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Universal Design of ICT

Interactive Evolution of Artificial Life Art

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OSLOMET

Preface

This master's thesis represents the culmination of months of effort for our master's degree program in Applied Computer and Information Technology (ACIT) under the Universal Design of ICT specialization.

This thesis would have not been successfully completed without the help and guidance from my supportive supervisors, Professor Stefano Nichele and Professor Pedro Lind, both from the Department of Computer Science and Artificial Intelligence who have been both very consistently helpful in providing me all the necessary information conducive to this thesis' completion and as well providing me practicable knowledge, guidance and advice all throughout the different phases of this thesis.

My gratitude goes also for all the participants who have registered for our online platform and performed the two different experiments and as well completing the short online surveys. I would also like to thank my family both in the Philippines and here in Norway especially my husband Chriss Rune Jonassen for all their encouragement and continuous support and last but not the least, for all the people who contributed and helped me in any way or form in accomplishing this study.

Glare Eugenio Dumo
Oslo, 16 May 2022

Abstract

In this thesis, we designed and presented an interface which is used for creating art using tools from artificial intelligence and artificial life. The interface is used for conducting two different experiments, one for the control group and one for the test group. It is tested and validated among our 34 participants who did both the said two experiments and a short online survey after each experiment with the aim of investigating how AI algorithms can be used for enabling all individuals even with disabilities or impairments, to express their artistic creativity. The interface uses evolutionary algorithms in generating animated images and short clips of life-like patterns of pixels which are based on MergeLife update rules describing local updates for cellular automata (CA). Participants are asked to select a sequence of rules representing various images which appear the most appealing to them, either randomly generated (control group) or assisted by an interactive evolutionary algorithm which considers the participant's previous choices (test group) within the 10 sets of image selection. The results have shown a significantly higher satisfaction of the test group with a significance level of 95% and a power of 82%. Finally, we also had a discussion for future directions of the said study and talked about the usefulness of such an interface for people with disabilities and limitations. I wrote a research paper together with my thesis supervisors called *An HCI experiment to explore interactive artificial life art* (Dumo, Lind, & Nichele, An HCI Experiment to Explore Interactive Artificial Life Art, 2022) which is based on this thesis. It has been accepted for publication and presentation in the *24th International Conference on Human-Computer Interaction* which will be held virtually from 26 June to 1 July 2022.

Keywords: Human-computer interface, Artificial life art, Cellular automata, Interactive evolution, Creative universal design.

Table of Contents

Chapter 1

Introduction

Scientists and artists share one common ideal trait, being creative. As both must be able to come up with their own original concepts, ideas and should have the ability to push boundaries and borders to pursue greater knowledge and creativity. But what could possibly happen when science meets arts?

There are some authors who already talked about artificial life in art even in the late 90s and one of the authors who has provided an elaborated inspection of the emergence of artificial life art by undertaking an extensive study about it through a book called Metacreation: Art and Artificial Life, which was released in the year 2004 by Mitchell Whitelaw. According to Whitelaw *"Artificial life, or a-life, is a young, interdisciplinary scientific field concerned with the creation and study of artificial systems that mimic or manifest the properties of living systems* (Whitelaw, 2004)*."*

Artificial life, over the years has been found quite engaging and people were fascinated especially with the none-player game called *The Game of Life* created by a British Mathematician, John H. Conway. Since then, Alife inspired other studies where their focus is to have a deeper perspective of life and how it functions according to its own way. But with this book of Whitelaw, he was able to show us how Alife could as well be stretched out to other fields like art. Hence, artists could create some artworks where interaction between technology and the study of life is achievable.

But originally, the term artificial life was introduced by Christopher Langton, an American computer scientist and as well the founder of the said field in the late 80s. According to the author, artificial life is "*the study of natural life, where nature is understood to include rather than to exclude, human beings and their artifacts* (Aguilar, Santamaría-Bonfil, Froese, & Gershenson, 2014)." It is said to be a multifaceted field of research wherein it successfully brought different professions

from diverse disciplines together such as computer scientists, philosophers, biologists, engineers, mathematicians, and artists among the many others.

Several artificial life environments have been introduced in the literature, such as *"The Past, Present and Future of Artificial Life. Frontiers in Robotics and AI* (Aguilar, Santamaría-Bonfil, Froese, & Gershenson, 2014)*"*, *"EvoCraft: A New Challenge for Open-Endedness* (Grbic D. , Palm, Najarro, Glanois, & Risi, Evocraft: A New Challenge for Open-Endedness, 2021)*"*, *"Biological Bits: A Brief Guide to the Ideas and Artefacts of Computational Artificial Life* (Dorin, 2014)*"*, *"Art and Artificial Life – A Primer* (Penny, 2009)*"* where cellular automata, evolutionary computation and interactive evolution have been examined and discussed.

This thesis aims to investigate the simulated artificial life environments as mediums in the creation of art through using a method called interactive evolution. According to Karl Sims, interactive evolution enables the user and the computer to collaborate with each other interactively which could lead to a new way of generating results wherein neither of the two cannot create alone (Sims, 1993). The said method will be thoroughly analyzed where users' contributions will play a vital role in the evaluation of the artificial life artworks. These users would be coming from different walks of life, from varying aspects like status, age, sexual orientation, ethnicity, and the like and as well not excluding people with any disabilities as they are also an important part of society where their opinions and different takes when it comes to studies like this, should be heard and fully acknowledged.

Conforming to the abovementioned, this thesis would like to further analyze how people with disabilities or limitations could have an interaction and connection towards artificial life art and how interactive their participation would be, regardless of any disability. This feeling of inclusion where people with disabilities are given acknowledgment when it comes to addressing their needs through designing a world accessible by each one of them, has been brought to familiarity when **universal design** was introduced to the world.

The term "*universal design*" was coined by a visionary and product designer, Ronald Mace, whose goal was to provide a design foundation where the world will be more

usable and accessible for everyone. According to Mace, universal design is used *"to describe the concept of designing all products and the built environment to be aesthetic and usable to the greatest extent possible by everyone, regardless of their age, ability, or status in life* (The Center For Universal Design, Environments and Products for All People, 2008)*."* The universal design movement which aims to provide the world with a design which is said to be accessible, barrier-free, inclusive, or simply a design for all, gives justice to its name – **universal** design.

National legislations from different countries and as well laws and policies are introduced and implemented in promoting social inclusion and to prevent discrimination in all forms. This compelled the design industry to make a significant change when it comes to giving focus to the accessibility of their products and services where all users, regardless of their limitations and disabilities, will all benefit from.

In accordance with that, this thesis would like to address the research question such as:

How can interactive evolution, together with artificial life, be a tool for supporting the universal design for art creation?

This research question can be divided into two (2) sub-questions such as the following:

1. How can the simulated artificial life environments be used for art creation and how can they be useful for understanding the process of human creativity?
2. What could be the possible ways that limited, impaired and disabled individuals express their creativity and eventually contribute to the beauty of arts in their preferred forms?

Chapter 2

Background and State of the Art

2.1 Interactive Evolution of Artificial Life Art and its Relevance to Universal Design

This study aims to find a connection and its relevance to Universal Design (UD) which is my master's program's specialization and which principle under Universal Design this study is most applicable with. *"Universal design means simply designing all products, buildings and exterior spaces to be usable by all people to the greatest extent possible* (Mace, Hardie, G.J., & Place, J.P., 1991)*."*

According to World Health Organization, over 1 billion people are living with some form of disability, and this said number of disability count is dramatically increasing (World Health Organization, 2020). We are also inevitably going to experience any form of disability at some point in our lives due to aging, health conditions and any other given factors and circumstances, either just temporarily or permanently. From the above definition, universal design is something that provides awareness and consideration for people with varying abilities, from abled, impaired and disabled letting any product, service and environment accessible and usable for everyone.

People with any form of impairments or disabilities' main concern is how they're able to practice their independence as much as possible regardless of their limitations. Thus, instead of being viewed by the society as people who are dependent with other people, they would greatly prefer to be dependent with assistive technologies or by enjoying universally designed products and environments where their varying abilities are accommodated and their independence valued.

Just like with arts creation, no one is ever identical and everyone differs in the way they express their creativity especially due to varying circumstances and abilities. But with this research, everyone, regardless of disabilities and limitations, is able to create their own art with the use of interactive evolution and artificial life. Since art is

subjective, it's open and accommodates everyone's perception of art, interpretations and views. This research aims to create arts that would satisfy the user's expectation of the result and how it has successfully expressed his creativity through his artwork.

2.1.1 Universal Design Principle 1 and why it is Chosen

In this research, we would be focusing and using the first principle which is the ***Equitable Use***. Since we would like to offer an art creation using interactive evolution and artificial life, but at the same time, making it universally designed, our users would not be limited to only abled but as well with people with impairments and disabilities. Thus, making the design accommodating and usable to everyone regardless of limitations. There would be no segregation and everyone would be equal in expressing their creativity when it comes to art creation.

An example under this principle is providing a website, an online marketplace platform like *FINN.no* for example, where they are making some research and efforts to have both their website and mobile application be universally designed and accessible so everyone even those who have different limitations and disabilities can enjoy the buying and selling industry online.

In this research, the art creation through interactive evolution using Cellular Automata with the use of an online platform that is specifically created to perform this experiment is based and inspired by the MergeLife Project (Heaton Research, 2020) which is accessible through any browser preferred by the participant. This experiment can be done wherever they are and on their most convenient time since it is accessible online and can be done using their desktop computers or laptops. This experiment is accessible online by using an internet connection and is being offered to all participants regardless of their limitations and disabilities.

A relevant paper called *Cellular Automata in Image Processing* (Popovici & Popovici, D., 2002) published in 2002 by Adriana Popovici and Dan Popovici said that *"a two-dimensional cellular automaton with a very simple transition rule may be used as a very efficient border detector in digital images. The border detection method based on a cellular automaton has a general applicability to monochromatic, gray level and*

color images. The obtained results are very promising, the border produced by the cellular automaton border detector in digital images without noise are very satisfactory (Popovici & Popovici, D., 2002)*."* This paper is somehow relevant when it comes to producing images where CA is applied successfully. And through this paper, they had some comparisons with the existing or typical edge detector algorithms where they found out that their proposed edge detector using CA is much faster and capable of producing satisfying results as well. If cellular model can produce such satisfying or much better performance when it comes to image processing, what more when it is applied to interactive creation of art where the participants would be asked after the art creation the level of their satisfaction, if the resulted artwork meets their expectation or their way of expressing their creativity.

No specific literatures or known studies have been found after some research with this kind of experiment where one of the seven universal design principles will be used particularly the principle 1 which is the equitable use.

2.1.2 Seven Principles of Universal Design and their Examples

Ronald Mace, the universal design's visionary and as well the one who coined up the term, together with other writers who came from different professions but particularly in designing, worked together to introduce the seven principles of universal design which have been presented in The Center for Universal Design in NC State University. The said seven principles are as follow (NC State University, 1997):

PRINCIPLE ONE: Equitable Use

The design is useful and marketable to people with diverse abilities.

Guidelines:

1a. Provide the same means of use for all users: identical whenever possible; equivalent when not.

1b. Avoid segregating or stigmatizing any users.

1c. Provisions for privacy, security, and safety should be equally available to all users.

1d. Make the design appealing to all users.

Examples (NC State University, 1997)**:**

- Power doors with sensor at entrances that are convenient for all users
- Integrated, dispersed, and adaptable seating in assembly areas as sports arenas and theaters

PRINCIPLE TWO: Flexibility in Use

The design accommodates a wide range of individual preferences and abilities.

Guidelines:

2a. Provide choice in methods of use.

2b. Accommodate right- or left-handed access and use.

2c. Facilitate the user's accuracy and precision.

2d. Provide adaptability to the user's pace.

Examples (NC State University, 1997)**:**

- Scissors designed for right- or left-handed users
- An automated teller machine (ATM) that has visual, tactile, and audible feedback, a tapered card opening, and a palm rest

PRINCIPLE THREE: Simple and Intuitive Use

Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.

Guidelines:

3a. Eliminate unnecessary complexity.

3b. Be consistent with user expectations and intuition.

3c. Accommodate a wide range of literacy and language skills.

3d. Arrange information consistent with its importance.

3e. Provide effective prompting and feedback during and after task completion.

Examples (NC State University, 1997)**:**

- A moving sidewalk or escalator in a public space
- An instruction manual with drawings and no text

PRINCIPLE FOUR: Perceptible Information

The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.

Guidelines:

4a. Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information.
4b. Provide adequate contrast between essential information and its surroundings.
4c. Maximize "legibility" of essential information.
4d. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions).
4e. Provide compatibility with a variety of techniques or devices used by people with sensory limitations.
Examples (NC State University, 1997)**:**

- Tactile, visual, and audible cues and instructions on a thermostat
- Redundant cueing (e.g., voice communications and signage) in airports, train stations, and subway cars

PRINCIPLE FIVE: Tolerance for Error
The design minimizes hazards and the adverse consequences of accidental or unintended actions.
Guidelines:
5a. Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded.
5b. Provide warnings of hazards and errors.
5c. Provide fail safe features.
5d. Discourage unconscious action in tasks that require vigilance.
Examples (NC State University, 1997)**:**

- A double-cut car key easily inserted into a recessed keyhole in either of two ways
- An “undo” feature in computer software that allows the user to correct mistakes without penalty

PRINCIPLE SIX: Low Physical Effort
The design can be used efficiently and comfortably and with a minimum of fatigue.
Guidelines:
6a. Allow user to maintain a neutral body position.
6b. Use reasonable operating forces.
6c. Minimize repetitive actions.

6d. Minimize sustained physical effort.

Examples (NC State University, 1997)**:**

- Lever or loop handles on doors and faucets
- Touch lamps operated without a switch

PRINCIPLE SEVEN: Size and Space for Approach and Use

Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

Guidelines:

7a. Provide a clear line of sight to important elements for any seated or standing user.

7b. Make reach to all components comfortable for any seated or standing user.

7c. Accommodate variations in hand and grip size.

7d. Provide adequate space for the use of assistive devices or personal assistance.

Examples (NC State University, 1997)**:**

- Controls on the front and clear floor space around appliances, mailboxes, dumpsters, and other elements
- Wide gates at subway stations that accommodate all users

2.2 Artificial Life

This thesis would be focusing on the interactive evolution of artificial life art, thus, one of the first fields of study to be discussed is artificial life or the computer simulation of life. Artificial life (ALife, A-Life) is an academic discipline wherein studies related to natural life and existence were examined thoroughly by researchers. The examination of these processes is carried out using different computer simulations and machine learning. The said branch of knowledge was introduced and defined by an American computer scientist and as well a theoretical biologist in the late 80s, Christopher Langton (Grand, 2021).

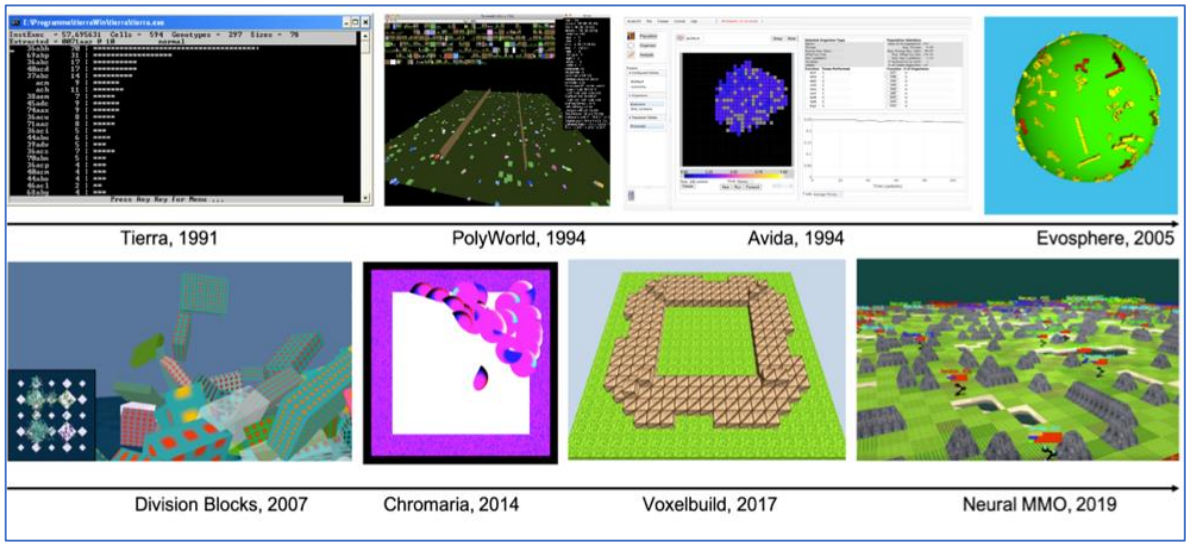


Fig. 1. *This figure shows a selection of existing artificial life evolutionary frameworks from the early 90s until the most recent released one in 2019* (Grbic D. , Palm, Najarro, Glanois, & Risi, Evocraft: A New Challenge for Open-Endedness, 2021).

A paper which has been published in 2021, which is called *EvoCraft: A New Challenge for Open-Endedness* by Grbic, Palm, Najarro, Glanois and Risi, introduced EvoCraft which is a framework for Minecraft that is created specifically to examine open-ended algorithms (Grbic D. , Palm, Najarro, Glanois, & Risi, Evocraft: A New Challenge for Open-Endedness, 2021). Minecraft permits the creation of whatever kind of structure. These creations' evolution can be either interactive or automated and both are examined thoroughly. *"Minecraft is a voxel-based environment in which the basic building blocks are different types of blocks such as wood, stone, glass, water, etc. Especially the addition of "redstone" circuit components in Minecraft (i.e., blocks that support circuits and mechanical components), has allowed players to build amazing structures, such as moving robots, fully functioning word processors, or even Atari 2600 emulators* (Grbic D. , Palm, Najarro, Glanois, & Risi, Evocraft: A New Challenge for Open-Endedness, 2021)*."*

The said paper proposed the use of Minecraft since it is a suitable environment for the ALife's study and its open-endedness characteristic. Furthermore, Minecraft, accommodates the construction of fixed set of different simple building blocks which is found as a relevant aspect of natural and biological life.

