23/4/2012

Evolutionary Art

And what it means to Art and Science | John Müller

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Introduction

Evolution and Art, two things not commonly referred together. Were they just thrown together by scientists to see what kind of fun things they could do or could they together be the next big thing in Art?

The 'Haags Gemeente Museum' had an exhibition in 2000 called 'Echt en Virtueel', included in this exhibition was a piece of interactive software which allowed visitors to evolve their own M.C. Escher drawing. Developed by A.E. Eiben, R. Nabuurs and I. Booij it was a piece of Evolutionary Art developed right here in the Netherlands, displayed in a museum known throughout the world for its Escher collection. [3] Knowing this, there must be something to this Evolutionary Art!

But what is Evolutionary Art? It starts off with a rather well known man named Charles Darwin. His theory of evolution is based upon the idea of natural selection. Given an environment that can host only a limited number of individual, and the basic instinct of individuals to reproduce, selection becomes inevitable if the population size is not to grow exponentially. Natural selection favors those individuals that compete for the given resources most effectively, in other words, those that are adapted or fit to the environmental conditions best. [1]

The idea to use Darwinian principles for automated problem solving was conceived as early as 1948 by Turing. By the 1960's the first computer experiment had been executed on "optimization through evolution and recombination". [1] Which eventually led us to modern day Evolutionary Computing.

But the idea to use an autonomous system to create art either in whole or part of it is much older. Generative Art, of which Evolutionary Art is a part, has been around even since the time of Wolfgang Amadeus Mozart. In his work "Musikalisches Würfelspiel" 1757 dice were used to select musical sequences from a numbered pool of previously composed phrases.

Evolutionary Art as we know it now has been around since Richard Dawkins book *The blind Watchmaker*, published in 1986, first mentioned the idea for a program which could evolve 'virtual creatures' or biomorphs. [2]

It uses evolutionary computing to create a drawing of all kinds of creatures after which the user indicates which he or she liked best and the program evolves a new set of creatures based on the choices of the user. The user could keep going until they found a biomorph to their liking.

Combining the fields of Evolutionary Computing and Art allows artists to explore things they never dreamed of. Giving them new ideas and new ways to create ideas.

In this paper we will give an overview of everything Evolutionary Art, we do this by asking the following questions: How does it work? What kind of Evolutionary Art is there? Who should you know in Evolutionary Art? Where can I find Evolutionary Art? What's next? By answering these questions this paper hopes to give some insight in to this special art form.

2 How does it work?

First I shall explain what an Evolutionary Algorithm (EA) or Genetic Algorithm (GA) is. These algorithms fall under the category 'generate and test'. Which means that to solve a certain problem a solution is generated and then tested to see how 'well' the solution solves the problem. They are stochastic and population based. Variety is provided by recombination and mutation, this to facilitate novelty in populations. Selection reduces diversity and works as a force to push to better quality. Fitness is the measure used to determine whether one individual in a population is better than another. The selection procedure for a new generation of a population can then select based on this fitness. Furthermore the crossover used to recombine individuals can use fitness to select two or more individuals for reproduction. [1] The genotype of an individual can be compared to the DNA of a living organism. It is the way the blueprint of organisms is encoded, it holds all the parameters of how many legs it should have, or how many eyes. In terms of an EA it thus holds the blueprint for individuals in the population. Borrowing the example from nature again, the phenotype is how an individual organism looks like. Organisms all share the same genotype, DNA, but we all look different because our parameters are different from each other. So every genotype has exactly one corresponding phenotype. In terms of an EA this means that the phenotypes are the different individuals in a population. EA's come in many different dialects, but all follow roughly these outlines.

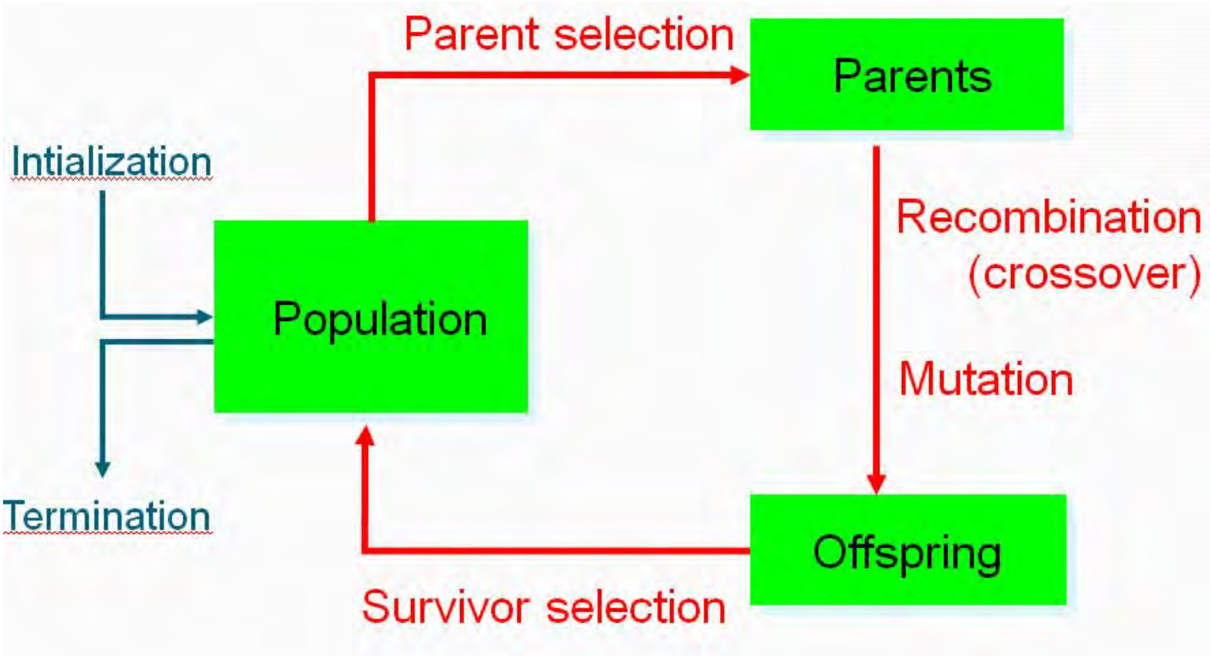


Figure 1: How does it work? From: Introduction to Evolutionary Computing, A.E. Eiben, J.E. Smith.

