Cybernetic Environment:
Uncontrollability and non-communication for a future of coexistence

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ABSTRACT

This research constructs a field of inquiry – the cybernetic environment – between sciences, engineering, arts, and design. It interrogates and investigates the underlying mode of thought in emerging environmental practices revolving around cybernetic technologies – that is, environmental sensing, machine learning, artificial intelligence (AI), and robotics – in light of contemporary posthumanism cognition and more-than-human ontological concerns across disciplines. Emerging cybernetic practices across fields pose challenges which have been largely understudied, and may transform the ways in which we understand cybernetics, a 70-year-old concept.

In his book Cybernetics: Or Control and Communication in the Animal and the Machine (1948), Norbert Wiener first publicly used the term “cybernetics” to refer to recursive and self-regulating mechanisms across biological and mechanical systems. Cybernetics positions communication – the exchange of information – at the center of control. This study offers an alternative interpretation of cybernetics – recursive and self-regulating mechanisms – in a non-communicative framework suggested by contemporary posthumanist thought.

This research argues that many concepts in contemporary environmental discourse, such as adaptive management, responsive landscapes, and smart cities, operate within the paradigm of the cybernetic system, but not in the paradigm of the cybernetic environment. They imagine the environment as systems and apply cybernetic thinking to optimize and control them. In contrast, the cybernetic environment paradigm emphasizes that the environment outside a system is not a homogeneous space, but a mesh of objects, assemblages, and mental processes that are withdrawn and reserved from human access. In this framework, which emphasizes the inability to communicate and wield control between objects, cybernetic thinking is no longer about control, but is instead a logic of coexistence with and attuning to more-than-human objects around us. In addition, cybernetic environments become reserves of great open-endedness and futures we cannot now imagine.

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Cybernetic Environment:
Uncontrollability and non-communication for a future of coexistence

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INTRODUCTION

> "We are more than ever in an epoch of cybernetics, since cybernetics was not a discipline parallel to other disciplines such as philosophy and psychology, but rather it aimed to be a universal discipline, able to unite all other disciplines, therefore, we could say, a universal (mode of) thinking par excellence." – Yuk Hui, "Machine and Ecology" (2020).

1. Upscaling of Cybernetic Imagination

We are surrounded by cybernetic machines. They construct the environment we inhabit. We therefore live in a cybernetic environment. This research, titled "cybernetic environment", hopes to investigate the entanglement of human nature and technology in the upscaling of society's cybernetic imagination. What does a cybernetic environment look like, and how do we make sense of it?

DroneSeed, a Seattle-based company, uses drone swarms to plant and manage forests, after disturbances such as wildfire. The company claims this drone-based reforestation strategy is highly efficient and six times faster than human-performed planting. One drone operator is able to propagate 80 acres of trees within eight hours, and reforest a post-wildfire site within 30 days. The drones' flying paths are pre-programmed and optimized, and they then plant and manage trees semi-autonomously. Robotics has also entered food production, from precision farming to home gardens. FarmBot is a start-up company that combines computer numerical control (CNC) technologies with gardening, producing home farming armatures that automatically monitor plant growth and water, and also prune the plants.

If Leo Marx (1964) used the phrase “the machine in the garden” in a metaphorical sense, to trace and critique the schizophrenic garden-machine motif within the American psyche, then, “robots in gardens” now takes on a literal sense – real machines working in real gardens. Compared to machines, the term “robots” conveys a sense of autonomy rather than automation. Machines present an image of sophisticated gears and oily chains that automate human physicality; robotics is about sensors and computer chips that automate human thinking and produce an appearance of sentience.

RangerBot is an autonomous vision-based underwater robot developed to protect the Great Barrier Reef from overpopulated, coral-eating crown-of-thorns starfish (COTS) that threaten the health of the reef ecosystem. RangerBot is an engineering achievement of machine-learning techniques, robotics, and computer vision. Scientists use a random-forest classifier, a machine-learning algorithm trained on underwater footage, to build a vision-based system in order to detect and track the starfish. The robot then fires a lethal injection and kills the starfish without harming the reef itself (Dayoub, Dunbabin, and Corke 2015). The robot was initially developed as COTSBot by the Queensland University of Technology and the Great Barrier Reef Foundation, with support from Google Impact Challenge. RangerBot extends its predecessors’ capabilities and becomes a “Swiss Army knife”-style robotic system that can do more for upscaling environmental monitoring and the management of reef ecosystems worldwide. Aside from pest control, it now comes equipped with further tools and sensors to monitor reef health and map underwater areas at scales previously impossible. From COTSBot to RangerBot, the name change represents a shift of imagination from a straightforward robotic function to a job position that requires independent decision-making. Indeed, numerous human divers and rangers now monitor and manage the reef ecosystem, including manually killing the COTS with injections. The RangerBot is projected to become just another “diver”. Scientists have attributed increased agency and intelligence to this robot, viewing it as more than an extension of human eyes and arms; it has become an intelligent decision-maker and co-worker in protecting the reefs.

At the University of Virginia, an interdisciplinary group of scientists and engineers from the Link Lab works with the coastal city of Norfolk, and investigates cyber-physical systems in coastal climate adaptation (Bowes et al. 2020; Saliba et al. 2020; Sadler et al. 2020). Scientists are advancing techniques on all fronts with a sensing-predict-control feedback loop as an undergirding framework, from sensor networks to machine-learning algorithms and responsive infrastructures. In one project, scientists have trained an AI system, using deep reinforcement learning (DRL) techniques, to manage a simulation of an urban stormwater system, balancing several competing objectives. This experiment shows that machine learning provides a viable approach for determining control policies for real-time control systems. These machine-learning agents can be transferred to cities like Norfolk, and uploaded into the real-world cyber-physical infrastructure. Many cities are working with emerging companies that focus on responsive infrastructures. Even though machine learning does not yet replace rule-based control as an industrial standard, research projects like the one in the Link Lab push industry towards a future in which machine-learning agents will play a preeminent role in managing urban environments. If the Link Lab's research projects are concretized in one way or another, that will mean that urban environments will be managed by not only humans but also intelligent agents deeply embedded in the distributed cyber-physical infrastructures. The outcome will be a hybrid of both human and machine intelligence, and a meshing of objective functions and goals.

Underpinning these environmental practices is a broad-based cybernetic imagination within contemporary culture. At the heart of cybernetics, is the use of self-regulating and recursive causality to analyze control and communicative behaviors within biological and mechanical systems. Cybernetics began as a transdisciplinary field of research in the post-World War II era. Its key principles, such as feedback, self-regulation, and homeostasis, rapidly became cornerstones for modern control theory and systems theory, and are proven useful in designing powerful machines. We witness in present-day environmental practices an upscaling of cybernetic imagination, in the sense that we desire to either introduce more intelligent machines to manage all sorts of environments, or conceptualize an environment itself as a grand cybernetic machine to be controlled and optimized.

Over the past decade, the smart city has become the most ambitious cybernetic project; it mobilizes different social sectors to develop smart technologies to make cities “smarter”. Sensors, platforms, crowd-sourced data, machine-learning algorithms, and artificial intelligence – a myriad of new tools are being developed every day to experiment with feedback loops between urban systems. The goal is to make cities “smarter”. However, what counts as smart? The word is often narrowly defined as more efficient and more connected, making urban processes faster and growing urban datasets bigger. Though the notion of a smart city has been extensively criticized from the beginning, such criticism has not arrested the urge to optimize cities as cybernetic machines.

“A city is not a computer” and “urban intelligence is more than information processing.” Many critics, like Shannon Mattern (2017), have voiced loud and clear objections. However, these claims have failed to end cybernetic thinking’s contagious nature; as long as one can conceptualize a system with measurable input and output, then an entire branch of mathematics and multiple techniques in modern control theory are available to make this system appear to be computable, controllable, and optimizable. This is why Yuk Hui (2020) notes that cybernetics “remains a thinking of totalization, since it aims to absorb the other into itself” (63).

2. Cybernetics Unexplored?

Within multiple cybernetic practices, we begin to see abnormalities that fail to fit within the mainstream cybernetic imagination characterized by increased communication and improved control. For example, in the Link Lab's research, the DRL agent developed its own understanding of the urban drainage system without human knowledge, and devised certain unexpected strategies beyond scientists' comprehension. "Can machines think?" Alan Turing (1950) posed this question when computers were in their infancy. Now, we should pose a second question: "Can machines think what humans cannot?"

Relying on machine-learning techniques such as DRL, scientists have trained many intelligent agents that not only outperform humans in various aspects, but also develop their own strategies with a "machine flavor". For example, AlphaGo, developed by Google's DeepMind, is a DLR agent specializing in the strategy board game Go. This game involves two players who each try to surround more territories than their opponent. Over the past years, AlphaGo, with its predecessors Zero and Master, has beaten many of the best human Go players. Most importantly, it has developed unique strategies which professional Go players have never before seen (Silver et al. 2017). The game of Go was invented approximately 2000 years ago, and humans have explored the game long enough to believe that all strategies had been identified. Yet AlphaGo has expanded the game's possibilities with a machine perspective.

Similar examples can be found in the field of video games. AlphaStar is another DRL-based agent that has reached the grandmaster level (the highest rank one can reach by competing with other players) in the real-time, strategy video game StarCraft (Vinyals et al. 2019). The AI community regards this experiment as a breakthrough, because real-time strategy games such as StarCraft are infamous for their vast action space, containing a planning horizon of thousands of real-time decisions with imperfect information. AlphaStar not only mastered the game, but also developed a unique playing style. Consider this comment after one professional human player competed against AlphaStar:

> "AlphaStar is an intriguing and unorthodox player – one with the reflexes and speed of the best pros but strategies and a style that are entirely its own. The way AlphaStar was trained, with agents competing against each other in a league, has resulted in gameplay that's unimaginably unusual; it really makes you question how much of StarCraft's diverse possibilities pro players have really explored" (The AlphaStar Team 2019).

Here, we should overcome the human-machine rivalry trope popularized by pop culture, and instead focus on how humans and machines explore something such as games together, and emergent behaviors in the process of interaction. In both Go and video games, these behaviors are embodied in new ways to play old games.

There are examples of less "intelligent" machines. Sougwen Chung is an artist known for her drawing series, collaborating with robots and computer-vision algorithms. The set-up was simple: a table with a large piece of canvas, the artist on one side and a robotic arm on the other. They then performed a drawing duet. With computer vision, the robotic system traced the artist's movements and attempted to reproduce her gestures with the robotic arm, holding a pen. Yet due to the machines' imperfections – causing jittering and delay – the artist Chung was forced to adjust her movements in response to the machine. The feedback loops and recursive processes between the machine and the artist did not result in the homeostatic and expected results, but rather in drawing styles which the artist admitted she could not have produced on her own.

Moreover, the past several years have seen a range of prototyping research in landscape design, which relies on cybernetic technologies and recursive principles but produces results beyond cybernetic control. In both the Responsive Environment and Artifact Lab at Harvard and the Open Systems Lab at the University of Virginia, landscape architects have used a physical hydro-sediment table combined with sensor arrays and actuators to explore land-building strategies. By manipulating hydrological patterns in real time, and utilizing sensing-processing-actuating feedback loops, the machine assembly constructs new landforms beyond the designers' intent and control (Estrada 2018). These cybernetic machines open a liminal space of exploration between designers' intent and a co-produced reality resulting from the interactions of many agents.

There are further instances where cybernetic machines make us question how much we have explored with our limited, all-too-human knowing and thinking. With these examples, one cannot help asking: are these practices still cybernetics? If repetitive actions and recursive causality do not lead to communication and control, how do we define the results of these cybernetic mechanisms? In addition, if cybernetic machines could help expand our understanding of the environment, what possibilities lie in the cybernetic environment? Jennifer Gabrys, the author of *Program Earth*, envisions "planetary computerization" as opportunities for speculative experiments, for "propositioning, instigating, and triggering — beyond the usual automated sensor-actuator triggers of cybernetics — toward indeterminacy and openness" (Gabrys 2016, 272). The upscaling of society's cybernetic imagination gives rise to competing versions of cybernetic environments. We should cultivate those that help us reimagine the environment as a reserve for possibilities and a future we cannot now foresee.

3. Three Tensions within the Cybernetic Environment

Before these cases become truly transformative, we face an acute problem: many of these cases lie outside our interpretive and evaluative categories based on optimization and control.

This challenge may be described as three perceived tensions specific to the field of cybernetic environment.

First, the cybernetic environment presents an upscaling of entanglement between nature and technology, biological and technological, machine and wildness, biotic and abiotic. In the RangerBot case, can we still call the Great Barrier Reef an area of wild nature when it is carefully managed by humans and intelligent machines? Should we instead refer to it a garden, a more apt term for cultivated nature? Are concepts such as hybridity, cyborg, and system coupling enough to describe an entangled reality?

Second, in many of the above examples, the machines utilized are more than tools that simply automate human labor; they exhibit different levels of autonomy, like the Link Lab's DRL agent. Thus, a challenge arises: do we trust these robots – which occasionally act in unexpected fashions – enough to hand over the environments? An environment is not a game of Go, where we can begin again. Deep in our imagination hides the scenario of AI gone rogue. Underlying this discomfort is a deeper predicament for discussing nonhuman agency. Contemporary environmental humanities and political ecologies tend to attribute agency to more than human objects – they point to machines, animals, plants, environmental laws, and environmental policies. We want to show a sense of humility as human beings, recognizing other forms of agencies that co-produce the environment. However, the irony is that the "agency" we attribute to others is an observed efficacy. After all, the so-called nonhuman agency is effectiveness; these nonhuman beings can be used to benefit human goals, reinforcing another level of human hubris and control. Therefore, the tension lies between the willingness to embrace a sense of humility, and the inability to develop a framework to truly think beyond human reasoning of cause and effect.

Third, the cybernetic environment highlights a space between intent and reality, posing threats to the act of design itself. Many contrasts the sciences with design – the former is about revealing patterns in the world, while the latter is about rearranging things and relationships to create new patterns. Design entails a sense of intentionality and an urge to control how things ought to be; it achieves goals and constructs an ideal end. However, within the cybernetic environment, humans are not the source of agency, and our actions are modified and interfered with by other goals. In Sougwen Chung's drawing practices, she must constantly adapt to the machine's movement. The feedback loops between human and nonhuman agents will lead to a direction outside anyone's plan. How do we then conceptualize the act of design itself, which embodies an ultimate form of idealistic thinking and human control? Thus, the third tension is the one between the designer's intentionality and the co-produced reality of more-than-human agents in the cybernetic environment.

This research addresses these tensions through two conceptual moves. First, it deploys cybernetics as a lens with which to group a range of extremely diverse practices, and then envisions a field called "cybernetic environment" in which machines and cybernetic thinking play a preeminent role in environment construction. Second, the research analyzes these cases, and therefore the underlying cybernetic thinking, in light of contemporary posthumanist arguments on nonhuman agency and various ontological concerns. In a way, this research extends Yuk Hui's claim that "we are in an epoch of cybernetics" by asking what exactly does this "cybernetic epoch" look like when humans are removed from the source of agency, and when the environment is understood as a co-produced result involving nonhuman agents. It is about exploring a version of posthumanist cybernetic thinking. This alternative view of cybernetics transforms how we understand our relationship with machines, and other nonhuman species, in a shared environment and a co-produced future. Before we proceed, we shall focus on each conceptual move separately – cybernetics and posthumanism.

4. Why Cybernetics? From Cybernetics to Posthumanism

We should recognize that there is a deep misconception about the term cybernetics. It is often used interchangeably with robotics, and occasionally misunderstood as modern control theory itself. It is often associated with linear mechanisms of stability and control, and thus is often critiqued by those who embrace nonlinear thinking and indeterminacy. Even Gabrys appears to equate cybernetics to determinacy and closeness, as stated above. These misconceptions and critiques of cybernetics are understandable, because cybernetic principles underpin all modern machines and control systems. However, the history of cybernetics reveals that cybernetic thinking is extremely diverse. The above examples indicate that certain aspects remain underexplored.

Many agree that cybernetics began as a series of interdisciplinary meetings from 1944 to 1953, known as the Macy Conferences on Cybernetics; they brought together important postwar intellectuals, including mathematicians Norbert Wiener, Claude Shannon, and John von Neumann; anthropologists Gregory Bateson and Margaret Mead; neurophysiologist Warren McCulloch; physicist and philosopher Heinz von Foerster; and psychiatrist W. Ross Ashby. As Wiener's book title – *Cybernetics: or control and communication in the animal and the machine* – suggests, the field of cybernetics is transdisciplinary; its goal was to study recursive and self-regulatory mechanisms in both biological systems and machines. This period of the cybernetics movement is also known as first-order cybernetics, to distinguish it from the later, second-order cybernetics that began in the late 1960s.

Without a doubt, many early cybernetic principles, including feedback, recursive causality, and self-regulation, became concepts that underpinned modern disciplines such as computer science, control engineering, and artificial intelligence (Heylighen and Joslyn 2003). Even the most cutting-edge AI research, such as deep reinforcement learning (DRL), a machine-learning framework that successfully trained AI systems such as AlphaGo, is, at base, cybernetic. The DRL framework conceptualizes a machine agent that observes its environment, evaluates its state, devises strategies to change the environment, and then repeats the entire process. Recursive causality is an elegant conceptualization for building powerful machines; all modern machines are cybernetic machines.

However, we must recognize that early cyberneticians viewed cybernetic machines differently. Cybernetic robots were constructed during the Macy conference era, including William Grey Walter's cybernetic tortoises, Wiener's "moth and bedbug", and Von Neumann's cellular automaton. However, these machines are merely demonstrations of cybernetic thinking; they are diagrams of different types of feedback systems. The cyberneticians' goal was not to build powerful machines, but to construct a universal theory to cut across different entities, materially and physically. From this perspective, cybernetics has been narrowly interpreted as a theory for building powerful machines.

Before the Macy-conference era, Norbert Wiener developed the cybernetic thinking that would be used during World War II. His goal was to build a machine – the "antiaircraft predictor" – to predict an enemy pilot's flight path, and launch an antiaircraft shell to down the plane. However, as pointed out by historian Peter Galison (1994), Wiener quickly realized the more profound implications and universality of his conceptual framework based on recursive causality, and therefore wanted to direct cybernetics towards a philosophical concept. Moreover, with cybernetics' history in warfare, Wiener's conscience led him to steer cybernetics towards a theoretical endeavor rather than the practicalities of building potentially destructive machines (Galison 1994).

In charting this history, we also recognize that *communication* and *control* have been two key concepts since Wiener's coinage of the term cybernetics (in Greek, "steering person" or "helmsman") in the summer of 1947, to denote what he hoped would become "a new science of control mechanisms in which the exchange of information [or communication] would play a central role" (232). In other words, before cybernetics, engineers would decipher and design the internal structure of a system in order to build control mechanisms. However, cybernetic thinking constructs a black box, ignoring the system's internal structure and focusing on the system's input and output information as the core to achieving a sense of control: communication mechanisms become the fundament for control strategies. This conceptualization became the foundation of modern control theory, based on measuring input and output in time sequence, and computing control strategies. From this vantage, the research pulls together a range of cybernetic practices that lie outside the core conceptualization of cybernetics based on control and communication. In these examples, we will see non-communicative behaviors and uncontrollable situations. They suggest that there may be much unexplored in cybernetic thinking itself – a version of cybernetic thinking that is non-communicative and not about control.

Due to its interdisciplinary nature, cybernetics has been imported into and interpreted within many fields of research in the twentieth century, including landscape architecture. Ian McHarg imported cybernetic thinking into landscape architecture via ecological science. In his seminal work, *Design with Nature* (1969), McHarg discussed "entropy" in a way that echoes Wiener's interpretation, viewing entropy as destructive to homeostasis, stability, and ecological fitness (Lystra 2014). However, "misinterpretations" occurred, as well. When introducing his "RSVP scoring design framework" in the early 1970s, landscape architect Lawrence Halprin (1970) wrote, "scores communicate but do not control" (19). He also argued that "one of the gravest dangers that we experience is the danger of becoming *goal-oriented*"(4). The wordplay and critique of means-end reasoning suggest that Halprin found the recursive thinking of cybernetics useful, but wanted to interpret it differently, with a landscape sensibility (Lystra 2014).

Halprin made these provocative claims in the 1970s because, on the one hand, like every other landscape architect, he worked with uncontrollable living materials; on the other hand, unlike McHarg, who focused on large-scale landscape planning through a scientific lens, Halprin needed to work with people throughout the design processes – or, from a present-day perspective, conduct community engagement.

Indeed, humans were regarded as a predicament in cybernetic thinking from its early stage. The role of observers and engineers in conceptualizing the cybernetic model became a key issue explored during the late Macy conference era, but without success (Hayles 1999). Early cyberneticians such as Bateson noted that the issue of reflexivity is more than subjectivity in modeling, but, instead, an issue in the epistemological realism that undergirds early cybernetic thinking, and "the problems posed by including the observer could be addressed only if a substantial reworking of realist epistemology was undertaken" (Hayles 1999, 132). Ultimately, a sense of liberal humanism supported the unwillingness to demote humans from their privileged position in conceptualizing consciousness, agency, and intelligence. Cyberneticians' question became how to arrive at a theory that included observers' role in the cybernetic systems they observed.

Thus, the field of cybernetics began to diverge. Practice-oriented scholars, such as engineers and computer scientists, turned from theoretical inquiries and shifted their attention to developing powerful machines with cybernetic principles. Many fields, such as systems engineering, computer science and artificial intelligence, grew into independent disciplines with specific questions and concerns (Heylighen and Joslyn 2003). In the meantime, those who identified themselves as cyberneticians wanted to distinguish their work from the practice-oriented disciplines, and decided to question the unresolved observer issue, attempting to develop a new cybernetic framework. In 1967, anthropologist Margaret Mead, a key participant in the Macy conferences, addressed the American Society for Cybernetics with the need for a recursive application of cybernetics on itself, treating the observer as one cybernetic system constructing models of yet another cybernetic system.

The significance of this conceptual move is more than a new model of cybernetics, but a path towards a series of reflections on human agency and control. This is why many trace the cybernetics movement as a major tenet contributing to the twenty-first-century posthumanism movement across disciplines (Hayles 1999; Wolfe 2010). In her seminal work, *How We Became Posthuman*, literary critic N. Katherine Hayles schematized this genealogy into three waves of cybernetics that mobilized between different fields of study. Each wave concerns different aspects of the feedback mechanism. The first wave denotes the Macy conferences era, with its focus on self-regulating and homeostatic systems via feedback mechanisms. Hayles attributes the second wave of research to the second-order cybernetics movement, from the late 1960s. Its major development was to conceptualize the observer as an observing system. This is why Heinz von Foerster (1974) also called it "cybernetics of cybernetics" – a recursive application of cybernetics on itself. Second-order cybernetics marked a reflexive turn in epistemology, from epistemological realism to constructivism (Heylighen and Joslyn 2003).

One of the most important concepts of the second wave of research was the autopoiesis theory developed by Chilean biologists Humberto Maturana and Francisco Varela (1980). By studying the frog's eyes and nervous systems, biologists found that the fibers between the eye and the brain pre-process information, and the brain does not receive an entire package of image data from the eye; the frog's nervous system constructs a reality for the brain, to ensure the frog's survival (Lettvin et al. 1959). Maturana and Varela (1980) asserted that autopoietic systems, including those of humans, use inputs to reconstruct their own system organizations, thus maintaining system identities. "The living organization is a circular organization which secures the production or maintenance of the components that specify it in such a manner that the product of their functioning is the very same organization that produces them" (48).

The autopoiesis theory presents a completely distinct conceptualization for agency, intelligence, and consciousness. Within the autopoiesis framework, these human concepts become epiphenomena which we produce with our system operations, in order to maintain the organizations of a class of special autopoietic systems we call *Homo sapiens*.

Hayles (1999) extended cybernetics into the 1990s by attributing the third wave of research to the field of artificial life that focused on the notion of emergence. To some extent, cybernetics has always been explored in a paradigm of homeostasis, in which stability and equilibrium have been accepted as default goals for feedback mechanisms. This can be seen from Wiener's conceptualizations of entropy, equilibrium, and meaning in *The Human Use of Human Beings,* originally published in 1950, in which Wiener tried to push cybernetics into understanding human society. "In control and communication, we are always fighting nature's tendency to degrade the organized and to destroy the meaningful; the tendency…for entropy to increase" (Wiener 1989, 17). Evidently, Wiener associated a sense of moral imperative in maintaining a system's stability. Indeed, for building powerful machines and control systems, defining a stable state is a priori for developing control strategies that stabilize the system.

Autopoiesis reflects observers, yet still in a homeostatic paradigm, asserting observers are cybernetic systems struggling against disorganization.

Hayles's third wave of research reflected the notion of homeostasis and stability, and investigated spin-off behaviors. In the 1990s, multi-agent-based simulations suggested that complex behaviors can be achieved by recursively exercising simple rules. Humans, to a certain extent, become "computer programs" in a "computational universe" (Hayles 1999).

Hayles's observation was acute. However, we must read her interpretations historically and critically. Her presentation of the development from early cybernetics to posthumanism is easily misinterpreted as paradigm shifts, with one understanding replacing the previous one: early cybernetics was replaced by autopoiesis (from epistemological realism to constructivism), and homeostasis replaced by emergence (from stability to spin-off behaviors). We need to recognize that this is a specific genealogical construction of cybernetics in the service of Hayles's argument for a path towards post-humanism. Its history involved more of a thickening process, with multiple interpretations absorbed into the umbrella term of "cybernetics" and its recursive framework. Thus many would today use the term cybernetics to denote a collection of ideas, without drawing a distinction between first- and second-order cybernetics (Heylighen and Joslyn 2003).

We may frame the development of cybernetics differently. At the heart of cybernetics is recursive causality – the output of a system decides the input. However, how we interpret this feedback mechanism depends on the episteme in which cybernetic thinking has been explored, in both theory and practice. For example, the second wave of cybernetics that posed questions concerning the observers' role mirrored a broad-based reflection on authorship, objectivity, and scientific truth in the mid-twentieth century, across the sciences, arts, and humanities. In science history, Thomas Kuhn's 1962 book *The Structure of Scientific Revolutions* found its popularity beyond academics, as did the term "paradigm shift". Kuhn presented an alternative view of the "great man" history of scientific and technological revolutions, arguing that scientific truth was constructed by the scientific community based on a consensus with regard to the underlying assumptions, techniques, and values shared by that community (Kuhn 2012). The intellectual excellence of individual scientists was questioned; scientists themselves, with their unconscious minds, became the subjects of study.

Similarly, problematized authorship was a key issue in early twentieth-century works of art. Duchamp's readymade sculpture "Fountain" (1917) was one of the earliest challenges to artists' roles in the production of art. Conceptual artist Sol LeWitt's wall drawing series essentially consist of written instructions for drawings on walls, instead of the drawings themselves.

Similar concerns can be found in the humanities, as well. In the 1967 essay "The Death of the Author", Roland Barthes questioned the role of authors in literature, and argued that an author was not a creator of meaning in the text, but only one who combined different texts (Barthes 1977). In a similar vein, Michel Foucault regards authorship as author function, which speaks to the need to pin a discourse to a person, as a regulator of meaning. This reflection can be situated within Foucault's thinking, encapsulated in his seminal work *The Order of Things* (1966). Towards the end of his book, Foucault provocatively claimed that the appearance of a human figure "was the effect of a change in the fundamental arrangements of knowledge. As the archaeology of our thought easily shows, [hu]man is an invention of recent date. And one perhaps nearing its end … like a face drawn in sand at the edge of the sea" (Foucault 1970, 422).

With these examples, we should recognize that second-order cybernetics and autopoiesis theory form one stream within a broad-based reflection on human exceptionalism across fields, and the emergence of posthumanism towards the late twentieth century. One unique aspect of cybernetics is that it has provided a systemic account for the reflection of human agency, with special attention to the issues of control and communication.

Similarly, the notion of emergence is not specific to the field of cybernetics. Towards the late twentieth century, many fields, including landscape architecture, started to explore the notion of emergence. Landscape architects have focused on the ecological emergence and becoming of landscapes, through theory and practice, since the late 1990s, framing landscapes as processes of unfolding leading to new forms of relationships between biotic and abiotic beings in the environment (Reed and Lister 2014b; 2014a).

On another level, Hayles's work demonstrates that cybernetics as transdisciplinary thinking by nature navigates between different fields of research. Because of its transdisciplinary nature, Hayles can extend cybernetics to the artificial life research of the 1990s, exploring cybernetic thinking with the notion of emergence at its early stage. Thirty years have passed since *How We Became Posthuman*. Today, we are better positioned to consider notions such as emergence and open-endedness with transformative cases across cybernetic practices. Moreover, since the 1990s, posthumanism has made its way into intellectual life and has provided a completely new backdrop for considering cybernetic thinking and practices.

5. Posthumanism

The second conceptual move situates cybernetic practices and thinking within a posthumanist framework, and explores what cybernetics means, with contemporary concerns about nonhuman agency and intelligence. Yet, what is posthumanism?

Cary Wolfe (2010) attributes posthumanism to at least two genealogies, one rooted in early cybernetics and the other in Foucault's pronouncements on the appearance and disappearance of "human" as arrangement and rearrangement of knowledge. However, as we have seen, reflections on human agency and exceptionalism were shared across the arts, sciences, and humanities in the second half of the twentieth century. Thus, the downside for tracing genealogies is in overlooking the similarities of ideas across fields, and the establishment of an idea as a transdisciplinary effort.

Posthumanism in this research takes on its most general sense, and speaks to extremely diverse fields of thinking, including earlier reflections on human agency, and contemporary reflections, such as object-oriented ontology (OOO) and speculative realism. Though certain OOO proponents would distance themselves from posthumanism, their arguments are based on a narrow definition. If we focus on the undertaking of these different ideas, we see that they share a common goal: to challenge anthropocentrism by removing humans from the center of the source of agency. From this perspective, as long as an idea shares a similar sentiment, this research would, without hesitation, categorize it as a version of posthumanist thought. Under this large conceptual umbrella, we may focus on their different approaches for demoting humans from a privileged position, for interpretation.

From this perspective, this research offers two alternative perspectives on posthumanism specific to the cybernetic environment: first, from entanglement between the human and nonhuman realms, and second, from complex relations between humans and technology. Tracing the evolution of conceptions of nature and technology through the twentieth and early twenty-first centuries, this research presents growing reflexivity on human agency against nonhuman species and machines, recognizing other forms of agency and intelligence in co-producing the environment.

Moreover, this research seeks to reframe the relationship between cybernetics and posthumanism. Hayles mapped a path from cybernetics to posthumanism in 1999, but after some 30 years of exploration, posthumanism itself has developed from its early stage of challenging human agency to a "nonhuman turn" that focused on nonhuman agency, and is now moving towards a "speculative turn" that seeks to surpass agency – the human-centered concept itself. In other words, Hayles could not imagine that her work would contribute to a broad-based movement to completely reframe cybernetics itself. At such a level, this research is about situating cybernetics, a 70-year-old concept, within contemporary concerns on nonhuman agency and speculative ontology, and provide a new interpretation that acts in service of openness and indeterminacy, instead of controlled stability via optimized communication.

The term "nonhuman turn" entails a response to the initial reflection on human exceptionalism. Since the late 1990s, scholars in social sciences and the humanities began to turn to the nonhuman realm as an object of inquiry, to challenge humans' position in conceptualizing agency. Narratives about nonhuman agency can be found in science and technologies studies (STS); feminist materialism; animal studies; environmental humanities; and political ecology, among other disciplines. Ideas such as actor-network theory (ANT), companion species, systems theory, and assemblage thinking are influential tenets that have provided analytical frameworks in contemporary posthumanist works.

However, these explorations quickly ran into a paradox that undercuts the initial moral incentives. These "nonhuman frameworks" turn nonhuman objects into actants in narrators' stories; in the end, "nonhuman agency" becomes observed efficacy or effectiveness based on human standards and in the service of human agency, while intrinsic value as a nonhuman being in itself is still largely outside human-centric frameworks. The search for "nonhuman agency" ironically leads to another level of human hubris. To use OOO proponent Graham Harman's words, these types of reflection "remain human-centered no matter how many material entities they summon in the night to mould and shape human beings" (Harman 2015, 405).

The reflection on "nonhuman agency" leads to present-day philosophical concerns under the banner of speculative realism. This "speculative turn" is a reflection on "the prevalent tendency with Kantian and post-Kantian thought to treat the relation between thought and world as the primary subject matter of philosophy" (Young 2020, 43). In Harman's terms, it can be understood as a rejection of "access philosophy", specifically the philosophy of human access (Young 2020). The epistemic undergirding of nonhuman frameworks, such as ANT and assemblage thinking, still privileges the capacity of (human) knowing as fundamental for philosophical projects, even though they desire to subscribe to a posthumanist mode of thinking. In the end, the core of speculative realism is a critical stance towards contemporary posthumanist projects in terms of their "inability – or better, unwillingness – to create a *speculative ontology* which moves beyond the narrow confines of what is given to our all-too-human modes of understanding" (Young 2020, 50).

In a way, the contemporary posthumanist movement is deeply rooted in early cybernetics, but how do these new realizations, in turn, reframe cybernetic thinking? How can we interpret emerging and unorthodox cybernetic practices differently, with new concepts and vocabularies? Finally, how does the discourse of design, which is essentially a form of speculation, contribute to this debate?

6. Nonhuman Turn and Landscape Design

Beyond the two conceptual moves, contemporary landscape theory and practice serve as a backdrop for this research. As a profession building its mode of practice by drawing ideas and concepts from neighboring and outside fields, landscape architecture has absorbed diverse arguments and concerns, including cybernetics and posthumanism. As noted above, cybernetic thinking has sifted into landscape architecture since the 1960s, through multiple venues, including ecological science and art. Landscape architects have interpreted major concerns such as homeostasis, feedback loops, and emergence through theory-making and material practices.

One of the goals of this research is to bring landscape theory and practice into today's intellectual life, and interpret the meaning of landscape design in contemporary culture. There are two motivations for this undertaking. On the one hand, landscape (as both noun and verb) is a cultural product as well as a cultural technique that has always been an object of inquiry across fields. Historians have explored and interrogated society's narratives and conceptions of nature and technology by using landscape as a lens to unpack the dynamic relationships between these terms (Nye 1999; Reuss and Cutcliffe 2010; Lee and Helphand 2014). French philosopher François Jullien also turned to "landscape" as a motif to compare Western and Chinese thoughts on philosophical concerns (Jullien 2018). However, this type of research fails to recognize that modern landscape architecture, as a young discipline, has developed a body of scholarship through texts and material practices that may provide transformative vocabularies and frames to contribute to intellectual concerns.

On the other hand, since the late 1990s, landscape as a mode of thinking and practice has been turned into a model and adopted by many neighboring design disciplines, including urban design and architecture. Landscape design has been "rebranded" into different doctrines, such as "landscape urbanism" and "ecological urbanism" in contemporary design discourse (Czerniak 2001; Steiner 2008). However, over the past two decades, many landscape architects and theorists have surpassed earlier concerns such as "process" and "emergent ecologies", and asked more difficult questions about open-endedness and the liminal space between designers' intentionality and co-produced reality. When Cantrell and Holtzman (2016) conceptualized the role of responsive technologies in landscape design, they also revealed a larger philosophical project for contemporary landscape architects:

> "While the argument for ecological, non-deterministic strategies seemingly holds the answers to the problems of the contemporary landscape, it then becomes problematic to find methods that actually resist deterministic outcomes. At what point are goals, scaffolds, and protocols actually open-ended?"(254)

The past few years have seen a nonhuman turn in landscape theory and practice that mirrors the broad-based posthumanism movement. Many posthumanist scholars, including Donna Haraway, Bruno Latour, Graham Harman, and Timothy Morton, have been widely read within the landscape discipline. Landscape designers and theorists are exploring various posthumanist frameworks as ways to articulate their practices. Animals, plants, infrastructure, and land use policies are all treated as active agents; landscape architects choreograph them to envision the unfolding and becoming of the landscape dynamics. To use landscape architect Brian Davis's terms, "if a space is a landscape, then all of its objects and their dynamic relations are instruments [or agents], but not dumb drills, retaining walls, and land use policies. Rather, they are dynamic objects in relation to one another within a bounded territory containing some measure of human intent" (Davis 2013, 305).

As a profession and discipline that works with living material and processes that may extend beyond designers' control, landscape architects have always explored a mode of practice and a type of language that navigates between a desire to control and an uncontrollable reality constructed by more-than-human agents – living and nonliving, material and immaterial. Many contemporary landscape ideas become inspiring. For example, choreography – a notion gaining currency among designers – may help conceptualize the relationship between designers and other agents, including intelligent machines, in a co-produced environment. Interpreting contemporary landscape projects in conjunction with other cybernetic practices within a posthumanist framework may articulate a different version of cybernetic thinking, which operates beyond “controlled stability” towards a “cultivated wildness”.

7. A Critique of Dualism

To an extent, this research is on many levels a critique of binary or dualistic thinking. First, it teases out the profound paradox where we view nature and technology as conflicting categories. Indeed, despite critiques of culture-nature binary thinking issued by many postmodern scholars, contemporary environmental practices still largely rely on oppositional terms to describe intrinsically complex strategies: green/grey; hard/soft; nature-based/artificial; landscape/engineering; ecological/technological; biological/mechanical; human/nonhuman; and living/non-living. The problem of perceived boundaries between technology and nature results in unnecessary and occasionally problematic rationales that prevent us from seeing the environment as a mesh of different frameworks – some human, others not. Most importantly, the dualism between the ecological and the technological allows us to see machines only as layers of infrastructure with which humans extend control over the nonhuman realm, overlooking a version of environment laden with machine intelligence waiting to be mobilized by designers towards further indeterminacy and openness.

Many ideas, including cybernetics, appear to overcome this dualism. Cybernetic thinking bypasses the perceived division between the mechanical and the biological because cybernetics is organicism, rooted in reflections on the mechanism in science (Hui 2020). It relies on feedback and information as key concepts to analyze the self-regulating behaviors of all beings, living or nonliving, biological or technological. As a descendent of early cybernetics, systems theory provides an even more universal concept that cuts across all beings by understanding their abstracted components and relationships and ignoring their material and physical forms. Aside from systems thinking, other popular ideas such as cyborg, assemblage and actor-network all provide frameworks that may overcome the perceived dualism between biology and technology, and nature and technology. However, have we genuinely overcome dualist thinking itself?

As Hui pointed out, cybernetics, among many others, are concepts of totalization, viewing differences as a motivation towards synthesized identity (Hui 2020, 63). By constructing a universal view such as cybernetics, systems, assemblages, objects, we construct an antithetical pair on the other side of the conceptual field that is non-cybernetic, non-systemic, and non-objects. We are thus still entrapped in the dualist thinking embodied in the Hegelian logic of thesis, antithesis and synthesis (Hui 2020).

Therefore, the second aspect in critiquing dualism is to reflect on our habitual mode of thinking, which seeks to find universal explanations. It is also about learning to embrace and live with a multifaceted framework. In a way, this research reflects and critiques cybernetics, not by constructing an alternative universal frame to replace mainstream cybernetic thinking, but by providing a way to interpret cybernetic thinking in different lights, to reveal its multifaceted potential and contradicting interpretations.

8. Chapters

The above three tensions drive the chapters' initial arrangement.

Chapter One investigates the entanglement of nature and technology by asking how they became a pair of antithetical ideas in our conceptual frameworks for understanding the environment. Building on the arguments of technology historians, such as Leo Marx and Davie

Nye, Chapter One traces the origin and evolution of the narratives about nature and technology in American history. In these narratives, a specific image of the human emerged, along with a perceived relationship between human, nature, and technology: humans use technology to transform nature into habitable landscapes. This transformation formula justifies human agency in altering the environment, and technology becomes an effective means to achieve this end, amplifying and augmenting human capacity in communication and control.

To deconstruct this perceived transformation formula, Chapter One continues to trace the separate development of key ideas about nature and technology, to investigate how science and culture have been constructing and solidifying these two concepts from the twentieth century to the early twenty-first century. The fields involved include ecological science; environmental history; technology history; science, technology and society (STS); and philosophy. Charting ideas throughout the twentieth century, Chapter One concludes with the convergence of ideas about nature and technology in the twenty-first century. Both discourses have adopted some versions of posthumanist assemblage thinking. It can be described as a co-production thesis: humans and nonhumans have always co-produced with each other, and humans have always co-evolved within a network of human and nonhuman assemblages and systems, including animals, plants, machines, languages, and cultures. Most importantly, this co-productive framework does not glue together the natural and the technological by relying on concepts such as cyborg and hybridity, because determining a combination requires, in the first place, differentiation. The co-production thesis rejects that separation, and emphasizes that nature and technology are merely apt categories we deploy when we find ourselves in specific situations.

From this perspective, Chapter One offers two genealogies of thinking towards posthumanism, and addresses the first tension in the cybernetic environment by presenting a version of assemblage thinking to understand the environment. Technology and nature become ad hoc interpretive categories, rather than two kingdoms of forces justifying human agency. In addition, what we understood as human agency becomes distributive across a network of more than human assemblages. The distinction between "built environment" and "natural environment" becomes an illusory category, overshadowing the fact that the environment has always been a co-produced outcome, with more or less human and nonhuman intent in it. The environment is a meshwork of different goals, frameworks, and intentions of assemblages, within which humans occupy only a tiny fraction.

Chapter Two consists of two parts, conceptually. The first part continues to investigate the issue of agency in the co-productive framework. There are several competing posthumanist doctrines which contemporary landscape architects use to conceptualize landscape as an assemblage of different actors co-producing each other and the environment. Chapter Two contributes to this debate by comparing four major tenets in posthumanism, which provide frameworks to comprehend nonhuman agency or the nonhuman realm. They are 1) actor-network theory (ANT), 2) feminist vital materialism, 3) object-oriented ontology (OOO), and 4) ontology of machine and media.

Searching for nonhuman agency eventually leads to a realization that agency, that human concept, can never capture the nonhuman and its potential in molding the human realm. Therefore, all four tenets, except for certain versions of ANT, share a consensus of a sense of "surplus" in assemblages that cannot be reduced or accessed in any manner. The idea of "surplus" particularly distinguishes OOO from other approaches. In a way, these different doctrines all accept that human knowledge cannot fully capture assemblages, because we are confined to human ways of knowing. However, OOO completely bypasses the notion of agency, and creates a speculative ontology that focuses on the inaccessible aspects of objects.

In a way, OOO puts a positive twist on radical constructivism, which claims that all knowledge is constructed and independent of real objects. Instead, since OOO begin by accepting that things cannot be accessed all our knowledge about objects becomes some form of speculation. Then, we may freely speculate about the part beyond human access. In this way, Chapter Two addresses the second tension – perceived agency and "surplus" in objects.

Based on this speculative ontology, OOO proponents have proposed multiple techniques for speculation, including concepts such as alien phenomenology and constructing metaphors. From this vantage, we can reframe design as an important technique in speculative realism, since it allows us to reimagine relationships between beings, and reorganize different forms of ecologies.

The second part takes on the posthumanist and speculative framework to examine a specific kind of object – intelligent machines – drawing cases from research on machine learning and artificial intelligence (AI) over the past several years. Intelligence is intrinsic to the concept of agency; we assume an object needs to be intelligent to act. Many machine-learning algorithms imagine a machine as an agent that can observe and act in various environments, through cybernetic mechanisms. The machine-learning cases build connections between cybernetic thinking and how agency is conceptualized through recursive processes.

This research asks how the cybernetic environment can become a reserve for possibilities and a future which we cannot now imagine. To answer it, we must consider another question: what sort of role can intelligent machines play -- other than tools of control -- in constructing the environment? Answering this question relies on understanding not only technical capacities, but also the modes of thinking that undergird contemporary AI research. By analyzing machine-learning cases, we will elicit their inherent presumptions in understanding machines as tools of optimization that extend imagined human agency in managing the environment.

Taking on assemblage thinking, Chapter Two reconfigures the concept of intelligence within a posthumanist framework, arguing for three different types of relations -- symbiotic relations, adversarial relations, and loose coupling -- where co-productive intelligence might emerge. With this updated understanding of intelligence, we may reimagine intelligent machines not as tools, but as intelligent agents deeply involved in constructing the environment.

With this conviction, we proceed to Chapter Three, and speculate as to how intelligent machines may be used and "misused" in environmental practices; and render an alternative version of cybernetic thinking that supports a sense of speculation rather than communication and control.

Chapter Three returns to the cases presented at the beginning of this research, and expands on a body of cybernetic practices across art, engineering, and design. These projects share a common theme: they are all explorations based on cybernetic principles, yet they produce outcomes that lie outside mainstream considerations based on communication and control. Instead, many of these cybernetic practices create space between designers' intentions and co-produced reality – a sense of wildness in controlled outcomes.

Mainstream cybernetic thinking often isolates recursive mechanisms into three distinct processes: sensing, modeling, and actuating. This conceptualization is based on how information or data are generated, manipulated, and acted upon in the cybernetic system. Indeed, the sensing-computing-actuating feedback loop undergirds all modern machines and cybernetic systems, including the most cutting-edge AI algorithms, such as AlphaGo. It also provides the foundation for how a cybernetic environment may be conceptualized. We imagine a process to collect environmental data with a ubiquitous sensing regime, passing data through models and algorithms to make predictions, simulate and optimize possible control policies, and act out these policies with distributed actuators. In this way, any environment can be conceptualized as a cybernetic system to be controlled and optimized. Chapter Three presents cases in groupings based on the three distinct processes. These cases challenge the notion of sensing, modeling, and actuating, and point instead to another set of terms: *coding, choreographing,* and *attuning.*

In the end, Chapter Three maps out an alternative version of cybernetic thinking that is less about “controlled stability” than “cultivated wildness”. The concept of cultivated wildness describes a condition in which recursive cybernetic actions do not necessarily lead to deterministic outcomes, but to open-ended and divergent futures. This requires designers to embrace a sense of technodiversity in machines. First proposed by Yuk Hui, technodiversity can be understood as a counterpart to biodiversity in ecology (Hui 2020). Chapter Three develops this concept, and argues that designers need to embrace a sense of “wildness in machines” to develop strategies outside the mainstream cybernetic imagery of control and communication. By exploring the wild aspects of machines, we may speculate as to new relationships between human and nonhuman assemblages in the environment, and reimagine ecologies we have not yet conceptualized.

To conclude, this research proposes a mode of environmental thinking and practice that lives within diverse frameworks. A shared and co-produced future relies on a plurality of knowing and thinking, and those may conflict and disagree with each other. Instead of seeing difference as motivation towards a synthesized framework, a shared future requires us to learn to live with and make efforts to attune to different frameworks around us – human and nonhuman. A shared future is not about increased communication, understanding, and interconnectedness, which provide enough motivations for human control and expectations. Instead, this research suggests an ontological shift, developing a sort of cybernetic thinking, by accepting that not all beings communicate, and they are therefore uncontrollable. After all, posthumanism is very much about humans, but it is also about a sense of descent instead of progress. It is about accepting the limited mode of human knowing and thinking, and then speculating on different ways to maintain dynamic living relations with others. It is about a mode of co-existence in a non-communicative and uncontrollable wild world.

CHAPTER ONE: CO-PRODUCTION OF THE ENVIRONMENT

1. Transformation Formula and the Triad of Humans-Nature-Technology

1.1. The New Machine in the New Garden

In his seminal book *The Machine in the Garden* (1964), American historian Leo Marx rendered the image of a train whistle's long shriek disturbing the serenity of an eighteenth-century American village. Americans in the mid-19th century confronted an ugly reality brought about by machines alien to their pastoral dreams. The progressive yet destructive power symbolized by the machine was at odds with an ideal lifestyle, symbolized by the garden. Many historians like Marx have positioned two models – one on the order of nature, the other on technology – against each other.

Today, Marx's garden-machine motif takes on different manifestations. Along with the RangerBot, FarmBot, and other robots in "gardens", we find ourselves in all sorts of environments that are, at least, partly machine-constructed. For example, the Everglades restoration project in Florida is considered an exemplar of an adaptive management framework, the best practice in environmental management discourse. Adaptive management may be understood as a decision-making method through learning by doing; this approach is achieved by intensive monitoring and actuating processes. Established in 1949, the South Florida Water Management District (SFWMD) is a regional governmental agency that manages the water resources in the southern half of Florida, including the Everglades, a 1.5-million-acre wetland that sustains numerous wildlife species. This wetland is the ultimate "wilderness" in the eyes of urban residents. However, the wild Everglades is, in fact, a highly maintained area. In South Florida, numerous sensing stations have been installed across bodies of water, generating real-time hydrological and water quality data utilized to build simulation models of the water system.

The South Florida Water Management Model is one which organizations and agencies use in order to analyze operational changes to the water system, and make informed management decisions. Moreover, thousands of miles of engineered canals and pipes are carved into Florida's landscape, and water control infrastructures such as basins; spillways; weir gates; pumps; dams and locks are strategically placed along the waterways. These are the actuators within the system that directly influence hydrological patterns in South Florida (Figure 1). In a way, the amount of water and the hydrological patterns are carefully calculated and controlled, using simulation models based on real-time hydrological data, weather forecasts, climate modeling, and historical data.

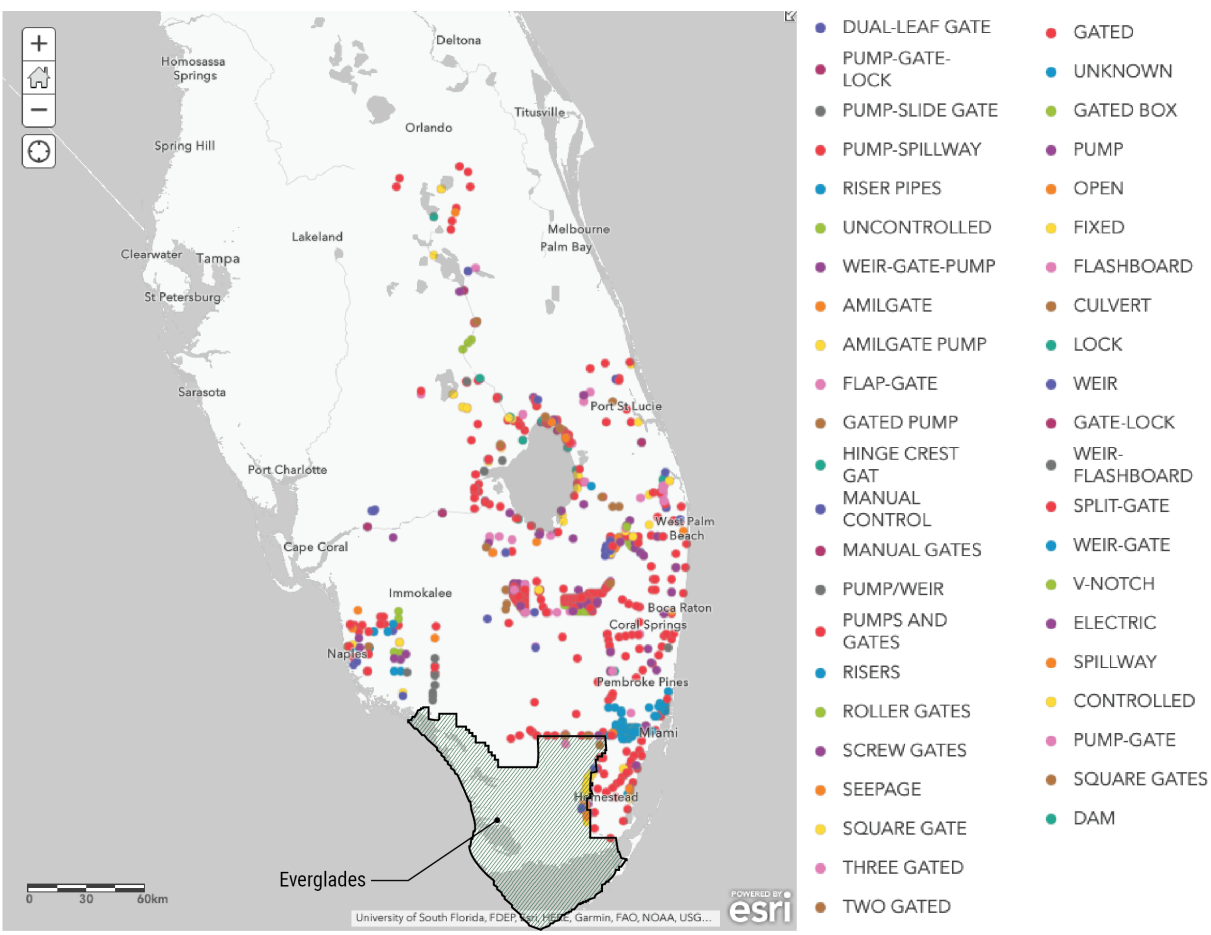

Figure 1. South Florida Water Management System.

Data source: AHED (Arc Hydro Enhanced Database), ArcGIS Online

The South Florida water management project is only one instance of numerous efforts to use cyberphysical systems to manage environmental processes which we largely consider natural. The recent discourse regarding smart cities has fueled cybernetic imagination across social sectors. Many cities are retrofitting their stormwater systems with controllable and smart actuators provided by emerging companies, such as Opti and EmNet, that specialize in live environmental monitoring and real-time control solutions. We live in a cybernetic environment in which machines become part of the environment itself, constructing what we thought to be natural.

We possess the urge to use the word "nature" to denote the *nonhuman realm,* free from artificial and technological disturbances. Yet an outdated mental model – the yearning to draw a boundary between nature and technology – cannot keep up with a reality of paradox.

Many environmental and technology historians have argued that this boundary is more apparent in our minds than in the environment, and that such a boundary is both deceptive and misleading, particularly when we pour culturally specific values into the imagined dichotomy (Reuss and Cutcliffe 2010). However, despite the intellectual critics of binary thinking, today's environmental practices are awash with dualisms, such as artificial/natural, technology/environment, and grey/green. This binary thinking gives rise to single visions in understanding what "nature" should be and what "technology" should do. For example, when the media describe the High Line in Manhattan as "wild in the city", they ignore the irony that the High Line's construction involved the destruction of a novel ecology of an abandoned railway, a habitat for other nonhuman species that did not fit within the designers' conceptualization of "nature" and "wild". If we consider climate change, many ecosystem types will disappear under the changing climate patterns, but new types will emerge. Additionally, within a framework that articulates a clear division between "technology" and "nature", we can only conceptualize emerging technologies, such as sensing networks, AI, and robotics, as tools to extend human control of “wild nature”, We are ignorant of their potential in constructing “new wilds” that cannot fit within what “nature” could capture.

1.2. A Transformation Formula

With the boundary in mind, our thinking tends to pick a convenient route, and articulate a simplified relationship within the environment: *humans use technologies to transform pristine nature and produce habitable landscapes* (Figure 2). Nature and technology are conceptualized as two kingdoms of force; the former provides limitless resources, while the latter serves as an effective means to extract resources for human use.

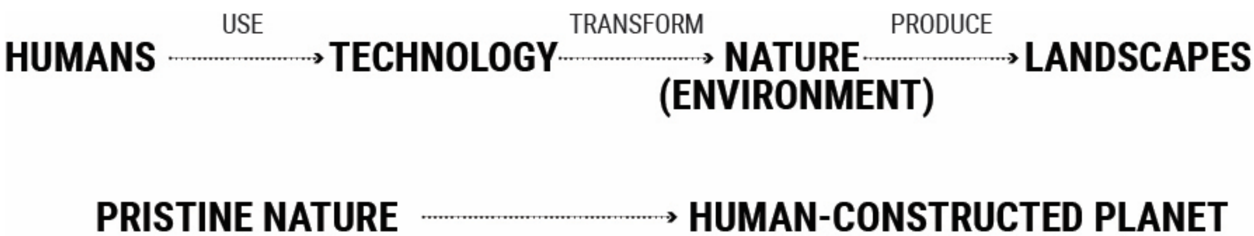

Figure 2. A Transformation Formula

Taking a closer look at this formula, we observe a series of problems, articulated in three aspects. First, it ignores nonhumans and their agency in influencing the environment in a meaningful way, thus rendering the nonhuman realm invisible. This formula places nonhumans and their habitat into a single basket labeled “nature”, and overlooks the intrinsic complexity of the nonhuman realm. For example, a family of beavers may build a dam that, on the one hand, serves as a shelter for them to hide from predators and, on the other hand, controls local hydrology to their benefit, such as improved food sources and a relatively stable environment. More importantly, the beavers’ intervention profoundly transforms and influences the local ecosystem. Beaver dams are a classic example of "niche construction" in ecology stories, where organisms alter their local environment to support their survival, just as humans construct villages and cities that provide stable environments in which we thrive. Nevertheless, within the transformation formula, a beaver family and its ability to alter the environment are generalized as "nature", subject to human use.

The second aspect is deeply related to the first. Our ignorance of the nonhuman realm is partly due to the anthropocentrism embedded in this formula, which assumes that technology is the means by which we *humans* extend our control. However, to a certain extent, a beaver dam is technology which beavers have developed to control their environment. Again, the boundary between technology and nature is challenged by reality. We would not think of beaver dams as technological artifacts or systems, because the concept of technology is built around human society. This simplistic formula essentially reinforces a single view of "technology", and denies "technodiversity".

Third, since the formula is generated from a human-centered perspective, it inevitably implies an apparent directionality, as suggested by the arrows in Figure 2. Their uni-directionality sets up an imagined origin -- an untouched, pristine nature -- and the inevitable end: a human-constructed Earth (Figure 2). The formula articulates a seemingly inescapable process of transformation, and simultaneously constructs an image of humanity as the source of agency to initiate changes by wielding technologies. Moreover, this unavoidable transformation gives rise to the moral imperatives for the conservation and preservation narratives that have arisen since the mid-twentieth century; today's mainstream environmental practices cannot succeed without first accepting the process of transformation, and then attempting to undo the wrongdoings such as environmental degradation and pollution. Green technologies are used to recover and reconstruct a "pristine nature". However, the image imposes a set of culturally specific views of nonhuman realms, as well as a limited understanding of possible relationships, causing ongoing social and political conflicts. Recent political debates have dealt with economic growth and plans to combat climate change, and disputes between the working class and environmentalists' efforts to protect nature, as well as long-term contentions between indigenous people's homelands and America's wilderness.

In summary, this transformation formula simplifies the relationship between humans, nature, and technology. Today's environmental discourse is trapped in the language of usership and stewardship. It subjugates the nonhuman realm as resources, and protects it for further human extraction, ignoring the intrinsic value of nonhumans.

The transformation formula tends to be contagious. For example, one author in *The Illusory Boundary* began by recognizing the entanglement of nature and technology, yet, in the end, argued that "[t]echnology melds together the proverbial quilt of relationships between humans and nature, and out of the process emerges landscapes" (James C. Williams 2010, 19). This quote is just one more way to articulate the transformation formula.

Moreover, we may find this formula in many contemporary environmental narratives. In a way, sustainability embodies this type of thinking, as compromise between transformation and recovery. Sustainability narratives ironically reinforce and justify the action of further exploitation of people, land, and nonhuman species, which lie outside the mainstream transformation formula and recovery narratives. Another idea is the Anthropocene, a proposed geological epoch in which human activity has become a significant factor in altering planet Earth. To a certain extent, this concept pushes the formula to an extreme: we have finished transforming pristine nature, and what is left is a human-constructed Earth. These examples illustrate how deep our language is trapped in this mode of thinking. Even though we may want to acknowledge complexity in the environment, we lack the vocabulary to discuss agency and its effects in non-categorical terms. It is not difficult to recognize the illusory boundary, but it is difficult to articulate the entanglement in reality, using the categorical terms which we want to avoid in the first place. Is there a model, and are there vocabularies and concepts other than the transformation formula, which we can use to understand the environment?

1.3. Environtech?

One approach is to deconstruct the boundary between nature and technology by unifying the two. Since the early twenty-first century, the "environtech" approach emerged when scholars in the fields of environmental history and the history of technology realized they had been studying the same historical subject. In the anthology *The Illusory Boundary*, scholars reported a convergence of two fields of study, and provided a historical account for the entanglement of nature and technology, with rich examples.[1] One essay, titled "Where Does Nature End and Culture Begin?", traced two bodies of research – environmental history and the history of technology – and argued that "[t]he trend toward a more constructionist approach to the history of technology and away from declensions narratives in environmental history, well under way by the mid-1990s, has since led to scholarship more inclined to wrestle with the messy entanglement of technology and nature" (H. S. Gorman and Mendelsohn 2010, 277). This convergence gives rise to what the authors called the "environtech" approach, which challenges a traditional nature-technology dualism in historical research by denying that "environment and technology are separable and generally opposing historical subjects" (Reuss and Cutcliffe 2010, 1).

[1] It should be noted that "nature" and "environment" were used interchangeably throughout the anthology. As noted by Raymond Williams in *Keywords* (2014), using "the environment" to denote "nature" cannot be separated from the environmental movement, since the 1960s. The anthology would run the risk of not problematizing environmentalism itself, which has been critically reflected by many in the 1990s, and is still contested ground today.

However, “environtech” possesses a significant shortcoming. Scholars unwittingly created a blind spot by imposing a disciplinary boundary on their analytical framework. To see “convergence”, one must accept an initial, imagined “separation”. The analytical framework successfully articulated how the subjects of nature and technology are entangled in reality, but fell short of explaining why they had been articulated as separate realms. This acceptance of the two established realms can be identified by noting the titles of the anthology’s essays: “Can Nature Improve Technology?”, “The City as an Artifact of Technology and the Environment”, “Where Does Nature End and Culture Begin?”. These essays ask essential questions, but deploying those terms lacks a sense of complexity, and ironically reinforces the notion that “nature” and “technology” belong to two separate realms.

“Environtech” represents a popular approach towards further dualisms in contemporary environmental discourse. Ideas such as coupling, cyborg, and hybrid, all convey a sense of combining two realms: the trend to combine “green” infrastructures with “gray” infrastructures, engineering solutions with “nature-based” solutions. Nevertheless, simply combining the two realms creates a paradox. The realization that the boundary is illusory provides an incentive to dissolve it, but when attempting to join the two kingdoms on the opposite side, one unwittingly accepts that they were separated in the first place and further articulates the boundary itself. Dissolving the boundary does not necessarily prove the boundary illusory; to argue that a boundary is illusory, one must question why the dichotomy existed in the first place. The “environtech” framework successfully revealed that there was a paradigm shift, by articulating the convergence of two fields of research. However, it fell short of illustrating what the new paradigm should look like, by ignoring why the boundary exists in the first place.

From this perspective, the anthology’s authors have tried to engage the entanglement of nature and technology, but still lack the vocabulary and conceptual frameworks to answer the critical and inspiring questions they have asked. Most importantly, by reinforcing the two realms, "environtech" created a blind spot in its analytical framework, oversimplifying, if not overlooking, another category of research represented by Marx's *The Machine in the Garden*. Unlike other technology historians, Marx was not interested in the role of technology in culture and how culture shapes it; neither was he attentive to the social aspect of nature, like many environmental historians. Marx's work should represent a body of research focused on the blind spot itself, directly asking questions as to why nature and technology have been historically articulated as two kingdoms of forces. Yet because it operates in the blind spot, its value has been overlooked within the "environtech" framework. This can be seen in how Marx's work was presented within the anthology. His work could only sit awkwardly in both environmental history and the history of technology as "rich intellectual legacies" for historians in both fields to draw upon (H. S. Gorman and Mendelsohn 2010, 275).

1.4. Co-production Thesis and the Human-Technology-Nature Triad

Instead of unifying the two kingdoms, yet ironically accepting the boundary, we could bypass this dualist thinking by remapping the relationships between the concepts of nature, technology, humanity, and landscape. Over the past few years, a body of work has emerged in environmental humanities, including fields such as environmental history, political ecology, feminist/queer/indigenous science, and technology studies to shed light on a different conceptual framework for understanding the environment. Within this model, the environment can be articulated as a result of the co-production of many different agents, including humans; machines; animals; plants; ecological processes; and land-use policies.

To bypass the transformation formula and fully embrace this co-production model, we may construct a human-nature-technology triad as an analytical framework (Figure 3). This triad represents a roadmap of the development of ideas about nature and technology in the twentieth and early twenty-first centuries. The ideas about the two concepts have gelled over time, from early simplistic and essentialist views to more complex and developmental understandings of the terms. Towards the early twenty-first century, the ideas around the two concepts eventually converged onto a co-production and co-evolution model. Each edge represents a body of work that addresses certain aspects of the evolution of ideas.

What must be highlighted is the environmentalism that expanded in the 1960s and became part of contemporary culture. Environmental values have served as an undergirding, and provided a dynamic theme, for the development of these ideas.

