Emergence and Generative Art

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THE CONCEPT OF EMERGENCE IN GENERATIVE ART

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Statement of originality

I declare that the research presented here is my own original work and has not been submitted to any other institution for the award of a degree.

Signed: . . . .

Date: . . . .

Abstract

Generative art is any art practice where the artist creates a process that in turn acts with some degree of autonomy to create all or part of an artwork. It represents a particularly intriguing interaction between art and science, as not only does the artist use technological means (typically computer programs), but also the art itself often relates to fundamental questions about life and what it is to be human in the face of rapid technical advance. Indeed much generative art is closely allied to the scientific discipline called Artificial Life, which asks similar questions from a scientific point of view.

A concept underlying much generative art, and the science of Artificial Life, is that of *emergence*. Broadly speaking, a system exhibits emergent behaviour if something "extra" occurs; in some sense more comes out of it than was put in. The concept of emergence has links to several disciplines, and it has no clear definition; it appears that there are several concepts going under the same name. This essay aims to tease out a definition of emergence suitable for discussions of generative art.

The first two chapters of the essay contain introductory remarks on definitions and on generative art. Chapter 3 considers examples of emergent phenomena in science; these examples are largely, but not exclusively, connected with Artificial Life. Chapter 4 discusses several definitions of emergence from the literature; again these are mostly connected with Artificial Life, and have some relation to discussions of generative art. In Chapter 5 a definition of "generative-art emergence" is proposed; this definition is specifically adapted to discussions of generative art. Chapter 6 applies the definition to a selection of generative artworks that are contenders for exhibiting emergence. The essay concludes with reflections on some of the issues raised.

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Style

For most questions of style I have followed the Australian Government *Style Manual for Authors, Editors and Printers*, 6th edition, John Wiley and Sons Australia, 2002. The referencing style follows the *Manual*, with some minor changes.

Bold face is used for words introduced by definition.

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1 Introduction

The idea becomes a machine that makes the art. (Sol LeWitt)

Generative art represents a particularly intriguing interaction between art and science. Automata have long fascinated people, going back at least as far as the the talking man of brass supposed to have been made by Albertus Magnus (D'Israeli 1838, p. 477); more recently the prevalence of computers and recent developments in biotechnology have added new urgency to fundamental questions such as: What is life? What is intelligence? What does it mean to be human? Artists have reacted to this situation in various ways; a generative artist creates a work with some degree of autonomy, a modern-day automaton, which may follow its own internal laws of development, or change in response to its environment.

A central notion in generative art is that of *emergence*; in some sense more comes out than the artist put in. Mitchell Whitelaw, in his survey of art inspired by Artificial Life, quotes a number of artists who refer to emergence, and goes on to say that "emergence can be seen to function as the focus of the field's collective desire" (Whitelaw 2004, pp. 212–217). Despite its importance, there is no agreed definition of the notion of emergence, and some authors have doubted that a simple definition exists. John Holland, a pioneer of genetic algorithms, has said "it is unlikely that a topic as complicated as emergence will submit meekly to a concise definition" (Holland 1998, p. 3); Whitelaw (2004, p. 208) writes "part of the appeal of emergence as a concept is that it defies clear definition". In fact there are several different concepts going under the one name. In this essay I consider a number of different definitions of emergence and attempt to formulate a definition suitable for discussions of generative art. The word "art" is used in a broad sense to include music, animation, sculpture, installation art and so forth.

My own interest in this topic arises from my involvement in generative art. Most of the works in the portfolio this essay accompanies are generative according to the definition given below, but emergence is at best weakly present in them, and I wish to move towards creating works that exhibit emergence more strongly.

1.1 What is a definition?

Definitions play an important role in this essay. Nonetheless, I think that precise definitions only occur in some restricted areas: some parts of mathematics and the natural sciences, some areas of law, and other areas where rules are prescribed. Most concepts in the world cannot be so neatly defined. Consider the concept of “chair”. The relevant definition from the Oxford English Dictionary (1989) is:

> A seat for one person (always implying more or less of comfort and ease); now the common name for the movable four-legged seat with a rest for the back, which constitutes, in many forms of rudeness or elegance, an ordinary article of household furniture, and is also used in gardens or wherever it is usual to sit.

The chair in which I am sitting as I type these words has five feet and a single central pole, being a gas-lift typist’s chair, so it is not a “four-legged seat”. The Oxford English Dictionary does list, without definitions, a number of types of chair, including “office chair” (used in 1874); nonetheless it is fair to say that the chair I am sitting on was not envisaged when the definition above was written, which was some time ago: the quoted definition is identical with that in the 1933 edition, which is the earliest I have been able to consult. Thus the concept of chair has fuzzy boundaries, and furthermore the boundaries can change with time, as new things are made that do not quite fit the previous understanding of the concept.

Most concepts, including “chair”, are **open concepts**, to use the terminology of Morris Weitz (1956), who introduced the term into discussions of art. Weitz states:

> A concept is open if its conditions of application are emendable and corrigible; i.e., if a situation or case can be imagined or secured which would call for some sort of decision on our part to extend the use of the concept to cover this, or to close the concept and invent a new one to deal with the new case and its new property. (Weitz 1956, p. 126)

The reference to “closing the concept” here is misleading; even if it is decided that the proper usage of “chair” requires four legs, so that my typist’s chair is not “a chair in the strict sense”, there may still arise four-legged objects that are only doubtfully chairs. Again, we may agree that a coffee cup is not a chair, but this decision does not close the concept of chair. Given that even a concept like “chair” is an open concept, I think that precise definitions are unlikely to be found for the much more problematic concepts discussed in this essay.

2 Generative Art

Philip Galanter, a practitioner and teacher of generative art, has given the following widely-used definition (Galanter 2003):

> Generative art refers to any art practice where the artist uses a system, such as a set of natural language rules, a computer program, a machine, or other procedural invention, which is then set into motion with some degree of autonomy contributing to or resulting in a completed work of art.

I adopt Galanter's definition in this essay. Marius Watz (2005), while basically agreeing with Galanter's definition, adds the caveat "the aspect of generativity must be dominant in the work". Alan Dorin and Jon McCormack, in analogy from biology, use the terms "genotype" and "phenotype":

> We use the terms genotype and phenotype as analogous representations of a productive methodology. Generative art practice focuses on the production and composition of the genotype. When run, interpreted or performed, the genotype produces the phenotype—the work to be experienced. (Dorin and McCormack 2001)

This usage has the problem that the "genotype" in Dorin and McCormack's sense may contain both genotypes and phenotypes in the terminology of Artificial Life. Whitelaw (2004, pp. 214–215) talks about the "technological substrate" and the "phenomenal and behavioral product" of the technological substrate.

In the same article in which he gave the definition of generative art quoted above, Galanter said:

> I often joke with my students that it is easy to tell if something is generative art. First it must be art, and second it must be generative. The joke here is, of course, I am begging the question. One difficult question is replaced by two difficult questions. What do we mean by art, and what do we mean by generative?

In the next section I discuss what is meant by "generative". At the end of the chapter I indicate my position on what constitutes an artwork.

2.1 Algorithmic art and generative art

The two terms "algorithmic art" and "generative art" are close to synonymous; the differences are of nuance and history.

2.1.1 Algorithmic art

The Oxford English Dictionary (1989) defines “algorithm” as:

> A process, or set of rules, usually one expressed in algebraic notation, now used esp. in computing, machine translation and linguistics.

“Algorithm” is currently used to mean a completely automatable process (Knuth 1973, pp. 1–9). This means that it has to be completely and precisely specified. This does not preclude the use of random numbers, as discussed below.

Algorithmic art, then, is art produced by an algorithm, with the implication that the algorithm is carried out (by hand or by computer), and when the algorithm has finished the result is the artwork. The artwork itself does not change once it is made. The phrase “algorithmic art” is particularly associated with the group of artists including Jean Pierre Hébert, Roman Verostko and Ken Musgrave who called themselves “algorists”, from a previously obsolete word meaning “one skilful in reckonings or figuring”. The definition of “algorists” used by the group is “artists who create art using algorithmic procedures that include their own algorithms” (Verostko 2006).

2.1.2 Generative art

As computers became faster and real-time work became more practicable, emphasis started to shift from the product to the process. It became possible to create artworks that changed over time (screen-savers being much-derided examples), or that responded to input from a gallery visitor. In the extreme we reach the situation described by Domenico Quaranta (2006):

> The author, therefore, sets into motion a process which develops itself autonomously, and, often, in an unpredictable way, under an amazed gaze. We seem thus to deal not as much with an artist, considered in the way we usually do, but rather with a minor God, who activates a system and then watch [*sic*] it coming to life.

The term “generative art” seems to have only come into use in about 1990, as a consequence of these expanded possibilities. In informal discussion “generative art” can carry with it a flavour of unpredictability, or real-time behaviour, or both. For example:

> “Generative” to me means a process which involves some element of “chance” / unpredictability / surprise / indeterminacy. I see “generative” as an overall category, under which things like stochastic and “aleatory” processes fall. (Posted by Andrei on the eu-gene list, eu-gene@generative.net, 15th October 2005.)

However, Galanter’s definition of generative art quoted above includes algorithmic art, and the inclusion of algorithmic art as part of generative art is largely accepted. Bogdan Soban (2006) lists more than a dozen definitions or near-definitions of generative art. One or two suggest that either interactivity or the possibility of multiple outcomes is required for something to be called "generative", but most follow Galanter's inclusive approach.

2.1.3 Randomness

Computer programs that make use of randomness require a source of random numbers. I distinguish between **real-world-random numbers**, obtained from a physical process such as radio-active decay, and **pseudo-random numbers**, obtained from a deterministic algorithm plus a single starting number (the **seed**). Pseudo-random numbers are not truly random in that they are predictable, given the seed and the algorithm; however the output of a modern pseudo-random number generator passes standard statistical tests for randomness, and for most purposes the distinction between real-world-random and pseudo-random numbers is only of philosophical interest. In many programs the date and time when the program is started (typically expressed as the number of seconds that have elapsed since January 1, 1980) is used as the seed. This ensures that each run of the program will use a different seed, and therefore a different sequence of pseudo-random numbers.

Random numbers are used extensively in a class of computer algorithms called Monte Carlo methods (Contingency Analysis 2006). An underlying idea is that if a process involves calculating some quantity at a large number of points, an approximate answer may be obtained quickly by using a random sample of points. Thus random numbers certainly play a role in science, even where the phenomenon being investigated is not itself random.

Although an artwork may use randomness, this does not imply that it is completely unorganised. To take a parallel from biology: the genetic make-up of a child is a random mixture of the genetic make-up of its parents, but the child is not a random jumble of bones, muscles, and organs. One example of a highly-structured piece of music that uses randomness in its construction is *Community Art: Resonant Energy* for percussionist and computer, by David Birchfield (Esler 2005). The score for this piece is generated in real time using a multi-level genetic algorithm, that is an algorithm based on the biological idea of random reshuffling of genetic material. The "genes" from the genetic algorithm specify the piece at several levels: individual notes, phrases and higher-level structures. Incidentally, although this work is both generated in real time and unpredictable, the title of (Esler 2005) is "Performing *algorithmic* computer music" (my emphasis).

2.1.4 Computers or not?

Although computers have come to dominate generative art, Galanter was careful not to restrict generative art to art made with computers, and many works that fit Galanter's definition do not use computers, or even machines. Galanter himself (2003) sees geometric designs found in many cultures as examples of generative art; they are certainly rule-based. Dorin (2001) sees wind-chimes and Japanese gardens as generative art (precisely, generative processes guided by artists). The composer John Cage is well-known for using "chance events" such as coin-tosses in his work (Pritchett 2006). Artworks that change in time need not be computer-based, or even motorised; witness the wind-driven mobiles of Alexander Calder (Marter 1991), and the *Condensation Cube* of Hans Haacke (Haacke 2003). Artists have also constructed artworks that decay; in a recent example, the painter Gay Chapman incorporated actual weeds into her paintings:

> Weeds invade landscape; their decay invades canvas as I invade the resulting imagery with my own marks. The canvas becomes a self-devouring microcosm where weeds and time are the medium. I use destruction as creation, the paintings sabotage the fine art process of conservation, and they themselves will decompose. (ArtsConnect 2004)

2.1.5 Other uses of "generative"

There are at least two specific uses of the word "generative" in artistic contexts that differ from Galanter's use of the term. A group of artists associated with the Art Institute of Chicago established a program in the late 1960s that in 1970 took the name "Generative Systems" (Sheridan 1983). This group had little to do with generative art in Galanter's sense; rather they were concerned with the artistic possibilities obtained by using and modifying photocopy machines and related technology. Also, Galanter (2003) mentions an art movement attributed to the Romanian sculptor Neagu, which practised a particular form of geometric abstraction under the name "generative art".

