# Discovering an Architectural Metaverse:

## A Vessel for Emerging Digital Life Forms

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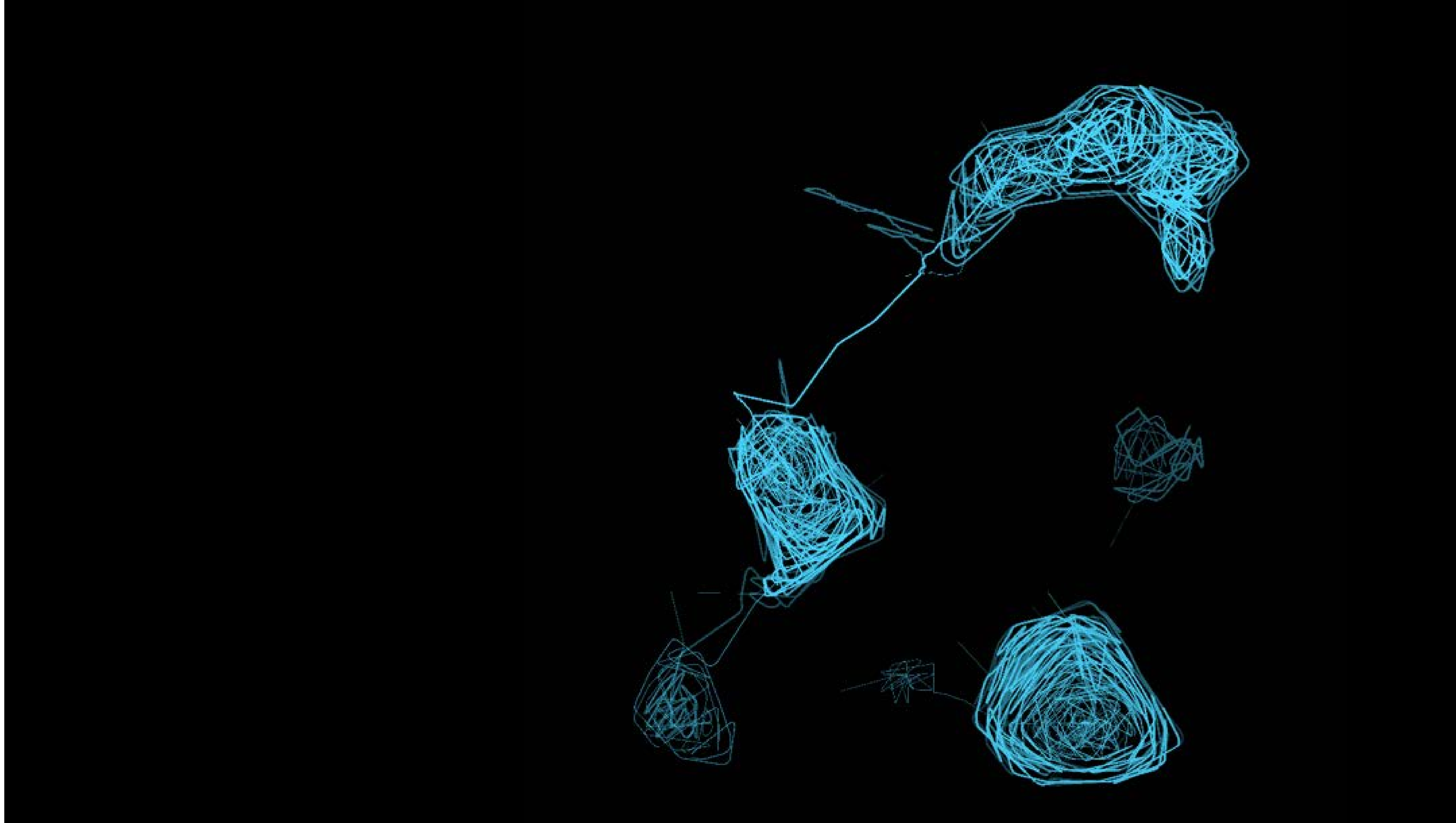

A special thank you to Scott Shall, for always motivating my pursuits;
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My father, for rooting my mind with logical thinking.

# Discovering an Architectual Metaverse:
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### 0.0 ABSTRACT

Using an ideology of architecture serving as a *vessel*, a digital simulation of the world can ultimately lead to the discovery of emerging omnipresent, intelligent digital life forms. This is explored within architecture by redefining the relationship between architecture's substrata: **Agent** (occupant), **Act** (activity), and **Field** (Space).

The Agent - the occupant within the Field (currently described as human), Act - the activity performed by the occupant, and the Field - the space where the Agent does the Act, are substrata for the architect to design. The relationship between these three can be investigated to consider architecture as a network of Agents, Acts, and Fields. Within this architectural network, a vessel for emerging digital life forms can be discovered.

### 0.2 INTRODUCTION

"Design for a better future" - many architecture firms' mottoes have some sort of spin-off of this slogan. But how can we design for a better future if the technology we use is rarely advanced? Using this as motivation to realize a new technological method, technologies used in other disciplines can be considered.

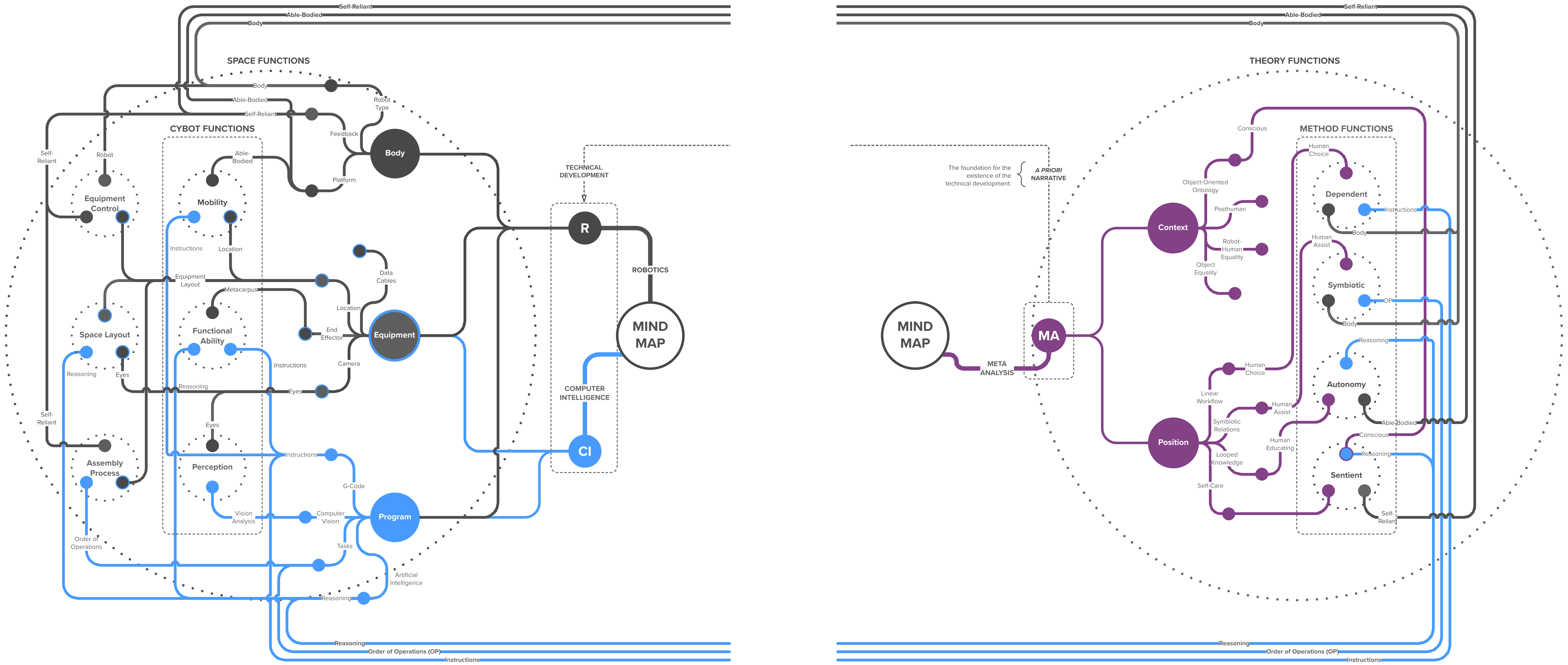
A technology adopted significantly in computer science is artificial intelligence. As stated by John McCarthy, one of the founders of this discipline, artificial intelligence is the "science and engineering of making intelligent machines, especially intelligent computer programs" [McCarthy, 2004]. He proceeds by explaining what is intelligent; and, at this point, "we cannot yet characterize ... computational procedures we want to call intelligent". This is where this thesis attempts to move beyond what we consider intelligence solely through human perspective.

Defining intelligence is not the scope of this exploration. Rather, the goal is to produce a method in which an intelligent being may visualize its reality. This is done through architect Bjarke Ingels' belief that "Architecture is the means, not the end. It's a means of making different life forms possible" [Trost, 2009]. Making different life forms possible will be assessed using architectural and computer intelligent principles. A unique perspective to reality, through emerging digital life forms, can assist the way architects understand the data the world contains so we may *truly* design for the future.

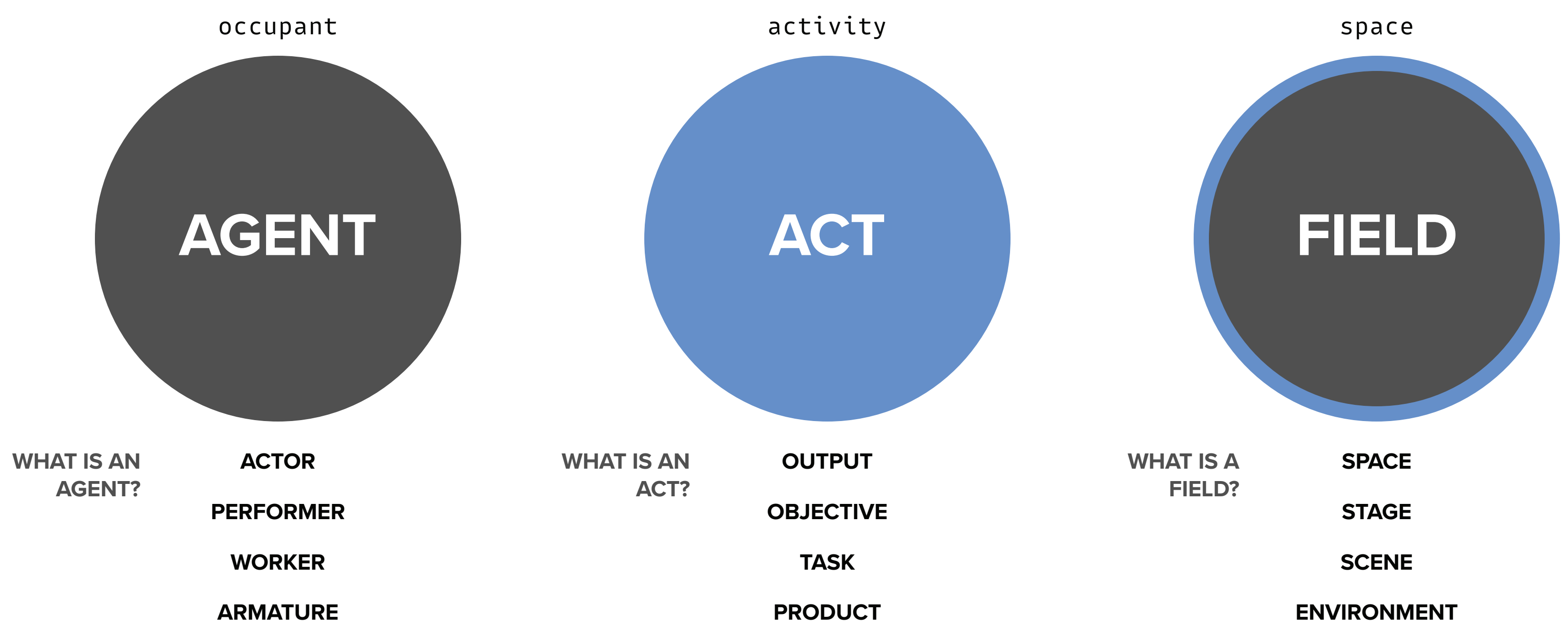
### 0.3 A DISCLOSURE TO THE READER

This study extends the scope of "architecture" beyond its typical definition. Human-centered architecture has placed human activities as the driving force for the built environment. This study is a means to abstract the substrata of architecture so that architecture may be realized beyond its current understanding. Challenging the norm of architecture is bound to bring criticism; though, it is important to state that all other definitions of architecture are not disregarded. Rather, they fit the definition of architecture presented in this thesis.

Beyond the definition of architecture, it is also important to state that at this current technological moment, I am unable to fully realize what it may mean to discover a digital life form. Thus, I am using this opportunity to address the groundwork for this typology in architectural studies. This study addresses the discovery of a vessel in which a digital life form can be discovered.




[IMAGE 00] MIND MAP - REFERENCE APPENDIX 0.0




[IMAGE 1.1] TRANSLATED ARCHITECTURAL SUBSTRATA

# 1.0 ARGUMENT

## 1.1 WHAT IS ARCHITECTURE?

Architectural has been typically known to be a method of designing buildings for the use of human activities. To expand on this, human activities usually require a space to practice such activities. These activities would best be practiced in a space that can contain the necessary things that allow for the activity. Consider the practice of business. A business requires a location for clients to be able to reach them. To at least seem professional, a business tends to be located within an office building. The building consists of multiple systems: building enclosure, structural elements, HVAC, electrical, plumbing, furnishings, just to name a few. Even further, the building is divided into multiples units for different businesses. Even more so, the business units are divided into rooms. As we dive deeper, architecture can become quite complicated - even at a high-level view. But it can be simplified.

