

Species in Morphogenesis: Introducing Symbiogenesis as an Additional Method for the Evolutionary Process of an Artwork

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Abstract

This paper demonstrates the introduction of a symbiogenesis inspired technique as an additional method for the evolutionary process into an adaptive multi-agent system called Morphogenesis. It was created in 2012 to represent the life process as an artwork, allowing the experience of what escapes our perception scale: The evolutionary process. To do so, Morphogenesis uses genetic algorithms to create visual abstract compositions with emergent artificial intelligence. It generates agents with locomotion, feeding, confrontation and reproduction behaviors, as well as more social ones, such as collaboration or submission. All of these behaviors are programmed into the agents' level and, from its interactions, collective patterns emerge. The collective interactions influence individual adaptation and maintenance over time, simulating natural selection. Nevertheless, as the previous versions of the system were based on the small-step mutation of the evolutionary process, the system's ecology tend to adapt with big colonies, making the aesthetic experience less diverse to the public. In this paper, we compare the results of the original system with a new one using symbiogenesis as the inspiration for an evolutionary leap. The symbiogenesis technique allowed the system to create different dynamics and diverse representations in its probabilistic arrangements, simulating the diversity of natural life inside its restricted environment.

Introduction

Morphogenesis is an evolutionary generative system first developed in 2012 (Pontes e Silva, 2019). It was presented at a collective exhibition in Museu Nacional da República in Brasília, Brazil in 2012 and 2013. Since then, it has been examined and modified by the authors for research purposes in the field of Evolutionary Art. The title was a tribute to the mathematician Alan Turing called The Chemical Basis of Morphogenesis, where Turing presents a study about emergence, showing how complex patterns can arise following simple rules, such as the latent potential in a seed to generate a flower. Nonetheless, the link between the system and its title is only inspirational, related by the expected emergence of the visual and acoustic arrangements originated from simple patterns. Therefore, the artwork Morphogenesis does not use the original mathematics suggested by Turing. Instead, it uses genetic algorithms to perform the selection of computational agents with a simple geometric representation, creating collective behaviors and more organic compositions.

It is a cellular automaton based on the Conway's Game of Life (Gardner, 1970), and artworks such as *Second Nature* of Miguel Chevalier, Biomorphs from Dawkins (1986), and Tierra from Thomas Ray (1994). The agents have a tendency towards the Brownian movement, and this becomes the core engine of the system. Depending on the agents' perception of the environment, a set of intentions is calculated, altering their displacement probability. These characteristics are transmitted to every descendant by a recombined DNA obtained from both parents, been also susceptible to mutation processes. It was developed with the graphical library Processing¹.

The geometric shapes that constitute the visual abstractions get their inspirations from paintings such as *Circles in a Circle* and *Several Circles* by Kandinsky, *Cat Encircled by the Flight of a Bird*, by Joan Miró, and *Kinetic objects*, by Palatnik. Following both ideas: Abstraction as a composing visual method and autonomous agents as individuals in Artificial Live, Morphogenesis is an authorial creative code that is not based on a specific swarm behavior algorithm. Instead, different functions were developed for the agents' behaviors by a balancing process of adjustment. This procedure is considered relevant due to the probabilistic nature of the system since its individuals are in constant mediation with the environment. Using a precise swarm intelligent algorithm or a pre-defined fitness function could have reduced the performance to a specific goal, decreasing the desired emergence level for the system.

The system was first created seeking for an answer to the questions pointed out by Galanter (2003; 2009; 2010) about the difference between the level of complexity existing in nature and the lack of it in the computational systems created by artists in general. For more information about the previous versions of the system and its relation to the concept of Effective Complexity, see Pontes e Silva (2019).

Aesthetics of Abstraction

Abstraction in Visual Arts represents a style where the elements of the composition are worth by themselves, independently of the narrative. In this sense, painting and its formal elements are presented as an autonomous reality opposed from the world perceived and constructed by the

1 Processing Foundation (<https://www.processing.org/>)

artist in a naturalistic or representational way. It was Wassily Kandinsky (1979) who contributed to the theorization of the abstract style in painting when describing the characteristics of the compositional elements on the surface: The point, which is the union between silence and words, found its practical utilitarian function in the finalization of the written sentence. However, when removed from this context and placed freely on the surface, the point becomes an autonomous being. The inner concept of the point is concise and permanent, the primary element of painting. Following this thought, a line also has autonomy, since it moves a point in a given direction. Thus, all the elements derive from the dynamics of line and point in a surface and have its autonomous relations with it. These relations are conditioned to the visual characteristics of dimension, height, depth and light of the element and its positioning in the surface.

Colors do not derive from the point because it is not shape but sensation. Color autonomy derives from its luminous potential, and each range influences the sensitivity of the surface differently. Just like the shape, the occupied dimension and its relationship with the other colors determines the dynamics of movement in the composition.

