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The Sonic Artificial Ecosystem

Abstract

The autonomous generation of visual and aural patterns characteristic of those we label "creative" is investigated through the software implementation of a sonic artificial ecosystem. This software replicates the dynamic interactions of organisms over time frames ranging from seconds to generations. Changes in individual agent behaviour and in the population as a whole are sonified and visualised to form a coherent generative work exhibiting many properties usually associated with autonomous creative systems.

Introduction

Researchers have explored the potential of various computational dynamical and generative systems for the composition of music. Previous examples include Cellular Automata (Dorin 2002; Miranda 2003), various kinds of networks (Dorin 2000; McIlwain and McCormack 2005), L-systems (McCormack 1996) to list a few. Nevertheless, the question remains open, "How does one automatically generate 'interesting' music?"

Of course there are countless debates, "What *is* music?" Given the complex links between art, culture and society I will sidestep the issue and treat any dynamic artwork as a temporal series of events in some space (aural or visual for instance). Hence, the question above is reframed as, "Can we construct a machine to generate patterns in space and time typical of those we characterise as artistic or creative?" I suggest that there are four (and a half) properties that are desirable in such a machine and leave it to the pundits to debate the assumptions I make about music or art in order to arrive at this conclusion. Note that these properties I offer below may be required to a greater or lesser degree in a system for art-making depending on the tastes of the artist and the work being created. Nevertheless, a useful system capable of automatically generating patterns in this context would incorporate several, possibly most, of them. The desirable properties of a machine for artistic pattern composition are:

1. Multi-scaled temporal complexity
2. Autonomous production of novelty
3. Responsiveness to (user) perturbation
4. Susceptibility to external (artistic) constraints
5. Maintenance of coherence and unity

The purpose of this paper is to describe a system from Artificial Life research that meets these criteria, the *artificial ecosystem*. Although the paper will address each criterion in turn, little attention will be given to point 3 in this publication as the work described is not interactive. Properties 1, 2 and 4.5 will primarily be discussed in the context of a software-based audio-visual artwork.

The artificial sonic ecosystem

This paper adopts an "ecological system" (ecosystem), the basic unit of ecology, for generating sonic and visual patterns. Ecosystems are communities of organisms and the physical environment with which they interact. It shall be discussed below how organisms within an ecosystem cause it to behave as a pattern-generating machine with the desirable traits listed above.

A musical composition, a work of visual art and an ecosystem are each *defined* by a series of interactions between their components. All of these are dynamic, *composite* entities. In the case of a musical work the components analogous to organisms are sounds. The analogy is useful in this instance since the proposal is that to build a machine for generating musical and visual compositions, one may build an ecosystem with sonic and visual components. To build such an artificial ecosystem one may model physical interactions between organisms in software.

An *artificial ecosystem* models a number of "agents" moving through a virtual space in search of resources and reproductive partners. The rules of interaction within the virtual space are laid down by the programmer. Agents may simulate predatory behaviour, transmit and receive messages, gain energy or consume it. Agents may give birth to offspring who inherit their parents' characteristics under the control of a genetic algorithm. Agents eventually die and are removed from the simulation. Artificial ecosystems of this type have been studied extensively. Well-known examples from Artificial Life research include *Polyworld* (Yaeger 1992), *Sugarscape* (Epstein and Axtell 1996) and *Echo* (Holland 1995). The *Creatures* games from Creature Labs adopt a similar model for the purposes of play and various artists have adopted the model for interactive works (Sommerer and Mignonneau 2004). A variation on the standard agent-based artificial ecosystem models its organisms as machine-code programs competing for virtual CPU time in order to execute their instructions and replicate. Examples include *Tierra* (Ray 1990), *Amoeba* (Pargellis 2001).

Here we define a *sonic artificial ecosystem* as an artificial ecosystem in which agents generate patterns that are sonified for humans to hear, or in which simulated audio is used as a mechanism for communication amongst the agents. Examples of these include *Living Melodies* (Dahlstedt 1999), *Listening Sky* (Berry, Rungsarityotin et al. 2001), *Eden* (McCormack 2001), *Evolving Intelligent Musical Materials* (Birchfield 2001).