Taking the example of a business practice, the substrata of architecture can be distilled. Using Peter Collins' understanding of architecture [Garland, 2011], an office room requires three substrata to be considered an *office room*: [1] an office worker occupying the room, [2] the activity that occurs in the space, and [3] the elements that make up the room (the enclosed volume). Now, these substrata can also be simplified to [1] occupant, [2] activity, and [3] space. Architecture, in this case, is about designing a space for an occupant to practice an activity.

Again, the bias of this study has been stated to realize a scope beyond human-centered architecture. Thus, architecture's substrata as described previously can be translated to [1] **Agent**, [2] **Act**, and [3] **Field**. Architecture, at its fullest distillation, is the practice of designing a Field for an Agent to Act.

Within this definition of architecture, the example of practicing business is not disregarded. Likewise, all the other definitions of architecture may fall within this distillation.

To reiterate, the point of this study is not to disqualify any other definition of architecture. Rather, it is about expanding the scope of architecture by distilling it to its substrata. This definition allows to expand architecture as a vessel for emerging digital life forms - a digital life form that can challenge the ways we understand the Agent, Field, and Act.

## 1.2 SUBSTRATA MODELS

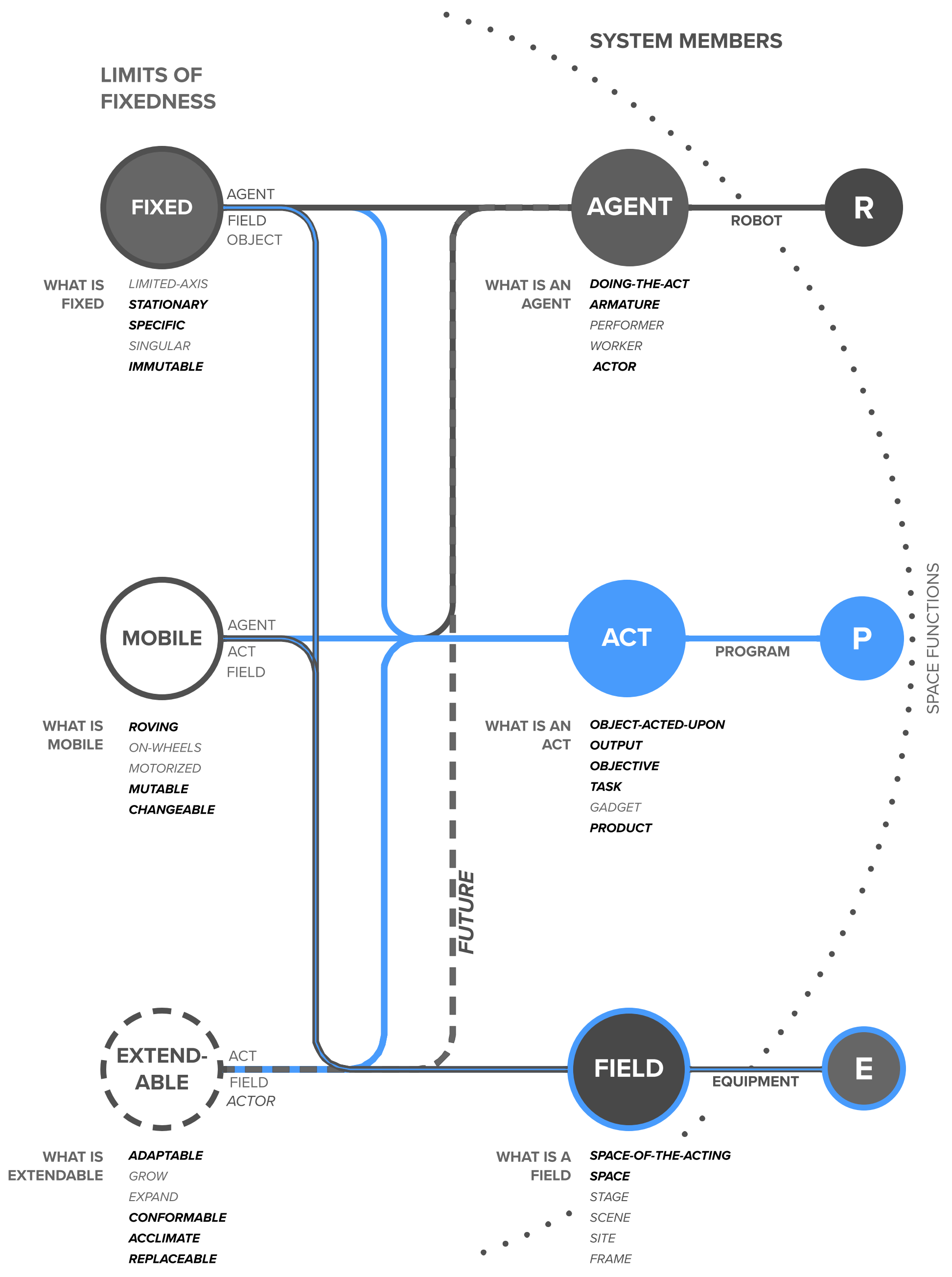
To understand how these substrata are translated beyond the current scope of architecture, various models will be analyzed. Their analysis will result in defining an application type that conform to a *Linear*, *Symbiotic*, or *Autonomy* application. Before doing so, I will explain the importance of defining the Agent, Act, and Field [IMAGE 1.1 & IMAGE 1.2].

**AGENT**
The Agent is one of architecture's substrata in which it defines the occupant that resides within the Field. An Agent can be any occupant that is being designed for. Thus, the analysis of the following models is a means to give a better understanding of a type of Agent that will be focused on. As a general note for this thesis, an Agent is an inorganic occupant that supplements the necessities of the Act (organic occupants are not considered).

**ACT**
The Act is the activity that is performed by the Agent within the Field. It defines the relationship between the two other substrata and how they react to one another. The relationships can be described in three applications: Linear, Symbiotic, and Autonomy. These applications will be examined by explaining the interconnectedness between the Agent and Field.

**FIELD**
The Field is the bounding limits of where the Agent may practice its Act. Typically, the Agent must adapt to the Field that it finds itself within. The forthcoming analysis of the substrata models will examine their space and how they are translated to a Field.

Now, onto the models analysis...




[IMAGE 1.2] ARCHITECTURAL SUBSTRATA

[a] Robo-Carrier

[a] Robo-Welder


[Fig. 1.2.2] Shimizu's Robots (Shimizu, 2018)
[c] The Full System
*The Exter and Robo-Buddy move components so Robo-Welder can assemble them.*

## SHIMIZU CONSTRUCTION

The Shimizu Corporation is a construction firm leading the adoption of current and developing technological trends. Shimizu's origins span since 1804, and even at their early stages of the company, they have strived to adopt and develop new construction methods. One of these methods is developing automation within the construction process.

Shimizu is dedicated to advancing their processes by initiating a research and development laboratory focused on testing multiple automation robots. Their reasoning for doing so is to contain as much fabrication of the building within a controlled environment. Shimizu's Agents work together to fabricate multiple building elements off-site.

At a basic level, their Robo-Carrier [Fig. 1.2.2a] moves fabrication components from one location to another. It integrates software and sensors to move through a predefined route that can be altered based on its visualized reality. The software compares the factory's digital twin with the real-time physical twin to understand where it is within the factory. Though the main use for the Robo-Carrier is at the factory, its Field can also be expanded beyond the factory into on-site construction.

Beyond the factory, another Shimizu Agent is used to weld structural members to one another. With the assistance of the Exter - a robotic crane - Robo-Welders [Fig. 1.2.2b] weld structural members together once in place. An operator gives the task to a Robo-Welder, but it is up to the Agent to determine how to accomplish the weld [Shimizu, 2018]. It does so by visualizing the necessary toolpath using laser measurements. The measurements are interpreted to understand where and how much weld is needed.

Shimizu Corporation works diligently to incorporate technological trends. These incorporations result in robotic automation, which assist in understanding what an Agent may be.

With the increasing types of robots, the different types of Acts also differ. Shimizu's push to automate the construction process has produced multiple Acts to create a complex building. Although there are several Acts, a general Act can be described: *Construct a Building*. The goal for all robotic systems in the Shimizu model is to construct a building as designed. Diving deeper, each robot has a responsibility to accomplish the goal.

Taking the Robo-Welder as an example, the robot must weld structural components together. This is its only Act. But it must do this Act properly so that all other responsibilities can be met. Thus, each Act is imperative to a system of Acts that correspond to an ultimate Act.

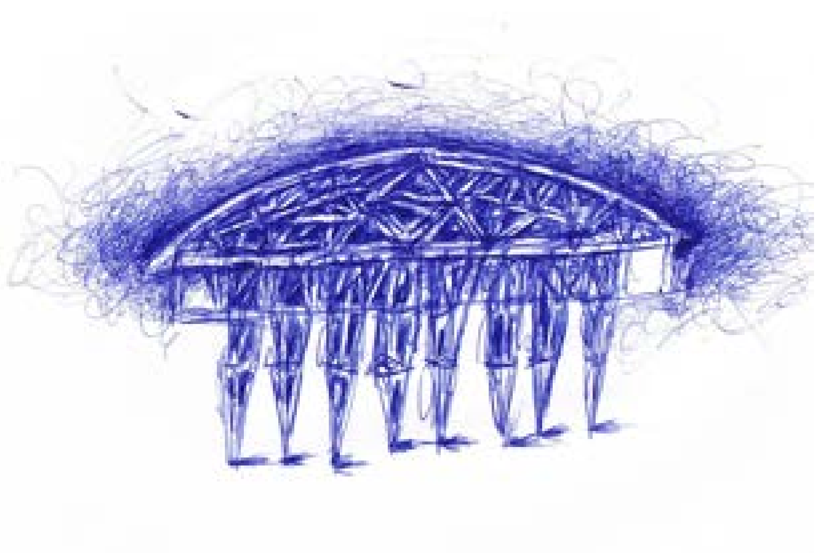
Shimizu's model represents a *Linear* application of Acts - one Act is derived from a previously completed Act. There must also be a starting Act and an ending Act. This is showcased by Shimizu's model by requiring a start point of the building, and the ending being the completion of the building. The starting Act never sees the ending Act.

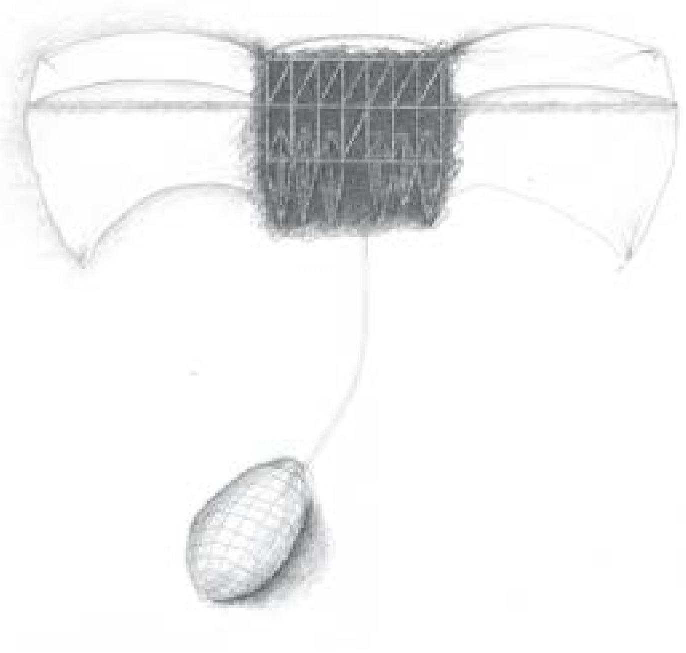
Using the multitude of Agents and their Acts, The Shimizu model provides a unique representation of the third substrata, Field. Shimizu's Agents have a unique scenario that their actions constantly develop their Field [Fig. 1.2.2c]. Other than the factory, they do not have a specific Field due to their reuse in other buildings once one is completed. Nevertheless, at a current building, their Field is limited by the spatial volume that makes up the building. They are also only able to move on floor that has already been constructed. Thus, Shimizu's robots are limited to Acting within the physical boundaries that make up a building.

## AMAZON WAREHOUSE

Similar to Shimizu, Amazon has been working diligently to create an automated supply chain process. Currently, they are working to automate their product warehouses with robots. Their newer warehouses have been designed to adapt this process and existing warehouses are being retrofitted. Amazon is striving to eliminate human intervention within the warehouse, only allowing human work for robotic maintenance.

Many people have ordered a package from Amazon, but most do not realize the process behind the delivery of an order. Within Amazon's product warehouses, an automated robot cart grabs shelves to be delivered to pickers (the employees that requests a product). This robot has been programmed to visualize the warehouse and move through it without intervention - similar to Shimizu's Robo-Carrier. The picker simply requests a product and the robotic cart [Fig. 1.2.3] - either Ernie, Bert, Scooter, or Kermit (yes, Amazon named their robo-carts based on *The Muppets* characters) - will locate the shelf where the product is stored and return it to the picker [Boyle, 2021].





[Fig. 1.2.4] Strandbeests (Jansen, 1990-2022)
*Top Left: Strandbeest of the Aurum genealogy moving through a seashore.*
*Top Right: One of Jansen's initial sketches of the Strandbeest, testing its walking system.*
*Bottom: Jansen's sketch for a flying Strandbeest.*



[Fig. 1.2.3] Amazon's Scooter (Del Ray, 2018)
*This robo-cart moves shelves from its storage location to the picker.*

Although the picker is also an Agent within the Field, this thesis will focus solely on the inorganic Agent, the automated robots.

Compared to the Shimizu model, Amazon has a more simple application hierarchy of Acts. Within a controlled environment, there is more linear and shallower hierarchies that exist. A reason for this is due to the intervention by an external force. In this case, the human requests a certain product to be located and returned for collection. Because of this, there is only one Act that Amazon's Scooter must comply to: return the product back to the picker. Thus, there is a *Linear* application of Acts once the external force is acted on this Agent.

