Life's What You Make: Niche Construction and Evolutionary Art

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Abstract. This paper advances new methods for ecosystemic approaches to evolutionary music and art. We explore the biological concept of the niche and its role in evolutionary dynamics, applying it to creative computational systems. Using the process of niche construction organisms are able to change and adapt their environment, and potentially that of other species. Constructed niches may become heritable environments for offspring, paralleling the way genes are passed from parent to child. In a creative ecosystem, niche construction can be used by agents to increase the diversity and heterogeneity of their output. We illustrate the usefulness of this technique by applying niche construction to line drawing and music composition.

1 Introduction

A 'grand challenge' for evolutionary music and art (EMA) is "To devise unique kinds of evolutionary 'software instruments' that offer the possibility of deep creative engagement and enable the creative exploration of generative computational phase-spaces." [1]

A major paradigm of the past for EMA has been the interactive genetic algorithm (IGA) whereby the difficulty of defining a machine-representable fitness function for aesthetics is bypassed in favour of human-based selection. In this scenario, the user becomes a kind of 'pigeon breeder', searching, often blindly, for some hopeful monster within the limitations imposed by aesthetic selection [2].

In recent years a new paradigm has emerged, that of the *creative ecosystem* [1,3,4,5]. In this approach, the focus is shifted from aesthetic fitness evaluation – either automated or manual – to the design of specific components and their interactions to form a dynamic ecosystem. Creative ecosystems may optionally incorporate evolution. The important features of this approach can be summarised by three observations:

- An ecosystem consists of *components* with carefully designed *interactions* between themselves and their environment;
- The ecosystem operates and is conceptualised within the generative medium itself, for example a sonic ecosystem operates in the medium of sound, rather than being a sonification of some other process;

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– Components within an ecosystem are interconnected in such a way that they can modify their (biotic or a-biotic) environment, often to their own benefit or that of their descendants.

Creative ecosystems exhibit the characteristic features of real ecosystems: heterogeneity, diversity, mutualism, stability under change, and complex feedback loops [6]. The ecosystem approach mirrors the realisation in Biology that evolution is more than just selection and adaptation – organisms not only adapt to environments, they actively change them in order to create local environments better suited to them and their offspring.

While 'ecosystemics' represents a promising new approach, a challenge remains to understand the classes of mechanisms most appropriate to creative applications. In this paper we look at mechanisms from Ecology, and show how they can be adapted for creative ecosystems to improve the aesthetic possibilities of generative systems. We focus on the concepts of *niches*, *niche widths*, *niche construction* and *ecosystem engineering*. We will demonstrate how these concepts can be applied to creative generative systems in order to improve the aesthetic properties and diversity of output. This will be illustrated using example line drawing and music generation systems.

1.1 Niches

Biological environments have two broad properties that determine the distribution and abundance of organisms: *conditions* and *resources*. Conditions are physiochemical features of the environment (e.g. temperature, pH, wind speed). An organism's presence may change the conditions of its local environment (e.g. one species may modify local light levels so that other species can be more successful). Conditions can change in cycles: diurnal, annual or according to the frequency of extreme events. Conditions can also serve as stimuli for other organisms. Resources, on the other hand, are consumed by organisms in the course of their growth and reproduction. One organism may become or produce a resource for another through grazing, predation, parasitism or symbiosis, for example.

For any particular condition or resource, an organism may have a preferred value or set of values that favour its survival, growth and reproduction. One such characteristic curve is shown in Fig. 1 (left).

The complete set of conditions and resources affecting an organism represent its *niche*, which can be conceptualised as a hypervolume in n-dimensional space. As an example, for two conditions c_1 and c_2, two different types of species relationships are shown in Fig. 1. The shaded area represents the 'viability zone' for the species. A species will only survive if conditions are maintained within this shaded area. A relatively large distance in any single dimension denotes a generalist *in that dimension* (s_1 is relatively generalist in c_2), specialists have small distances (s_3 is more specialised in both c_1 and c_2). This size is referred to as *niche width*, and may vary for each dimension.

