Evolutionary computation in creative design

Jussi Ängeslevä
Computer Related Design
Royal College of Art
2001

Table of contents:

1. Introduction 3
1.1. Background and motivation 3
1.2. The computer in the design process 4
2. Ghost in the shell 5
2.1. Macy conferences and the cybernetic outlook 5
2.2. Universal Darwinism 6
2.3. Memetics 7
2.4. From T-Ford to Formula 1 9
3. Intentional evolutionary design 11
3.1. Self-organising architecture 11
3.2. Evolving software and public betas 13
4. Evolution as search 15
4.1. Evolutionary Computation paradigm 15
Figure 1 Iterative aesthetic selection of table designs. 16
Figure 2 Single solution evolution of table designs. 16
Figure 3 Canonical Genetic Algorithm process 18
Figure 4 The mixing of chromosomes from two parents and a mutation of a child. 18
4.2. The Library of Babel 19
4.3. Dawkins' biomorphs 21
Figure 5 Samples of the Biomorph Land's occupants. 22
Figure 6 A sample of William Latham's evolutionary art creations. 23
Figure 7 Carl Sims's evolved infinitely detailed 2D artwork. 24
5. Complexity 24
5.1. Code and its manifestation 24
5.2. Paradox of complexity 25
6. Humane technology 26
6.1. Interface design 26
6.2. Examples: Lighting design, object design 27
Figure 8 The development of green pepper models out of a random initial population 27
Figure 9 Green pepper evolution with coarse adjustment of initial parameters 28
7. Evolution in design process 29
7.1. Evolutionary computation in the process, ... 29
Figure 10 The parameter space and the psychological space 30
7.1.1. Evolutionary optimisation 30
Figure 11 Satellite boom optimisation initial form and the evolved structure 30
Figure 12 Human designed, and GA designed load cells under pressure. 31
7.1.2. Evolutionary computation in Creativity 31
7.1.2.1. Evolutionary Ideas Search 32
7.1.2.2. Integral evolutionary design 33
Figure 14 The selected table and the realised outcome 34
7.1.3. Evolutionary approach in controlling an evolutionary design system 34
8. Reactive and adaptive / Metadesign 35
8.1.1. Tuning to an individual 35
8.1.2. Embracing the end user 35
Figure 15 Samples of the space generated in real time with Turboid. 36
8.1.3. Design of style. 36
Figure 16 Sequence of ever different 3D models generated by "BORGO" 37
9. The ethics of evolutionary design 37
10. Conclusions 39

1. Introduction

> *"Animals evolve by incorporating into their bodies new technology, whether by growing longer teeth or by modifying their digestive systems. Human evolution works in the opposite manner. With the first inventions, human evolution suddenly shifted from the realm of biology to that of technology. Animals incorporated ; we discorporated. We extended into the environment various parts of the body, various limbs and organs and, with electricity, the central nervous system. Most recently, computer technology and its children now extend around the globe the hemispheres and other elements and organs of the brain. It remains only to extend the mind itself. (Eric McLuhan, 1998)*

1.1. Background and motivation

We are breaking ourselves apart. The Human Genome Project, genetically modified crops, artificial intelligence research and distributed systems amongst others all rest on observing, analysing and experimenting with the living world around and within us. This kind of process of rationalising and turning into science of everything results in a rather dark view on the world, and ultimately, on us. When everything can be, at least in principle, explained through a scientific line of reasoning, there is not much left for higher meaning, religion or magic.

Isaac Newton's persistent research in optics, which resulted in a scientific explanation of the formation of a rainbow, got wide criticism from his contemporaries in terms of taking away the wonder in nature. Though it was a great step in advancement of technology, it did make the infinitely complex nature around us one step more predictable, and hence less mystical. More recently, Richard Dawkins' book ”The selfish gene” explored the social dynamics of evolutionary perspective and introduced the study of memetics to the general public, dividing the audience in half; those praising his achievements in understanding man, and those who felt it extremely opposing, lowering the higher ideals of human race into totally deterministic, causal relationships between the body and the environment, in which we are only puppets. To this, Dawkins responded with writing ”Unweaving the rainbow”, an allusion to his colleague's opposition few hundred years before. Instead of having to decompose the human cognition and ideals to the underlying struggle of the survival of the fittest, Dawkins suggests that these two levels can coexist. The unweaving of the rainbow is more than replaced by the immense complexity and elegance on which the teleology[1] and higher goals supervene.

In the field of art and design, this modern outlook is very confusing, as it directly challenges our old views on creativity. The motivation for me to explore these matters have been brewing in my mind for a few years now, as a practitioner in this field. Especially so, when I am dealing with computerised systems every day; systems that embody the more mechanistic and deterministic approach to our behaviour. Though treatise of machines in creative design begs for a critical discussion about the philosophical foundations of creativity and art[2], it is not at the forefront of this paper. This work attempts to reveal this kind of symbiosis of man and machine on a more practical level, how the machine is beginning to extend the human mind, and instead of fine art, addressing the field of design, where form and function are closely bound.

I propose that an evolutionary approach can be applied in design at various levels; in the initial brainstorming and conceptual design, to aid in processing the ideas, communicating the ideas to the others, analysing the designs validity, and ultimately, have the outcome as part of the process; to design something that will find it's final form (if such can be found), at the hands of the end user.

1.2. The computer in the design process

John Gero distinguishes 3 roles for the computer in the design process: in drafting, in analysis and in design synthesis support aid.(J.Gero 1996) The computer as a drafting tool is the most common application. CAD/CAM tools enable extremely accurate descriptions of 3 dimensional objects in virtual world before the idea is turned into real world, from bits to atoms.

As a tool for analysis, especially in the field of engineering design or architecture, the computer can be used to simulate how different laws of physics affect the design, traffic and other kind of flows in its usage, and the structural properties of the proposed designs, before the decision is made to physically constuct the designs.

---

[1] Teleology, as defined in the Encylopedia Britannica is (from Greek telos, “end”; logos, “reason”), explanation by reference to some purpose or end; also described as final causality, in contrast with explanation by efficient causes only. Human conduct, insofar as it is rational, is generally explained with reference to ends pursued or alleged to be pursued; and human thought tends to explain the behaviour of other things in nature…)

[2] Mitchell Whitelaw, John Gero and Peter Bentley have written extensively on the matter, work which is widely available.

Design synthesis support aid refers to the potential of using computer as a tool to generate the ideas what to design, and how. Instead of only ”feeding in” an already constructed design idea, the machine can be used as a reflexive agent, to iteratively develop a concept.

2. Ghost in the shell

2.1. Macy conferences and the cybernetic outlook

During, and right after the second World War, interdisciplinary meetings, what came to be known as the Macy Conferences, were held amongst the experts of various scientific disciplines; neuropsychology, electical engineering, philosophy, semantics, literature and psychology(K.Hayles, 1999 p.51) to name a few.

These gatherings discussed disembodied information, cybernetics and reflexivity, often presenting views that would hardly have been considered scientific before, and began to formulate the foundations of a cybernetic organism, crudely speaking mechanising the human into being another machine that happens to be made of flesh and blood. Something whose internal structure ”steers” [cybernetics= the science of control, based on a latin word for a steersman] the behaviour of the body, identical to the way in which a computer program executes to reach the target set for it.

An idea of information as being detached from any particular medium as formulated and discussed in these conferences, can be seen everywhere today. Computers have converted increasingly much of matter into pattern, when we do not really care about where the information physically recides, but only its internal meaning or message.

The essence of what the Macy Conferences instantiated can be compressed into four postulates:

1 Informational pattern is priviledged over material instantiation, where biological substrate is seen as an accident rather than an inevitability.

2 Consciousness is only a recent upstart in the process of evolution and only a minor sideshow.

3 The body is the original prostesis we learn to manipulate, so that extending or replacing it becomes a continuation of a process that was begun far before we were born.

4 Most importantly, the human is viewed so that it can be seamlessly articulated with machines. There is no essential difference between bodily existence and computer simulation, cybernetic mechanism and biological organism or robot teleology and human goals. (K.Hayles, 1999 p.3)

Even though the modern scientific view today is somewhat more in favour of embodied consciousness, in that the body consists of an irreversible, and integral part of the thought mechanisms, and hence ”uploading, and downloading” minds, having ghosts in the shell[3], seems farther away than in the mid-last century (S. Pinker 1999, A.Clark 1999), yet the principle that cybernetic mechanisms and biological organisms can evolve and function in principle in the same way, is very much as postulated at the Macy Conferences.

2.2. Universal Darwinism

Evolution is a controversial term, with no absolute consensus about its meaning. Sometimes almost any kind of change is seen as a form of evolution and sometimes it is restricted to a very specific process, that which takes place in genetic systems, most importantly, in biological evolution.

For the purpose of this study it leads nowhere to get too deep into the debate of these different approaches. The theory of Universal Darwinism (R.Dawkins, 1976) is taken as its foundation. It encapsulates the bare essence of evolution, and has inspired a wide body of research in fields quite far away from biology, probably most notably in the field of cultural evolution or memetics.

In a nutshell, Universal Darwinism can be compressed to the following prerequisites:

*a) **heritability***	the information must be transmissible in some way.
*b) **variability***	*although fidelity is important, there must be some scope for errors to creep in, a perfectly replicating system cannot evolve.*
*c) **selection***	*some variants may be more efficiently replicated or more durable than others; those variants will tend to increase in frequency in the system as a whole. Selection need not be continuous; a variable hereditary system may drift for long periods between episodes of selective*

---

[3] A popularisation of the concept ”Deus ex Machina – God from the Machine” in a japanese Anime scifi movie of the year 2029, where the world is made borderless with the net, and where the people can download their minds into the machine and live in the Gibsonian cyberspace.

> *pressure, without necessarily losing any of its potential to respond to selection should the situation demand. (D.Gatherer 1999)*

To explain his theory Dawkins proposed a scenario, in which life would emerge somewhere else in the universe, when the conditions would be just right. The thought experiment was […] to propose that evolution was not restricted to the forms of biology as we know it, with DNA as its basis, but instead that the process could take place in any information-carrying system, where heritability, variability and selection could take place.(D.Gatherer, 1999)

Other candidates for evolving systems with their own replicators include the immune system, neural development, and trial and error learning (S.Blackmore 2001), and culture as a whole.

2.3. Memetics

> *Most of what is unusual about man can be summed up in one word: `culture' […]. Cultural transmission is analogous to genetic transmission in that, although basically conservative, it can give rise to a form of evolution.(R.Dawkins, 1976 ch.11)*

Along with the theory of Universal Darwinism, the whole discipline of Memetics was instantiated by Richard Dawkins some 20 years ago (R.Dawkins, 1976 ch.11), though cultural evolutionism, the domain to which memetics belongs, can be traced back to the 19th century and before.(D.Gatherer, 1999) It was only through memetics, that a strong enough scientific foundation was laid for a new area so as to launch it as a discipline of its own right.