2.1Genetic Programming

One dialect was first described by one of the founders of Evolutionary Art, Karl Sims in 1991 in his paper Artificial Evolution for Computer Graphics. He proposed a dialect where instead of using bit strings as the way to represent the genotype of an individual, a mathematical expression could be used as the genotype. An expression like $abs(sin(s * 3 * \pi) + cos(t * 4 * \pi))/2$ can be represented as a tree graph structure, made up of mathematical functions and operators at internal nodes, and constants or variables at the leaves. [4] Crossover could now take place by randomly placing one tree in another, or cutting trees in parts and recombining these in to one new tree. Mutation was still a small change in the genotype. It could be changing a variable in a constant, inserting or deleting an internal operator or changing a node from one function to another. [4] Another change made to facilitate the making of art was to make the population size smaller then was normally used in Genetic Algorithms. Instead of using 100 to 1000 or more the population size would be between 20 and 40. Also instead of selecting a certain part of the population for reproduction only one or two parent(s) were to be selected from the population for reproduction. This was all done because the evaluation was done be human picking the pictures they liked best and therefore no global optimum exists, since this is different for every person who uses it. [5]

2.2 How this relates to Art.

The first pioneer in the field of Evolutionary Art First images were made with the bit string approach, where you had fixed number of parameters and fixed expression rules because of the inherent limitations of the bit string. There were solid boundaries on the set of possible phenotypes, and no possibility of a new parameter or new expression evolving from one generation to the next. More specifically, the N-dimensional genetic space will remain N-dimensional. [5] In terms of art, if we take drawing as an example, the most beautiful and diverse stick figures could be drawn, but stick figures they remained.

Karl Sims saw these limitations and came up with the Genetic Programming algorithm to get around them. To stay with our example he not only though how he could make the stick figures even better, but how could he make more than just stick figures.

2.3 Example of evolving an image.

We shall now give an example of how an image is evolved by using the GP algorithm described by Karl Sims in his paper Artificial Evolution for Computer Graphics. [5]

As described above a GP algorithm uses symbolic expressions as genotypes. To evolve the next generation of images the genotype needs to be mutated. Equations calculate the color for each pixel coordinate (x,y) in an image and these equations are evolved using a function set containing things like standard *multiplication* or *subtraction* or *minimum*, *maximum*, or *absolute value*. Or even vector transformations or image processing operations. Anything that you can come up with that you can make return values that are within the boundaries of accepted input for the image can be implemented. For example Boolean operations like *and*, *or* and *xor* can cause fractal-like grid patterns. And iterative function systems like *ifs* can generate fractal patterns and shapes.

To create the initial population for the user to choose from simple random expressions are generated by choosing random functions from the function set and then generating as many random arguments as that function requires. Arguments for these functions can be either scalars or vectors, and either constant values or images of values. These random functions then return images and the initial population is build.

This initial population is shown to the user and the user is asked to choose which images he or she likes best. The images selected by the user are then reproduced with mutations for each new generation and more complex images will evolve and hopefully be more and more to the liking of the user.

2.3.1 Mutation of symbolic expressions

For evolution to occur the symbolic expressions must be mutated. However it is always important to find a balance between very large mutations of the genotype that can take images in to unexpected directions that were not thought of before but may lead to images that are not at all desirable or small mutations that fine tune specific ideas in to hopefully the best possible image, but will not generate completely new directions.

A recursive mutation scheme is used to mutate expressions. It is important to remember that these expressions are tree structures and each node can be mutated. Each type of mutation occurs at different frequencies depending on the type of node:

1. Any node can mutate into a new random expression. This allows for large changes, and usually results in a fairly significant change in the image.
2. If the node is a scalar value, it can be adjusted by the addition of some random amount.
3. If the node is a vector, it can be adjusted by adding random amounts to each element.
4. If the node is a function, it can mutate into a different function. For example *(abs X)* might become *(cos X)*. If this mutation occurs, the arguments of the function are also adjusted if necessary to the correct number and types.
5. An expression can become the argument to a new random function. Other arguments are generated at random if necessary. For example *X* might become *(* X .3)*.
6. An argument to a function can jump out and become the new value for that node. For example *(* X .3)* might become *X*. This is the inverse of the previous type of mutation.
7. Finally, a node can become a copy of another node from the parent expression. For example *(+ (abs X) (* Y .6))* might become *(+ (abs (* Y .6)) (* Y .6))*. This causes effects similar to those caused by mating an expression with itself. It allows for sub-expressions to duplicate themselves within the overall expression.

Of course just as with the function set you can implement any kind of mutation scheme as long as it keeps the expressions valid.

To keep the expressions from growing towards very large and slow forms the frequencies of mutations that cause decreases in complexity should be slightly higher than the frequencies of mutations that increase complexity. Expressions should still grow larger, but this should be due to the selection of improvements.

To find the aforementioned balance of large and small mutations the frequencies of the mutations can be experimented with. For example the user could be asked after every generation if they want the next generation to be close in appearance to the current one or nothing like it at all. This way the user can indicate whether the image is close to an optimal (beautiful) solution. The overall frequency of mutation becomes smaller the larger the parent expression was. This is to maintain some stability of the images from one generation to the next.

It is important for these algorithms to keep the calculation times between generations from getting to large, to keep the interactive feel these programs give to the user. To make sure that these times don't get too large before a new generation is shown to the user, estimates of compute speeds for each function are saved and a new mutation is evaluated by summing these speeds to see if they stay within acceptable bounds. If the mutation is deemed to slow in advance a new random mutation is evaluated and this process is repeated until an acceptable one if found. This way the user never has to wait too long.

2.3.2 Crossover of symbolic expressions

In Sims article he describes two ways to mate two parents and make a new single individual.

For the first method the two parents need be close to each other in terms of structure. The basic idea is that you traverse the two trees and when you find a difference between them you give each tree equal opportunity to copy its part in to the new tree. For example:

Parent 1: *(* (abs X) (mod X Y))*

Parent 2: *(* (/ Y X) (* X -.7))*

Child 1: (* (abs X) (mod X Y))

Child 2: (* (abs X) (* X -.7))

Child 3: (* (/ Y X) (mod X Y))

Child 4: (* (/ Y X) (* X -.7))

This method is useful when you don't want your crossover to cause large variations from generation to generation.

The second method uses a different approach all together. It chooses a random node in a randomly selected parent and replaces it with a random node from the other parent. This method gives a far greater possibility of variations between parent and child. The example above for instance has 61 possible unique children instead of the four from the first method.

3 What kind of Evolutionary Art is there?

3.1 Images

Images come in many different categories, think of the work described above by Karl Sims, but also painterly renderings or line based drawings. When the creation of images via Evolutionary methods started it was done by using mathematical functions to calculate pixel values for the image to be created. By the work of men like Stephan Latham, William Todd and Steven Rooke, more complex functions and more parameters were added to create ever more complex images.

But other kinds of uses have been found for Evolutionary Algorithms in image creation. Some use existing images or photographs as starting points, others optimize existing images.

Painterly renderings done by Collomosse use Genetic Algorithms to find 'optimal' paintings. Explained as follows.

