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GenePool: Exploring The Interaction Between Natural Selection and Sexual Selection

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Gene Pool is an artificial life simulation designed to bring some basic principles of evolution to light in an entertaining and instructive way. Most significant is the aspect of sexual selection — where mate choice is a factor in the evolution of morphology and motor-control in physically-based animated organisms. We see in the examples of deer antlers, peacock tails, and fish coloration a magnificent world of variation that makes the study of animals fascinating for us — aesthetically — driven humans that we are. But aesthetics is in the eye of the beholder. And sometimes aesthetics can run counter to the rules of basic survival. Gene Pool was designed to explore this topic.

1.0.1 History

In 1996, an animated artificial life simulation, called Darwin Pond, was designed, and a paper was published describing the simulation [13]. In Darwin Pond, hundreds of physically-based organisms achieve locomotion via genetically-based motor control and morphology. The ability to have more offspring is a direct outcome of two factors: 1) better ability to swim to within a critical distance to a chosen mate, and 2), the ability to attract other organisms who want to mate.

Because Darwin Pond was developed at a computer game company (Rocket Science Games, Inc.) it included a significant interactive component. Rocket Science did not survive as a company, and after much effort, Darwin Pond was released from the corporate and legal complexities of the software games world, and it was published for free at, where it has remained.

Gene Pool was developed as a derivation of Darwin Pond. Although it has fewer interactive aspects, it extends Darwin Pond in terms of the simulation by emphasizing the effects of sexual selection on morphology and behavior. The term “swimbot” was chosen to describe the organisms in GenePool, because of their robot-like mechanical appearance and the fact that they evolve into virtual swimming machines. A subsequent paper [14] discusses this work.

1.1 Background

Chaos theory and Fractals popularized the notion that the complexity we appreciate in nature can often be described with a small number of parameters or rules. The key is iteration — the repeated application of those rules over time. The Genetic Algorithm (GA) [4, 5] mimics an aspect of nature's way through the iterative application of the principles of Darwinism over many populations. The GA has been used for generating adaptive behavior in simulated organisms, such as locomotion [7, 10, 12]. These explorations have shown how artificial evolution can be used to solve certain design problems which are too complex or multi-dimensional for humans to solve. Animal locomotion is an appropriate problem for this technique — it came about through evolution after all.

1.1.1 Dawkins' Call

The classic GA however does not model the asynchronous nature of population evolution. This limitation is what motivated further exploration into building a more realistic Darwinian model for evolving locomotion. Richard Dawkins had expressed a wish for more naturalistic models in artificial life [2], whereby the dynamics of genetic evolution are not constrained to the lock-step generation updating used in the classic GA, but rather, are asynchronous and autonomous, and where the definition of "fitness" is not arbitrary. Darwin Pond was an attempt to answer this call.

1.1.2 Physics, in Various Forms

Many artificial life simulations explore the adaptation of organisms or populations within an environment — which can be quite abstract. These simulations are less concerned with the accuracy and verisimilitude of physical modeling as with the nature of the organisms' adaptation that takes place within, and in accordance with, the environment. Tierra [8] is a compelling and lifelike artificial life simulation which has no physics — at least not in the Newtonian sense. In contrast, Sims' Blockies [10] uses a sophisticated 3D physical model — but here again, the main emphasis is the way in which the population adapts to accomplish a goal — and in this case the realism of the physical environment allows their adaptive solutions to be appropriately complex, as well as familiar to our own goal-oriented behaviors.

Gene Pool uses an abbreviated physical model, implemented in 2D. This simplification of mechanics is meant to strike a balance between having realistic enough physics to allow sufficient complexity of morphology and motor control, yet at the same time being computationally lean so it can animate hundreds of organisms in real-time on average desktop computers, and thus allow detailed visualization and interaction.

1.1.3 Sexual Selection

Autonomous mating naturally brings us to the question of mate choice, which is what Gene Pool addresses. Could a simulation be built which demonstrates the effects of sexual selection which run counter to the need for energy efficient locomotion? In other words, can a simulation show an inherent conflict between the forces of natural selection and the forces of sexual selection? If so, what similarities to the natural world might emerge? Gene Pool implements a number of possible “attractiveness criteria” allowing interactive exploration of sexual selection forces on the evolution of swimbots. Thus, the primary scientific inquiry that Gene Pool hopes to shed light on is the interactions between natural selection and sexual selection, especially in regards to energy-efficiency.