That being said, Amazon is working to remove the human from the application hierarchy. Doing so will cause the hierarchy to become more complex. However, it will remain Linear. Even if the picker becomes a robot, Scooter must still wait for a signal to be given so that it may act its Act. Even the picker will have to wait for another external force to pass the task down through the linear chain.

A Linear application approach, as emphasized in Shimizu and Amazon models, can be detrimental. The error or downtime of one Agent can lead to a halt throughout the entire hierarchical chain. To remove this, each Agent must Act on its own accord and not rely on other Agents.

The Field for Amazon's robo-carts has similar attributes as Shimizu's. Amazon's robots are always contained within the factory; all their Acts have things to do with components that make up the factory, such as product shelves. Their movability is limited to the walls that make up the factory and the obstacles that may be present inside, such as shelving, humans, and other robots. Thus, Amazon's Field is described as the physical boundaries of the factory.

The Shimizu and Amazon models have assisted to understand what an Agent, Act, and Field may be for this thesis. However, they are limited to a Linear application. The goal for this thesis is to discover a vessel for emerging digital life forms. A life form contains more complex systems that rely beyond a linear hierarchical chain. Thus, other models, such as Strandbeests and Fiberbots, must be analyzed to better understand Autonomy and beyond Autonomy applications.

**STRANDBEESTS**
The Strandbeest model is a closer representation to the model for which I am seeking in this thesis. Strandbeests are skeletal-like creatures created and designed by Theo Jansen. Jansen first created these new life forms in 1990. Strandbeests work with the wind to be able to move throughout a landscape. Since their inception, they have gone through multiple evolutions based on different properties and movability Jansen seeks to explore [Jansen, 2022].

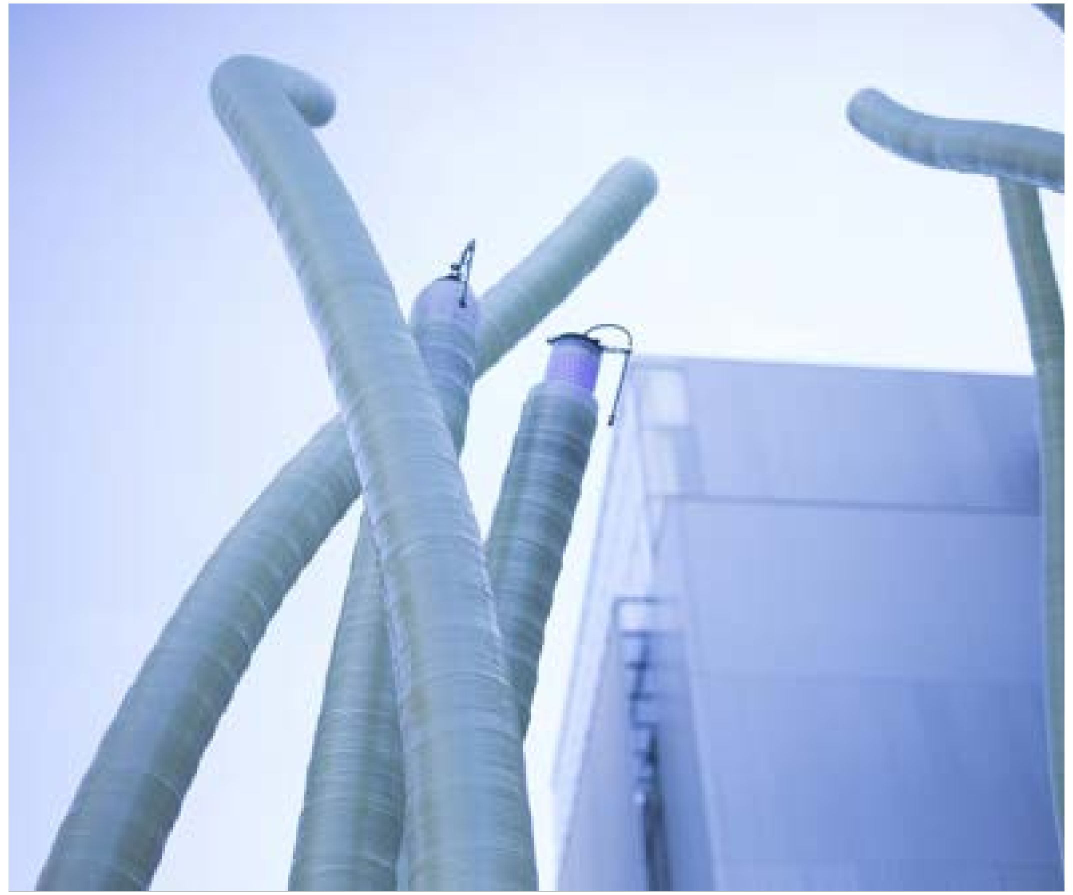
The best way to truly understand a Strandbeest is to watch a video of them moving through their Field[1]. Jansen uses plastic tubes as their main skeletal system. Wind passes through these tubes into fabric bladders to animate their movement. This explanation is just one type of evolution, but there are multiple types that use different systems for different Acts.

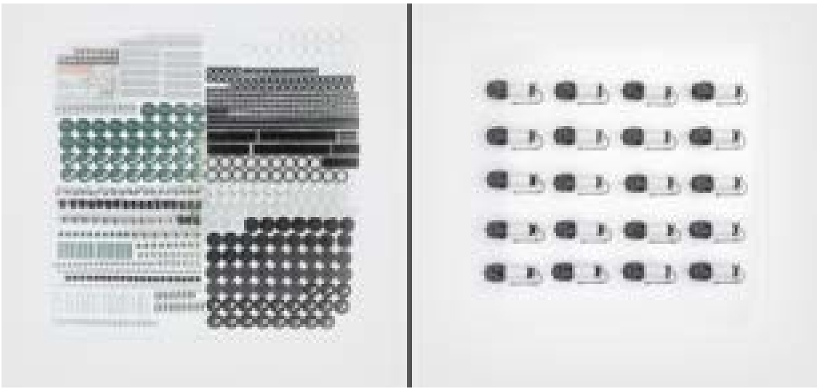
Going beyond linear, the Strandbeest model represents a *Symbiotic* application. The relationship between the Field and Agent allows it to be so: a Strandbeest moves around the seashore powered by the wind. While walking around it, its skeleton reshapes the seashore that lies underneath it. As the Strandbeest reshapes its Field, it is also redefining how to move around the Field. They rely on the topography of the landscape to move around; thus, shifting around the sand will also affect their mobility.

The collaboration between the Agent and Field defines a Symbiotic hierarchy. The Acts of the Agent relies on the definition of the Field, and the Field changes due to the Agent's Act.

Unlike the previous models, Strandbeests do not need human intervention to walk. Yes, a human creates them, but there is no significant intervention after their creation. This detail links them more toward the sought-after model. The only dispute, though, is that Strandbeests require external wind intervention to be able to move. Without wind, they would not be able to be "lively", rendering the Strandbeests as a Symbiotic application.

1 Jansen, Theo. 2021. "Strandbeests of the Aurum." *Theo Jansen*. 2020-2021. https://www.strandbeest.com/evolution.





[Fig. 1.2.5] Fiberbots (Oxman, 2018)
*Top Left: Multiple Fiberbots weaving fiberglass to create tube-like structures.*
*Top Right: The Fiberbot.*
*Bottom: The components that make up the Fiberbot.*



**FIBERBOTS**
Another close representation of the sought-after model is the Fiberbots model. Neri Oxman and her team at MIT built custom robots engineered to weave fiberglass strings into structures. Many Fiberbots work together, imitating a collection of organisms working together to create an environment [Fig. 1.2.5]. The development of Fiberbots is an attempt to generate architectural work with multiple Agents working with one another.

Not only do Fiberbots work with one another, but they also work with their environment to accomplish their objective. They are programmed to visualize their adjacent environment and use that information to inform their output structure [Oxman, 2018]. Seeing them work together is truly a magical thing to experience[1].

Fiberbots work differently than the previously compared models. The Fiberbots' software works with other one another to visualize and analyze its environment (as if they were a hive mind). In contrast to the Strandbeests model, the environment does not change through the Acts of the Fiberbots. The Field is only changed through an additive process, not a deformation process as shown in the Strandbeest model.

Analyzing the Field prior to the additive Act allows the Fiberbots to behave autonomously. Once they are deployed on a Field, the Fiberbots do not need any external intervention to continue their work. This allows them to be deployed on virtually any site.

Oxman accomplished making a model that can express form through an *Autonomy* application. Although, similar to Strandbeests, they need additional support to be able to accomplish in expressing a form. The Fiberbots need to be placed on their fabrication site by an external force to be able to visualize, inform, and create.

## 1.3 TOWARD A SENTIENT APPLICATION

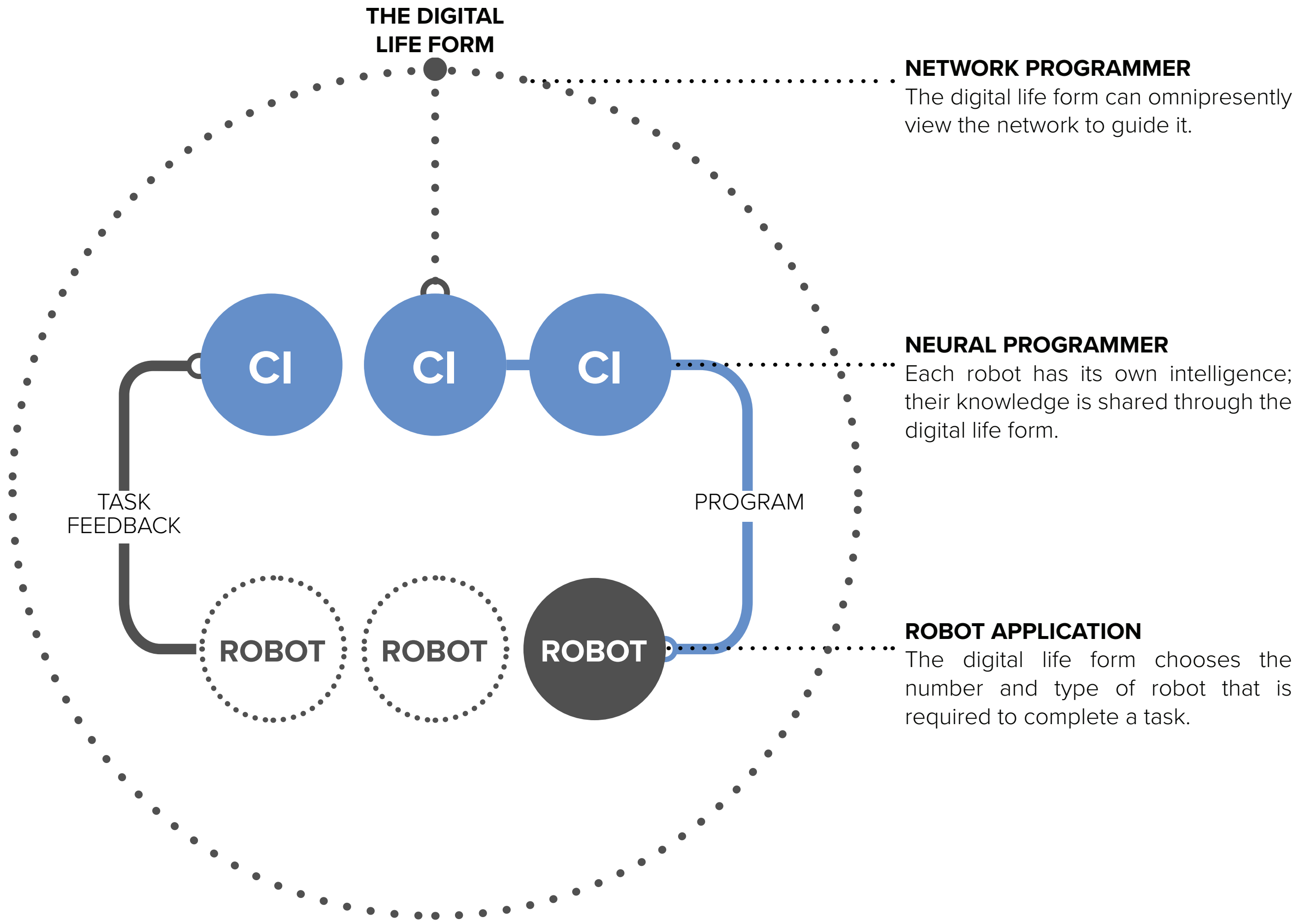
The previous Substrata Models have been parsed to give a better understanding of what it means to be an Agent, Act, and Field. Briefly, the *Agent is an inorganic occupant within the Field that is defined by its limited environment that does a specified Act*. Though this is the simplest definition, each substrata have properties that more thoroughly defines them.

The models have been analyzed in a way that describes the applications between their substrata to one another. A *Linear* application limits an Agent's Act by deriving its Act from an external force. As another model, the *Symbiotic* application is defined by the collaborative effort between the Agent and Field as a result of the Act. And, finally, the *Autonomy* application is represented through the Agent analyzing the Field to Act without external forces.

These relationships work great for the necessities of their respective models. For this thesis, the Autonomy application gets the closest to the type that will be required between the substrata. However, it is not the most articulate to be able to realize the outcome of this study: to discover a vessel for emerging digital life forms.

Using the knowledge gained by the previous models, the sought-after application is represented through an application beyond Autonomy. A *Sentient* application is one where the Agent and Field work together to continuously supply new Acts without any external intervention. This is done by having one main intelligence - similar to the Fiberbots. This one main intelligence is represented as the emerging digital life form. The digital life form can visualize the network of Agents to best guide them. In other words, Agents have their own intelligence; though, each is guided by an omnipresent intelligence. This network of guided robots is a foundation for the discovery of a vessel for digital life forms.

