GRAPHAGOS: EVOLUTIONARY ALGORITHM AS A MODEL FOR THE CREATIVE PROCESS AND AS A TOOL TO CREATE GRAPHIC DESIGN PRODUCTS

by

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GRAPHAGOS: EVOLUTIONARY ALGORITHM AS A MODEL FOR THE CREATIVE PROCESS AND AS A TOOL TO CREATE GRAPHIC DESIGN PRODUCTS

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ABSTRACT

GRAPHAGOS: EVOLUTIONARY ALGORITHM AS A MODEL FOR THE CREATIVE PROCESS AND AS A TOOL TO CREATE GRAPHIC DESIGN PRODUCTS

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Evolution is a substrate-neutral algorithm that creates design, working with three conditions: replication, variation, and selection. The memetic theory posits that elements of human culture are subject to the algorithm of evolution as the memes that code for them are replicated, varied and selected. Within this paradigm, human creativity can be explained as an evolutionary process within the brain where random variations are unconsciously selected in milliseconds.

Digital evolutionary algorithms are being used today to create design and to solve optimization problems. Graphic design, due to its functional nature, has the potential to be a very fruitful area of research and application for evolutionary algorithms. Gráphagos uses genetic algorithms to randomly mutate and replicate the designs according to a human user's evaluation. The program is primarily designed as a model for the creative process occurring in the system that consists of the graphic designer and the sketching medium.

Gráphagos demonstrates how graphic design can emerge when random mutations are selected and accumulated. The program additionally offers a new tool for making graphic design. It may also be used as a tool for gathering data about our visual preferences.

Keywords: graphic design, evolution, memetics, evolutionary design, genetic algorithm, Processing

The CD includes: samples.pdf

ÖZ

GRAPHAGOS: BİR YARATICILIK MODELİ VE BİR GRAFİK TASARIM ÜRETME ARACI OLARAK EVRİMSEL ALGORİTMA

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Evrim, ortamdan ve malzemeden bağımsız, üç koşulla – eşlenme, çeşitlenme ve seçilim – işleyen bir algoritmadır ve çıktısı tasarımdır. Memetik kuramına göre insan kültürünün öğeleri, kendilerini kodlayan memler eşlenir, çeşitlenir ve seçilirken bu algoritmaya göre evrilirler. Bu bağlamda, insan yaratıcılığı da, beyindeki rastgele çeşitlenmelerin milisaniyeler içinde bilinçdışı seçilimlerden geçtiği evrimsel bir süreçtir.

Dijital evrimsel algoritmalar bugün tasarım üretmek ve optimizasyon problemlerini çözmek için kullanılmaktadır. Grafik tasarım da, işlevsel doğası nedeniyle, evrimsel algoritmalar için verimli bir araştırma ve uygulama alanı olma potansiyeline sahiptir. Gráphagos, insan kullanıcının yaptığı değerlendirme sonuçlarını kullanan ve rastgele değişiklikler ile yeni tasarımlar üreten bir genetik algoritma ile işlemektedir. Program, aslen, grafik tasarımcı ve onun eskiz ortamından oluşan sistem dahilinde gerçekleşen yaratıcı süreci modellemek üzere tasarlanmıştır.

Gráphagos, grafik tasarım ürünlerinin, rastgele değişikliklerin seçilmesi ve birikmesi ile ortaya çıkabileceğini gösteren bir örnektir. Ayrıca, grafik tasarım üretmek için yeni bir araç sunmaktadır. Bunlara ek olarak, görsel tercihlerimiz hakkında veri toplamak için bir araç olarak da kullanılabilmektedir.

Anahtar sözcükler: grafik tasarım, evrim, memetik, evrimsel tasarım, genetik algoritma, Processing

CD içeriği: samples.pdf

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I dedicate this work to Bilge. Without her, I would not be the person that I am today.

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CHAPTER 1. INTRODUCTION

How do designers design? What is creativity? Are we “godlike creators of ideas, manipulating and controlling them as our whim dictates, and judging them from an independent, Olympian standpoint”? (Dennett 1990) Or is it more accurate to see our brains as battlegrounds of ideas coming from imitation, communication and education, without an independent self in control? (Blackmore 1999: 210) We know since Darwin that all the design that we see in nature has emerged without a designer. Could it be the same with human designs?

Many biologists, mathematicians, and computer scientists prefer today to define evolution as a substrate-neutral algorithm – with three conditions: replication, variation, selection – and biological evolution as one of its material instantiations (Dawkins 1983; Dennett 1995; Nowak 2006). The output of the algorithm of evolution is design, as the myriad different designs of living things emerge in nature. Human culture is another layer of designed objects (language, clothing, diets, ceremonies, religion, art, design, technology, etc.) which begs for explanation, and evolution, the great ‘designer’, is the first explanation that comes to mind.

According to the *memetic* theory, every element of human culture is subject to the algorithm of evolution as the *memes* (the counterparts in cultural evolution of genes in biological evolution) that code for them are replicated, mutated and selected (Dawkins 1976). Memetics explain the creative output of artists/designers as products of evolutionary processes working at the information level in the brain (Campbell 1960; Calvin 1987; Gatherer 1999). On the other hand, quite independently from these theoretical questions, digital evolutionary algorithms are employed today in various design and optimization problems (Bentley 1999; eds Bentley & Corne 2002; Lewis 2008).

In light of this framework, I presented in my master thesis project an evolutionary approach to visual design, based on replication, random variation, and selection. What I tried to model in this project is the creative process that takes place in the system which consists of the designer and the sketching medium. I designed a program where every individual has a genome that is translated into a visual design product according to a specific embryogeny. The program uses genetic algorithms to randomly mutate and replicate the genomes and thus the populations of designs according to the human user's evaluation.

The principal aims of this study are to explore the evolutionary theories of human creativity and to propose a working evolutionary model for the creative process of a graphic designer. Scientists, researchers and thinkers like Richard Dawkins, Daniel Dennett, Susan Blackmore, Jan Michl, Karl Sims and Peter Bentley explored similar issues and their work is the main influence behind the construction of this thesis.

In the next chapter, I will define the algorithm of evolution and examine biological evolution as one of its instantiations. A discussion of theories of cultural evolution and evolutionary theories of human creativity will follow. The chapter concludes with an overview of digital evolutionary algorithms. In the third chapter of the thesis, I will review the existing literature on visual evolutionary programs, briefly examine graphic design in comparison with visual arts, and present my own model for evolutionary graphic design. After describing the software in detail, I will elaborate on some implications of the model based on an analysis of the output from different users of the software.

CHAPTER 2. EVOLUTION AS ALGORITHM AND ITS INSTANTIATIONS

2.1. The Algorithm of Evolution

In computer science, *algorithm* is defined as “a finite set of operations for solving a specific type of problem” (Knuth 1997: 3). Basically, algorithms are like recipes, carefully tailored to detail to be followed by novice cooks.

Philosopher of science Daniel Dennett (1995: 50) lists three important characteristics of algorithms:

1. substrate-neutrality: the algorithm is a *logical* structure and can work in many different material instantiations.
2. underlying mindlessness: however wonderful the final result may be, each step of the algorithm is tediously simple – simple enough to be carried out without a conscious deliberation.
3. guaranteed results: an algorithm always does what it is supposed to do, if all its steps are correctly executed.

To many people, the word ‘evolution’ refers only to the biological evolution. A classical textbook definition of biological evolution is “change, over the course of generations, in the properties of populations of organisms, or groups of populations”; it consists of “descent with modification, and often includes diversification from common ancestors” (Futuyma 1998: 15). However, many biologists, computer scientists, and philosophers prefer today to define evolution as an algorithm, and biological evolution as one of its material instantiations.

Harvard biologist and mathematician Martin Nowak cites replication, mutation, and selection as the three basic building blocks of the algorithm of evolution:

> These are the fundamental and defining principles of biological systems. They apply to any biological organization anywhere in our or other universes and do not depend on the particular details of which chemistry was recruited to embody life. (2006: 9)

Oxford zoologist Richard Dawkins, one of the leading figures in theoretical biology, has adopted this view that he dubbed “Universal Darwinism” (1983). Dennett (1995: 343) phrases the same idea in a more generic vocabulary, without reference to biology at all, when he states that evolution occurs whenever the following conditions exist:

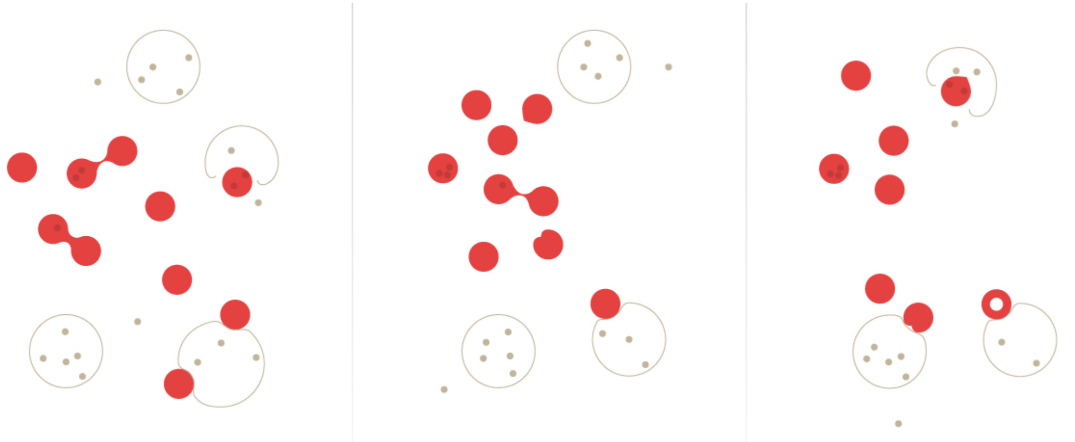
> 1. variation: there is a continuing abundance of different elements
> 2. heredity or replication: the elements have the capacity to create copies or replicas of themselves
> 3. differential “fitness”: the number of copies of an element that are created in a given time varies, depending on interactions between the features of that element and features of the environment in which it persists.

To express in simpler language, (1) if something is being copied, and (2) if the copying process is not perfect in that sometimes mistakes (variations) occur, and (3) if some sort of selection between different types of copies takes place (i.e. if some of them make more copies of themselves than do the others), evolution just happens. This is the algorithm of evolution; and it is substrate-neutral, mindless, and foolproof. Evolution has absolutely no need for planning or foresight; it is “a scheme for creating Design out of Chaos without the aid of Mind” (Dennett 1995: 50).

The substrate-neutrality of the algorithm is of key importance to the main argument of this thesis. In Susan Blackmore's words:

> A human with a pencil and paper, a hand-cranked adding machine, and a digital computer can all follow the same algorithm for some mathematical procedure and come to the same answer. The substrate does not matter – only the logic of the procedure does. In the case of Darwin's own argument the substrate was living creatures and a biological environment, but as Dennett points out his logic would apply equally to any system in which there was heredity, variation, and selection. (1999: 11)

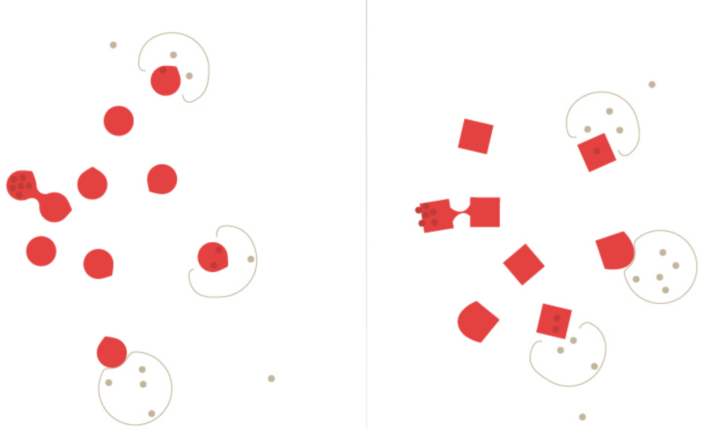
To illustrate the point, Figure 1 is an example of the algorithm of evolution working on an imaginary system of populations of replicating orange rounds.



The orange rounds REPLICATE – they make copies of themselves. The ones that happen to penetrate a bubble and reach the little energy packets inside will be able to make more copies of themselves. There is no evolution here because we have one condition missing: VARIATION.

As the replication goes on, mistakes occur. Some copies are a little different from their "parents". These variations are completely random: no one designs them, they are just errors in the copying process.

A lot of these mutants are no better than their parents, but some may have little advantages in getting to the resources, like a pointed corner making it easier to penetrate the bubbles.



If there is a mutant that does better than the rest of the population in the unconscious COMPETITION for finding the energy packets, it will make more copies of itself than the average orange round. With time, this new shape will dominate the population.

Given enough time, this process will repeat itself and may give rise to a population dominated by squares that are very good at penetrating the bubbles.

Figure 1. The algorithm of evolution working on a population of orange rounds.

The example in Figure 1 can also be used to clarify an essential point about evolution which often confuses people: single entities do *not* evolve. However striking they may be, the changes that an individual thing experiences are not considered evolution (Futuyma 1998: 4). Evolution is a differential and cumulative process working on *populations* of reproducing entities (Nowak 2006: 9) as seen above.

The fact that this example has a very basic setup designed to illustrate the three conditions of the algorithm of evolution may lead to a popular misunderstanding which can be summed up by the phrase “to complete the evolution”. In fact, evolution is not something that can be completed. (Except for some idealized cases of digital evolutionary algorithms; see section 2.4.) It is *not* a linear progress towards a specific long-distance goal, or an ideal ‘perfect’ design. Three facts help clarify this truth: (1) the environment of an evolving system, thus the selection pressures acting upon it, hardly stay the same; (2) there usually are multiple alternative solutions to a problem; (3) the ‘necessary’ mutations for a type of solution may not always arise. (Dawkins 1986: 21–193) Evolution is a process of elimination (‘evolution-away-from’) rather than a process of progression (‘evolution-toward’) (Bradford & Dill 2007).

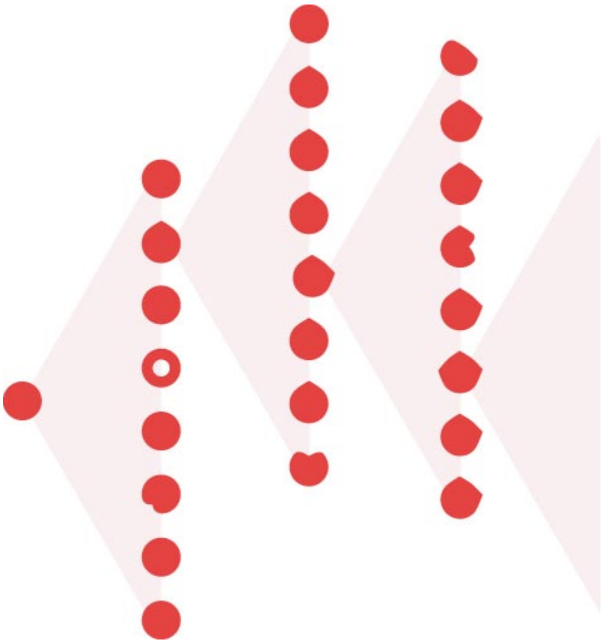


Figure 2. The possible evolutionary history of the population of orange rounds.

2.2. Biological Evolution

A theory of evolution first appeared in the domain of biology, not in physics or chemistry, because "biology is the study of complicated things that give the appearance of having been designed for a purpose", while physics and chemistry deal with rather simple things and principles that do not evoke design (Dawkins 1986: 13).[1] In fact, the word 'design' was frequently used in the 18th century and later in theological arguments about the existence of God, asserting that the intricate adaptations of living things imply that they were 'designed' by some rational 'designer' (Michl 2002).[2]

The most famous example of such arguments is the watchmaker argument of the eighteenth-century theologian William Paley. Paley argues in his *Natural Theology* that if he were to find a stone on the ground, he would not bother explaining how it got there; but if he finds a watch lying on the ground, with all its cogs and springs perfectly put together to function, he would definitely 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. (1802: 6)

Paley was right that the existence of design needs explanation, but he was wrong about the explanation itself (Dawkins 1986: 4). It was British naturalist Charles Darwin – "the towering *design theorist* of the 19th century", according to design historian Jan Michl (2006) – who formulated the right explanation and showed that design is the inevitable output of the algorithm of evolution (Blackmore 1999: 12).

Theories of biological evolution are detailed multi-level explanations of how different designs emerge in nature over the course of millennia without a 'designer' or any other kind of foresight. Although modern theories consist of vast improvements on what Darwin wrote in *The Origin of Species* in 1859, the skeleton remains unchanged (Dennett 1995: 48). Here is how Darwin originally depicted that skeleton:

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[1] See Dennett (1995: 124–35) and Dawkins (1986: 1–18) for discussions on how to define and 'measure' design.

[2] This kind of empirical proof for the existence of God is referred to as the 'Argument from Design'. (Dennett 1995: 28)

> **If** during the long course of ages and under varying conditions of life, organic beings vary at all in the several parts of their organization, and I think this cannot be disputed; **if** there be, owing to the high geometric powers of increase of each species, at some age, season, or year, a severe struggle for life, and this certainly cannot be disputed; **then**, considering the infinite complexity of the relations of all organic beings to each other and to their conditions of existence, causing an infinite diversity in structure, constitution, and habits, to be advantageous to them, I think it would be a most extraordinary fact if no variation ever had occurred useful to each being's own welfare, in the same way as so many variations have occurred useful to man. But **if** variations useful to any organic being do occur, assuredly individuals thus characterized will have the best chance of being preserved in the struggle for life; **and** from the strong principle of inheritance they will tend to produce offspring similarly characterized. This principle of preservation, I have called, for the sake of brevity, Natural Selection. (1859: 121) [my bolds]

It is not hard to notice that Darwin described the algorithm of evolution – using ‘if/then’ statements, but without having a concept of algorithm as we do now – in two parts, respectively:

1. if (variation) and if (selection) then (adaptation)
2. if (adaptation) and if (inheritance) then (evolution)

It is only a simple logic move to add up these two algorithms, substituting the *adaptation* in the second algorithm with its *if* conditions in the first one, resulting in:

if (variation) and if (selection) and if (inheritance) then (evolution)

Biological evolution is a material instantiation of the algorithm of evolution; biological design is the cumulative consequence of processes of replication, variation, and selection. But what is it exactly that is being replicated, varied, and selected in nature? What is the *unit* of natural selection? Darwin seems to think that the individual organism is the unit in question (“useful to each being's own welfare”). Although, by mid-20th century, many biologists thought that species or groups of organisms were what was being selected – a problematic perspective called *group selectionism*, famously expressed by the phrase “for the good of the species” – and it took a “painful struggle” to return to Darwin's ground (Dawkins 1982: 6).

It did not stop there, as the work of people like R. A. Fisher, G. C. Williams, J. M. Smith, W. D. Hamilton and R. L. Trivers, together with the advances in bioinformatics and computer technology, has caused another paradigm shift: a flip of the Necker Cube as Dawkins describes (1982: 1–8). Molecular biology supplemented evolutionary theories with a clear information-theoretic perspective (Nowak 2006: 28), and according to this new perspective, *genes* are the units of natural selection; information encoded in the genes is what is being replicated, mutated and selected. This view found its most clear expression in Dawkins's distinction of *replicators* and *vehicles*, and the story of how they came to be – the story of how life on Earth began.

According to the theory that Dawkins recites, the Earth was teeming with free-floating molecules before there was life; big and small, stable or unstable, haphazardly forming and degrading, affected by their chemical environments, sunlight, volcanoes, or thunders. One day, a curious molecule came to existence by chance – a molecule that acted like a mold or a template, and created copies of itself, which were in turn able to create more copies of the same structure. It was the very first *replicator*; thus "a new kind of 'stability' came into the world". As opposed to the old way of molecule formation by chance, replicator molecules were actively spreading more and more copies of themselves – as long as the building blocks were available in the environment.

But this copying process was not perfect and when mistakes occurred, they propagated as replication continued, resulting in populations of varying kinds of replicators that had descended from the same ancestor. Dawkins states that this random *variation* was the second condition for the algorithm of evolution to work. Because these mistakes were random, many of them were deleterious: they decreased the stability of the molecule, or its capacity to replicate. On the other hand, some resulted in more stable molecular structures, or faster or more accurate replication. These variants proliferated at the expense of the others as they used up all the free-floating building blocks. This was *natural selection* on the job, the third component of the algorithm of evolution. Further mistakes of these 'successful' molecules resulted in even more accurate or faster replicators, and this process continued as 'good' mistakes accumulated and bad ones died out in the unconscious competition. Dawkins describes this growing versatility:

> The process of improvement was cumulative. Ways of increasing stability and of decreasing rivals' stability became more elaborate and more efficient. Some of them may even have 'discovered' how to break up molecules of rival varieties chemically, and to use the building blocks so released for making their own copies. These proto-carnivores simultaneously obtained food and removed

> competing rivals. Other replicators perhaps discovered how to protect themselves, either chemically, or by building a physical wall of protein around themselves. This may have been how the first living cells appeared. Replicators began not merely to exist, but to construct for themselves containers, vehicles for their continued existence.

Dawkins goes on to tell that some of these vehicles, or *survival machines*, continued to get bigger and more elaborate as millions of years passed. Some specialized in water environments, some exploited land, and some managed to fly. They include all living things on Earth that we know. Although they look and behave in hugely different ways, they still have one thing in common, and that is their original reason for existence: all of them preserve and propagate the replicators inside. We now call these replicators *genes*, and "we are their survival machines". (1976: 13–20)

The paradigm shift that this theory caused is this: *genes* do not exist for the reproduction of organisms, but *organisms* exist for the replication of genes (thus the term *vehicle).* This difference is more than semantics because such a shift allowed sound explanations for previously incomprehensible features of biological systems such as non-reciprocal altruistic behavior or sterility in social insects (Futuyma 1998: 594–9). Dennett expresses what is different in this view with an analogy:

> Lawyers ask, in Latin, *Cui bono?*, a question that often strikes at the heart of important issues: Who benefits from this matter? (...) The fate of a body and the fate of its genes are tightly linked. But they are not perfectly coincident. What about those cases when push comes to shove, and the interests of the body (long life, happiness, comfort, etc.) conflict with the interests of the genes? (1995: 325)

Such cases were somehow mysterious for biologists until the renowned evolutionary biologist G. C. Williams (1964) posited the gene-centered view to be adopted and famously presented by Dawkins in *The Selfish Gene* (1976). The theorem of the selfish gene can be summarized with one phrase: "An animal's behaviour tends to maximize the survival of the genes 'for' that behaviour" (Dawkins 1982: 233). In other words, "when push comes to shove, what's good for the genes determines what the future will hold" (Dennett 1995: 326).

The genome – the complete set of chromosomes of a living thing – acts like a recipe for building the organism and making it work throughout its life, as "genes always exert their final effects on bodies by means of *local* influences on cells"

(Dawkins 1986: 52). How to define a gene is a controversial issue. Dawkins derives his definition from Williams: “any portion of chromosomal material that potentially lasts for enough generations to serve as a unit of natural selection” (Dawkins 1976: 29). Douglas Futuyma gives the short definition in the glossary of *Evolutionary Biology* as “the functional unit of heredity” before adding that it is a complex concept and referring to the chapter 3 of the book (1998).

