# Towards an Artificial Life Approach to the Origins of Music

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**Abstract**

We are investigating how musical forms may originate and evolve in artificially created worlds inhabited by virtual communities of musicians and listeners. Origins and evolution are not, however, studied here in the context of genetic mutations, but rather in the context of cultural conventions. We consider that variations in musical styles, for example, result from the emergence of new rules and/or from the shifting of existing conventions for *music making*. In this paper we introduce fundamental theoretical and philosophical issues that substantiate our research.

## 1 INTRODUCTION

In the editorial of the first issue of the journal *Artificial Life and Robotics*, John Casti draws our attention to a shift that is occurring in scientific research methodology which will certainly play a key role in the Arts and Sciences of the twenty- first century: Casti observes that Science is increasingly shifting its attention from *matter* to *information* (Casti, 1997). He observes that contemporary Science is no longer primarily concerned with the study of the material composition of nature, but rather with the study of the functional characteristics of its tangled systems, most notably the interaction between the components of a system, the interconnection of different systems and the emergence of global behaviour. Thanks to computer technology, scientists can now create surrogate artificial worlds to perform very complex experiments that would otherwise be impossible to perform. These artificial worlds are analogous to the more familiar laboratories (test tubes, retorts, etc.) used by scientists for centuries to investigate the structure of atoms, chemical components, cells, and so forth; the main difference is that these artificial worlds are used to simulate natural phenomena in order to study them in terms of the functional activity carried by patterns of information. The emergence of fields such as Artificial Life (Alife), for example, is a natural consequence of this shift of paradigms.

*Alife* is a discipline that studies natural living systems by simulating their biological phenomena *in silico* (Langton and Shimohara, 1997; Olson, 1997). The attempt to mimic biological phenomena on computers is proving to be a viable route for a better theoretical understanding of living organisms, let alone the practical applications of biological principles for technology (robotics, nanotechnology, etc.) and medicine. Because Alife is dealing with very complex phenomena, its development has fostered the creation of a pool of research tools for studying complexity. It is interesting though, that these tools are also proving to be useful in fields other than Biology, most notably Social Sciences (Epstein and Axtell, 1996) and Linguistics (Steels, 1997b; 1997d). In this essay we propose that the Alife paradigm also has great potential for Musicology.

We are investigating how musical forms may originate and evolve in artificially created worlds inhabited by virtual communities of musicians and listeners. Origins and evolution are not, however, studied here in the context of genetic mutations, but rather in the context of cultural conventions. We consider that variations in musical styles, for example, result from the emergence of new rules and/or from the shifting of existing conventions for *music making* (the term “music making” is used here to mean both creating music and listening to music). Musical styles maintain their organisation within a cultural framework and yet they are highly dynamic; they are constantly evolving and adapting to new cultural situations (Reck, 1997). Whilst the criteria for natural selection in Biology are chiefly based upon physical fitness and reproductive capability, in Music these criteria will depend upon on the effects of the new rules on the music making experience.

In this context, musical forms can be studied as live organisms and as such Musicology can benefit hugely from Alife’s research paradigms. Particularly interesting paradigms that have emerged recently include *genetic algorithms* (Koza, 1992), *cellular automata* (Ermentrout and Edelstein-Keshet, 1993; Wolfram, 1994), *evolutionary modelling* (Epstein and Axtell, 1996) and *autonomous robots* (Steels and Brooks, 1995), to cite but a few. Indeed, several musicological investigations have already begun to look closely at these developments, notably by composers interested in the organisation principles that underlie Alife-based pattern-generation algorithms (Degazio, in this book; McAlpine *et al.*, 1999; Miranda, 1993; 1994). We have come to believe, however, that the great potential of Alife for Musicology has yet to be explored: *evolutionary modelling*. Our hypothesis is that the mechanisms for generating complexity commonly found in biological systems may also explain the spontaneous origins and evolution of musical forms.

Most of this essay sets the background scenario of our research. The elements of this scenario include Wittgenstein, talking chimpanzees, babbling babies and a couple of philosophers of the French Enlightenment. As we shed light onto the various points of this rather eclectic scenario, we hope to clarify various fundamental issues that underlie our work. Here we focus mainly on the importance of the interplay between language and music, and the reasons for taking on board the Alife paradigm. Next we introduce the notion of evolutionary modelling and discuss its fundamental mechanisms, followed by some concluding comments.