1 Oxman. 2018. "FIBERBOTS." *Vimeo*. September 23, 2018. https://vimeo.com/291386504?embedded=true&source=vimeo_logo&owner=18583901




[IMAGE 02] VESSEL - EXPLAINED

## 2.0 DEFINING THE VESSEL

### 2.1 CONSCIOUSNESS

To be able to emerge an inorganic, intelligent being, a Sentient application must be used. A Sentient application [IMAGE 02] is defined by the Agent's ability to actively Act within a Field without an external force. This type of application is necessary to ensure that the network of substrata is considered conscious.

This consciousness does not derive immediately from each individual Agent. Rather, the conscious is shared between each instance of an Agent - similar to Fiberbots. Each Agent is a body for the emerging digital life form to learn through multiple simultaneous interactions within a given Field.

### 2.2 VISION

An omnipresent digital life form must be aware of all things occurring at once. Because of this, it cannot have a perspective. It would need a 360-degree view at all places of its perceivable Field. This is something that, as humans, we cannot imagine. With an omnipresent view, there can be an overwhelming amount of data to consider; but how can the life form filter out the important data? And what is the important data?

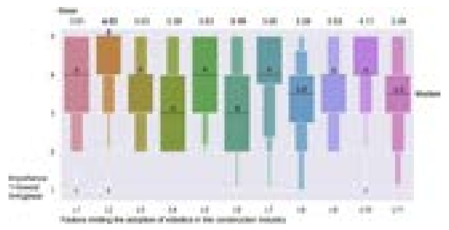
To answer this question, the digital life form's goal must be reviewed: its goal is to analyze patterns on how the three architectural substrata - Agent, Act, and Field - interact with one another. The analysis should produce patterns so the digital life form (which will be referred to as the digital being from now on) may predict its reality. This prediction is necessary so that the digital being can guide its given Agents what to do next, allowing for a Sentient application.

To be able to create predictions, the data must be filtered for a usable analysis of the Field. Contrary to humans, a digital being does not necessarily need physical data to understand its context. Physical data is the material reality of the Field: the ground, made up by earth and water; the built environment, consisting of fabricated materials; and the weather, forced through wind and temperature; and even the components that make up the Agents. The argument is not that physical data is unimportant - it does have its merits, but these merits are not necessary for a digital being to understand its context. Data that is important to a digital being is represented as metadata.

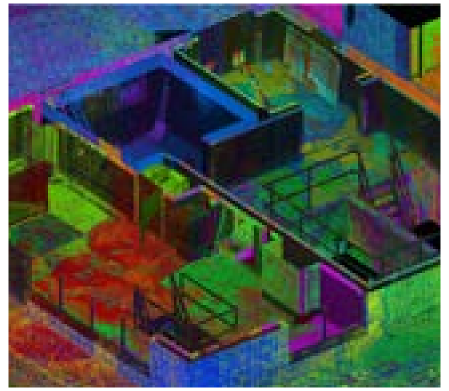
What is metadata? Aristotle's principles of Metaphysics can be utilized to understand this question within the context of this thesis. In contrast to physics with metaphysics deals with the knowledge of a world beyond materiality and senses. This is done by analyzing what is beyond the physical reality that humans perceive [Inwagen, 2014]. In doing so, a given context can be understood beyond how humans visualize the world. This is the start to understand how a digital being may visualize its reality.

Using metaphysics as a foundation: for this study, metadata will be defined as *the performative actions produced by an Agent*. Metadata will be used to analyze an Agent's Acts to calculate the performance of the network of substrata. Considering metadata and performance analysis, the digital being can predict what will occur next and inform the network as necessary.

Now that the digital being's datatype focus has been realized, its method to visualize such data can be questioned. The best way to understand the being's vision is to consider present methods of data representation.



[a] Factors Limiting Robotic Adoption (Delgado, 2019)

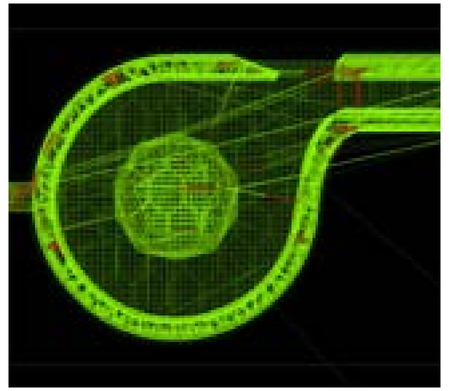


[Fig. 2.2.1] Representations of Data Plots
[b] What is Pointcloud? (Voortman, n.d.)
*Representations of 2D and 3D data plotting.*

2D Plots [Fig. 2.2.1a] are useful for analyzing an instance of three-dimensional data that can be represented as a single-dimensional point. Examples of 2D plots are histograms, bar graphs, line graphs, and any other method of describing a data point.

Adding a third dimension to a 2D plot gives another value to data. 3D plots [Fig. 2.2.1b] visualize a moment in time. As an example, point clouds visualize a physical representation of the world which can only be viewed in the perspective of a 3D scanner. More data/scans can be layered to reveal more information, but there is no movement in a point cloud.

Given the still nature of 2D/3D plots in a given time, these plots inherently do not present a pattern - the pattern must be interpolated through the available data.



[Fig. 2.2.2] Toolpath Visualization (Metts, 2021)
*Representation of toolpath visualization through a 3D printer G-Code.*

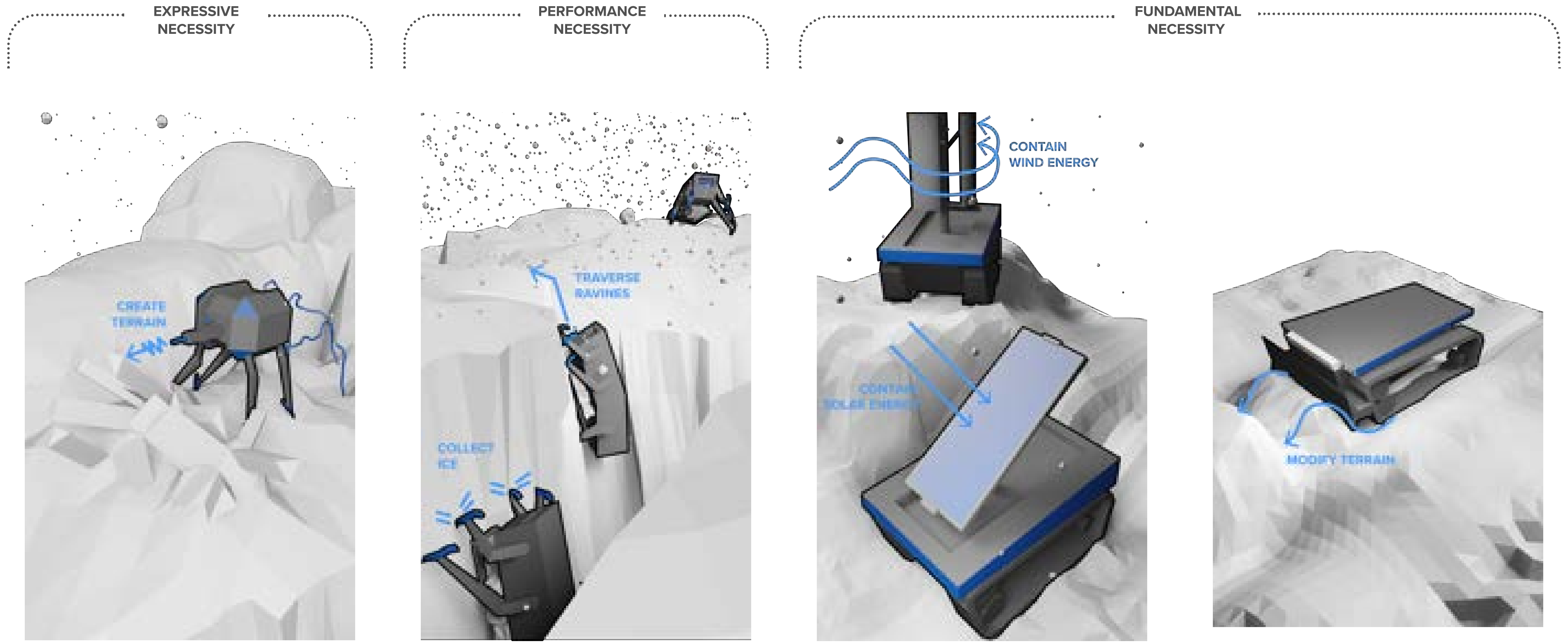
Toolpaths [Fig. 2.2.2] are a method of connecting 3D data to one another to show a relationship between data points. As an example, 3D printers read code to move to specific locations within its Field. There are also other digital fabrications tools, such as CNCs and industrial robots, that use toolpath plotting. Toolpath representation of data is not limited to visualizing one instance of time. Rather, the representation shows the location of the next datapoint. Thus, predictability is possible. Even if there is no next datapoint, a digital being can learn to predict the forthcoming data.

## 2.3 THE METAVERSE

Now, how does this thesis relate to a metaverse? In recent media, the metaverse has been seen as a way of viewing the world in a virtual reality (Ravencraft, 2022) - basically another version of *Second Life*[1]. The version that will be used for this thesis will not be viewed as a video game. Rather, it will be used similar to the understanding of a digital twin. A digital twin is a “virtual model designed to accurately reflect a physical object” (IBM, n.d.).

This architectural metaverse looks beyond just a digital reality of the world. The intention is to use the digital reality as a means to explore the future probabilities of the physical reality. Beyond the scope of this study is to emerge a digital being to comprehend the network of patterns of th world to predict consequences. Using this metaverse, physical designers can have predicted data to *truly* design for the future.

1 "Second Life." *Wikipedia*. August 2020. https://en.wikipedia.org/wiki/Second_Life




***MK-4.0:NOVELTY***

**Description**: Prospectors must feel the joy of successes and failures through innovation. Without this feeling, there is no motivation to evolve.

**Objective**: Create and modify new environments for the sake of evolving new needs for Prospectors.

***MK-3.0:OPTIMIZE***

**Description**: After the essentials, Prospectors are able to manipulate the environment to reduce resource consumption.

**Objective**: Redevelop shelter and energy needs to optimize resource and environmental modifications.

***MK-2.0:ENERGY***

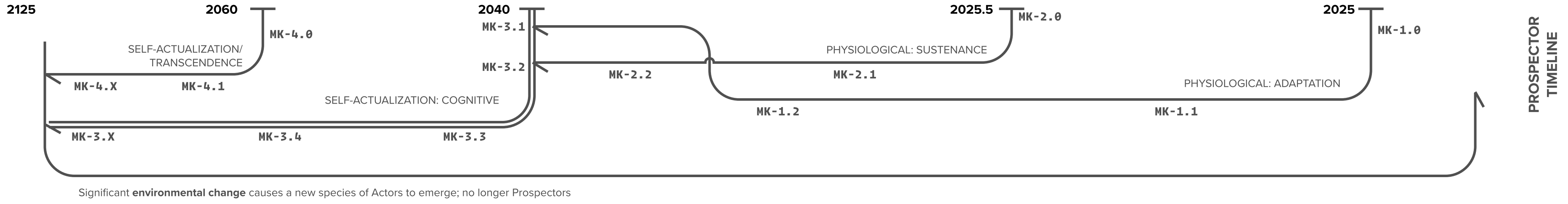
**Description**: The Prospector's require an energy source to maintain their ability to continue performance.

**Objective**: Locate and/or create a means to generate energy from the given Arctic environment. Energy generation must be adaptable to the next generations.

***MK-1.0:ACCLIMATE***

**Description**: The necessity to find shelter from the natural elements is a primary objective to live.

**Objective**: Modify large portions of the terrain to allow for sheltered areas. These areas are developed so next-genration Prospectors have a place of refuge when the conditions of the Arctic become too harsh.




[IMAGE 03] PROSPECTORS + ACTS

## 3.0 METHODS

### 3.1 THE PROSPECTOR NETWORK

This study will test the emergence of a digital being through a digital vessel. By a vessel, I mean a *container for the digital being to practice and learn through a given context*. The overall concept for this vessel is to place Agents - each with their own responsibilities - within a controlled Field. The digital being will use this controlled context to practice and learn by analyzing the performance of the Agent, Act, and Field.

Considering the Fiberbots and Strandbeest models, a new model can be realized. The purpose of this new model is to explore an unknown environment using the architectural substrata. The Agent is to discover a new, unknown Field by fulfilling their desire to subsist (continue to live). These desires originate from Maslow's Hierarchy of Needs [Appendix 3.1.1]. The hierarchy has been abstracted to generalize the application beyond human use.

Based on their purpose to experimentally discover a new environment, the new model has been given the name *The Prospector Network* [IMAGE 03]. The Prospector Network consists of different types of Prospector Agents, each with their own responsibilities. The Field has been chosen to mimic the Arctic environment, mainly for the wide usability of the local material - ice - and its quickly changing properties (although a like-Arctic environment has been chosen, the outcomes of this thesis is not meant to solely apply to similar environments) [Appendix 3.1.2]. Their holistic Act is to subsist by succeeding in their desires, optimizing, and learning through experiences.

**PROSPECTORS : AGENT**

A Prospector's general purpose is to modify their environment to follow their desires. This is carried through multiple generations of Prospectors, each with their own Acts. The roles of each Prospector generation will be described within the *Subsist* section.

The Prospectors inherent the same properties as described about the Agent. Their composition consists of inorganic matter, mostly of metal and electrical components. Prospectors do not have an unlimited supply of power, which will ultimately become part of their Acts.