The term *phenotype* refers to the physical – morphological, physiological, biochemical, or behavioral – expression of the *genotype* (the genetic profile) (Futuyma 1998: 37). The relationship between phenotype and genotype is highly complex: many phenotypic traits are results of interactions of multiple genes (*polygeny*); one gene may have multiple effects on different traits (*pleiotropy*); and the expression of a gene is often controlled by other genes (*epistasis*) (Futuyma 1998: 42–56).

Snustad and Simmons explain in *Principles of Genetics* that genes are encoded with the sequence of four molecules called *bases* (adenine, guanine, cytosine, and thymine) along the deoxyribonucleic acid (DNA) chain, arranged in separate volumes called *chromosomes*. (Some viruses encode their genetic information in a slightly different chain, the ribonucleic acid; RNA.) This coding system is often referred to as a four-letter alphabet (A, G, C, T). DNA is a double-stranded molecule made of pairs of bases (A paired with T and G with C), so one strand of a DNA molecule is the exact complementary of the other.

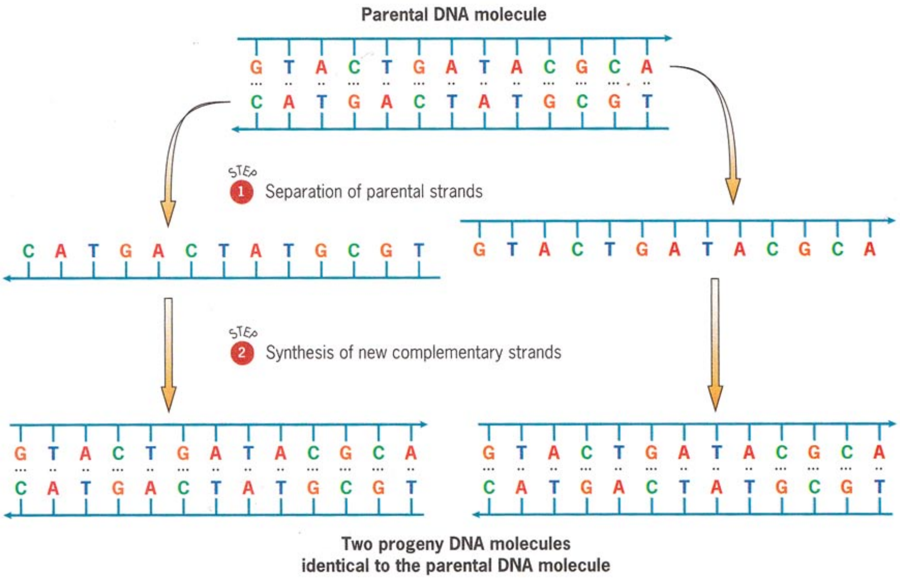

Figure 3. DNA replication. (Snustad & Simmons 2003: 18)

The genetic information is copied from parent to offspring and from cell to cell during development by an accurate replication of the sequence of bases in DNA (Figure 3). Every cell in a multicellular organism has the complete copy of the genome (except for the sex cells; see p. 15f), but different parts of it are ‘read’ in different types of cells. The application of the recipe encoded in the genome takes place through complex processes called *transcription* and *translation* (Figure 4) resulting in the synthesis of *proteins* – large molecules made out of amino acids that “catalyze the metabolic reactions essential to life and contribute much of the structure of living organisms”.

Gene expression starts with transcription: the creation of a single-stranded RNA molecule corresponding to – in other words, complementing in base pairs – a sequence of bases on one strand of the DNA. (This RNA molecule is called mRNA since it acts like a *messenger* between DNA and proteins.) Then comes the translation where amino acids are put together to form proteins according to the sequence of bases on the mRNA molecule.[3] (Snustad & Simmons 2003: 17–8) The structure and the function of the

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[3] The mRNA molecule is read in *codons*, triplets of three adjacent bases, each assigned to one type of amino acid. Since there are (4 × 4 × 4) 64 different codons and 20 amino acids, the code is said to be “degenerate: two or more synonymous codons code for each of the most of the 20 amino acids.” (Futuyma 1998: 45)

protein depend on the order of the amino acids, thus on the sequence of bases on the mRNA molecule, thus on the sequence of bases on the DNA (Dawkins 1986: 120).

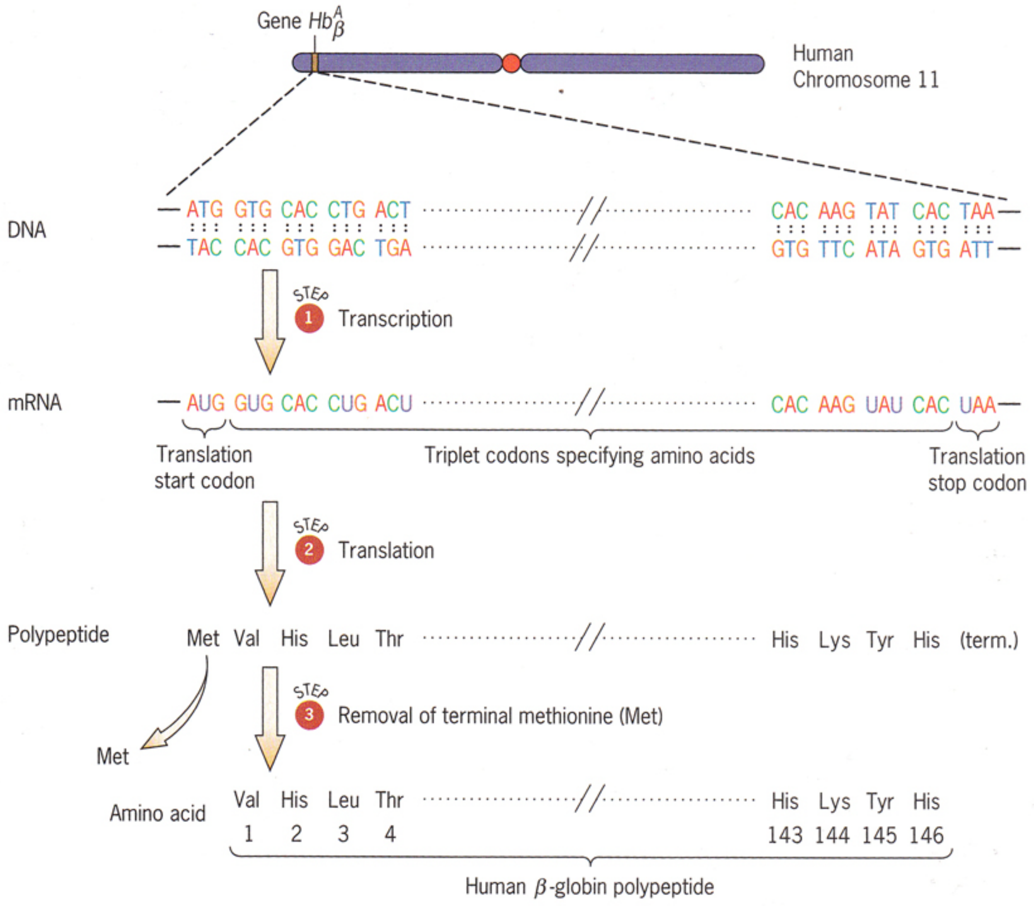

Figure 4. Transcription and translation. (Snustad & Simmons 2003: 19)

This causal chain explains what is meant by the phrase “genetic information encoded in DNA”. Dawkins (1986: 119–20) illustrates this encoding and decoding of information with a lucid analogy with computers:

> When the information in a computer memory has been read from a particular location, one of two things may happen to it. It can either simply be written somewhere else, or it can become involved in some 'action'. Being written somewhere else means being copied. We have already seen that DNA is readily copied from one cell to a new cell, and that chunks of DNA may be copied from one individual to another individual, namely its child. 'Action' is more complicated. In computers, one kind of action is the execution of program instructions. In my computer's ROM, location numbers 64489, 64490 and 64491, taken together, contain a particular pattern of contents - 1s and 0s which — when interpreted as instructions, result in the computer's little loudspeaker uttering a blip sound. This bit pattern is 101011010011000011000000. There is nothing inherently blippy or noisy about that bit pattern. Nothing about it tells you that it

> will have that effect on the loudspeaker. It has that effect only because of the way the rest of the computer is wired up. In the same way, patterns in the DNA four-letter code have effects, for instance on eye colour or behaviour, but these effects are not inherent in the DNA data patterns themselves. They have their effects only as a result of the way the rest of the embryo develops, which in turn is influenced by the effects of patterns in other parts of the DNA.

The genome length of different species varies greatly, ranging from about 10^4 bases for small viruses, to 3×10^9 for humans, to 140×10^9 for lungfish (Nowak 2006: 27). The DNA of a single lily seed or a single salamander sperm has enough information capacity to store the *Encyclopaedia Britannica* 60 times over (Dawkins 1986: 116). Although these numbers are large, very little of the genome actually encodes functional products.[4] For mammals in general, less than 10 percent of the DNA is functional (Futuyma 1998: 45). To pursue the analogy with computers, this amounts to about 30 megabytes of information for our species (around 5 percent of the genome) (Bentley 2001: 201).

The central dogma of molecular biology, first articulated by Francis Crick in 1958, states that genetic information flows (1) from DNA to DNA during its transmission from generation to generation and (2) from DNA to protein during its phenotypic expression in an organism. Although some viruses manage to partially reverse the flow as the viral RNA gets transcribed into the host's DNA, the transfer of information from RNA to protein is always irreversible. (Snustad & Simmons 2003: 275) The changes in an individual's phenotype that occur throughout its life thus do not get transcribed back into its genome. In other words, acquired characteristics, such as the muscles that an athlete develops, are not inherited to his children. (Futuyma 1998: 26)

Peter Bentley reminds us that this fact is the reason why the unit of selection is the gene and not the organism: when organisms reproduce, they do not provide their offspring with copies of themselves, they provide them with copies of their genes. If a person loses her left thumb in an accident, her future children will not be born without thumbs. Reproduction happens at the level of genes, not organisms. (2001: 49)

Futuyma expresses that the variation that biological evolution needs comes from the random mutations (mistakes in replication) that occur when germ cells that give

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[4] This is a fact predicted by the selfish gene theory (Dawkins 1982: 156).

birth to new generations are produced. In unicellular organisms, every cell is also a germ cell. In sexually reproducing multicellular organisms, *gametes* (e.g. sperms and eggs in humans) are the germ cells responsible for the creation of the next generation; mutations in the genes of these cells are copied to every cell of the offspring and expressed in its phenotype.[5] Mutations in the somatic cells (such as liver cells or skin cells) of such organisms do not have evolutionary consequences; they are extinguished with the organism's death (1998: 267).

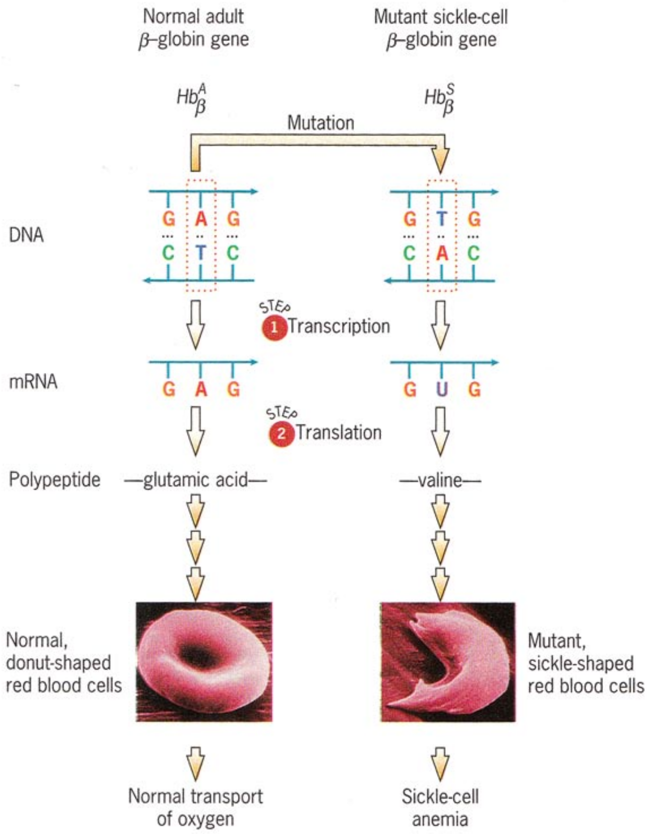

Figure 5. Mutation causing sickle-cell anemia. (Snustad & Simmons 2003: 20)

Futuyma explains that the rate of mutation is affected by environmental factors (e.g. chemicals, radiation). The phenotypic effects of mutations range all the way from

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[5] These cells are produced by a special kind of cell division called *meiosis* in which the genetic material is randomly recombined and divided into two, thus resulting in gametes with half the genetic material. When these organisms ‘have sex’, the two gametes from the two parents merge into one cell with the right amount of genetic information (a mix from the two parents) which will then replicate itself to construct the new organism. (Snustad & Simmons 2003: 32–6)

undetectable to very great, and from destructive to beneficial. Those differences in survival or reproduction pass through the filter of natural selection or drift randomly if undetectable by natural selection. (1998: 26–7)

> Mutation is not systematically biased in the direction of adaptive improvement, and no mechanism is known (to put the point mildly) that could guide mutation in directions that are non-random (…). Mutation is random with respect to adaptive advantage, although it is non-random in all sorts of other respects. It is selection, and only selection, that directs evolution in directions that are non-random with respect to advantage. (Dawkins 1986: 312)

For instance, a mutation in a tiger sperm may cause the offspring to have less sharp teeth. This new mutant gene will not last long in the successive generations as the mutant tigers will prey less efficiently and have less offspring. In other words, the gene will be eliminated by natural selection along with the tigers who carry it. Another mutation may result in sharper teeth, which will make the tiger kill prey more efficiently than others and hence have more offspring which will carry the new mutant gene. This mutant genotype will replace the old one altogether within the population as generations pass by. (Dawkins 1986: 122)

Maybe the most counterintuitive aspect of evolution is that variation is randomly generated by mistakes in replication. We humans tend to see randomness as something erroneous and unwanted within our technological paradigm, but in evolution, randomness is a way of exploring new avenues (Calvin 1987). It is true that random variation on its own cannot be responsible for all the design work in nature; it is when random variation is selected and accumulated over millennia that evolution happens. As Dawkins recapitulates, “mutation is random; natural selection is the very opposite of random” (1986: 41).

2.3. Cultural Evolution

2.3.1. Lineages of Objects

Theories of biological evolution continue today to shed light on the details of life on Earth. Yet there is one species whose curious properties challenge – and defy, according to many thinkers – biological explanations. Homo sapiens is unique in that it has developed *culture*, a term that scientists use to define the complex sum of language, clothing, diets, ceremonies, religion, art, design, engineering, technology, etc. Could culture be explained by theories of biological evolution?

Dawkins takes one step further to extend the explanatory power of the gene-centered perspective so as to include subjects such as animal artifacts and manipulation by defining the 'central theorem' of the *extended phenotype*: "An animal's behaviour tends to maximize the survival of the genes 'for' that behaviour, *whether or not those genes happen to be in the body of the particular animal performing it"* (1982: 233) [my italics]. This means that the behaviors exhibited by an organism because of a parasite affecting it should be traced back to the parasite's genes. Similarly, the dams that beavers build are included in the phenotype of the beaver genes, and the evolution of these dams could be analyzed within a science of "extended genetics". (1982: 203)

The torrent of tools and behaviors called 'culture' may look as if it belongs to what Dawkins means by *extended phenotype.* However, the author claims that culture does not qualify for the concept of extended phenotype because cultural information is not transmitted through genetic means. So although some of it seems to have positive effects on the fitness of our species, culture is not a direct product of genetic evolution (Dawkins 1976: 189–90).

According to Dennett, culture is "an extra medium of design preservation and design communication" (1995: 338). With culture, we get another layer of designed objects which begs for explanation and evolution, the great 'designer', is the first explanation that comes to mind. Only this time, it works on a different medium:

> Today the Earth is embedded with artifacts like computer networks and circuses that cannot be accounted for by appeal to either the properties of matter or biological evolution. That is, biological evolution does not provide us with adequate explanatory power to account for the existence of computers any more

> than the properties of matter can explain the existence of giraffes. Computers are manifestations of yet another causal principle: the evolution of culture. (Gabora 1996)

To emphasize the distinction between the biological medium and the cultural medium, British psychologist Henry Plotkin reminds us that a natural science of culture can be of two different kinds, working at different levels. The first concentrates on the claim that culture is a direct consequence of the biological evolution of humans. The other sees culture as an evolutionary system on its own, independent from – or partly dependent to – the biological evolution.[6] (2000: 70)

The idea that culture develops by some kind of descent with modification has been elaborated by many thinkers since before Darwin published *The Origin of Species*. After all, compared to the geological timescales in which biological change operates, it is much more obvious that "any new thing that appears in the made world is based on some object already in existence" (Basalla 1988: 45). Michl notes that, especially in the 18th century, thinkers such as David Hume, Edmund Burke, Adam Smith and Adam Ferguson came close to an evolutionary perspective on human society. What Darwin did, by revealing the mechanism by which design emerges in nature, was to offer a much more solid structure to these historical interpretations of the apparent design behind elements of human culture, from institutions like language, laws and money to physical artifacts. (2002)

One particularly interesting example is Augustus Henry Pitt-Rivers, a Victorian General influenced by Darwin, who worked on creating evolutionary trees out of his personal collection of primitive weapons and tools (Basalla 1988: 16–7).

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[6] Plotkin believes that a proper science of culture will arise from the unification of these two perspectives.

Figure 6. Pitt-Rivers’s evolutionary tree of primitive tools and weapons. (Basalla 1988: 19)

However, just as Darwin observed nature on the phenotype level without the knowledge of genetics, these attempts to ‘darwinize’ culture depended on formal observations of cultural objects, without an information-theoretical perspective like the one that genetics provided in biology in the 20th century. More importantly, they could not explain cases where cultural traits do not create advantages for the people exhibiting them.

Although the American anthropologist F. T. Cloak published a paper with similar ideas in 1975, it is Dawkins, in his 1976 book *The Selfish Gene*, who is acknowledged to have laid the foundations for a new perspective in theories of cultural evolution that attempted to solve these problems. After describing and advocating the ‘gene's eye view’ in biology throughout the book, he introduces the concept of *meme* in the last chapter and looks at culture from the meme's eye view.

2.3.2. Memetics

Dawkins sees the *meme* as a new kind of replicator with its own self-interest that has created culture as its ‘vehicle’ (i.e. phenotype). Meme is the counterpart in cultural evolution of gene in biological evolution; it is a piece of information that codes for a cultural trait – it is the *unit* of cultural transmission. (Dawkins created the word by abbreviating the Greek work *mimeme*: “that which is imitated”.) According to the memetic theory (or *memetics*), every element of human culture is subject to the algorithm of evolution as the memes that code for them are replicated, mutated and selected.

> Examples of memes are tunes, ideas, catch-phrases, clothes fashions, ways of making pots or of building arches. Just as genes propagate themselves in the gene pool by leaping from body to body via sperms or eggs, so memes propagate themselves in the meme pool by leaping from brain to brain via a process which, in the broad sense, can be called imitation. If a scientist hears, or reads about, a good idea, he passed it on to his colleagues and students. He mentions it in his articles and his lectures. If the idea catches on, it can be said to propagate itself, spreading from brain to brain. As my colleague N.K. Humphrey neatly summed up an earlier draft of this chapter: `… memes should be regarded as living structures, not just metaphorically but technically. When you plant a fertile meme in my mind you literally parasitize my brain, turning it into a vehicle for the meme’s propagation in just the way that a virus may parasitize the genetic mechanism of a host cell.’ (Dawkins 1976: 192)

This chapter was the manifesto that started the science of memetics, and like every revolutionary first step, it contains some problematic tentative definitions and examples to be refined in later stages. Perhaps it is better to mention some of these problems before proceeding to look at the implications of the memetic theory.

Dawkins admits that he was “insufficiently clear about the distinction between the meme itself, as replicator, on the one hand, and its ‘phenotypic effects’ or ‘meme products’ on the other”. He goes on to tell that the meme should be defined as a unit of information residing in the brain, and its phenotypic effects (what Wilkins calls *phemotype*) as outward manifestations in the form of words, music, images, styles of clothes, etc. (1982: 109) Dennett expresses this duality with a memorable phrase: “A wagon with spoked wheels carries not only grain or freight from place to place; it carries the brilliant idea of a wagon with spoked wheels from mind to mind.” (1991: 204) Similarly, Salingaros and Mikiten posit that an architectural style exists in two different forms: (1) as an ideology taught in schools and described in books, and (2) as images represented in the built environment (2002). Nevertheless, the distinction between *memotype* and *phemotype* remains a topic of discussion. (see Aunger 2000: 6; Hull 2000: 59–60; Blackmore 1999: 63–66)

Another problem with the famous passage quoted above is that some of the examples that Dawkins cites as memes (scientific theories, ways of making pots, etc.) are too big and complex to be units of selection. Dawkins clearly expresses that he is aware of the issue and that he uses the ‘X meme’ talk (e.g. the god meme) as a shortcut (1976: 195), but this simplistic language, still adopted by some memeticists today without warning, is often turned against the memetic theory by critics speaking in sarcastic tones in order to condemn it as an oversimplification.[7]

Although it is true that memeticists have not agreed yet upon a single strict definition for the term *meme* (Aunger 2000: 2–5), it is highly likely that, whatever it will be, it will not be that simple a definition to allow us to talk about “the chair meme”, let alone “the general relativity meme”, for the same reasons why we do not talk about “the bird gene”, or even “the wing gene”, or even “the feather gene”, and so on. As John Wilkins (1998) reminds, “there is no smooth reduction of memetic structures from cultural behavior to atomic memes, just as there is no smooth reduction from phenotypic traits to single genes”. In this perspective, a cultural object is a memetic construct, resulting from the interactions of maybe thousands of memes that we may not readily map one-to-one onto the properties that we perceive and talk about on a semantic level.

Maybe the most revolutionary side of the memetic theory is that it answers the ‘Cui bono?’ question in a radically different way. Unlike the other theories of cultural evolution that existed before it, memetics treats items of culture as replicators and vehicles on their own right without appealing to genes or ‘person’s, and asserts that the ultimate beneficiary of culture is culture itself – that is, another type of cluelessly replicating bits of information. For instance, “each image has a set of attributes that makes it more or less likely to stick in memory and to be transmitted to others” (Salingaros & Mikiten 2002). Memes spread themselves without regard to whether they

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[7] See Adam Kuper’s section titled ‘The Ecology of Ideas’ in Aunger 2000 for a perfect example.

are useful (e.g. agriculture), neutral (e.g. music), or positively harmful (e.g. cigarettes) to us (Blackmore 1999: 7).

> Memes don't necessarily make you more biologically fit, nor are they necessarily going to make you less fit. Memes aren't fit themselves simply because they make you live healthier lives. Memes are fit only insofar as they are propagated successfully; forget the effects they have on biology. (Wilkins 1998)

Furthermore, Hull emphasizes that memetic processes should not be analyzed with genetic evolution in mind as the essential analog to which other forms of evolution must resemble: the only common basis is the algorithm of evolution (replication, variation and selection) and the further details may differ endlessly. All examples of evolution should be treated equally. (Hull 2000: 45) The anthropologist William Durham called it “Campbell's Rule” in reference to the American psychologist Donald Campbell who expressed this principle in 1960.

