ARTIST'S ARTICLE

Chaos and Creativity: The Dynamic Systems Approach to Musical Composition

Peter Beyls

ABSTRACT

This article outlines a connective model for computer-generated composition, focusing on complex dynamics as tools to reach higher levels of human-machine interaction.

Traditional channels for introducing intelligence in computer-music systems are firmly rooted in the knowledge-based approach: methods and computational strategies borrowed from the field of artificial intelligence (AI). Expert systems for composition and pattern-directed inference systems for real-time human-machine improvisation attempt to introduce independent creative decision making through computer simulation of human creativity. Impressive statements have been produced along these lines, in music as well as rule-based computer graphics. Two observations have led to the consideration of a totally different method. First, expert systems become problematic if situations occur that were not anticipated by the programmer, and sooner or later the programmer is faced with a complexity barrier. Second, the appreciation of the pattern-making potential of nature led to the study of concepts like self-organization.

Complex dynamic systems are an alternative to the constructivist approach in composition, i.e. the critical assembly of architectures of time according to some explicit scenario. Complex dynamic systems consist of many elements interacting according to very simple laws but giving rise to surprisingly complex overall behaviour. Composition becomes experimentation with attractors—instead of creation of a rule base—as well as the design of tools that allow the topology of the composer to interact with the system's internal activity.

The idea is to critically push the system out of equilibrium, using tactile motor control to explore the various degrees of freedom of a given system. The implicit behaviour is then mapped to the musical problem domain. Improvisation becomes navigation in a hypothetical work in which the composer is both inventor and explorer. Strange and intricate imagery, in both space and time, is found in physics, biochemistry, fluid dynamics, ecology and nonlinear mathematics. We have implemented and evaluated various models for spontaneous pattern formation, including one-dimensional cellular automata, direct computer simulation of chemical instabilities (as witnessed in the BZ-reaction) and a spatial model exploring equilibrium behaviour in a society of interactive agents moving in two-dimensional space.

Peter Beyls (composer, educator, researcher), Octaaf Vandammestraat 73, 9030 Gent, Belgium. E-mail: peter@arti.vub.ac.be

This article is based on a paper presented at the Second International Symposium on Electronic Art (SISEA), Gröningen, The Netherlands, 12–16 November 1990.

Received 18 April 1991.

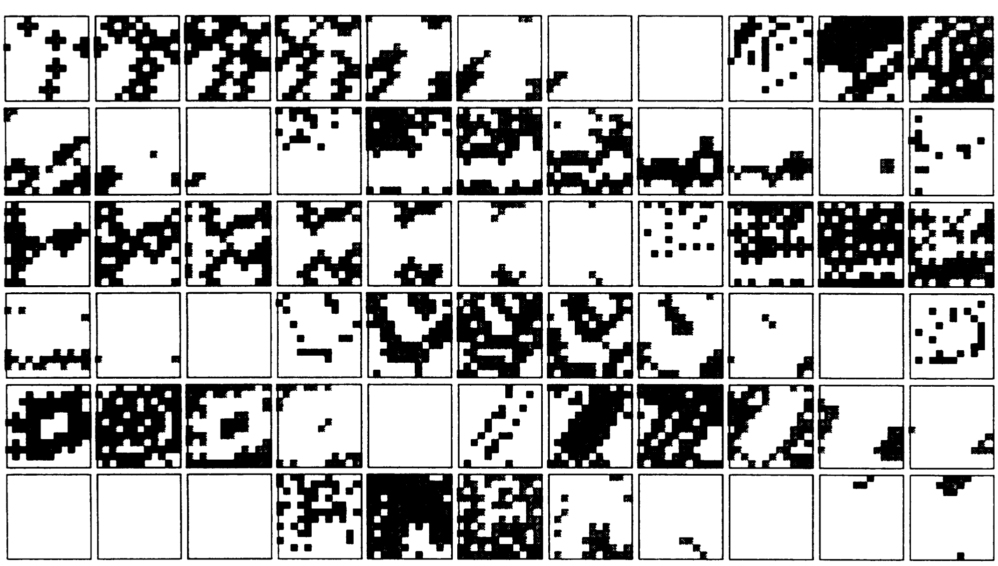


Fig. 1. Example of interactive cellular automaton. In this case, the current situation as well as the previous generation will determine the next generation. The internal dynamics evolve according to the following uniform rule: any cell is switched 'on' if any of its orthogonal neighbors are 'on' in the current configuration and if it was 'off' in the last two generations. Propagating structures are observed as a result of the interplay of internal dynamics and external activation.