1.2 Description of the Software

Gene Pool is modeled as a continuous two-dimensional square area constrained by four boundaries. These boundaries do not wrap — as in a torus topology. Gene Pool uses simulation time rather than clock time. Time cannot be run backwards due to the nature of the forward dynamics affecting the positions and orientations of the swimbots. Within this continuous field are two kinds of entities: swimbots and food bits.

1.2.1 Initialization

At the start of a simulation run, 200 swimbots are initialized with random gene values (these genes are explained below). They are accompanied by a number of food bits, which serve as packets of energy for swimbots to consume. The total energy in the environment is stored in swimbots and food bits (the number of food bits being typically over 1000, depending on the total energy setting.) Both swimbots and food bits are distributed randomly in a disk region, as shown in Figure 1.1.

This disk region allows sufficient density of swimbots and food bits to give the few slightly more fit swimbots a chance to get to food and or mates before running out of energy, thus giving evolution a jump-start. Sometimes, as luck would have it, all the swimbots die off after a while. But in most cases, small clusters of swimbots appear in a few locations in the disk region — groups of genetically-related swimbots, or “gene pools” — and eventually one gene pool takes over the whole environment.

Figure 1.2 shows a close-up view of a group of swimbots to show variation in an un-evolved population. Food bits can be seen scattered around.

1.2.2 Food Bit Behavior

Food bits replicate by periodically sending imaginary spores out which appear nearby. Thus, the food bits occupying the initial disk region begin to spread, as swimbots consume them.

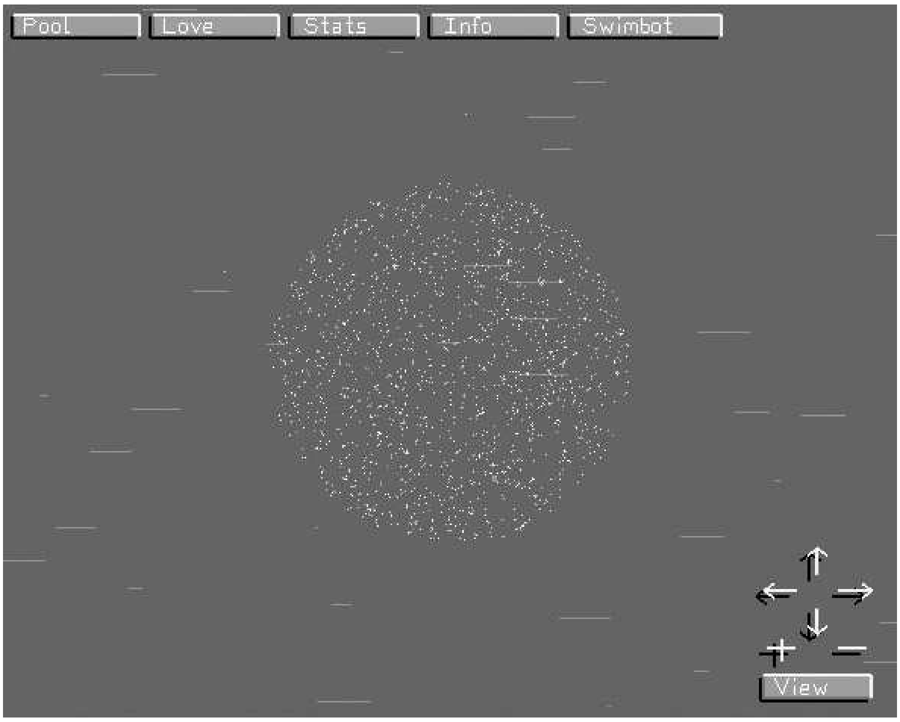

Figure 1.1. Initial distribution of 200 swimbots and food bits.