> We need to remember Campbell's Rule when we compare memes and genes. Genes are instructions for making proteins, stored in the cells of the body and passed on in reproduction. Their competition drives the evolution of the biological world. Memes are instructions for carrying out behaviour, stored in brains (or other objects) and passed on by imitation. Their competition drives the evolution of the mind. Both genes and memes are replicators and must obey the general principles of evolutionary theory and in that sense are the same. Beyond that they may be, and indeed are, very different — they are related only by analogy. (Blackmore 1999: 17)

One of the most popular criticisms towards memetics is that no one knows exactly where and how memes are encoded (Aunger 2000: 6). We know now that genes are encoded with the sequence of four bases in a long chain called DNA, and the details of that mechanism are meticulously studied by scientists all over the world. What is the substrate for memes? Wilkins, for one, argues that many memes reside as neural net structures in human brains, but many also emerge at a higher cultural level: “All memes have neural substrates, but not all are encoded in those substrates” (1998). Hull suggests at this point that memeticists should work on both theoretical and experimental fronts simultaneously with tentative operational definitions and assumptions; more sound ones can emerge only as we start *doing* memetics (2000: 46–9).

One other fundamental attack on the memetic theory concerns the ways in which memetic novelty occurs – in other words, how human creativity works. Unlike the evolutionary processes where there is no foresight, the argument goes, humans are ‘autonomous’ designers with predetermined purposes in their minds (Blackmore 1999: 249). In fact, Dawkins himself makes use of this distinction to teach evolution when he likens nature to a blind watchmaker, as opposed to a true watchmaker (of Paley) who has foresight and plans his actions according to a specific purpose (1986: 5). So human design cannot be evolutionary because it is “apparently both directional and able to take enormous leaps (in evolutionary jargon, ‘saltatory’)” (Gatherer 1999: 96). But is it really?

2.3.3. An Evolutionary Account of the Human Creative Process

In *Darwin's Dangerous Idea*, Dennett asks how Johann Sebastian Bach was able to create *the St. Matthew Passion*, and goes on to explain that the composition was the result of years of work by Bach who had the “benefit of forty-two years of living” and who was influenced by the Christianity which took roughly two millennia to develop in a social and cultural context that emerged in hundreds of millennia thanks to the species Homo sapiens which evolved in roughly three-and-a-half billion years: “billions of years of *irreplaceable* design work”. Bach was lucky in his genes as he did come from a family full of musicians, and he was lucky to have lived in the cultural atmosphere teeming with the memes that led him to compose *the St. Matthew Passion*. (1995: 511–2)

This is a snapshot of the vision of creativity that the memetic theory entails. This view is elegantly illustrated in Ernst Gombrich’s quotation of the art critic Heinrich Wölfflin’s words: “… every picture owes more to other pictures painted before than it owes to nature.” (Gombrich 1954: 376)

Within this perspective, Paley’s watchmaker argument is flawed from the outset in that it fails to recognize that no watch is the result of a creation *ex nihilo* by a single watchmaker: it owes its intricate design to a centuries long tradition of watchmaking that has accumulated efforts and trials and errors, small and large, by hundreds of watchmakers and other mechanical designers (Michl 2002).

Accordingly, Michl is particularly unhappy with the common understanding of the concept of *design* as tightly related to terms like *creativity*, *originality*, *genius*, *intention*, *plan*, or *project*, all referring back to individual persons and individual brains.[8] As a design educator, he further complains that

> expressions such as *to be influenced, to be inspired, to take over a solution, to start out from, to build further on,* or *to steal,* are used with an apologetic, or accusatory, undertone as though they implied a reprehensible lack of independence on the part of the designer, as though the designer ought really to be uninfluenced and indeed immune to influence by others, as though she ought to be 100% original in the sense of starting from scratch, i.e. creating exclusively out of her sole head.

The author proclaims that human design is instead a supra-individual and cumulative process, and designers always start off where other designers (or they themselves) have left off; it is practically *impossible* to start from scratch. He speaks of a "common pool of knowledge" – reminiscent of the gene pool concept in evolutionary biology – in which designers of present and past, living or no longer living, collaborate. (2002)

As Blackmore recapitulates, new ideas come from the variation and the combination of the old ones (1999: 15). Now the question is: Can this process of variation and recombination be considered evolution? Does it fulfill the three requirements of the algorithm of evolution? Derek Gatherer makes a strong case for it:

> If the design process begins with the production of novel ideas generated from random combinations and mutations of existing ideas, continues with selection of those ideas for applicability to the problem at hand, and then proceeds to the (not necessarily accurate) transmission of those ideas, then the conditions necessary for an evolutionary process exist. That, in a nutshell, is the basis for an evolutionary theory of the design process. (1999: 102)

In fact, Campbell preceded memetics when he described the same evolutionary mechanism with random variation for creative cognitive processes in 1960, building

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[8] "Designer labels – selling a product with the help of the designer's name (and/or signature) – further strengthen the illusion that products have a single and clearly identifiable originator." (Michl 2002) Gatherer (1999: 100) notes that the conception of an individual design genius was a product of the growth of individualism during the Renaissance, reminding that many philosophers before the 14th century used to attribute their works to some important figure of the past such as Aristotle in order to ensure a wider readership.

upon what thinkers like Ernst Mach, Paul Souriau and Henri Poincaré had written. But does the production of novel ideas really generate from *random* changes? Here arises the issue of human consciousness or foresight, mentioned at the end of the previous section. Human creative activity is generally seen as closely linked to consciousness. However, this explanation of creativity leads to a metaphysical conception where consciousness somehow creates ideas in a rather magical way independently from the underlying physical brain activity.[9] (Blackmore 1999: 206) The memetic model implies that the human brain is a generator and selector of random novelty (Gatherer 1999: 97). It posits evolution as the way to get good design, without any conscious, teleological design decisions, and yet we humans seem to make perfectly conscious and autonomous decisions with specific endpoints in mind. What does it mean anyway to make a decision and who in the first place does it?

Research in cognitive sciences and neuroscience suggests that there is not a central decision-maker in the brain where all the input comes together and is transformed into output (Dennett 1991; Blackmore 1999). The brain is a parallel processor without a boss and we are not "godlike creators of ideas, manipulating and controlling them as our whim dictates, and judging them from an independent, Olympian standpoint" (Dennett, 1990). Dennett argues that the way in which our minds work (to generate speech, in the case of his argument) can be explained by a Pandemonium model in which

> a torrent of verbal products emerging from thousands of word-making demons in temporary coalitions could exhibit a unity, the unity of an evolving best-fit interpretation, that makes them appear as if they were the executed intentions of a [inner] Conceptualizer.

According to this theory of mind, the decisions that we make are the products of super fast unconscious evolutionary processes going on in our minds and they do not require an 'inner Conceptualizer' or 'Central Meaner' (1991: 227–52). Cognitive scientist Rosaria Conte affirms that "a decision-based process is not necessarily explicit

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[9] As opposed to this view, some scientists focus solely on the *intelligence* of the creative *individual*, although this explanation also is problematic in that it ignores the transaction and the transformation of ideas between the individual and the cultural environment. (Blackmore 1999: 206)

and reflected on: mental filters do not necessarily operate consciously, so agents may not be able to report on them.” (2000: 93)

Similarly, theoretical neurobiologist William Calvin suggests that the human brain is a “Darwin machine”, making use of random noise to create millisecond-long generations of alternatives and shaping them through series of unconscious selections (1987). It is precisely because we only experience and remember some of the steps that are comprehensible and useful that the human creative process appears to have a direction (Souriau 1881 and Poincaré 1913 cited in Campbell 1960; Gatherer 1999: 97;). The human designer’s brain is a memetic environment where memes get mutated randomly, selected at levels many of which are not conscious at all. Just like in biological evolution, this process creates what looks like foresight in retrospect (Blackmore 1999: 241). The subjective sense of intentionality, insight and autonomy that the designer feels is in fact an illusion produced by selection (Campbell 1960: 384; Gatherer 1999: 98).

> But if it is true that human minds are themselves to a very great degree the creations of memes, then we cannot sustain the polarity of vision with which we started; it cannot be “memes versus us,” because earlier infestations of memes have already played a major role in determining who or what we are. The “independent” mind struggling to protect itself from alien and dangerous memes is a myth. (Dennett 1991: 207)

Memes, just like genes, are selected against the background of other memes in the meme pool (Dawkins 1976: 194) and the ‘me’ that does the choosing is itself a fluid and dynamic memetic construct installed in the brain (Dennett 1991: 431; Blackmore 1999: 241): it provides the memetic background (or environment) that new mutations are selected against.

> The designer may protest: ‘But *I* solved it’, but the memeticist would reply: ‘No, you were the brain/processing unit in which the cultural solution to the problem arranged itself.’ (Gatherer 1999: 98)

2.4. Digital Evolutionary Algorithms

The memetic theory is considered to be in its infancy, and debates continue as to whether it is a progressive scientific research program at all (Aunger 2000: 2–3). Nevertheless, anthropologist Dan Sperber admits that the very idea that the Darwinian model of selection is not strictly limited to biology is theoretically interesting, whether there actually are memes or not (2000: 163).

After all, quite independently from the big question of whether human culture really is the product of replicating bits of information, the algorithm of evolution is being technically used today in solving engineering and optimization problems or in creating art, design, and artificial life, mostly thanks to computers (Bentley 1999: 6). People program computers to create populations of solutions, allow better solutions to ‘have children’ with some random variation, and make worse solutions ‘die’. By repeating this process, better and better generations of solutions are evolved.

The father of this field of research and application is accepted to be John Holland who also coined the term *generic algorithm* in his 1975 book *Adaptation in Natural and Artificial Systems*. Nevertheless, there were several other people who had proposed similar ideas in 1960s, like Ingo Rechenberg and Hans-Paul Schwefel, or Lawrence Fogel. (Reeves & Rowe 2003: 2)

British computer scientist Peter Bentley is especially interested in the application of evolutionary algorithms to design and art. He asks “Why evolve designs?” in his introduction to *Evolutionary Design by Computers* and cites the following answers (1999: 4–5):

1. Evolution is a good, general-purpose problem solver.
2. Uniquely, evolutionary algorithms have been used successfully in every type of evolutionary design.
3. Evolution and the human design processes share many similar characteristics.
4. The most successful and remarkable designs known to mankind were created by natural selection, the inspiration for evolutionary algorithms.

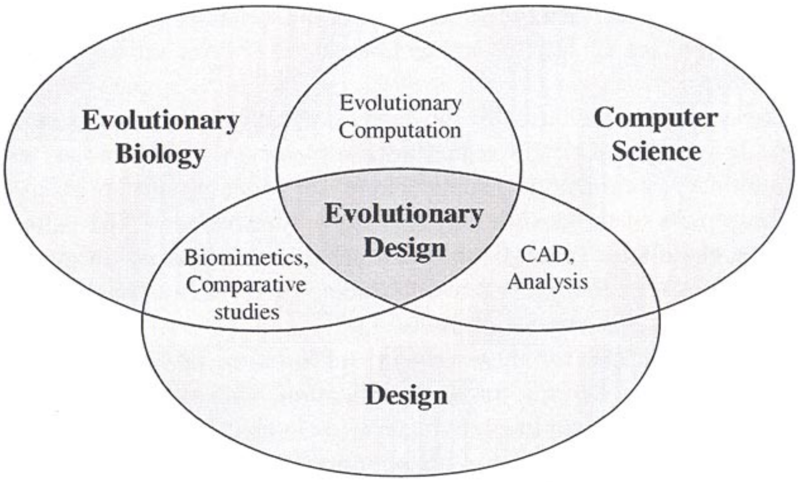

Figure 7. Evolutionary design as the intersection of evolutionary biology, computer science, and design. (Bentley 1999: 35)

The author notes that there exist various types of digital evolutionary algorithms of which the *genetic algorithm* is the most widely used and resembles biological evolution the most. Genetic algorithms have two separate virtual spaces: the search space containing *coded* solutions to the problem – *genotypes* – and the *solution* space containing actual solutions – *phenotypes*. *Genotypes* are transformed into *phenotypes* through a specific mapping (*embryogeny*) so that the solutions – their *fitness* – can be evaluated. Strings of genetic information are called *chromosome*s.

A simple genetic algorithm works as follows. First, an initial population of individual solutions is created with completely random genotypes. After the initialization, the main loop begins. Phenotypes of every individual are generated through the mapping, evaluated and given fitness values according to how 'good' they are with respect to a problem objective or *fitness function*.

Then the genotypes of the individuals are copied into a temporary space usually called the *mating pool* with one important condition: the higher the fitness value of an individual, the more copies of its genotype are placed into the pool. ‘Parents’ for the next generation to be created are then randomly picked from this pool, thus more fit genotypes are more likely to be chosen. ‘Children’ genotypes are created by applying random mutations or crossovers to these parents. (Crossover is the technique of mixing two chromosomes into one, by splitting two chromosomes from two different parents at one point and switching the parts.) New children are created until the new population is full.

This is the last step of the main loop, and this loop – genotype-phenotype transformation, evaluation, regeneration – is repeated for a specified number of generations or until a proper solution evolves. (Bentley 1999: 8–10)

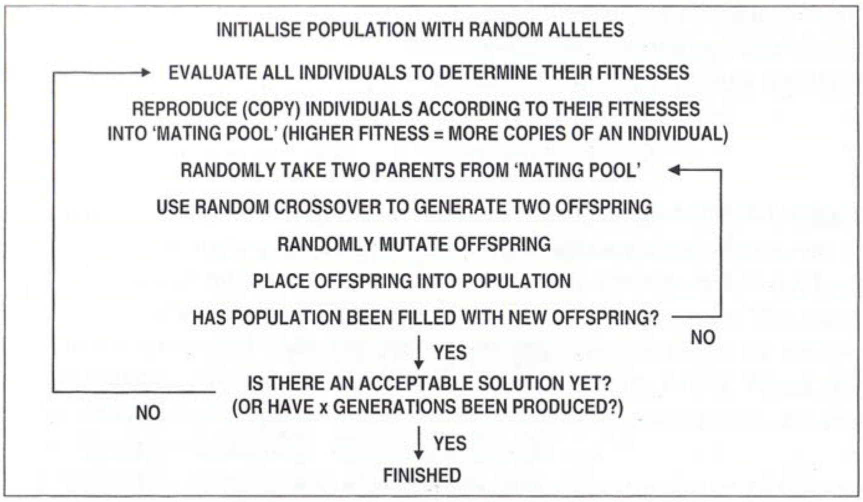

Figure 8. Flowchart, the basic genetic algorithm. (Bentley 1999: 9)

Evaluation is usually made by built-in fitness functions that automatically analyze and grade solutions, but in some cases – especially when aesthetic choices are involved – human evaluators make the selection (Bentley 1999: 30). Some researchers work on implementing artificial neural networks for fitness evaluation involving aesthetic preferences (Lewis 2008: 11). Selection methods range between deciding on which individuals will reproduce and deciding on which individuals will 'die' without children (*negative selection*) (Bentley 1999: 30–33).

Digital evolutionary algorithms are successfully used to evolve designs of jet engine turbine blades, aerodynamic cars, satellite structures, photorealistic faces, factory schedules, school timetables, fraud-detection systems, architectural plans, or game-playing strategies (Bentley 2001: 57). There are programs such as GenJam that evolve melodies, or 'evolutionary artists' such as Steven Rooke who work with software that evolve abstract images (eds Bentley & Corne 2002).

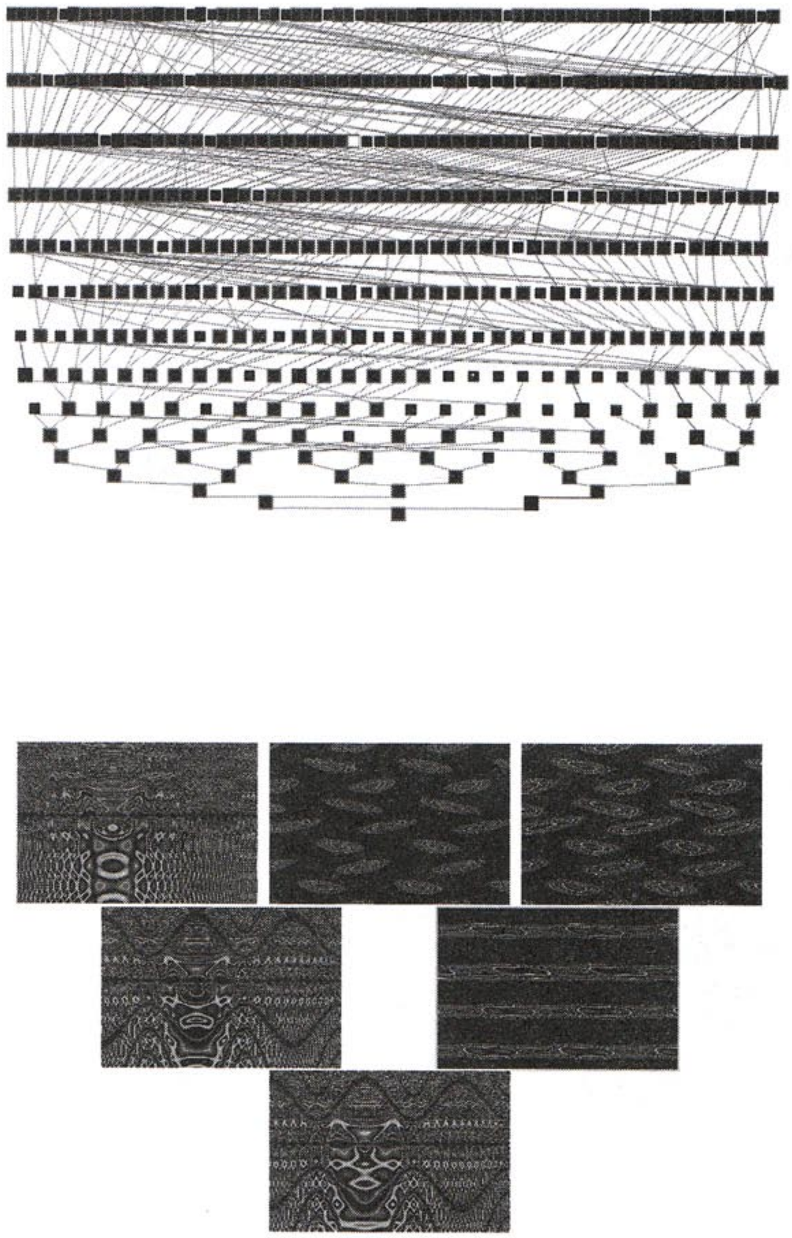

Figure 9. Fourteen generations of ancestors of an individual image entitled “Afman” by Steven Rooke (above) and Afman’s two parents and three grandparents. (eds Bentley & Corne 2002: 344)

It is important to acknowledge that “[e]volution is not simulated in these algorithms, *it actually happens.* (...) An evolutionary algorithm no more simulates evolution than a pocket calculator simulates addition, or a typewriter simulates text.” Evolution is a substrate-neutral process, and every instance of it in every medium is an equally valid form of evolution as the biological one. (Bentley 1999: 6f)

CHAPTER 3. EVOLUTIONARY GRAPHIC DESIGN: GRÁPHAGOS

3.1. Visual Evolutionary Programs: Art versus Design

Dawkins was one of the first to apply evolutionary algorithms to ‘pictures’. He created the program The Blind Watchmaker in 1986 to explore the artificial interactive evolution of branching figures (*biomorphs*) generated by simple *tree-growing* procedures with the selection criterion defined as “the appeal to human whim” (1986: 57). Although his intention was to use the program as a pedagogical tool to teach biological evolution, his footsteps were followed in the early 1990s by Karl Sims and William Latham (with Stephen Todd) who combined genetic algorithms with sophisticated abstract color graphics (Lewis 2008: 3).

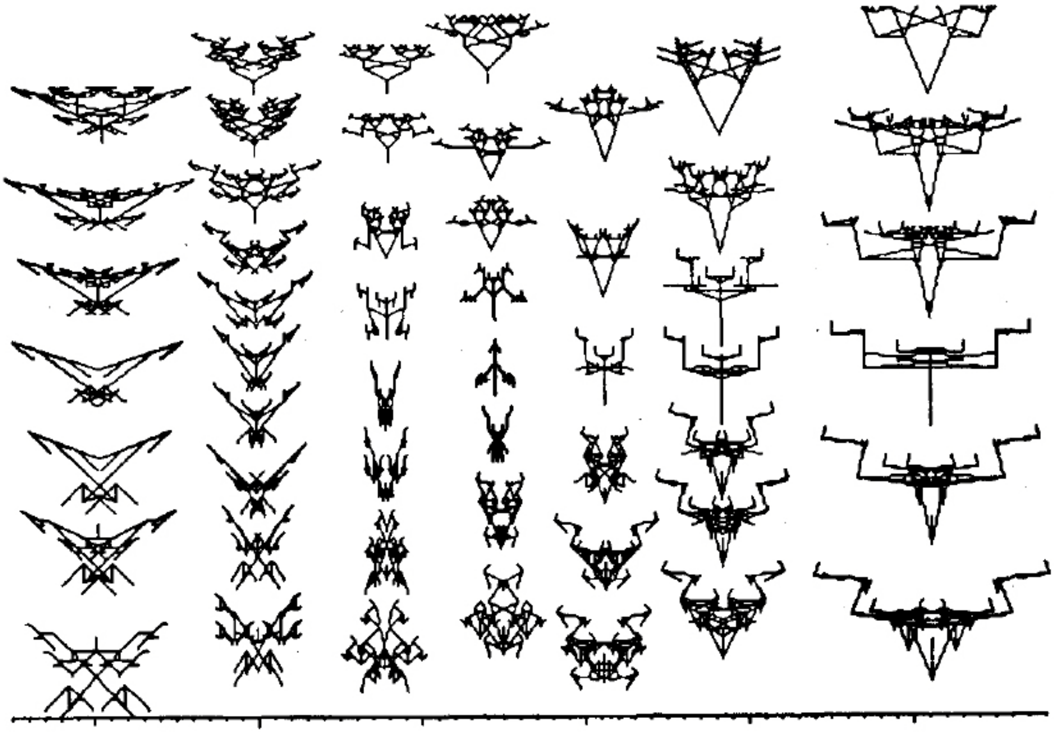

Figure 10. Dawkins’s biomorphs.

Sims was the pioneer researcher who introduced the expression-based approach to image evolution, which involved using mathematical expressions like $abs(sin(s * 3 * \pi) + cos(t * 4 * \pi))/2$ as genotypes. Steven Rooke, Tatsuo Unemi, and David Hart are some of the important figures who followed this method in evolving images.[10] (Lewis 2008: 7)

The use of fractals is also common in image evolution systems. One famous example is the Electric Sheep of Scott Draves – an online system of evolving abstract screen savers evaluated by thousands of people over the internet, which is the most widely used evolutionary design project to date according to Matthew Lewis. Some programs that evolve abstract images such as ArtMatic, Evolvotron, Kandid, and Softology are released for others to use with varying degrees of commercialization. Some systems make use of collective evaluation via an online server, after the original example by Mount, Neil-Reilly, and Witbrock. (Lewis 2008: 9–10)

Figure 11. An evolved product in Scott Draves's Electric Sheep.