## 2 LANGUAGE GAMES AND THE ORIGINS OF MEANING

In *Philosophical Investigations*, Wittgenstein (1963) proposes the notion of language games: simple linguistic plots specifically designed to illustrate particular points he wanted to make. At the start of his book, Wittgenstein proposes a simple language game as follows: imagine a language that is meant to serve for communication between a builder and his assistant. The builder is constructing a castle with building-stones: there are blocks, pillars, slabs and beams. The assistant has to pass him the stones, and in the order in which the builder needs them. For this purpose they use a language consisting of the words: "block", "pillar", "slab" and "beam". The builder calls them out and the assistant brings the respective material he has learned to bring, in compliance to such-and-such a call. When the builder says "block", for example, he causes an action to take place; the success of this action is conditioned to the fact that the assistant passes a block to the builder.

As far as the builder is concerned, it is sufficient that the assistant has learned only these four words without learning the all of the English language. The point that Wittgenstein wanted to illustrate with this simple game is that, in principle, the assistant could have learned the language only by associating words with actions and not with labelled pictures of different stones that may or may not appear "catalogued" in his mind. The indication that the assistant has learned the meaning of the words is given when he performs the right actions. To put it simply, Wittgenstein's point is that words (and sentences, for that matter) have meaning only when they have a role in specific contexts within the web of human activities.

Although Wittgenstein was not primarily concerned with the philosophy of language himself, his notions of *language games* and of the *action- based origins of meaning* have made a great impact on our research.

## 3 CAN SARAH BUILD CASTLES IN SPAIN?

Scientists' efforts to teach language to chimpanzees have made tremendous progress since the 1960s. Chimpanzees such as Sarah, Nim Chimpski, Washoe, and Kanzi (Premak, 1976; Terrace, 1979; Gardner and Gardner, 1989; Savage- Rumbaugh and Lewin, 1994) caught the imagination of the world for having learned to play rather sophisticated language games with their tutors. Washoe, for example, was reported to be able to communicate with her teacher by means of simple gesticulation sequences made from a repertoire of over one hundred signals (similar to the signals of the American sign language devised for the deaf). More recently, Kanzi has been featured in the news media interacting with a person on the telephone, using a talking keyboard (Bindon, 1998). These apes have demonstrated their capacity to learn some primitive form of human communication, including evidence that they can spontaneously create new "meaningful" combinations of signs and that one chimpanzee can indeed pick up the language simply by watching their peer chimpanzees using it.

Even though some may still argue that these chimpanzees have simply learned to play with signs in order to please their teachers and get some form of reward, these experiments address important issues concerning the development of language in early humans, let alone the pedagogic techniques for teaching apes that were developed; e.g., Primack's *reinforcement principle* (Primack, 1963). Perhaps the most important issue that has been addressed here is the orthodox linguistic scholar's belief that there is a missing link, that is, an unbridgeable divide between humans and the rest of the animal kingdom. These experiments with apes strongly suggest that the difference may rather be a matter of a gradation of linguistic capacity; that is, we humans are better at learning to speak, at using symbols, at acquiring a grammar and at using it to generate complex sentences, and so on.

In this context, language is better seen as a cultural phenomenon that emerges from sociological interactions, rather than as a ready-made feature of the infant's brain. Humans learn a language by engaging in countless language games, for all kinds of situations. As the games and situations become increasingly complex, children develop a myriad of multi-layered networks of utterances and meanings, and engage in increasingly advanced forms of linguistic understanding. Terms that are learned in more rudimentary games become part of higher-level contexts, and vice-versa. A child that learns to play a "building" game by putting Lego bricks together in order to build a toy castle, for example, will soon build other structures spontaneously and will probably also experience the concept of a castle in another context. This child will then develop the capacity to transfer the meaning from specific games to other contexts, and so forth. Linguistic maturity then is reached when one is capable of making sense of metaphorical settings; for instance, the English expression "to build castles in Spain" denotes a dream that is very unlikely to be realised.

In principle, chimpanzees could learn to build a castle, but not in metaphorical Spain. The point we want to raise here is that even though scientists manage to make further progress in teaching language to apes, we believe that this sort of "apeish" linguistic ability is not sufficient to study the intellectual capacity found in humans.