Memetics, is based on the study of memes, cultural replicators, analoguous to genes. Coined by Dawkins, meme comes from both, greek word for imitation, *mimeme*, and French for memory, *même*. It is a clever analogy, as both of the base words describe aspects of the essence of how memes work.(R.Dawkins, 1976 ch.11)

Similar to genes, the memes are considered as the building blocks of higher level structures or organisms, or in this case, information structures that manifest themselves in culture, language, art movements, music compositions, religions and disciplines of science (memetics included). What defines a meme though, is not its content value as such, but simply its ability to reinstantiate itself in another medium. Also, similar to how genetic code can be considered flexibly from the scale of individual genes, through sequences describing some higher level structures as eyes, limbs etc. to the whole genome of a species, also memes can be explored from being individual features of an idea to concepts of the complexity of a whole culture.

The Oxford English Dictionary's version defines meme as: *"[…] An element of a culture that may be considered to be passed on by non-genetic means, esp. imitation".*

In the research community, there are today a number of slightly differing definitions. The fundamental questions between these definitions are *"(1) Whether memes exist only inside brains or outside of them as well, and (2) the methods by which memes may be transmitted."(S.Blackmore 1999)* Even Dawkins himself has been changing his view over time back and forth between considering the brain as the only possible medium in which memes can reside and allowing media, newspapers, books, computer hard drives etc. to be considered as equal carriers, as long as they facilitate transmission and replication.(S.Blackmore, 1999) The question now is, to what extent the other media can also be involved in *actively evolving* the memes, not only waiting for human agent to extract them and mutating and recombining further.

Memetic transmission does not mean that a specific kind of neural structure would need to be reinstantiated in another brain one to one, but instead that the concept this idea contains, is mediated. For instance, in case of a language, there are no individuals, whose neural structure would be identical, yet they easily communicate with each other.

So, to fit memetics to the Universal Darwinism paradigm, it has to fulfill the three prerequisites of a) heritability, b) variability and c) selection. When memes progress from one brain to another, the new instance inherits the essence of the original (prerequisite a)), but instead of being a duplicate of the original, it does transform to something different due to differing framework of undestanding of different individuals and incomplete communication between them (prerequisite b)). Depending on the empowerment the new meme gives to an individual, when compared to competing ones, it will either be kept and reinforced, or forgotten over time (prerequisite c)).

Derek Gatherer presents a clarifying example of memetics at work:

> *Thomas Alva Edison (1847-1931) provides an interesting case history in design 'genius'. […] Edison's Menlo Park laboratory was run on a combination of his own idiosyncratic originality and the technical prowess and practicality of the engineers and scientists with whom he surrounded himself. Ideas thrown out by the maestro*

> *were left to the underlings to troubleshoot and optimise.[...] The secret of his phenomenal success seems to have been the practical application of earlier scientific developments, in particular those of Michael Faraday,[and Nikola Tesla] by whom he was profoundly influenced. Edison displayed an openness to memes that were already in circulation, making to a large extent discoveries that were waiting to be made. It may seem churlish to speak of a great inventor in this way, but only to those who are wedded to the idea of the designer as demiurgic auteur. (D.Gatherer, 1999)*

The impact of Memetics to human teleology is remarkable. Similar to how Darwin's theory of natural evolution removed the necessity of a "grand designer" in the natural realm, memetics suggests that thinking of human beings as fundamentally teleological organisms, whose action is driven by a deeper reason, is a fallacy of equal magnitude. Of course, our actions appear to us to be driven by a reason, and at a certain level, they are, but this level is only a supervening[4] property on top of the structure of cultural replicators, that function only according to the laws of evolution. "*What we have not previously considered is that a cultural trait may have evolved in the way that it has, simply because it is advantageous to itself*." (R.Dawkins, 1976)

2.4. From T-Ford to Formula 1

From a memetics point of view, progression of design is a form of evolutionary process. It is one example of a merger between technological advancement and cultural movements and of style and preference. The designs of today are iterated mutations and improvements of cultural and technological heritage, or meme pool, of the past, from which the designers draw their inspiration, or recombination of memes, for their new ideas.

As an evolutionary progression, "[…] the Formula 1 racing car and the Honda Civic are both 'descendants' of the Benz Motor-Wagen of the 1890s […], they have adapted in the meantime to perform quite distinct roles, to fit into very different evolutionary niches." (D.Gatherer, 1999)

Most of the time designs tend to go step by step, improving progressively to fit certain need. At some point, a bifurication may occur, when there are more than one direction of evolutionary pressure that pulls the design into opposite bearings. Then single base design functions as a

---

[4] A property that cannot be explained from its constituting parts only.

starting point for two different objectives, and the successive generations will draw these two different developement hierarchies further away from each other. Later on, when comparing individuals from these two niches, it is hard to believe that they are based on a common ancestor, but by tracing back through the intermediate steps, the connection becomes clear.

Marshall McLuhan talked about the *horseless carriage* referring to the early automobile, that took it's appearance directly from the preceeding technology, the horse carriage. Only later the idiosyncrasies, or requirements of the horse carriage were removed, as more efficient, economical or culturally more approved forms became to replace them. Today, if you put the state-of-the-art Ferrari Formula 1 next to early 18th century station wagon, it may be difficult to see the connections in their design.

Occassionally it may happen, that design takes a saltatory (paradigmatic) leap in some field, suddenly coming up with something that can not directly be derived from the previous stages. In memetic terms such a leap may happen either a) through a novel recombination of memes of different fields. Something, that is impossible to predict beforehand, but when at one time these different schemata happen to recide in one brain, (or in the brain of a designer group), they form a synthesis, a hybrid meme, that becomes the invention. Another possibility b) is that the meme goes through serious mutation when being transferred between two brains, or even within one brain, when it has not been recalled for a long time and it has mutated itself into something different than the original.

Examples of such would be for instance: *"the "Eureka!" of Archimedes as the water flowed over the sides of his bath […]. Here the random diversity generator of the brain is on more open display and its capriciousness is more evident." (D.Gatherer, 1999)*

Evolutionary computation paradigms may well be one of the few idiosyncratic modes of using the computer, as it enables one to do something that before was simply impossible. Unlike making word processing easier, drawing or modelling easier and database management more automated, evolution just simply could not be instantiated without the sheer computational power now available.

3. Intentional evolutionary design

Based on the outlooks of Cybernetics and Memetics, it is, at least in principle, possible to extend creative thought with an environment or a machine, as the underlying processes are considered similar, though today still in a vastly different scale of complexity. To bring this kind of framework into practice is very complicated, and it can be applied to only a relatively narrow range of design tasks.

The evolution of design as described above, takes place over generations, and cannot be consciously used in in a single design task, though it must be noted that the speed is increasing exponentially. Awareness of new styles, inventions and movements spread like forest fire, and is quickly adapted to next generations.

The more conscious approach, and taking place within single design process can be called *”Intentional evolutionary design*” as it highlights the active role of evolution as a tool in the process. This means, that ideas and designs are evolved through different means, where the designer/designers are involved throughout the process.

3.1. Self-organising architecture

> *Frank Lloyd Wright believed that once you built the buildings...that you should come back in a year to see where to put the sidewalks.*[5]

I do not know if the suggestion above ever was utilised in real life, but it nevertheless, describes quite nicely the potential of intentional evolutionary design. By letting the people use the building without any predefined paths between the structures, the people’s daily routines, habits and preferences define the requirements for such paths from ground up. Paths will begin to form where people walk the most, and the already walked paths will be even more reinforced as other people adjust their optimal paths to the closest collective optima.

This kind of a phenomenon is called *stigmergy*, most notably seen in the construction of ant nests, where the seemingly dumb individual ants seem to work as if they understood the functionings of the nest on a much higher level.(Eric Bonabeau et al. 1999) In order for stigmergy to take place, it requires some kind of manipulation of environment to store individual actions. In ants this trail is certain chemical that the ants continuously release, leaving a

---

[5] http://www.halfbakery.com/idea/
organic_2c_20responsive_2c_20bioengineered_20sidewalk

vaporating invisible path behind them, to which the other ants then react to. In the case of designing paving for building complexes, there would need to be a way for the people to observe the trails of the others. In northern countries this is easy, as snow functions as a natural tracing paper for the footprints, fading the marks over time as new snow falls on top.

Another experiment of creation of optimal structures in public spaces was done by Hochschule der Kunste's architecture students, who set a video camera at the television tower at Alexander Platz in Berlin[6], that recorded the people's walking paths in the square for one day. Then they traced the paths over time, and got a map of the intensities of where the most traffic was to propose an alternative structure to the square. This kind of a process is much less stigmergic, though, as the individuals can only react to the other people simultaneously in the space. The history does not build up, (as the traces in snow,) and the analysis of such data is then always an averaging decision about where the heaviest traffic is, and where to draw the ”golden middle way”.

Having introduced these examples as evolutionary design, it must be noted, that there is much controversy in to what degree they can be considered truly evolutionary, and to what degree they are examples of iterative self-organisation, where the prerequisites of Universal Darwinism are not fulfilled.

The *population* of possible paving layouts is all the individual paths people walk through the architecture. The *heritability* can be seen in how one path creates a bias for the future paths due to the trace it created. *Variability* comes from the differing needs of individuals, how they always are going somewhere, yet the individuals change every day, and their comings and goings change also. *Selection* takes place on a local level, the selection of which path to follow to what extent, and when to break off and create your own path, that the following generations can follow.

---

[6] I have not been able to confirm this from any bibliographical source, and rely only on a discussion with Prof. Joachim Sauter from HDK in summer 2001.

3.2. Evolving software and public betas

It all began in a small student flat of a Finnish computer science student, who was frustrated of the limitations of Minix operating system[7] , and decided to learn and understand the underlying structure of what goes on in a computer the hard way, building everything from the ground up. As it was the early days of the Internet, he would log in from the university's network, and probe on a news site, if there was someone else interested in his project. Soon enough he would find out that there was an army of keen hackers willing to get involved.

From the beginning, everything was done very openly. Since no-one was making money out of the project, all the source code was, and is, always freely available. What this meant, was that instead of having a closed group of engineers, as in case of traditional sofware houses, anyone could play around with GNU/Linux modules, and give his/her experience and source codes of programs to the others.

Many times several people would work on the same component of the system around the world, independently or as a group, and post their work into the public domain. Other hackers would then download the new code, compile it, and run it on their machines. If it was found good, the word would spread and more people would try it, and eventually it might find its way to the official distribution databases, and in this way be integrated to the core system. Otherwise, the programmers would get feedback from the community what was good and what not, suggestions in different solutions and other hackers might start doing their own modifications and additions.