Pergamon Press plc. Printed in Great Britain.
0961-1215/91 $3.00+0.00

Randomness/determinism and chance/necessity seem at the heart of creativity and happen to be central to the music of our time. Emergent properties from initial random configurations can be viewed as a subtle alternative for both constraint-based reductionist handling of randomness as well as rule-based composition by way of some generative grammar. Complex dynamics can be viewed as a creative, generative principle and a channel for higher levels of human-machine interaction.

Background

Since the advent of computer music, composers have tried to introduce musical intelligence in a machine by imitating certain aspects of human musical intelligence in a computer program. Pioneers [1] built programs that simulated a given musical style by establishing musical rules borrowed from existing musical paradigms, using constraints to filter the output of a random number generator. This method, however, proved to be highly inefficient; more control was needed. By the early 1970s, cross-fertilisation with the emerging discipline of AI resulted in the adoption of the rule-based method for musical composition. In addition, more sophisticated programming methods, such as object-oriented programming, were introduced. Style imitation remained at the heart of much work [2,3].

However, tools for exploring musical decision making were now available because expert systems allow for automatic tracing of the computational process. More importantly, composers could learn about their own musical objectives from the circular process of rule specification and an understanding of the consequences of the rules. One of the strongest arguments for using computers in the arts is that these media allow for gradual specification of objectives. The potential of an idea is often unclear at the start of a programming session. Once implemented, the idea may be evaluated, i.e. interesting discoveries are made, or the idea may prove to lead nowhere and result in it being rejected as useless.

Expert systems have led to powerful statements in the arts in general; consider, for instance, the knowledge-based drawings of Cohen [4] and intricate compositions guided by very high level musical abstractions [5]. Many visual artists continue to see computer media, unlike music, as tools, and have little interest in process-oriented production methods. Cognitive approaches remain sporadic. In music, expert system technology, which introduces very high levels of abstraction within the human-machine dialogue, has proven to be useful for the creation of composers' assistants and intelligent sound editors. In interactive composing, so-called pattern-directed inference systems allow for real-time composition following a scenario of rules while at the same time keeping channels open for perception and interpretation of outside influence. These programs are capable of expressing an individual musical character while simultaneously accommodating requests for attention of an external, human musician [6]. The flexibility of the program is determined by its responsiveness and ease of adaptation to large changes in a musical context. For instance, a reflex reaction in the machine-musician is needed to accommodate sudden, unexpected dramatic increases in the complexity of musical material suggested by the human-musician. However, a clear definition and concise description of the problem area is needed for real-time performance. In addition, only simple representation methods and efficient search techniques can lead to successful applications. Rule-based systems represent aspects of the world in symbolic form. Problem-solving behaviour, as observed in human experts, is reconstructed in a program that reasons and searches through this symbolic space. Logical inference is at the heart of these programs.

Complex Dynamics

In recent years, two observations have led to the consideration of alternative programming methods in AI. Firstly, conventional expert systems remain helpless when faced with situations in which knowledge is missing or incomplete. Moreover, expert systems are constructed 'by hand', and the expected performance of the system has to be formulated in explicit statements. At a certain level of complexity, it becomes very difficult to keep track of this performance and to debug such systems. In summary, traditional expert systems do not show graceful degradation when situations occur that were not anticipated by the system's designer, and the programmer forces a complexity barrier.

Secondly, observation of the pattern-making potential of nature has led to the investigation of the constructive forces behind forms of natural organization. For instance, organized patterns are created spontaneously in biological workspaces. Consider the self-organizing behaviour in societies of termites; large artefact are constructed without any plan indicating which actions should be taken and when. Snow crystals are a combination of order and disorder; they grow according to the delicate interplay of microscopic and macroscopic forces. The geometry of nature was put in perspective [7] by drawing attention to the fractal dimension of naturally grown shapes. These are said to be scale-invariant, which means that detail is everywhere and one observes more detail as one approaches the shape. I suggest viewing this as a metaphor for zooming in on complexity as such because our appreciation of artefact seems strongly influenced by the dynamic interplay between the detection of detail and the simultaneous perception of overall appearance.