1.2.3 Swimbots

Swimbots are made of parts, ranging in number from 2 to 10. Parts are rigidly connected from end-to-end, and rotate off each other in pendulum fashion, using sine functions. Parts come in six colors (red, orange, yellow, green, blue, and violet). Figure 1.3 shows a swimbot which has six parts.

Genes for morphology determine the length, thickness, color, and “resting angle” of each part. (The resting angle of a part is relative to the angle of the part to which it is attached). Genes for motor control determine the phases and amplitudes of the sine functions, per part. Figure 1.4 shows how three unique sine waves, determined by six genes, combine to create a unique periodic swimming motion in the whole body.

Frequency of sine-wave motions is constant among all the parts, but can vary among swimbots according to another gene.

Within the simulation environment, swimbots have position and orientation, translational velocity, and rotational velocity. They can transform their positions and orientations autonomously by way of the articulated motions of their parts. When a part moves perpendicular to its axis, it has a greater effect on swimbot position and orientation than if the part moves parallel to its axis. Compare to a canoe paddle: setting the paddle in the water with its plane perpendicular to its motion forces the

Figure 1.2. Swimbots

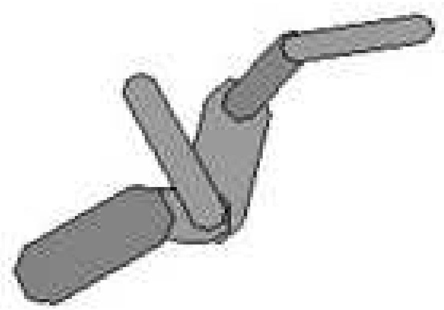

Figure 1.3. An example swimbot with 6 parts

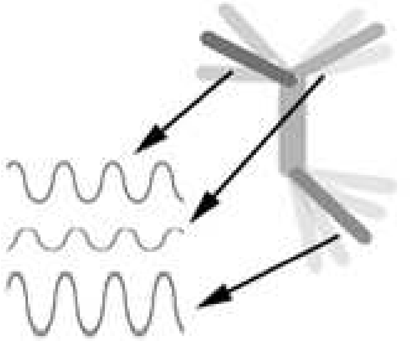

Figure 1.4. A schematic showing variations in amplitude and phase among body part angular motions.

paddler (and thus the canoe) in the opposite direction of the sweep. Thrusting the paddle in the water in the direction of its axis has little effect.

1.2.4 Locomotion Is Required for Mating

With as many as 10 body parts, each having many possible lengths and widths, attached in many possible ways, and rotating back and forth with various possible phases and amplitudes, the phenotype space is very large. The majority of swimbots at the beginning of a simulation are bound to be poor swimmers, and never reach their destinations of food bits or mates before dying. Those few who are lucky enough to be initialized with genes allowing their motions to propel them in the direction of their goal are the ones who will be able to mate, and thereby pass on their more fit genetic building blocks into the future.

1.2.5 Special Body Parts

Swimbots have no heads, torsos, or explicitly-defined limbs with special functions. There is one special exception to this rule: there is one part (the root part) which has a genital at one end and a mouth at the other end. These two locations correspond to the two goals in a swimbot's life, and are used in computing the distance from the genitals of potential mates, and food bits, respectively.

Mouths and genitals are visualized using a vector attached to these locations, and aimed in the direction of the swimbot's goal. When a swimbot is pursuing food, the mouth vector is shown and a green dot appears at the end of it. When the swimbot is pursuing a mate, the genital vector is shown and a white dot appears at the end of it. The length of these vectors is important for the detection of swimbots coming to within proximity of a goal — it visualizes the radius of critical contact. Figure 1.5 shows a circle and a white line superimposed on a swimbot pursuing a food bit to emphasize the mouth vector and to indicate the radius.

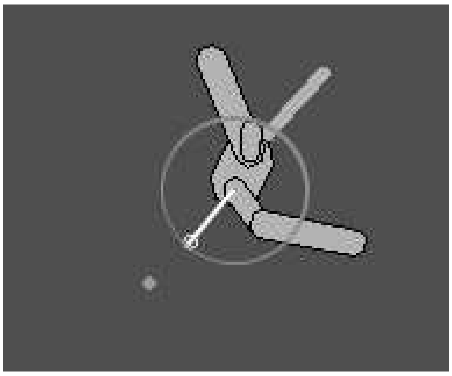

Figure 1.5. The mouth vector and a circle showing the critical distance for eating a food bit.