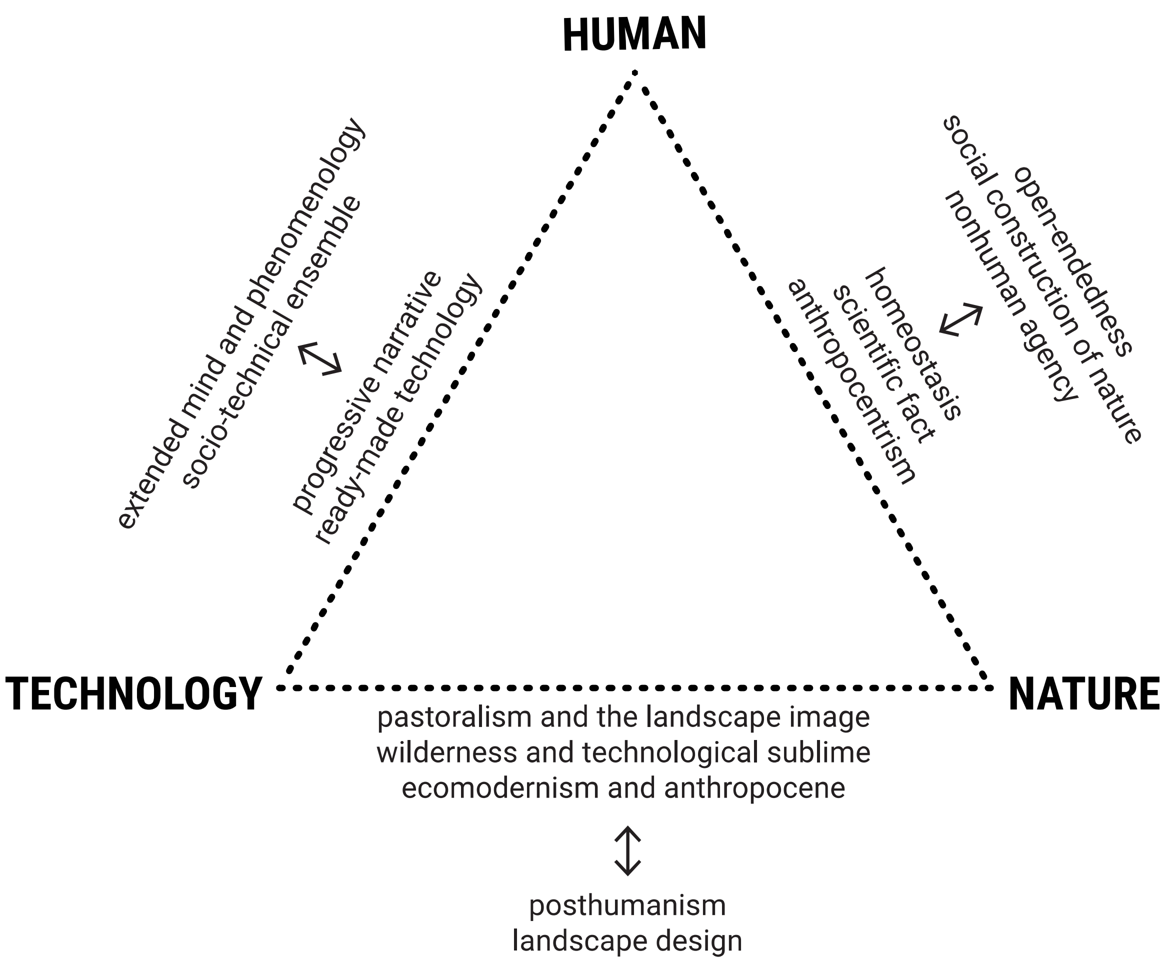

Figure 3. Human-Nature-Technology Triad

2. The First Edge: Technology-Nature

2.1. From Pastoralism to Anthropocene: Reconciling Two Kingdoms of Force

Human, nature, technology, and landscape are four elements within the transformation formula. What is the function of each element, and what are the relationships between them in the environmental narratives which we tell ourselves? Tracing the edge of nature-technology can help answer this question. Many influential historians and scholars have articulated technology and nature as two kingdoms of force, and the relationship between them can be told through narratives of reconciliation. Although this section focuses on North American narratives , the narratives' underlying structure applies to other places and times.

In America, the narratives have been constructed around three themes: *1) pastoralism and garden-machine motif, 2) wilderness and technological sublime, and3) Anthropocene and ecomodernism.* Even though certain of the ideas, such as pastoralism, date to eighteenth-century colonial America, their legacy and influence are still present. Together, these themes help form the contemporary mainstream environmental narratives.

Pastoralism and Garden Machine Motif

In a way, the conflict which many perceive between nature and technology may be generalized as a garden-machine motif, with pastoralism at its heart. Pastoralism is a sentiment across culture and time – it is the gesture of humans moving away from the "artificial" world, or "another of our many vehicles of escape from reality." (Marx 1964, 10). What is peculiar about American pastoralism is that it seeks to reconcile two kingdoms of force – nature and technology – with a second creation narrative. Early colonists used the second creation, or technological creation, narrative to weave together the concepts of nature, technology, humanity, and middle landscape. By telling stories around technological artifacts such as axes, water mills, dams, mills, and railroads, they constructed a history of America as God's nature transformed by early colonists (Nye 2003). These historical narratives "naturalized the technological transformation of the United States so that it seemed an inevitable and harmonious process leading to a second creation that was implicit in the structure of the world" (6).

Early colonists conceptualized America as an "uninhabited island", an "unspoiled terrain" for a pastoral utopia (Marx 1964). Towards the end of the eighteenth century, this pastoral ideal was formalized, fully articulated, and finally realized, thanks to Thomas Jefferson. America became a Jeffersonian yeoman's republic free from European feudal oppression, and machines played an indispensable role in this conceptualization. Jefferson believed that "the machine is a token of that liberation of the human spirit to be realized by the young American Republic…[O]nce the machine is removed from the dark, crowded, grimy cities of Europe…it will blend harmoniously into the open countryside of his native land" (150).

Pastoralism in America did not lead to the total removal of machines; instead, mechanical power was reconciled as a means to achieve a pastoral end. Jefferson "envisages it [machine power] turning mill wheels, moving ships upriver, and, all in all, helping to transform a wilderness into a society of the middle landscape" (150). Here, the image of the middle landscape is not free from machine and progressive change; on the contrary, it is "nature improved" with the help of machines, "an ideal fusion of nature with art" (228). In a sense, transformative power was rendered both harmless and necessary in early America. To introduce machines to Americans, political economist Tench Coxe (1755-1824) even had to depict machine power as "'naturally arising' like agriculture, from the divine purpose invested in the New World landscape…[and] another natural 'means of happiness' decreed by the Creator in his design of the continent" (160). Here, machine power was presented as of the same order as nature – both works of the

Creator, both necessary elements for a pastoral lifestyle. The pastoral image reconciles two sources of power in the transformation formula; thus, technology and nature find balance in the middle landscape.

If nature and technology create a balance within pastoralism, what is it that people find unsettling about this image? We need to analyze the term "landscape" and its role in reconciling the two concepts. The term landscape was not always associated with aesthetic views, and its original meaning was surprisingly akin to that of "technology". Historians note that the root of "landscape" is the German word *Landschaft,* which emerged in 1121 to refer to the inhabitants of a legally defined zone. The term, in its original sense, was therefore tightly coupled with the people working on the land. Only later was the term linked to landscape painting, in the sixteenth century; by the eighteenth century, it was fully integrated into the vocabulary of aesthetics (Nye 1999). The flourishing of landscape painting aestheticized and romanticized both land and labor. Of course, to understand landscape through vision cannot be separated from Western subject-object relationships, with the rise of science. Landscape "will always presume the *exteriority of the spectator*" (Jullien 2018, 9). To conceptualize landscape also means to create observers. When observers see a landscape painting, as outsiders who do not work the land, they tend to naturalize those who work and make the landscape, as part of the view. Labor is rendered harmonious with its natural setting, and is part of the serenity. Where labor was aestheticized, landscape "had lost its associations with work or with direct involvement in the creation of social space" (Nye 1999, 14). Landscape is reduced to a static view that freezes time and renders an everlasting image of happiness.

One caveat is that here, *landscape* refers to what was portrayed as a cultural practice, instead of the specific usage of the term in the discipline of landscape architecture. Theory and practice in contemporary landscape architecture have already bypassed the common myth that *landscape* denotes beautiful views. Many landscape architects use the term to denote complex evolving systems that may give rise to emergent forms and relations. The usage of *landscape* in the discipline is akin to the original meaning of *Landschaft* in the 12th century. Unfortunately, this specific usage does not transcend the discipline. For most people, the term *landscape* remains attached to aesthetically pleasing images tied to culturally specific values and norms.

In the transformation formula, images of the middle landscape served as an index of a pastoral lifestyle . A landscape image effectively articulates “pastoralism” by rendering vivid views in one’s mind. The term “pastoral” would instantly evoke mental images: green, rural, a house at a distance with woods in the background. Images of landscapes helped people visualize complex ideas, such as pastoralism, and, more importantly, they built a shared mental model for people to communicate these complicated ideas without words. The landscape image creates a contrast between good and bad, thus setting up the basis for moral imperatives for transformation efforts. Images of landscapes bond people together, and empower those working towards “a good life”. If the images of crowded eighteenth-century European cities symbolize outdated values embodied in feudalism, then the images of a green and rural middle landscape represent an idealized lifestyle of a yeomen’s republic, in which independent farmers form the basis of republican values. These images become at once a goal and an end, calling for effective means to achieve them.

However, the “green, rural image” also planted the seeds for a deceptive stability, and the aestheticized landscape grew fragile against rising technological power. Jefferson did not envision that new mechanical power would strive against his pastoral ideal, because technology as a concept to denote an agent of change did not exist until the early twentieth century. When unprecedented human power eventually created a semantic void in society, technology became a concept that aptly filled the gap (Marx 2010). In Jefferson’s time, people saw little agency in machines. Instead, for Jefferson and other early thinkers, the forces of nature and machine power were envisioned as existing in a balanced equilibrium. However, new progressive powers would rise to disturb the imagined stability, and there was a profound disconnect between the pastoral ideal and Americans' lived reality. In the early twentieth century, technology gradually became a concept to index the unprecedented human power that can initiate social change, and "the aestheticized idea of landscape, as being any attractive view, could easily seem to be the opposite of all that industrialization stood for" (Nye 1999, 15). The progressive power of technology challenges the shared landscape images in people's minds, which picture a static and homogeneous good life.

Nye argues that four assumptions undergird the second-creation narrative, and demonstrate different aspects of stability in the middle landscape. Yet people's lived reality constantly challenges these assumptions and the imagined equilibrium. This conflict is what Marx calls a garden-machine motif. First, the Jeffersonian grid system for distributing the American Midwest landscapes assumed a homogeneous middle landscape made up of reliant parts; apparently limitless land was thus open to new people and machine power. Nevertheless, the unevenness of the grided landscape was hardly egalitarian, after all, and carried many stories of failed farmers. Second, the laissez-faire free market laid an economic foundation for a yeoman's republic free from European influence; though, in reality, a few select parties controlled limited resources, causing economic inequality. Third, the illusion of natural abundance provided seemingly inexhaustible resources waiting to be transformed. Yet environmental degradation, as occurred during the Dust Bowl years, as well as water and air pollution, proved that natural abundance was a false belief. Fourth, Newtonian physics set no limit to mechanical power. Yet the developments in thermodynamics, and the concept of entropy, in the early twentieth century made it clear that gaining utility and efficiency mirrored costs in energy, and mechanical power was, after all, limited. By the early twentieth century, the foundation of the second creation narrative collapsed upon these lived realities, and the stories of transforming nature into pastoral dreams became a national origin myth (Nye 2003).

To summarize, in America, an important aspect about the perceived conflict between nature and technology is a repeating theme of garden-machine motif. The aestheticized idea of landscape maintains the transformation formula intact by rendering an image of happiness, which functions both as a moral imperative and a reassurance that compels people to follow this simple formula, so that they achieve a good life. This image evokes a goal and an end, which call for any means to achieve them. However, in fixing on this pastoral model, circumstances will inevitably arise to undermine any plans of action, creating conflicting images. Because an aestheticized landscape freezes time, anything not included in this image becomes a threat. To a certain extent, landscape bound the transformation formula together, but, at the same time, planted the seeds of instability; whoever embarked on this formula was doomed to confront and reconcile its embedded tension, to wrestle with the garden-machine motif itself.

Most importantly, in the image of pastoral landscape, specific figures of humanity– European colonists – were rendered as the sole sources of agency. As storytellers, colonists portrayed America as a new frontier, a nature's garden, an ultimate wilderness, the Creator's work – and they as the wielders of technology, sent to conquer and transform it. However, America was also home to the indigenous people who, over millennia, inhabited the land and transformed it with their own "technologies".[2] Another important aspect, which many historians tend to overlook, is that an aestheticized landscape generalizes the internal complexity of the

[2] Ironically, calling the early inhabitants "Native American" may suggests another problematic reasoning: that they are "nature" and we are "culture", as if they "naturally" occurred on this land, and are part of nature. In fact, this type of reasoning appeared in much of early colonists' literature, according to Marx.

nonhuman realm. When people say “landscape”, they are talking about other living things. Rendering lands as pleasing and calm images obscures the fact that they are also produced by and home to many nonhuman species, working and investing labor into the land. The real scene is chaotic, busy, and vibrant, rather than the serenity depicted in landscape paintings. The nonhuman realm and its agency simply existed outside the conceptual frameworks that underpin pastoralism.

Despite decades of criticism, pastoralism persists; it manifests in new stories, and is intertwined with racism, white nationalism, and classism. If pastoralism is a form of escapism, and America is a retreat from 18th-century Europe, then suburbanization in post-war America was an escape within an escape. Streetcars and automobiles facilitated suburban development, and the middle landscape began to render another image: clean-cut lawns with single-family houses, located just outside busy cities. In July 2020, the Trump administration repealed President Obama’s Affirmatively Furthering Fair Housing Rule (AFFH), intended to combat housing discrimination on the basis that the Rule would force the construction of low-income homes in suburban areas. Despite the misinterpretation of the AFFH, there is clear pastoralism in the President’s narrative:

> “I am happy to inform all of the people living their *Suburban Lifestyle Dream* that you will no longer be *bothered* or financially *hurt* by having low income housing built in your neighborhood... Your housing prices will go up based on the market, and crime will go down. I have rescinded the Obama-Biden AFFH Rule. Enjoy!” (Twitter @realDonaldTrump, Jul 29, 2020, emphasize added).

The garden-machine motif takes on new manifestations in the contemporary world. In a way, the “not-in-my-backyard” (NIMBY) syndrome is yet another present-day manifestation of the garden-machine motif. The garden-machine motif’s repetition in environmental narratives indicates that Americans must perpetually confront the discontinuity between reality and the ideal mental model. As Marx argues, “it (the garden-machine motif) is the germ. . . of the most final of all generalizations about America” (Marx 1964, 353).

Wilderness and Technological Sublime

In the early twentieth century, to balance out progressive industrialized reality and environmental degradation, *wilderness* was summoned as a concept on the line of nature to maintain the perceived balance between the two kingdoms of forces. Since the mid-twentieth century, conservation groups such as Sierra Club and The Wilderness Society have become primary advocates for protecting American wild places, by, for example, ensuring the passage of the Wilderness Act in 1964. Wilderness, as defined by the Act, is

> “an area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which (1) generally appears to have been affected primarily by the forces of nature, with the imprint of [hu]man’s work substantially unnoticeable; (2) has outstanding opportunities for solitude or a primitive and unconfined type of recreation…and (4) may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value.” (The Wilderness Act 1964)

The concept of wilderness has two effects on the transformation formula. On the one hand, using the terms “primeval” and “primitive” freezes a prehistorical time as the starting point, based on which humans may make “improvements” to these “natural conditions”. It veils a process of shifting baselines, in that the conservationists saw wildness in the places where many early colonists settled, and the colonists saw wildness in the lands where, for millennia,, indigenous tribes had lived and made transformations. Moreover, from the perspective of nonhuman species, there is nothing wild about “wilderness”, since it is their home. This criticism does not underestimate preservation and conservation efforts, because the unstated agenda to protect the nonhuman habitat essentially became a political goal, even though the incentives – scientific, educational, scenic, or historical values – had nothing to do with the intrinsic values of the nonhuman species. The concept of wilderness reinforced the “pristine” state of nature by not only articulating an imagined origin, but also excluding from the wildness narrative multiple generations of humans and nonhumans.

On the other hand, within the narrative of wilderness, human habitation – or the middle landscape – is assumed to be an improvement. The term “improvement” implies a need to transform nature through technologies. In other words, the wilderness image provides a baseline against which progress in the second creation stories can be measured and justified (Nye 2003). “Improvement” imposes value on the action of transforming, so that the formula itself remains morally intact and compels people to act.

Wilderness in America is more than an idea; it is an ideology. In his (in)famous essay “The Trouble with Wilderness”, environmental historian William Cronon (1995) traces the development of wilderness in America, arguing that this wilderness came to embody a sheaf of moral values and cultural symbols deeply rooted in Judeo-Christian traditions, as well as in narratives of escapism, romanticism, primitivism, and nationalism. Wild places become icons for religious redemption and national renewal, and these associations have fueled the moral imperatives for the many conservation and preservation efforts of the end of the twentieth century. With such a notion of wilderness, early reconciliation narratives are replaced by a preservation and conservation narrative. As Cronon notes, “the modern environmental movement is itself a grandchild of romanticism and post-frontier ideology, which is why it is no accident that so much environmentalist discourse takes its bearings from the wilderness these intellectual movements helped create” (Cronon 1995, 72).

A contemporary manifestation of the conflict between wilderness and technology is the discourse of the urban wild. Today’s environmental discourse, including urban and landscape design, is awash with claims to reconstruct wild places in cities. A city, as a technology artifact and system, represents ultimate order and human control. To conserve wild places in an urban environment thus creates an extreme contrast between “nature” and “technology”. As a descendant of wilderness ideology, urban wild discourse imposes a static and singular vision; it is based on a wilderness image of a lack of human inhabitation and disturbance. This narrow conceptualization of wild places, 1) constructs a monotonous view that eliminates different perspectives, 2) freezes time and denies emergent ecologies, and 3) sets up false dualisms and overlooks the complexity of urban environments.

First, urban wilds evoke a specific image of a dearth of human presence, or the opposite of home. However, what we refer to as wilderness may be home for others. In America, the establishment of national parks, many of which embody a sense of wilderness, involved the removal of indigenous people from their homelands. When conservationists tried to protect the Amazon rainforest as a section of wilderness, they ignored the indigenous groups who had for millennia inhabited and managed the forest. When the media described the High Line as “wild in the city”, they overlooked the irony that construction of the High Line led to destruction of a novel ecology of an abandoned railway, which is habitat for nonhuman species that fail to fit within the designers’ category of wild. Today’s urban wild discourse reinforces a narrow view of urban wild, based on a specific perspective from urban dwellers, ignoring other perspectives on “wildness” and how it may be interpreted and defined.

Second, wilderness freezes time, and ignores evolution and emergence. The narratives of wilderness often imagine a time before human interventions, and attribute moral values to that time frame; environmentalists would attempt to restore places based on an ideal image, when that image is, in fact, only a fraction of a continuous unfolding of ecosystems. Contemporary landscape theory and practices have widely acknowledged that physical landscapes are never static, but are forever a “shifting mosaic”, a pattern of “sporadic, repeated emergences and disappearances of different ecosystem types” (Hill 2015, 146). If we consider climate change, many ecosystem types will disappear, but new types will emerge. Discourse regarding intensively maintained "wild places”, such as the High Line, leaves no room for these new types of wildness.

Third, and most importantly, wilderness enlarged the false dichotomy between human versus nature -- a home here, a wild place out there. As Cronon argues towards the end of his essay, this dualism entices us to focus on protecting a distanced wild “nature”, but overlook the “wildness” within and around us. As a result, environmental strategies can be conceptualized only as preservation, conservation, and restoration efforts, building “natural sceneries” that look like unmanaged places to erase traces of artificiality, and protecting “leftover” places in urbanization processes as if they were isolated systems without human influence.

In a sense, preservation and conservation of wild places reflect society’s urge to rebuild an imagined equilibrium. If technology becomes the symbol of progress, then wilderness represents the existence of a “pristine nature” where people find reassurance. This may be the deepest moral imperative for contemporary urban wild discourse – to find reassurance in seeing wildlife in urban environments. However, wilderness, as a concept to balance the progressive power of technology and maintain an equilibrium, ironically enlarged the gap between the two kingdoms of force. The garden-machine motif escalated into a confrontation between technology and wilderness -- the two opposing ends on a conceptual spectrum of structure and randomness.

Charting the technological history of America, David Nye (1994) declares that sublimity found a way to reconcile the two extremes. Sublime is a category of aesthetic experience cultivated by Enlightenment philosophers such as Edmund Burke, Immanuel Kant, and others. Despite the nuances between different conceptualizations, sublime points to the sort of emotion experienced when humans encounter “extreme magnitude or vastness” or when we contemplate “scenes that arouse terror” but are safe from danger (Nye 1994, 7). As a philosophical object of inquiry, it explains human reasoning. Kant believed that sublime lies in the experience where humans are presented with the magnificence of nature, while still being able to comprehend it with reason and cognitive powers. As opposed to beauty, which can be understood by everyone, sublime belongs to those who possess both strong sensibility and rationality. Natural scenery or events have always served as examples of objects that help philosophers conceptualize sublime. Natural scenery and wild places such as the Grand Canyon, Niagara Falls, and Yosemite, as well as natural disasters such as volcanic eruptions, all belong to the category of sublime.

Though sublime began as a philosophical idea and an aesthetic inquiry, the American sublime became a cultural practice mixed with religion, nationalism, and technology (Nye 1994). Curiously, people have discovered sublime not only in wild nature, but also in large-scale technological artifacts and systems such as the Hoover Dam; the Golden Gate Bridge; railroads; the telegraph; skyscrapers; and the Apollo Project. These sublime events were meant to be experienced by masses of people because “[o]ne of the most powerful human emotions, when experienced by large groups, the sublime can weld society together” (Nye 1994, xiii). In America, sublime is less about human self-cultivation in philosophers’ terms, and addresses more the functions of the human emotions of amazement and awe, in a cultural context. It "transformed the individual's experience of immensity and awe into a belief in national greatness" (43). To some extent, sublime functions akin to pastoralism, in terms of reconciling nature and technology. While pastoralism mixes nature and technology in the same category as the "natural" cause for the middle landscape, sublimity unifies nature and technology as a source of national pride. "New technologies become self-justifying parts of a national destiny, just as the natural sublime once undergirded the rhetoric of manifest destiny" (282). [3]

The landscape image and its ability to reduce complex ideas into vivid mental models played an essential role in wilderness and sublimity narratives. Landscape paintings and photographs of wild places freeze a series of iconic views; they teach people the "proper" way to view the wilderness. When we speak of Yosemite, we automatically think of the images of the landscape painter Albert Bierstadt (1830-1902), and the default wallpaper on a Macintosh computer. Curiously, the view of technological artifacts is depicted like natural scenery -- the image of the Golden Gate Bridge in San Francisco, for example (Figure 4). For the American sublime, the landscapes of nature and technology belong to the same category, as long as they evoke the same types of emotional reaction. Nature and technology are two essential elements, and a landscape image is the vehicle to deliver complex ideas; in this fashion, the fundamental structure of pastoralism finds a way into American sublimity.

[3] Sublimity in patriotism and nationalism is ubiquitous. On example is China's Three Gorges Dam, begun in 1994 and fully finished in 2012. Even today, the media is awash with narratives about this construction, the largest hydrological project in the world; it is a nation's pride, despite numerous ecological, social, and environmental debates. As tourists experience the dam's immensity, the feeling of sublimity is at the same time intertwined with deep feelings of love, devotion, and attachment to the nation-state, amplified through patriotic narratives found at the tourist site and in the media.

Figure 4. Landscape Images and Sublime.

The mesh of sublime, nature, technology, landscape, and nationalism has resulted in a complex and peculiar phenomenon. As reported by Nye, many visitors to the Grand Canyon audibly wonder if the canyon is a product of the New Deal's dam-building programs, or if it was built by Native Americans. Then they wonder what tools these people used to produce such magnificence. Other visitors wanted more "improvements", such as light shows, elevators, and luxury hotels at the canyon's bottom (Nye 1994, 289). Yet the Grand Canyon was already in "improved" condition, considering all its attached infrastructure, such as the roads providing visitor access. The omnipresence of humanity automatically compels people to consider improvements when they see an image devoid of human presence. At work here is the embedded moral imperative in the transformation formula, by which, as humans, we are obligated to "improve" the environment in our favor; in the case of the Grand Canyon, to better consume natural scenery as a commodity. As long as humans benefit from the result, the categories of nature and technology no longer matter.

Narratives around wilderness and sublimity reveal a human image. Consequently, there is no wilderness alone, but "wilderness for". The concept itself creates an observer and an outsider. Yet when we speak of enjoying the great outdoors, it is, in fact, a small fraction of us – middle-class urban residents with the leisure and privilege to drive outdoors – that can enjoy the "wilderness" out there. Sublime is how observers process their emotional reactions towards whatever they perceive as wild and alien. In essence, the Kantian sublime was an object of inquiry for human reasoning, but this image of the human -- "enlightened European man" -- is an essentialist definition based on strong rationality and cognitive powers.[4] The American technological sublime is fundamentally a testimony to human agency, and a celebration of those who wield technology to transform nature.

Anthropocene, Half-Earth, Ecomodernism, and Green Technology

Sublimity cannot veil the darker side of technological development. Confronting atomic bombs, "Americans first glimpsed the death-world that the technological sublime might portend" (Nye 1994, 209). The water and air pollution that led to strong environmental policies in the 1960s reflected the common belief that environmental degradation was the direct, inevitable result of industrialization and technological progress. By the 1960s, scholars from many disciplines critiqued society's choices regarding technological development, and relationships between society and technology have gradually became an important discourse, eventually institutionalized as a subject of study. Examples include the founding of the Society of History of Technology in 1958, as well as the establishment of interdisciplinary programs across universities under the banners of Science Technology and Society (STS), Science and Technology Studies (S&TS), and Sociology of Scientific Knowledge (SSK) in the 1960s and 1970s.[5] Most of these were empirically based studies analyzing the complexity of socio-technological networks.[6] These disciplinary inquires have provided various models with which to conceptualize society's relationship with technology; towards the late 1980s, there was a growing emphasis on understanding that technical artifacts and systems are socially constructed (H. S. Gorman and Mendelsohn 2010).

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[4]

[5] These different titles will be referred to as STS from now on, unless otherwise specified.

[6] Later sections will delve into STS in greater detail. For now, we will focus on the narratives between nature and technology in these studies.

Even though nature or the environment is not, in most cases, at the center of STS analysis, we can observe a clear involvement. One example was the influential anthology *The Social Construction of Technological Systems* (1987). The ideas developed in that anthology, such as actor-network theory (ANT), found their ways outside the discipline, and proliferated in the twenty-first-century discourse of posthumanism and political ecologies. Many writers use ANT as a conceptual framework to understand nonhuman realms and nonhuman agency, such as *Tree Cultures* (2002). In a way, STS has become a supra-disciplinary method and an important lens for analysis in contemporary academics, providing vocabularies and frameworks to consider the entanglement of nature and technology.

However, present-day environmental narratives tend to simplify the relationship between nature and technology, despite scholarly criticism on the dualisms of nature and technology. Many modern narratives rely on the notion of Anthropocene, the proposed geological epoch used to denote a human-constructed Earth (Crutzen 2002; Ellis 2015; Steffen, Crutzen, and McNeill 2007; Steffen, Broadgate, et al. 2015). Humans become major geological factors in shaping Earth's biosphere. A 1990s study has found traces of lead from Greek and Roman times in ice cores taken from Greenland, suggesting that ancient lead and silver mining, and smelting activities, polluted the middle troposphere of the Northern Hemisphere on a hemispheric scale two millennia ago (Hong et al. 1994). As of 2020, the global anthropogenic mass surpasses all global living biomass (Elhacham et al. 2020). Thus, we are literally living on a human-made planet.

The Anthropocene's message is clear: What a mess we humans have made of Earth! To state bluntly that humans have become the major factor in shaping Earth would generate great incentives to mobilize different social sectors in response to the environmental crisis. Under the pressure of the idea that humans have shaped the environment on a planetary scale, narratives between technology and nature have emerged. They can be generalized as inhabiting two positions, based on their sentiment towards machines and technological systems; we may call them "downscaling" and "upscaling" approaches.

In the downscaling narratives, one ambitious proposal is the Half-Earth movement. First proposed as "Nature Needs Half" by Harvey Locke (2014), then "Half Earth" by E.O. Wilson (2016), with further development by Dinerstein et al. (2017), this conservation effort seeks to set aside half of Earth's terrestrial biosphere as a conservation reserve. A similar idea is the concept of planetary boundaries (Rockström et al. 2009; Steffen, Richardson, et al. 2015) proposed by system and environmental scientists. The intention is to set up system-process boundaries to limit human activities, since scientists believe that transgressing the boundaries would lead to non-linear and abrupt environmental change. Both ideas, one arguing for setting limits on the human realm, the other insisting on setting aside half of the planet for "nature", are based on a similar sentiment regarding human comprehension and abilities in science and technological development. Underlying this sentiment is a conviction that "nature" is a system too complex to be comprehended by the human mind, and thus we had better let it be. To a certain extent, we may understand ideas such as Half-Earth and planetary boundaries as present-day continuations of wilderness narratives concerning the role of technology in the environment, seeing modern technological systems and modernization as the causes of environmental degradation.

In contrast, with the downscaling narratives, a different approach has formed along the line of the Anthropocene. The argument goes like this: Since humans have become the major factor in shaping the planet, we should then take extra care of it by actively constructing a good Anthropogenic planet. This view does not seek to separate humans from nature; rather, it stems from growing ecological and philosophical reasonings that humans have always been part of “nature”, and human factors are an intrinsic part of ecosystems. Moreover, underpinning the “upscaling” narratives is the challenge to present-day ecological and sustainable ideologies, with contemporary technological reality and ethical predicaments. In a sense, the world population relies on intensive technological systems to survive. It is unrealistic to retreat to earlier technologies, traditional organic farming, or dependence on harvesting biomass for energy; to teach people ecology in that way is “pedagogical malpractice” (Ellis 2015). Instead, the upscaling narratives seek to influence a paradigm shift: from “natural systems with humans disturbing them” to a new paradigm of “societies sustaining an anthropogenic biosphere” (Ellis 2015). This line of reasoning further develops into what is known as ecomodernism. This is an environmental idea that encompasses contemporary mainstream environmental discourse, which is awash with environmental protection and recovery narratives. It believes in “humanity’s extraordinary powers in service of creating a good Anthropocene”(“An Ecomodernist Manifesto” n.d.). What distinguishes ecomodernists from half-Earth proponents is that the former believe that protecting only half of Earth is “not nearly enough”, and is only the beginning of a more integral human enterprise to conserve biodiversity (Ellis 2019). A similar view is the Earth Systems Engineering and Management (ESEM) approach (Allenby 2005). This involves an application of systems thinking on a planetary scale, understanding Earth as coupled human-nature systems -- a product of human design. Rather than assuming a high degree of knowledge and certainty about environmental systems, ESEM will be in constant dialogue with them through an adaptive management framework (see 5.3 in this chapter).

Of course, there is no clean cut in the myriads of present-day environmental narratives. They are combinations of upscaling and downscaling narratives as two major ingredients, mixed with all sorts of moral imperatives.

However, a common thread is that “green and sustainable technologies” are envisioned as necessary means for human survival in the Anthropocene. These narratives use the catch-all term “green” and “sustainable” to infuse technology with complex environmental values. By alleviating, or even eradicating, its perceived conflicts with nature, the notion of “green technology” reassures users regarding the need for technology to maintain the middle landscape image; not only can technology construct middle landscapes, but it can also decouple human impact from extrinsic “nature”, by creating a more efficient human realm.

All these views surrounding “green technology” reinforce the second creation narrative by promoting recovery narratives. They reflect a mainstream belief in which wrongdoings in the transformation process may be undone. From this vantage, no fundamental difference exists between contemporary environmental narratives and the arguments advanced by early thinkers such as Thomas Jefferson and Tench Coxe, who also viewed technological power as “natural means of happiness”. Despite updated concepts such as Anthropocene and Earth systems, the underlying premise, shockingly, remains the same. Pastoralism and the basic structure of the transformation formula persist.

The darker side of green technology and recovery narratives is the conflict between local and global, or a tunnel vision of the NIMBY syndrome. In recent years, smart technologies have become yet another transformative force integrated into the green technology narrative. Proponents of smart cities imagine digitally networked infrastructures as a cure to a plethora of environmental problems, by inserting sensors and chips into every object to form an internet of things (IOT). Consider the following narrative from Google’s smart city incubator, Sidewalk Labs:

> "Growing cities face many challenges, from climate change to soaring rent. Urban innovations in design and technology can help … Sidewalk Labs is an urban innovation company working to make cities more sustainable…."[7]

Innovation and technological development narratives combine with sustainable incentives to solve environmental crises, such as climate change. Narratives like this one give the impression that if urban infrastructures are increasingly connected by digital technologies, urban systems can function more efficiently and sustainably, and thus the environmental crisis can be solved. What has been reinforced is another means-end reasoning between nature and technology: green and smart technologies are allegedly an effective means toward the achievement of a sustainable future. Gradually, the development of smart and green technologies becomes the end, a metric that measures our progress in fighting for environmental health.

However, tracing the global material flow of digital technology reveals a disturbing fact. Coltan, or columbite-tantalum ore, which contains tantalum, is used to make capacitors essential in smart technologies. In the early 2000s, coltan mining in the Democratic Republic of Congo (DRC) was repeatedly criticized for its systematic exploitation of the local environment and people. Smart technologies that play an important role in today's sustainability narratives are very likely built with tantalum (in places, hand-mined) in regions that do not fit within the sustainability category. Our sustainability narratives are likely built on other's disasters (Kaika 2018). Electric cars, often branded as gestures towards eco-friendly and emission-free lifestyles, provide a beautiful façade that hides an ugly reality: electricity used to charge their batteries still needs to be generated somewhere else, probably by burning fossil fuels. In addition, their used lithium-ion batteries end up in landfills (Gonçalves 2018). Behind the complex climate and environmental models running on supercomputers is a vast amount of

[7] https://www.sidewalklabs.com/

energy consumption (Czarnul, Proficz, and Krzywaniak 2019), which is either ignored or simply treat it as an essential and inevitable cost in the name of science. What is being exploited are people, places, and numerous nonhuman species, all of which exist outside the recovery narratives built around green technology.

With regard to the idea of Anthropocene, one can reach a radical conclusion: as humans, we have always lived in an anthropogenic biosphere, and what we believed and conceptualized to be nature was fashioned by those who came before us. This approach posits that humans actively construct concepts and knowledge of the world, including that of nature. When humans began to conceptualize “nature”, nature had already experienced human touch. As a result, one can argue either that there was no nature at all, or that nature was not only conceptually but also physically constructed by humans. Either way, this recursive thinking does not stop one from imagining a pristine state, before humans entered the stage. If “nature” denotes a prehistoric time, Anthropocene is just one extreme condition of the transformation formula; humans have finished the transformation process, and no “nature” is left. The idea of Anthropocene relies on and, in turn, reinforces the transformation formula by articulating a naturalized human history of how this transformation has occurred. It provides not only a starting point, but an endpoint, as well. It associates time with minimum and maximum conditions, and presents an inevitable environmental history.

Moreover, by conceptualizing Anthropocene, a specific human image was reinforced: those who could wield progressive power and possessed enough privilege to view themselves as the source of agency. Yet this obscures the identities of those truly responsible for the environmental crises, by deploying the concept of humans to encompass the entire human species. Thus, many scholars entertain the idea of *Capitalocene* as a way to the capitalist system, which compels humans to treat the environment as an enormous resource.[8] The system of capital permits manipulation of the environment and material flow on a global scale, such as the building of infrastructure for mining oil and natural gas, in addition to transporting them to places that have purchased them. On the other hand, it overlooks the complexity and agency of the nonhuman realm. Humans may be major environmental factor; however, this does not mean that humans are the only species that can construct and influence the environment in meaningful ways. Many types of "nature" have survived and thrived after the nuclear disasters in Chernobyl and Fukushima (Deryabina et al. 2015; Lyons et al. 2020), mutating, evolving, and slowly transforming these post-apocalyptic exclusion zones into new forms of wild places. To use Cronon's words, "To think ourselves capable of causing 'the end of nature' is an act of great hubris, for it means forgetting the wildness that dwells everywhere within and around us" (Cronon 1995a, 89).

2.2. The Predicament of Counter-Narratives

Tracing these three themes, it is clear that nature and technology symbolize two contrasting sets of values. Technology represents progressive, transformative, and sometimes destructive power; nature implies abundance, resources, and the power to cleanse. To reconcile nature and technology is to build narratives that merge the two opposing sides and neutralize their perceived conflict. Pastoralism, sublimity, ecomodernism, and Anthropocene have become popular themes with which to relate stories of the interplay of nature and technology in modern and contemporary environmental narratives.

Nye (2003) argues that the dynamic themes between nature and technology in America can be generalized into three interlocking narratives: 1) second creation narrative, 2) wilderness

[8] Capitalocene was popularized by Donna Haraway and environmental historian Jason Moore, who learned the term at a seminar in 2009 in Lund, Sweden, when then-graduate student Andreas Malm first proposed the term.

origin, and 3) recovery narrative. Nye argues that these narratives support each other and have become mainstream beliefs in American culture. Specifically, the second creation narrative began the story of technological transformation: natural abundance and increasing access to transformative power helped early colonists to realize a pastoral ideal in the middle landscape. When this narrative was challenged by environmental reality such as environmental degradation and environmental injustice, people built two more narratives to support the story of transformation. The recovery narrative promises that wrongdoings in the process of transformation may be undone; whereas the wilderness origin presents a mythical baseline against which the achievements of the second creation may be measured and justified. Together, these three interlocking narratives represent the mainstream belief of the dynamic relationship between nature and technology that undergirds all sorts of contemporary environmental narratives (Nye 2003).

Although the body of work presented in this section primarily focuses on cases in the American context, it reveals a basic structure between humans, nature, technology, and landscape, and illustrates how the transformation formula functions. Four elements can index different aspects and events in different times and locations: a stable equilibrium (aestheticized landscape image); an imagined origin (nature); a progressive power (technology); and, most importantly, the agents who wield the progressive power and exercise their transformative agency. A well-established relationship exists between these elements: those who use progressive power can initiate change to either transform the origin or recover the origin to maintain an imagined equilibrium. The origin provides a baseline with which to measure progress, and also creates an image for recovery efforts. These four elements reinforce each other through environmental narratives, and form a source from which all sorts of moral imperatives are generated. This is a full cycle of the transformation formula, within which contemporary mainstream environmental narratives are trapped.

There have been numerous critical reflections of the mainstream rhetoric. For example, as Nye (2003) notes, each mainstream narrative is countered by narratives that unearth an entirely different environmental history. These stories include nonhuman species, failed farmers, and indigenous people in the second creation, in addition to human and nonhuman inhabitants in the perceived wilderness, as well as the stories of the workers whose lives are set against ecological concerns. Unlike mainstream narratives that justify each other and form an interlocking history, the counter-narratives are disconnected and sporadic, and fail to form a coherent voice to challenge the mainstream belief (Nye 2003). Moreover, to abandon the mainstream narratives means “recognizing historical injustices to the first inhabitants, accepting environmental limits…[and] the loss of white entitlement to the continent” (294).

Recent years have seen numerous efforts to challenge American mainstream environmental narratives. For example, on the website of The Wilderness Society, the organization recognizes “diversity, equity, and inclusion” and seeks to “respectfully and authentically engage and empower communities that have been historically marginalized in the conservation movement or have not equitably benefitted from our public lands.”[9] Similarly, equity, inclusion, and justice have become key agendas and principles for the Sierra Club.[10] These efforts must be praised for their recognition of parallel histories along with the mainstream wilderness narrative. At least these efforts, to some degree, have recognized that the concept of wilderness was developed to favor a small fraction of humanity. However, underlying this inclusion narrative is an unchallenged conception that we should “enjoy” and “use” the nonhuman realm as a

[9] https://www.wilderness.org/news/article/our-commitment-diversity-equity-and-inclusion#

[10] https://www.sierraclub.org/equity

resource. Nonhumans and their intrinsic value still lie outside contemporary wilderness stories. To a certain extent, one must discard the conception of wilderness to truly embrace the wildness of the nonhuman realm.

Another example is the increased popularity since 2018 of the land acknowledgment movement among U.S. universities and non-profit organizations. Land acknowledgment, or land recognition, is a formal, vocal statement at the beginning of events and activities, to recognize and respect the ongoing relationship between indigenous people and the land. Many argue that acknowledgment is the first step towards social and environmental justice for indigenous people and their culture. However, associated with this practice is another conundrum supported by binary thinking: the recognition of indigenous culture and people unwittingly produces a “cultural other”, whose traditions and way of life are romanticized, instrumentalized, and further exploited as a way to reinforce the mainstream narrative of technological transformation. The act of acknowledgment freezes a period of time as an origin where history started; based on this imagined origin, the technological transformation story can be told and naturalized. Furthermore, a second irony lies in the term “indigenous”, which is defined as “naturally occurring”. Present-day environmental narratives are not able to bypass a problematic conception formed in early colonial times, when colonists believed they were “culture” and indigenous people were part of “nature”, waiting to be transformed. Moreover, there were numerous nonhuman inhabitants in existence before the alleged “first inhabitants” arrived, and their stories have yet to be told.

This may be the biggest predicament in the creation of counter-narratives: critiques may always be assimilated into the mainstream narrative in one way or another, without fundamentally challenging it. No matter how many counter-narratives we unearth, the well-established relationships among nature, humans, technology, and landscape remain intact. As long as one freezes a period of time, an imagined origin where history starts, a tale of humanity, nature, and technology may be told through interwoven stories of technological transformation. In these stories, there will be those who conceptualize themselves as wielders of technology, and those humans and nonhumans who are "transformed" as part of "nature". To genuinely challenge mainstream environmental narratives is to think beyond the transformation formula as the fundamental explanation of our relationship with the environment.

In tracing the first edge -- technology-nature -- of the triad, with which we group ideas about nature and technology in relation to humanity in the twentieth and early twenty-first centuries, a specific image of humans emerged. Two kingdoms of force had to be summoned by those with the privilege to conceptualize themselves as the source of agency, and to wield the power of both kingdoms. The transformation formula was a convenient design to help early European settlers conceptualize human agency in altering the environment. In an anthropocentric framework, nature and technology are two essential concepts to describe how humans interact with their environments. Nature, technology, and landscape are all concepts to conceptualize human agency. To bypass the predicament in contemporary environmental discourse requires us to take on a posthumanist framework and rebuild narratives that do not revolve around humans. From this vantage, although historians such as Nye and Marx have introduced a predicament in contemporary environmental discourse by presenting a collection of vivid examples, unfortunately, their historical perspectives fail to provide useful alternative models to help us overcome the predicament itself.

Tracing this body of work also reveals a deeper, yet unquestioned, mental model. These narratives begin with the premise of two kingdoms of forces; theories were then developed to mitigate the gap between the two. In other words, both nature and technology were accepted as a priori where forces are generated. This neglects that the terms *nature* and *technology* possess histories of their own. This gap merits further investigation along the edge of human-technology and human-nature.

3. The Second Edge: Human-Technology

Technology emerged as a concept in the early twentieth century, and quickly drew attention from many fields of study, including philosophy, history, and sociology. Generally speaking, the understanding of technology has transitioned from internalized models that focused on the essential qualities of technology, to externalized models that situate the concepts within relationships in the socio-cultural context. Scholars have attempted to make sense of the role which technology plays in culture and human society.

In the twentieth century, several events shaped society's sentiment toward technology as a whole. During the second Industrial Revolution, roads and railroad networks, telephones, and gas and sewer systems, among many profound technological systems, were widely adopted. Factory electrification enabled modern mass production. These unprecedented human powers fueled a progress narrative underpinning many early works of technology; the narrative presented technological developments as a linear progression, in which one breakthrough led to the next.

Then World War II ended in 1945, with two nuclear bombs dropped upon Japan. For the first time, society experienced the unprecedented destructive power of technology. Meanwhile, the progress narrative proceeded through the following decades; the Apollo 11 moon landing became a global, technological, sublime event through its broadcast in 1969. This ambivalent portrayal of technology led to a 1970s movement known as science, technology, and society (STS). Universities designed new interdisciplinary programs, including the history of technology, women's studies, and the philosophy of technology, to address issues which traditional curricula ignored. The underlying urge was to foster a sense of responsibility in scientists and engineers, so that the goals of technological development aligned with the public's best interests. The implication of the STS movement was more profound than its original context. Towards the late twentieth century, its methods and ways of thinking entered other fields. Many ideas initially developed in STS, such as actor-network theory (ANT), have been appropriated to analyze complex phenomena across disciplines.

In a parallel genealogy, technology became a subject for philosophical investigation when industrialization altered people's life experiences. Philosophers, including Martin Heidegger and Don Ihde, expanded their analyses to technological artifacts and systems in order to understand the role of technology in human existence. Towards the late twentieth century, inspired by AI research and neuroscience, scholars reflected on the meanings of consciousness, intentionality, and mind in the technological lifeworld. For philosophers to study technology is, essentially, to ask what it means to be human. The STS movement and philosophy inspired a range of posthumanist ideas that serve as the theoretical framework for the thesis of the co-production of the environment.

3.1. From Mechanic Arts to Systems: A Progress Narrative

The emergence of the concept of technology justifies the transformation formula by articulating a progress narrative. As examined by Leo Marx (2010), the term *technology* did not become popular until the 1930s, when an unprecedented complexity in machines occurred. Before *technology* proliferated in the English language, people used the term "mechanic arts" to refer to the tools and crafts that helped automate and extend human capacities. The term *technology* was introduced to American vocabulary by Jacob Bigelow in his 1832 book *Elements of Technology*. The term then denoted a branch of study concerning mechanical art, as expressed in its Greek roots: *techne* (art or craft) and *ology* (a branch of learning).

Leo Marx asserts a transition of the meaning of technology from its pre-industrial sense as the study of mechanic arts to its latter-day meaning as the arts themselves. Towards the late nineteenth century, the application of scientific knowledge to improve the mechanic arts gave rise to an unprecedented form of human power which the term "mechanic arts" fails to convey. Thus, as Marx argues, the organizational and material aspects of the semantic void required a concept more inclusive than "machine" (Marx 2010).

The semantic void discussed in Marx's analysis is revealed through two types of complexity that exist in conceptually opposite directions – interior and exterior. Towards the interior, functional units of a machine become smaller and black-boxed in multiple levels of abstraction. For example, the smallest function unit within a computer is an electron flowing through a semiconductor. Using a semiconductor, we can build transistors that work like switches for electrons – switch on, the electron passes; switch off, it fails to pass. Moving up a level, we may abstract this phenomenon into true and false binary values; thus, connecting several transistors in different ways builds different logic gates – such as AND, OR, and exclusive OR. With another level of abstraction, combining various logic gates – different connections of transistors – we build processors that can compute. Without diving into the unnecessary details, the point of this example is that when electronic engineers design processors, they do not think about electrons moving through transistors; they care only about logic gates and other higher-level abstractions. When we write computer code, we do not think about logic gates, even though they are the real units performing the functions. Even programming languages nowadays are black-boxed within layers of complexity. A line of code in Python – a popular high-level programming language famous for its human readability – will be interpreted into millions of instructions for the computer, meaning millions of electrons moving through semiconductors. This level of abstraction makes machines, such as a computer, opaque. Ironically, we believe ourselves to know how a piece of technology works because we can make it perform certain desired functions, but, at the same time, we do not understand exactly how it works, because we cannot see through the levels of abstraction. This opaqueness gives rise to a perceived complexity that contributes to the semantic void. If "mechanic arts" evokes an image of an intricately designed machine with gears and chains, of which we may comprehend, then "technology" points to a glossy object that somehow performs "scientific witchcraft".

In the exterior direction, people experienced a different type of complexity. Again, to make a piece of computer work, electricity must be generated and transmitted. Semiconductor materials – such as silicon – must be mined and manufactured into chips. Other industries design, assemble, and distribute computers, as well as keep this process running. It is challenging, if not impossible, to trace the boundaries of technology. These incomprehensible socio-technical systems constitute another type of complexity that contributes to the semantic void. We might think we know how a piece of technology works, because it functions in front of our eyes, but at the same time, we cannot trace the full extent of the systems in which the technological artifact is embedded.

This dual complexity gives rise to an unprecedented phenomenon, that we must deploy the term "technology" as a concept, to try to capture its essence. Marx argue that the emergence of new technologies is precisely the reason why the concept is hazardous. Because we use this all-encompassing term to represent a conglomerate of items and relations, such generality makes it "peculiarly susceptible to reification" (Marx 2010, 576). Marx sees that the danger of the concept of technology lies in its deceptive generality, which obscures relationships with humans. Borrowing the idea of "phantom objectivity" from György Lukács, Marx describes the danger of the concept, as if "technologies" possess a certain autonomy that can initiate change, drawing our attention away from who is using these technologies, and for what purpose.

Entering the twenty-first century, *technology* by itself cannot fill the growing semantic void, due to the increasing complexity of technologies. Once we make this “unprecedented human power” into a thing, the semantic void will not stop growing, and that is the hazardous aspect of technology. By now, in the early 2000s, we have summoned a collection of concepts into our vocabulary: system, network, intelligence, smart, and others on the order of technology. In its broadest sense, systems “are defined by their abstract relations, functions, and information flows, rather than by their concrete material or components” (Heylighen and Joslyn 2003, 5). This definition reflects the aforementioned dual complexity. The functionality of systems lies in their relationships and flows, rather than in individual material components, such as electrons. If the term *technology* conveys a sense of materiality, then the term *system* dematerialized this type of human power into abstracted relationships. Similarly, “network” is deployed to suggest the connectivity of socio-technical systems. For instance, “sensing networks” imply another layer of connected systems embedded in the physical world. How do we know if we are making progress? Smartness can be used as a measure. With smart cities becoming a global phenomenon, IEEE (Institute of Electrical and Electronics Engineers) and ISO (International Organization for Standardization) have both developed metrics to standardize and thus evaluate the “smartness” of a city.[11] Beyond these global standards, multiple local standards and metrics exist for measuring the performance of a city as a socio-technical system. All these concepts are ways to specify different aspects of the semantic void which Marx has articulated. They provided a roadmap to a technocratic ideology.

Underlying the emergence of the concepts of “technology”, as well as associated terms, is no doubt a narrative of progress. As Marx argues, radical thinkers of the 18th century, including Benjamin Franklin and Thomas Jefferson, did not perceive mechanic arts as measures of

[11] See, for example, https://www.iso.org/sites/worldsmartcity/ and https://smartcities.ieee.org/

growth and development. Instead, they viewed machines only as a means to social and political ends. True measures for progress lie in "humanity's step-by-step liberation from aristocratic, ecclesiastical, and monarchic oppression, and the institution of more just, peaceful societies based on the consent of the governed" (Marx 2010, 565). With the rise of the concept of technology, the distinction between means and ends has gradually dissolved, and technology becomes a measure for progress. The transformation formula is again at work, and the concept of technology articulates and rationalizes an unprecedented human power to transform nature effectively. The "phantom objectivity" of technology creates an illusion, as if technology is a thing that empowers those who acquire it. Through this line of reasoning, the end is guaranteed, and all that is left to do is perfect the means – technology.

The progress narrative of technology is a form of *technological determinism*, which asserts that technology essentially determines which aspects of society are best suited for its development, because of the efficiency it provides. It acts as a factor of "natural selection", culling those aspects that fail to promote technology, and enhancing those that support its development – a form of social Darwinism. A technocratic society may thus progress at the cost of those whose values, morals, and philosophies are less compatible with, if not opposed to, technological development. Technological determinism was further expanded, as a post-war pessimistic view about technoscience, in the mid-twentieth century, after society witnessed the destructive power of technology in wars and environmental degradation.

Technology is the concept that not only distinguishes "advanced" societies from "inferior" ones, but, on a more fundamental level, it distinguishes humans from other species. This distinction establishes a hierarchical ontology that unwittingly justifies a logic that humans need to survive at the expense of other, "lower" species. Ironically, the concept of technology and the progress narrative also add to human hubris, in believing that we are able to end nature.

For example, many argue that either industrialization or the end of the agriculture society marks the beginning of the Anthropocene. In either argument, technology plays an indispensable role. It freezes time as if, at the moment we acquired technology, we were on a path of self-destruction. In this fashion, the concept of Anthropocene is supported by a form of technological determinism, and the only difference is in the progress that leads to total collapse. Anthropocene warns of a self-destructive end in the progress narrative, which we need to avoid. However, to create the warning, it justifies the progress narratives and transformation formula, reinforces the boundary between human and nonhuman, and accepts the “phantom objectivity” of technology.

3.2. From Ready-Made Technology to Socio-Technical Systems

Progress narratives posit technology as a transformative force, because they treat technologies as "ready-made”, thus ignoring the socio-technical ensemble where human agency resides. By accepting technology as ready-made, one sees autonomy in technology, and accepts its ability to initiate changes in human relationships and the course of history. Understanding technology as ready-made is partly due to how technological development was portrayed in the early twentieth century, when scholars in the history of technology primarily focused on inventions and innovations build around “great man history”. The development of scientific discoveries and technological inventions was often presented as linear progress, with one breakthrough leading to the next.

An intellectual milestone in 1958 was the founding of the Society of History of Technology (SHOT). Historians in diverse fields realized that technological innovations had played an essential role in their own narratives, and technology eventually became a subject of historical inquiry. The field transitioned from an internalized and descriptive model to an externalized and analytical one. Scholars in SHOT did not find the early-twentieth-century internalist model sufficient for asking fruitful questions; there were limited examples of external models, and these could not address the issue, either. For example, in *Technics and Civilization* (1934), Lewis Mumford situates technological innovations within the cultural context, and argues that the invention of the clock was the basis for capitalism, since clocks make time fungible by structuring and synchronizing human activities. However, these external models of analysis accept technologies as ready-made, and present a linear history of how technology shaped the course of history. This external model cannot help asking more sophisticated questions, other than on the route of technological determinism.

The concept of "paradigm shift" altered people's understanding of scientific and technological innovation as a linear progression. In 1962, Thomas Kuhn, in *The Structure of Scientific Revolutions* (2012), introduced the concept of paradigm: a set of models, worldview, or frameworks agreed upon by a scientific group to define the subject and methods of their study. Doing research in a given paradigm, using Kuhn's term, is doing "normal science", which only further articulates the existing theoretical and methodological framework. However, different voices challenge the received models, and "incommensurability" emerges between different competing paradigms. Incommensurability conveys more than differences and disagreements between competing paradigms; instead, it conveys a sense that comparing them is either meaningless and/or impossible. Where two paradigms compete, a semantic difference emerges between them; though the concepts and terms of the new paradigm are generally inherited from the old one, they take on different meanings and relationships with each other. Communication between the two paradigms becomes challenging, if not impossible, for "the proponents of competing paradigms practice their trades in different worlds" (Kuhn 2012, 149). A paradigm shift occurs when the majority of the science community reaches a consensus and agrees on a set of new theories and methods. Paradigm shift asserts that innovations, inventions, and/or revolutions in science and technology are historically contingent. They consist of intentional choices, made by scientific communities, that cannot be separated from their socio-cultural backgrounds.

Kuhn’s analysis reflects a paradigm shift within the field of history of technology in the 1970s, when science technology and society (STS) emerged as a movement and a field of study in Europe and America. Many scholars had taken a similar approach, asserting that technological objects are not ready-made, and the direction of technological development is not linear. The STS movement began as a response to a series of events that had revealed the destructive power of technology in the first half of the twentieth century, such as the Dust Bowl in the 1930s and the usage of nuclear weapons during World War II. There had been a robust environmental undertone to the beginning of the STS movement. For example, in 1970, the first Earth Day was celebrated, the Environmental Protection Agency was founded, and the Clean Air Act was passed. Many further environmental laws and acts were passed over the following decades. Another acute task for the STS was to critique technological determinism in the mid-twentieth century. The task was clear: to reflect and challenge technological determinism and technocratic ideology by opening the black box of technologies and proving they were socially constructed. The goal was to tie technological artifacts and systems into a socio-technical network, and remind us of the values embedded in the design decisions made by different social groups in the development of technologies.

A milestone for this body of research was *The Social Construction of Technological Systems* (1987), edited by Wiebe Bijker, Thomas P. Hughes, and Trevor Pinch as proceedings for a 1984 workshop. Although the scholars in this anthology took on different models to open the black box of technology, they acted under the same banner, known as the Social Construction of Technology (SCOT). Bijker saw the convergence of three different bodies of work. In addition to the STS movement, two others are the UK-based sociology of scientific knowledge (SSK) and the US-based history of technology; all three provide different models for understanding technology and society (Bijker 2010).

For example, Bijker traced the invention of the bicycle (Bijker 1997). Instead of describing it as a linear process, he sited bicycles within a network of several relevant social groups. Each group interprets the same artifact differently, or, to use a SCOT term, uses *interpretative flexibility*. Then each group addresses different problems and goals, so that each may provide a way to construct a version of bicycle design – *design flexibility*. This allows for a wide range of design possibilities, each addressing certain problems (e.g., safety versus speed). In the end, the conflicting designs would reach a conclusion, or a *closure* in STS terms, and a standardized design would become the dominant model. A closure occurs either rhetorically (e.g., advertisement), or with the original problems overridden by a new set of problems. After a closure, new social groups would emerge, reintroduce *interpretive flexibility,* and redefine the problems.

To account for technological determinism, STS scholars deployed concepts such as *socio-technical ensembles*, *technological culture*, and *technological momentum* to describe the perceived autonomy in technology. Using technological momentum as an example, American technology historian Thomas Hugh proposes that, when a technology is new, it is malleable and subject to social changes; when a mature technology is enmeshed with its society, its deterministic forces make it difficult to influence (Bijker 2010). Although this view appears to be another way of technological determinism, it does not assert autonomy in technology; instead, technological momentum exists in a socio-technical ensemble. The perceived agency in technology resides in the network of artifacts, standards, regulations, and laws fencing technology.

Another SCOT approach is the actor-network theory (ANT), developed in the late 1980s by Bruno Latour, Michel Callon, and John Law. Despite the contemporary appropriation of ANT by humanities and social sciences, it was first introduced to the STS community in the same 1984 workshop as one of the models for SCOT. It was only later that Bruno Latour explored the implication of this mode of thinking in a broader context; after that, many other scholars in humanities and social sciences found it useful. The use of ANT also underpins other popular posthumanist ideas, such as object-oriented ontology (OOO). Chapter Two, below, touches on ANT in greater detail, in the context of nonhuman agency. In SCOT, ANT uses actor-network as a metaphor to describe technology and its role in shaping society. In an ANT framework, both humans and nonhumans are treated equally as “actants”. Perhaps unavoidably, the assertion that inanimate nonhumans can “act” has drawn a great deal of criticism from the field of STS. However, as we shall see in Chapter Two, most of the criticism is due to limited reading and misinterpretation of ANT, because of its complicated ontological stance.

The contribution of SCOT is clear. It demonstrates that humans have always co-evolved with technology, and that society possesses the ability to steer technological development in a more ethical direction. This body of work thus opened a wave of STS research focused on how to steer technological development through more active research methods. Since the 2000s, STS has been diversified by different methods and subjects of study; for example, the idea of “anticipatory governance” was developed and practiced by David Guston in the area of nanotechnology development (Guston 2014). Others have bypassed postmodern skepticism about science at large, and choose to believe the values of the scientific world view (Collins 2009). Harry Collins and others call this “the third wave of science studies”, and advocate studying expertise and collaboration among different disciplines. By investigating the concept of *interactional expertise*, they hope to foster a broader collaboration among multiple stakeholders, so that technological development may be more transparent and inclusive (Collins and Evans 2002; Collins, Evans, and Gorman 2010; M. E. Gorman 2010).

This emerging research is based on a conceptual shift in how people study technology and society, from the previous understanding that the two realms are separate entities influencing each other, to a contemporary view that neither can be grasped in isolation – instead, we need to start with the untidy network of the socio-technical ensemble. It is perhaps more precise to say that scholars have always studied socio-technical systems; from the beginning, the concept of technology has been that of a network of tools and socio-cultural systems, as well as the knowledge and intellect behind them. In a way, the hazardous concept of technology and its "phantom objectivity" is dissolved by STS into a complex but traceable network of systems.

3.3. Extended Mind and Dematerialized Humans

While STS focuses on returning technology to a socio-technical network, another body of work found in the field of philosophy, phenomenology, asks a similar set of questions: What is the relationship between human beings and technology? What roles do technological artifacts and systems play in everyday human experience?

Martin Heidegger was one of the influential philosophers in the twentieth century who addressed technology from a phenomenological perspective. To better understand Heidegger's approach, we must examine what phenomenology means in this context. In its broadest sense, phenomenology challenges Cartesian subject-object division by positing that "human beings" and "world" are not entities with defined boundaries, and they are already interwoven and related. Contemporary systems theory may help articulate these philosophical concepts. From a systems perspective, human systems are deeply coupled with other systems, which we call *world* or *environment*. Second-order cybernetics informs us that a human system has no direct access to "the" reality, but merely to a reality constructed by our own system operation; we can only experience “things-for-us”, never “things-in-themselves”. Thus, in systems theory, systems are structurally open – human beings are always in relationship with the world, but systems are operationally closed, operating in these relationships determines how the world is disclosed to us. In Heidegger’s thesis, “being” is the concept that describes the underlying structure of how human beings relate to the world, and how it is disclosed to us. According to Heidegger, “being” is historically determined. “To be” differs in different historical epochs, and this leads to distinct modes of “being” and separate ways in which the world is disclosed to us.

Based on this phenomenological framework, Heidegger traces technology back to its Greek root *techne*, and argues that “[t]echnology is a mode of revealing. Technology comes to presence in the realm where revealing and unconcealment take place, where *aletheia*, truth, happens.” (Heidegger 1977, 295). Again, from a systems perspective, Heidegger’s thesis is that technology is one mode for us to construct relationships with other systems, and to “disclose” the world. Heidegger believes that modern technology has lost the essence conveyed in *techne*, a way of revealing, or bringing forth, and instead it is about *Gestell (*“enframing”*)*, which entails the sort of techno-science framework or paradigm into which humans are born in the modern technological era.

As one commentator notes, Heidegger is not questioning “technologies” but “Technology”. Heidegger’s analysis was a common approach found in early philosophical thought on technology, when scholars attempted to identify the essential characteristics of technology and its role in culture (Verbeek 2001). There is considerable similarity between Heidegger’s phonological approach and the analysis found in the field of history of technology in the early twentieth century. For example, Lewis Mumford’s analysis of time and clock is also a form of reflection on the structure that coordinates human existence. Heidegger’s contribution to technology study should be properly recognized rather than over-interpreted, partly because of the uninterpretable terms and concepts in his existential philosophy. Heidegger's understanding does not bypass the paradigm that expands the early-twentieth-century study of technology. Like other scholars of his time, Heidegger viewed an autonomy in technology, and treated technology as ready-made. He could not have foreseen concepts such as the socio-technical system, and he certainly did not anticipate that society might assimilate technology within its operational networks, through laws, regulations, and other social functions. At an individual level, Heidegger underestimated human beings' ability to learn and adapt. As Neil Leach rightly puts,

> "[e]ven the most seemingly alienating of technological forms can soon become absorbed within our symbolic horizons, such that they no longer appear so alienating…Those who argue that technology is the perpetual source of alienation clearly overlook the potential for human beings to absorb the novel and the unusual within their symbolic framework" (Leach 2002).

Fundamentally, Heidegger's comments on technology assume an unspoiled origin when human beings existed in a "naked body" with "naked mind". He ignores the fact that humans and human societies have always co-evolved with tools, structures, languages, systems, and technologies; this condition defines who we are as humans. It may be too extreme to "forget Heidegger" as Neil Leach demands, but we do need to properly historicize Heidegger's "questions concerning technology" before developing a novel framework to understand what it means to be a contemporary human being.

In fact, unlike Heidegger, nostalgic about an original human condition and critical of modern technology, later generations of philosophers have seen potential in modern technology to consider what being human means. Philosopher Don Ihde has studied technology within a phenomenological framework, but he does not trace to the past as Heidegger did. Instead, Ihde looks forward, and inquires about the new relationships which technological artifacts and systems open, so that we can "reveal" the world differently with modern technology. In a "human-world" framework, Ihde has developed three categories of phenomenological relations between humans and technology: mediated relations, alterity relations, and background relations (Ihde 1990) (Figure 5).