> Collomosse and Hall's algorithm makes use of a Genetic Algorithm (GA)to search the space of possible paintings, so locating the optimal painting for a given photograph. Their optimality criterion is a measure of the strength of correlation between the level of detail in a painting and the salience map of its source image. ...
>
> ... Furthermore the GA approach adopted allows different regions within a painting to be optimized independently, and later combined to produce improved solutions in later generations. [6]

Thus using photographs as a base and then finding some kind of optimum.

Another kind of image is the line based drawing, shown in the work of Gary Greenfield. We already mentioned his work with 'ant paintings' but he also experimented with 'Robot Paintings'. [7]

These robot paintings create line based drawings by having simulated robots create an image where the fitness function depends on the global properties of the resulting robot paintings and on the behavior of the simulated robots that occurs while making the paintings. Therefore they implement an optimization algorithm that can be used to try and help indentify robot paintings with desirable aesthetic properties.

The goal of his work was to better understand how art making by a collection of autonomous cooperating robots might occur in such a way that the robots themselves are to participate in the evaluation of their creative efforts.

Figure 2: Karl Sims, Panspermia.

3.2 Animation

Evolutionary Art and animation go hand in hand. It has been used by Karl Sims and Jon McCormack in the early 1990's to create animated plant life in surreal landscapes. [5][8][9] But also Traxler's evolution of realistic trees and Jacob's Mathematica based educational examples. [10][11]

Another one of the interesting uses of evolutionary art animation was to evolve human figure character geometry primarily for use in games and animation. For example DiPoalo developed the FaceLift interface for evolving Sims2 game characters. [12]. Aoki and Takagi used an Interactive Genetic Algorithm to build a lighting support system, comparing user performance in a manual lighting task with users employing an aesthetic selection interface. [13][14] They have also conducted research into the evolution of particle system design, in the context of fireworks animations. [15]

As seen by the examples above the creativity allowed by EA is well suited for animation purposes.

3.3 3D art

3D art was already created by Karl Sims in his early work. [5] He used the same techniques as he used for the creation of the 2D art by adding a third dimension to the output of his mathematical functions.

But true 3D artifacts had their origin in the earliest of William Latham working with Stephen Todd of IBM UK around 1990. [16] The complex branching (frequently animated) organic forms created using their software proved to be a strong inspiration for many of the earliest evolutionary artists.

There have been several implementations of their work both as individual projects and as commercial software. Their *Mutator* software was already mentioned as a software package that allows artists and designers to explore objects in all three dimensions. Other implementations include Rowbottom's Form software, which was an early PC-based implementation of Latham's approach, but also Groboto, an interface which allows children to build and experiment with these sorts of forms. [17][18]

Figure 3: William Latham, «The Garden of Unearthly Delights», 1992

3.4 Installation

To give a clearer picture of what to expect from an installation using Evolutionary Art, two examples will be given. Galápagos by Karl Sims and Morphogenesis by Bernd Lintermann.

3.4.1 Galápagos

> *Galápagos* is an interactive Darwinian evolution of virtual "organisms." Twelve computers simulate the growth and behaviors of a population of abstract animated forms and display them on twelve screens arranged in an arc. The viewers participate in this exhibit by selecting which organisms they find most aesthetically interesting and standing on step sensors in front of those displays. The selected organisms survive, mate, mutate and reproduce. Those not selected are removed, and their computers are inhabited by new offspring from the survivors. The offspring are copies and combinations of their parents, but their genes are altered by random mutations. Sometimes a mutation is favorable, the new organism is more interesting than its ancestors, and is then selected by the viewers. As this evolutionary cycle of reproduction and selection continues, more and more interesting organisms can emerge. [19]

Galápagos was installed at the Intercommunication Center in Tokyo, Japan from 1997 to 2000, and was exhibited at the DeCordova Museum in Lincoln, USA as part of *Make Your Move: Interactive Computer Art* and the Boston Cyberarts Festival 1999.

It was named Galápagos after the islands that Charles Darwin visited in 1835 where the unusual varieties of wildlife inspired his idea of natural selection.

Galápagos is a beautiful example of a piece of Evolutionary Art with an IGA at its center. It was easy to understand for the public and could create things they had never seen before.

Figure 4: Karl Sims, Galápagos

3.4.2 Morphogenesis

> The installation is about the evolutionary development of a three dimensional organic form. It consists out of two coupled systems. One system exists in real space, visitors interact with a virtual organic projected onto a 4 by 3m back projection screen via a special interface box constructed for that purpose. The second system uses the World Wide Web as user interface.
>
> In both systems users evolve a three dimensional organic object created using genetic algorithms. The organic is defined by a genome, a set of components, which is successively mutated by the users. Out of six randomly generated mutations users select one, which in the next step is the starting point for new mutations. This way users choose a thread through a space out of approximately 1080 possible forms.
>
> In the real space users additionally change the shape and behavior of the life like organic object via the interface box. Both systems are coupled and operate on the same data set constituting the genome, actions in the web space effect the real space and vice versa. If a change on the web happens, the organic in the real space slowly morphs towards the web selection, a change in real space directly affects the next web action. [20]

This installation not only used an IGA that could be directed by visitors at the site but also by visitors of the webpage of Morphogenesis, a way to create even more input for the mutations and crossovers of the organic form.

3.5 Music

The first time Music and Evolutionary Computing were linked together was in the 1991 paper *Algorithms and Computer-Assisted Music Composition* by Andrew Horner and David Goldberg. It was shortly followed by a surprisingly mature system called NEUROGEN developed by Gibson and Byrne. I had multiple levels and Neural Net fitness. [21]

> NEUROGEN was designed to produce small diatonic, western-type, four-part harmony compositions using the knowledge extracted from a set of example musical fragments provided by the user. The aim has been to produce a piece of coherent music that resembles that typically found in traditional hymns. [21]

One of the more notable efforts that followed was done not by a person with a technical background but rather a new music composer, Rodney Waschka II. He created GenDash a Genetic Algorithm tool that he tweaks for every new piece he creates. Some of the key things with GenDash are that it is very collaborative and artistic. [22] Amongst other things he has created orchestral music, a 1-act opera, and harp music. He does a lot of research in the area of EA and music but is known as a serious composer first and a technologist second.

Like in every field of EA the fitness function in Evolutionary Music remains a problem, different things have been tried. Automatic fitness functions based on rules, but just because something follows a certain set of rules does not mean it also sounds good. Others use rules learned through a neural network or learned through statistical data, the problem there is that they seldom seem to work because they can't capture the essence of a piece nor can they place pieces in context. Like with images interactive fitness functions are used where a person evaluates every candidate in the population, but here the problem is the same like with images, there is only so much a person can evaluate at one time. It is actually even more time consuming with music then with images because humans can go through images far quicker than music, where every piece has to be listened to one at a time. The problem is that it is just hard to code 'that sounds good'.