In a nutshell, the development of GNU/Linux is a school book example of an evolutionary development process. The deep expert knowledge in a traditional softwarehouse manifested in a small group of top programmers was replaced with first hundreds, then thousands, and now probably hundreds of thousands of hackers at different levels of expertice, who would explore the space of possibilities with breadth never possible in corporate domain. To contrast the development of GNU/Linux to Universal Darwinism, there was much of :

---

[7] Minix project that was initiated as an academic exploration and education in OSes and was never meant to grow into usable OS for the general public. Well written history of the GNU/Linux movement can be found in Glyn Moody's "Rebel Code: Linux and the Open Source Revolution", Perseus Pr. 2001

a) ***heritability***	in the form of different programming styles being mimicked, adjusted and incorporated to new modules as well as simply utilisation of already written code by someone else.
b) ***variability***	because the sheer number of people involved would have such a diversity in their skills, approaches and objectives and
c) ***selection***	where the core group, who would begin to collect the completed modules (or modules that had reached a certain stage so that they could be considered as ready version number n), into single distribution that would then be considered as an official distribution of GNU/Linux. Today there are a number of distributions that all have slightly different fitness criteria, and hence they accept different modules into their distributions

As (at least in the beginning) the project was not a full time job to anyone, it lacked certain seriousness, that one has got to do this and that, but instead people would be more relaxed in looking at various directions. (analoguous to having relaxed fitness function enabling exploration beyond the closest local maxima in evolutionary algorithms. see below)

The hackers would spend countless number of hours to develop their own little share of the GNU/Linux simply because they could. Because the source code was available, and there were other people interested in it. Not all of the hackers were top class programmers, though undeniably a fair proportion were, and none of them worked full time on it, but their communal effort would yield unprecedented results.

The GNU/Linux approach has today been adopted by many commercial software houses. For example, Apple released it's next generation operating system as a ”Public Beta”, which meant that it acknowledged that the OS was not ready yet, but instead of doing the testing and fine-tuning in-house, they let the user community to do the work. This way they could get much more breadth in their beta-testing and also having the system tested in real life situation, speeding up and improving the development significantly.

4. Evolution as search

> *“Evolutionary computation is all about search. In computer science and in artificial intelligence, when we use a search algorithm, we define a computational problem in terms of a a search space, whic can be viewed as a massive collection of potential solutions to the problem [...] A commonly used term in this context is ”optimisation”, which just means ”finding the best.” For example, just as you might browse through a bookself to find the book that best suits to your specifications.(P.Bentley 2001)*

4.1. Evolutionary Computation paradigm.

Search algorithms are plentiful. Evolutionary search algorithms are a relatively recent addition to the list. *”These [evolutionary] algorithms typically use an analogy with natural evolution to perform a search by evolving solutions to problems.”*(P.Bentley, 2001, p.5) This means that instead of considering one solution at a time, evolutionary approach looks at a large set, a population, of slightly varying solutions at once, and then, through the processes of mutation and reproduction, new generations of the populations are created and evaluated until good solutions are found.

Let us consider the process through a very simple example of evolving furniture. First, a set of constraints, different parameters that the evolutionary algorithm can vary, are set. Those constraints can be for example, thickness of the boards, length of the table top, length of the legs and the legs’ horizontal position. Then a random population of individuals are generated, as the first generation in figure 1. This means that to the parameters already defined, random values within the set boundaries are substituted, and these ”value lists” are then stored into memory. One such sample table could be: *[#Width of the top= 6, #Top thickness = 1, #Left leg thickness=3, #Left leg height = 4, #Left leg position= 3, #Right leg thickness = 2, #Right leg height = 4, #Right leg position = 8]*

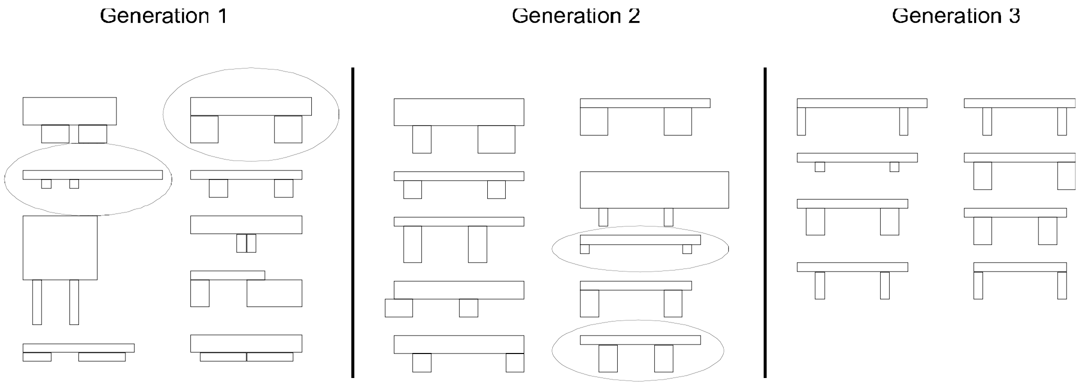


Figure 1 Iterative aesthetic selection of table designs.

From each generation, the most “fit” (in this case according to aesthetic selection) individuals are selected for reproduction and mutation. In the example, one can see, how the variation quickly “homes in” to relatively “good” solutions (banal, ikeaish style tables in this illustrative example).

More traditional approach to evolve a single solution better is described in figure 2. By varying one variable at a time, a single solution is reached after a greater number of steps, and a much more analytical touch than in the evolutionary approach.[8] This is known as “Local search” with a single solution instead of locus of solutions as in the previous example.

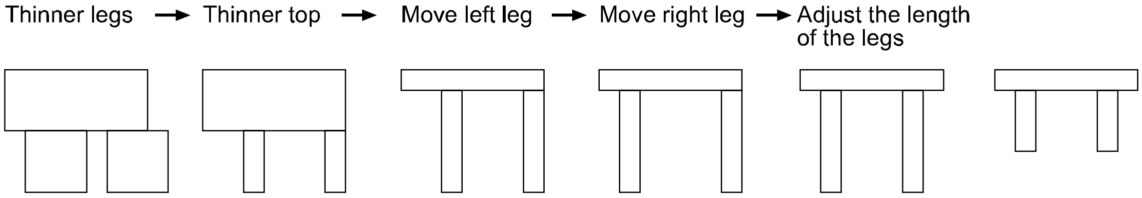


Figure 2 Single solution evolution of table designs.

The strength of evolution is in its capability to deal with large number of different variables, or dimensions all in parallel. In the above example, by selecting one individual with an appealing thickness of the table top but with undesirable legs, and another one with a bit too thick, but not outrageous, tabletop, and more desirable legs, the next generation is already much closer to the wanted outcome.

---

[8] (Again, nobody would of course apply evolutionary, or any other search algorithms to such a simple problem as this. It is only chosen to illustrate the functionings of the algorithms, and the extrapolation to some more meaningful problems comes later.)

Also, when compared to the single solution strategy, evolutionary approach is more automatic, ie. instead of having to tailor everything from the ground up, the organisation process can be left for the evolutionary algorithm. The further problem with manually tailoring the process is that the outcome may more easily curb into *local optima*, a solution that seems to be the best, because altering the variables a little bit to one direction or another makes the solution worse. There may, however be solutions that are better than the local optima, but in order to reach there, the structure would need to be altered a lot, and in a way that is not evident when looking at the point of view of the local optima.

Evolutionary computation has its roots as far as in the 1950s[9], but it was only after John Holland's development of Genetic Algorithm, that the field became popular in wider audience (John Holland, 1975). Though neither necessarily the most efficient nor the first, Genetic Algorithm is probably the most used evolutionary algorithm today. (P.Bentley, 2001)

> *It is fruitful to view a GA as making use of two separate spaces: the search space and the solution space. The search space is now a space of coded solutions to the problem, and the solution space is the space of actual solutions. Coded solutions, or genotypes, must be mapped onto actual solutions, or phenotypes, before the quality of fitness of each solution can be evaluated. (P.Bentley, 2001 p.11)*

Genotype is usually a set of values, or alleles, of different parameters, that describe, as in the above example, the thickness, the length and the position for instance. They are simply a string of ones and zeros in a computer's memory, that the evaluation program substitutes to different variables in the phenotype template. It's biological correspondent would be a chromosome that defines the physical appearance of an organism.

The simplest form of Genetic algorithm*, the canonical or simple GA* works as follows:

---

[9] In the early 1950s , the well-known statistician George E.P. Box came up with an innovative idea first written up in an internal report for Imperial Chemical Industries Ltd., for improving productivity in a chemical process plant. Calling the idea "Evolutionary operation," Box proposed a system whereby plant control settings (such as temperature and percentage concentration of reactants in a chemical process) could be deliberately and systematically varied during plant operatino, and the results […] could be recorded. Control settings for further batches could then be set according to an analysis of the results found so far. (P.Bentley, 2001).

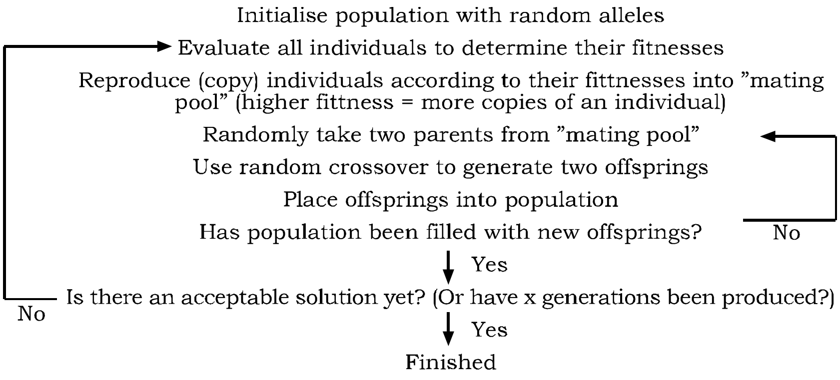


Figure 3 Canonical Genetic Algorithm process (P.Bentley, 1999, p.14)

In the beginning, a random population of alleles are set. Then for each individual, those alleles are substituted to the phenotype template, that describes the form/ function of the individual. Then a fitness value is set, and depending on it, n copies of the original are sent to the ”mating pool”. Once the whole population is evaluated, then two parents at a time are taken from the mating pool, and their chromosomes are cut at a random point, and reconnected together (crossover), as illustrated in figure 4. These ”children” are then put into new generation of population, and re-evaluated again, until an acceptable solution is reached, or the set limit of generations reached.

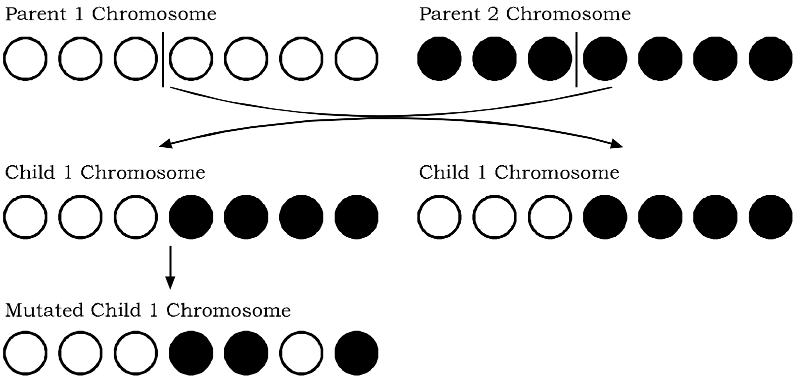


Figure 4 The mixing of chromosomes from two parents and a mutation of a child.[10]

A careful reader may have wondered how such an approach could be used in the above mentioned example of evolving tables. Indeed, it would not really be too easy, as the example relies on *aesthetic evaluation* of the fitness, and hence the individuals chosen to the mating pool would all have a fitness of one, and the others that of zero. The example was used to illustrate

---

[10] Slightly altered from (P. Bentley, 2001 p.13). The chromosomes can be considered either as alleles or as genes, the latter resulting in much more open ended evolution, as it enables structurally different designs.

the principle how evolution works, and the deconstruction of canonical GA was to give a flavour on what goes on generally under the hood.