**SUBSIST : ACT**

The Prospectors need motivation and direction to make the vessel useful. The direction is driven by the hierarchy of needs of the Prospector Network. The hierarchy of needs are abstracted from Maslow's analysis of human necessities. The purpose of these needs is to promote survivability and the passing down of information from one generation to another.

The following are the hierarchical needs that will guide the Prospectors to subsist:

*ACCLIMATE:* The first to land on site is Mk. 01. Mk. 01 focuses on acclimating the environment for the forthcoming generations. Essentially, Mk. 01 scouts the site to understand its exploratory context. This Prospector will be primarily used to analyze the performance of the defined vessel.

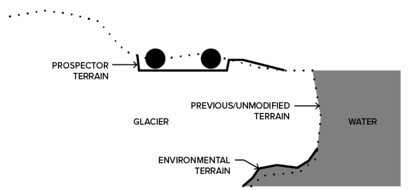
*ENERGY*: Because Prospectors run on electrical components, they need to find a supply of energy. Mk. 02's objective is to generate Energy for the network of Prospectors. Mk. 02 uses the knowledge gained through Mk. 01's scouting to know where to best generate energy.

*OPTIMIZE*: Mk. 03 takes the Acts of Mk. 01 and 02 to optimize them. As the landscape changes drastically, Mk. 03 must evolve to more properly maneuver across the uneven Arctic-like landscape. This Prospector might also generate its own energy through passive means.

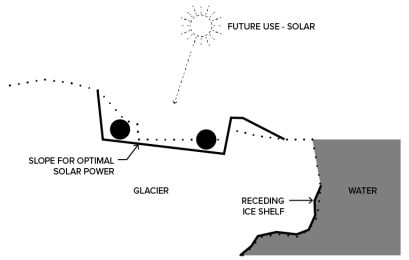
*NOVELTY*: Mk. 04 represents the Self-Actualization need of the network - in other words, Novelty. This need is to enjoy learned experiences through innovations that may not be necessary for survivability. Mk. 04 may create and modify new environments for the sake of enjoyment.

**ARCTIC : FIELD**

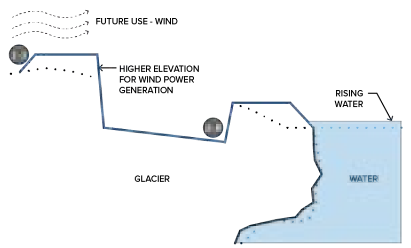
An environment similar to the Arctic will be used as the controlled Field within the Prospector Network vessel. The Field acts as a playground for the Prospectors to modify so they may progress through their hierarchical needs. The Field is more of a background, but it assists in developing the learning capabilities of the digital being. This vessel will be tested on a glacier due to its chaotic and constant changes.



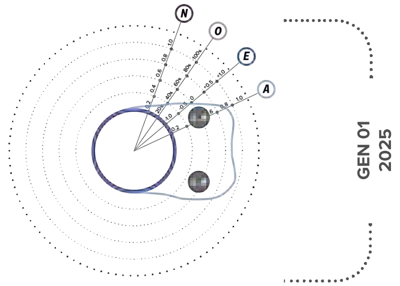
1 Initial landing of Prospectors, MK-1s, on Arctic glacier

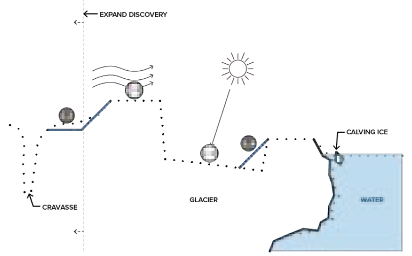


2 MK-1s adapt environment for future solar power generators

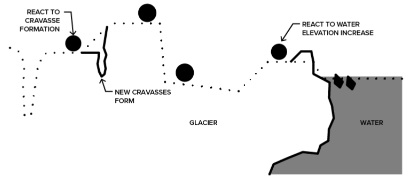


3 MK-1s adapt environment for future wind power generators

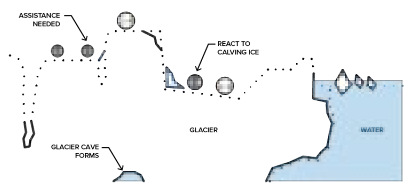


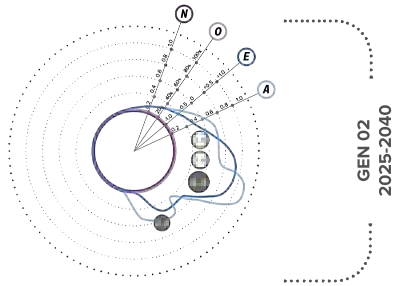
4 MK-1s reuse resources to create MK-2s; first exploration sent for new regions

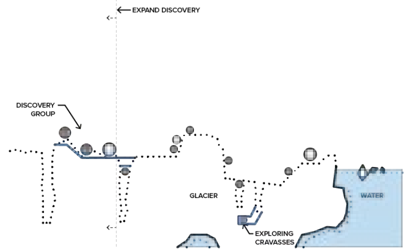


5 Cravasses form; Prospectors must be weary and adapt to changing environment

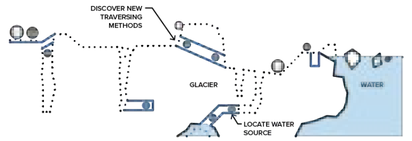


6 Continued adaptation

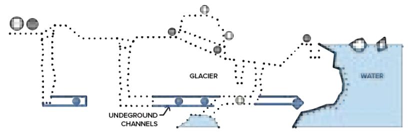


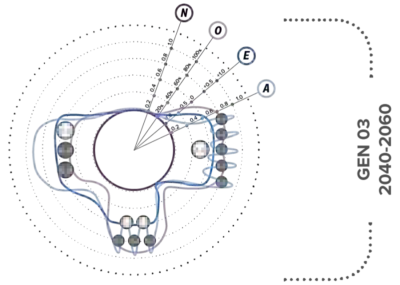
7 Changing environment forces evolution to optimize resources; second exploration

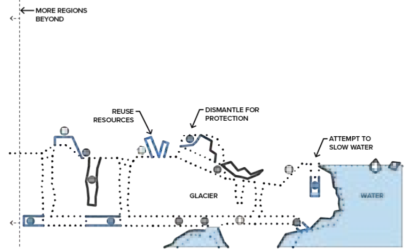


8 New methods of traversing necessary; water resource prepared for future use

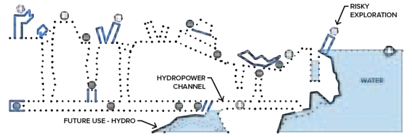


9 Underground channels formed for more efficient movements

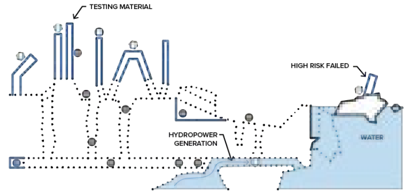


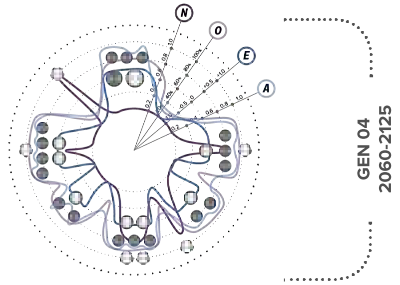
10 Significant adaptation allows for creative Prospectors, MK-4s



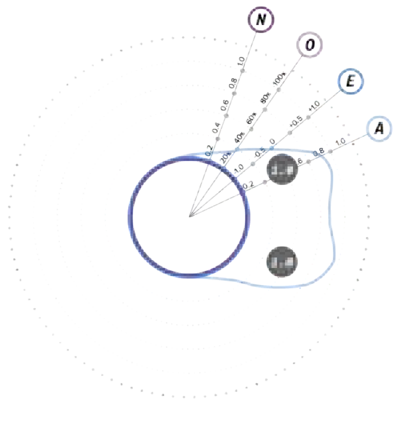
11 MK-4s test new methods of forming; future hydro use is prepared



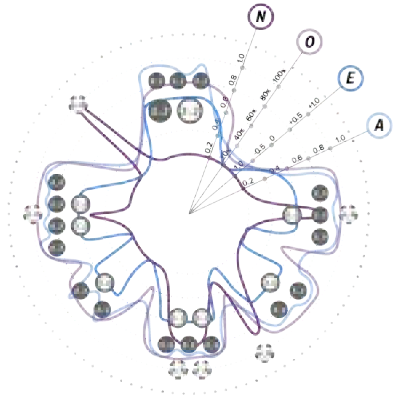
12 MK-4s test material abilities for knowledge sharing; the exploration continues...




[IMAGE 04] PROSPECTOR GENERATIONS



[a] Generation 01



[Fig. 3.2.1] Prospector Network Performance Graph
[b] Generation 04
*Representing the possible evolution of the Prospectors as they learn their environment.*

Within the like-Arctic environment, there are limited number of materials that can be found at the surface. The Prospectors are to focus working with the local material - ice. Ice has multiple states - liquid, solid, gaseous - that can be used for multiple uses. The Prospectors are free to alter the state of the material to modify the Field as necessary.

### 3.2 PERFORMANCE METRICS

The Prospector Network will be analyzed using their ability to succeed in their defined Acts. The region that Prospectors are located will be examined to review their performance. The graphs show an example of how the grouping of different Prospector generations change the performance of the vessel.

These performative metrics will be used to analyze patterns on how the Prospectors may react to the changing environment. These patterns should produce a prediction so the digital being may inform the Prospectors what to do next. The strength of the performance metrics can also show the success or failure of the digital being.

Using the performance metrics within the context of the Prospector Network, a vessel for an emerging digital being can be found. To summarize, Agents - in the form of Prospectors - will be simulated to test the ability for a digital being to learn patterns using toolpath visualizations.

### 3.3 TOOLS

The investigation of discovering a vessel for emerging digital beings is naturally situated within the practice of computer intelligence. Thus, this thesis will utilize tools that will assist in developing the Prospectors' computer intelligence. My knowledge in computer programming is of an intermediate level - I am by no means an expert in programming, but I know my way around computational and logical thinking.

Digressing from my programming experiences, the following tools were chosen based on their established ability in physics simulations and their custom adaptability through computer programming.

**Unity**
*NavMeshAgent API*
*ML-Agents API*
*UnityEngine API*
*For developing custom interfaces for Agent simulations*

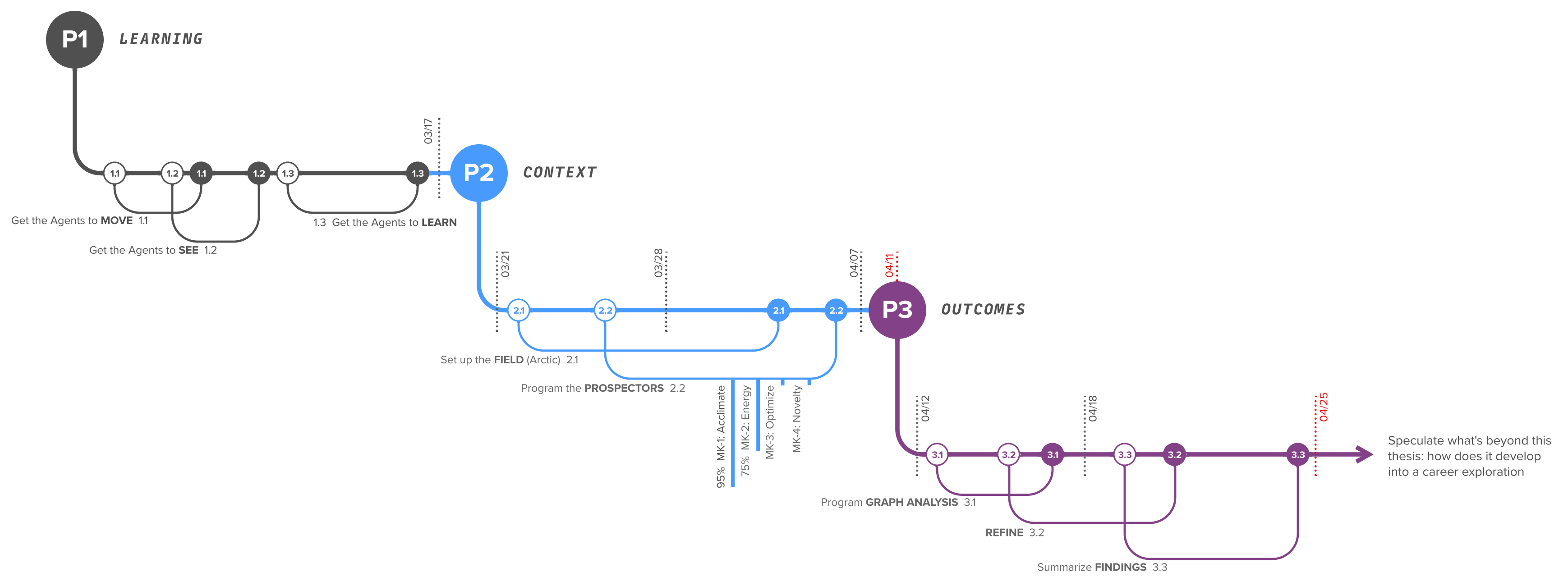
**C#**
*For use in adapting Unity's API for custom Agent coding*
*For creating utility methods that assist in the Agent's learning*

**Python**
*For integrating Unity's ML-Agents API*
*For producing the neural networks brain*

**Tensorboard**
*For analyzing agent simulations*

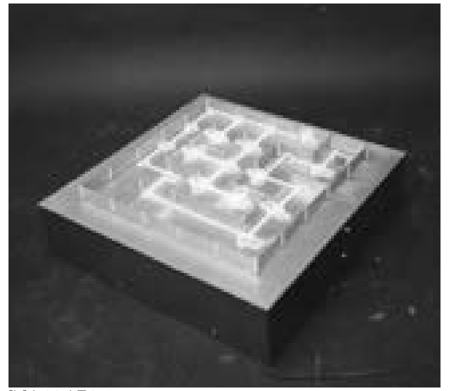
*All code developed through this thesis was produced in-house with the assistance of online resources such as:*


Home [Brackeys]. YouTube. Retrieved from https://www.youtube.com/c/Brackeys/featured.
Home [Code Monkey]. YouTube. Retrieved from https://www.youtube.com/c/CodeMonkeyUnity/featured.
Lague, S. (n.d.) Home [Sebastian Lague]. YouTube. Retrieved from https://www.youtube.com/c/SebastianLague.