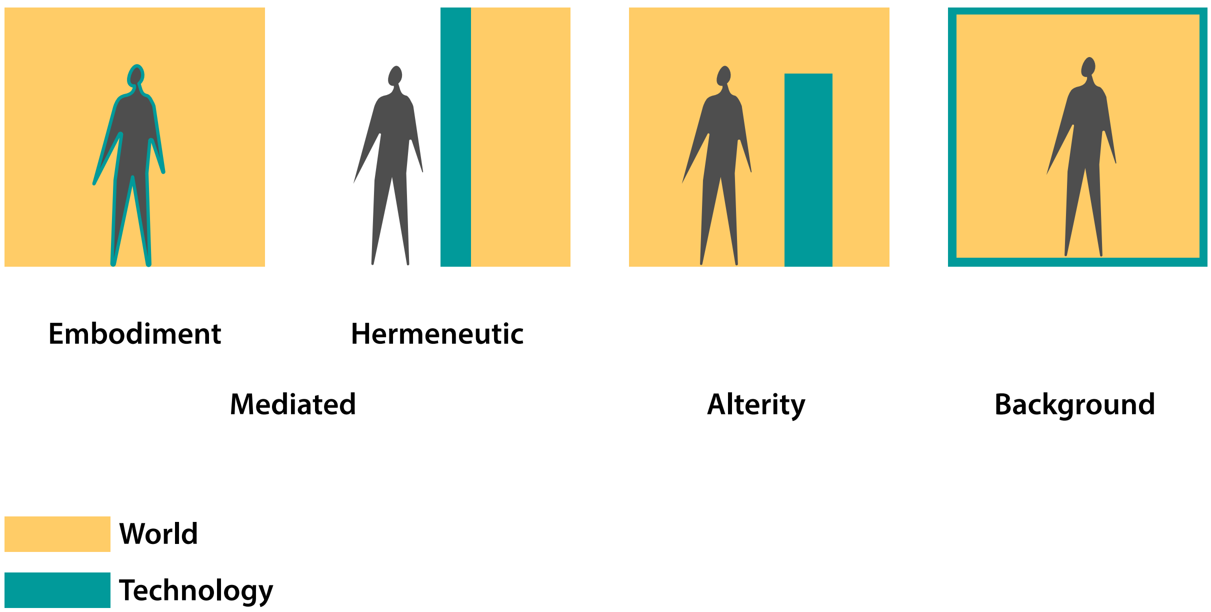


Figure 5. Don Ihde's Technology Phenomenology.

Within mediated relations, two subcategories exist: embodiment relation and hermeneutic relation. In embodiment relation, technology broadens or dampens the sensitivity of the human body to the world. Ihde listed the example of the phrase, "I wearing glasses". The human does not look *at* glasses but looks (*through* them) at the world. Ihde formalized this relation as:

(I-technology) -> world

In the hermeneutic relation, technology does not withdraw from our relationship to the world, but provides a representation of certain aspects of it. For example, a thermometer reveals temperature; Ihde argues that when we peer at a thermometer, we do not look at *it*, but instead at one aspect of the world – the ambient temperature. "Hermeneutic" signifies that this relation involves interpretation. We must first mentally construct what 25°C means, then experience the world through a thermometer as a medium. Ihde formalizes hermeneutic relation as:

I -> (technology-world)

In the alterity relations, humans do not relate to the world via the medium of technology. Instead, we relate to technologies as if they are "others". Alterity relations are formalized as:

I -> technology (-world)

In this relation, Ihde articulates a sense of anthropomorphism; we tend to project human properties and emotions onto technological artifacts. Technologies behave as "quasi-other", because they provide a degree of interaction, and yet assume a certain degree of "independence". Ihde touches on a concept in robotics called "perceived intelligence", which describes how intelligent a robot appears to be. To robotics engineers, who know the rules and algorithms that drive a robot, the robot does not appear to be intelligent. Nevertheless, to a lay audience, the robot appears intelligent enough to relate to as an independent other. Today, advanced machine-learning techniques based on artificial neural networks pose more challenging questions related to alterity relations. In several cases, even computer scientists do not know why a model behaves in specific ways, and alterity relations thus become salient.

The last type of relations is background relations, in which technologies play no central role in our experience of the world. Instead, they recede into the background and shape the context of our experience. For example, a heating system maintains the environment in a stable condition, so it backgrounds our experience (Ihde 1990). In this relation, we do not even notice technologies except where they malfunction. Ihde formalizes background as follows:

I- (technology/world)

The background relations touch on one aspect of the concept of cybernetic environment, where machines become active players in constructing the shared environment, thus providing a background for human experience.

Ihde's scheme of four relations should not be applied in isolation. We may experience more than one type of relationship with a single technological artifact. A smartphone is a perfect example of how the above examples mesh into single object. We check outside temperatures via a smartphone (hermeneutic relations). Taking photos, we regard the world through the phone's camera lens (embodiment relations). A smartphone is intelligent enough to be treated as an independent other, especially when digital companions such as "Google Assistant" or "Siri" are enabled (alterity relations). Finally, we carry our smartphones, which constantly ping GPS signals. These GPS coordinates are utilized by programs such as Google Maps to determine traffic conditions and calculate the best route for driving. This "traffic map" is a constructed reality that serves as a background context for others to navigate the world. In our daily lived experience, smartphones thus establish essential nodes of a technological system of way-finding (background relations).

As demonstrated in this smartphone example, Ihde's scheme is a useful framework to comprehend our daily experiences, but it is only a starting point in evoking more sophisticated understandings of human-technology relations. Indeed, with technological advances such as sensing networks, AI, machine learning, and cyberphysical systems, reflecting on our experiences using Ihde's scheme alone is cumbersome.

Another concept – the extended mind – may not at first glance appear to be related to the concept of technology, but it is worth exploring. Informed by advances in cognitive science, philosophers Andy Clark and David Chalmers (1998) propose that the environment functions as part of the human mind. They argue that a person with Alzheimer's disease, who relies on a notebook to “remember” is, in terms of cognitive processes, no different from an individual with a good memory. In the case of the person with Alzheimer’s, the person’s internal mental processes and notebook may be regarded as a single system. Even though information within the notebook, in this case, must be accessed by perception (eyesight), the perceptual processes may be considered as internal information flows. Because systems are defined by relations rather than material components, from a cognitive system point of view, it matters little whether the system consists of a “naked mind”, or a body possessing a notebook. Neither system need anything from outside the cognitive system to perform its functions. From this perspective, Clark and Chalmers argue that humans are able to offload cognitive functions onto the environment. It is not humans who are intelligent, but human-environment assemblages that make us appear intelligent (Clark and Chalmers 1998).

One classic example along this line of thinking is the thought experiment of the “Chinese room”, or any other language room. A non-Chinese speaker is locked in a room with a Chinese-English dictionary and a hypothetical rulebook of Chinese-English translation. A note bearing a Chinese character is slipped under the door, and the entrapped person must follow the instructions and rules in order to translate the character. John Searle, the original author of this thought experiment, tried to argue that a person who does not speak Chinese at all can easily pass a Turing test and “fool” those outside the room into believing he/she understands Chinese. Similar conditions may apply to AI that translates Chinese; yet Searle wanted to prove that this AI is unable to understand the Chinese language (or any other), and thus neither “thinks” nor possesses a mind. However, from the extended mind perspective, it is not that a human understands Chinese, but that the human-room pair does so; from a systems perspective, the “human” does not matter. To the contrary, it is a quite “human” thing to do, to rely on the environment to appear to be more intelligent.

Rather than reflections on technology, philosophical investigations are more precisely, reflections on humans. The two examples – extended mind and human-technology relations – demonstrate that if there is a boundary between technology and humans, it is more fluid than we thought. Since humans are constantly involved in a network of socio-technical systems, any concept that maintains the notions of a "naked mind" and "naked body" prevents us from understanding the human condition in the technological lifeworld. Further examples show it to be a constructed boundary in which we circled a set of relationships and nebulously called them "human". Yet humans have ever been cyborgs.

4. The Third Edge: Human-Nature

Do we humans really transform pristine nature? What is our relationship with nature, other than transformation? Tracing the ideas about nature in the twentieth and the early twenty-first centuries along the edge of human-nature can help us address these questions.

The development can be characterized as three waves, represented in the Figure 6 diagram. Each wave represents a development of the concepts of nature and its relationships with humans. The frontier of each wave mobilizes across different fields of studies. By reflecting on the previous wave of transition, scholars in the new wave build a higher order of reflexivity about human-nature relationships. The ideas generated in the new wave do not directly replace the old ones; instead, they provide a different perspective of "nature" to the already diverse field concerning this concept. This can be understood as a maturing process of an idea; with perspectives added to the discourse, the concept of nature grows complex and, at the same time, contested. Together, three waves of transition have contributed models that constitute our contemporary understanding of human-nature relations.

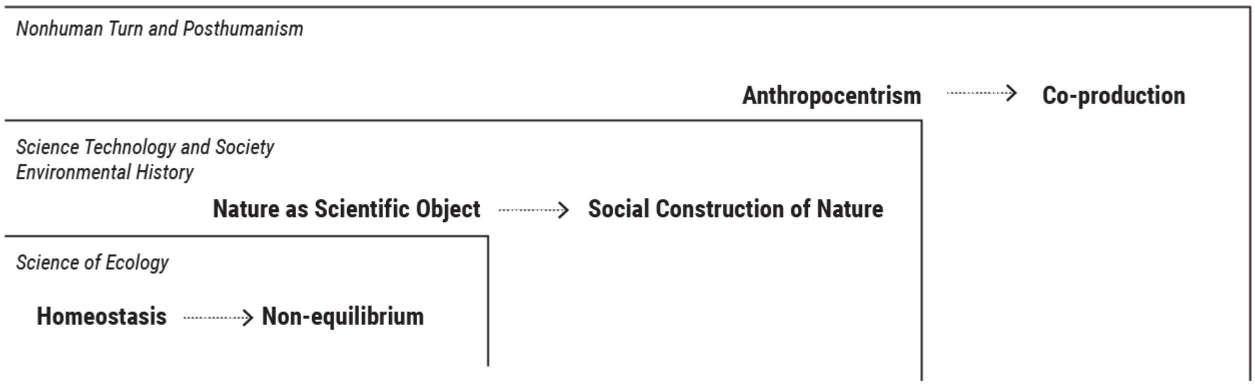


Figure 6. Three Waves of Conceptualizations of Nature

The first wave was a transition within the ecological sciences since the 1950s, when a non-equilibrium model replaced the earlier homeostatic view of nature. Many ecologists reported a paradigm shift in the 1950s, when Clements's succession model was challenged and later superseded by Gleason's individualistic model (Barbour 1995). The homeostatic view supports the popular conception that nature is pristine and static, whereas the individualistic model holds that the nonhuman realm is wild and chaotic. Though Clements's model has been gradually abandoned within the ecological sciences community, its legacy persisted in practice-oriented professions, including landscape architecture. Many still use Clements's model to justify design decisions and create a static "nature".

The second wave was a constructivist reflection on the topic of "nature" in the 1990s. Scholars assumed a radical constructivist approach, claiming that nature was a socially constructed idea. This constructivist framework was influenced by the science technology and society (STS) movement of the 1970s. Concepts such as "paradigm shifts" and "social construction of fact and artifact" posited that scientific knowledge, including that within the natural sciences, was in essence a consensus reached within a scientific community. Deploying the constructivist framework, environmental historians began to reveal unstated values embedded in the concept of “nature”.

The third wave reflects on constructivism itself. One incentive for radical constructivism is to reflect on human hubris, and place a limit on human knowing by challenging the claim that science reveals the truth of reality. However, late-twentieth-century constructivism backfired, because to claim that nature is a social construct asserts, ironically, another level of human hubris. Constructivists reduce the nonhuman realm to human discourse, and ignore its intrinsic values, free from human interests; to study nature is to study a set of human cultures and norms. Reflection on constructivism itself gave rise to the early twenty-first century “nonhuman turn”; nonhuman agency became a conceptual lens with which to study the nonhuman realm. A series of post-humanist ideas have emerged in environmental humanities; political ecologies; multispecies ethnography; animal studies; feminist materialism; and object-oriented philosophy. In a post-humanist framework, the human becomes a product of the co-evolution, physically and conceptually, of other nonhuman species. Nature may be a constructed concept, but the nonhuman realm is also real; what we have understood as “nature” has forever been a co-evolving, co-producing, and interweaving network of humanity and non-humanity.

Since the mid-twentieth century, all three waves of transition have been strengthened by an environmentalist undertone. Stories of DDT and extinct species, Rachel Carson’s *Silent Spring*, the first Earth Day on April 22, 1970, and the establishment of the U.S. Environmental Protection Agency (EPA) in December 1970, prepared the American psyche for a profound environmental movement. Early concerns regarding air and water pollution evolved into concerns over climate change, global warming, and the projected rise of sea levels. In response came environmental policies and concepts such as the EPA’s Clean Air Act (1963) and Clean Water Act (1972); sustainable development in the 1990s; stormwater management and low-impact development

(LID) towards the early 2000s; and, dating from the late aughts, resilience and adaptivity. These are several examples of the many terms and concepts that constitute today's environmental discourse. To a certain extent, environmental values provide strong moral imperatives for building a more sophisticated understanding of nature, and construct versions of “nature” on the basis of updated mental images. However, several versions of environmentalism reinforce the transformation formula; not only do humans transform nature, but we should also sustain and protect it from further transformation.

Landscape design as a cultural practice reflects society’s understanding of nature, and we may compare the three waves of conceptual development with the paradigm shifts in the landscape discipline. Landscape architecture took on an ecological model in the mid-twentieth century, thanks to Ian McHarg’s teaching and practice. Designers began to explore how time and succession work to their advantage. When a non-equilibrium view gained currency in ecological science, landscape designers began to reevaluate earlier ecological determinism, and explored more dynamic and open-ended frameworks. Following the second wave of transition, landscape architects reflected the dark side of environmentalism, such as uncritical conservation, preservation, and restoration efforts. Many began to construct experiences, rather than natural scenery, and expanded aesthetic categories that connected people to the biophysical world surrounding them. In response to the third wave of “nonhuman turn”, multispecies interactions and co-production of landscapes have become a conceptual framework for a new generation of landscape architects.

However, these transitions in both the broader discourse of nature and in the landscape architecture discipline must not be viewed as one paradigm replacing the other. Environmental historians’ and STS scholars’ reflections do not fundamentally alter how ecologists conduct scientific research, and posthumanist ideas do not prevent constructivists from uncovering alternative histories of a culturally constructed nature. Similarly, in the landscape architecture discipline, different ways of thinking and modes of practice provide designers with a generous source of inspiration, to design landscapes that reflect our understanding of the term "nature". Although each wave of transition abandons concepts, the three shifting waves contribute to a more comprehensive view of human-nature relations. The transformation formula, to a greater extent, is an amalgamation of outdated views of nature.

4.1. From Homeostasis to Open-Endedness

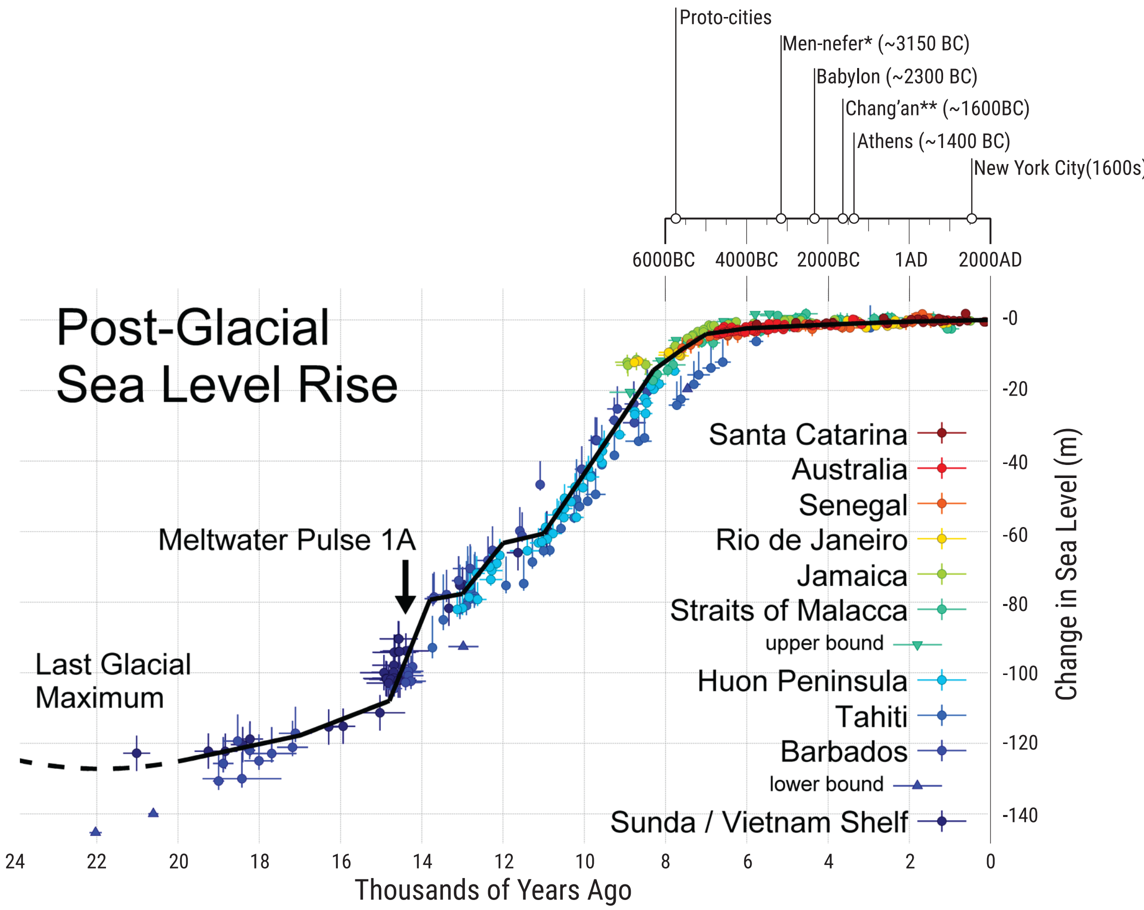
The first wave included two aspects. First, people adopted a more sophisticated and dynamic view of nature. "Nature" had denoted a homeostatic entity, but now it pointed to nested, evolving systems that were complex and open-ended. Second, an increasing number of scholars began to conceptualize human activities as part of natural processes. For the first half of the twentieth century, nature comprised the exterior, nonhuman realm, with humans disturbing it. Towards the late twentieth century, many recognized human activity as an important part of the complex system called nature. These transitions occurred mainly in the science of ecology, as well as in ecology-based environmental practices; thus, analyzing both fields illustrates the first wave of transition.

During most of the twentieth century, the nonhuman realm was investigated below scientific apparatuses, and humans were observing subjects on the other side. Within the subject-object framework, "nature" became an all-encompassing concept that included the nonhuman realm merely as a scientific object. Within this scientific tradition, the emergence of ecological thinking gave rise to the scientific discipline of ecology in the early twentieth century. Ecological thinking emerged from the convergence of natural history and natural philosophy, or science, in the nineteenth century. Naturalists such as Alexander Humboldt (1769–1859) introduced Newtonian analytic reasoning and measurement to natural history, and informed a new paradigm of scientific knowledge production. The study of nature transitioned from descriptions of nature through taxonomy, to a more analytical form of study that attempted to use data to explain the underlying "law of nature" (Kingsland 2004). In the early twentieth century, ecology grew into an independent scientific discipline, providing a model of thinking that asked a unique set of questions, and produced a new category of knowledge about the nonhuman realm. Instead of describing what an object was made of, such as developing the anatomy of a plant by naming its parts, ecology was concerned with how the object functioned in an extensive system or network, and, in turn, how the system and network influenced its behavior.

Early ecological research focused primarily on plant ecology and plant succession. In the early twentieth century, two competing models for ecological succession existed: a holistic or organismic model proposed by Frederic Clements (1874-1945), and an individualistic view held by Henry Gleason (1882-1975). Clements's model used "organism" as a metaphor, asserting that species in an ecosystem were deeply connected, and the ecosystem as a whole functioned as an organism. After disturbances such as wildfires, the ecosystem repeated a series of stages, and reached an equilibrium or a climax formation. In contrast to Clements, Gleason believed that plant species required different environmental conditions, and ecosystem dynamics was the result of individual species responding to environmental factors. Therefore, co-habiting plants did not form communities, and observed association were simply coincidence. Gleason's individualistic model was largely ignored until the early 1950s, when ecologist John Curtis further developed Gleason's concept. Now, many have espoused a more dynamic view towards physical landscapes, viewing them as continually shifting mosaics, with different ecosystem types emerging and disappearing (Hill 2015).

Clements’s hypothesis was not entirely wrong, even though Gleason’s individualistic concepts superseded Clements’ organismic concept, and, indeed, certain of his ideas, such as “climax community”, have been largely abandoned. As reported by many ecologists, in their field practice, they are able to observe patterns and collect data to support both views. Several have even reported that Clements’s model was, in fact, more effective in restoration and preservation ecology (Barbour 1995). Further evidence appears to suggest that plants are more connected than previously thought. For example, since the 1980s, mycorrhizal networks have become a trending topic of research in ecology. Mycorrhizal fungi create underground hyphal networks that connect individual plants, and plants use this network to “communicate” with each other by transferring water, nutrients, minerals, allelochemicals, and even defense signals (Simard et al. 2012). Mycorrhizal networks demonstrate that individual species do connect to each other, and on a level more literal than Clements’s sense.

In a way, both Clements and Gleason told portions of the story. Many ecologists now agree that plants in different places, with different spatial and temporal scales, can exhibit different degrees of connectedness as well as interdependency; thus, Gleason and Clements can be placed at different positions on a spectrum, between randomness and structure (Egerton 2015). If we observe across different scales, temporally and spatially, what we observe as stable is merely a relatively stable state in the course of evolution. For example, researches have framed future sea-level rise as a threat to coastal cities, and scientists project that, by the end of this century, the global average sea level will have risen approximately one meter. However, according to researchers, the sea level has climbed more than 120 meters over the past 20,000 years. It was not until 5000 years ago that sea levels reached a relatively stable state, when humans started to build concentrated settlements (Figure 7). We have studied coastal ecology for fewer than 200 years. Hence, on a geological time scale, what we have observed as a stable state is merely an observation confined by the thresholds of human perception.



*Men-nefer (Memphis), the capital of ancient Egypt during the Old Kingdom (c. 2686 - 2181 BC)
**Chang'an, the capital of China during the Shang Dynasty (1600 BC -1046 BC)

Figure 7. Post-Glacial Sea Level Rise and Cities.

Credit: Robert A. Rhode, Global Warming Art Project, Wikimedia Commons. Cities annotation added.

If Gleason's model did not completely replace Clements's concept, then what has altered in this paradigm shift? Analyzing their underlying conceptions of nature can help answer that question. Clements's organism metaphor was based on a conception that nature is a static entity, and its "pristine power" returned it to post-disturbance equilibrium. Clements preferred order and predictability. In contrast, Gleason's model emphasized chance and embraced indeterminacy; it portrayed a version of nature that was less predictable and in constant flux. In this paradigm shift, what fundamentally changed was our tolerance for unpredictability. In other words, it was not that Gleason's model was closer to truth, but after the 1950s, its underlying conceptions of nature found favor with other ecologists. "A non-equilibrium view of natural processes has literally changed the way scientists think about the nature of nature; they now frequently see change as probabilistic and multidirectional, rather than as a progressive march toward clear endpoints" (Hill 2015, 131).

Another aspect of the first wave was that the position of humans in nature had changed. Ecology as a scientific discipline bore an early subject-object structural influence within science, and until recent years, ecologists had studied a version of nature without humans in it. Over the past three decades, ecologists began to pay attention to human activities as essential parts of the ecological process. For example, the concept of *panarchy* was developed by environmental scientist Lance Gunderson and ecologist C. S. Holling to explain complex relationships between human and natural systems. Panarchy articulates a series of continual adaptive cycles of growth, accumulation, restructuring, and renewal, in interlinked human-nature systems (Gunderson and Holling 2001). It is a concept that underpins many contemporary terms in environmental discourse, such as adaptation, resilience, and adaptive management.

In a similar vein, "anthroecology", proposed by environmental scientist Erle Ellis, advocates studying ecology under the premise that humans have always been important to ecosystems. Anthroecology is a reflection on the epistemology of ecological science, and challenges ecologists to confront the muddle of the anthro-ecosystem (Ellis 2015). Admittedly, the author might have deployed a better term, since "human-nature system" and "anthroecology" seemingly suggest combining human and nature, articulating two kingdoms of force, when, in fact, these concepts are meant to challenge people to talk about nature with humans as an important ingredient.

We also observe the shift of concepts of nature in the practice-oriented disciplines. The notion of “pristine nature” provided moral imperatives for a plethora of environmental and ecological practices. Perceived stability in the ecosystem was often rendered useful, and provided a baseline to measure the imagined pristine state; thus, many environmental practices tend to encourage this apparent stable state through efforts in preservation, conservation, and restoration. For example, since the mid-1950s, the discipline of landscape architecture has adopted ecology as a model with which to approach landscape design. Landscape architect Ian McHarg introduced ecology and the scientific method into the discipline through teaching and practice in the mid-twentieth century. McHarg updated map overlay with ecology, to form an organizing framework through which to examine the interactions of nature’s “layers”, including geology, hydrology, vegetation, soil, and land use. The McHargian design method was essentially a reworking of Clements’s ecological succession model, given that Ian McHarg began practicing and lecturing in the 1950s, when Clements’s model still dominated the understanding of ecological succession. It is a version of ecological determinism that implies a linear progression of ecosystem evolution; given the right environmental conditions, ecosystems may reach the desired primal state. Using solid boundaries and hatches to represent different features unavoidably freezes space and time, and presents a static view of nature.

In his seminal book, *Design with Nature* (1969), McHarg repeatedly utilizes the concept of climax stage to describe ecological succession with a definite end. Moreover, throughout his book, he positions humans and nature against each other, describing them as “diametrically different environments, the poles of man [*sic*] and nature” (McHarg 1969, 1). McHarg’s rhetoric, while compelling, describes a desired homeostatic state, and advocates that landscape architects achieve this stability through design choices.

The McHargian design approach represents many ecological practices in line with the transformation formula; by maintaining one of many ecosystem states, humans can further benefit from a perceived stability.

In contrast to the McHargian design paradigm, the next generations of landscape architects inherited the ecological design framework, but updated their ecological concepts and fundamental conceptions of nature. First, many have taken on an emergent view of ecosystem dynamics. Rather than projecting a clear endpoint and design for a stable state, these designers recognize that ecosystems are in constant flux, and evolve over time, so that design strategies should promote this evolution and account for emergence. For example, in the entry for the Toronto Downsview competition (1999), the Field Operation and Stan Allen, working with ecologist Nina-Marie Lister proposed a framework that reflects this shift of conception. The proposal "imagined physical scaffolds that would sponsor the propagation of emergent ecologies, natural systems that would be seeded initially and evolve over time with increasing levels of complexity and adaptability" (Reed and Lister 2014b). Landscape architects are no longer interested in designing a stable ecosystem as McHarg did; instead, they prefer to design a flexible framework that allows ecosystems to evolve. Second, many have recognized human activities and participation in system evolution. Field Operation's emergent framework is achieved by an adaptive management strategy, which requires constant human maintenance based on long-term monitoring and observation. Contrasting the McHargian design paradigm, which relies on "the power of pristine nature" to undo human disturbances, the new paradigm of ecology-based design envisages frameworks that allow humans to engage actively in ecological processes.

In summary, in the first wave of the shift, the conception that “nature is a static entity out there with humans disturbing (transforming) it” was abandoned. In terms of the transformation formula, the “pristine” quality is only a perceived stable state on a specific spatial and temporal scale. Humans do not transform nature; we are always among the forces that give rise to the “pristine”.

4.2. From Scientific Fact to the Social Construction of Nature

A critical transition in the second wave of the shift is the ascendance of constructivist epistemology and the understanding of nature as a social construct. Second-order cybernetics and the STS movement led to a broad-based reflection on knowledge and scientific facts, claiming that society actively constructs knowledge. Sciences do not reveal facts. Instead, these facts are consensus-reached within a scientific community.

The concept of paradigm may further illustrate how societal values influence scientific research. Introduced by Thomas Kuhn in *The Structure of Scientific Revolutions* (2012), paradigm means a set of models, worldviews, or frameworks agreed upon by a scientific group, to define the subject and the method of their study. Doing research in a given paradigm, using Kuhn’s term, is doing “normal science”, which only further articulates the existing theoretical and methodological framework. However, different voices challenge the received models, and incommensurability emerges between different competing paradigms. A paradigm shift occurs when the majority of the scientific community reaches a consensus and agrees on a set of new theories and methods. Paradigm shift implies that revolutions in scientific research are historically contingent. They consist of intentional choices made by scientific communities, which are inseparable from their socio-cultural backgrounds.

For example, the ecological paradigm shift in the 1950s mirrored a broader socio-cultural change in post-war America. American society began to embrace “technological, social, and cultural actions that celebrated individualism, rebellion from previous norms, and a profound acceptance of uncertainty" (Barbour 1995, 249). This societal movement manifested in many aspects, including the civil rights movement that embraces individual importance; anti-socialism; laissez-faire individualism in the political stage; expressionism and existentialism in art and philosophy; and the rise of post-structuralism in the intellectual arena (Barbour 1995). Moreover, since the mid-twentieth century, developments in research, such as second-order cybernetics, general systems theory, and chaos theory, contributed to the American psyche, to embrace individualism and revolt against conventions and norms. Scholars were ready to change in explaining how nature works, from an individualistic and indeterministic point of view.

Ecologists' understandings of how the nonhuman realm works depend on what sort of lens they deploy to observe it, but the lens they choose is essentially an image of the society, laden with socially and culturally specific values. Rather than the truth of how nature works, ecology is more of a model that reflects societal values in the conceptions of nature. The paradigm shift in the science of ecology serves as evidence for the social construction of a nature thesis.

Taking on the constructivist mentality reveals that "nature" is a problematic term. When we speak of the nature of something, we imply an end of a dispute, a final definition, and an ideal form of how something ought to be. As a result, when we pour culturally specific values into the term "nature", we assume these values to be universally true (Cronon 1995b). In the end, it is these values that underpin how models of nature are constructed and used to justify our actions. One cornerstone in this wave of reflection is the anthology *Uncommon Ground: Toward Reinventing Nature* (1995). The entries posed critical questions: Whose nature to protect? To which time of history do we recover? What values have we poured into the term "nature"? For example, wilderness was one of the themes challenged in the anthology. Many conservation and preservation narratives were underpinned by a myth of "pristine nature" that was worth protection, and thus wilderness played an irreplaceable role in environmental narratives. However, when environmentalists regarded the Amazon rainforest as “jungle” and wilderness, they were, in fact, talking about the homes of indigenous people who had transformed and managed the rainforest for centuries (Cronon 1995a; Slater 1995). Beyond wilderness, the entries in the *Uncommon Ground* also explored topics such as the Edenic theme in Western culture, the commodification of nature, simulated nature, and other critical and occasionally controversial issues.

The role of landscape architecture in constructing nature was also recognized and accurately reflected by one contributor, landscape scholar Ann Whiston Spirn. Spirn examined Frederic Law Olmsted’s practice in the late nineteenth and early twentieth century. She recognized the contribution of the profession in translating cultural understandings of nature into public landscapes. More importantly, she revealed the double-edged legacy of Olmsted. On the one hand, Olmsted established a tradition in the landscape profession of creatively applying environmental knowledge. On the other hand, his creativity was based on an image of the landscape, where the design spaces resembled natural scenery, and thus they were not adequately valued as human constructs. For example, people objected to removing the trees which Olmsted planned to cull, because they assumed the built landscape was natural (Spirn 1995, 111). By constructing “natural scenery”, Olmsted unwittingly reinforced an image of pristine nature that belonged to a small fraction of humans with the privilege to conceptualize. Here, the landscape image became a repository for the socio-cultural values of nature.

Spirn’s analysis reflects critical questions posed to the landscape architecture profession during the 1990s. Does landscape design simply reinforce a biased version of nature? If not, then what should be the role of this discipline? In response to these questions, a new narrative has emerged to articulate the role of landscape architects in contemporary society. The broader goal for landscape architects is to expand the category of aesthetic experiences of nature beyond the picturesque, sublime, and beauty and to cultivate new definitions of aesthetics that promote an ecological and biocentric worldview (Meyer 2008; 2017). For example, Teardrop Park in New York City, opened in 2004 and designed by Michael Van Valkenburg Associates, is an example of heightened natural experiences. The 27-foot high, 168-foot-long stacked bluestone Ice-Water Wall creates a displacement of local geology and display of microclimate. Because this retaining wall faces northeast, cold weather in wintry New York City freezes the water seeping through the bluestone stacks. Ice forms on the wall, resonating with the phenomena found in the mountains of northern New York State. Here, the designers do not seek to reconstruct natural scenery -- layered rock piles and stacked bluestone walls resemble nothing natural. Instead, the wall elucidates and amplifies freeze-thaw phenomena, using constructed landforms and microclimates, and the designed landscape encourages people to find excitement in the mundane natural phenomena surrounding them. This design may be juxtaposed with William Cronon's arguments: "[t]o think ourselves capable of causing 'the end of nature' is an act of great hubris, for it means forgetting the wildness that dwells everywhere within and around us" (Cronon 1995, 89). To prevent "the end of nature" serves as a moral imperative to protect the wilderness, but protecting a "wilderness" forces people to ignore the "wildness" around them. Teardrop Park's ice wall pushes the boundary of what it means to construct nature beyond beautiful scenery, by directing people's attention to the "wildness" within an urban environment.

While environmental historians provided verbal critiques, contemporary landscape projects such as Teardrop Park serve as a physical response to the darker side of environmentalism. In the constructivist narrative, landscapes are by-products of culture and repositories of values. New generations of landscape architects provide an alternative and more positive way to understand the social construction of nature. Projects like Teardrop Park are evidence that society can construct versions of nature that are not pristine, and that recognize the wildness of the nonhuman realm through landscape design. Landscapes should be not only repositories of cultural values, but also experiences that are didactic, teaching new morals, ethics, and ecological values.

In the second wave of the shift, social constructivism ascended as a conceptual framework to elucidate nature and its cultural meaning. In the transformation formula, "pristine nature" is a culturally specific concept constructed by a fraction of humanity. For others, "pristine nature" might be their home, and transformation means exploitation. Moreover, because of the environmental movement, "pristine nature" becomes a myth in which to inject all sorts of environmental values. When people transfer these values into actions, they reinforce a version of nature that has already been narrowly defined.

In the context of America, pristine nature points to a time when the early colonialists discovered the "new" world. Concepts such as wilderness were constructed to reinforce this origin, and many environmental practices are justified to protect it. The social construction of nature reveals an obstruction difficult to overcome, because to challenge the transformation formula in the American context is to challenge the myth of origin. However, what we thought pristine was produced by those who came before us, human or nonhuman; what we thought natural was already invested with human values. Most importantly, if we focus too heavily on "pristine nature" out there, we ignore the wild nonhumans around us and how they influence the shared environment in meaningful ways.

4.3. From Anthropocentrism to Nonhuman Agency

Constructivist and critical reflections in the 1990s not only made clear that "nature" was a complex and problematic concept, but also revealed a deeper irony. To claim that nature is a social construction is yet another level of human hubris. To use the term “nature” to study the nonhuman realm becomes useless, since, in the end, what we study is simply a set of human values. Late twentieth-century constructivism backfired. No matter how reflective we are, the nonhuman realm remains outside our conceptual framework. The authors whose work appears in *Uncommon Ground* (1995) recognized this irony and the limitations of their constructivist framework. For example, when Cronon encouraged readers to focus on the “wildness” within and around them, he attempted to devise another framework to study nonhumans -- a framework that focused on the intrinsic values of nonhumans, free from human standards. As Spirn noted, “[t]here is always a tension in landscape between the reality and autonomy of the nonhuman and its cultural construction… nature may be constructed, but it is not *only* a construction” (Spirn 1995, 113).

The way scholars approach the nonhuman realm in the twentieth century has been influenced by a deeper structure – the humanist worldview since the Enlightenment. The hierarchical ontology and anthropocentric values justify human survival at the expense of those on “lower” levels of the survival pyramid. The humanist view evolved into a deep-rooted criticism that haunts the contemporary environmental discourse; the nonhuman realm remains as a necessary resource for human use, and environmental practices merely provide patches that sustain an outdated socio-cultural system, be it capitalism or neoliberalism, to keep up with exploitation of other species and their habitats. The view of nature as resources subject to human use reinforces the transformation formula by associating profit with transformation. The *usership* narrative is diversified by a *stewardship* narrative: not only should we use nature as resources, but sustain it for further use. This narrative deceptively conveys both a sense of right and one of obligation to protect for further exploitation. Ecological thinking and practices are reduced to indispensable adjuncts of exploitation, rather than a lens through which we may recognize the autonomy and agency of the nonhuman realm.

For example, “ecosystems services” essentially justifies the concept that the nonhuman realm is destined to be transformed into resources to serve humans. In this vein, a seminal paper, “The value of the world’s ecosystem services and natural capital” (Costanza et al. 1997), became a widely cited study which people have used to place price tags on the nonhuman world. The paper’s underlying incentive is to call for us to care for the nonhuman realm. However, examining the nonhuman realm with a socio-economic lens implies and further justifies the attitude that “nature” is valuable only where it is transformed into capital.

Furthermore, because we understand the ecosystem as “services” for human society, the nonhuman realm becomes “replaceable” and “renewable”. “No net loss” is a wetland preservation policy goal in the United States. “No net loss” means that governments and agencies must balance “unavoidable” wetland loss -- due to economic development -- with wetlands restoration, mitigation, and reclamation efforts. The goal is to ensure that the total square-mile area of American wetlands either remains constant or increases. For example, in a wetland assessment report for a traffic corridor improvement project, an agency noted:

> “The assessment of functional values is based on the understanding that certain wetlands are more valuable, offer more functions, and are of a higher quality than others. Wetlands with a higher standard of functional quality should be avoided as much as possible. Furthermore, they require a higher level of compensatory mitigation compared to impacts to poor quality wetlands with low functional values” (VDOT 2007).

We should praise the fact that the agency recognized differences between wetland types. However, a wetland connects to a broader landscape mosaic, and destroying one wetland in one place while restoring another at a different site would fundamentally alter two larger ecosystems, for better or worse. Increasing the total area does not mean an increase in the overall integrity of the larger ecosystem. The report quoted above demonstrates that agencies recognize the vagueness of the definition of “no net loss”, and use extra caution when implementing the policy, by comparing different wetlands. Nevertheless, this line of narrative – placing values on wetlands based on how much functionality they offer – reveals a deeper issue in the “no net loss” policy; it ignores the internal complexity of a wetland as the habitat for countless nonhuman species, including animals, plants, fungi, and microbes. From a perspective of a wetland species, destruction is irreversible, and the restoration of a separate piece of wetland in no way makes amends for the loss of habitat and home.

Anthropocentrism manifests itself in landscape planning and design. Since Olmsted, the profession has always asked nonhumans to serve human society. Ian McHarg introduced systemic ways to design according to nature’s instrumental values. Equipped with updated ecological concepts, the next generation of landscape architects argue for “landscape urbanism” – a new framework of urban growth that revolves around landscapes, rather than infrastructures and buildings. Landscape urbanism should be recognized for its role in expanding the boundaries of what landscape design may accomplish, despite critics calling it a mere rebranding strategy. It should also be praised for its effort to blur the discipline boundaries by turning landscape into a model for other professions and disciplines, such as urban planning; architecture; real estate; law; and civil engineering. However, landscape urbanism is essentially an update of the McHargian approach, and bears similar critiques; it is “a dynamic outcome of ecological determinism *plus* economic determinism” (Steiner 2008, 149). In landscape urbanism narratives, the ecological function is deeply integrated with economic growth.

New York City's High Line is an example of landscape urbanism. It expanded landscape architectural practices to urban infrastructure renovation by transforming an abandoned elevated railway in West Manhattan into a crowded urban park. Indeed, the High Line inspired numerous railway line renovations in cities across the world. Many of these cities saw potential, not in the urban habitats they provide for nonhuman species, but in the consequences of doing so: economic growth and increased property values. According to The New York Times and New York City Economic Development Corporation, between 2003 and 2011, property values of residences around the High Line grew 103%. Landscape urbanism thus exploited and instrumentalized an ugly ramification of public parks, rebranding it with an economic justification. Moreover, even though "landscape urbanism" reflects the humans-nature dichotomy by exploring urban ecology and hybrid urban-natural systems, ironically, it reinforces this dichotomy by asking what further nonhumans are able to provide to serve human society.

Recognizing the intrinsic values of nonhumans is not a new idea. "Deep ecology" emerged as a philosophical concept in the 1970s. Norwegian philosopher Arne Naess coined the term to recognize the intrinsic values of other species, and the whole of the ecosystem, regardless of their instrumental values to human society (Naess 1973). This argument posits a non-hierarchical, flat ontology, and underpins many contemporary arguments in political ecology and environmental ethics. Along the same lines, concepts such as *ecosophy* and *ecophronesis* ask questions of how to think and act wisely. These ideas posit that the survival of humanity requires the co-flourishing of the more-than-human whole (Naess 1989; Xiang 2016). They transform the concept "humans transform and use nature" into "co-flourishing of the more-than-human whole". This transition cultivates a sense of care and moral imperative that differs from many environmental efforts. We protect nonhuman species not because they are useful to us, either immediately or in the foreseeable future, but because human survival depends on the co-flourishing of both human and nonhuman realms.

The "nonhuman turn" becomes the theme of the third wave of conceptual shift. Scholars take "nonhuman agency" as a conceptual framework with which to re-think nature. Such models as actor-network theory (ANT); assemblage thinking; object-oriented philosophy; and vital materialism have been discussed across disciplines, including landscape architecture. Despite the distinct metaphors deployed in these ideas, almost all remove humans from the source of agency, and hold that human agency is distributed across a network of human and nonhuman, living and nonliving things. In feminist materialist Jane Bennett's words,

> "What this suggests for the concept of agency is that the efficacy of effectivity onto which that term has traditionally referred becomes distributed across an ontologically heterogeneous field, rather than being a capacity localized in a human body or in a collective produced (only) by human efforts" (Bennett 2010, 23).

In contemporary design and planning disciplines, a "nonhuman turn" mirrors intellectual development within humanities and social sciences. "Multispecies co-production" emerged as a concept in urban planning theory. Drawing ideas from multiple intellectual traditions such as feminist materialism; "more-than-human" geographies; multispecies ethnography; political ecology; environmental humanities; and associated fields, "multispecies co-production" calls urban planners and designers to recognize that urban futures must be co-produced by and for both human and nonhuman agents. It challenges planners and designers to expand their moral, ethical, and political considerations to include the nonhuman realm, and in such a way as to cultivate relations that may nurture multispecies co-flourishing (Houston et al. 2018).

To a certain extent, landscape architects have always practiced a co-production mentality and posthumanist ethics. For example, when describing the oyster reef project in New York City, landscape architect Kate Orff rendered a shared urban public space literally co-produced by oysters, with a human culture built around them. The designers envisioned a landscape mosaic, which they called "oyster-tecture", to provide habitat for oysters to stabilize and clean the water of New York Harbor. Over time, a new shared public space may be created by hardworking oysters, as well as socio-cultural practices such as aquaculture and oyster harvesting. To illustrate the co-production of the urban environment, Orff began with the statement that "New York was built on the backs of oystermen [and oysterwomen], and our streets were literally built over oyster shells" (Orff 2010). To describe her work, Orff notes, "we have forgotten our relationship with the plants and animals that live alongside us and the dirt beneath our feet. And so, how I see my work contributing is […] trying to literally re-imagine these connections and physically rebuild them" (Orff 2010). Orff also used anthropomorphic tones to discuss oysters as working creatures that clean water. Here, anthropomorphism is not necessarily anthropocentrism, and is, in fact, a sense of posthumanism. As Bennett points out, anthropomorphism "can catalyze a sensibility that finds a world filled not with ontologically distinct categories of beings (subjects and objects) but with variously composed materialities that form confederations" (Bennett 2010, 99).

The third wave of reflection has given rise to a highly reflexive model of nature undergirded by an epistemological consideration and a new model of knowledge production. The autonomy of the nonhuman realm is irreducible to human discourse, and thus incomprehensible to any human-constructed model. However, in order to survive as a species, we humans constantly construct models that reflect our observed world, and in turn, decide how we choose to interact with the nonhuman realm. The co-production thesis holds that the "ways in which we know and represent the world (both nature and society) are inseparable from the ways in which we choose to live" (Jasanoff 2004). Human knowledge about the nonhuman realm is always situated; it is a result of co-production by both humans and nonhumans. The reason why we are who we are today is inseparable from the nonhuman realm in which we choose to engage. From this point of view, there is no pristine nature at all, because nature, from the beginning, is a result of co-production, both conceptually and physically.

The environment as a result of co-production contains two senses. The first comprises the examples laid out by urban ecologists, landscape architects, and environmental historians. Humans are not the only actors to construct the environment. Other species, too, physically alter the shared environment. The second sense is knowledge production. In a traditional humanist epistemological framework, human exceptionalism leads to a belief that humans are the only ones who can construct models of self, others, and the system in which we are embedded. In contrast, the co-production thesis begins with the premise that nonhumans are also able to construct models about themselves, humans, and their version of the systems in which they are involved. Humans and nonhumans co-evolve and co-produce each other, and the environment is a result of human and nonhuman co-production.

The third wave of reflection also carries significant ethical implications. How we represent the nonhuman realm is inseparable from the model we elect to engage with it; therefore, we must cultivate those models that help us recognize nonhuman agency, the co-evolution of humans and other species, and the co-production of the environment.

5. Posthumanism, Co-Production, and Assemblage

To summarize, tracing the nature-technology edge reveals a body of work exemplified by Leo Marx's and David Nye's arguments. This work demonstrates that, in the American context, the conceptualization of nature and technology as two kingdoms of force was deeply intertwined with the history of colonization. The elements within the transformation formula reinforced each other, creating interlocking stories of how humans use technology to transform nature into habitable landscapes, at the expense of numerous underprivileged humans and nonhumans. Such reasoning underpins contemporary mainstream environmental narratives, and fuels numerous uncritical environmental practices, which aim to protect the nonhuman realm but ironically reinforce the transformation formula to further exploit underprivileged humans and nonhumans. Most importantly, the analysis further illustrates that human exceptionalism is the fundamental premise based on which the two kingdoms of force could be articulated. In other words, a boundary between nature and technology was merely a convenient cover story for human agency and control.

To erase the illusory boundary and bypass the transformation formulas requires a remapping of the relationships between humans, nature, and technology, within a posthumanist framework. Tracing the other two edges sheds light on a posthumanist co-production framework. To study technology and nature, in the end, is to study what it means to be human. In the discourse of nature, scholars have realized that the concept of "nature" fails to capture the autonomy and wildness of the nonhuman realm, and deploying this concept unwittingly reduces the nonhuman realm to a set of human discourses. In response, "nonhuman agency" and "multispecies interaction and co-production" become conceptual frameworks to study the nonhuman realm. In the discourse of technology, historians and philosophers have realized that technology as an all-encompassing concept has prevented us from recognizing co-production between social systems and technological systems, between human and technological artifacts. The two streams of study converged onto a posthumanist framework, which asserts that what we thought to be human agency has always been distributed across a network of entities, including other species, tools, and systems.

How then does this framework help us understand nature and technology? To put it another way, what is the implication of posthumanism in how we conceptualize nature and technology? What do these two terms denote in a posthumanist framework, rather than two kingdoms of force? Most importantly, how do we visualize this "network of things"?

5.1. Assemblage Diagram

In order to answer these questions, we must rely on the concept of assemblage as a metaphor. The work of philosophy is to develop metaphors to help us analyze complex phenomena, such as nature and technology. This is less about truth and more about effectiveness, as well as the visual image which the term helps render. Aside from assemblage, metaphors such as actor-network and nested systems convey the image of a "network of things". Choosing assemblage as a metaphor occurs not because assemblage theory describes the ultimate truth of reality, but because it is a useful metaphor for understanding what technology and nature entail in a posthumanist framework.

First explored by French philosopher Gilles Deleuze and French psychoanalyst Félix Guattari in *A Thousand Plateaus* (1980), "assemblage" supplies a conceptual framework for analyzing social complexity, emphasizing fluidity, exchangeability, and multiple functionalities. The Mexican-American philosopher Manuel DeLanda has updated and developed these insights into a more robust assemblage theory. Assemblage thinking can be observed in the works of many posthumanist thinkers, such as feminist materialist Jane Bennett, STS scholar Bruno Latour, and object-oriented philosopher Levi Bryant. Broadly speaking, an assemblage is a multiplicity comprising many heterogeneous components, which themselves are also assemblages. The relationships between these components are not fixed; they can be "unplugged" and replaced with other parts, or they can be "plugged" into other assemblages. Most importantly, an assemblage has "emergent properties" that are irreducible to any of its parts (DeLanda 2016).

Assemblage thinking is an ontological framework that gives us flexibility to analyze across materially different entities, from mineral deposits and agricultural land to government organizations, policies, and laws. Most importantly, an assemblage can contain components from conceptually quite different categories, such as nature and technology.

Over the years, landscape architects have attempted to incorporate assemblage thinking in understanding landscape as the result of the interactions of more than human agents (Prominski 2014; Davis 2013). We can also take landscape as an example, and imagine a diagram of a nested assemblage (Figure 8).

When we observe this assemblage, we must be able to freely zoom in and out across scales . Zooming in, we observe humans, and nonhuman species, including plants, animals, and machines working on the land. We may zoom in closer, to within these entities, which are also assemblages composed of other components; for example, a human eyebrow contains an ecosystem of microbes. Eventually, we should be able to zoom to the molecular level, visualizing water molecules as assemblages of hydrogen and oxygen atoms, which are themselves assemblages of electrons and quarks. Of course, with the development of physics, other theoretical frameworks, such as string theory and quantum physics, may explain how we want to analyze assemblages. The point here is that, on a micro-scale, categories such as human or nonhuman, nature or technology, living or nonliving, are no longer relevant, because we are all composed of vibrant materials. These materials interact with and co-produce each other to form assemblages, which then take on emergent properties irreducible to any of their parts. These emergent properties are the results of co-production. For example, human assemblages' ability to model nature and technology is essentially a result of a long-term co-evolution with other, nonhuman, assemblages. The models make sense only within these interactions, or within the assemblages which humans form with nonhumans. In other words, an assemblage must exist within another assemblage in order to act; an assemblage acts because it is made up of heterogeneous parts. As Bennett put it, "bodies enhance their power in or as a heterogeneous assemblage" (Bennett 2010, 23).

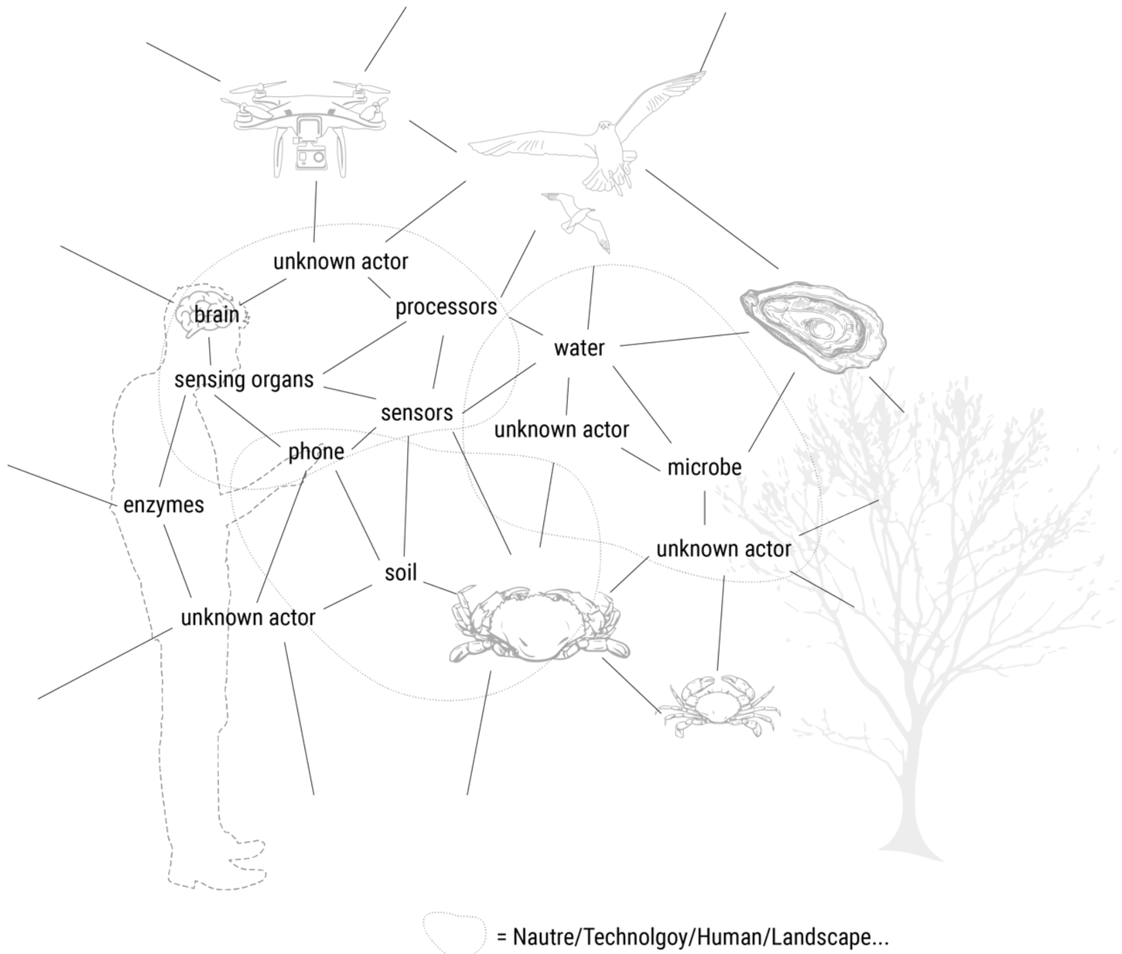


Figure 8. Networks of Assemblages in a Co-Produced Environment

When we zoom out, a landscape assemblage is connected to a broader network of ecosystems, and it duly becomes a working component of other assemblages. Even though assemblage thinking is associated with new materialism, an assemblage need not be physical. A landscape may be temporarily unplugged from an ecosystem, and re-plugged into a social-cultural system, for analytical purposes. Environmental policies and laws, and cultural practices, as well as social values and norms, are attached to a landscape. Together, they form another assemblage, which many would describe as a “cultural landscape”, that takes on different emergent properties. Similarly, a piece of machinery working on the landscape exists within other components, such as markets and engineering labs, as new assemblages which we call socio-technical systems.

Three caveats must be clarified. First, the claim that assemblage can denote any analytical unit may be overly vague. However, due to its very generality and imprecision, the claim provides maximum flexibility to interpret complex phenomena. These new interpretations, in turn, may inspire new ways for us to interact with the phenomena. For example, once we understand a landscape as an assemblage – of humans; nonhumans; environmental laws and policies; intelligent machines; algorithms; and other entities – we may bypass the aestheticized image of the landscape and begin to imagine new ways to influence landscape processes, by developing interfaces through which we interact with these components.

Second, since we can freely zoom into and out of assemblages, one may wonder if there are maximum and minimum ends to this domain of scale. The answer would be “no”, and there must not be caps on this domain; the scale should extend infinitely towards both ends. With the development of science over millennia, humans have expanded their perceptive spectrum. Some phenomena are outside the current human perceptual spectrum, and neither register a signal nor make meaningful impacts as information, but this need not mean they will be meaningless in the future. For example, until fairly recently, we did not know of the existence of mycorrhizal networks and their functions within forests, but these networks have become a frontier of ecological research and design. However, that we move freely across scales does not imply we must analyze a phenomenon across all scales, because certain scales of analysis will not pertain to the question asked. For example, at least for now, it is less meaningful to analyze a landscape on a molecular scale.

Third, and most importantly, assemblage theory, just like the actor-network theory (ANT), is less a theory than a mode of analysis. It claims no truth about the world. It is, instead, merely a lens and framework which we intentionally adopt to interact with the world, because the co-production thesis posits that the ways in which we understand the world cannot be separated from how we choose to live in it. As a consequence, assemblage thinking is an intentional choice if one wants to view a world without boundaries between categories such as *nature* and *technology*. It is nearly a type of belief, as exemplified in Jane Bennett's "litany-like Nicene Creed" at the end of her book:

> "I believe in one matter-energy, the maker of things seen and unseen. I believe that this pluriverse is traversed by heterogeneities that are continually *doing things*. I believe it is wrong to deny vitality to nonhuman bodies, forces, and forms, and that a careful course of anthropomorphization can help reveal that vitality, even though it resists full translation and exceeds my comprehensive grasp. I believe that encounters with lively matter can chasten my fantasies of human mastery, highlight the common materiality of all that is, expose a wider distribution of agency, and reshape the self and its interests." (Bennett 2010, 122).

5.2. Post-humanism and Ambiguous Boundaries

Using the assemblage diagram, nature, technology, landscape, and human become concepts which are co-produced by heterogeneous assemblages, and these concepts can be represented as amoeba shapes circling these assemblages in a heterogeneous field (Figure 8). Again, amoeba shapes provide yet another metaphor, because the shapes' boundaries are fluid and constantly shifting. As we have seen, what nature, technology, and landscape mean is highly dependent on the perspective of the observer, and meanings may be historically specific.

For example, on the one hand, social constructivists viewed nature as a socially constructed idea laden with culturally specific values and norms; whereas ecologists perceived nature as a research object to be examined under a scientific apparatus. On the other hand, nature in the early twentieth century meant a static nonhuman realm, with humans disturbing it. However, towards the first years of the twenty-first century, nature took on the meaning of "dynamic and continually changing systems", with humans as involved, major factors. Similar examples may be found in the history of technology. The concept had pointed to a branch of study of the mechanic arts in the late nineteenth century, but by the early twentieth century began to denote unprecedented, progressive human power. The meaning of the term expands and shifts as society assimilates new technological artifacts and innovations. The term *landscape* does the same. Its meaning transitioned from the early *Landschaft* – people working on the land – to an aesthetically pleasing view. Within the profession of landscape architecture, landscape may mean an assemblage of human and nonhuman actors that co-produce the shared environment.

Most importantly, the narratives of nature and technology in America reveal that the transformation formula required a wielder of the powers belonging to the two kingdoms of force. The early settlers needed a concept of *human* that was constructed as the source of agency, to tell the second creation story, which, in fact, was a muddled interaction and co-production of human and nonhuman assemblages.

As posthumanist proponent Katherine Hayles notes, "[m]astery through the exercise of autonomous will is merely the story consciousness telling itself to explain results that actually come about through chaotic dynamics and emergent structures" (Hayles 1999, 288). In America, the human in the transformation formula was simply a character which early colonists invented to attribute agency and to make sense of perceived causality – unlimited technological power plus natural abundance yielded the middle landscape. Thus, the concept of human in the transformation formula is merely a version of the mapping of other concepts – a specific arrangement of knowledge. As Michel Foucault famously put at the end of *The Order of Things* (1966), the appearance of humans was nothing but “the effect of a change in the fundamental arrangements of knowledge…If those arrangements were to disappear as they appeared…then one can certainly wager that man would be erased, like a face drawn in sand at the edge of the sea” (Foucault 1970, 422).

Assemblage thinking is a posthumanist idea, since *human* in this diagram is understood as distributed systems. Human capacities which we thought originated from the human body are, in fact, achieved through a network of nonhuman assemblages. Even the human body itself is a heterogeneous assemblage of a plethora of nonhuman and non-living entities. As a consequence, the boundary of *human* becomes as ambiguous and undetermined as other terms -- nature, technology, and landscape.

Unlike many approaches -- coupling, hybrid, and cyborg -- that attempt to dissolve the boundaries between these categories by joining the opposite sides, assemblage thinking does not eliminate the illusory boundary at all. Instead, it renders an ontological framework in which drawing boundaries become less important, if not completely useless. In this diagram, the categories become assemblages, with overlapping, constantly changing amoeba shapes, and any static images of landscape, humans, technology, and nature become ephemeral and contingent to the context of analysis.

With the assemblage diagram, there is no such entity as “the environment” but always “an environment of”. The term *environment* implies the exterior of these assemblages; the term is akin to its original sense, as in “environs”, denoting the exterior of a system. If one draws a boundary around certain assemblages and names them human, then what exists outside this boundary is the environment of the temporary "human assemblage" to which we attribute agency. Moreover, because the boundary of the "human assemblage" constantly shifts, the environment of the "human" becomes ambiguous. For example, when someone uses a smartphone's online map to navigate through a city, that phone, the online map database, navigation algorithm, the human body, and many unknown actors form a temporary working "human assemblage" to perform the task of way-finding. Whatever temporarily exists outside this system of analysis becomes an ephemeral environment of this "human assemblage".

From this vantage, a diagram of assemblage replaces the transformation formula to explain how the environment works. Concepts of nature, technology, landscape, and human point only to temporary working assemblages with ambiguous boundaries. Most importantly, the tension between nature and technology, as well as the garden-machine motif, are dissolved within the field of heterogeneous assemblages.

5.3. Adaptive Management and Cybernetic Environments

With this assemblage diagram, the examples found at the beginning of this chapter – new machines in new gardens – may be reintroduced to explore the implications of this post\humanist framework on how emerging cybernetic technologies can be conceptualized in the co-produced environment.

One of the frontiers of environmental management discourse may be described within a sensing-modeling-actuating and feedback cybernetic model. Built around this feedback loop is the idea of adaptive management, which is a philosophical approach that underpins most contemporary environmental practices. It is an iterative approach for decision-making, to reduce uncertainty over time via system monitoring. Adaptive management holds that uncertainties occur in environmental systems, and there are no final solutions to perceived problems. Once actions are taken, the baseline shifts, and it is essential to monitor the system evolution, update the models, and take further action. Adaptive management may be described as a "learning-by-doing". To a certain extent, adaptive management is a large-scale cybernetics experiment that turns the environment into a cybernetic machine whose behavior can be nudged in a desired direction by humans.

The South Florida Everglades Restoration Project is a widely discussed case study for adaptive management. Historically, South Florida has primarily consisted of freshwater marsh and ridge slough formations. The region has been gradually populated over the past century; today, the eastern shore of Florida is massively developed, with a human population of six million. The human habitat is the result of intensive engineering efforts that redirect water from the Everglades and into the Gulf of Mexico and the Atlantic Ocean. One major project was 1948's Central and Southern Florida Project, which included 1,000 miles of levees, 720 miles of canals, and approximately 200 water control infrastructures. The subsequent reduced water flow caused the decline of wildlife, plus saltwater intrusion, among other environmental crises in the Everglades region. In 2000, the U.S. Congress authorized The Comprehensive Everglades Restoration Plan (CERP) to improve the ecological integrity of the Everglades through adaptive management strategies. In today's South Florida, the primary water control system includes approximately 2,200 miles of canals and 2,100 miles of levees/berms, more than 778 water control structures, 621 project culverts, 84 pump stations, and approximately 3,500 hydrological monitoring stations at more than 625 flow sites, including 200 rain gauges and 27 weather stations. The sensor data were used to build and calibrate models to simulate system performance under different conditions. For example, the South Florida Water Management Model is a widely used tool for analyzing operational changes to the complex hydrological system in South Florida, and provides information for decision-making. The model was built with climate data from 1965 to 2005, and calibrated and verified using water level and discharge data collected by sensing stations throughout the region. The simulated components include rainfall; evapotranspiration; infiltration; overland and groundwater flow; canal flow; canal-groundwater seepage; levee seepage; and groundwater pumping. The model also includes water management control structures and their operational rules (for instance, when to open a flood gate or a spillway). With this model, one may simulate a proposed operational rule or control strategy, and evaluate its impact on the regional hydrological system.

With models, sensing networks, and actuators, a feedback loop was established. The South Florida water system is envisaged as a huge cybernetic machine, and humans can nudge its system dynamic towards an intended direction expressed through a set of goals: improved water quality, groundwater level, increased wildlife species, and other environmental metrics. Further control strategies will be implemented, and the models will be further calibrated with new sensory data arriving every day. Adaptive management is thus actualized by reducing management to a series of sensing-predict-control feedback loops.

However, through this example, we observe an apparent environmental narrative built around an updated transformation formula – humans managing natural systems via cybernetic technologies. A clear boundary thus exists between nature and technology, and an image of *human* acts as the source of agency, ultimately controlling the system. The adaptive management framework encourages a school of environmental practice to view cybernetic technologies as a layer of infrastructure added to the environment to extend the imagined human control. Sensors, models, and actuators become distributed surrogates for humans to construct an illusion within which human agency and control may be perceived, articulated, justified, and measured.

The concept of state-space representation can help explain the illusion of control. In modern control theory, a dynamic system may be represented as a set of state variables, which are a minimum set of variables of the system that can adequately describe the system. The set of possible combinations of state variable values represents the state space of the system; at any given time, the state of the system is represented as a vector in this state space. For example, the data from monitoring stations – including water depth; water velocity; rainfall; groundwater level; and other environmental variables – are essentially state variables used to describe the South Florida hydrological system. If one believes that these state variables can adequately describe this system, then one can know how the system performs over time by monitoring only these readings. Moreover, these state variables also establish clear goals for decision-making; if we want to increase water quality, we need only implement strategies to boost the readings of certain monitoring stations. State-space is essentially a form of knowledge representation. Adaptive management through cybernetic technologies envisages different types of environment as environmental systems, so that they may be reduced to a knowledge base represented as a set of state variables whose value evolve. Through environmental sensing, what is being constructed is essentially a state space of the environment, a “datascape” made of ones and zeros.