Fig. 2. *Minecraft's examples of human-built structures where on the top left shows a large moving robot* (Cubehamster, 2015)*, below it shows an Atari 2600 emulator* (SethBling, 2019) *while on the top right show a functioning word processor* (Steamed, 2014) *and below it shows a neural network digit classifier* (SirBeNet, 2020).

Artificial intelligence is quite relevant with arts and their forms as they pursued approaches in developing aesthetics and to embrace creativity fully. This AI's initiative has been successful by coming up with respective evolutionary computation and approaches which resulted to distinctive artworks ranging from diverse visual arts like paintings, designs, and even through performance art such as music.

AI Art

Fig. 3. *This figure shows an AI-generated art called "faceless portraits" by Ahmed Elgammal and AICAN which was exhibited in Chelsea Gallery, NYC* (Bogost, 2019).

The above images are part of a print exhibition called “Faceless Portraits Transcending Time” which was shown in one of Chelsea’s galleries in New York City (Bogost, 2019). At first, people would assume that these images are created using traditional arts like painting, but these are all a computer’s artworks.

AI Design

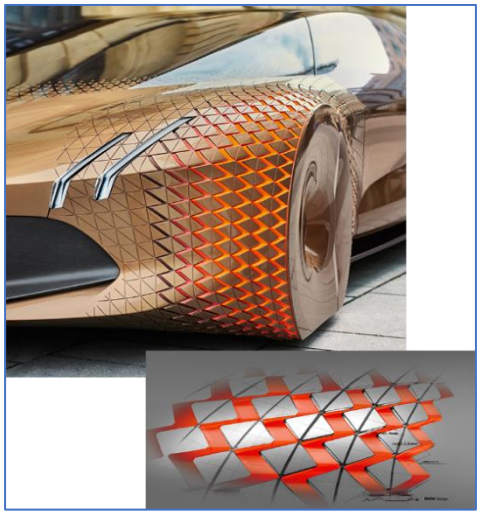


Fig. 4. *This figure shows a concept car which is called “Alive Geometry” of the BMW VISION NEXT 100 concept car which came as a result of generative design* (BMW Sheer Driving Pleasure, 2018).

The President of BMW subsidiary Designworks, Holger Hampf, together with his team, were trying to apply the techniques of generative design or making the AI design in the automotive industry be known and utilized.

AI Music

Fig. 5. *This figure shows one of AIVA’s original AI music compositions called Genesis* (AIVA, 2016).

AIVA is an AI music composer of emotional, piano, and symphonic orchestra music which was launched in 2016. In their official site, you can try and listen to any of their original compositions and are also available in YouTube such as the music below: I am AI (Variation) - Song composed by AI | AIVA - YouTube

Support in Artificial life art was shown and supported by several artists which was evident through the 1993 Arts Electronica Festival where different works were produced and created by a significant number of artists. In the year 1999, The Vida Art and Artificial Life International Awards began and its presence in the artificial life art's promotion and endorsement stays active.

Although artificial life's influence has left a significant mark in different fields like in the abovementioned examples like AI in art, design and music, its creation is said to have left implications within our society to some extent. The advancement of AI in arts, design and music quite put some uneasiness to artists, designers, and composers, who still prefer to express their creativity in a traditional way, but what if in the future, their contribution in the art and different industries could also be done and performed by AI? Could AI somehow replace people's services where their help would no longer be needed? This would leave some worry and pose some threats to some.

2.2.1 Cellular Automata

One of the most significant aspects for modern Artificial Life according to Alan Dorin, author of Biological Bits, is the cellular automata (CA). The term was introduced by John von Neumann in the 1950s, thanks to his fellow mathematician friend, Stanislaw Ulam's suggestion when he was trying to create a computer program which can reproduce itself. The main goal on his study is to determine the type of cognitive connection's fitness, wherein an automaton's self-reproducing capacity will be present.

A cellular automaton consists of a model that refers to an arrangement of cells with their corresponding attributes such as grid, state, and neighborhood.

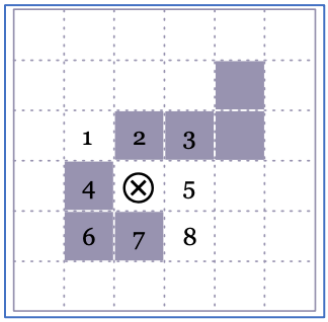


Fig. 6. *A two-dimensional array of squares is shown through a grid of finite state machines (FSMs) as presented in the figure where colored grey squares indicate ON state while white squares indicate an OFF state* (Dorin, 2014).

A known and popular type of CA is The Game of Life which was designed and introduced by mathematician John H. Conway as early as the 1970s. The rules of the said game are pretty much simple and can be described as follows (Dorin, 2014):

if (cell is OFF)
if (exactly 3 neighbors are ON) cell turns ON
else cell stays OFF
if (cell is ON)
if (2 or 3 neighbors are ON) cell stays ON
else cell turns OFF

Dorin has mentioned that some researchers perceived that the universe that we are currently living in is a type of a CA. A book called *"A New Kind of Science"* which was written by Stephen Wolfram[1] and released in 2002 contains Cellular Automata as one of the known computational systems. These systems, according to him, can be referred to *simple programs* which he strongly believes are quite suitable to other branches of science.

There are different extensions to the simple elementary CA and one of them is called **Neural Cellular Automata (NCA)**, where CA rules that each cell which is executing is replaced by a neural network. Furthermore, it is referred to something that is "*capable of learning a diverse set of behaviours: from generating stable,*

[1] WOLFRAMSCIENCE, 2021

regenerating, static images, to segmenting images and to learning to "self-classify" shapes (Niklasson, Mordvintsev, Randazzo, & Levin, 2021)*."*

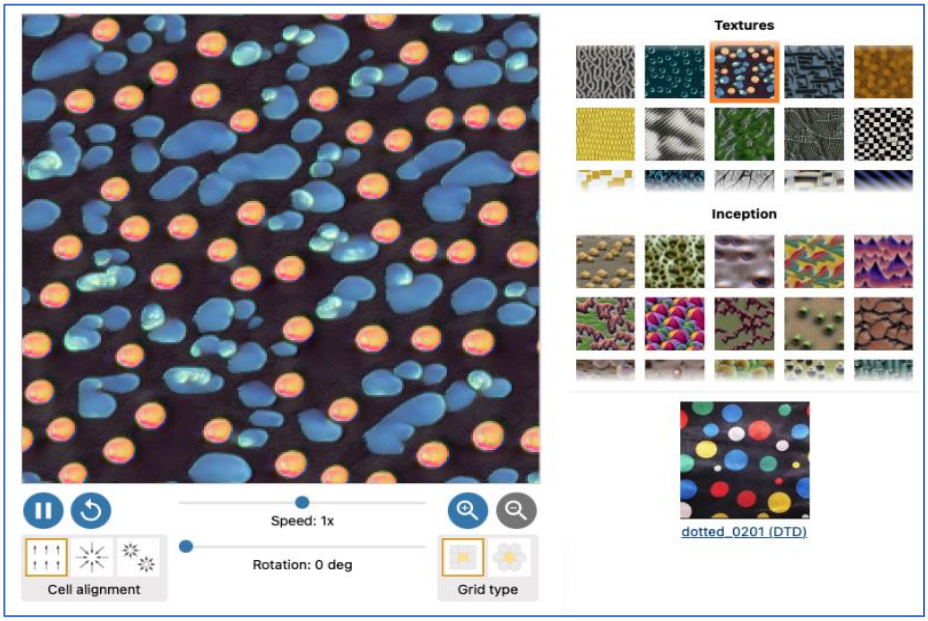


Fig. 7. *This figure shows different textures and inceptions of neural cellular automata model of pattern formation which can be found on the website called "Self-Organizing Textures"* (Niklasson, Mordvintsev, Randazzo, & Levin, 2021)*.*

Another type of CA is called **Lenia** which is described as a continuous CA family capable of producing naturalistic self-organizing and self-governed designs. These said designs or patterns which are known for being self-organized and autonomous are referred to as **solitons** (Chan, 2020).

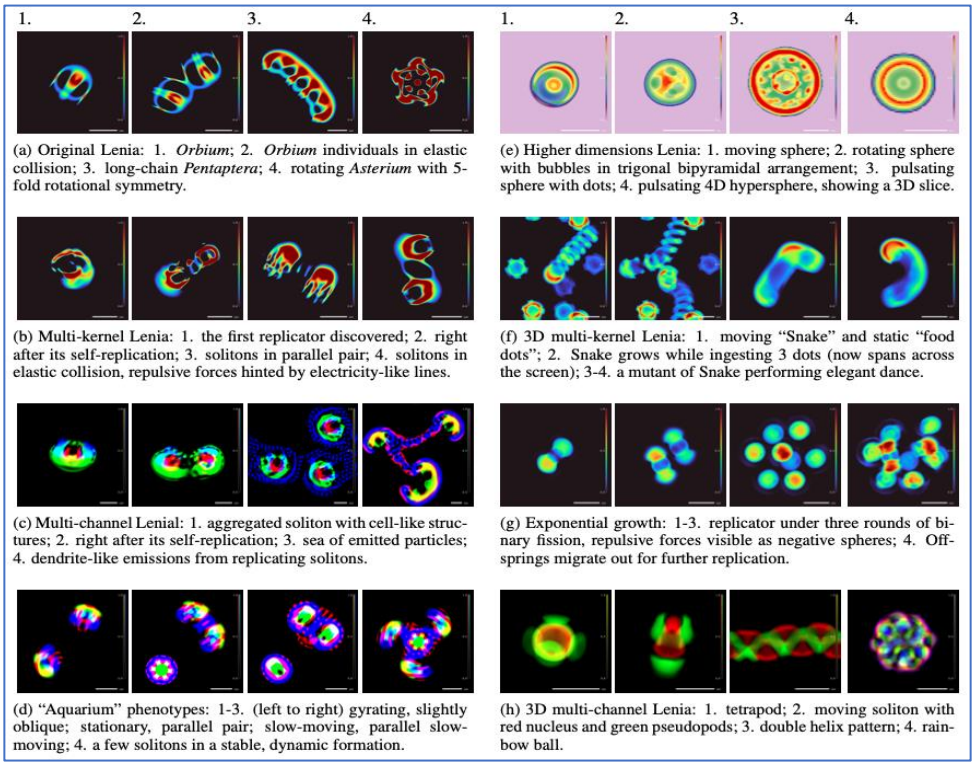


Fig. 8. *This figure shows a solitons' sample. Kernel radius R is represented through a scale bar at the lower right of each image* (Chan, 2020).

The difference between CA Lenia and Neural CA is their corresponding self-organized and self-governed designs where Neural CA focuses towards stable, finite, and fixed patterns while CA Lenia's goal is to discover new and innovative patterns and designs through the help of genetic and developmental algorithms.

2.2.2 MergeLife

Aside from these two abovementioned types of CA, there is also one that is capable of evolving continuous CA and as well being described as a genetic algorithm or GA, the **MergeLife**. This MergeLife can produce full color dynamic animations based on the aesthetic specifications by the users. There is a simple 16-byte update rule that is being presented wherein it is developed and changed through an objective function that requires only initial aesthetic guidelines from a user (Heaton, 2019). This MergeLife is the type of Artificial Life that this online experiment would be using and focusing on.

Genetic Algorithm (GA) is used to discover different MergeLife rules and according to Heaton, MergeLife can be perceived as an aid in making completely new CA that are quite alike with The Game of Life by John H. Conway. He provided complete implementations of MergeLife using different libraries in particular programming languages like Java, Python and JavaScript that are readily available on GitHub (Heaton Research, 2020).

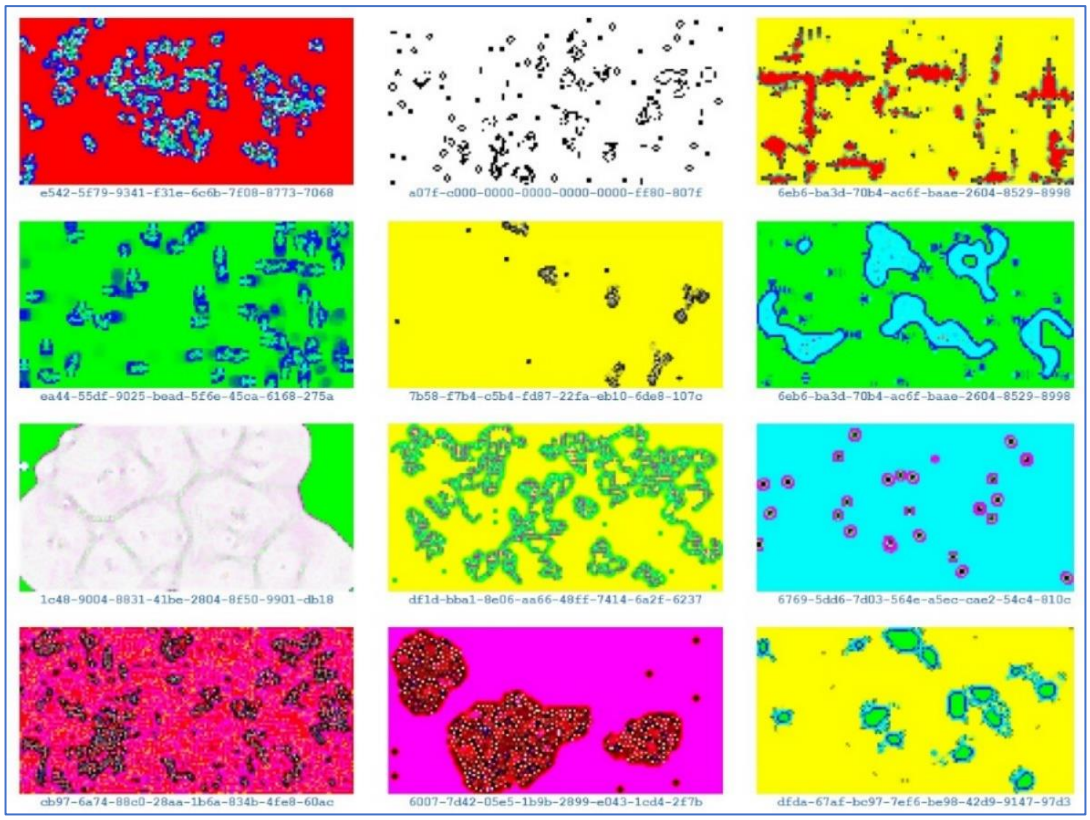


Fig. 9. *Some still images being screenshotted from the Heaton Research MergeLife official page that shows different MergeLife CA with their corresponding model that can be run by clicking the rule hex string. The images are clickable on the official page where you can run their respective CA* (Heaton Research, 2020).

MergeLife Update Rule

Both the MergeLife and the Game of Life (GOL)'s rules are said to have had the same format where GOL identifies and counts the total number of neighbors which are alive which can be selected between the four sub-rules. Each subrule in GOL indicates the corresponding cell's change of state, either it is dead or alive. Just like in MergeLife which sums the 8 neighbors' RGV values to select between up to 8 sub-rules. Any of these 8 sub-rules can identify the change to be applied to the

current cell's color to one of the 8 key-colors correlating to every sub-rule (Heaton, 2019).

High (**α**)	Range	Key-color	Pct. (**β**) (%)	Index (**Ɣ**)	Octet-1	Octet-2
216	0–215	Blue	83	5 (blue)	1b (27)	6a (106)
320	216–319	Blue	−67	4 (yellow)	28 (40)	aa (−86)
632	320–631	White	−18	7 (cyan)	4f (79)	e8 (−24)
768	632–767	Black	−65	8 (white)	60 (96)	ac (−84)
848	768–847	Red	91	2 (red)	6a (106)	74 (116)
1048	848–1047	Purple	59	6 (purple)	83 (131)	4b (75)
1088	1048–1087	Yellow	−50	3 (green)	88 (136)	c0 (−64)
1624	1088–1623	Red	−82	1 (black)	cb (203)	97 (−105)

Table 1. *This table shows the decoded MergeLife update rule (cb97-6a74-88c0-28aa-1b6a-834b-4fe8-60ac) from Heaton Research* (Heaton, 2019).

How to Decode a MergeLife Update Rule

This is the MergeLife update rule that refers to a hexadecimal string which serves as a decoding example under the MergeLife Research (Heaton, 2019):
cb97-6a74-88c0-28aa-1b6a-834b-4fe8-60ac

These update rules are encoded into hexadecimal strings made up of 8 pairs of octets that occupy a total of 128 bits wherein, these strings serve two purposes. First is the ability of the users to represent and exchange the update rules under MergeLife and the second as having this hexadecimal string that serves as a genome that the genetic algorithm (GA) applies to the crossover of two MergeLife update rules and as well to the mutation of a MergeLife update rule (Heaton, 2019).

Genetic Algorithm (GA) Design

The said MergeLife GA being used in Heaton's research is based on crossover and mutation where the MergeLife update rules are kept as arrays of a 16-byte-number

that derived directly from the MergeLife hexadecimal rule structure which has been already mentioned in the earlier part of this paper. An objective function is used to assign a score to all the genomes being used where they are classified as either superior or inferior genomes. These superior genomes are chosen to have their offspring through crossover and mutation while the inferior genomes are opted to be killed or eliminated (Heaton, 2019). This is different to our experiment since we do not use an objective function or no tournament has been carried out for scoring since the user or participant of the experiment would be the one to choose their desired update rule based on how aesthetically pleasing it appears to them. So these selected update rules will serve as the superior genomes that will be used as parents to produce their offspring while the other update rules which are not selected by the participants are the inferior genomes which will eventually die or diminish.