1.2.6 Swimbot Mental States

Swimbots have four continuous mental states: 1) looking for a mate, 2) pursuing a chosen mate, 3) looking for a food bit, and 4) pursuing a chosen food bit, as illustrated in Figure 1.6. The acts of eating and mating are brief — they are instantaneous states.

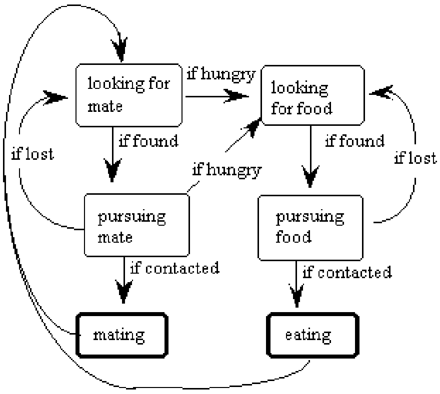

Figure 1.6. Swimbot mental states

1.2.7 Energy Flow

Energy is stored in three locations, (1) in swimbots, (2) in food bits, and (3) in the ambient fluid of the pool as a whole. New food bits take energy from the pool and appear randomly in the Pool within the vicinity of other food bits. Swimbots get their energy from these food bits. Swimbots expend energy by moving their parts — that energy is dissipated back into the pool (Fig. 1.7).

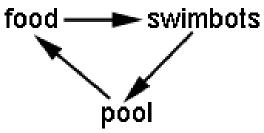

Figure 1.7. Energy flow in GenePool.

"Efficient" swimmers expend less energy while covering larger distances and more rapidly converging on a goal. These swimbots spend more time pursuing mates and less time pursuing food. When a swimbot's energy dips below a specific threshold (the hunger level), the swimbot becomes hungry and looks for a food bit to pursue. If the swimbot's energy reaches zero, it dies. If a swimbot has succeeded in reaching a food bit, that swimbot's energy goes up — if its energy level is high enough (above energy threshold), it begins to look for a mate. A successful mating which produces an offspring causes the energy level of each parent swimbot to decrease by 50% — that energy is given to the offspring.

1.2.8 Turning

Each swimbot has an innate orientation, or heading, determined by the axis of its main body part. While pursuing a goal, the direction from the swimbot to its goal is compared to its orientation at every step, as illustrated in Figure 1.8.

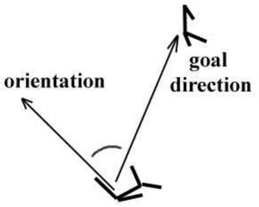

Figure 1.8. Swimbot orientation compared to goal direction modifies genetically-determined turning mechanisms.

The size and sign of the resulting angle is used to modify the phases and amplitudes of all the part motions. Genetic factors determine the amounts that these phases and amplitudes are modified, per part. No explicit definition of turning is provided — the solutions are those of a blind watchmaker. Turning solutions are among the more complex emergent behaviors in swimbots, and are difficult to describe objectively.

1.2.9 Perceiving and Choosing Mates

When a swimbot's mental state switches to looking for a mate, it scans all the swimbots within a specific radius (its "view horizon") at one instant, with a "snapshot".

It then chooses the one which most satisfied the attractiveness criterion (see the list of attractiveness criteria below). Each attractiveness criterion has an associated algorithm which is used to measure a particular phenotypic feature in the body of each swimbot scanned. The swimbot with the greatest value is the one chosen. This design was meant to enable the phenomenon of runaway sexual selection, whereby the population will try to maximize its attractiveness, even if at the expense of overall efficiency.