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[10] A similar line of research and application, initiated again by Sims with Latham and Todd, focused on evolving virtual 3D structures, sometimes resembling biological structures like coral polyps or plants. This body of work is usually linked to the field of artificial life. (Bentley 1999: 43–5)

There are many more examples of evolutionary ‘art’ software in the literature. However, whether the abstract images evolved by computers interacting with humans should be acknowledged as art is a controversial issue (Bentley 2001: 59). Lewis notes that very few of the people who design these image evolution programs have formal art training, and asks some critical questions:

> In the space of evolutionary design research, the boundary around projects comprising “evolutionary art” is fuzzy. Are evolved creatures art when presented at an a-life conference versus a gallery installation? Are certain regions of software’s potential design space art, while others are not? Which is the more critical task: the creation of evolutionary art interfaces or the crafting of the design spaces they represent? (2008: 4)

‘Evolutionary art’ may be a slippery term as our understanding of art has gone beyond the creation of beautiful images and become intertwined with philosophy in the last century. *Design*, on the other hand, is another matter. As one can so impressively observe in nature, evolution generates design – it creates adaptation within an environment; in other words, it explores functional solutions within a context. This is exactly what human designers do, whether they design a bridge or a poster for an event. The nature of the distinction is etymologically explicit in the categorization of *autonomous arts* (referring to fine arts) and *heteronomous arts* (referring to design, and also crafts) that are practiced with bound creativity (Michl 2002).

Application of digital evolutionary algorithms to ‘heteronomous’ design problems has many examples. Bentley’s own program called GADES is applied to a variety of design problems from coffee table designs to hospital floor plans (Bentley 1999: 405–23). Genometri’s commercial product Genoform™ integrates with CAD software for product design. Kim and Cho proposed a fashion design aid system using interactive genetic algorithms (2000). Typeface design is a plausible area for evolutionary algorithms, with the existing efforts of Schmitz, Unemi, and Butterfield and Lewis (Lewis 2008: 13). Architecture is perhaps the most popular field among researchers interested in generative design and genetic algorithms (see eds Bentley & Corne: 2002).

However, there are very few researchers who apply evolutionary algorithms to graphic design.[11] Among them is Gatarski who created an evolutionary system where advertising banners continuously and automatically re-design themselves in interaction with their viewers (2002). Oliver et al. implemented genetic algorithms to evolve basic HTML web page designs (2002). As in evolutionary art, the fact that these researchers do not have formal design training does affect the relevance of their work to graphic design in a negative way.

Figure 12. Banners evolved by Gatarski.

Figure 13. Web page layouts evolved by Oliver et al.

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[11] Icosystem’s Hunch Engine™ and Affinnova’s IDDEA^{SM} are some of the commercial applications of genetic algorithms to visual design, although these companies do not share the output of their products, making assessment impossible.

3.2. What Is Graphic Design?

According to design historian Philip Meggs, graphic design shares a “universal language of form” with other visual disciplines such as painting or architecture, yet it has a specific goal and a special visual language of its own. The goal of graphic designers is “to solve problems, organize space, and imbue their work with those visual and symbolic qualities that enable it to convey visual and verbal information with expression and quality”. (1992: viii)

French designer Philippe Apeloig defines graphic design as the intersection point between art and communication (ed. Fiell, 62). According to Abbott Miller, it is

> a meta-language that can be used to magnify, obscure, dramatize, or re-direct words and images. It can be powerful, elegant, banal, or irrelevant. It's not inherently anything at all, but pure potential. (ed. Fiell, 218)

This sentence reveals why graphic design can be a very fruitful area of research and application for evolutionary algorithms. As opposed to ‘autonomous’ abstract images, a graphic design product exists in a context determined by the content that it has to communicate. It has to function in that context, just like an animal has to function in its environment, although this does not restrict it totally as there are many different ways to function, i.e. to communicate a message. Evolving abstract images is more like genetic drift whereas evolving visual design products resembles more natural selection where functionality is predominant.

Graphic designers “bring a resonance to visual communications” with a variety of graphic materials in such a way that a *gestalt* emerges – a German word for situations where the whole is greater than the sum of its parts (Meggs 1992: 1). Crawford Dunn (1970) deconstructs graphic design by distinguishing between three signals:

1. alphasignal: the content of the message that needs to be communicated.
2. parasignal: the visual signal that travels alongside alphasignal to amplify and to support it.
3. infrasignal: the visual information that can betray the sender as it contradicts the alphasignal.

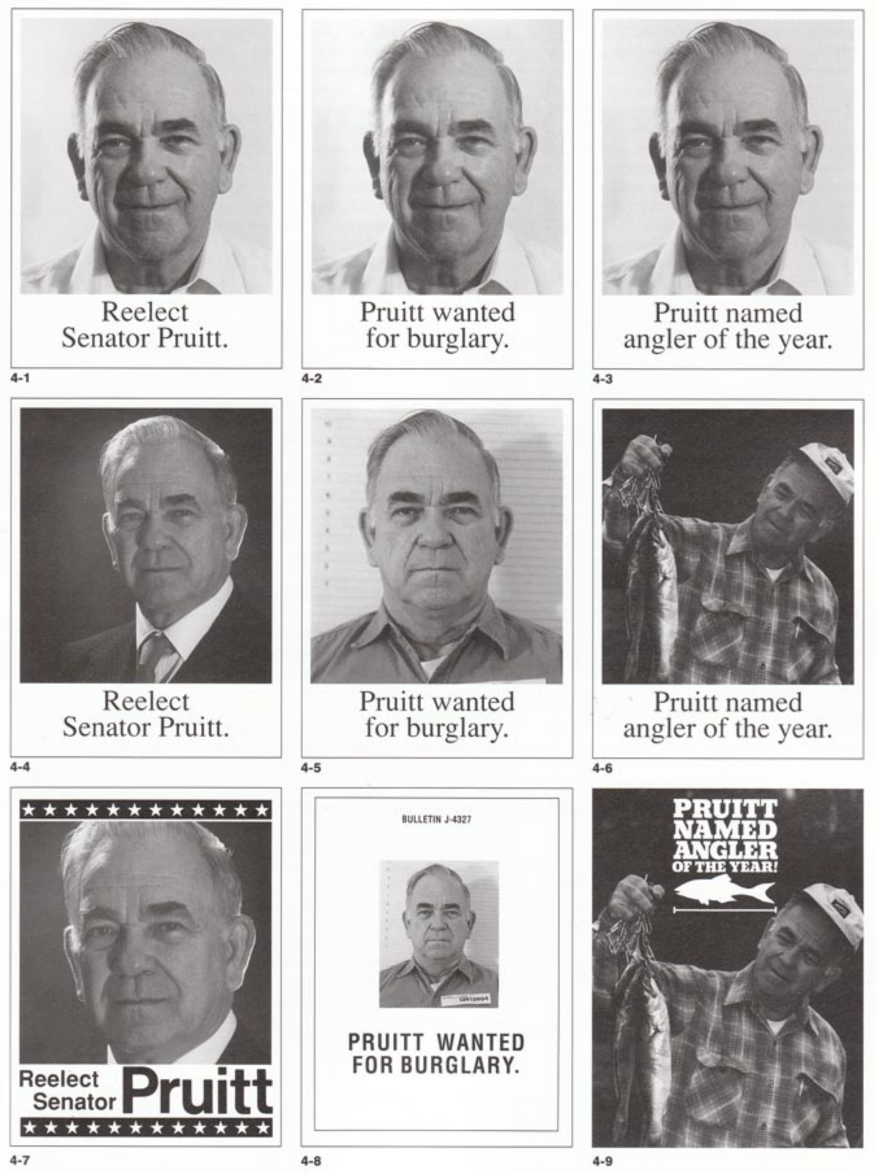


Figure 14. Example, resonance in graphic design. (Meggs 1992: 119) It shows how different parasignals build up in a design process to support different alphasignals.

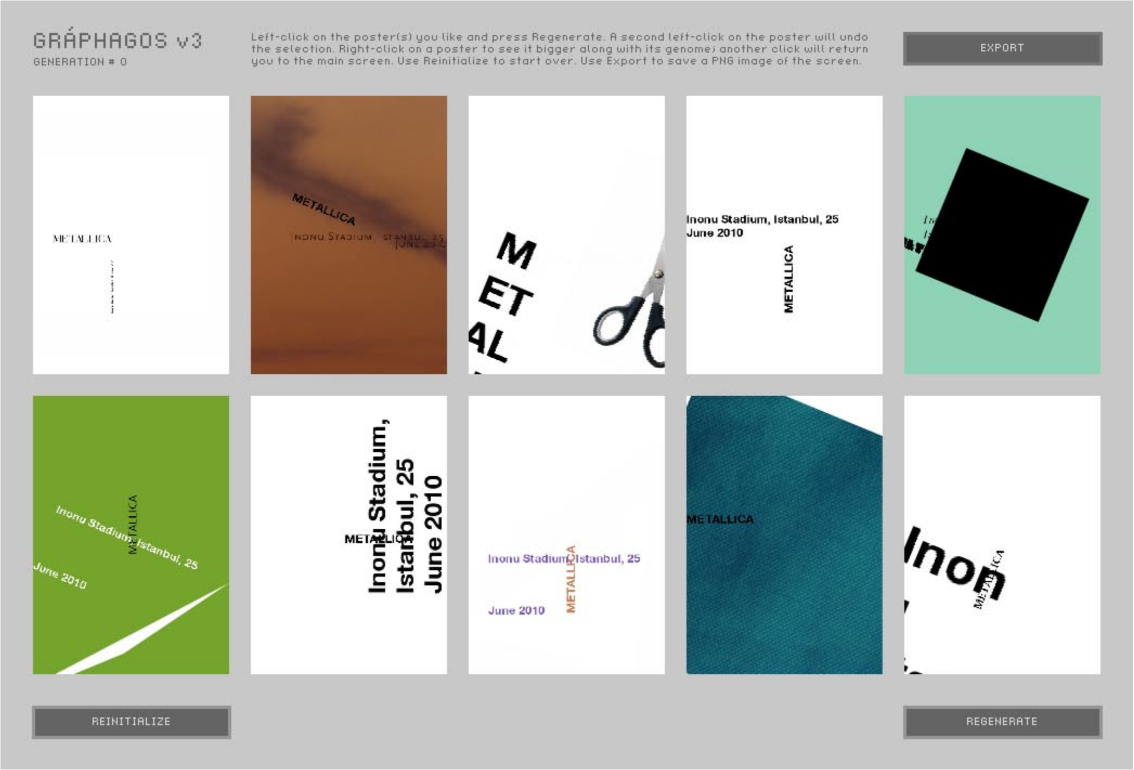
In this context, the graphic design activity can be defined as the search for parasignals for a certain alphasignal. This requires to a certain degree the elimination of infrasignals that might come about during the search. Dunn’s model clarifies how and why evolutionary algorithms can be used to generate graphic design products: with a given alphasignal, evolution will search for possible parasignals by eliminating infrasignals.

3.3. Gráphagos, An Introduction

Gráphagos is an evolutionary approach to graphic design. Technically, it consists of a program – written in Processing – which:

1. initially generates random designs with the given textual content,
2. offers them to a human user for selection,
3. uses the selection results to create the next generation of mutants with random mutations, and then returns to step 2.

The program aims to generate visual *design* products that *function* to communicate a message. Just as in a conventional design process, the textual content – the alphasignal – is given as input to Gráphagos before the design work – evolution, in this case – starts. Furthermore, just like a human graphic designer, Gráphagos makes use of *found objects* – image and font pools – instead of creating every element from scratch.



Left-click on the poster(s) you like and press Regenerate. A second left-click on the poster will undo the selection. Right-click on a poster to see it bigger along with its genome; another click will return you to the main screen. Use Reinitialize to start over. Use Export to save a PNG image of the screen.

Figure 15. Screenshot, Gráphagos interface with a random initial population.

Left-click on the poster(s) you like and press Regenerate. A second left-click on the poster will undo the selection. Right-click on a poster to see it bigger along with its genome; another click will return you to the main screen. Use Reinitialize to start over. Use Export to save a PNG image of the screen.

Figure 16. Screenshot, Gráphagos interface with a population at the 75th generation.

Gráphagos is primarily designed as a model for the creative process of the designer, in light of the evolutionary theories of human creativity discussed in Chapter 2. Examining the model and the different lineages of solutions that it generates under different selection criteria can reveal valuable information about graphic design as well as human creativity and the memetic theory. In addition, Gráphagos offers a new practical tool for making graphic design.

The image pools can be recreated specifically for each poster project, with the images chosen according to the textual content of the poster. However, generic image pools with lots of seemingly irrelevant images can be much more accurate in modeling creativity, because this setup includes the creation of new semantic relationships into the process of evolution – this way, mutations (having an effect on which image is pulled from the pool) are free to offer new metaphors.

In addition to the few researchers and companies that applied evolutionary algorithms to graphic design, there are programs that generate graphic design products without using evolution. nGen® by Move Design (2001) is one of them; it creates good design in one shot. Evolution, however, is a differential and cumulative process, depending on selection to favor good *blind* mutations from bad ones. The solutions that Gráphagos generates are truly random and need generations to evolve towards good design. There is much more freedom and richness here when compared to the fine tuned algorithms of nGen®: Gráphagos navigates an endless space of designs, being created on-the-go.

Many people who create evolutionary design programs try to imitate natural growth rules in their digital universes in order to obtain designs that resemble the patterns in nature. Some researchers even become “digital gardeners growing digital plants within their computers” (Bentley 2001: 144). I tried to avoid this situation in designing Gráphagos as there is no point in restricting a digital universe of graphic design to the forms and patterns of the biological universe. When comparing Gráphagos and biological evolution, one should be aware of the fact that they are only analogous in the way the algorithm of evolution works and in the way information is encoded, *but not in the way forms are generated*. The shape grammars of Gráphagos have nothing to do with biology, and this case exemplifies the substrate-neutrality of the algorithm of evolution.

3.4. Elements of Graphic Design

In order to apply evolutionary algorithms to a problem, proper genotype and phenotype representations must be created (Bentley 1999: 51). This process involves a deconstruction of the parasignal – in other words, the visual language – in graphic design.

The parasignal is constructed with diverse elements. On a purely visual level common to visual design and visual arts, the basic elements can be listed as color, line, shape, texture, value and volume (Blakeman 2005: 20–1). Within the graphic design context, Meggs uses a different categorization; signs, denotations and connotations, typography, images, image transformations, and graphic support elements (1992).

Typography is the most important element in graphic design as it is in direct contact with the alphasignal; it exists to “honor content”, which is the meaning provided by the words and the subject (Bringhurst 2004: 17). Thus, typographical parameters such as *typeface*, *type size*, *leading* or *alignment* are among the first ones to be included into the ‘genetics’ of graphic design. The relationship between the text and the typeface is of central importance in a graphic design product:

> Letterforms have tone, timbre, character, just as words and sentences do. The moment a text and a typeface are chosen, two streams of thought, two rhythmical systems, two sets of habits, or if you like, two personalities, intersect. (Bringhurst 2004: 22)

The term *leading* refers to the vertical distance between the baselines of lines of text. Leading can act as a design element by affecting the ‘lightness’ of the text block or, more dramatically, by allowing strands of text to intertwine. Alignment is also a major element of typographic design. Designers prefer to set a body of text flush left to allow a comfortable reading with an organic flow. Flush right can be used as “a welcome departure from the familiar”, whereas centered text blocks have a static effect with historical associations. (Lupton 2004: 83–5)

Using images (from pictographs to photographs), sometimes with alterations or in combinations, is an essential method of resonance in visual design (Meggs 1992: 19–22). Graphic support elements such as lines, shapes or textures can also act as powerful tools to increase the resonance with the alphasignal (Meggs 1992: 240).

Color aids organization, emphasizes, and provides direction (White 2002: 67). It also offers a rich scale of emotional associations and symbolic connotations depending on its relationships with other elements (Meggs 1992: 10).

Alex White notes that all the elements of a design product should exist in a unity that serves to communicate the message. He mentions are several ways to obtain a unity between elements:

- proximity (or grouping): placing elements physically close to each other.
- similarity (or correspondence): using different elements with similar properties like size, color, shape, or position.
- repetition: directly repeating any of the properties listed above.

Some other relationships can also be manipulated to create a gestalt, such as the figure/ground relationship of an element with its surroundings and our perceptual tendency to close gaps and complete unfinished forms. Balance (symmetrical or asymmetrical) and a correct hierarchy of information are also crucial to achieve unity in design. (2002: 59–65)

In short, the positioning of an element in the whole layout, its size and its relationships to other elements are of great importance in design. These are all parameters that should be included in the genetics of graphic design.

3.5. The Software

3.5.1. Genetics

In Gráphagos, the search space and the solution space are distinct: genotypes are mutated and then translated onto phenotypes for evaluation.

What the user deals with after the initial random generation are ‘quasispecies’: “ensembles of similar genomic sequences generated by a mutation-selection process” (Nowak 2006: 31). A single design product in Gráphagos – an individual of a quasispecies – will be called a *graphago*.

The genotype of a graphago is divided into distinct chromosomes as a solution to grant the special status of the textual content in graphic design. Since the job of graphic design is to communicate a message, the textual elements should be present in the layout by default, while all the other secondary elements such as shapes and photographs are optional. To ensure that the *presence* – not the *design* – of the textual content does not depend on the information on the genome and its mutations, Gráphagos devotes separate chromosomes for the styling (typography, color, etc.) of each textual element and executes the operation that inserts the element after (and outside) the chromosome. This way, whatever the information in the related chromosome is, the textual element will be included in the layout from the start. (Although it is always possible that it may not be visible because, for example, it may be colored white on a white background.) Every other design element is coded for in the first chromosome. So the chromosomes of a graphago with two textual elements would be:

Chromosome 1 – Visual Elements
background color, translate, scale, rotate, stroke, fill, tint, draw line, draw parallel lines, draw dotted line, draw dot matrix, draw rectangle, draw square, draw ellipse, draw circle, draw vertex, insert photograph, insert image, insert texture, insert brush, blur filter, threshold filter, invert filter, grayscale filter

Chromosome 2 – Textual Element 1
translate, scale, rotate, text color, text box width, type size, leading, align (left, center, right), font

Chromosome 3 – Textual Element 2
translate, scale, rotate, text color, text box width, type size, leading, align (left, center, right), font

The program reads the chromosomes from left to right, and executes the drawing operations in that order. Consequently, the *layering* of the elements – an important feature in graphic design, and in related programs like Adobe Photoshop – depends on their positions on the chromosome. Similarly, the order of the chromosomes is also relevant in that the textual elements will appear on top of everything drawn by the first chromosome.

The genetic alphabet of Gráphagos consists of four letters, A, T, G, and C, and the translation is made through 3-letter codons; for example, the sequence "ATA" is mapped onto the function *rotate(PI/8)*.[12]

---

[12] I preferred this analogy with DNA for several reasons. Paying a humorous homage to biology was one of them. Second, since I usually had to present this project to designers and artists who knew little about the details of evolution, I thought that using the same coding/translation system would eliminate the need for a higher level conceptualization and help people understand Gráphagos *and* the biological evolution, acting as a pedagogical tool. The third reason was my – later confirmed – hunch that this parallelism would somehow prove useful *to me*, in designing the software or in analyzing the data.

Left-click on the poster(s) you like and press Regenerate. A second left-click on the poster will undo the selection. Right-click on a poster to see it bigger along with its genome; another click will return you to the main screen. Use Reinitialize to start over. Use Export to save a PNG image of the screen.

```
GCTCGAAAC.TAACGGAGGGCCGGTTACCGCGTTTATCC
GCGGATCCGCGATCGTAAGAAACACCCAGGGCTGACC.C
CCAATTGGTTGACCTCATTCCTAATAGGATGAGTTATA
GTCT.GTTTATGGCCTTAATACAGCAACGTGATTCCGCT
GGTTGGACAAAGTT
```

Figure 17. Screenshot, Gráphagos interface showing an individual design at generation 86, and its chromosomes separated by periods.

For simple operations like *rotate*, *translate* (move) or *scale* with fixed parameters, single codons can be sufficient. However, more complex functions such as *fill color* or *insert image* require extra information, on what color to fill or which image to insert, to follow the examples. Obviously, it is not possible to assign a codon to each possible combination of these commands because there are thousands of them and only 64 codons. My solution to this problem was inspired by the *start codons* in genetics which initiate the translations (Snustad & Simmons 2003: 323).

Complex functions that require extra parameters in Gráphagos work like start codons; a codon initiates the operation and the information of the parameters is gathered from the next codons. A good example would be the *fill color* operation.

Processing uses RGB (or alternatively HSB) color codes for color operations, with the syntax ‘fill (value1, value2, value3)’ where the *value* parameters correspond to the Red, Green and Blue values respectively, each ranging between 0 and 255, thus capable of coding for a palette of 16 million colors.

When the *fill color* codon is read on the chromosome, the information of the color to be filled is drawn from the next three codons by a translation of the letters A, T, G and C into numbers for RGB values. Since there are 64 possible codons and the range for one color value is 0–255, the translation takes a few steps. Consider the example of a string of chromosome like '...TGG**GCA**ATGCCTGACCTA...' where 'GCA' is the *fill color* codon. First, the next three codons are translated into numbers from 0 to 63. To do this, each letter of the codon is first substituted with a number between 0 and 3 according to a simple algorithm:

```
GCA ATG CCT GAC
    012 331 203
```

```
if (x == ‘a’) {
y = 0;
} else if (x == ‘t’) {
y = 1;
} else if (x == ‘g’) {
y = 2;
} else if (x == ‘c’) {
y = 3;
}
```

Then these three-digit strings are read in *base 4* system to be transformed into numbers between 0 and 63 in our familiar *base 10* (decimal) system:

```
GCA ATG CCT GAC
    012 331 203
      8  61  35
```

```
(c[0] * 16 + c[1] * 4 + c[2]);
```

Now that the codons are transformed into numbers from 0 to 63, the numbers are multiplied by 4 to cover the 0–255 range by steps of 4 (0, 4, 8, 12, 16, … , 252). This allows a rich color scale (250,047 colors) with the information of color being hereditable, subject to mutation and to selection.

```
GCA ATG CCT GAC
    012 331 203
      8  61  35
     32 244 140
```

So the resulting operation is:

```
fill(32, 244, 140);
```

This system is applied to other operations, as the next codons determine the width and the height of the rectangle to be drawn with the *draw rectangle* operation, or which image from the pool will be inserted with the *insert image* operation. Once the codons after a start codon are read for parameter values, they are not re-read for whatever operation they stand for in the mapping; the translation goes on from the end of those codons, without going back.

Questions may arise as to why ‘GCA’ codes for the *fill color* operation, and not the *blur filter* operation, for instance. How was the codon-function mapping determined? Because I did not have the expertise or the time to engage in *genetic programming* in order to let the mapping evolve by itself, I chose to incorporate – at some level – the wisdom of the biological mapping which evolved in billions of years.