These ideas influenced the creation of the Morphogenesis. The agents' shapes and colors (and sounds) are related to their phenotype because of genetic information, but their interactions are also perceived as expanded forms, creating compositions. Hence, its arrangements, organic lines, geometric shapes, colors, and sounds are molded by evolution, suggesting narratives about the living individuals in a poetic about life as a collective process. As a result, dynamic ephemeral compositions are created, resembling images from a fictional microscopic universe. Although based on simple constructions, they express organic outputs that can refer to the desired aesthetic experience. In this sense, we express the desire to explore the tension between science, technology, and the field of art, acting in an overlap between aesthetics and the experimentation of biologic evolution, approaching a simulation of the improbable as a poetic.

Symbiogenesis and the Evolutionary Process

In the symbiogenesis approach, evolution occurs with the establishment of mutual interaction involving physical association between individuals of different species. According to Margulis and Sagan (Margulis, 1999; Margulis and Sagan, 2003; Huxley, 1942), several evolving strains had their origins in symbiogenesis, which is the combination of different genomes that form a symbiotic consortium as a single entity. Because symbiogenesis usually creates stability in the consortium, it differs from other types of interactions such as parasitism. According to the authors, the acquisition of an entire genome might conflict with the principle of gradual evolution as suggested by the modern synthesis. Also, the authors suggest that specification began only with the earliest eukaryotes. They emphasize that

“the popular evolutionist’s view that organisms evolve by the accumulation of random mutation best describes evolutionary processes in bacteria. All larger, more familiar organisms originated by symbiont integration that led to permanent associations.” (Margulis, 1999 p.6)

For example, plant cells have integrated four entire complete genomes: the motile eubacterium, the protein-synthesizing archaeobacterium, the oxygen-respiring proteobacterium and cyanobacterium. Another classic example are the lichens, that are not individual organisms, but intimate associations of two radically different life forms: An alga and a fungus.

Symbiogenesis does not deny the existence of mutations, but the authors suggest that no induced mutations are known to lead to new organisms (Margulis, 1999, p.11) and 99.9% of mutations are deleterious. Even the fusion in symbiogenesis is not random, as the relationship occurs under specific environmental conditions. In this view of evolution, natural selection remains the relentless force which

“eliminates beings whose form, physiology, behavior, and chemistry are not suited for that given environment at that given time and place (whatever the details).” (Margulis, 1999, p.6).

Because of that, natural selection biotic potential is seldom reached, and most life does not persist through time. In this paper we describe how this idea of acquiring a genome with permanent associations was added to the evolutive system Morphogenesis, and what are the comparative aesthetic results against the old version where mutation was the only source of genetic change through time.

Related Work

Lenia by Bert Wang-Chak Chan (2020) is a Cellular Automata that, like Morphogenesis, produces self-organizing autonomous patterns. According to the artist, Lenia in its Extended Universe presents growth by ingestion and saw the emergence of individuals named as virtual eukaryotes. In Lenia it is described that those complex individuals possess an internal division of labor and type differentiation. This description can be directly related to symbiogenesis, as the author also describes aesthetic options from early studies of Margulis (Margulis, 1999) when she used to sign as Sagan in 1967. In Lenia, new individuals happen by Crossing, Mutation and Symbiogenesis, and other principles such as Contraction, Fission, Deflection, Conversion, and something described as a Complex Reaction in which many individuals are somehow converted into different forms. Also, Lenia uses self-replication as a way of creating new individuals.

As previously mentioned, Morphogenesis adopts Brownian Motion as a visual locomotion principle. There are several attempts to illustrate this movement that can be seen in the works of Deshmukh, Saudagar and Khan (Anwar et al. 2010), Philip Joyce (Joyce, 2020), Pierre Brémaud (Brémaud, 2020) and Giovanni Zocchi (Zocchi, 2018) to name but a few. A related artwork can also be found in Pedro Miguel Cruz (Laboratório da Visualidade e Visualização, 2011). In the Morphogenesis system, the agents' intentionality occurs just by weighting the probabilities of displacement in the Brownian movement. From that, all the consequent actions are then defined. This differentiates the system from these other approaches, creating some agency for the individuals that can be latter transmitted to the next generations in order to represent the evolutionary process.

Morphogenesis' Evolutionary Approach

Genotype and Phenotype Characteristics

In Morphogenesis each agent has a genotype of 66 genes, organized in 33 pairs of variables that are considered together to determine the individual's phenotype. These characteristics are related to the aesthetics of abstraction, used in the system as representatives of the fundamentals of visual language. Therefore, the individual starts from a basic line created by an initial sequence from 4 to 8 points with Bezier curves. The agents start from this act of "scribble on a paper" to create their uniqueness, like a handmade signature that tends to be maintained over time. Once the line is defined, its curves and points become the agent's body, and its movement on the canvas is conditioned to it. Their next visible phenotype are their heads, middle bodies, and tails, which are defined by a geometric shape that can have from 1 to 6 sides: a circle, small line, triangle, square, pentagram, or hexagram (Fig. 1).

