Design For A Mind With Many Bodies:  
Cybernetic Micro-Interventions in the Cryosphere

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Design For A Mind With Many Bodies: Cybernetic Micro-Interventions in the Cryosphere

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Abstract

Historically, designs that function within the realm of ecological interventions have heavily gravitated towards attempting to gain full authority and control over the particular ecosystem in order to reform it. This approach is seen far more often than that of working in tandem with the ecosystem through an adaptive and autopoietic manner. [1] According to Pickering, this predominant, hegemonic, and static mode of operations “ignores emergence [and] assumes that we know all the chains of cause and effect.” The thesis proposed here instead suggests that through a soft, cybernetic approach of aggregated micro-interventions a higher degree of adaptability and autopoiesis could be attained within the realm of interventions in natural ecosystems. The approach attempts to highlight the importance of a reactive quality in systems designed to monitor, mediate, and activate the evolving needs of an environment. The logic behind micro-interventions being that the design is not a single large-scale intervention, but rather an aggregate, dispersed, and flexible network that generates the necessary influence through incremental accrue. The work culminates in a step towards the design of one mind with many bodies; a network of soft robotic agents functioning through a responsive and iterative organizational system.

In order to investigate this hypothesis, the ongoing degradation of the ice caps in the cryosphere is examined as the setting. The increasing speed at which melting is taking place, and will continue to take place, calls for a focused exploration of intervening directly at such remote and fragile ecosystem in order to mitigate their ongoing atrophy. Recent research shows direct
correlations between the subsurface structures of a glacier and the activity observed on its surface, as well as how it decays and moves through time. [2] Similarly, the study of ice suggests that, depending on its composition, environmental flux, and method of freezing, its structure has an array of properties varying in ductility and plasticity. [3]

The work developed here investigates the potential of cybernetic micro-interventions as the approach to monitor, mediate, and activate the evolving needs of a dynamic equilibrium within various ice formation in the cryosphere. The thesis is composed of four elements. First, an extensive survey maps the flux between elements of the ecosystem and their relationship to self-regulating performance. Second, a series of ice experiments explore methods of strategic melting and snow capturing. Third, a series of design studies suggest utilizing tessellated folding surfaces as a potential method of pneumatically activating the agents. Lastly, a catalogue of speculative scenarios illustrates strategic melting on glaciers as a method to facilitate self-regulation through increasing snow retention while decreasing mass and relieving stress.

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Abstract

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Introduction

1.1 A Design Thesis

This thesis is about design. In particular, it is about a methodology and strategy of embedding the iterative process of design into the design itself. It is centered on autopoietic designs capable of methodically reevaluating priorities, redefining constraints, recharacterizing roles, revealing relationships, and rechanneling presupposed trajectories of elements in its Umwelt. [4] It acknowledges that relationships become; they are born, they grow, and they develop over time through a back-and-forth evolution. Here, I argue for an approach of responsive adaptability; of a soft, malleable, and sentient type of design that evolves through interacting with its environment rather than simply attempting to control it from the start. It is about designing a novel way of interfacing with our environments, with space, that gradually facilitates mediation and change through incremental accruement.

Historically, designs that function within the realm of ecological interventions have heavily gravitated towards attempting to gain full authority and control over the particular ecosystem in order to reform it. This approach is seen far more often than that of working in tandem with the ecosystem through an adaptive and autopoietic manner. [1] Accord-
ing to Pickering, this predominant, hegemonic, and static mode of operations “ignores emergence [and] assumes that we know all the chains of cause and effect.” The thesis proposed here instead suggests that through a soft, cybernetic approach of aggregated micro-interventions a higher degree of adaptability and autopoiesis could be attained within the realm of interventions in natural ecosystems. The approach attempts to highlight the importance of a reactive quality in systems designed to monitor, mediate, and activate the evolving needs of an environment. The logic behind micro-interventions being that the design is not a single large-scale intervention, but rather an aggregate, dispersed, and flexible network that generates the necessary influence through incremental accruement. In designing the system of cybernetic micro-interventions, I similarly argue that it is necessary to consider both the logic and the processes of operations, the mind, and the methods of physically interacting with the environment, the many bodies. The work culminates in a step towards the design of one mind with many bodies: a network of soft robotic agents functioning through a responsive and iterative organizational system.

In order to investigate this hypothesis, the ongoing degradation of the ice caps in the cryosphere is examined as the setting. The increasing speed at which melting is taking place, and will continue to take place [5], calls for a focused exploration of intervening directly at such remote and fragile ecosystem in order to mitigate its ongoing atrophy. A wide range of current analysis into the dynamics of the cryosphere are beginning to show distinct methods of inherent self-regulation embedded in the materiality of ice, flux of the ecosystem, and a relationship between form and performance. Recent research shows direct correlations between the subsurface structures of a glacier and the activity observed on its surface, as well as how it decays and moves through time. [2] Similarly, the study of ice suggests that, depending on its composition, environmental flux, and method of freezing, its structure has an array of properties varying in ductility and plasticity. [3] Likewise, structural glaciology investigations highlight relationships between atmospheric conditions and the formation ice masses. [6][7]

The work developed here investigates the potential of cybernetic micro-interventions as the approach to monitor, mediate, and activate the
evolving needs of a dynamic equilibrium within various ice formation in the cryosphere. The thesis is composed of four methods. First, an extensive survey maps the flux between elements of the ecosystem and their relationship to self-regulating performance. Here, I introduce the wide range of dynamic elements to the cryosphere as a method of listing constraints, scenarios, and roles relevant to the design of the system. I will discuss what self-regulation means in the context of ice masses as a way to highlight how one might go about interacting with an evolving ecosystem.
This survey serves as the foundation by which the mind and the bodies are organized through.

Second, a series of ice experiments explore methods of strategic melting and snow capturing. This is will be a key portion of the thesis that plays with the rechanneling of trajectories and recharacterizing of presumed roles. In other words, I investigate how we can rethink melting, from something that perishes to something that enables. If melting typically plays the role of decaying, how can we recharacterize it so that it plays the role of enforcing? Can we strategically utilize it for the benefit of mediating the integrity of the ice mass rather than for its presumed decay? Similarly, I look into the relationship between geometry and texture of a surface and its ability to capture and retain snowfall.

Third, a series of design studies suggest utilizing tessellated folding surfaces as a potential method of pneumatically activating the agents. This section serves as an initial step in designing a methodology of in-
teracting with the environment physically. In other words, it seeks to find ways of physically embodying and playing out the logic of the mind. These studies begin to define the robotic agents in the cryosphere in a cybernetic manner [8], not by what they are, but by what they do.

Lastly, a catalogue of speculative scenarios illustrates strategic melting on glaciers as a method to facilitate self-regulation through increasing snow retention while decreasing mass and relieving stress. These scenarios illustrate the mind, the body, and what the outcome their interactions are in time. They are organized to show the system’s logic of evaluation and adaptation as well speculative suggestions of what the result might be. This hypothesis is explored through proposing aggregated patterns of focused melting in order to relief stress through reducing mass, as well as through subtly patterning melting into the geometry of surfaces in ice that may facilitate snow capturing and retention.
2.1 Background

From robotics to environmental design, from self-assembling materials to embodied cognition, from choreography to artificial intelligence: currently, there is a wide variety of relevant work, spanning across a range of fields, which investigates one form or another of organized flexibility in design. In this section I will go over three main themes, each with a few examples of relevant projects.

The first theme will be Responsive Environments; here I highlight a previous research of mine that inspired this quest for a micro-interventions logic. The project looks into softly and incrementally influencing the transfer of sediment flow along a river through gradually reshaping the riverbed topography. [9] Subsequently, I will introduce an ongoing transdisciplinary project at the M.I.T. Media Lab called Tidmarsh. [10] The approach follows a series of in-situ sensors as a method to track changing phenomena in the marshland. Lastly, I will highlight key aspects of deployed projects aimed at mitigating environmental issues. The first being the Los Angeles reservoirs balls, [11][12] the second a water robot designed to protect the reef of Australia. [13][14]
In Adaptive Logics I introduce work that looks at exploring design methodologies of responsive processes: one designing body motion, through the choreographic strategies of William Forsythe at the Ballet Frankfurt & The Forsythe Company. [15] The other example plays out such a method through the design of a mechanically dynamic wall that responds to nearby individuals. [16][17][18]

The last portion is a survey of current research in “informal” robotics and passive methods of actuation. In particular, I will briefly discuss the emerging field of Soft Robotics and frame it in relation to adaptive systems. Similarly, I will walk through what Prof. Chuck Hoberman classifies as “Informal Robotics,” [19][20] as well as give a couple of examples of ongoing research in the field. Lastly, I will discuss research in methods of passive actuation, or self-assembly. [21] This method embeds the desired strategy into the material itself, so that as it interacts with the world, it follows a prescribed path of change.
2.2 Responsive Environments

_Soft Topographies_

As part of the class “Cyborg Coastlines” given at Harvard’s Graduate School of Design by Brad Cantrell, I explored the logic I’ve since called Micro-Interventions. Through this project, I researched a novel method of activating the riverbed in order to incrementally influence the ecosystem in desired manner.