## 4 BABBLING IS MUSIC

But what are the limitations of apes? Why do we have such amazing intellectual capacity? Attempts to answer these questions abound in literature: apes are not intelligent enough because their brains are too small (Deacon, 1997); the vocal tracts of monkeys were not designed for speech (Lieberman, 1984); humans developed language because our sophisticated sensory-motor ability allows for better management of time and space (Calvin, 1983); chimpanzees do not have the "language organ" (Chomsky, 1980); to cite but a few. These are by all means plausible hypotheses, but they certainly do not work in isolation; these features must have coevolved. For instance, as the brain of Neanderthal man increased in size, a resonating chamber emerged in the mouth and the position of the larynx was lowered, and our sensory-motor system was improved, all resulting in a suitable physical platform for spoken language. We believe, however, that there is an important component of this coevolution phenomenon that has been largely ignored by our fellow researchers: *music*.

Music is one of the most intriguing phenomena of the human kind. Our sensitivity to timing and imitation, our tendency for imposing order on auditory information, our ability to categorise sound, our tendency to recognise and imitate sound patterning, and so on, are all unique to humans (Storr, 1993). These are essentially musical abilities that form an ideal platform for language development. We believe that the bipartite functioning of our hearing system is the crux of this musical platform: babies are generally more sensitive to *rhythmic patterns* in the left ear and to *pitch* and *timbre* in the right ear (Best, 1988).

As a rough scenario to illustrate our hypothesis, let us consider the fact that babies have a unique disposition to extract little chunks of sounds from the undulating patterns of speech and to imitate these sounds (Jusczyk, 1997). In order to extract these little chunks of sounds, the left ear seeks timing cues in the signal; e.g., starting and ending of longer periodical signals (e.g., vowels) demarcated by short non-periodical bursts of energy (e.g., consonants). The task of the right ear is to listen for sound colouration cues such as the tone of the voice and the melodic contour of the utterances. Indeed, babies do seem to respond better to clearly articulated syllables and exaggerated melodic contours. In the early months, the only response babies can make to heard utterances is to babble; this is because they are still learning how to play with the raw building materials of language. (Virtually all human babies babble; even deaf children seem to babble with their hands.) During this learning process babies develop their neural and muscular apparatus, firstly by learning how to recognise utterances and then by trying to imitate them. Preferences for listening to and imitating the sounds of the mother tongue begin to emerge due to positive feedback responses which babies receive from their interlocutors. Sooner or later children start to form lexicons, to make sentences, shape grammars, and to engage in increasingly sophisticated linguistic experiences.

We by no means assume that people are born with a ready-made music machine. What we are suggesting here is that our musical predisposition forms the basis for the development of the sophisticated discrimination and categorisation machinery that are very important for language. But our musicality, so to speak, develops together with language as we grow up.

## 5 EARLY PHILSOPHY DOES MAKE SENSE

The notion that our linguistic capacity is closely related to our ability to both make and appreciate music was prominent in Enlightenment thinking in the eighteenth century (Thomas, 1995). Reflections on how primordial utterances, cries and vocalisations would have evolved into language naturally brought musical considerations within the scope of the writings of philosophers such as Condillac and Rousseau.

Condillac in his *Essay on the Origins of Human Knowledge* depicted the earliest spoken language as being composed of action-orientated vocal inflections such as warnings, cries for help, shouts of joy, etc. (Thomas, 1995). But most interestingly, Condillac proposed that these inflexions were accompanied by variations in pitch and timbre. In short, he suggested that the early hominids did not prioritise the invention of different "words", but tended to produce the same form of utterance at different tones in order to express different things;

presumably by varying pitch, loudness and duration. Condillac thus suggested that primordial languages did not have consonants but vowel-like intonations. The prosody of earlier languages must have sounded like a kind of primitive song (Arbo, 1998).

Rousseau also purported the idea that language is derived from natural sounds produced by our vocal organs. For Rousseau, however, song and speech have a common ground: *passion*. In the beginning, vocal utterances expressed primarily feelings (e.g., "I am sad."), whilst gestures were normally preferred to express rational thoughts (e.g., "Go hunting, I am hungry!"). Rousseau agrees with Condillac that primeval spoken languages must have sounded like melodies of vowel-like utterances, but Rousseau has an interesting story for the emergence of consonants: as hominids' dealings with one another grew in complexity, spoken language needed to become less passionate and more precise. In his *Essay on the Origins of Language* Rousseau argues that language was motivated by the increasing necessity for social bonding (Thomas, 1995). Within this bonding process, the amount of tone variations decreased, giving rise to the appearance of consonants. New articulations needed to be formed, and consequently grammatical rules for making sequences of utterances soon emerged. For Rousseau, modern languages (such as his own mother tongue French) no longer spoke to the heart alone, but also to reason. As language followed the path of logical argumentation, those melodic aspects of the primordial utterances evolved into music instead. Music thus developed from the sounds of passionate speech.

