an app called Gene Pool Laboratory as an online platform that provides the tools for evaluating the ecological and evolutionary results of Gene Pool simulations—much in the same way an ecological or molecular genetics laboratory would have the tools for extracting and visualizing patterns in DNA, diversity, and coexistence! Much of this app is still under development but we look forward to sharing updates as we progress.

For now, we've been able to extract the evolutionary trees of swimbot species. Evolutionary trees—also called phylogenetic trees—represent the evolution and relatedness of species in one simple diagram. Each straight branch segment represents one distinct species, and the branch that it connects to is its closest ancestor—the species that it evolved from. Where a branch ends, well, that's where a species goes extinct. Finally, as you move up from the base of the tree, time progresses, such that the species that evolved most recently are at the top, and the oldest ancestor from which everything else evolved is at the very bottom. But how does this connect to coexistence? The cool part is that if you were to pick any point in time along the evolution of the tree and draw a horizontal line, the total number of tree branches (species) that the horizontal line crosses is a direct measure of the number of species that are all coexisting at that point in time! The more time that you can have multiple lineages of surviving species, the stronger the coexistence.

For now the branches of our trees tend to cross each other, making the trees look a bit funky (hope to fix that soon), but check out the figure below and see if you can tell which of these two trees is the result of evolution where swimbots have two different types of food to choose from. (Hint: two different foodbit niches should allow two different species to coexist while evolving through time.)



Conclusion

We have only briefly touched upon the basic points of Chesson's framework of co-existence, and provided an impressionistic overview of the various ways we have begun making adjustments to the Gene Pool simulation, to test these ideas. Gene Pool Laboratory will give us an increasing number of dimensions for visualizing and perhaps even statistically testing the relevance of these evolutionary experiments—perhaps the first empirical test of Chesson's framework in the context of artificial life. In the process, we are adding some new dimensions to the simulation that will open it up to new possibilities.

And so begins our quest to increase the co-existence and diversity of swimbot *species.* Our motivation comes from more than just scientific curiosity: we share a deep love for the aesthetic beauty of biodiversity, and a desire to show its importance for the health of the planet, and the human species.

References

Chesson, P., 2000. Mechanisms of maintenance of species diversity. Annu. Rev. Ecol. Syst. 31:343–366.