Properties of real and artificial ecosystems

A wander through a forest reveals a marvellous array of organism-generated sonic events that change with the time of year or day, the situation of individual organisms or the state and location of entire populations. A soundscape such as Gilbert's *Kakadu Billabong* (Gilbert 1995) captures some of the complexity of the ecosystem as a sound-generator. A snapshot of any forest similarly shows a range of approaches to reproduction and resource acquisition, variation in morphology between plants, even within single species.

How do ecosystems measure up against the desirable properties listed above? In particular, what makes sonic artificial ecosystems suitable candidates for music and visual composition? The following subsections will address each of the desirable characteristics in turn.

Multi-scaled temporal complexity

The ecosystem is constituted by countless multi-scaled transformations of its organisms and the environments they inhabit. Changes occur in the morphology and behaviour of species over evolutionary time periods. Amongst these changes sound-generating techniques are acquired and varied to suit the prevailing conditions. At an individual level, agents are born, develop to maturity, reproduce and die. These life-cycle events each involve transformation of the morphology and behaviour of organisms over a period of seconds, days or years depending on the organism. Some of these transformations are easily associated with typical sonic markers: cries for a juvenile to attract the attention of a parent, playful calls made by adolescents to siblings or cries made by adults to assert dominance and attract mates. On a finer temporal scale, organisms engage in countless behaviours based on their current situation. Often these too are marked by sonic events: warnings to their kind or to frighten unwelcome guests, calls to indicate the presence of food, calls to locate related organisms. In addition to deliberately instigated sonic events, organisms generate countless incidental sounds as they go about their daily, annual and life cycles.

Autonomous production of novelty

Each species fills an ecological niche that is repeated across ecosystems worldwide. Some of these niches require an organism to generate unique sounds in order to survive. These sounds and the morphological traits necessary for producing them are formed as a result of evolutionary pressure. Some sounds made by organisms are superfluous to their needs and neutral with respect to evolution, although their mode of production may not be. For instance, the fact that its leaves rustle does not assist a tree to acquire resources. However the fact that the leaves are of a structure that results in their rustling *is* a result of evolutionary pressure. In fact leaf rustling has the potential to be a trait directly selected *for* or *against* by evolution. Therefore novel leaf forms may evolve to rustle in distinctive ways (for instance a pollinator may evolve to approach a tree that makes a certain sound when the wind blows) or not to rustle at all (insects may evolve to eat the leaves of trees that rustle).

Of course organism diversity is not confined to sound production. Organisms vary in their behaviour and physical characteristics from species to species, and due to the different situations in which they find themselves, on a temporal and spatial basis from individual to individual. Therefore evolution is always searching for any novelty in structure or behaviour that has the potential to improve reproductive ability. Diversity in biological organisms is one trait that recommends the ecosystem to artistic composition. If this feature can be harnessed in a computational dynamical system, it promises rich and surprising musical and visual forms.

Responsiveness to perturbation

This criterion refers to an ecosystem's response to perturbation. Ecosystems are notoriously counter-intuitive — seemingly tiny changes may have drastic effects on their stability. For this reason, the constraints placed on user interaction with artificial ecosystems must be carefully considered. Nevertheless, if the changes wrought on an ecosystem are catastrophic, life has a knack of filling in the gaps. New pathways for energy transfer between organisms and their environment appear, or old pathways are maintained by new species. So although a specific ecosystem may break down, with some re-organization a new one often emerges in its place.

This means that as a collaborator, an ecosystem may be quite unwieldy and unpredictable. This is a source of novelty, but it is desirable at least to have some degree of control over the generation of new components. It would be desirable to have the ecosystem respond gently to a caress and move smoothly but rapidly to a new basin of attraction in response to more dramatic perturbation.

Susceptibility to external constraints

This criterion refers to the fundamental constraints placed on the system to limit the scope of its behaviour. Ideally, the extent to which a composition system responds to a human artist may be adapted to suit the individual. Real ecosystems do not typically run under human control and are notoriously difficult for us to constrain. However some constraints do exist as a result of the building blocks that are available for construction and the physical/chemical laws that govern the interactions of these components. For instance, no large organisms utilise biological wheels for locomotion, elephants cannot jump as many body-lengths into the air as fleas and whales cannot move using cilia.