Although dating back to the eighteenth century, these two philosophers' conjectures do continue to make sense to a certain extent. For instance, some non-Western languages, such as Chinese, have mechanisms in which multiple intonations of the same word convey different meanings. This is not to say that Chinese is primitive or less rational, but rather to indicate that the Chinese language took a different route. More recently, researchers found out that the structure of Neanderthal man's vocal tract could not produce plosive consonants such as /k/ and /g/ but it could produce almost all vowels, except /i/, /u/ and /a/ (Lieberman, 1998). Interesting though is that the most difficult vowels for the Neanderthal man, that is /i/, /u/ and /a/, are the ones that appear in an average of 85% of more than 300 recently catalogued human languages (Maddieson, 1984; Ladefoged and Maddieson, 1996).

Since Condillac and Rousseau, the relationship between the origins of language and music has hardly been systematically addressed again. Their writings seem to have been overshadowed by the Romanticism that prevailed in Europe in the nineteenth century, most notably in music; influential philosophers who were interested in music often associated its origins with the mystical, the ineffable and the hidden (Monelle, 1992). Indeed, in the 1880s, the prestigious Linguistic Society of Paris sought to impose a ban on the theme of the origins due to a wave of wild unsupported writings that appeared at the time.

## 6 EVOLUTIONARY MODELLING

Thanks to the evolutionary modelling techniques that emerged from Alife research, the Enlightenment's quest for gaining a better understanding of the origins of language is now being brought back into play with a promising agenda (Noble and Cliff, 1996; Steels, 1997a; Arita and Koyama, 1998) and music will undoubtedly play a key role in this research. Furthermore, the investigation of the role of music in the evolution of language inevitably urges musicologists in the pursuit of the *origins of music* itself.

Music can be modelled as an adaptive system of sounds used by a number of individuals, or *distributed agents* in computer science jargon, engaged in a collective music making experience; some may only listen to the sounds ("audience") while others may be fully engaged in the generative process ("musicians"). Our hypothesis is that music emerges from the interaction of the agents when they engage in such music making experiences. There is no "global" supervision taking place and the agents do not have direct access to the musical knowledge of the other agents, apart from hearing what they actually do during the interactions. This model could be metaphorically compared to a jam session in a jazz club, where people, who have not necessarily met before, can join in and play, or simply watch. A contrasting scenario would be an orchestral concert where musicians follow a common score under the direction of a conductor; in this case we would say that there is very little room for music evolution.

On the opening pages of the first issue of *Evolution of Communication Journal*, Luc Steels proposes four fundamental mechanisms for studying the origins of language: *evolution*, *coevolution*, *self-organisation* and *level formation* (Steels, 1997b). As these mechanisms also seem to work well for the study of other cultural phenomena, we have taken them as the starting point of our research into the origins of music.

Before we discuss these mechanisms, it is important to clarify the contexts in which the term “evolution” appears in our research. In Natural History, evolution is frequently associated with the idea of transition from an inferior species to a superior one. It is also generally assumed that this transition is accompanied by an increase in the species' complexity. The Darwinian argument that humans originated from anthropoid apes is a typical example of this approach to evolution. Indeed, this approach made a serious impact on nineteenth century Cultural Anthropology, which maintained that human kind has become increasingly sophisticated during the “linear” course of history. The legacy of this argument is the general popular belief that the Stone Age, for example, represents far less sophistication than the Iron Age (Ullmann, 1983).

This approach to evolution suffers from taking for granted that one can "measure" evolution entirely based on materialistic criteria. For example, one should not take for granted that European classical music is more sophisticated than African drumming solely based on the technological sophistication of the instrument used. The rudimentary technological development of most non-European societies (e.g., Pygmies) gave rise to very sophisticated social systems and complex religious rituals. A remote community living in an environment where prey and crops abound would not be under pressure to develop sophisticated hunting weaponry or irrigation technology, for instance. These people would probably give priority to the creation of a belief system in which a religious ritual would have to be performed occasionally in order maintain the richness of their habitat.