The Crossover of Two MergeLife Update Rules

It takes two parents to carry out this crossover wherein they are able to produce two offspring genomes which would be based or derived completely from the genomes of their parents. This crossover is done by selecting a cut point among the MergeLife 8 sub-rules wherein the selected cut point should be the same among the two parents. See example below:

Parent 1: 0de6-3496-8507-7cc7-34c6-d5a9-**bcfd**-2355
Parent 2: 8503-5eb6-084c-04df-7657-a5b3-**6044**-3524
Offspring 1: 0de6-3496-8507-7cc7-34c6-d5a9-**6044**-2355
Offspring 2: 8503-5eb6-084c-04df-7657-a5b3-**bcfd**-3524

In this example, the cut point which has been selected is the seventh sub-rule. These two parents produced two offspring wherein parent 1 produced offspring 1 where the seventh sub-rule is interchanged to parent 2's sub-rule while the parent 2 produced offspring 2 having the parent 1's seventh sub-rule (Heaton, 2019).

The Mutation of a MergeLife Update Rule

In mutation technique, a single parent's update rule will have a random shuffle among two values within the hexadecimal string to produce its offspring such as below:

Parent 1: d8a**b**-8915-629**7**-2248-6055-fc87-ef92-15f5
Offspring 1: d8a**7**-8915-629**b**-2248-6055-fc87-ef92-15f5

If you want to check how this parent 1 and offspring 1 look like after their mutation, the MergeLife Rule Viewer can be used and you will notice the much more organized CA of the offspring after shuffling these two values from its parent wherein, the parent's update rule appears to be quite turbulent and disorganized (Heaton, 2019).

2.2.3 Art and Artificial Life Collaboration

Since Artificial Life and Artificial Life Art, have both existed for quite such a long time now, 20 years to date, their emergence, collaboration with other fields as stated on the earlier parts of this paper and as well their evolution became evident in today's technology.

Artificial Life is considered as a path that is not quite easy to pursue especially for people who do not have enough familiarity of how it works, thus, making it to appear quite challenging. But it is not impossible since Art can have a beautiful collaboration with Artificial Life where an artist and a computer scientist's partnerships could lead to an aesthetically successful artwork or project.

Artificial Life works are often considered or perceived exclusively with practices which had just something to do with computers, robotics, systems, and other technological programs in the late 80s. But fortunately, this has changed over the years and many research and discussions were carried out to allow the emergence of communities among the arts and computers' collaborated works.

When artificial life and arts meet, creative and different art forms can be a result since artificial life is said to have an essential concern with nature's natural power and creativity. And arts on the other hand is said to be generative especially if they are created according to identified and specific rules, this is where artificial life and arts can walk hand in hand.

2.2.4 Artificial Life Development

Life is the most significant facet of the universe's existence, and this is where artificial life focuses on and is continuously providing collaborative studies and significant changes to different technological fields in the past and up to present.

There are three extensive and interconnected branches of artificial life such as soft, hard, and wet artificial life where each of them has their own features, attributes and corresponding artificial approaches. In addition, cognitive science is also said to be quite related and rooted similarly with artificial life wherein possible multiple connections are highly anticipated to materialize in the future.

Soft: Software-based
This type of Alife is focused with software which cover computer simulations. There are three techniques which are existing and available such as cellular automata (CA), artificial neural works and neuroevolution. This paper will use this type of Alife where its focus will be based on CA since the latter and Alife share a tight history together.

Hard: Hardware-based
This next type of Alife is concerned with hardware implementations of life-like systems like robots and as well on developing new computing architectures or frameworks.

Wet: Wetware-based
The third type is concerned with wetware wherein scientists would like to combine chemistry and biology to be able to create life from scratch

Artificial life has evolved through the years and many of its influences are present from multiple areas and developments ranging from the language that people use, synthetic cells and even down to complexity's advancement. These artificial life's continuous progress and innovations might also lead to the change of how we perceive cognitive science in the future.

2.3 Evolutionary Computation and Digital Evolution

Since this thesis is focusing on artificial life in art, the next topic to be discussed is a subfield of artificial intelligence which is an evolutionary algorithm that aims to provide solutions to real world problems. Nature possesses aesthetics which are quite diverse and constantly encountered by any individual but unfortunately, these are only seen and appreciated on the exterior part. People tend to overlook that nature's beauty consists of multiple layers wherein there are different natural processes and patterns which can all be combined in creating the said stunningly beautiful nature. As nature is not only sensory but as well a feeling, it would be hard to be replaced by something man-made since its beauty comes after its natural or intrinsic characteristic.

These natural processes and patterns are referred to the activities of **biological evolution** which is defined by author Jeffery as *"the change in inherited traits over successive generations in populations of organisms. Evolutionary modification of traits occurs when variation is introduced into a population by gene mutation or genetic recombination or is removed by natural selection or genetic drift* (Jeffery, 2012)*."*

This genetic change in the population would always be inherited over the succeeding generations which might range from small or large scales of changes. These changes can be easily observed, distinguished or unidentifiable at all.

The English naturalist Charles Darwin developed a theory called Darwinism (The Editors of Encyclopaedia Britannica, 2021) which is a theory of biological evolution.

Natural selection is highly believed to be the main force of this theory under evolution wherein organisms are capable to change and adapt to their environment to survive and multiply their kind.

Individuals in each population are said to be changeable and adaptable or in short, they are quite unique and different in some ways. These differences could lead for these individuals to have better or more suited capabilities to adapt and survive to their environment.

There are four (4) requirements which should be present before natural selection is substantiated in evolution such as the following (Dorin, 2014):

1. Every individual within a given population differs from one another.
2. Most of the differences are passed on by both parents to their offspring.
3. Some characteristics like being able to succeed, survive and reproduce more are present to some individuals more than others.
4. The different characteristics and traits inherited by the offspring from their parents lead them to be successful, survive and later pass on these characteristics as well to their future offspring.

Digital Evolution

The beauty and creativity of evolution is not strictly limited to the natural world but wherever applicable since evolution can happen where selection, imitation and adaptation have a crossover (Lehman, Clune, & Misevic, The Surprising Creativity of Digital Evolution: A Collection of Anecdotes from the Evolutionary Computation and Artificial Life Research Communities, 2020). This is called digital evolution wherein evolution is externalized digitally but still has a similarity to biological evolution due to its experiments' results which tend to be creative, random, and unpredictable.

A book called *Adaptation in Natural and Artificial Systems* was written by John Holland in the year 1975 wherein a method of problem analysis based on Darwinian natural selection was introduced and was referred to Genetic Algorithm (Penny, 2009). In the said system, an evaluation is carried out based on a particular criterion towards a population with their corresponding characteristics, those which fall under

the set criterion are determined to be the most likely to succeed and survive. Evolutionary algorithm results from the very thought of digital evolution's various processes which are responsible for carrying out roles from selection, duplication, and adaptation. **Fig. 10** shows and explains how evolutionary algorithm works, with its algorithm cycles from the beginning which is the initialization down to the final stage which is survivor selection.

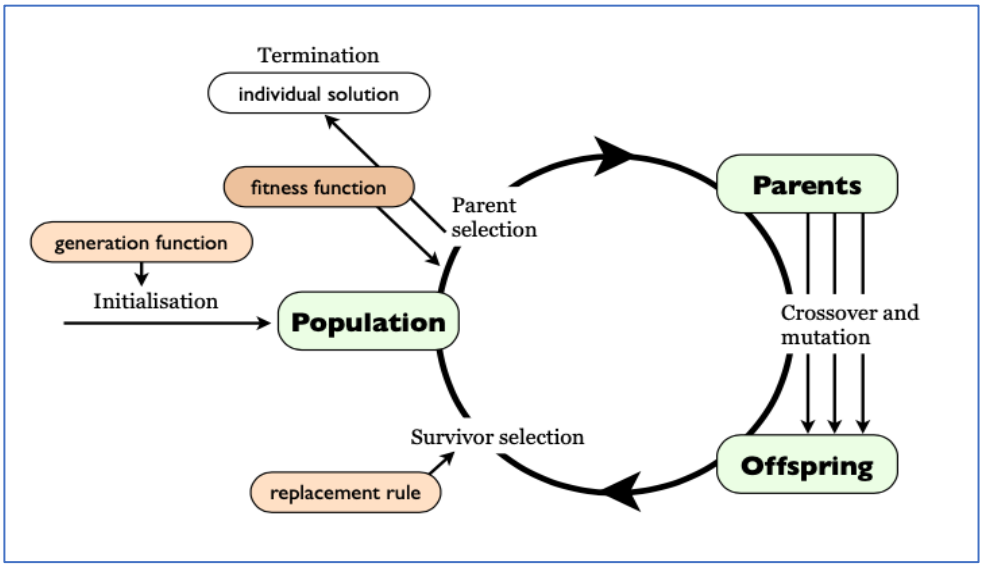


Fig. 10. *This figure shows the evolutionary algorithm cycles as illustrated from Dorin's book called Biological Bits* (Dorin, 2014).

Biological evolution's creativity is not limited to its own physical medium but as well a present feature to digital evolution, thus, researchers from the digital evolution field believe that evolution's creativity does not need to be restricted in the natural world but as well can be externalized digitally (Lehman, Clune, & Misevic, The Surprising Creativity of Digital Evolution: A Collection of Anecdotes from the Evolutionary Computation and Artificial Life Research Communities, 2020).

One of the most known examples of a design made with evolutionary algorithms is the automated and fight antenna that successfully flew on NASA's Space Technology 5 (ST5) mission presented by NASA Ames Research Center.

"NASA's Space Technology 5 (ST5) mission is part of the New Millennium Program, and its goal is to launch multiple miniature spacecraft to test, demonstrate and flight qualify innovative concepts and technologies in the harsh environment of space for application to future space missions. The ST5 mission consists of three miniaturized

satellites, called micro-sats, which measure the effects of solar activity on the Earth's magnetosphere over a period of three months. The micro-sats are approximately 53 cm across, 48 cm high and, when fully fueled, weigh approximately 25 kilograms. Each satellite has two antennas, centered on the top and bottom of each spacecraft (Hornby, Globus, Linden, & Lohn, 2006)*."*

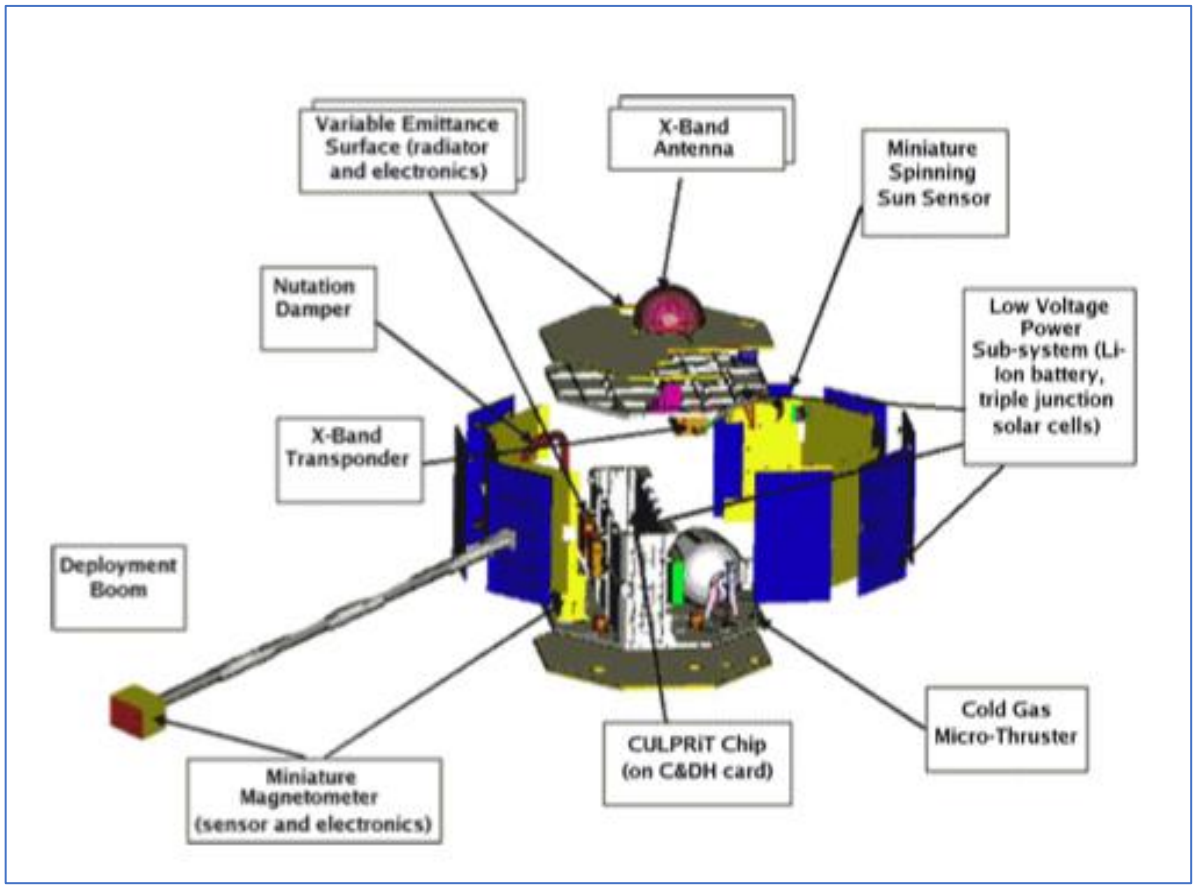


Fig. 11. *This figure shows an artist's depiction of the spacecraft model showing the different spacecraft components* (Hornby, Globus, Linden, & Lohn, 2006).

Evolutionary algorithms and their said family which can be identified into five (5) such as genetic algorithm (1), genetic programming (2), differential evolution (3), the evolution strategy (4) and last but not the least, the evolutionary programming (5), are various techniques which are used and applied to different applications in the industry (Kwasnicka H. & Slowick, 2020).

Despite the basic differences between biological and digital evolution, the differences between how the organic world and nature build things and the way man-created systems build things, it is true that digital evolution has been influenced and got its inspiration to what the biological evolution does and performs.

Digital evolution finds suitable solutions by exploring a fitness landscape. In fitness landscape, the existing solutions in each problem, although they may not be the best, can still be improved. This optimization algorithm can increase the level of improvement to the present poor solutions by continuously discovering the best and adequate solutions. The higher the fitness, the higher the possibility of providing success in reproduction (Dorin, 2014).

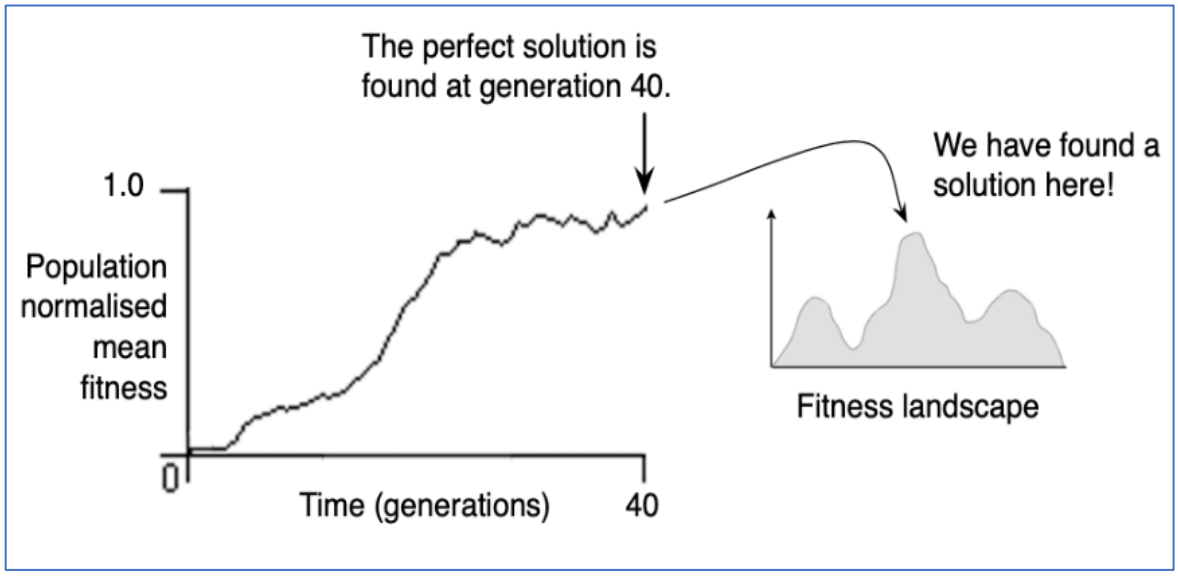


Fig. 12. *This figure is an example of a fitness landscape: A Fitness vs. Time Plot from Dorin's book called Biological Bits* (Dorin, 2014).

"A fitness vs. time plot for an imaginary evolutionary process within a stable environment. At generation 40, one or more members of the population are born that exhibit the optimal value of the trait(s) depicted in the fitness landscape (Dorin, 2014)."

2.4 Interactive Evolution and Novelty Search

This is the part where the thesis is going to delve into creating an environment where users would be allowed to explore their creative side by having their own input or participation in the generation of an interactive art. **Interactive Evolutionary Computation (IEC)** is also called as **aesthetic selection** where the fitness evaluation is replaced by a human evaluation. This kind of human evaluation, from

the word itself, is called aesthetic due to its assessment towards a particular object's attractiveness and visual appeal.