Given the ongoing coastal erosion and land-loss crisis in southern Louisiana, the significance of maximizing the amount of suspended sediment that reaches the coast flowing via the Mississippi & Atchafalaya Rives plays a key role in protecting and improving the ecological well-being of the region. The advancement of methodologies that prevent sediment fall and improve transfer would benefit various ecological functions including the creating of new marshes, restoring barrier islands, and aiding sediment starved wetlands [21]. The hypothesis of this proposal suggests that through strategically activating the riverbed, water currents carrying sediment can be heavily influenced to induce and perpetuate the amount of sediment transferred in the state of suspension. Through deploying a network of adaptive and responsive soft robots along the riverbed, tactically located around sediment diversions channels throughout the rivers, the transfer of such sediment can be strategically enhanced.

The methodology of the project begins with a series of experiments that examine the kinetic effect that varying frequencies of sounds have on physical particles and on water at various salinities and viscosities. The kinetic properties of suspended sediment are used as a basis from which to design the mobility and adaptability of the soft robotic network. Furthermore, a study of the effect that the topography of riverbeds has
on water currents influenced the relationship that the various classes of soft robot families have within the network. Understanding various formations of seabed marine biology likewise influenced the form of each robot class. This network of soft robot would effectively act as a woven layer that gives the riverbed the ability to activate itself in adaptive patterns to directly effect water current as to perpetuate sediment transfer.

This research is played out through physical simulations on a Movable Water Table. These simulations studied the affects of soft robots on flow and transfer of medium and coarse sediment. In the adjacent figure, we see an example of the soft robots organization diffusing the current by repeatedly bifurcating the flow of water. This process spreads the force of currents that could otherwise inhibit the build up of sand in marshlands.
The Responsive Environments Lab at the M.I.T. Media Lab has been working on a project that, through a series of custom designed and built sensor kits; utilize a series of in-situ sensors as a method to track changing phenomena in the marshland. The work takes place in tandem with the restoration and conservation of a large plot of marshland in Plymouth, MA. The team, given the dominant environmental forces of the site, designed and built a custom sensor kit to continually monitor the changing phenomena of the site. The kits are distributed through the marshland and they track atmospheric temperature, barometric pressure, sound, and pH levels of the water flowing through the site. From this data retrieval, they then developed a virtual 3D environment that allows one to navigate and observe the physical phenomena being monitored through
the array of in-situ sensors. They have termed this portion of the project the “Living Observatory” which is a multi-sensory observation exploration that documents the restoration of the Plymouth wetland.

The key difference between this research and the thesis developed here is that Tidmarsh focuses on monitoring and uses that to reveal to a broader audience the ongoing change of a physical space. Tidmarsh does not, however, extend the monitored data as a way to generate or in turn influence the interaction of the system with the environment. Although the visualizing of real-time data could influence how the restoration is approached, these processes seem remain separate and fairly autonomous.
LA Balls & Water Bots

In 2015, the Los Angeles Department of Water and Power released 20,000 plastic balls into the L.A. reservoir as a method to mitigate the ongoing problems of draught in the state of California. [11][12][24] This project was seen as a solution through creating an aggregated shaded system that would prevent evaporation due to the heat of the sun. When deployed, the 4-inch diameter polyethylene spheres would cover approximately 90% of the water surface in the reservoir. [11][25] This proposal suggests that the balls not only block light and therefore reduce heat, but also decrease the algae growth and toxic chemical reaction. [24] Although this is in part seen as a very innovative solution to California’s water shortage problem, some studies suggest otherwise. [26][11][12][27] According to Prof. Liboiron, “plastics leach chemicals into water, plastic fragments are ingested by marine life…” The critic suggests that this technical fix may actually entail unforeseen harm to the water. [11][26] Since the many shade balls can conform their overall arrangement to the many shapes of the reservoir, this project, through its aggregated approach, employs a certain level of flexibility. However, there is very little control over how the balls interact with the reservoir once they are deployed. The project does not embed a mechanism by which it can evaluate its effect on the environment; it has no method of gauging the context’s response to the intervention.
A piece of related work that more directly employs the use of robotics as method to intervene is the Nanoengineering project by the University of California, San Diego. The Calcium Micro-Motors, lead by UCSD Jacobs School of Engineering, were designed to extract carbon monoxide from water and create calcium carbonate. This strategy employs the use of robotics specifically designed for tactical interventions in a specific environment. In an initial experiment, the micro-motor was able to remove up to 90% of the carbon dioxide in the water.

A similar work that uses robotic agents as a tool to mediate the environment is the COTSbot project. The mini-submarine like devices was designed to protect coral reef from crown-of-thorns-starfish (COTS) in Australia. The robot is let loose in the reef, and through specifically designed tracking software, it locates its targets, and kills the threat. One of the project’s engineers, Dr. Feras Dayoub, highlights that the COTS-detecting software, “…would continue to learn from its experiences in the field.”. This project is an example of designing an object with an objective to aid the well-being of a fragile ecosystem. Similarly, the COTSbot has an embed logic of incrementally influencing the ecosystem while continuing to learn from its interactions. Given that the scale of the interaction is rather humble, the method leaves room for a reflective process to develop over time.
2.3 Adaptive Logics

Terms such as adaptability and responsive can mean very different things in different fields. In robotics for example, a responsive design might refer to how the driving program maps sensed inputs into actuated outputs. In other words, what does the robot do when it senses varying types of data? Meanwhile in choreography, it might refer to a logic by which the motion of the many dancers is organized as the performance evolves. In the art of Jazz, it may relate to the real-time improvisational aspect of reacting to emerging rhythms, and evolving patterns of the group. Although these differing fields may play out adaptability and responsiveness in very different ways, there is something to be learned and derived from them; there is a common thread. In this section, a few examples of related works that function through an adaptive logic are highlighted.

Frankfurt Ballet’s choreographer William Forsythe for example, suggests that he is “no longer a choreographer.” [32] Mark Goulthorpe states Forsythe is “no longer the controlling director of movement.” [32] As he works with his dancers, he composes a series of rules, of guiding principles by which the performers engage with, and evolve in motion through time. Forsythe speaks of form, structure, motion, force as a means to navigate the motion and the evolution of motion in the performance. The dancers read one another while reading their own motion, force, etc. Here I suggest again that the design of the dance, as we typically think of it, is unfinished; it is not determined, but it is given a framework by which to manifest itself as it responds to the internal agencies and external forces.
Through a similar logic, Goulthorpe’s Hyposurface embeds a series of rules by which a dynamic wall responds to a near by person. Through the use of compressed air, a series of metal panels are individually controlled through a program that takes in information about the environment and people interacting with it, as a way to guide the motion. This logic evolves over time to adapt and maintain a degree of unpredictability. In other words, the motion of the wall is dependent on both the context’s stimuli and the logic’s guideless of motion and adaptability.

At a very different scale, we can see a similar adaptive logic in the traffic and navigation app Waze. Although this system has a series of preprogramed algorithms that generate routine driving directions, the software takes into account real-time traffic patterns to produce the travels path most optimal for the current conditions. \cite{33} Waze simultaneously monitors and mediates. In other words, it gathers information about traffic from its network of users, and inserts the live data as key component to generate a suggested navigation path. This is a great example of a design that has a framework by which it can complete, so to speak, itself; the navigation path is not predetermined, but it is given a logic by which to form based on information of its current context parameters.
2.4 Adaptive Technologies

The third portion is a survey of current research in “informal” robotics and passive methods of actuation. In particular, I will frame the emerging field of Soft Robotics in its relation to adaptive systems. Similarly, I will walk through what Prof. Chuck Hoberman classifies as “Informal Robotics,” [19][20] as well as touch on ongoing research in the field. Lastly I will discuss research in methods of passive actuation, or self-assembly. [21] This method embeds the desired strategy of activation into the material itself, so that as it interacts with the world, it follows a prescribed path of change.
Briefly defined, soft robotics is the field that studies and produces elastic silicone-based robots powered by a pneumatic setup. The body of a soft robot is traditionally designed to have a series of air channels in shapes that direct its affordance of motion. In other words, the air channels are distributed in a way that allows the increase of air pressure to drive movement. Due to the elasticity of the silicone, as air is pumped into the channels of the robot it inflates and moves. Degrees of motion of the robot are very dependent on the form of the body; sections with a thinner membrane will expand a lot more than thick ones. I’m classifying this field as an adaptive technology since it is in great part modeled after the physical flexibility of marine animals such as an octopus. [34] Researcher Kevin Galloway of Harvard’s Wyss Institute for example, speculates that this type of technology would be developed to aid medical surgery pro-
cedures. Since the anatomy of our bodies is so delicate, developing a way to actuate motion through soft materials could allow a higher degree of safety to a delicate operation. In other words, this particular technology seeks to create a physical way to shape itself as a response to its context. This type of physical adaptation would add a performative layer to a reactive Mind with Many Bodies.