In addition, the dynamics of shifting focus in and out within the process of creation is characteristic of an exploratory attitude; scrutiny of detail may lead to better understanding of the overall problem at hand. The most popular images of chaos are mathematical formulae expressing fractals as a static generator of visual design, in sharp contrast to the image of dynamic systems as a metaphor for exploration and discovery. Natural dynamics can be observed in many other fields, such as biochemistry, ecology, biology, fluid dynamics, neuroscience and nonlinear mathematics. Any system consisting of many properties evolving in parallel over time may be considered complex if it exhibits emergent properties. Emergent properties are sudden, spontaneous structural changes in a system that is out of equilibrium and in constant interaction with its environment. Such patterns—which can be referred to as dissipative structures—in time and/or space are a product of self-organization [8].

Behaviour

Optimally, composers will avoid the problems mentioned above, instead borrowing generative principles from examples found in nature. In addition, as an artist, I am more interested in models of evolution and change than in theories of structural design. What can we learn from the creative forces shaping the natural phenomena within the realm of our objective: the introduction of aspects of human creativity to artificial computer music systems? Current approaches to this problem are strongly polarized. Some express faith in symbolic computing, adhering to knowledge-based strategies of problem solving [9]. Others claim that only a behavioural approach using methods of subsymbolic computing can lead to successful results when modelling aspects of human musical cognition [10]. We will examine the strength and weakness of both approaches from the standpoint of pragmatic experimentation in the problem domain of real-time improvisation and interactive composing. The differences are briefly summarized in simple terms as follows.

Symbolic computing is based on the exploitation of knowledge stated explicitly as facts and rules that act upon symbols under the guidance of a supervising mechanism. Subsymbolic methods use analogical representations, which keep what they represent implicit in their representation. Examples are regular arrays as seen in cellular automata and matrixes expressing weights in connective networks. Such distributed representations are attractive because of their direct visual appeal: what you see is what you get. The activity in these systems is no longer guided by a supervisor, but issues from the local interaction of many participating agents. The distinction between knowledge-based and behaviour-based intelligence is important. For instance, when designing a building, architects draw on knowledge of materials, construction practice, financial considerations, etc. They know how to tackle very specific problems by reasoning and making choices. However, they do not use similar knowledge to express themselves in words when they speak about their problem.

Speech, perception and locomotion are examples when behaviour is at the heart of the activity. Improvisational jazz music exemplifies this type of intelligence; the musical intensity of a virtuoso keyboard improvisation has more to do with spontaneous motor control than with declarative knowledge of musical scales. Some cultures emancipate the behavioural idea to its fullest. According to Indian musical practice, musicians must study ragas for 20 years, yet when they go on stage, they forget everything they know and just 'let it happen'. In the Indian language this is called *uppaj*, which means 'imagination' or 'flying like a bird'. Cognitive activity during real-time interactive composition includes perception, imagination and reaction. Behavioural strategies seem appropriate here since they can establish a direct relationship between perception and action. It takes too much time to interpret auditory stimuli using search-and-mapping-over symbolic representations. In addition, within the process of 'social' interaction between human and machine, the flux of relationships between performer and computer program may be totally unpredictable.

CREATIVITY

So far, we have traced the AI context of our basic problem: the construction of intelligent systems for musical composition while insisting that the system exhibit aspects of creativity. A creative statement should be new and useful. Something new raises questions in the perceiver. Fundamental questions, therefore, are products of advanced creativity. If we expect new ideas, would a program functioning as the logical consequence of a set of rules be considered creative? For instance, Chomsky's theoretical work on generative grammars was inspirational for computer-based musical composition [11] and computer-aided visualization [12]. Grammars are devices for advanced productivity, but human creativity is needed to design them. One may add metalevel reasoning about the rules in order to change and adapt them according to the circumstances they generate. Again, methods of circular thinking are characteristic of human creative behaviour. Ultimate creativity seems connected to the discovery of new paradigms, new ideas that go beyond the potential embedded in rules.