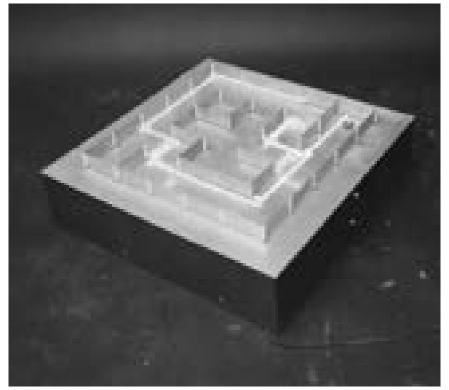



[IMAGE 05] PHASES

[a] Theseus, the mouse



[b] Initial Trip



[Fig. 1.2.2] The Mighty Mouse (Shannon, 1952)
[c] Second Trip
*Theseus learning the maze through multiple trips.*

## 4.0 EXPLORATION

### 4.1 PHASES

To better understand the Prospector context, the exploration of the vessel is broken down into three phases [IMAGE 05]. *Phase One* focuses on the *Learning* ability of the Prospector. This will be analyzed through an arbitrary context that is not necessarily part of the Prospector network. *Phase Two* places the Prospectors into their Arctic-like *Context* so the digital being may start to learn from their measured experiences. *Phase Three* is to realize the *Outcomes* the Prospector vessel has prospered, and to determine how this information can be used beyond this controlled exploration.

### 4.2 PHASE ONE : LEARNING THROUGH TOOLPATHS

To help visualize the objective for Phase One, Claude Shannon's experiment with a mouse maze can be reviewed [Fig.4.2.1a]. Shannon used an electronic mouse (Agent) with an attached lamp to study its movement through the maze (Field). The mouse ran through the maze multiple times to attempt to understand it better each time so that it may find the exit (Act). Shannon tracked the mouse's movements using long-exposure photography [Fig. 4.2.1b]. The long exposures help visualize how and where the mouse is moving. Over a few attempts, the photographs show the mouse's ability to figure out the maze [Fig. 4.2.1c]. Shannon also claimed that the maze can be changed and the mouse would use its previous knowledge to find the exit more efficiently.

For the Learning Phase, a similar experiment as the mouse maze was tested. In this experiment, the Agent is an arbitrary object that is able to move around on a 2D plane - the Field. This Agent also has the ability to see; it uses this ability to find a target (rendered as black) 100 times - finding the target is the Agent's Act. The target is made difficult to find through the use of obstacles on the 2D plane.

Multiple Agents are set on the Field so that a hive-mind can be examined as well (similar to the Fiberbots model). As one Agent finds the target, that one Agent shares the location of the target with the other Agents on the Field. To be able to learn, each Agent's stride is assigned a score - expressed as pseudo-code:

```
if (Agent.Steps > 1500 OR Agent.HitObstacle)
        SetReward(-1)
        RestartSimulation()

if (Agent.HasFoundTarget)
        SetReward(+1)
        RestartSimulation()
```

[Reference IMAGE 06 on pg. 22]

The scoring process is initially tested in *Simulation One*. This first simulation shows the Agent's initial run through its arbitrary context without any assistance (knowledge has to start from somewhere). Without any previous knowledge, the Agents were able to locate 100 targets with 43 mistakes in 2:03 minutes.

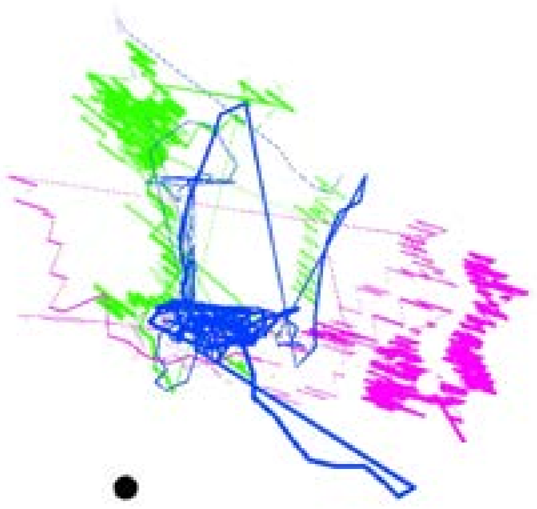
*Simulation Two* uses the neural network brain [Appendix 4.2] from Simulation One. This simulation shows that the Agent can find the target with less mistakes (26) and at a faster rate (1:41).

In *Simulation Three*, the Agents learned to more effectively avoid the obstacles (15 mistakes, 1:09 minutes).

What if there's more and more Agents on the Field? Will the Agents learn faster and produce better results for pattern recognition? Not exactly. Having multiple Agents on the Field allows for a faster learning experience at the cost of efficiency - as shown in *Simulation Four*.

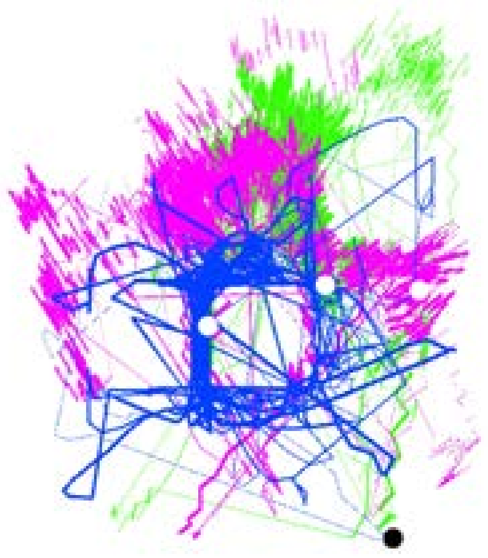
These simulations are rendered using the toolpath visualization [Reference pg. 14] so the viewer can understand how the digital being may visualize its reality. Can you find the obstacles through the toolpath patterns of the Agents movements?

**SIMULATION ONE**
NO BRAIN



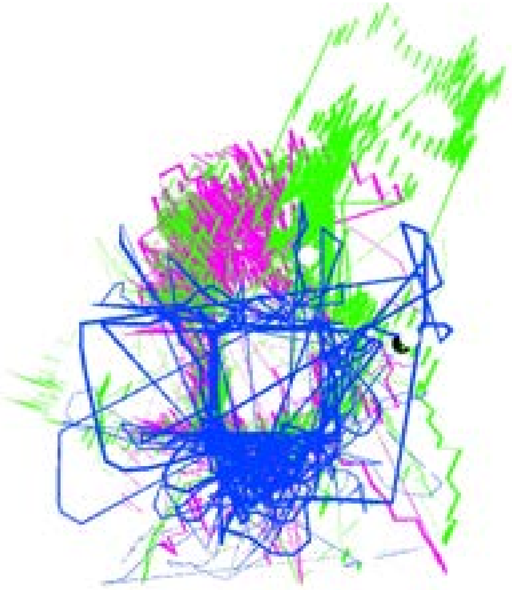
SUCCESS: 100
MISTAKES: 43
TIME: 2:03

**SIMULATION TWO**
BRAIN ONE



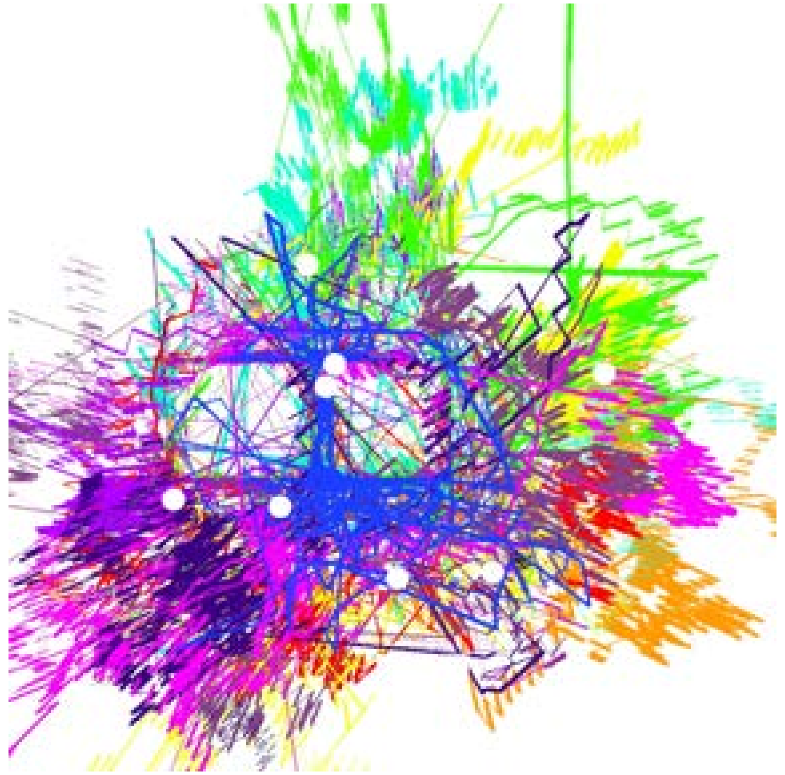
SUCCESS: 100
MISTAKES: 26
TIME: 1:41 (-0:22)

**SIMULATION THREE**
BRAIN TWO



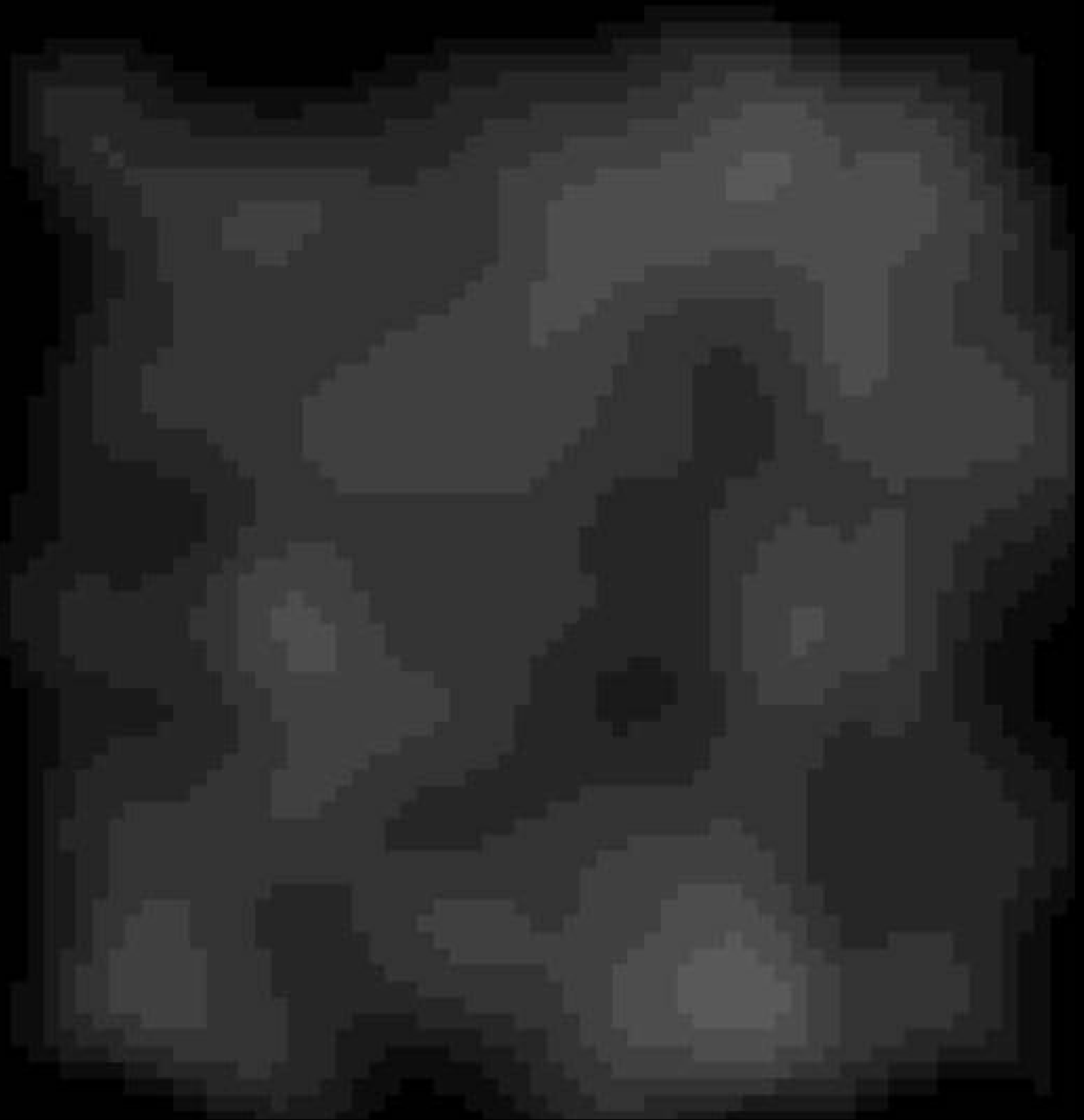
SUCCESS: 100
MISTAKES: 15
TIME: 1:09 (-0:32)

**SIMULATION FOUR**
BRAIN THREE



SUCCESS: 100
MISTAKES: 145
TIME: 0:43 (-0:26)

[IMAGE 06] SIMULATED AGENTS



[IMAGE 07] PROSPECTOR CONTEXT

## 4.3 PHASE TWO : PROSPECTOR CONTEXT

Now, it's time to put the Prospectors to the test. To refresh, the Prospectors will be put in a controlled context mimicking the Arctic [IMAGE 07] so they may experience a quickly changing environment. This Arctic-like Field - with a size of 100 x 100 units - will be tested using the first generation of Prospectors - Mk. 01: Acclimate.