In parallel, the field of what Chuck Hoberman calls “Informal Robotics” [19][20] has been likewise emerging. Here we can think of it as a related series of investigations in robotic sciences that utilize and employ non-standard, not-formal, methods of actuation. Although soft robotics could be considered a domain within Informal Robotics, that is not its only facet. Origami robots for example, employ folding patterns as a technique to active, guide, and control motion. Work by MIT’s Daniela Rus
for example, [35][36][37][38] looks at using folding techniques to create motion in miniature robots. Rather than working through gears, bearings, and hinges, the origami robots could be made up of a more homogeneous material that derives its ability to move from the particular pattern of its creases. Some potential applications can be seen through her most recent project of the “Ingestible Origami Robot” [41] where the robot would be ingested into the human body, perform its function, and is passed through the body without harm. The logic of motion through pattern formation allows a much simpler assembly of a robot. In this project, the agent could then be utilized to perform specific tasks inside the person’s body. The logic of what a robot does inside the body is not the aspect of the proj-
ect that is adaptable. However, the technique of activating through the folding of a homogeneous surface is what holds a lot of promise in the systems ability to respond to its environment. In other words, a folding pattern could enable an array of different types of motion. This advantage would be multiplied if a surface were embedded with multiple patterns that yield different paths of movement. Combining this technology with adaptive logics discussed in the previous section could yield a system that is capable of evaluating current conditions, and reacting through a range of physical activation methods.

Both of the previous techniques, although non-standard, informal, and certainly innovative, continue to separate the sensed input, form the actuated output. They utilize an active method of actuating. There is other work, however, that sets out to use more passive techniques of actuating, of inducing motion, of creating designed change. Here we see an image of a wooden 3D printed sheet that folds up into the shape of an elephant with very passive external forces. The project, created by MIT’s Self-Assembly Lab, [41][42] utilizes the natural mechanism of expansion and contraction in wood fibers as a method of activating a shape change. The thin sheet of wood is constructed with particular patterns of ridges that lead the wood to shrink and grow through changing moisture and heat in the air. Various research groups have explored similar techniques. This approach to actuation has the logic of responsiveness embed into the material itself. It uses the natural material properties of wood as the framework by with to adapt to, in this case through shape change.

Fig. 26
Programmable Material
Self-Assembly Lab, MIT
Briefly defined, Cybernetics is the science that studies how a thing-in-the-world learns to organize itself based on interactions with its environment. It is an enormous and evolving field with a rich history, a wide set of research, and an even wider range of applications. [1][43][44] It is worth noting that the focus of this thesis is not a direct study of the field of Cybernetics per se, but rather of utilizing the logics presented, as an approach to design. Here, certain work of cyberneticians serves as a foundational set of principles by which the design of a mind with many bodies arises from. This thesis primarily looks at the organizational techniques introduced by William Ross Ashby, [8] as well as the implementations proposed by Andrew Pickering. Its logic stands apart from the dominant method of computing (and in this case the dominant methods of design) that function through predefined models of abstraction. [1][45][46] Ashby proposes methods of defining, categorizing, and filtering factors of the environment that are relevant to the system at hand. Moreover, he defines several cornerstone terms such as adaptive, stability, and system to name a few. [47] Meanwhile, Pickering unfolds such logic through examples of the “performative” ranging from Grey Walter's cybernetic
Fig. 28
Cybernetic Tortoise
Grey Walters, 1953

Fig. 29
Adaptive Dam
Dujiangyan Dam
Tortoise, to China’s 2200-year-old Dujiangyan Dam. [1] In the case of the tortoise, there are no preprogrammed functions; the agent learns how to function through a back-and-forth interaction with its context. In the case of the ancient dam, rather than simply blocking the river flow, it functions through a flexible process that directs the water between an inner and outer river.

The particular type of framework Ashby describes is most concerned with enabling a system to function in an adaptive and responsive manner. He specifically frames the term of adaptability as a form of behavior. [47] In his words, he proposes the definition that “a form of behavior is adaptive if it maintains the essential variables within physiological limits.” Briefly summarized, first, the framework needs to acknowledge the fundamental internal components, or variables, that make up the system. [47][8] Second, it defines influential external parameters that interact with the system. [47][8] Third, it establishes a feedback mechanism by which the system and its environment react to one another in order to remain within the defined “stable” boundaries. [47] In other words, a system is adaptive if it has an embedded mechanism that enables it to react to external stimuli, or change, in a manner that helps preserve a dynamic equilibrium with its context. Ashby goes on to define that:

“Some external disturbance tends to drive an essential variable outside its normal limits; but the commencing change activates a mechanism that opposes the external disturbance.”
— Ashby Ross [47]

This suggested feedback is key to designing a mind with many bodies that is adaptive. First, the environment changes. Then, the system reacts to the change. Then, it assesses how the environment responded to that specific form of reaction. At this point it is able to gradually evaluate a relationship between internal variables and external parameters. As this process is repeated, the system would increasingly surmise the relevance and importance of various factors within its given context. In regards to this thesis, while the process of classifying relationships in the cryosphere will be discussed in more detail in Chapter 5, the proposed methods of evaluation will be elaborated upon in Chapter 8. But for the time being, I will begin by broadly discussing what a cybernetic approach to design could be.
“Our hegemonic way of engaging with the environment is the one I have just described – which Martin Heidegger (1977) called “enframing”. It entails a detour, as Bruno Latour would say, through science. We turn the world into scientific representations, figure out how to dominate those, and then remake the world in line with our calculations.”
— Andrew Pickering [12]

3.2 A Cybernetic Approach to Design

The design strategy proposed and investigated through this thesis pushes away from a deterministic, top-down, static approach where the design is an ordained and calculated product, rather than an emergent instrument. As opposed to producing an artifact that attempts to control nature through enframing, [48][1], it sets out to compose a process by which revealing [48][1] is prompted and pursued. It suggests a methodology by which the iterative process of design gets embedded into the design itself. Such an iterative process allows the design to develop, adapt, and evolve given its particular context and affordances of interfacing. In other words the design is un-finished, in a manner of speaking, yet equipped with a framework by which it can self-organize in accordance with its specific environment. It’s physical capabilities of sensing and interacting likewise play a key role in how it is able to adapt. The aforementioned logics elaborated in the filed of cybernetics serve as an important aspect of such framework.

Heidegger presents the concept of the essence of technology as being about “revealing” rather than about “enframing.” [48] Pickering similarly points out that “we dominate nature through knowledge”, by presupposing and encapsulating chains of cause and effect into a system, rather than allowing the system to reveal the nature of its relationship to its environment. [1] While static non-responsive designs take for granted the possible effects of future or dormant unknown conditions, an adaptive design would have room to develop in response to unforeseen stimuli.
As this mind, through its many bodies, repeatedly tests what influence it bears on the environment, it expands its framework of self-organization.

Maturana’s concept of autopoiesis [49] can be thought of in this context as how a-thing-in-the-world reproduces, not necessarily itself, but rather its actions, its interventions – what it does. It is not strictly speaking about how it regenerates its material self, but analogously how ‘what it does’ evolves through time. In other words, its behavior is autopoietic; as one instance of intervention plays out, the next is informed and adjusted per the impact of the first. It is precisely through this iteration process that the roles of variables and parameters in the system come into evaluation, thus making room for becoming redefined – recharacterized.

In the case of the cryosphere, this thesis proposes utilizing the ongoing melting that exists in nature at the moment, and repurposing it in a way that could potentially prove to benefit the health of the ecosystem. If it doesn’t, it simply stops, reevaluates, and tests a different trajectory. In parallel with Hylozoism, as Pickering elaborates, [1] the idea here would be to make use of what already exists in the world, and “latch on to it.” However, rather than continuing with the traditional trajectory, the system would recontextualize it so as to perform in an alternative way. The proposed agents are not designed to be the direct method of creating change, much less forcing it onto the environment – but rather about enabling the existing world to self-regulate through novel ways of responding to change.
3.3 Macro Vs. Micro

For the past several centuries, we’ve seen a predominant design approach that assumes full knowledge of its context, and attempts to control it through large, single-instance interventions. In the design of the modern dam, the forces of the environment are calculated, the constraints of building technologies are considered, and the intentions of the intervention are mapped out. As Heidegger might outline it, the designers of the system enframe a series of assumed conditions and manifest it in a programmable manner. The large forces of nature are opposed with a calculated larger force of the intervention. In this strategy, future unforeseen events cannot be worked into the equation of opposition, meaning that the manner in which the environment responds to the intervention is not built into the design.