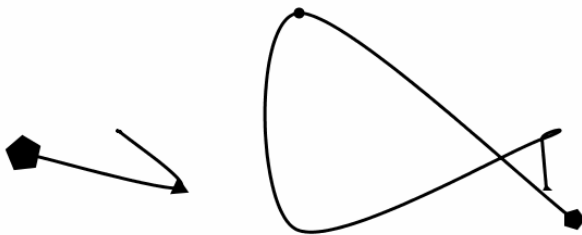


Figure 1: Two agents drawing structures with lines, heads, middle bodies, and tails, resembling their individuality.

Their apparent simplicity is intentional: They consist only of three abstract shapes connected by a line. This aesthetic choice was made to favor their collective behaviors over individual representations. The agents have other properties that are less striking in terms of drawing, but just as relevant to represent their aesthetics and individuality on the canvas. Some of these can be described as their movement capability, their easing - the accelerating relief between the internal points of their bodies, their line thickness, their colors, the potential for retraction of their geometric shapes and the instrument and note that define their individual sound. Those properties are randomly defined when agents are created in generation zero. From that generation on, all the following agents are created by mating with DNA recombination.

There is no ideal genotype condition for a fitness function in the system. Each agent spends energy on its own internal processes. When its value becomes zero, the agent dies, in a continuous process. This means that the system does not induce the selection of any specific genetic attribute. Otherwise, it fosters the combination of different genes for diverse phenotypic strategies, also being affected by chance.

Morphogenesis' Agency

Agents in Morphogenesis are guided by a group of intentions that influence their displacement on the canvas. They move around looking for food, protection and mates, also escaping from threats and repulsive situations. Within this process they

fight, group, breed and eventually die. They act as a behavior trend, as they are probabilistic. Also, this likelihood is defined by the agents' DNA in reaction to a situation in the environment, changing over time by the evolutionary process.

Fig. 2 presents an encounter of Agent A with two others (B and C). In this possible scenario, Agent A finds another agent, Agent B, which is alive. In this case, Agent A checks if Agent B belongs to the same species of itself. Species in Morphogenesis can be visually identified by the agent's head. In its standard configuration, agents consider themselves to be of the same species when their head has a shape with up to 1 side of difference (e.g., triangles and squares). In this scenery, Agent B belongs to a different species, and as a result, Agent A checks if Agent B is stronger than itself. Because Agent B is stronger and from another species, Agent A tries to escape. While escaping, Agent A encounters another agent, Agent C. It verifies if Agent C belongs to the same species, which in this case is affirmative. So, Agent A checks if Agent C is mature enough to mate and receives another affirmative answer. Therefore, Agent A goes in the Agent C direction.

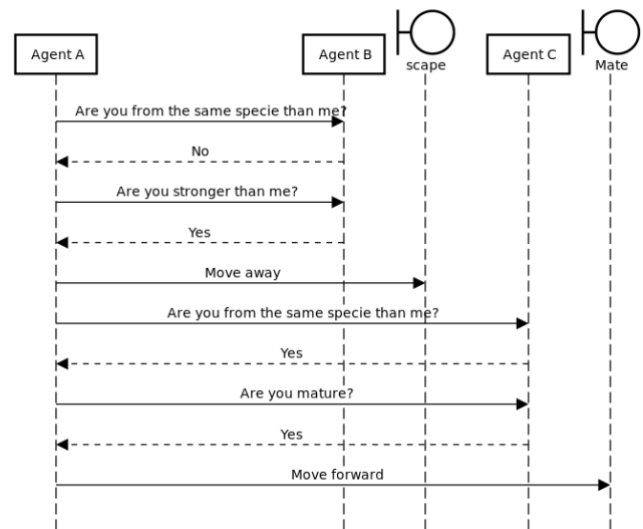


Figure 2: Sequence diagram where Agent A encounters agents B and C, fleeing the first and moving towards the second.

The environmental conditions can also change the fate of an Agent. For example, if an agent encounters a dead agent, its reaction will depend on if it belongs to the same species or not. In this case, if a dead agent is from a different species, it can become food for energy gain. But being from the same species will provoke an act of repulsion, making the agent to get as far away as possible.

Another mixing social and environmental condition is mating itself. In Morphogenesis, members of the same species mate if they are mature enough. Otherwise, they can just walk away. But if they consider themselves as part of the same community, they rather stay nearby each other. This happens when their tail shape is also compatible. In this case, they can be part of a group seeking for protection. Also, they start to consider the energy of the entire group for the fight decisions (should run or attack?). Those social premises can be regulated by the authors in runtime in order to study the possible outcomes.