3.6 Verbal Art

As with installations two examples will be given of Evolutionary Art in Verbal Art. *Evolutionary Assistance in Alliteration and Allelic Drivel* is about the generating of poetry by Raquel Hervás, Jason Robinson, and Pablo Gervás. [23]And *Interactive Evolution of Adaptive Parameter for Speaker Verification Systems*, which looks at the possibility of improving ones public speaking voice by Yuji Sato. [24]

3.6.1 Poetry

> This paper presents an approximation towards an evolutionary generator of alliterative text. A simple text is given along with the preferred phoneme for alliterations as input. Then the evolutionary algorithm (with the aid of a phonemic transcriber, Microsoft Word and Google) will try to produce an alternative sentence while trying to preserve the initial meaning and coherence. A bigram language model and the evaluation of the phonetic analysis are used to assess the fitness of the sentences.

Because the definition of alliteration is not set, they used the widest possible definition of it and saw the Evolutionary Model as the perfect way to search through the enormous search space. They used Microsoft Word for its ability to find synonyms and anonyms for almost any word in almost any language. This not only allows them to keep the meaning of a sentence by doing easy checks like; do not replace a verb with a noun.

Their fitness evaluation is described as follows:

> A sentence in the population is considered better or worse depending on two factors: the number of appearances of the desired phoneme and the coherence of the sentence.

The first part is calculated as the percentage of appearances of the phoneme out of the total number of phonemes in the phrase. The second part is calculated by using bigrams. Every pair of consecutive words in the sentence is sent as a query to Google to get the number of appearances of the pair on the internet. The following describes how the calculations are done.

> This value is normalized using the number of appearance of each of the words separately compared to the number of times they appear side by side, as shown in Formula 1, and the coherence of all the bigrams is summed up to obtain the coherence fitness of the whole sentence.
>
> $coherence(w1, w2) = app(w1 + w2)/(app(w1) + app(w2))$ (1)

> The final fitness value for the whole sentence is the sum of the phonetic and the coherence fitnesses. With this measure, we are trying to obtain the most alliterations in a phrase with the minimum loss of coherence.

They describe the results as promising but not yet on the level of even a mediocre human writer. It was hard for them to take into account all the different things that make up a good alliteration, but were hopeful that that laid a good base on which to continue the research it this area.

3.6.2 Public Speaking Voice

In some professions having the right voice can be the difference between success or failure, Barrack Obama always sounds impressive and even Margaret Thatcher had her voice trained to lower the pitch, to sound more authoritative.

In his work Sato used a Genetic Algorithm to evolve an improved voice. The algorithm starts off with a few sample sentences by the voice to be enhanced and analyses the voice signal to determine which aspects of it need to be enhanced or suppressed to produce the required effect.

From this three genes are made from the voice, corresponding to changes in voice pitch, volume and speed. From these three genes a generation is randomly created and the observers rank them according to the required criteria. In other words an IGA is used.

3.7 Architecture

As with Verbal two examples of Evolutionary Art in Architecture shall be given. *IGAP: Interactive Genetic Algorithm Peer to Peer* by Juan C. Quiroz, Amit Banerjee, and Sushil J. Louis and GENR8 by Martin Hemberg and Una-May O'Reilly. [25][26]

3.7.1 IGAP

IGAP, a peer to peer interactive genetic algorithm which reflects the real world methodology followed in team design. The methodology is applied to floor planning. Through collaboration users are able to visualize designs done by peers on the network, while using case injection to allow them to bias their populations and the fitness function to adapt to subjective preferences.

The idea behind it is to take advantage of evolutionary computing to breed new design ideas quickly, and allowing collaboration to be fast and efficient by sharing of ideas amongst designers by visualizing and case injection of peer individuals into a designer's population.

IGAP allows for fitness functions to be based upon both the functionality of a floor plan and the aesthetics of one. Thus creating an easy way to explore the space of different floor plans, while taking in to account the wishes of the designer(s).

One of the results of the research done with IGAP was that it created more diverse and unique floor plans than floor plans created by an individual.

3.7.2 GENR8

GENR8 is a design tool for surface generation, based on Evolutionary Algorithms and Map L-Systems. It was developed as a plug-in for Alias|Wavefront's Maya by the Emergent Design Group at MIT. The tool searches the universe of surfaces with an evolutionary algorithm. It is meant to be an aid for designers trying to find new surfaces and it demonstrates the usefulness of Artificial Life in the field of architecture.

Instead of the standard GE model of genotype → phenotype they used an additional mapping step from the grammar to the phenotype.

4 Who should you know in Evolutionary Art?

4.1 Richard Dawkins

Richard Dawkins is a British ethnologist, evolutionary biologist and author. Dawkins came in to the spotlight with his book *The Selfish Gene* published in 1976, which popularized the gene-centered view of evolution. It was also this book which introduced the word *meme* a word also used in the field of Evolutionary Computing. Memes are described as the means of cultural transmission, like genes are the means of biological transmission. [1] [27] In the field of adaptive systems and optimization techniques, it is the idea of memes as agents that can transform a candidate solution that is of direct interest. This can be thought of as adding a learning phase to an evolutionary cycle as a form of meme-gene interaction. [1] Richard Dawkins is also well known as a critic of *Intelligent Design* and *Creationism*.

Richard Dawkins was important for the field of Evolutionary Art not just as someone who helped the field of Evolutionary Computing, but more directly as he was the first to work with an *Interactive Genetic Algorithm*(IGA) for his Biomorph software described in his book *The Blind Watchmaker*. [2] The Biomorph software starts with creating a tree shape and then via IGA lets the user go on from there. This was the first time the role of aesthetic fitness evaluation – a problem difficult to represent in algorithmic form – is performed by the user of the interactive evolutionary system, who selects individuals based on their own aesthetic preferences. Selected individuals become the parents for the next generation and the process is repeated until a satisfactory result is obtained or the user runs out of patience.

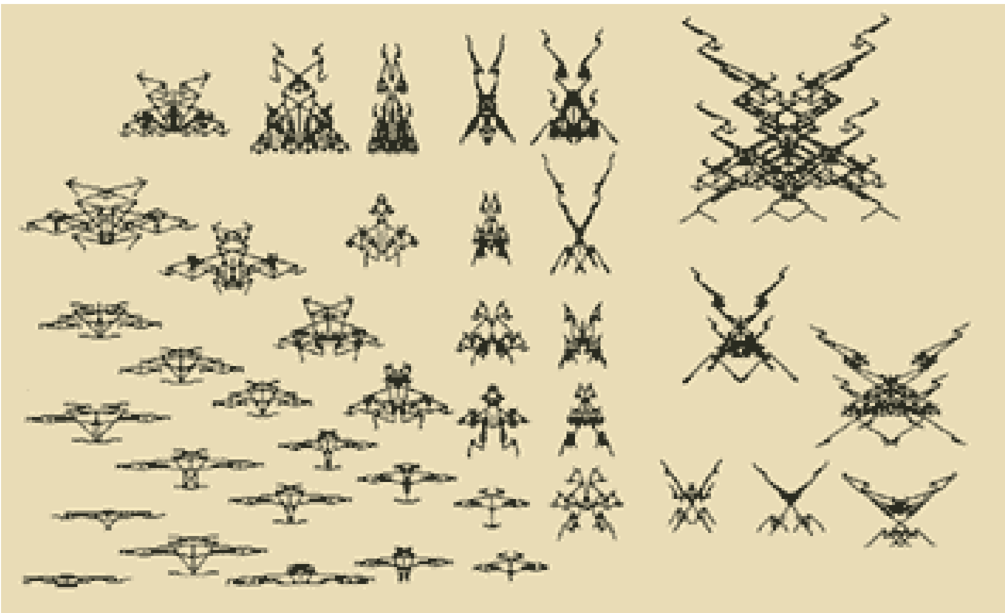


Figure 5: Example of 'Biomorphs'