2.1.6 Related art movements

A recent movement related to generative art is **software art**. Watz characterises the differences between software art and generative art as follows:

> Software artists are interested in software as a social and political construct, and often take an ironic or demagogic position. Many are involved in the Open Source movement as a part of their practice.
>
> Generative artists focus on aesthetic systems, where the software is just an abstraction or tool used to create and display the work. Software art demands to see the code behind the systems ruling our world, while generative art is more often "out of this world", unconcerned with social responsibility. (Watz 2005)

An important sub-genre of generative art is art inspired by Artificial Life, so-called **a-life art**. **Artificial Life** (a-life) is defined as follows by the leading practitioner Thomas Ray:

> Artificial Life (AL) is the enterprise of understanding biology by constructing biological phenomena out of artificial components, rather than breaking natural life forms down into their component parts. It is the synthetic rather than the reductionist approach. (Ray 1994, p. 179)

In fact Artificial Life is currently concerned very largely with computer simulations that can be considered as abstractions, or simple models, of processes similar to those found in living things. Christopher Langton, the founder of Artificial Life as a discipline, said:

> We expect the synthetic approach to lead us not only to, but quite often *beyond*, known biological phenomena: beyond *life-as-we-know-it* into the realm of *life-as-it-could-be*. (Langton 1992, p. 40; emphasis in original)

The slogan "life as it could be" has become something of a rallying call for a-life practitioners; artists have modified the slogan to "art as it could be" (Moura and Pereira 2004). Artists were attracted to the ideas in Artificial Life from its beginning (Huws 2000, p. 39), and a-life art has become a very large part of generative art. (Whitelaw 2004) is a survey of a-life art; Part II of (Bentley and Corne 2002) is devoted to evolutionary music.

2.2 What is an artwork?

Since traditional theories of art do not consider works of art made by machines, I will indicate my position. For this essay I am adopting a variant of George Dickie's revised institutional theory of art (Dickie 1984). I make the following definitions:

1. An **artwork** consists of objects, words or actions of a kind intended to produce an art-experience in a public.
2. An **art-experience** is a type of experience accepted as an art experience by a public.

Here the word "public" is used in Dickie's sense of an "artworld public". The apparent circularity in this style of definition is addressed in (Dickie 1984, p. 79); the definitions are intended to be anchored by the general knowledge we already have about art.

I use the term **experiencer** for someone engaging with an artwork (as a viewer, listener, audience member, participant in an interactive event, and so on).

According to my definition Marcel Duchamp's *Fountain* is an artwork, and by Duchamp, not by the original designer or fabricator of the urinal, as Duchamp was the person who had the intention of making an art-experience. An artwork executed by a machine, computer or robot is not authored by the machine, but by the person who designed or programmed the machine, as it is the person who has the intention of making something that will produce an art-experience. This is not intended as carbon-based chauvinism; if the day comes when machines can reasonably be said to have the intention of producing art-experiences, then this statement will need revision.

An artwork is not the same as its material embodiment or perceivable content. This fact is brought out sharply by considering fakes: witness the furore that erupted when the novel *The Hand That Signed the Paper* turned out to be, not by the Ukrainian-Australian Helen Demidenko with a supposed family connection to the events described, but by the English-Australian Helen Darville (Gunew 1996); the words making up the novel did not change. Thus our knowledge of the context of an artwork affects our experience of it; in particular an installation with an explanatory text produces a different art-experience from the same installation without the text. More generally, art-experiences are strongly conditioned by the cultural background of the experiencer. It is beyond the scope of this essay to give a detailed account of art-experiences, but they certainly contain cognitive elements ("this work was painted in the seventeenth century") as well as purely aesthetic elements ("this work exhibits unity").

My approach to defining artworks differs from Dickie's in my emphasis on the experience produced. My emphasis on experience was influenced by work of McCormack and Dorin; in (McCormack and Dorin 2001, p. 2) they *define* art as "experience in context"; subsequently McCormack (2004, p. 56) states "experience in context is a necessary but not sufficient criterion for defining art". An emphasis on experience goes back to John Dewey; in his *Art as Experience*, he stated:

The *product* of art—temple, painting, statue, poem—is not the *work* of art. The work takes place when a human being coöperates with the product so that the outcome is an experience that is enjoyed because of its liberating and ordered properties. (Dewey 1934, p. 214; emphasis in original)

3 Examples of Emergence in Science

Brief histories of the concept of emergence (in a scientific or technical sense) are given in (McCormack 2004, pp. 59–60) and (Whitelaw 2004, pp. 208–212). The concept arose in the nineteenth century from the philosophy of science, as a word to describe the creation, or *emergence*, of new properties in complex situations. The paradigmatic example is the emergence of life from non-life. When applied to artificially constructed systems, the general meaning of "emergence" is that the system does something "extra", behaves in a way that is not immediately obvious from its specification.

Before we consider definitions of emergence in detail, it is helpful to have some examples of phenomena that are widely agreed to exhibit emergent behaviour in some sense. As noted above, the emergence of life from non-life is a fundamental example. Beyond this, every major development in biology appears to involve emergence: eukaryotic cells, sexual reproduction, multi-celled organisms, consciousness, intelligence. The examples I give below are artificial, and mostly connected with Artificial Life. In general they were not created for artistic purposes.

3.1 Langton's Ant

Consider a large grid of square cells, each of which is either black or white; initially they are all white. Langton's Ant is a virtual creature that moves from cell to cell. At any time it faces one of the four directions (north, south, east, west), and moves according to the following rules.

1. If it is on a white square, change the square to black, turn to face left, and move one step forwards.
2. If it is on a black square, change the square to white, turn to face right, and move one step forwards.

One might predict that after a few steps, repetitive behaviour would start, with a period of perhaps four or eight steps. In fact the ant moves in an apparently random manner for about 10,000 steps, and then starts to make a "highway", with a periodic action of period 104 steps.

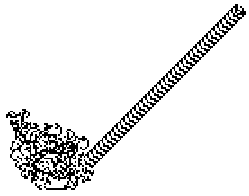

Figure 3.1: Langton's Ant

This behaviour is certainly unexpected for such simple rules. The ant was introduced in (Langton 1986), where it is called a "vant" (short for "virtual ant"); (Witham 2001) is a Java applet that runs the ant, and from which the image above was captured.

3.2 Conway's Game of Life

The "Game of Life" is an example of a **cellular automaton**: there is a grid of cells, each of which can be in one of a finite number of states. Time moves in discrete steps; at each time step all the cells change state according to their previous states and the states of their neighbours. The Game of Life, created by the mathematician John Horton Conway (Gardner 1970), uses a square grid; each square can be in one of two states, "alive" or "dead". A cell is considered to have eight neighbours, namely the cells with either an edge or a corner in common with it. The rules are:

1. A cell that is alive now and has two or three live neighbours remains alive on the next time step.
2. A cell that is alive now and has zero or one live neighbours dies from loneliness; a cell that is alive now and has four or more live neighbours dies from overcrowding.
3. A cell that is dead now and has exactly three live neighbours will come alive on the next time step.

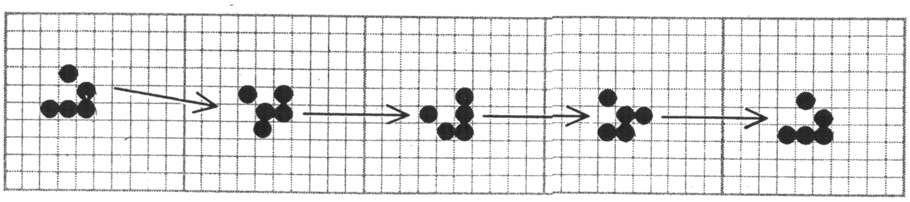

Figure 3.2: A glider in Conway's Life (Gardner 1970)

At the start only a small number of cells are set to be alive; the rest are dead. Some striking behaviour occurs, and it is not obvious what a starting configuration will lead to. Some starting configurations die immediately; some form “still lives” that do not change from time step to time step; some exhibit periodic behaviour; some change without any obvious pattern. The question of predicting what happens is discussed in Section 4.7 below.

With the help of a computer, Conway and collaborators discovered a “glider”, a configuration of five live cells that after four steps has reformed one square diagonally from its original position. This shows that squares arbitrarily far away from the initial configuration of live cells can become live. However, it wasn’t clear that a starting configuration of a finite number of live cells could be found such that the number of live cells would grow indefinitely (with the glider, the number of live cells remains at five). Conway conjectured that the number of live cells could *not* grow indefinitely, and offered a prize of $50 for a proof or disproof. A group at M.I.T. found a disproof in the form of a “glider gun”, a configuration that emits an endless string of gliders (Gardner 1971). Thus the number of live cells *can* grow indefinitely, and the behaviour of the Game of Life was not apparent even to an first-rank mathematician like Conway.

Cellular automata in general have generated considerable attention from both scientists and artists. A visual artist who has made extensive use of cellular automata is Paul Brown; some of his work is described in (Brown P. 2002). Cellular automata have also been used to create sound and music, at both the note level and the level of sound synthesis (Burraston and Edmonds 2005).

3.3 Reynolds’s Boids

Craig Reynolds’s *Boids* (Reynolds 1987, 2001) constitute an archetypal **flocking algorithm**. (“Boid” is short for “bird-oid”, that is bird-like object.) Reynolds describes the principles under which his simulated birds operate as follows:

> Stated briefly as rules, and in order of decreasing precedence, the behaviors that lead to simulated flocking are:
>
> 1. Collision Avoidance: avoid collisions with nearby flockmates
> 2. Velocity Matching: attempt to match velocity with nearby flockmates
> 3. Flock Centering: attempt to stay close to nearby flockmates
>
> (Reynolds 1987)

Thus each boid only obeys local rules. Nonetheless, convincing flocking behaviour results. With the addition of one extra local behaviour for each boid, namely obstacle avoidance, the flock is capable of dividing to flow round obstructions in its path.

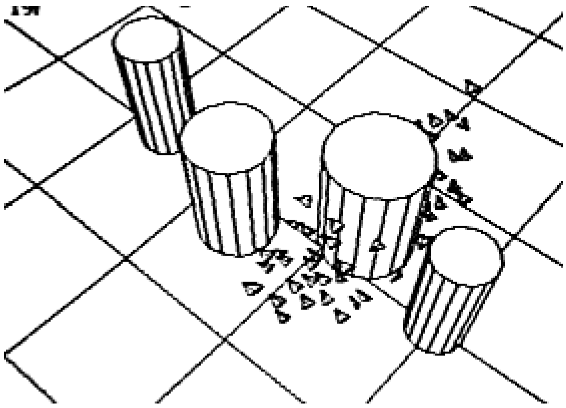

Figure 3.3: A flock dividing to flow round obstacles (Reynolds 2001)

3.4 Insect simulations

Insect simulations are similar to Reynolds's boids in that there are many simple entities, each obeying only local rules. But where the boids react only passively to their environment (avoiding obstacles), insects, both real and simulated, typically modify their environment by picking up things and carrying them, or by laying trails of pheromones. Among the most spectacular behaviours of social insects is the ability to build elaborate nests (Bonabeau, Dorigo and Theraulaz 1999, pp. 3–5 and 205–212), where each insect obeys only relatively simple rules, but the result is large nests with many specialised chambers, ventilation passages, and so on. The construction of the nest emerges from the simple behaviours of the insects.

The behaviour of real insects has inspired a variety of computer algorithms based on the idea that the local interactions of relatively simple agents will produce useful global results. Algorithms for routing in communications networks, data analysis and robotics are considered in (Bonabeau, Dorigo and Theraulaz 1999).

3.5 Tierra

Ray (1992) created a system, called *Tierra,* for evolving artificial creatures. A creature consisted of a small segment of computer code (in a virtual machine carefully designed by Ray). Ray seeded the system with one self-replicating creature (the "ancestor"), which replicated by copying itself into an unused part of memory. After some time several hundred creatures existed. Owing to a mutation procedure, variants of the original creature appeared. Since a creature could execute instructions belonging to other creatures, the possibility arose of "parasites", which utilised the copy procedure of a "host" creature. Ray also observed creatures that were immune to parasites, hyper-parasites that exploited the parasites, and "social" creatures that could only reproduce when two or more clustered together. (This is not sexual reproduction, as the creatures reproduce asexually; it is a form of symbiosis.) Ray states that "no functionality was designed into the ancestor beyond the ability to self-reproduce, nor was any specific evolutionary potential designed in" (Ray 1992, p. 121). Parasitism and the other behaviours mentioned above emerged.

A difficulty with this remarkable work is that it apparently required painstaking analysis to identify the various behaviours. This is not explicitly stated in (Ray 1992), but it is possible to deduce it from such statements as "at least some of the size 79 genotypes demonstrate some measure of resistance to parasites" (p. 126). It is not surprising that identification of a characteristic such as immunity to parasitism is difficult, as it is an indirect effect of the particular sequences of machine-code instructions in the various creatures.