As an example, if the attractiveness criterion is “big”, then to determine attractiveness in a potential mate, the areas of all its parts are added up to determine the total body area. This is one of the more straightforward algorithms. Attractiveness criteria having to do with motion and body pose (such as “hyper”, or “straight”) are more involved — they refer to the instantaneous velocities of the parts, or to the pose the body happens to be in during the snapshot. Presumably, a swimbot may appear uncharacteristically attractive during the snapshot only because of the particular configuration or motions of its body parts at that time. But these misinterpretations of attractiveness would be rare and small, due to the fact that many swimbots are evaluated per snapshot — the attractiveness gradient is fairly robust, especially over evolutionary time.

1.2.10 Pseudo-FlatLand

Although swimbots occupy a 2D plane, perception is not modeled as occurring in this imaginary space, as in the entities of Flatland [1]. This kind of visual modeling would be ambiguous at any rate. Instead, swimbots are assumed to have the ability to perceive the body structures of other swimbots as if looking down upon the picture-plane. This is admittedly an abstraction. A true 3D simulation would allow more realistic visual modeling and consequently more interesting emergent behaviors in terms of range of mate selection criteria. But for the purposes of the basic experiment in Gene Pool, this is sufficient.

1.2.11 Mating and Birth

When two swimbots mate (i.e., at least one of them is pursuing the other, and the distance between their genitals is less than the length of the genital vector) one offspring appears in-between them, which inherits genetic building blocks from both parents. A standard genetic-algorithm crossover technique is used, and some random mutation occurs in random genes.

1.3 Usage

Although the animated computer graphics aspect of Gene Pool is not critical to the simulation, it is always running, so that the user can explore various aspects of the simulation at any time. Overlaid on top of the animated simulation view are various menu options. These include:

1.3.1 Pool Menu

The Pool menu allows the user to save and load pool files, or start a new “Primordial Pool” from scratch.

1.3.2 Love Menu

The Love menu allows the user to set the attractiveness criteria. For instance, if the user sets the attractiveness criteria to “ong”, then from that point forth all swimbots will tend to choose swimbots as mates which have longer bodies (at the point in time in which the swimbot scans for attractive swimbots). There are ten attractiveness criteria: five primary attributes, each with an opposing attribute, as shown:

Similar Color	Opposite Color
Big	Small
Hyper	Still
Long	Short
Straight	Crooked

1.3.3 Stats Menu

The Stats menu brings up a graph which shows food population vs. swimbot population in a time series graph. In mature populations, familiar oscillations of predator/prey populations can be observed.

1.3.4 Info Menu

This is the help page for Gene Pool.

1.3.5 Affecting Views

An important aspect of Gene Pool is the Microscope, a tool for controlling the view, as seen in Figure 1 at the lower-right. The microscope has left, right, up, and down translation controls, and zoom in/out. In addition to this, it has the following special settings:

- Whole Pool: The microscope backs up to view the entire pool.
- Auto-tracking: In auto-tracking mode, the view shifts around according to the positions of swimbots, so as to always keep some kind of activity in view.
- View Selected Swimbot: When the user selects a swimbot with the mouse cursor, that swimbot becomes the selected swimbot. This microscope setting keeps the selected swimbot within view at all times.

1.3.6 Ways to Use Gene Pool

Gene Pool can be used in three ways:

1. As Reference Material for Continuing Artificial Life Research: Some references of Gene Pool in artificial life research include [9].
2. As a Children's Software Toy: GenePool/Darwin Pond can captivate youngsters. Children have been observed exploring and manipulating swimbots from many minutes to nearly an hour. This is an indication that young children have an opportunity to catch a glimpse of the complex world of evolutionary dynamics, while at the same time having some fun. An ultimate goal in developing entertaining artificial life simulations is that it will help prepare children's minds for the kinds of environmental, ecological, and social problems we face today — understanding complex dynamical systems is important to the future stewards of the earth.
3. As an Introduction to Evolution for Science Students: A handful of high school and college teachers have expressed interest in GenePool and Darwin Pond as tools for learning about evolution, and have included them in their courses.