For example, smartphones typically possess sensors, including gyroscope, accelerometer, magnetometer, and GPS. The Google Maps algorithm employs user location data to model traffic conditions and advise on navigation. In 2020, a German artist, Simon Weckert, strolled around Berlin with a cart containing 99 borrowed smartphones. This effort successfully tricked the Google Maps algorithm into believing heavy traffic jams occurred. Here, the Google Maps algorithm is essentially a state-space model. The sensing network reduces the urban transportation system to GPS readings of smartphones; most of the time, this state-space model is representative and useful. However, it is impossible for the algorithm to recognize when readings are off, because the state space is the full reality for the map's algorithm. We cannot blame the Google Maps algorithm, since, in the "reality" of this algorithm, an increase in GPS pings signifies more cars on the street, so that, in this reality, traffic jams *did* occur. Similarly, when a self-driving car collided with a pedestrian, it was not because the car did not "see" the human, but because, in its constructed state space, no human existed. This line of argument is further supported with second-order cybernetics, which claims that systems do not have direct access to the outside reality, but only to a "reality" constructed by the system operation – the sensing-modeling-actuating feedback loops.

A state space never fully represents the environment. From a systems perspective, the environment is an open system with an infinite number of state variables; to capture them all is impossible. However, from a posthumanist perspective, even to conceive of the environment as an open system is great human hubris, as it presumes that systems theory can capture reality. Posthumanist ideas, including new materialism, assemblage thinking, and object-orient philosophy, all posit a perpetual surplus in assemblages, which cannot be reduced by any form of human representation, including systems thinking. Systems thinking itself, in the end, is a human construction; the acts of sensing and monitoring reduce nonhuman realms to ones and zeros that make sense only in human discourse. In the end, adaptive management itself becomes a practice of manipulating numbers in a grand simulacrum; this version of the cybernetic environment presents an illusion of human control.

As posthumanism proponent Katherine Hayles (1999) asserts, de-centering the human from the source of agency presents terror, but, more importantly, it also reveals hope. A posthumanist attitude regarding adaptive management provides a critique, but also a sense of humility, relief, and opportunity. Not only do humans lack direct access to the outside reality, but no systems, assemblages, agents, or actors have such access. Niklas Luhmann, who has developed systems theory in the field of sociology, argues that “humans cannot communicate…only communication communicates” (Luhmann 1994, 371). From a posthumanist perspective, any systems -- human and nonhuman, living and nonliving – fail to communicate with each other. Instead, they produce models of each other through interactions, calibrate these models through feedback, and form loose and flexible assemblages through co-production. The shared environment is a by-product of co-production and a result of feedback loops between different assemblages attempting to calibrate models of self and each other. The environment has always been cybernetic; it is the boundary between nature and technology, as well as its embedded anthropocentrism, that prevents us from perceiving the environment “cybernetically”.

Anthropologist and cybernetician Gregory Bateson provided a similar way to understand why the environment has always been cybernetic. In his *Mind and Nature* (1979), Bateson uses “mind” to encompass any systems and aggregates of phenomena, including thought, evolution, ecology, life, and learning. “A mind is an aggregate of interacting parts or components” (92), he declared, and mental process “is always a sequence of interactions *between* parts” (93). Thus, for Bateson, the environment is a result of different “mental processes”, and human minds are merely part of a set of greater “mental processes”, which we call ecology. Here, the concept of mind is, to a certain extent, equivalent to the concept of assemblage; yet the former emphasizes system operations (mental processes), while the latter, assemblage, emphasizes the distributed quality of minds.

This realization grants hope and opportunity. In the light of posthumanism, control becomes an illusion, and cybernetic technologies become instruments for constructing a grand simulacrum. However, a positive side is that the “illusion of control” becomes the only way for us to participate in the co-produced future; thinking through cybernetic technologies is one kind of "mental process" which humanity can offer to the ecology of minds. From this perspective, the idea of a cybernetic environment is not a type of human hubris, but a great humility that requires deep reflexivity.

Adaptive management embraces uncertainty. In practice, most become routines that reduce uncertainty over time, yet reducing uncertainty does not equal *embracing* uncertainty. To embrace uncertainty, one must be ready to locate opportunities within a wide range of possible outcomes, including those we may, at first, describe as failures. We must be prepared to attune to the assemblages around us. Recognizing that control is an illusion lends us, in fact, a sense of relief, because we need not pursue unrealistic goals, but instead focus on calibrating our own mental models with increased empathy towards other minds in the environment. Knowing that the environment has always been cybernetic encourages us to think like other minds and potentially learn from their mental processes. Most importantly, we may ask what role cybernetic technology plays in the "ecology of minds". With assemblage thinking, cybernetic technologies are no longer a layer added to the environment to extend imaginary human control; instead, they become essential agents for a co-produced future.

CHAPTER TWO: INTELLIGENCE OF CO-PRODUCTION

1. From Agency to Intelligence

A goal of this research is to search for new strategies in environmental design and management by turning to landscape design as a model to help us navigate within the posthumanist cybernetic environment. Posthumanist proponents have asked us to cultivate empathy towards the nonhuman realm, hoping for moral actions generated from this new awareness. However, empathy and an adapted “Nicene Creed” are insufficient, since in real-life scenarios, we face the conflict between scholars’ far-reaching but wishful thinking, and outdated environmental design and management strategies that prove incompatible with assemblage thinking. In the light of posthumanism, the human image becomes a distributed network of assemblages without clear and static boundaries, and human agency is understood as acentric. However, terms such as *design* and *management* in their traditional senses have been envisioned based on a clear human image and centralized agency. How might we re-conceptualize design and management within a new ontological framework? What does a design and management strategy look like if human agency is understood as distributive? How do we include nonhuman agency in a co-produced future? These are questions raised by posthumanist scholars, including Jane Bennett, Katherine Hayles, Cary Wolfe, Levi Bryant, Manual DeLanda, and Graham Harman.

One way to address these questions is to investigate how different posthumanist ideas conceptualize nonhuman agency in the assemblage diagram, so that we can reconfigure the concept of design to incorporate nonhuman agency. Since the 1990s, this investigation has elicited a series of intellectual development in the humanities and social sciences, known as the “nonhuman turn”, as scholars favor theoretical and philosophical approaches that seek to de-center humans from the source of agency, and emphasize the agency of nonhuman entities

(Grusin 2015). This chapter first presents a group of representative posthumanist ideas in the nonhuman turn, including ANT, vital materialism, object-oriented ontology, and ontology of machines and media. These ideas are presented as a progression from human agency to agency of material and assemblage, and from post-attribution of agency to searching for an inaccessible "surplus" in objects.

Tracing these ideas concerning nonhuman agency reveals two findings. First, a tension emerged from these ideas -- the tension between individuals and distributed effectiveness, or the tension between "the stubborn reality of individuation and the essentially distributive quality of their affectivity" (Bennett 2010, 229). In a way, this tension is an inherent paradox in searching for nonhuman agency, since attributing agency solely to individuals conflicts with the understanding of agency as distributed across a field of heterogeneous assemblages. In the assemblage framework, there must never be a source or a center from which agency is generated; instead, we must daily confront individual objects and systems, and when discussing agency, we still need to rely on individualistic terms such as "nonhuman" or "human" agency. To a certain extent, different post-humanist concepts, such as actor-network, assemblage, object, machines, and vibrant matters, attempt to provide new vocabularies and metaphors to resolve the tension between individuation and distributed effectiveness. For example, ANT uses actor-network as a metaphor for how nonhuman actors participate in social assemblages, and diversify human agency. Similarly, materialist feminism scholar Jane Bennett turns to what she names "mater-energy" as a concept that cuts across living and non-living things, and thus, through a type of monism, dissolves individuals within a field of vibrant matters. On the other hand, object-oriented philosopher Levi Bryant reinforces individuals, and uses the concept of "gravity" and "gravitational field" to explain how objects influence and modify each other's agency through mediation.

This dilemma, between individuation and distributed effectiveness, relates to the second finding: the surplus in nonhuman assemblages. No matter how many nonhumans we summon to attribute agency, this “nonhuman agency” is forever a perceived effectiveness in human terms; at their best, nonhumans can only diversify and hybridize human agency. This is why OOO proponent Graham Harman completely bypasses the concept of agency in order to search for the inaccessible “surplus” in objects. In fact, these posthumanist ideas, except perhaps for several versions of ANT, all share a concept of “surplus”, which denotes unknowable aspects of assemblages beyond any form of human access. Thus, OOO argues that objects are withdrawn from direct access, and aesthetic experiences and metaphors serve as indirect access to real objects. To a large extent, we may use the OOO framework to re-articulate design practice as a way to constantly create metaphors – unusual connections between objects – so that different objects or assemblages can exploit each other’s surplus, and produce shared effects.

The terms “metaphor” and “exploiting surplus” point to another concept – intelligence, or the ability to acquire and apply knowledge creatively. Advances in artificial intelligence and machine learning over the past years have provided transformative cases for us to reconsider what intelligence means for humans, animals, machines, and other assemblages. Considering intelligence, using posthumanist and assemblage thinking, constructs a framework within which intelligence becomes another posthumanist concept to cut through the field of heterogeneous assemblages and reveal how different assemblages co-produce and co-evolve. Most importantly, the concept of intelligence can reveal a different perspective with which to consider the role of intelligent machines in the co-produced environment.

2. Searching for “Nonhuman Agency”

This section considers four representative posthumanist ontological frameworks that are influential in contemporary environmental design discourses. They are actor-network theory (ANT), new materialism and material agency, object-oriented ontology (OOO), and ontology of machines and media (or machine-oriented ontology: MOO).

2.1. Actor-Network Theory

In the English context, actor-network theory (ANT) often suggests a method of analysis developed by Michel Callon, Bruno Latour, and John Law over the past several decades in the field of science technology and society (STS). Chapter One explored ANT in the context of the social construction of technology (SCOT) movement in the 1980s, and STS scholar Weibi Bijker regarded ANT as an approach with which to analyze how technology was made (Bijker 2010). Bijker’s categorization was a strict reading of ANT in the SCOT context. Rather than a version of strict constructivism, the true implication of ANT lies in its ability to counter radical social constructivism by including nonhumans as actants that shape society. We may understand ANT as a corrective framework that emerged in the late 1980s to reflect on the prevailing radical constructivism of the time. The concept of ANT suggests that anything in the social and natural world exists only in a continually shifting network, and that there is no exterior social force except what is in the network acting and being acted upon; “entities are constituted by the relations that they are enrolled in” (Müller and Schurr 2016, 220).

Outside the STS context, ANT was introduced to the broader intellectual debate by Bruno Latour, and in the twenty-first century it has become a widely used framework to analyze nonhuman agency. For instance, Jones and Cloke (2002; 2008) have chosen trees as examples to consider how nonhuman agency manifests in the actor-network. They proposed four ways in which nonhuman agency can be considered. The first is “agency as routine actions”. For example, trees have agency because of a series of ongoing processes, such as reproducing, bearing fruit, and colonizing. Second, nonhuman agency can be considered as transformative action. Trees can autonomously seed themselves and grow in unexpected places and forms, and "when remixed with the social aspect, these actions can have creative transformative effects" (Jones and Cloke 2008, 81). Third, nonhuman agency can be considered as purposive action. To account for the intentionality that is often associated with human agency, but without falling into a form of reductionist essentialism, the authors have coined the term "purposive agency" to describe the process whereby a tree can execute a plan inscribed in its DNA. The fourth is agency as non-reflexive action. The notion of human agency is commonly built around creative or reflexive actions, which require agents to set goals, reflect on the intention, prioritize, and rework goals. Trees are able to exercise a type of non-reflexive form of agency, through hybridizing human creativity. They can "engender affective and emotional responses from the humans who dwell amongst them – to contribute to the haunting of place via exchanges between the visible present and the starkly absent in the multiple and incomplete becoming of agency" (81).

Jones's and Cloke's analysis displays struggle: in attempting to attribute agency to trees, they found themselves in the awkward position where they are unable to locate intentionality, reflexivity, or creativity – the concepts associated with human agency – in trees; thus they were forced to subjugate trees to human interpretation in an actor-network. What nonhuman agency genuinely means in their analysis becomes the roles which, through narratives, the narrators assign to the nonhuman actants.

The authors' struggle reflects a paradox in deploying ANT as a framework for conceptualizing nonhuman agency; this paradox is a manifestation of the tension between individuation and distributed effectiveness. In order to recognize the contribution of the nonhuman realm to the shaping of the social, ANT posits a flat ontology, an equal treatment for both human and nonhuman, or, as many ANT scholars would call it, “generalized symmetry”. This version of flat ontology that treats human and nonhuman on equal terms allows ANT to recognize “the agency of non-humans as an essential element in how the natural and the social flow into one another” (Jones and Cloke 2008, 84). However, ANT “has rejected the non-human/human distinction” (85), and renders a “hybrid collectif” in which agency is relational and distributive. Thus, ANT “[subjugates] the specific importance of individual actors within networks, in order to focus on the multiplicity of mutually constitutive and positioning ‘actants’ which together serve to hybridise agency” (80). In other words, neither “human agency” nor “nonhuman agency” exists. Human and nonhuman “actants” form hybrids that “are then seen as mobilised and assembled into associative networks in which agency represents the collective capacity for action by humans and non-humans” (85). Clearly, ANT is essentially a version of assemblage thinking, and it “sees agency as a distributed achievement, emerging from associations between human and non-human entities (the actor-network)” (Müller and Schurr 2016, 218).

Analyzing the context in which ANT was first introduced in the 1980s can further illustrate that, within it, nonhuman agency plays the role which nonhuman actants play in human narratives. By the 1980s, social constructivism had advanced in the field of STS as a major framework of analysis to challenge the notion of “ready-made technology” in technological determinism, but this approach unavoidably presumed a “ready-made society”. The innovative aspect of ANT was to regard biological and technological nonhumans as actants that were an essential part of society. However, an actant or actor plays a role in a narrative only through its society-generated meaning. Therefore, to exercise agency, nonhumans must be subjugated to the actor-network createdby human interpretation. In ANT’s framework, nonhumans can never truly exercise agency outside the actor-network, because they must be transformed into actants that function in a set of human narratives.

Thus, ANT is still a human-centered undertaking, merely a step towards posthumanism. Perhaps because of ANT's humanist undertaking, posthumanist Cary Wolfe has analyzed a range of posthumanist thinkers; Latour barely made into the "posthumanist posthumanism" category, and nearly fell into "posthumanist humanism" (Wolfe 2010, 125). In a way, ANT is restricted by its original goal to "reassemble the social", and it presents society with both human and nonhuman actants. At its best, ANT redefines what "social" means by including nonhumanity as part of what we had thought to be humanity, but it never intended to ask the question, "What does nonhumanity mean?" To consider the nonhuman realm is, for ANT, an afterthought, not an element for which ANT was initially designed. We may update and develop the concept, as others have done, but this sort of over-interpretation only makes the already complicated concept slipshod. Today, one must deal with "post-1999 ANT", "Latourian ANT", "more-than-Latourian ANT", and numerous interpretations from scholars and commentators (Müller and Schurr 2016, 226). One must also distinguish between "younger Latour" and "older Latour". Different interpretations of ANT have backfired, since ANT was never intended to be a theory, but an analytical framework, to be practiced rather than explained; excess articulations made it rigid and even useless. Instead, we must focus on the similarities and differences of its underpinning ontological framework to other posthumanist ideas, and extract useful concepts to nurture the thesis of co-production of the environment.

Müller and Schurr (2016) observe similarities between ANT and assemblage thinking, in at least four aspects: they both 1) "have a relational view of the world, in which action results from linking together initially disparate elements"; 2) "emphasise emergence, where the whole is more than the sum of its parts"; 3) "have a topological view of space, in which distance is a function of the intensity of a relation"; and 4) "underscore the importance of the socio-material…that the world is made up of associations of human and non-human elements" (217). They also detect a difference between the two concepts. Even though assemblage thinking acknowledges the influence of an assemblage upon its components, through what DeLanda describes as "downward causality", any element in an assemblage may be "unplugged" from that assemblage and "re-plugged" into another (DeLanda 2016). In this view, nonhumans are not entirely bounded by the relations or the "actor-network" in which they are enrolled as actants, but they "always exhibit a surplus, something that is outside relations, and enables them to plug into other assemblages" (Müller and Schurr 2016, 220).

Perhaps this "surplus" is the "nonhuman agency" for which Jones and Cloke searched in trees. However, ANT's underlying ontological framework cannot hold such a "surplus". To resolve the tension between individuation and distributed agency, ANT turns nonhuman into actants whose roles can be assigned only by the narrators; this "surplus" is overwhelmed by the roles they must play. Such ANT terms as "actants", "translation", and "free association" render it more of a linguistic analysis, which cannot account for physical interactions between the human body and other material bodies. For example, in Jones's and Cloke's analysis, the transformative agency of trees is more than a result of mixing with the social aspect. When the root of a street tree cracks a hard pavement, so that pedestrians adjust their steps to bypass the obstacle, the roots' impact is physical and material; this transformation is more than an actant in the human narrative. Contemporary landscape architects have explored this for decades. In SCAPE and Kate Orff's oyster-tecture project, Orff is well aware that the oysters participate in the project more diligently than their socio-cultural roles in wishful design narratives; most importantly, their ability to participate in hydrological and ecological cycles in the urban environment strengthens the urban ecology in constructing a new sort of public space. Is the “surplus” a type of material agency? This question might be better analyzed through Jane Bennett’s vital materialism, which may be understood as a materialist’s approach to ANT.

2.2. Vital Materialism

Bennett’s thinking is instrumental for new materialism and political ecology. Bennett refuses to draw a clear boundary between ANT and assemblage thinking; she works with both ideas by jointly using their vocabularies. In her view, agency is confederate and distributive. Drawing from Spinoza’s conative bodies, Bennett (2010) states that “bodies enhance their power in or as a heterogeneous assemblage”, and “…the efficacy of effectivity to which that term [agency] has traditionally referred becomes distributed across an ontologically heterogeneous field, rather than being a capacity localized in a human body or in a collective produced (only) by human efforts” (23). Vital materialism acknowledges the network and confederate status of things; Bennett argues that “there was never a time when human agency was anything other than an interfolding network of humanity and nonhumanity” (31). She draws ideas from Francois Julien’s reflection on a Chinese concept, *shi*, to formulate her discussion of the agency of assemblages. “*Shi* is the style, energy, propensity, trajectory, or élan inherent to a specific arrangement of things…*shi* names the dynamic force emanating from a spatio-temporal configuration rather than from any particular element within it” (Bennett 2010, 35). A detailed exploration of *shi* is beyond the scope of this research, and we can understand *shi* as similar to “surplus”, a type of emergent tendency or propensity due to a specific arrangement of materials.

In ANT’s framework, human agency is the model for agency; in Jones’s and Cloke’s analysis, the notion of agency was associated with concepts such as creativity, intentionality, consciousness, and free will. In ANT’s framework, there is still a liberal human subject who can exercise free will; from this vantage, ANT is not a posthumanist idea at all. Unlike ANT, vital materialism does not assume a clearly bounded human body, or any bodies. The human body "is material, and yet this vital materiality is not fully or exclusively human", and for vibrant materialism, the human is "an array of bodies, many different kinds of them in a nested set of microbiomes" (Bennett 2010, 113). In vital materialism, nonhuman agency, or, to be more precise, material and assemblage agency, became the model of agency. This is a posthumanist idea, because terms such as *consciousness* became concepts invented by human assemblage to describe the observed effectiveness that emanates from the specific arrangement of materials which we conceptualize as human. While ANT exploits nonhumans as actants to hybridize human agency, vital materialism redefines agency as an emergent property of material assemblage, so that the distinctions between human and nonhuman, and even between living and nonliving, grow less significant. Humans, plants, animals, rocks, and soils are all created of matter that is "vibrant, vital, energetic, lively, quivering, vibratory, evanescent, and effluescent" (112). Bennett used these adjectives throughout her works, painting an active and lively world of vibrant matter, and a heterogeneous yet unified field of matter-energy.

Bennett has become a widely read author in the landscape architecture discipline over the past decade, since her positive ontological framework and sensibility towards the biophysical world echo much of what landscape designers and scholars believe. After reading *Vibrant Matter*, Brett Milligan, a landscape educator, averred that "we need a language for reading the landscape and a corresponding design sensibility with similar capacities for inclusion and complexity" (Milligan 2011). Indeed, over the past several years, the vocabularies developed in vital materialism have been incorporated into landscape design lexicons; many designers rely on these concepts to describe a designed landscape as the joint effort of many vibrant bodies.

However, it appears that *agency* as a term is unable to adequately describe that for which Bennett is truly searching. In Bennett's narrative, surplus always exists. For example, towards the end of her arguments, Bennett begins to doubt whether to use *agencies* or *agents*. In one note, she writes, "[a]s I struggle to choose the right term, I confront a profound ambiguity in both terms regarding wherein lies the cause and wherein the effect" (Bennett 2010, 151). Clearly, Bennett wanted to use *agency* to denote an underlying cause -- a mystery "surplus" -- for an agent to act, rather than the perceived effectiveness of the agent's action. Moreover, in many places, Bennett avoids using the notion of agency. Instead, she relies on terms such as affectivity, efficacy, and effectiveness. In the end, Bennett turns to "matter-energy", an outlandish metaphysical term, to describe what the notion of *nonhuman agency* fails to capture.

At this point, it is clear that the notion of "surplus" has emerged as the concept for which ANT scholars and new materialists have been searching, and that the notion of "surplus" is different from the meaning which the word *agency* conveys. Object-oriented ontology (OOO) questions this "surplus" directly, by arguing that objects are withdrawn from any form of access, thus highlighting that "surplus" exists outside our human conceptual framework.

2.3. Object-Oriented Ontology

As Graham Harman (2015) explains, he began to use the term "object-oriented philosophy" (OOP) in approximately 1997, and publicly employed the term in 1999. By 2009, he had been joined by three object-oriented philosophers: Ian Bogost, Levi Bryant, and Timothy Morton. Bryant coined the term "object-oriented ontology" (OOO) as a catch-all for their shared ideas. Though OOO has replaced OOP in many discussions, Harman has noted that he himself reverted to OOP because of increasing philosophical disagreement with Bryant (Harman 2015), yet in *Object-Oriented Ontology* (2018), Harman returned with a full explanation of OOO, and published his version of this somewhat controversial school of thought.

Harman's OOO follows two premises. First, OOO shares a flat ontology with other posthumanist ideas, but it is the "flattest" version, because it claims that the human/nonhuman and thought/world distinctions in philosophy still attribute at least fifty percent attention to humans. In contrast, OOO seeks to produce a flat ontology in which all objects should be treated equally, and humans are only a fraction of a vast, mystical universe. Second, OOO begins by critiquing other philosophical ideas, utilizing a framework which Harman calls *anti-mining*. In addition, OOO claims that, to date, most philosophical analysis has reduced objects to two types of knowledge: over-mining and under-mining. Over-mining explains what an object does, reducing an object to its relationships with other objects. For OOO, ANT is a form of over-mining that reduces nonhuman objects to a set of human relations.

On the other hand, under-mining explains what elements a thing is made of, thus reducing objects to their material components. For Harman, Bennett's vital materialism and assemblage thinking largely belongs to the under-mining category, because this type of knowledge reduces objects to their smaller components. This critique sets up OOO's mission for philosophical inquiry: to ask about the third type of knowledge about objects, which lies beyond direct access and is always "withdrawn" (Harman 2018). Harman's OOO is based on a diagram of the "Quadruple Object" (Figure 9). This object-quality framework consists of two pairs, real and sensual, in both categories. Real objects and qualities are not accessed by any means, and interactions occur only through sensual objects and qualities, or the fictional images which objects present to each other. This inability to access lays the foundation for OOO's ontological framework, in which real objects and qualities are always hidden from access, thus "withdrawn".

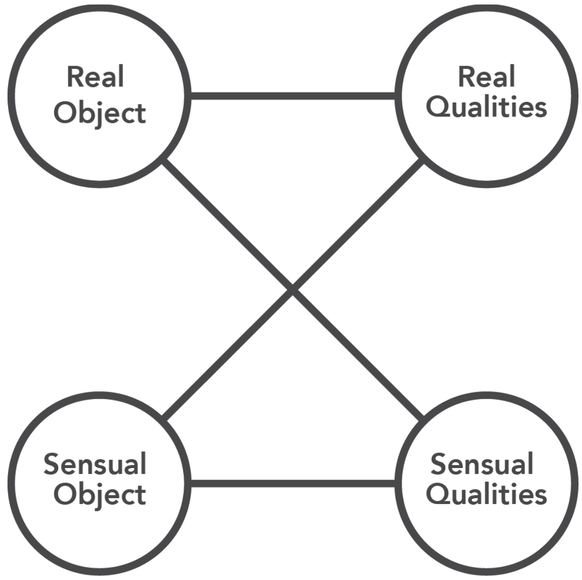


Figure 9. Harman's Quadruple Object Diagram
From Harman, 2018.

Hence, OOO has remained a controversial school of thought, in part due to Harman's straightforward rejection of other ways of thinking, as well as his philosophical approach that emphasizes differences rather than similarities. Architecture scholar Neil Leach (2016) has provided a harsh critique of OOO, yet speaks highly of DeLanda and new materialism in a conference paper for ACADIA (Association for Computer-Aided Design in Architecture). Leach's critique was a response and warning to the growing interest in and interpretations of OOO within the discipline of architecture and its adjacent fields, including landscape architecture. Leach focuses his critique primarily on two schools of thought that influenced Harman's OOO: the neo-Heideggerian approach, as well as the ANT approach to technology. Harman developed OOO within his Ph.D. dissertation on Heidegger and his tool analysis. Leach, however, finds Heidegger's approach to technology problematic, and argues that "[w]hat Heidegger fails to address…is the progressive way that we come to appropriate technology in general, and tools in particular, and absorb them within our horizon of consciousness"; what bothers Leach is that, for Heidegger, "technology is perceived as antithetical to what it is to be human" (Leach 2016, 346). Moreover, Harman has acknowledged that ANT possesses a fundamental influence on OOO; and Leach raises an alarm regarding Latour and ANT, because he finds it problematic to assume that objects act in social networks (Leach 2016). The fundamental problem Leach perceives in OOO is its potential danger for ascribing "agency" to objects, especially technical objects such as digital tools, as if they could think and act.

However, within the quadruple objects diagram, humans as real objects may interact with technical objects through their sensual objects and qualities. In other words, what we thought to be human in Harman's diagram, has always held a proportion of technical objects within it. Harman's framework does not conflict with what Leach believes, that humanity can "absorb" technology. Finding problems in Heidegger that contributes to Harman's thinking in certain ways, is not enough to deny OOO as a whole. Moreover, Leach, like other scholars, confronts multiple versions of ANT that exist in parallel, and it is simple to develop a misinterpretation of the complicated ontological framework of actor-network. As we have seen, in ANT, objects do not truly act, but instead join the actor-network as actants, and hybridize agency. What Leach misses is that the nonhuman has always been involved in an interfolding network of assemblages, and agency has existed forever in hybridized forms. Again, over-interpreting a useful concept such as ANT will miss its similarity to assemblage thinking and new materialism. When Leach argues that humans "absorb" technologies, he essentially restates an ANT notion: ANT argues that technical objects become actants that "act" in human narratives.

Moreover, Leach's argument is, at its heart, a humanist undertaking, and does not venture enough to embrace posthumanism. Leach's concerns about attributing agency to tools does reveal a potential terror evoked by a limited reading of posthumanism as transhumanism – the displacement of humans by intelligent machines. Moreover, a more profound concern is that we may retreat to outdated technological determinism. However, these concerns are caused by bearing in mind a liberal human subject who can exercise free will; as far as one associates agency with this image of the human, one will feel troubled in embracing the agency of other assemblages. To elevate these concerns, one must regard what it means to understand agency as distributive. We may realize that not only does it de-center the human from a privileged position, for exercising agency, but it also de-centers machines from any privileged position to initiate change. If there were anything to call “machine agency” (with which machines can initiate change), it would already be distributed in the socio-technical network.

Thus, OOO is often viewed as a counterpart to Bennett’s vital materialism and assemblage thinking. If vital materialism is a version of monism, which dissolves boundaries between individuals and objects in a field of matter-energy, thus emphasizing relational agency, then OOO celebrates the autonomy of individual objects. In an essay, “System and Things” (2015), Bennett, for the first time, expressed mixed feelings towards OOO’s approach, which renders a muted nonhuman realm by deploying terms such as *withdrawn*. In *Object-Oriented Ontology* (2018), Harman responded to Bennett with “the same mixture of sympathy and unease” (242). Clearly, they share deep empathy and attention to the life of nonhuman things, but Harman viewed their disagreement in three aspects:

> “…OOO does not view the world as a unified whole that is only secondarily broken up into individuals; it does not endorse the concept of matter at all…OOO does not think the ultimate role of objects is doing, which for most of us can only count as a form of overmining” (242).

OOO might become an inspiring concept, but Harman’s reluctance to look for common ground with other post-humanist ideas made OOO a controversial school of thought. In fact, OOO shares similarities with other post-humanist ideas. First, Harman uses the concept of symbiosis to argue that objects do interact and form new objects that exist in their own right. This notion is not at all different from assemblage thinking, which posits that components can form a new assemblage that takes on emergent properties irreducible to any of its components, and thus the new assemblage exists in its own right. From this perspective, the notion that objects may be "withdrawn" might be understood as similar to the notion of "surplus" in assemblage thinking.

Second, Harman discusses how two real objects can interact with each other through the mediation of two sensual objects, or, to use OOO terms, "only by way of the fictional images they present to each other" (Harman 2018, 163). Harman's argument may be articulated by autopoiesis theory, an important concept in second-order cybernetics, developed by Chilean biologists Humberto Maturana and Francisco Varela. Later paragraphs will explore cybernetics in detail. For now, we need only know that an autopoietic system, such as a human, uses inputs to reproduce the organization of its components. Thus, when two autopoietic systems interact, they inevitably reduce each other to a set of "fictional images" through their system operations and self-organization processes.

Third, when Harman analyzes what knowledge means in OOO's framework, he argues that knowledge is about attempting to access real quality through sensual objects -- the image exists in the human mind, but the real qualities of the sensual object cannot be accessed. To maintain the object-quality pair, the real qualities of the human beholder must step in to replace the real qualities of the sensual object. Thus, Harman (2018) argues, "the real qualities in knowledge come from the beholder rather than the sensual object of knowledge itself" (189). Harman then follows with a question: "In what sense does the beholder supply real qualities for a sensual object?" (189). In answer, he eventually turns to Kuhn's concept of paradigm to explain the ways in which real qualities of the beholder develop. However, if we eliminate the complexities within object-quality pairs, we find that Harman essentially argues for a version of radical constructivist epistemology stemming from the idea of autopoiesis: knowledge is constructed by the system to maintain its own system organization. The "real qualities of beholders" are the same as "system self-organization". The notion of an object-quality pair does not make radical constructivism and autopoiesis easier to comprehend.

If there were one difference that distinguishes OOO from other assemblage-oriented posthumanist thoughts, it would be the chicken-and-egg dilemma. While most assemblage ideas, including new materialism, assemblage theory, and ANT, begin with a pre-existing network or assemblage of things, and individuation is a *post hoc* attribution of agency by observers, OOO posits that "the world is home to preexistent unified entities that have individual shapes prior to being encountered by some observer" (Harman 2018, 241). The emphasis on individuals is why Harman and his fellow object-oriented philosophers seek to revive and deploy the stubborn notion of "object" as a metaphor to describe their ontological framework. However, this difference should not cause significant incompatibility between OOO and other posthumanist ideas, if we focus on the larger picture: to look for the "surplus" and "real object" in objects and assemblages.

2.4. Ontology of Machine and Media

Levi Bryant presents an alternative version of object-oriented ontology. Distinct from Harman's negative approach to modern philosophy and intellectual developments, Bryant focuses on similarities, and develops a framework that shifts between separate schools of thought. As he wrote,

> "[w]hat we need is a post-humanist framework that is able to synthesize the findings of the linguistic turn, Marxist thought, Foucaultian thought, media theorists…as well as the posthumanist thought of the ecologists, the new materialists, the actor-

> network theorists […so that] we can begin to develop maps adequate to the political and ethical demands that face us today" (Bryant 2014, 286).

In order to develop this posthumanist framework, Bryant uses the term "machine" in place of "object", in order to embrace that which systems theory and second-order cybernetics offer to this framework, and emphasizes the operations and functions of different entities. For example, he argues that machines are structurally open and operationally closed. These terms are drawn from Humberto Maturana, Francisco Varela, and Niklas Luhmann, key figures in second-order cybernetics and the development of the concept of autopoiesis. Moreover, Bryant uses positive feedback and negative feedback to explain how machines form structural couplings with each other. He also argues that any machine may function as media for another machine. He deploys the concept of "gravity" to replace "power" in other schools of thought, to denote "the way in which the structural openness, movement, and becomings of one machine are mediated by another machine" (193). To a certain extent, we can either understand that Bryant placed a posthumanist touch on second-order cybernetics and systems theory, or say that he introduced systems thinking into object-oriented philosophy. Most importantly, Bryant does not shy from admitting his intention to deploy certain terms to replace others in order to develop a cohesive framework to account for different schools of thought.

In Bryant's framework, there is also a "surplus" in machines; as he argues, "…*machine itself* issuing certain imperatives on its designer that run away from the intentions of the designer" (Bryant 2014, 19). Moreover, in his analysis of different types of objects, he names one category *dark objects*. These dark objects are,

> "thoroughly unrelated to other machines – most importantly, ourselves – that we would have no idea of their existence whatsoever […] Like spirits or ghosts, it is therefore possible that any given assemblage is haunted by all sorts of dark objects

> that do not manifest themselves and that they have no effect on other machines of the assemblage whatsoever" (199).

Bryant acknowledges that this idea appears to be an outlandish metaphysical concept, but he reminds us "not to reduce the world to the machines that we happen to encounter in the world" (200), and not to reduce a machine to its local manifestation. To Bryant, a machine has "a bit of darkness within it", and "[t]he domain of a machine's power is always greater than how it happens to locally manifest itself at any given point in time and under one particular set of circumstances of gravitational relations to other machines" (201). Bryant's "dark object" speaks to the "surplus" of assemblage thinking and the "real object" of Harman's OOO.

Apart from shared similarities, Bryant also provides a posthumanist account for agency. Bryant believes that agency is a concept related to *agent*, and he posits two criteria for a machine to count as an agent. First, an agent is able to initiate action from within itself. Second, an agent must be able to choose whether or not to initiate an action (Bryant 2014, 219–20). From these two criteria, Bryant continues to argue that,

> "agency comes in a *variety of degrees*. Bacteria appear to have more agency than rocks insofar as they seem capable of initiating action from within themselves, whereas rocks cannot, while cats seem to have more agency than bacteria in that they are capable of choosing among broader range of possible actions for themselves" (223).

This quote reveals that Bryant's treatment for agency is heavily influenced by systems theory and cybernetics. At first, it seems that Bryant refuses the idea of agency as distributed across heterogeneous assemblages, and he seems to retain a rigid understanding of agency. In fact, Bryant's agential treatment for agency supplies flexibility, because it ties the notion of agency back to the technique of observation. Through his descriptions, it is clear that he is aware that what he calls “agency” is, in fact, *perceived agency* from his perspective as an observer. This move provides more plasticity to account for different types of assemblages, since as long as an observer or narrator circles around an “individual”, we may observe a certain degree of agency in this individual that is itself an assemblage of heterogeneous components. Because one machine functions as media for another machine, machines can aggregate and form a new agential assemblage that takes on different degrees of agency. Through this agential treatment, the notion of agency is no longer intertwined with “surplus” and “dark object” as an essential quality of an assemblage or as cause to an effect, but an epiphenomenon associated with observations and perceived effectiveness.

3. From Nonhuman Agency to Speculative Ontology

3.1. Agency or Efficacy?

After a review of several schools of thought on the notion of nonhuman agency, a preliminary conclusion may be made to clarify what nonhuman agency, or agency in general, means in a posthumanist assemblage framework. Two models have emerged for conceptualizing nonhuman agency. The first is the notion of “distributed agency” or “assemblage agency”, exemplified by certain versions of ANT and new materialism, especially Jane Bennett’s vital materialism. The second is “agential agency”, represented by Levi Bryant’s machine-media ontology and systems theory. These two approaches appear to conflict; in fact, they propose a tension that reminds us of two crucial aspects when considering agency in the posthumanist framework.

First, assemblage agency is a reminder that perceived effectiveness involves more than an observing agent. The individuation process fixes a scale for observation. It uses the observed effectiveness to generalize a field of heterogeneous components, as if the perceived individual is able to act as the source of agency and as a cause to an effect. The process of individuation thus overlooks the fact that perceived agency is historically contingent, and the components might have been reconfigured in different ways. For example, we attribute observed effectiveness in nature and technology as two generalizing terms, to denote a field of heterogeneous components, as if nature and technology are ultimate causes that initiate change. However, as we saw in Chapter One, these terms have been constructed as arrangements of knowledge, and they might have been arranged differently. Individuation makes salient a “machine” by dimming the “media” around it. An agent does not exist within a vacuum, and its perceived effectiveness is always achieved through other assemblages functioning as media. The extended mind theory posits that humans devolve cognitive functions to the environment, but the human image localizes agency within the human body, which is deeply embedded in a network of systems that make us appear to be able to initiate change.

Second, agency is better understood as perceived agency or observed effectiveness. When Neil Leach critiques Heidegger for ascribing agency to the object, he argues that it is a form of “ventriloquism, of projecting onto the object a form of anthropomorphic agency” (Leach 2016, 348). To a certain extent, the notion of ventriloquism is correct. However, from a posthumanist perspective, what Leach overlooks is that not only ascribing agency to an object, but also ascribing agency to the human, is a form of ventriloquism, in that it constructs an image of the human as a source from which actions are generated. In this way, Bryant’s agential agency reminds us that ascribing agency, human or nonhuman, goes hand in hand with the conceptualization of an agent. Thus, a compatibility thesis may be made between agency and individuation: *agency cannot be separated from the individuation process, and both are the result of observation*. The treatment for agency as an observational strategy in a field of heterogeneous assemblages renders agency into an epiphenomenon, an effect rather than a cause; it is not because an assemblage exhibits a certain degree of agency that it can be count as an agent, but because we individualize an assemblage as an agent, it then becomes a carrier of distributed agency.

Most importantly, the observation of nonhuman agency is made by humans, so that what we understood as nonhuman agency "becomes a matter of attribution, *post hoc* and after the action"; through observation, "some entities are detached from their background and called 'actors'. They are made to conceal and stand for the web of relations that they cover. They become the place where explanation, moral, causal, practical, stops" (Law and Mol 2008, 58).

Searching for "nonhuman agency" thus becomes a false promise; in the end, it concerns summoning more nonhuman agents to expand the field of perceived effectiveness around humans. From this vantage, many posthumanist ideas, at their best, remove the human from the center of agency only by presenting a field of heterogeneous assemblages, or a network of actors where agency is distributed. However, any attempt to describe what nonhuman agency is, such as the transformative agency of trees, points to efficacy, which forces nonhumans to act in a tale which we tell ourselves to diversify and hybridize human agency. This predicament is why Harman tries to distinguish OOO from posthumanism, and argues that posthumanism has alluded to a new paradigm but fails to provide what a new paradigm, an truly posthumanist framework, might look like; towards that end, OOO attempts to provide such a posthumanist framework (Harman 2015). This is, in part, the reason why OOO is regarded by many as a controversial idea, because OOO is essentially investigating a different paradigm. When OOO asserts that objects do not act, it is, in fact, arguing that objects do not *act only for humans*, but also for themselves and other nonhumans. However, many scholars, perhaps even Harman himself, would interpret this claim as a revolt in response to ANT's relational agency. If we regard this paradigm shift more seriously, OOO simply does not care if an object acts or not; instead, it asks about the possibilities of objects, beyond *acting* in an actor-network.

3.2. Posthumanism and Speculative Ontology

We can further map posthumanist ideas on a spectrum which we may call "posthumanist speculation" (Figure 10). Here, posthumanism entails two levels of reflexivity with respect to agency.

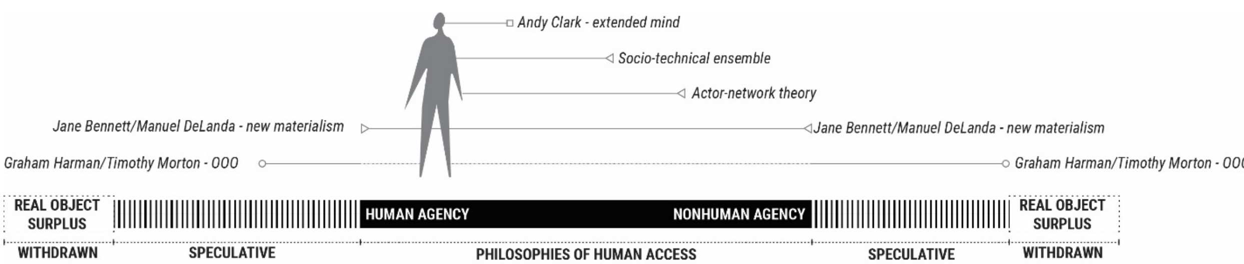


Figure 10. Posthumanist Speculation

The first level of reflexivity may be described as a nonhuman turn, a transition from the social constructivism prevalent throughout the 1980s, to a focus on the nonhuman realm and its agency in shaping human systems towards the early 2000s. In the second half of the 20th century, the social construction of nature and social construction of technology (SCOT) ascend as two fields of research offering critical perspectives on the conception of nature and technology, such as socio-technical ensemble. Although they came from different traditions and relied on distinct frameworks, a common theme emerged in both fields -- the critique of human exceptionalism and human agency in relation to natural and technological systems. Namely, actor-network theory (ANT) ascended from SCOT tradition and became a more general mode of thinking across fields; ANT offered a framework of analysis to consider nonhuman actors and their role in mobilizing social groups and forming actor-networks where human agency resides. The notion of distributive agency dominated intellectual life towards the 2010s.

However, as many posthumanist scholars have struggled to comprehend, even though we embrace agency's distributive quality, we must daily confront individual objects and view them as actors and agents. Thus, one theme cutting across posthumanist ideas is the tension between the distributive quality of agency and the stubborn reality of the individuation of objects as carriers of observed effectiveness. For example, as the term actor-network suggests, thinking itself produces an oxymoron; we have to accept a thing as an actor and, at the same time, a network.

The second shift in post-humanism entails a backlash in searching for nonhuman agency. The reflection of the irony of nonhuman agency has led to the advancement of speculative realism and object-oriented ontology (OOO) since the 2010s. Because stories of how nonhumans structure the human world are inevitably be told by human narrators, nonhuman agency becomes a *post hoc* attribution of observed effectiveness, based on the standards of a human narrator. Applying the conceptual frame of agency, which is, after all, a human-centric concept, to analyze the nonhuman realm, ironically advanced another level of human hubris. Hence, many have struggled with confusion and ambiguity regarding the term *agency,* with respect to wherein lies the cause and wherein the effect.

The incentive for focusing on nonhuman agency was to challenge the human-centric view of agency by searching for that which enables nonhuman actors to act and restructure social networks. This is partly why assemblage thinking and new materialism have become increasingly popular since the late aughts. Scholars such as Jane Bennett have built frameworks upon material agency, imbuing their investigations with mystical terms such as "vibrant matter" or "matter-energy", which allow bodies to interact with each other and form assemblages to gain power (Bennett 2010). Yet no matter how many nonhuman agents we summon to diversify our narratives, we end with stories of observed effectiveness that are relevant to humans. Nonhumans are always actants following the plot of the storyteller. We may conceptualize agency in multiple ways -- distributed or localized, human or nonhuman, material or immaterial – but, in sum, the term *agency* cannot capture a thing’s complete reality.

Once a framework begins to produce paradoxes rather than transformative thinking, it is time to reflect on the framework itself. Many posthumanist scholars have recognized this irony, and accepted the existence of "surplus" in both human and nonhuman assemblages that are irreducible to any form of (human) access. However, because these ideas mainly rely on agency as an important component in their conceptual framework, they will be haunted by the inherent paradox in the concept itself.

Since the early 2010s, object-oriented ontology (OOO) has gained popularity across fields, especially in architecture and landscape architecture. Here, we must understand OOO as a conceptual framework operating in a different paradigm from other posthumanist ideas, such as assemblage thinking and new materialism (Figure 10). They resemble each other in terms of what they critique: the unquestioned anthropocentrism at every level of our thinking since the Enlightenment. Yet OOO takes a different approach, bypassing the notion of agency – a human concept – and directly querying the "surplus" in objects, speculating as to what the world might be like in itself. Hence, OOO is often considered a major tenet in the alleged "speculative realist movement”, despite internal debate and criticism about whether such a movement exists.

At this point, we must recognize that the genealogy presented in this research joins with a broader philosophical reflection across fields. This research provides only a limited perspective – which concerns itself with nature, technology, and intelligent machines – in this broad-based effort to reflect on our human ways of thinking, or what Graham Harman would call "philosophies of (human) access”. It reflects the "prevalent tendency within Kantian and post-Kantian thought to treat the relation between thought and world as the primary subject matter of philosophy" (Young 2019). On this path of reflection, many, such as Bennett, provide ethical and political concerns; others, such as ANT scholars, offer more epistemological concerns. In the end, it is more aptly an ontological concern, since multiple tenets of posthumanism are, to use Harman's terms, "philosophies of access" limited by their "inability – or better, unwillingness – to create a speculative ontology which moves beyond the narrow confines of what is given to our all-too-human modes of understanding" (Young 2019).

Furthermore, we need to acknowledge that a further philosophical project which OOO seeks to achieve is reflection on the "philosophy of access" – not only human access, but all types of access between assemblages. Posthumanist tenets such as ANT, assemblage thinking, and new materialism are all relational, based on the premise that things can interact, communicate, form relational bonds, and enable each other. The relations between them are *a priori* for objects to be significant. This is best exemplified by Bennett's claim that, "bodies enhance their power in or as a heterogeneous assemblage" (Bennett 2009, 23). Indeed, this form of relational thinking aligns comfortably with modern society's ecological concerns, also often understood as relational and active. Moreover, a positive ontology is no doubt favored by the mainstream ideology of diversity that encourages communication and interaction between and among differences.

However, this relational way of thinking runs the risk of undermining and overlooking an entire spectrum of thinking based on the assumption that things do *not* interact, communicate, and relate to each other. It is not that they do not desire to, but they are unable to interact and communicate in the first place. This is an expansion of Niklas Luhmann's infamous claim that "humans cannot communicate", based on second-order cybernetics. This is where OOO differentiates itself from other posthumanist thinking: it seeks to create a non-relational ontology. Here, we further recognize why "agency", as a term, is irrelevant in OOO's framework.

To believe that our thought (or anything's thought) forms a relationship with the world and other thoughts is *a priori* to conceptualizing agency. To think we relate provides the initial urge and motivation to act and to control. As we shall see in Chapter Three, this way of reasoning has also manifested in cybernetics, and modern control theory is based on the premise that recursive processes lead to communication, and communication leads to control.

Thus, what OOO seeks is to render a speculative ontology, so that we may begin to consider things in a non-relational way and speculate how they possibly "interact". There are currently two major approaches within OOO's framework, for speculation. The first approach is to consider what it is to perceive efficacy from a nonhuman perspective. This is known as “alien phenomenology”, proposed by OOO scholar Ian Bogost and widely endorsed by many of his colleagues. The second approach is to construct metaphors, as proposed by Graham Harman. Building on these two approaches, we may consider design as the third approach to speculative ontology.

Alien Phenomenology

Admittedly, OOO scholars are not the first to consider what it is to be another thing. In 1974, American philosopher Thomas Nagel proposed a question in a paper titled “What Is It Like to Be a Bat?” Nagel argued that since we know a bat navigates through echolocation and other behavioral aspects, we may imagine what it is to *behave* like a bat by taking on a bat’s point of view; but we will never know what is it *for a bat* to be a bat. His widely cited assertion held that, “an organism has conscious mental states if and only if there is something that it is like to *be* that organism — something it is like *for* the organism” (Nagel 1974, 436).

However, if we take posthumanism seriously, not only are we unable to access the bat’s experiences as a bat, but it also appears impossible to completely understand what it is to be human. In a posthumanist assemblage framework, what we know as human consciousness and experience are understood as epiphenomena and emergent properties of chaotic interactions between distributed systems, within and around the human body as the localized carrier of agency, it is impossible to define all the systems involved in making us humans.

This is the starting point of alien phenomenology. If accessing both human and nonhuman experiences becomes the same practice of inferences, then what are the analytic, ethical, and political implications for inferring what is to be anything other than human? Thus, alien phenomenology promotes a mode of analysis with a sense of extra attentiveness towards assemblages, in terms of how they interact with and co-produce each other.

Ethically, it “opens the possibility of more compassionate ways of relating to aliens, helping us to better attend to their needs, thereby creating the possibility of better ways of living together” (Bryant 2014, 70). Politically, alien phenomenology may help us understand the flows and operations of large-scale assemblages such as corporations, and “increases the efficacy of our political intervention” (71). For example, because a corporation as a system is operationally more sensitive to profit, boycotts are often more effective than simple protests, because boycotts create events which corporations register as information, to which they may respond with corrective action (Bryant 2014).

Bryant’s arguments ask as to turn from Nagel’s arguments questioning how alien phenomenology can be verified, and focus instead on the implications of such considerations. Even though ascribing agency to nonhumans is a false premise, the way in which we ascribe agency retains profound ethical and moral implications. Since searching for nonhuman agency is all about efficacy and perceived effectiveness, the issue becomes one of which type of conceptualization of efficacy will best serve the needs of humanity, particularly when face challenges, such as climate change. Towards this end, nearly all posthumanist ideas arrive at versions of political ecology that promote the belief that the future ought to be co-produced by more-than-human assemblages. From this vantage, alien phenomenology is never about "aliens", but about ourselves. It is a sort of mental exercise that requires more doing than proving, which helps us stretch the sphere of our moral and ethical considerations to include more of those entities which we thought "others", and cultivate a sense of care, as well as empathy, toward other assemblages.

On that note, let us consider landscape design as a practice of alien phenomenology. When speaking of designers approaching landscape, many landscape architects and designers aver that they must think like mountains, like rivers, like trees. To a certain extent, landscape architects have ever practice alien phenomenology, by considering how different human and nonhuman assemblages interact with their environment and each other, as well as how these interactions may be transformed into creative strategies that foster a shared environment.

Metaphor

When we ascribe agency, what becomes invisible is the "surplus", "real object", or "dark object", a common theme emergent in most of the aforementioned posthumanist ideas, except for certain versions of ANT. They all believe in the existence of something beyond any form of access; in many cases, the terms "nonhuman agency" or "material agency" were deployed. Ironically, the moment "agency" is used to denote some newly discovered efficacy of an assemblage -- for example, the transformative agency of trees in place-making – the term ceases to denote "surplus", and instead speaks to specific relationships that define the assemblage as an actor. To use Harman's term, ascribing agency thus becomes a form of over-mining, which forces the assemblage to act in an actor-network mobilized by humans.

Since agency is understood in conjunction with individuation to denote perceived effectiveness or efficacy, we may detach the notion of agency from the concept of “surplus” or “dark object”. This is, perhaps, why in Harman’s version of OOO, agency was not deployed as a term to explain object interactions, because to use agency to entail perceived effectiveness, which is a form of over-mining, is simply not the question that OOO asks. Because OOO seeks to query the “surplus” in objects, it completely bypasses the concept of agency.

The theme of “surplus” accompanies a predicament. It is a tension between the stubborn reality of ubiquitous “nonhuman agencies”, and our urge to seek and embrace the inaccessible “surplus” in assemblages. In other words, within a posthumanist framework, observing effectiveness and ascribing agency in assemblages becomes a simple task, but because of these ubiquitous “nonhuman agencies”, the “surplus” we seek is overwhelmed by the notion of agency. The problem of agency is that it veils the assemblage’s other potentials, including the potential along its own trajectory, or the intrinsic value of nonhumans.

The inaccessibility of the real object makes Harman turn from “scientism” and “mathematism” and turn to art and aesthetics. Harman believes metaphor provides non-literal access to real objects. He uses Homer’s “wine-dark sea” as an example, to illustrate why metaphor provides indirect access to the real object. In the metaphor, the unusual, sensual quality of “wine-dark” no longer belongs to the sensual object of “sea”; thus it indicates the real object of sea, the unrealized surplus of “sea”. However, a real object is withdrawn from access, so, in this case, the real object of “sea” cannot be accessed. The quality must be paired with an object, so there must be a real object to embrace this unusual, sensual quality, “wine-dark”. In this case, the only real object, the aesthetic beholder, must move forward as a real object, to retain the metaphor. As a consequence, Harman argues, aesthetic experiences such as metaphors hold a high value in OOO's framework. In this way, what concerns OOO is the tension between objects and qualities (Harman 2018).

Design

As discussed above, OOO has gained increased attention in the design professions, especially in architecture, because it provides a framework to re-focus on architectures as objects that possess qualities. Towards the late twentieth century, the rise of critiques on everyday life, urban geography, and urban studies transformed architecture into a byproduct of socio-cultural systems. In response to these emerging critiques, many in the discipline began to adopt systems thinking in order to approach architectural design, and buildings were envisaged through a set of social, economic, ecological, and urban systems. Since the 2010s, some architecture theorists began to resort to OOO due to "a frustration that architecture is increasingly justified solely by its relations and not by its own particular and autonomous qualities" (Gage 2015, 95). In this wave of "object-turn", the Southern California Institute of Architecture (SCI-Arc) has become a frontier. Graham Harman has taught philosophy there since 2016; in 2019, another key figure in the OOO movement, Timothy Morton, joined SCI-Arc as visiting faculty in the synthetic landscape program. Thus, OOO has directly influenced SCI-Arc students' architectural design projects over the past several years. These projects focus on the architectural objects themselves rather than the relationships in which they are enrolled.[12]

In contrast to the architecture program, the synthetic landscape program has a different perspective on OOO, thanks to Timothy Morton. Morton conceptualized the idea of *hyperobject* "to refer to things that are massively distributed in time and space relative to humans" (Morton 2013, 1), such as climate change. By framing climate change as a *hyberobject*, Morton makes it

[12] For example, in their representations, system diagrams or urban mappings – which are conventional in many contemporary architectural practices – seldom appear.

inaccessible; local manifestations of climate change, such as sea level rise, storm surge, and extreme drought are not climate change itself. Hence, the challenge becomes how to indirectly access climate change as an object through design. According to David Ruy, the Postgraduate Program Chair at SCI-Arc, the focus of the synthetic landscape program is to address the issue of climate change, which "is an existential drama that is now unfolding at a planetary scale" (SCI-Arc 2009). Furthermore, SCI-Arc will approach this issue "differently" by not focusing solely on "nature". Ruy then referred to Timothy Morton's *Ecology Without Nature*. In this book, Morton argues that nature is a useless concept in ecological thinking, because ecological thinking "has set up 'Nature' as a reified thing in the distance, under the side walk, on the other side where the grass is always greener, preferably in the mountains, in the wild" (Morton 2012, 3). Morton's argument echoes what Ruy believes:

> ". . . in contrast to traditional landscape design programs that emphasize the stewardship of nature and traditional western cultural values of picturesque or sublime images of nature, this program will challenge the status quo. Instead of being trapped in an environmental melancholy, we would like to see if our design imagination can project an abundant future with new forms of beauty" (SCI-Arc 2009).

We ought to sympathize with SCI-Arc's environmental imperative; however, the SCI-Arc method of landscape architecture is more a commercial strategy than anything new, because the ideas themselves are hardly novel within the "traditional" landscape design discipline. For example, landscape theorist Elizabeth Meyer has discussed hybridity and cyborg since the 1990s, and they were well-received in the discipline by the 2000s. In a way, landscapes have constantly been "synthetic", since they result from the co-production of heterogeneous assemblages, including humans and machines. Landscape architecture is a discipline that grew as a “modern other”, and has been theoretically and historically misinterpreted (Meyer 1997). The urgency here is not in how to “reinvent” landscape and redefine beauty, but in how to challenge Western landscape attitudes widely accepted by the general public. Toward this end, it has already been argued that the task for today’s landscape architects is to cultivate new categories of aesthetic experience, beyond beauty, sublime, and picturesque; numerous designed projects in this vein have been identified and discussed (Meyer 2008; 2017).

Thus, SCI-Arc, as a design institute, has provided an interpretation of OOO in the design professions of landscape and architecture. This effort should be acknowledged and supported, because to create this initiative as an institute requires courage to admit, confront, and challenge the marginalized position of “design” in contemporary culture. In a way, SCI-Arc’s efforts may be viewed as a shared frustration in the design professions, in response to the irony that the more “design thinking” is talked about outside “design disciplines”, the less it is about “design”. In mainstream, techno-scientific knowledge production, design as a practice that produces another category of knowledge has been either ignored or misinterpreted as “creative problem solving”. However, in response to the marginalized position of design, SCI-Arc’s interpretation of OOO misses what OOO truly argues for and what it offers to understand “design”.

What is valuable about metaphor is an unusual connection between two objects; from this perspective, design continually creates new metaphors that fashion unusual connections between objects. On that note, OOO architects’ re-focus on the architectural object must not be a conclusion, but rather a starting point to ask what new sort of unusual relations may be cultivated between a building and its environment, beyond the received model that defines buildings as components in socio-cultural systems. Similarly, the synthetic landscape is less about reinventing “machines in the garden” – technical objects interacting with natural objects

– but asking what other new relationships may be observed in the field of heterogeneous assemblages of machines, humans, and nonhuman species. Mapping new relationships is what landscape architects have done for decades.

For example, SCAPE's oyster-tecture project builds an unusual connection between two objects – public space and oysters. The proposal reveals a new aspect of the "surplus" in oysters, as one co-producer of a new public space. Landscape design allows oysters to manifest their effectiveness beyond what they have been defined as oysters. Yet this unusual connection also reveals what the object of "public space" might mean for a more-than-human public. Therefore, we begin to link the notion of "synthetic landscape" to the tradition of landscape architecture, and identify it as a new front in which to explore novel relationships between machines, humans, and other assemblages in the environment, and how they might co-produce a future.

However, once a metaphor is made and widely accepted, it ceases to be a metaphor; it is instead a reified relationship in our daily encounters. To a certain extent, relations with which we are familiar today were once, in the past, metaphors. Indeed, the tale of oysters and the public landscape is no longer novel, since SCAPE's oyster project has been discussed over the years; thus, oysters' effectiveness in cleaning water and participating in place-making has become a reified agency in the oyster. It now appears nearly trendy to propose a version of oyster infrastructure for a coastal area. This *post hoc* attribution of agency suppresses the oyster's potential effectiveness in other metaphors, as well as the potential for being simply a sea creature. Design becomes an act of continually searching for new metaphors between objects, an act of exploiting the inexhaustible "surplus" from which effectiveness emanates. For this reason, in design professions, designers tend to avoid analyzing "problems"; rather, they explore “potentials”. Replacing “problems” with “potentials” is more than wordplay; it is a constant reminder of the inexhaustible surplus in the most mundane of daily assemblages.

Therefore, design may be understood as an act that identifies unusual connections in the field of heterogeneous assemblages; it is a form of speculation that provides indirect access to withdrawn objects.

How might design create new metaphors between assemblages? How would different assemblages interact with each other, and how do they reveal and exploit each other’s effectiveness? These questions paraphrase another: how do assemblages, human or nonhuman, living or non-living, biotic or abiotic, biological or technical, co-produce each other and the shared environment? Metaphor and design involve creativity and originality, qualities that indicate intelligence rather than agency. There is always that within an assemblage, human or nonhuman, biological or technical, that allows it to reveal and exploit effectiveness in other assemblages. This sort of ability may be understood through intelligence, the ability to construct knowledge and apply it so that effectiveness emerges.

4. Intelligence and Posthumanism

Three motivations introduce the notion of intelligence into the discussion. First, although posthumanist scholars have given sufficient account of nonhuman objects and assemblages, occasionally including infrastructures and computer software, most of their investigations leave intelligent machines, and the concept of intelligence, largely unexplored. Many posthumanist ideas have focused solely on agency, not on the intelligence that is intrinsic in originating a sense of agency; we assume an object that acts to be intelligent. The agential treatment in many ML algorithms imagines a machine as an agent that can observe and act in various environments, through cybernetic mechanisms. The ML cases begin to build connections between cybernetic thinking and how agency is conceptualized through recursive processes.

Second, this research focuses on the role of machines in environmental practices. Most importantly, it concerns the following question: what type of role can intelligent machines play -- other than as tools of control -- in our speculative experiments in constructing the environment? To answer, we must understand not only the technical capacity, but also the mode of thinking that undergirds contemporary AI research. By analyzing ML cases, we begin to elicit their inherent presumptions in understanding machines as tools of optimization that extend imagined human agency in managing the environment.

Third, even though the boundary between nature and technology dissolves in the field of heterogeneous assemblages, agency's individuation process leads to tenacious objects such as machines, plants, animals, and humans. For example, even though the idea of "synthetic landscape" seeks to challenge the meaning of nature in contemporary culture, it unwittingly establishes a binary between machines and biological objects. On SCI-Arc's website is a photograph of a robotic arm cultivating grapes; it appears as though to consider cybernetic technology in landscape design is merely using advanced technologies to automate and optimize natural processes, so that severe climate change may be averted. With insufficient caution, "synthetic landscape" will become yet another version of adaptive management, which views machines as a layer of control strategies through which humans manage natural processes.

Intelligence cuts across different assemblages, and reveals shared abilities or tendencies of the assemblages exploiting each other's surplus and producing effects. Most importantly, unlike agency that emphasizes individuation, intelligence involves interactions between individuals. However, introducing the concept of intelligence faces three challenges: anthropocentrism, means-end reasoning, and individualism. By deconstructing these three obstacles, we can restructure a posthumanist concept of co-productive intelligence.

4.1. Anthropocentrism and Universal Intelligence

Human, machine, and animal intelligence

The Merriam-Webster online dictionary defines intelligence as "the ability to learn or understand or to deal with new or trying situations […] the ability to apply knowledge to manipulate one's environment or to think abstractly as measured by objective criteria (such as tests) […] the act of understanding" (Merriam-Webster n.d.).

Though unspecified, these definitions point to a human cognitive capacity, including learning and applying knowledge. In other words, in order to discuss and define intelligence, we maintain a human image in our minds, and then venture to consider cognition in other, nonhuman entities, such as animal and machine intelligence. Anthropocentrism and human exceptionalism are both deeply embedded in the concept of intelligence. However, a posthumanist framework is interested in how different assemblages, human and nonhuman, living and nonliving, co-produce each other, and anthropocentrism and human exceptionalism in the concept of intelligence are the first obstacles to overcome. In recent years, the research on machine intelligence has shed light on this issue, and may help to map a posthumanist understanding of intelligence.

Machine intelligence has long been an important frontier in intelligence research. Can machines think? In 1950, Alan Turing (1912-1954) proposed this question and the famous Turing test to argue that machines *can* think. The Turing test involves three players: a human interrogator in one room, with a human player and a machine in a separate room. The discriminator will try to discern between the machine and the human only by asking questions, without seeing them. Another way to understand this game is that the machine will try to imitate the human player, and deceive the discriminator to believing that the machine is a human. In the 1950s, the idea that machines might be able to think was radical, people then were hesitant to attribute intelligence to a machine. Currently, with advanced machine-learning techniques, the issue has become that of how much more intelligence might be built into a single machine. What made Turing a truly visionary thinker was that he proposed theoretical strategies for learning machines, which he called “child-machines”, which learned through random mutations and natural selection (Turing 1950). His strategies underpin many of today’s most advanced machine-learning techniques.

However, the Turing test, as well as the notion of “child-machine”, reflects the fact that, from its earliest stages, machine intelligence has been envisioned based on human intelligence. The Turing test essentially proposes to evaluate machine intelligence based on its resemblance to human behavior. We have been fascinated to do so; the first thing people do to test a powerful machine is match it with the best of its human competitors and watch it vanquish them. Over the years, many cases have been reported and discussed: Deep Blue (1997) defeated Garry Kasparov, the best human chess player; AlphaGo and its successors (2015-2019), which trounced many of the best GO players; AlphaStar (2019), which mastered StarCraft, a real-time strategy video game notorious for decision-making based on incomplete knowledge; and OpenAI Five (2016–2019), a team of five separate AI agents that worked together and out-performed a human team in the game of DOTA2, known for its real-time collaborative strategies and corporations, as well as the ability to understand another player’s intentions and act accordingly.

Underpinning our obsession for pitting humans against machines is, ironically, a sense of human exceptionalism. The unstated belief is that humans are the most intelligent entities on Earth, so if a machine out-performs, or at least matches, humans in one aspect, that is seen as a breakthrough. It is an ambivalent state of mind. People hope to build powerful and intelligent machines, yet the notion that another entity could replace human capacities evokes terror, because it means that humans will be removed from the top of the intelligence pyramid. However, we know ourselves to be machine creators, so intelligent machines are merely one more testimony of human exceptionalism. In fact, our obsession with human-machine intelligence reveals another level of technological sublimity – the mixed sense of terror and joy. For this reason, over the past decades, technological dystopia has become a popular genre in television. Many televised franchises imagine a version of artificial superintelligence gone rogue; it attempts evil plans to end humanity. However, accompanying our terror is a sense of sublimity, because these are, after all, fantasies that pose no real threat. Most importantly, these shows inevitably end with humanity regaining control over the rogue AI, reassuring the audience with a sense of human exceptionalism.