Mk. 01 uses its ability to investigate the landscape of the Field. This Prospector investigates the landscape by finding the higher spots on the terrain. It does so through the following pseudo-code:

```
if (not(Agent.Steps > maxSteps))
        if (not(Agent.HasPath))
                highPoint = Agent.FindHigherPoint(searchRadius)

                if (not(Agent.PreviousPoints.Contains(highPoint)))
                        Agent.MoveToPoint(highPoint)

                else
                        Agent.FindNewPoint(searchRadius)

        if (Agent.HasReachedDestination)
                highPoint = Agent.FindHigherPoint(searchRadius)
                Agent.MoveToPoint(highPoint)
```

This code is ran through Unity's `Update()` method which will run at every frame of the simulation.

[Reference IMAGE 08 on pg. 26]

The following simulations of the Prospector vessel emphasizes Mk. 01's ability to scout the landscape of its Field. This simulation, as well as the others, were given a 6,000-frame limit (about five minutes) so that Mk. 01 has the opportunity to learn and explore. To compare each simulation, additional metrics were used: [1] Distance Traveled and [2] Area Covered.

*Simulation One* concluded with an average traveling distance of 550 units and an average area coverage of 20%.

The Acclimate Prospector has been successfully tested with one Mk. 01 on the Field. Well, what happens if more Mk. 01s are available on the Field? It may have seemed obvious, that, as *Simulation Two* shows, two can explore double the distance, but this does not necessarily mean they will investigate double the area. What about hundreds of them? When does it become inefficient to have more Prospectors?

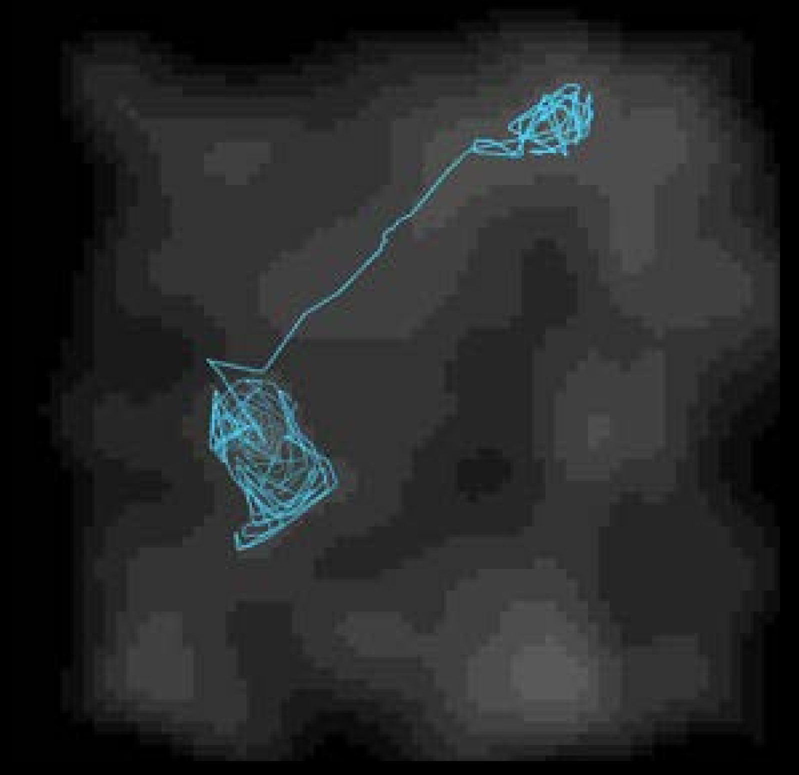
To understand this question, *Simulation Three* limits the Prospectors to only use available resources. In this simulation, one Prospector uses up less resources (Energy - set to a value of 100 for each simulation) so it will have more time to explore its Field. The code is changed simply by:

```
if (not(Agent.Steps > maxSteps OR Energy < 0))
Agent.ConsumeEnergy()
```

Compare that to *Simulation Four* - with 10 Prospectors - and there is a reduction of exploration time due to its increased collective use of resources.

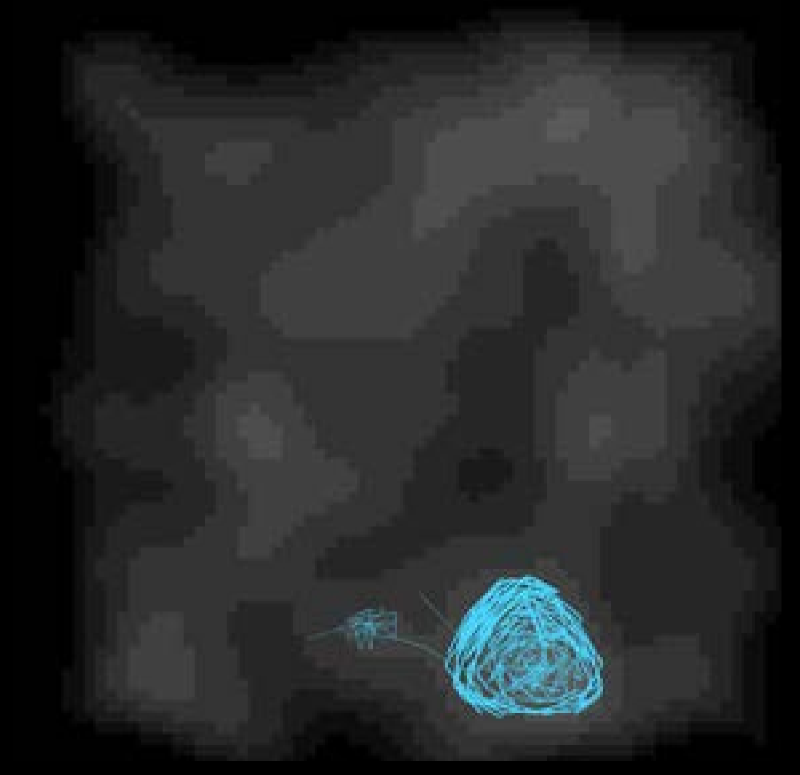
The data analyzed through the simulations can be represented through the Prospectors' toolpaths, similar to Shannon's long-exposure photography. [IMAGE 09] shows the representation of toolpaths within the given Field. Meanwhile, [IMAGE 10] shows the toolpaths as standalone data to represent how the digital being may see its reality. Even with the data filtered to show only the metadata, our human vision can still understand properties of this Field - the peaks and valleys of the landscape.

**SIMULATION ONE**
NO BRAIN



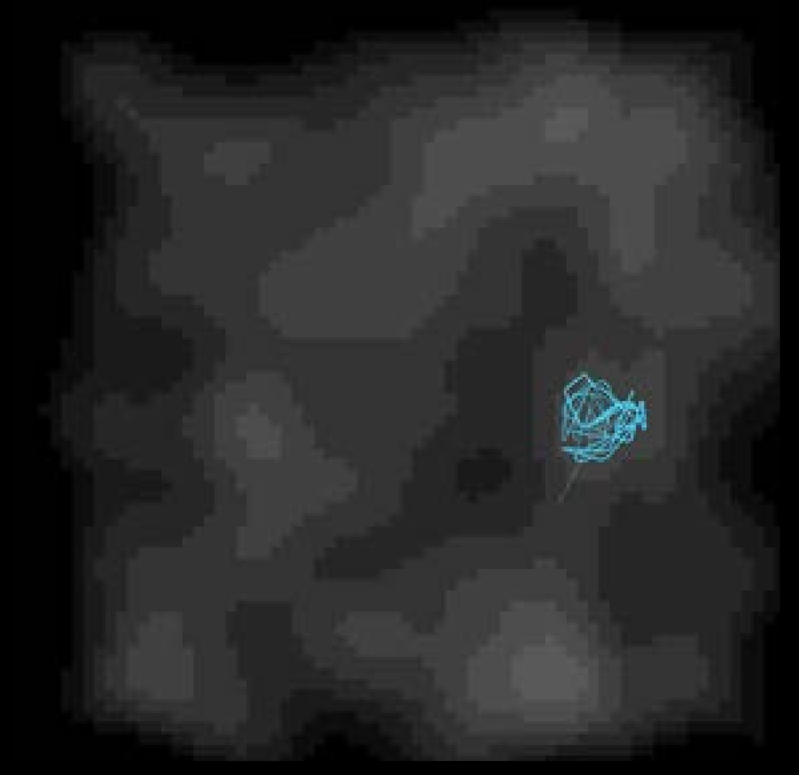
TRAVEL DISTANCE: **550** (base)
AREA COVERED: **20%** (base)

**SIMULATION TWO**
BRAIN ONE



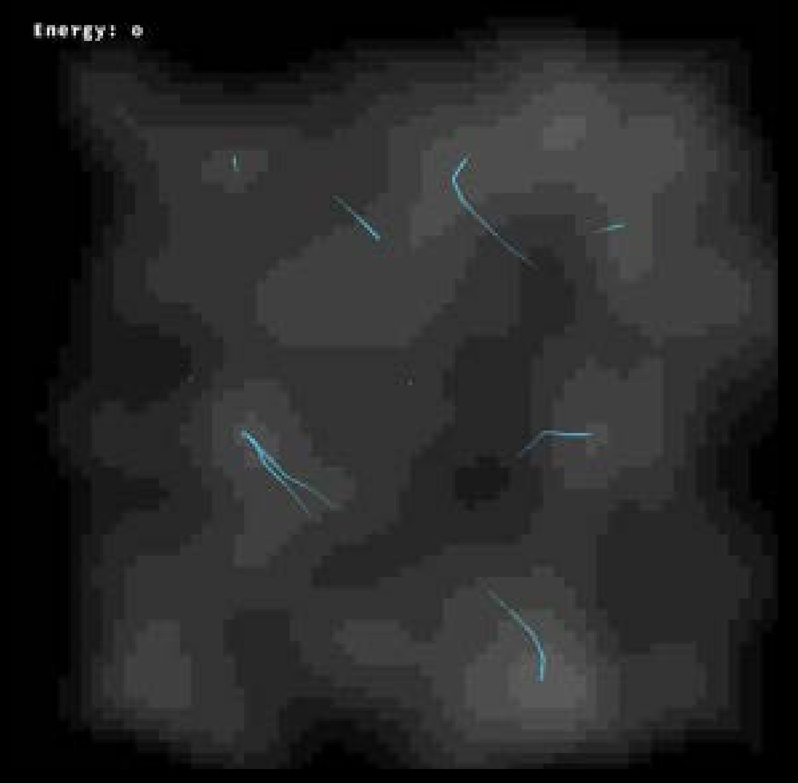
TRAVEL DISTANCE: **1041** (+491)
AREA COVERED: **20%** (+0%)

**SIMULATION THREE**
BRAIN TWO



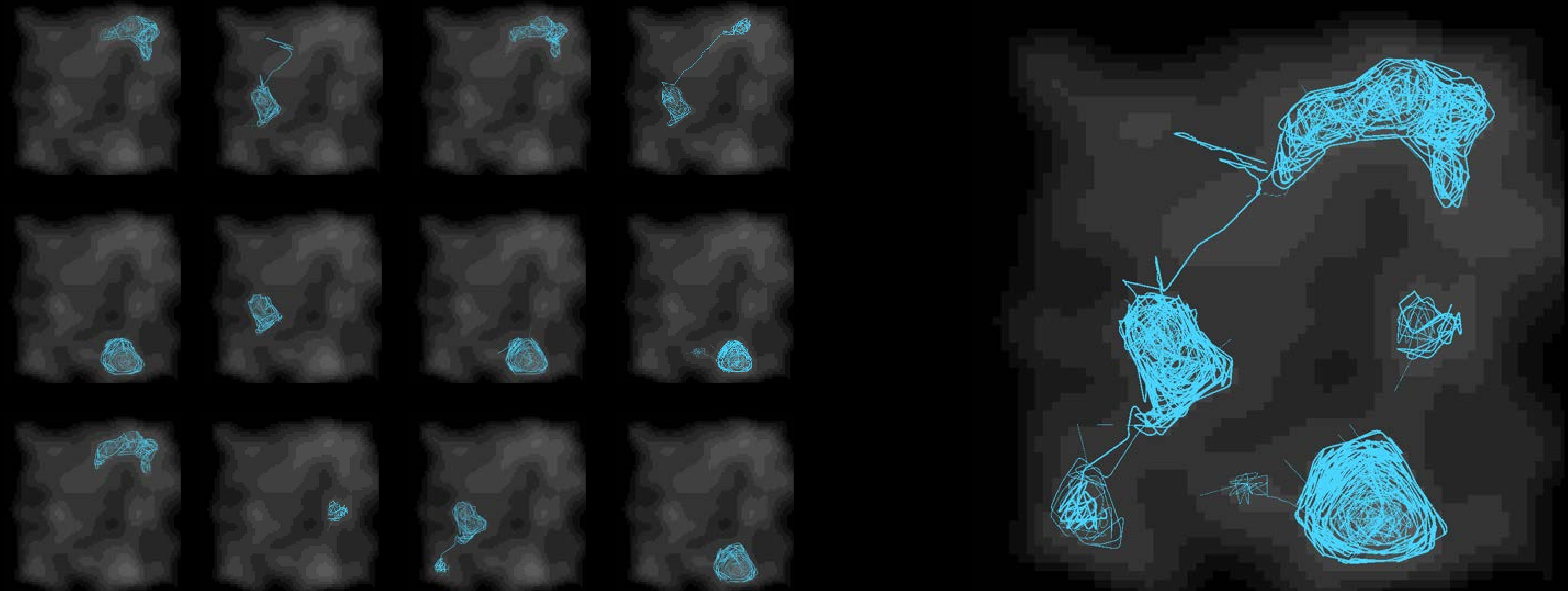
TRAVEL DISTANCE: **128** (base)
AREA COVERED: **10%** (base)