Although humans do not determine the constraints imposed on real ecosystems, software ecosystems are subject to the desires of their programmers. Rules might easily specify that all agents only produce a three-tone musical call in a particular key or that no agent lives longer than twenty time steps. In practice, the programmer has complete control over the kinds of processes that will unfold during a simulation, even though the model operates autonomously.

Maintenance of coherence and unity

One way of interpreting this requirement is to say that a collection of organisms is coherent if their interactions constitute an ecosystem. That is, by *definition* an ecosystem is unified. Adopting the implicit coherence of the ecosystem as a starting point, we may define a kind of art that is coherent logically, if not aesthetically, by virtue of it being generated by the relationships of organisms within a virtual ecosystem.

We may claim analogously that coherent sonic events form music. In this second case we have not explained what is meant by sonic coherence since earlier we sidestepped the specification of a working definition for music. Nevertheless, the requirement of aesthetic coherence ensures that the composer or programmer's role is to constrain the system to their personal requirements. Hence, the sonic artificial ecosystem will generate logically coherent music, but it is up to the composer to determine how this will be interpreted aesthetically. The following section describes how this goal may be met without destroying the artificial ecosystem's ability to produce novelty.

Bio-diversity: enhancing novelty without destroying coherence

Artificial ecosystems require careful tweaking to live up to their potential. Of particular importance is the balance between autonomous exploration of novelty and coherence. Without novelty production, the ecosystem loses its primary value for the present application. However, the system can also generate too much novelty — an incoherent jumble. A range of possibilities is required that will allow the system to move from Steve Reich to Merzbow Project-like noise, without going beyond the extremes.

An evolutionary algorithm operating within an artificial ecosystem maximises the reproductive success of its agents and in so doing the environment and agents define an implicit fitness function for evolutionary selection. Unless the conditions within the simulated environment change, convergence may occur as a population of organisms becomes homogeneous and well adapted to the presence of similar organisms. The opposite extreme, complete lack of convergence, may result when the mutation rate is too high for evolution to act since highly mutated offspring do not resemble their parents.

In the context of artistic composition, the extremes of a generative process are uniformity and randomness. Sonically, a composer may wish to move between them. In keeping with the criteria listed above, this can be achieved by ensuring the system maintains a diverse range of agents simultaneously. The virtual environment must support the formation of various niches in which organisms with different strategies (and therefore different sonic and visual activity) may co-evolve and long-term convergence is avoided. We require a policy of *biodiversity* to be implemented.

Human input may be used to alter the virtual environmental conditions of the agents, forcing them to adapt to the change and making it impossible for them to fall into homogeneous stasis. If the system must operate autonomously, a function that alters a basic property of the virtual environment over time will similarly force the agents to adapt. These strategies are adopted in *Eden*. Firstly, user movement around the work encourages the growth of plant-like agent food. Secondly, the amount of energy available for the growth of the food resource undergoes simulated seasonal variation (McCormack 2001). By forcing adaptation the system ensures that its agents are rewarded for diverse survival strategies and that no specific strategy will suffice over long time scales.

Introducing barriers that restrict intermingling amongst agents from different heterogeneous regions may also assist agent niche formation. This facilitates the formation of disparate species and behaviours uniquely suited to distinct locations of the virtual environment, an approach adopted in *Polyworld* (Yaeger 1992).

A self-organized, distributed approach was adopted in *Diseased Squares* — a model of disease transmission described below. Disease encourages niche development by culling dense, homogeneous populations. This results in the growth of separate communities of heterogeneous agents. The disease therefore enhances the system's ability to simultaneously explore several phenotypic solutions. Consequently, various sonic and visual patterns are maintained in the environment to be brought to the fore at times, or pushed into the background without suffering extinction. The disease model is a helpful aid in maintaining bio-diversity.

A new sonic artificial ecosystem

The sonic artificial ecosystem *Diseased Squares*, models cuboid agents sliding on a continuous plane. Each agent has its own dimensions, colour and preferences for mates based on these attributes. Agents have a simple vision system that allows them to steer towards desirable agents and away from those they find undesirable. Agents move at a speed inversely proportional to their volume and acquire energy proportional to their horizontal surface area from a virtual sun. They expend this energy at a rate proportional to their volume in order to metabolise or move. Agents may mate with one another if their bodies intersect and each desires to mate. Reproduction employs the standard genetic crossover and mutation operators acting on an array of floating point values. Agents jumpstart their offspring by donating energy to them at birth. Further details of the system are provided elsewhere (Dorin 2005).