1.3.7 A Sample User Session

This is what is recommended as a suggested user session, in the INFO page of GenePool:

How to use Gene Pool:

1. Start up a primordial pool from the 'Pool' menu
2. Select the attractiveness criterion from the 'Love' menu
3. Explore mate choice behavior by using the microscope (controls at lower right)
4. Go away
5. Come back after a while and notice what has evolved.
6. If you like what you see, save the pool in one of four files, as specified in the 'Pool' menu

1.3.8 Mini-Dramas

While global dynamics are going on, one can witness on local scales events such as two swimbots racing to reach a common food bit, a swimbot dying from starvation, or a swimbot chasing another swimbot it has chosen as a mate, who is chasing yet another swimbot that it has chosen as a mate. Emergent behavior occurs on the local scale as well as the global scale. One can choose among the following Mini-Dramas:

- Most Loved: shows the swimbot who has produced the most offspring (as pursued)
- Best at Mating: shows the swimbot who has produced the most offspring (as pursuer)
- Biggest Eater: shows swimbot who has eaten the most food bits

- Mutual Love: shows two swimbots pursuing each other as mates (if found)
- Love Triangle: shows three swimbots in a circular loop of mate pursuit (if found)
- Competition for food: shows group of swimbots pursuing a common food bit (if found)

1.3.9 Anthropomorphizing

A special setting of the simulation can be run in which all the swimbots are initialized with genes for morphology set to roughly resemble human forms. Motor control, however, is randomized, to allow differential swimming ability at the start of the simulation. Watching these anthropomorphized figures struggle to swim can be amusing, as we project our own bodies onto them. Figure 1.9 shows a screenshot of two such swimbots immediately after they have mated (offspring appear small and white between the parents and grow to full size within a few seconds). Both swimbots are pursuing the food bit at top-right.

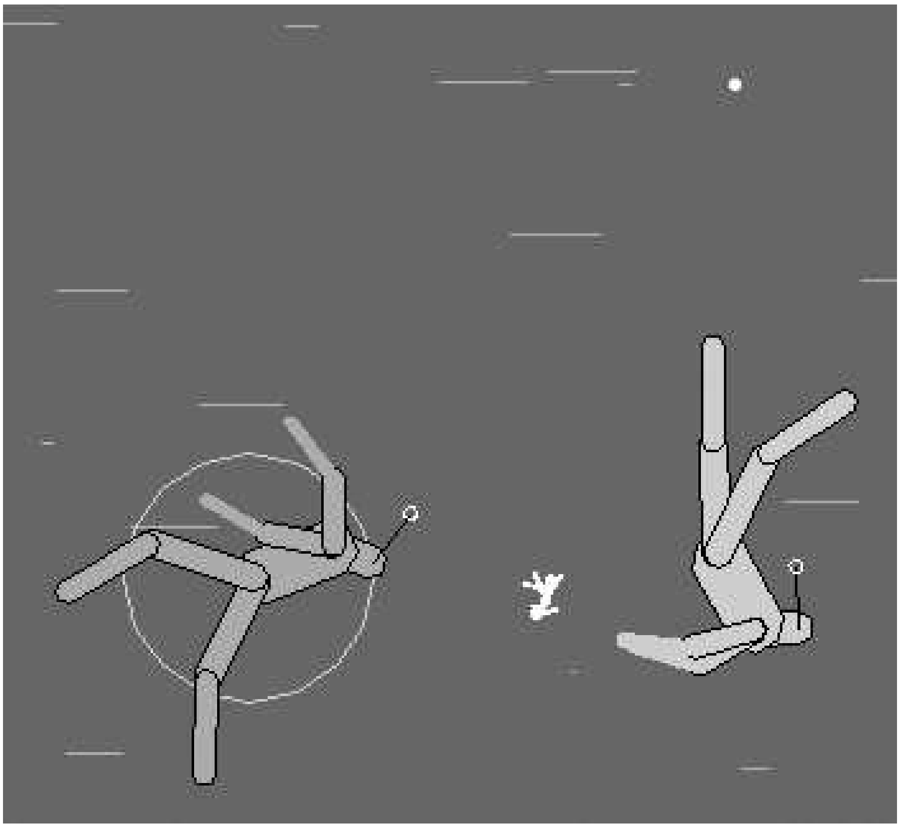

Figure 1.9. Swimbots with morphological genes initialized to resemble a human-like figure.