An individual's creativity varies in extents and levels but with aesthetic selection, a particular software like Picbreeder, can generate aesthetic forms by having specific user to select them while on the same time being bred by the computer automatically. The assessment is done through an individual's unique own taste, creativity, and preference. With this, it is quite hard to put a limit and this selection could be vast.

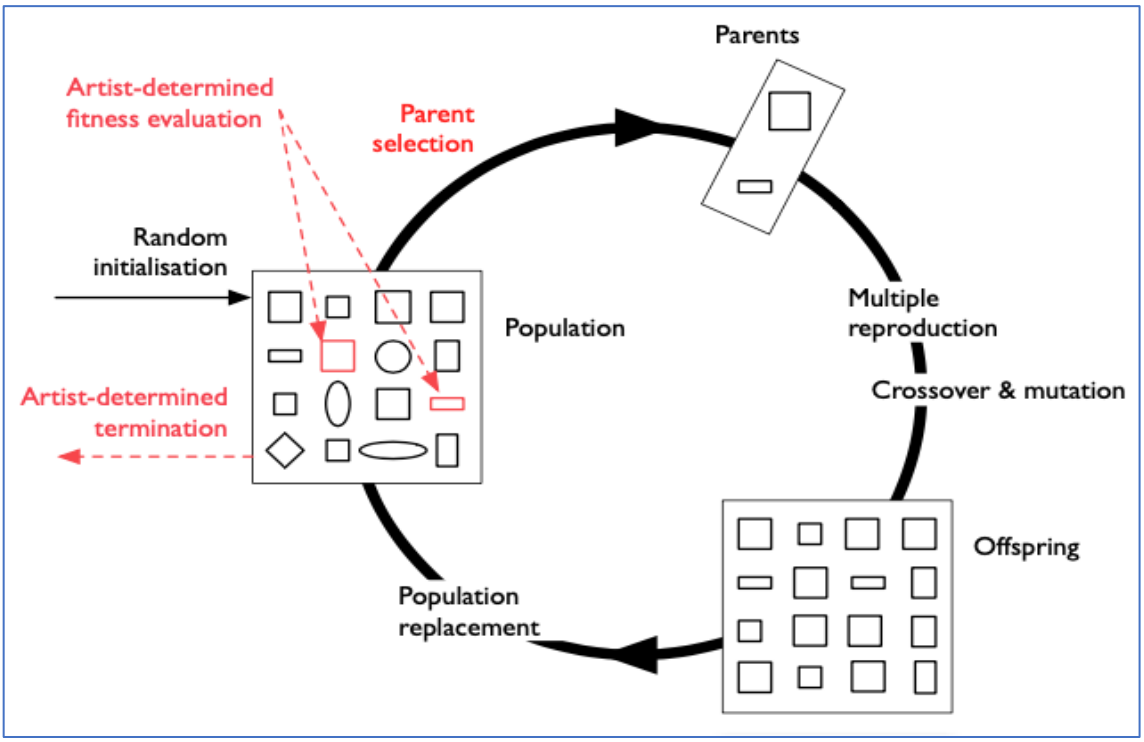


Fig. 13. *This figure shows an artificial evolution of shapes using purely aesthetic criteria for fitness from Dorin's book Biological Bits* (Dorin, 2014).

A random initialization of a given population of forms will begin its process wherein a user will choose any form that he or she prefers manually. This principle under aesthetic selection is introduced by a zoologist named Richard Dawkins and was evident in his invented interactive software released in the year 1986 called *The Blind Watchmaker* (Dorin, 2014).

An example of interactive evolution is Picbreeder. *"It is a collaborative art application based on an idea called* ***evolutionary art****, which is a technique that allows pictures to be bred almost like animals. For example, you can evolve a butterfly into a bat by selecting parents that look like bats* (Picbreeder, Inspired by how organisms evolve and complexify in nature, 2021)*."*

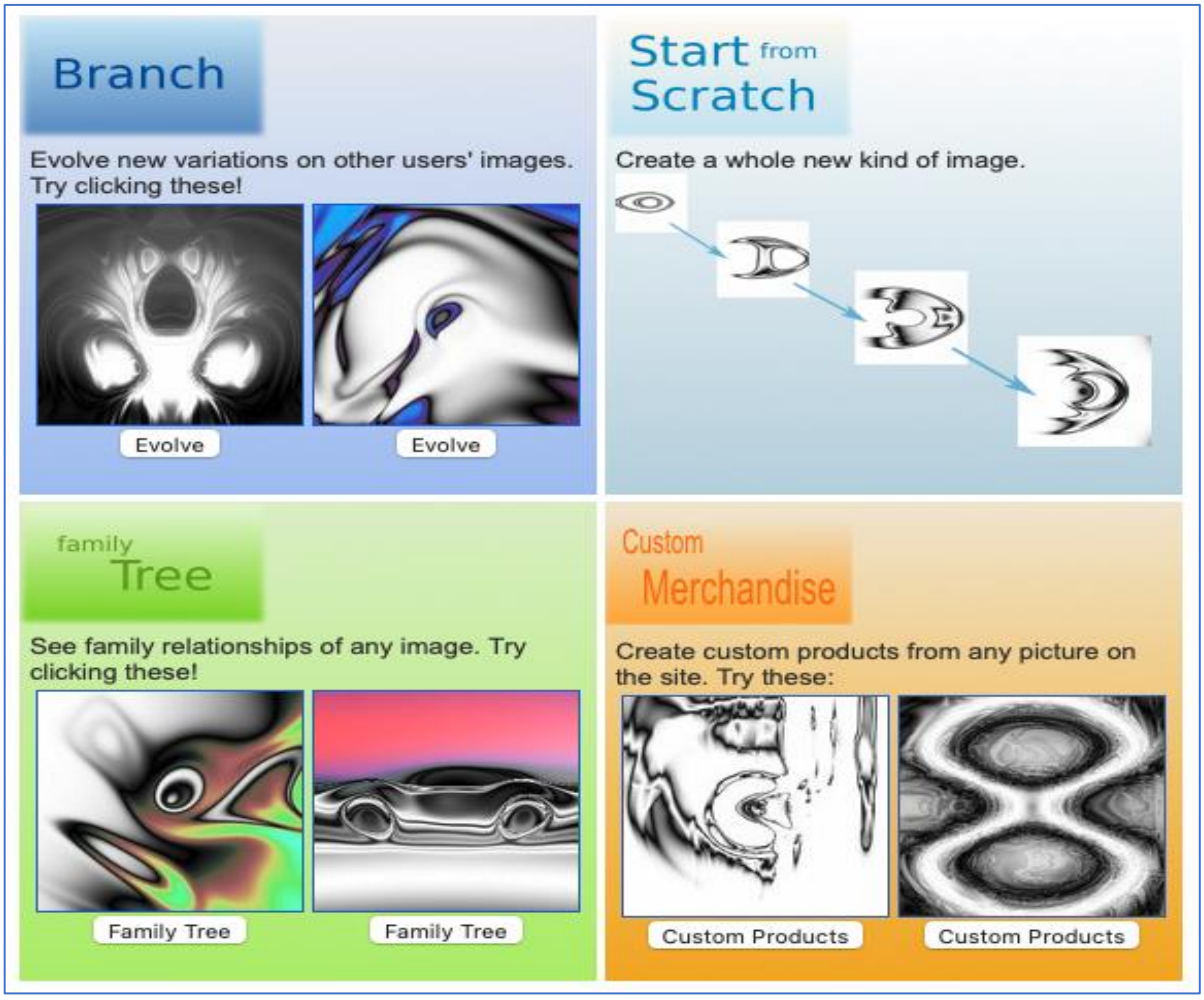


Fig. 14. *This figure shows the top categories of evolutionary arts in Picbreeder platform* (Picbreeder, Inspired by how organisms evolve and complexify in nature, 2021).

Picbreeder is one of the best examples of a collaborative interactive evolution and has been successful in showing that individuals have the capability to uncover multiple, complicated, and yet exciting characteristics and traits of the available organisms in the platform. Picbreeder's innovative approach makes it look visually appealing and adds surprise to the users where they can let their creativity and imagination contribute to the final artwork in the platform.

One of the most significant aspects when creating computational algorithms dedicated to art is the ability to comprehend and measure up an individual's creativity and imagination. In line with this, a paper which is called *Unplugging Evolutionary Algorithms: an experiment on human-algorithmic creativity* was published in 2014 which aimed to provide the emergence of new and evolutionary approach to creativity and art from an evolutionary point of view as well by different artists aside from their beliefs, inspirations, and practices.

"This paper describes the motivation, methodology and the experiment leading to XY a collective work produced by an adapted version of the Interactive Evolutionary Algorithm (IEA) that eventually became the EADCC 2013 award-winning. The work focuses on the algorithm when it is run outside of the computer, giving rise to the Unplugged Evolutionary Algorithm, and the lessons we can learn when applying it (Fernandez de Vega, et al., 2014)*."*

The work was created by a total of six people where five are artists and the other one is a coordinator with a collective work consisting of 50 varied paintings. The methodology which the team used, and the experiment carried out, led them in producing collective artworks and information on the creative process that these artists developed based on the evolutionary algorithm's perspective. The team evaluated both the information they received from all the participating artists with their corresponding artworks together with the public opinion's take about the results.

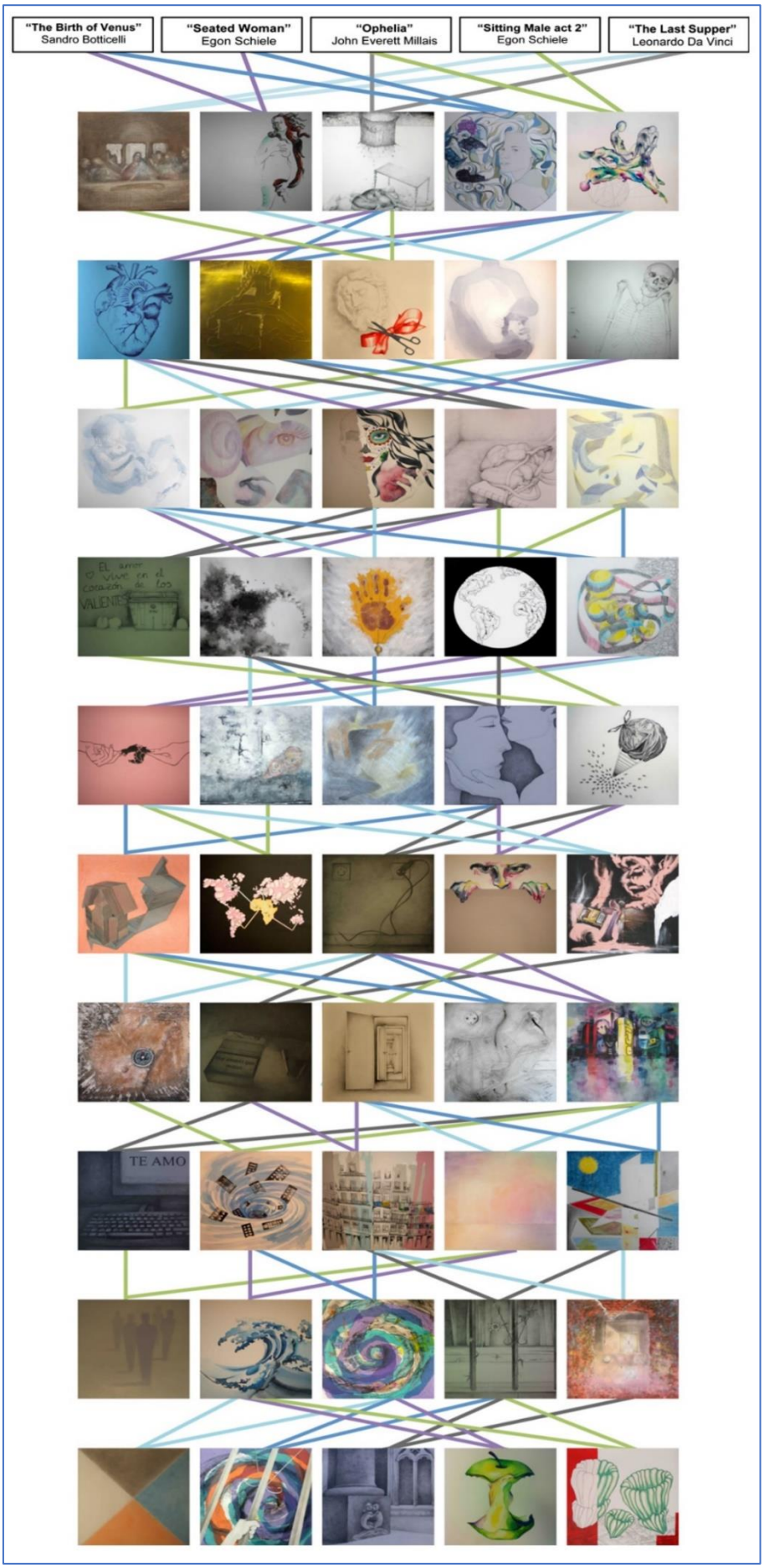


Fig. 15. *This figure shows the 50 varied paintings, the collective work of the five artists and a coordinator that shows their artworks' genealogy ranging from top to down initial population, from genealogy number 1 to number 10* (Fernandez de Vega, et al., 2014).

Novelty Search

Every experiment in digital evolution is run and performed through what we referred as fitness function in the world of artificial intelligence. In line with this, each experimenter has a clear and absolute objective being perceived which is contrast to novelty search that is not driven by objectives.

It is said that the most fundamental pattern in evolutionary algorithm is to ultimately search for a defined and fixed objective which could possibly lead to limitations of goals to be attained. Evolution and developmental processes in biology are described to be open-ended and do not possess a fixed objective, thus, the kind of algorithm which can be applied to this case is the novelty search.

According to Lehman and Stanley who define novelty search as a divergent evolutionary technique which contrasts with most evolutionary algorithms which all described as convergent. Behaviors which are different, new, and innovative are rewarded instead of the progress being attained towards the defined and fixed objective. Thus, novelty search is said to be highly inspired by natural evolution's motivation towards novelty and uniqueness (Lehman & Stanley, Beyond Open-Endedness: Quantifying Impressiveness, 2012).

2.5 Concepts from Statistics: Hypothesis Testing and Power Analysis

A power analysis in every experiment is an essential measure that every researcher should carry out since it is capable of determining which sample size will provide a high probability for the null hypothesis to be correctly rejected. In line with validating the outcomes in our research, we will perform a hypothesis testing which will be identifying an experimental hypothesis and a null hypothesis. The result should just support one hypothesis, thus, the other one would be rejected.

There are two hypotheses that a hypothesis test is made up of such as the null hypothesis and the alternative hypothesis. The null hypothesis refers to the existing

or present situation that everyone is assuming to be true until you came and contest it (Rumsey, 2009). The alternative hypothesis on the other hand refers to the alternative version or the opposite stance of the null hypothesis or where researchers will provide any proof to disprove or invalidate the null hypothesis (Rumsey, 2009).

Our experiment aims to support the experimental hypothesis and reject the null hypothesis wherein it claims to not have any differences or effects in the outcome between two groups in any given experiment like the control and test group. The control group experiences no intervention compared to the test group where intervention is present and implemented. If the researcher would like to support the null hypothesis, he is validating and accepting the claim that there is no difference or any effect that can be detected (Rouder, Speckman, Sun, Morey, & Iverson, 2009). Just like in our experiment, the null hypothesis would be not having any differences or effects when it comes to completing the two types of AI algorithms towards the experimental or test group versus the control group in expressing their artistic creativity.

The assumed experimental hypothesis that we would like to support and validate is that there is a possible effect or difference which can be identified after our experiment is completed. We would like to assume that the experimental hypothesis can be that the use of the two types of AI algorithms allows participants to distinguish which one is effective in how their artistic creativity is best expressed. If this experimental hypothesis is accepted, the null hypothesis will be rejected then but if there are no effects or differences present in the experiment's result, the null hypothesis will therefore be accepted (Rouder, Speckman, Sun, Morey, & Iverson, 2009).

In every experiment, it is quite significant to have a better understanding of the data collection and data analysis through the different statistical tools used in providing information about all the data collected. These tools can range from the mean or the average reflected from the values, standard deviation, confidence intervals, p values, which can all be useful for hypothesis testing whether you'd accept or reject the null hypothesis.

Mean – is also referred as the arithmetic mean or an average which is being used when there is an equal or normal distribution spread of the data (Harris & Taylor, 2021).

Standard Deviation – is said to be used when there is a normally distributed data or the one that is used for indicating how much a set of values is spread around the average or mean (Harris & Taylor, 2021).

Confidence Intervals – instead of normally having the mean or average value of a given sample, these confidence intervals are used when we would like to have a range containing probable population's true value (Harris & Taylor, 2021).

***P* Value** – since the null hypothesis claims to have no differences or effects between two treatments, we would like to validate how likely this said hypothesis is true through the use of a *P* Value that allows probability of any identified difference or effect occurring by chance (Harris & Taylor, 2021).

Power Analysis is involved in estimating any of these four different experiment parts such as (1) effect size, (2) sample size, (3) significance and (4) statistical power which is said to be an effective tool in both the design and analysis of any experiments that we would like to gain knowledge and interpretation of by using statistical hypothesis testing (Anand, 2020).

In the following chapter, we go into and talk about the methodology and experimental design used in our research.

Chapter 3

Methodology and Experimental Design

3.1 Overview

We conducted an experiment to show how artificial life and interactive evolution together with universal design are capable of helping people, both abled and disabled express their creativity and to produce artistic outputs using the MergeLife Project (Heaton Research, 2020).

The experiment is based on an online platform which has been created specifically to implement the creation of visual art based on MergeLife Project (Heaton Research, 2020). The main objective of this research is to provide a way for art creation where any individual - abled or disabled - is capable in expressing their creativity and be satisfied with the result.