This is a list of the amino acids separated into four groups based on their polarity and charge, and the DNA (not mRNA) codons coding for those amino acids (Baldi & Brunak 2001: 117):

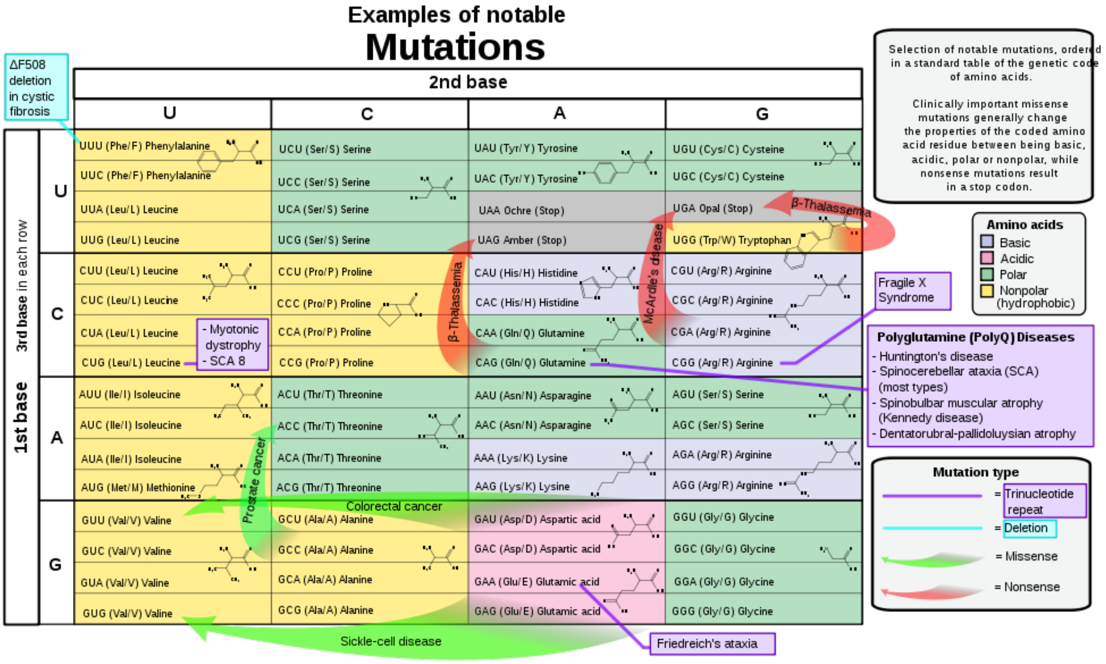
POLAR
serine AGA, AGG, AGT, AGC, TCA, TCG
asparagine TTA, TTG
threonine TGA, TGG, TGT, TGC
glycine CCA, CCG, CCT, CCC
glutamine GTT, GTC
tyrosine ATA, ATG
cysteine ACA, ACG

NONPOLAR
methionine TAC
tryptophan ACC
phenylalanine AAA, AAG
leucine AAT, AAC, GAA, GAG, GAT, GAC
isoleucine TAA, TAG, TAT
valine CAA, CAG, CAT, CAC
proline GGA, GGG, GGT, GGC
alanine CGA, CGG, CGT, CGC

BASIC
histidine GTA, GTG
lysine TTT, TTC
arginine GCA, GCG, GCT, GCC, TCT, TCC

ASIDIC
aspartate CTA, CTG
glutamate CTT, CTC

What importance does this grouping have for genetics? Snustad & Simmons explain that mutations that cause jumps *between* these groups tend to be deleterious, as the Table 1 shows, because the behaviour of the amino acids belonging to different groups have different effects on how the proteins (chains of amino acids) are folded; so amino acids belonging to the same group can – to some degree – substitute for each other in a protein. Accordingly, evolution has made sure that the *distances* (in the bioinformatics sense) between codons for amino acids belonging to different groups tend to be high. In other words, codons belonging to the same group are closer to each other – like CTA, CTG, CTT, CTC of the *asidic* group – so that the point mutations (causing single letter substitutions) tend to stay within groups and cause less ‘trouble’. (2003: 324–25)



Examples of notable
Mutations

1st base	2nd base: U	C	A	G
U	UUU (Phe/F) Phenylalanine	UCU (Ser/S) Serine	UAU (Tyr/Y) Tyrosine	UGU (Cys/C) Cysteine
	UUC (Phe/F) Phenylalanine	UCC (Ser/S) Serine	UAC (Tyr/Y) Tyrosine	UGC (Cys/C) Cysteine
	UUA (Leu/L) Leucine	UCA (Ser/S) Serine	UAA Ochre (Stop)	UGA Opal (Stop)
	UUG (Leu/L) Leucine	UCG (Ser/S) Serine	UAG Amber (Stop)	UGG (Trp/W) Tryptophan
C	CUU (Leu/L) Leucine	CCU (Pro/P) Proline	CAU (His/H) Histidine	CGU (Arg/R) Arginine
	CUC (Leu/L) Leucine	CCC (Pro/P) Proline	CAC (His/H) Histidine	CGC (Arg/R) Arginine
	CUA (Leu/L) Leucine	CCA (Pro/P) Proline	CAA (Gln/Q) Glutamine	CGA (Arg/R) Arginine
	CUG (Leu/L) Leucine	CCG (Pro/P) Proline	CAG (Gln/Q) Glutamine	CGG (Arg/R) Arginine
A	AUU (Ile/I) Isoleucine	ACU (Thr/T) Threonine	AAU (Asn/N) Asparagine	AGU (Ser/S) Serine
	AUC (Ile/I) Isoleucine	ACC (Thr/T) Threonine	AAC (Asn/N) Asparagine	AGC (Ser/S) Serine
	AUA (Ile/I) Isoleucine	ACA (Thr/T) Threonine	AAA (Lys/K) Lysine	AGA (Arg/R) Arginine
	AUG (Met/M) Methionine	ACG (Thr/T) Threonine	AAG (Lys/K) Lysine	AGG (Arg/R) Arginine
G	GUU (Val/V) Valine	GCU (Ala/A) Alanine	GAU (Asp/D) Aspartic acid	GGU (Gly/G) Glycine
	GUC (Val/V) Valine	GCC (Ala/A) Alanine	GAC (Asp/D) Aspartic acid	GGC (Gly/G) Glycine
	GUA (Val/V) Valine	GCA (Ala/A) Alanine	GAA (Glu/E) Glutamic acid	GGA (Gly/G) Glycine
	GUG (Val/V) Valine	GCG (Ala/A) Alanine	GAG (Glu/E) Glutamic acid	GGG (Gly/G) Glycine

Selection of notable mutations, ordered in a standard table of the genetic code of amino acids.

Clinically important missense mutations generally change the properties of the coded amino acid residue between being basic, acidic, polar or nonpolar, while nonsense mutations result in a stop codon.

Polyglutamine (PolyQ) Diseases
- Huntington's disease
- Spinocerebellar ataxia (SCA) (most types)
- Spinobulbar muscular atrophy (Kennedy disease)
- Dentatorubral-pallidoluysian atrophy

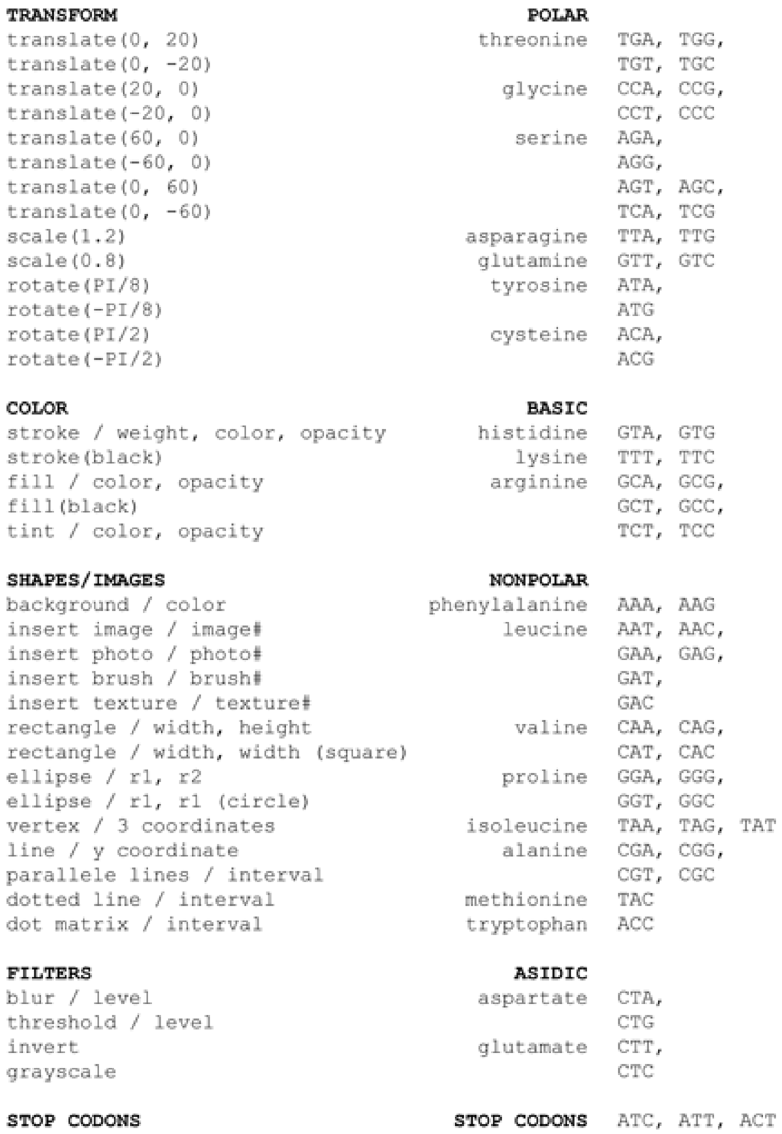
Table 1. Example, notable mutations ordered in a standard table of the genetic code of amino acids (with the correspondent codons in mRNA). (Mikael Häggström from Wikipedia, available at: http://en.wikipedia.org/wiki/File:Notable_mutations.svg)

In Gráphagos, functions can be grouped into main categories. For instance, in the case of the first chromosome, there are four main categories as well:

1. TRANSFORM – basic operations like translate, rotate, scale, working on the next objects drawn.
2. COLOR – operations about coloring shapes and images; fill, stroke, tint.

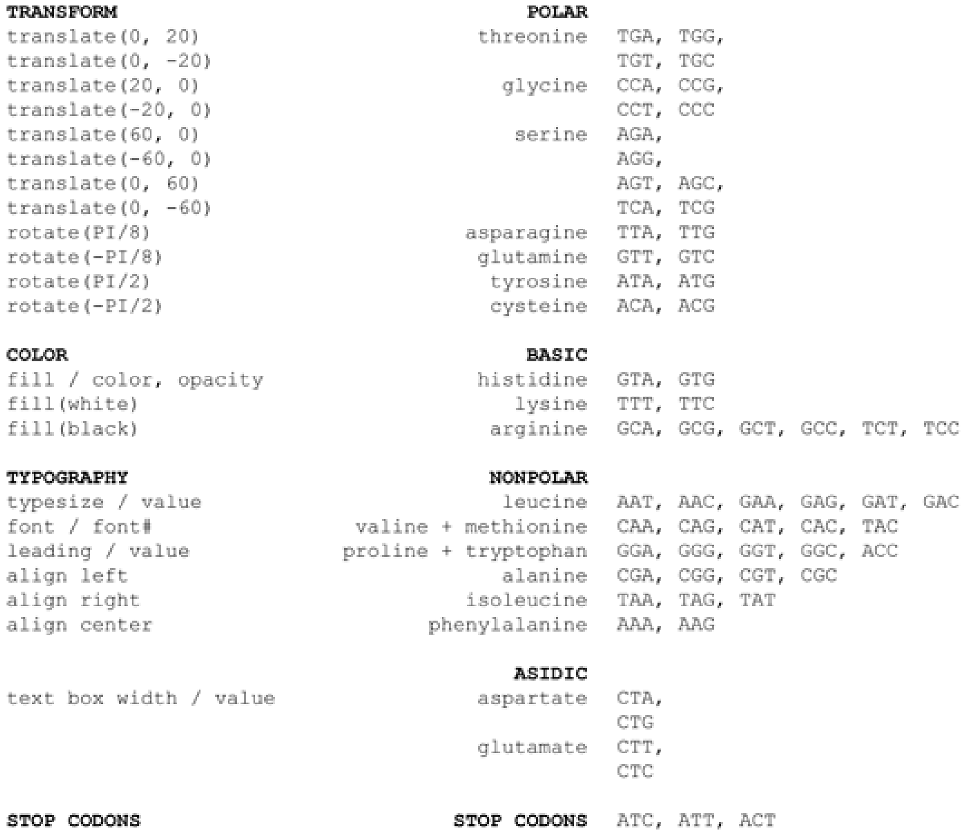
3. SHAPES/IMAGES – every operation that draws a shape or inserts an image from a pool.
4. FILTERS – filter operations (invert, blur, threshold, grayscale) that affect everything drawn beforehand.

These four groups are mapped onto the four amino acid groups (Table 2). A similar mapping is done for the typography chromosomes (Table 3).



TRANSFORM	**POLAR**	
translate(0, 20)	threonine	TGA, TGG,
translate(0, -20)		TGT, TGC
translate(20, 0)	glycine	CCA, CCG,
translate(-20, 0)		CCT, CCC
translate(60, 0)	serine	AGA,
translate(-60, 0)		AGG,
translate(0, 60)		AGT, AGC,
translate(0, -60)		TCA, TCG
scale(1.2)	asparagine	TTA, TTG
scale(0.8)	glutamine	GTT, GTC
rotate(PI/8)	tyrosine	ATA,
rotate(-PI/8)		ATG
rotate(PI/2)	cysteine	ACA,
rotate(-PI/2)		ACG
COLOR	**BASIC**	
stroke / weight, color, opacity	histidine	GTA, GTG
stroke(black)	lysine	TTT, TTC
fill / color, opacity	arginine	GCA, GCG,
fill(black)		GCT, GCC,
tint / color, opacity		TCT, TCC
SHAPES/IMAGES	**NONPOLAR**	
background / color	phenylalanine	AAA, AAG
insert image / image#	leucine	AAT, AAC,
insert photo / photo#		GAA, GAG,
insert brush / brush#		GAT,
insert texture / texture#		GAC
rectangle / width, height	valine	CAA, CAG,
rectangle / width, width (square)		CAT, CAC
ellipse / r1, r2	proline	GGA, GGG,
ellipse / r1, r1 (circle)		GGT, GGC
vertex / 3 coordinates	isoleucine	TAA, TAG, TAT
line / y coordinate	alanine	CGA, CGG,
parallele lines / interval		CGT, CGC
dotted line / interval	methionine	TAC
dot matrix / interval	tryptophan	ACC
FILTERS	**ASIDIC**	
blur / level	aspartate	CTA,
threshold / level		CTG
invert	glutamate	CTT,
grayscale		CTC
STOP CODONS	**STOP CODONS**	ATC, ATT, ACT

Table 2. Codon-function mapping for the first chromosome. The functions using the start codon system are shown with slashes followed by their parameters that are read from the next codons.



TRANSFORM	**POLAR**	
translate(0, 20)	threonine	TGA, TGG,
translate(0, -20)		TGT, TGC
translate(20, 0)	glycine	CCA, CCG,
translate(-20, 0)		CCT, CCC
translate(60, 0)	serine	AGA,
translate(-60, 0)		AGG,
translate(0, 60)		AGT, AGC,
translate(0, -60)		TCA, TCG
rotate(PI/8)	asparagine	TTA, TTG
rotate(-PI/8)	glutamine	GTT, GTC
rotate(PI/2)	tyrosine	ATA, ATG
rotate(-PI/2)	cysteine	ACA, ACG
COLOR	**BASIC**	
fill / color, opacity	histidine	GTA, GTG
fill(white)	lysine	TTT, TTC
fill(black)	arginine	GCA, GCG, GCT, GCC, TCT, TCC
TYPOGRAPHY	**NONPOLAR**	
typesize / value	leucine	AAT, AAC, GAA, GAG, GAT, GAC
font / font#	valine + methionine	CAA, CAG, CAT, CAC, TAC
leading / value	proline + tryptophan	GGA, GGG, GGT, GGC, ACC
align left	alanine	CGA, CGG, CGT, CGC
align right	isoleucine	TAA, TAG, TAT
align center	phenylalanine	AAA, AAG
	ASIDIC	
text box width / value	aspartate	CTA,
		CTG
	glutamate	CTT,
		CTC
STOP CODONS	**STOP CODONS**	ATC, ATT, ACT

Table 3. Codon-function mapping for the text chromosomes. The functions using the start codon system are shown with slashes followed by their parameters that are read from the next codons.

Obviously there is no meaningful connection between ‘polar’ amino acids and the ‘transform’ category; which groups are matched is determined according to the number of the codons and the operations to be matched. Although, the main point is preserved, as cross-group mutations will tend to be deleterious in Gráphagos, while within-group mutations will tend to be non-deleterious, and the biologically evolved distances between codons make sure that we see less deleterious mutations.

Note that there is a parallelism between amino acids and Gráphagos functions, and that the *degeneracy* of the genetic code is preserved: multiple codons are mapped to single functions, so that more common functions are encoded by a greater number of codons, and that there is no codon left without a corresponding function. The stop codons (ATC, ATT, ACT) that terminate the reading of the chromosome (Snustad &

Simmons 2003: 324) are also added in Gráphagos, for the prospect that they may lead to interesting simplifications in the designs, if arisen by mutation.

Gráphagos has some degree of epistasis: it has a genetic representation with genes whose phenotypic effects rely on the other genes on the chromosome (Bentley 1999: 56). For instance, the phenotypic effect of a *draw rectangle* gene will be modified by the *transform/fill/stroke* codons before it.

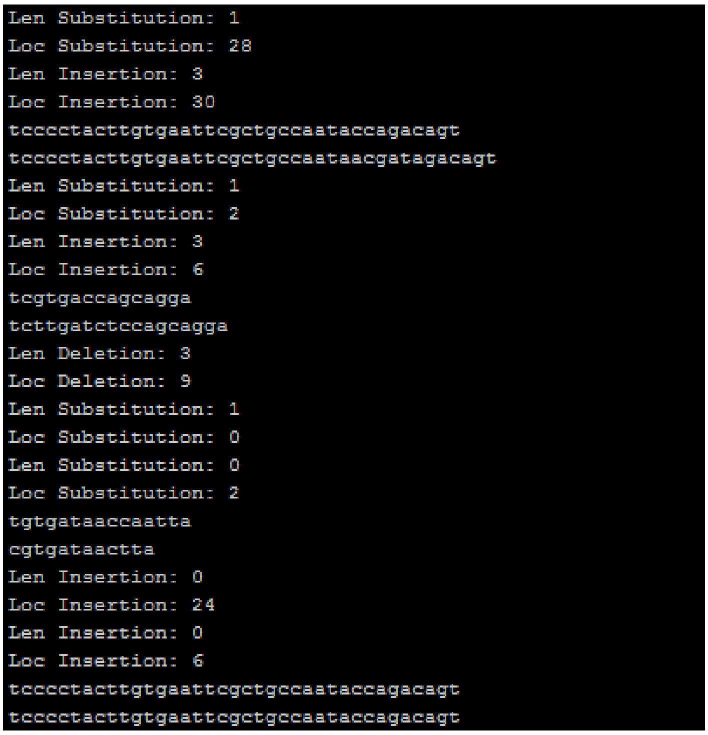
Since the chromosomes are read from left to right and the drawing operations are accordingly layered on top of each other, the operations that are encoded in the ending region of the chromosomes may – syntactically or visually – overwrite previous operations. Thus, genomes may be said to accumulate *junk* information that is not expressed in the phenotype as the evolution progresses and the chromosome lengths increase. This tendency is known as *bloat* (Langdon & Poli 1997). However, in Gráphagos, the accumulated parts can be expressed again if a stop codon that causes an early termination of the translation arises by mutation.

3.5.2. Possibilities in the Design Space and Mutations

The algorithms conducting the evolution are designed as blind and unbiased as possible to make sure that any type of design can evolve. However, there are some minute compromises in some variables in order to obtain a healthy real-time interaction with the human user. Dawkins expresses the same concern for his software, by pointing out that mutation probabilities are very low in biological evolution, and that human users do not have the patience to wait a million generations for a mutation when interacting with an evolutionary program (1986: 57).

One of the few examples is the *rotate* operation, working with a limited number of angles each assigned to one codon, instead of using a richer scale of angles that can be implemented with the start codon system (as in the *fill color* operation). The reason to limit the *rotate* operation to 90 and 22,5 degrees is to ensure that elements are rotated in a modular diagonal grid so that they get aligned more readily when compared to a complete freedom of 360 degrees – human users do not have the patience to wait for the right mutations to align things in custom angles. This adjustment actually reshapes the design space itself: the tuning of the ranges for parameters to be biased in favor of acceptable designs (Lewis 2008: 22).

Other than a few such minor limitations built in the mapping, there is no strong constraint handling prevention or correction mechanisms in Gráphagos. Mutations are not conditional; they are not guided by visual design rules. There are no built-in preferences concerning positions of the elements, or color harmony: objects can completely bleed out of the canvas, and every ‘ugly’ color combination can arise.[13] Gráphagos keeps an ‘open mind’ about everything and relies on selection.



```
Len Substitution: 1
Loc Substitution: 28
Len Insertion: 3
Loc Insertion: 30
tcccctacttgtgaattcgctgccaataccagacagt
tcccctacttgtgaattcgctgccaataacgatagacagt
Len Substitution: 1
Loc Substitution: 2
Len Insertion: 3
Loc Insertion: 6
tcgtgaccagcagga
tcttgatctccagcagga
Len Deletion: 3
Loc Deletion: 9
Len Substitution: 1
Loc Substitution: 0
Len Substitution: 0
Loc Substitution: 2
tgtgataaccaatta
cgtgataactta
Len Insertion: 0
Loc Insertion: 24
Len Insertion: 0
Loc Insertion: 6
tcccctacttgtgaattcgctgccaataccagacagt
tcccctacttgtgaattcgctgccaataccagacagt
```

Figure 18. A sample snapshot, the chromosomes of posters mutated in Gráphagos, with the list of mutations followed by the before/after states of the chromosome (Len: length of; Loc: location of).

Gráphagos makes use of three types of mutations: substitution, insertion and deletion. The numbers and the lengths of the mutations are randomly determined according to the Poisson distribution with different λ values. The locations are also

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[13] Lewis reports that in many of the expression-based image evolution systems, specific color (sub)spaces – saturated tones, predetermined groups of selected colors, etc. – are favored in the palette representations. This restricts the user from freely exploring color combinations. (2002: 22)

random within the length of the chromosome. The letters substituted or added are randomly picked, by a probability of one out of four (A, T, C or G), so there is absolutely no implied direction in the mutations, as it should be in a true Darwinian evolution. This is essential to the main aim of this project, namely to show that good graphic design can arise from a blind process of replication and mutation.

In nature, because the genetic code is read in triplets, the insertion or deletion of one or two base pairs causes shifts in the reading frame.[14] These are called *frameshift mutations* and result in "radically different – and usually nonfunctional – gene products" (Snustad 20). The deletion and insertion mutations in Gráphagos are adjusted in a way that they delete or insert codons (triplets), not letters, with respect to the reading frame (not in the middle of an existing codon but at the end of it) in order to prevent frameshift mutations. Though exploited successfully by some viruses to store different messages in different frame readings (Dawkins 2003: 117), it is highly unlikely that frameshifts will lead to anything interesting in Gráphagos. This is another adjustment preferred to sustain a healthy interaction with the user.

The existence of insertion and deletion mutations causes that the chromosome length is a variable in evolution, allowing a range of solutions between very simple and very complex designs.

Mutation rates in general randomly vary at every regeneration in Gráphagos, causing some generations to have more variety than others (see Appendix), just like environmental factors have stochastic effects on mutation rates in nature (Futuyma 1998: 26). The frequencies for each type of mutation can be experimented with for an optimal user experience (Sims 1991).

Bentley notes (1999: 45) that crossover mutations (which recombine parts of the chromosomes from two parents) are not employed in most evolutionary art systems in order not to have *convergence*. Accordingly, in Gráphagos, there is no crossover in order to preserve the diversity of the solutions.