In addition to the usual features of artificial ecosystems, *Diseased Squares*, incorporates an extended simulation of disease transmission based on the classic *Susceptible, Infected, Removed* (SIR) model of epidemiology (Kermack and McKendrick 1927). Agents are susceptible to infection if their colour matches that held by an infectious disease within another agent (either living or decaying) in close proximity. Agents carrying a disease must expend energy to overcome the disease during their infection. If an agent is unable to overcome the disease by providing sufficient energy, the agent dies and decays before being removed from the simulation. Agents that successfully overcome a disease acquire immunity to it, however a disease mutates within living organisms and may eventually re-infect previous hosts. In summary, diseases and agents co-evolve, providing a dynamic environment in which each continually adapts in order to survive.

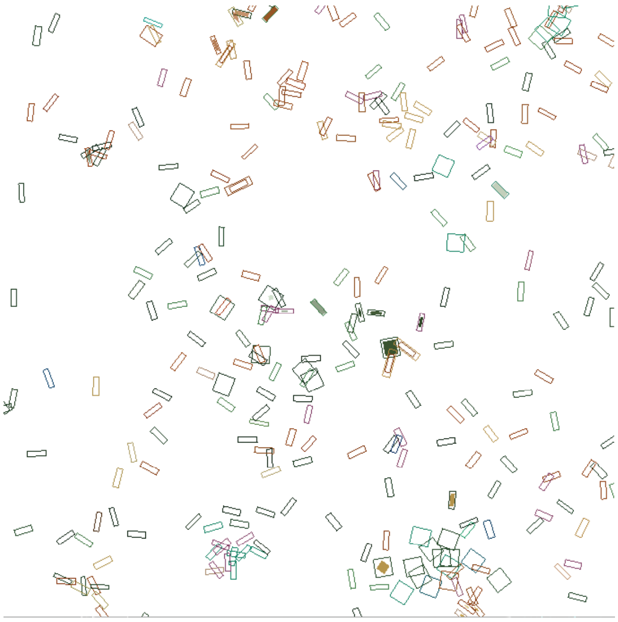

Figure 1. *This visualization of Diseased Squares illustrates agents of different dimensions and shape (hollow rectangles), latent diseases (filled diamonds within agents), infectious diseases (filled squares within agents).*

Agent visualisation

The interactions of the agents are currently visualised in an orthographic, plan view of the system using OpenGL (figure 1). Agents are represented as coloured rectangular outlines according to their dimensions and genetically determined colour. Their height is not depicted. For debugging purposes, within this outline, a second rectangular outline is depicted in the colour of the agent's favoured mates. Diseases are visualised within agents as solid diamonds (dormant) or solid rectangles (infectious). An agent displays immunity to a disease as a dotted line surrounding its outline in the colour of the immune response that is being activated. A decaying agent is shown as a filled, translucent green rectangle.

Agent sonification

There are three sets of data available for sonification (and visualisation) within *Diseased Squares*. The means by which this data is presented determines to a large extent the degree to which the sonic artificial ecosystem meets the proposed criteria for generative systems listed above. The data available may be classified loosely as follows.

Dataset 1: Some events within the life cycle of an individual agent in *Diseased Squares* occur only once, or occasionally within a single lifespan: agents are born; maturity is reached; agents mate; grow old; become ill and die. These incidents are interpreted sonically in the current system as discrete, audible events of different, manually constructed timbres (and visually as the coloured rectangles discussed above).

Dataset 2: The agents of *Diseased Squares* possess parameters that remain unchanged during their lifetime but may change for a population over evolutionary timescales. For instance, these specify the colour and dimensions of an agent, properties that may gradually shift over time as the species evolves, but that do not change within an individual's lifetime. These parameters are used to vary the pitch and duration of the timbres triggered by each agent in response to dataset 1.