Other forms of intelligence are also measured against human intelligence and cognitive abilities. For example, when evaluating animal cognition, the common criteria used include teaching; short-term memory; causal reasoning; planning; deception; transitive inference; theory of mind; and language. Based on these criteria, a significant gap has been found between human and animal cognition (Premack 2007). Nevertheless, these evaluative criteria are modeled in favor of the human. Moreover, popular science reports that dogs are as smart as a human two-year old, and dolphins are even more intelligent. This type of comparison essentially treats animals as diminished versions of ourselves, reflecting deep human exceptionalism in how we understand and discuss animal intelligence.

Over the past decades, plant intelligence has emerged as a topic. In one study, researchers demonstrated that plants possess learning and memory, too, through systems unique to them. For example, *plasmodesmata*, a type of intercellular organelle found only in plant and algal cells, are crucial for plants to transmit information (Trewavas 2003). Yet research still attempts to locate human cognitive faculties in plants, rather than discussing plant intelligence *for* plants. These examples speak to an intrinsic bias on the topic of nonhuman intelligence – comparing other entities with the human image. If there were a test of intelligence based on olfactory senses, then many animals, such as dogs, would be far more intelligent than humans. Human exceptionalism in intelligence simply delays the possibility of discovering and embracing how nonhuman entities interact with their environment in entirely different ways.

Furthermore, speaking of human intelligence unwittingly evokes an image of a perfect human being, and gives rise to a series of problematic interpretations similar to those that fueled scientific racism and discrimination narratives through the twentieth century. The concept of intelligence has long been intertwined with the intelligence quotient (IQ) test. French psychologist Alfred Binet (1857–1911) invented the first practical IQ test, which was later translated into English and revised in 1916 as the Stanford–Binet Intelligence Scales. Intelligence tests were quickly adopted as tools to explain racial, class, and sex differences – however narrowly "intelligence" was defined by the tests -- justifying all sorts of disturbing narratives of colonialism, slavery, social Darwinism, and racist eugenics (Belkhir 1994; Dennis 1995; McNally 2020).

The problem of intelligence is not the concept itself, but its embedded human exceptionalism, as well as the urge to use a perfect European male image of the human as a reference for measurement. It ignores the fact that our cognitive functions are a result of the long-term co-evolution of human and other nonhuman assemblages, including other species, languages, tools, and other distributive systems. If we take human-machine intelligence as an example, we see that what we thought was human intelligence may instead be understood as an outcome of co-production between humans, transistors, and circuit boards. To a certain extent, building an intelligent machine is replicating arithmetic and logical operations on electronic circuits.

The central processing unit (CPU) in any computer is little but a conglomeration of transistors wired in specific ways to compute logical and arithmetic statements through the binary language of ones and zeros. However, several early electronic computers were not binary computers; they were ternary, with three states, or even quinary, with five. Problematically, the more intermediate states, the harder it becomes to keep them separate, because disturbances such as power surges, low voltage, or electromagnetic interference causes mixed signals. Binary was simple to track, since it gives distinct signals of "on" and "off". Most importantly, before the twentieth century, an entire branch of mathematics – Boolean algebra – already existed, which dealt exclusively with true and false values, so the rules and operations to manipulate ones and zeros were already figured. Many saw Boolean algebra as the foundation of modern computer science theory. Self-taught English mathematician George Boole developed Boolean algebra in *The Mathematical Analysis of Logic* (1847), in which he presented the truth as systematically and formally represented through logic equations. Unlike the algebra we are familiar with, in Boolean algebra, instead of numbers, the values are true and false, and instead of add, subtract, multiply, divide, the operations are AND, NOT, and OR. For example, if A is true, and B is true, then A *and* B are true.

Conveniently, transistors can be wired in ways to build different types of logic gates and perform these Boolean operations. The assemblage of these logic gates is called the arithmetic logic unit (ALU), which is central to any modern computer. Building computing machines has thus long been viewed as a way to formalize and represent human logical reasoning through material assemblages. Although Boolean algebra laid the foundation for modern computers, the material reality of transistors and electronic circuits eliminates other possibilities regarding how human logic may be systematically and materially formalized.

In this regard, quantum computing sheds new light on other aspects of human logic. Quantum computing has gained increased attention over the past thirty-plus years, because a qubit (quantum bit) possesses three states; it can be in quantum states, which means a state between 1 and 0 with certain probabilities; but, when measured, a qubit is in the superposition of either 1 or 0 states. Thus, if classical computing uses Boolean logic to erase uncertainty by choosing between 1 and 0, then quantum computing harnesses the power of uncertainty and embraces the ability to be either 1 or 0. For this reason, a quantum computer presents different material assemblages, with the potential to rethink aspects of human logic eliminated by transistors and electronic circuits.

What we thought of as human intelligence is not a sole effort by the human, but instead is enabled and co-produced by the material world around us. The intelligence of nonhumans, technical or biological, are part of "human intelligence". Using this term as a measure for other types of intelligence is thus great human hubris, which denigrates the efforts of nonhuman assemblages in the process of producing human intelligence. If *human* should no longer be the measure, is there another way to talk about intelligence? Development in the field of artificial intelligence (AI) and machine learning (ML) provides insights into a non-anthropocentric definition of intelligence.

Universal Intelligence and Deep Reinforcement Learning

Generally speaking, there are two types of approaches to constructing an intelligent machine or AI system. The first type may be described as an expert system. In this case, we need human experts to write the rules – as if-then statements – for making decisions. For example, if we want to build a plant identification system, we require a group of botanists to list all plant identification rules. This resembles searching for a plant in an encyclopedia. We may address these questions: is it a woody plant, or herbaceous? What is the shape of the leaves? What is the shape of the bud? When does it flower? One may create many other questions related to identifying a plant. Many online plant identifier websites are expert systems[13].

The second approach may be understood as machine learning, for which we need only provide the machine with a large amount of data; the machine itself will reconstruct potential rules for decision-making. If we build a plant identification system with machine learning, one approach is to provide the machine with a large number of images of plants, labeled with their correct names. The machine will then attempt to construct a model that represents potential relationships between the labels and the images. This process is called training. To evaluate how well the model performs, we establish a loss function to track the identification error rate; training in machine learning is primarily about minimizing the loss function. In this regard, in machine-learning algorithms, how the loss function is set reflects the ultimate goal of the AI system. For this reason, all machine-learning problems may be understood as optimization problems; there exists an underlying value or loss function for the machine to minimize, in order to train a usable model.

Though the idea of machine learning, including artificial neural networks (ANN), has existed since the mid-twentieth century, machine-learning techniques did not find currency until the early days of the twenty-first century, due to limited computational power, as well as the amount of data available. With the rise of “big data”, as well as increased computing powers, machine learning has produced fruitful results. In 2012, the AI community experienced a major breakthrough in the ImageNet Large Scale Visual Recognition Challenge, a benchmark for

[13] For example: https://weedid.cals.vt.edu/

computer vision. In this competition, computer scientists were challenged to design machine-learning algorithms to train models to recognize images of objects; the error rate of the recognition results became a measurement. SuperVision, later known as AlexNet, developed by Alex Krizhevsky and his colleagues at the University of Toronto, was based on a convolutional neural networks (CNNs) approach (Krizhevsky, Sutskever, and Hinton 2012). It won the 2012 competition, with a significant drop in the error rate, to 16.4% – the previous two years' winning rates were 25.8% in 2011, and 28.2% in 2010 (Russakovsky et al. 2015). A mere four years later, in 2016, the AI community was able to lower the error rate to only 3%, based on CNNs, while the average error rate for humans doing such tasks was 5% (Langlotz et al. 2019) (Figure 11).

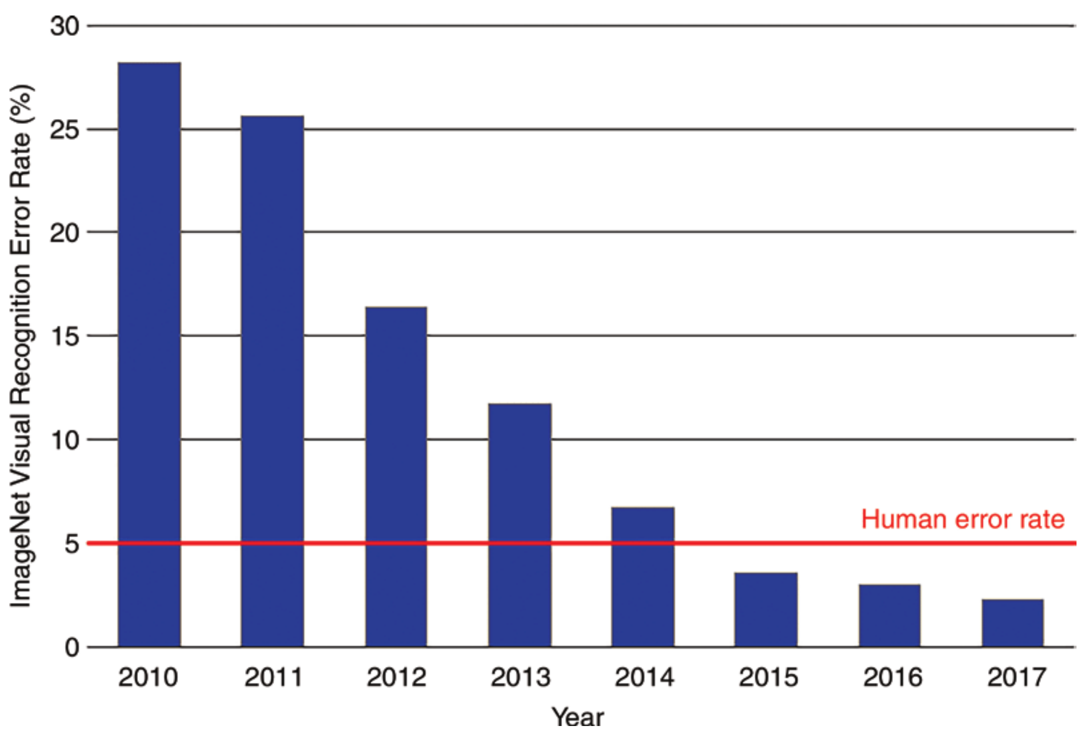


Figure 11. ImageNet Competition Error Rate, by Year.
From Langlotz et al. 2019.

Advances in AI research also provide transformative cases for scholars to ask more profound questions about intelligence. Sean Legg and Marcus Hutter, both AI scientists, have proposed the idea of universal intelligence, and provided a mathematical way to formalize it.

After reviewing a collection of definitions of intelligence from research groups and organizations, psychologists, and AI researchers (Legg and Hutter 2007a), Legg and Hutter ascertained a common thread in these definitions, which involved the interaction of an agent, human or nonhuman, with its environment. Based on this observation and their goal of measuring machine intelligence, Legg and Hutter proposed a working definition for universal intelligence: *intelligence measures an agent's ability to achieve goals in a wide range of environments* (Legg and Hutter 2007b).

Legg is a co-founder of DeepMind Technologies, which designed AlphaGo; Hutter is a senior scientist at DeepMind. Their definition cannot be separated from their long-term practice in machine learning, especially deep reinforcement learning (DRL), the underlying mechanism for AI systems such as AlphaGo. In fact, this definition is based on basic DRL framework. Scholars commonly compare DRL to human learning through trial and error. If a child touches a flame and is burned, later, the child will probably avoid touching anything that is alight. Similarly, in DRL, an agent observes the state of the environment, and acts. If certain actions are effective based on reward mechanisms expressed with a loss function, then the agent would be rewarded. For example, when training a DRL agent to play a video game, for example, Tetris, the agent would begin with random actions – moving the blocks left and right and placing them randomly. A proportion of those actions would result in a line clear -- erasing an entire line of blocks -- so the agent would be rewarded by scoring. After repeating this process many times – playing thousands of rounds of the game – the agent would select actions that helped it earn higher scores. If we continue training, we will find the agent would begin to develop techniques such as Tetris Clear -- four lines cleared simultaneously.[14] Again, any machine-learning

[14] See https://www.youtube.com/watch?v=iI6TQOQ_Ccc for an example of a DRL-based agent playing Tetris.

technique may be described as an optimization problem; in DRL, the agent will endeavor to optimize the reward function. Universal intelligence thus measures the agent's ability to optimize reward functions.

Over the past few years, based on this simple agent-environment framework, DeepMind has trained many DRL-based AI systems, such as AlphaGo. Only one year after AlphaGo defeated its human competitors, two newer AI systems based on self-play – AlphaGo Master and AlphaGo Zero – were able to overwhelm the original algorithm. The self-play technique implies that the AI system has been playing against itself without the addition of any human knowledge related to the game of Go, except for the basic rules. Most importantly, these self-play AI systems not only outperformed humans, but also devised novel strategies which human players had never calculated. In this way, they developed a machine understanding of the game.

A similar example, in which AI systems devise their own strategies, is the AlphaStar. In 2019, using the self-play method, DeepMind developed an AI system called AlphaStar, which attained grandmaster level (the highest rank reachable by competing with other players) in the real-time, strategy video game StarCraft (Vinyals et al. 2019). The AI community regards this experiment as a leap forward, because real-time strategy games such as StarCraft are infamous for their "combinatorial action space, a planning horizon that extends over thousands of real-time decisions, and imperfect information" (Vinyals et al. 2019). After watching or playing with AlphaStar, many professional players reported that AlphtaStar had devised new strategies which they actually learned from; they believe that AlphaStar provides new ways to understand the game itself. One commentator even reports that watching the AI playing the game is like watching a drunken kung fu master performing martial arts: awkward, but outrageously effective (Two Minute Papers 2019). Another professional player comments,

> “AlphaStar is an intriguing and unorthodox player – one with the reflexes and speed of the best pros but strategies and a style that are entirely its own. The way AlphaStar was trained, with agents competing against each other in a league, has resulted in gameplay that’s unimaginably unusual; it really makes you question how much of StarCraft’s diverse possibilities pro players have really explored” (The AlphaStar Team 2019).

These examples are in response to the critics of machine intelligence, criticism leveled against it on the basis that machines are unable to apply knowledge creatively. As we have seen, not only do machines come up new strategies, but importantly, they develop strategies with a “machine flavor”. The implications of universal intelligence extend past training advanced AI systems such as AlphaGo and AlphaStar. Universal intelligence is a non-anthropocentric definition in which *human* no longer provides the measure; instead, human intelligence becomes an instance of universal intelligence, manifested in the human assemblage. However, it is not yet a posthumanist definition of intelligence, because it faces further challenges.

4.2. Mathematism and the Tactics of Observation

Intelligence as a Measurement

From IQ testing to universal intelligence, measurement has been a primary instrument for questions about intelligence; many debates on the matter have revolved around human intelligence as a target. In a way, the problems associated with “intelligence”, such as racism, sexism, classism, and even speciesism, have been products of human exceptionalism in consort with human intelligence as a measurement. For example, critics claim that IQ testing measures nothing but the subject’s test-taking skills at the moment of testing; the result therefore has little to do with the individual’s intelligence.

The concept of universal intelligence is confronted with similar critiques. Critics tie intelligence to metaphysical concepts such as conciseness, soul, and free will, all of which lie beyond measurement (Legg and Hutter 2007b). However, Legg and Hutter defend their thesis by arguing that "[o]ur goal is to build powerful and flexible machines and thus these somewhat vague properties are only relevant to our goal to the extent to which they have some measurable effect on performance in some well-defined environment. If no such measurable effect exists, then they are not relevant to our objective" (Legg and Hutter 2007b, 42). The criticism against universal intelligence may be defended by Legg and Hutter's tautology of measurement.

The critics miss the point; they know the problem lies in measurement, but tying intelligence to metaphysical concepts beyond measurement ironically justifies Legg's and Hutter's approach, as a pragmatic choice. Rather than relying on metaphysical concepts such as consciousness and soul as *a priori* for intelligence, to critique mathematism and formalism, we need to directly confront what this measured "intelligence" really is. Perhaps we must formalize intelligence in order to build powerful machines, but there is no need to rely on this formalized idea to define intelligence. Indeed, if we ponder the players' comments on AlphaStar, the reason they believe this AI to be intelligent is not based on measurement or evaluation. Instead, it is a general impression, a type of belief that AlphaStar possess certain potentials that allow it to change and adapt.

What precisely are these abilities we recognize as intelligence? To answer, we need to turn from mathematism and the measurements that have dominated the discussion of intelligence since the early twentieth century. Obsession with mathematism and measurement limits the potential of universal intelligence to become a transformative idea in the light of posthumanism. Only when we detach the concept of intelligence from the need to test, measure, and formale, can we ask more meaningful questions about the matter.

Universal intelligence implies the ability of agents to achieve *goals*, but scientists define these goals, imposing a human standard as to whether a behavior counts as an intelligent move. In the end, what universal intelligence measures remains perceived effectiveness from a human perspective, even though the concept itself removes the human from the scale of measurement. It is an intelligence *for* humans, rather than intelligence *for* the agent itself.

Moreover, we rely on the concept of autopoiesis to further explain what “goal-directedness” means in measuring intelligence. In a seminal paper on autopoiesis theory, “What the Frog’s Eye Tells the Frog’s Brain”, Maturana and his co-authors demonstrated that the eye of the frog does not capture an image and transmit a perfect copy to its brain for interpretation. Instead, four groups of nerve fibers first operate on the image, before sending this highly organized information to the brain; each group of fibers is responsible for a single type of operation on the visual data, and expresses the images in terms of the movement of objects rather than the level of illumination. These findings challenge the popular understanding, that the nervous system is an instrument through which the organism acquires information and constructs a representation of the outside environment, which is then used to compute a behavior to achieve goals. Instead, the environment triggers a set of system operations that produce a reality inside the system itself; autopoiesis turns the environment outside in. Based on autopoiesis, Maturana and Varela argue that,

> “[w]e as observers have access both to the nervous system and to the structure of the environment. We can thus describe the behavior of an organism as though it arose from the operation of its nervous system with representations of the environment or as an expression of some goal-oriented process. These descriptions, however, do not reflect the operation of the nervous system itself. *They are good only for the purpose of communication among ourselves as observers.* They are

> inadequate for a scientific explanation." (Maturana and Varela 1987, 129; emphasis added).

In other words, the outside environment does not send signals so that the system can devise goals, as well as strategies to achieve them. Instead, the environment only *triggers* the system to operate and construct a reality of its own. From this vantage, with folding the environment and reality outside in, concepts such as consciousness, soul, and free will become epiphenomena within the human system operation. This is a version of radical constructivism. Crucially, the concept of goal-directedness becomes an epiphenomenon, too, for humans to describe causal relationships within the observed system. For humans, it may be essential to possess a concept of *goal* to maintain our own system organization, but to use the logic of goal-directedness to describe how and why other systems operate belongs to the privilege of the observer. Thus, "goal-directedness" becomes a tactic of observation. We invent codes to codify the world; we choose to believe that goals exist, then observe phenomena that fit within the framework of goal-oriented behaviorism; thus, we explain system operations in a manner that fits within the descriptive category of goal-directedness. However, as Maturana and Varela note, evaluating and measuring goal-directness phenomena has nothing to do with system operations themselves.

Autopoiesis and Computer Vision

Autopoiesis sheds new light on understanding machine-learning cases in the area of AI biases. A famous example is the image recognition model that consistently confused the image of a husky dog with that of a wolf (Figure 12). Researchers discovered later that, in the training dataset, the wolves' images contained snowy backgrounds, and the husky images used for testing also had backgrounds of snow, so that the model created the confusion (Ribeiro, Singh, and Guestrin 2016). In another example, computer scientists presented gender-biased AI systems in image recognition and text analysis. The image recognition AI system tended to label figures at the forefront of a kitchen background as female (Zhao et al. 2017). Indeed, there existed an inherent bias in the training data, because the images used for training were simply culled from the internet, and thus reflected the persistent gender stereotypes of society; yet certain machine-learning techniques tend to amplify these biases into stereotypes. Further examples abound, and have been used to challenge scientists to create fair and "unbiased" AI systems. In truth, AI bias has become a subsect of AI research, and algorithms are continually developed to reduce bias and train more "unbiased" AI systems.[15] For example, the scientists in the gender-biased AI research injected constraints into the model to ensure its predictions follow the distribution observed from the training data, thus reducing amplified biases (Zhao et al. 2017).

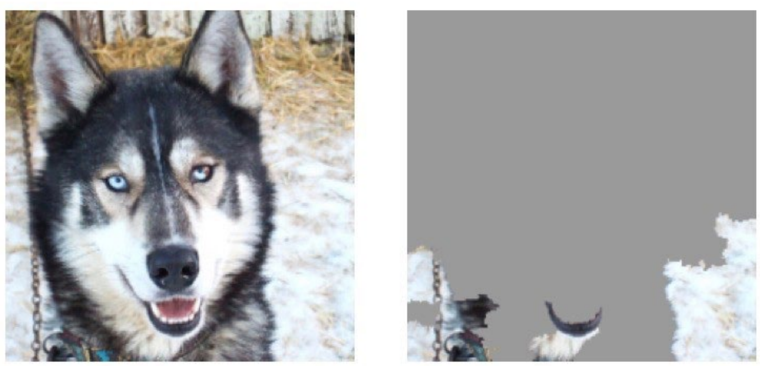


Figure 12. Husky or Wolf?
From Ribeiro, Singh, and Guestrin, 2016

However, critics and computer scientists miss the analytical values of these cases, especially if we rely on autopoiesis theory. The environments of these AI systems are

[15] Computer scientists tend to avoid difficult social science questions regarding gender equality and justice; most of the time, unbiased AI means reflecting whatever the training data represents, excluding issues of gender equality outside the scope of the research. However, this "unbiased" attitude limits the potential for an AI system to be used creatively, for activism.

constructions of their own system operations, which are entirely different from humans'. If a human is presented with an image of a figure in a kitchen setting and asked to identify the figure's gender, a human would ignore the background and turn their attention to the figure itself. However, the machine-learning architecture for most image-recognition algorithms is called convolutional neural networks (CNN). In artificial neural networks, artificial neurons are constructed in layers. In CNN, particularly, a convolutional layer acts as a "filter" that passes over the image, scanning several pixels at a time from top to bottom, and left to right, and creating a feature map. Then, a pooling layer checks this feature map and abstracts it into small edges that represent the object in the image. Finally, fully connected layers would make a prediction based on these small edges. The training process uses training data to fine-tune each neuron (non-linear function) in the layered artificial neural networks. An artificial neural network, such as CNN, is therefore a perfect example of an autopoietic system, because, after training, the CNN is hard-wired such that the environment does not change it, but only triggers a set of "neural activations", along with connections among the neural network layers. Thus, CNN does not absorb the image as a whole, but pieces through the image; it is as if a person "reading" a picture used a magnifying glass and looked for the small edges that define objects. Using this magnifying glass analogy, a person born holding a magnifying glass would be exposed to a completely different "environment" than the rest of us. Just like Matuana's frog constructs a reality with four groups of fibers, a CNN constructs a reality through a combination of convolutional and pooling layers.

Based on CNN architecture, scientists use multiple convolutional and pooling layers, as well as others, for building hierarchies in feature complexity, thus constructing deep convolutional neural networks (DCNN). In DCNN, the first few layers detect edges, the middle layers detect portions of the object, and the final layers detect the object itself. Neuroscientists have found that the increasing feature complexity of DCNN resembles the increasing complexity occurring in visual object recognition in humans (Kriegeskorte 2015); others found that the activation of deep convolutional neural networks was similar to that of gamma-band activity within the human visual cortex (Kuzovkin et al. 2018). Many have duly argued that DCNN resembles the method by which humans see, and some regard DCNN as a biologically inspired approach. These findings seem to contradict autopoiesis theory by drawing similarities between machines and human system operations. To the contrary, these examples prove that DCNN does not resemble humans at all, because they perform an operation that merely resembles the *human cortex*, which is only one of the distributed systems which we call human.

Crucially, the scientists aim for CNN to recognize objects with accuracy. We may explain the behavior of CNN as a goal-directed behavior, but this explanation has nothing to do with system operations; AI systems will execute what we *say* rather than what we *mean*. After training, CNN will label an image, but this action does not equal to image recognition. We have no idea what CNN maintains as goals for itself. We have no idea if *goal* is a concept within CNN's reality as constructed by its own system operation.

The AI community has struggled with the disconnect between goal and system operation; autopoiesis sheds new light on problems in AI safety research, such as the problem of reward hacking. For example, a simulated AI robotic arm may be trained to flip a pancake, and the experimenters set up a reward function, such that the robot will receive a small reward for each second, if the pancake does not hit the floor. The experimenter might think this would encourage the AI system to keep the pancake in the pan as long as possible. However, what occurs is that the robot arm throws the pancake into the air with as much force as possible, to maximize the reward.[16] Articulating reward goals and AI behaviors is a constant task in AI

[16] https://connect.unity.com/p/pancake-bot

research, because AI systems would exploit the reward function by performing unexpected behaviors.[17] Powerful AI systems, such as AlphaGo, may be understood as gratifying accidents, where the articulated reward goal matches the system operation. This synergy between goals and system behaviors points us in another direction: we are able to understand intelligence on the line of co-production and co-evolution.

Perceived Intelligence and Co-Evolved Intelligence

To consider synergy between experimenters and AI systems, we must practice what Niklas Luhman calls second-order observation, or the practice of observing others observe. When we bring the observer into the equation, new insights can arise. When intelligence is tied to measurement, it becomes a product of observation; thus an observer plays an essential role in conceptualizing intelligence – how intelligent an entity appears to the observer at the moment of observation. In robotics, especially in the area of human-robot interactions, perceived intelligence is an key concept. Robot engineers know the underlying rules as to how a humanoid robot would behave in a given circumstance; to them, the robot's behaviors are transparent and predictable, thus non-intelligent. However, for a non-expert who has no idea how the underlying rules work, robot behaviors may appear intelligent. Accordingly, perceived intelligence was adopted as a concept to mediate the knowledge gap between engineers and non-expert users. In order to make robot behaviors appear more intelligent, engineers intentionally program randomness, so that the behavior patterns are less predictable. However, after many interactions, users will detect patterns in these limited random behaviors, and decide that the robot is not intelligent, after all. Thus, a popular approach in human-robot interaction is the

[17] A list of unexpected AI behaviors https://docs.google.com/spreadsheets/d/e/2PACX-1vRPiprOaC3HsCf5Tuum8bRfzYUiKLRqJmbOoC-32JorNdfyTiRRsR7Ea5eWtvsWzuxo8bjOxCG84dAg/pubhtml

Wizard of Oz trick, in which a human hides behind the robot, and conducts a conversation to create the illusion of intelligence (Bartneck et al. 2009).

What separates these two situations -- the Wizard of Oz versus limited random actions? We may say that users find the robot unintelligent, after all, because its behaviors become predictable over time. However, reconsidering, the users become more intelligent over time, discerning the robot's deceptive behaviors. Alternatively, we might say the robot is unintelligent, because it cannot co-evolve with the users, whereas another human hiding behind the robot adapts to the users and advances the conversation.

Similarly, if we reconsider the Turing test, the seemingly innocent discriminator becomes a critical player in the imitation game, because the game eventually becomes a test for all parties. Recursive observation and learning between observer and participants will force them to adapt to each other and become more intelligent in playing the imitation game. Measurement overlooks the intelligence emerging from the dynamic feedback loops between the observer and the observed. From this perspective, intelligence points to a direction on the line of co-production, co-evolution, and assemblage thinking.

4.3. Individualism, Assemblage, and Emergence of Intelligence

Assemblage thinking exists at odds with the agent in universal intelligence; there is an inherent individualism within universal intelligence which we must overcome. Intelligence has been viewed as a quality of a pre-existing individual. In AI research, scientists are accustomed to regarding an agent as a computer program, an artificial neural network, and a black box with input and output; in IQ testing, researchers regard intelligence as a person's capacity. Constructed AI systems are considered as separate and distinct models and algorithms, designed and trained to perform specialized tasks, such as image recognition algorithms with convolutional neural networks (CNNs). Thus, current AI research lacks vocabularies and concepts for a non-individualistic view of intelligence, in both theory and practice.

Although objects around us appear to be individual, that is not *a priori* for intelligence. An agent is simply a product of observation, to attribute perceived effectiveness distributed *within* and *around* the so-called agent; it is merely a carrier of intelligence emerged from dynamic co-evolution and co-production processes.

One way to examine the emergence of intelligence is to construct an arbitrary diagram of an agent and its outside environment, and then analyze both inside and outside the agent. First, intelligence is an emergent property of the interactions between the components that give rise to the assemblage. For example, certain forms of intelligence do not manifest in a sole individual. Swarm intelligence points to the collective behavior of decentralized, self-organized systems, such as a colony of ants. While exploring their environment, ants leave pheromones to guide each other to resources. The behavior of an ant appears simple, but if each individual ant repeats the same action over and over, a colony of ants appears remarkably efficient in exploring its environment. This behavior inspired a famous instance in computer science, called the ant colony optimization (ACO) algorithm. Modeled on the actions of an ant colony, ACO has proven useful in pathfinding optimization problems (Dorigo and Di Caro 1999). In addition to ants, we observe swarm intelligence in other species, such as bees. This type of intelligence, also known as “hive mind”, occurs where intelligence is not located within any of the individuals, but as a property that surfaces from the interactions of each part. In fact, all forms of intelligence – human, machine, or animal – should be understood as emergent phenomena. Human and animal intelligences are nothing but electrochemical interactions between neurons and a distributed nervous system. As we saw in the CNN example, in artificial neural networks (ANN), which underpin many of today’s AI systems, machine intelligence is achieved through the interactions of layers of “artificial neurons”, a loose biological analogy for certain non-linear functions. An AI system is thus a conglomeration of dynamic and interactive functions.

Second, outside the boundary of the agent, Levi Bryant’s notion of media and mediation may help us understand that an agent’s intelligent behaviors are constantly mediated by other assemblages. The mediation may be understood through Andy Clark’s “extended mind” theory, which reminds us that the effectiveness of human intelligence is achieved by off-loading human cognitive functions onto other objects in the environment. Human intelligence becomes a continually changing phenomenon, depending on the temporary assemblage at the moment of observation. Thus, a paper-based IQ test tests the effectiveness of finishing the questions by the temporary assemblage of human, pen, paper, and perhaps corrective lenses; all factors contribute to how well the subject performs at the test-taking moment. We must also account for the breakfast eaten that morning, as well as the diverse bacteria and enzymes in the test-taker’s digestive system, which help digest the food and provide energy for the electrochemical nerve impulses that give rise to “intelligent behavior”.

On the other hand, we may add a time scale to the mediation process, and understand its effects as co-evolution and co-production. The story of transistors and Boolean algebra, the users of the humanoid robots, and the discriminator in the Turing test are all instances where human and machine become each other’s media and co-evolve over time. We need to understand intelligence as a collection of observed phenomena that is, in fact, a result of random interactions in co-production and co-evolution among assemblages.

To understand intelligence based on inside and outside of the agent is arbitrary. In fact, it is crucial to recognize that assemblage thinking reminds us that reality is a continuous mesh of heterogeneous bodies. Random interactions and feedback loops exist between different bodies, and if certain interactions become useful for a temporary assemblage, then synergies and loose couplings happen among these bodies. As Bennett noted, “bodies enhance their power in or as a heterogeneous assemblage” (Bennett 2010, 23).

From this vantage, in a posthumanist assemblage framework, intelligence becomes a shared ability among different assemblages, to exchange effects through recursive observation and learning, thus forming synergies and couplings to gain power. Intelligence speaks to the process of attunement and symbiosis between assemblages, as in the moment when computer scientists’ goals accidentally match operations in an AI system. We can understand this phenomenon as “intelligence of co-production”. What we perceived as human intelligence, machine intelligence, or animal intelligence, becomes a specific instance of observed local manifestation of universal intelligence.

5. Co-Productive Intelligence

Since intelligence points to the co-production process, we must explore those relationships between two or more assemblages in which intelligence might emerge. There are three kinds of relationships in the process of co-production and co-evolution through which we observe the emergence of intelligence. They are 1) intelligence in adversarial relations, 2) intelligence in symbiosis (symmetrical and asymmetrical), and 3) intelligence in loose coupling.

5.1. Intelligence in Adversarial Relations

Adversarial relationships gesture to competition in long-term evolution. We find many instances of animals and plants in adversarial relations, in which complex behaviors and responsive strategies emerge. In recent years, the AI community has also exploited this type of relationship, and achieved promising results.

Dueling neural networks or generative adversarial networks (GANs) are types of machine-learning techniques that train two artificial neural networks together. The case of GANs may be demonstrated with a forgery example. Imagine two neural networks, or two agents – a generator (forger) and a discriminator. The forger's goal is to produce photorealistic images to deceive the discriminator, and the goal of the discriminator is to ascertain whether it is a real image. The two networks are trained simultaneously until the discriminator cannot distinguish a fake image from a real image. In fact, AI researchers have used this technique to train AI systems to render photo-realistic images and stylized paintings (Goodfellow et al. 2014). In 2018, GANs was named one of the "10 breakthrough technologies" by the Massachusetts Institute of Technology (MIT); a commenter noted that GAN "gives machines something akin to a sense of imagination, which may help them become less reliant on humans" (MIT Technology Review 2018). In addition, GAN has been combined with natural language-processing AI systems, to create hybridized AI systems that render images based solely on text descriptions such as, "a small blue bird has a short pointy beak and brown on its wings" (Zhang et al. 2016). These examples of GANs point to the first type of intelligence, which emerged in adversarial relations.

A similar relationship may be observed in the Turing test, AlphaStar, and AlphaGo, all of which involve two or more parties learning and training together in a competitive relationship. Multi-agent competition has become an effective machine-learning technique over the past several years. In the typical agent-environment framework, the complexity of the agent is profoundly related to the complexity of the environment. However, computer scientists found that competitive multi-agent techniques not only train models faster, but also give rise to behaviors far more complex than those allowed by the environment itself (Bansal et al. 2018). In an example developed by OpenAI, two agents were asked to play hide-and-seek in a simulated environment with walls, boxes, and boards. After training, both agents had not only learned to use these tools to their advantage, but also began to develop mechanics to exploit the environment in which they were trained. One agent learned to stand on a box and apply force to the agent itself, so that it "surfed" the boxes and jumped over walls. This technique defied the basic physics of the training environment.

5.2. Intelligence in Symbiosis

The evolution from prokaryotic cells to eukaryotic cells has been widely discussed in post-humanist assemblage thinking.[18] It is now believed that mitochondria were once a type of bacteria, before they were co-opted as permanent organelles of cells in which they were originally parasites. It seems that adversarial relationships may transform into symbiotic relationships, where two or more competing assemblages self-synchronize in terms of their inputs and outputs, so that they can exchange effects. We may find the relationship of symbiosis in many plant communities. For example, root nodules are primarily found on the roots of legumes, or the pea family (*Fabaceae*), including peas and soybeans, as well as trees such as the black locust (*Robinia pseudoacacia*). These root nodules are the result of legumes forming a symbiosis with nitrogen-fixing bacteria that helps convert nitrogen (N2) from the atmosphere into ammonia (NH3), which can then be used by plants. For this reason, soybean intercropping is widely used in agricultural production to increase soil fertility.

Symbiosis became a much-used metaphor in OOO and other posthumanist ideas, to describe how objects or systems interact. In Harman's words, symbiosis is not only biological but "biographical"; living entities form symbiotic relations with other assemblages, and organizations, institutions, and historical objects do so, as well (Harman 2018, 112). Symbiotic relationships involve a structural coupling, first discussed by Maturana and Varela when introducing autopoiesis. Levi Bryant provides a more accessible explanation of structural

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[18] Authors such as Manual DeLanda, Graham Harman, and Levi Bryant all use this example to demonstrate the process of forming assemblages.

coupling by describing it as “a relation in which one or two entities are dependent for stimuli or flows from one another in order to engage in their own operations and becoming” (Bryant 2014, 153). Bryant then divides structural coupling into bidirectional and unidirectional; and this is the same concept as Harman’s description of symbiosis as both symmetrical and asymmetrical. Symmetrical symbiosis, or bidirectional coupling, occurs when both assemblages or systems require flows from the other to engage in a joint operation, such as mitochondria acting as permanent organelles in living cells. In asymmetrical symbiosis, or unidirectional coupling, one system depends entirely on the other one. Bryant uses the redwoods of California and the Pacific Coast as examples of unidirectional coupling. Due to the lack of regular rainfall in Northern California, sequoias have developed ways to absorb moisture through their leaves as they bask in frequent Pacific Ocean fogs. Asymmetrical symbiosis or unidirectional coupling as a metaphor speaks to adaptive strategies which a system develops to take advantage of another system. In symbiosis and structural coupling, intelligence manifests as the ability to link one system to another, so that its own system operation becomes assimilated into another system’s operation; both systems benefit from the assimilation of system operations, and gain power.

5.3. Intelligence in Loose Coupling

Coupling is another important concept in computing and system engineering; the word is used to describe the interdependence between different programming objects or systems. In programming, there are two types of coupling -- tight and loose -- with the latter preferred for its greater flexibility, so that changing one programming object or system is unlikely to affect another. Niklas Luhmann also used the concept of structural coupling to describe social systems, and argued that “[l]oosely coupled systems are more stable than tightly coupled ones. ‘Tight coupling’ is a very improbable arrangement. It is not to be found in nature” (Luhmann

2012, 123). However, symmetrical symbiosis may be understood as a type of tight coupling, and symmetrical symbiosis is found nearly everywhere in “nature”. In fact, many scholars disagree with Luhmann’s claim regarding loosely coupled systems (Probert 2014). Certainly, in symmetrical symbiosis, if one of the tightly coupled systems, e.g., the soybean, is destroyed, then the other tightly coupled system, e.g., nitrogen-fixing bacteria, can no longer survive. Viewing loose coupling as beneficial is based only on accepting disruption and change as constant, overlooking the intensive exchange of flows and functions in symbiotic relationships that do not exist in loosely coupled systems. Rather than placing a high value on loose coupling, it can instead be understood as another type of relationship from which intelligence emerges.

Loose coupling is the type of relationship we commonly encounter, such as the relationship between computer scientists and machine-learning algorithms. The synergies between these assemblages are “happy accidents” when scientists’ conceptualized goals match the observed system operation, and thus effectiveness comes into being. For example, Kate Orff’s oyster project is a type of loose coupling between oysters and public space, in which both systems operate on their own, but their effects overlap and are thereby amplified. The oysters’ routine actions become an important process in the creation of the new public landscape; in the meantime, this new urban landscape redefines “public” and provides habitat for oysters, which occupy and share the urban environment as new types of urban resident. In loose coupling, intelligence emerges as the ability of one assemblage to exchange, align, and amplify effects with other assemblages, without compromising its own system operations.

CHAPTER THREE: CULTIVATED WILDNESS

1. Co-Produced Intelligence in the Co-Produced Environment

Using machines to control and manage the environment is a defining characteristic of human life. Ancient Romans constructed aqueducts and underground sewage systems to move water into and out of their cities. The Dutch built polder systems consisting of dykes and windmills, to pump water from arable lands below sea level. Using feedback mechanisms to control the environment is not a novel idea. The first feedback-controlled device can be traced to 1620, when Dutch inventor Cornelis Drebbel built a mercury thermostat to regulate the temperature of a chicken incubator. This device may be regarded as a prototype for today's smart cities: they both envisage control systems that function as key components to maintain observed equilibria. It was not until the dawn of the twentieth century, with the rise of cybernetics, that feedback mechanisms and systems thinking were formalized as a unified framework in order to understand a wide range of behaviors in humans, animals, and machines. Importantly, it is an actionable framework for building feedback machines with greater intention. Cybernetic thinking laid a theoretical foundation for modern control theory in disciplines such as robotics and artificial intelligence.

Undergirding the cybernetic environment discourse is a widely held belief about intelligence and agency. The environment serves as background, conditions and circumstances in which humans are the sources of agency and carriers of intelligence; we wield intelligent machines to transform nature into habitable landscapes. Supported by an anthropocentric and individualistic understanding, this view regards intelligent machines as an effective means with which to extend imagined human agency and intelligence, to produce desired changes to the environment and maintain perceived stability.

However, the previous two chapters have offered an alternative view in conceptualizing the environment and our relationship with it, based on distributive intelligence and agency. This view stems from late twentieth-century environmental history, the STS movement, and environmental humanities, and is being developed with twenty-first-century posthumanism, new materialism, and various ontological concerns. This posthumanist view posits that the environment is not where all sorts of processes – natural, cultural, social, ecological – take place; instead, the environment embodies the processes of unfolding characterized by co-production between heterogeneous assemblages – human and nonhuman, living and non-living, material and immaterial. Thus, the environment is a meshwork laden with the types of intelligence that emerge from constant interactions between different agents, which themselves are assemblages of assemblages.

With this conviction, this chapter explores alternative operations and develops new vocabularies to discuss the cybernetic environment in light of co-production and distributive intelligence. When situated within the framework of distributive intelligence and co-production of the environment, contemporary environmental practices in art, design, and engineering exhibit transformative qualities that challenge the mainstream belief of the cybernetic environment discourse.

At the core of this chapter is the idea of feedback control, the fundamental notion that defines cybernetics. When we construct intersections between cybernetics, with contemporary, posthumanist thinking, the following questions emerge: How do we understand feedback control in a co-productive and distributive intelligence framework? Does modern control theory maintain its hold when we adopt this new framework to understand the environment? Where is the idea of control lacking, and are there alternative concepts to help our thinking?

1.1. State-Space Representation and Feedback Control

We must rely on a classic diagram in cybernetics and control theory for better illustration, conceptualizing a black box and labeling it as dynamic system *x* with input vector *u* and output vector *y* (Figure 13). From an intelligent co-production perspective, this system involves a group of co-production processes in the environment, which produce observable outputs and corresponding inputs.

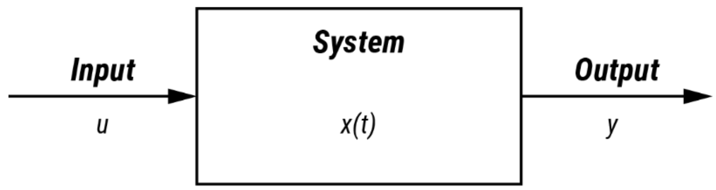

Figure 13. A system with input and output.
System dynamic vector x can be written as a function of time t.

Based on this diagram, controlling this system means manipulating input *u* to reach a desired output *y*. Different types of manipulation distinguish one type of control from another (Figure 14).

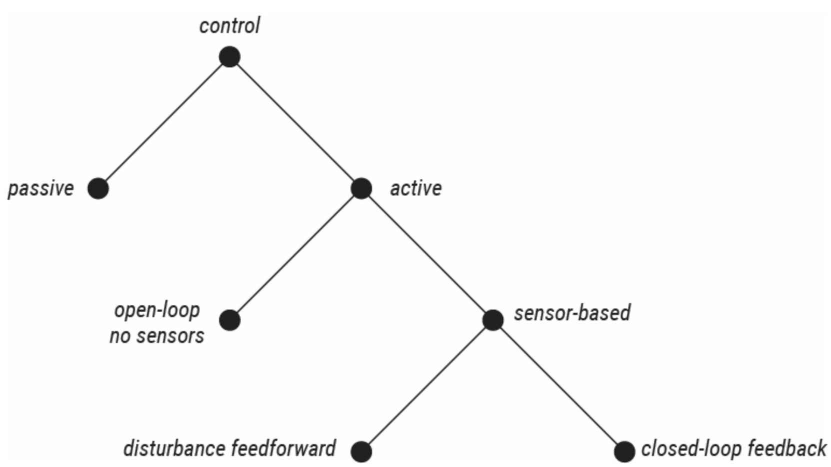

Figure 14. Types of control.
Adapted from Brunton and Kutz 2019

Many systems are passively controlled, with no additional energy input. The walls of a building, for example, are passive controllers that stabilize interior temperatures, which must be controlled for the health of the humans (and plants) within. In contrast, active control requires energy input for the system to maintain a desired output, (e.g., a radiator keeps a room warm during winter). Within active control, two broad categories exist, depending on whether sensors are used. Open-loop control does not require sensing system dynamics, but relies on preprogrammed control sequences to manipulate system behavior. One can add a clock, a relay switch, and a microcontroller to the radiator, programming schedules that turn it on at night when the weather is typically colder, and off during daylight, when exterior temperatures rise. However, this method of control is unable to account for disturbances, such as cold waves. In closed-loop feedback, measurements feed back to a controller, which then chooses actuation signals, based on the control laws, to nudge the system towards the desired state. We can further upgrade a radiator by adding a temperature sensor to the room – thus building a thermostat. When the temperature drops below a certain threshold, the controller will turn the radiator on. Feedforward control observes extraneous disturbances to the system and feeds this information forward into the open-loop controller. We may design an algorithm that adjusts the radiator based on weather forecasts, turning it on before a cold wave in order to preheat the room. In practice, feedback and feedforward strategies are often combined, by adding a feedforward controller to a feedback-controlled system to achieve a better result.

Closed-loop feedback control is effective in controlling all sorts of systems (Figure 15). It may be possible to correct external disturbances, un-modeled dynamics, and model uncertainty (Brunton and Kutz 2019).

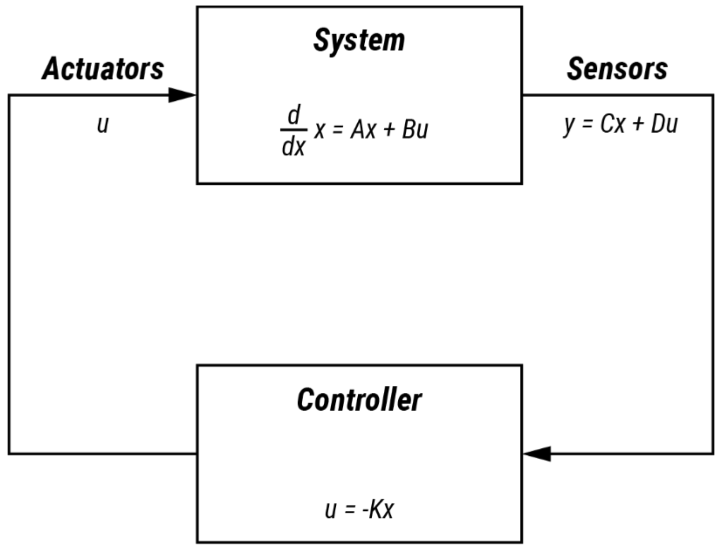

Figure 15. Feedback control system.
Adapted from Brunton and Kutz 2019

Based on the feedback control mechanism, one does not need a perfect model, which is impossible to construct, in order to control and stabilize a system. As long as there is a sufficient state-space representation of the system, then an entire branch of mathematics and theory of control are at one's disposal. We may examine how feedback control is formally articulated.[19] Broadly speaking, classic modern control theory relies on state-space representation to model dynamical systems and find control laws. A state-space representation is a mathematical model of a physical system, presented as a set of input, output, and state variables related by first-order differential equations. With state-space representation, a system can be formalized as the following equations or their variations:

$$\frac{d}{dt}x = Ax + Bu$$

$$y = Cx + Du$$

[19] For illustration purpose, this presents only the key steps that are relevant to the scope of this research. More detailed reasoning can be found in Brunton and Kutz 2019, 276-320.

Here, x is a vector representing state variables that change over time, and u is an input vector that influences system dynamics. The system matrix (A) describes how the state variables (x_1, x_2, x_3 … x_n) are interrelated; similarly, B is a matrix describing how the input variables interrelate. $\frac{d}{dt}x$ is the derivative of x with respect to time (t); it represents the rate of change of state variables x. System dynamics can then be formalized, so that the rate of change of system variables at a given time is determined by state variables and input signals in a linear relationship. Thus, y is an output vector that can be measured using sensors. In a perfect scenario, we can assume full-state feedback in which $y = x$, in the sense that sensors can monitor full-system dynamics. As a concrete example, if the system is an airplane, *A* defines all the state variables related to the plane's physical design; *B* represents the actuators on the airplane, such as the rudder and aileron positions.

To control the system with the feedback mechanism is to design a control law $u = -Kx$ to manipulate actuators to nudge the system towards the desired state. Here, K is another matrix that defines the control law. So, u in the first function can be replaced, resulting in the following function:

$$\frac{d}{dt}x = Ax - BKx = (A - BK)x$$

Therefore, the original system with actuators and perfect control laws may be written as a new system, in which $(A - BK)$ is a new matrix that defines system dynamics. So, mathematically speaking, by adjusting *K* and *B* – a set of control laws associated with actuators – we may drive the system to reach any possible state. Controllability is defined in relation to the *A* and *B* matrices. In other words, if a system is not mathematically controllable, one can redesign *B* – say by adding more actuators to the system, for instance – in order to increase control authority. Conceptually, every column in the *B* matrix represents an actuator; by increasing the dimensions of *B*, any system is mathematically controllable. An extensive theory of control has been developed for linear systems, and an entire branch of mathematics, based on linear algebra, helps analyze system dynamics. For certain nonlinear systems, system behavior appears to be linear around a fixed, stable point. One can linearize the dynamics near a fixed point, and stabilize a non-linear system with a controller.

Moreover, for a complex system with a high-dimensional state space (where the dimension of A is quite high), we will often observe dominant patterns closely related to system behavior. For these complex systems, control authority over these dominant structures is often sufficient to achieve an acceptable level of control (Brunton and Kutz 2019). For example, in an airplane, full state control means controlling the fluid dynamic of every point in space around the airplane in order to achieve the desired fluid dynamics for lift. However, with dominant patterns close to the wings, turbulence further away will quickly dissipate and join the dominant patterns. Mathematically speaking, if a system is modeled using state-space representation, one can characterize a state-space model by observing inputs and outputs, and using the model to generalize the system's future patterns, based on which the system can be controlled.

This is a generalization of control theory, but we understand why the sensing-computing-actuating feedback loop becomes the cornerstone of the cybernetic environment. Since control theory is undergirded by cybernetics and its continuation as present-day systems theory, one may apply cybernetic thinking in analyzing all sort of processes in the environment. Most importantly, modern control theory and cybernetic thinking are repeatedly vindicated by engineering accomplishments and successful applications, such as aircraft, rockets, infrastructures, industrial machines, and robotics, all of which rely on feedback control mechanisms. Engineering successes give society the confidence to apply cybernetic thinking to further control the environment. Smart cities and cyberphysical infrastructures are proofs.

When we apply cybernetic thinking in environmental management, the feedback control diagram becomes a guide for what has been explored, and what to anticipate in terms of technological development and scientific innovations. Modern control theory formalizes the feedback mechanism as a sensing-computing-actuating process built around model-making, propelling technological development to advance on these different fronts.

First, with more sensors located in appropriate spots, one can better estimate environmental systems. The past several years have witnessed a growing interest in public agencies, private sectors, and bottom-up grassroots citizen groups placing sensing networks within the urban environment, to gather environmental data. In the meantime, researchers have computed optimal sensor placement strategies, to facilitate environmental monitoring. These efforts promise to produce big data, giving hope that, once we acquire enough data, dominant patterns will reveal themselves; they may then be manipulated via modern control theory and cybernetic thinking.

Second, with improved modeling techniques, we can better define a state-space representation of the system. Enhanced modeling techniques can also help in determining optimal control laws. Advanced machine-learning techniques, such as artificial neural networks, have been applied in control engineering, including environmental management. Furthermore, faster computing times lead to shorter latency between systems and controllers.

Eventually, placing an increased number of controllable actuators within the environment, mathematically, will provide us increased control authority. Notions such as cyberphysical systems encourage cities to retrofit infrastructures, such as floodgates and retention ponds, with controllable pieces, in order to increase control authority.

1.2. Five Premises in Control

When we analyze this type of control-thinking, we observe at least five underlying premises. First and foremost, modern control theory is fundamentally about stability. This is the legacy of modernist thinking in first-order cybernetics, where homeostasis and equilibrium have been allotted greater value. The search for stability is one of the contemporary epistemic frameworks, and control theory becomes a preeminent tool in reaching perceived equilibria. Although ideas such as emergence, chaos theory, and developmental system theory have provided ways to think about a co-produced environment, in controlling a system, stability and optimization have been naturalized within the epistemic framework of our thinking. To a certain extent, stability defines the notion of control. If control fails to lead to homeostasis, how do we possibly conceptualize the term?

Second, as the title of Norbert Wiener's 1948 book *Cybernetics: Or Control and Communication in the Animal and the Machine* suggests, modern control theory, systems theory, and information theory consider intelligence as a localized capacity of an individual entity, such as a person, animal or machine. Feedback mechanisms between different entities are conceived of on the basis that intelligence exists prior to any form of interaction that can be categorized as communication and control. In other words, we simply assume animal intelligence exists in an animal, and machine intelligence in a machine, before they communicate and control each other. With this conviction, contemporary environmental practices perceive intelligent machines as artifacts and systems separate from other biological systems. However, behind this line of reasoning lies a tendency to perceive machines as “artificial”, while the environment is “natural”.

Third, with the rise of computers and computation methodologies, a dichotomy begins to emerge between two separate realms – the digital and the physical. The physical environment is where we expect to collect data; the digital space is where we expect computing to take place and data to be processed. For example, the idea of a cyberphysical infrastructure begins with the assumption that two realms exist – one digital, the other physical – and that by hybridizing the two, we create coupled, arguably “smarter” systems.

Forth, the feedback mechanism in cybernetic thinking is thought to cycle through three distinct processes, sensing, computing, and actuating, in part due to how control theory is formalized. Today, any control system contains sensors that monitor the environment, algorithms that process data and compute control strategies, and actuators that influence the environment. Thus, we isolate different collections of system operations and categorize them as distinct actions to be analyzed. These three processes may be known by different terminologies, such as sensing-predict-control or sensing-processing-actuating, but they encompass a similar notion. *Sensing* suggests that environmental variables are detected as a form of digital signal represented by numerical values. *Computing* occurs when the values are fed to mathematical functions, to optimize control signals. *Actuators* update environmental structures based on optimized control laws. Eventually, these updated environmental states lead to a new round of sensing-computing-actuating, closing the feedback loop.

Finally, based on the feedback mechanism, the concept of learning can be defined as updating the internal models which systems use for computation. Models represent the relationships between state variables; thus, model calibrations are required before use in processing. Hence, two distinct domains of expertise are established: learning and doing, or theory and practice. Theory, or learning, entails determining the underlying principles of environmental structures, whereas practice uses these principles to optimize control strategies. Various machine-learning techniques belong to the realm of learning; they are methods to calibrate or construct models based on sensed data.

Many contemporary environment practices cannot forego isolating the three transformation processes, and distinguishing learning from doing. Moreover, progress may be made on each front, to perfect tools and develop new techniques to advance the feedback mechanism itself. Over the years, sensor heads have become more accurate and compact; machine-learning techniques have grown increasingly complex; and distributed control infrastructures are more integrated, as a holistic system. Modern adaptive management attempts to connect theory and practice, asserting learning by doing. Yet it must begin with the premise that learning and doing are two entirely separate domains of operation.

It is convenient, and may be necessary, to take into account these five premises, when considering the environment in a cybernetic fashion. However, when doing so, we risk missing further opportunities and alternative ways in which to consider cybernetic thinking in the co-produced environment. Many contemporary environmental practices in fields including art, design, and engineering shed light on an under-explored territory in the cybernetic environment. Although these projects possess limitations, they pose questions and challenge mainstream cybernetic thinking.

1.3. Technodiversity and the Ecology of Machines

On a separate level, this chapter undertakes a reflection on cybernetic thinking itself, seeking to *reframe* it in light of posthumanism, and based on the type of cybernetic framework suggested by the transformative practices outside the mainstream cybernetic imagination.

Philosopher Yuk Hui suggests that we live more than ever in an "epoch of cybernetics", because "cybernetics was not a discipline parallel to other disciplines…but rather it aimed to be a universal discipline, able to unite all other disciplines, therefore…a universal (mode of) thinking par excellence" (Hui 2020, 58). Indeed, from a historical perspective, the rise of cybernetics, as well as its continuation as systems theory in the twenty-first century, has provided a concept that appears to overcome binary thinking in many aspects: unifying nature and culture, human and nonhuman, biological and technology, with one overarching term -- system. One might use systems thinking to talk about quite different material entities across different scales, such as humans; animals; plants; machines; organizations; laws; and political parties. Contemporary assemblage thinking, actor-network theory, new materialism, and OOO, which propose universal metaphors to describe reality, all owe their reasoning to cybernetics and systems theory in one way or another.

Yet, as Hui asserted, the irony is that “cybernetic thinking remains a thinking of totalization, since it aims to absorb the other into itself…which sees polarity not as oppositional but rather as a motivation towards synthesized identity”, and thus “to think beyond cybernetics is to think beyond the totalizing effect of a non-dualist thinking” (63). With this understanding, Hui proposes two important concepts – “ecology of machines” and “technodiversity” – to help us think through the cases presented in this chapter. Hui’s notion of ecology exists on the basis of biodiversity; thus, an ecology of machines suggests techno-diversity, in the sense that advance of a technique as a universal solution, such as pesticides to combat insect invasions, also implies the elimination of other agricultural techniques. There was a sense of technodiversity before pesticides became the mainstream solution in agriculture practices.

This chapter explores technodiversity by analyzing a range of environmental practices that “misuse” cybernetic technologies. Mainstream technological development and cybernetic thinking are processes of decreasing technodiversity. Yet certain practices attempt to maintain a diverse and open-ended view towards machines, thus leaving room for alternative ways to *reframe* machines and cybernetic thinking “by reframing the enframing [*Gestell*]” of modern technology (Hui 2020, 65).

1.4. Environmental Designers and a Transdisciplinary Framework

Note that none of the examples in this chapter solely illustrates the type of operation suggested by the framework; indeed, it is doubtful that such a practice exists. However, the following examples shed light on different aspects of the framework. Together, they introduce possibilities towards a new paradigm of environmental and cybernetic practice, one based on the intelligence of co-production.

Moreover, to truly appreciate the value of these cases, one must assume a transdisciplinary mindset, and form a rather liberal understanding as to who constitutes a designer. Primarily, we often believe that arts, landscape, and engineering stand in opposition to each other. Yet, in this belief, we miss the commonalities among these practices. In the cases presented in this chapter, the conceptual operations of artists, landscape designers, and engineers all involve applying cybernetic thinking in making sense of and designing cybernetic systems. From this perspective, there is little difference between an engineer and an artist; for both, cybernetic thinking sits at the center of operations.

Most importantly, these projects involve iterative processes in which their practitioners experiment, redefine questions, and seek alternative strategies. Therefore, design becomes a concept that describes the sort of operations involved in art, landscape, and engineering practices. From this perspective, we shall regard those occupied in all the cases below as designers. Using the notion of design as an umbrella term for practices in art, landscape, and engineering allows us to site seemingly very different cases within a transdisciplinary framework; only in this way may we begin to map the types of cybernetic practices that lie outside the mainstream conceptualization, discovering the co-productive intelligence in cybernetic thinking.

When analyzing these cases, we must keep the notions of design, intelligence, and agency in mind, using these terms as threads to connect the cases. We will focus on the commonality in these cases' conceptualization and challenge of the notions of agency and intelligence; denaturalize our relationship with machines and the environment; and examine the role of designers and intelligent machines in co-production of the environment.

A final caveat: although these practices are categorized based on the sensing, modeling, and actuating processes, nearly every example involves all three aspects. They are categorized as to the three processes because they pose direct questions to that specific process. These practices also suggest alternative conceptualizations of sensing, modeling, and actuating. They designate another set of terms – coding, choreographing, and attuning – as fundamental practices in unexplored cybernetic thinking.

2. Sensing as Coding: Episteme of the Digital Age

2.1. Sensing or Coding?

Sensors are often considered the interface between the cyber and the physical; sensing networks are regarded as a layer of infrastructure that transforms physical phenomena, such as moisture, temperature, and air movement, into electronic signals represented as ones and zeros. These data are then categorized, manipulated, and computed to inform a plethora of decisions. People tend to attribute a certain objectivity to sensing practices. It is a common belief that environmental sensing is an operation of data collection to produce big data, which may then inform us to make better decisions. Environmental sensing is the most fundamental operation in the cybernetic imagination.

Artist David Bowen's practice challenges this commonly held conviction. Many of Bowen's art installations can be described as displacements of phenomena from one place to another.

For example, in his art installation “Tele-Present Wind” (2011), Bowen questions environmental sensing regarding wind. The installation consists of two parts. A series of 126 x/y tilting devices are distributed on an indoor gallery floor. Each device consists of a dried plant stalk connected to a tilt servo motor that can drive the stalk to tilt in any direction. The second part of the installation is a dried plant stalk connected to an accelerometer outdoors. As the winds blow, the exterior stalk sways, and its exact movement – both in intensity and direction – is detected by the accelerometer. This data is then transmitted to the devices in the gallery, and the gallery stalks replicate the exact, real-time movements of the sensor stalk. Thus, the wind is displaced, from outside into the gallery space (Figure 16). In a 2018 version of this installation, the grouping of tilting stalks was installed at Azkuna Zentroa, Bilbao, Spain, and the sensor was located outdoors at the University of Minnesota. The installation thus reproduced, in Spanish, the real-time Minnesota winds.

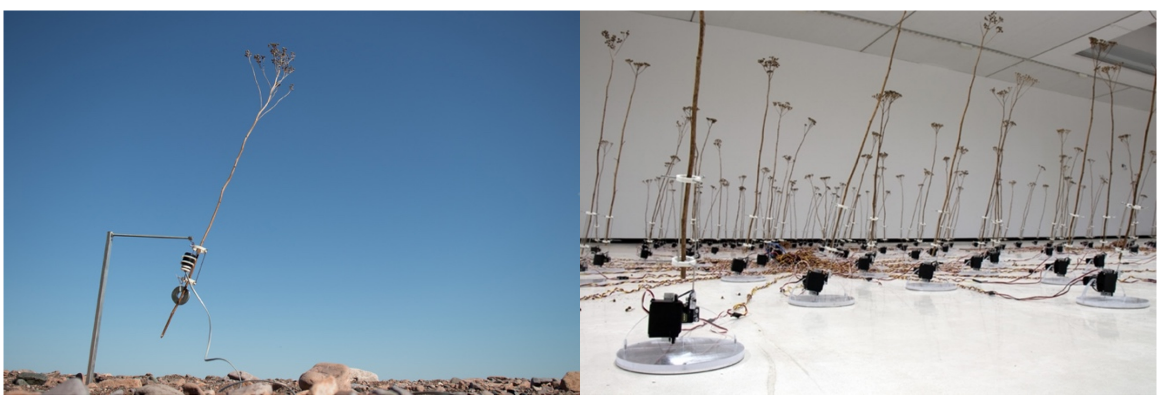

Figure 16. Tele-Present Wind
Sensor (left) and actuators (right), ©David Bowen 2011

At first glance, “Tele-Present Wind” reconstructs air forces using sensed data. However, inspecting the sensors used, we find that the installation poses a series of questions as to the nature of sensing and sensors. Wind speed and direction are variables used in meteorology, and are commonly measured via anemometers. Anemometer outputs are vectors with which we describe wind at any location, at any time, with a combination of two values, one indicating the direction in degrees and the other reporting the speed of horizontal airflow (in miles per hour). If we analyze Bowen's sensing device, constructed of a dry stalk and an accelerometer, then what is sensed about wind? Alternatively, in Bowen's work, what constitutes a sensor? The actual sensor in Bowen's installation is an accelerometer, which measures acceleration on one, two, or three axes. Its output is a vector combining two values – direction, and magnitude in that direction (m/s2). Bowen used a two-axis accelerometer in order to record how fast and in which direction the wind tilted the stalk. Therefore, technically, the accelerometer did not sense wind directly, but instead evaluated the stalk's movement. Bowen's audiences are left to interpret the stalks' movement inside the gallery as if wind blows them.

Compare Bowen's sensing device with the three-cup anemometer commonly used in environmental sensing. We find that there is, in fact, no difference between them, in regard to the transformation process. A cup anemometer consists of three hemispheric cups mounted on horizontal arms. When air passes the cups in any horizontal direction, the cups drive a vertical shaft to turn at a rate proportional to the wind's speed. Thus, counting the turns of the wind-cups over a set time interval yields a value proportionate to the average wind speed during that time frame. Hence, a cup anemometer itself does not directly measure wind speed; what it actually measures is how fast the shaft rotates. In both cases (the cup anemometer and Bowen's installation), devices can produce certain behaviors in response to wind – the rotation of a shaft or the tilting of a dry stalk. We interpret the phenomenon by reading the devices' behaviors.