3.6 Zipf's Law

Zipf's law in linguistics, introduced by George Kingsley Zipf, states that the frequency of occurrence of any word in a natural language (for example English), is roughly inversely proportional to its **rank**, where the most common word has rank 1, the second-most common word has rank 2, and so on. Thus the second-most common word should occur about half as often as the most common word, the third-most common word about one third as often as the most common word, and so on (Zipf 1949, pp 23–26). Figure 3.4 (Grishchenko 2006; I added the labels to the axes) shows that the law holds fairly well for the 5000 or so most common words in Wikipedia (a text with tens of millions of words). Rarer words appear to obey a different law.

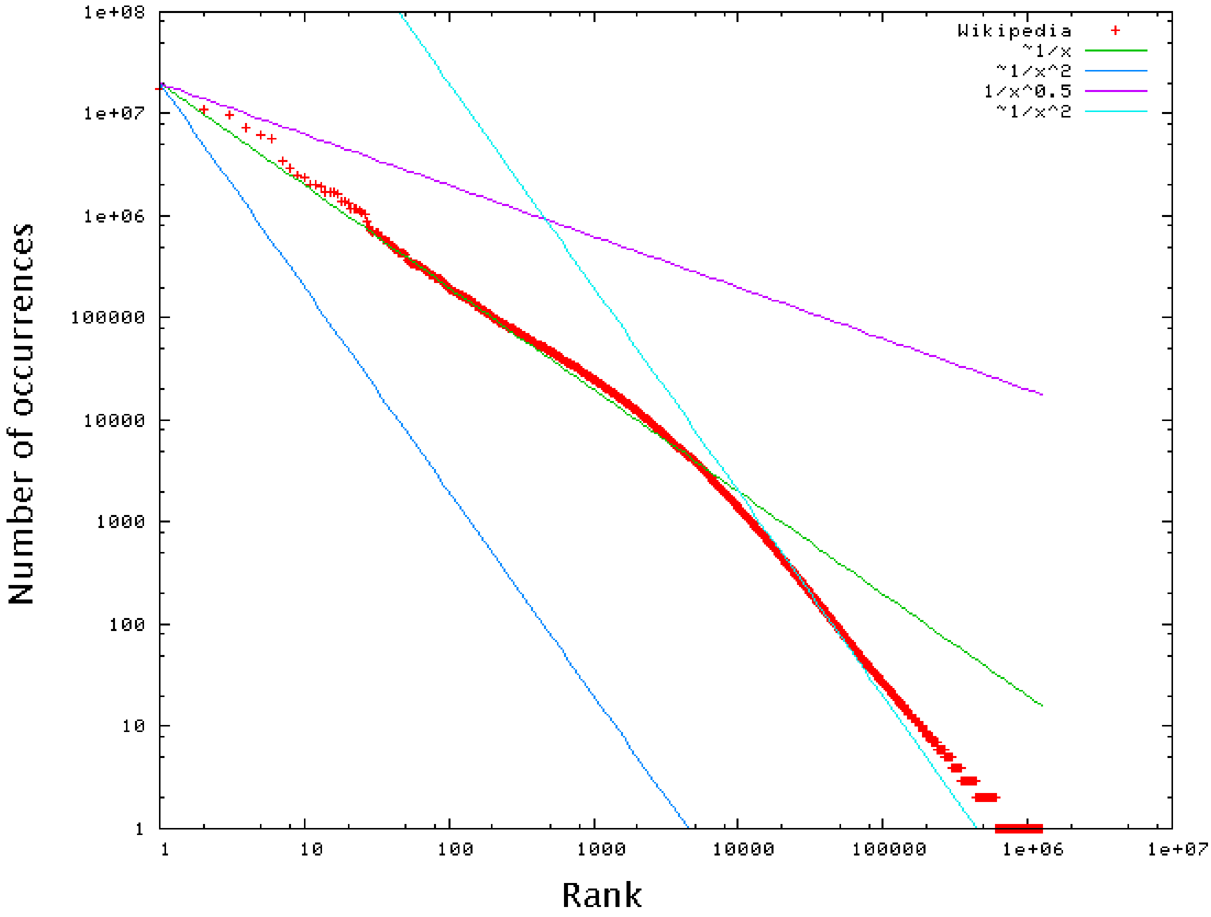

Figure 3.4: The frequency of words in the English version of Wikipedia

R.I. Damper (2000) discusses Zipf's Law at some length, in the context of emergence. Zipf's Law is an example of a **power law**, where one quantity is proportional to some power of another quantity; in Zipf's Law, the frequency of a word is proportional to a power of the rank; this power is -1, or very close to it. Damper quotes M. Schroeder as calling this "one of the most surprising instances of a power law in the humanities"; Damper then points out that Wentian Li (1992) gives a simple probabilistic argument to show that a randomly generated text will also obey a power law similar to Zipf's, with a power close to -1. As Damper points out, power laws are now recognised as occurring widely in the physical world (Section 3.7 below); Damper concludes his discussion of Zipf's Law by saying "I prefer to take Li's result as indicating that 'surprising' emergent phenomena can indeed be explained, sometimes very simply". Against this, Zipf had many diverse examples of his law, including the sizes of cities (Zipf 1949, p. 375), the number of performances of different musical works (p. 531), and the number of species in different genera of beetles (p. 253). Li's argument has nothing to say about these, and indeed the eminent physicist Murray Gell-Mann has said

“Zipf’s law remains essentially unexplained” (Gell-Mann 1994, p. 97). So the question of emergence remains open.

3.7 Edge-of-chaos behaviour and self-organised criticality

Stephen Wolfram has classified the behaviour of one-dimensional cellular automata into four classes, which may be described as: static, periodic, chaotic (not in the sense of chaos theory) and complex (Wolfram 1984). The last category hovers between order and chaos, and exhibits the most interesting and least predictable behaviour. A related idea is that of *self-organised criticality*, where a system organises itself to a “critical state” where any small disturbance will produce a response that could be of any size (Bak, Tang and Wiesenfeld 1988). Bak, Tang and Wiesenfeld discuss a sandpile model in detail, where adding one grain of sand may cause an avalanche of any size; the distribution of sizes of the avalanches follows a power law similar to Zipf’s Law; the authors point out that such laws have been observed in various physical systems, including the intensity of sunspots and noise in electronic circuits.

Artists have utilised these ideas: two musical examples are a composition based on a sandpile model (Hancock 1999) and a composition based on a cellular automaton with complex behaviour (Burraston 2005). A remarkable scientific example is the simulated birdsong of Kunihiko Kaneko and Junji Suzuki (1994): “birds” emitted songs generated by the logistic map, which is known to exhibit chaotic behaviour; in an evolutionary competition, the winners were birds that could imitate other birds’ songs (in a certain sense) but in turn were difficult for other birds to imitate. The system evolved to the edge of chaos.

3.8 Pask’s Ear

In the 1950s the cyberneticist Gordon Pask constructed an electrochemical device whose main part was a solution of copper sulphate with electrodes in it. Metallic threads would form depending on the current supplied (Pask 1960, p. 246). The system could be “rewarded” by supplying more current. Pask states that the network could be trained to discriminate between two sound signals, one of about 50 cycles per second, and one of about 100 cycles per second; he called the system an “ear”. The network was slightly sensitive to vibration to begin with, and the reward system caused it to configure threads that increased the sensitivity. “The ear, incidentally, looks rather like an ear. It is a gap in the thread structure in which you have fibrils which resonate with the excitation frequency." (Pask 1960, p. 261).

It is certainly surprising that an electrochemical network could "grow" a sensory organ like this. Peter Cariani, in work discussed in Chapter 4, sees a specific sort of emergence here.

3.9 Evolved electronic circuits

A group at the University of Sussex has carried out various experiments using genetic algorithms to evolve electronic circuits. Circuits are created in a field-programmable gate array, which is a chip with a number of electronic components whose connections can be changed by signals from a computer. In one experiment the group evolved a circuit to distinguish between two square waves at different frequencies; the circuit gave different outputs for a 1 kHz input and for a 10 kHz input. These input signals have transitions at least 50 microseconds apart. The components in the circuit react thousands of times faster than this, and there is nothing resembling a system clock, so it is a mystery how a circuit using only about 20 of the cells on the gate array could "remember" for such long periods. A paper by Adrian Thompson and Paul Layzell (1999) describes the circuit as "probably the most bizarre, mysterious, and unconventional unconstrained evolved circuit yet reported". The paper gives a partial analysis of the circuit, but does not explain the fundamental mystery of its operation.

A later experiment by Layzell and Jon Bird used a similar configurable array of components to evolve an oscillator whose active components consisted of ten transistors (Bird and Layzell 2002). Some of the successful solutions turned out to be making use of radio waves emitted by PCs in the lab; part of the circuit was using printed circuit board tracks as an aerial. This behaviour was completely unexpected (Graham-Rowe, 2002), and was described by Bird and Layzell as an "evolved radio".

4 Definitions of Emergence

The relevant definition of "emergence" in the Oxford English Dictionary (1989) is:

> The process of coming forth, issuing from concealment, obscurity, or confinement. *lit.* and *fig.* Also said of the result of an evolutionary process.

As noted at the start of Chapter 3, the concept of emergence in a technical sense originated in the philosophy of science, being a specific application of the meaning "the process of coming forth". The term has now spread to the fields of cognitive science, systems theory and Artificial Life; a number of specialised meanings have arisen. In addition the word has been used freely by generative artists. There seems to be no limit to the number of definitions of emergence; the definitions considered below have mostly come from the Artificial Life literature and have some connection with discussions of generative art.

I introduce a dichotomy depending on our knowledge of the system under consideration: I use the phrase **complete knowledge** as shorthand for "essentially complete knowledge of the construction of the system", with negation **incomplete knowledge**. Complete knowledge of the *construction* of a system does not imply complete knowledge of its *behaviour*. The typical case of complete knowledge is a computer program where the source code is known; commonly the viewpoint is that of the creator of the program. There are two typical cases of incomplete knowledge: a natural system (for example a forest), and a program where the source code is not known. The second case covers the viewpoint of someone engaging with a computer art system. Where there is incomplete knowledge, we may work with (formal or informal) **models** of the system when trying to understand what it is doing.

The italicised definitions given in this chapter are mine; each one is intended to summarise the discussion following it.

4.1 Definitions arising from the philosophy of science

The term "emergence" was used up to the middle of the twentieth century to describe, for example, the way in which living matter appeared to have laws of its own not deducible from the laws governing non-living matter. It was held that higher levels of organisation (such as life, and mentality) had their own natural laws (McCormack and Dorin 2001). This is the usage of "emergence" referred to by the part of the dictionary definition quoted above that reads "also said of the result of an evolutionary process". With the further development of physics and biology, it appeared that it was not necessary to posit special laws of this type, and opinion shifted against them. Nonetheless part of the resonance of the concept of emergence derives from this echo of vitalism.

Richard McDonough (2002) discusses no less than 27 definitions of emergence. Almost all of these are what McDonough calls "metaphysical", and are variations of the position just mentioned, that some aspects of wholes (e.g. consciousness of a person) are really not explained by knowing all the parts and their relationships. These metaphysical definitions are not relevant to this essay.

4.2 Basic emergence

> *Emergent behaviour is behaviour that is not specified directly in the description of the system.*

This is a weak definition; it includes too much rather than too little. A slightly more focused version of this definition arises from a distinction made by Luc Steels (1995, p. 90) between "controlled" and "uncontrolled" variables: a controlled variable can be influenced directly by the system under consideration; an uncontrolled one can only be influenced indirectly. Andy Clark (1996, p. 267) used this distinction to define emergent phenomena as "any phenomena whose roots involve uncontrolled variables".

4.3 Categorical emergence

> *The language used to describe the construction of the system is not adequate to describe its behaviour; new descriptive categories are needed.*

This style of definition is adopted by Steels, who summarises his discussion as "emergence can be defined in terms of the need for new descriptive categories" (Steels 1995, p. 89, section heading). For example, the language that suffices for describing an individual bird does not have the appropriate categories for discussing the behaviour of the flock. Mark Bedau (2003) calls this **nominal emergence**.

4.3.1 Levels of emergence

A common idea in discussions of emergence is the idea of considering a system at different "levels". Joris Deguet and co-authors, in a survey (Deguet, Demazeau and Magnin, 2005), consider that the existence of at least two levels is required for emergence. The levels may be thought of as design versus observation, as local versus global or as micro versus macro. In categorical emergence the design level language is inadequate for the observation level.