To measure the level of their satisfaction based on their art creation and creativity, we have introduced a short online survey for both the control and test group which can be found under the appendices, see Appendix C. For the rest of this section, we are presenting a description about the experiment process, participants' recruitment and the usage of the online platform that is accessible to all the participants and as well the approach for data collection and analysis.

3.2 The Participants

We recruited a total of 34 participants for the online experiment, where all of them are used both for the control and test group. The participants are OsloMet's master students, employees and as well some who are outside OsloMet such as working individuals where age will range from 25-45 years old. All the participants are invited through email within OsloMet and as well through social media for those participants that are not students or employees from OsloMet and are already working either

here in Norway or back in the Philippines. All these participants are invited to join the experiment through email and social media, particularly on Facebook where they are directed to a consent form through *nettskjema*[2] where additional information such as the purpose of this experiment is introduced, their names and email addresses are asked as well for contacting purposes.

3.3 Ethical Requirements and Data Management

Due to any ethical issues which could transpire within any given experiment, we would like to ensure that such would not happen by registering to NSD (Norwegian Centre for Research Data) and have our experiment be approved first by them before recruiting participants. With such, all the data to be collected from the participants would be safely kept and stored with the said institution. As mentioned earlier, a consent letter through *nettskjema* is sent and shared to the participants for them to fill out and have a deeper understanding of what this experiment is about and as well the goal it aims to reach. NSD application form and as well the nettskjema consent form are shown under the appendices of this paper, see Appendix A (NSD Application) and Appendix B (Nettskjema Consent Form).

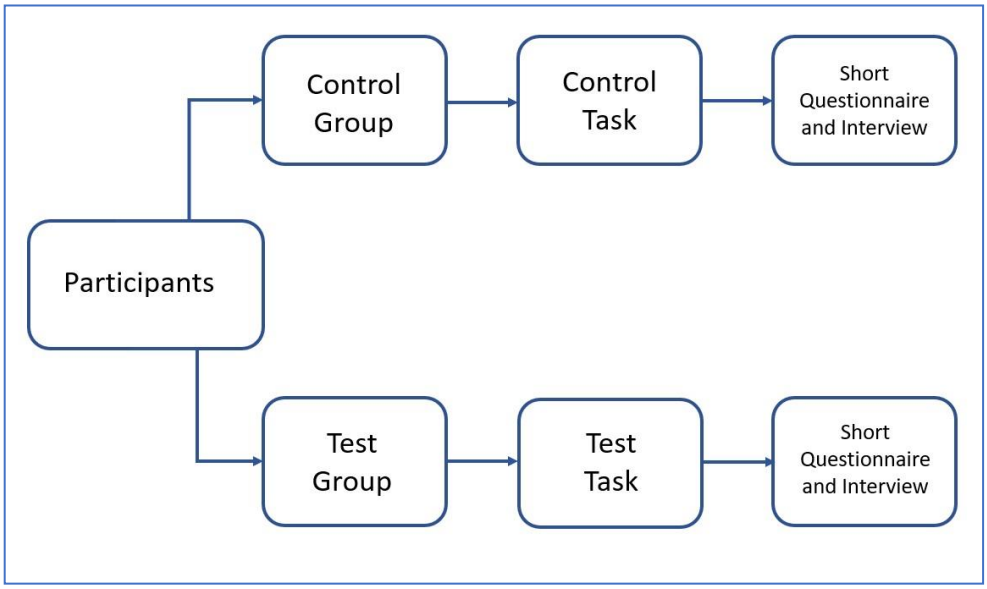


Fig. 16. *This figure shows the experimental design of this study.*

[2] UiO: University of Oslo, 2021

We are recording the data based on the short online survey that we are providing both for the control and test group after each experiment and they are stored and kept in Google Forms where they are organized and analyzed accordingly. The forms are separated for each type of experiment where the first batch of the 34 participants, the first 17 started their experiment with performing the control group first then followed by the test group. The second batch or the remaining 17 participants did the opposite wherein, they started the experiment with the test group first which is then followed by the control group. All the 34 participants performed both the control and test group and the data to be collected based on their answers from the short online survey after each experiment, are strictly kept confidentially to preserve the integrity of the data to be collected and for the short online survey to be carried out legally and ethically. To ensure the integrity and security of all the data to be collected from our experiment, we have sought permission from NSD (Norsk Senter for Forskningsdata) (NSD, 2021) which is an organization that ensures safekeeping and ethical collection, storing and sharing of data from people within the society. They are responsible as well in making assessments for any project that requires publishing of data collection that it has met all the legal and ethical requirements to do so. This experiment has an application reference number from NSD which is **885778** which has been assessed and approved last 02 December 2021. The said NSD application can be checked and seen under this paper's appendices, see Appendix A.

3.4 Equipment, Online Platform and Short Online Survey

Since the experiment is done online, participants can browse and access the link to the experiment through their desktop computers or laptops running either with windows or macOS with an internet connection or WIFI to access the link online. The online platform is accessible using any internet browser that the participant preferred to use but not recommended to be opened using their smartphones, tablets or iPads since they are not compatible with the online platform's program. Our experiment will be based on the MergeLife Project where our online platform uses evolutionary algorithms in generating images based on these MergeLife update rules and for describing local updates for cellular automata (CA). All the participants performed

the said two experiments which are under the control and experimental or test group. The 17 participants out of the 34 registered ones started the experiment with performing the control group followed by the test group, while the remaining 17 participants started with the test group then followed by the control group. This is to check if there would be any differences or effects with the results upon carrying out the two experiments in different order among the participants. Input devices from the computer or laptop such as a mouse, a mouse pad and a keyboard are needed for the participants to enter their chosen images with their corresponding MergeLife update rules and to confirm their selections and as well completing and answering the short online survey within the whole experiment.

3.4.1 Data Analysis and Visualization

After our data collection from the total 34 participants, we imported the data from the online platform which is the list of all the saved MergeLife update rules under the test group and as well their answers from the short online survey which are stored and kept in Google Forms.

We used **Box Plots**, one of the available and recommended charts called Box & Whiskers under Microsoft Excel, which is used to provide a graphical representation of various numerical values within any given dataset. In the box plot, the numerical data is divided into three quartiles such as the first quartile (the top line on the box), second or median quartile (the middle line on the box) and the third quartile (the bottom line on the box) while the maximum (on top) and the minimum (on the bottom) values are represented with small horizontal lines which are also called as the whiskers. We used the box plots to visualize the data that we collected from the two experiments, control and test groups from all of our participants' answers to the short online survey for each experiment group.

The list of questions under the short online survey which is provided among all the 34 participants is presented below and the real short online survey form (Google Forms) is available under this paper's appendices. See Appendix C.

3.4.2 Short Online Survey

1. Concerning the last set of images, how satisfied are you with your artwork's final result?
    - Very satisfied (++)
    - Satisfied (+)
    - Neutral (0)
    - Not so satisfied (-)
    - Not satisfied at all (--)

This question is more important and more relevant to the test group since the participants' selections will influence the proceeding images (MergeLife update rules), thus, it's their own selections which will contribute completely to their artwork's creativity. But to check if they can notice or identify it, the control group has also been asked with this question where any of their selections are quite unrelated to the proceeding real-time executions of MergeLife update rules through those animated images being provided to them.

2. How much do you feel that your selections influenced the process of selecting the sequence of images?
    - Strong positive influence (++)
    - Weak positive influence (+)
    - No influence (0)
    - Weak negative influence (-)
    - Strong negative influence (--)

This question is asked both for the two experiments, the control group and the test group. This question aims to identify the participant's ability to distinguish the relevance of their selections to the proceeding MergeLife update rules and see if they will find more satisfaction if what they are choosing are the ones being used for future art creation and not with the control group where they are provided with random images with their corresponding MergeLife update rules. These MergeLife update rules under the control group, find no relevance among the participants' selections at all.

3. Concerning the last set of images, please select from the following characteristics **the one** that best describes your artwork's final result:
    - Still images
    - Geometric images
    - Random images
    - Periodic or repeating patterns
    - Lifelike patterns or shapes

The animated images that they are selecting both on the control and test group are all representing the real-time executions of MergeLife's CA which will start with running the rule and will end or stop at some point around a few seconds later, making them look like still images. But it depends on the participants if how they would find these different update rules based on their aesthetic attributes. These five options are the possible ways of describing these update rules and how they appear to the participants.

Chapter 4

Implementation of the Experimental Interface

The online platform used in carrying out the two experiments such as the control and test group, is created and inspired from Jeff Heaton's MergeLife Project (Heaton Research, 2020) wherein MergeLife is identified as one of the family members under cellular automata (CA). Each of this said family is represented by a hexadecimal code that is synonymous or a representation of the MergeLife's update rules. Under the MergeLife Project, the author was able to locate over a thousand MergeLife update rules which are all visible and available in GitHub. With our online platform, the update rules are set randomly using the hexadecimal rules consisting of 8 subrules. MergeLife update rules are also said to have been identified through the use of Genetic Algorithm (GA) where it is considered as a means of Cellular Automata (CA)'s creation comparable to the most popular form of CA, The Game of Life by John H. Conway.

The interface is accessed by the participants using their preferred browser online using their desktop computer or laptop only since the interface is not compatible with mobile and has been mentioned through email when they are given the link for the experiment. The total 34 participants were divided into 2 where the first half or the first 17 participants were sent a link for the control group where the experiment is performed first with the control group, then followed by the test group. The link of the said control group can be accessed using this link: https://merge-life.github.io/a/index.html. The second half or the remaining 17 participants were sent a link where they were asked to do the experiment under the test group first, then followed by the control group. The experiment under the test group can be accessed through this link: https://merge-life.github.io/b/index.html. A short instruction is shown before proceeding with the experiment explaining to the participants that they will perform two different experiments where each one is followed by a short online survey. They are also informed that one of these two experiments will use an interactive evolutionary algorithm where the successive set of images will be based

on their previous image selections. The 17 participants out of the total number of 34 participants started with the control group wherein participants are asked to select two real-time executions of MergeLife cellular automata rules out of the eight provided ones which appear the most appealing or aesthetically pleasing to them within ten continuous sets. The canvas size that refers to each box containing its corresponding MergeLife update rule has a width and height of 250 cells and the reason why we chose to use only 8 is due to the screen's compatibility. We would like all the 8 canvases to be visible right away without using the scroll bars by scrolling them up or down for the ease of the participants, requiring them only with less physical effort through using the mouse or the mousepad. Also, we want all the MergeLife update rules' executions to be seen all at the same time where scrolling the screen up or down will make the participants miss how these canvases look like with their fast execution of their corresponding MergeLife update rules. Each canvas corresponds to random MergeLife update rules coming from the 16-byte digits which derived directly to the hexadecimal strings. There are eight random update rules canvases, labeled from 1 to 8, provided for the participants where they can enter to the two provided text boxes the canvas numbers which appeared the most appealing or aesthetically pleasing to them then a confirmation button to submit their selection. This would be done until the 10^{th} set is reached and completed. After the control group is done, it would be followed by an experiment that uses an interactive evolutionary algorithm which is the test group wherein, the participants are asked to select again two real-time executions of MergeLife CA rules being represented by those 8 canvases that look the most aesthetically pleasing to them, but this time, instead of random MergeLife update rules to be provided after their selections, crossover and mutation of the two selected update rules by the participants would lead to offspring where the selected parents would always be shown together with their corresponding offspring taking the 25%, half or 50% would always fall under the crossover and the rest which consists of 25% is for the mutation. This would be done within the 10 sets of the MergeLife update rules being represented by the 8 canvases where parent 1 and parent 2 would be selected by the participants as the two most aesthetically pleasing canvases, and from there, the crossover and mutation would take place, leading to their corresponding offspring. Then the second half or the remaining 17 participants can perform the two experiments the other way

around, where they can perform the test group first then to be followed by the control group.

Once they are done completing each of the two different experiments, a short online survey is shown on the screen after each experiment where they need to input their answers.

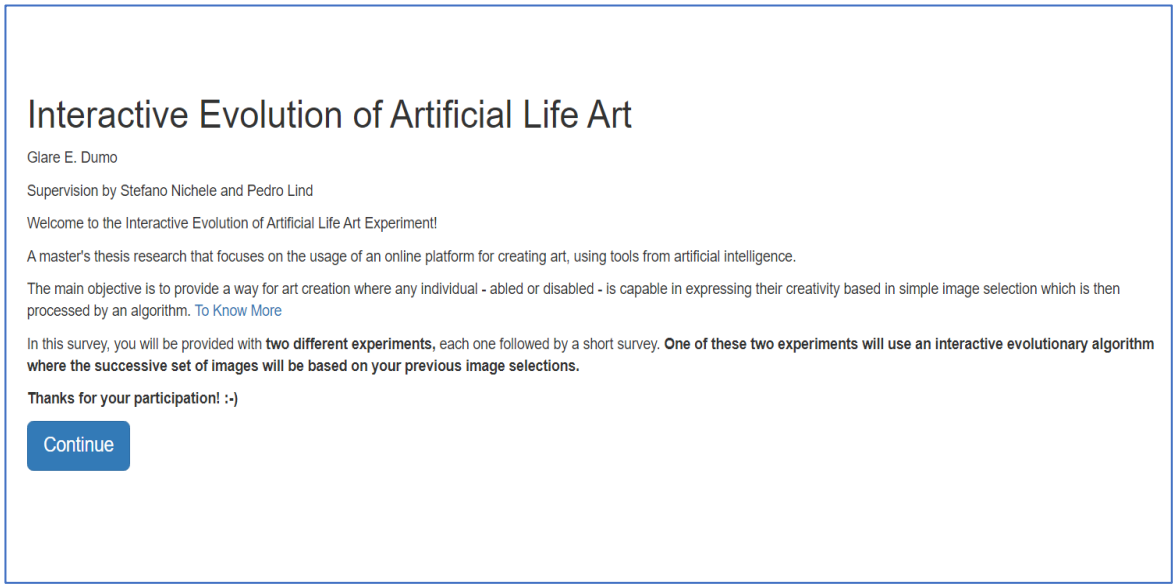


Fig. 17. *This figure shows the first or welcome page of the online experiment where when the participants click the hyperlink* ***To Know More****, they will be directed to another tab where they can read more about the experiment.*

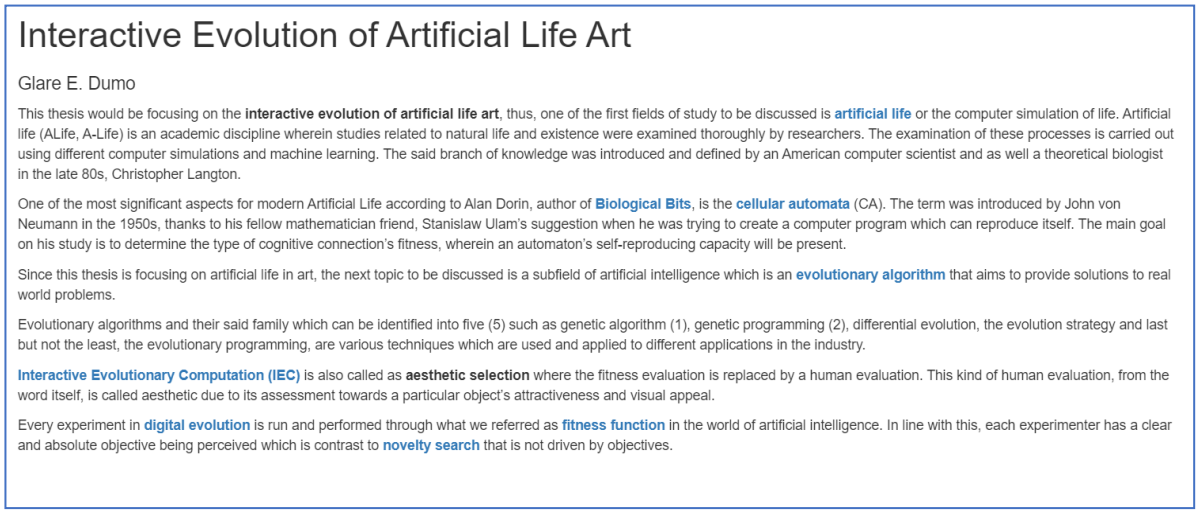


Fig. 18. *This figure shows the content under the* ***To Know More*** *hyperlink from the first or welcome page for any participants who would like to gain more information about the thesis.*

4.1 Control Group

But for those who would just want to go straight to the experiment, they just need to click the Continue button so they can proceed to one of the two experiments. There are 34 registered participants, the first batch or the 17 participants out of the total 34 participants performed the experiment in this order, control group first, followed by the test group. **Fig. 19** shows how it looks like with the first type of experiment which falls under the control group.