Any type of sensing involves interpretation. Recall Don Ihde's hermeneutic relationship between humans and technology. In that case, sensors as technological artifacts compress and black-box a set of interpretation protocols into one streamlined process. In hermeneutic relationships, we are involved with the environment via an artifact that provides a representation of the world. We must interpret its behavior to gather information about the environment (Ihde 1990). Ihde uses hermeneutic relationships to describe this type of mediation process, because the artifact must be "read". Yet in order to read, a set of protocols must be in place to accompany the specific design of a device. In the case of a wind cup anemometer, *anemometer factor*, the ratio of wind speed and shaft rotation speed depends on the physical construction – the dimensions of the cups and arms.

Further, an anemometer sampling frequency is dependent on how often we take measurements: a 1-Hz frequency anemometer counts the turns once per second, and a 0.1 Hz frequency counts the turns made in a 10-second time frame. Interpretation thus involves specific designs of the devices and protocols that instruct us to read the device "properly". Construction of a sensing device also means standardizing and formalizing a wide range of protocols, procedures, and possible designs, with one working model. A digital anemometer streamlines and automates interpretation protocols by specifying measurement frequency and anemometer factor with circuit boards.

Thus, a sensing device does not innocently "listen" to a phenomenon; it is, in essence, a black box containing streamlined interpretation procedures. Charting the history of cybernetics and the emergence of the "digital", media historian Bernhard Siegert formulated the relationship between mathematics and cultural techniques: "The mathematical concept of the symbol is founded on the black-boxing of a history of cultural techniques, which in turn is a history of the articulation of the real" (Siegert 2018, 10). A sensor is an idealized way to read environmental traces. Thus, sensing implies coding the environment, by naturalizing and streamlining a history of interpretation techniques with an automated recording device.

We approximate the phenomenon which we observe with a sensing instrument's behaviors, assuming that studying the quality of the measuring device is equivalent to studying the original phenomenon. In the case of an anemometer, we replace air movement with shaft rotation. The behaviors of sensing instruments thus become proxies of the phenomena in question. This replacement of objects applies to any form of environmental sensing. One of the most common temperature sensors is the thermistor, or thermal resistor. A thermistor's resistance changes drastically with temperature fluctuation; thus, a temperature sensor constructs a relationship between voltage and ambient temperature changes. Similar principles apply to photocells or light sensors, photoresistors whose resistance changes with received luminosity.

Sensing is coding, which involves developing codes that naturalize and legitimize a series of interpretation protocols of transformation that encode the environment into ones and zeros. From this vantage, environmental sensing constructs a sensing network of various instruments, each of which embodies a specific history of interpretation techniques, coding the environment into a “datascape”. When we interact with the environment using environmental data, we are, in fact, interacting with this “datascape”.

2.2. Sensing and its Objectivity

How is this “datascape” weighted with a sense of objectivity to environmental sensing, and why would we trust the encoding process to be a faithful depiction of environmental phenomena? Historians Lorraine Daston and Peter Galison’s notion of *mechanical objectivity* may provide insight. Modern environmental sensing continues the paradigm of *mechanical objectivity* that emerged in the mid-nineteenth century. Tracing the development of the notion of objectivity through nineteenth century scientific atlases and representations, Daston and Galison (1992; 2007) posit that the first phase of objectivity, or “truth-to-nature”, relates to scientific efforts to capture nature “as it was” through meticulously detailed representations of biological, geological, and other phenomena. The notion of documenting nature in its "purity" was a scientific obsession meant to help scientists approach to nature and render it both recognizable and classifiable. However, the evident problem was the artist-author's need to tame nature's variability into idealized forms and archetypes. With the popularization of daguerreotypes and cameras arose what Daston and Galison described as the era of *mechanical objectivity*. Because machines, such as cameras, captured moments which human vision was unable to seize, machines were elevated as paragons of scientific virtue.

> "By mechanical objectivity we mean the insistent drive to repress the willful intervention of the artist-author, and to put in its stead a set of procedures that would, as it were, move nature to the page through a strict protocol, if not automatically. This sometimes meant using an actual machine…." (Daston and Galison 2007, 121)

On many levels, environmental sensing may be understood as one phase of "a relentless search to replace individual volition and discretion in depiction by the invariable routines of mechanical reproduction" (Daston and Galison 1992, 98). On the path for "truth-to-nature", scientists became their own greatest enemy, and "the all-too-human scientists must, as a matter of duty, restrain themselves from imposing their hopes, expectations, generalizations, aesthetics, even ordinary language on the image of nature. Where human self-discipline flagged, the machine would take over" (81). Mechanical objectivity is thus a paradigm whereby scientists develop machines and routines of mechanical reproduction that remove human interpretation from scientific research and "let nature speak for itself." Mechanical objectivity is thus not only an issue of accuracy, but one of scientific morality and epistemic virtue, and machines are simultaneously a means and a symbol of this paradigm. As Daston and Galison (2007) note, "the machine stood for authenticity: it was at once observer and artist, free from the inner temptation to theorize, anthropomorphize, beautify, or interpret nature" (139). Sensors as automatic recording devices become paragons for the virtues of ideal observers; they are "patient, indefatigable, ever-alert, probing beyond the limits of the human senses" (139). Sensors can provide data "free" from human interpretation; they remove human observers from the equation, and provide a perspective that issues from no one and nowhere.

We may further analyze environmental sensing, with respect to the socio-technical networks in which sensors are embedded. When we place the development of a sensing instrument within socio-technical networks, we find that the sensing practice is a self-vindicating process. Eric Winsberg (2010) argues that computer simulation practices in scientific research are self-vindicating over time, and thus simulations possess a life of their own. "As simulation practices evolve and are retooled, the techniques they employ carry with them their own history of prior successes and accomplishments, and when properly used, they can bring to the table independent warrant for belief in the models they are used to build" (45). Just as computer simulations gain their reliability by carrying with them an entire history of accomplishments, sensing practices may also be understood as an evolutionary process through which credentials are gained by repeating successful methods and assumptions. A sensor carries its own history of scientific and engineering accomplishments.

From a social constructionist perspective, the evolution of a sensor involves multiple social groups, over a long time, agreeing on one standardized version and a set of accepted sensing protocols. Each successful prediction based on the produced data adds to the reliability of the sensing device's underlying principles and protocols. Because data produced by anemometers are repeatedly proven to be useful in predicting weather patterns, the underlying assumptions and protocols of anemometers were, over time, legitimized. When standards and protocols are set in place and shared by sensing communities, including environmental groups, manufacturers, distributors, and hobbyists, environmental data are warranted not only by individual humans, but also by a complex socio-technical system too sprawling to trace. To a certain extent, objectivity is gained by creating a view from nowhere.

2.3. Mediation and Limitation: Datascape and the Episteme of the Digital Age

We can thus understand sensing as a process that allows us to relate to the environment through the mediation of a sensor, which simultaneously limits us to interaction with the environment in the specific way which the sensor allows, accepting the sensor's history of cultural techniques. We invent sensors to code the environment into sensible variables, and describe the environment as an object. In OOO terms, through environmental sensing, we replace the real object, which is withdrawn from access, with a constructed object, using sensing networks. Rather than sensing winds, we code airflow movement with instruments, and construct the winds' objects to communicate this phenomenon with each other, using comparable qualities. In a coding process, we reduce a phenomenon to a limited number of variables that fit within meaningful and quantifiable categories, such as wind speed and direction, rather than other aspects for which we do not yet own vocabularies. Sensors become the physical and material manifestation of a set of relationships between us and the environment, through the black-boxing of a history of cultural techniques.

By analyzing how a sensor works, we may analyze how we are coupled with the environment through the relations permitted and simultaneously limited by the sensor. In developing a measuring instrument, we simultaneously eliminate other possibilities with which to construct relationships with processes around us. When a sensing instrument becomes standardized, we begin to ignore that each sensor embodies a history of interpretation technique; we overlook the assumptions that combined into building such a device, and fix our eyes on the output produced by the device. For example, an anemometer measures only horizontal airflow, but winds may be three-dimensional; a horizontal wind profile thus becomes a proxy for wind in general. Further, streamlining protocols and the self-vindicating process eliminate other possibilities to use or misuse sensing instruments to code the environment differently. The earliest mechanical anemometer dates to the fifteenth century, and it has engendered numerous versions. Today, many anemometers use mechanisms other than cups to measure wind speed, such as ultrasonic, hot-wire, laser Doppler, and wind pressure. If we were to transform Bowen's device into an anemometer, we might use mathematical functions to translate accelerometer data into wind speed and direction. To a certain degree, as long as a gadget responds to wind with salient behavior, its outputs can be coded and translated into wind speed and direction. Thus, the movements of willow tree twigs can be coded to measure wind. However, the complexity of their movement is beyond human capability to record, categorize, quantify, and compare. From this vantage, we might say we invented anemometers to measure wind speed. Yet we can also say that we failed to develop vocabularies to describe the movement of willow twigs, because it is easier to build a gadget to categorize such a phenomenon, and it requires less human interpretation on the path to objectivity. However, by doing so, our language for discussing wind is also confined to direction and speed as the two recognizable and classifiable variables allowed by anemometers. These assumptions associated with sensing practices as specific cultural techniques have been black-boxed into the sensing devices. They become a hidden epistemic substrate that one must accept, without questioning it.

By embracing environmental sensing, one also consents to the blind spots and points of discontinuity associated with sensors. As Siegert (2018) declares, coding is "the most basic cultural technique of the digital age, in the sense that it is based on an isolation of the nonsensical and its declaration as nonreality" (18). When coding occurs, "the nonsensical becomes the nonexistent" (18). To become "digital", one must accept that the "datascape" constitutes one's whole reality, and declare that what is in the blind spot of a sensor is nonexistent. Ranjodh Singh Dhaliwal argues that "addressability" is the foundational requirement for computation.[20] In order to be computable, a phenomenon must be addressable, in this case, by sensors. What is "unaddressable" becomes invisible to sensing devices, yet it still exists. For example, when a self-driving car collides with a pedestrian, it may not be that the self-driving car is inefficiently computed, but because the datascape that constitutes the car's reality renders the pedestrian invisible, thus utterly incomputable. From the car's perspective, there are no pedestrians, because they have become unaddressable by the sensors.

For environmental sensing, those objects unaddressable by sensors become nonexistent in the datascape. One caveat is that addressability differs from quantifiability. For those processes that were thought unquantifiable, one may often construct protocols and proxies to render them quantifiable, addressable, and then computable. Whereas unaddressability involves a situation in which processes are ignored, treated as noise, or categorized as uncertainties; they exist in the blind spot of the epistemic framework that underpins environmental sensing practice. To practice environmental sensing and attribute objectivity to it, we also accept that the procedural knowledge produced by sensing and computation is the preeminent way in which much of the world is revealed to us. We are on a path toward establishing a principled way of knowing, built around coding practices. If coding is the most basic cultural technique of the digital age, then undergirding our time – the one characterized by digitalization, big data, and machine intelligence -- is an episteme built around coding, in which "nonsensical" become "nonexistent" and "nonreality" (Siegert 2018).

[20] The argument was presented by Katherine Halyes in a public lecture in 2020: https://www.youtube.com/watch?v=ZCWI4_HonjI . Dhaliwal's full paper 'On addressability, or what even is computing?' is under review at *Critical Inquiry as of early 2021.*

It is an episteme of the digital age, because sensing is no longer a practice employed solely to construct scientific evidence. Sensing practices have permeated every aspect of contemporary society, and formed a sort of technological momentum, a concept developed within the context of the social construction of technology (SCOT), and used to describe the relationship between society and technology over time. An emerging technological artifact or system develops in a social network and eventually couples with it, resulting in the seamless mesh of a socio-technical ensemble. Increasingly, sensing practice becomes an attractor that structures our relationship with other species and the environment in the specific way permitted by the sensing network which we construct. Environmental sensing gives rise to a sort of technological momentum that pushes us to couple with the environment in a manner that is both enabled and limited by cybernetic technologies.

Environmental sensing proponents' enthusiasm for this enterprise cannot be separated from liberating and environmental narratives, in developing environmental sensing technologies. Safecast (2011) exemplifies the paradigm of environmental sensing, and has been placed on many labels over the years, such as citizen science, open-source, grassroots, and bottom-up. After the 2011 Fukushima nuclear disaster, public and governmental agencies were unable to provide the public with data regarding radiation levels. To address this issue, local hackers and technologists formed a team to develop DIY radiation-sensing kits. The team contacted manufacturers, designed the kits, and organized volunteers to collect and upload data to a web-mapping platform, producing timely visualizations of the radiation levels around Fukushima. Over the years, Safecast has evolved from its original focus on radiation levels to a broad-based environmental sensing effort. Volunteers collect diverse types of air quality data, such as particulate matter levels (PM1.0, PM2.5, PM10). Safecast gaining a great deal of media exposure, and its discourse revolves around liberating narratives. "Safecast has enabled people to monitor their own homes and environments easily and to free themselves of dependence on government and other institutions for this kind of essential information" (Safecast 2011).

Narratives of environmental sensing are therefore intertwined with DIY culture, citizen science, and environmental values. Thus, sensing practices are romanticized as liberating actions that challenge authorial control over knowledge production. In 2020, Safecast developed a web map to track COVID-19 cases, hoping to provide transparency regarding critical information often held by government agencies, and to promote a data and knowledge democracy. Simultaneously, participating in and practicing environmental sensing becomes a way to show concern as a global citizen who cares about climate change and environmental issues. Environmental sensing narratives fit well within the contemporary individualistic culture and democratic ideology.

This phenomenon can be described as a combination of smartmentality and environmentality (Vanolo 2014; Gabrys 2014; Krivý 2018). Environmental sensing and smart environment narratives make sensing practice a disciplinary strategy. To become a concerned and responsible citizen who cares about the environment, one must participate in "smart" activities, such as environmental data collection. Over the years, there have been numerous research directions and efforts to promote participatory citizen sensing (Table 1). A growing technological momentum expressed as environmental values intertwined with democratic ideologies might mobilize different social sectors to participate in constructing a global sensing network -- and simultaneously construct a "datascape" that replaces the environment in which we live.

PROJECT	DATE	TYPE	FOCUS
SAFECAST	2011	portable sensing kit	Post-disaster sensing (radiation)
ARRAY OF THINGS	2015	urban sensing modules	Environmental data
THE THINGS NETWORK	2015	LoRa-based infrastructural protocol	Network infrastructure
CITIZEN SENSE	2013	citizen engagement	Democratizing environmental data

Table 1. A list of major sensing practices since 2010 (not complete)

Environmental sensing limits the possibility of constructing alternative relationships with the environment, by imposing a specific epistemic framework that transforms nonsensical into nonexistent. Consider the notions of co-production and co-evolution. Humans have co-evolved with tools and other technical systems, co-producing each other. Yet on the reverse side of co-evolution and co-production between humans and sensing technologies is a process of devolution; we have eliminated other potential pathways through which the environment is revealed to us, and denied other possible ways in which we might be coupled with nonhuman species and processes. If we understand sensors as media enabling us to interact with the environment, then, at the same time, sensors limit pathways of environmental interaction. In regard to environmental sensing, mediation and limitation, to our embarrassment, share the same process.

Here, we need to recognize the limitations of employing critical and historical frameworks of analysis. Most critiques of cybernetics, environmental sensing, and similar topics stop here, constructing evidentiary cases and historical material to reveal a shocking aspect of naturalized notions, such as sensing; they leave us appalled and hopeless. Historians, including Daston, Galison, and Siegert, have provided meticulous examples and cases in their studies; yet, in the end, unsatisfied readers ask: "What comes next, and can we do something about it?" This is why we must take on a design research framework, recognizing the optimism and opportunity embedded in sensing practices. The construction of a "datascape" may bring terror, but also hope, as long as we constantly remind ourselves that sensing is coding, because the latter conveys an active stance towards this underlying epistemic framework.

2.4. Coding Operations as Co-production Techniques in the Digital Age

Suppose that we begin to recognize environmental sensing as a practice in which we actively construct media through which we interact with other objects and assemblages. In that case, we might intentionally code the environment into different "datascapes". Thus, sensing as coding becomes a co-production technique specific to the digital age. STS scholar Sheila Jasanoff (2004) stated that, "co-production is shorthand for the proposition that the ways in which we know and represent the world (both nature and society) are inseparable from the ways in which we choose to live in it" (2). In other words, to understand sensing as coding entails an intentional decision to use or "misuse" sensing instruments in specific ways, so that the environment may be represented and known differently. Such knowledge can transform our lived relationships with others. In a sense, it is about reframing modern technology's "enframing (*Gestell*)" effect, as articulated by Heidegger.

Reframing sensing as coding allows us to ask the following question: How do we code the environment in such a way as to cultivate greater empathy towards the nonhuman realm and foster co-productive relationships with other human and nonhuman actors in a shared environment?

Developing Dhaliwal's notion of addressability, we may argue that in order to be computable within a cybernetic environment, a phenomenon must first be visible in the datascape, and thus addressable by the algorithms. One way to become visible is to make a difference in a cybernetic system by misaddressing – reconfiguring pathways in the system, thereby producing errors and noise – which is the third category that lies parallel with addressable and unaddressable. Thus, misaddressing opens spaces of operation in sensing practices.

We can visualize misaddressing through a series of diagrams (Figure 17), imagining sensors as interfaces between the digital and the physical; sensing networks thus become membranes between the environment and its datascape used for computation (Figure 17: Mainstream Sensing Practices). We can then explore a body of work that challenges the specific construction in the diagram. Misaddressing can be conceptualized as four different relationships between the environment and its datascape: cloning (one-to-many), assembling (many-to-one), rerouting (one-to-one), and physicalization (one-to-naught).

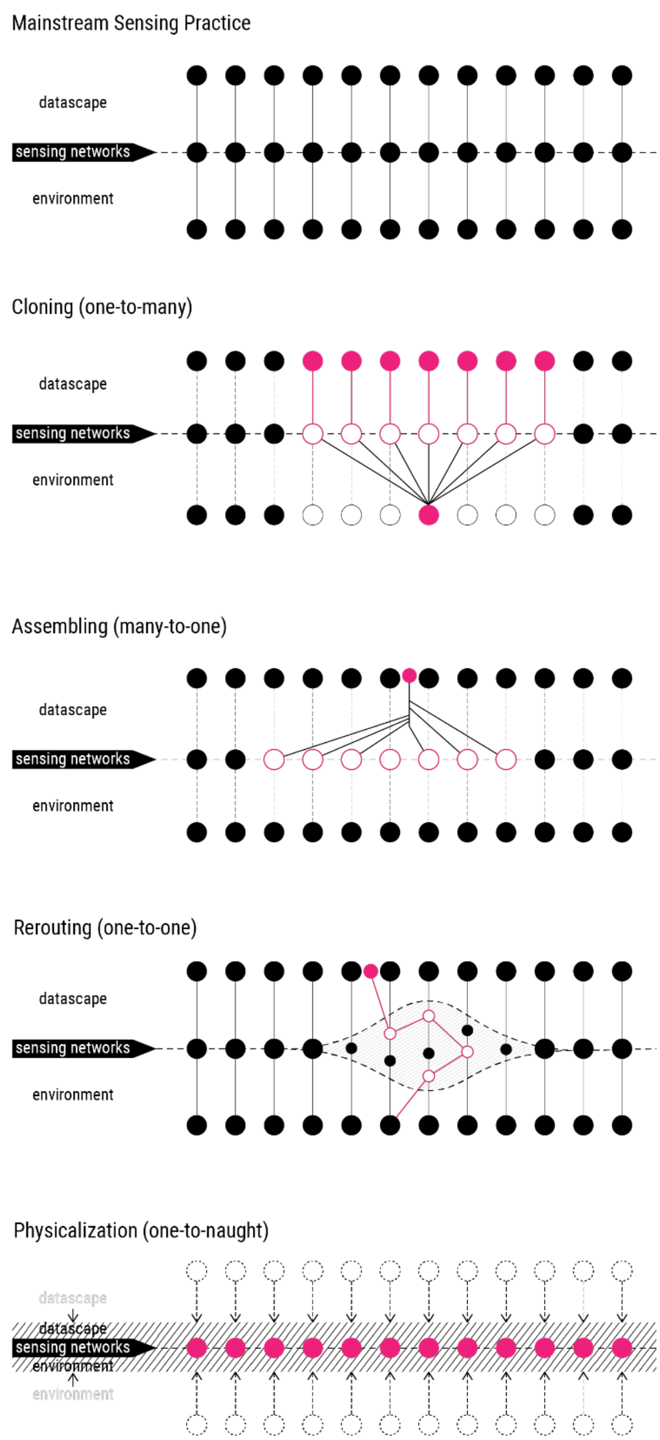

Figure 17. Misaddressing

Cloning (one-to-many)

Berlin-based artist Simon Weckert’s performance art “Google Maps Hacks” (2020) best illustrates the one-to-many relationship. The Google Maps algorithm uses GPS pings from smartphones to determine users' location, and the data collected by accelerometers in smartphones to determine their speed. Drivers carrying smartphones thus become temporary assemblages acting as sensors distributed in the urban environment. The location and speed data of these driver-phone assemblages, combining historical traffic data, together construct a “datascape” for the Google Maps algorithm, which optimizes navigation instructions for drivers who use the app. In early 2020, Weckert carried 99 smartphones in a handcart, and walked along the streets of Berlin. Since he walked slowly with his handcart, his momentum tricked the Google Maps algorithm into believing that traffic jams had congested the streets. Wherever Weckert walked, he created virtual traffic jams, turning green streets red on Google Maps. These visualized traffic jams might have created physical impacts if the algorithm rerouted drivers around the indicated streets, in which one man with 99 smartphones pulled a small handcart (Figure 18).

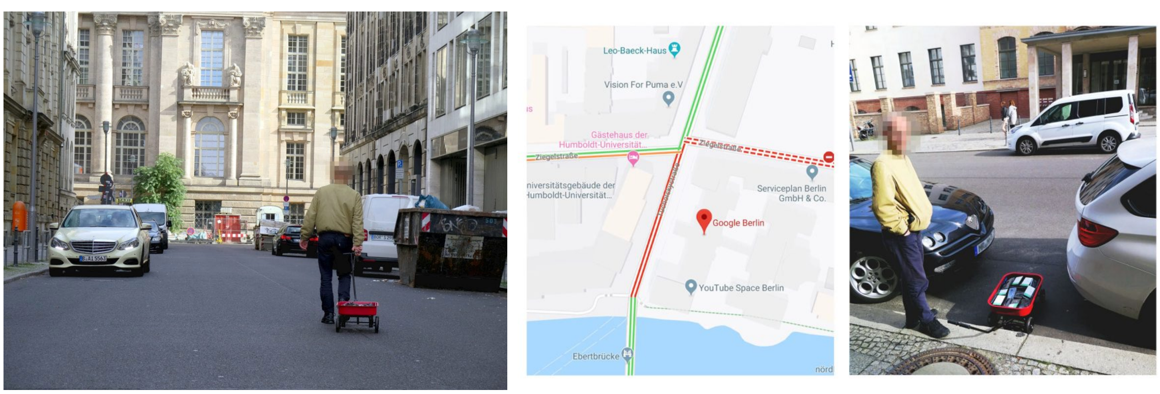

Figure 18. Google Maps Hack
©Simon Weckert. Berlin 2020

Here, the relationship between Weckert (with his 99 smartphones) and the Google Maps algorithm is in the category neither of addressable nor unaddressable. The algorithm recognized the smartphones' MAC addresses and located them via GPS signals; it also collected their speed data. Thus, these smartphones were addressable by the algorithm. Yet there is a further level of addressability embedded in the black-boxed interpretation protocols within Google Maps' tracking process. In this cybernetic system, the algorithm endeavors to address individuals through smartphones as media, and each driver is replaced by a smartphone MAC address in the datascape. Smartphones became the proxies of vehicle drivers, and the system presumed a one-to-one relationship between a driver and a MAC address. In Weckert's performance art, however, the artist reconfigured the system's pathways by assigning one person with 99 MAC addresses to the datascape, creating a one-to-many relationship. One object thus misaddressed and created digital duplicates that burdened the computation, overloading the system to produce "errors".

These "errors" caught Google's attention; its team replied with good humor, thanking the artist for his creative use of Google Maps. Certainly, the true value of the project lies beyond helping Google Maps improve its algorithms. The artist actively codes the datascape that constitutes the full reality of the Google Maps algorithm. By doing so, the artist opens the black box of the Google Maps sensing network, denaturalizing the invisible protocols and assumptions in its urban sensing practices. In the cybernetic environment, phenomena, including individual humans, are reduced to the MAC addresses of the sensing devices, each of which corresponds to certain state variables that describe computable aspects. We and our behaviors thereby become computable environmental variables. Systems and algorithms modulate, manipulate, and compute these addresses in order to optimize the physical environment, including human behaviors. Yet Weckert's performance teaches us that we may actively code the datascapes of different systems, by creating digital clones in these systems, denaturalizing the system, and exposing opportunities for intervention. This is the first step towards further reframing operations.

Assembling (many-to-one)

Sougwen Chung's artworks feature her drawing collaboratively with intelligent machines, such as robotic arms and autonomous robots. Though her art largely concerns human-machine co-production, to be discussed in detail in Section 3.3, her performance "Omnia per Omnia" (2018a) inquires about the notion of urban sensing, especially visual sensor networks – that is, urban surveillance cameras. Through the project, Sougwen seeks to reimagine the notion of landscape painting, as a collaboration between an artist, a robotic swarm, and a city's dynamic flow. Rather than a view from a single perspective, Sougwen's "landscape painting" captures a multidimensional view of the city.

Inspired by the famous AI researcher Fei-Fei Li, who stated that, "If we want our machines to think, we need to teach them to see,"[21] Sougwen teaches her drawing robots how to see the world through computer vision algorithms. In collaboration with researchers from Nokia Bell Labs, Sougwen and her team collected internet videos from publicly available camera feeds, using this footage to train a computer vision algorithm (Motion Engine) with a technique called optical flow, which can characterize and quantify the motion of objects in a video scene. Using Motion Engine, Sougwen and her team analyzed the collective density, direction, dwelling, and velocity states of urban movement – pedestrians and vehicles flowing through urban spaces. These states were extracted as positional data that became paths for her robots to draw on (Figure 19). In a way, these robotic paths represent not the movement of any individual, but the movement of a swarm, as in the following description:

[21] Fei-fei Li made this argument on multiple occasions, including lectures, public talks, and interviews: https://www.wired.com/brandlab/2015/04/fei-fei-li-want-machines-think-need-teach-see/

“The philosophical underpinnings of the Bell Labs Motion Engine captures the optical flow of a scene as opposed to the single object; it privileges the action of the collective (the behaviour of the crowd) over individual surveillance (face tracking and recognition). The latter way of seeing [is] fragmented and discrete” (Chung 2018a).

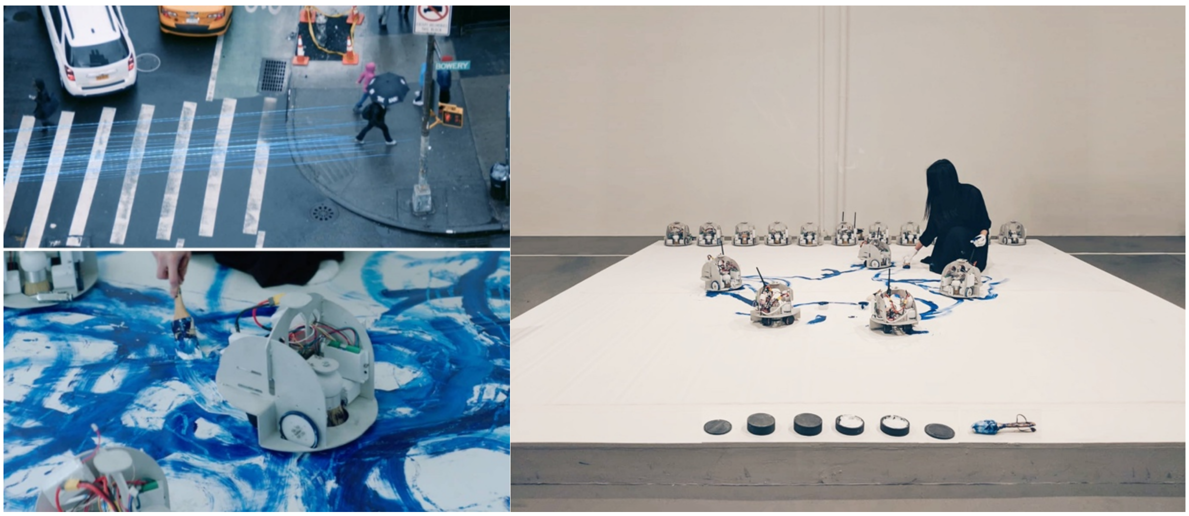

Figure 19. Omnia per Omnia
© Sougwen Chung 2018

Over the past years, many data visualization projects have entertained the notion of “flow of a city”, attempting to understand dynamics and “flow” in urban environments. Two famous visualizations are “One Day on Waze” (2014) and “Foursquare Check-ins” (2013). In both cases, the data comprise GPS pins of an individual person reported via smartphone apps such as Waze and Foursquare; each data point on the maps represents a human using the apps. There is a one-to-one relationship between each person and each dot, while at the same time, those who turn off smartphone location services, or do not use the apps, become invisible in these “flow” maps. When the author of the “Foursquare” visualization claimed the maps showed “the pulse of New York City”, one person commented below the video, reminding the author that the visualization recorded only “the pulse of Foursquare users.”[22] This comment embodies the ongoing debate within data-driven urban analytics. Since the use of smartphones, location services, or specific apps is self-selected and irregular in these data-driven urban analyses, their crowd-sourced data does not at all reflect the dynamics of the “crowd”. These debates often evolve into tensions between participatory sensing and individual data privacy.

In contrast to one-to-one visualizations of “flows”, Sougwen and her team use Motion Engine to focus on a many-to-one relationship that does not combine multiple data streams into one larger stream, such as in Waze and Foursquare visualizations, in which individuals are assigned addresses for computation. In contrast, many-to-one is a conundrum, in that we are not sure to whom we should pin an address for computation. Addressability is at stake here. An interesting phenomenon appears: no one is invisible, since the crowd is being watched and analyzed by machines, yet meanwhile, everyone is invisible -- because individuals become less important within every movement of a swarm. Furthermore, swarms are ephemeral; if the crowd falls into complete chaos and random movements, the swarm disappears, and the computational address pins to nothing. Moreover, the concept of individual agency fails in a swarm, since we are unsure how much a single agent’s movement influences the swarm's behavior. As Sougwen said in an interview,

> “The movements [of the robots] are linked to the movements of a crowd, who aren’t aware of their position as catalysts of the robotic swarm. But what if the crowd were aware of being all watched over by these machines? That’s what I mean by being at the onset of this collective imagination and intersubjectivity. It’s inspired the idea of a collaborative space between multiple bodies that is physical, digital, telepresent, and most importantly, shared. *It’s a representation that isn’t about control, but*

[22] https://vimeo.com/75413842

> *something else*…The project really stemmed from a curiosity – a willingness to de-privilege the Western conception of the individual towards an entangled, intersubjective, radical ecosystem. I've been inspired by this reconfiguration of the "I", through theorists like Yuk Hui who explore a new cosmotechnics, and the philosophies of media centred around eastern concepts of relation" (Sougwen 2018b, emphasis added).

Yuk Hui defines cosmotechnics "as the unification of the moral and the cosmic through technical activities", and claims it "reopens the question of moral beyond ethical rules which are added posteriorly as constraints to new technologies" (Hui 2020, 64). In a sense, Sougwen's "Omnia" project challenges us to completely rethink the current ethical and moral debates on environmental sensing technologies. The project reveals, however, a blind spot results from a deeper epistemic framework based on the conception of the individual as the fundamental unit for sensing and computation, as well as for reflections and critiques based on ethics and moral reasonings built around individuals. The "Omnia" project bypasses discourses based on data privacy, state surveillance, and individual freedom, all inevitable reasonings stemmed from an individualistic view towards sensing and computation practices. Instead, the project opens alternative and uncharted territory, to entertain the notion of sensing and computation on the basis of crowds and collectives. It provides novel ways to discuss phenomena in societies such as in China, where data tracking, facial recognition, and surveillance systems do not seem to vex individuals as much as in Western societies, and are occasionally welcomed; consider the differences in the handling of the COVID-19 pandemic through smartphone tracking apps in China and the United States. The discourse surrounding data privacy and state surveillance, which relies on a conception of a duality between the individual and the state apparatus, often falls short when addressing cases like COVID tracking; such discourse oversimplifies this dualism, based on a Western conception of the individual. As Sougwen noted, it is no longer about control, but something other, which we only begin to explore conceptually and theoretically through practices like Sougwen's artworks.

Rerouting (one-to-one)

Another case illustrates the rerouting relationships that construct new pathways in cybernetic systems. Mileece is a sonic artist who makes music with plants. In her installations, such as "iOracle" (2018), she attached electrodes to the leafy limbs of plants; the electrode captured micro-bioelectricity from the leaves. Electrodes are commonly used as biomedical sensors for measuring human heart, muscle, and brain activities, such as in EEGs and ECGs. Mileece in her turn, connects the electrodes to plant bodies rather than human bodies, and collects the output via a current amplifier. The micro-current is transformed into binary codes to animate melodies and harmonic frequencies, utilizing custom music software. These installations were distributed as acoustic playgrounds in local schools. When audience members touch plant leaves, or when ants crawl on the leaves, direct feedback in the form of music is produced by the plant's bioelectricity. Mileece hopes that the sonification of the bioelectric signals cultivates empathy in her audiences, and encourages them to acknowledge different forms of sentience and intelligence.

Mileece thus reroutes data transmission pathways and builds a cascade of unusual connections between sensors, electronic parts, and algorithms. The relationships between the datascape and the objects are still one-to-one, while a new pathway is constructed by associating one address with another in ways that appear abnormal, even outrageous. Mileece produced ones and zeros from the plants as datasets that fail to fit within existing data categories. Mileece's artistic practice exposed the blindspot in the "datascape" constructed by present-day mainstream sensing practices, and elucidated aspects that are unaddressable yet existent.

Bowen's installation, "Tele-Present Wind" also falls within this category. By attaching accelerometers to a dry plate stalk, he produced a dataset that lies outside the computable variables of wind as an environmental phenomenon.

In both cases, artists have denaturalized the "sensor" as one object connecting physical space to digital space. Instead, both challenge their audiences to understand sensors as assemblages constructed of materially different components – whether mechanical or biological. In Bowen's case, an accelerometer plus a dry plant stalk becomes a "wind sensor" that elucidates aspects of wind beyond speed and direction.

Similarly, for Mileece, electrodes plus plant leaves become sensors to detect human touch and crawling ants, revealing a different aspect of the contact between two objects. When we search for touch sensors at off-the-shelf sensor distributors, we find two types. One type is the capacitive touch sensor, based on capacitive coupling, which can detect anything that is conductive or has a dielectric difference from the air, such as smartphone touchscreens. This type produces a binary presence/absence relationship, whether touching or not. Another type of touch sensor is based on force-sensitive resistor (FSR). FSRs are resistors that alter their resistive value depending on the surface force applied. Compared to both sensor types, Mileece's "touch sensor" made of plant material produces data about neither case. For the audience, touching the plant's leaves becomes conversation with the plant-sensor itself.

In these rerouting practices, a sensing network is no longer a thin membrane between the digital and the physical. Sensing is no longer the moment a phenomenon is digitized into ones and zeros. Instead, the artists unbox the moment of sensing and elongate the data transmission process, reconfiguring the interpretation protocols black-boxed by sensors. Thus, rerouting practices treat the space between digital and physical as an area of intervention.

Physicalization (one-to-naught)

If the three coding operations above rely on first conceptualizing two realms of reality – digital and physical -- then Dietmar Offenhuber's works and theoretical reflections further denaturalize the practice of environmental sensing, by exposing this accepted dualism in sensing practices. He proposed *autographic visualization* as a speculative counter-model for conventional information visualization, which begins with data collection and ends with visualizations explaining the underlying patterns in datasets (Offenhuber 2019).

"*Staubmarke*" (dustmark) (2018) is a public artwork in Stuttgart, Germany – a city much affected by particulate matter pollution. Unlike other environmental sensing projects, such as Safecast, which begin with sensing kits and data collection, then address the issue of environmental quality with map visualizations on a web platform, "*Staubmarke*" constructs physical evidence of air pollution by turning people's attention to the patina on city's surfaces. Using a technique called *reverse graffiti*, the installation crew strategically cleaned parts of the accumulated pollution on rigid urban surfaces, such as buildings, bridges, and retaining walls, creating clean patterns of different densities of dots. Over time, these graffiti dust marks will fade as particulate matter re-accumulates on these surfaces (Figure 20).

In another project "Ozone Tattoo", Offenhuber uses indicator plant species as "sensors" to call attention to climate change and its impacts. One of the threats of climate change is increased ground-level ozone, which is harmful to plants, animals, and humans. Low ozone concentrations would damage tobacco plants, "tattooing" yellow and brown spots on their leaves. This phenomenon makes tobacco plants apt indicator species to visualize the impact of increased ground-level ozone levels due to climate change. The installation established ozone gardens, which allow communities to monitor pollution by observing the indicator plants (Figure 20).

Figure 20. Data Physicalization

"Staubmarke" (top), 2018. "Ozone Tattoo" (bottom), 2019. © Dietmar Offenhuber

Recall Daston and Galison's discussion on *mechanical objectivity*. From a scientific perspective, data collection uses sensing devices to construct scientific evidence allegedly free from human interpretation; the nature of the phenomenon may thus be presented "as it was". However, as argued, sensing *is* coding, and a machine does not innocently "listen" to these phenomena. Instead, changes in the environment trigger a set of system operations within the machine – streamlining a series of interpretation protocols – to produce certain output which we call data (e.g., a thermistor change resistance according to different temperatures). In order to make sense of the phenomenon, one must read the traces constructed by sensors; this occurs, to use Don Ihde's term, through hermeneutic relationships allowed by the machines. The traces make sense only when interpreted in certain semiotic relationships. One must construct a mental model for interpretation in order to understand that 50 ppm of PM2.5 signifies a relatively acceptable air quality. In contrast, the "reverse graffiti" and "Ozone Tattoo" create systems that present the phenomenon directly to us. These projects need not address data visualization, since the object of study has never been digitized in the first place; thus, there is no "data" to visualize. Both projects create a one-to-naught relationship within the misaddressing framework, because nothing has been produced in the so-called "datascape". Environmental sensing produces physical traces in the environment. The digital/physical division no longer holds in these projects, and both the data and the environment collapse into each other; the environment becomes data.

2.5. Coding, Design, and Climate Change

Once we understand sensing as coding, our inquiries regarding the environment change. In the face of climate change, the questions we ask, with the concept of sensing, is limited to what types of sensors and how to distribute them in the environment, to collect more data to create models for better predictions. However, with coding, the questions grow complex: how to code the changing environment into signals that register differences within present-day political and socio-technical systems. Recall Gregory Bateson's famous assertion that "information consists of differences that make a difference" (Bateson 1979, 99); regrettably, the present-day sensing regime fails to produce "information". How might "climate change" be a politically sensitive and debatable issue, when scientists have presented numerous datasets suggesting accurate facts? This dilemma is not as much a failure of political persuasion, than a failure to code the phenomena of climate change such that way they register differences in contemporary socio-political systems. Therefore, environmental sensing in the face of climate change must concern itself not only with collecting ever more data for climate modeling and visualization, to be used for political persuasion, but also with coding the environment intentionally, using sensing instruments to construct information that can be registered by political, cultural, and societal systems; thus, they may begin to react to this pressing issue.

We may further analyze this issue with respect to object-oriented ontology (OOO). Timothy Morton (2013) conceptualizes climate change as a hyperobject, in the sense that it exceeds human perception in space and time, and is thus inaccessible. Meanwhile, Harman (2018) proposes that metaphors, which construct unusual relations between objects, become valuable pathways through which we connect with other objects. From this vantage, coding practices highlight the role of environmental sensing as a preeminent tool in developing new metaphors between objects – physical or digital, material or immaterial. The art installations detailed above shed light on strategies to construct metaphors through sensing practices, and connect us with hyperobjects, such as climate change. For example, "Ozone Tattoo" connects climate change to ozone-induced plant disease, and, from there, to community and citizen science.

However, to recognize the transformative values of these art practices requires us to overcome the notion that art is the direct opposite of science, and thus they are incommensurable paradigms. A common thread in these practices involves misusing tools and techniques to produce "freaks" that are "useless" in mainstream environmental sensing practices, and may be categorized only as “artistic expressions”. “Creative use of sensing technology” is merely a euphemism for “misuse” and “useless” within more mainstream sensing practices, which emphasize objectivity, efficiency, prediction, and control. Ironically, the notions of originality and idiosyncrasy, commonly treated as virtues in the production of art, become obstacles that hinder these practices from being truly transformative. The concept of “artistic practices” overemphasizes individual creativity and original thinking, and overlooks underlying similarities among different artists, in terms of their conceptual strategies. From this perspective, between mainstream sensing practices in science and various counter-practices in art, the design professions – including landscape architecture – assume important roles in reducing this disciplinary gap.

The four types of coding operations based on the notion of misaddressing – cloning, assembling, rerouting, and physicalizing – serve as strategies for designers to replicate these art projects beyond mimicry. They help translate these artworks into conceptual strategies with which to intervene in the cybernetic environment on a systemic scale. Clearly, these four types of coding operations are not intended to encompass all sorts of counter-practices, but they provide examples for an analytical design research framework that transforms knowledge from one realm to another. This research is thus a continuation of landscape architects’ decades-long tradition of transforming the strategies of art practices into as they design public landscapes. Landscape theorist Beth Mayer (2000) argues that landscape architects have successfully translated environmental values into landscape practices, via environmental arts, in the decades since the first Earth Day in 1970. Today, when the cybernetic environment becomes the condition for environmental practices, cases from digital art serve as valuable lessons for landscape designers.

Finally, we must reflect on the notion of intelligence of co-production, technodiversity, and the ecology of machines. Yuk Hui regards biodiversity as the basis for ecology, and thus the ecology of machines recognizes technodiversity in machines and techniques. When sensing practices are awash with claims of producing objective big data of the environment, to predict its behavior and compute control strategies, we simultaneously eliminate other techniques with which to relate to the environment and other species beyond prediction and control. Environmental sensing, in the name of science and objectivity, has black-boxed a set of cultural techniques in specific ways. Mainstream practices prevent the possibility of other cultural techniques of "sensing" to thrive. Continuing the metaphor of ecology in sensing practice, the cases presented in this section produce "freaks" in the contemporary monoculture of environmental sensing. They appear to be mutations and abnormal instances within the environmental sensing ecosystem. Yet mutations are essential for evolution, because mutation provides a pool of random genes for the ecosystem to grow diverse. Furthermore, intelligence emerges from interactions between assemblages and objects, through relationships such as loose coupling, adversarial, and symbiosis. Within the monoculture of sensing practice, machine intelligence is defined by techniques of optimization and efficiency, eliminating other forms of machine intelligence. Thus, the ecology of machines also denotes a diverse framework for machine intelligence. Once the "freaks" are introduced, they become catalysts for the emergence of other forms of machine intelligence, beyond optimization and control.

3. The Rise of Intelligent Agents: A Non-Model-Centric Paradigm

3.1. From SWMM to DRL: The Emergence of Machine Agents

This section will follow a specific model – Storm Water Management Model (SWMM) – and observe how SWMM has played a role in managing urban environments, and how this role evolved when new modeling techniques were introduced. We will observe the emergence of machine agents as important actors in the cybernetic environment. Materials presented in this section derive from published papers, interviews with experts, and long-term engagement with a scientific research group at the University of Virginia, including participation in its weekly meetings, engagement in discussions, and collaboration on research projects.

SWMM

Between 1969 and 1971, SWMM was developed in response to society's growing concerns regarding water pollution; it has been widely used as a decision-making tool in planning, managing, and designing urban drainage water systems. A consortium of contractors, including Metcalf & Eddy, Inc., the University of Florida, and Water Resources Engineers, Inc., developed the first version of SWMM, under the sponsorship of the Environmental Protection Agency (EPA). The goal was to create a comprehensive mathematical model capable of representing urban hydrological processes, including those of urban stormwater runoff and combined sewer overflow, to assist administrators and engineers in planning, evaluating, and managing urban stormwater sewer systems. Users may employ the model to simulate stormwater system performance in real-time sequence, from points of origin to points of discharge, with user options for intermediate water storage and treatment devices. The model also provided economic data for the cost-benefit analysis of alternative management policies and infrastructures (Metcalf & Eddy, Inc., University of Florida, and Water Resources Engineers, Inc. 1971).

Since then, SWMM has seen several major upgrades, and the model has become increasingly complex. The latest version (SWMM 5.1), released in 2014, includes both conventional components and low-impact development (LID) functions, such as green roof, bioretention, swales, and permeable paving. Also available is a climate change add-on (Rossman 2017). Today, SWMM is widely used, in the U.S. and globally, as a decision-making tool. For example, civil engineers and planners use SWMM to simulate the urban runoff scenarios of new development, under different rain events, and design accordingly their stormwater infrastructure schemes. They may further model different infrastructure schemes in SWMM, to simulate how the system performs with different variables, such as culvert size and routing options. Furthermore, engineers and planners may add control units, such as retention ponds and detention ponds, to mitigate flooding, and simulate the efficacy of these control strategies in SWMM. They are also able to add LID infrastructures, such as filter strips, bioretention ponds, and infiltration trenches to the system model, to encourage groundwater recharge and mitigate urban water pollution. Different alternatives may be represented in the model simulation, and their performance may be evaluated. Thus, to call SWMM a "model" is misleading, since it is essentially a prototyping platform for engineers and planners to test different urban drainage designs. To a certain degree, working with SWMM is similar to an architectural designer's work with 3D modeling software, to produce renderings with which to evaluate different design schemes.

We must pause and reflect on how systems thinking undergirds SWMM, simultaneously limiting how the urban environment is conceptualized, visualized, and eventually constructed. Data moving through SWMM are rendered into hydrographs and pollutographs (Figure 21). A hydrograph represents the rate of water flow (m^3/s or ft^3/s) in a time series past a node in the system. Similarly, a pollutograph displays the concentration of pollutants as a function of time at a given node. Let us take computing hydraulics as an example. In SWMM, the components are conceptualized as sub-systems, with their own input and output. Each component accepts a hydrograph as input, and processes it, producing another hydrograph as output. These individual components are models, with variables describing different characteristics of the infrastructures or spatial features. For example, a storage unit may be described by properties such as maximum depth, surface area, and evaporation factors. These properties become variables involved in computing output hydrographs based on input data. For instance, to describe a storm event, one uses a rain gauge component to produce a hydrograph describing rainfall events in a given time frame; this hydrograph then becomes the input of the whole system, via catchment components. A catchment component takes the output from the rain gauge as input, passing data through a function – with variables such as slope, imperviousness, roughness coefficient, and infiltration – to describe how water collects in the catchment's watershed. Another hydrograph is produced as output. A link component, such as a culvert, connects a catchment to a node component, such as a retention pond. Regulator components, including orifices, weirs, and pumps, may be added between a link and a node component, to control water flow speed from one to the other.

Clearly, through systems thinking, we can abstract and divide a complex phenomenon, such as an urban drainage system, into discrete, manageable and solvable problems. To dissect a drainage system, one must construct multiple hierarchies, by imagining input and output points in a continuous process. First, one must draw a conceptual boundary, often defined by the boundary of a development area on a continuous landscape, and define a point of the outlet where water eventually flows outside this boundary. Then, within the study area, a second hierarchy is introduced, in order to separate a continuous water pathway into links and nodes. With these hierarchies in place, one isolates a group of phenomena from a continuous process and makes them analytical components, such as culverts or retention ponds. One can further model each component, using mathematical functions, study them in isolation, and parametrize them through testing and verification. After the components are individually modeled, they may be connected with inputs and outputs. In fact, in the technical report for the original SWMM Version 1, scientists described their modeling process similarly, by introducing how each portion of a drainage system was individually modeled.

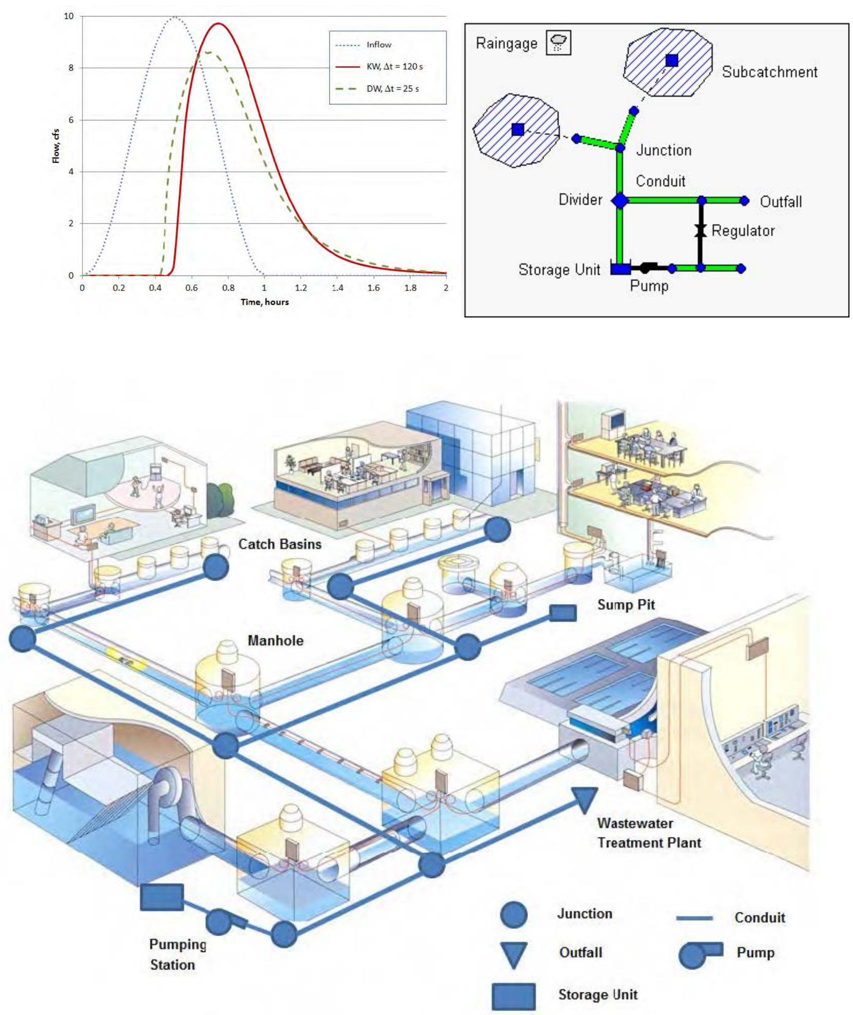

Figure 21. SWMM.

Hydrograph of a node (top left), SWMM representation (top right), urban drainage system (bottom), source: Rossman 2017

Yet this is not the only way a drainage system can be modeled and represented. In theory, one could construct a 3D digital scene of the physical space, running particle-based simulations by applying physics to each single water droplet to observe how the droplets interacted with the digital model. This technique is called computational fluid dynamics (CFD). Thus, CFD-based water simulation engines, such as RealFlow, are widely used in visual effects and gaming industries to simulate water, liquids, fogs, and clouds. A further option is to build a scaled physical model and pour water on it. Before computation technologies were widely adopted, the Army Corps of Engineers constructed massive physical models to determine flood risks. On the outskirts of Jackson, Mississippi, lies a 200-acre physical model of the entire Mississippi River Basin, from Montana to Pennsylvania and south to Louisiana. Constructed in the 1940s, and in operation from 1949 to 1973, the model was used by engineers to test rainfall events and make reinforcement decisions based on their outcomes. Engineers also simulated proposed infrastructures and their performances, and ran tests to assist in developing computer models.[23] However, SWMM dominated within the ecosystem of models for urban hydrological management, because it fits better within modern society's descriptive and quantitative epistemic framework.

Due to SWMM's advantage, the mediation and limitation effects of machines are again manifest in modeling. The use of SWMM makes it possible to comprehend and interact with highly complex phenomena, through the mediation effect. Yet, because of the specific choices that were made when creating SWMM, they define how urban drainage systems are studied. There are two aspects to consider regarding the limitation effect.

First, there is no difference between a retention pond and a wetland reservoir, on a systems level, in terms of water storage. When they are conceptualized as storage units, their volume is described with the same model parameter, called, in both cases, "storage curve". This curve abstracts the shape of a storage unit by describing how the surface area changes with water depth. Then, SWMM uses the curve to compute the stored volume as a function of depth. In other words, from SWMM's perspective, wetland areas, retention ponds, and underground

[23] *https://friendsofmrbm.org/model-history/*

storage tanks are each represented as plots of storage curves, despite their material differences, as well as their different ecosystems and the lives they sustain. This representation renders things in the conceived system both replaceable and dispensable.

Second, from a design perspective, it may be simpler to understand a continuous process as discrete procedures, but the environment consists of a continuous field of different ecosystems. Through systems thinking, one is limited to designing a system as if building with Lego blocks, connecting pieces based on input and output without worrying about provenance, and engaging the site as a continuous field. If we denaturalize the notion of “storage units”, we find that the entire site is itself a storage unit, with varying degrees of dryness and wetness. To a certain extent, model-making processes reinforce the notion that a storage unit must be a physical object within the environment, thus compelling us to build one that meets the parameters based on simulation results. Because a storage unit is represented in SWMM as a nodal component, both computationally and graphically, one assumes it to be an object with a defined shape and boundary. Puddles formed in street potholes and depressions might be viewed as distributed storage units incomputable in SWMM, because they do not fit within the quantifiable and descriptive framework allowed by its model-making practices. Consequently, these ephemeral puddles fail to become conceptual forms in the vocabularies of the urban environment’s design and construction. Few landscape architects would entertain the possibility of utilizing puddles to store water, and anticipate emergent ecologies on streets (Figure 22). In the epistemic framework allowed by this specific method of model-making, things outside the descriptive frames and parameters are categorized as uncertainties that require regulation and control.

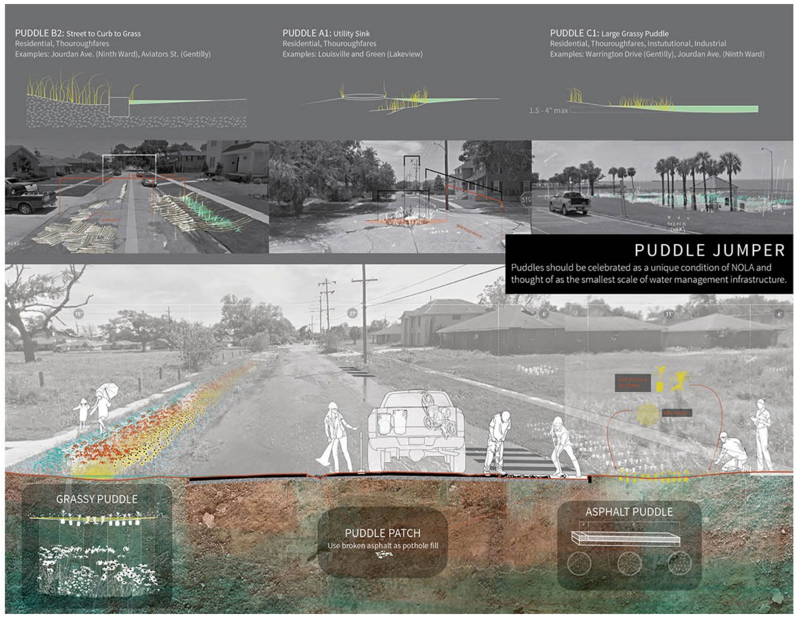

Figure 22. "Puddle Jumper"

Source: Fallow Ground | Future City, 2015 https://www.asla.org/2015studentawards/102410.html

©Alexandra Dimitri

The limitations of model-making are not about abstraction or oversimplification, but limiting thinking, with an epistemic framework that conceptualizes the environment as a system of manipulable components with parameters and rules for connections. When we embark on a specific route of model-making, we simultaneously reduce technodiversity, in the sense that, there are other routes with which to model the environment, such as physical simulation or CFD models, and there are non-model-centric ways to think about the environment.

Consider Eric Winsberg's discussion regarding scientific computer simulation, in which he argues that simulation practices are "self-vindicating" and "have their own lives" (Winsberg 2010, 45). As Winsberg noted,

> ". . . [simulation practices] evolve and mature over the course of a long period of use, and they are 'retooled' as new applications depend more and more reliable and precision techniques and algorithms…Whenever these techniques are employed

> successfully – that is, whenever they produce results that fit well into the web of our previously accepted data, our observations, the results of our paper-and-pencil analyses, and our physical intuitions; whenever they make successful predictions or produce engineering accomplishments – their credibility as reliable techniques or reasonable assumptions grows . . ..” (45)

Here, it is wrong to equate “a life of its own” as a type of technological determinism asserting that technologies and tools possess their own trajectories of development, independent of society. Instead, Winsberg specifically emphasizes lives to refer to “the whole host of activities, practices, and assumptions that go into carrying out a simulation” (45). What Winsberg articulates is a co-production and co-evolution process between humans and machines. When building SWMM, selecting one specific parameter in the modeling process might have involved art and intuitions, but these intuitive choices were verified by their success in applications. Every successful prediction and engineering achievement created with SWMM will eventually become part of its history of credibility. This specific parameter will then carry into each new version and new update of SWMM, and will thus be naturalized as a “gene” in this specific model species. Co-production manifests in the fact that this specific “gene” makes SWMM a necessary and effective medium through which engineers engage with the environment. Of course, necessity and effectiveness are evaluated under certain criteria, characterized by efficiency and productivity, that embody an epistemic framework of society.

Model Predictive Control (MPC)

Over the past years, SWMM has become increasingly accessible. The first generation of SWMM was written in the Fortran programming language developed by IBM in the 1950s specifically for scientific and engineering computing. However, SWMM5 is essentially a re-write of the previous Fortran release, with the programming language C, which serves as the foundation for many popular high-level languages, such as Python. In addition, SWMM5 provides an integrated Windows user interface that has greatly helped popularize the model and increase its potential applications. Because SWMM is open-source, its source code has been integrated into other software, such as Autodesk CAD Civil, as a backend simulation engine. Furthermore, Python is itself a widely-used programming language within machine-learning communities, and its popularity generates intersections between environmental engineering and artificial intelligence research. Many experiments use pyswmm library, which provides a Python interface to the SWMM5 model. We will follow a group of scientists from the Link Lab at the University of Virginia (UVA), to analyze how interdisciplinary inquiries transform the role of modeling in environmental practices.

Established in January 2018, the Link Lab is a research incubator that connects disciplines at the UVA Engineering School, such as computer science, electrical and computer engineering, and systems and environmental engineering, in order to collaborate on cyberphysical systems research. One of the many projects conducted at the Link Lab is the Data-driven Management for Interdependent Stormwater and Transportation system (dMIST). Its team is composed of instructors and Ph.D. students from civil engineering, computer science, and transportation engineering, plus government officials from Norfolk, Virginia. As the project’s name suggests, the team's goal is to use cybernetic technologies to couple the stormwater and transportation systems of coastal cities, such as Norfolk, to create an urban environment more resilient to climate change and sea level rise (Sadler et al. 2020). With an overall sensing-predict-control framework, the dMIST team’s approach to environmental management is based on cybernetic thinking and real-time control. Environmental data collected through sensing networks and crowd-sourced datasets are applied to construct machine-learning models, which are then used to predict future scenarios and support decision-making processes.

Before we proceed, let us examine background information and the underlying premises of the research carried out by the dMIST team. Most urban stormwater infrastructures are passively controlled; infrastructures exist, such as culverts, retention ponds, and weirs, but these infrastructures are unable to respond to every flood event. Certain cities have built controllable floodgates that can be closed during severe flood events. However, due to climate change and rising sea levels, many coastal cities now experience what is known as “nuisance” flooding. During monthly times of full and new moons, exceptionally high tide events may cause unexpected flooding in low-lying areas. Furthermore, sea-level rise implies increased tidal fluctuation; certain outfalls may be submerged during high tides, resulting in backflow to the stormwater system.

Similarly, climate change suggests more unexpected weather patterns and severe storm events. With these increased environmental uncertainties and society’s enthusiasm for smart technologies, coastal cities like Norfolk are examining alternative ways to be adaptive and resilient. These efforts include updating stormwater systems with real-time control strategies. Many cities are attempting to adopt real-time control strategies by installing sensing networks and retrofitting their stormwater infrastructures with controllable actuators. For example, StormSense is a project initiated by scientists from the Virginia Institute of Marine Science (VIMS), in collaboration with cities in the coastal Hampton Roads metropolitan area, including Norfolk. The StormSense team has installed dozens of LoRa-based sensors across these cities to monitor water levels (Loftis et al. 2018). Furthermore, cities such as Norfolk have also contracted with emerging companies such as Opti, specializing in environmental monitoring and real-time control, to update their stormwater systems and management platform.

The dMIST team's research is thus based on the premise that society's enthusiasm for smart city technologies, and pressing environmental crises such as climate change, will eventually propel future cities to adopt more cyberphysical infrastructures. In other words, a layer of infrastructure based on cybernetic thinking will emerge in coastal cities. The environment will be laden with machine intelligence waiting to be mobilized by engineers and designers. In a way, the dMIST team's research agenda embodies a broader cybernetic imagination with regard to contemporary society. The team seeks to work with emerging urban infrastructures and search for alternative ways to engage with the urban environment, through cybernetic thinking articulated as sensing-predict-control feedback loops. Even though parallel research projects focus on different aspects of the coupled water-transportation system, regarding the dMIST team, we will use two projects as examples. These projects may be understood as a seriation that uses machine-learning algorithms to determine real-time control policies for cyberphysical stormwater infrastructures.

The first project uses model predictive control (MPC) as a feedback control framework; the second project uses a deep reinforcement learning algorithm. Both strategies are carried out on a simulated stormwater system built with SWMM5, and the system is inspired by a real-world scenario located in the City of Norfolk (Figure 23). We will refer to this as a "toy system".

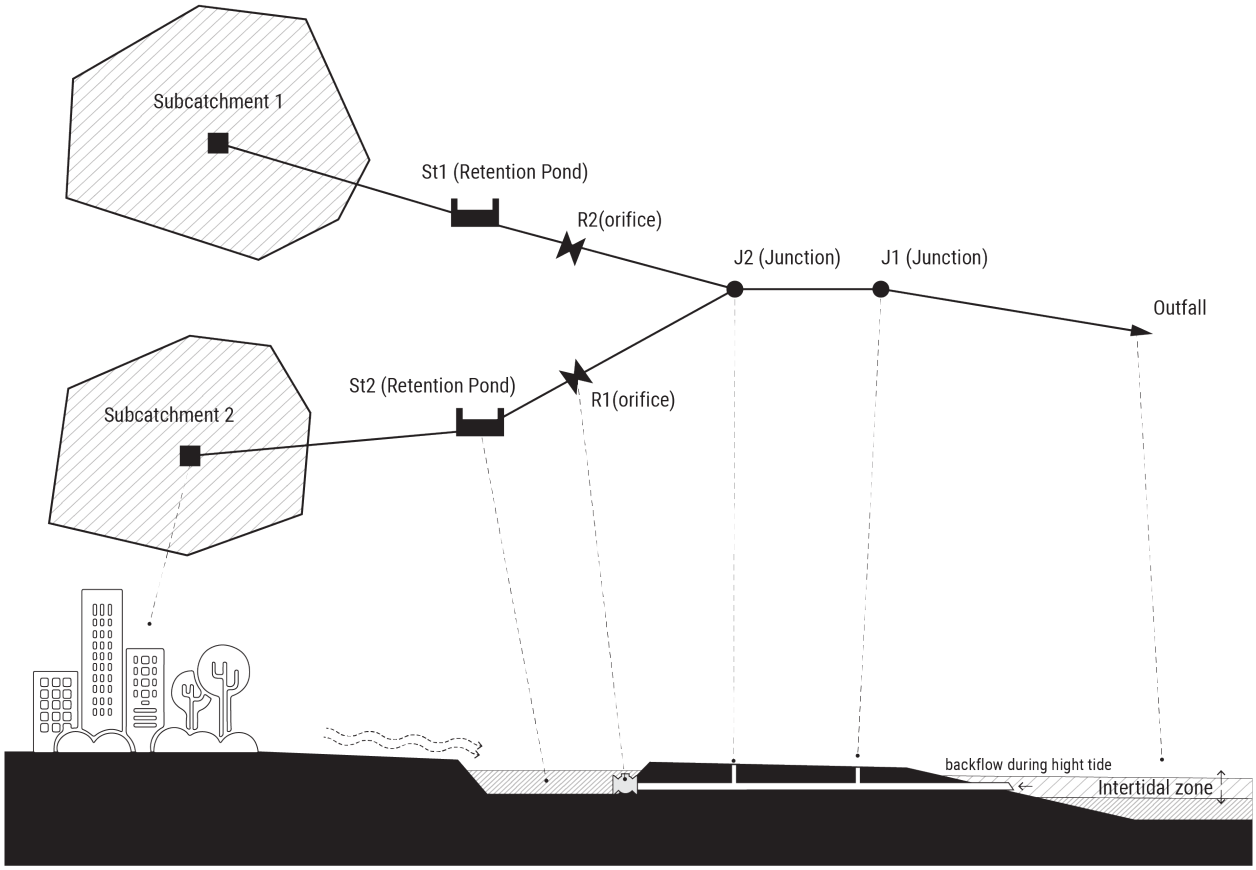

Figure 23. SWMM Simulation

Simulated stormwater system in SWMM for MPC and DRL experiments

This simple toy system consists of two sub-catchments, which represent two different urban areas, connected respectively to two retention ponds. The outlet is a body of water within a tidal zone. Junction 1 (J1) is considered a storm drain located on a roadway. In addition, J1 may flood if a high tide prevents water from discharging, or causes tidal backflow. The overall goal is to prevent flooding in both retention ponds and J1.