Creativity may be seen as searching through a very large problem space [13]. However, focus in a creative process is mobile. Perhaps a programmer finds a solution for a problem that he or she had not anticipated—and the original problem is forgotten altogether. In other words, creativity is an unpredictable, nonlinear process. Incidentally, nonlinearity also happens to be a native characteristic of complex dynamic systems. In a broader context, true creativity has more to do with self-revision than with self-confirmation, i.e. the application of procedures, ideas, etc., that have proven to be useful in the past. One way to introduce unpredictability is the use of random numbers. Randomness is often used to simulate musical intuition. However, total randomness, like absolute repetition or total predictability, does not carry much meaning. Paradoxically, while some artists express faith that chance procedures may help people to generate ideas and creative playfulness, others view it in opposite terms. Surrealist artists felt that random techniques assured the exclusion of personal involvement and intuition from the creative process. In interactive composing, the illusion of musical intelligence is a by-product of minimal decision making. Randomness injects energy; it tries to activate all available levels of activity in a given software-defined process. Interactive composing allows motor activity from a human performer to adjust levels and degrees of freedom.

It is important to note that interaction happens in real time; a composition emerges from intimate human-machine interaction. The performer/composer provides feedback to a generative process of his or her own design; the emergence of musical shapes in this abstract, conversational process may be taken literally in the light of emergent properties in complex dynamic systems. Random methods involve selection by imposing constraints on the output of random generators. Grammars, as mentioned above, are examples of constraints imposed at the generative level. In interactive composing, we should be able to provide feedback to such programs. Predetermined rules and constraints would be optimized according to continuous evaluation at both sides of the screen; first, the program should learn which suggestions are more successful than others, and, second, the performer would learn about the current direction of his or her musical objectives.

Such natural awareness of unspoken relationships is still unique to human ensemble improvisation. Here, appreciation of human musical intelligence includes awareness of a collective physicality in which musical intensity radiates from unspoken, deep rules/constraints imposed by culture as well as by the topology of the human body. By the way, considerations of physical parameters are extremely well developed in ultra low-technology environments (such as those found in ethnic music), overdeveloped in many popular musical id-

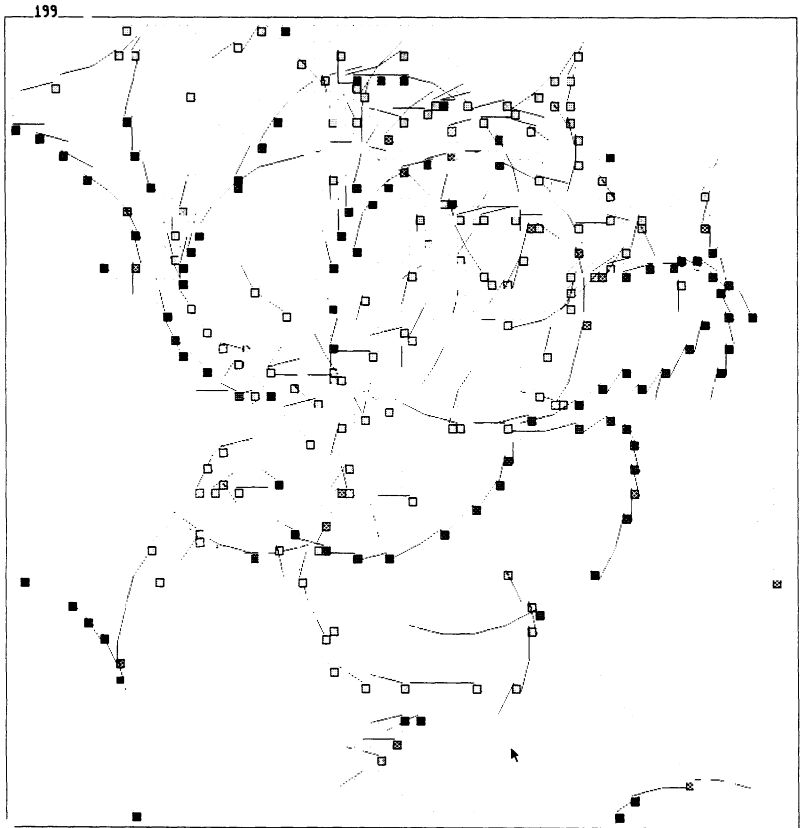


Fig. 2. Tracing activity in a spatial model. This figure shows the state of affairs after approximately 100 generations of eight agents moving in two-dimensional space. All agents express individual affinities for integration and expression toward all other agents in this virtual society. In addition, agents interact (execute simple rules) when navigating in each other's neighborhood. As a result, complex macroscopic behaviour results from simple microscopic activity.

ioms, and often underdeveloped in the avant-garde.