Whitelaw comes close to making a definition of the idea of levels. He identifies a notion of emergence shared by a-life artists in the following words:

> This shared notion of emergence can be transcribed into a structural template made up of two levels: a local (computational) level, where complex interactions are driven by a set of formal rules, and a global level, where behaviors appear as patterns in time or space. (Whitelaw 2004, p. 214)

Whitelaw goes on to give a broader formulation of this idea:

> The computational level can be thought of more generally as a technological substrate, a designed framework of software and hardware. Similarly, the global emergent level can be thought of as the phenomenal and behavioral product of that technological substrate. (pp. 214-5)

More than two levels can be considered, giving a hierarchy. Holland (1998, p. 188) refers to "levels of description" and Damper (2000) to "levels of abstraction". A paradigmatic example is the relationship of the various sciences: the laws of chemistry can in principle be derived from the laws of physics, but in practice chemists work with concepts such as valence without continually referring back to quantum mechanics. In the same way, biology rests on chemistry (Damper 2000). In this spirit, Holland (1998, pp. 197–200) gives an account of the glider in Conway's Life, something that has given rise to considerable debate. Holland takes the common-sense position that the glider is a higher level concept, which can be described as an entity moving, in the absence of interference, in the pattern shown in Figure 3.2. If there is interference (that is there are live cells in the path of the glider), we have to resort to the low-level rules of Conway's Life to find out what happens; Holland compares this to a scientist who has to abandon the laws of chemistry when a nuclear-level phenomenon is encountered.

4.4 Simple-to-complex emergence

> *Simple rules give rise to complex behaviour.*

A paradigmatic example of simple-to-complex emergence is Langton's Ant, discussed in

Section 3.1 above. The behaviour certainly seems much more complex than the rules. Holland sees some board games as providing examples of emergence:

> Board games are a simple example of the emergence of great complexity from simple rules or laws ... Chess and Go have enough emergent properties that they continue to intrigue us and offer new discoveries after centuries of study. (Holland 1998, p. 23)

A mathematical example is given by Newton's inverse square law of gravitation, which is very simple to state. It gives rise to some unexpected behaviour, including the "gravity assist effect" or "slingshot effect", whereby a spacecraft can be speeded on its way to Saturn by sending it to loop around Venus (Jet Propulsion Laboratory 2007). Newton's law of gravitation can also give rise to chaotic behaviour (in the sense of chaos theory), and such chaotic behaviour actually occurs in the solar system, thus invalidating the cliché "Newtonian clockwork" (Wisdom 1987).

4.5 Many-agent emergence

Many simple agents together produce complex behaviour.

Langton (1992, p. 66), discussing Reynolds's *Boids*, says "the global behaviour of the aggregate of Boids is strictly an emergent phenomenon, none of the rules for the individual Boids depends on global information". Perhaps the commonest use of the word "emergence" in Artificial Life contexts, and a very common use in artistic ones, is to refer to the global behaviour of a system of entities (cells, agents) whose behaviour is only specified at the level of the individual entities. In the flocking simulation, each Boid follows simple local rules, but the resulting flock is capable of, for example, smoothly dividing to flow around an obstacle, though no single bird directs this behaviour. I also class the large body of work on cellular automata under many-agent emergence. Further, many-agent emergence appears to be important in human behaviour, as considered in organisation theory and the like. An example of a "self-organising managerial system" is given by (Lansing and Kremer 1994).

There is a clear conceptual difference between the behaviour of a system with just one active agent, like Langton's Ant, and the behaviour of a system with many active agents, such as Conway's Life. Nonetheless, the distinction is not absolute: this is because a system with one active agent can simulate the behaviour of a system with many active agents; indeed this is what happens when a computer realises a cellular automaton.

The word "agent" has some implication of autonomy; I am using it here in a broader sense than some would allow. One researcher says:

> For an object to be referred to as an agent it must possess some degree of autonomy, that is, it must be in some sense distinguishable from its environment by some kind of spatial, temporal, or functional boundary. To make the definition of agent useful, we often further require that agents must have some autonomy of action, that they can engage in tasks in an environment without direct external control. (Rocha 1999)

A cell in a cellular automaton only doubtfully qualifies as an agent in this usage.

4.6 Surprising emergence

> *The system surprises me in some way (even if I have complete knowledge in the sense defined on page 18 above).*

This is sometimes seen as an essential part of emergence, and is undoubtedly part of what artists are looking for. Of course, one person may be surprised where another is not, and some commentators rule out the use of surprise as a criterion for this reason; Clark (1996, p. 266) dismisses the idea out of hand, saying simply "some writers associate emergence with unexpected/unprogrammed behaviours; but this yields an overly 'observer-relative' notion of emergence". On the other hand Edmund Ronald and co-workers argue that "the existence of an observer is a sine qua non for the issue of emergence to arise at all" (Ronald, Sipper and Capcarrère 1999, p. 235). Ronald, Sipper and Capcarrère give the following definition of emergence. They presuppose a system designer and a system observer (who can be the same person).

1. *Design***.** The system has been constructed by the designer, by describing *local* elementary interactions between components (e.g. artificial creatures and elements of the environment) in a language L_1.
2. *Observation***.** The observer is *fully aware* of the design, but describes *global* behaviors and properties of the running system, over a period of time, using a language L_2.
3. *Surprise***.** The language of design L_1 and the language of observation L_2 are distinct, and the causal link between the elementary interactions programmed in L_1 and the behaviors observed in L_2 is *non-obvious* to the observer—who therefore experiences surprise. In other words, there is a cognitive dissonance between the observer's mental image of the system's design stated in L_1 and his contemporaneous observation of the system's behavior stated in L_2.

(Ronald, Sipper and Capcarrère 1999, p. 228; italics as in original)

Ronald, Sipper and Capcarrère state clearly that their test applies to artificial systems with what I have called complete knowledge. They draw an analogy with the Turing test for intelligence (Turing 1950), which also requires an observer. It is not clear to me that the words "local" and "global" in the definition are necessary, or indeed that L_1 and L_2 need to be distinct; the essence of the definition is that the causal link between the program or construction and the observed behaviour is non-obvious. I further discuss the work of Ronald, Sipper and Capcarrère in Chapter 5.

4.7 Definitions related to computational intractability

4.7.1 Difficulty-of-prediction emergence

> *The fastest way to predict what the system is going to do is to simulate it (run it and see what it does, if it is a computer system).*

This definition is given by Vince Darley (1994), in the following form. Suppose that we have a system of (finite) size *n*; suppose that it can be simulated (or run) in $s(n)$ computational steps, and we have another approach to prediction involving "understanding" the system that takes $u(n)$ steps. If $s(n) \leq u(n)$ the system is emergent.

Darley's definition attempts to capture what is a common intuition about complex systems: the only way to find out what they do is to watch and see. Prior to Darley's paper, Claus Emmeche, commenting on Cariani's work discussed below, said:

> In the case of Alife models with chaotic and algorithmically complex behaviour this form of 'prediction' will be the somewhat pathological form of predictive model duplicating the very system ... This may therefore be seen as a quasi-form of genuine emergence ... (Emmeche 1992)

Bedau (1997, 2003) subsequently discussed this concept under the name **weak emergence**. The problem with Darley's and similar definitions is that there appear to be no systems that have been *proved* to exhibit this form of emergence. However, it is very likely that many, even most, complex systems have behaviour that is infeasibly difficult to predict. This is further discussed in the Appendix.

4.7.2 Turing-complete emergence (or computationally complete emergence)

> *The system has the computational power of a universal Turing machine, and is therefore unpredictable in principle.*

A **Turing machine** is a simple abstract computer, with a potentially unlimited amount of memory. In contrast to the situation with the difficulty-of-prediction emergence discussed above, which deals with systems of fixed finite size, proofs do exist here. Alan Turing (1936) showed that there is no general method for predicting what a Turing machine will do. In particular it is not possible to predict whether a Turing machine will go on for ever, or will stop after some finite number of operations. It is also not possible to predict whether it will ever fall into repetitive behaviour.

Conway's Life has the computational power of a universal Turing machine. As a consequence, there is no systematic way of answering any of the following questions:

- Given a starting configuration, will it eventually become static?
- Given a starting configuration, will it eventually become repetitive?
- Given a starting configuration, will it eventually have live squares arbitrarily far away from the initial region of live squares?

These results are covered in detail in (Berlekamp, Conway and Guy 1982, ch. 25).

Turing’s work is closely related to Kurt Gödel’s on the incompleteness of mathematical systems. As a consequence, there is no systematic way of determining whether an arbitrary mathematical statement is true or not; mathematics is the ultimate emergent system! (Boolos, Burgess and Jeffrey 2002).

4.8 Emergence relative to a model

The system deviates from my model of it.

Unfortunately the phrase “emergence relative to a model” has been used in two rather different senses, which I will call “loose” and “strict”. The loose sense is simply that we have a system and a model of the system, and the model is wrong in some way. For example, my model for Langton’s Ant was a subconscious mental model that presumably went something like this: “Well, there are four possible directions for the ant to face, and two colours. So it seems that there are eight possibilities, and we could get periodic behaviour with period eight.” McCormack and Dorin (2001) discuss the situation of a user of a computer artwork, saying:

> To achieve relative-to-the-model emergence, engagement with the computer needs to suggest that the work is *more* than its design intended it to be—it must be *informationally open.* (emphasis in original)

This appears to be an example of the loose usage, especially as one of McCormack and Dorin's examples is the work *Ima Traveller* (discussed in Chapter 6), which is a computer program whose construction is known, at least in principle.

The loose sense of "emergence relative to a model" is similar to surprising emergence, but a little more concrete, as I can be surprised without having any definite expectations of what is going to happen. The strict sense is discussed next, in connection with Cariani's definitions of emergence.

4.9 Cariani's definitions

Cariani (1992) identifies three "discourses" on emergence: "computational" (cellular automata, a-life simulations), "thermodynamic" (based on ideas from dynamical systems, and grounded in physics), and "emergence relative to a model". Of the last, Cariani says:

> The emergence-relative-to-a-model view sees emergence as the deviation of the behavior of a physical system from an observer's model of it. Emergence then involves a change in the relationship between the observer and the physical system under observation. If we are observing a device which changes its internal structure and consequently its behavior, we as observers will need to change our model to "track" the device's behavior in order to successfully continue to predict its actions. (Cariani 1992, p. 779)

This is what I am calling the "strict" sense of emergence relative to a model: *our model was previously correct, but ceases to be so*.

Cariani then uses ideas from systems theory to define emergence. A system is observed; at any one time it will be in one of a number of **states**, where a state is "any well-defined condition or property that will be recognised if it occurs again" (Cariani 1992, p. 782; Cariani takes this definition from the cyberneticist W.R. Ashby). It may be that state A (say) always leads to state B, in which case we have a computation, or a **syntactic** state transition. If state A sometimes leads to state B and sometimes to state C, this can be described as a measurement, as information is coming in from the outside world. Cariani also describes "control" transitions, which produce actions on the environment, as with robot arms and the like, which Cariani calls "effectors". The transitions that are not syntactic are called **semantic**; they involve the environment in some way.

From these considerations Cariani identifies two types of emergent behaviour, both of which come under emergence relative to a model in the strict sense. Is is supposed that we have a hitherto accurate model of the system under observation in terms of states and transitions. The first type is **syntactic emergence**:

> If the pattern of syntactic state transitions changes such that new computational transitions are formed, then the device or organism will appear to be *syntactically emergent*. (Cariani 1992, p. 785; emphasis in original)

An example of syntactic emergence is a neural network being trained on data coming in from the outside world. Cariani's second type is **semantic emergence**:

> If the pattern of semantic state transitions changes such that new measurement or control transitions are formed, then the device or organism will appear to be *semantically emergent*. (p. 785; emphasis in original)

This implies that the device constructs new sensory organs or new effectors. It seems that the only examples of semantic emergence are Pask's Ear and the Evolved Radio, discussed in Chapter 3.

Cariani goes on to comment on the implications of his views for computer simulations of the sort used in Artificial Life. In the case of a (non-interactive) computer program, once the program starts there is no outside input; all state transitions are syntactic in Cariani's terminology. Indeed we have a finite state machine, which in principle is known completely, and will eventually fall into repetitive behaviour. Thus we have a completely accurate model of what is happening, at the level of computer instructions, and this model stays completely accurate as long as the computer functions normally. Hence there is no possibility of emergence relative to a model, so in Cariani's view no possibility of emergence. Cariani concludes:

> *The interesting emergent events that involve artificial life simulations reside not in the simulations themselves, but in the ways that they change the way we think and interact with the world.* Rather than emergent devices in their own right, these computer simulations are catalysts for emergent processes in our minds; they help us create new ways of seeing the world. (Cariani 1992, p. 790; emphasis in original).