These human-like forms generally do not persist over evolutionary time, usually giving way to simpler body-types. Often, the vestiges of a human-like ancestor can be detected.

1.4 Discoveries

1.4.1 Sexual Dimorphism?

In specific simulation runs, an attraction criterion was chosen which was intentionally in conflict with normal pressures for efficient swimming: attraction was set to "still" (i.e., swimbots exhibiting the least amount of motion become the most attractive). The prediction was that this would cause mass extinction. But many populations actually thrived, converging on a distinct bifurcation among body types, with the majority being small and nearly motionless, and a small minority being similar with the exception of having whip-like tails enabling them to swim rapidly. These rapid swimbots (the "breeders") are largely responsible for propagating the genes throughout the population, while the majority of swimbots simply lie around being attractive (the "sitters"). The breeders expend more energy and eat more food bits, while the sitters eat very little and expend very little energy.

A number of simulation runs with the same attractiveness criterion have converged on similar results. Figure 1.10 shows one of the breeders (top-center) among some sitters.

An hypothesis is as follows: these populations had discovered a way to take advantage of a mutation at a specific locus of the genotype which accounts for this phenotypic difference — possibly a few genes are involved. This bifurcation of the phenotype may be an expression of the inherent conflict between swimming efficiency and attractiveness, which, in this case, are at odds. Natural selection pressures exploit this mutation for the sake of propagation, while sexual selection keeps the majority of the population in a generally stable state of motionlessness.

1.4.2 Celebrating Diversity

One of the attractiveness criteria is "similar color". When this is turned on, swimbots will choose mates whose bodies contain the closest spectrum of colors to their own. One experiment was to encourage interracial mating by adding a new attractiveness criterion called "opposite color" — as shown above. Not surprisingly, when this is turned on, the population converges on a perpetual state of psychedelic diversity.

1.5 Future Development

Three main enhancements to Gene pool are planned:

Figure 1.10. A “breeder” (top-center) among a majority of “sitters”.

1.5.1 Recursive Embryology

The current mapping of genotype to phenotype is without structure in terms of topological arrangement of parts, part proportions, and motor control among parts. Thus, there is no innate tendency towards segmentation, symmetry, or regular limb-branching. This was intentional in the original scheme, so as to remove any bias and to focus only on emergent behaviors. But this lack of structure may inhibit certain creative solutions. In the works is a new recursive scheme for embryology such that fewer genes are required to determine morphology and motor control, and forms of symmetry and segmentation can emerge.

1.5.2 Parental Investment and Gender

The sexual dimorphism-like behavior described above suggests further exploration. Females typically invest more energy and/or time towards birthing and raising offspring, most specifically in terms of investment in gametes. Without specifying gender difference explicitly, new attributes could be added to the swimbot genotype/phenotype causing them to have differences in parental investment (i.e., fraction of energy given to offspring in the event of mating — currently it is set to 50% per parent — an arbitrary ratio indeed). This gene might evolve in correlation with emergent behaviors such as rate of energy burn, attractiveness, and perhaps other, unforeseen behaviors.

1.5.3 Environmental Variation

One reason GenePool converges so quickly is that the environment is simple and undifferentiated. Having the food bits move according to fluid flows, or according to their own evolvable traits would make for a more dynamic fitness landscape. Also, more complex barriers to genetic flow would help (besides the “Great Wall” tool — a line the user can place as a barrier to encourage localized isolated gene populations).

1.6 Similar Simulations

A number of alife software simulations share common features with Gene Pool:

- Framsticks [3]: far exceeds Gene Pool in functionality and physical simulation, including features for many variations of 3D simulation and user-manipulation. Like GenePool, Framsticks creatures consist of jointed body parts which rotate against each other.
- SodaPlay [11]: demonstrates great variety of form and motion using 2D graphics, in an entertaining format. SodaPlay uses a more “molecular” style of physics modeling, base on spring forces, to affect the positions and orientations of potentially-large-scale spring structures having semi-coherent positions and orientations.
- LifeDrop [6]: shows intriguing biomorphs breeding in an ethereal setting, with ways to interactively change the view. Like Gene Pool, LifeDrop shows multiple biomorphs interacting at once.

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