HEURISTICS

The task of simulating human musical creativity has been recognized as very difficult—if not impossible. In the context of advanced knowledge-based programming methods, composition may be seen as a problem-solving process. A solution is found for a given musical problem by exploring a very large search space. Since the search space is by far too large to be explored by exhaustive search, specialized short cuts, known as heuristics, are needed. Heuristics are formalized in rules that dictate what to do given certain circumstances; rules can be thought of as surface knowledge. However, the deeper knowledge consists of the constraints that are based on the physical properties of musical material or on a particular aesthetic theory [14]. Composing means scanning a search space looking for a musical structure that satisfies the constraints. This involves the creation of a schedule [15], prioritizing all available options from most desirable to least desirable. The program then evaluates this schedule to find an option that satisfies all constraints. If no single option proves acceptable, the program resorts to backtracking, trying to revise previous decisions in the decision tree and then to obtain a valid solution from there.

Expert composers exhibit a highly developed, natural sense for applying appropriate heuristics facing given constraints. This expert knowledge is extremely difficult to capture in the process of knowledge acquisition because it occurs on the subconscious rather than the conscious level. This leads many to believe that artificial approaches to creativity are doomed to fail since they lack expert knowledge in the form of musical consciousness or intuition, which are prerequisites for true imagination. However, intensive work in the field of machine learning reveals the potential of having programs learn their own heuristics, leading to second-generation expert systems [16]. The idea is to automatically build up a heuristic knowledge base through introspection of the program's own problem-solving behaviour. This seems absolutely necessary since heuristics are not consciously available. In addition, we know that even if heuristics were available, they would be too complex. This is one of the reasons, apart from the introduction of learning, that led to the consideration of a completely different, programming paradigm suggested by interesting behaviour in complex systems.

Explorers of nonlinear systems believe that the laws of unpredictability, chaos and irreversible time are keys to natural creativity—the ultimate example might be the emergence of life through natural selection, a process by which the nonequilibrium dynamics of the environment lead to self-organized structure. Prigogine [17] even suggests the concept of an entropy barrier, meaning that any system of sufficient complexity will become unstable, losing its initial conditions, and will behave unpredictably. With such systems, time is irreversible—it is impossible to backtrack previous states; there are too many. This is easily and convincingly demonstrated, even with simple cellular automata rules like those found in Conway's Game of Life. Life is a computer game played on a two-dimensional array. Its output can be very unpredictable in spite of its very simple rules. Each cell may be 1 or 0, i.e. live or dead. At any moment in time, the next generation is computed from interpretation of the current generation. The same rule is applied to every cell, and a cell is born or dies according to the evaluation of its neighborhood cells. For instance, if a cell has exactly three 'on' neighbors, the cell will be on in the next generation. Life is not backwardly deterministic—a given pattern often has many patterns that may have preceded it. A pattern has only one future but many possible pasts. The recognition of probabilistic evolution and chaotic propagation as driving forces in creative processes contrasts sharply with the reductionist view of creativity.

Randomness and Chance

In a complex dynamic system, randomness may be used to explore all degrees of freedom potentially available to the system. However, principles other than constraint-based critical filtering stimulate the birth of automatic musical structures. These principles include self-organization, activation/inhibition, spreading activation and relaxation. Dynamic systems are useful because of their inherent flexibility and speed of reaction (when compared to rule-based systems), because they are adaptive by nature and because they use distributed ways of knowledge representation (more robust than rule-based systems), in addition to allowing the conception and control over musical structures in terms of underlying images of these structures. These images, known as analogical representations, let us grasp the effect of generative principles in a single picture. In addition, gestural techniques, which are common practice in computer graphics (e.g. pointing, dragging), may act directly upon these images. In fact, any sensory mechanism may be mapped to such representations. For example, in a recent piece for infrared violin with computer extensions [18], sequential melodic material as extracted from physical gestures on the instrument was accumulated in a transition network. This network activates a two-dimensional cellular automaton. Simple local rules push global overall structures to surface. These are then interpreted by a rule-based algorithm that arranges for automatic orchestration of the original monophonic lines into full 8-voice polyphony. The system exhibits attractors because points of relative stability fluctuate through time and space. The output of such systems ranges from quasi-periodic oscillations to the building up of strange attractors due to internal feedback (Fig. 1).