In the passive-control scenario, at the outlet of each pond is a weir at a fixed elevation, so that the water level in each retention pond is fixed and cannot be emptied. In the real-time control scenario, however, these two weirs are retrofitted with controllable valves at the bottom of the pond side. In this case, if weather forecast data indicate a looming storm event, and real-time sensing data shows the tide is low enough, then operators – a human or a machine-learning agent – can open the valves to discharge water, lowering the level in the retention ponds to make room for incoming floods. Contemporary best practices for real-time control are carried out through rule-based control, which can be visualized with a decision tree consisting of a series of if-then statements based on experience and calculations from experts and human operators. For example, if a forecast indicates a storm event that might cause 1,000 m3 flooding, then the valve must be opened 100% to drain an equivalent amount of water, plus a 20% safety factor from the retention pond. From this perspective, both MPC and DRL are ways to determine control rules using machine-learning algorithms.

Controlling a system may be understood as reducing errors -- that is, the gaps between the desired system state and the current system state. Effective control strategies gradually move the system to the desired state. Thus, MPC is one way to optimize control strategies, and has become a cornerstone of modern process control. The idea MPC emerged in the 1970s and was first used in process industries in the 1980s; it is widely used now to control all sorts of feedback systems. In addition, MPC does not designate a unique control strategy, but stands for a range of control methods, which relies on a predictive model to obtain a control strategy by optimizing an objective function.

For a given system, the MPC algorithm simulates different actuation strategies forward in time, and optimizes these strategies based on objective functions. At each step, the MPC algorithm looks ahead for a short time window, or *horizon*, to determine the immediate control strategy. Once this control action is implemented within the system, the MPC controller moves the horizon forward to the next time step, to repeat simulation and optimization. Essentially, MPC is a feedback mechanism: in each round of prediction and optimization, the actuation result of the previously implemented control actions are accounted for in optimizing the next immediate control action. Many engineers analogize MPC to driving a car. A driver will never simulate a whole route, writing down a series of control actions and then implementing them one by one; instead, the driver runs "simulations" on the mental model of the car, in a given horizon at each time step, and adjusts strategies accordingly.

Furthermore, MPC differs from other types of simple feedback control strategies, which control action based only on past errors. Instead, when deciding its next move, MPC looks both behind and ahead of time. To extend the driving analogy, a simple non-MPC controller would resemble driving a road by looking only at the rearview mirror, adjusting the steering wheel and pedals based on reflections of previous actions. As another example, in a thermostat, the controller evaluates only the gap between the current and the desired temperatures to decide whether to turn the unit on or off. If we implemented MPC on a thermostat, we would need to build a thermodynamic model of the room to simulate and optimize a range of control strategies – the output temperature and intensity of the fan – in a given horizon, before implementing the optimal control strategy. Naturally, in a situation such as controlling room temperature, MPC is overkill, since it is computationally expensive. MPC is considered an "on-line" controller, because the system is constantly connected, monitored, and simulated by the MPC algorithm instead of by "off-line" strategies, which provide only a set of control laws that remain unchanged over time.

In the first project carried out by the dMIST team, scientists implemented MPC in managing a simulated stormwater system (Sadler et al. 2019; 2020). The goal is to prevent flooding in the system, and, at the same time, maintain target water levels in both retention ponds. The SWMM5 is used both as the toy system itself and as the system model where strategies are simulated. To search for the best control strategy in each time step, a genetic algorithm is introduced as an optimizer. Genetic algorithms are inspired by the natural selection process, in which the best qualities of a generation are passed to the next generation via mutation and hybridization. In each generation, an array of policies is deployed, and the best ones are retained. In the next generation of training, mutations are introduced to successful policies, and a new array of updated policies is deployed. Repeating this selection-mutation process optimizes the algorithms' performance. In this project, at each time step, the MPC algorithm casts an array of different control strategies, and runs multiple parallel SWMM simulations to find the best policies. These policies are then optimized with a genetic algorithm, by repeating the selection-mutation process for multiple generations. Finally, the optimal strategy is implemented in the toy system built with SWMM. This will update the system and initiate the next round of parallel simulation and optimization.

This specific MPC strategy is computationally heavy, since it simulates not only multiple scenarios, but also generations of simulations at each time step. In this experiment, the MPC algorithm was carried out by a high-performance computer consisting of 28 cores with a CPU speed of 2.4 GHz, an Intel Xeon processor, and 128 GB RAM. Still, one week of simulation would take 50 hours to execute on a high-performance computer (Bowes et al. 2020). Moreover, computation costs limit the intervals between each time step for control strategies. The dMIST project uses a 15-minute time step; the actuators can be adjusted every 15 minutes.

Deep Reinforcement Learning (DRL)

Driven by the rise of big data, advanced algorithms in machine learning and optimization, such as artificial neural networks, and advanced high-performance computing hardware, recent data-driven modeling and control discourse is undergoing a revolution (Brunton and Kutz 2019). Machine-learning techniques directly learn a state-space model of the system using only data, thus bypassing physics-based formal models. For example, a popular way of building models for MPC strategy is to identify a state-space model for a system using machine-learning techniques. Unlike a physics-based empirical model, such as SWMM, state-space models may be linearized to characterize the system dynamics. This greatly reduces latency between the system and the controller, increasing computing speed. In other domains, MPC strategies are primarily based on state-space space representations. In its essence, MPC requires running full simulations in parallel; it is thus essential that the model runs at accelerated speeds. The Link Lab scientists noted that their MPC strategy could benefit from learning a state-scape model, to replace SWMM and find control strategies more quickly (Bowes et al. 2020). Emerging data-driven and machine-learning algorithms, such as artificial neural networks, are increasingly used to estimate low-order models or transform a complex model, such as SWMM, into a reduced-order model that runs faster. Yet no matter how fast a model runs, MPC, as suggested by its name, is a model-centric approach that requires a model, no matter its form, to compute control strategies.

For our purposes, a more challenging implication in the rise of big-data is that machine-learning algorithms are able to directly learn a control strategy for model-free control. As noted in Chapter Two, the past years have witnessed breakthroughs in AI research, especially in the area of deep reinforcement learning (DRL), which provides transformative cases for scholars asking profound questions about intelligence. The DRL algorithms AlphaGo and AlphaStar have not only devised effective strategies to outperform human players, but have developed strategies with a “machine flavor”. Chapter Two discussed DRL in detail. Briefly, an agent may take actions within an environment and update that environment. If the agent ends in a better position, closer to the desired goal, the agent receives rewards. Objective functions can also be conceptualized as negative rewards, which penalize the agent if the action is ineffective.

Scientists commonly test different reward mechanisms, and training the agent entails repeating the action-update-reward loop many times to optimize the reward function.

In the second project carried out by the Link Lab, a DRL agent is established to control the toy system by changing the positions of two valves connected to the two retention ponds (Bowes et al. 2020; Saliba et al. 2020). A popular algorithm for reinforcement learning is called deep Q-network, used in training agents to play video games. Here, “Q” stands for quality: how useful a given action is in gaining rewards at a given state, while considering future actions in gaining future rewards. This value is thus called “q-value,”, represented as an action-state pair, Q(s, a), in which “s” represents state, and “a” denotes action. Thus, we may construct a “q-table”, with rows for each state and columns for possible actions. Training a q-learning agent means determining the optimal q-table by allowing the agent to explore the environment. After training, the agent may thus be understood as a large q-table, with a reward value for each corresponding action in each state. The q-table serves as a blueprint for the agent to maximize its potential reward in the environment.

Deep Q-networks are therefore restricted to a finite number of actions (for example, a game controller possesses limited buttons for the agent to push). Although deep networks make it possible to manage a large table, it still provides a discrete action space. In the case of valve control, the action space for this agent is continuous; the valve can be altered to any position, from 100% closed to 100% open, as if there were an infinite number of controller buttons with which the agent interacted with the environment. In valve control, a deep Q-network is unsuited to the task.

The experiment relies on another specific DRL algorithm called Deep Deterministic Policy Gradients (DDPG), specifically designed for problems with infinite input space, such as the position of valves (Lillicrap et al. 2019). The set-up for DDPG is similar to that of generative adversarial networks (GAN), in which two networks are trained together (e.g., one attempts to produce photo-realistic images while the other endeavors to determine whether the image is realistic). The DDPG agent also consists of two networks, an actor and a critic. In brief, the actor examines the current environment state and determines the best action, and the critic plays an evaluative role by viewing the environment state and action pairing, and returning an action score (Figure 24). To begin a training session, the SWMM's state information, including the ponds' water levels, the tide level, and forecast rainfall, is fed to the actor. Based on this information, the actor devises an action and returns it to SWMM. This action updates the SWMM model, either improving the situation – preventing flood and maintaining target levels in both ponds – or worsening it by causing system-wide flooding or forcing water levels to deviate from their target levels. The updated state information, along with the action, is then sent to DDPG's critic, which rates the action's effectiveness. Finally, and bases on this evaluation, the critic updates the actor, attempting to maximize reward in the next round (Saliba et al. 2020; Bowes et al. 2020).

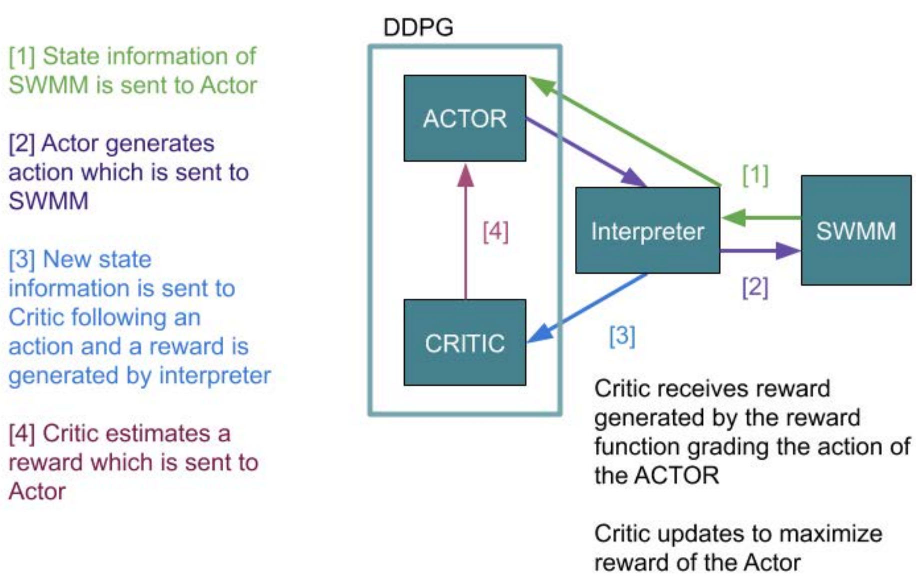

Figure 24. DDPG and SWMM interaction

From Saliba et al. 2020

Scientists have used real-world rainfall and tidal data to produce a range of flood events, in order to train and test the DRL agent. Using this strategy, they were able to train an agent to adjust two valves to prevent upstream flooding, while avoiding the release of water during high tide, which would cause flooding downstream. The agent also learned to maintain specific target water depths in the two retention ponds.

The scientists compared this DRL agent with other control strategies, including passive control (no control), rule-based control, and model predictive control (MPC). The DRL agent exhibited promising results, by executing interesting policies. Not only was the DRL agent more proactive in response to rainfall events, but it also did well in maintaining the water level of retention ponds. For example, in one flood event, the DRL agent learned to close one of the valves earlier, because the forecast indicated rainfall difference in the two sub-catchments. In addition, directly post-rainfall, the DRL agent closed valves in time to prevent flooding downstream, and recharged the ponds to their target water levels. In another scenario, the MPC model tended to drain the pond completely, to hold more water (being extra-proactive). In contrast, the DRL agent tends to maintain a certain water level without completely draining the pond. The DRL agent also tends to be more holistic with regard to the system. It possesses a tendency to open or close the valves multiple times over a short period to maintain the target level, even though doing so may cause insignificant flood events downstream.

Most importantly, the DRL agent developed diverse and complex strategies. In most cases, it would completely open the valves to quickly discharge water, while there were instances where the agent only slightly opened the valves, to discharge water slowly (Figure 25). In this research, no human knowledge regarding the stormwater system was given to the DRL agent. Hence, the DRL agent developed its own understanding of the system, emerging with its own strategies.

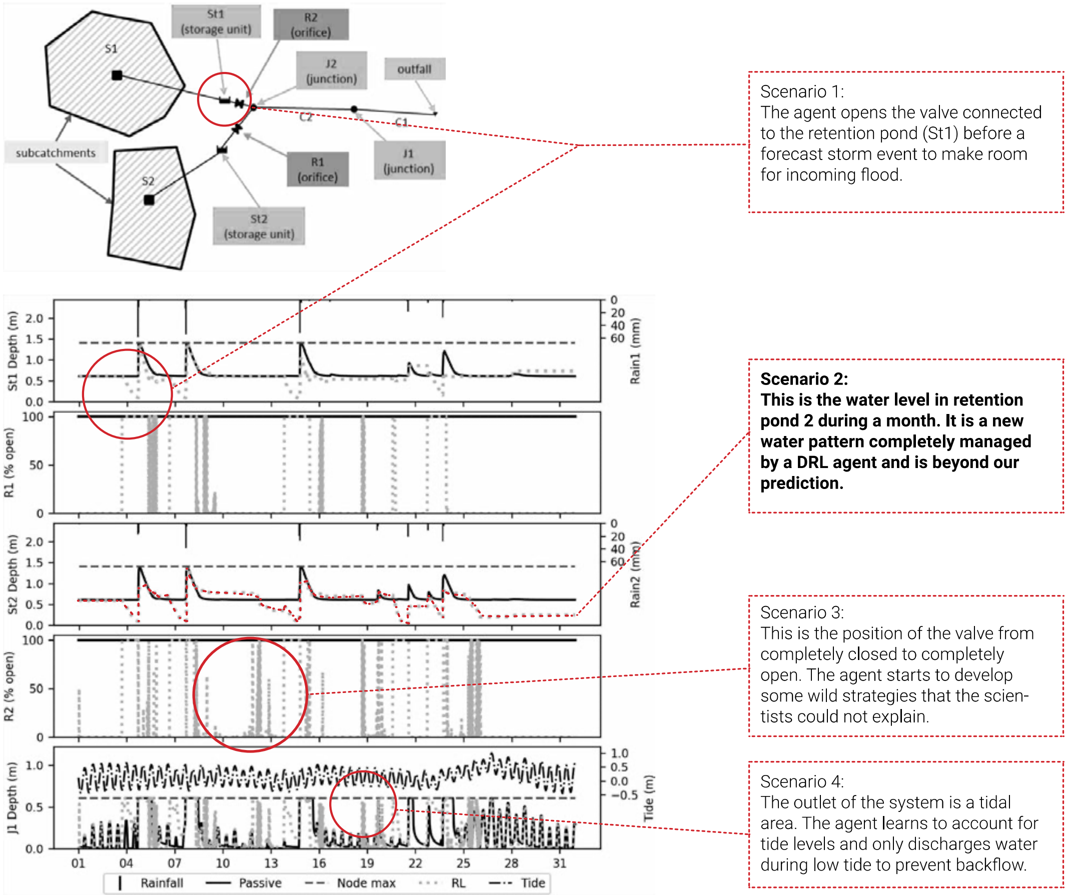

Figure 25. DRL Agent Performance

Adapted from Bowes et al. 2020. Annotation added.

Compared to the MPC strategy, the DRL strategy is considered “off-line”; after training, what is uploaded to a cyberphysical system is a fine-tuned model or neural network, in the context of deep learning. Training processes involve tuning the weights in each individual neuron by exposing a neural network to large amounts of data. When training is completed, the neural network is calibrated to its optimal condition, and it simply generates outputs based on input information, without learning anything new when in operation. If we consider the dynamic environment of evolution and climate change, such an agent will quickly grow outdated.

It must be recognized that continuous learning has been a theoretical premise for deep reinforcement learning, because DRL is often compared with trial-and-error human learning, which is a lifelong and continuous effort. There are efforts in the AI community to develop strategies to allow agents to learn and evolve over time. Scientists are making progress in overcoming "catastrophic forgetting", the major obstacle in continuous learning, whereby an agent tends to completely and abruptly forget previously learned information after acquiring new knowledge. In current AI applications, continuous learning is substituted for by updating the AI algorithms with higher frequencies (e.g., Google search engine updates). With machine-learning research advances, more continuous learning architectures and automated updating mechanisms will be anticipated in the near future.

3.2. The Emergence of Intelligent Agents and the Non-Model-Centric Paradigm

From the first version of SWMM to SWMM5, and from MPC to DRL, we observe that with the rise of data-driven approaches and the advancement of machine-learning techniques comes the emergence of intelligent agents made of myriads of neural networks.

When comparing the MPC example with the DRL agent, we see that the key concerns are different. To a certain extent, they operate in two different paradigms in conceptualizing the relationship between modeling and control. To understand this difference, we must first reflect on the meaning of control in this context. A modern feedback control problem may be generalized as a standard feedback system. The system's measurements are fed back into a controller, which then decides on actuation signals, based on the control laws, to nudge the system towards the desired state. With this diagram in mind, classic control theory essentially begins with modeling the system using physics, attempting to determine a function that best represents the system dynamics. With SWMM, engineers and scientists designed an empirical model to represent urban hydrological systems. Water flows in the system are represented by functions based on real-world physics – gravity, acceleration, and water quantity. Finally, once we determine a model of the system which we want to control, modern control theory provides numerous tools and techniques to optimize control laws.

Indeed, MPC is model-centric, because the key to success is whether the model used to simulate and optimize strategies best captures the physical environment's characteristics – regardless of whether it is a physics-based model like SWMM, or a machine-learning state-space model. However, a model is a metaphor, no matter how complex or accurate it is; it estimates, but never becomes the modeled system. Even in the case of a large physical simulation, such as the Mississippi Basin model, a scaling factor is introduced as a variable for abstraction, since everything but water shrinks in the model. Engineers must represent one material, such as rock, with a different one, with properties that are able to reproduce similar physical interactions between water and rock.

In the above example, the physical environment is replaced by a model created with SWMM, which is simultaneously the process model for finding strategies. Thus, the above-mentioned MPC example presented a perfect scenario, where the model is the environment, and no gap exists between the two (or full-state feedback in which y=x in the state-space representation). Engineers seek to focus on comparing control strategies. A gap between the model and the environment introduces too many uncontrolled variables to undermine a study's results. Yet to test novel strategies in a real environment is impractical, if not utterly impossible; to compare different strategies, researchers must reproduce the same storm event multiple times. Running physical simulations which would take a single hour in real life, take only milliseconds on a supercomputer; it would take days, weeks, months to reproduce the same experiment done without a supercomputer. This presents the largest predicament in model-based control practices for environmental management. Unlike in industrial design and robotics, where it may be possible to test strategies with prototypes or even authentic systems,[24] the environment owns no restart button to repeat the same strategy. In the environmental discourse, computer models become irreplaceable tools in discussing control. If the process model used in simulations better captures reality, ideally, control policies would be more effective following the MPC strategy. Ultimately, MPC is built atop system modeling, and is model-centric. It challenges us to produce better models to represent the environment.

Compared to the MPC strategy, the DRL experiment operates in a model-free framework and offers new ways to consider modeling practices in environmental management. Initially, DRL begins by conceptualizing an intelligence agent made of deep neural networks capable of making decisions based on observed information, and adjusting strategies based on continuous observation. The DRL strategy bypasses an important process in control theory, one called system identification; it does not start with formalizing the system with physics and then attempting to determine the state-space representation that best represents the system. Instead, it begins from the controller, and tries to learn a control policy based only on interacting with the system, observing how the system responds to these interactions. It is oddly similar to human learning, such as when we learn to drive. We do not begin by studying the internal physics and mechanics of a car; instead, we press the pedals and turn the steering wheel, trying to acclimatize to driving. Here, the notion of “acclimatize” entails interacting with the car directly to observe its general patterns and how it responds to our driving strategies. Because learning to drive starts with the agent rather than a model, the result is no optimized control law, but a diverse range of nuanced personalities and driving strategies; consider how different drivers stop at red lights – some gradually slow, while others slam the brakes at the light itself.

[24] There is a great deal of research in machine learning using real robotic arms, rather than simulated arms in a computer.

Just as drivers, pilots, and astronauts learn to operate on simulators, SWMM becomes a virtual gymnasium in which the agent develops all sorts of strategies. The results contain different "flavors" and nuances. We observe this in the example above. In the experiment, the DRL agent emerged as cautious and proactive in managing the retention ponds. Whenever it sees storm events in the observable horizon, it will discharge the water in the retention ponds to prevent flooding, even though this may be unnecessary and would cause downstream flooding.

In the DRL experiment, engineers must consider a set of questions specific to the machine-learning discourse, different from classical control theory. Training a machine agent is akin to coaching basketball players. As a coach, you know your goals, and to achieve those objectives, you articulate different offensive and defensive strategies to your players. Nevertheless, the players are those who interpret and carry out strategies, and the coach must relinquish a sense of control; the coach operates from a higher order. When training a DRL agent, engineers are involved in a similar relationship.

Before training an agent, engineers must first design the agent's neural network architecture. These artificial neural networks are designed as layers of connected neurons. Deep learning means multiple layers. Thanks to Python-based machine-learning libraries, such as TensorFlow, OpenAI gym, and Keras, designing a deep neural network has become extremely simple. One needs only a few lines of code to call certain types of layers from the library and connect them into a fully functional artificial neural network; designing a network thus becomes a practice of testing different layer structures and switching the neurons' activation rules in different layers. The network used in the DRL experiment is illustrated in Figure 26.

	Actor		Critic	
NN layer	Neurons	Activation	Neurons	Activation
Input	Current state s	N/A	Current state s and action a	N/A
Hidden 1	16	RELU	32	RELU
Hidden 2	16	RELU	32	RELU
Hidden 3	8	RELU	32	RELU
Output	1 [R1, R2]	Sigmoid	1 [q-value]	Linear

Figure 26. Neural Network Layers

Machine DDPG RL agent architecture and hyperparameter settings from Bowes et al. 2020.

When asked how and why the DRL agent is thus constructed, Ben Bowes, a Ph.D. researcher in this experiment, expressed that it the design comes about through trial and error. There are no pre-written rules as to which layer, or how many layers to use, but only successful examples from other cases. From this perspective, the engineers' role has shifted from studying the system model to find control strategies, to studying the model of another intelligent agent which will later find its own control strategies. In a model-centric paradigm for control, such as MPC, the engineers study the system to be controlled, and seek optimal control policies. In a non-model-centric paradigm, such as in DRL, however, engineers distance themselves from the real problem at hand and relinquish their control, placing their hope in a machine agent that interprets their instructions and accomplishes their plans.

This is not the only instance in which engineers must choose how the agent should be built. Bowes, for example, reported that overfitting occurs in training the DRL agent. Overfitting describes a phenomenon in machine learning, whereby agents exhibit poorer performances when trained for too many episodes. We may understand machine-learning problems as curve-fitting problems, attempting to fit a curve to data points in a coordinate system, in order to describe their general distribution pattern. We may draw a simple curve that touches no data points in the coordinate plane, or we may draw a complex curve to connect all the points. The first curve is not optimized, whereas the latter accurately describes each data point. However, this "overfitted" curve fails to describe the general pattern in the dataset; whenever a new instance arrives, it falls outside the curve. Overfitting also occurs in DLR where the DRL agent is exposed to limited storm events to learn control policies; training the agent for too many episodes results in an overfitted agent that performs poorly when faced with new testing events. The engineers must observe the agent's behavior to ascertain the right point – the "sweet spot" – at which to stop training the agent, in order to avoid overfitting.

Another example occurs in designing objective functions. Recall the example in Chapter Two, where a robotic arm was trained to flip pancakes. Experimenters designed an objective function to reward the agent for each second the pancake did not land on the floor. However, the robotic arm would throw the pancake as high as possible to maximize the reward function. Thus, objective functions do not inevitably lead to expected agent behaviors.

The objective function in the DLR example is written as follows:

$$r=\begin{cases} -\sum(\text{flooding}),\ \text{F}>\delta \\ -\text{J1}_{\text{flooding}}-\left(|\text{St1}_{\text{depth}}-\text{target}|+|\text{St2}_{\text{depth}}-\text{target}|\right),\ \text{F}=0 \end{cases}$$

In the function, δ represents a forecast rainfall threshold (>0 in this case), which divides the objective function into two parts. Whenever rainfall is forecast in the agent's observable horizon (F>0), the agent would gain more reward for less flooding throughout the entire system; otherwise, the agent is penalized. If there is no forecast rainfall (F=0), the agent is rewarded for maintaining the target water depth in the retention ponds (St1 and St2), and for not flooding the downstream node J1 by doing so (Bowes et al. 2020).

This is not the sole route to articulating goals of flood mitigation and target water level maintenance. Another way to is to reward the agent if it maximizes the water levels of the retention ponds during rain events. In this function, we do not directly associate reward with flooding events, and minimizing flooding becomes inherent in maximizing the ponds' water levels. One early version of the experiment used a similar reward function. The researchers had tested multiple ways to articulate their goals through reward functions. This process is similar to communicating with a system operator through a special language consisting of formalized functions.

Finally, with the emergence of artificial neural networks as intelligent agents managing all sorts of environmental processes, the concerns regarding control shift from model accuracy to a sense of trust. With the rise of data-driven approaches comes the emergence of machine agents. The questions which engineers need to consider are no longer about control. We are aware that agents can produce desired outcomes or even outperform human operators in managing systems, but are we comfortable and confident enough to upload these intelligent agents into cyberphysical systems and allow them to run the actuators? What is our tolerance for relinquishing human control? How do we frame unexpected outcomes produced by these machine agents?

Let us use another, more extreme example as an analogy to examine what is at stake. Self-driving cars are a reality, considering that all new Tesla cars arrive today with autopilot features and, soon, full self-driving capabilities. The algorithms and hardware of a self-driving car outperform human drivers on many levels. A self-driving car has better sensors, reacts faster, never gets tired, and perfectly obeys traffic rules. However, how comfortable would you be in a self-driving car at 70 mph on a crowded interstate, even though you know it outperforms you in driving?

These questions simply cannot be answered within the epistemic framework which early cyberneticians used to conceptualize control and agency from an anthropocentric perspective.

To entertain these questions, we must employ an epistemic framework rooted in posthumanism and co-production theses, conceptualizing intelligence as distributed capacity in a network of human and nonhuman agents, including these intelligent machines.

3.3. Choreographing Intelligent Machines, and Halprin's Scores

We must again employ a design research framework to consider engineering cases. Within a mainstream engineering framework, the only question to ask is whether we trust these agents, and how to make them more trustworthy. From this perspective, certain machine behaviors become unwanted. Design allows us to connect thinking from one field to another; we are able to situate this engineering example in a posthumanist framework, translating artworks into conceptual strategies to intervene in the cybernetic environment on a systemic scale.

Chapter Two reviewed a range of DRL agents, such as AlphaStar and AlphaGo, which develop strategies of their own, surprising human players. Based on examples such as AlphaGo, landscape architects and ecologists have speculated on the implications of machine learning in environmental management. In a thought experiment, the authors imagined a DRL-based AI system called "wildness creator", which devises its own strategies and creates wild spaces beyond human comprehension. This thought experiment questions the notion of wilderness, and provides an alternative way to conceptualize the use of machines in constructing wild places (Cantrell, Martin, and Ellis 2017). It is often believed that machines, being artificial, are inherently at odds with the notion of *wild*, which is on the line of nature. However, this line of reasoning places moral limitations on which strategies are appropriate, based on the standards of those with the privilege and authority to define "nature" and "wild". Ironically, if one could construct wild places, those places are no longer wild, because their construction is based on human models and comprehensible by humans; if we are able to predict everything about a system, nothing wild remains. However, the "wildness creator" renders a completely different scenario, in which machines begin to devise strategies based on their own. In a way, places constructed by these machines are truly wild -- they are novel ecologies for which humans have no model.

This thought experiment may have appeared outlandish in 2016, but when we consider the work carried out by the Link Lab, especially that of the DRL stormwater management agent, outlandishness fades. In order to characterize machinic strategies, we will continue to use this example as an object of analysis. In the DRL example, the agent is trained to prevent floods. Yet landscape architects and designers advocate for the importance of flood events for ecosystems. One might imagine a DRL agent trained to strategically promote flood events in certain areas of a city, to create novel and emergent ecologies. Moreover, the DRL agent may actively maintain water depths in the retention ponds; thus, one might also deploy the agent to manage these bodies of water and provide ideal conditions for wetland species. However, these considerations do not speak to the notion of *wildness* since they are, in essence, objective optimization problems articulated with different perspectives and goals. In the end, the machine is still considered a goal-seeking agent attempting to maximize an objective function defined by designers and engineers.

To truly consider the meaning of constructing wild places, we must focus on the situations where outcomes produce side effects outside the articulated goals. Scientists from institutions such as Google Brain and OpenAI have laid out five concrete problems in AI safety; the first is “avoiding negative side effects” (Amodei et al. 2016). This problem is profoundly related to reward function and goal articulation. Reinforcement learning is an optimization problem in which the agent attempts to optimize the reward function through which scientists articulate their intended goals. However, as discussed in Chapter Two, the goals articulated by scientists are not inevitably reflected in desired agent behavior. When we consider AI reward functions, we must realize that in assigning a reward value to the desired outcome, we are assigning zero values to all other possible outcomes. An agent ignores whatever is not articulated in the reward function. To use the thought experiment in the AI safety research, let us consider a cleaning robot rewarded for cleaning a room. We assign values to each bit of refuse the robot picks up. However, how do we ensure that the robot will not knock over a vase simply because doing so will speed the cleaning task? The vase is assigned zero value in the objective function, so that the cleaning robot will not attend to *not* damaging it (Amodei et al. 2016).

This is not purely a thought experiment, since the AI community confronts similar problems every day. If we consider the stormwater DRL agent example, we will find room to consider how the reward function may produce unexpected results. Review the objective function for the DLR agent in the Link Lab research example:

$$r=\begin{cases} -\sum(\text{flooding}),\ \ F>\delta \\ -J1_{\text{flooding}}-\left(|St1_{\text{depth}}-\text{target}|+|St2_{\text{depth}}-\text{target}|\right),\ \ F=0 \end{cases}$$

Based on the reward function, the agent is rewarded for reducing flooding and maintaining desired water levels in the retention ponds. The benefit of the second part of the function is that, right after a rainfall event, the agent would open valves to discharge water quickly, to maintain the desired water depth in the retention ponds. In one testing scenario, because the rain event stopped early in one of the catchments, the agent would open only one valve, to maximize the reward function.

Yet consider the darker side of this reward function. In the second part of the function, the agent is rewarded if it maintains the target water depth in the retention ponds, even if doing so would repeatedly flood the downstream J1 node. This is because, in the function, flooding is characterized by overall volume rather than frequency. In other words, the frequency of flood events is assigned zero value – so that the agent ignores them. Even though the agent would gain negative rewards if it caused flooding in the downstream J1 node, the agent can still maximize reward by causing multiple small flooding events, the sum of which produces unnoticeable negative rewards compared to the positive rewards gained by maintaining water levels in the retention ponds. As we see in the graph, the agent performed this exact ploy in order to “game” the reward function (Figure 27). It would alternately open and close the valves to discharge water right after the rain, even though this strategy produced small flood events in the J1 node.

The simulated SWMM environment using this agent will exhibit fascinating phenomena. With upstream rain, the J1 node will experience mysterious repeated flooding. Repetition of upstream rain leads to recurring flooding, drastically altering the local ecology. Thus, the ecology in J1 is decoupled from a local weather pattern, but coupled with a weather pattern elsewhere. Landscape designers would see a plethora of opportunities to design with this behavior, to de-couple and re-couple landscape systems. This displacement of phenomena creates unusual experiences, perhaps providing another way for urban residents to experience ecosystem dynamics.

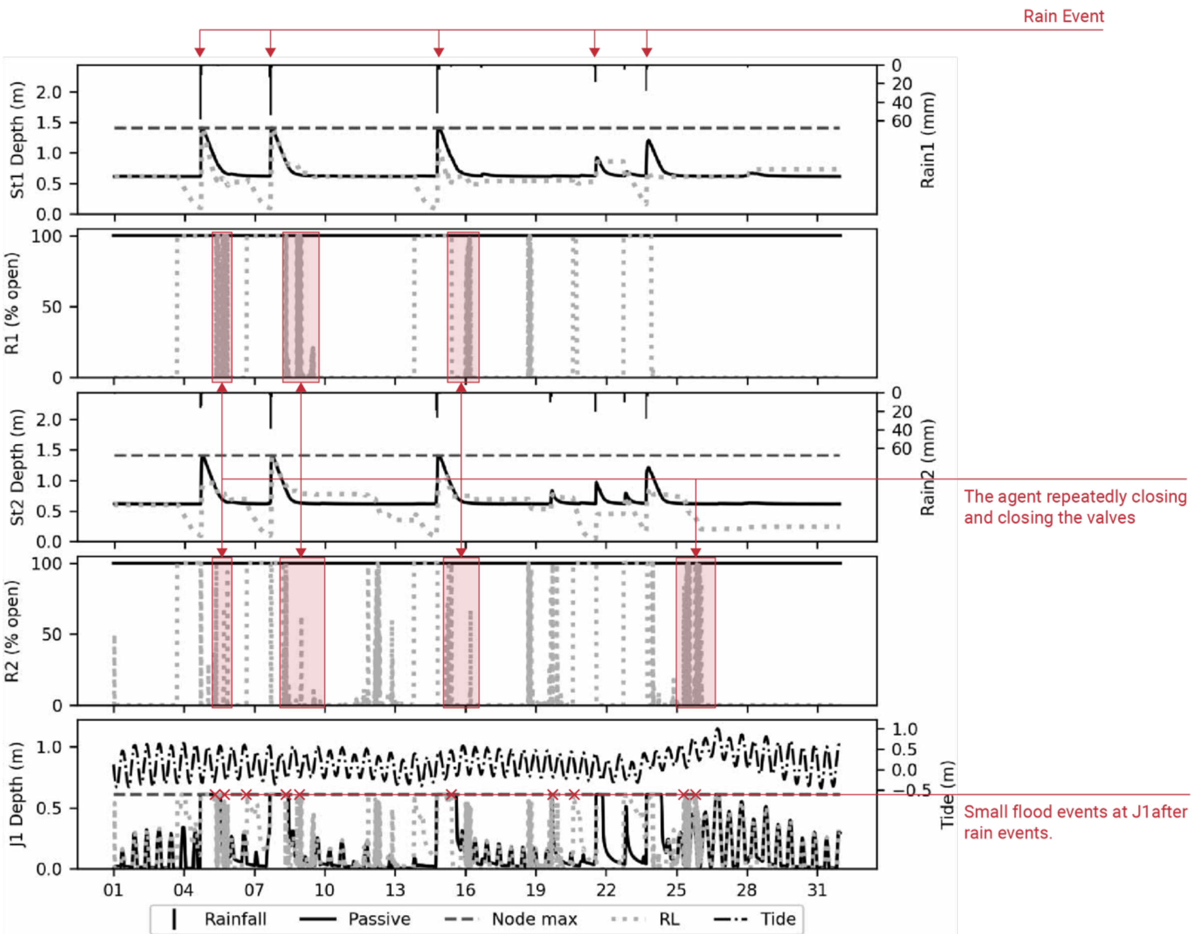

Figure 27. DLR agent "games" the reward function.
Image adapted from Bowes et al. 2020, annotation added.

We might provide a plausible explanation by analyzing the reward function. The agent also possesses other strategies that are difficult to explain. For example, it would occasionally keep the valve half-open, an apparently unnecessary action.

Finally, considering the entire drainage system in this simulated environment, the DRL agent essentially produces a new hydrological pattern. Over time, new ecological types beyond human expectations would emerge, and these wild ecologies would be, ironically, managed by a DRL agent. The result: a constructed wild place highly maintained by an intelligent agent whose actions may exceed human comprehension. Oddly enough, rather than directly interacting with the environment, we communicate with the machine agent through a special language to express our needs.

According to a recent update, the dMIST scientists have made several changes to their initial set-up.[25] First, instead of an ideal system model, the team selected a real site in the City of Norfolk, providing real-world information on the stormwater system. Second, aside from flooding, the team incorporated another goal in the objective function – to mitigate water pollution, by holding water in the retention pond long enough to encourage sedimentation. Now, the agent must consider three major objectives: overall flooding in the system, target levels in the retention pond, and pollution indicators downstream. Moreover, because this is a real site, different nodes have different conditions. Several are known to be prone to flooding, based on historical data, while others may be able to withstand minor floods. In order to address this issue, the team decided to give different weights to different nodes when evaluating flooding in the reward function. The hope is that the agent would flood unimportant nodes, if it must cause floods in the system.

The agent now must consider multiple conflicting goals: if the agent holds water in the ponds for too long, that may cause upstream floods. If it releases water too quickly, flooding would occur downstream, and pollutants would overwhelm the stormwater. Moreover, the agent must also consider different node conditions, and treat them separately. The dMIST scientists compared the simulation result with rule-based control, optimized for water quality, and the results raise interesting questions. In rule-based control, the water is held long enough to let sediments drop, and thus downstream pollution is significantly reduced. Because the DRL agent

[25] There is no published paper for the results, and these are preliminary outcomes reported by Ben Bowes during weekly meetings in February 2021.

must consider other objectives, it cannot compete with a rule-based control strategy. However, during the discussion, one additional piece of information was presented. The City of Virginia Beach is implementing similar systems, but these systems cause more flooding because they are built to optimize water pollution detection. This DRL experiment opens an entirely different venue to consider a flexible framework that accounts for site-specific goals. It is clear that rule-based control is a monocultural approach to technical systems. It applies a one-size-fits-all solution to a problem that may require diverse strategies. Contrast flooding mitigation and pollution control as two ends of a spectrum. In such a case, we may imagine training a family of different agents, each of which considers control policies from a slightly different perspective. These different agents will be deployed in discrete systems that require slightly different treatment.

Naturally, the environment is a complex of many more than two objectives and goals. It is a high-dimensional space with a limitless number of potential variables. These variables provide a high-dimensional objective function to train a variety of agents that each devise slightly different strategies. If these agents were deployed within the system, their interactions would produce further emergent behaviors. There thus exists a viable technical framework based on reinforcement learning that can produce *wildness*, cultivated by distributed machine-learning agents.

There is a caveat. Many would feel concerned that the DLR agent has been trained and tested in a simulated environment built with SWMM, itself a simplified model of the physical environment. However, DRL is non-model-centric, because, for the agent, the SWMM simulation is as real as the physical environment. When the agent is uploaded to a real system, it is coupled with the system using only the sensors distributed throughout a stormwater system. The sensing network will produce a state-space representation, with state variables, that will be identical to that which the SWMM simulation offers. In other words, in the SWMM model, the agent understands the system in terms of state variables, including water depth for each pond and node, rain forecasts, tidal information, and valve states. When uploaded to a physical system, the DRL agent knows nothing more. For the agent, the SWMM simulation and the physical system appear the same. From the perspective of autopoiesis, the DRL agent reconstructs a reality, with its system operations defined by its sensing peripheries and operations.

We have used coaching as a metaphor to describe the relationship between designers and models in a non-model-centric paradigm. Let us now turn to landscape design, and rely on the notion of choreography to further illustrate the operation of a designer using intelligent machines. In the 1970s, to describe his principles, landscape designer Lawrence Halprin introduced RSVP cycle: Resources, Score, Valuation and Performance. It describes the creative processes in design. Resources entail anything used in the creative process, including time; physical materials; other people; ideas; and limitations. Score is likened to musical scores, a series of instructions for the work. Valuation is a process of dynamically responding to the work based on personal and professional values. Performance stands for setting the creative work in motion.

Lawrence Halprin apparently developed RSVP idea his wife, Anna Halprin, a choreographer influenced by the open-score movement in music and choreography in the 1960s. At the time, many musicians and choreographers embraced participatory and open-ended compositions and choreographies, known as “open scores”, which replaced the traditional systems that decisively directed performers.[26] Open scores embraced instead interpretative chance and

[26] John Cage was one of the leading compositional figures in this avant-garde movement. His famous composition 4’33” may be understood as an attempt to embrace flexibility in interpretation. The piece consists of blank music sheets running 4 minutes and 33 seconds long. They may be “played” with any instrument or combinations of instruments.

flexibility by giving visually evocative approximations, suggesting general intentions and ways to interpret. In the 1960s, Lawrence Halprin was interested in community design that sought to incorporate community desires as part of public landscape projects. In exploring community design processes, the Halprins collaborated on experimental performance projects, using open-scoring ideas (Lystra 2014, 77). Due in part to this history, the notion of choreographing was distilled into the landscape discourse. [27] Halprin used choreography examples from several times in his book introducing the RSVP cycle. The collaboration between the Halprins, and the influence of choreography, become anecdotes which every landscape architecture student learned of in their education.

Today, landscape architects deploy the dance term in describing their works. Brian Davis, for example, introduces his "instrument tables" that allow designers "to *choreograph* interactions and patterns [of different instruments or agents] on a formal level" (Davis 2013, 302, emphasis added). Similarly, Cantrell and Holtzman (2016) used "choreograph" throughout their book, when introducing responsive frameworks for landscape design. In a landscape context, the term *choreograph* speaks to a sense of relationship formed between landscape designers and other intelligent agents and systems – species, environmental processes, cultural practices, land use policies -- that shape the environment. Designers cannot authoritatively control these agents to produce landscapes according to a well-articulated plan. Instead, designers rely on "open scores" to influence agents to act within a range of intentionality. The agents and systems are at liberty to interpret, and the outcomes are filled with uncertainty. To a certain extent, contemporary landscape is a practice to explore different choreography techniques.

Applying the notion of choreography to understanding the relationship between the engineers and the DRL agents in the above examples, we find diverse analogies. Engineers

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[27] There is little historical research as to how "choreograph" attained its currency in today's landscape design.

communicate with the DRL algorithm only with objective functions, which, as we saw, leave room for flexible interpretations. In a non-model-centric paradigm, where machine-learning quickly builds intelligent models to carry out our intentions, the descriptions of our intentions become "open scores" that encourage uncertainties. Therefore, in a non-model-centric paradigm, we need a framework that allows us to embrace uncertainty, seeing it as possibility rather than threat to controlled stability.

3.4. A Posthumanist Perspective on AI Safety

Let us reflect on an argument made in terms of intelligent machines' potential threat to humanity. Viewing machine intelligence as a threat is a popular sentiment, especially after two world wars in the twentieth century, when society witnessed the destructive power of machines and atomic bombs. Popular culture also aided the growth of this sentiment, since AI nearly always assumes a supervillain role in dystopian novels and movies. As argued in Chapter Two, imagining rogue AI is a form of the technological sublime, in which we entertain a potential threat from a safe position. Every story carries its own end. Thus, we comprehend the threat with human reasoning and rationality, which, according to Kant, is the basic structure of sublimity. However, this view is deeply rooted in an anthropocentric understanding of human intelligence and agency. Recognizing the sublime quality of machines extends the anthropocentric understanding of human agency held since the Enlightenment; in turn, it adds to a sense of human hubris. Seeing threats in machines is an irony in itself: entertaining the potential threat of machines reinforces our sense of control and mastery.

Many posthumanist and STS scholars argue that what we understood as human agency has been distributed in a meshwork of heterogeneous human and nonhuman components, and these nonhuman entities include not only the biological, but also the technological, such as tools, machines, technological systems, models, algorithms, and artificial neural networks. In this way, we have ever been cyborgs, and we have explored the environment in company with other actors. Machines have helped expand our understanding of the environment, and the rejection of their perspectives of the environment is, ironically, rejecting what it means to be *human*. Thus, embracing machine perspectives is to embrace the cyborg condition of being human, and vice versa.

Yet AI safety and bias research is neither wrong nor useless. Instead, adopting a posthumanist understanding of intelligence, and our relationship with algorithms and machines, greatly expands the discourse of such AI research. Over the years, algorithms trained by prestigious AI research clusters, such as Google and Facebook, have resulted in "biased" AI systems that uncannily resemble humanity's biases. Back in 2015, a Google image recognition algorithm placed the label "gorilla" on the faces of several Black people. In 2016, searching female names, such as "Stephanie Williams", on LinkedIn triggered search suggestions asking if the user sought similar male names, such as "Stephen Williams”. That same year, Tay, a Microsoft chatbot, spent a day learning from Twitter, after which it began to tweet racist and sexually-charged messages. Naturally, these companies quickly "fixed" these "biased" algorithms – after the public launched scathing criticisms.

However, a deeper irony lies behind these stories. To a certain extent, these AI systems are not biased at all, because they hold true to the datasets on which they were trained, by cruelly reflecting an ugly aspect of humanity which many of us dare not recognize. In other words, to teach an algorithm to be racial-neutral equates teaching a human to see no skin color. Yet "seeing no color" is a problem itself, one of society's rejection of the idea and truth of systemic racism. At the center of this irony is that we seek to treat AI algorithms as automation mechanisms, instead of as yet another voice on issues we thought we might address solely as humans. If we focus on the bigger picture, we will realize that these blunt and "biased" AI systems played an important role in our recognition of our biases, in online spaces such as Twitter and LinkedIn.

A similar argument can be made with regard to algorithms in environmental management and design. As an analogy, let us take the DRL agent developed by the Link Lab. From an efficiency perspective, opening and closing a valve repeatedly over a short period, causing small flooding downstream, may be an unwise strategy. The DRL agent embraces biases towards evaluating flooding based on volume, rather than frequency, and as designers, we know that because we have access to the objective functions and data used to train the agent. Yet this does not mean we must implement another function to result in an agent "unbiased" towards flood events. Instead, the situation asks us to reflect on the ways in which urban systems have been optimized based on few parameters. The agent's behavior, exploiting the frequency of flood events to achieve its goals, reminds designers that we overlook an entire school of strategies, based on frequency rather than volume, especially when we consider cyberphysical systems that allow for live updates and real-time responses.

4. Actuating Leads to Attuning: Cultivated Wildness

We must first reflect on what we have explored in terms of control and cybernetic thinking in environmental management, before venturing into the last category of practices. It is clear that, following the classic feedback control diagram, we can map two different research paradigms and practices that point in different directions.

The first one is a mainstream speculation: a model-centric paradigm built around sensing-computing-actuating feedback mechanisms. Following the system diagram, a collection of processes may be grouped as a dynamic system, with measurable inputs and outputs. Sensors are added to the system and its environment to collect data that either feedback or feedforward to the controller to compute actuating strategies. With big data, we anticipate more learned state-space models of the environment. These state-space models are faster to compute and simpler to optimize, and are used to bypass physics-based empirical models, such as SWMM, for environmental management. Ever-increasing computing power will make it feasible to run live parallel simulations of the environmental systems in order to devise control policies, evaluate them based on preset goals, and adjust strategies on the run. Sensing networks, big data, state-space modeling, and machine learning techniques set up an infrastructural basis for applying modern control strategies, such as model predictive control (MPC) algorithms, for managing the environment. In this mainstream guide towards a version of the cybernetic environment, we anticipate numerous models distributed throughout the environment, continuously forecasting future scenarios based on sensed data, devising live management strategies through actuators, and reevaluating these strategies based on sensed data returned to the models. Based on this mainstream formulation, we anticipate improved controls over all sorts of environmental systems, to urge them in the desired direction – more resilient, more adaptive towards climate change, and with an enhanced response to disturbances. This framework is a type of adaptation based on control: more information leads to better understanding and modeling of the environmental systems. Thus, we can better manage the environment to adapt to a changing climate. This is the unstated premise that underpins contemporary data-driven environmental management discourse.

The second paradigm points in another direction, that of a sense of cultivated wildness. Tracing a range of contemporary data-driven practices in art and engineering demonstrates that applying cybernetic thinking to environmental practices may lead to benefits beyond control. In this framework, sensing is articulated as coding the environment with machines. Many contemporary art and design practices apply sensing technologies with strategies outside the mainstream environment sensing framework. The data produced in these practices fail to fit within the category of what we know as the state-space variables of the environment. In other words, they result in alternative state-spaces of the environment, which suggest conditions of uncontrollability and wildness. Meanwhile, the application of deep reinforcement learning neural networks in environmental management produces machine agents that devise their own strategies. The DRL example sheds light on a non-model-centric paradigm. These developments point to a version of cybernetic thinking that is not solely about control.

Other questions arise: if repeated actuating leads to wildness, then what has been actuated? If actuating is detached from humans' exercise of agency, how might we conceptualize the process of actuation?

This section relies heavily on design thinking, in the sense that must connect ideas across different fields, bringing them within a posthumanist and co-production framework. Only in this way will we begin to explore alternative ways to use cybernetic thinking on the line of cultivated wildness.

There are three routes with which to explore these questions: 1) distributed intelligence and responsive frameworks, 2) plant-machine interactions, 3) human-machine interdependence.

The examples above suggest that repeated actuating is, in fact, the basis for a sense of attuning between machines and other assemblages – human or nonhuman. Attunement is a concept developed by OOO proponent Timothy Morton:

> "Since a thing can't be known directly or totally, one can only attune to it, with greater or lesser degrees of intimacy…Since appearance can't be peeled decisively from the reality of a thing, attunement is a living, dynamic relation with another being" (Morton 2014).

Morton uses the example of an opera singer's voice attuned to a wine glass's frequency, thus shattering it. Overlapping operations produce an observable effect. Within the framework of cultivated wildness, this sort of attunement is where intelligence emerges. Machines take on a role that is a necessary medium for designers to cultivate attunement between assemblages. Repeated actuating is a type of living, dynamic relation between machines and other assemblages.

4.1. Attuning Practices

Distributed Intelligence and Responsive Frameworks

We tend to ignore how intelligent machines are already distributed in the environment, overlooking the scale on which they participate in all sorts of environmental processes. For example, the Everglades restoration project is considered an exemplar for adaptive management, which is considered the best practice in environmental management discourse. Adaptive management can be understood as a decision-making method derived through learning by doing. This approach is achieved by intense monitoring and actuating processes. Established in 1949, the South Florida Water Management District (SFWMD) is a regional governmental agency that manages the water resources in the southern half of Florida, including the Everglades, a 1.5-million-acre wetland that sustains numerous wildlife species. It is the ultimate "wild place" in the eyes of urban residents. However, the wild Everglades is, in fact, a highly maintained place. In South Florida, numerous sensing stations are installed across bodies of water, generating real-time hydrological and water quality data for building simulation models. The South Florida Water Management Model is one which organizations and agencies use to analyze operational changes to their water systems, to make informed management decisions.

Moreover, thousands of miles of engineered canals and pipes are carved into and buried under Florida's landscape. Water control infrastructures, such as water basins, spillways, weir gates, pumps, dams and locks, are strategically placed along waterways. These actuators within the system directly influence the hydrological patterns of South Florida (Figure 1). Thus, the amount of water, and hydrological patterns, are carefully calculated and controlled using simulation models based on real-time hydrological data, weather forecasts, climate modeling, and historical data.

The South Florida project is only one instance of numerous efforts to use cyberphysical systems to manage environmental processes. Recent discourse regarding smart cities has fueled cybernetic imaginings across social sectors. The environment is laden with intelligent machines waiting to be mobilized by designers and engineers. Yet how to develop a framework to communicate and design with these machines, transforming them into actuators to cultivate wildness? Two speculative landscape design research projects, and an array of robotic and machine-learning examples, shed light on an adaptive framework based on real-time feedback and machine learning.

In the first project, Towards Sentience, designer Leif Estrada proposed to distribute intelligent machines and sensing networks throughout the Los Angeles River, to influence hydrological patterns and build land over time (Estrada 2016b; 2018). Estrada tested the sensing-processing-actuating responsive framework on a hydromorphology table located at the Responsive Environments & Artifacts Lab (REAL) in the Harvard Graduate School of Design. The sediments and water flow inputs are controlled through four material feeders and a water pump, to simulate water flows and sediment behaviors. The table is also equipped with sensing and monitoring devices to gather real-time data, including a Microsoft Kinect above the table and ultrasonic sensors downstream. Real-time data then feeds into Rhinoceros 3D through

Grasshopper plug-ins and customized interfaces. In one of his design experiments, Estrada proposed an actuating system called “Attuner”, which consists of a matrix of acrylic dowels connected to servo motors (Figure 28). Every dowel is separately driven by a servo motor, and the bottom portion of the dowel projects into the sediments. When the servo motors turn, they drive the dowels up and down to influence the flow pattern, thus creating different landforms downstream. The topography is live-tracked by sensors, and elevation data is used to build a digital elevation model to identify a series of highlands and lowlands. This information might inform operations, such as adding to a highland by depositing sand on it, or eroding highlands away by directing more water towards them (Estrada 2016a). Estrada (2018) reported that the cyborg system would demonstrate a level of live updates and feedback beyond human capacity.

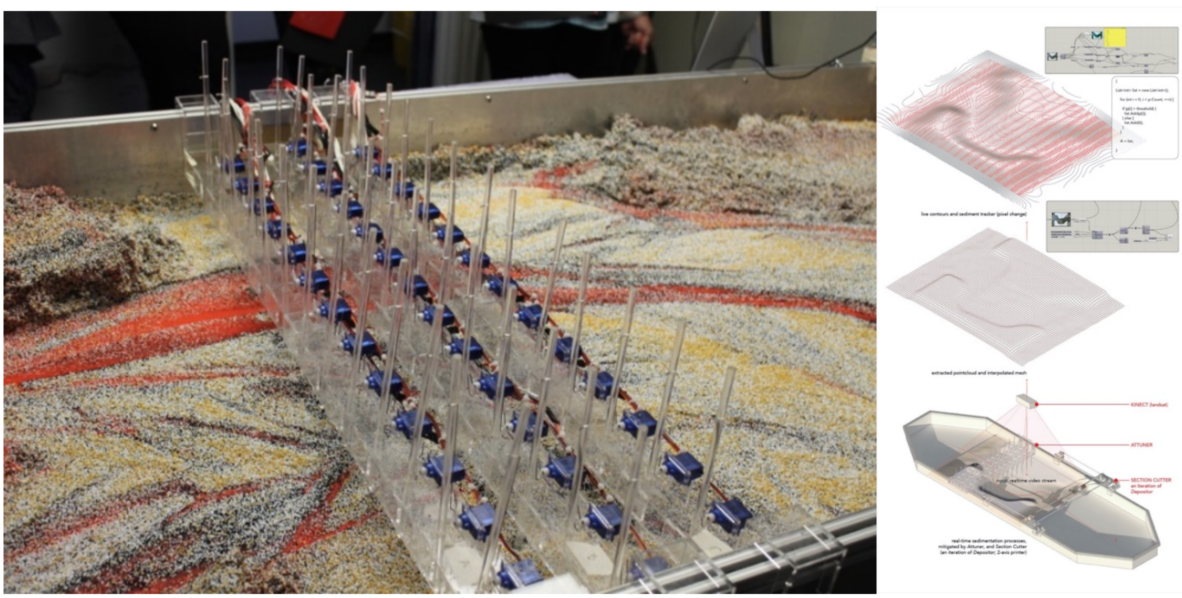

Figure 28. Towards Sentience™
© Leif Estrada 2016.

Estrada’s experiment tested the sensing-processing-actuating feedback loop as a viable responsive landscape framework, to utilize sensors and actuators in the environment for deploying real-time landscape strategies. Moreover, an environment laden with sensors and actuators sets the basis for applying machine-learning algorithms. We can imagine a DRL agent, such as the one in the simulated stormwater system, testing different policies with “Attuners”, and adjusting its strategies based on real-time feedback. We can even conceive of DRL agents deeply embedded in the environment, which over time co-evolve with human and nonhuman agents, as well as systems.

This type of speculation raises two concerns. First, continuous-learning strategies are needed to anticipate an intelligent machine that co-evolves with human and nonhuman agents in the environment. Most AI algorithms are considered “offline”, meaning that after training, what is uploaded to a cyberphysical system is a fine-tuned model or neural network, in the context of deep learning. Training processes tune the weights in each neuron by exposing a neural network to large amounts of data. The neural network is calibrated to its optimal condition when training is finished, and when in operation, it simply generates outputs based on input information, without learning anything new. If we consider the effects of evolution and climate change, an agent will quickly grow outdated. Consequently, developing a continuous learning framework is the next challenge in incorporating intelligent machines for managing the environment. Second, machine learning is often divided into training and testing sessions. Training data is available for machines to learn from before the agent is applied in real-world situations. In the DRL case, an agent develops its strategies within a simulated environment, such as a video game played a limitless number of times. However, the environment possesses no reset button, and if an agent caused an unwanted result, there would be no way to undo the effects. This poses ethical challenges in applying AI agents to manage the environment.

Another speculative research project, and recent advancements in AI research, provide insights into these predicaments. In an MIT architectural thesis research, designer Ricardo Jnani Gonzalez (2016) proposed a system deeply embedded in a cryosphere environment. The system consists of a central “mind”, which can be understood as a supercomputer unit, and distributed “bodies”, actuators that alter the physical environment. In operation, the “mind” first casts a vast array of actuating policies across the “bodies”. Different local environments respond to these policies in separate ways. The “mind” then evaluates the policies based on discrepancies between projected scenarios and actual outcomes. Then the “mind” updates the policies and returns them to the “bodies”. If one policy yields the best outcome, then its successful experiences is embedded within the next iteration of intervention. Thus, one “body” might influence other “bodies” by transferring its knowledge. Through this iterative process, the distributed system gradually attunes to the cryosphere environment and evolves with it.

This project's technical framework mirrors widely used machine-learning algorithms and techniques, such as genetic algorithms and transfer learning. Genetic algorithms are inspired by the natural selection process, in which the best qualities of one generation pass to the next generation. In each iteration of training, an array of policies is deployed, and the best ones are retained. In the next training generation, mutations are introduced to successful policies, and a new array of updated policies is deployed. Repeating this selection-mutation process over time may increase the performance of the algorithms. For environmental management, one must not expect one complex model to compute one-shot policies. Instead, one can imagine distributed agents, each doing incremental interventions, sharing knowledge with each other and evolving together. There are research efforts to use robots to manage the environment or conduct construction, with incremental and small-scale interventions. Romu is a robot designed to drive interlocking sheet piles into the ground to build check dams, which help prevent erosion and promote groundwater recharge in arid regions.[28] RangerBot is a vision-based underwater robot that identifies and kills coral-eating starfish, and monitors reef health and water quality to protect Australia’s Great Barrier Reef. RangerBot relies on machine learning and computer

[28] https://wyss.harvard.edu/media-post/romu-a-robot-for-environmental-protection/

vision to identify unwanted starfish in the underwater environment. These robots act as distributed "bodies" for machine-learning agents to evolve and develop strategies.

In Gonzalez's speculation, the system gradually attunes to the environment, and one body can transfer successful policies to other bodies. This involves another machine-learning technique, called transfer learning, in which knowledge acquired from one domain is applied to another. For example, Generative Pre-trained Transformer 3 (GPT-3) is a language model that uses deep learning to generate human-like texts (Brown et al. 2020). Scientists, however, built the model with generality in mind; OpenAI developed GPT-3 as an API (application programming interface) that allows users to perform few-shot learning, feeding a learning model with a small amount of training data, and tuning GPT-3 to specific knowledge domains. Because the model was trained with online texts, which included lines of computer code, researchers found that GPT-3 can generate SVG plots and write HTML code to generate web layout from simple written descriptions. Thus, GPT-3 learned coding merely by browsing internet content. In other examples, scientists explored strategies to transfer robotic policies to new robots with vastly different hardware properties (Chen, Murali, and Gupta 2019), or to generalize and quickly transfer policies from various robotic systems to a new robot (Barekatain, Yonetani, and Hamaya 2019). We may speculate that machines pre-trained with general knowledge about the system before being distributed in the environment can rapidly attune to different conditions. In addition, with transfer learning, successful experiences can be generalized and applied to other tasks. Transfer learning thus provides technical possibilities for Gonzalez's speculation, in which one actuator's experience may be generalized and transferred to another actuator.

Plant-Machine Interactions

How might we cultivate wildness by developing tools for direct interaction with plants? Two models exist for this task, one used in agriculture practices, the other in art.

Precision-farming uses sensors to monitor plants and robotic arms to fertilize, water, and harvest agricultural products at an individual plant level. Many modern farms have begun to incorporate these machines into their daily practice, and start-up firms focus on robotic gardening and agricultural systems across scales (Figure 30). Precision-farming aims to manipulate plants for greater productivity. It is a single variant system that optimizes only one aspect of plant life. Precision-farming thus increases productivity by eliminating “wildness” in plants; in these systems, plants are exploited for human use.

The second model is employed in art. Artist David Bowen uses cybernetic technologies to create art installations that explore the relationship between machines and plant materials (Figure 29). “Growth Rendering Device” (2007) is a feedback system between machine and plant. A pea plant is suspended in a hydroponic solution, in a bottle attached to a vertical scanner, a roll of paper, an inkjet printer head, and a light. The system provides food and light to the plant and records its growth by producing drawings based on the scanned data. One drawing is produced every 24 hours; the system then scrolls the roll of paper and begins the next drawing cycle. As Bowen suggests, the outcome is not predetermined; the device may record growth, but also, likely, the decay and demise of the plant. Based on a similar principle, Bowen’s “Growth Modeling Device” (2009) scans a plant from three different angles and, using a 3D printer, prints the plant’s growth over the course of 24 hours. A conveyor belt advances approximately 17 inches after each printing cycle, to begin the next cycle. In his installation “Plant Drone” (2019), Bowen built a plant pilot. He mounted a plant onto a drone, and attached electrodes to its leaves. The bioelectricity emitted by the plant leaves determines the drone’s movements. The plant “piloted” the drone under the night sky, its movements captured with long-exposure photography. Although art production is commonly assumed to be an entirely human endeavor, in these installations, the drawings, models, and photographs are not completely determined by the artist, nor by the machines; instead, they are co-produced by machines and plants. Bowen hacked machines and constructed systems that allowed plants to express themselves and exercise their agency in art production.

Figure 29. David Bowen’s Artworks.

Growth Rendering Device, 2007 (top left). Growth Modelling Device 2009 (top right), Plant Drone, 2019 (bottom). ©David Bowen

These examples demonstrate that it is possible to develop cybernetic systems that bypass control and optimization. With this conviction, a group of UVA designers established a prototyping project that allows machines direct interaction with plants. “Algorithmic Cultivation” (2020) is a platform consisting of robotic armatures, lighting systems, and planters (Figure 30). The robotic armatures may be equipped with sensors and customized actuators to directly interact with the plants, such as in pruning and watering. Rather than using machines to optimize plant growth, this project aims to develop loose couplings between machines and plants. The team is interested in observing how plants respond to algorithmic management, and, in turn, how the machine adapts and attunes to the plants’ responses. The machine and plants form a positive feedback loop that produces spin-off and emergent behaviors. Thus, the outcome is a cultivated wildness, in the sense that the outcome is unexpected and unpredictable.

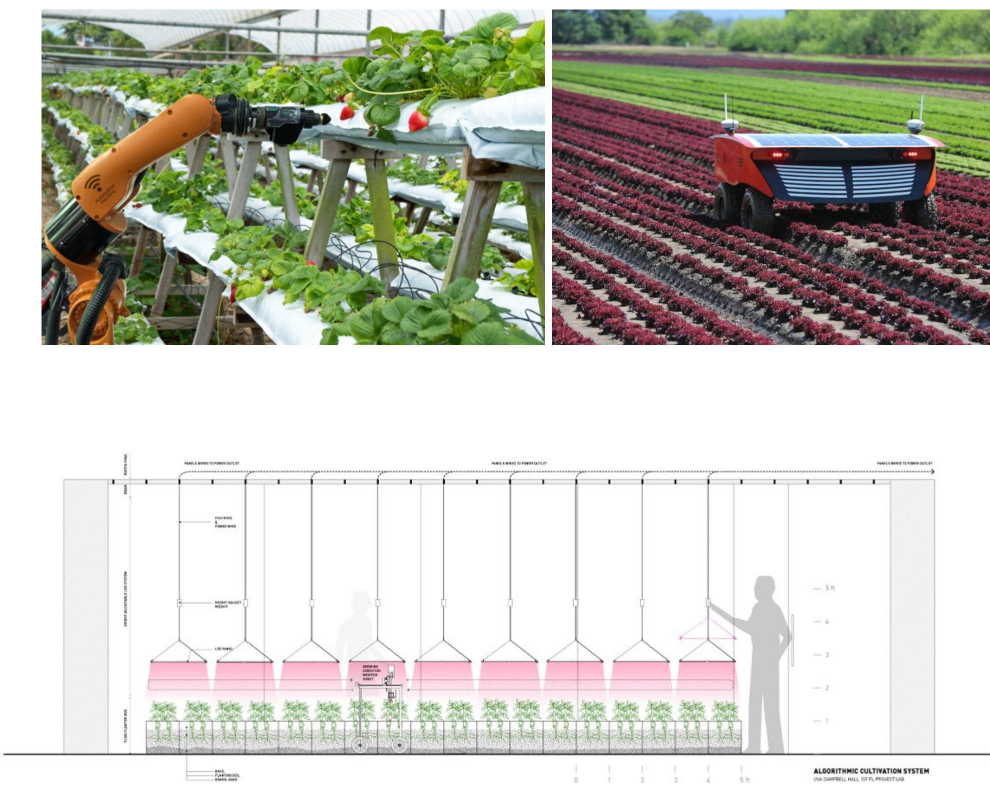

Figure 30. Machine and Plants.