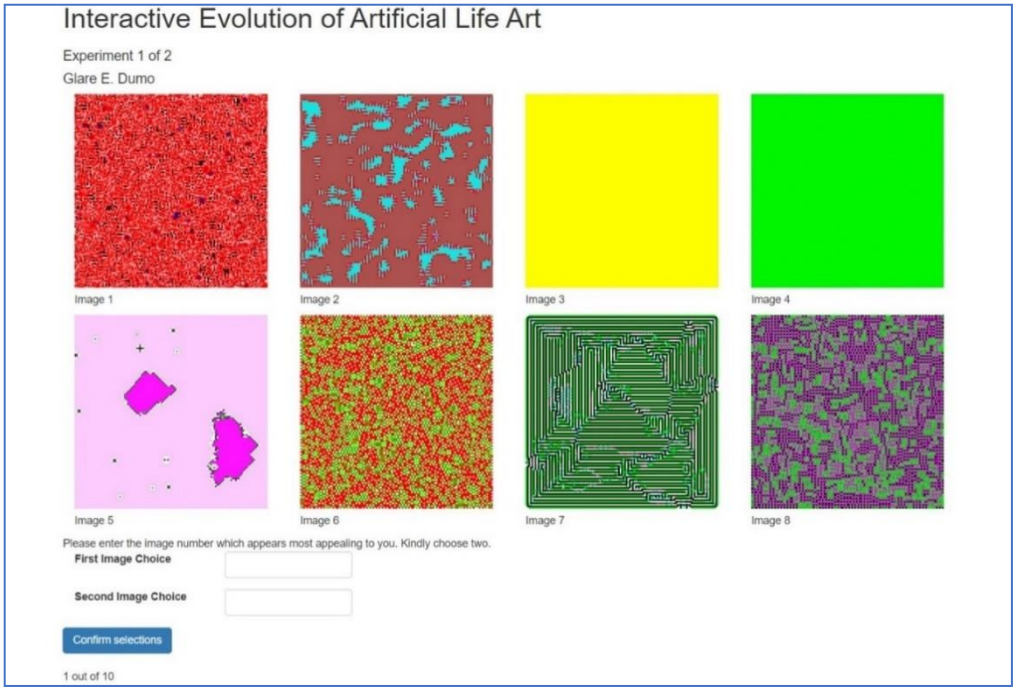


Fig. 19. *This figure shows the first part out of the two experiments (Experiment 1 of 2) of this online interface which is under the* ***control group****.*

In here, the participants are presented 8 different random MergeLife update rules representing each image with an animated output but here, since it is a screenshot of the online interface, the images are still. Participants are required to choose 2 images out of these 8 presented images per set which appear the most appealing to them by putting the image number in the text boxes before clicking the Confirm selections button to proceed to the next set of images. Participants are required to perform this within 10 sets of images or 10 times, thus, a counter on the left bottom part that says which set the participants are currently in for them to keep count or be aware of the number of sets they have already completed. These two input text

boxes have some restrictions wherein, the participants cannot input image numbers less than 1 or greater than 8 or outside the range which is from image 1 to 8 only. A message will appear that says, *Please choose 2 images from image 1 to 8 only.*, if ever they would be inputting values outside the said range. If for example, they mistakenly repeated the image number which was entered in the text boxes, a message will appear that says, *Image selections must not be the same image number.* If ever the participants accidentally click the Confirm selections button without entering their 2 preferred images yet, a message will appear that says, *Please enter your selections first.,* to avoid proceeding to the next set of images without any inputs being provided.

Under this control group experiment, the participants would be provided random MergeLife update rules and the participants' selections of images are not relevant to the proceeding sets of images compare to the experimental or test group where crossover and mutation of the selected images which are the parents would generate their own offspring based on their corresponding MergeLife update rules. Here in the control group, regardless of which 2 images they selected on their current set, the following sets of images are random and they can notice that they keep on changing and no relevance at all. After the said first experiment, a short online survey will appear where they need to answer a few questions by choosing from the radio buttons or choices and this will be submitted and collected together with the second experiment as well. The image of the said short online survey form can be found under the appendices. See Appendix C.

4.2 Test Group

As mentioned earlier, the first batch out of the total number of 34 participants or those 17 participants who have already performed the control group of experiment first will then perform the next type of experiment which is under the test group. Under this experiment, the same instruction and sequence are applied where participants are required to choose 2 images out of the 8 provided images per set out of 10 sets of images that appear the most aesthetically pleasing to them as shown on **Fig. 20.**

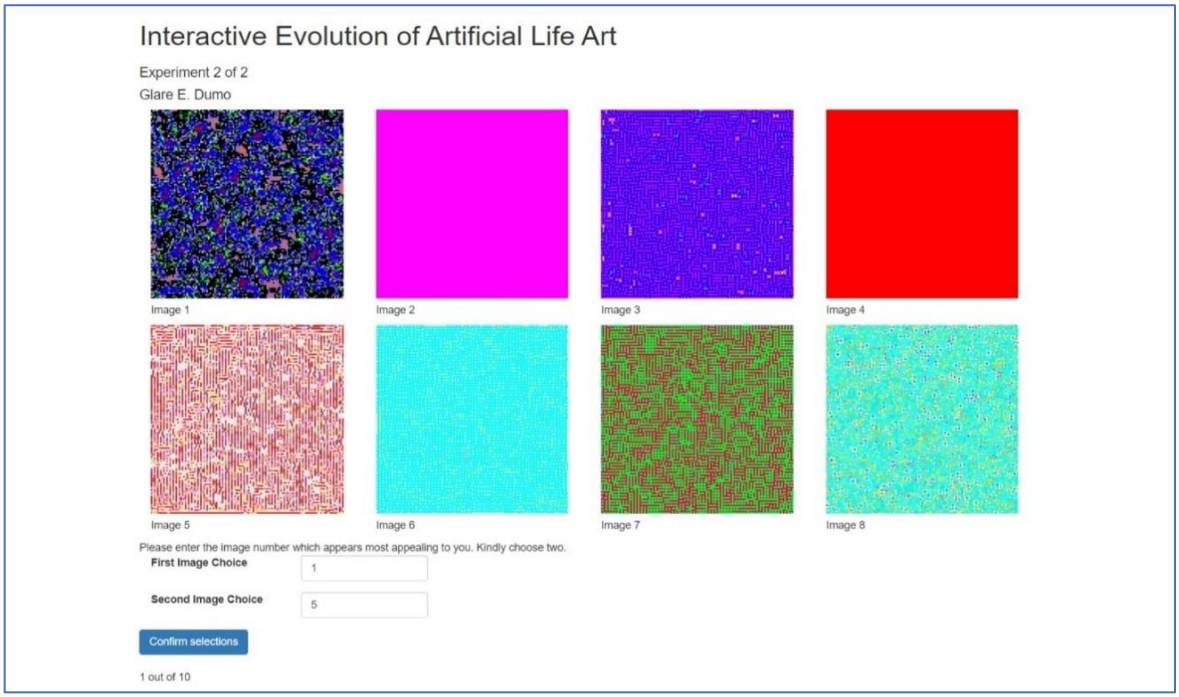


Fig. 20. *This figure shows the second experiment (Experiment 2 of 2) which is under the* ***test group****'s first set out of 10 sets of images where a participant selected images 1 and 5 out of these 8 provided images which are the most aesthetically pleasing MergeLife update rules for the said participant.*

In here, the two selected images that the participants will make will be the two parents that will be used in generating their corresponding offspring for the next set of images where crossovers and mutations will take place.

As mentioned on the earlier part of this paper, MergeLife (Heaton, 2019) is classified as that type of CA that can evolve continuously based on a crossover and mutation following the genetic algorithms or GA generation which is **interactive** since the fitness function, unlike with the MergeLife Research by Heaton, is replaced by the user's choice or selection. These parents and as well their offspring consist of MergeLife update rules which are kept on a 16-byte-digit which derived directly from the hexadecimal rules under the MergeLife update rule structure. But unlike with the MergeLife Project which uses an objective function to assign a score for the given genomes which can be classified as superior and inferior genomes, this is not the case with our experiment since objective function is not applicable but instead, it is being replaced by the participant's selection of the two parents. These two parents being selected by the participant are said to be the superior genomes which are capable of producing their own offspring while the other update rules which are not

selected by the participant are referred as the inferior genomes which will later be eliminated or killed giving way to those superior genomes or the selected parents by the participant which are chosen to produce or generate their offspring for the proceeding interactive GA generation through crossovers and mutations (Heaton, 2019).

4.2.1 Crossover of Two MergeLife Update Rules

Parent 1: 0de6-3496-8507-7cc7-34c6-d5a9-bcfd-2355
Parent 2: 8503-5eb6-084c-04df-7657-a5b3-6044-3524

Offspring 1: 0de6-3496-8507-7cc7-34c6-d5a9-6044-2355
Offspring 2: 8503-5eb6-084c-04df-7657-a5b3-bcfd-3524

In this crossover technique (Heaton, 2019) as you can see on the above example, two parents with their corresponding MergeLife update rules are producing two offspring genomes which as you can notice are based completely on the said parents' genomes. This is done by performing two cut points selection which is selected **randomly**, in this case, we have chosen randomly the seventh subrule out of the 8 total subrules per update rule and flipped or switched them together to produce these parents' 2 offspring. The first offspring is created with having the first parent's update rule except for having the second parent's seventh subrule while the second offspring is based on the update rule of its second parent except for the seventh subrule which is from the first parent. In our online interface, this crossover is done among 4 canvases with their corresponding image numbers (image numbers 2 & 6 and image numbers 4 & 8) out of the 8 provided images where the rest of the 4 images will contain the selected 2 parents from the previous set while the rest of the 2 images will show the mutations of those 2 parents selected.

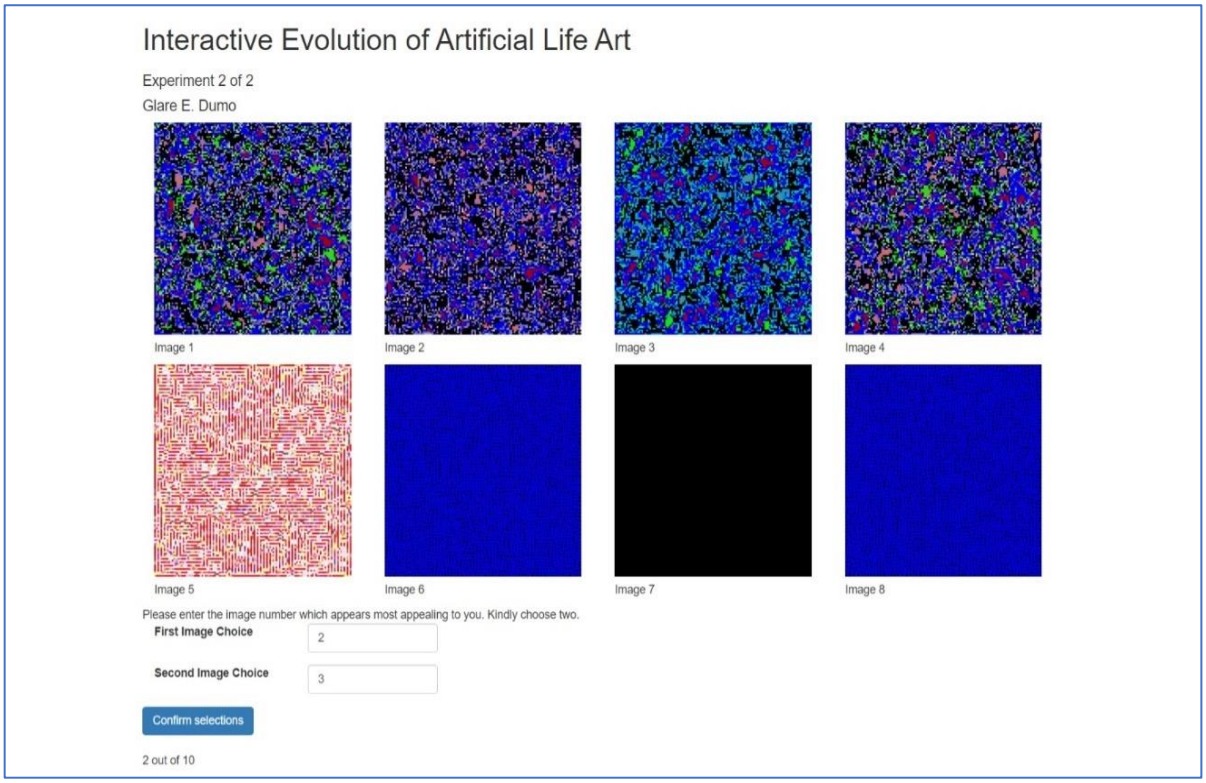


Fig. 21. *This figure shows an example test run of the second set out of the ten sets of experiment 2 of 2 (test group) where the participant selected images 2 and 3 as the most aesthetically pleasing images out of these 8 provided images.*

On **Fig. 20**, the first 2 images being chosen by the participant serve as the parents where the participant for example chose images 1 and 5 on the first set so on this second set as shown on **Fig. 21**, those two parents are made visible again for the participant where they are now located on the two left part of the images, images 1 and 5. We decided to make the structure of the proceeding sets by following the below sequence:

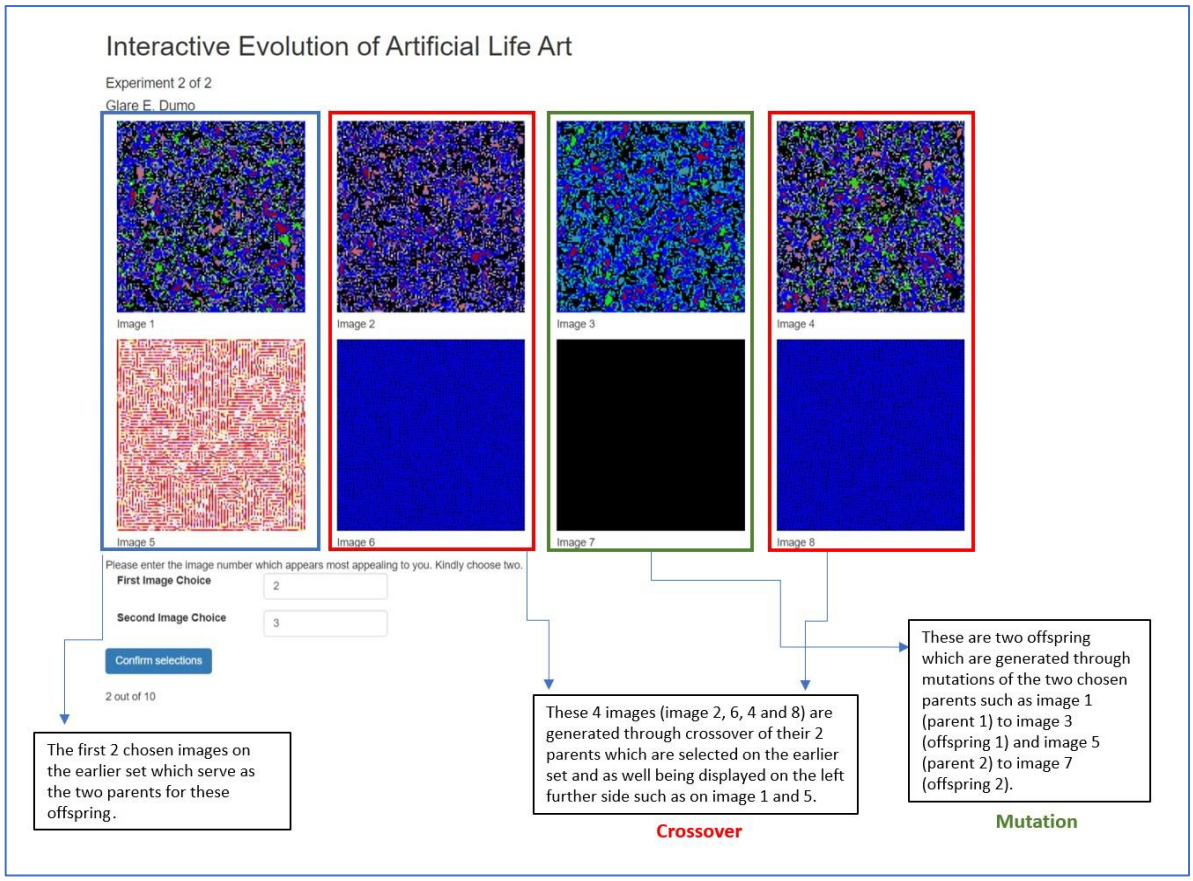


Fig. 22. *This figure shows the designated locations of the parents chosen with their corresponding offspring generated through crossovers and mutations.*

4.2.2 Mutation of a MergeLife Update Rule

Parent 1: d8a**b**-8915-629**7**-2248-6055-fc87-ef92-15f5

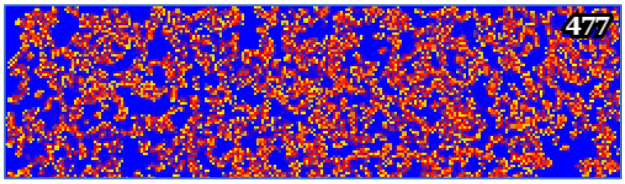


Fig. 23. *This figure shows how the Parent 1 looks like with its corresponding update rule based on MergeLife Project website's rule viewer* (Heaton Research, 2020).

Offspring 1: d8a**7**-8915-629**b**-2248-6055-fc87-ef92-15f

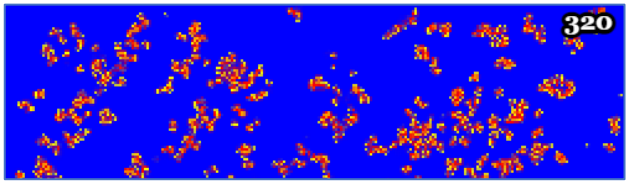


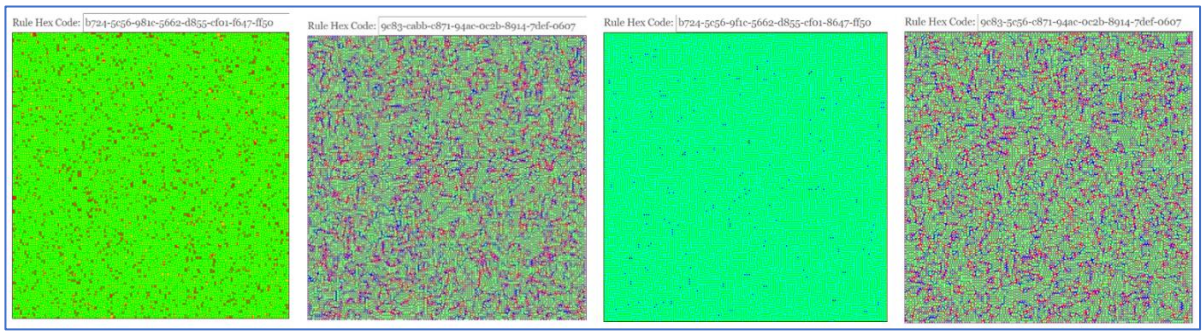
Fig. 24. *This figure shows how the Offspring 1 looks like with its corresponding update rule based on MergeLife Project website's rule viewer* (Heaton Research, 2020).