On top of the Genetic Algorithm(J.Holland, 1975), there are today four families of evolutionary algoriths: Evolutionary Programming (EP)(L.Fogel, 1963), Evolutionary Strategies (ES) (I. Rechenberg 1973) and Genetic programming (GP)(J.Koza, 1992). It is not in the scope of this work to describe in detail all their functions, and for now instead of discussing thier differences, it is enough to summarise their similarities. As stated by Dawkins' Universal Darwinism, the criteria for evolution to take place are the presence of *reproduction, inheritance, variation* and *selection*. In evolutionary algorithms, this translates to saying that:

> *"[… A]ny point in EA[evolutionary algorithm -based] design space must represent an algorithm in which new individuals can be generated (reproduction), these new individuals are often largely similar to old ones (inheritance), but with some differences (variation), and there is some bias toward inheritance from "better" individuals (selection). [..]*
>
> *Points in EA design space will also all share certain other features. Namely, there will be some way of initializing the population, some way of evaluating the fitness of candidate solutions, and some way of determining when to stop."(P.Bentley, 2001 p.34)*

So far the evolutionary programming has been described as a way of doing effective search. Let us stay a little longer in the search paradigm before looking at the flip side of the coin.

4.2. The Library of Babel

When researching for his book "Out of Control: the new biology of machines", Kevin Kelly browsed through the works of Argentinean author Jorge Luis Borges. One of the interviews he came across, Borges was asked about his concept of the Library:

> *[INTERVIEWER]: "I read in one of your essays about a labyrinthine maze of books. This library contained all possible books. It was clear that this library was born as a literary metaphor, but such a library now appears in scientific thought. Can you describe the origin of this hall of books to me?"*

> *BORGES: The universe (which others call the Library) is composed of an indefinite and perhaps infinite number of hexagonal galleries, with vast air shafts between, surrounded by very low railings. There are five shelves for each of the hexagon's walls; each shelf contains thirty-five books of uniform format; each book is of four hundred and ten pages; each page, of forty lines, each line, of some eighty letters which are black in color.*
>
> *[INTERVIEWER]: What do the books say?*
>
> *BORGES: For every sensible line of straightforward statement in the books there are leagues of senseless cacophonies, verbal jumbles and incoherence. Nonsense is normal in the Library. The reasonable (and even humble and pure coherence) is an almost miraculous exception.*
>
> *[INTERVIEWER]: You mean all the books are full of random letters?*
>
> *BORGES: Nearly. One book which my father saw in a hexagon on circuit 1594 was made up of the letters MCV, perversely repeated from the first line to the last. Another (very much consulted, by the way) is a mere labyrinth of letters, but the next-to-the last page says Oh time thy pyramids.*

Borges’ Library is a hypothetical construct of all the possible permutations of letters arranged in an almost infinitely large library, where all the books, past, present and future could, in principle be found. Actually, it is today not all that hypothetical anymore, as such a program is easy enough to create in a computer. Of course, not all the combinations exist as a ”hard copy” on some sector in a hard drive (as there would not be big enough storage for them all) , but rather, the library is dynamically created, when a user explores it. A traveller in such a library soon finds out that, as Borges states, to find anything even remotely sensible, is very hard indeed, and most of the time the books are just an incomprehensible sequence of letters. It does not matter that the books are in perfect order, the next volume being predicted accurately by the previous, as the sheer number of the possibilities is so massive, that to find a copy of Shakespeare’s Hamlet, it would take very much longer than to write it from scratch without having ever read it in the first place!

One can imagine similar Borgian libraries of two dimensional images, three dimensional forms, music compositions etc. All of them, though containing the masterpieces of the past and future, would be impossible to use due to the immense amount of possibilities. Ways to tackle the problem are:

a) to limit the library into more manageable proportions, where there still is abundance of variety, but it is not so overwhelming, that one can eventually find, with an efficient search method, something inspiring, and

b) to explore the space with an efficient method. One such method is human-guided evolution.

4.3. Dawkins' biomorphs

An early explorer of one kind of Borgian library is Richard Dawkins with his synthetic universe called Biomorph Land. It is a space of possible biological shapes constructed with short straight lines and branches. ”Dawkins wrote Biomorph Land as an educational program to illustrate how designed things could be created without a designer. He wanted to demonstrate visually that while random selection and aimless wandering would never produce a coherent design, cumulative selection […] could.”(K.Kelly 1995)

Dawkins had written the program to evolve tree-like structures, but to his amazement, a wonderfully versatile world of different motives began to unfold, as he explored the space. He discovered areas, where the genotype would translate into insect-like creatures, ranging from weird bugs to butterflies and from scorpions to frogs. (K.Kelly 1995) To describe the feelings of his early explorations, Dawkins said later: "I was almost feverish with excitement. I cannot convey the exaltation I felt of exploring a land which I had supposedly made. Nothing in my biologist's background, nothing in my 20 years of programming computers, and nothing in my wildest dreams, prepared me for what actually emerged on the screen."(K.Kelly 1995)

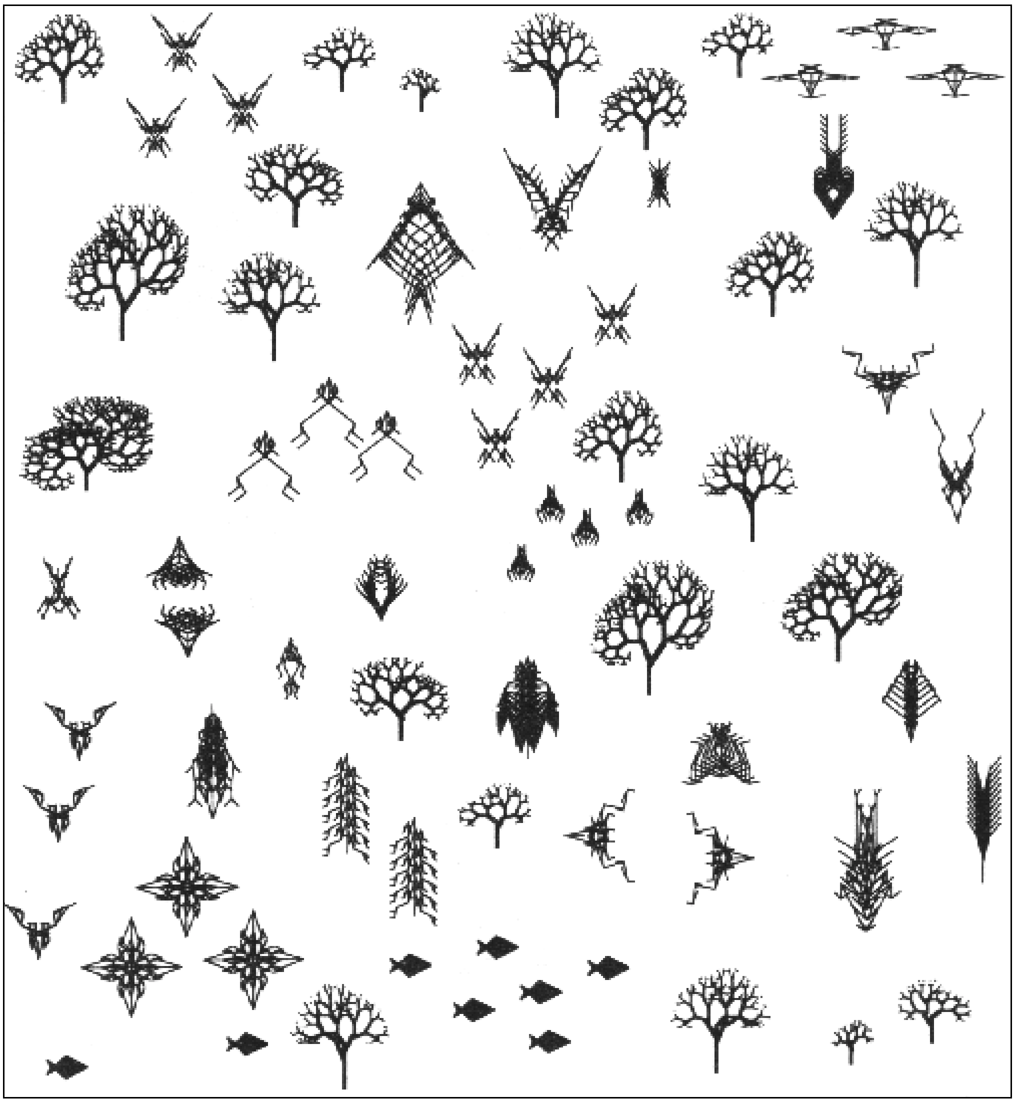


Figure 5 Samples of the Biomorph Land's occupants.

The experience from the Biomorph Land later materialised in the writing of the book ”Blind Watchmaker”11. Following the view established in memetics, Dawkins described in the book the dual metaphor of evolution and search:

> *"When you first evolve a new creature by artificial selection in the computer model, it feels like a creative process. So it is, indeed. But what you are really doing is*

---

[11] Blind Watchmaker was an allusion to an eighteenth-century priest William Paley, who claimed that, *”[even] if you didn't know what a watch was, the obviously designed character of its cogs and springs and of how they mesh together for a purpose would force you to conclude "that the watch must have had a maker: that there must have existed, at some time, and at some place or other, an artificer or artificers, who formed it for the purpose which we find it actually to answer; who comprehended its construction, and designed its use. " If this is true of a comparatively simple watch, how much the more so is it true of the eye, ear, kidney, elbow joint, brain? These beautiful, complex, intricate, and obviously purpose-built structures must have had their own designer, their own watchmaker - God. (R.Dawkins, ”The improbability of God” in Free Inquiry magazine, Volume 18, N.3 Online: www.secularhumanism.org/library/fi/dawkins_18_3.html)*

> *finding the creature, for it is, in a mathematical sense, already sitting in its own place in the genetic space of Biomorph Land."(K.Kelly, 1995)*

This is the very essence of how the cybernetic outlook, the evolutionary programming and memetics all approach creativity. They do not draw a distinction between search, creation and evolution. They are just three different ways of explaining the same thing.