In the context of our research, however, the term “evolution” is associated with the idea of improvement. “Coevolution” then is used to denote the concept of transition from one state of affairs to another, and is not therefore necessarily associated with the idea of improvement.

## 6.1 Transformation and Selection

When a transformation process creates variants of some type of entity, normally there is a mechanism which favours the best transformations and discards those that are considered inferior, according to certain criteria. For example, the criterion in Biology might be fitness for survival, whilst in Linguistics the selection of an utterance could involve a compromise between the effortless use of the speaker's articulatory mechanism and the degree of understanding by the listener. What is important here is that these transformations must *preserve the information* of the entity; otherwise the entity is destroyed rather than transformed.

In Music, the selection of sound objects is based upon psychoacoustics (e.g., the interplay between repetition and variation) and physical criteria (e.g., the capability of the musical instrument(s) available). These selection criteria are the crux of the design of realistic evolutionary models for Music.

A plausible methodology for studying evolutionary mechanisms in Linguistics has been proposed by Steels and co-workers (Boer, 1997; Steels and Vogt, 1997). Inspired by Wittgenstein's concept of language games, they have devised a number of different games for investigating different processes of language formation: phonology, meaning, syntax, lexicon, and so forth.

An experiment which demonstrates a plausible theory for the origins of pitch systems, such as musical scales, involving transformation and selection mechanisms will be reported in a forthcoming paper (Miranda, 1999).

## 6.2 Coevolution

Coevolution involves the interaction of various contiguous transformation and selection processes. Selection criteria are not fixed, but rather they are affected by an environment that is also in a state of flux. Whilst evolution tends to drive a system towards the improvement of particular aspects, coevolution tends to push the whole system towards greater complexity in a *co-ordinated manner*.

For example, the evolution of musical styles should normally be studied in close association with the evolution of musical instruments, and vice-versa.

As an example, consider the case of the keyboard class of instruments: the evolution of the piano is popularly associated with the settlement of the equal-temperament tuning system (a tuning system in which all notes of the scale are equally separated by exactly half a tone) and with the increasing use of expressive dynamics in compositions; the piano can produce a much wider band of variations in dynamics than the harpsichord, from extremely loud to extremely quiet notes. On the one hand, the equal-temperament system alleviated the problem of tuning different instruments in an ensemble but, on the other hand, it increased the scope for composers to explore much more complex harmonic structures in their music; e.g., the modulation to different tonal keys within the same piece (Campbell and Greated, 1987).

## 6.3 Self-organisation

The notion of self-organisation is closely related to the notion of coherence. The origins of coherence in distributed systems with many interacting agents is a vast research topic. To put it in simple terms, three ingredients are needed for self-organisation to take place in a system: (i) a set of possible variations, (ii) random fluctuations and (iii) a feedback mechanism. Random fluctuations in the system will eventually strengthen some of the fluctuations because of the feedback mechanism: the more a fluctuation is strengthened, the more predominant it becomes. As an example, imagine a musical game as follows: a group of virtual agents engage in a drumming session but none of the agents is an experienced musician; i.e., they have no musical training. Each agent can bring in a different percussion instrument but an agent must never have played its instrument before. They all agree that they should start playing sounds simultaneously in any way they wish. To begin with, they will certainly produce a highly disorganised mass of rhythms; in this case we say that the system is in equilibrium. The set of possible variations in this system is the set of all noises and rhythms that can be produced by the instruments. Next, imagine a situation in which at some point an agent A makes a very distinct sound pattern that catches the attention of a fellow agent B. The fellow agent then attempts to imitate it. The imitation may not be exact (for example, because agent B's instrument is different from agent A's one), but agent A recognises it as an imitation of the pattern and instinctively reproduces the original pattern again; that is, agent A gives a positive feedback to agent B. The other agents will probably be keen to imitate this pattern as well and variations will certainly start to emerge. After a while, the pattern that was originated by agent A, plus its variations, should become successful conventions. The next time these agents engage in a jam session they will certainly remember these and other patterns, and will probably play them during the session. The more the patterns are played, the more conventional they become. When not engaged in jam sessions, some agents may even consider adapting their instrument to better produce those patterns, whilst others will spend a great deal of effort practising ways to produce them.