4.2 Karl Sims

Karl Sims is an American digital media artist, computer graphics research scientist, and software entrepreneur. He is the founder of GenArts, Inc. of Cambridge, Massachusetts, which creates special effects software for the motion picture industry. Karl Sims first well known paper was Artificial Evolution for Computer Graphics published in 1991. Like mentioned earlier this was one of the first times that Genetic Programming was proposed. This was not just the first time it was proposed for the use in Evolutionary Art, but for the field of Evolutionary Computing in general.

His work in working with an expression based approach to evolving images resulted in new complex and beautiful images not seen before by the hands of a computer program. In doing so he created a template which for many artists and programmers became the reason to get in to the field of Evolutionary Art. His work in EA continued with research in to 3D-art, animation, and physically animated creatures.

Figure 6: Karl Sims

4.3 William Latham

William Latham is a British computer artist and Professor of Computing at Goldsmiths, University of London. His work at IBM(UK) is well known and resulted in a book co-authored with Stephen Todd, entitled 'Evolutionary Art and Computers'. [16] It describes generating 3D-models and Organic Life forms using genetic algorithm based techniques to mutate base forms into artistic creations. It is this work together with the aforementioned work of Karl Sims, that laid the groundwork for Evolutionary Art as it is known today.

He is well known for his blend of organic imagery and computer animation. His work deals with the themes of artificial life and man's manipulation of the natural world. [28]

He is also known for his artistic system *Mutator*, which helps an artist explore the world of three-dimensional forms. This allows you to create anything from shampoo bottles to buildings. [29]

His work has been featured in magazines like Wired, New Scientist, Scientific American and newspapers like the Financial Times and even TV programs like Beyond 2000 and Tomorrow's World. His work with organic imagery has been exhibited in the UK, Japan, Germany, Australia, Spain, France and Hong Kong. All of this has led to him to being one of the most recognizable faces of the Evolutionary Art world. [28]

Figure 7: William Latham

4.4 Penousal Machado

Penousal Machado, is a Portuguese Researcher at the Department of Informatics Engineering of the University of Coimbra and senior researcher at the Cognitive and Media Systems group of the Centre of Informatics and Systems of the University of Coimbra. He conducts research in the fields of Nature Inspired Computing, Computational Art and Design, and Artificial Intelligence. [30]

He has authored numerous papers in various fields including Evolutionary Art and has been the chair of the only conference dedicated solely to Evolutionary Music and Art, Evo Musart, which is a one of the annual conferences in the Evo Star family.

He is also known as one of the creators of NEvAR, an Evolutionary Art Tool. It is special in the way that it allows for storage of previously created images, so that they may be used as a starting off point for new images. It runs on a parallel evolutionary algorithm, meaning more than one experiment can be run at the same time, and these experiments do not need to run synchronous. [31]

He is also the recipient of several scientific awards, including the prestigious award for Excellence and Merit in Artificial Intelligence granted by the Portuguese Association for Artificial Intelligence. Recently his work has been featured at Wired Magazine UK and the MoMA exhibition catalogue for “Talk to Me”. [30] Making him one of the few artists to have worked published in more mainstream place. “Talk to Me” was an exhibition in the MoMa that ran from July 24–November 7, 2011, which explored the enhanced capabilities for communication in the 20th century and the new balance between people and technology.

Figure 8: Penousal Machado

4.5 Steven Rooke

Steven Rooke is an American Evolutionary Artist. Originally a geologist he found a dual interest in Algorithmic Art and Ecosystem Theory, he hoped to write a computer graphic system to explore complex ecosystem interactions, perhaps even to simulate aspects of Gaia Theory using genetic algorithms artificial life and simulated evolution. When he realized the enormous scale of his endeavor, he shelved the project hoping to complete it at a later time. He then visited the 1992 Artificial Life III conference at Santa Fe, which led to his work in Evolutionary Art.

He is mostly known for the large body of work of expression based imagery he produced in the late '90's, a direct continuation of the work of Karl Sims.

He went in to great detail on his website [32] on how to evolve potentially hundreds of generations of images and then 'tuning' the colors and the region of image space in the images. [4]