Competition and other species interactions are important in determining habitat distribution. Niche differentiation can permit coexistence of species within a biotope. Higher number of species can coexist by utilising resources in different

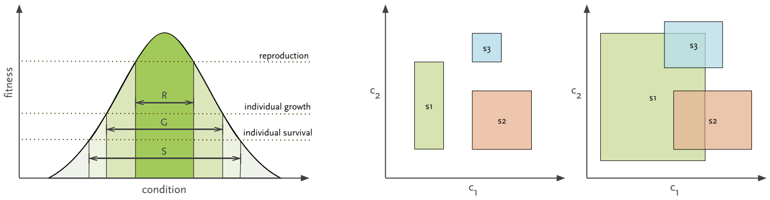

Fig. 1. Example organism viability zones for reproduction, growth and survival (left) and exclusive and overlapping niche areas for a two-dimensional set of conditions

ways. It is reasonably well understood in Biology how these mechanisms give rise to species diversity and specialisation. The challenge in EMA research is to devise useful ways of employing these mechanisms in creative contexts. Here the question is how to devise mappings between conditions and resources, and establish trade-offs for an individual's survival based on tolerances to specific conditions in order to enhance the quality and diversity of output in a creative generative system.

2 Niche Construction

Niche construction is the process whereby organisms modify their own and each other's niches. They do this by modifying or influencing their environment. Proponents of niche construction argue for its importance in understanding how the evolutionary process works in nature [7]. By modifying their niche, organisms may provide a heritable environment for their offspring. Hence niche construction can create forms of feedback that modify the dynamics of the evolutionary process, because ecological and genetic inheritance co-influence in the evolutionary process. Computational models of niche construction show that it can influence the inertia and momentum of evolution and introduce or eliminate polymorphisms in different environments [8]. Other models have demonstrated that a simple niche constructing ecosystem can support homeostasis and bi-stability similar to that of Lovelock's popular *Daisyworld* model [9].

Whereas standard evolutionary algorithms tend to converge to a single (sub)-optimum, niche construction can promote diversity and heterogeneity in an otherwise fixed and homogeneous evolutionary system. In systems where the design of an explicit fitness function may be difficult or impossible (as in many EMA systems), niche construction provides an alternate mechanism to explore a generative system's diversity over an IGA. An ecosystemic approach to creative systems does not necessarily parallel, or serve as a replacement to, traditional Evolutionary Computing methods, as creative ecosystems are not defined by a single algorithm or method. An important consideration is that the ecosystem must be developed specifically to the domain and creative system desired. A process such as niche construction serves as a 'design pattern' [10] to help facilitate the design of such systems. In order to illustrate the utility of niche construction we will now describe two different experiments where niche construction influences the structure and variation of the creative artefacts produced.

2.1 Line Drawing

In order to demonstrate the power of niche construction in a creative context, we begin with a simple, agent-based line drawing program and show that by adding a niche constructing component, the aesthetic sophistication and diversity of drawings created by the system increases significantly.

Our system is inspired by Mauro Annunziato's *The Nagual Experiment* [11], principally because this system actually produced interesting drawings from an artistic perspective, but also because of its simplicity. The system consists of a number of haploid drawing agents that move around over a two-dimensional drawing surface – initially a blank, white canvas. Agents move over the surface, leaving an ink trail as they go. If an agent intersects with any existing trail, either drawn by itself or by another agent, it dies. Agents may produce offspring that grow out from their parent at their time of birth.

The characteristics of the path an agent chooses to draw is determined by its genes. The actual path is determined by a stochastic process. An agent's genome has the following alleles, each represented as a normalised floating point number:

curvature controls the rate of curvature of the line. Varies from a straight line (0) to a maximum curvature rate (1);
irrationality controls the rate and degree of change in the rate of curvature according to a stochastic algorithm (see Fig. 2);
fecundity (f), the probability of the agent reproducing at any time step. New agents are spawned as branches from the parent;
mortality the probability of the agent dying at any time step;
offset the offset angle of child filaments from the parent;

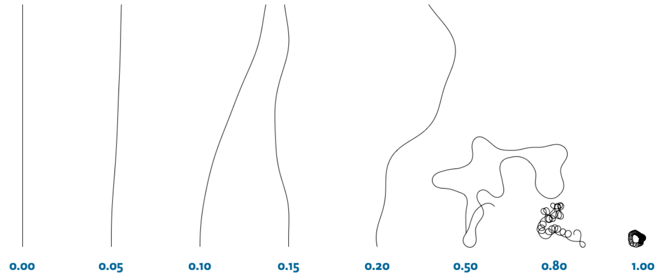

Fig. 2. Individual line drawing agents with different measures of irrationality

The canvas is seeded with a number of drawing agents who proceed to draw according to the characteristics described by their genes. A drawing is complete when all the agents have died. The system produces a variety of interesting drawings, due in part to the interaction between agents and the lines they draw (Fig. 3). Initial 'founder' lines can carve out spaces and prevent other lines from drawing into them due to the rule that line intersection causes death.