The biomorph Land was the first practical example of using evolutionary computation in generation of form, and though its original purpose was only to illustrate the theoretical principles in progressive selection, it soon followed with a generation of artists-scientists exploring this new area.(Figures 6 and 7)[12] One of the better known artists in this field is William Latham, who together with Stephen Todd and IBM research team, generated very complex and organic looking 3D images and animations.(Figure 6)[13]

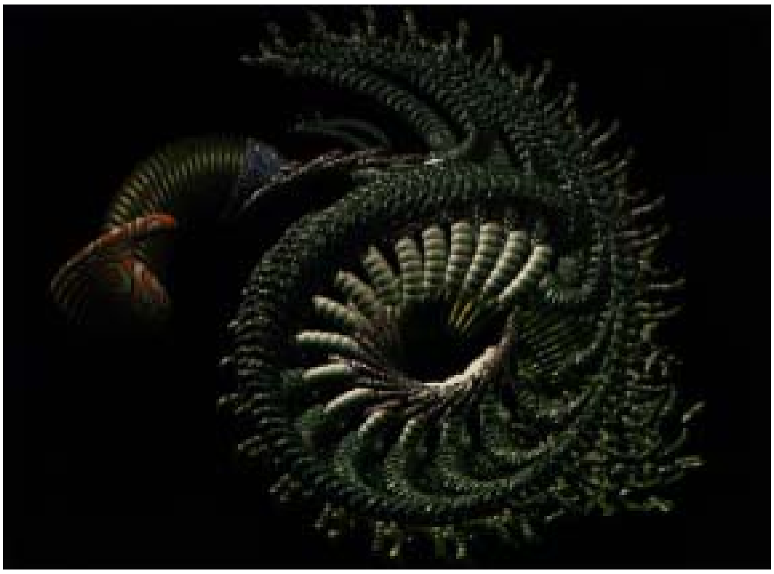


Figure 6 A sample of William Latham's evolutionary art creations. [14]

---

[12] List of most notable EA artists: Steven Rooke, William Latham, Carl Sims…

[13] He later on announced having lost interest in the pure art-making, and found ComputerArtworks, a games company that today utilises evolutionary computation in games design. Their latest success is a game called Evolva, in which the characters evolve and mutate in response to their gameplay and encounters with different creatures.

[14] http://www.nemeton.com/axis-mutatis/latham.html

Figure 7 Carl Sims's evolved infinitely detailed 2D artwork.

5. Complexity

5.1. Code and its manifestation

It is easy to forget that practically all computerised design tools/(or any computer tools for that matter), are operating on two different levels not dissimilar to genotype and phenotype, even though they otherwise do not follow an evolutionary process. The underlying code can be considered analoguous to the genotype, which is the description of the shapes, the mathematical functions that define the surfaces and volumes, the numerical values of the curves, polygons, colours etc. The phenotype is then what we see on a screen, or is realised with a aCNC router.[15]

In order to be able to generate any form (phenotype) one has to work with the genotype, in a way or another. Traditionally the mapping is a two stage process: First, decompositing the design idea into manageably small structures of curves, shapes, fillets and bevels, and then recompositing this mathematical-logical stucture as a code, that then commands the computer to draw the model on the screen.

> *The implicit modeller [where the user controls the shapes' variables directly] still demands the user's undestanding of which parameter to adjust to perform a*

---

[15] To describe evolutionarily generated description as code is slightly misleading in a sense, that code normally implies some kind of human logic, that the code is understandable to at least some expert. In the case of genetic code, this is rarely the case, and hence, though description, it is not "code" in its traditional meaning.

> *desired modification. Additionally, generic understanding of the geometric modelling also helps them to produce the quality shapes effectively. These requirements, however, enforce the users to become familiar with the modelling operations among others, significantly preventing them from concentrating on the actual design task. (H.Takagi et al. 2001)*

Of course with the higher level modelling packages of today, this does not mean that the designer has to analyse his/her design concept down to which degree polynomials would describe the contours of the form, but instead this is done interactively, by manipulating the shapes on screen. One can respond to their appearance, rather than their parameters. It however is closely linked to the underlying mathematical structure, and in order to be able to create a good and optimised model, one has to be at least to some extent aware of the underlying world of numbers.

5.2. Paradox of complexity

In the traditional, logical approach to computer modelling, basic forms are relatively easy to create, their genotype is simple, and the final outcome, the phenotype is equally simple. Complex shapes, in contrast, are much harder to generate, and have consequently much more complex description.

In evolutionary paradigm the same logic does not apply. Simple designs tend to have already quite complex description, as the evolutionary optimisation does not try to optimise the genotype itself, but the phenotype when assessed through the fitness function at hand. There may also be a remarkable amount of ”junk code” in the description (described in detail below) that does not affect the outcome, but is an undividable part of the description.

The decoding of organic, mathematically very complex shapes, (though perceptually or psychologically potentially quite simple) is very hard in computer medium. This is because the shapes have to be described centrally, in a non-distributed fashion.[16]

The tendency in computer modelling today is much in shifting the control into higher level, where the designer controls such concepts as *particle systems* and *terrain types*, instead of

---

[16] When pouring, say, a glass of sand on a table, the shape it creates falls naturally, and without much effort. All the grains are defining their own location in the whole, the information does not have to be channeled through some central hub before perceived by an observer. When dealing with computer medium, even a distantly accurate description of such a pile of sand would require tens or hundreds of thousands of coordinates in 3 dimensions, just to denote the location of every individual sand grain let alone the appearance of them.

individual drops or blades of grass. These tools, however, though very useful, are not paradigmatically different from the modelling of simple curves and deformed planes. They require the human control of certain variables, and execute their genotype to phenotypical form with absolute accuracy as dictated by the control variables.

To attain even a relatively simple geometric shape (perceptually), with evolutionary process normally results in very complex and potentially largely obsolete code (except when working on manipulating *parameters* with evolution, like in simple genetic algorithm, and not the *description formulae* themselves). This code is very similar to the “junk DNA” of which our own blueprints contain over 50 percent[17]. It is code that has been isolated from the functional description over generations, and does not get executed into the phenotype. Ocassionally some sequences of such junk code can be revitalised by a fortunate mutation, and then the old code is given a new chance in a new environment. This might potentially result even more unexpected results.

On top of this kind of excess, evolutionary code does not tend to find the path of least resistance in its genotypical form, though certainly attempts in the phenotype. This means that for instance a function y=2x might be arrived to in an evolutionary process as y=4+5x/(10/4) –5 +(x^2/x)*0+1. The latter *can* be simplified to the former, but usually the complexity is paradigmatically higher than what illustrated here and is hence very hard to attain.

6. Humane technology

6.1. Interface design

The engineering approach in software design tends to favour an approach, where the internal structure of the program is made more accessible to the user, which paradoxically makes the whole software *less accessible* because of it’s unnecessary complexity in the interface. Instead of manipulating the appearance of an image, we adjust it’s parameters, instead of controlling the shininess and texture of a 3D object, we manipulate their uv-coordinates and vertex normals.

This kind of approach is many times necessary to achieve the wanted outcome, but this means that much of the effort has to be put into crafting and adjusting the design idea into being realisable in the computer medium.

---

[17] www.nhgri.nih.gov/NEWS/vignettes.html

Often, a more intuitive approach can be used, where all the underlying parameters are hidden from the user, he/she only concentrating in refining/finding the desired outcome.

In evolutionary computation paradigm this kind of thinking is central, where the whole process is about *evaluating* the design critically, and where there is no absolute single solution.[18]

6.2. Examples: Lighting design, object design

One big problem in adapting intentional evolutionary techniques in design is to tailor the software to one's needs. As evolution has to be controlling and affecting some physical parameters of the design, to define those parameters may be very difficult. Let us have a look at a few succesful applications and their outocomes:

A joint project between Oita University, Kyushu Institute of Design and Yonsei University developed ”A 3D Modelling System for Creative Design”(H.Takagi et al. 2001) that is based on Interactive Evolutionary Computation, where the user is an integral part of the evolutionary loop as an evaluator and as direct manipulator of the created shapes.

One of the main objectives of the project was to create a system that would enable non-professionals to easily create complex, organic shapes, and explore novel shapes that one would not have otherwise thought.

Figures 8 and 9 describe the history of modelling Green pepper from roughly sketching the initial shapes, and then evolving the designs through interactive evolution. The attributes that the evolution controls in this example are the size, location and scale of the sub-primitives as well as their taper, shear, twist and blend.

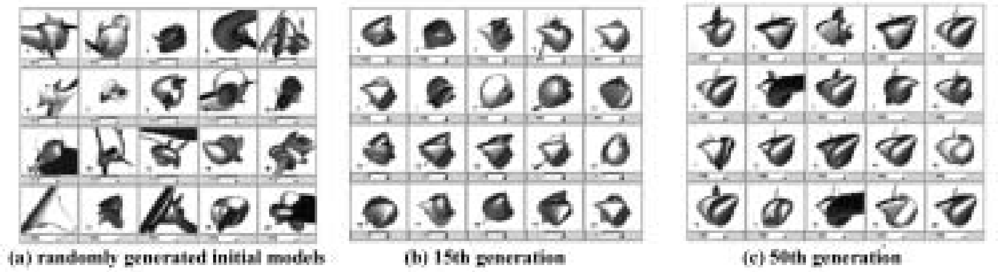
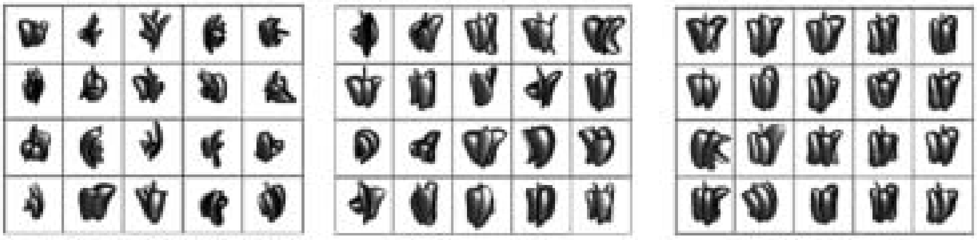


Figure 8 A sequence of the development of green pepper models out of a random initial population. (H.Takagi et al. 2001)

---

[18] At least within the evolutionary phase of the design. Of course one can then alter on switch into tuning individual parameters etc.



(a) roughly modelled initial population (b) 5th generation (c) 10th generation

Figure 9 Green pepper evolution with coarse adjustment of initial parameters. (H.Takagi et al. 2001)

Another work at the Kyushu istitute of Design deals with Lighting design. The basic setting is to use 3 Light sources in 3D space consisting of a room or a persons face and to create different kind of atmospheres: happy, gloomy or scary for example.(N. Hayashida 2000)

Instead of knowing exaclty where the light sources have to be to produce a given expression, it is much easier to evaluate what is good lighting or bad lighting, or which one of the samples is better than another, guiding the process until one reaches the desired effect.

Experiments with the lighting design showed that people with little or no experience in 3D modelling or lighting design reached good solutions significantly faster than with traditional method of adjusting the paramenters by hand. On the other hand, for professional modellers, the Interactive evolutionary approach was equally efficient as when they adjusted the parameters by hand.

This study shows how the complexity of the task and the skill set of the users go hand in hand. The more complex the task or the less experienced the user, the more is to be gained from evolutionary approach, where the user’s role is more of an evaluator rather than controlling every individual parameter one by one.