Micro-interventions on the other hand, function through incremental accrualment of the many aggregated points of interaction with the context. A design that functions through such micro-interventions, offers the possibility to evaluate how the context responds to the incremental interactions. This is a much more humble approach that acknowledges that the chains of cause-and-effect evolve; it acknowledges that as interventions change the environment. They shift the parameters the design has to respond to and work within. It is a slower and more careful approach that functions through a feedback loop with its environment. Moreover, since this type of system has many discrete bodies to intervene through, it allows the design to iteratively test different methods of interaction. At that point it would be able to systematically compare outcomes while
evaluating the influence and relationships between methods of activation and variables in the field.

The recent proposal to pump water into Antarctica [50] takes on a similar large-scale approach that does not infuse the intervention with the advantage of a feedback loop to its environment. The 2016 report “Delaying future sea-level rise by storing water in Antarctica” highlights problems with this proposal. For one, it calculates that the ocean water would flow out back down into the ocean faster than would be optimal. [50] The report acknowledges “the delay time depends strongly on the distance from the coastline at which the additional mass is placed and less strongly on the rate of the sea-level rise that is mitigated.” Through this preemptive report a new important variable was found. I would suggest that this analysis serve as a method of evaluation that the original proposal did not embed into its design.
The project Rebuild by Design on the other hand, is a different type of macro-intervention. As a response to the destructive happenings created by Hurricane Sandy in 2012, The Rockefeller Foundation, among others, [50] sponsored an initiative to coordinate a design competition. This group essentially seeks multi-disciplinary strategies to increase resilience and preparedness for future natural disasters. It is an “interdisciplinary, creative process to generate implementable solutions for a more resilient region.” [50] It starts off with a thorough series of research reports in economic analysis, governance, infrastructure, etc. From there, rather than following an established procedure of addressing an issue, the project attempts to generate, through a competitive interdisciplinary forum (the design competition), unconventional and innovative solutions to a rapidly emerging global problem. It acknowledges the many layers that an issue of this magnitude would tie into.
Even though this project begins to weave in a broader range of facets, the proposals generated heavily gravitate towards large-scale interventions. The thought pattern continues to be; large-scale problem equals large-scale intervention. Although some of the proposals introduce methods of flexibility through landforms and programmatic resilience, the frameworks provided do not seem to embed and iterative process of testing, evaluating, and reacting through their designed methods of resilience. The project certainly contributes greatly to the rising global issues of our changing environment – but the point I want to stress here, is that it does so through a macro-intervention mentality. The strategies predominantly assume, as Pickering would say, knowing “all the chains of cause and effect.”
Through micro-interventions, the cybernetic logic is given a way to play-out in the design for an interface with the environment. This methodology enables a constant re-evaluation of roles that the elements of design play in the larger system. Rather than relying on the deterministic and controlling design of a single macro intervention, you diffuse the force of the intervention into millions of very small and discrete insertions. Dispersal of force in the mediation allows real-world evaluations of how the environment is responding to the intervention, and how to assess and conduct further interactions. In other words, this design typology can be thought of as a perpetual series of tests. The design of the interaction is never truly done, never complete; it is driven by an underlying method of self-evaluation and appraisal of the functions carried out by the elements it interacts with.
Fig. 36. Design Study: Casting Molds for Soft Robotic Bodies
2.3 One Mind, Many Bodies

In 1934, biologist and theorist Jakob von Uexküll introduced the notion of Umwelt. Briefly interpreted, it refers to the particular world of an organism given its specific biological and physical affordances and limitations to sense and interact with its environment. Through the primary example of the sensory interaction of a tick, amongst others examples, Von Uexküll poses that even though various species might share the same environment, their Umwelt would be entirely different since it is composed only of the sensory phenomena they have access to. For example, while the Umwelt of most humans includes the sense of hearing, the sonar abilities of a bat extend its Umwelt beyond ours, allowing them to echolocate through sound. This notion makes a strong case for the intertwined and symbiotic relationship between what the body feels, and what the mind experiences. Similarly, Levi Bryant’s discourse of Alien Phenomenology points to the fact that the physical and sensory affordances of a species influences how it’s able to operate and communicate with its environment and with other species. In other words, if a body-in-the-world does not perceive particular stimuli in the environment, than it is not able to interact with, or respond to it. Furthermore, he speaks of species or bodies as “machines” when he argues that:

“… Once a flow enters a machine it takes on a different functional value — causally or in terms of meaning — than it had for the machine from which
the flow issued... When one machine encounters a flow issuing from another machine, it encounters that flow not as it is, but rather in terms of how its operations transform it. Such would be the meaning of Kant's [Copernican Revolution]…”

– Levi Bryant [52]

In the case of Kant's declaration of the relationship between our mind and its influence on our experience of the world, [90] there seems to be a back and forth between observing (physically), assessing (mentally), and as it applies to this thesis, interacting (both physically and mentally).
In terms of the design strategy proposed here, when designing an adaptive system that learns from its surroundings, it is crucial to consider both the logic by which it evaluates, and the methods by which it interfaces with the physical world. Both the mind and the bodies need to have a built-in logic that evaluates how the environment responds to both a single small intervention, as well as to the aggregation of the many micro-interventions. This is why the design is for the physical and mental states of interaction.

Why many bodies? The plurality argued for here, is essential for mediating through the accruement of many, aggregated, micro-interventions. An antithesis of this would be a dam – a singular body, acting massively in a prescribed way. Through dispersing the function into many small bodies, the system is able to at once test different forms of interaction, while capable of tuning the magnitude of the intervention. Why only one mind? The mind serves as a method for all of the bodies to be in tune with each other, to learn from the trials of one another, and evolve their methods of activation in a homogeneous manner.

These points are key in analyzing and perhaps recharacterizing what roles the stimuli of the environment play in the symbiotic system. In the subsequent chapters, I will introduce a series of studies as the first step in the design for a mind with many bodies, in particular, within the context of the cryosphere. But first, a survey of what the cryosphere is, what elements might be relevant to the system given their current relationships.
4.1 A Melting World

According to recent studies, even if our society were to stop carbon emissions overnight, it would take hundreds of years to stop the environmental effects of global warming. [50] Sea levels would continue to rise; melting in the ice caps would continue to occur. The increasing speed at which melting is taking place, and will continue to take place, calls for a focused exploration of intervening directly in order to mitigate the ongoing atrophy. It is worth noting that even though I use the cryosphere and ongoing melting as the context, this is not a thesis of environmental remediation. However, the work presented here uses this setting to play out what a cybernetic approach to design might look like. In part, this approach works within the context of melting in order to reshape the role of melting, from that of decay, to that of fortifying. In other words, I’m reframing melting from that of decay to that of reinforcing in order to augment existing methods of self-regulation. Can we mitigate the “negative” so carefully as to turn it into a potential “positive”? This question and notion of rechanneling natural mechanisms, is fundamental to the design strategy proposed here.
The cryosphere is a very dynamic and complex array of atmospheric conditions and states of material. It consists of the areas in the world most prone to be in below-freezing temperatures. This includes the Arctic, Greenland, Antarctica, and many places of high elevations. Before knowing how to interact within an ecosystem, you have to study the natural elements and mechanisms in place. Therefore, I will briefly walk through some of the key elements within the cryosphere and how they function within their ecosystem.
Sea Ice

Sea Ice is the thick, icy, slushy ocean threshold into many areas of the cryosphere. It effectively mutes the currents and forces of the ocean, thus protecting ice formations further in. [63]
Ice Shelves

Ice Shelves form directly on top of water. [62] When they calve into the ocean, they do not directly contribute to sea level rise. [56] The difference in color between ice and water adds to warming. While the light ice reflects most of the heat coming from the sun, the dark blue water absorbs it. Therefore, the less ice, the more water, the faster it warms. Similarly, water below the glacier slowly heats the surfaces and plays a part in its deterioration. [56]
Moraines
Glaciers form on top of land instead of water. As a glacier melts, all of its water drains downward towards the ocean. This does directly contribute to sea-level rise. [58] As the glacier begins to push downwards due to gravity and low friction at the glacial bed, it begins to push earth & sand, and starts to bury itself under the earth along the edges. [64] This edge is an example of natural structures found in glaciers. [57][59]

Crevasses
Crevasses have an array of formation types and methods of being made. They form in different patterns depending on where they are on the glacier. [66] They form as a way of relieving stress due to the many forces acting on the glacier mass. Crevasses occur not only on the surface, but also within the thickness of the mass. [65]
**Moulins**

Similarly to crevasses, Moulins can be found throughout glaciers. Here we see a Moulin being formed through the erosion of flowing water. They form on the surface, and travel through the thickness of the glacier, down towards the bottom, allowing water to reach the sea. [61]
Snowfall Formations

Atmospheric conditions greatly influence formations of snow and it accumulates. There is a wide range of snow formations, crystal, covers, and snowfalls. This image shows an example of Sastrugi being formed by heavy winds.[67]
Ice Structures

Here we see an example of another natural structure occurring through erosion; the Ice Cave. They typically consist of vaulting created through heavy flows of water and sediment. As water flows through them, their surface slowly erodes away due to friction, and temperature difference.