This mutation technique (Heaton, 2019) is done by having a parent producing its offspring by shuffling **randomly** two values out of the 8 subrules or the 32-value hexadecimal rule such as shown above. This selection of values to shuffle is always done randomly. In here, the values **b** and **7** from the parent 1 are shuffled to generate its offspring 1 where it now has **7** and **b** on its hex string. As you can notice from these two images which are generated using the MergeLife Viewer (Heaton Research, 2020) based on their corresponding MergeLife update rules, by shuffling b and 7 from the parent 1 to generate its offspring, it shows that it makes quite a difference when it comes to spacing making the offspring less chaotic and more organized compare to its parent. This new CA from the offspring as a mutation being generated from its parent has a bigger and more spacious background so we can easily see the spaceships for example, moving and running in different directions compare to the original parent which is quite compact and less spacing.

Just like on the control group, participants are required to perform selections as well of their preferred images on this test group, 2 on each set with a total of 10 sets, thus, for each participant, 20 images or 20 MergeLife update rules are being selected and recorded under this test group. This online platform can generate a report of all those rules being selected by the participants under the test group, so if we have a total of 34 participants, a total of 680 rules are saved in a Google Spreadsheet report connected to the online platform for data analysis. A screenshot of the rules saved under the test group among the total 34 participants is shown on **Fig. 25.** Each participant has a total of 20 saved MergeLife update rules and it's quite long for each row so the screenshot is cut. **Fig. 25** is showing two sets, Set A and Set B participants, where Set A participants started with the control then test group while the Set B participants started with the test and then followed by the control group experiment.

Fig. 25. *This figure shows the screenshot from the Google Spreadsheet report for the total 680 saved MergeLife update rules among the 34 participants under the test group where each participant has a total of 20 saved MergeLife update rules (2 selected images per set out of 10 sets).*

The first four Mergelife update rules and their corresponding images based on the first participant's image selections during the test group experiment which are generated using the MergeLife rule viewer are shown on **Fig. 26.**



MergeLife update rule 1 MergeLife update rule 2 MergeLife update rule 3 MergeLife update rule 4

Fig. 26. *This figure shows the first four images based on generating their update rules using the MergeLife Viewer from the first participant's image selections under the test group* (Heaton Research, 2020).

These four images or screenshots from the MergeLife Viewer do not give justice to how these rules' beauty really is and how aesthetically good they appear since these screenshots are still images compare to the MergeLife Viewer where they are all animated at some point before they stop generating and make a final image of how they look like.

Chapter 5

HCI Experiment Outcome

In this chapter, the results that are represented and drawn from our data collection are presented and described. Each of the two experiments, the control and test group, has a similar short online survey form that consists of three questions with five options or choices of answers. Each answer has a corresponding score from 1 as the lowest and 5 as the highest. We collected the scores and compile them in an excel format where we also did the box plot to have a data visualization of the scores among all the 34 participants. The choices for questions Q1 and Q2 and their corresponding scores are listed below:

Question 1: Concerning the last set of images, how satisfied are you with your artwork's final result?

Choices	Score
o Very satisfied (++)	5
o Satisfied (+)	4
o Neutral (0)	3
o Not so satisfied (-)	2
o Not satisfied at all (--)	1

Question 2: How much do you feel that your selections influenced the process of selecting the sequence of images?

Choices	Score
o Strong positive influence (++)	5
o Weak positive influence (+)	4
o No influence (0)	3
o Weak negative influence (-)	2
o Strong negative influence (--)	1

Fig. 27 shows the screenshot of the list of answers from questions Q1 and Q2 and their corresponding scores based on the 34 participants who did both the two experiments where they are classified into two groups, Set A and Set B. Set A

participants started with the control group then followed by the test group where the first half or the 17 participants out of the total 34 participants were under this Set A. While the Set B participants consisting of the second half or the remaining 17 participants started with the test group first and then followed by the control group. The average scores from questions Q1 and Q2 are also presented.

	Control Group			Test Group		
	Q1	Q2	Average (Q1+Q2)	Q1	Q2	Average (Q1+Q2)
Participant 1 (Set A)	4	4	8	5	4	9
Participant 2 (Set A)	3	5	8	4	4	8
Participant 3 (Set A)	4	4	8	5	5	10
Participant 4 (Set A)	4	4	8	5	5	10
Participant 5 (Set A)			0			0
Participant 6 (Set B)	4	5	9	4	3	7
Participant 7 (Set B)	5	3	8	5	5	10
Participant 8 (Set A)	5	3	8	5	5	10
Participant 9 (Set A)			0	4	5	9
Participant 10 (Set A)			0	5	5	10
Participant 11 (Set A)	3	4	7	3	2	5
Participant 12 (Set A)	4	5	9	4	4	8
Participant 13 (Set B)			0	5	4	9
Participant 14 (Set B)			0	4	4	8
Participant 15 (Set A)	4	4	8	4	4	8
Participant 16 (Set B)	5	5	10	5	5	10
Participant 17 (Set B)	3	2	5	3	5	8
Participant 18 (Set B)	5	5	10	4	5	9
Participant 19 (Set B)			0			0
Participant 20 (Set A)	2	3	5	4	5	9
Participant 21 (Set A)	4	4	8	4	5	9
Participant 22 (Set B)	4	5	9	5	4	9
Participant 23 (Set B)	4	5	9	3	5	8
Participant 24 (Set B)	3	3	6	1	3	4
Participant 25 (Set A)	4	3	7	4	5	9
Participant 26 (Set B)	3	3	6	5	5	10
Participant 27 (Set A)	5	2	7	4	5	9
Participant 28 (Set B)	5	3	8	4	5	9
Participant 29 (Set B)	4	5	9	4	4	8
Participant 30 (Set B)	4	1	5	3	5	8
Participant 31 (Set B)	4	3	7	2	5	7
Participant 32 (Set A)	5	2	7	3	5	8
Participant 33 (Set B)	5	5	10	5	5	10
Participant 34 (Set A)	4	3	7	3	5	8

Fig. 27. *This figure shows the corresponding scores among the 34 participants' answers from questions Q1 and Q2 and as well these Q1 and Q2's average scores.*

We are also presenting the results using the data visualization box plot which is one of the available and recommended visualization charts under Microsoft Excel. Below is the list of the box plot scores based on the minimum, first quartile (Q1), second quartile (Q2 or Median), third quartile (Q3) and the maximum scores for the questions Q1 and Q2 and their average scores as well both for the control and test group.

	Control Group			Test Group		
	Q1	**Q2**	**Average (Q1+Q2)**	**Q1**	**Q2**	**Average (Q1+Q2)**
Minimum	2	1	0	1	2	0
Q1	4	3	5.25	3.75	4	8
Median	4	4	7.5	4	5	9
Q3	5	5	8	5	5	9
Maximum	5	5	10	5	5	10
Mean	4.035714	3.678571	6.352941176	4	4.53125	8.029411765
Range	3	4	10	4	3	10
IQR	1	2	2.75	1.25	1	1
	1.5	3	4.125	1.875	1.5	1.5
Lower IQR	2.5	0	1.125	1.875	2.5	6.5
Upper IQR	6.5	8	12.125	6.875	6.5	10.5

Fig. 28. *This figure shows the scores for questions Q1 and Q2 both for the control and test group and as well their average scores using the box plot five-number summary of a data set such as the minimum, quartile 1 (Q1), quartile 2 or median (Q2), quartile 3 (Q3) and the maximum.*

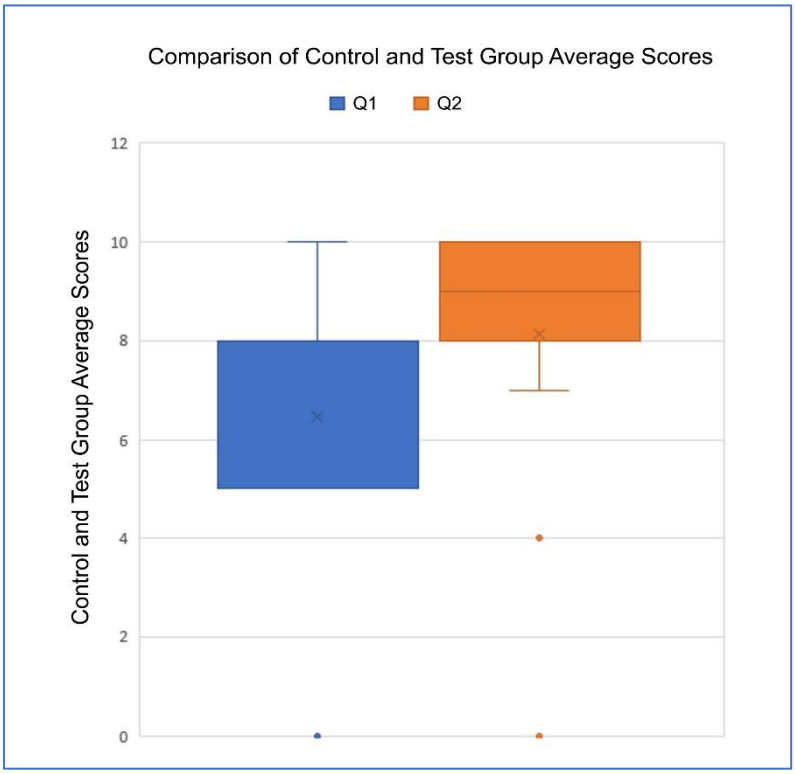


Fig. 29. *This figure of a box plot shows the comparison of the control and test group average scores.*

As you can see from **Fig. 29**, both the minimum score for the control and test group is 0 since there are some participants who were not able to answer the online survey form either in the control or test group and just proceeded right away with performing

the experiment although there has been a message prior to performing the experiment that they need to answer and complete the survey form before continuing to the next experiment. Some participants must have overlooked such message unfortunately. The quartile 1 (Q1) for the test group is higher than the control group since the test group has 8 compared to the control group that only has 5. The quartile 2 (Q2) or median value is 8 for the control group, a little lower compared to the test group that has a value of 9. The quartile 3 (Q3) for the test group is also higher with a value of 9.25 compared with the control group which only has an 8. However, they have similar or equal value for the maximum which is both 10 for the control and test group.

We also make a comparison of the five-number summary for the data set of questions Q1 and Q2 scores for both the control and test group as shown on **Fig. 30.**

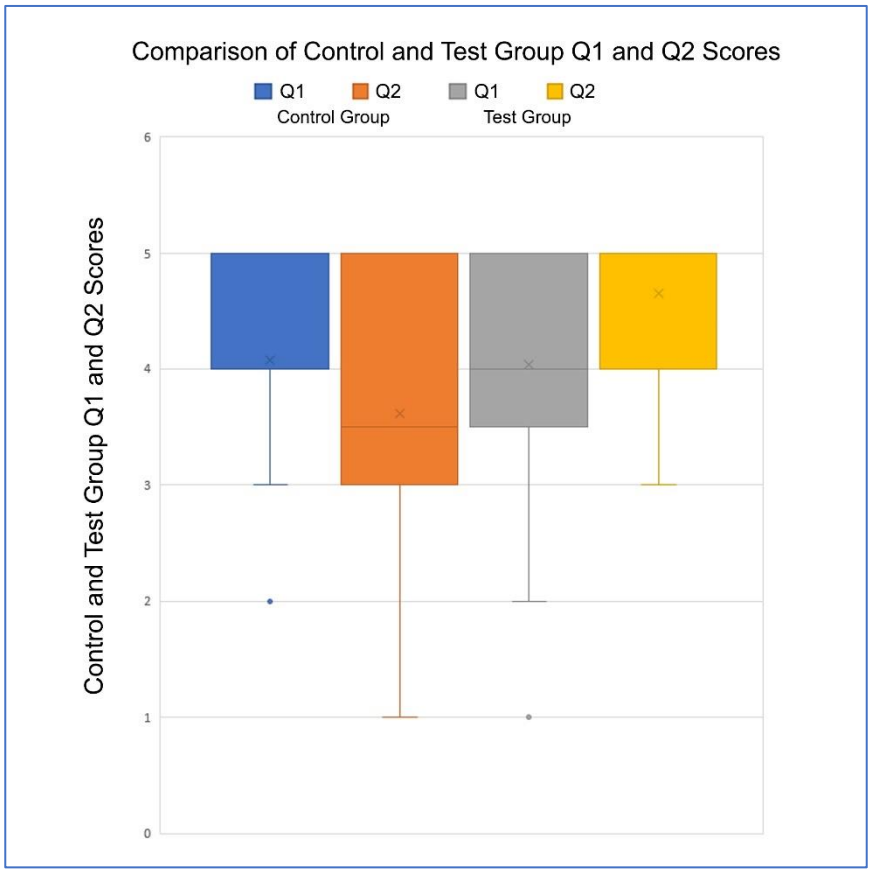


Fig. 30. *This figure of a box plot shows the comparison of the control and test group Q1 and Q2 scores.*

In the next chapter, under the discussions, we are going to present a quantitative analysis from these results and talk about their significance or how vital these results are in this study.

Chapter 6

Discussions

Our assumption or the test hypothesis that we came up is that the average score for both questions Q1 and Q2 of the test group μ_t is significantly higher than the average score for the control group μ_c. Our null hypothesis is $\mu_t = \mu_c$. To have a more thorough quantification of these assertions, a power analysis has been carried out towards our results. These overall results are shown already through the box plots in **Fig. 29** and **Fig. 30** found in chapter 5 of this paper. We are also presenting these overall results in **Table 2.**

	Control group	Test group
Mean	μ_c = 6.35	μ_t = 8.03
Standard Deviation	σ_c = 3.26	σ_t = 2.44
Pooled standard deviation $\tilde{\sigma}$	2.85	
Effect size *D*	0.59	
Sample size for α = 0.05, 1 – β = 0.8	18	
Power for α = 0.05 and *N* = 34 participants	0.82	

Table 2. *This table shows the overall results of the online experiment for both the control and test group with the questions Q1 and Q2 among all the 34 participants.*

The means and standard deviations for both groups, the control and test group as shown in **Table 2**, the effect size *D* can be estimated as

$$D = \frac{|\mu_c - \mu_t|}{\tilde{\sigma}} .$$

Where $\tilde{\sigma}$ is the pooled standard deviation, $\tilde{\sigma} = \sqrt{(\sigma_c^2 + \sigma_t^2)/2}$. The effect size *D* based on this equation is with a value of 0.59 or *D* = 0.59 which has then led to the rejection of our null hypothesis since of its high value. In fact, supposing the Z-scores with a significance level of 1 − α = 0.95 and a power of 1 − β = 0.8, a minimum sample size in each group, the control and test group should be measured using the following equation:

$$N \sim \frac{(Z_\alpha + Z_{1-\beta})^2}{D^2} \lesssim 18.$$

Furthermore, through using the above equation where population size or the total number of our participants being represented by N = 34 and fixing a significance level of 95%, produces a power Z-score of $Z_{1-\beta}$, that is a power of 1 − β = 0.82.

Fig. 29 found in chapter 5 shows the comparison of the control and test group's short online survey average scores from our 34 participants being presented in a box plot. While **Fig. 30** also found in chapter 5 shows the separate scores for questions Q1 and Q2 of the control and test group experiments and their comparison.

For question Q3 comparison, where they are asked with the question below and provided them with the five options or possible answers to this question such as:
Question 3: Concerning the last set of images, please select from the following characteristics **the one** that best describes your artwork's final result:

- Still images
- Geometric images
- Random images
- Periodic or repeating patterns
- Lifelike patterns or shapes

We identified that the control group which has been provided with random images or random MergeLife update rules, a total of 5 out of the 34 participants chose the one that best describes their artwork's final result is with "Random images" and the majority answered that it's like "Lifelike patterns or shapes" with a total number of 11 participants. Since the MergeLife update rules are like animated images which start with a different color, pattern, shape, size and then evolve after a few seconds, thus, most participants might have interpreted these images as lifelike patterns or shapes. In the test group, the total number of participants who chose the characteristic "Lifelike patterns or shapes" is a little lower compare with the control group, with a total number of 10. There is also a total of 13 participants under the test group that perceived that their final artwork's result is with "Periodic or repeating patterns" simply because under this group, crossovers and mutations of their selected images would be provided, thus, the similarities of these said images are present. You can also check from **Table 3** the breakdown of these 34 participants' answers to question Q3.