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[14] Consider an imaginary person who can only read by triplets. He will not have a problem in understanding the message "hispenwasred". Now suppose that the 'i' is deleted and he is given the message "hspenwasred". He will not be able to understand a thing because he will perceive it as "hsp, enw, asr, ed".

3.5.3. Selection and Regeneration

As Nowak (2006: 30) puts, evolution is a trajectory through sequence space and it needs an efficient guide. In nature, the guide is natural selection. In Gráphagos, it is the human user evaluating the mutants, because "it is difficult to automatically measure the aesthetic visual success of simulated objects or images" (Sims 1991).

The evaluation consists of selecting the best graphagos by clicking on them with the mouse. There is no negative selection, i.e. choosing which individuals will 'die'. The next generation will consist of the mutated versions of the selected graphagos. Gráphagos adopts an *elitist* strategy for regeneration: the selected individuals are directly copied to the next generation and only the remaining members are replaced with new mutants. Elitism is preferred to guarantee that the best solutions that evolved with considerable effort are not lost (Reeves & Rowe 2003: 45).

In the examples shown here, generations consist of 10 individuals. Sims also recommends small generation sizes (20–40) for two reasons: (1) where visual aesthetics are involved, there are many interesting local optima instead of a single global optimum, and (2) the program should maintain a healthy interaction with the human user who has a limited capacity to compare and evaluate. For the same reasons, he prefers a reproduction process based on only one or two individuals. (1991)

In Gráphagos, no practical limit exists for the number of individuals that the user can select. However, for the reasons that Sims expresses, choosing only one individual in each generation is recommended. (Sims mentions selecting two because he includes crossover in his systems; there is no crossover in Gráphagos.) This way, the next generation will consist of the mutated versions of the one individual that the user selects.

Choosing more than one graphago will create separate, non-interbreeding groups of offspring. Since there are always multiple good solutions in a design project (i.e. the fitness function is *multimodal*), this is a valid method for exploring those different solutions in parallel (Bentley 1999: 33). Nevertheless, because an elitist strategy is adopted and the generation size is constant, choosing a small number of elites will allow more space in the population for the new mutants to fill.[15]

3.5.4. Interface

Since the user interface screen of Gráphagos is an arena where all kinds of different designs with every imaginable color combination compete for attention, the interface design is very neutral. The background is gray, standing at an equal distance to dark and light graphagos. The visual fitness marks are also a shade of gray, and they appear as lines under the thumbnails – instead of frames around them, as in many other similar softwares – in order to minimize the effect they have on how the graphagos are perceived by the user.

A bitmap font, the 8 px Bavaria Extended by Semplice Pixelfonts, is used for the interface of Gráphagos. In contrast with the vectorized outline fonts, bitmap fonts are designed pixel by pixel to look sharp at a specific size on screen and should be used in even multiples of that size to retain their crispness (Lupton 2004: 57). Bavaria Extended is used at an 8 px size for the buttons and the instructions on the Gráphagos screen, and at an 16 px size for the genome displayed on the individual display screen.

3.6. Implications

3.6.1. What A Designer Is: A Model for Creativity

As an experiment, a variety of people used Gráphagos for several imaginary design projects such as book covers or event posters. These projects all made use of the same pools; the only difference in the input was the textual content.

The difference between designs evolved by designers and by other people is worth examining (see Appendix). Designers using Gráphagos are able to arrive at ‘final’ solutions in the sense that these solutions can match a normal graphic design output in quality. The graphagos evolved by lay people do not look like they are designed; they

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[15] The option of branching into different *islands* (populations on separate spaces – screens – that do not interact) is a possible solution for this space problem.

miss a lot of the attributes of what designers consider ‘good’ design. The most salient difference is that lay people tend to fall for a single beautiful photograph and ignore typography.[16] The absence of balance and hierarchy in these graphagos is also striking.

Since both groups joined in the design process only in selection, the results suggest that the difference between designers and lay people lies not so much in their technical ability to create beautiful images as in their ability to choose between images of varying quality. This explains why mastering design software (Adobe Photoshop, Adobe Illustrator, etc.) is not sufficient to become a good designer. As Gatherer phrases, “[t]he function of the designer is not to produce novel memes in the sense of increasing the memetic mutation and recombination rate, (…) but to be the first step in the application of selective pressure to those ideas”. (1999: 98)

In this context, a designer is someone who can distinguish between good and bad design moves, and design education is not about learning technique but learning to make decisions. In memetic terms, design education amounts to an installation of the meme complexes that will act as an environment generating the right selection pressures on the creative processes. The Gestalt principles such as unity, symmetry or hierarchy are among the built-in selective criteria in a designer’s mind (Campbell 1960: 389). The selective memes also come from seeing other people’s work (Salingaros & Mikiten 2002). ‘Looking around’ is an important part of a designer’s job, because it is a way of

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[16] I had complaints from the users that, in the latest version of Gráphagos, they could not get interesting and complex designs like the ones they did in the early versions. When I checked their evolved results, I observed that they really tended to stop evolving at the early stages (at around the 10th generation) with designs consisting of just a photograph and the text elements on top of it. Further conversations with the users helped identify the problem: the difference with the favored early versions was the addition of image pools in the new versions, and photographs are so strong attractors that whenever they arose, they caused convergence. The ‘interesting’, complex designs with overlapping colorful shapes are still fully available in the design space of Gráphagos, but photographs subtly attract users away from those designs; they are the ones making that choice even if they complain about it afterwards. This creates the illusion that the design space has shrunk in the new versions whereas the opposite is the case. This fact about the power of photography is echoed in designers’ choice of using large photographs without sophisticated graphics and typography in mainstream advertisements.

gathering memes that will create the selective environment as well as contribute directly to future designs.[17]

Distinguished graphic designer Paula Scher's insightful description of her way of designing provides an illustration for the memetic theory of graphic design:

> I have a pile of stuff in my brain, a pile of stuff from all the books I've read and all the movies I've seen. Every piece of artwork I've ever looked at. Every conversation that's inspired me, every piece of street art I've seen along the way. Anything I've purchased, rejected, loved, hated. It's all in there. It's all on one side of the brain. And on the other side of the brain is a specific brief that comes from my understanding of the project and says, okay, this solution is made up of A, B, C, and D. And if you pull the handle on the slot machine, they sort of run around in a circle and what you hope is that those three cherries line up, and the cash comes out. (…) I allow the subconscious part of my brain to work. That's the accumulation of my whole life. That is what's going on in the other side of my brain, trying to align with this very logical brief. And I'm allowing that to flow freely, so that the cherries can line up in the slot machine. (Millman 2007: 45-46)

Accordingly, the fact that some people are 'better' designers has a purely memetic explanation in addition to the genetic explanations concerning brain structure: "The more of the meme pool we can download, the more material our minds have to work on" (Gatherer 1999: 98). This view puts emphasis on the cultural milieu to which the individual is exposed, including the individual's extra efforts to get her/himself exposed to more than her/his natural habitat – one of the ways in which internet transforms the design scene in our day. Campbell also argues that designers may differ in the number and range of *variations* that they can produce, and in the number and types of the *selection criteria* that they can maintain (1960: 391–2).

This paradigm has implications concerning design education, cutting the magical 'insight' and the legendary 'creative genius' down to size:

> While "insight" is accepted as a phenomenal counterpart of the successful completion of a perhaps unconscious blind-variation cycle, its status as an explanatory concept is rejected, especially as it connotes "direct" ways of knowing. Furthermore, when publicized as a part of an ideology of creativity, it can reduce creativity through giving students a feeling that they lack an important gift possessed by some others, a feeling which inhibits creative effort and increases dependence upon authority. (Campbell 1960: 390)

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[17] Langrish (1999) uses the term *selecteme* for memes that create selection pressures.

The role of the designer is redefined here as an agent contributing in a supra-individual and cumulative process, who has every right to be influenced and to build upon existing solutions (Michl 2002). This role is not a passive one, however, as the model places great importance upon internalized selective criteria (Campbell 1960: 389).

Figure 19. Vocal autostimulation. (Dennett 1991: 196)

Where does the use of computers – or sketching in general – stand in this framework? Dennett (1991: 195–6) talks about *autostimulation* in *Consciousness Explained*: he explains that talking to oneself, for instance, may well be a required tool of stimulating one’s own brain.

> Suppose (…) that although the right information for some purpose is already in the brain, it is in the hands of the wrong specialist; the subsystem in the brain that needs the information cannot obtain it directly from the specialist — because [biological] evolution has simply not got around to providing such a “wire.” Provoking the specialist to “broadcast” the information into the environment, however, and then relying on an existing pair of ears (and an auditory system) to pick it up, would be a way of building a “virtual wire” between the relevant subsystems

According to this explanation, graphic designers constantly stimulate their own brains as they sketch on paper or on a computer. This visual feedback loop causes the designer and the computer screen (or the sketch book) to merge and become a functional unit of evolutionary information processing. The *found objects* (photographs, fonts, etc.) that are included in this system combine with the memes that were already present in the designer’s brain to create candidate designs. In addition to mutations occuring in the designer’s brain, technical accidents or random changes made without thinking in the sketch contribute to the variation that evolution needs. As ‘bad’ variations – in the brain or in the physical sketch – are eliminated by the selection pressures caused by the memetic environment in the designer’s brain, the final design product emerges. The designer may be said to collaborate with her/himself, constantly modifying her/his own previous solutions (Michl 2002), as the solutions replicate back and forth between the brain and the sketching medium.

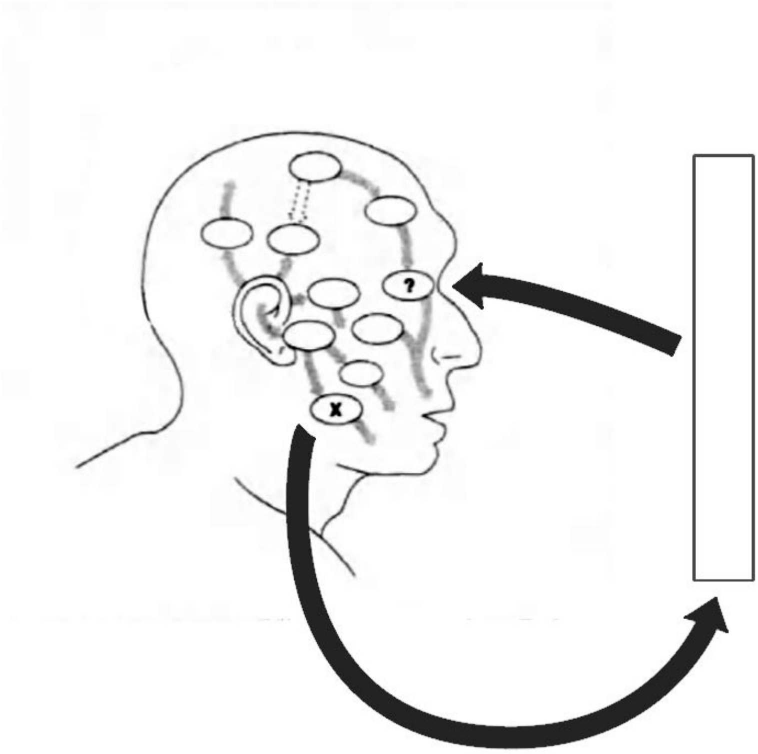

Figure 20. Visual autostimulation. (Based on Dennett 1991: 196)

In short, a graphic designer and the external device (computer, sketch book, etc.) may be working as an evolutionary system where memes replicate, mutate and get selected – mostly unconsciously – with respect to the meme complexes coming from design education and from exposure to other visual designs. Even though Gráphagos currently relies on humans to do the selection, it provides a demonstration of the fact that good graphic design can emerge when *random* mutations are selected and accumulated.

3.6.2. Gráphagos As A Design Tool

3.6.2.1. Who and Why

Gráphagos, as a program, can be practically applied to evolve event posters, flyers, book covers, product package graphics, etc. The first reaction of graphic designers seeing Gráphagos is the fear of losing their jobs. Although the program gives the impression that it can substitute for designers, it needs a person to select ‘good’ mutants and such an individual should be able to distinguish good mutations from bad ones – and this is what design education is all about.

So why would one prefer to use Gráphagos for real design work? According to Bentley,

> Evolutionary design systems are advanced software tools which are intended to be used by people, not to replace people. They are the latest in a number of computer software advances created to improve the productivity, quality, speed and reduce the expense of designing. (1999: 1)

First of all, Gráphagos can be said to speed up the design process or help overcome “*design fixation* or limitations of conventional wisdom” (Bentley 1999: 2) for designers as it can save the trouble of trying to derive original layouts as well as eccentric design ideas. Because the mutations are completely random, Gráphagos basically offers the user really ‘crazy’ ideas to choose from. What the software does for a designer is similar to “what Gregory calls Potential Intelligence – in the creation of Smart Moves (or what Gregory calls Kinetic Intelligence)”.

> Gregory observes that a pair of scissors, as a well-designed artifact, is not just a result of intelligence, but an endower of intelligence (external potential intelligence), in a very straightforward and intuitive sense: when you give someone a pair of scissors, you enhance their potential to arrive more safely and swiftly at Smart Moves (Dennett 1995: 377).

Of course, once the designer gets an original idea for a design, s/he may choose not to wait for the evolution and to finish the job her/himself by doing the fine adjustments in regular design software.

On the other hand, Gráphagos can help people who do know about design but cannot use graphic design programs for some reason. The program gives the user a lot of indirect control over the creation of design products while “the user is not required to understand the underlying creation process involved” (Sims 1991). This prospect is the opposite of the situation in which people master design software (Adobe Photoshop, Adobe Illustrator, etc.) without any design education.

Gráphagos also can enable an original way to do collective graphic design by having a voting system for selection. This can be used by groups of lay people as well as groups of designers. Application of voting among specific profiles of people (housewives, college students, etc.) can offer insight about what they generally prefer to see in graphic design products.

“The signature or ‘style’ of a given evolutionary design system very frequently seems stronger than the differences that might result from different users.” The signature of the program usually is the product of certain mathematical expressions or techniques to generate the images (Lewis 2008: 22). Since Gráphagos does not use expression-based generation techniques or limit the design space with constraint handling rules, the signature problem is not as evident as in many other image evolution programs. Instead, different styles of the different human users can find their expression in Gráphagos.

3.6.2.2. A Real Project: *Yüreklendirme Konseri*

Prof. Kemal İnan at Sabancı University is an ‘amateur’ violinist and performed, for the first time in his life, at Cemal Reşit Rey Concert Hall on May 15, 2010, along with other amateur and professional musicians. Prof. İnan wanted me to make use of Gráphagos in creating the poster for the event titled ‘*Yüreklendirme Konseri*’ (‘Heartening Concert’). I put together a pool with related images and kept some of the unrelated ones from the generic pools for reasons mentioned in section 3.3. Some of the results are shown in Figure 21.

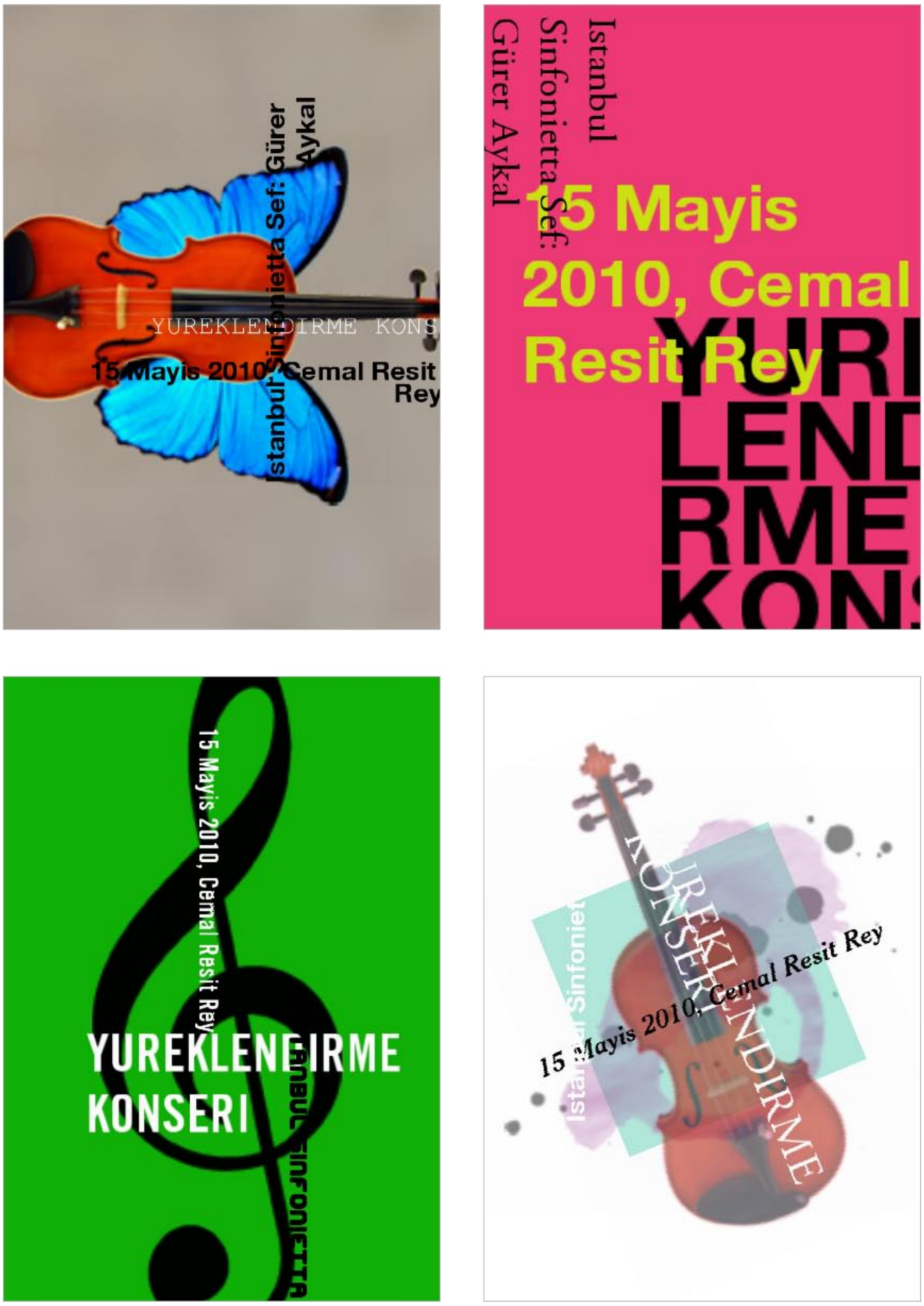

Figure 21. Results from Gráphagos for the poster of *Yüreklendirme Konseri* (‘Heartening Concert’).

The design at the bottom right is used as a printed poster after some retouching. (See Appendix for its final version and its evolutionary history.) After this experience, I, as a designer, can safely say that Gráphagos is helpful as a design tool, with its ability to offer different styles in short time periods as well as ‘creative’ semantic relationships (e.g. the winged violin). Because it is completely unbiased unlike a human designer, it works in a mind-opening way, arming the designer with the minds of other designers; most of the results shown above are designs that I would never arrive at on my own, because of my predispositions.

3.6.2.3. User-friendly Version for Practical Use

Gráphagos is mainly an exploration of a model for human creativity and remains concentrated on the theoretical framework of evolutionary theories of mind. However, the fact that it turned out to be a practical software that offers a new way of ‘making’ graphic design creates a different, commercial framework as a by-product. The highly commercial nature of graphic design itself also strengthens this framework.

Naturally, these two frameworks lead to quite different briefs. The theoretical perspective requires that the decisions about the structure of the software are made strictly with reference to the principles of evolution, whereas the commercial framework asks for user-oriented adjustments – compromises according to the former. This tension continues to bedevil the processes of designing and presenting Gráphagos.

Another version for practical/commercial application can always be developed, with features such as an ‘undo’ option, user interface controls for variables like mutation rates/types, built-in constraints for mutations according to rules of color harmony or readability, or an intervention mechanism for the user to directly manipulate the evolving design whenever necessary.[18]

These options are not included in the current version for several reasons. First, their existence would drive the model away from a purely Darwinian evolution, thus revoking its possible theoretical implications. Moreover, imposing constraints according to what we ‘know’ about design would diminish the richness of the design space currently navigated by Gráphagos.

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[18] The level of epistasis in Gráphagos may be a drawback in implementing a manual refinement tool.

3.7. Future Work

Gráphagos records the evolutionary histories in the purely textual format of sequences. This vast data collection can be subject to further computational analysis. Here, another benefit emerges from the fact that the genetic alphabet of Gráphagos is the same as the biological alphabet: the sequence data from Gráphagos can be directly analyzed by existing bioinformatics tools.

With a wide enough database of evolutionary histories, the analysis may reveal patterns of sequences that are universally favored by human selectors. The correspondent drawing functions will be elements that people like to see in graphic design. This may well be a step towards a *population memetics of visuality*.

This research may be conducted with specific target groups such as college students or middle-aged housewives to deduce their idiosyncratic preferences; “graphic approaches used on a Frank Sinatra recording would be totally inappropriate for the audience for a heavy metal rock recording” (Meggs 1992: 4).

The automatization of the selection process is rightfully one of the major challenges in the field of evolutionary art and design. Lewis reports that various techniques are being used to achieve automated selection, from static fitness functions to neural networks. Some researchers propose using gaze data or physiological data (measuring emotional reactions) as indicators of fitness. Others suggest mining the data from selections made by humans to construct a selector model. (2008: 25) Bentley speaks of a selection system operating by comparing evolving designs with a database of various good designs (1999: 58).

I predict that modeling selection in visual design should be easier than modeling selection in systems that evolve abstract images because design products, in contrast with ‘artworks’, need to have particular functions and satisfy predetermined criteria by definition. These characteristics of design give us more definable fitness functions and selection criteria to model. Methods of negative selection (killing ‘bad’ individuals rather than trying to choose the ‘good’ ones) may prove useful in evolving graphic design. Agent-based modeling can be applied to the selection problem; this task can be carried out as a project in collaboration with computer scientists.

CHAPTER 4. CONCLUSION

Evolution is a substrate-neutral algorithm – with three conditions: replication, variation and selection – that creates design as its output. In nature, genes are replicated, varied and selected, and the algorithm generates adaptation within an environment. The memetic theory posits that elements of human culture are also subject to the algorithm of evolution as the memes that code for them are replicated, varied and selected. Some scientists and philosophers suggest that the creative process of the designer can be explained as an evolutionary process within the brain where random variations are unconsciously selected in milliseconds.

Digital evolutionary algorithms are being used to create design and to solve optimization problems. Many researchers experimented with evolving abstract images, although graphic design has been largely neglected in this field. It has the potential to be a very fruitful area of research and application for evolutionary algorithms because graphic design products are functional as opposed to abstract images.

Gráphagos is an evolutionary approach to visual design, based on replication, random variation and selection. It is primarily designed as a model for the creative process taking place in the system consisting of the graphic designer and the sketching medium. The famous quote by physicist Richard Feynman expresses the motivation behind this project: “What I cannot build, I cannot understand.”

The program uses genetic algorithms to randomly mutate and replicate the designs according to a human user’s evaluation. The project has a useful by-product: independently from its relevance to the theoretical issues in question, Gráphagos offers a new tool for making graphic design. It may also be used as a tool for gathering data about our visual preferences. Its first implications mentioned in Section 3.6 are in accord with the memetic theory of creativity.