We have studied many methods for acquiring spontaneous activity in environments for interactive composing, including one-dimensional cellular automata [19], direct computer simulation of nonlinearity as observed in biochemical processes and a spatial model [20]. The latter case is an example of a combination of constraint-satisfaction and local operations: abstract musical entities, uniquely defined 'actors', express opinions about each other and interact in two-dimensional space. This micro-world accommodates external gestures from the composer. Strange patterns of variable coherence emerge as a result of both internal spontaneous activity and external goal-directed activity. Figure 2 provides a snapshot of eight interacting agents taken after about 100 generations. As a final example we will briefly describe yet another model, inspired by research in fluid dynamics. This is an example of activation/inhibition.

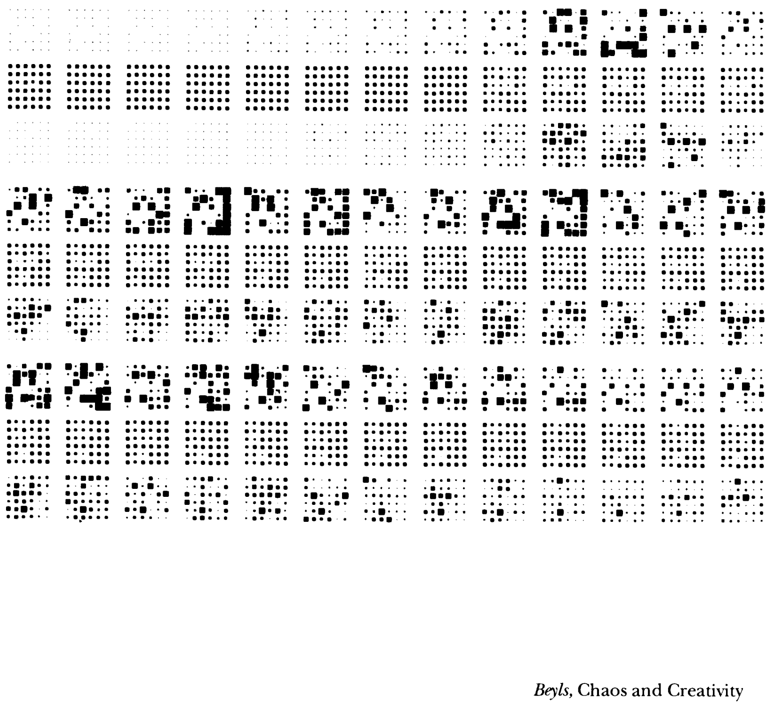
A Connective Model

The initial idea for the current model came from the appreciation of strange phenomena in fluid dynamics such as Benard convection [21] and the dripping faucet experiment [22]. Such systems allow gradual degrees of complexity through the control of a single external parameter. The suggested model is a connective structure. It is a specialized cellular automaton, a micro-world represented as a regular array of cells, with each cell representing a 'virtual musician'. Cells are active units called 'agents', according to the terminology suggested by Minsky [23]. These are very simple in themselves, but collective complexity results from their mutual interaction combined with external influences. We proceed as follows:

1. Design a simple agent, i.e. definition of a native character.
2. Create initial random affinities between agents.
3. Specify global constraints acting as global parameters.
4. Provide gestural input to particular (groups of) agents.

The resulting behaviour is mapped to the problem, creating musical structures from emergent properties in a complex dynamic system. The system is a collective of agents exhibiting evolving connections among each other. Any two agents connect if they exhibit sufficient affinity toward each other. The other attributes of the agents include individual levels of activation and inhibition, energy and position in space. The principle responsible for pattern formation in such organized networks is known as 'spreading activation'. Agents are thus linked in a network, the links being of variable strength because every agent features an activation level and an inhibition level. The motional flexibility of the agent is a function of its level of activation, which is in turn a nonlinear function of external constraints. In addition, the system as a whole dissipates energy, and the value of the dissipation factor introduces variable inertia. Figure 3 illustrates the dynamics of 36 agents organized in a regular 6-by-6 array, with time running left to right, top to bottom. Activation, inhibition and local gradient (tension) are shown for 39 generations. Notice peculiar, oscillatory behaviour and how the system moves to a different limit cycle

Fig. 3. Activation/inhibition in regular structure. Per generation, levels of activation, inhibition and gradient field are visualized.



from the accommodation of external disturbances at generations 10 and 24.