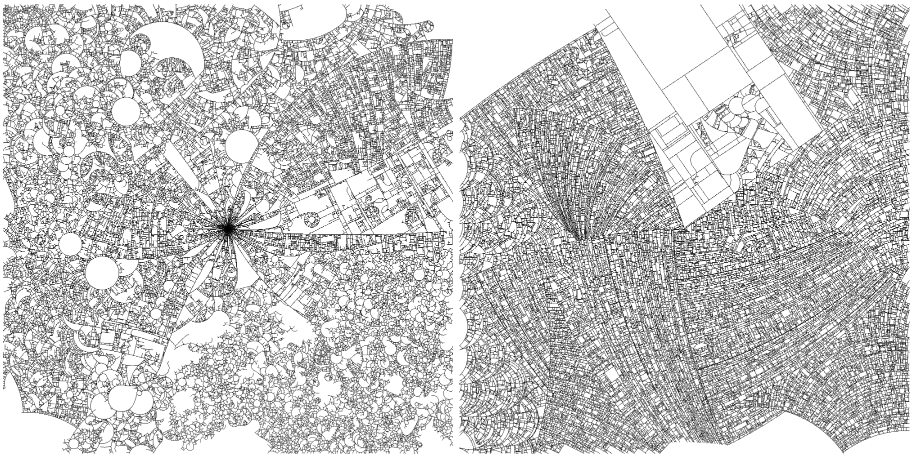

Fig. 3. Two example drawings produced by the agent system (no niche construction)

While the drawings are interesting, they are largely homogeneous, both in terms of the style and overall tonal density observed in the images produced. By adding a niche construction process the images become much more heterogeneous and exhibit greater aesthetic variation.

The Drawing Niche Construction Model. To add niche construction to the drawing model, each agent is given an additional allele in its genome: a local density preference δ_i (a normalised floating point number). This defines the agent's preference for the density of lines already drawn on the canvas in the immediate area of its current position, i.e. its niche (Fig. 4). In a preferred niche, an agent is more likely to give birth to offspring and has a better chance of survival. As children inherit their parent's genes they are more likely to survive as they have a similar density preference. So in a sense, parents may construct a niche and pass on a heritable environment well-suited to their offspring.

For each agent, i, δ_i defines it's preferred niche. Local density (the ratio of inked to blank canvas per unit area) is measured over a small area surrounding the agent at each time step. Proximity to the preferred niche determines the probability of reproduction of new agents, given by: $Pr(reproduction) = f_i \cdot \cos(\mathrm{clip}(2\pi(\Delta_{\boldsymbol{p_i}} - \delta_i)), -\frac{\pi}{2}, \frac{\pi}{2})$, where $\Delta_{\boldsymbol{p_i}}$ is the local density around the point $\boldsymbol{p_i}$, the agent's location. f_i is the agent's fecundity and 'clip' is a function that limits the first argument to the range specified by the next two. Being in a non-preferred niche also increases the chances of death.

Agents begin with a low density preference, uniformly distributed over $[0, 0.25]$. Beginning the drawing on a blank canvas means that only those agents that prefer low density will survive. As the drawing progresses however, more ink is added to the canvas and agents who prefer higher densities will prosper. At each birth the agents genome is subject to the possibility of random mutation (proportional to

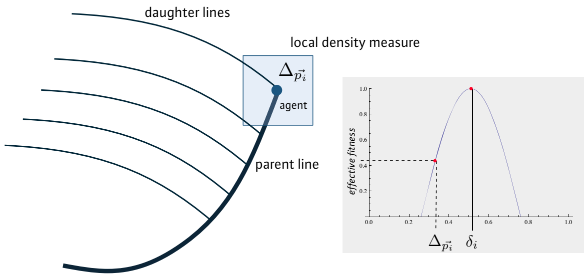

Fig. 4. The niche construction mechanism for drawing agents, who try to construct a niche of local density that satisfies their genetic preference

the inverse of the genome length), allowing offspring to adapt their density preference and drawing style as the drawing progresses. Eventually the population becomes extinct, since high density favouring agents don't have much room to move, and the drawing finishes. Some example drawings are shown in Fig. 5. Notice the greater stylistic variation and heterogeneity over the images shown in Fig. 3.