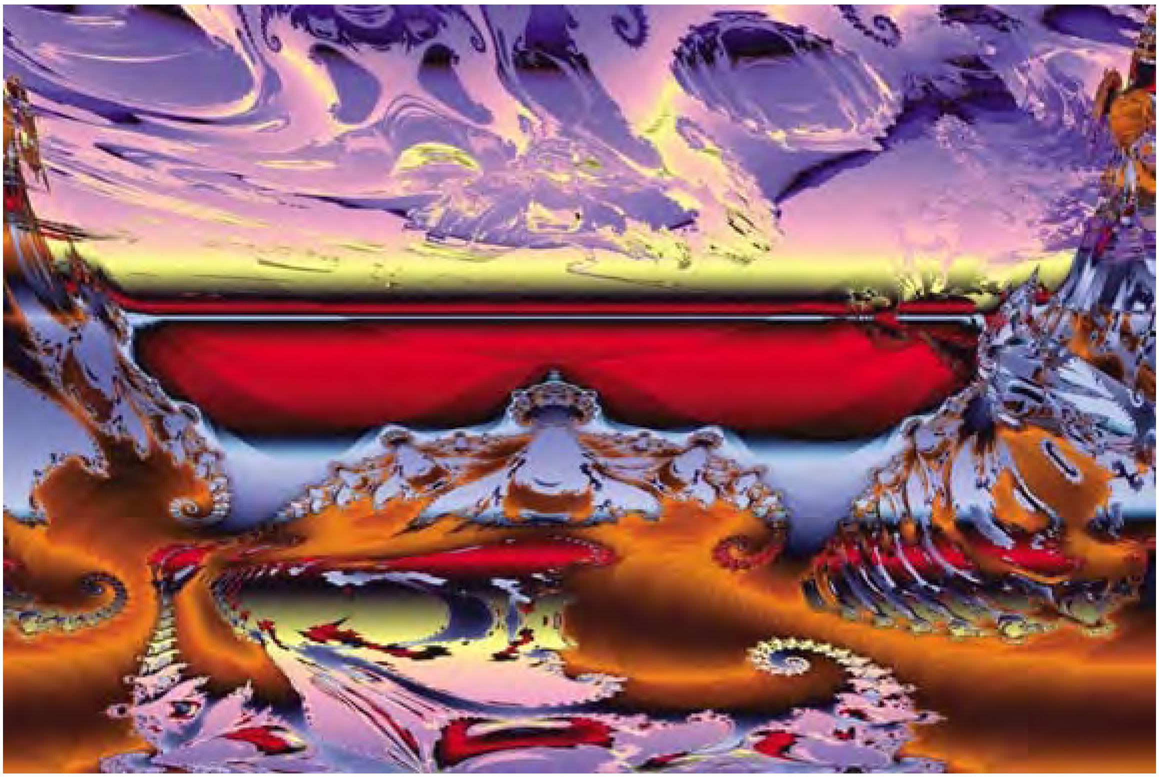


Figure 9: Steven Rooke, Hypersea

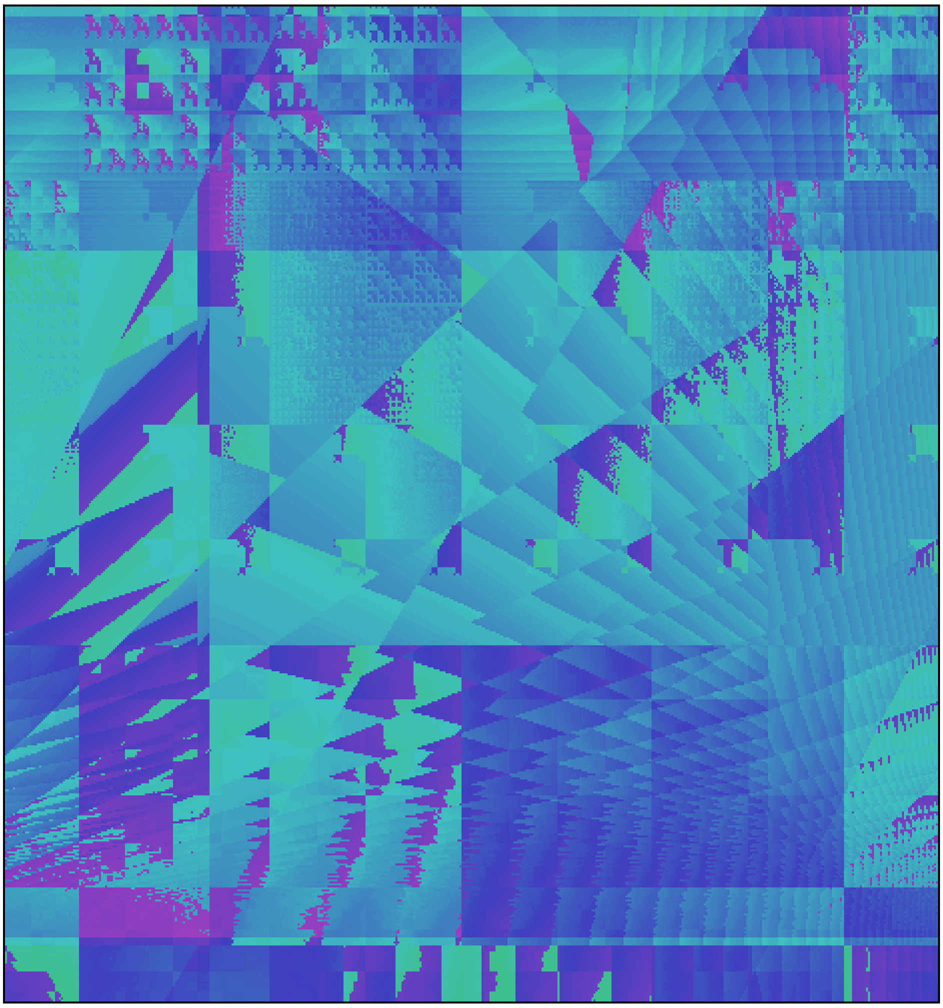
4.6 Gary Greenfield

Gary Greenfield is a retired American Professor of Mathematics and Computer Science at the University of Richmond. He has a BA in mathematics and a PhD in algebra and has a diverse set of interests. They include: division algebras and Brauer groups, cryptography, artificial life, evolutionary computation and algorithmic art. [33]

Amongst the thing he is known for in the Evolutionary Art world is his work with simulated ant and robot parameters, experimenting with various automated fitness functions to achieve varying aesthetic visual results. [4] This is different compared to all the aforementioned people, who all used IGA's and thus humans for their fitness functions. Much of his work is in the area of finding suitable automated fitness functions.

His work with ant colony optimization models to evolve "ant paintings", are different from other research in this area in two ways. First, like mentioned before he uses an automated fitness function and second compared to other work in with ant models he allows the pheromone trail to serve as both a repelling and attracting force. [34]

Some of his other well known work is that with the use of digital and color filters with coevolution. [4]



"Untitled" c 1994 Gary R. Greenfield

4.7 Jon McCormack

Jon McCormack is an Australian electronic media artist and researcher in computing. He is currently Associate Professor in Computer Science an ARC Australian Research Fellow and co-director of the Centre for Electronic Media Art (CEMA) at Monash University in Melbourne. His research interests include generative art and design, evolutionary systems, machine learning, L-systems and developmental models. [35]

CEMA is an interdisciplinary research centre established to explore new collaborative relationships between computing and the arts. It conducts research, gives trainings and produces electronic media arts. [36]

Since the late 1980s McCormack has worked with computer code as a medium for artistic expression. Inspired by the complexity and wonder of a diminishing natural world, his work is concerned with electronic "after natures" – alternate forms of artificial life that may one day replace the biological nature lost through human progress and development. [35]He is also known for his work with installations, eco systems with A-life influences.

His artworks have been widely exhibited at leading galleries, museums and symposia, including the Museum of Modern Art (New York, USA), Tate Gallery (Liverpool, UK), ACM SIGGRAPH (USA), Prix Ars Electronica (Austria) and the Australian Centre for the Moving Image (Australia).

One of his important papers *Open Problems in Evolutionary Music and Art* [37] is one where he sets five questions to focus the research field of Evolutionary Music and Art. More detail will follow in chapter 6.

Figure 10: Jon McCormack

5 Where can I find Evolutionary Art?

5.1 EvoMusart

EvoMusart is a conference on Evolutionary and Biologically Inspired Music, Sound, Art and Design. In 2012 it was the tenth European event on Evolutionary Music and Art. Before 2012 it was a workshop in the larger annual Evo* conference, but due to the success of the previous events and the growing importance of EMA it has become an evo* conference with independent proceedings. Therefore EvoMusart 2012 was the first international conference ever in this field.