Total of 34 Participants	Control Group	Test Group
Still images	6	6
Geometric images	4	2
Random images	5	1
Periodic or repeating patterns	2	13
Lifelike patterns or shapes	11	10
Total	**28**	**32**
No answer	6	2

Table 3. *This table shows the comparison of the control and test group answers towards question Q3 among all the 34 participants.*

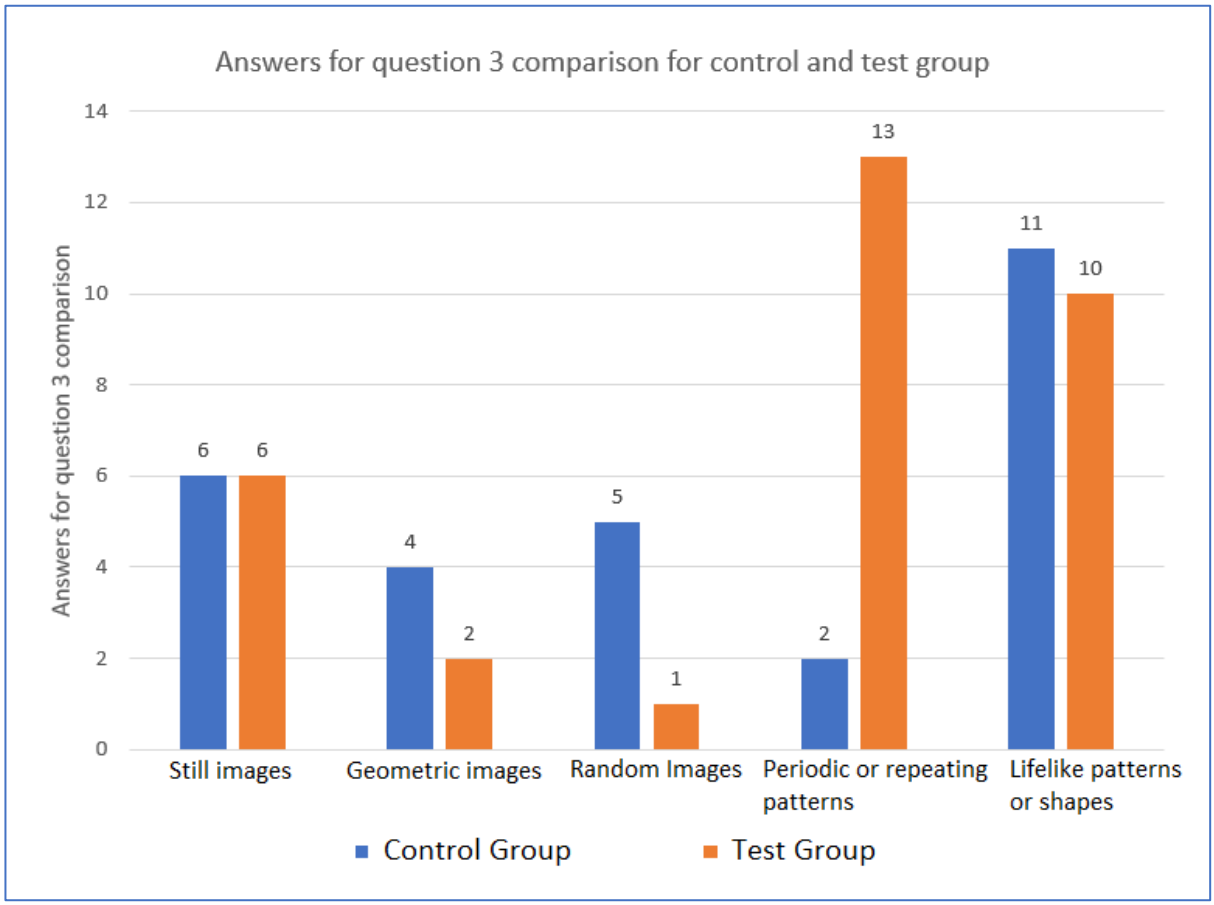


Fig. 31. *This figure shows the answers for question Q3 in comparison between the two groups, the control and test group.*

As you can see from **Fig. 31**, there are 6 participants who both described their final artwork's result as "Still images" simply because they might have focused only more on how the MergeLife update rules looked like after a few seconds which would look like still images and no longer as animated ones since it took only just a few seconds before these rules corresponding animated images stopped to their final "look". There are 4 participants who described their artwork as "Geometric images" under the control group compared to the test group, which is lower, with a total of only 2

participants. There is quite a difference between the control and test group scores for “Random images” answer where the control group has a total of 5 participants who noticed that those images that they were selecting didn’t really have any relevance to the succeeding images within the following sets, thus, describing their final artwork’s result as random images. There is only 1 under the test group who answered that the artwork is random images simply because the majority of the test group’s participants described their artwork as periodic or repeating patterns with a total of 13 participants while there is only a total of 2 participants under the control group who answered such description of their final artwork’s result. Quite a big difference between these two groups and I can understand that those participants who used that description to their artwork is simply because of how the images per set look exactly alike since those images are the results or offspring of the participants’ selected parents which are producing such offspring through crossovers and mutations of the MergeLife update rules. The last description or the fifth answer under that question Q3 which is referring to their final artwork’s result as “Lifelike patterns or shapes” received almost the same total number of participants where the control group has a total of 11, while the test group has 10. This is quite not surprising to have received almost the same number of answers from both the control and test group simply because these rules look alive especially in the beginning or when the new sets of images are presented since they are animated and full of vibrant colors. You can even see from the predefined rules which are enumerated under the MergeLife Viewer (Heaton Research, 2020) that these 6 predefined rules such as *red world, Conway's Game of Life, yellow world, shrinking cells w/ spaceships, still life & oscillators* and *sustained cellular* all are producing images that are lifelike such as living organisms.

After having a comparison of the results between the participants’ answers both for the control and test group, we would also like to add under this chapter 6 referring to the discussions section how the interface used in this online experiment is universally designed or useable not just by abled but as well with the disabled users or people with any disabilities, impairments and limitations.

The online platform has been assessed based on Web Content Accessibility Guidelines or WCAG 2.1 (W3C, 2018) where the assessment contains the following pros and cons:

Pros

- ✓ Usage of simple text from headings, titles and contents
- ✓ Not using marquee or flashing texts
- ✓ Tab keys can be used to input numbers in the text boxes and as well selecting the buttons like the confirm selections and just tapping the enter button from the keyboard to proceed to the next set of images. This is good especially if the mouse is not working or to avoid fatigue by clicking or using the mouse multiple times
- ✓ Usage of sans font style such as Arial instead of serif, so that it can easily be read by everyone even those who have dyslexia

Cons

- × The canvases' animated images based on the participants' chosen MergeLife update rules appeared to be a little dizzying based on some participants' comment, but these can't be changed since that's how they're going to look like based on their chosen update rules
- × Some participants click the continue button even without answering, completing or submitting the survey forms first even though there's a reminder to do so. This has led to 6 participants under the control group to have not answered the short online survey and only 2 participants under the test group. The short online survey forms are put on the screen using a frame source from Google Forms and since it's long, the participants need to scroll down before they see the complete 3 questions and the "submit" button

Suggestions

- ✓ Images can be selected using the mouse, an alternative to inputting the image number using the text boxes
- ✓ Usage of an eye tracker in selecting the images for those who have motor disabilities and can't use the mouse and keyboard

- ✓ Voice control compatibility, the participant can select the images through voice and then their selections can be put in the text boxes

Limitations

Since the online interface uses only simple algorithms based on the MergeLife Project where they are able to provide animated images through the crossovers and mutations of the parents selected by the participants, leading to offspring of different update rules, the online interface has been limited to such scope of artwork generation. But this study can be developed into a wider area where it could be more useable and enjoyable to use by people with disabilities, impairments and limitations such as those who can't use the desktop computer's mouse, laptop's touch pad and both of their keyboards when it comes to image selection being quadriplegic, experiencing hand malformations due to hand pain, arthritis and the like, the online interface can be universally designed where it can be accessed using speech recognition, head movement, eye gaze or eye tracker so that all, regardless of any form of disabilities such as being mentioned above, can still be able to use the said online platform for art generation.

There is a community in reddit (reddit, 2012) which at present has a total of 18.2K members who are talking about and into Cellular Automata (CA) and you can see how many people are enjoying the MergeLife Project and the Visions of Chaos (Softology, 2021) and how they are able to create even more aesthetically looking art in different mediums and channels, one of those artwork examples using CA that I think is a good example of what this online platform can generate more is the artwork below:

Fig. 32. *This artwork is called an "automatization of a human-figure"* (jabberwocky_automata, 2022) *created by reddit's member jabberwocky_automata.*

Another limitation of this study is the use of simple and short online survey form or questionnaire where people with disabilities applicable questions are not included. This study can use a more detailed, universally designed questionnaire highlighting questions that people with disabilities can benefit and contribute from.

Chapter 7

Conclusion and Future Directions

We presented the results of our designed online platform consisting of two different experiments, the control and test group to test and identify how evolutionary algorithms can serve as a means or help humans be supported in pursuing artistic expressions through various sequences of images which are based on their preferences aesthetically. From a total of 34 participants, the overall results of our experiment reject our null hypothesis up to a confidence level of 95% and a power of 82%, having an effect size of $D = 0.59$.

Through these promising overall results being presented, we believe that our study can be a standard or serve as a benchmark when it comes to developing future interfaces which can be enjoyed and used not just with abled artists but as well with artists who have any special needs, disabilities and limitations.

This thesis' result acquired from the experimental design or the online platform for art creation which is quite high in percentage is said to have contributed, even in a small way, to the world of EA and visual arts. This thesis aims to make this said online platform to be accessible by everyone regardless of disabilities and limitations, thus, perceiving it to be developed more in the future where its usability is taken much into consideration since art creation, creativity and artistic expression are not limited within just a set or group of people, but for everyone. Arts and many of their forms, are indeed extensive and universal. With the use of this online platform using EA for art creation, it simply shows how EA is a great means of opening doors for people's art expression to be acknowledged or taking out the artist in them regardless of their disabilities.

People who are into arts or creativity share something in common with people who are into science and technology. They are both designer or inventor with creative power and strong vision of what the future could be like. Thus, this thesis, although it only has a small amount of impact when it comes to EA domain, it still has an

influence and significance which could serve as a great component of the bigger EA field’s whole picture.

Appendices

Appendix A – NSD application

Appendix A shows an application to the Norwegian Centre for Research Data or “Norsk Senter for Forskningsdata” (NSD) with reference number 885778 was sent last 20 October 2021 and was assessed and approved on 02 December 2021.

Fig. 33. *This figure shows the NSD application which was sent and approved for this experiment.*

Appendix B – Nettskjema for the consent form

Appendix B shows how the consent form looks like under Nettskjema where all the needed information about the experiment is provided among all the 34 participants where their names and email addresses are needed for contacting purposes.

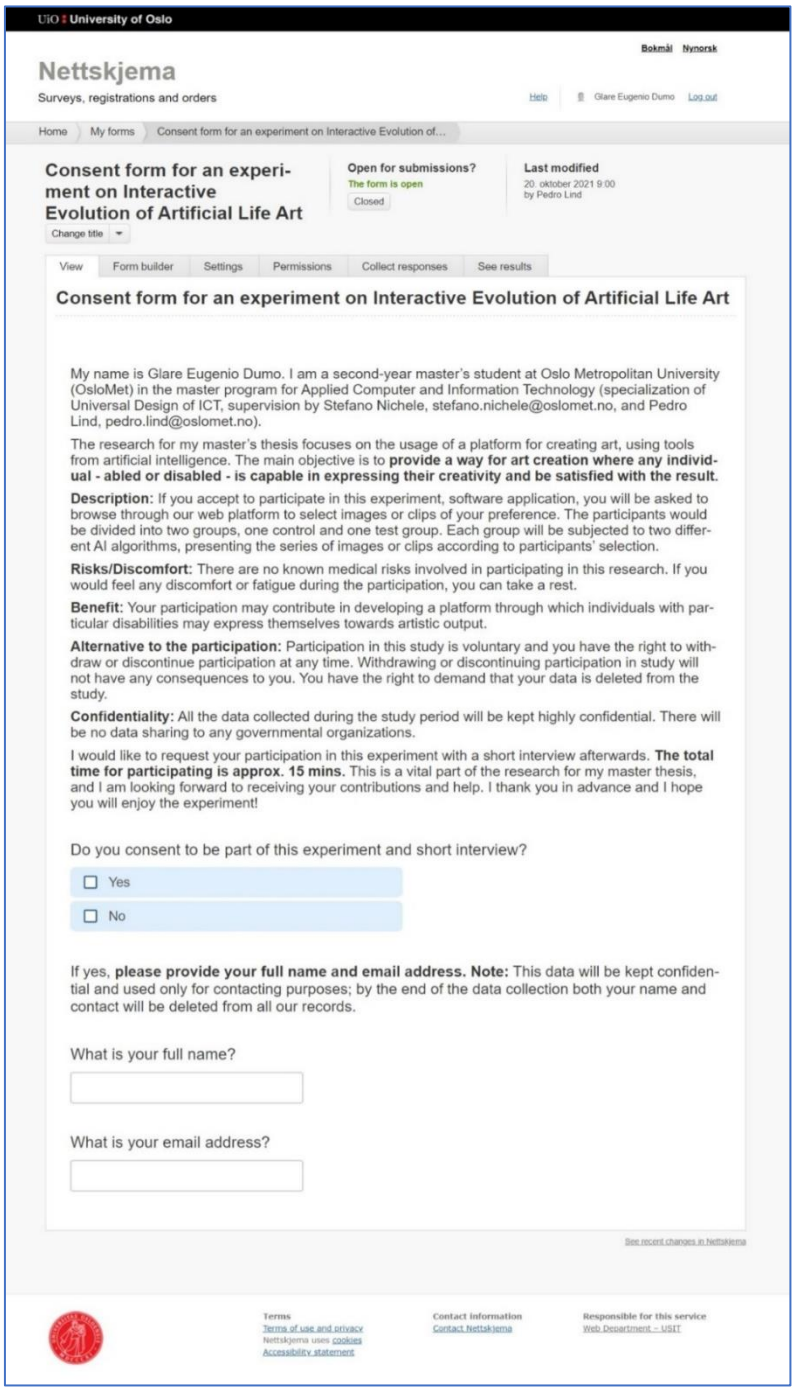


Fig. 34. *This figure shows the consent form being sent to all the participants for this experiment.*

Appendix C – Short online survey forms for the two experiments such as the control group and the test group

The questions under these two short online survey forms are the same but we need to have separated forms for the results' comparison and data analysis. The order of the two experiments was dissimilar where the first batch or the first 17 participants among the 34 total participants started with the control group then followed by the test group while the remaining 17 participants did the opposite.

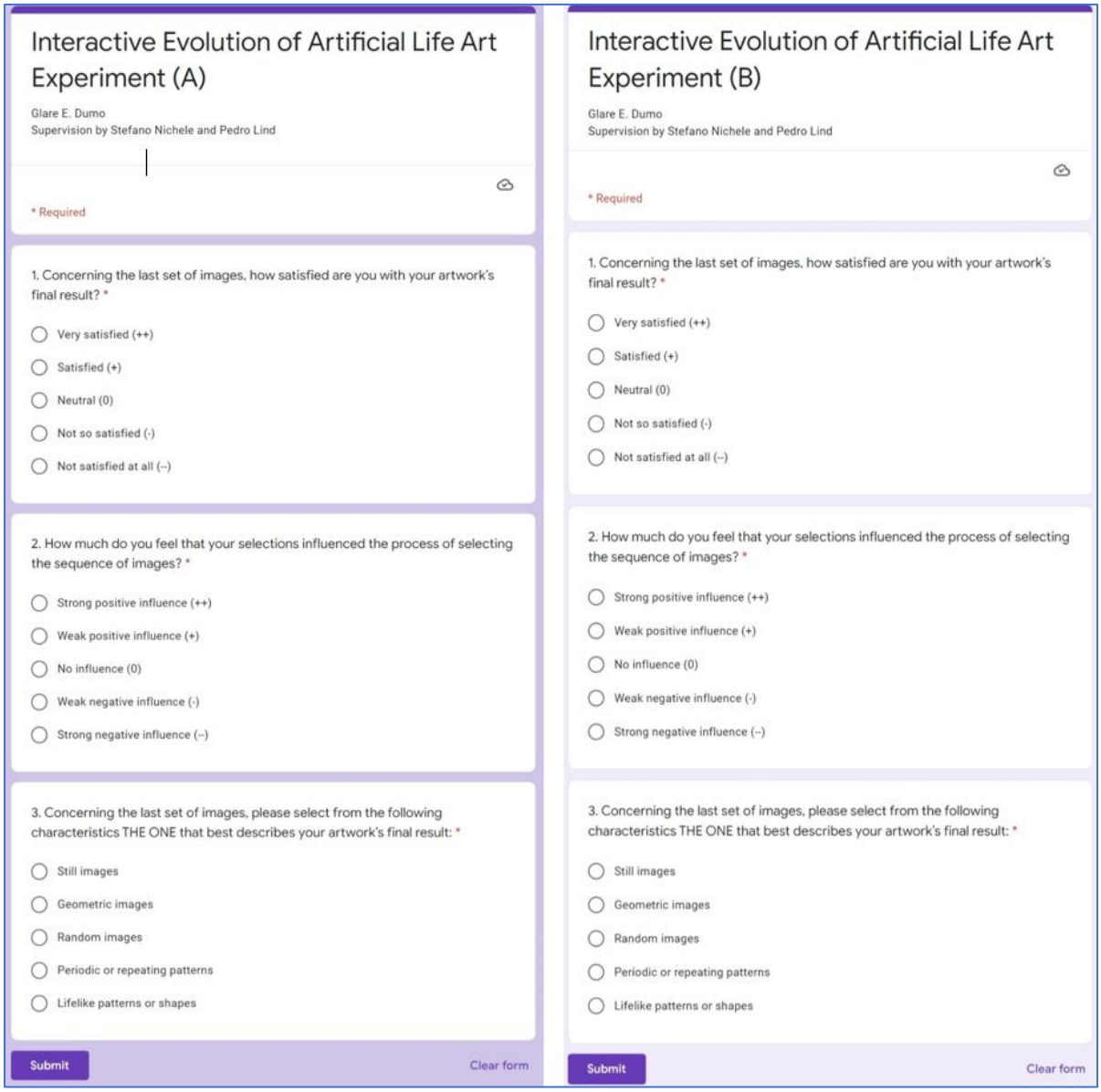


Fig. 35. *This figure shows the two separate short online survey forms – Experiment (A) for the control group and Experiment (B) for the test group.*

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