It is when the geometric shapes of the agents' heads overlap that the situations of fight, eating or mating occur. Those consist of the moments of greatest action and tension in the system, as they are the determinants of disputes, feeding processes or the formation of new generations. When this happens, the shapes and colors flash on the screen, their sounds become more frequent, and the movements become quicker. These situations also have the more intense consequences, as in the fights, for example, where in a matter of seconds, an entire colony of agents that have been carefully engineered by the agents can be completely wiped out.

Sexual Crossings and Mutation

When two mature creatures from the same species touch each other (see Fig. 3a), the mating process is started. This process is divided into two stages, the copulation and the birth of a descendant. During the copulation stage, there is a visual representation of the relationship between the creatures. The geometric shapes of the agents' heads and tails come together, and they start to perform an accelerated movement and pace. To facilitate visual identification of this significant moment of the agents, a circle with the quadruple of the diameter of their heads is drawn at their first point (head), and their geometric shapes rotate faster (see Fig. 3b). The size of its geometric shapes also tends to grow gradually in this situation, increasing the chance of becoming more exposed to others over time (see Fig. 3c).

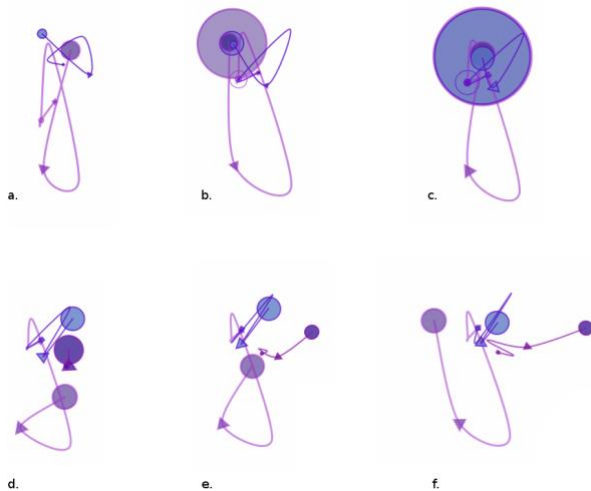


Figure 3: Mating in Morphogenesis. In the picture (a) represents two agents of the same species, (b) and (c) the moment of copulation, (d) (e) and (f) shows the newborn agent with mixed attributes from its parents.

During the crossing, depending on the speed of each individual and the rest of the interactions with other beings, they can "disengage", with a high probability of coming together again. All visual effects, such as shapes, geometries, speeds, angles of rotation, as well as the effects on the behavior, such as maturity or energy spent, are applied on both agents at the same time. Still, several individuals can try to participate in the same coitus, but new individuals are created based only on the two who succeed.

On the second stage, the new creature is born. It arises in the middle of its parents (see Fig. 3d, e, f). All the newborn attributes, as line curvature, colors and sounds are determined by the parents' DNA. For that, just one gene from each pair is transmitted from the parents to the new agent. It is a relevant feature because, even when stored as a continuous variable in the DNA, the original value of one pair must be transmitted. This allows some asymmetry in the pair registration, which sustain the genetic variability within the system over time. If instead the system just transmitted the total value of the pair, genetic variability would be lost, as a sequence of average calculations with central tendency.

However, there is a central issue related to how the geometric shapes of the parents are considered in the construction of the children's bodies. Unlike the other attributes, there must be a 50% chance that the child's shape will be that of each pair. In these cases, the phenotype of the creatures does not result from the two values of the DNA pair, but only from one of them, as a dominant gene. In the initial moments of the system's execution, this characteristic does not have an apparent effect. But, over time, 'non-active' genes that suffer mutations can be determinants of the characteristics of their children, despite not visible at the parents' bodies.

In this evolutionary approach, that corresponds to the old version of the system, the authors have adopted mutation as the most important phenomenon of flexibility, differentiation, and evolution, aimed to expand the population variability, sustained by the DNA recombination process. The mutation allows small variations, which in many generations results in specification. Evolution occurs cumulatively, promoting major transformations in the long run. Thus, it is mutation the only source of evolution of new attributes in that version.

Additionally, there is a population control mechanism. As discussed before, all agents spend energy just by living. They gain more energy by feeding from a dead body, or even by stealing energy "biting" enemies in fights. The energy loss rate increases when chasing, fighting, and mating. If an agent has no more energy, it is doomed to die. Besides this, the energy loss rate is also linked to the number of living agents, making it harder to live on a crowded ecosystem. This feature was implemented to prevent an uncontrolled life grown, considering the system's limited computational resources.

Adding Symbiogenesis to the Process

The assimilation of another agent in a consortium is the major change in Morphogenesis with the addition of symbiogenesis as an evolutive process. This new approach has two relevant situations: the moment when the symbiogenesis happens, and when the consortium generates descendants. The symbiotic process happens when an agent collides with the line of another agent's body. Depending on the middle body shape of the agent, it might just get stuck, as if it were hooked. This is the submission scenario, when just one agent benefits from the interaction (parasitism). Nevertheless, when that happens, there is additionally a small chance of assimilation (0.01% per frame). If the assimilation event is triggered, they become one, as if the agent converts to a limb of the other - adding a dash to the scribble. With the consortium established, the main agent protects its limb, and the limb allows the main agent to gain more energy, as if it were its own mitochondria. Fig. 4 illustrates the creation of a consortium.