Gráphagos provides a demonstration of how graphic design can emerge when random mutations are selected and accumulated. This may come across as condescending to some designers, but Gráphagos currently relies on designers to do the selection and to put the finishing touches. Even though modeling selection mechanisms is a plausible future project, creating a program that will substitute for a talented human designer is a long-distance goal. It is not an *impossible* goal, however, because “all our talents as designers, and our products, must emerge non-miraculously from the blind, mechanical processes of Darwinian mechanisms of one sort or another” (Dennett 1995: 135).

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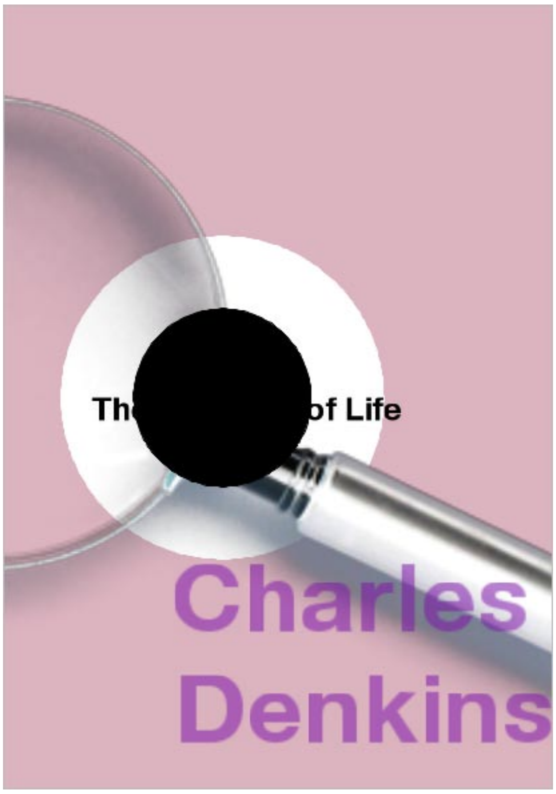
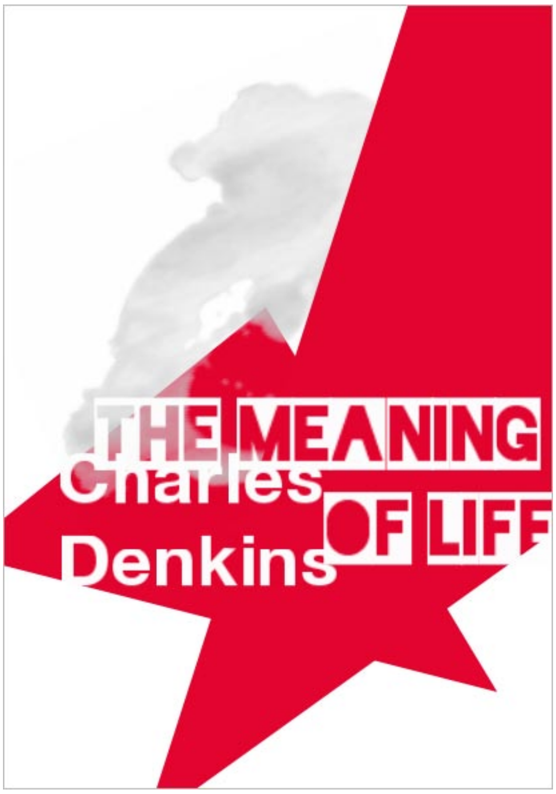
APPENDIX

Sample graphagos evolved with selection applied by designers.



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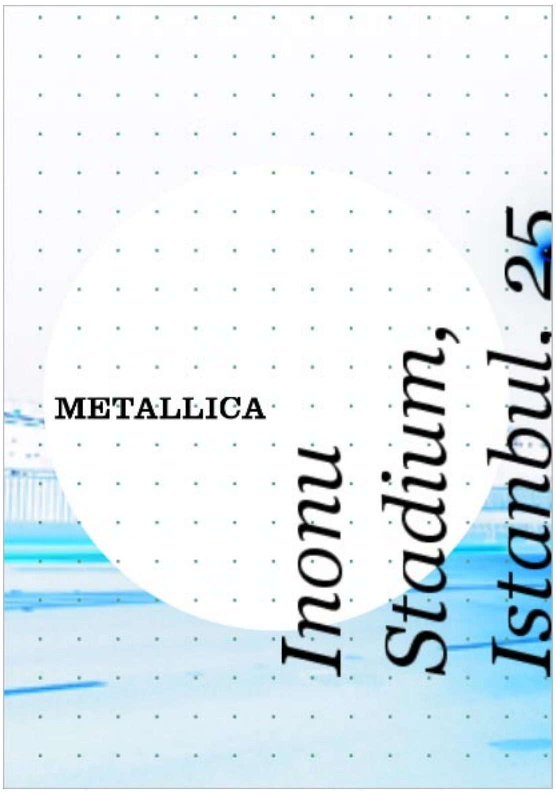
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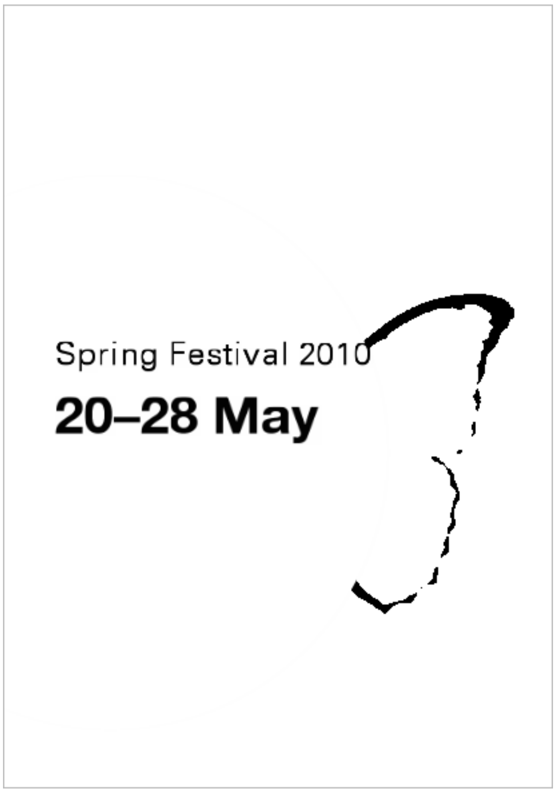
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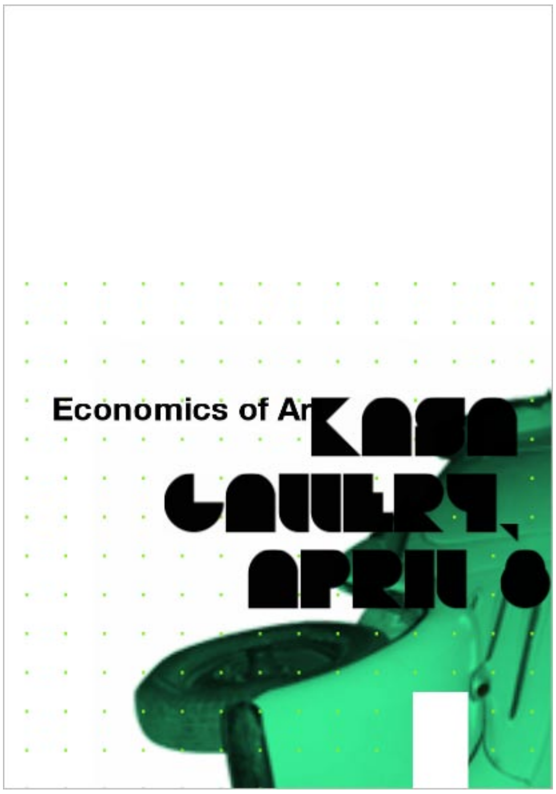
20–28 May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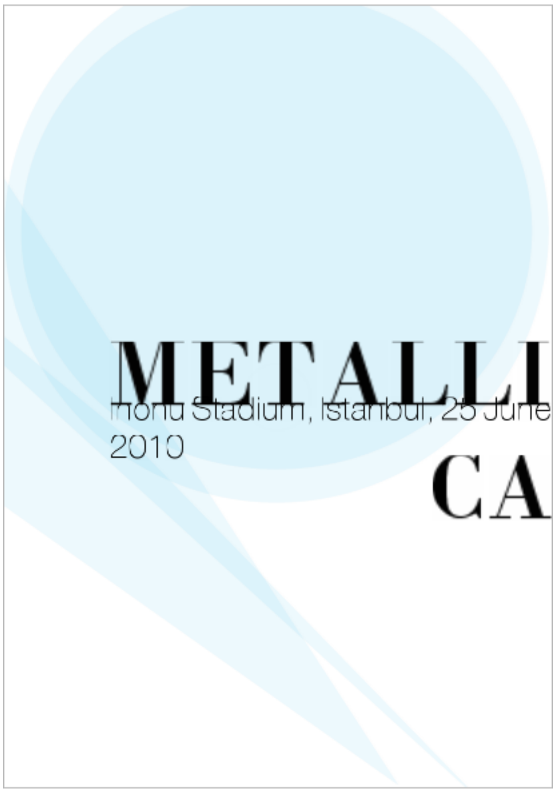
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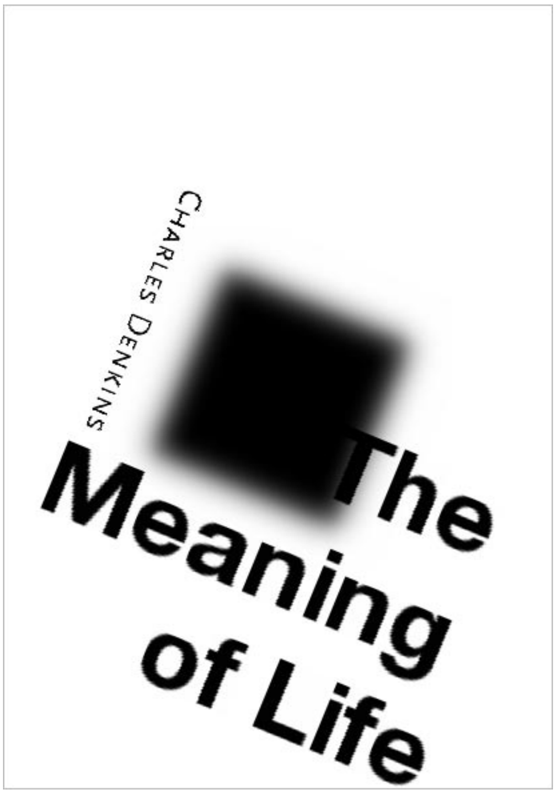
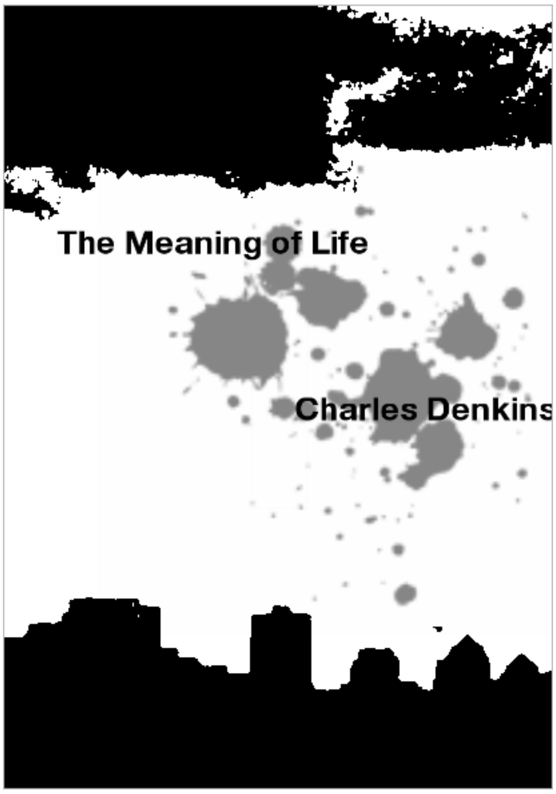
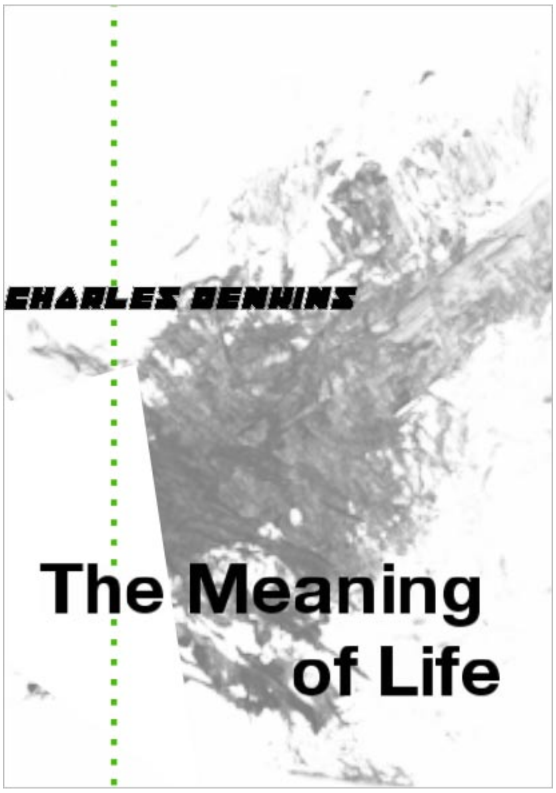
Sample graphagos evolved with selection applied by lay people.

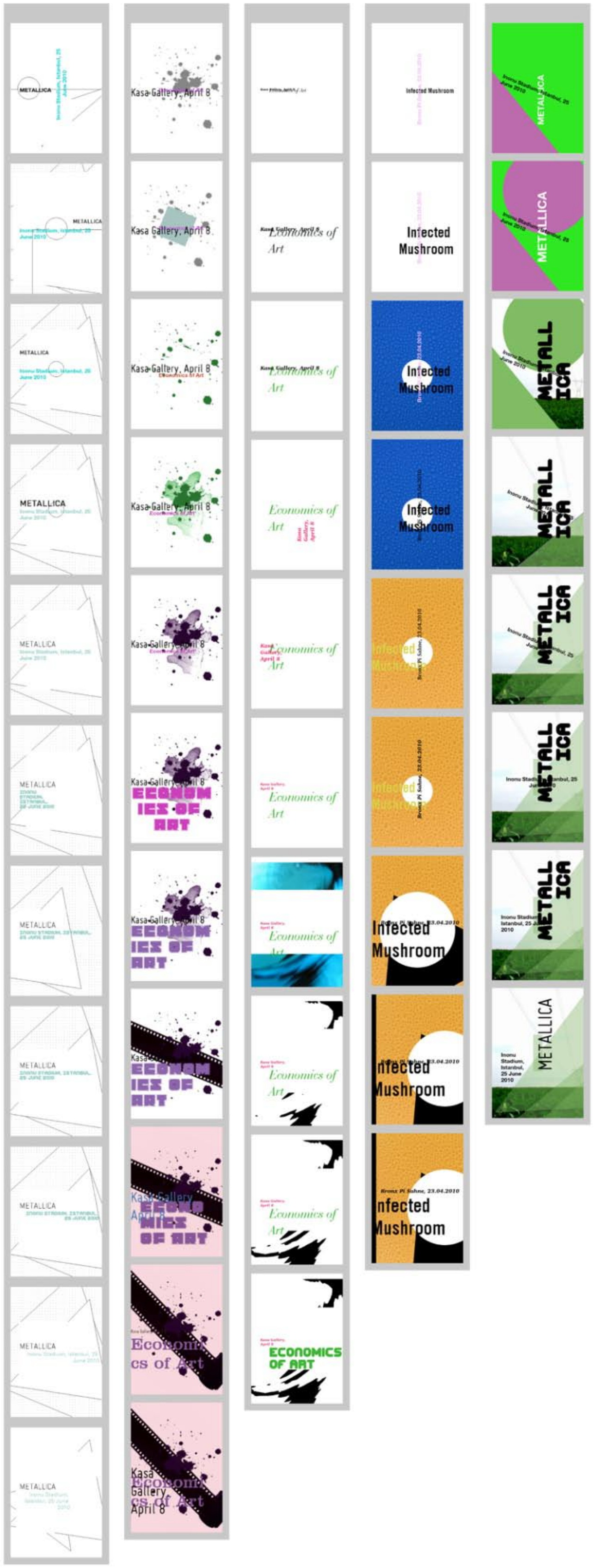
Some ‘successful’ graphagos evolved with selection applied by lay people.



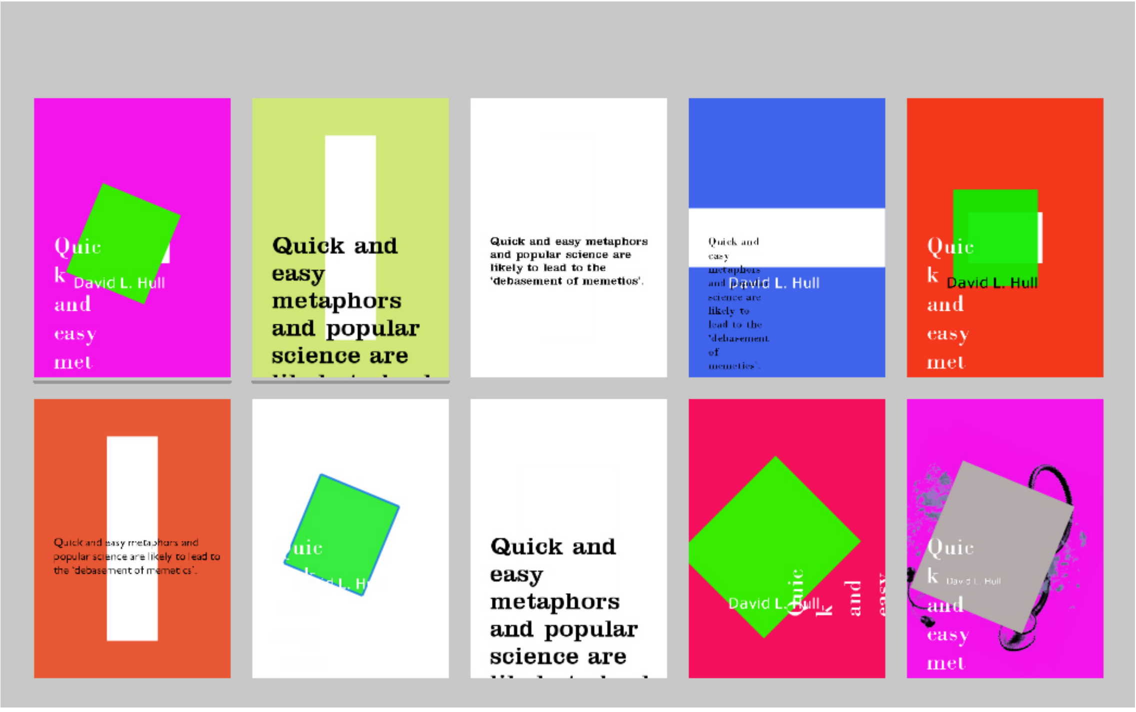


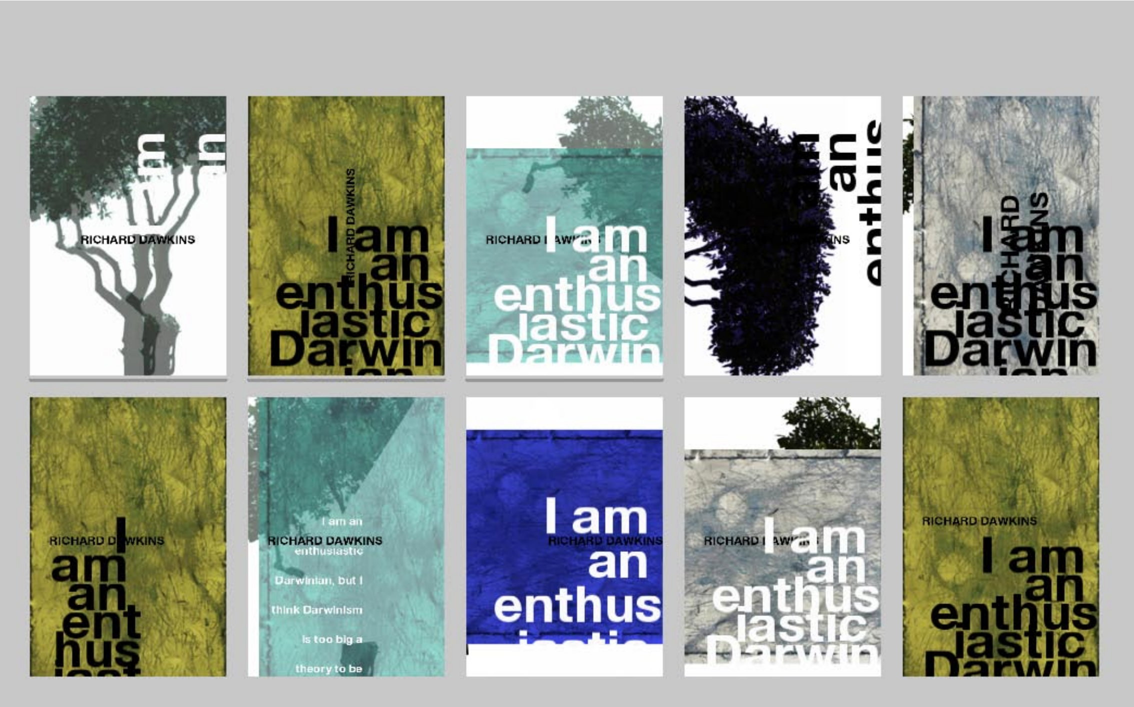


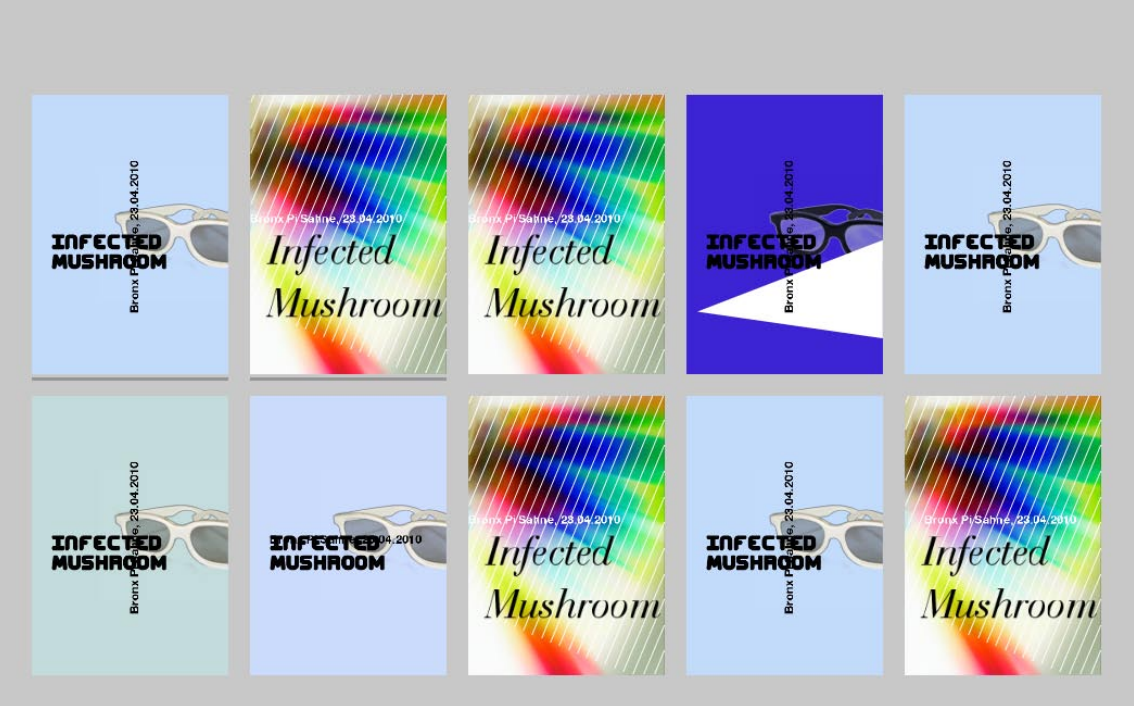
Sample evolutionary histories on Gráphagos.