4.9.1 Responses to Cariani

Cariani's position appears to deny the validity of much work in Artificial Life, and hence also hopes for emergence in generative art. Ray (1992, p. 138) pointed out that the injection of even a small amount of real-world randomness undercuts Cariani's argument about predictability, proposing as a thought-experiment the use of a Geiger counter. In fact devices for supplying computers with real-world randomness exist, perhaps the most baroque being the one created by Silicon Graphics engineers using six lava lamps (Peterson 2001). Ray also remarks that pseudo-random numbers and real-world-random numbers would give essentially the same results; he cannot see that the repeatability of pseudo-random numbers (if we use the same seed, we get the same sequence) matters; indeed he regards this as a bonus.

My own response combines that of Ray with a consideration of the difficulties of prediction. Firstly, I agree with Ray that an argument depending on the difference between real-world-random and pseudo-random numbers is unlikely to have practical consequences. Secondly, I wish to see what Cariani's approach would mean in practice.

Consider a computer program that occupies just one kilobyte of memory, a minuscule amount by today's standards. If we consider this little chunk of memory (8192 bits) as a finite-state machine it has $2^{8192} \approx 10^{2466}$ states. So after at most this many steps its behaviour will start to repeat, and once it starts repeating it will follow the same cycle for ever; hence we can in principle determine its behaviour completely, just by running the program for 10^{2466} steps. Now consider the practicalities. Suppose that each atom in the observable universe could be turned into a super-computer capable of examining a trillion trillion trillion states of our finite-state machine per second, and that all these super-computers work in parallel. It would still take immensely longer than the lifetime of the universe to examine all the states of our little finite-state machine[1]. So in any real sense we don't know what it is going to do.

In the Appendix I give an argument from the theory of computational complexity to show that, given plausible assumptions, there is no way in general of finding out in reasonable time what a computer program will do. Thus in practice we cannot in general predict what a computer system will do, even though we have an accurate model of it in Cariani's sense. I conclude that Cariani's approach is not helpful in the context of this essay, being too much of a God's-eye view to be relevant to artistic or scientific practice. There may indeed be obstacles to emergence—one possibility is mentioned in Section 7.2—but I do not think that Cariani's argument is among them.

1 A trillion trillion trillion is 10^{36}, and the number of atoms in the observable universe has been estimated at 10^{80}, so all our supercomputers combined will examine only 10^{116} states per second. The age of the universe is very roughly 10^{18} seconds, so in the lifetime of the universe so far the supercomputers would have examined 10^{134} states, an extremely small fraction of 10^{2466}.

4.10 Frankensteinian emergence

Where the system outdoes its creator.

Holland sees emergence occurring when the draughts-playing program written by Arthur Samuel learnt to out-perform its creator (Holland 1998, p. 5). The idea that a machine can outdo humans in an activity that has previously been a prized attribute of humanness can give rise to extravagant emotions. The work of David Cope on using a computer program to create convincing works in the style of various composers, including Bach, Mozart, Chopin and Prokofiev, has provoked considerable discussion. The book *Virtual Music* by Cope (2001) contains, as well as a description by Cope of his *EMI* program and its workings, extensive discussions by several authors, including Douglas Hofstadter. Hofstadter, considering the consequences of Cope's achievement, lists three possible pessimistic conclusions:

> 1. *Chopin* (for example) is a lot shallower than I had ever thought.
> 2. *Music* is a lot shallower than I had ever thought.
> 3. The *human soul/mind* is a lot shallower than I had ever thought.
>
> (Cope 2001 p. 80; emphasis in original)

Hofstadter also quotes the chess champion Garry Kasparov, before he played IBM's chess-playing computer Deep Blue in 1997, as saying

> To some extent this match is a defense of the whole human race. Computers play such a huge role in society. They are everywhere. But there is a frontier that they must not cross. They must not cross into the area of human creativity. It would threaten the existence of human control in such areas as art, literature and music. (Cope 2001 p. 40)

Of course Deep Blue won the match.

5 A Definition of Emergence for Generative Art

This chapter contains an attempt to provide a definition of emergence specifically adapted to generative art; I call it **generative-art emergence**. Of the definitions considered in Chapter 4 it is most closely related to the surprising emergence of Ronald, Sipper and Capcarrère.

1. This definition applies to artworks as considered in Section 2.2 above.
2. The artwork exhibits some coherent observable behaviour, or a perceptible output.
3. The observed behaviour or output is inobvious or difficult to predict, even when we have complete knowledge of the system.
4. The observed behaviour or output evokes feelings of surprise-wonder-mystery-autonomy, even when we have complete knowledge of the system.

5.1 Some comments on the clauses of the definition.

Clause 1

Langton's Ant provides a test for the first clause, since the behaviour of Langton's Ant is probably not aesthetically interesting enough to be considered an art-experience by the artworld, though Langton's Ant passes the other tests in my definition, and Ronald, Sipper and Capcarrère consider that it passes their definition (1999, p. 229).

Clause 2

A system may be producing emergent behaviour, but this behaviour may be hidden. In this case the work is not *exhibiting* the behaviour, so it does not satisfy the definition. *Tierra*, discussed in Section 3.5, is a borderline case, as it took painstaking analysis to find out what the program was doing.

Clause 3

It is certainly possible to have behaviour that is not specified directly in the description of the system and requires new vocabulary or new categories to describe, and still claim that the behaviour is obvious. Ronald, Sipper and Capcarrère (1999, p. 231) discuss the wall-following behaviour of a robot described by Steels (1995, pp. 90–92); the behaviour emerged from the interaction of two simpler behaviours. Steels claimed the behaviour as an example of (categorical) emergence, but the behaviour is not particularly surprising, so Ronald, Sipper and Capcarrère state that the behaviour fails their test.

Clause 4

There does not appear to be a single word to describe what I am trying to point to in this clause; "surprise" is certainly not adequate by itself. To be grammatically correct, the phrase "evokes feelings of surprise-wonder-mystery-autonomy" should be expanded to "evokes feelings of surprise-wonder-mystery and a perception of autonomy", but I consider that there is a single complex idea here, for which I use the single compound word "surprise-wonder-mystery-autonomy". I consider the fourth clause in more detail below.

5.2 Comments on the fourth clause in the definition

5.2.1 Surprise

The relevant definition of "surprise" from the Oxford English Dictionary (1989) is:

> The feeling or mental state, akin to astonishment and wonder, caused by an unexpected occurrence or circumstance.

Thus for the Oxford English Dictionary, unexpectedness is an essential part of surprise. Yet the word is not always used that way: the mathematician Keith Devlin, discussing the possible symmetries of wallpaper patterns, says: "I still find it surprising that there are exactly seventeen ways to repeat a fixed pattern" (Devlin 2000, p. 81). Devlin had undoubtedly known this fact for at least 30 years when he wrote this comment; he presumably means something like "initially this was unexpected, and it is still mysterious, even though I have complete knowledge (know a proof)". Again, Ronald, Sipper and Capcarrère hedge their definition by stating immediately after it that "the question reposes ... on how *evanescent* the surprise effect is" (Ronald, Sipper and Capcarrère 1999, p. 228; emphasis in original). In another paper Ronald and Sipper take an engineering point of view to distinguish between "unsurprising surprise" and "surprising surprise": unsurprising surprise is what an engineer feels when a neural network designed to recognise handwriting works as expected; Ronald and Sipper say “the emergent nature of neural networks means that you—the designer—are surprised every time you think about them hard, *even when they are working as designed!*” (Ronald and Sipper 2000, p. 526; emphasis in original.) In unsurprising surprise, the surprise “is contained within well-defined bounds”; in surprising surprise “we are totally and utterly taken aback” (p. 525).

I think that surprise is a necessary but not sufficient condition for emergence. The behaviour should be inobvious, so that when we first encounter it we are surprised. But even when the behaviour is no longer new to us, it should still generate a sense of mystery or wonder.

Related to surprise is deception. In science the question of deception arises only in abnormal circumstances. In art, some artists like to use deception to destabilise expectations, show up credulousness, and so forth, creating surprise when the deception is revealed. In my view deception as such is antithetical to emergence, and certainly if we have complete knowledge of the system there is no possibility of deception. However, a typical experiencer of a generative artwork will not have complete knowledge of the artwork, and such a person needs a credible assurance that the observed behaviour does arise from the system. In my view this credible assurance is part of the art-experience.

5.2.2 Wonder and mystery

Under the heading “Wonder” a thesaurus (Chapman 1994) gives (among other words) *wonder*, *astonishment*, *surprise*, *awe*, *marvel*, *mystery* and the abstract nouns *transcendence, inexpressibility*, and *ineffability*. My phrase “surprise-wonder-mystery-autonomy” can be taken as shorthand for the complex of ideas indicated by the words from the thesaurus; I take the list as evidence that “surprise-wonder-mystery-autonomy” is not an arbitrary concatenation of words. However, “wonder” and “mystery” are not synonymous: for me the Eiffel Tower is wonderful but not mysterious; the occurrence of a symmetric configuration at the end of the work *Dissonant Particles* (in the portfolio that this essay accompanies) is mysterious to me, but I would not call it wonderful.

5.2.3 Autonomy

The idea of “going beyond”, for which I have used the word “autonomy”, is evident in the thesaurus entry mentioned above. Bedau (1997) states the apparently contradictory theses:

1. Emergent phenomena are somehow *constituted by*, and *generated from*, underlying processes.
2. Emergent phenomena are somehow *autonomous* from underlying processes.

   (emphasis in original)

Bedau (1997, 2003) sees his notion of weak emergence, discussed in Chapter 4, as providing a way out of the dilemma; the details are beyond the scope of the essay, but the observation of autonomy is pertinent. Again, Whitelaw, referring to programs that "breed" artworks, says that when success occurs "the evolved form can be considered an emergent phenomenon, one that has somehow exceeded or *pulled away* from its mechanistic substrate" (Whitelaw 2004, p. 215; my emphasis). For emergence to occur it is not enough that the observed behaviour should be difficult to deduce from the rules of the system; it should have coherence, "a life of its own"; in a word, autonomy.

My definition of generative-art emergence is very subjective, even more so than the surprising emergence of (Ronald, Sipper and Capcarrère 1999). In dealing with art, subjectivity is surely unavoidable.

6 The Definition Applied to Representative Artworks

The artworks discussed here are exhibit emergence in some sense. Generative art is a large field; the works here are a representative sample, with some bias towards works involving sound. A difficulty with generative artworks is that they tend to be realised as installations that are only exhibited in one or two locations for short periods. In such cases one has to rely on whatever documentation is available.

6.1 Art derived from Julia sets and the Mandelbrot set

Fractal art came to prominence in the mid 1980s and the characteristic graphics rapidly became ubiquitous. Arguably the purest form of fractal art is that which takes the Mandelbrot set (for example) as a given, and tries to find a visually attractive region and an appropriate colouring (Mitchell 1999). This form of fractal art is exploration of a complex object given by a concise formula. The Mandelbrot set *M* can be described in two lines as follows (Peitgen, Jürgens and Saupe 1992, pp. 844, formula 14.1):

> Let $\mathbb{C}$ be the complex plane. For $c \in \mathbb{C}$ define $f_c : \mathbb{C} \rightarrow \mathbb{C}$ by $f_c(z) = z^2 + c$.
>
> Then M is the set of $c \in \mathbb{C}$ such that $\{f_c^n(0) \mid n \in \mathbb{N}\}$ is bounded.

The Mandelbrot set, along with Langton's Ant, provides an example of simple-to-complex emergence that is not an example of many-agent emergence. The concept of "agent" does not apply to the Mandelbrot set.

In my view, fractals no longer provide compelling examples of generative-art emergence. While I still have a sense of wonder that the formula given above produces such an extraordinarily intricate object, fractal art fails the first clause of the definition, as the images have become clichéd, and so are ceasing to provide art-experiences. This would put most fractal artworks in the same category as Langton's Ant, though a sufficiently skilled fractal artist may still be able overcome the familiarity to give us art-experiences.