Of course it is naive to propose that evolutionary design process could replace all applications of creative design. It is especially hard to design systems that succesfully apply evolution in computer medium that can be used in real life situation, not only to demonstrate the possibilities of such approach.

7. Evolution in design process

An evolutionary approach can be applied in both the process and the outcome of design. In process it means using evolution as a feedback loop, enhancing or creating designs in an iterative fashion. In outcome, it implies adaptability and uniqueness, where no two individuals are the same or where the solutions change in use.

In the following sections different approaches in combining evolutionary computation in design process are discussed, some more closely linked to the area of creativity and others more to formal processing and fine tuning.

7.1. Evolutionary computation in the process,

In the process of design, evolution can be applied (more consciously, faster, and paradigmatically different than before without evolutionary computation) in different stages of design, or as Peter Bentley suggests, integrating all the stages into one *Integal Evolutionary Design*, as described later. When integrated in the process, the approach can be used in traditional design applications, where the target is to generate functional, aesthetically pleasing/interesting, fixed design (with fixed I mean that once ready, the outcome will not change, except from wearing).

Different approaches have been taken in incorporating the human agent in evolutionary cycle. (ie. Interactive Genetic Algorithm, Interactive Evolutionary Computation, Visualised Interactive Evolutionary Algorithm), and they all address different demands of the process.

When integrating human in the process, the downside is that the evolutionary scale has to be tuned down seriously. Because of the sheer speed, computers can deal with numbers of generations similar to those in natural evolution, where hundred thousand generations can pass by without any significantly major changes.(R.Poli et al. 1997) When a human evaluator would need to do judgement after every cycle, the number has to be seriously smaller. This means that the changes in every generation of population are much larger, or that the automatic evolutionary process is stopped only every nth generation for human evaluation.

The biggest advantage, on the other hand, is that instead of relying simply on manipulating the feature parameter space, all the parameters / functions that affect the appearance and function of the phenotypes, human evaluator’s psychological space directs the search in the parameter space.(Figure 10)(H.Takagi, 2001) Hideyuki Takagi talks about KANSEI, ”the total concept of intuition, preference, subjectivity, sensation, perception, cognition […]” as a part of Interactive Evolutionary Computation when there are no clear fitness functions that can be used.

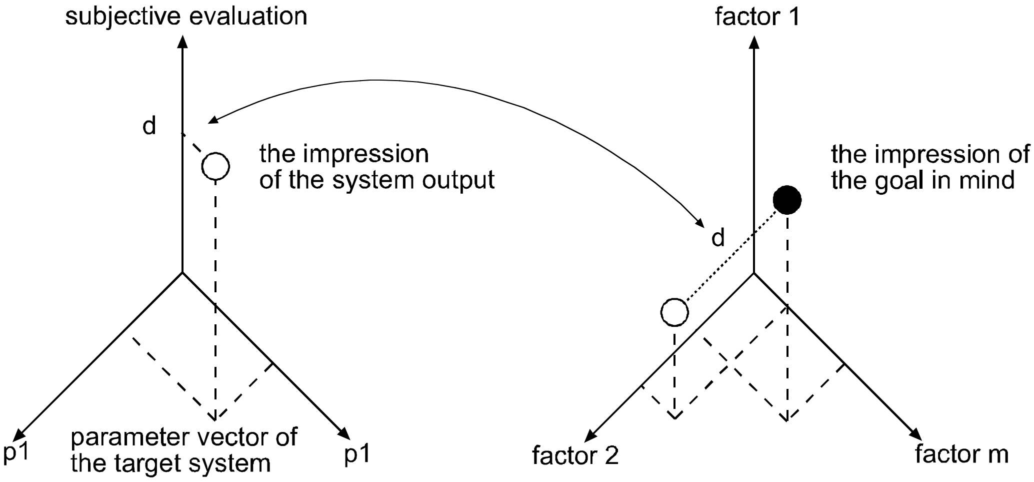


Figure 10 The evolutionary algorithm searches in a parameter space, whereas a human agent searches in psychological space. (H.Takagi, 2001)

7.1.1. Evolutionary optimisation

As already mentioned, the first applications of evolutionary computation were dealing with optimisation. Having a clear defined problem, evolutionary search is a very efficient tool to finding good solutions to the problem. In the design realm, this is very applicable especially in cases where the function plays a much more important role than the form.

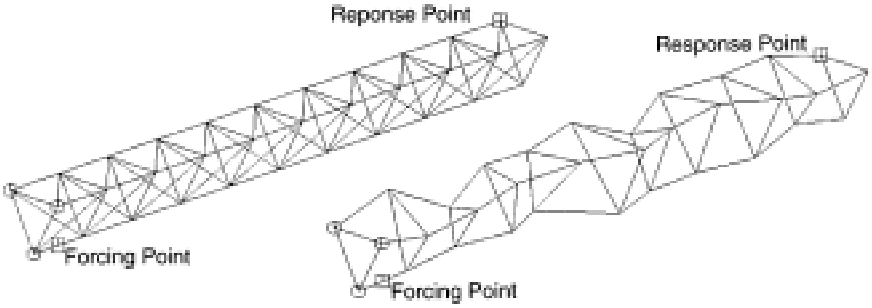


Figure 11 Satellite boom optimisation initial form and the evolved structure. (P.Bentley, 1999, p. 149 and 152)

Over the last fifty years, Evolutionary optimisation has been used in a huge range of different design tasks, ranging from optimising satellite booms (with minimised frequency averaged response of the end of the beam)(Figure 11)(G.Robinson et al. 1999 p.149), and aircraft design(P.Husbands 1996) to design of an improved Load Cell (a strain gauge force transducer, that should ideally distribute the force applied to it uniformly over its contact surface.)(Figure 12)(G.Robinson et al. 1999 p.1153) or strong bridge structures.

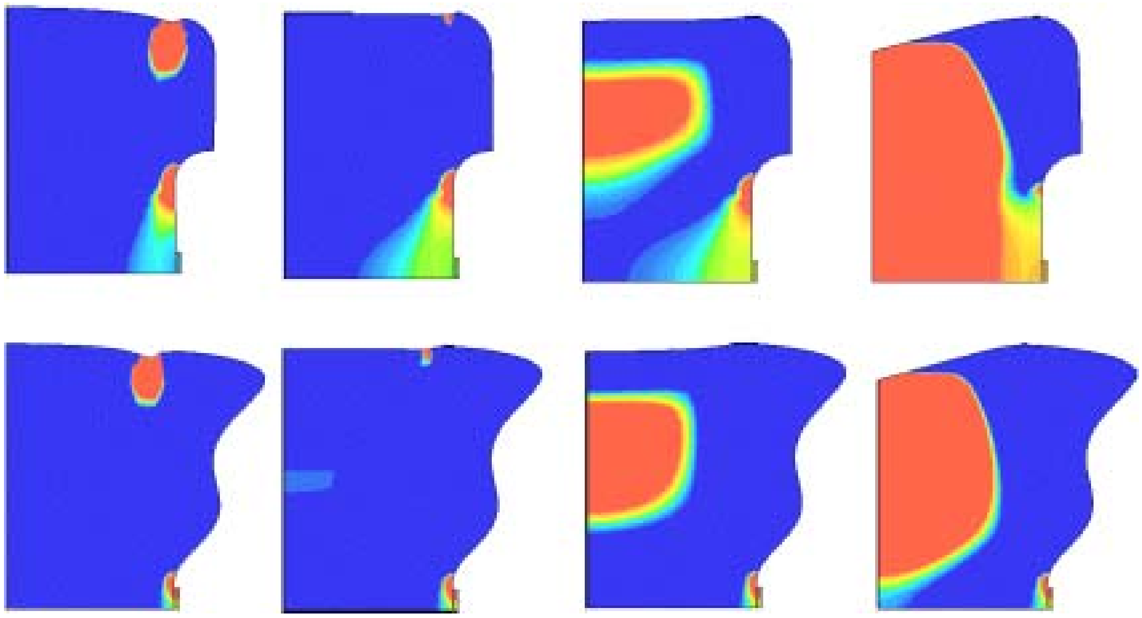


Figure 12 A comparison between human designed, and GA designed load cells under pressure. Ideal design spreads the load uniformly across the whole surface. [19]

The basic principle is that once one aspect of the design has been settled with, whether it be the outline, amount of material that can be used in it, it’s structural properties or required surface area, evoltionary computation is used to match the other aspects of the design to it. Having come up with a design idea, the big picture, evolutionary optimisation takes care of optimising the details or exploring the material requirements and possibilities.

7.1.2. Evolutionary computation in Creativity

When discussing anything generated by computer as creative raises probably more questions than it answers. Looking from the cybernetic point of view, there is, in principle, no contradiction except in the scale of complexity between man and a machine. J. Gero highlights the difference between designing creatively (calling it the cognitive view on creativity) and having a design which characteristics can be considered as creative within the cultural context (social view on creativity).(J.Gero, 1999 p.38) From the latter perspective, it should be possible to consider

---

[19] http://www.soton.ac.uk/~gmr2/loadcell.html

machine designs alongside with human designs, and judging their creativity independent from the process.

Rosenman's desctiption: "*The lesser the knowledge about existing relationships between the requirements and the form to satisfy those requirements , the more a design problem tends towards creative design*" captures the essential feature, to which evolutionary computation can be applied.[20]

7.1.2.1. Evolutionary Ideas Search

To tackle *imagination stagnation*, or just to come up with a few new leads, evolutionary processes can be utilised in quickly running through wide range of different ideas. This may sound similar to the approach in generation of Evolutionary Art, where the user is being lead by the process into new, interesting images when there is no predefined goal other than to find "pleasing" or "interesting" forms. The main difference, however, is that when solution or application is searched for some specific problem or task, there are already quite a few different restrictions, that have to be fulfilled anyhow. These restrictions, physical, material, spatial etc., can be coded into the fitness evaluation and parameters of the evolutionary program, and hence all the proposals, all the generated ideas already satisfy to some degree the basic requirements of the task. These ideas can then be taken further and refined through traditional design process, to make more "sense" into the work, but this is readily possible, because of the good "fitness" of the initial form.