The musical plot described above would equally apply to studying the emergence of spoken language, for example. In this case the agents would be engaged in linguistic communication. The need for explicit communication of rational meanings would exert pressure for the formation of different types of syntactical conventions. The intention of the social interaction defines the rules of the game: for example, in a linguistic situation, it may be better that the agents engage in a one-to-one interaction rather than in a simultaneous one. Also, the nature of the coevolutionary phenomena may differ according the intention of the game. For instance, an utterance that is difficult to produce due to the limitations of the vocal tract will have low priority for becoming part of a language, whereas in music such a limitation would be much relaxed because the agents could, for example, modify their musical instruments or even create new ones.

Most cultural phenomena seem to follow identical self-organising principles in some way; see for example an interesting account for the origins of the flamenco song style in a paper by Washabaugh (1995) that appeared in *Journal of Musicological Research*.

## 6.4 Level formation

By level formation we mean the formation of higher-level conventions, such as both semantics and syntactical conventions in language, for example.

Suppose that at some point in the musical scenario described above, agents start remembering rhythmic patterns in terms of repeated short sequences grouped together as units; for example, shorter sounds may be grouped by similarity in duration and proximity in time, and repeated patterns may be grouped as units based on their parallel structure. This figurative conceptualisation of rhythm should then yield more abstract conceptualisations such as metric rules and sense of hierarchical functionality; for example, the concept of strong beat versus weak beat (Bamberger, 1991). Multiple rhythmic conventions for groupings and hierarchical organisations would soon start to emerge in the community of agents.

## 7 CONCLUSION

Musicology can benefit hugely from Alife research. Alife researchers have developed a number of tools for studying complexity, some of which are proving to be very useful for a variety of fields other than Biology.

As we are interested in studying the origins of music, Alife paradigms such as cellular automata and evolutionary modelling have been very influential in our research. We are currently using evolutionary modelling techniques to investigate how musical forms may originate and evolve in artificially created worlds inhabited by virtual communities of musicians and listeners.

In this essay we have glanced at historical and philosophical concepts of great importance for our work, with emphasis on the notion of language games, action-based meaning formation in language, the evolution of human intelligence and some eighteenth century writings on the origins of language and music. In this overview we have stressed the importance of the interplay between language and music in our research; we have suggested that, for humans, our musical abilities are crucial for the development of our linguistic abilities, and vice-versa.

By gaining a better understanding of the origins of music we hope to not only enrich our know-how for the design of better computer music systems and interfaces, but also to broaden our understanding of human intelligence and to contribute to the shaping of the musical praxis of the twenty-first century.

## REFERENCES


Arbo, A., “La trace du son. Expression et intervalle chez Condillac”, *L’espace: Musique/Philosophie*, Chouvel, J-M. and Solomos, M. (eds.), Paris: Editions L’Harmattan, 1998.

Arita, T. and Koyama, Y., "Evolution of Linguistic Diversity in Simple Communication System", *Artificial Life*, Vol. 4, pp. 109-124, 1998.

Bamberguer, J., *The Mind Behind the Musical Ear: How Children Develop Musical Intelligence*, Cambridge (MA): Harvard University Press, 1991.

Best, C. T., "The emergence of cerebral asymetries in early human developement: A literature review and a neuroembryological model", *Brain Lateralization in Children*, 5. Molfese, D. L. and Segalowitz, S. J. (eds.), New York: The Guildford Press, 1988.

Bindon, J., *Can Chimps Talk?*, http://www.as.ua.edu/ant/bindon/ant101/syllabus/chmp_tlk/chmp_tlk.htm, 1998.

Calvin, W. H., "A Stone's Throw and its Launch Window: Timing Precision and its Implication for Language and Hominid Brains", *Journal of Theoretical Biology*, No. 104, pp. 121-135, 1983.

Capmbell, M. and Greated, C., *The Musician’s Guide to Acoustics*, London/Melbourne: Dent & Sons Ltd, 1987.

Casti, J., "Information versus matter", *Artificial Life and Robotics*, 1 (1), 1997.

Chomsky, N., "Rules and Representation", *Brain and Behavior Sciences*, Vol. 3, pp. 1-15, 1980.

Deacon, T., *The symbolic species*, New York: W. Norton and Co., 1997.

Epstein, J. M. and Axtell, R., *Growing Artificial Societies*, Cambridge (MA): The MIT Press, 1996.

Ermentrout, G. B. and Edelstein-Keshet, L., "Cellular Automata Approaches to Biological Modeling", *Journal of Theoretical Biology*, No. 160, 1993.

Gardner, R. A. and Gardner, B. T., "A Cross-Fostering Laboratory", *Teaching Sign Language to Chimpanzees*, R. A. Gardner et al. (eds.), pp. 1-28. Albany: State University of New York Press, 1989.