6.2 The bats in *Batman II* and other flocking processes

Flocking algorithms have been used in a number of movies to avoid having to animate by hand each separate member of a crowd of animals or people. The designer Carsten Kolve describes some of his visual effects (vfx) work as follows:

> *Troy* was my first vfx feature ... [I became] one of the core R&D developers of *ALICE*. ALICE is the acronym for **A**rtificial **LI**fe **C**rowd **E**ngine and a Maya based multi agent animation system ... I developed various parts of the ALICE: nodes to control crowd dynamics (math, (fuzzy) logic, state machines, flow control, etc.), the integration of crowds with particle systems (for arrow impacts, dust kicks, blood splashes, etc.) ... Most of the fighting between the two armies [in *Troy*] is done using artificial life techniques (or just a good layout and extensive use of randomness and noise) ...
>
> *Batman Begins* was the chance for me to add another dimension to crowd simulation - the third one. ALICE had so far only been used to produce simulation running in 2d, but for the swarms of bats this was clearly not sufficient. After creating a suitable simulation bat rig in conjunction with the Rigging TD I extended the crowd system to support full 3d movement of agents. In addition I build [*sic*] a Maya dependency graph rule network which would emulate the flight behaviour of bats. Custom tools to control the flight motion (e.g. guide curves, flow fields and obstacle detectors) helped the Shot TD's to direct the bats, artificial live techniques (like the well known flocking behaviour) added additional variation. (Kolve 2007)

The general name for this sort of work is **procedural animation**; the animation is done by a computer procedure rather than a human. In the *The Lord of the Rings* films elaborate procedural animations were used. In the battle scene at Helm’s Deep in the second film, the warriors had “brains” consisting of networks with 7,000 to 8,000 nodes each (New Line Productions 2007).

A work on a more domestic scale is the *Flocking Orchestra* of Tatsuo Unemi and Daniel Bisig (2005, 2007). The software is available as a download for Macintosh computers that have a webcam. It allows the user to conduct two flocks of shapes (with several hundred shapes per flock), each of which emits musical notes via MIDI from time to time. One flock emits melodic notes and the other percussive notes. The mapping is simple: the x coordinate of position maps to panning, y to pitch and z (front-to-back location) to volume. Left to themselves, the creatures go to the back of the virtual space, so the music becomes quiet. Movement detected by the camera attracts the creatures towards the front of the space, and the flocks can be “conducted” by waving a hand.

Ronald, Sipper and Capcarrère consider flocking algorithms in the following words:

> The flocking behavior exhibited by the artificial birds [Reynolds’s *Boids*] was considered a clear case of emergence when it first appeared in 1987. However, one now could maintain

> that it no longer passes the emergence test, since widespread use of this technique in computer graphics has obviated the element of surprise. This example demonstrates that the diagnosis of emergence is contingent upon the sophistication of the observer. (Ronald, Sipper and Capcarrère 1999, p, 231)

Similarly, Whitelaw (personal communication, 2005) has rather cautiously said:

> Global emergent behaviours such as flocking are now a commonplace in generative art practice; with respect to that field they are no longer surprising and therefore, in one sense, not emergent.

For me, flocking behaviour satisfies my definition, but not very strongly. I sense that the applicability of Clause 3 is weakening: we now have considerable experience with flocking behaviour, so we now have a fair idea of how the behaviour will turn out; it is no longer so inobvious.

Procedural animation in films raises the questions of intention and of audience knowledge. The producers presumably turned to these techniques as a way of creating scenes that would have been difficult or impossible to realise by other ways. With respect to *Batman II*, visual effects supervisor Dan Glass has said:

> Basically, we wanted everything to be reality-based ... We did experiment with shooting some real bats, but we found them hard to control. Even when flying freely, their help for our purposes was rather limited. So, instead, we scanned a dead bat in super high detail and shot a lot of separate film and video footage of real bats ... Throughout shooting, in scenes with bats, we just had a stuffed bat on a stick, got him on film and digital stills, and then rotoscoped in our CG bats moving as we had designed. (Goldman 2005)

It seems likely that the people who were actually realising the Artificial Life techniques were interested in the techniques for their own sake; Stephen Regelous, who worked on the *Lord of the Rings* films, has said:

> Before there was any thought of making crowd systems for *Lord of the Rings*, I was already interested in Artificial Life ... When Peter Jackson asked me to put together a system I said that I wanted to create it ... using Artificial Life-inspired approaches. (New Line Productions 2007)

Thus the producers and the ordinary film-goers will not have an experience of emergence; they may simply go with the spectacle, or they may be interested that crowd scenes can be done (cheaply, for producers) on the computer, but they will not realise, or not care, that the behaviour was specified only indirectly. Those in the know may well have an experience of generative-art emergence.

6.3 SimCity

The game *SimCity* (Electronic Arts 2007) is a city-building game that is all about emergence. Steven Johnson (2001. p. 66) heralds the game, first released in 1989, as one of the first applications of the bottom-up or emergent approach to entertainment.

In *SimCity* the (one) player is “mayor” of a simulated city. As mayor, the player can set tax rates, build infrastructure (roads, railways, power stations, schools, etc.) and can zone land as residential, commercial or industrial. But whether people come to the city, and what type and quality of buildings appear on the zoned land, is not under the player’s direct control. Many aspects of the development of the city arise only as indirect consequences of the player’s actions; for example, the simulated people in the city commute between home and work, and traffic management soon becomes a major part of the game. The traffic is a doubly indirect effect, in that the arrival of the people, and to a considerable extent where their houses and workplaces are located, are indirect effects of the player’s actions, and then the traffic jams are an indirect effect of the needs of the simulated people. Thus the traffic (in particular) is an emergent phenomenon.

In my view SimCity is neither wonderful nor mysterious, nor indeed particularly surprising: we all know too much about traffic jams! I have played a version of *SimCity*, and I found more or less that things happened as I expected. Thus SimCity fails to exhibit generative-art emergence.

6.4 Sims’s genetic images

Genetic Images by Karl Sims (1991, 1993) was an installation in which visitors guided the evolution of two-dimensional abstract images. There was a display of 16 images on 16 screens; users chose which images would be used as the parents for the next generation by standing in front of the corresponding screens. Each image was generated by a small computer program (a Lisp expression) and mutation and breeding processes were applied directly to these expressions. Details are given in (Sims 1991).

Figure 6.1:One of Sims's evolved images

The images are quite striking. The one in Figure 6.1, which is taken from (Sims 1991), has been reproduced several times, for example in (Whitelaw 2004, p. 24). This image is interesting because Sims's program did not record the expression that gave rise to Figure 6.1, so its genetic information is lost. In particular, the image cannot be further evolved (Sims 1991, Appendix).

In my view this work exhibits generative-art emergence.

6.5 Sims's evolved virtual creatures

The second work by Sims that I consider is somewhere between art and science. Sims (1994a, 1994b, 1994c) developed a framework in which creatures made of rectangular blocks can evolve. There are joints connecting the blocks, and what amount to virtual muscles enabling movement. The creatures also have sensors indicating when something touches one of the parts of the creature, and may have a light-detecting sensor. The sensors are connected to the muscles by a "brain" that is a modified version of a neural network. The bodies and brains of the creatures are subject to evolution. There is a sophisticated physics simulation, so that the creatures are subject to gravity and can push each other around.

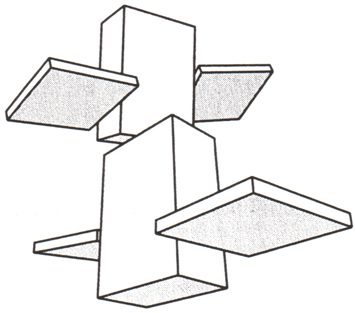

Figure 6.2: One of Sims's virtual creatures (Sims 1994a)

Sims set two different tasks for these creatures. The first was to evolve swimming, walking or jumping behaviour (Sims 1994a). The second task was to evolve competitive behaviour, in that two creatures competed for possession of a small cube (Sims 1994b). The results for both tasks can be seen in the movie (Sims 1994c). The results are impressive.

Sims subsequently made an interactive evolutionary artwork called *Galápagos*, briefly documented in (Sims 1997). Here users selected creatures that they liked, to be parents for the next generation. The creatures were animated, and according to Whitelaw (2004, p. 30) "some of the same techniques [used for the evolved virtual creatures] for the evolution of three-dimensional forms appear in ... *Galapagos*". The creatures in *Galápagos* are curvaceous and brightly coloured, unlike the virtual creatures of (Sims 1994a, 1994b).

In my view the evolved virtual creatures and *Galápagos* exhibit generative-art emergence. In the case of the evolved virtual creatures, there is the question of intention: did Sims intend to create art? There is no attempt to prettify the creatures by, for example, texturing the faces of the blocks, but this alone does not disqualify the work from being an artwork; arguably it enhances the art-experience by focusing attention on the behaviour of the creatures. I am inclined to think that Sims had a dual intention, to create something that was interesting both scientifically and artistically, though against this Sims did not exhibit the evolved virtual creatures as an artwork. Certainly such a dual intention is possible; I had a dual intention with respect to art and science when working on a sonification of brainwaves (*What Are You Really Thinking?*, in the portfolio this essay accompanies).

6.6 Ima Traveller

Ima Traveller is a work by Erwin Driessens and Maria Verstappen based on a modified cellular automaton. The work is described on their website as follows.

> With *Ima* we defined a system which can create images that explore the unseen, without determining beforehand what this would look like or imposing any specific meaning. In this program we use a feedback mechanism to achieve coherence, but at the same time the results are unknown and undefined as a result of the chance factors built into the process.
>
> The *Ima* process uses the specific capabilities of the computer in such a way that artificial life (systems designed to spontaneously display unpredictable behaviour) is created. In this way we provide the computer with an autonomous, unhuman way of thinking which is interesting because it generates unforeseen results.
>
> Starting with one single pixel the *Ima* algorithm generates new generations of pixels. While breeding, each pixel divides into four new pixels. The new pixels are more or less autonomous cells that are able to define its own colour (hue, brightness and saturation) by interaction with the surrounding pixels. Each pixel has its own way of dealing with its environment: some like to merge with others, some are very individualistic, but most of them more or less adapt themselves.
>
> Repetition of this breeding process refines the tissue, and unpredictable images, with a more or less coherent structure, arise. (Driessens and Verstappen 2007)

This work differs from a standard cellular automaton in two ways: the cells subdivide, and there is use of chance. I have seen this work installed; the cells constantly move outwards towards the edges of the screen, so the experience is of constantly moving or falling inwards. The apparent growth point or origin is controlled by the mouse, so it is possible to steer the zooming process. McCormack and Dorin (2001), evidently deeply impressed by the work, use it as the sole example of what they call the "computational sublime", which they describe as "the instilling of simultaneous feelings of pleasure and fear in the viewer of a process realized in a computing machine". I found the work quite compelling to watch, but not fear-inducing. A demonstration program for PC, which runs for only 30 seconds, is available at <http://www.xs4all.nl/~notnot/ima/IMAtraveller.html>; Figure 6.3 was captured from this program.

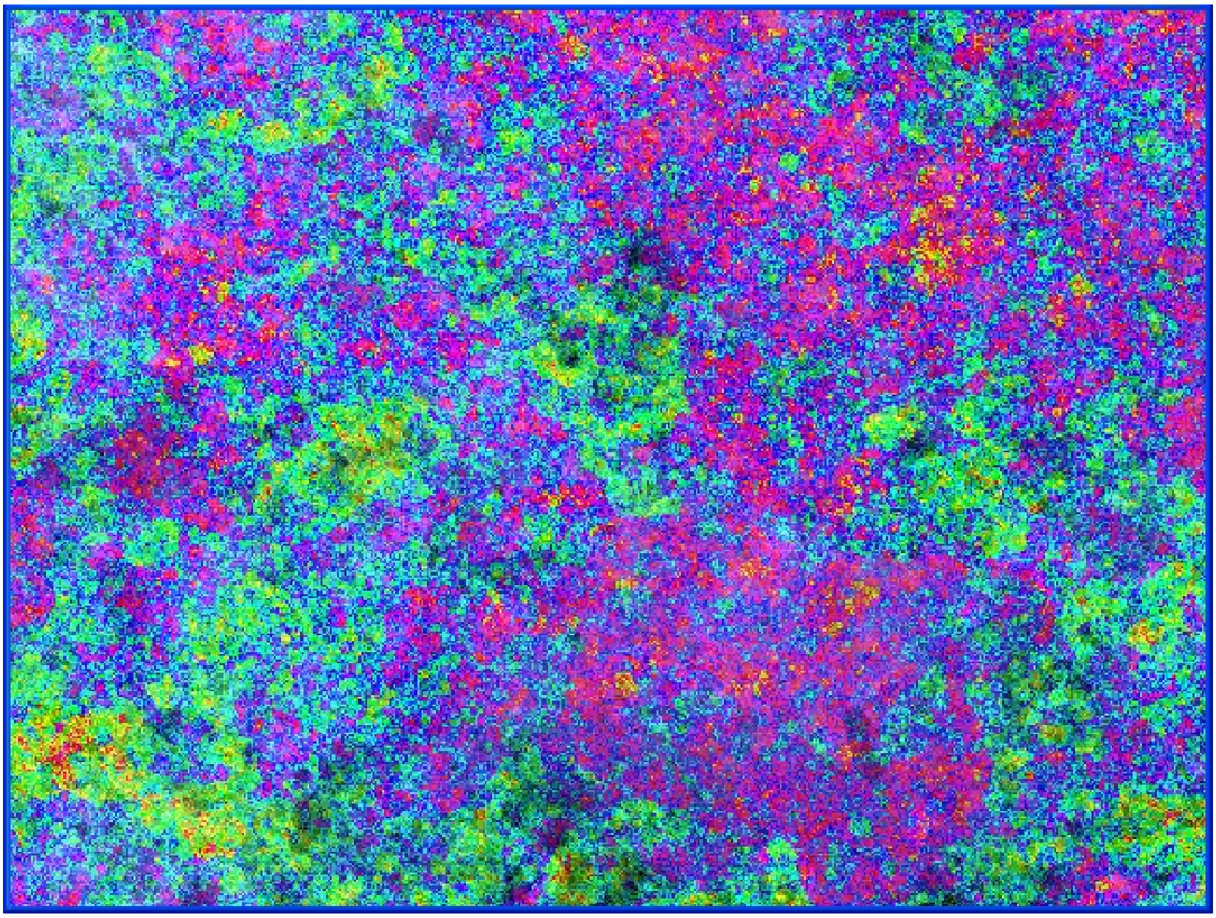

Figure 6.3: A screen shot from Ima Traveller

In my view *Ima Traveller* exhibits generative-art emergence.