[68]
**Firn**

When precipitation falls in the form of snow, it slowly condenses into a heavier and denser layer called Firn. Due to the particular compactness & spacing between the condensed snow molecules, Firn is particularly good at refreezing water that flows through, thus making it an essential layer in the well-being of a glacier. [69][70][71][72]
4.3 Self-Regulation

Through analyzing a series of Structural Glaciology principles, [6] as well as different cycles in the dynamics of the cryosphere, [53] a pattern of self-regulation amongst the ice masses emerges. This theme of self-regulation can be observed both at the minute scale of snow crystal composition, and the global scale of the over all glacier. For example, a crevasse can only be so deep due to the lateral pressure of the ice as the crevasse travels downward. [66] However this maximum depth changes as soon as water is introduced to the crevasse, or moreover if there is flow that begins to erode the ice away. The following diagrams illustrate several key mechanism inherent to the way-of-life of glaciers as they emerge from, decay into, and change within the dynamic states of the cryosphere.

- Diagram A: Glacial Balance Zones
- Diagram B: Natural Processes of Accumulation and Ablation
- Diagram C: Glacier Balance Zones and Formation of Crevasses
- Diagram D: States of Snow Crystals per Types Snowfall
- Section A: Crevasses Depth to Ice Pressure
- Section B: Formation of Moulins
- Section C: Ablation Through Moulins
Fig. 56. Diagram A: Glacial Balance Zones
Fig. 57. Diagram B: Natural Processes of Accumulation and Ablation
Fig. 58. Diagram C: Relationship Between Balance Zone and Formation of Crevasses
Fig. 59. Diagram D: States of Snow Crystals per Types Snowfall
Fig. 60. Deep Glacial Crevasse
Fig. 61. Section A: Crevasses Depth to Ice Pressure
Glacial Surface

Maximum Depth

Extended Depth due to Standing Water
Fig. 63. Section B: Formation of Moulins

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Fig. 64. Section C: Ablation Through Moulins
Through the Glacier Mass Balance method, the regions of a glacier are categorized by whether an area looses, gains, or maintains ice mass throughout a season cycle. In the higher altitudes of a glacier, the Accumulation zone gain mass through wind, avalanches, and precipitation such as snow and rain. At the Equilibrium Line, mass loss and gain throughout the year cancel out for a net of zero change. In this diagram I show it as a region, rather than a single line because of its variability of location. In other words, the location of the line changes as environmental conditions change the amount of gain and loss. The line retracts in the summer when there is a negative mass balance, and extends in the winter when there is a positive mass balance. Below the equilibrium line is the Ablation Zone. Here the mass of the glacier is reduced through evaporation, sublimation, surface melt, etc. Overall, this is the region of the glacier that loses mass and contributes to a negative balance.

These three regions also influence the formation of crevasses on the surface of the glacier. Both supraglacial crevasses and deep glacier crevasses form in part due to the many forces acting on the mass. Gravity, internal pressure, subglacial sliding, and direction of dominant flow, among others, all play a role in generating these gigantic cracks. The surface of the glacier responds to these many forces by relieving stresses in particular patterns along its surface and through its thickness. In the diagram we see that in the accumulation zone, Transverse Crevasses form in a perpendicular direction to the dominant flow of water and pressure. As you move closer to the equilibrium line, Marginal formations begin to form towards the perimeter of the glacier. As you move downwards, Longitudinal crevasses form as ice flow begins to slow down. Finally, lateral compression and sideways extension contribute to a Splaying formation near the tongue of the glacier.

There is a wide array of snow crystals, each of which have specific ways of forming and perform very differently. Firn for example, takes approximately two season cycles to form. First, fresh snow gathers on the surface of the glacier. Then, when the summer heat comes, it melts the snow in a particular way that enables some of the water content to flow down and begins compacting itself into a higher ratio of water to air. Eventually, this slight melting of snow refreezes in a more granular formation that contains about 30% air, as opposed the previous 50%. Research has found that Firn plays a particularly important role in the re-
freezing process in a glacier that is crucial to the overall health and positive mass balance gain. The specific ratio of air to water, and the gaps between snow granules create a great way of reducing refreezing of water that falls into those pockets of air.

In Section A, we can see that the pressure of the ice mass increases as the depth increases. This pressure opposes the force of the surface trying to increases the size and depth of the crevasse, acting as another mechanism of self-regulation. Here, the materiality and weight of the ice play a key role in maintaining a dynamic equilibrium of crevasses depth and overall integrity.

As water flows through some of the openings on the surface of the glacier, it begins to erode ice away. This is due to both to the friction of the flowing water (similar to how a canyon form on land), and the interchange of temperature difference between the ice mass and the flowing water. The water, being higher temperature than the ice mass, slowly warms the surface it interacts with, effectively melting the surface of the Moulin gradually, thus increasing in size. This continues as gravity pulls the water towards land or sea. Eventually, the water creates an outlet-draining channel by which to relieve weight and pressure of water flow.

4.4 Cryoconites

Cryoconites on the other hand, are a biological example that key into these mechanisms of self-regulation. The microbes’ physical make up, their dark color, enable them to utilize solar heat to melt the surface of the glacier right below them. They heat the ice into little pools in which they fall. [81] As the surface refreezes they become enclosed in their new micro-ecosystem. In other words, they utilize what happens naturally as a way to create their ideal living environment.

The phenomenon of concentrated melting already exists in nature. Here we see a pattern produce by accumulated black soot that captures heat, and increases melting. In this case however, it happens randomly, and the melting does not derive structurally sound forms. Similarly to how cryoconites utilize existing mechanism to from their living environment, this thesis proposes a similar Hylozoistic approach. Through strategically utilizing melting, this thesis questions if we can tap into natural phenomena to gradually influence beneficial change through the inevitable melting in the cryosphere.
Fig. 66. Section E: Cryoconites, Stage 1
Fig. 67. Section F: Cryoconites, Stage 2
Ice Experiments

5.1 Strategic Melting

The focus of the following studies is not on gaining scientific findings of ice per se, but simply on exploring how this system might begin to tweak the roles of elements, in this case melting, through a cybernetic design approach. This is a key portion of the thesis that plays out the rechanneling of trajectories and recharacterizing of presumed roles. In other words, I investigating how we can rethink melting from something that perishes to something that enables. If melting typically plays the role of decaying, how can we redefine it so that it plays the role of reinforcing? Can we strategically utilize it for the benefit of mediating the integrity of the ice mass rather for its presumed decay?

In the same way that through reducing mass, while maintaining certain performative forms increases the soundness of common structural elements, we can imagine a parallel logic to utilize the inevitable melting to influence their stability. Here, focused melting is proposed as the method to induce these performative forms. It utilizes the inevitable melting to facilitate a higher, and perhaps novel, way of self-regulation in masses of ice.
The structural properties of ice have been studied in the past. From Heinz Isler’s tents to MIT’s Frozen Forces course, the flexibility and at once rigidity of ice can be observed. Similarly, you could begin to imagine how sub-surface structures of glaciers could begin to influence their integrity.
Fig. 71
Structural Reduction of Mass Diagram
Steel I-Beam

Fig. 72
Structural Reduction of Mass Diagram
Gothic Battresses
Through the affordance of material properties, I began to test methods of strategically increasing and decreasing melting. I attempt to either strategically attract melting through a black non-permeable surface, or reduce heat with the use of reflective mylar.

First, water is boiled twice before freezing in order to reduce the amount of air bubbles in the ice. Once at room temperature, the water is poured into two 8” X 10” X 2” trays and left to freeze for 12 hours. Then, both frozen blocks of ice are placed under a heat lamp side by side. In this first study, I laid a black non-permeable nylon sheet over a third of one block, and a reflective mylar sheet over a third of the other block. The hypothesis was that melting would happen faster under the black material, which absorbs heat, and slower under the mylar, which reflects it.