Jusczyk, P. W., *The discovery of spoken language*, Cambridge (MA): The MIT Press, 1997.

Koza, J., *Genetic Programming: On the Programming of Machines by Means of Natural Selection*, Cambridge (MA): The MIT Press, 1992.

Ladefoged, P. and Maddieson, I., *The Sounds of the World's Languages*, Oxford (UK): Blackwell, 1996.

Langton, C. G. and Shimohara, K. (eds.), *Artificial Live V: Proceedings of the Fifth International Workshop on the Synthesis and Simulation of Living Systems,* Cambridge (MA): The MIT Press, 1997.

Lieberman, P., *The biology and evolution of language*, Cambridge (MA): Harvard University Press, 1984.

Lieberman, P. *Eve Spoke*, London: Picador/Macmillan, 1998.

Maddieson, I., *Patterns of Sounds*, Cambridge (UK): Cambridge University Press, 1984.

McAlpine, K., Miranda, E. R. and Hoggar, S., "Composing Music with Algorithms: A Case Study System", *Computer Music Journal*, 23(2), 1999.

McIntyre, A., "Babel: a testbed for research in origins of language", *Proceedings of COLING-ACL 1998*, Montreal, 1998.

Miranda, E. R., "Cellular Automata Music: An Interdisciplinary Project", *Interface / Journal of New Music Research*, 22(1), pp.3-21, 1993.

Miranda, E. R., "Music composition using cellular automata", *Languages of Design*, Vol. 2, 1994.

Miranda, E. R., "Granular Synthesis of Sounds by Means of a Cellular Automata", *Leonardo*, 28(4), 1995a.

Miranda, E. R., "Modelling de fundamental mechanisms of musical evolution: an Artificial Life approach", *Proceedings of the ICMC'99*, Beijing, China, 1999 (to appear).

Premack, D, "Rate differential reinforcement in monkey manipulation", *Journal of the Experimental Analysis of Behaviour*, No. 6, 1963.

Premack, D., *Why Chimps Can Read*. New York: Harper & Row, 1976.

Reck, D., *Music of the Whole Earth*, New York: Da Capo Press, 1997.

Storr, A., *Music and the Mind*, London: Harper Collins, 1993.

Terrace, H. S., *Nim*, New York: Alfred A. Knopf, 1979.

Thomas, D. A., *Music and the origins of language*, Cambridge (UK): Cambridge University Press, 1995.

Ullmann, R. A., *Antropologia Cultural*, Porto Alegre: Escola Superior de Teologia São Lourenço de Brindes, 1983.

Savage-Rumbaugh, S. and Lewin, R., *Kanzi: The Ape at the Brink of the Human Mind*, New York: John Wiley & Sons, 1994.

Steels, L. and Brooks, R., (eds.) *The Artificial Life Route to Artificial Intelligence: Building Embodied Situated Agents*, Hillsdale (NJ): Lawrence Erlbaum Associates, 1995.

Steels, L. and Vogt, P., “Grounding adaptive language games in robotic agents”, *Fourth European Conference on Artificial Life - Brighton*, Husbands, P. and Harvey, I. (eds.), Cambridge (MA): The MIT Press, 1997.

Steels, L., "The Spontaneous Self-Organization of an Adaptive Language", *Machine Intelligence 15*, Muggleton, S. (ed.), Oxford: Oxford University Press, 1997a.

Steels, L., "The Synthetic Modeling of Language Origins", *Evolution of Communication Journal*, 1(1), 1997b.

Steels, L., "Synthesising the origins of language and meaning using co-evolution, self-organisation and level formation", *Evolution of Human Language*, Hutford, J. (ed.), Edinburgh: Edinburgh University Press, 1997c.

Steels, L., “Constructing and Sharing Perceptual Distinction”, *Proceedings of the European Conference on Machine Learning*, Someren, M. and Widmer, G. (eds.), Berlin: Springer-Verlag, 1997d.

Washabaugh, W., "The Politics of Passion: Flamenco, Power, and the Body", *Journal of Musicological Research*, Vol. 15, pp. 85-112, 1995.

Wittgenstein, L., *Philosophical Investigations*, Oxford (UK): Basil Blackwell, 1963.

Wolfram, S., *Cellular Automata and Complexity*, Reading (MA): Addison-Wesley, 1994.