The main goal of EvoMusart is to bring together researchers who are using biologically inspired computer techniques for artistic tasks, providing the opportunity to promote, present, and discuss ongoing work in the area.

It is the only conference solely dedicated to Evolutionary Music and Art.

5.2 Generative Art International Conference

Is a conference dedicated to Generative Art. Currently chaired by Celestino Soddu, who is also the director of Generative Design lab of Politecnico di Milano University.

Evolutionary Art being a part of Generative Art it is one of the fields of interest of the conference. Papers submitted for the conference range from *Use of Art Media in Engineering and Scientific Education* [38] to *Brain Art: Abstract Visualization of Sleeping Brain*. [39] There are also live performances, installations, movies and artworks on display. It thus offers a wide array of fields that are linked by their use of computers to generate art.

5.3 CEC, Congress on Evolutionary Computation

Is part of the IEEE World Congress on Computational Intelligence (IEEE WCCI). Which consists of three conferences: the International Joint Conference on Neural Networks (IJCNN) the IEEE International Conference on Fuzzy Systems (FUZZ-IEEE) and IEEE CEC. It is currently chaired by Gary Greenwood.

The following topics are covered:

Ant colony optimization
Artificial life
Agent-based systems
Bioinformatics and bioengineering
Coevolution and collective behavior
Combinatorial and numerical optimization
Constraint and uncertainty handling
Evolutionary data mining
Evolutionary learning systems
Evolvable/adaptive hardware and systems
Evolving neural networks and fuzzy systems
Molecular and quantum computing
Particle Swarm Optimization
Artificial immune systems
Representation and operators
Industrial applications of EC
Evolutionary game theory
Cognitive systems and applications
Computational finance and economics
Estimation of distribution algorithms
Evolutionary design
Evolutionary scheduling

It encompasses keynote lectures, special sessions, tutorials and workshops, panel discussions as well as poster presentations.

5.4 GECCO, Genetic and Evolutionary Computation Conference

Is a conference that recombines the International Conference on Genetic Algorithms (ICGA) and the Annual Genetic Programming Conference (GP). It presents itself as the largest conference in the field of Genetic and Evolutionary Computing. It is currently chaired by Jason Moore.

Some of the papers accepted for the 2012 version are; *Sensitive Ants Are Sensible Ant* , *Adaptive Learning Evaluation Model For Evolutionary Art*, and *Photogrowth: Non-Photorealistic Renderings Through Ant Paintings* authored by Penousal Machado and Luis Pereira.

As can be seen by the papers submitted Evolutionary Art is present at the conference amongst a wide variety of subjects within the Evolutionary Computing field.

6 What's next?

Like mentioned before Jon McCormack wrote an article *Open Problems in Evolutionary Music and Art* where he defines the goal as follows:

> The aim of this paper is to define a small set of 'open problems' in EMA. The goal is not to be critical of previous work, but to provide a well-defined set of challenges for the EMA research community. [37]

It has been shown before that such open problems and goals can help a research community. [40]

The reason he wrote the paper is that in his eyes while there have been important developments in the field, big successful results have not been there yet. He argues that a stronger overall research plan is needed to ensure long term development and to attract more researchers to the field.

He divides his open problems in two distinct categories.

> I make a primary distinction between (i) research where the resultant music and artwork is intended to be recognized by humans as creative (i.e. art) and (ii) research which explores the concept of creativity in general. [37]

The first is explained as research with the goal to not be a researcher but an artist. The work created is intended to show creative intention or aesthetic judgment by the creator. Whether this is a man or a machine does not matter.

The second it a much more open and creativity should be seen in a wider context and not necessarily limited to being recognized by people as creative or aesthetic. It could be explained as everything we can imagine but even more so that which we can't imagine ourselves. For example when NASA had to design a satellite which maximized the vibration resistance of the design to make sure it did not break, they ran an evolutionary algorithm that gave them an answer that made sense once they saw it but could not have thought of themselves. We might call this creativity since it the algorithm came up with something new and unexpected. Now instead of getting creative with designing a piece of equipment, we get creative with creativity.

The following section gives a short introduction of the open problems and then the problems themselves that were presented in the paper.

6.1 Searching for Interesting Phenotypes

As described the field started with the mathematical functions that Karl Sims used to make images. All of these images belonged to a certain 'class' of images, namely images created by mathematical functions. Later more complex functions and even more parameters were added by Steven Rooke to create more complex images. But still images belonged to the class 'images created with complex mathematical functions'. The creation of Evolutionary Art is limited to the creativity the programmer or artist shows when coming up with a representation and parameterization they think will lead to interesting art. So to date humans have guided the evolution of EA, but what we want is to create a system that evolves art on its own. Thus leading to the first open problem:

Open problem #1: To devise a system where the the genotype, phenotype and the mechanism that produces phenotype from genotype are capable of automated and robust modification, selection, and hence evolution.

Once found you actually have Evolutionary Art, you turn it on and it will create art without any outside influence. And the best part is that you have no idea what kind of thing will come out.

6.2 The Problem of Aesthetic Selection

When most people think of art they will probably think about something like the *Mona Lisa*, yet when we look at the art created by EA it does not usually conform to something like that unless we took that as a starting off point. The problem is that if one were to start off with any kind of mathematical function image and have to guide it to the *Mona Lisa* or something equivalent it would probably not only take more time then is realistic to find it, it could probably not even be found because to get to images that complex it would take the algorithm creating it so much time to calculate one generation that it would almost definitely not even show you the option because it calculated for you that it would take longer to generate it then you're willing to wait on the next generation. So we are limited by the amount of selections a human can make and we are limited by the representation and recourses available.

Open problem #2: To devise formalized fitness functions that are capable of measuring human aesthetic properties of phenotypes. These functions must be machine represent able and practically computable.

Obviously this is extremely difficult, not only because 'beauty is in the eye of the beholder' but also because a lot of Art is beautiful because of the context it is placed in. Scientific theories deliberately choose levels of abstractions applicable for physical laws to be 'universal', however with aesthetics it seems that it exactly the details that get left out this way are the ones that matter the most.

6.3 What Is Art?

The question of 'what is art?' has probably been around as long as art itself. Frieder Nake proposed that anything exhibited in art galleries is art. [41] Now there have been many exhibitions of 'computer generated' art and even EMA, but many of these works were selected because they are created by computers and not because they are art. So the next step is for EMA to be recognized as art for what it is instead of how it was made.

Open problem #3: To create EMA systems that produce art recognized by humans for its artistic contribution (as opposed to any purely technical fetish or fascination).

One might consider this a new version of the Turing test, where artistic outcomes of EMA systems might be compared alongside those done by humans. If the audience cannot tell the difference, or at least considers both worthy of the title 'art' then the test has been passed.