6.7 Biotica

Biotica, by Richard Brown and collaborators (Brown R. 2001), was an ambitious attempt to create an artwork in which a-life creatures of increasing complexity would emerge:

> The initial ambition for Biotica was to create some kind of primordial soup out of which would emerge an ecology of simple lifeforms that an observer could interact with. (Brown R. 2001, p. 78.)

Note that Ray's *Tierra* (Section 3.5) did not attempt this; Ray's inspiration was the "Cambrian explosion", the relatively sudden emergence of multi-celled animals, which took place well after life was established (Ray 1992, p. 111).

The basic element in *Biotica* was a "bion", a moderately complicated entity that had simulated mass and electric charge, a chemical system and a set of internal states like a cell in a cellular automaton; the bions also emitted sound. The bions could form creatures with some complexity of behaviour, but the system was not sufficiently robust:

> In too many cases, however, the system had to be painstakingly coaxed, and behaviour had to be explicitly programmed to a degree that would not warrant the description emergent. There was no sense, as with *Tierra*, of leaving the software to its own devices and returning to find some new form or ecology had emerged. (Brown R. 2001, p. 78)

In order to make an artwork suitable for exhibition, a progression was imposed: the number of bions per creature starts at two and increases to twelve. Within this progression a variety of behaviours can occur (Brown R. 2001, p. 58). The user experience was intended to be immersive, employing a stereoscopic projection system and motion detection; the user interacted with the system by making gestures.

Although *Biotica* did not live up to its initial aims it certainly exhibited complex interactive behaviour. I have not seen the work, but from the description in (Brown R. 2001) I would think that it was capable of giving experiences of generative-art emergence.

6.8 Eden

McCormack's *Eden* (McCormack 2003; 2004 pp. 102–103; video on DVD included with 2004), is also an artwork containing an ecosystem of simulated creatures (agents). The agents move about on a lattice and have the ability to eat, move, fight and mate. They can "see" the immediate neighbourhood and can make virtual sounds; they can "hear" sounds emitted by agents some distance away. Each agent contains rules that controls its behaviour; there is a learning mechanism so that the rules change with time, and the changed rules can be passed on to offspring.

The world is represented in a semi-abstract way, as shown in Figure 6.4; the agents simply appear as bright circles. The main information, from both the agents' and the audience's point of view, is in the sound, and indeed McCormack describes *Eden* as an "evolutionary sonic ecosystem" (2004, p. 102; title of 2007). The agents can make and receive sounds in three simulated frequency bands; these virtual sounds are used to trigger real sounds through a quadraphonic speaker system. Unlike the sounds in *Biotica*, the sounds have meaning within the system and agents can learn to use them to find mates, for example. There is an indirect form of user interaction, in that the system detects the positions of people in the installation space and rewards agents near to people with more food. McCormack states that "on some occasions the creatures have learnt to use sound to keep people within the space, hence increasing their chances of survival" (2004, p. 103).

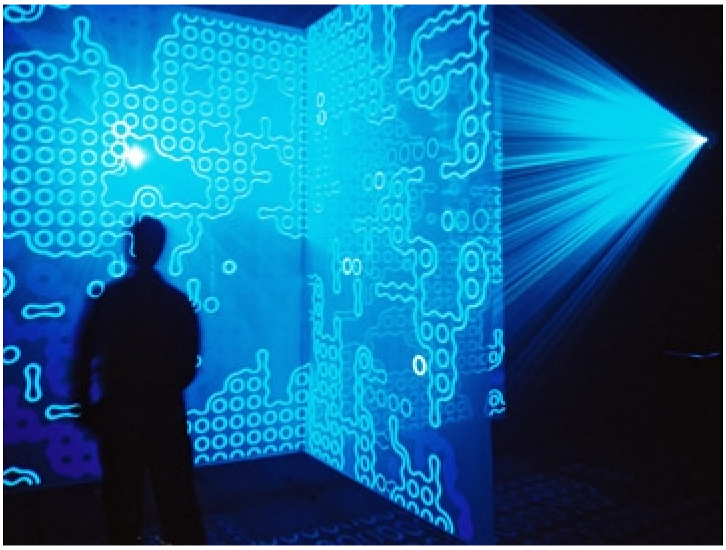

Figure 6.4: The Eden *installation (McCormack 2007)*

Eden is perhaps the most subtle of the artworks I am considering, and the one I found it hardest to get a sense of from the documentation (I have not seen the installation). As noted above, the main information is in the sound, and since there was only a quadraphonic sound system I assume it was often difficult to tell which creature was making a sound (as far as I know the creatures do not flash or otherwise give visual indications when they are emitting sounds). My feeling is that the more one knows about the processes underlying *Eden*, the stronger the sense of emergence would be.

6.9 Cope's Experiments in Musical Intelligence

Cope's composing program *EMI* (Experiments in Musical Intelligence) was mentioned in Chapter 4. To compose a work, the program is primed with a database of pieces, and then "recombines" elements from them to create a new piece. The program carries out a very sophisticated analysis of the pieces in the database. Elements of this analysis include:

- Signatures: "Contiguous note patterns which recur in two or more works of a single composer and therefore indicate aspects of that composer's musical style ... [Signatures] usually consist of composites of melody, harmony, and rhythm." (Cope

2001, p. 109)

- Earmarks: Gestures that foreshadow important structural events, such as the lead-in to a cadenza.
- Segmentation into thematic sections, based on a combination of several different procedures.
- An elaborate hierarchical analysis on Schenkerian principles, intended “to differentiate between groupings which may appear identical or similar but which sound different due to context” (p. 130). This process is used in particular to analyse tension in the music.

The sample pieces supplied as input to *EMI* must be stylistically consistent; an example is slow movements from Mozart piano concertos (p. 143). The program apparently operates automatically once the user has set a considerable number of global parameters (p. 178), and creates a new piece by a synthesis process just as elaborate as the analysis; it includes measures for both short-term and longer-term coherence in the generated music.

The program clearly exhibits emergent behaviour: even Cope does not always know why the program does one thing rather than another:

> The complex interactions between the various rules governing [construction of bars approaching a cadence] make such decisions impossible to reverse-engineer. (p. 159)

The question arises as to how much control or selection Cope exercises on the output. Cope states that the ratio of works he accepts to those he rejects varies from 1:4 to 1:10 (p. 182). Since the program produces whole works, or at least whole movements, this sounds quite favourable to me; a human composer may well make many attempts at a composition.

The *EMI* program is a producer of artworks rather than an artwork itself, a distinction blurred in most of the other works considered here. In other works, we can see the generative process being played out; the artwork is the program or device in action. In *EMI*’s case the artwork is the new “Chopin” mazurka (say), together with the knowledge that it was created by *EMI*.

Hofstadter’s account of *EMI* certainly indicates that for him the program was producing far more than he expected any such process to be able to yield. His reaction adds horror and chagrin to the surprise-wonder-mystery-autonomy complex.

6.10 The applicability of other definitions

I briefly consider how the definitions in Chapter 4 apply to the artworks considered above. In my view, all of the artworks discussed, except possibly those generated by Cope's program, satisfy categorical emergence[1], all satisfy simple-to-complex emergence, and those that have many agents satisfy many-agent emergence. I suspect that most of them exhibit some form of difficulty-of-prediction emergence, though this could be hard to formulate, let alone prove. Surprise has been discussed at some length above. Emergence relative to a model, in the loose sense, does not seem to apply very well, as in most cases it is not clear what our model might be. *Very* loosely, our general expectations of mechanical processes might be that they do not behave the way these artworks do. We have seen that almost nothing satisfies Cariani's definitions. Finally Hofstadter, at least, finds Cope's work threatening, and possibly McCormack and Dorin would consider *Ima Traveller* as an example of Frankensteinian emergence.

1 Cope's program contains so many musical concepts that the sort of category we would need to fit Steels's definition would be something like "convincingly the product of human genius".

7 Reflections and Conclusions

7.1 Patterns, anthropomorphism, and the mind of the beholder

Even in science, identification of emergence often relies on human pattern-recognising ability; the glider in Conway's Life was discovered when "some guy suddenly said, 'Come over here, there's a piece that's walking!' " (Berlekamp, Conway and Guy 1982, p. 821; the "guy" was apparently Guy). The converse is the problem: how do we know if emergent behaviour is happening? Cariani has asked: "If we randomly come across a computer simulation and have no clue as to its purpose, can we tell if its computations are emergent?" (1992, p. 776.) This raises the question as to where the boundary between the simulation or artwork and the experiencer is to be drawn. From the scientific point of view, Ronald, Sipper and Capcarrère state bluntly:

> We do not think, however, that emergence should be diagnosed ipso facto whenever the unexpected intrudes into the visual field of the experimenter. (Ronald, Sipper and Capcarrère 1999, p. 225).

And Cariani, as quoted in Section 4.9 above, thinks that *all* of the emergence takes place in the observer. For art, my own view is that to ascribe emergent behaviour to an artwork, the perceived behaviour should largely be a property of the artwork and not of the human perceptual or nervous system. For example, I am happy to say that Sims's virtual creatures do exhibit behaviours and that these behaviours are emergent; in particular they are a property of Sims's program and not of my nervous system.

At a higher level, a kind of misguided reasoning by analogy leads us to ascribe properties of living things to objects that are not alive: there are persistent reports that even adult owners of Sony's AIBO dog-like robots ascribe to them properties that they do not have, for example the right to attention:

> "I am working more and more away from home, and am never at home to play with him [AIBO] any more ... he deserves more than that." (Friedman, Kahn and Hagman 2003, quoting a participant in an online forum.)

An analogous criticism has been made of research in Artificial Life. Whitelaw (2004) discusses this at some length. He quotes the artist and critic Simon Penny as referring to "the (quite wrong) assumption that modern computational techniques are structurally similar to the deep structure of biological life" (p. 195), and more specifically, referring to work of Katherine Hayles, highlights the use of biological language such as "parasite" in Ray's account of *Tierra* (Section 3.5 above). Whitelaw quotes Hayles as saying about *Tierra*: "the program operates as much in the imagination as it does within the computer" (Whitelaw 2004, p. 197). The question with respect to a generative artwork and emergence is: how much is the artwork actually doing, and how much are we projecting our habitual assumptions or our own framework of understanding onto what we perceive?

7.2 How much emergence?

In Chapter 6 I have indicated several artworks that I consider exhibit generative-art emergence. Nonetheless the degree or number of levels of emergence is limited. Whitelaw fantasises about a program that would evolve without limit:

> A Lathamesque spiral sphere tentacle-shell might become a string of cubes, then a lofted procedural skin will cover the cubes, which in turn will be interpolated with three-dimensional shapes imported from the Net ... At each stage in this transformation, a new computation appears involving a transformation not only in the form but in the syntactical structure specifying that form. (Whitelaw 2004, p. 221)

There is no such program. This relates to a fundamental unsolved problem of Artificial Life, how to generate "unbounded" or "open-ended" evolution. Even a work like *Tierra* (Section 3.5) only produced approximately three "levels": self-sufficient creatures, parasites on these and parasites on the parasites. Steen Rasmussen and co-workers have formulated an *Ansatz* (basis; starting-point; fundamental approach or attitude) as follows:

> *Ansatz*. Given an appropriate simulation framework, an appropriate increase of the object complexity of the primitives is necessary and sufficient for generation of successively higher-order emergent properties through aggregation. (Rasmussen et al 2002)

To turn this around, a given set of types of primitive will produce only a certain number of levels of emergent behaviour. The *Ansatz* is stated in a specific context, but it seems to apply generally. An apparent natural counter-example is the enormous variety of living creatures produced by combinations of not very many kinds of atom, but there seem to be no convincing artificial counter-examples to the *Ansatz*.