Fig. 5. Two example drawings produced with the addition of niche construction

2.2 Musical Niche Construction

The *RiverWave* model is a sonic ecosystem in which agents contribute to the construction of an evolving additive synthesis soundscape. The agents inhabit a sonic environment which they contribute to and this environment in turn defines selection pressures for the agents. The model explores the long term evolutionary dynamics of a system in which environmental conditions and genetically determined behaviours coevolve, and demonstrates the efficacy with which an artist-programmer can design a set of interactions that produce interesting continuous change. The model was designed to be run as a durational audio visual installation in a corridor space as part of the 2008 NetAudio Festival[1]. The intention was to establish coherent behaviour that varied over short and long term time scales, that passers by would revisit to explore its varying behaviour over time.

The Environment. The environment is a toroidal one-dimensional space consisting of 300 cells, each of which produces a single sine tone along a microtonal pitch scale. Each cell stores an amplitude value for the frequency assigned to it. Together the cells produce a continuous sound which is the sum of the individual weighted sine tones. The amplitude of each cell is represented visually as the height of the line. Heights are constrained to the interval $[-1, 1]$ with negative values mapped to positive amplitudes. This amplitude value is affected by agents, and also obeys physical laws which make the line behave like an elastic string: the amplitude values for each cell decay exponentially to zero, and adjacent cells pull on each other's amplitude values in proportion to the difference between their respective values. This acts as a smoothing function on the line, which relaxes to zero in the absence of agent forces.

The environment has two natural properties that can be used as conditions to which agents are exposed: a height, y, and a gradient dy. These define the environmental conditions to which agents may be more or less adapted.

The Agent. Agents inhabit this one-dimensional environment, occupying a single cell for the duration of their lifetime. Agents apply forces to the line at their current location and at the location of the cell to their left, affecting the amplitude of these cells and their neighbours via the physical properties of the line (left of Fig. 6). Agents also have genetically determined preferences for y and dy, as well as a degree of specialism with respect to each of these conditions. Agents receive discrete fitness rewards if each of the local environmental conditions are within their preference range, with more specialist agents obtaining greater fitness rewards.

At each time step, the rewards accumulated from this environmental interaction contribute to the agents' health. Since these rewards are added independently, an agent can be poorly adapted to one niche dimension, but well adapted the other and still survive. The agent's health value decays exponentially in proportion to the number and proximity of other agents in the space (many agents nearby reduce health by a large amount, few agents far away reduce health by a small amount), and by the agent's age (older agents' health decays more rapidly). Since the agent's health can accumulate and be stored over multiple time steps, agents can survive without health gains for some time. Agents are given an initial maturation period during which they can modify their environment but cannot reproduce or die, after which an agent's health is used to determine whether it

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[1] An annual festival of internet-based digital music, held at *The Shunt Vaults*, London, in October 2008. See `http://www.netaudiolondon.cc`

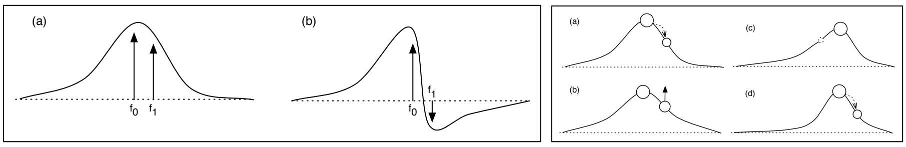

Fig. 6. Left: Agents exert two independent forces on two adjacent points along the line, which can be in the same (a) or opposite (b) directions. A smoothing function along the whole line draws adjacent points closer together over time. Right: Example of drift. Agents are adapted to slopes. Energy is represented by size. (a) An agent produces a child to its right. (b) The child gains energy because it is on a slope and pushes upwards. (c) The parent dies. It has lost energy because it is on a peak. (d) The child is now on a peak but still with high energy, and produces a new child on the slope to its left.

dies or gets to reproduce. The maturation period is useful in providing a window of opportunity for agents in poor environments to improve their conditions, thus increasing the efficacy of niche construction.