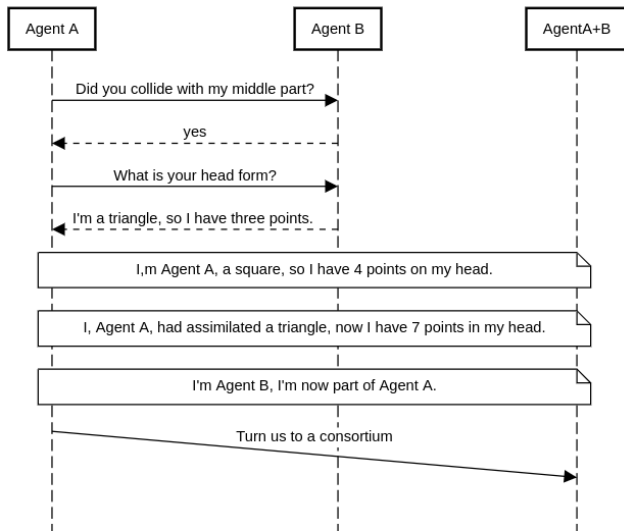


Figure 4: Symbiogenesis event, an Agent B collides with Agent A, which perceives it and absorbs Agent B in a third consortium Agent A+B.

In Fig. 4, the assimilated Agent B will be acquired in the consortium. To maintain certain proximity with the scientific concept of symbiogenesis, the Agent B is not devoured, it flows its energy to Agent A, starting to act in a synergistic ensemble. The energy is critical because it works as a counter, maintaining the agent alive.

The new consortium Agent A+B becomes a new species, having a modified shape in the head, resultant of acquired DNA from Agent B. To prevent the undefined grow of the number of sides of the creatures' head, making it difficult for the public to visually identify the geometric shapes with many sides, an internal control mechanism was created. If the sum of the sides is smaller than 10, then they are added. Otherwise, the consortium receives the absolute result of their subtraction. For example, if an agent with a pentagon head (5 sides) joins in consortium with another agent with triangle head (3 sides), the result would be an octagon head (8 sides) new agent. But if an agent with a pentagon head (5 sides) joins in consortium with another agent with hexagon head (6 sides), the result would be a circle head (1 side only).

When symbiogenesis happens, the assimilated agent, Agent B, will maintain his body connected to the line of what was before Agent A. With time, Agent B loses its own colors, turning itself visually related to the consortium. However, in this circumstance, the original drawing lines are maintained (see Fig. 5). Once the consortium is created, it becomes a symbiotic agent, a permanent association. This new species is not allowed to mate with the old ones, but only with the new shapes that respect the similarity rule (an equal or one side difference). For this to happen, this agent should find mating partners within another group, or wait for a similar consortium to take place in the environment.

This corresponds to the second moment in adding symbiogenesis to the evolutive approach in Morphogenesis. If a symbiotic agent generates a new descendant, this new generation will suffer the regular transformations of DNA, losing the original network of lines presented in the original

symbiont. This is an important decision because it resumes the original process, not demanding the cumulative computation of overly complex structures to the system, which would compromise its execution after a few days. In short: the son of a symbiote is a regular agent (see Fig. 6).

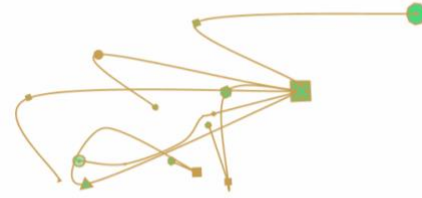


Figure 5: Symbiogenesis consortium is created by an assimilator agent, which will maintain a free head, and the assimilated agents connected.



Figure 6: Two symbionts of the same species had mate, generating a new descendant (small figure between the two distinguishable heads), the new descend is born by symbiont DNA but loses the symbiotic network lines of the parents.

While adopting symbiogenesis as an additional model, the authors had to add new rules of agents' relationship to the environment. In this version of Morphogenesis, the assimilated agent gradually provides energy for the assimilator. However, the assimilator now is a consortium, and they share the total energy of the group, differentiating the phenomenon from a situation of parasitism. Nevertheless, the entire consortium now is more visible to others inside of the environment scaling up their chance to be chased.

In the addition of symbiogenesis as an inspiration to the artwork, the authors were concerned about maintaining some principles of the original aesthetics. The Abstraction elements of lines could not be maintained in the descendants due to the necessary resources for processing those computations after many generations. But they were preserved during all the lifetime of a new symbiont, allowing an observer to notice the development of a distinguished being formed by consortium. Also, the changing head shape and colors acquired by the consortium have an abstraction element in showing a new group distinguishable from the previous social group where

agents maintain its colors and head shapes. The sounds that characterize the agent species were also modified in this version. This is especially relevant when colonies are made on the system after many generations, as sound and image must be synchronized to maintain aesthetics consistency.