Figure XX shows the surface of the ice that was covered by the mylar. It is raised; therefore less melting occurred with the intervention of the reflective sheet. This study was repeated a couple of times with similar results.
Fig. 74
Mediating Melting through Material Properties

Fig. 75
Ice Block Section Protected by Mylar
The second type of ice melting study I explored froze the two materials into the blocks of ice, rather than just placing them on the surface. The question here was whether you could begin to melt strategically, not just on the surface of the mass, but inside of it; through its thickness. Would these materials be able to melt the space below them, while maintaining not affecting the surface area of the ice? In the case of the black material, melted pockets of water formed underneath the fabric. The study showed promise in being able to melt ice below the material while suspended in the mass.
In another study I casted a section of the nylon fabric in a tube formation to see what would happen to the ice inside the volume of the material. As anticipated, the ice inside the tube melted the quickest. The presumed reason would be that the nylon captured and retained the most heat in and around itself.
I then wanted to look at a couple of different interactions between the ice surface, and the material. I tested if a material in direct contact would influence melting differently than one creating a volume under the fabric. Here, direct contact melted much quicker than a heated volume. Through this direct contact, you could begin to shape melting on the surface of the ice in a much more tactical and deliberate way.

While simply covering the entire ice caps with a reflective insulation material would protect them from evaporation, this thesis attempts a more modest approach. Rather then proposing to fully shade the cryosphere to prevent evaporation, through the accruement of micro-interventions, it attempts to aggregate many smaller points of protection as way to maintain resilience.
Fig. 81
Remaining Melted Pattern through Contact

Fig. 82
Remaining Melted Pattern through Contact

Fig. 83
Two Folding Versions of Chevron Pattern
5.2 Snow Capturing

Once having seen the possibility of shaping an ice surface through strategic melting, I wanted to study how the geometry and texture of a surface could influence its ability to capture and retain snow, while potentially enabling refreezing to occur. As I introduced the importance of firn to the health of the glacier; would it be possible for certain geometries to facilitate the creation of firn and therefore increase the stability of the overall mass? Would creating certain formations allow the shape of the surface to protect fragile zones from the elements? Would some textures interact better with certain types of snowfall than others?
Fig. 86
Surface Geometry &
Textures for Snow
Capturing

Fig. 87
Surface Geometry &
Textures for Snow
Capturing
I will highlight again that the aim of these studies is not to find scientific conclusions of this phenomena, but rather to simply tease out a potential method of augmenting existing mechanisms. In other words, could cybernetic micro-interventions facilitate an environment’s ability to self-regulate?
Fig. 90
Flat Surface Capturing Snow as Control

Fig. 91
Grid Geometry Capturing Snow
Through these studies I found that different patterns interacted in unique ways with different types of snowfall and atmospheric conditions. The grid for example, seemed to more easily hold on to large, moist flakes of snow. This increased the speed at which a base layer of snow was formed since it wasn’t constantly getting blown around. This type of texture could perhaps augment snow’s self-insulating properties by allowing it to build up quicker.
Fig. 94 Snow Capturing Geometry
Matrix of Conditions

6.1 Classifying Relationships

Given the incredibly dynamic and complex ecosystem that the cryosphere proves to be, any system that aims to interact with it at a multidimensional level of monitoring, mediating, and activating, should begin with a basic classification method of the relationships between the various elements. Through the lens of early Cybernetics, one key part of this process is to first categorize these components into variables internal to the system, and external parameters that affect or influence the system. Ashby proposes defining the Operator, the Operand, and the Transform. [8] To ground these terms, he gives the example of pale skin turning dark with light from the sun. In this scenario, the sunlight is the Operator (the force that induces change), the pale skin is the Operand (that which the force is applied to), and the darker skin is Transform (the change state of the operand). Through a slight reinterpretation of these categorization techniques, this thesis classifies the cryosphere and methods of intervention as follows. First, the many different States of Material are grouped as variables internal to the system, i.e. the Operand. Second, Atmospheric Conditions are set up as the external parameters that affect the system, i.e. the Operator. A third category I add here is Methods of Activation. This
category aims to place itself between the operator and operand and strategically mediate the effect one has on the other, as a catalog of possible hylozoistic intervention techniques. These methods serve as a mechanism to enable the system to further self-regulate and maintain within its defined limits of dynamic equilibrium.

• Atmospheric Conditions
• States of Material
• Methods of Activation
Fig. 97 Iris Diagram of Element Category Relationships: Scenario A
Fig. 98 Iris Diagram of Element Category Relationships. Scenario B

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-40 Degrees F
Freezing Point of 32F
UV 0 - 3
> 100 kPa
< 10 kPa
24.5 Degrees
22 Degrees
Reflective
Expanded
Static
Diagonal to Flow
Parallel to Flow
Perpendicular to Flow
Solo
Pellets
Divergent
Columns
Snowflake
New Snow
Rain
Winter
Snowflake
Accumulation Zone
Snow Formation Type
Trace Formation
Assembly Type
Motion Type
Activation State
Materiality
Current Earth Obliquity
Barometric Pressure
Wind Force
Ultra Violet Index
Temperature Range
Annual Season
Glacial Balance Zones
Crystal Shape
Consistency to Density Shape
Snow-cover Type
Precipitation Type
Snow Crystal Stage
Pulse
Augmented-Transverse
Augmented-Marginal
Augmented-Splaying
Ribbing
Vaulted
De-focused
Focused
Circular
Grid
Crosshairs
Herringbone
Connected
Aggregated
In-Place
In Motion
Contracted
None
Mixed
Attractive
Mid Obliquity
Mean Pressure
UV 11+
UV 8 - 10
UV 6 - 8
UV 3 - 6
Fall
Summer
Spring
Hail
Graupel
Irregular
Stella
Plates
Needles
Glacier Ice
Firn
Ice Granules
End Moraine
Ice Shelves
Cryoconite-Holes
Sun Cups
Snow Rollers
Snow Bridge
Sastrugi
Ripple Marks
Penitents
Megadunes
Cornice
Moulin
Glacier Ice
Powder
Perennial Snow
Seasonal Snow
Old Snow
New Snow
Firn
None
Snow-Field
Seasonal Snow
Perennial Snow
Powder
Glacier Ice
Sapiens
Moulin
Cornice
Glacier Ice
6.2 Atmospheric Conditions

This section of the Iris diagram has seven primary factors that influence the system. From calculating when the next ice age might arrive, to looking at where you are on the glacier, these atmospheric conditions are the external parameters the mind would consider as it goes through a decision making process to evaluate the most appropriate method of activation. This family of elements is composed of the following.

Season:

- Winter
- Spring
- Summer
- Fall

Temperature:

- < -20º F
- 32º F
- >60º F

UV Index:

- 0-3
- 3-6
- 6-8
- 8-10
- 11+

Wind Level:

- Cat 0
- Cat 1
- Cat 2
- Cat 3
- Cat 4
- Cat 5

Barometric Pressure:

- Level 1
- Level 2
- Level 3

Earth Obliquity

- Range 1
- Range 2
- Range 3
6.3 Material States

It is often casually said that Eskimos have over 50 words for snow. [82] Although it is in part debated that it’s just academic myth and “sloppy scholarship”, [82] it is true that several cultures have many names for the varied states of ice and snow. The Sami people for example have at least 180 words to define the complexities of this material. [83] Here, I utilize the National Snow & Ice Data Center’s classification system [67] supplemented with Kenneth G. Libbrecht’s (Caltech Professor of Physics) [78][79] taxonomy of snow crystals as a way to categorize the many states of material. They are divided into types of snowfall, formations, precipitation types, consistency-to-density shape, etc.

<table>
<thead>
<tr>
<th>Glacial Balance Zone:</th>
<th>Types of Snow Cover:</th>
<th>Sun Caps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accumulation</td>
<td>New Snow</td>
<td>Cryoconite-Hole</td>
</tr>
<tr>
<td>Equilibrium Line</td>
<td>Firn</td>
<td>Ice Shelf</td>
</tr>
<tr>
<td>Ablation</td>
<td>Neve</td>
<td>End Moraine</td>
</tr>
<tr>
<td>Snow Crystals Stage:</td>
<td>Old Snow</td>
<td>Consistency to</td>
</tr>
<tr>
<td>Snowflake</td>
<td>Seasonal Snow</td>
<td>Density Shape:</td>
</tr>
<tr>
<td>Hoarfrost</td>
<td>Perennial Snow</td>
<td>Snowflake</td>
</tr>
<tr>
<td>Graupel</td>
<td>Powder</td>
<td>Ice Granules</td>
</tr>
<tr>
<td>Polycrystal</td>
<td>Glacier Ice</td>
<td>Firn</td>
</tr>
<tr>
<td>Granular</td>
<td></td>
<td>Glacier Ice</td>
</tr>
<tr>
<td>Precipitation Type:</td>
<td>Snow Formations:</td>
<td>Crystal Shape:</td>
</tr>
<tr>
<td>Rain</td>
<td>Flat</td>
<td>Columns</td>
</tr>
<tr>
<td>Hail</td>
<td>Crevasses</td>
<td>Needles</td>
</tr>
<tr>
<td>Sleet</td>
<td>Moulin</td>
<td>Plates</td>
</tr>
<tr>
<td>Snow flurry</td>
<td>Cornice</td>
<td>Stella</td>
</tr>
<tr>
<td>Snowstorm</td>
<td>Crust</td>
<td>Irregular</td>
</tr>
<tr>
<td>Squall</td>
<td>Megadunes</td>
<td>Graupel</td>
</tr>
<tr>
<td>Burst</td>
<td>Penitents</td>
<td>Hail</td>
</tr>
<tr>
<td>Blizzard</td>
<td>Ripple Marks</td>
<td>Pellets</td>
</tr>
<tr>
<td>Blown</td>
<td>Sastrugi</td>
<td></td>
</tr>
<tr>
<td>Drifting</td>
<td>Snow Barchan</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>Snow Bridge</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Snow Roller</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 100 Iris Diagram of Element Category Relationships: Material States
5.4 Methods of Activation

Here I begin to speculate an array of methods of intervention. From utilizing material properties, to creating surface patterns to influence snow retention, these methods would be combined in different ways to potentially induce different beneficial behaviors of self-regulation.