Agents also have a genetically determined offspring displacement value: the position at which their children are placed relative to their own position. This displacement property was inspired by the idea of life along a river, or in the context of seeds being carried in a prevailing wind direction, defining established geographic pathways. This genetically inherited displacement value is mutated at a low rate, but without upper limit, hence a growing population will tend to fan out along the line in discrete steps.

Examining Model Behaviour. The system demonstrated divergent evolutionary pathways, believed to be due to its niche constructing nature. Although the environment starts out flat ($y = 0$ and $dy = 0$), the randomly initialised population may be poorly adapted to that environment (preferring non-zero values) and may also inadvertently affect the environment by exerting forces on it, regardless of what kind of environment they prefer. In these initial stages, environmental modification may be unintentional, but still has the effect of determining future evolutionary pressures in an undirected manner.

Fig. 7 shows the evolution of the sound spectrum across six runs of the model with the same settings but random initial populations. A number of different population behaviours can be observed in the model, as well as sharp transitions in qualitative behaviour. Run 5 shows diagonal movement of spectral peaks, which is caused by populations drifting horizontally as children replace parents and in turn produce further descendants with the same, or similar, fixed offspring displacement. This collective behaviour may in theory be one that is reinforced through evolution, as illustrated on the right of Fig. 6: a mature agent pushes the line up to a peak and then produces a child at a slight displacement, the child therefore being born on a slope. If the child is adapted to living on slopes it will gain energy. Meanwhile, the parent, who, like the child, is also adapted to slopes, loses energy and dies. Once the parent's force on the line has gone,

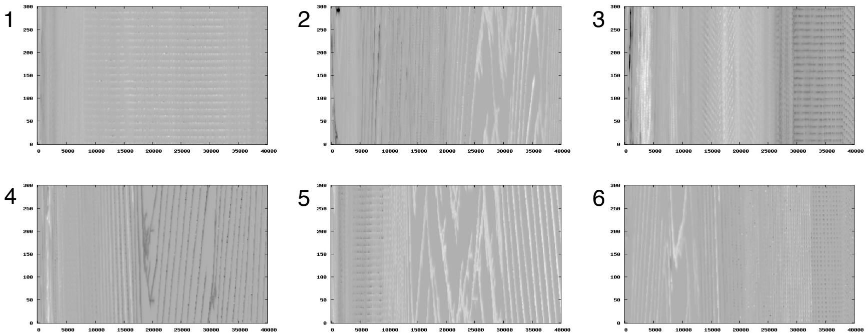

Fig. 7. Multiple runs of the same simulation, with time step on the horizontal axis, cell index on the vertical axis and amplitude represented by shading

the child's location shifts from a slope to a peak. In the meantime, the child has produced its own offspring, who now lives on a slope, repeating the cycle. At least in theory, this is a self-sustaining situation, which can be interpreted as the construction of suitable niches by parents for their offspring. However, the situation may be unstable due to alternative selection pressures, or simply because the cycle may become broken.

3 Conclusion

In this paper we have considered how niche construction as a biological phenomenon can be applied to creative ecosystems in order to increase the heterogeneity and the diversity of output in both visual and musical systems. In the visual case, we compared the same model with and without niche construction and demonstrated how niche construction drives a more heterogeneous and aesthetically diverse environment. In the audio case, we demonstrated how a niche constructing system could be designed using properties derived from the aesthetic medium – the sound spectrum – to drive ongoing evolutionary change. In this case, we did not attempt to compare models with and without niche construction; the model was directly inspired by the process of niche construction and a non-niche construction version would have made little sense. These studies demonstrate how the niche construction 'design pattern' facilitates a move from a predefined regime of interactions between an agent and its environment to an evolving one. Further study into the use of such mechanisms may lead to more general guidelines for how to establish rich behavioural complexity in generative artworks.

Acknowledgements

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