Results

In this session, we present the results of symbiogenesis as an additional method for the evolutionary process in the Morphogenesis. The original motivation for this experience was to find inspiration in science to simulate the impossible as a poetic, aiming to contribute to the field of Evolutionary Art. As such, our results present a discussion about compositions in art more than the simulation of evolution as a reliable reality, or even the discussion of concepts that belong to another epistemological field.

Symbiogenesis was implemented as a principle of mutually beneficial association using a coupling with another agent. We considered the acquired agent as an independent machine, capable of individual processes, that becomes part of another. When an agent becomes a fixed member of another, the energy previously produced for the individual is now integrated into the assemblage. This change in Morphogenesis represents a significant aspect for the performance of the symbionts in the environment. For example, through a short period of time, symbionts are at an advantage over other agents. It happens because, with the increase of their total energy, they can get a little faster and spend more energy over time. Nevertheless, we highlight that this situation does not eliminate the other described effects, such as aging and the environment's natural selection.

When the symbiogenesis occurs, also the specification happens by the acquired DNA, that allows the representation of new types of agents. It is visually perceived by the number of sides at the agents' head. As well as seems to happen in nature, the new species tends towards isolation, which makes reproduction by mating more difficult. Nonetheless, the agents often overcome isolation finding compatible species that arise either by slow evolution with mutation or befalls by a parallel symbiogenesis.

Before symbiogenesis, collaborative groups were the strongest structures in Morphogenesis, making colonies the most likely occurrences. But the presence of symbiogenesis has increased its dynamics, where we now have groups and consortiums interacting. This diversity impacted in different kinds of competition and collaboration between agents. Symbiotic forms represent assemblages of capacities, improving individuals' potential energy at each acquired member. It also allowed the strengthening of the individual narratives as a counterpoint for the dominant collective behaviors to be experienced by the public.

Over time, we also noticed that some symbionts specialized as a predator or colony thruster, occupying a leading role in the formation of distinct colonies. We observed that symbiogenesis accelerates diversification in colony formation over the generations, which could be considered a leap (see Fig. 7, 8 and 9). Those leaps helped maintain diversity and variability in Morphogenesis, which is very useful in art exhibitions in galleries with long periods of time in a single run of the system.

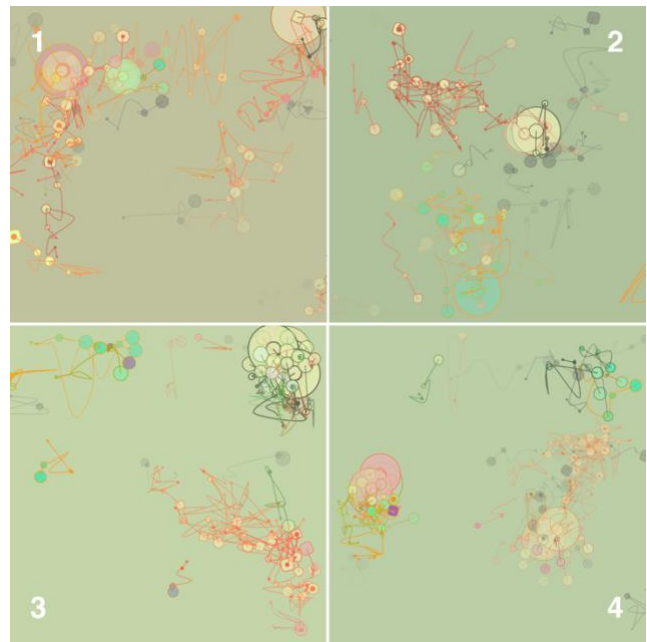


Figure 7: Four stages in different generations of the creation of new colonies from symbiotic agents demonstrating the provided evolutionary leap for the environment. At 7.1 a colony of octagons can be seen, which generated some symbionts (with a mark on its head). At 7.2 we can see that the colony seems stronger (opacity), with a greater dynamism, represented by the disposition of its scattered agents through the environment. At 7.3, the dispersed agents formed new subgroups. At 7.4, the old colony appears weaker (opacity) with a new colony of circles at its side, created by the symbiotic crosses of the original octagon colony.