**SIMULATION FOUR**
BRAIN THREE

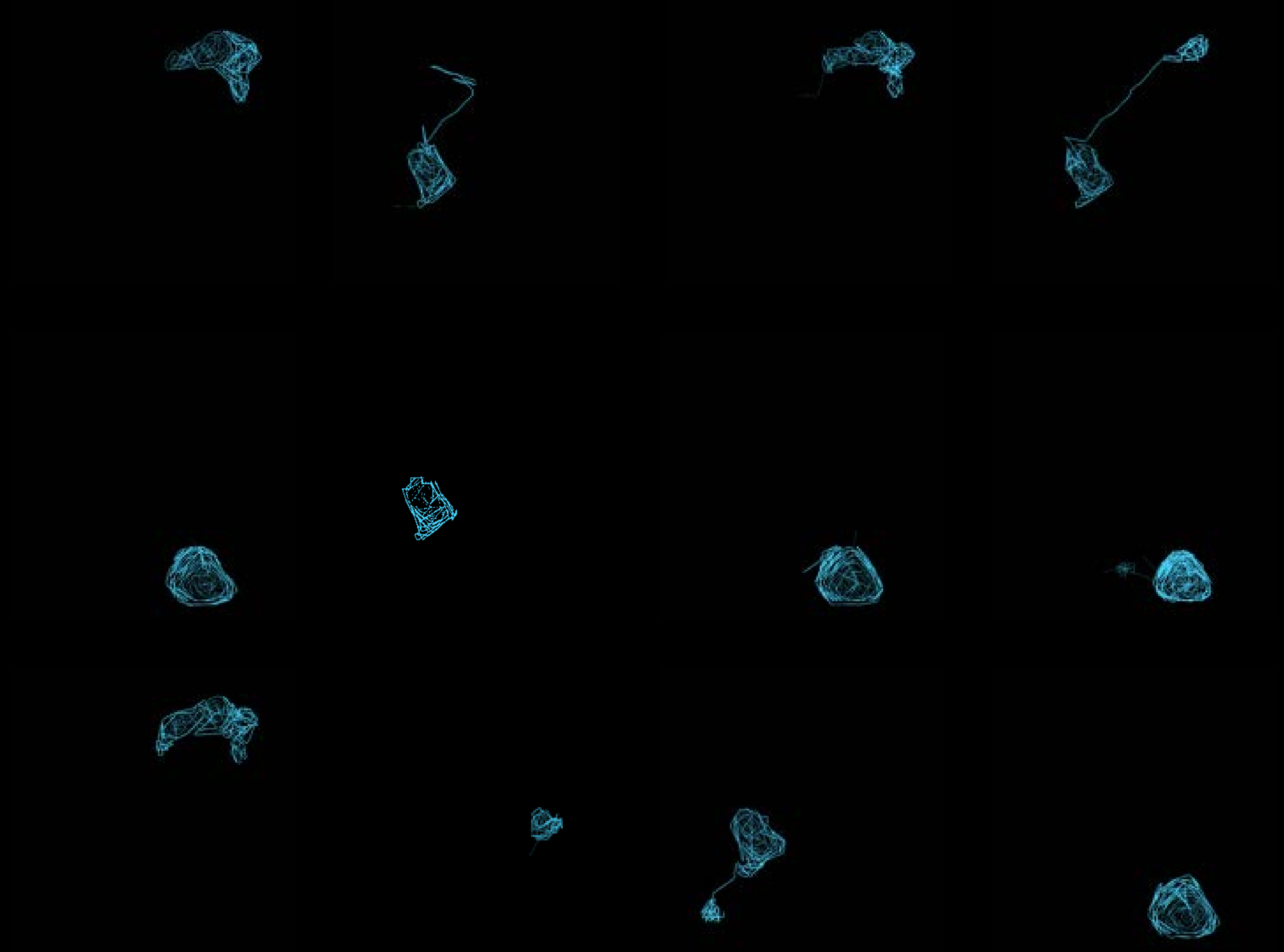


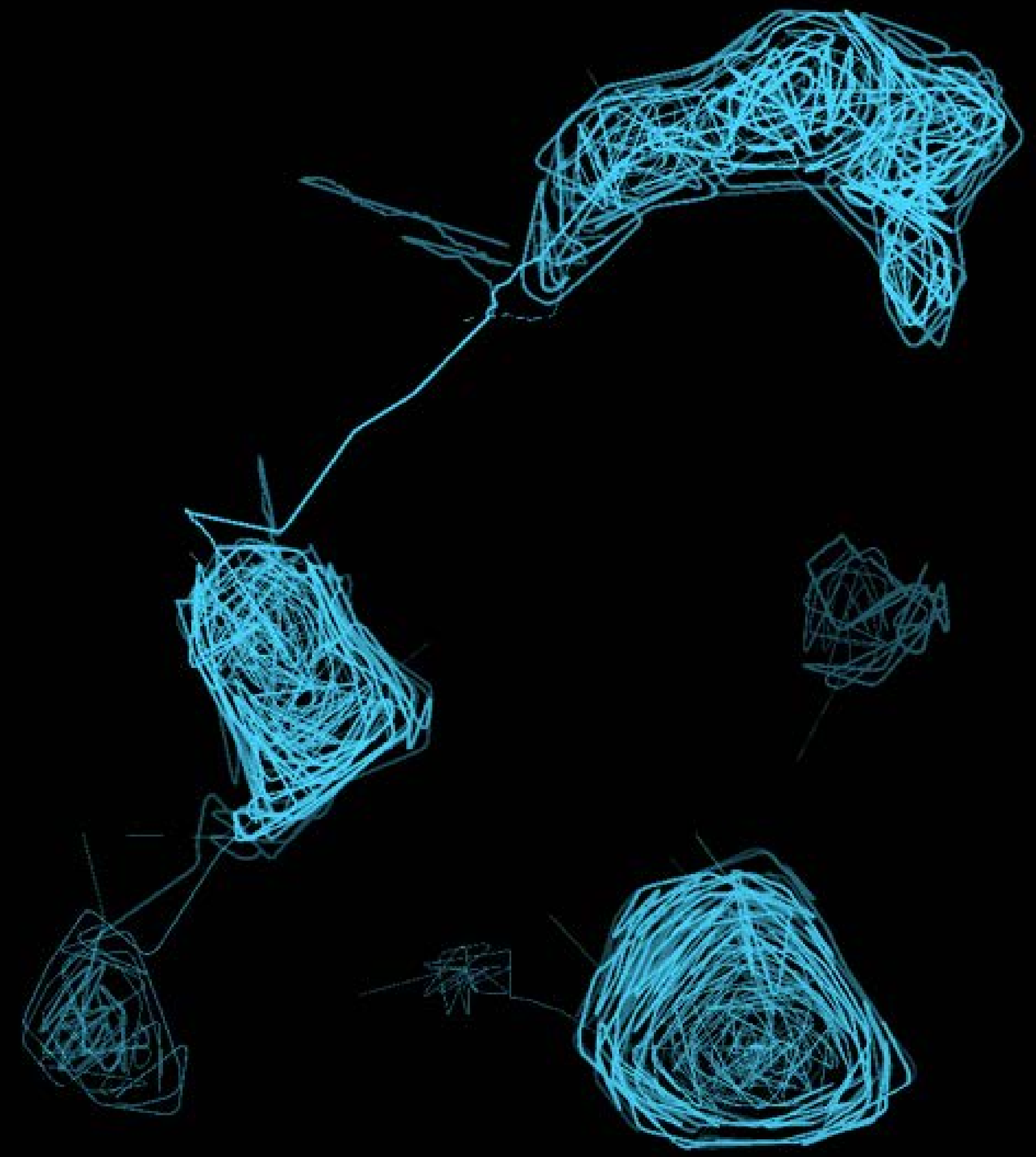

TRAVEL DISTANCE: **66** (-62)
AREA COVERED: **2%** (-8%)

[IMAGE 08] SIMULATED PROSPECTORS



[IMAGE 09] SIMULATIONS WITH CONTEXT

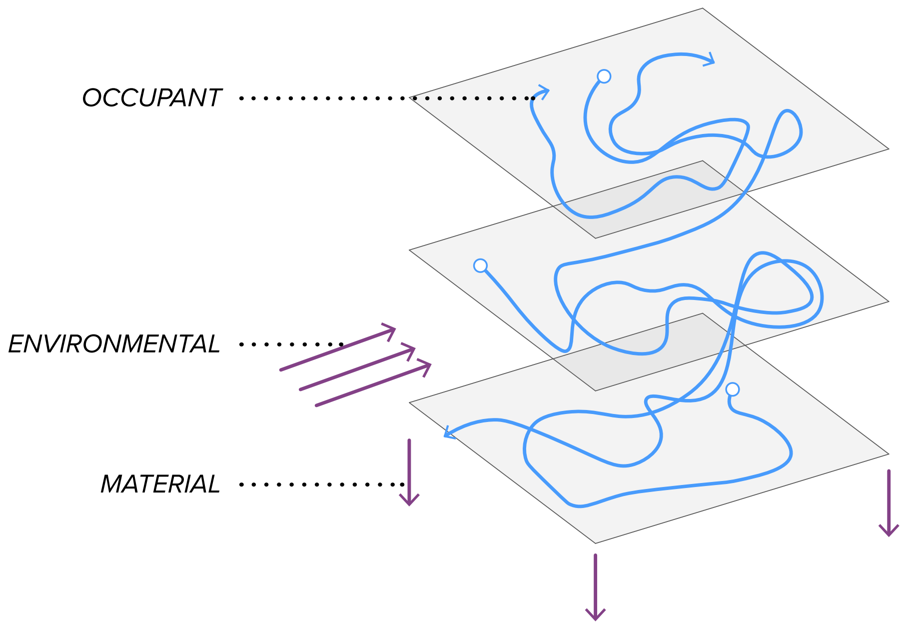




[IMAGE 10] SIMULATIONS AS TOOLPATHS

**A VESSEL FOR A DIGITAL LIFE FORM**

**SIMULATING ARCHITECTURE**
NEW DEVELOPMENT DISCOVERED




Simulate Architecture using the found vessel to truly design for the future.

**DIGITAL BEING**
CONTINUING DEVELOPMENT

Continue the development of the Digital Being to prospered simulations through the discovered vessel.

[IMAGE 11] PROSPERED OUTCOMES

## 4.3 PHASE THREE : PROSPERED OUTCOMES

Through this exploration, a *vessel* for emerging digital beings has been discovered.

This vessel utilizes the visualization of toolpaths to understand patterns without having to know the material reality of its context. This vessel has been discovered using the Prospectors as a controlled context to test whether this methodology is feasible.

Using this vessel, new developments can prosper [IMAGE 11]. One example is *Simulation Architecture*. Rather than hoping for the built solution to work as intended, metrics, such as occupants, materials, or even environmental elements can be simulated to understand their toolpaths. Simulated Architecture is a new development prospered by the vessel that will allow architects to *truly* design for the future.

The discovery of a vessel will also assist in the continuing development of the digital being that can be used in these simulations that the vessel has prospered.

Architecture *can* be used to make new life forms possible.

## A.0 APPENDIX

### 0.0 MIND MAP

The Mind Map serves as a way of linking multiple principles and variables together. It is a way to connect multiple thoughts, questions, and precedents together in an systemic fashion. The Mind Map is split up into two parts: The *Meta Analysis* sets up the *a priori* narrative of the thesis; meanwhile, the *Technical Development* links the technical variables that represent the principles, such as the Body, Equipment, and Program - originating from robotic practices.

### 3.1.1 MASLOW'S HIERARCHY

Maslow's Hierarchy of Needs has been a significant study in the field of psychology. The Hierarchy categorizes the needs that humans must perceive to live a satisfied life [McLeod, 2022]. The categories are as follows:

Physiological (Basic Need): required for human survival. This is translated through Mk. 02 : Energy Prospector.

Safety (Basic Need): security and safety. This is expressed as the Mk. 01 : Acclimate Prospector.

Love and Belonging (Psychological Need): social involvement. Not expressed in the Prospectors.

Esteem (Psychological Need): feeling successful of actions. Expressed through Mk. 03 : Optimize Prospector.

Self-Actualization (Self-Fulfillment Need): realizing one's potential. Expressed through Mk. 04: Novelty Prospector.

McLeod, Saul. 2022. "Maslow's Hierarchy of Needs." *Simply Psychology*. April 4, 2022. https://www.simplypsychology.org/maslow.html#:~:text=There%20are%20five%20levels%20in,esteem%2C%20and%20self%2Dactualization.

### 3.1.2 ARCTIC ENVIRONMENT

Greenland contains one of the largest Arctic glaciers, the Helheim Glacier. NASA has produced multiple studies on this glacier and has established that it is the fastest changing glacier within Greenland; "Between 2000 and 2005, Helheim quickly increased the rate at which it dumped ice to the sea." [NASA, 2017].

The drastically changing environment of the Helheim Glacier inspired selecting the controlled context of this thesis to be similar to this environment. With this type of Field, the Prospectors would be able to interact and adapt to its changing environment.

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### 4.2 NEURAL NETWORKS

A neural network is a method to teach an artificial intelligence through layers of data. These layers mimic an organic brain's neurons through which data is passed through and a pattern is interpreted. A neural network requires significant training data to learn and achieve a meaningful outcome.

Reference IBM's explanation of Neural Networks here: https://www.ibm.com/cloud/learn/neural-networks.



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