CONCLUSION

Does it make sense to view the disorderly behaviour of complex systems as manifestations of true creativity? For the mathematician, the concise formulation of some complex, physical phenomenon in a neat, compact, simple formula may be experienced as an aesthetic artefact. The overwhelming visual complexity of fractal pictures is intriguing. However, our focus should be not on visual appeal but on what these pictures represent. In addition, computer simulations demonstrate the unexpected behaviour of chaotic systems—the delicate interplay of chance and determinism; that is, possibilities are discovered in retrospect. Self-organization may be seen as a powerful alternative to the constructivist approach in musical composition. We no longer specify recipes for the critical assembly of musical atoms, e.g. the hierarchical structuring of notes, phrases, etc. Here, composition is seen as the architecture of time. In contrast, we aim for spontaneous pattern formation from experimentation with attractor systems. This experimental attitude is strongly related to the invention of hypothetical worlds of which the composer is both inventor and explorer. Composition thus becomes navigation in an attractor field—the interactive, conversational exploration of levels of stability and sensitivity. In essence, we observe a continuous confrontation of two dynamic systems; one is embedded in a computer program, the other is present in the composer's opinion and reaction to its current output. Since the interaction relies heavily on real-time visualization, it is a good example of the integration of computer music and computer graphics.

Acknowledgments

I am indebted to the complex dynamics group at the AI lab of Brussels University for instructive feedback. Work described in this paper is supported by Yamaha and Atari Corporation.

References and Notes

1. L. Hiller and L. Isaacson, *Experimental Music* (New York: McGraw-Hill, 1959).

2. C. Fry, "The Flavors Band: A Language for Specifying Musical Style", *Computer Music Journal* **8**, No. 4 (1984).

3. D. Cope, "Experiments in Musical Intelligence, On-Linear, Linguistic-Based Composition," *Interface* **18**, No. 1–2 (1977).

4. H. Cohen, "What Is an Image?", *Proceedings of the International Joint Conference on Artificial Intelligence Conference* (Tokyo: IJCAI, 1979).

5. C. Barlow, *Journey to Parametron* (Cologne, Germany: Feedback Editions, 1988).

6. P. Beyls, "Introducing Oscar", *Proceedings of the International Computer Music Conference* (Cologne: Feedback Editions, 1988). See also P. Beyls, "Musical Morphologies from Self-Organizing Systems", *Interface* **19** (1988).

7. B. Mandelbrojt, *The Fractal Geometry of Nature* (San Francisco: Freeman, 1977).

8. I. Prigogine and I. Stengers, *Order Out of Chaos* (Bantam, 1984).

9. O. Laske, "Articulating Musical Intuitions by Way of Rules", *Proceedings of the International Workshop in Artificial Intelligence and Music* (Detroit, MI: IJCAI, 1989).

10. M. Lehman, "Symbolic and Subsymbolic Information Processing in Models of Musical Communication and Cognition", *Interface* **18**, No. 1–2 (1989).

11. C. Roads, *Grammars as Representations for Music: Foundations of Computer Music* (Cambridge, MA: MIT Press, 1985).

12. A. R. Smith, "Plants, Fractals and Formal Languages", *Computer Graphics*, Siggraph Conference, **18**, No. 3 (1984).

13. L. Steels, "Learning the Craft of Musical Composition", *Proceedings of the ICMC* (The Hague, The Netherlands: ICMC, 1986).

14. L. Steels, "Artificial Intelligence and Complex Dynamics", *AI Memo* (Brussels: Vrije Universiteit, 1984).

15. C. Ames, "Stylistic Automata in Gradient", *Computer Music Journal* **7**, No. 4 (1983).

16. L. Steels and W. Van de Velde, "Second Generation Expert Systems", *Journal on Future Generation Computer Systems* **1**, No. 4 (1986).

17. Prigogine and Stengers [8].

18. P. Beyls, "The Musical Universe of Cellular Automata", *Proceedings of the ICMC* (Columbus, OH: ICMC, 1989).

19. Beyls [18].

20. P. Beyls, "Subsymbolic Approaches to Musical Composition: A Behavioural Model", *Proceedings of the ICMC* (Glasgow: ICMC, 1990).

21. A. Babloyantz, *Molecules, Dynamics and Life: An Introduction to the Self-Organization of Matter* (New York: John Wiley and Sons, 1986).

22. S. Wolfram, "Computer Software in Science and Mathematics", *Scientific American* (March 1984).

23. M. Minsky, *The Society of Mind* (New York: Simon and Schuster, 1986).