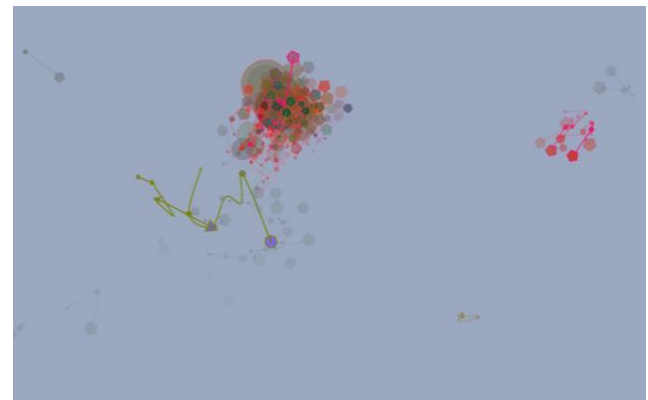


Figure 8: Example of predatory behavior, in which the symbiote (purple heptagon) evolved to feed on a colony of weaker agents (red and green pentagons). This is considered a more individualistic behavior of the agent, which ends up not generating a new colony but enacts with the other colonies of the environment.

As examples of the Morphogenesis in motion, there is an accelerated video ([link](#)), and others with the regular time and sound from the start ([link](#)) and in small clips ([link](#), [link](#)).

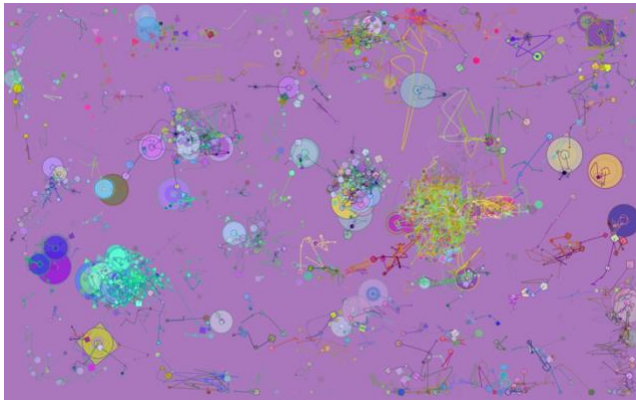


Figure 9: Macro view of the diversity of colonies and behaviors provided by the new dynamism of the system that combines evolution through slow mutations and symbiogenesis.

To use the system in guided tours or interactive installations, the manipulation of the main variables related to its evolutionary inspirations was implemented. With this feature, it is possible in real time of execution to modify the probabilities of mutation or symbiogenesis, as well as the thresholds that determine the degrees of distance between species, or even the speed of creatures' internal metabolism, making life, for example, less likely in the environment.

However, if symbiogenesis is set up to become more likely, it would repeatedly lead to the failure of the internal ecology of the system. In these scenarios, this fosters the creation of super individuals that later die by isolation (see Fig. 10). In aesthetic terms, changing the parameters of symbiogenesis, or even mutation, can generate extreme representations. While the extreme situations can be useful to capture dramatic moments in the system and illustrate strong positions in science about evolutionary processes, like in classes or guided tours, the maintenance of equilibrium helps to sustain diversity, which leads to life continuity and promotes more relevant situations to the public.

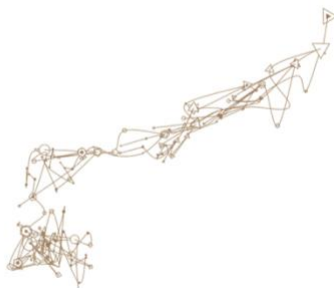


Figure 10: Super individual created from an extreme symbiotic configuration in the system, in which the creature eliminated all the diversity of the environment and will die by isolation without new descendants, interrupting the life cycle.

To exemplify the effects of the symbiogenesis on the genetic variability of the system, a controlled survey of the frequency of species was carried out over time with different configurations of its evolutionary process. Four scenarios were created in which the number of live agents per species

was recorded in 50 occurrences performed every 2,000 frames away. Despite a single simulation for each scenario won't support further inferences, they illustrate better the distinctive kinds of narratives provided to the public.

In the first one, the system was configured to not perform any mutation or symbiogenesis process (Fig. 11). As can be seen, the genetic variability of the population is reduced, as only one species (n5 - pentagon) dominates the environment. Without the possibility of mutation or symbiogenesis, there is no evolution of species, a monotonous situation for the public.

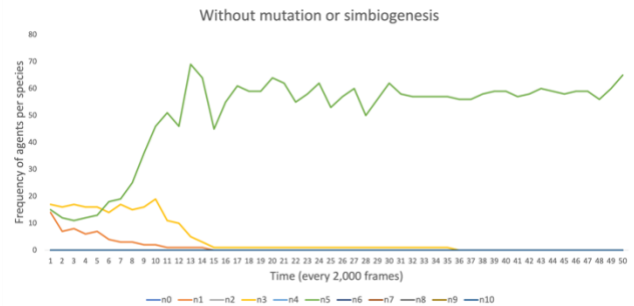


Figure 11: Frequency of live agents by species in 50 occurrences at 2,000 frames away in the configuration without mutation or symbiosis. It is possible to verify the absence of evolution in the system, dominated by a single species.

In the second example, the system was configured to perform only the mutation process with an occurrence probability of 1% at the time of the DNA recombination for the birth of a new agent (Fig. 12). The graph demonstrates the process of gradual transformation of species as generational cycles in small steps, as suggested by the Theory of Evolution by Natural Selection. With time, they become predictable.