Material:
- Reflective
- Attractive
- Mixed
- None

State:
- Expanded
- Contracted
- In Motion

Motion Types:
- Static
- In-Place
- Ambulant
- Assembly: Solo
- Aggregated
- Connected

Trace Formation:
- Perpendicular to flow direction
- Parallel to flow direction
- Diagonal to direction of flow
- Herringbone
- Crosshairs
- Grid
- Circular
- Focused
- Defocused
- Vaulted
- Ribbing
- Natural-Transverse
- Natural-Marginal
- Natural-Splaying
- Pulse
- Divergent

Fig. 101 Iris Diagram of Element Category Relationships: Methods of Activation
The Mind:
Logic & Process

7.1 Hierarchy

If we start by imagining the yet-to-be-experienced Umwelt of one of these robotic cryospheric creatures, what would be it? Given the vast array of atmospheric conditions and states of material introduced in the previous chapter, which of those would influence it the most? Which one would influence it the least? How would its mind decide the hierarchy by which it operates, by what it responds to first, second, third, etc.? And if we have an answer, how can we be sure that this hierarchy will prove befitting of the cyclical variation inherent to the cryosphere? Is hierarchy even important?

Given that the core focus of this design strategy is the ability to repeatedly reassess its interactions, to reinvent its function, to recharacterize its role, what type of hierarchy would befit this autopoietic mind? It appears that it would be crucial for the mind to be entirely malleable and capable of adapting to any situation, however this is not entirely the case. Structure, a framework of sorts that binds the soft and flexible, is required. This mind has two governing segments: A Root Hierarchy and A Fluid Hierarchy.
The Root Hierarchy is the decision-making process division that serves as the foundation on which to apply the Fluid Hierarchy. It is composed of elements that affect the ecosystem at the largest and slowest scales. For example, the Earth’s cycle of precession which plays a key role on whether we are in an ice age or not, is approximately 26,000 years long. Similarly, the Earth’s obliquity, which is key to the Milankovich Cycle, is roughly a 41,000-year cycle. As you can see in the table, the Milankovich Cycle components are the first portion to the Root Hierarchy. An oversimplified example of a possible result of this portion would tell you that; you are currently not in the middle of an ice age. From this, the second tier of factors relate to the glacial mass balance of an ice mass; indicating location on the glacier either in a state of growth or recession. The final tier of the Root is the shift in annual seasons. This short periodic turn around is a similarly anticipated cycle. The result of Root segment is a conditions-set that captures an array of atmospheric and periodic assumptions to which to test from.

Fig. 103 Decision Making Tree Process of A Mind
The hierarchy of the second division, the Fluid Hierarchy, will depend on which condition-set is arrived to as active. For example, in the case of a wintertime operation on the accumulation zone of a glacier in recession, the U.V. index level would be considered an earlier priority to calculate than the current atmospheric temperature. The assumption being that since you are in the accumulation zone during a winter on a glacier, the atmospheric temperature is likely below freezing, but the mass might be gaining heat through light. Therefore, that's the factor with a stronger hierarchy. Through the evaluation method, which will be dealt with in more detail in chapter 8, the system might realize, through the aggregation of its micro-interventions, that such assumption was not accurate. In that case, that item would get bumped to a lesser priority. Hence, the hierarchy of this second division is fluid in two ways. First, it is dependent on which state the Root arrives to. Second, it is able to reevaluate the priority levels assessing the environments response to its interaction. Here, note the importance of routinely reevaluating the importance and relevance of the contextual elements, especially while experiencing how the environment responds to the intervention.
Fig. 104 Decision Making Tree Process of A Mind: Root Hierarchy Segment
Fig. 105 Decision Making Tree Process of A Mind: Transition into Fluid Hierarchy
7.2 Evaluating Trajectories

As the design interacts with its Umwelt, it assesses both its procedure of mediation, and the subsequent response of the environment. Through utilizing the categories introduced in Chapter 5, the system comparatively evaluates the changes through time of: atmospheric conditions, states of material, and methods of activation. It compares the previous states to current conditions, and projects an anticipated scenario based on previous iterations. Depending on the accuracy of its projection to the actual response of the environment the mind evaluates likely reasons for discrepancies. These likely reasons are based on observed relationships, i.e. degrees of influence, between internal values and external parameters.

After this assessment it adjusts its strategy and tests once again. Given the advantage of micro-interventions, the mind is able to cast a variety of activation strategies across different bodies. Depending on which strategy yields the closest outcome to its projection, it informs the others and embeds that experience into their next iteration. If after distributing the new logic to the rest of the bodies there continues to be some with discrepancies, the system picks out the variations of atmospheric and material conditions in order to fine tune the reason for the deviation.
Hydrology State
Current: None
(Value Range: 22º –> 24.5º)

Snow-cover Type
Current: Perennial Snow

Precipitation Type
Current: None
(Value Range: e•sin(ϖ) –> e•sin(ϖ))

Snow Formation
Current: Smooth Sloped
(Jan. 1 –> Dec. 31)

Consistency to Density Shape
Current: Firn
(Value Range: -10 –> 10)

Crystal Stage
Current: None
(Value Range: -10 –> 10)

U. V. Index
Current: 0.0167
(Value Range: .0034 –> .058)

Wind Force / Speed
Current: 23.5º
(22º –> 24.5º)

Atmospheric Temperature
Current: .02
(Value Range: e•sin(ϖ) –> e•sin(ϖ))

Relative Humidity
Current: January 27
(Jan. 1 –> Dec. 31)

Barometric Pressure
Current: -6.5
(Value Range: -10 –> 10)

Chance of Precipitation
Current: +7.2
(Value Range: -10 –> 10)

Fig. 105 Evaluation Charts for Micro-Interventions
Many Bodies

8.1 Not What It Is, But What It Does

In the design of the many bodies, it is less crucial to define them as what they are, than it is by what they do. [8] The following set of design studies investigates utilizing tessellated folding surfaces as a potential method of pneumatically activating the agents. In other words, is it possible to utilize the various folding patterns to enable the many bodies a shift of properties through a shift of shape? If varying surfaces of the pattern are made up of different materials, through changing its form it can change its performance. In Chapter 6 I introduced a list of activation methods that appear to yield a promising range of influences on the operands. First, and foremost, given the promise of using material properties of surfaces to mitigate melting, as seen in Chapter 5, when and how to deploy such surfaces comes into question. For addressing this, I will discuss the use of multi-material tessellated folding surfaces as a method of controlling what material properties are hidden versus active.
The adjacent figures show a range of folding patterns. Since each pattern operates differently, they enable various types motions. The Resch pattern for example [84][85] is able to fold from a flat surface into a structure with an adjustable volume; the tighter the fold contracts, the smaller the surface area becomes, but the larger the volume underneath gets. On the other hand, a Grid V chevron pattern [86] for example, would give a range of structures to fold into. This is the pattern I used in Chapter 5 to compare melting in direct contact versus that with a heated volume.
Fig. 109
Resch Triangular
Folding Pattern in
Expansion

Fig. 110
Resch Triangular
Folding Pattern in
Contraction

Fig. 111
Resch Triangular
Folding Pattern with
Variable Materials
Fig. 112
Waterbomb Folding Pattern in Contractin

Fig. 113
Waterbomb Folding Pattern in Expansion

Fig. 114 Folding Patterns With Varied Materials
Fig. 115
Interior of Grid V
Folding Pattern
If folding could allow the bodies to shift performative properties as they change form, how could they be hard wired, so to speak, in a way that would enable them this physical flexibility? For this I explored a couple of pneumatic assemblies. As air pumps into the body it activates motion, changes to a different form, and exercises different properties.