I consider two ways of thinking about the natural world from the point of view of the *Ansatz*. It may be that atoms are indeed very complex, complex enough to support many levels of emergence, and very much more complicated than a cell in a cellular automaton (say). As an alternative to the *Ansatz* it may be that enormous *numbers* of primitive elements are required. Thus it may be that, let us say, to go up one level of emergence in an artificial system requires a 100-fold increase in power (computer speed, memory, or other resources). Then ten levels would require a 10^{20}-fold increase compared to a primitive element, which is probably unattainable. If there is a fundamental law along the lines of the *Ansatz,* or a law requiring huge numbers of primitive elements, there would be definite limits to practically realisable artificial emergence. There would also be definite limits to natural emergence on Earth, but these would be much more generous: there are estimated to be maybe 10^{14} (100 trillion) cells in one human body, and a biological cell is already a very complicated thing.

7.3 An art of ideas?

I have stressed that art-experiences have cognitive aspects, and I referred to "complete knowledge" in the definition of generative-art emergence. Is the idea the important thing? Is generative art just a branch of conceptual art?

In a much-quoted piece the conceptual artist Sol LeWitt has said:

> In conceptual art the idea or concept is the most important aspect of the work. When an artist uses a conceptual form of art, it means that all of the planning and decisions are made beforehand and the execution is a perfunctory affair. The idea becomes a machine that makes the art. This kind of art is not theoretical or illustrative of theories; it is intuitive, it is involved with all types of mental processes and it is purposeless. It is usually free from the dependence on the skill of the artist as a craftsman. (LeWitt 1967)

LeWitt was a relatively conservative conceptual artist, compared to say Robert Barry, who created invisible artworks using radio-activity, electromagnetic fields, inert gases and even telepathy (Meyer 1972, pp. 35–41). It seems that much of conceptual art was directed against the idea that art had to be in a gallery, promoting what would have been documentation of an artwork to the role of artwork itself:

> When art does not any longer depend on its physical presence ... it is not distorted and altered by its reproduction in books. It becomes "PRIMARY" information ... When information is PRIMARY, the catalogue can become the exhibition. (Seth Siegelaub, quoted in (Meyer 1972, p. xiv)).

Paradoxically the "earthworks art" movement, treated along with conceptual art in the book *Six Years: The Dematerialization of the Art Object from 1966 to 1972* (Lippard 1973), involved works whose physical presence was so imposing that they could not fit in a gallery;

one example is *Double Negative* by Michael Heizer, which involved moving 40,000 tons of rock (Lippard 1973, p. 78).

All of this has little to do with generative art as discussed in this essay. In most cases there is no process "set into motion with some degree of autonomy" as required by Galanter's definition of generative art. It is also clear that in the artworks discussed in Chapter 6 the execution is just as important as the underlying idea, and the work is certainly not the same as its documentation. We could modify LeWitt's dictum to say *The idea becomes a machine that makes the machine that makes the art.* Incidentally LeWitt's own wall drawings (Lippard 1973, p. 201) are generative in character and are claimed as such by Galanter (2003, Section 9.9).

Another candidate for an art of ideas is Islamic art: Laura Marks (2006) has made an intriguing comparison between computer art and Islamic art, describing them as "the two largest bodies of aniconic art", and listing properties that they have in common. Some of the properties listed by Marks:

1. Latency: a tendency for the work's underlying structure to remain invisible or latent, perhaps to be manifested over time or to be teased out by the attention of observers.
2. Algorithmic structure: a structure based on a series of instructions that manipulate information to produce actions or images.
3. An emphasis on performativity rather than representation: the work of art plays out in time, unfolding image from information and information from experience, in the carrying out of algorithms and/or the attentive recognition of observers.

   (Marks 2006, p. 38; the numbering differs from that in the original.)

These points make what seems to me to be a good case for a surprising similarity in aims and methods. In the third point the expression "plays out in time" need not imply a kinetic art form, as Marks's main Islamic examples are architectural. Again, Marks would agree that the execution is as important as the idea: Marks says (p. 40) "[good computer art] invites the perceiver to marvel at the richness with which the perceptible image unfolds from the numeric base".

7.4 Form, structure, narrative

Humans like stories. Unfortunately evolution and other natural processes don't necessarily fit human patterns of narrative or artistic form. Art that seeks to imitate such processes can be expected to have a problem with large-scale form. Thus, as noted in Section 6.7, *Biotica* did not live up to its creators' original ambitions and a structure had to be imposed on the work. Again, the much-hyped but as yet unreleased generative computer game *Spore* (by Will Wright, who was the person behind *SimCity*) begins at the level of single-celled life and ends up with space-faring civilisations (Electronic Arts 2006). However, it appears that there are a series of artificially imposed stages of development in the game; the progression does not arise naturally from the internal structure of the process. There is no obvious solution to the problem.

7.5 Is emergence enough?

In the introduction to this essay Whitelaw was quoted as saying that "emergence can be seen to function as the focus of [a-life art's] collective desire". Yet Whitelaw also quotes the artist Bill Vorn as saying about a-life art:

> Artists are now able to do things that have no sense, let them interact, and the overall meaning is going to emerge just by itself. Artificial Life is the Spirograph of the 90s. (Whitelaw 2004, p. 234.

Mladen Milicevic (1996), commenting on music produced by complex processes, says:

> There is an easy misunderstanding of emergent behavior which lies in the assumption that whatever is produced on the verge of chaos is good or creative.

And Tim Burke (2003), discussing emergence, refers to artists seeking "unexpected but coherent" events; complete unpredictability is not artistically useful. A related point is made by Johnson (2001, p. 20), discussing the natural world, when he writes "emergent complexity without adaptation is like the intricate crystals formed by a snowflake: it's a beautiful pattern, but it has no function."

So maybe emergence as such is not enough. In science, as Johnson indicates, adaptive systems are important, and the book *Emergence* by Holland (1998) is largely about adaptive systems. Yet *Ima Traveller*, a successful art work exhibiting emergence, is not adaptive at all. The way forward may be to analyse in detail how artworks give rise to feelings of surprise-wonder-mystery-autonomy, a task certainly beyond the scope of this essay.

I believe that the definition of generative-art emergence given in this essay comes closer than previous definitions to capturing what artists are looking for under the name of emergence.

The new definition also enables a finer-grained analysis of the reasons that an artwork may fail to be classified as emergent.

Appendix: Computational Complexity and the Difficulty of Prediction

In this Appendix I use the theory of computational complexity to show that, given plausible assumptions, there is no way in general of finding out in reasonable time what a computer program will do.

Computational complexity is concerned with how long it takes to solve certain problems; an example is to sort a jumbled mass of data into alphabetical order. We assume that the input is in a computer file, and the size of the problem can be taken as the size of the input file in bytes, or some similar measure. We want to know *how long the problem will take to solve*, that is how many **steps** (basic computer operations) will be needed. The answer will be expressed as a function of the size of the input.

Suppose the input size is n. Computer scientists generally draw a line between problems that take a time polynomial in n, say n^2 or n^3, and a time exponential in n, say 2^n (Cook 2007, pp. 4–5). In Section 4.9 we considered the problem of determining the behaviour of a program restricted to one kilobyte, i.e. 8192 bits, of memory. Suppose that we take $n=8192$. Then n^2 is about 67 million, and n^3 is about 550 billion. Depending on how long it takes to carry out one step, we could expect a current personal computer to solve a problem requiring n^2 steps in seconds, and one requiring n^3 steps in hours or days. However, we have seen that if the problem requires 2^n steps, it is completely beyond reach.

Now consider a computer program such that the program, plus data and working space, fits into n bits. We assume that one of the possible instructions for the program is “stop”, and we wish to know whether the program will stop, or go on for ever. This is about the simplest thing we could wish to know. There is a brute-force solution: run the program for 2^n steps; if it hasn’t stopped by then, it never will. This is essentially Cariani’s position; we have seen that in practice it does not provide a useful test. However, in some cases we can do better (that is, find a short-cut). For example, if the first instruction in the program is “stop”, we know immediately that it will stop. If we look at every instruction in the program (which will take maybe *n* steps), and there are no stop instructions, we know it will never stop. But if there are some stop instructions in the middle of the program, we don't know if they will ever be executed, so the mere existence of stop instructions somewhere in the program doesn't tell us anything.

I wish to consider the possibility that there is what I will call a **short-cut algorithm** which can inspect any program (including data and working space) that fits into *n* bits; the short-cut algorithm will infallibly tell me whether or not the program will ever stop, and it will take time $f(n)$ steps, where $f(n)$ is a polynomial. I will show that if we assume a plausible conjecture known as **P ≠ NP**, then there is no such short-cut algorithm. I conclude from this that in general there is no practicable way to tell what a computer program will do, even if we know its source code. It seems very likely that almost all programs are intractable in this way. (Indeed the whole point of structured programming, object-oriented programming and similar techniques is to produce programs that are in the small subset of programs with comprehensible behaviour.)

A problem is in class **P** if it can be *solved* by some procedure that takes time polynomial in the size of the problem. A problem is in class **NP** if a purported solution can be *checked* in polynomial time[1]. For example, consider the problem of factorising an *n*-digit number, e.g. 232,604,759,349,334,488,811 (21 digits). No algorithm for factorising numbers in time polynomial in *n* is known. But if I am given a supposed factor of 232,604,759,349,334,488,811, say 123,491, I can check in time polynomial in *n* whether it is a factor or not (Cook 2007, p. 3). If **P** = **NP**, then for many problems finding a solution of the problem is not much harder than checking a proposed solution to the problem, and this seems implausible. However, it has not been proved, and a prize of US $1,000,000 has been offered for a solution at <http://www.claymath.org/millennium/>; (Cook 2007) is the official statement of the problem, by Stephen Cook, one of the pioneers in the field. Cook remarks (p. 10) that "most complexity theorists believe that **P ≠ NP**".

There is an intriguing class of problems known as **NP-complete** problems; if any one of these is soluble in polynomial time, then **P** = **NP**. One of them is known as *SUBSET-SUM* (Sipser 1997, p. 268). An example of *SUBSET-SUM*: suppose that we have some odd pieces of pipe,

1 NP originally stood for "non-deterministic polynomial time", from an alternative definition of the concept (Sipser 1997, p. 243).

of length (in centimetres) 12, 12, 15, 27, 30, 46, 79, 82. Can we join some of them together to make a pipe exactly one metre long? (Yes, because $12+12+30+46=100$.) Can we join some of them together to make a pipe 101 cm long? (No, but on the face of it this requires checking every combination.)

Suppose now that I have my short-cut algorithm, which can inspect any program (including data and working space) that fits into n bits, and tell me in time $f(n)$ steps whether or not the program will ever stop, where $f(n)$ is a polynomial. I write a program to solve *SUBSET-SUM*; and I arrange that if the answer to a *SUBSET-SUM* problem is "yes", my program stops; if the answer is "no", my program goes into an infinite loop. For an input file (list of lengths for *SUBSET-SUM,* including the total the pieces are supposed to add up to) of length n bits, my program, including the input data and working memory, fits into $n^2+1{,}000{,}000$ bits. (This is very generous, allowing 1,000,000 bits for my actual program, and plenty of space for copies of the input, etc.; actually something much smaller would suffice.) The program checks every combination of the input lengths, one at a time, so it will take a long time to run, but this doesn't matter; all that matters is that it eventually obtains the answer. Note that the program doesn't need enormous amounts of space just because I deal with one combination at a time, so I only need working space for one combination.

I now apply the short-cut algorithm to my program. In $f(n^2+1{,}000{,}000)$ steps the short-cut algorithm tells me whether or not my program is going to halt. So, in $f(n^2+1{,}000{,}000)$ steps I have found out the answer to my *SUBSET-SUM* problem. But, since f is a polynomial, $f(n^2+1{,}000{,}000)$ is also a polynomial function of n. This means that I have solved *SUBSET-SUM* in polynomial time, which in turn means that **P** = **NP**.

Thus, if **P** ≠ **NP** there is no short-cut algorithm.

The above shows that we cannot answer in reasonable time the simplest question about a program: whether or not it ever stops. Other questions we might want to know the answer to will fall to similar arguments. The two assumptions I have made are:

1. The distinction between a polynomial number of steps and a greater-than-polynomial number of steps corresponds to the distinction between feasible in practice and not feasible in practice.

2. **P ≠ NP**.

Even on these assumptions, the argument does not show that there are any systems that satisfy Darley's definition of emergence (Section 4.7 above), where a system shows emergence if the fastest way to predict what the system is going to do is to simulate it. It does show that there is no general way of determining in a reasonable time what a computer program will do.

The argument given above is not taken directly from any of my sources, but it would be an easy exercise in a course on complexity theory.

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