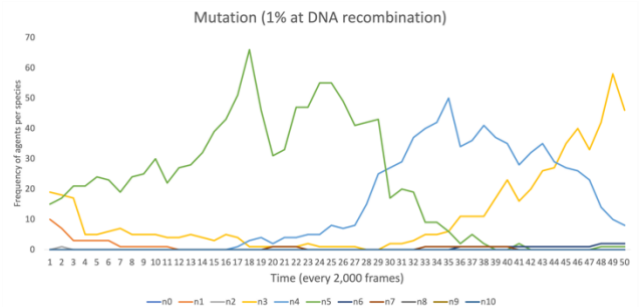


Figure 12: The agents' frequency with only mutation. It is possible to verify the gradual evolution of species in the system (first green, then blue, and in the end yellow).

The third configuration involved only the symbiogenesis process, configured for a 0.01% chance of occurrence per frame while one agent is stuck in another's line (Fig. 13). This probability needs to be less than the previous one (of mutation) because the agent's imprisoned time is undetermined and the consequences for the environment can be drastic, as discussed earlier. The graph shows that symbiogenesis alone is capable of providing genetic diversity to the system, as well as in mutation. However, it manages to provide this effect in more dynamic situations, without the

predictable regularity of generational cycles that gradually navigate the creatures' genetic space.

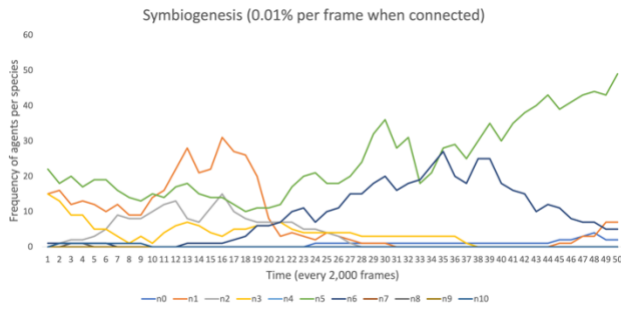


Figure 13: The agents' frequency with only the symbiogenesis configuration. It is possible to verify the evolution of species in irregular leaps in the system.

Finally, the fourth investigated situation consists of the accumulation of the two previous functions: mutation and symbiogenesis (Fig. 14). As can be seen, it combines both effects of gradual progression through the genetic space of the populations, as well as the evolutionary leaps that allow the coexistence of different species in the limited environment of Morphogenesis, creating distinctive situations for the public.

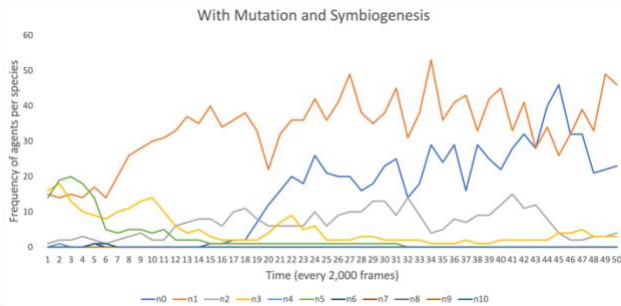


Figure 14: The agents' frequency with mutation and symbiosis. It is possible to verify both the effects of gradual evolution and evolutionary leaps, favoring the coexistence between species in a more organic and dynamic composition.

As a result, we conclude that symbiogenesis has its contribution to the field of Evolutionary Art, as it establishes assemblage possibilities for evolution instead of a slow emergency based on the gradual steps, which could take more time and processing power to promote changes, been also more predictable in the Morphogenesis. Thus, we believe that this resource can facilitate and accelerate the aesthetical potential of evolutive artistic compositions as it creates new ways of demonstrating the evolutionary process.

It is key to highlight that the main goal of each of these features is to allow aesthetic experiences related to the life process and the way that evolution shapes the diverse configurations and behaviors of life. Accordingly, the addition of symbiogenesis allowed the expression of narratives that are relevant to the system as a work of art. They modify the collective and individual processes of the agents in Morphogenesis, deepening the space of possibilities provided by the poetic.

Conclusion and Future Work

Morphogenesis has become an aesthetic simulator of several evolutive processes, representing improbable lives, but still able to illustrate organic processes that are hard to be perceived, as they occur on a time scale unapproachable by human senses. It was formerly implemented to improve its variability with mutation, and now also works with the symbiogenetic approach, enhancing the possible narratives expressed to its audience. Besides that, it also can express evolution by other perspectives such as Lamarckism, or even from an exclusively competitive point-of-view.

This is a new step towards its continuum experimentation, that will remain with different new possible representations, like assortations, for example. We expect to test the boundaries of some strong scientific principles in evolution to understand its aesthetics potentials and continue to prompt it to a wider audience. We also intend to continue the research of the aesthetics of artificial life, increasing the tension of the overlap between simulation and poetics.

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