The assembly is made up of a series of layers, each serving a different purpose. The outermost layers can be made up of either black TPU coated nylon, or reflective mylar. Moving inwards on each side, there is a layer of double-sided, acid free, adhesive film. This has a cutout pattern that will serve as the channels for air to flow in the given pattern. Then a rigid layer is scored with the particular folding pattern of the actuation.
All of the layers are stacked, and the outermost fabrics are heat sealed to create an airtight assembly. Given the cutout pattern of the adhesive film, barbed tube fittings puncture one side of the outermost layer at specific points in order to drive air through the internal channels. As air is pumped into the assembly, the middle layer folds per its score pattern. Another assembly type used a folding pattern as a guide to seal off pockets of air. As air is pumped into one pocket the assembly inflates on that section and pulls the rest of the body in a particular pattern.
Fig. 120 Grid V Tessellated Folding Pattern: Testing in Snowfall
9.1 The Bodies Sense, Move, and Connect

In line with the practice in Cybernetics to define something not through what it is, but rather by what it does; the bodies sense phenomena; the bodies move as intervention; and the bodies connect to the context and to one another.

Their skin continuously senses their environment and monitors its own motion. It reads external temperatures, pressure, moisture, etc., while tracing its own magnitude of expansion and degrees of movement. This layer of physical sensing serves as a backbone to the framing of their Umwelt. Similarly, it functions as a continuous method of monitoring the flux in the ecosystem thus increasing the amount of data the mind has to inform its decision making processes. Through this layer, the system is also able to evaluate how the context responds to the iterations of micro-interventions.

The many bodies tap into the ongoing natural mechanism of the cryosphere to extend their breadth of monitoring. Through activating their black surface they replicate the cryoconite microbe’s technique, as they concentrate solar heat and melt discrete pools on the surface of the glacier. As the particular area begins to melt, the bodies are able to drop
a series of sensors into the depth of the glacial mass. Then, they pull away and deploy their reflective properties in order to refreeze the area. Through this process, the system gains another level of monitoring and a new type of information. As this process repeats throughout the glacier, the bodies themselves serve as nodes of sensing that eventually build up to an extended network; a sentient second skin that is applied onto the glacier surface and through its thickness.

As air pumps into an agent it activates the body’s motion, changes its form, and exercises a different set of properties. Depending on the folding pattern, the pneumatic activation allows varying types of movement. Grid V tessellations for example, enable an accordion-like pushing and pulling thus giving the bodies a method of locomotion. As one part of the body contracts, another expands. Through this rhythmic motion, the bodies slide & crawl through the snow to where they are needed. A similar technique is used to inflate the agent. Air can flow into or out of parts of the body in order to increase or decreases its volume and surface area they affect, enabling them to shrink up completely and almost become non-existent, or enlarge to shield the maximum amount of area. Since varying surfaces of the pattern are made up of different materials, through changing its form it changes its performative properties.

The bodies are able to connect to each other, in part to extend their network of sensing, but also to aggregate into various formations. They work together to gradually enable patterns of change, enhance self-regulation, and incrementally influence.

9.1 The Bodies Sense, Move, and Connect

These speculations exhibit the embedding of the iterative design process into the design itself. Whether it’s through locating a weakness and defining a method of mediation, or cycling through motion rhythms that reshape a surface, the system works to facilitate the cryosphere’s self-regulation methods. Here, the mind and many bodies tap into the natural phenomena to shift the form of the material in a performative manner. The system would learn from its environment and adapt to the different conditions.
In the case of an emerging problematic crack for example, the mind goes through both the root and the fluid hierarchy segments of the decision tree in order to define a method of intervention. First it acknowledges the state of the material, and how it may be affected by the current and forecasted atmospheric conditions. In this case, it defines that the force of the crack could be opposed by increasing the mass of adjacent areas. The mind deploys a group bodies to the specific locations that would wield maximum impact. The bodies expand into a form that exercises its reflective properties over their maximum surface area. When it snows, the creatures slide away, allowing the mass to grow; when the sun comes out, they return to continue deflecting. As time goes by, while the exposed glacier surfaces slowly melt away through the summer months, the protected areas maintain their original mass. Since the impact is acquired gradually over time, the system has the capability and opportunity to adjust the location of the nodes. Slowly, forms emerge out of the glacier surface – flanking the crack, opposing its force, and still allowing pressure to be relieved naturally throughout the remaining surface.

In other scenarios, a series of incremental interventions work to promote specific glacial surfaces in order to encourage the refreezing of ice. Here, for example, we are in the zone of ablation during the fall. As the last months of sunshine elapse, the system defines a potential way of maximizing mass gain during the coming months of winter. The mind choreographs a series of bodies to use the remaining sunlight to reshape a portion of the glacial surface. The emerging surface geometry materializes as an expression of their patterns of motion. Now, as winter approaches, the augmented glacial surface is capable of retaining higher amounts of snow. As years go on, the mind and bodies iterate through a series of geometries as they adjust their approach through the constant evaluation of the environment’s response. The mind observes how the context changes, and adjusts its methods to reflect the emerging phenomena.
Fig. 121 Agent Bodies Sensing Field of Firn
Fig. 122 Speculative Bodies Creating Deep Sensing Network
Fig. 123 Grid V Tessellated Folding Pattern, Testing in Snowfall
Fig. 124 Grid V Tessellated Folding Pattern. Testing in Snowfall
Fig. 125 Grid V Tessellated Folding Pattern Locomotion Diagram
Fig. 126 Grid V Tessellated Folding Pattern. Testing in Snowfall
Fig. 127 Grid V Tessellated Folding Pattern Expansion Diagram

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Fig. 128 Evaluating Method of Mediation of Problematic Crack

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Fig. 129 Resulting Mediation. Formed Ice Mass Structures
Fig. 130 Mediated Surface Geometry for Snow Capturing
Fig. 131 Mediated Surface Geometry for Snow Capturing
Fig. 132 Grid V Tessellated Folding Pattern. Study in Snowfall

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Conclusion

10.1 Synopsis

Through developing this design approach, the thesis proposes a strategy of micro-interventions as a way to embed the iterative process of design into the design itself. It is this iterative process that gives the design a framework to reevaluate priorities, redefine constraints, recharacterize roles, reveal relationships, and rechannel presupposed trajectories of elements in its Umwelt. The work pushes away from the dominant approach to intervene through attempting to gain full control over the environment in a single, static, macro-intervention. Through cybernetic micro-interventions, the work suggests a higher degree of responsive adaptability in designs that monitor, mediate, and activate complex environments. This approach stems in part from Cybernetics, focusing on how a thing-in-the-world learns to organize itself through its interactions with the environment. Here I suggest that the design, as we typically think of it, is unfinished; it is not determined, but it is given a framework by which to manifest itself as it responds to the internal agencies and external forces. It then plays out in the cryosphere through what I call A Mind with Many Bodies; the mind being the cybernetic logic, and the many bodies being the aggregated micro-interventions. The work utilizes the cryosphere to investigate the potential of cybernetic micro-interventions as the approach to monitor, mediate, and activate the evolving needs of a dynamic equilibrium within various ice formations.
10.2 Reflections & Future Work

Given the many facets of this thesis, there is a range of different types of next steps one would take in order to develop this approach further. In the case of the cryosphere for example, a logical next step would be to go through a series of physical simulations to test parameters inducing melting in ice for reinforcing. However, a cybernetic counterpoint to this step would be that as you experiment through simulations, you remove a lot of the interactions the system would have in the real context. Pickering might argue that this follows Heidegger’s concept of enframing rather than that of revealing. [48] Nevertheless, the physical simulations could be the foundation to which the starting iterations evolve out of. In other words, observations from control experiments could yield results that inform the composition of the framework by which the system adapts.

In the case of the Mind with Many Bodies, a next step would be to test alternative decision-making procedures and variations of its hierarchy. In the case of the developing the bodies, it would be worthwhile to integrate some of the self-assembly technologies and passive methods of activation discussed in chapter 2. Would there be a way to embed some features of the agents to inherently respond to atmospheric conditions without the need to go through the logic of the mind every time? Would some methods of activation benefit from this short cut? If so, which ones?
The design approach of A Mind with Many Bodies dovetails a wide range of fields and topics. From robotics to choreography, from self-assembly to cybernetics. As the work developed, it continuously curated concepts from the varying fields as a way to envision what a design approach of cybernetic micro-interventions might look like. This exploration similarly prompted a series of fundamental questions to investigate in order to further develop the logic. Future work would need to explore the following questions.

What aspects of an adaptive framework do you design?

What aspects of the framework are fixed, and which are fluid?

To what degree do you design it and to what degree does it design itself?

What agency do you give the framework?

Which elements are preprogrammed, and which are responsive?

Ashby categorizes behavior into reflexive and learned. [47] One is ingrained and hardwired into the physiology of the being, the other is acquired through interactions with the world. Although Cybernetics typically focuses on the latter, how can we design a system with both mechanisms? How can we make these two symbiotic? And how do we define which aspects are reflexive versus learned?
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Design For A Mind With Many Bodies: Cybernetic Micro-Interventions in the Cryosphere

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