6.4 Artificial Creativity

To explore the concept of creativity we need not only define creativity but also allow creativity. Definitions of creativity are varied.

> In developing computational models of creativity, Partridge and Rowe require that creativity involve production of something *novel* and *appropriate* [42]. In addition, novelty may exist relative to the individual (Boden's P-creativity), and for society or the whole of human culture (H-creativity in Boden's terminology) [43]. For their computation model of creativity, Partridge and Rowe see novelty involving the creation of new representations through *emergent memory*.

Whatever the definition chosen for creativity, as with open problem #1 it is important that this creativity is not hindered by restrictions inherent to the system. And thus allowing anything creative, as long as it does not break the system.

> Open problem #4: To create artificial ecosystems where agents create and recognize their own creativity. The goal of this open problem is to help understand creativity and emergence, to investigate the possibilities of 'art-as-it-could-be'.

The challenge for EMA will be to keep with our ever advancing understanding of creativity and to convincingly demonstrate the autonomous emergence of agents capable of generating and recognizing novelty in their interactions.

6.5 Theories of Evolutionary Music and Art

As with any research in any field it must be mindful of theories related to such practices from the disciplines themselves. So while there are theories for art and music themselves, they must also exist for Evolutionary Music and Art.

> If this art is to progress, there must be critical theories to contextualize and evaluate it and its practitioners.

> Open problem #5: To develop art theories of evolutionary and generative art.

For EMA to be accepted as art, there must be some artistic theory that is associated with them. The first steps are already taken in this field. [44]

7 What did Evolutionary Art Contribute?

This final chapter will take a look at what contributions Evolutionary Art has brought to art and science and what we might expect it to contribute in the future.

To look at what its contributions was to art I asked my father for his thoughts on EA. I chose my father because after his retirement some six years ago he has been following Art History course at the Vrije Universiteit Amsterdam and visited many exhibitions on all kinds of Art all over the world. This coupled with his lifelong appreciation for the arts made him in my mind perfectly suited to share his view on what EA is. I asked him to place Evolutionary Art within Art as a whole, but also what kind of feeling the images I sent gave him. The images I send were some selected works by all the major players I mentioned.

To see what kind of contributions Evolutionary Art brought the world of science I had a conversation with Eelco den Heijer. PhD researcher at the Computational Intelligence group at the VU under A.E. Eiben. His research is about investigating various aspects of evolutionary art and he is currently focusing on the use of various aesthetic measures in the context of unsupervised evolutionary art systems. This conversation together with my research for this paper gave me some insight into the contributions of EA to science.

7.1 To Art?

My father wrote the following:

> "Your question if I could place these images in "Art" I can in general say yes. I will not go into what art exactly is, since there are as many definitions for it as there are ways of expressing it.
> I shall thus keep it simple, 'What do I see, what do I think when I look at these images?'
> Because of the nature of the medium, I am looking at my computer monitor, It determines in part how I judge the images or how I experience them.
> In that way the images conjure up a lot of different associations, some of the pictures remind of:
>
> - Abstract figurative work
> - Nature photographs, whom might have been made with an electron microscope
> - Photographs of fossils, whom at first glance remind of the work of M.C. Escher
> - Plain portraits/plants
>
> If I look at the total picture you can use Evolutionary Art is an excellent way of making Art. You can use it to; express views, to provide insight into structures and you have access to all colors and shapes. In other words it is a nice new painting/tool box."
>
> Harold Müller

7.2 To Science?

The contributions of Evolutionary Art to science are a subject with problems that can be traced all the way back to its roots. Richard Dawkins *biomorphs* were never meant to inspire a whole new form of art. He as a biologist was merely interested in the way things evolved and what they may look like. Engineers like Karl Sims picked it up and thought it would be a fun way to make some images, and that it has with a few exceptions stayed that way, engineers who on the side do some work in Evolutionary Art but leave it at that. Does this mean it could never become a fully fledged art form, destined to be the plaything of engineers looking to do something else? The few exceptions mentioned earlier seem to indicate no. What is needed for this art form to develop are artists, creative minds who come up with original ideas for Evolutionary Art and not just engineers.

This does not mean EA has not contributed anything to science, it has given valuable insight into what people like and don't like and it has given a better understanding of what art is. But probably the most important contribution up to date was the work it created with Interactive Evolutionary Algorithms. Because of the difficulties of creating a fitness function that can capture human aesthetic judgment, Interactive algorithms were created. Dawkins was the first one to describe this in *The Blind Watchmaker*. [2][45] Not only were IEA or Interactive Evolutionary Computation (IEC) handy for aesthetic judgment but they also proved to be well suited for use in areas other than EA, like Knowledge Acquisition and Data Mining, Hearing Aid Fitting, Database Retrieval or Speech Processing. [45] Thus Evolutionary Art made at least one important contribution to science.

If we take the research questions that Jon McCormack outlined as a general direction for Evolutionary Art to follow in the future what could we expect?

We can expect new art theories, current art theory is not like theories in the exact sciences which have definitions and proofs, but in art they only definition seems to be that there is no definitive definition. [46] In this case it comes in handy that most of the practitioners of Evolutionary Art are engineers, if and when they find some theory behind EA, they will be able to clearly write it down, in a way we know from the exact sciences.

But the most important thing that we can expect from EA in the future is that it will continue as a test bed for Computational Creativity and Novelty Search.

In the case of CC it allows the exploration of what creativity is and how it can be created in a computer environment. This would not only be of importance for the field of CC but for anyone in any field who wants to use or create creativity.

If the first open problem by Jon McCormack is solved and a system is created which is truly able to evolve everything about itself, from fitness function to representation then you basically set your search space to everything. And thus allowing for Novelty Search. Whether it would mean anything to us if such a system was truly left alone without any sort of guidelines is another question but it would allow us glimpses in to areas we probably never even thought of.

8 Concluding remarks

Evolutionary Art was in my opinion the perfect subject to write a paper about. I knew hardly anything about the subject when I started and had little idea what to expect. The articles I read for this paper were interesting and gave me a view in to an art form that I on one hand never expected to be this advanced and on the other hand I probably expected more of.

I think some wonderful things have been created with Evolutionary Art, I especially like Jon McCormack's work, and think that with the right people interested the art form can continue to grow and maybe one day be accepted as 'Art' instead of the just be seen as 'Art created by computers'.

I expected more true artists in EA then I found in my research, I strongly get the feeling that EA for the most part now is a plaything of scientists who stumble upon it, publish a few papers in the field and then let it go. I think this is the main reason why apart from a few exceptions EA is little known. I hope that it will be taken a little more serious in the future by scientists so that they may solve the open problems of McCormack.

I enjoyed researching and writing this paper and would like to thank Guszti Eiben and Eelco den Heijer for their support, thoughts and help. Most of all I would like to thank them for introducing this subject to me!

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