One example of such a conceptual tool is TRADES (TRAnsmission DESigner) (Pham and Yang, 1993), though it falls more in an engineering paradigm, which "*uses genetic algorithm to evolve the organisation of a set of conceptual building blocks (such as rack and pinion, worm gear, belt drive). When given the type of input (e.g. rotary motion) and the desired output (e.g.) perpendicular linear motion), the system generates a suitable conceptual transimmion system to convert the input into the output."(P.Bentley, 1999 p.39)*

---

[20] M. Rosenman "The Generation of Form Using and Evolutionary Approach". In Dasgupta, D. and Michalewicz, Z. (eds.) Evolutionary Algorithms in Enginbeering Applications, Springer-Verlag, pp. 69 –86. as qoted in (Bentley 1999. p.39)

7.1.2.2. Integral evolutionary design

John Gero’s description of the computer’s potential role in different stages of design as drafting, analysis and system support tool, is taken a step further in Integral Evolutionary Design(J.Gero, 1999 p.48), where different phases of traditional design process are all merged into one: The initial brainstorming and conceptual design, refining few alternatives and eventually detailed design, or blueprint of the final outcome.(I.Parmee, 1999 p.119)

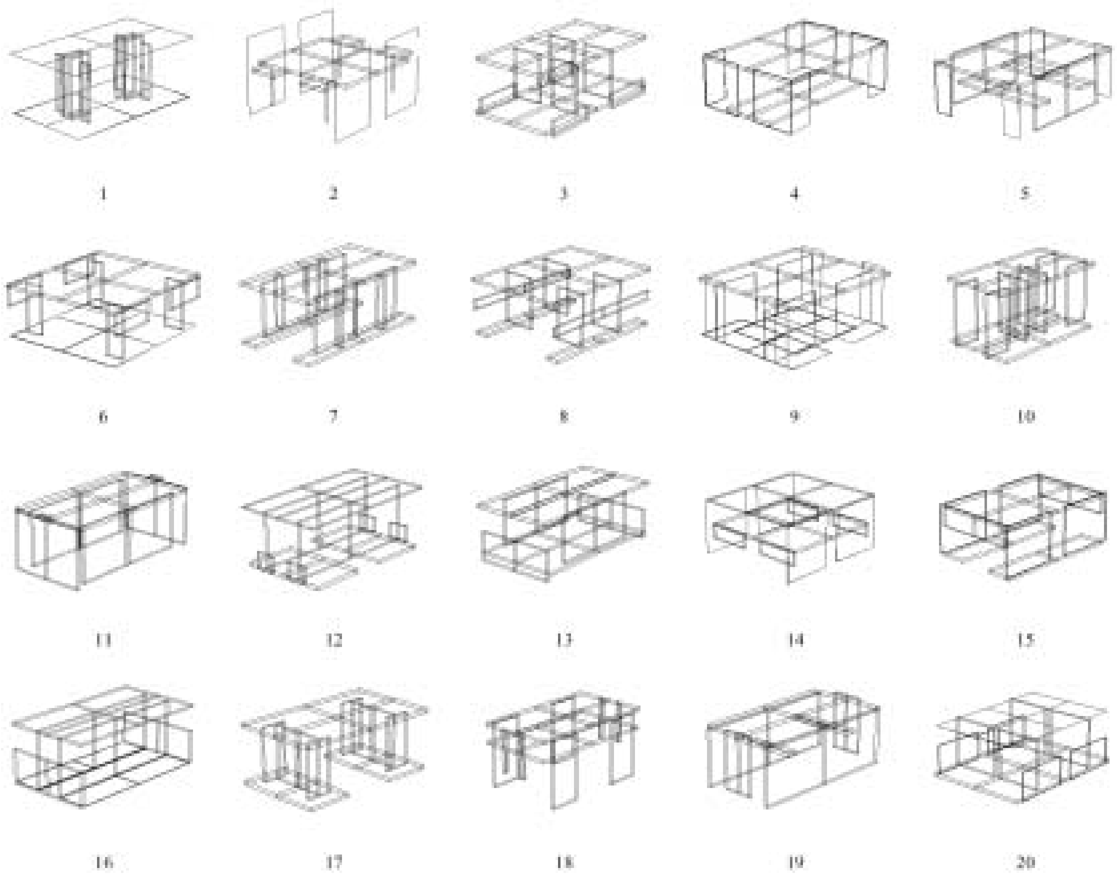


Figure 13 A population of table designs by GADES (P.Bentley, 1999c)

Peter Bentley accounts his software GADES (Genetic Algorithm Designer) as a tool for such a design process.(P.Bentley,1999b p.406) He describes a personal experience of how he, a computer scientist, pursues a creative design task through using the software and ends up with a pleasing, surprising and very functional design (Figures 13 and 14).

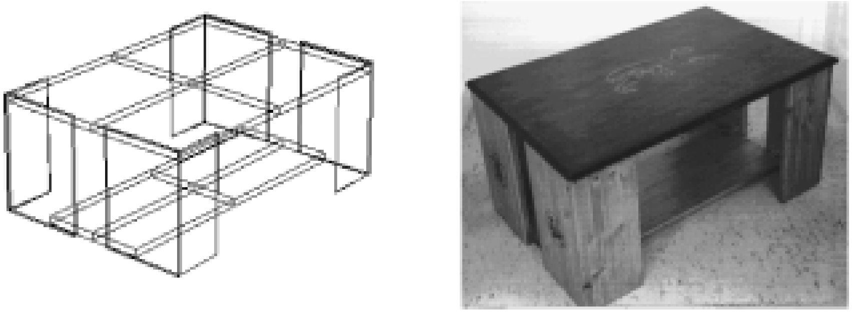


Figure 14 The selected table and the realised outcome.(P.Bentley, 1999c)

7.1.3. Evolutionary approach in controlling an evolutionary design system

As recognised in the beginning of section 6, human fatigue is one major drawback of using slowly converging evolution with human agent in the process. Instead of allowing larger fluctuations in a population, or reducing human interaction to every, say, 1000th generation, Riccardo Poli & Stefano Cagnoni propose an alternative of training a fuzzy system or neural network to ”learn” the human preference, and then later on use the model to guide the evolution.(R.Poli et al. 1997)

> *This can be achieved by first observing and recording the user’s choises together with some parameters describing the most important features of the solutions under selection and by later using these data to induce a program mimicking the user’s behaviour(R.Poli et al. 1997).*

Whether this kind of approach can really achieve what it suggests, that is, externalising the human objective, the target towards which to steer an evolutionary design process, remains to be seen. On one hand, the overlap between the psychological space and the parameter space is, of course existing, as far as there are solutions in the parameter space that fulfill the ideal in the psychological space, but to what extent this relationship can be formalised into an algorithm, is dubious. When considering, say, a certain style of design, there is a strong correlation between the different parameter values that add up to certain kind of appearance, but when it comes to deeper meaning, this kind of translation hardly is capable of capturing its essence.

8. Reactive and adaptive / Metadesign

Instead of collapsing the final design into a single solution, the outcome can embody evolutionary adaptatation in itself. This can be either in a form of a product adjusting to individual requirements or preferences, or in defining a design family, the metadesign of objects.

A century of mass production dominated designing, the idea of designing to individuals is not evident. The production line today, however, does not have the same kind of restrictions as before, and the machines are controlled more with software and computers rather than physical templates and molds. Hence, there is no need to necessary follow the ”one-size-fits-all” ideology. Tailored products can be made in an assembly line.

This gives new possibilites to the collaboration between the designer and the end user, where the bigger picture is designer’s responsibility, but the final tuning and adjusting is left for the user.

8.1.1. Tuning to an individual

Very often, there is no unversal solution. Everyone is different, and hence have slightly different needs. The product can adapt, using evolution, to these individual differences, instead of trying to come up with a compromise pleasing everyone.

Good examples of such are the hearing aid designs(H.Takagi 1998), that are taught to manipulate the incoming sound in such a way as to maximise the clarity to individual hearing defects or the tuning of force-feedback armature, where every individual experiences the response of the motors slightly differently. By adjusting their relative forces, more natural interaction can be achieved.

8.1.2. Embracing the end user

Instead of searching for one best solution, the evolution can be the outcome itself. One could imagine virtual landscapes, that span into different directions, infinitely, in which one’s preferences of the appearance steer his/her direction of wandering.

Pioneering work in this area is done by two Nethetherland artists Erwin Driessens and Maria Verstappen, whose software Turboid is a Borgian Library of one style of tunnel geometries, through which the user can travel for infinitely long, never crossing the same point twice.

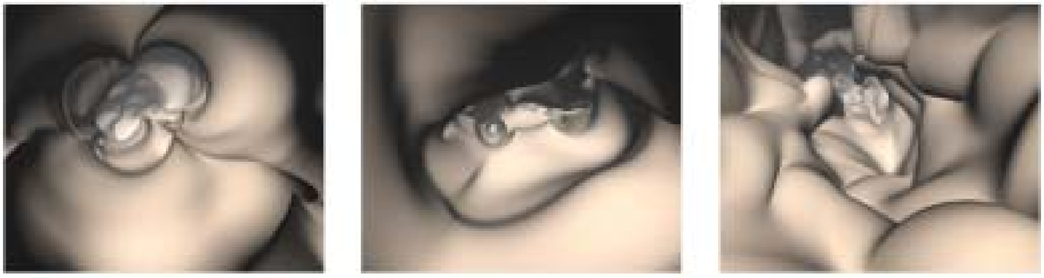


Figure 15 Samples of the space generated in real time with Turboid. [21]

The reactive generation of music in GenJam is an excellent example of the potential use of evolvability as the final outcome. In GenJam the user (a solo artist) is controlling his band in evolutionary fashion, voting ”good” or ”bad” for the instrument phenotypes, altering the ensemble in real time. The evolving system is never ”ready”, as it always generates new melodies and harmonies and is altered through the preformance.

This kind of approach cannot be directly applied to the design of physical shapes direclty. The phenotype has to be accessible to alteration all the time and has hence got to be in digital form.

8.1.3. Design of style.

”Most of us can recognise a good design, though might not be able to generate it”: is a quite a brave claim, but it does postulate the possibility of generation of style. Creation of the genotype of a family of objects, graphic styles and environments.

Celestino Soddu’s work in generative architecture shows a potential of style generation (Figure 16). Though more of an expert system externalising Soddu’s own architectural style into computerised form rather than truly evolutionary system, it illustrates the idea, how from one population of genes a family of distinct, yet recognisably similar designs can be created. One could imagine the designer to create an ”Alessi” genotype, that could then be used to generate cutlery, kitchen gadgets, and office stationery all distinct but similar.

---

[21] http://www.xs4all.nl/~notnot/tuboid/TUBOIDsoftware.html

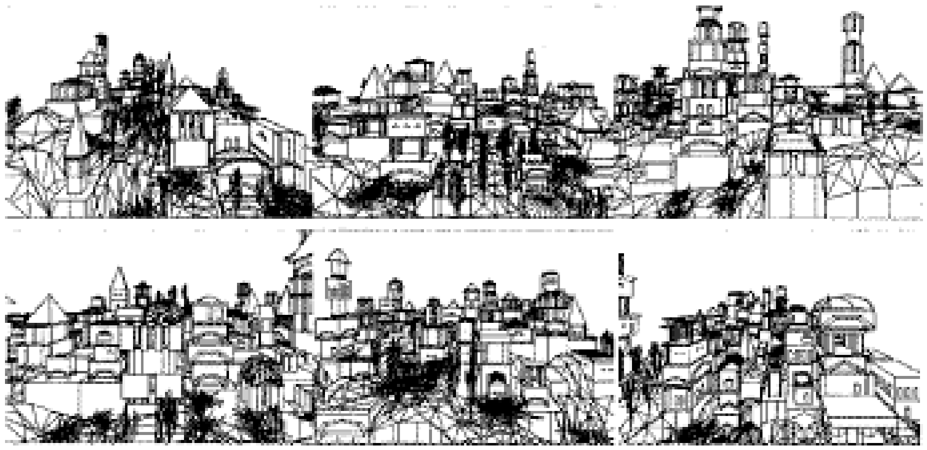


Figure 16 Sequence of ever different 3D models generated by "BORGO". [22]

Peter Bentley is more optimistic in thinking that anyone could use an evolutionary system, generate populations of designs, and then pick the good designs. (Good designs in this context do not mean that they fulfill the function, but that they make sense in design.) It remains to be seen in the future, but the current state of creative evolutionary systems that anyone can use, are anything but convincing in this respect. The table or sports car designs are only crude examples of the principle, and do not even nearly reach the creativity of human designer working without evolutionary tools. They, however, illustrate the potential of augmenting human creativity in the future.