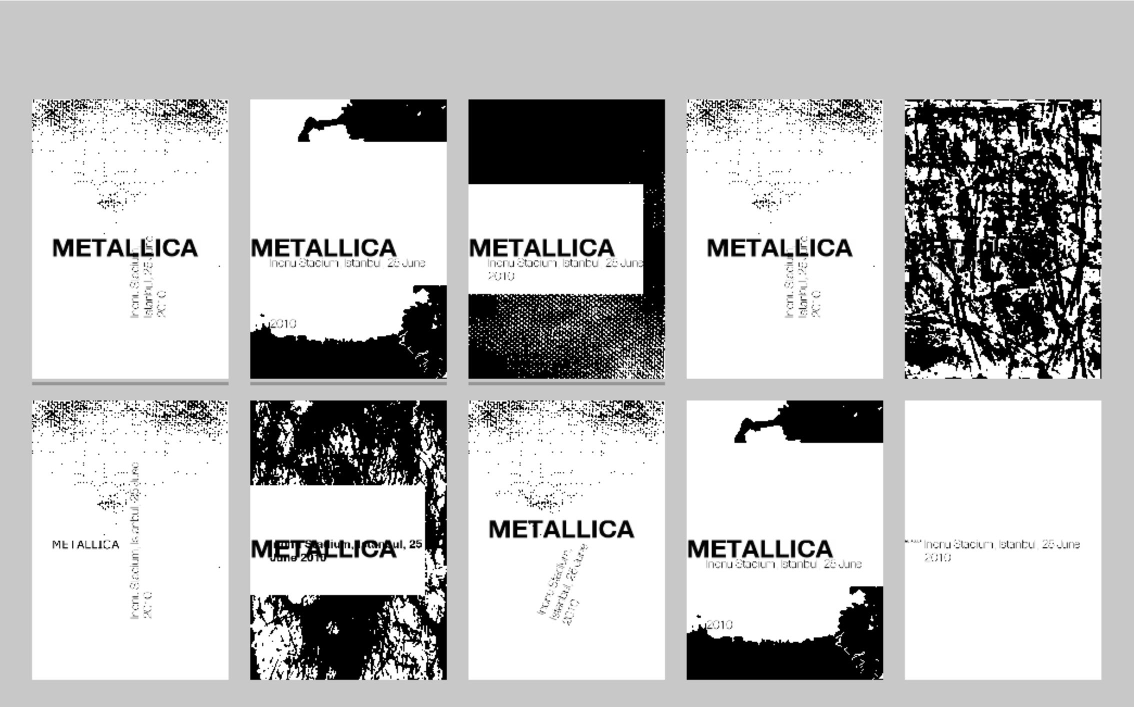


Sample generations with varying mutation rates.




RICHARD DAWKINS
I am an enthusiastic Darwinian, but I think Darwinism is too big a theory to be
I am an enthus iastic Darwin


INFECTED MUSHROOM
Bronx P/Sahne, 23.04.2010
Infected Mushroom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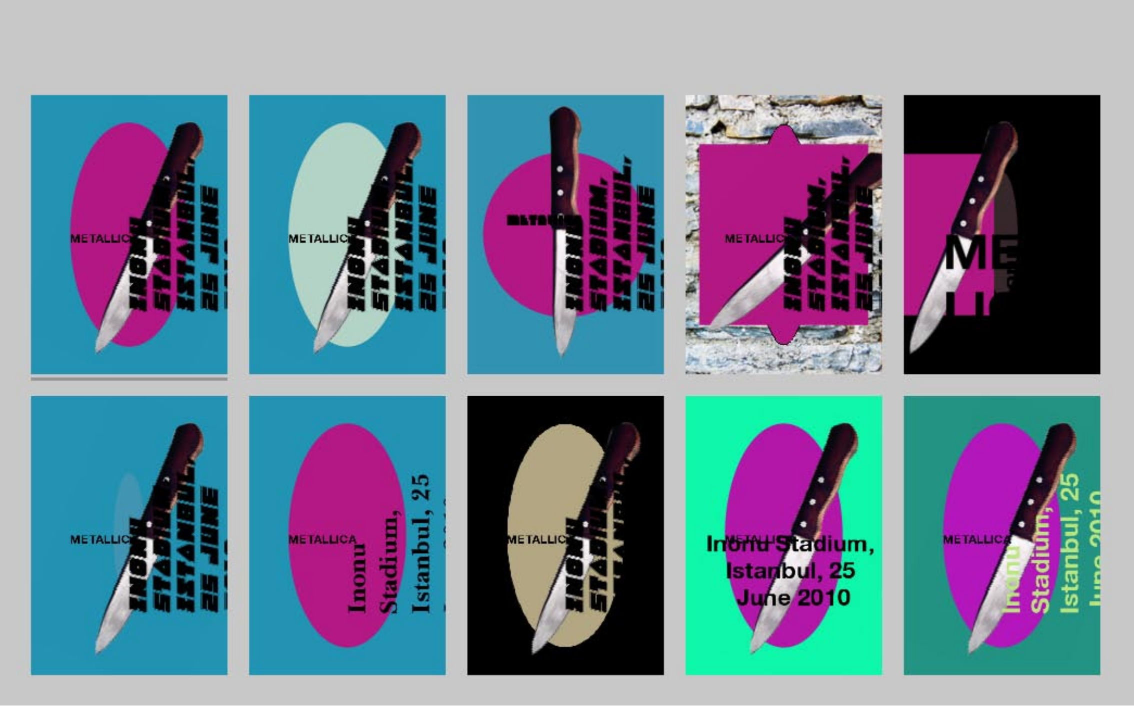
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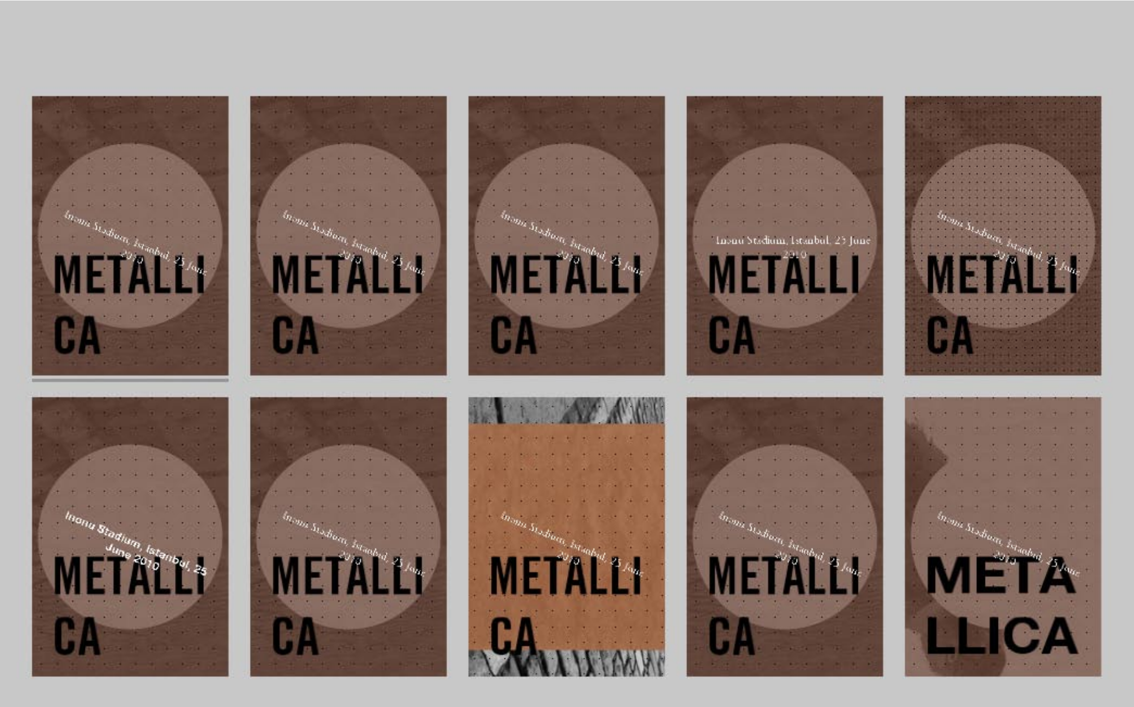
Inonu Stadium, Istanbul, 25 June 2010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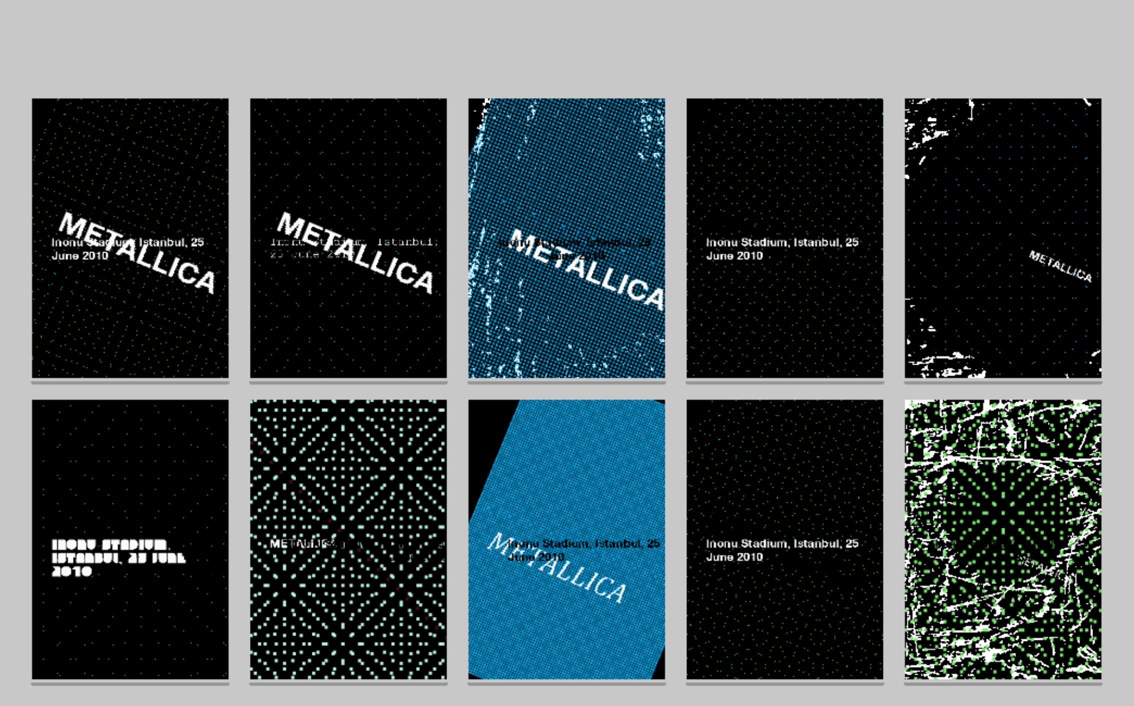
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INONU STADIUM, ISTANBUL, 25 JUNE 2010
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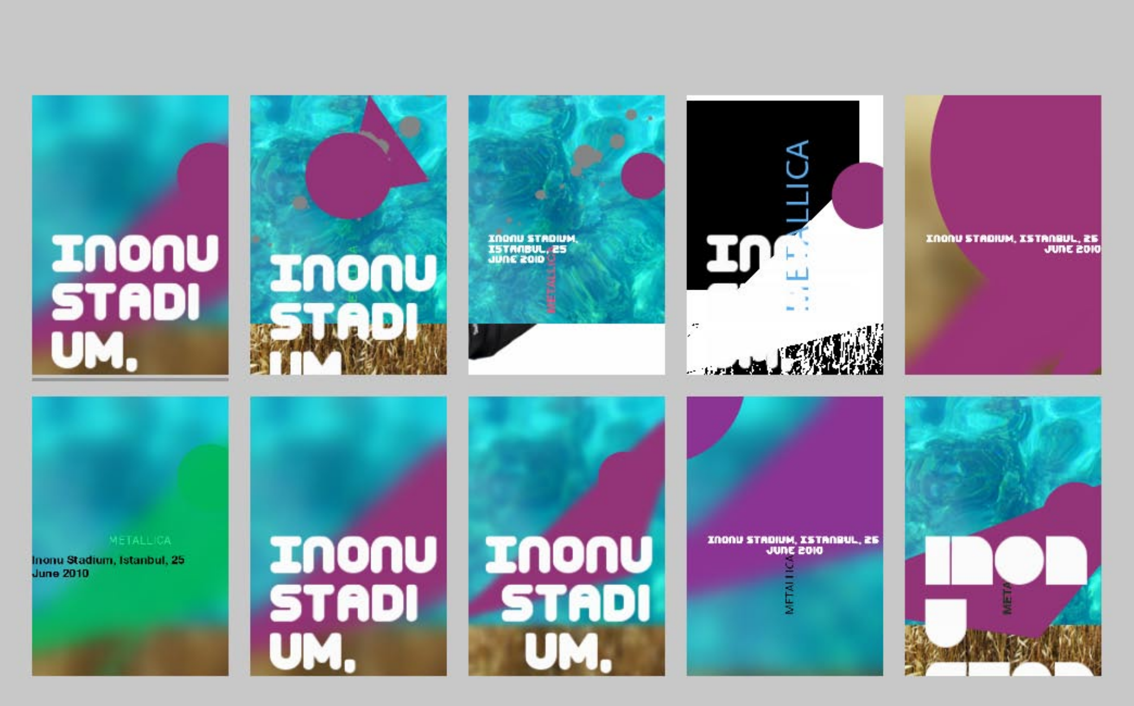
Inonu Stadium, Istanbul, 25 June 2010


RICH ARD DAWK INS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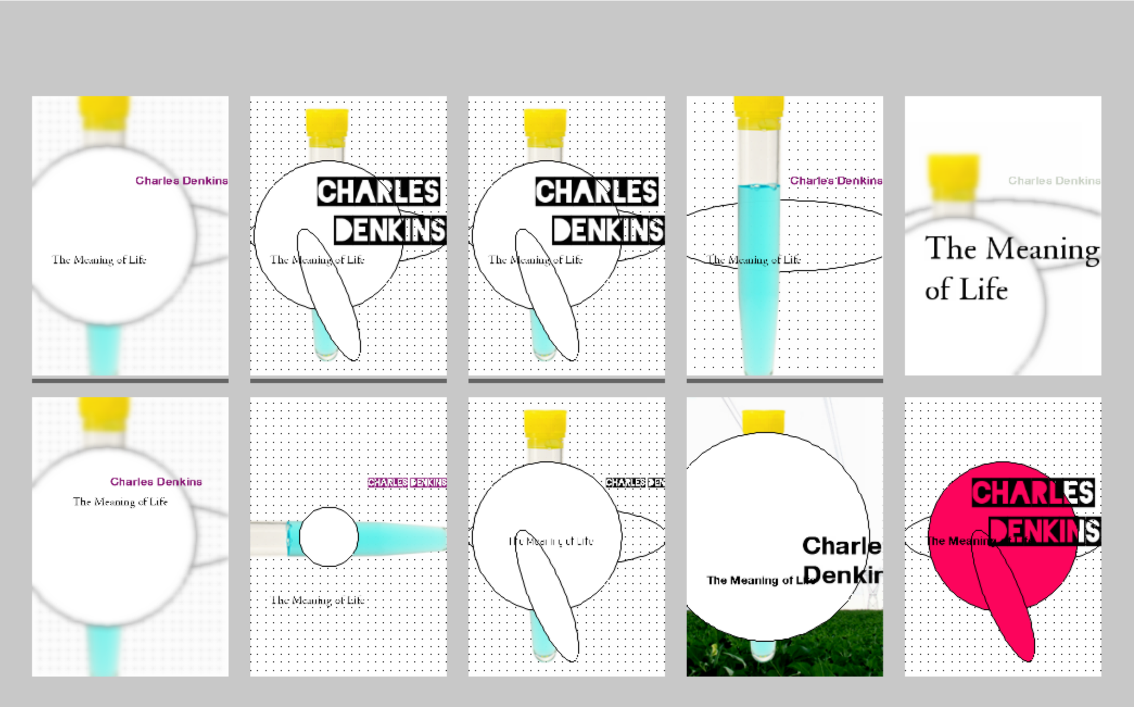
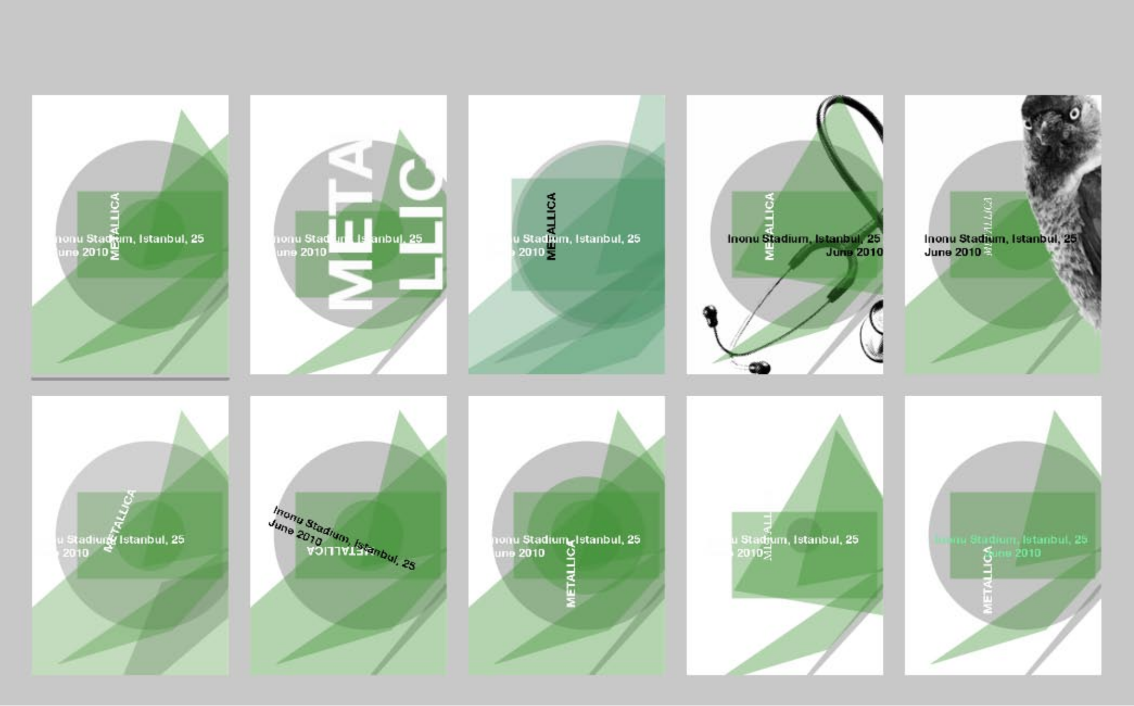
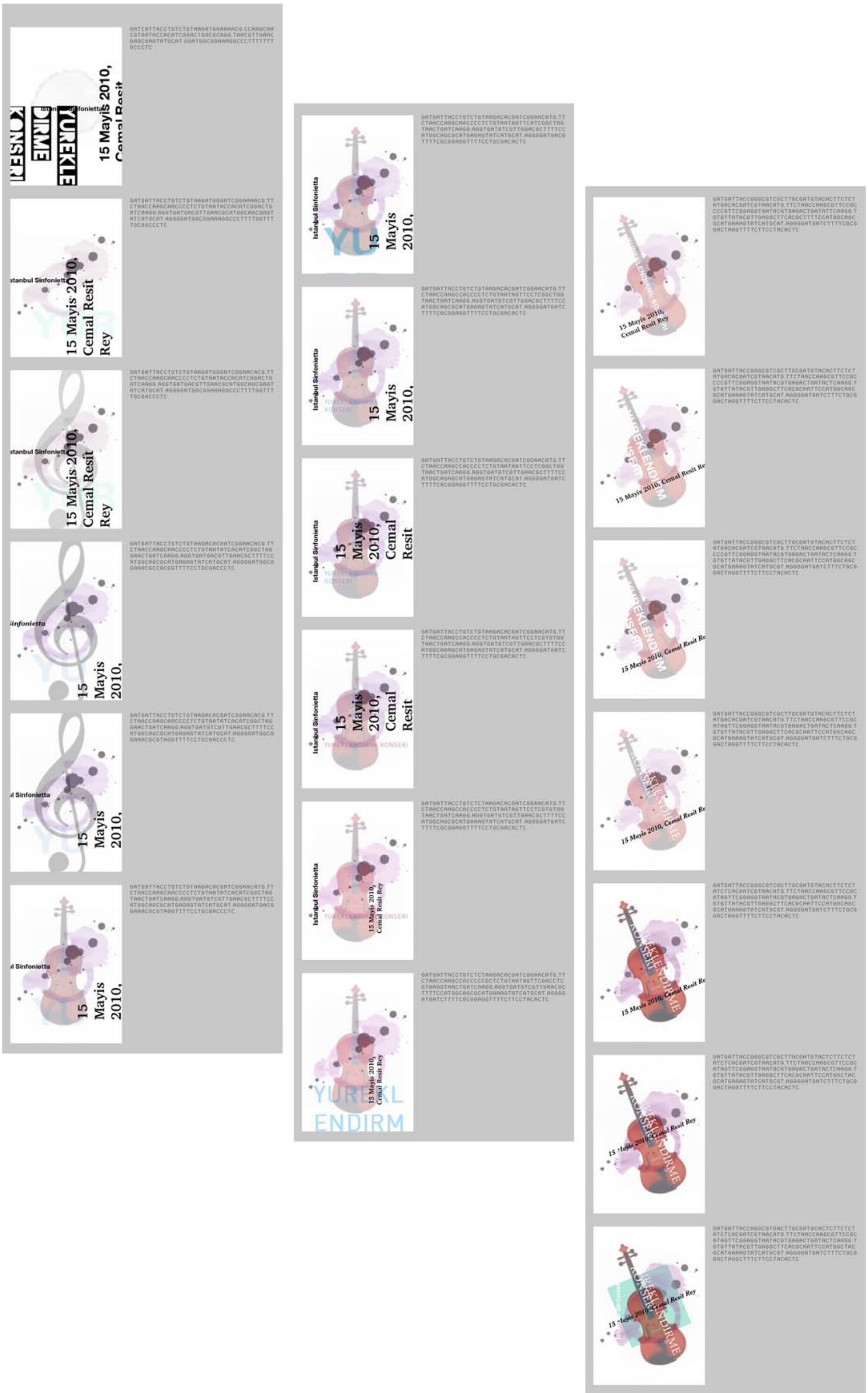

Charles Denkins
CHARLES DENKINS
The Meaning of Life


METALLICA
Inonu Stadium, Istanbul, 25 June 2010

Evolutionary history of the poster for *Yüreklendirme Konseri*.



The evolved poster for *Yüreklendirme Konseri*, its edited version and a photograph of the print in use.