Dataset 3: Some agent parameters map to attributes that change from moment to moment during an individual's lifetime. These include position, velocity and energy level. Currently this data set is not sonified explicitly (it is however observable through the animation of the agents as described in the previous section).

The reader is asked to note that this system therefore generates its audible patterns by sonifying the *behaviour* and *characteristics* of agents; the agents do *not* communicate using sound. Hence, the audible output is unlike that of an ecosystem in which agents call and respond to one another. In the present paper, the audible patterns are those of the system's dynamics, not of agent signalling.

Results of the visualisation and sonification are described below.

Results and Future Work

This section describes the resulting *Diseased Squares*. The discussion is largely qualitative, since the scope of the objectives is primarily subjective.

The audible and visual "streams" generated by the system map births and deaths and allow the sonic comparison of their rates and temporal relationships. Over evolutionary time-scales the pitch of the birth and death tones varies as the genetic composition of the agents in a population shifts. Additionally, since the simulation supports genetically heterogeneous agents, subpopulations develop characteristic pockets of sound.

The coupling of the sonification and visualisation clarifies the relationship between birth and death rates and the effects of disease in the simulation. Diseases with particular virulence are accompanied by an increased death rate for obvious reasons. They are also accompanied by a lowered birth rate since agents do not have an abundance of energy to expend on reproduction. Diseases that are spread rapidly through a population of susceptible agents are signified audibly by multi-layered drones. Occasional outbreaks that are quickly contained are not diverse in pitch but complex rhythmically due to the rapid spread of infection and regaining of health by the agents. Such outbursts are followed by periods in which immune responses are frequently activated.

It is not clear that anything much may be learned from the sonification of the system that could not also be discovered by watching its visualisation. However, the work is not here discussed as a contribution to data presentation, but as a generative electronic artwork.

What then can be said concerning this work in relation to the desirable criteria for generative systems in art?

Concerning multi-scale temporal complexity, the results are promising. Over a period of hours the system moves between various sonic textures as it explores the pitched spectrum of births. In shorter temporal timeframes, births occur in frenzied bursts as a community rapidly develops where agents that have abundant energy and mates invest their resources in producing offspring. This continues until disease arrives visually and sonically in the new community, the birth rate slows and the death rate creeps up until few of the creatures in the pocket remain healthy enough to give birth, nor densely packed enough to support the further spread of disease. Each of these occurrences has its own sonic and visual impact on the patterns produced by the system.

Autonomous production of novelty by the ecosystem occurs largely through the exploration of combinations of events, rather than through the exploration of a specific parameter set. Visually and sonically the system is not parameterised to allow a wide range of possible phenotypic traits. As it stands, whilst a full spectrum of colours is accessible to agents resulting in obvious visual variation, this is not matched sonically. For sonic diversity to be explored, a system with complex generative timbres might be preferred. In hindsight, pitch and duration selections seem too limited for exploring sonic novelty in this context. This improvement would require a real-time synthesizer that allowed specification of time varying filters, envelopes and their modulation.

The timbres sounded and the visual forms (coloured boxes) gliding over a black screen were not generated by the system, the programmer specified them. Maintenance of coherence and unity is therefore assured as a direct result of the limits placed on the sonic and visual patterns the system may produce. As indicated earlier, the ecosystem's aesthetic form is highly constrained by the programmer.

The author at least is satisfied with this system in so far as it meets criteria 1, 4 and 4.5. The system as it stands appears to meet criterion 2 but further exploration is required with a more complex parametric, generative model. Nothing can be said about the system's response to user perturbation (criterion 3) as it is not interactive. Whether or not others feel similarly about *Diseased Squares* can only be decided once the work has been exhibited publicly. Prior to this, it would be desirable to develop a new audio system that allows for the spatial positioning of the sonic events in such a way that they mesh with a visual projection in a gallery space, perhaps on its floor. The current MIDI audio system does not allow for this.

Conclusions

The resulting system is an absorbing sonic and visual work that evolves over time. The system's results are sonically and visually organized much like one would expect of an ecosystem. Short-term features of the work are particularly interesting and surprising, especially the generation of strange rhythms and the emergence, disappearance and re-emergence of various textures. To a large extent the author's personal aims have been met. Whether or not others are similarly pleased will only be known when the work is exhibited.

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