It is also notable, that many of the explorers of evolution in art context tend to generate images or shapes that are, though individual, largely identifiable to the software they are created with. Hence, it is questionable, to what extent it would be the designer who use evolutionary programs, or the programmer of such, who fixes the style to strict limits.

9. The ethics of evolutionary design

Evolutionary design greatly changes the ethics of design. Who is responsible? Who is the author? Who to praise and who to blame?

In essence, evolution is a trial-and-error procedure, where one ends up with good solutions, but does not have the explanation to it. This means, that even though it works, one does not know why, and where are its boundaries.

---

[22] Simulation tools for the dynamic evolution of town shape planning http://soddu2.dst.polimi.it/oxford.htm

A. Thompson’s work in evolving analog circuitry at the University of Sussex provides some insight to the problems: He created a system that evolves circuit designs for specific tasks first in computer medium, but then ”downloads” the arrangement into physically connected components for fitness evaluation.

One task for the circuit was to distinguish between two tones (which is the first step to speech recognition), and in 5000 generations and 2 weeks of computing time, the system evolved an excellent solution. [23]

Strangely, of the 100 elements available only 32 were at use, and the logic how it functioned was beyond comprehension. According to Thompson human design would have needed 10 to 100 times as many logic elements to perform the same task.

Though simple in arrangement, the circuit was very complex in function. The current was feeding back and forth in the components, and some of the active 32 components seemed to be out of the loop, yet disconnecting them would stop the circuit from working. The circuit seemed to also have adapted ”radio-magnetic coupling”, broadcasting signals between the components wirelessly. Something that is never done in traditional cicuit design. Further if, say, the temperature was altered, the circuit would stop working.

The evolved circuit was extremely efficient, but beyond comprehension. This raises the question of responsibility. Who is to blame when something goes wrong, if nobody built it, and nobody understands how it works? Though it might do the task perfectly in normal situations, it is impossible to predict, what might change its performance and how.

If one optimises large physical structures with evolution, one can only test its sturdyness in simulation. But what if there is one pivot point, that will be holding the whole thing together, and damaging that, will collapse the whole structure in one unfortunate chain reaction?

Evolution can empower us to do designs, that are literally beyond us, beyond in form and structure as well as in understanding. It can provide us with greater insight into the possibilities, but it may also blind us from the potential effects.

---

[23] Gary Taubes, "Evolving A Conscious Machine" http://208.245.156.153/archive/output.cfm?ID=1455

10. Conclusions

Cybernetics, design memetics and evolutionary computation see man as an information processing system similar to any such system, whether in flesh or silicon. Eric McLuhan’s suggestion of extending our minds with non-biological means is becoming a reality. Our designs are not purely human anymore, but a collaborative effort of human and human made processing.

Evolutionary computation can be used in different stages of design, as a generator, as processor and as an outcome. In conceptual planning fresh and unexpected ideas can be found through this method. In design analysis and detailed design, evolution can be used to optimise and search for different structural possibilities to fulfill the proposed idea. As an outcome, products can be made to adapt to individual users or to provide open-ended synthetic systems, that are infinite in scale.

Evolution has proven very successful in optimisation and as an adaptive design, that adjusts to the user. But as an augmentation of truly creative design, it remains yet to be proven. Defining a creative task as parameters that cannot take ”meaning” into account, tends to create designs that are either rather predictable, or at best, interesting as a curiosity. Truly creative design draws from the surrounding culture, and its appearance and function cannot be explained without wider understanding of its social context.

When the concept of designer is expanded to contain both, human and machine agent, the authorship and responsibility issues become very complex. To address the designer, is to address the man *and* the machine. In reality, however, when considering creative design, simplicity is usually at the forefront, and understandability is often a measure of good design. Only when the underlying structure gets beyond comprehension (like in circuit design), not the description how the structure was attained, things are getting out of control.

For the time being, evolutionary computation remains as a tool in creative design, but a tool that is challenging and augmenting human intelligence beyond where biological and cultural evolution alone could reach.

References:

Books:

Eric Bonabeau, Marco Dorigo, Guy Theraulaz, *”Swarm Intelligence: From Natural to Artificial Systems”*, Oxford University Press 1999

Andy Clark, *”Putting mind, body and world together again”*, The MIT Press Cambridge 1999

Richard Dawkins, *”The Selfish Gene”*, Oxford University Press 1976

Lawrence Fogel, Alvin Owens, Michael Walsh ”Artificial Intelligence through Simulated Evolution” John Wiley, New York 1966

Katherine Hayles, *”How We Became Posthuman: Virtual Bodies in Cybernetics, Literature and informatics”,* University of Chicago Press, 1999

John Holland *”Adaptation in Natural and Artificial Systems”* University of Michigan Press, Ann Arbor 1975

Kevin Kelly *”Out of Control: The New Biology of Machines, Social Systems and the Economic World”*

John Koza *”Genetic Programming: On the Programming of Computers by the Means of Natural Selection”* MIT Press, Cambridge, MA 1992

Eric McLuhan, *”Electric Language: Understanding the message”*, St. Martin’s Press 1998

Glyn Moody ”Rebel Code: Linux and the Open Source Revolution”, Perseus Pr. 2001

S. Pinker, *”How the mind works”,* W.W. Norton & Company 1999

Ingo Rechenberg *”Evolutionsstrategie: Optimierung technischer Systeme nach Prinzipien der biologischen Evolution”* Frommann—Hozboog Verlag, Stuttgart 1973

Articles:

Derek Gatherer, *”The memetics of Design”* in Bentley, P. (ed.), Evolutionary Design by Computers,

Peter Bentley *”An Introduction to Creative Evolutionary Systems”* in Peter Bentley, David W. Corne (ed.) Creative Evolutionary Systems, Morgan Kaufmann Publishers 2001, pp. 1 - 76

Gordon Robinson, Mohammed El-Beltagy and Andy Keane, *”Optimisation in Mechanical Design”* in Bentley, P. (ed.), Evolutionary Design by Computers, Morgan Kaufmann Publishers, Inc., San Francisco 1999

J.Gero *”Computers and creative Design”* in Bentley, P. (ed.), Evolutionary Design by Computers, Morgan Kaufmann Publishers, Inc., San Francisco 1999, pp. 38.

P.Bentley, *”From coffee tables to Hospitals: Generic Evolutionary Approach”* in Bentley, P. (ed.), Evolutionary Design by Computers, Morgan Kaufmann Publishers, Inc., San Francisco 1999

Ian Parmee *”Exploring the Design Potential of Evolutionary Search, Exploration and Optimisation”* in Bentley, P. (ed.), Evolutionary Design by Computers, Morgan Kaufmann Publishers, Inc., San Francisco 1999

Hideyuki Takagi, *”Interactive Evolutionary Computation: System Optimization Based on Human Subjective Evaluation”* 2001 accessed at www.kyushu-id.ac.jp/~takagi/TAKAGI/IEC_papers.html in March 2001

P. Husbands, I.Harvey, D.Cliff, A.Thompson, N.Jakobi *”Evolutionary robotics: the Sussex approach”* Robotics and Autonomous Systems, In Press 1996

P. Bentley *”Is Evolution Creative?”* 1999 in P. J. Bentley and D. Corne (Eds) Proceedings of the AISB’99 Symposium on Creative Evolutionary Systems (CES). Published by The Society for the Study of Artificial Intelligence and Simulation of Behaviour (AISB). pp. 28 – 34. RN/99/3

Riccardo Poli, Stefano Cagnoni*, ”Evolution of Pseudo-Colouring Algorithms for Image Enhancement with Interactive Genetic Programming”,*University of Birmingham, Technical Report CSRP-97-5, 1997

Hideyuki Takagi, *”Interactive Evolutionary Computation – Cooperation of computational intelligence and human KANSEI”,* in Proceedings of the 5th International Conference on Soft Computing and Information/Intelligent Systems, 1998, pp. 41-50

John Gero, *”Design Tools That Learn: A ¨Possible Future”*, in Kumar, B. (ed.), Information Processing in Civil and Structural Design, Civil Comp Press, Edinburgh 1996, pp. 17 – 22

Morgan Kaufmann Publishers, Inc., San Francisco 1999, pp. 91 - 104

Susan Blackmore *”Evolution and Memes, the human brain as a selective imitation device”* in Cybernetics and Systems, 32:1, Tayolor and Francis, Philadelphia 2001, 225 – 255

Perseus Pr. 1995 (I used the online version, and cannot name the page numbers)

Hideyuki Takagi, Sung-Bae Cho, Kouichi Utsumiya *”A 3D Modelling System for Creative Design”,* in the 15th In’l Conf. on Infromation Networking(ICOIN-15) Beppu, Japan pp. 479, Jan. 31 – 2. Feb 2001

Norimasa Hayashida, Hideyuki Takagi *”Visualised IEC: Interactive Evolutionary Computation with Multidimensional Data Visualisation”* IEEE Int’l Conf. on Industrial Electronics, Control and Instrumentation (IECON2000), Nagoya 2000 pp. 2738 - 2743

Riccardo Poli, Stefano Cagnoni, *”Evolution of Pseudo-Colouring Algorithms for Image Enhancement with Interactive Genetic Algorithm”*, 1997

Websites:

”Organic, responsive, bioengineered sidewalk” http://www.halfbakery.com/idea/organic_2c_20responsive_2c_20bioengineered_20sidewalk accessed 4.10.2001

William Latham, CSpace http://www.nemeton.com/axis-mutatis/latham.html accessed 4.10.2001

www.nhgri.nih.gov/NEWS/vignettes.html accessed 3.5.2001

Gordon Robinson ”Genetic Algorithm Optimisation of Strain Gauge Load Cells http://www.soton.ac.uk/~gmr2/loadcell.html” accessed 4.10.2001

Notnot’s Turboid software http://www.xs4all.nl/~notnot/tuboid/TUBOIDsoftware.html accessed 4.10.2001

Celestino Soddu ”Simulation tools for the dynamic evolution of town shape planning” http://soddu2.dst.polimi.it/oxford.htm

Gary Taubes, "Evolving A Conscious Machine" http://208.245.156.153/archive/output.cfm?ID=1455 accessed 4.10.2001