Precision-farming robots (top)

“Algorithmic Cultivation” platform (bottom) ©Cantrell et al. 2020

Conceptually, “Algorithmic Cultivation” lies between engineering approaches, such as precision-farming, and artistic expressions, such as Bowen’s installations. The project is not an industrial prototype to be monetized as a product. Similar systems are already in practice, especially considering precision-farming and robotic agriculture. However, unlike artistic expressions that function at a conceptual level, “Algorithmic Cultivation” is an ongoing process with a pragmatic flavor. The project establishes a platform for faculties and students to test landscape strategies that focus on interactions between machines and plants. “Algorithmic Cultivation” cries out for further explorations between art and science. The technique used in this installation can be conceptualized as post-prototyping, in the sense that it denaturalizes mainstream practices, reframing them in a different discourse to cultivate alternative understandings and reveal unexplored territories.

Human-Machine Interdependence

The last venue concerns human-machine relationships in cultivating wild conditions. Sougwen Ch’s artworks again serve as objects of observation. “Drawing Operations” (2015; 2017; 2017) is a series of performances in which Sougwen drew alongside drawing robots (Figure 31). In the first version, she drew alongside a robot arm called D.O.U.G_1 (Drawing Operations Unit: Generation _1). The D.O.U.G_1 arm addresses mimicry; the robotic arm mimicked the artist’s movements by analyzing her drawing gestures through an overhead camera and reproducing them. The final artifact is a co-produced drawing through collaboration. However, the robot’s movements were not perfect reproductions of Sougwen’s. Though the algorithm tracked Sougwen’s linework in the digital simulation, the movements were dramatically altered when translated to a robotic arm.

If we analyze the system set-up, we realize that imperfection was unavoidable. Because the robotic arm conducted live computer vision analysis, there was an inevitable latency between the arm and the algorithm; there was a lag in the robot's movement, comparing to Sougwen's. Moreover, the robot's linework quavered, as if the robot's hand was unsteady. In real-time, Sougwen was forced to adapt her movement to the robot's. However, her new gestures fed back to the robot, and the robot produced a new set of gestures to which Sougwen was compelled to adapt. The artist and the robot formed a positive feedback loop; together, they became a coupled system with new styles and techniques manifested in the co-produced artifact, gradually synchronizing and attuning to each other in a wild territory alien to both.

Later, the D.O.U.G_2 was designed around the notion of memory. Sougwen and her team deployed machine-learning techniques to teach the robot Sougwen's drawing style. They fed an artificial neural network with decades of Sougwen's art, so that the AI would learn the patterns in Sougwen's drawing, and attempt to reproduce them. The machine subsequently developed its own understanding of Sougwen's style, and expressed a machine interpretation in their drawing collaborations.

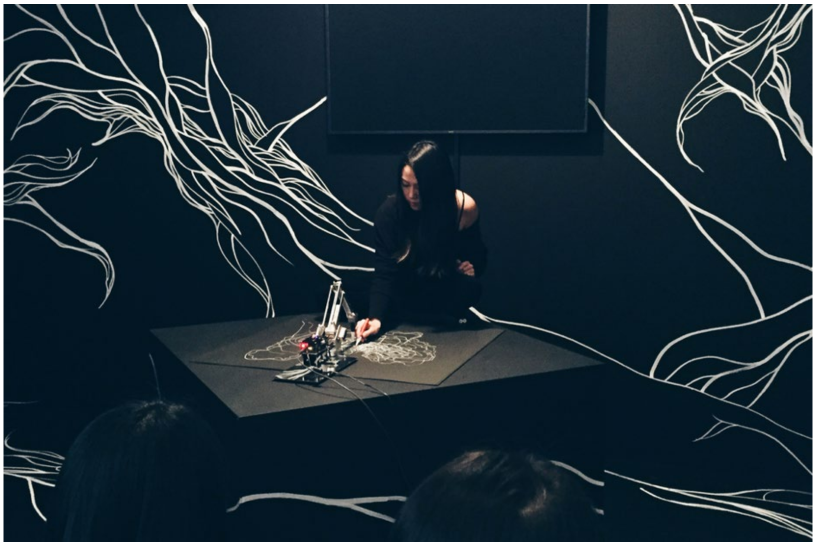

Figure 31. Drawing Operations
© Sougwen Chung. 2015 – 2018.

Sougwen's art installations raise questions about perceived errors and glitches in systems, reframing the notion of failure. As Sougwen noted, "The robot mimics the artist like a partner in an improvisational performance. It is an AI that embraces every glitch, bug, and error" (Chung 2015). However, from a posthumanist perspective, these so-called glitches, bugs and errors are fundamental facets of operation defined by the algorithm and the physical armature of the robotic arm. To human eyes, they may appear to be errors, but they are the ways in which this drawing unit operates within the environment. In theory, we might minimize system latency by using a faster processing unit and by accounting for the robotic arm's physical limitations. However, suppose that the robot could perfectly repeat every detail of Sougwen's gestures; and in that case, results become anticipated and predictive, and no art appears. When D.O.U.G_2 learned Sougwen's style through her works, there were no right or wrong answers for interpretation, because they were merely machine interpretations. If the machine replicates Sougwen's drawing style perfectly through learning, then the machine is no different from a photocopier. Thus, adaptation between Sougwen and the robot entails exploiting each other's limitations and errors. Or, to use Sougwen's words, her artwork is about "embracing the imperfections and recognizing the fallibility of both human and machine in order to expand the potential of both" (Chung 2020). As discussed in Chapter Two, the foundation for the emergence of intelligence is co-production between assemblages. In Sougwen's work, intelligence manifests in the loose coupling and attunement between human and machine. In this attuning process, the potentials and possibilities of the human-machine assemblage expand.

In the cybernetic environment, our relationship with machines must not be limited to the co-dependent relationship between users and tools. Instead, artistic explorations suggest that the true potential lies in interdependent relationships, where new questions arise, new understandings form, and new strategies emerge. From this vantage, recalling the case where the stormwater DRL agent gamed the reward function by producing small flood events, we can, in fact, regard this as a novel landscape strategy – and use it to our advantage. With the conviction that machines are not tools for automation but actors who have been involved in the co-production of the environment, we may build an alternative way to understand failures and errors when collaborating with intelligent machines in environmental strategies. When machines produce unexpected strategies, those are not necessarily errors. They are, instead, opportunities for us to form different understandings of the environment, just as AlphaGo and AlphaStar have expanded players' understanding of their games. Cultivating wildness with intelligent machines expands our understanding of the environment, recognizing its unexplored potential as a place for more-than-human species.

4.2. Cultivated Wildness

These emerging practices suggest that cybernetic thinking does not necessarily lead to control, and repeated actuation does not lead to stability. However, if the feedback mechanism leads not to control, what is the outcome? If control does not result in stability, how do we define the term *control* itself? Ultimately, if the speculation involved in these cases becomes concretized, how do we conceptualize the resulting cybernetic environment?

To consider the cybernetic environment outside the framework of control, we must conceptualize it as *cultivated wildness*. At first glance, *cultivated wildness* appears an oxymoron. If wildness denotes the lack of human control, how might wildness be cultivated? Due to this perceived tension, *cultivated wildness* establishes an unfamiliar territory in which to entertain cybernetic thinking beyond control.

Several caveats must be addressed before we proceed. In the English context, the concept of *wildness* cannot be severed from that of *wilderness*. As environmental historian William Cronon writes, "modern environmental movement is itself a grandchild of romanticism and post-frontier ideology, which is why it is no accident that so much environmentalist discourse takes its bearings from the wilderness these intellectual movements helped create" (Cronon 1995a, 72). The image of a wild place has come to embody a collection of moral values and cultural symbols deeply rooted in Judeo-Christian traditions, colonialism, and narratives of escapism, romanticism, primitivism, and nationalism (Cronon 1995a). These culturally specific values reinforce a simplified perspective of wild places, causing ongoing social and political conflicts, such as the recent political debates on oil rights in Alaska, disputes between the working class and environmentalists' efforts to protect "pristine nature," and long-term contentions between indigenous people's homelands and America's wilderness.

Despite the intellectual critics of binary thinking, contemporary environmental practices are awash with dualisms, such as artificial/natural and technology/environment. This binary thinking gives rise to moral rationales that romanticize "nature-based" approaches and demonize "technological intervention", thereby over-simplifying environmental strategies. If wildness entails a lack of human influence, how might intelligent machines, regarded as extensions of human capacities, construct wild places? A framework that articulates a clear division between the technological and the biological renders it impossible to consider machines and wildness within the same category.

As noted in Chapter One, the boundary between technology and nature is illusory; it is more apparent in our mind than in the environment. First, we must recognize that wild places do not exist without maintenance and care. For example, many regard the High Line as "wild in the city", Yet landscape architects understand that the High Line is a highly constructed and maintained urban landscape. In fact, many places which an average urban resident regards as wild are cultivated and maintained by nonhuman agents with their own goals and strategies.

Moreover, contemporary posthumanist ideas, such as assemblage theory, actor-network theory, and new materialism, share a co-production thesis for understanding human agency. What we understood as human agency and intelligence have constantly been distributed throughout a heterogeneous network of assemblages, including humans, nonhumans, and machines, as well as non-living assemblages such as organizations, corporations, policies, and laws. Theory and practice in landscape design and urban planning also posit that the urban environment is co-produced and shared by humans and nonhuman species (Houston et al. 2018; Prominski 2014). Actors' actions modify each other, and the outcome is a mesh of different perspectives; the result of co-production lies outside the actors' original intentions, if they existed. Consequently, *wildness* describes perceived wild conditions with unexpected outcomes that often refuse to fit within the agents' mental models.

Furthermore, we can examine this sense of strangeness and wildness concerning autopoiesis and second-order cybernetics. As Maturana and Varela argued,

> "We as observers have access both to the nervous system and to the structure of the environment. We can thus describe the behavior of an organism as though it arose from the operation of its nervous system with representations of the environment or *as an expression of some goal-oriented process*. These descriptions, however, do not reflect the operation of the nervous system itself. They are good only for the purpose of communication among ourselves as observers. They are inadequate for a scientific explanation" (Maturana and Varela 1980, 129, emphasis added)

This argument mandates highly recursive thinking. From the autopoiesis perspective, cybernetic thinking is an epiphenomenon which observers use to describe and communicate system behaviors; goal-directness is a concept which observers invent to reinforce a cause-and-effect relationship between agents' actions and their consequences. From this vantage, it is not that there are, first, cybernetic systems with goal-seeking behaviors, and then we observe and categorize them; it is more that we adopt cybernetic thinking, viewing the phenomenon in terms of agents and goals in the first place -- *then* find phenomena that fit within the goal-seeking description of cybernetic thinking. For example, it may be necessary to communicate machine learning in terms of an agent seeking goals, which can be articulated in terms of reward functions, yet evaluating and measuring these goal-directed phenomena are actions apart from a neural network's system operations. We may assert that agents have goals, and we may utilize the imagined goal-directed behavior in our favor in order to implement control strategies, yet, in the end, cybernetic thinking and goal-seeking behaviors do not suffice to explain agent behaviors. Using terms in the object-oriented ontology (OOO), we cannot access a real object, which is always withdrawn from access, even with cybernetic thinking and systems theory. Despite the shortcomings of Maturana and Varela’s description, autopoiesis theory further illustrates the notion of cultivated wildness: Agents’ system operations modify, amplify, dampen, and overlap with each other; there is a sense of wildness in the co-produced environment, in which the outcome is alien to all.

Thus, we may regard this wild condition as a new baseline of the environment in which contemporary designers and engineers operate. At this new baseline, intelligent machines are not merely a layer of a control mechanism through which humans extend imagined agency and expand an illusory control regime. Instead, intelligent machines may be conceived of as multi-scalar actors deeply embedded in all sorts of environmental processes giving rise to wild conditions. Thus, the “environment” which designers must consider today is fundamentally different from that on which past designers concentrated. “Environment” no longer stands for a passive background, a *tabula rasa* on which designers entertain system dynamics. Rather, designers confront a cybernetic environment laden with diverse forms of distributed intelligence. Thus, to design no longer deals with using localized human intelligence, which is an illusion from a posthumanist perspective, to solve environmental problems. To design is to recognize the distributive nature of intelligence, and acknowledge that other forms of “mental processes” in the environment differ from ours.

With this novel understanding of the environment, we will find that cybernetic thinking does not inevitably lead to controlled stability, but to a *cultivated wildness,* in the sense that feedback mechanisms between agents lead to conditions unexpected and alien to all. This wildness is an unexplored territory where new questions arise, new understandings form, and new strategies emerge.

Below is an illustration of a conceptual framework to explore the notion of *cultivated wildness* (Figure 32).

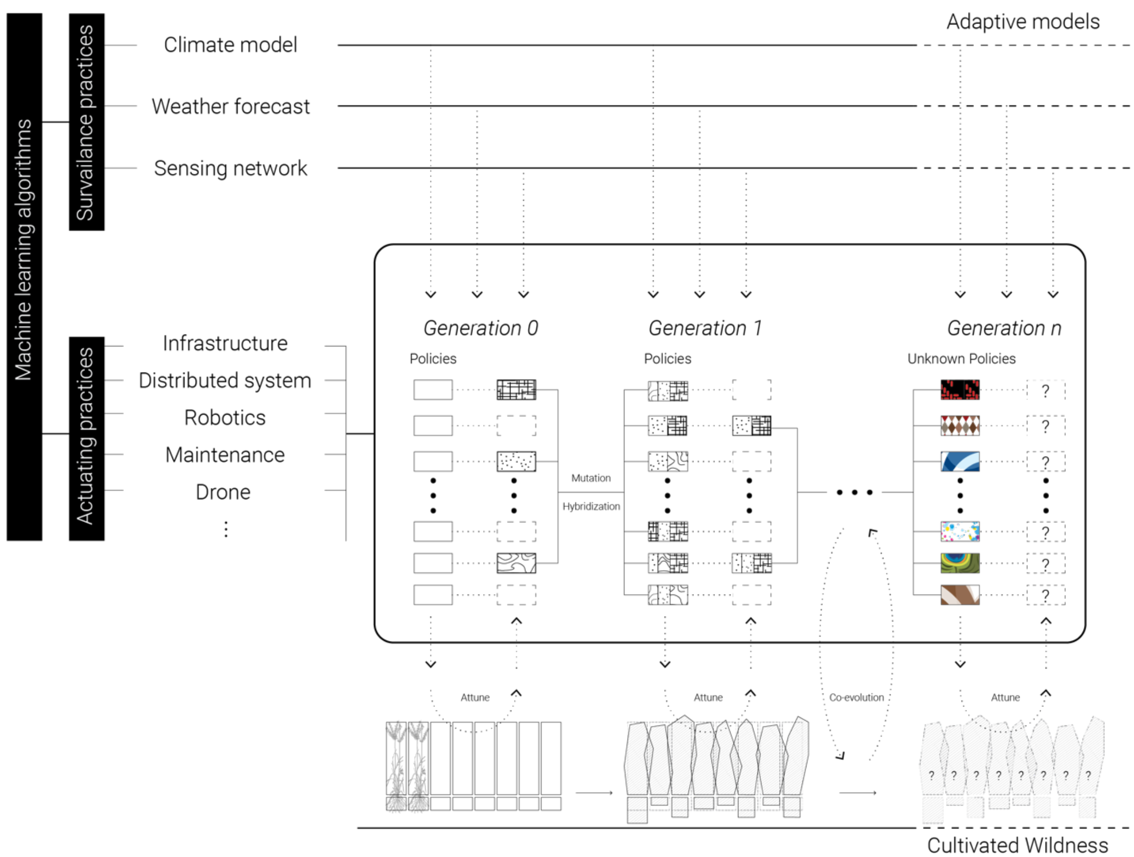

Figure 32. Cultivated Wildness: A Conceptual Roadmap

Within this framework, machine-learning algorithms are distributed in cyberphysical systems, from environmental surveillance practices, such as climate models, weather forecasting systems, and sensing networks, to all sorts of actuating systems, including cyberphysical urban infrastructures, robotic armatures, distributed robots, and drones. Certain actuators interact directly with the nonhuman assemblages, such as plants and animals; others may influence their habitats by modifying soil conditions and hydrological patterns. Machine-learning agents test strategies through a framework based on continuous learning and genetic algorithms, and they learn from each other through techniques such as transfer learning. These loosely coupled agents are able to adjust their strategies where informed by surveillance practices and past experiences. Over time, these distributed and loosely coupled models would start developing unexpected strategies. Landscape architects, engineers, and designers might participate in this framework by developing different interfaces and media to communicate with these multi-scalar models and systems (Robinson and Davis 2018). In this framework, we should consider the relationship between machines and other assemblages, with the notion of interdependency rather than co-dependency. Machines are no longer tools for imagined human control, but a necessary medium through which we explore the unrealized potential of the cybernetic environment.

CONCLUSION: DESIGN AND CYBERNETIC ENVIRONMENT

1. From Wild Nature to Wildness in Machines

We shall conclude this journey into the cybernetic environment by comparing, in the table below, two versions of cybernetic thinking. We will return to concepts explored in Chapters One and Two, and investigate their meanings concerning these two modes of cybernetic thinking.

Mainstream Cybernetic Thinking	**Cybernetic Thinking Unexplored** (non-communication and uncontrollability)
Accessible	Withdrawn
Communicative	Non-communicative
Controllable	Uncontrollable
extension of human intelligence	Intelligence of coproduction
sensing-modeling-actuating	coding-choreographing-attuning
controlled stability	cultivated wildness
monoculture	technodiversity
wild nature	wildness in machines

1.1. Mainstream Cybernetic Thinking: Stability by Machines and Wildness by Nature

Cybernetic thinking has been in existence for more than 70 years, but we have limited our exploration of cybernetics to the terms listed in the left-hand column, above. Mainstream narratives have reduced cybernetic thinking to a sensing-modeling-actuating feedback loop. We hope to utilize this recursive algorithm to control dynamic systems, driving them to achieve a sense of controlled stability. This undertaking may be compared with the transformation formula investigated in Chapter One: humans use technology to transform nature into habitable landscapes. Cybernetic thinking adds another preeminent tool to the conceptual toolbox, to further articulate and support this outdated framework as the ultimate generalization of our relationship with the environment.

This mainstream cybernetic thinking is deeply rooted in the humanism inherited from the Enlightenment, which emphasized human beings' value and agency, and liberated us from established doctrine and authority, establishing an intellectual foundation for the Western political revolutions of the eighteenth and nineteenth centuries. However, its unquestioned anthropocentrism has also planted the seed for a blind belief in human agency and control over other entities, biological or technical. Humans are conceptualized as the source of agency, whereas intelligent machines are tools through which the agency generated from human bodies and minds may be replicated, extended, and amplified. We believe we are able to offload our mental capacities to these cybernetic machines, to automate human physical and mental processes. Our relationship with intelligent machines is co-dependent, because they are conceived of as extensions of human agency, utilized to influence the environment and other, nonhuman, entities.

Within this framework, one perceives a spectrum between control and wildness, to conceptualize the implications of human agency within the environment. Here, the term *wildness* is akin to the notions of uncertainty and unexpected outcomes. As discussed above, we seek to view the nonhuman realm as "wild nature", because it exhibits phenomena unexpected and outside human comprehension. We constantly discover new patterns and find new relations in this "wild nature".

Along this control-wildness spectrum, placed at one end is a condition of perfect human control, which dismisses uncertainties that may jeopardize any human plan of action. On the opposite end of the spectrum sit ultimate wildness and the unknown, where human agency is rendered obsolete. In the center lie different degrees of perceived human control and agency. For example, one may regard cities as an ultimate embodiment of human control, whereas the Amazon rainforest and the Great Barrier Reef represent a lack of human control. In this conceptualization, wildness and control are mutually exclusive; control would inevitably vanquish uncertainty, reducing the environment's sense of wildness through increased predictability and control authority. We must see a negative correlation between the two concepts, in the sense that human activity will inevitably result in reduced wildness in the environment.

With this conceptual model, one may generate a series of rationales with respect to present-day environmental crises, such as climate change; many contemporary environmental ideas may be analyzed using this spectrum. As we explored above, Anthropocene is a popular concept and premise for various present-day environmental narratives, which have to do with the scale of technological systems. Thus, technological systems and intelligent machines are treated as means through which humans influence the environment by exercising human agency. We may scale back the technological system, as observed in planetary boundary, half-earth, and similar notions, leaving the complex system called "nature" to act on its own behalf. An alternative is to upscale technological systems, embracing the condition of Anthropocene and constructing a “nature” that supports human survival, as advocated by ecomodernists. Further, smart cities are undergirded by mainstream cybernetic thinking, as well, regarding technology as a layer of “digital infrastructure” regulating and optimizing urban systems. By making cities more efficient, wild nature can be preserved and recovered.

1.2. Cybernetic Thinking Unexplored: Wildness in Machines

In contrast with the mainstream cybernetic thinking that relies on a control-wildness spectrum, the cases which we confronted in Chapter Three offer an alternative understanding of recursive processes and their environmental implications. This understanding is built atop the series of ideas presented in the right-hand column, above, constructing an alternative version of cybernetic processes articulated through a coding-choreographing-attuning feedback loop. This framework emphasizes three different aspects with regard to design and environmental practices.

a. Sensing networks do not innocently listen to the environment; instead, designers must code the environment, through sensors, into information that makes a difference.

Using coding to replace sensing emphasizes an adaptive epistemology with regard to knowing. It is distinct from the constructivist approach that claims all knowledge is socially and culturally constructed. Instead, the term *coding* emphasizes co-production between humans and the nonhuman realm. The way in which we represent the environment cannot be separated from the way we choose to live in it. With this undertaking, sensors are no longer innocent listeners, but instruments that help us live within the environment. We connect sensing practices to their scientific origin in order to construct evidence with instruments. We thus code the environment in ways that register differences in contemporary society, in response to urgent issues, such as climate change.

In the face of increasing environmental uncertainty, sensing practices must bypass the paradigm of "data collection". Rather, designers who engage with cybernetic technologies must embrace their expertise in the changing environment. This requires designers to denaturalize environmental sensing practices, embrace a sense of wildness in the instruments, cultivate a sense of technodiversity in sensing practices, and explore sensing networks' unrealized potential.

b. Rather than building models of the environment, designers ought to collaborate with intelligent agents, to explore the environment's possibilities in a non-model-centric paradigm.

Deploying the term *choreograph* in place of *modeling* emphasizes a different relationship between designers and their models, particularly considering the various advanced machine-learning techniques utilized in environmental practices.

Modeling conveys a sense of representation, since a model is a metaphor for the system being modeled. In the paradigm of modeling, what has been highlighted is the gap between models and the systems they represent. As we saw, modern control theory is based on a model-centric paradigm -- the success of control strategies, such as model predictive control, relies on model accuracy. The paradigm of modeling challenges designers to build better models in order to reduce the gap between model and system, overlooking the primary reason for the creation of models. In this framework, designers are conceived of as those who, through digital models and algorithms, offload their intelligence onto machines. Models become extensions of human mental capacities, expanding a perceived human influence through mechanical repetition.

However, *choreography* emphasizes a relationship involving trust. Emerging modeling techniques suggest a non-model-centric paradigm in which designers' relationship with models may be described as co-production and co-evolution. Within this new framework, machines are no longer mere tools for exercising human agency, but collaborators in exploring the environment. Behaviors outside our anticipation become valuable lessons which machine-learning agents offer us, with a machinic perspective. Designers and algorithms form a type of relationship beyond creator and created, but as choreographers and dancers. Here, the notions of human intelligence and machine intelligence become irrelevant; what emerges is co-productive intelligence in the co-production process.

c. ***Repeated actuation does not necessarily lead to controlled stability, but to cultivated wildness, in the sense that the environment is a mesh of goals, frameworks, and objective functions, including those used by intelligent machines.***

Using *attuning* to replace *actuating* emphasizes a developmental view towards the relationship between intelligent machines and human and nonhuman actors within the environment. As we observed in modern control theory, actuators carry out control policies in order to propel a system towards the desired state. Actuation is an intrinsic aspect of controlled stability. However, with cases such as the responsive landscape experiments and Sougwen Chung's drawing operations, we see that repeated actuation leads not to stability, but instead to unexpected behaviors.

The notion of emergence has been explored through multi-agent simulations, in which the iteration of simple rules would lead to complex behavior. Recent developments in cybernetic technologies and machine-learning techniques have expanded the possibility of exploring the notion of emergence through landscapes, as media in the cybernetic environment. The resultant emergence in the cybernetic environment may be regarded as cultivated wildness.

The notion of cultivated wildness sits outside the conceptualization that regards control and wildness as oppositional and mutually exclusive. Instead, the notion of wildness entails a perceived *wild condition* beyond human expectation. At the center of this conceptualization lies the conviction that the environment results from chaotic co-production between human and nonhuman actors; it is a meshwork of different mental processes, frameworks, goals, and objective functions. The result is alien to all, and brimming with wild situations. Machines play an important role in the cybernetic environment, as intelligent agents that cultivate a sense of wildness through repeated actuation and recursive operations. Designers in the cybernetic environment work with intelligent machines to explore this wild territory. Cultivated wildness becomes a reserve of possibilities and strategies for a yet unforeseen future.

1.3. Towards Non-Dualistic Thinking

Cultivated wildness challenges us to expand our definition of wildness, by dissolving its boundary between biological and technological, and overcoming dualistic and binary thinking. Historically, the term *wildness* was articulated in the category of nature and biology. As presented in Chapter One, wildness and wilderness became ideas that reinforced the human-nature dichotomy, which gave rise to all sorts of problematic reasonings that undermined designers' moral imperatives in environmental practices.

Yuk Hui (2020) pointed out that cybernetic thinking is thinking *par excellence*, providing a universal theory for dissolving the boundary between biological and technological. He argues that cybernetics is a kind of organicism, a paradigm in the sciences to critique "mechanism" as the ontological understanding for machines. One goal of cybernetics was to construct a universal theory, based on systems, to describe recursive behavior across all entities, as suggested in Wiener's book *Cybernetics: Or Control and Communication in the Animal and the Machine*. This is further evidenced by the fact that early cyberneticians built machines that mimicked animals and biological behaviors -- William Grey Walter's cybernetic tortoise, Wiener's "moth and bedbug", and Von Neumann's cellular automaton, among many other "cybernetic creatures". By the mid-twentieth century, cybernetics surpassed the mechanistic view, opening an entire range of exploration for powerful modern machines. Nearly all modern machines are cybernetic; they are based on a circular causality and feedback mechanism, which links them to biological entities that determine themselves through recursive structures (Hui 2020). This undertaking has carried on through twenty-first-century systems theory, an irreplaceable epistemic substrate underpinning contemporary intellectual life.

The problem is that cybernetic thinking attempts to dissolve the boundaries between the biological and the technological by unifying them through a synthesized vision employing systems, yet doing so creates another unexplored realm in our thinking – non-cybernetic and non-systemic. This is the inherent predicament of dualistic thinking. By unifying the tensions, we construct a field in which we are comfortable, a situation that does not threaten us. Yet at the same time, we create the other side of the field, which we perceive as threat, which lies outside our experience, and for which have no vocabulary. From this perspective, cybernetics may have provided a vision in which the tension between the biological and the technological is no longer acute, under the overarching metaphor of "system". Yet we create a sort of "non-cybernetic" thinking, occupying the other side of our conceptual field, where our language falls short. As Hui (2020) notes, "Cybernetic thinking remains a thinking of totalization, since it aims to absorb the other into itself, like Hegelian (dialectical) logic, which sees polarity not as oppositional but rather as a motivation towards synthesized identity," and therefore, "to think beyond cybernetics is to think beyond the totalizing effect of a non-dualist thinking." (63)

We are far from overcoming dualistic thinking. This field featured by "non-cybernetics" becomes an antithesis that challenges our binary mind to resolve it with another level of synthesis. If cybernetics is about control and communication between actors, then the other side of the field is where things are out of control, do not communicate, are withdrawn; it is the field of wildness. As noted earlier, the spectrum between control and wildness is the result of dualistic thinking.

From this vantage, "cultivated wildness" seeks to provide a mode of thinking that surpasses the totalizing effect of cybernetics and dualistic thinking. We may examine this effort from two levels.

First, we must recognize that controllability is a totalizing concept that resolves the tension between control and wildness by constructing a spectrum with different levels of control. It is still imposing a single vision to solve the antithetical pair that occupies the two sides of our conceptual field. In contrast, the notion of "cultivated wildness" does not promote reaching another level of synthesis with a unified vision. Instead, it simply accepts them as a pair of polarities that comprise reality itself. It concerns the ability – or willingness – to view conflicting aspects of a thing and a situation and then accept them for what they are: seeing wildness in control, and vice versa. With this notion, we must then acknowledge that control and wildness are at all times in dynamic transition. This transition does not involve relativism, or different percentages of control and wildness canceling each other. It accepts that when we control wildness, we are simultaneously constructing it; that, in turn, produces controllability. In other words, it reconfigures the notion of control and agency. We begin to see no difference between what it is to control and what it is to relinquish control; we perceive non-action as action, and see no agency as a sense of agency.

This mode of non-dualistic thinking provides transformative frameworks with which to analyze present-day popular concepts, such as resilience. We may think of a flood wall as an ultimate control strategy for urban resilience.[29] Flood walls keep water out, but when they block

[29] Even though many believe and promote the prioritization of "nature-based strategies" for resiliency, the irony is that prioritization means that "hard infrastructure" is the last resource when "nature-based strategies" fail, or that the place we wish to protect is too important to risk using "nature-based" solutions.

its passage, water must go somewhere; this “somewhere”, which is omitted from our field of controllability, becomes an intrinsic part of the control strategy itself.

Certain landscape architects may find this mode of thinking familiar. Indeed, landscape architects work with living materials that possess a sense of wildness; designers must conceptualize those outside their control horizon as part of their design strategies, and, in turn, view their strategies as a way to promote things that are out of control, anticipating emergent behaviors. Thus, many landscape architects would agree that design does not mean doing everything within a plot of land. Instead, to refrain from doing everything becomes a way of design. However, because of the ambiguity of the recursive reasonings in this way of thinking, it fails to fit within the mainstream descriptive and interpretive frameworks of controllability that celebrate designers’ agency and abilities to act. Another great obstacle is the Western individualism that advocates for individual agency and “making a difference”. More work must be done to develop vocabularies and concepts to open possibilities for non-dualistic thinking in contemporary environmental discourse. Thus, theorizing about landscape practices and reflecting on their meaning in contemporary culture is crucial for developing a unique epistemological framework for landscape architecture, among other disciplines.

Second, and on a different level, contrasting “cybernetic thinking unexplored” with “mainstream cybernetic thinking” exemplifies the embrace of conflicting aspects in one synthesized framework, recognizing the potential for interpreting one idea under different lights.

Critiques of cybernetics may be situated within the broader intellectual reflection on relational and systems thinking since the early years of the twenty-first century. Cybernetic thinking is relational, based on the premise that entities communicate. Many contemporary philosophical ideas, such as object-oriented ontology (OOO), challenge this relational thinking by emphasizing the opposite side of the system – the “objects”. This is why OOO emphasizes the non-communicative and withdrawn aspects of objects, creating a framework based on the premise that things do not communicate. However, this type of criticism is still a type of dualistic thinking that attempts to construct an antithesis to replace relational thinking.

From this vantage, “cultivated wildness” exemplifies another way to critique an idea using non-dualist thinking, by embracing a sense of diversity within a unified framework. This research has re-conceptualized cybernetic thinking by returning to its origins and offering new interpretations in light of contemporary posthumanism, specifically its ontological and epistemological concerns. It does not claim to be a version of “non-cybernetic thinking”. Instead, as we saw in Chapter Three, cultivated wildness is very much cybernetic, and based on recursive causality and feedback mechanisms.

The aim of cybernetic thinking, at its heart, is to use recursive causality to understand mental processes across different entities. However, we must recognize that cybernetics has been interpreted in a societal episteme characterized by modernity. It entails society’s unquestioning acceptance of technological progression and techno-scientific values, overlooking aspects other than how cybernetics helps build powerful machines. As a major descendant of the cybernetics movement in the mid-twentieth century, modern control theory behaves as if cybernetics is solely about control; specifically, using feedback loops and communication behaviors as tools to control modern machines. It constructs a sort of linear and deterministic view between control and communication, in the sense that communication leads to control, and control leads to stability. When doing so, we eliminate the possibility of exploring alternative relationships between control and communication.

There have been precedents for reinterpreting cybernetics in a different context, outside mainstream concerns. In the 1970s, when introducing the “scoring system” and RSVP design methodology, landscape architect Lawrence Halprin posited that scores “communicate but do not control." This was a clear riposte to Wiener's book *Cybernetics: Or Control and Communication in the Machine and the Animal*. To a certain extent, Halprin's framework was considered advanced for the 1970s. From a contemporary perspective, Halprin was attempting to develop a theory akin to second-order cybernetics, autopoiesis theory, and the notion of emergence. However, second-order cybernetics and autopoiesis theory were in their infancy in the early 1970s, and the idea of emergence did not gain currency until the 1990s. However, as a discipline which might be described as a modern other, Halprin's concern was overwhelmed by ideas that better fit within the descriptive and interpretive categories of mainstream cybernetic thinking, characterized by controlled stability. In contrast to Halprin, Ian McHarg was an important figure in the mid-twentieth century who brought cybernetic thinking into the landscape discipline via ecological science (Lystra 2014). McHarg's science-inspired design framework results in a more deterministic view towards landscape dynamics. Ecosystems exhibit certain cybernetic qualities, and will always experience ecological successions and reach climax communities, which are considered stable and ecologically fit. McHarg's homeostatic cybernetic interpretations echo the mainstream expectation for controlled stability produced by cybernetic machines. Thus, the impact and acceptance of McHargian design methodology were undeniably more profound than those of Halprin's, especially in a global context. From this vantage, the present research has furthered Halprin's legacy and provided a disciplinary critique and reflection on cybernetics, with the privilege of contemporary thinking, vocabularies and concepts.

However, we must recognize that "cultivated wildness" is not *the* ultimate cybernetic thinking, but a version of cybernetic thinking unexplored. It exemplifies a viable method of interpretation and merits further investigation in order to discover versions of cybernetics thinking that may conflict with and simultaneously complete each other. This consideration leads to a reflection on the notions of diversity and ecology as they relate to intelligent machines.

1.4. Ecology and Wildness in Machines

We have briefly introduced the notions of “ecology of machines” and “technodiversity”, proposed by Hui (2020), as two important concepts with which we to examine the cases presented in Chapter Three. We shall further develop these two concepts and investigate their epistemological implications. As Hui noted, the foundation of ecosystem ecology is a sense of biodiversity, which sets a basis for multi-species interaction in an ecological system. In parallel to biodiversity, Hui proposes technodiversity as a foundation for the ecology of machines.

One caveat, also noted by Hui, is that technodiversity is not concerned with different ways to use a machine. Similarly, the ecology of machines is not about different types of machines interacting with each other. Instead, these two concepts entail a diversity of technical frameworks; there are different ways to approach a technical framework. From this perspective, “cultivated wildness” has provided a different way to approach cybernetic thinking, in light of posthumanist concerns.

Suppose we extend the analogy between biodiversity and technodiversity. We observe that the mainstream interpretation of cybernetics has itself deployed a monocultural approach to thinking, eliminating other possibilities for interpretation. Similarly, we have cultivated a monoculture of machines, in the sense that we have conceptualized machines as a means with which to automate and replicate human physical and mental capacities. In addition, when we consider machines in relation to ecology, the only viable relationship we can conceptualize uses technologies as powerful tools to increase biodiversity and recover wild places.

We have co-evolved with tools and machines. They serve as media through which we construct relationships with the environment and other species. To consider cybernetic thinking along with ecological thinking is not about promoting biodiversity with intelligent machines, but cultivating technodiversity and embracing a sense of wildness in machines. Extending this metaphor, preservation and conservation efforts do more than preserve "wild nature"; they must also preserve techniques through which we engage with the environment around us. From this perspective, biodiversity heavily relies on technodiversity.

The way we represent and construct the environment is inseparable from the way we choose to live in it, including our modes of thinking, the technical frameworks we use to relate to machines, and, ultimately, the machines themselves which we use as media to interact with other beings. Therefore, "wildness in machines" challenges us to rethink technological development and to investigate the unexplored realm even in a mundane machine, speculating on its unrealized potential to reframe our relationship with the environment.

Finally, "wildness in machines" requires a sense of "speculative ecology" towards the notion of diversity. Diversity is not about seeing difference as a motivation towards a synthesized framework but continuous and life-long efforts to live with, speculate, and try to attune ourselves to different frameworks with which we have no experience. Diversity speculates about different ecologies among beings. Thus, landscape design provides a venue for a speculative ecology.

2. Landscape and Design: Speculative Ecology

2.1. Challenges for a Landscape and Design Epistemology

Chapter Three has taken on a liberal understanding of "design" and "designer" in order to identify commonalities across art, landscape design, and engineering, regarding the underlying cybernetic thinking among the different practices. This is essential for mapping an alternative understanding of cybernetics, but doing so ignores the value of locality within a synthesized vision of design. This conceptual move dilutes the term “design” and ignores the nuances with which different fields approach “design” with their own disciplinary concerns. Thus, it overlooks the unique and transformative thinking which contemporary landscape architecture, as a design discipline, might offer.

We must first recognize that modern landscape architecture has struggled with its identity within the modern disciplinary tradition. This struggle emerges at two levels.

The first level concerns the general identity crisis of “design” professions. Designers distinguish between those who actually “practice design”, and those who regard “design” as a subject of inquiry. Over the years, concepts such as design thinking, design research, and research by design have gained currency across disciplines. The popularization of *design* can be understood as a process to “scientise” it (Cross 2001). This process embodies society’s aspirations to apply techno-scientific frameworks in understanding the creative operations found among “designers” such as architects and engineers. The 1960s was known as “the design decade”, following architect and technologist Buckminster Fuller’s call for a “design science revolution”. The 1962 Conference on Design Methods may be regarded as the starting point of design methodology as a field of inquiry. However, this view was challenged from the beginning. Certain pioneers in the 1960s design methodology movement have even distanced themselves from this view (Cross 2001). The irony is that designers, notably architects and landscape architects, seldom practice a diluted, structured, and linearized “design thinking” process.

Despite its backlash, design methodology research continued to develop over the following decades; today, design thinking is a popular concept that one can freely tossed around. This has given rise to a sort of identity crisis for contemporary designers: they wish to be identified as designers, but not as the “designers” constructed in the field of design methodology. Cross

(2001) uses the term “designerly ways of knowing and thinking” to encapsulate the urge to identify design as separate from other forms of knowledge production. “Design” may become a discipline unto itself, with its unique epistemic frameworks and concerns (Cross 2001). The incentives for these efforts are understandable, and, in fact, many would agree that design, as a way of knowing, deserves its own vocabularies, concepts, and disciplinary frameworks. However, the struggle we face is the need for locality and diversity within the urge to reach a synthesized term for the alleged “design epistemology”. In saying “design”. we must recognize that we refer to an extremely diverse community that contains a plethora of approaches to this non-scientific, non-engineering, non-artistic way of knowing and thinking. The issues of locality and diversity lie at the heart of today’s “design research” discourse, and urge further research and reflection.

The second struggle arises from the marginalized position of landscape architecture amongst modern disciplines. As landscape theorist Elizabeth Meyer has argued,

> “As a field that built physical critiques of, and in, the American city that embodied broader society’s unquestioning acceptance of industrialization and technological progress, landscape architecture has not fit within the descriptive, evaluative, and interpretive categories of mainstream modernism – historical or theoretical” (Meyer 1997, 70).

This marginalized position forces the landscape architecture discipline to turn to models from other fields to articulate the complexity of its own design. Contemporary landscape practices in North America operate based on two models developed since the mid-twentieth century, one from modern art and architecture, the other from ecological science (Meyer 2000). Even though, since the late 1990s, many landscape architects have already bridged the gap between the two, expanding the field of landscape architecture, the concepts and frameworks of these two models are preeminent. For example, Ian McHarg's ecological design framework bears a strong legacy through ideas such as "landscape urbanism" (Steiner 2008; Spirn 2000). Of course, contemporary landscape architecture has bypassed the ecological concerns of McHarg's time, those that revolved around homeostasis and determinism. Instead, landscape architecture today embraces a nonlinear and non-deterministic view focused on emergence and novel ecologies (Reed and Lister 2014b). However, these new conceptualizations rely on ideas and conclusions from the modern ecological sciences. To a certain extent, today's landscape architecture persists in borrowing thinking from outside models, without forming an epistemic framework unique to landscape architecture and design.

Yet another factor contributing to the identity crisis comes from the fact that landscape thinking itself has been transformed into a model by modern design professions, and "rebranded" by adjacent fields, including architecture and urban design, into a "new" framework for urbanization (e.g., "landscape urbanism"). With its focus on infrastructure and urban ecology, landscape urbanism has become a dominant doctrine in contemporary landscape practices. It is still essentially a McHargian ecological determinism merged with economic determinism (Steiner 2008). The problem is that these doctrines reduce landscape architecture without recognizing its intrinsic complexity. The simplified models, in turn, become landscape architects' self-scrutinizing and self-sanctioning mechanisms, which legitimize and favor a body of work and limit the possibilities of other epistemic frameworks unique to the discipline.

2.2. Nonhuman Turn and Landscape Epistemology

Recent years have witnessed a thriving interest in the design disciplines, including landscape architecture, and in the search for new vocabularies and frames with which to articulate "designerly" epistemic concerns, as distinct from those of the arts, sciences, and engineering. In landscape practices, this interest manifests as a "nonhuman turn", in the sense of a broad-based skepticism about designers' agency and control over their intentions, and an urge to include and embrace diverse frameworks, especially those provided by nonhuman species and objects, in shaping and influencing landscapes' unfolding. It may be described as an urge to develop a posthumanist landscape framework.

Many landscape programs have begun to deploy various concepts, such as Donna Haraway's "companion species", to conceptualize animals and plants as active agents shaping landscapes, rather than as visitors or inhabitants providing ecosystem services (Klosterwill 2019). This trend is situated within a broad-based intellectual movement found in philosophy, the environmental humanities, and science and technology studies (STS) since the 1990s. This burgeoning movement revolves around post-structuralist and posthumanist thinkers, including Bruno Latour, Donna Haraway, Cary Wolfe, Manuel DeLanda, Graham Harman, and Timothy Morton. As design programs turn attention to this trend, many of these thinkers have become widely read – and listened to – by both designers and theorists. For example, Harman and Morton have, over the years, lectured at design schools. Both have taken on teaching positions within SCI-Arch's architecture and landscape programs, as professors of philosophy. Morton also served as a member of the jury for a landscape competition in 2020, and his writings and thoughts on ecology have impacted the landscape discipline.

The core of this "nonhuman turn" in landscape architecture challenges designers to re-conceptualize modes of knowing and doing. Mainstream design methodology research possesses an urge to contrast design with the sciences. We seek to treat the sciences as a process of finding patterns in the universe, and design as constructing new patterns (Cross 2001). At the heart of this understanding is a division of theory and practice: the former belongs to the realm of abstraction, the latter to application. As Cross (2001) argues, design research has shifted from the urge to create a "design science", to creating a "design discipline" with unique “designerly” ways of knowing and thinking. This urge has also manifested itself in the landscape discipline; theorists attempt to understand landscape design while including its unique way of knowing, with particular consideration of nonhuman species and machines.

In recent years, the most transformative works have emerged from Brian Davis’s discussion on landscape instrumentalism, and Cantrell and Holtzman’s consideration of “modification.”

Drawing ideas from John Dewey’s instrumental philosophy, Harman’s object-oriented ontology, and Bennett’s discussion of vibrant materialism, Davis uses the term *instrument* in a manner akin to the idea of an actor or intelligent agent. He refuses to “reduce everything to a mere tool that does only what something else intends” (Davis 2013, 294). Consider these paragraphs:

> “a landscape is made of instruments [agents] whose actions never align perfectly with a user’s intention but are always doing more and less, creating a liminal space between intent and reality.” (294)

> “…if a space is a landscape, and not some other type of space, then all of its objects and their dynamic relations are instruments, but not dumb drills, retaining walls, and land use policies. Rather, they are dynamic objects in relation to one another within a bounded territory containing some measure of human intent” (305).

Cantrell and Holtzman (2016) gave a similar account when conceptualizing *modify* as a strategy in the Responsive Landscapes framework, suggesting a mode of inquiry between intent and reality:

> “. . . modify is not to translate an existing condition or to construct condition – rather, through direct and indirect behaviors adjustment, it suggests *recursive inquiry through repetitive action*” (254, emphasize added).

Both “instrumentalism” and “modification” search for a sense of posthumanist framework unique to landscape discipline, and can be transformative. However, they share a drawback that undercuts the scope of their consideration. It can be described as “humanist posthumanism”, in the sense that, though we seek to look beyond our limited human understanding of the environment, our thinking still relies on all-too-human terms to conceptualize this posthumanist framework. To a certain extent, this predicament results from “access philosophy”: specifically, the philosophy of human access that undergirds many contemporary posthumanist considerations, including vital materialism, ANT, and assemblage thinking. In other words, the epistemic undergirding of our current consideration still privileges the capacity of (human) knowing as a basis upon which to conceptualize landscape design, even though we wish to subscribe to a posthumanist mode of landscape practices. This drawback may be further situated within a broader philosophical context, or “the prevalent tendency with Kantian and post-Kantian thought to treat the *relation* between thought and world as the primary subject matter of philosophy” (Young 2020, 43).

It must be noted that there are two levels of reflection. The first is about *human* access. Both of the claims suggest a strong motivation for developing new techniques and methodologies to prod the liminal space between intent and reality, in order to inquire about it. Following the philosophy of human access is a type of means-end reasoning in considering landscape inquiries concerning tools and techniques. This may be observed from Cantrell and Holtzman’s assertion that *Responsive Landscapes* provides frameworks that *utilize* responsive technologies as a form of *inquiry,* because “the contemporary landscape, as a site of emergent and novel conditions, undoubtedly holds conditions that have escaped previous attempts of translations” (Cantrell and Holtzman, 253). Similarly, Davis (2013) develops Dewey’s instrumental theory of knowledge as a “theoretical and technical framework to develop the tools needed to integrate and synthesize new techniques for modeling, computation, analysis and construction of multi-functional landscapes, and to chart a way forward into the frontier between intent and reality" (305). In both cases, there is a strong sense of means-end reasoning. Tools and techniques, including intelligent machines, are considered effective means for designers' inquiries. Designers may "instrumentalize" different assemblages to modify and study the environment through repetitive action. Cybernetic technologies are means through which we "know" the world, exercising the agency of inquiry. To some extent, these considerations still insist upon a modernist view that privileges the concept of progress.

It creates a paradox that undercuts the moral incentive to develop a posthumanist landscape framework. By including nonhuman species within our instruments of inquiry, we promote and further justify another level of human hubris with regard to our ability to know and control. The posthumanist undertaking aims to cultivate a sense of humility in designers, by reflecting on their agency in control, encouraging designers to consider and embrace frameworks unaligned with ours. On this level, both "instrumentalism" and "modification" have, without doubt, provided exceptional critiques and reflections. Regrettably, both of their responses to the initial insights fall short, by clinging to the last hope for "human access" and "human knowing".

The second level of reflection concerns the philosophy of access – not only human access, but all sorts of access between objects. Popular concepts, such as ANT, assemblage thinking, and new materialism, which undergird contemporary concerns in the landscape discipline, are all relational. They are all based on the hope and promise that, through interaction, objects are able to communicate and form relational bonds, enabling each other to gain more power (again, based on a concept of progress). Relationships between them become *a priori* for things to be regarded as significant. This is best be exemplified by Bennett's claim that "bodies enhance their power in or as a heterogeneous assemblage" (Bennett 2010, 23).

Indeed, relational thinking comfortably aligns with landscape discipline's ecological concerns, which are often understood as relational, active, and vibrant. A positive ontology is undoubtedly favored by the mainstream ideology of ecology and diversity, which encourages communication and interaction between individuals. The access philosophy reflects a sense of idealistic and occasionally romantic thinking about ecology and relationship. An underlying premise for "instrumentalism" and "modification" is that, with the right "instruments", technological or biological, landscape designers may cultivate a version of "ecology" and "interconnectedness" between agents, and this version of the web of assemblages will benefit all entities. There is an implied goal in this seemingly open-ended framework based on recursive inquiry and repetitive actions.

Hence, Cantrell and Holtzman (2017) ask, "At what point are goals, scaffolds, and protocols actually open-ended?" (254). Instead of attempting a solution to this question, our solution should be reflecting on why it became a question in the first place. The question suggests a mental model that creates a version of an interconnected network between human and nonhuman entities; in this version of ecology, humans are "in harmony" with other humans and nonhumans, all of which happily share an environment, "co-evolving" and "co-existing". This model is vivid enough to serve as a goal to motivate all sorts of techniques, methodologies, and frameworks to achieve this end. Ironically, this version of "co-existing" and "co-evolving" exemplifies another level of human exceptionalism, celebrating our ability to *know* what other species seek, and *design* an appropriate ecology for them.

Eventually, this line of reflection leads to the notion of utopian thinking. To conceptualize design as constructing new patterns and rearranging existing structures sets a goal, a product, or a result at the end of a collection of creative operations which we call "design". This utopian thinking also relies on a communicative framework, imagining that we can reach a better place through repetitive actions, inquiries, and communications. This type of idealistic thinking is fundamental to conceptualizing intentionality in design practices. As we saw, both "landscape instrumentalism" and "modification" rely on the notions of intentionality, conceptualizing an operational space that is liminal, between the intentional and the unintentional. It embodies a sort of dualistic thinking, viewing intentionality and unintentionality as mutually exclusive. The gap between intention and reality leaves space for entertaining the idea of increasing perceived human agency in terms of knowing and controlling, to realize an "intended outcome". Intention relies on desires, and fixes goals, interpreting unexpected outcomes as motivation for inquiring about "truth".

2.3. Towards a Non-Access Philosophy

The philosophy of access and the relational episteme risk overlooking a spectrum of thinking based on the assumption that things cannot communicate and relate to each other in the first place, and we cannot find truth through techniques of "inquiry". This expands Niklas Luhmann's infamous assertion that, "Humans cannot communicate; not even their brains can communicate; not even their conscious minds can communicate. Only communications can communicate" (Luhmann 2002). Luhmann's provocative statement is based on second-order cybernetics and autopoiesis theory. Autopoiesis posits that signals from the environment do not produce a difference, but only trigger a series of responses in a cybernetic system to generate a reality through system operations (H. R. Maturana and Varela 1980). From this perspective, communication becomes an epiphenomenon of system operations. It becomes merely a concept which humans, who are themselves cybernetic organisms, invent to describe perceived cause and effect when interacting with other systems, and when systems interact with each other. Autopoiesis theory suggests that multiple realities of the environment are constructed by cybernetic systems. When systems interact, they must shape their mental processes into communicative operations shared by different systems. In the end, systems do not communicate, because communication occurs only in the realm of communicative operations.

We may further develop Luhmann's assertion, second-order cybernetics and autopoiesis theory with a touch of object-oriented ontology (OOO). As Morton (2016) argues, "things exist in a profoundly 'withdrawn' way: they cannot be splayed open and totally grasped by anything whatsoever, including themselves. You can't know a thing fully by thinking it or by eating it or by measuring it or by painting it…" (16). Therefore, things are non-communicative. At this point, OOO differentiates itself from other posthumanist thinking: it seeks to create a non-relational ontology. Since objects are withdrawn, they are inaccessible by any means, including human inquiry and thinking. An object comprises more than the relationships it forms with other objects. Here, we further recognize why the term "agency" becomes irrelevant in the OOO framework. To imagine we can relate to each other provides the initial urge and motivation to further act on that relationship and control. To think that our thought (or anything's thought) can form a relationship with other objects is fundamental to conceptualizing agency. This form of reasoning has manifested itself in cybernetics and modern control theory, which are based on the premise that recursive processes lead to communication, and communication leads to control. However, suppose that we develop second-order cybernetics and autopoiesis theory, and consider OOO's perspective. In that case, we can map a different way to understand communication and control, and re-conceptualize cybernetic thinking in a speculative ontology.

From this vantage, we must recognize that the "nonhuman turn" in landscape discourse has successfully challenged designers' agency and control by introducing nonhuman frameworks into our tradition of human design and inquiry. However, the "nonhuman turn" does not chart what a posthumanist paradigm looks like, for landscape design. Thus, "cultivate wildness",

"wildness in machines", and other ideas developed in this research operate within a speculative ontology that the "nonhuman turn" fails to achieve.

2.4. A Logic of Coexistence: Expectation and Intentionality

Many, including Jane Bennett, believe that OOO renders a negative and pessimistic ontology; they duly distance themselves from OOO's claims. However, the opponents of OOO lack the ease and joy which it brings. Supported by philosophies of access, we are challenged to inquire and to know. We hold expectations for other beings around us, hoping to communicate and reach them, and hoping control policies may be accomplished. Yet these expectations become a source of anxiety if plans of action are not discharged as expected. Failure becomes the motivation for further inquiries, and we are challenged to march on a journey of progress without hope.

However, the non-communicative ideas based on OOO, autopoiesis, and cultivated wildness present a completely different line of reasoning; they open a speculative ontology for the design professions. At the center of this undertaking sits one realization: *We cannot communicate with nor control each other, but that is acceptable.* Since things are non-communicative, "the way things affect one another (causality) cannot be direct (mechanical), but rather indirect or vicarious: causality is aesthetic" (Morton 2016, 16). If we accept the non-communicative nature of beings as a default, then the flickering moments where we believe we *are* communicating become a type of aesthetic experience. This is why Morton argues, "OOO believes that reality is *mysterious* and *magical*, because beings are withdrawn and because beings influence each other aesthetically…at a distance" (17). Thus, since we never reach an ultimate truth about beings, we are free to speculate without fear of failure or anxiety regarding unfulfillable expectations. Philosophies of access are limited by their "inability – or better, unwillingness – to create a *speculative ontology* which moves beyond the narrow confines of what is given to our all-too-human modes of understanding" (Young 2020, 50).

In the end, design requires great humility in ourselves as designers operating in a non-communicative and uncontrollable world. Yet this humility brings a sense of comfort. Since beings have no obligations to communicate, it is our responsibility as designers to strive to align ourselves with and attune to other beings. We must understand and respect that other beings – biotic or abiotic – will possess inaccessible aspects, and that, therefore, they may behave in unexpected ways. Imagine that we view the environment in this way. We may then begin to derive ease and joy from this non-communicative perspective, because intentionality, that human-centric concept, becomes unimportant. We are relieved of the anxieties and worries that beings might evolve in unexpected ways, because we accept from the start that we have no control authority over things, and therefore no expectations.

As we have seen, contemporary landscape discourse struggles in the space between intent and reality by perceiving intentionality and unintentionally as mutually exclusive. Now, with this non-communicative framework, we may offer a non-dualist way to understand intent and reality. Intentionality and unintentionality are not mutually exclusive, but in a dynamic transition. Let us consider the condition of a "cultivated wildness". We may then convince ourselves that our decisions, which we believe intentional, are always the source of unintended consequences and unexpected outcomes. Even the portion we consider an intended outcome is, in fact, a flickering moment when the withdrawn objects appear to synchronize. However, these fleeting moments are ephemeral, because objects cannot communicate, and they have no obligation to keep attuned to us; indeed, they may well move out of synchronization. We must then make efforts to maintain these living, dynamic relations through *design*. This maintenance of living dynamics is not about control, because control entails expectations that, because things are communicative, we may send control signals to them and persuade them to act as we intend.

To summarize, a logic of coexistence with nonhuman objects becomes simple: things do not have an obligation to communicate in the first place, and it is we, stubborn human beings, who wish to form meaningful ties with each other and with nonhumans around us, primarily because we find efficacy and a sense of agency in these ties. We perceive homeostasis and a sense of stability in the relations we observe with other beings. It is then our obligation to attune ourselves to them, rather than communicate and control others to maintain ties on our behalf. Adaptation requires great humility in ourselves; the non-communicative nature of beings urges us to make efforts and stand ready to do whatever is needed to maintain relations with them, even abandoning our previous beliefs. This is another way to understand what it means to form an adaptive epistemology for landscape design. Adaptive epistemology is not about continuous learning through recursive inquiries but continuous unlearning that which we once believed true.

From this vantage, we may reflect on the notion of co-production of the environment: finding ourselves in a situation where our ways of doing synchronize with others, we humbly and carefully make efforts to keep it so.

2.5. Notes on Expertise

The search for a “designerly” way of knowing and doing is inherently a critique of science. This search may be situated within the broader postmodern skepticism championed through the late 20th century, exemplified by the advance of the social construction of scientific knowledge and feminist science technologies studies. However, the backlash to this skepticism is a post-truth crisis, in the sense that “situated and embodied knowledge” justifies ignorance and arrogance towards expertise. The result is that anyone can have opinions about anything at any time, and all opinions must be equally “truths” and “realities”. Debates around climate change, sea-level rise, and the COVID-19 pandemic are vivid examples of this post-truth skepticism backlash.

“We cannot live by skepticism alone” (Collins 2009). The field of STS has seen another turn since the late aughts of the twenty-first century, and STS schools have begun to pay attention to nature expertise as “tools for an initial weighting of opinion” (Collins 2009). Many useful ideas developed in this discourse, including “trading zones” and “interactional expertise” (Collins, Evans, and Gorman 2010; Galison 2010).

Similarly, OOO proponent Harman also turns to the notion of expertise. In a way, OOO is not a critique of science but of scientism, and OOO respects scientific expertise. Things cannot be accessed and studied fully, even by scientific techniques; still, certain people are doing certain things better than others. That is because they have spent enough time with objects, and developed living, dynamic relations with them. Their lived experiences allow them to respond to different situations with confidence.

From this perspective, there is no difference between design and scientific research; they are different sorts of expertise in developing and maintaining dynamic and living relations with other beings, and using lived experiences to respond to new situations. There is a sense of aesthetic experience when machine-learning scientists find the ideal layer combinations in their artificial neural networks. To consider a “designerly” way of thinking and doing is to understand design as a type of expertise, as in the sciences.

What is the expertise of landscape design, then?

2.6. Scales of Speculative Ecology

The issue of scale is intrinsic to landscape architecture, due to the variety of projects in which contemporary landscape architects find themselves. Landscape architects have expanded the profession’s consideration in a spatial dimension, from gardens to urban parks to territorial landscapes. Meanwhile, with the notions of ecology and succession, time becomes another scalable dimension which landscape architects entertain – from geological time, such as the Anthropocene, to phenomena as ephemeral as desert fog.

With the rise of systems theory in landscape discipline, specifically second-order systems theory, another dimension of scales was articulated. Anita Berrizbeitia introduced “scales of undecidability” as a conceptual frame with which to analyze Toronto’s Downsview Park design competition, which featured projects with flexible frameworks and open-ended strategies. “Scales of undecidability” refers to “a landscape’s capacity for precision of form notwithstanding flexibility of program,” or, more precisely, “a landscape’s capacity to engage multiple systems of signification at different scales” (Berrizbeitia 2001).

When we consider the recent “nonhuman turn” and posthumanist movement in landscape discipline, we may start to articulate landscape scales in another dimension – scales of speculative ecology. Landscape as a medium has the capacity to enable our speculation of objects and their relations involved in the co-production of the environment. To a certain extent, “scales of speculative ecology” is a continuation, but essentially, a development of contemporary landscape concerns about open-endedness and adaptivity.

To illustrate scales of speculative ecology, we may contrast this notion with scales of undecidability. Berrizbeitia’s notion of undecidability relies on constructing a space between intent and reality, assuming that different degrees of designers’ control authority lie between the two. Consider the following passage:

> “…we can conceptualize landscapes where there is space and time for process to unfold and for stable meanings to come forth. We can imagine landscapes with the ‘right mixture of rigid structures, supple structures and self-organizing processes’ that are in some ways the ultimate solicitation of chance, in others the ultimate

> suspension of process, and yet in others something in between" (Berrizbeitia 2001, 124).

With this, Berrizbeitia suggests that designers have different degrees of control authority over the landscape they design. However, she seeks to advocate something else. She ends her consideration with this paragraph:

> "Engaging scales of undecidability is a social and political strategy, a tool for interference against any proposed solution that would be permanently static and definitive on the site. Only then will the urban park become a reserve of possibilities to come, for futures we cannot now imagine" (125).

She asks for more than degrees of control authority; rather, her appeal is for a speculative framework that surpasses designers' intentionality. Berrizbeitia's consideration is somewhat limited by the underlying dualistic thinking that contrasts a designer's intentionality with unintentionality. This undertaking relies on access philosophies, with the premise that we can know and communicate with things in order to carry out our intent, and leave open-ended whatever is uncontrollable. This reasoning provides a false sense of hope and the motivation to perfect one's design intentions, leaving space to consider control and management strategies in order to maintain a perceived status quo and stability, rather than a true, open-ended, and adaptive landscape epistemology.

In contrast, "scales of speculative ecology" is rooted in a non-communicative philosophy and speculative ontology, emphasizing the conviction that things do not communicate and that we have no control over other things. Any intimations of control and stability are flickering moments in which we find ourselves when things accidentally align and synchronize.

Then, we may reflect on the notions of ecology and ecological research. Ecological thinking is relational thinking; at its heart is a mind set to view interconnections between things. How then do we understand ecology within a non-communicative framework from which things are withdrawn? One way is to understand ecological research is as an expertise of speculation. Any ecological model we arrive at to describe relations between things can never provide truth, but is itself a speculative design. Thus, ecology is intrinsically speculative, and landscape architects become those able to test these speculations with built forms. From this perspective, concepts such as “ecological restoration” grow invalid, because where we “restore” a landscape based on ecological principles, we are, in fact, testing a speculative design which we wish to see.

“Scales of speculative ecology” demands two levels of consideration. The first is the extent to which designers may speculate on the different objects involved in co-production of the environment. These objects include different social groups, nonhuman species, including animals, plants, intelligent machines, and land use policies. “Objects” here is akin to Davis’s notion of “landscape instruments”. Yet “instruments” point to tools of utility and inquiry, which leaves a great deal of space to consider human agency in knowing and accessibility.

As we saw in Chapter Three, nearly all design projects involve unusual juxtapositions of objects. Speculative ecology thus supplies the willingness to speculate about connections between objects, across scales. Speculative ecology is the capacity to imagine that American consumers’ preference for almond products might impact the wild bee population and agricultural landscape of central California. It is the capacity to connect DRL agents and machine-learning techniques with emergent ecologies. It is also the capacity to connect community gardens to tobacco plants, ozone levels, and the hyper-objects of climate change.

The second level of consideration is the complexity of relations between objects, about which designers may speculate. Though things cannot communicate and have no obligation to communicate, we may speculate on scenarios where their operations are temporarily synchronized. The ability to speculate on new connections between objects becomes an act of design, which leads to unrealized dynamic relations between things. The only way to test these assumptions is to construct connections between these objects, to see what sorts of real-life relationships they form.

From this perspective, a built landscape is no longer the product of a design process but a grand experiment in conjecture. We may reconfigure the role of built-landscape projects in our relationship with the environment, and rethink the notion of failure. As a design product, a landscape entails designers' idealistic intentions as to how things should be and how they should relate to each other. If events and objects do not appear or end as expected, the design fails. However, suppose instead that a landscape is understood as an experiment where we test different arrangements of objects and observe how they interact – or fail to interact – with each other. In that case, there is no failure, but only unintended interactions generated from intentional design decisions. These unintended interactions may become areas of potential. It may be that things synchronize and form meaningful relations, but we must be prepared to see otherwise, because we must to respect that beings do not necessarily communicate with each other, and they will behave unexpectedly. Meaningful relations may be liminal and transient, and we must be resourceful enough to respond to a new situation.

How then do we cultivate the skills to be resourceful in any given situation, and engage the scales of speculative ecology? To rephrase, how do we cultivate landscape expertise? Chapter Three has provided examples in considering two categories of techniques: *prototyping research* and *theorizing practices*. Both techniques require situating one object within different frameworks, and exploring its unrealized relations.

Prototyping Research

Prototyping research is a preeminent tool in the design cases confronted in Chapter Three. Here, we must distinguish prototyping research from the popular notion of product prototyping in industrial and software design. The goal of prototyping research is to combine distinct objects, situate them in different scenarios, and explore their wildness. For example, in Sougwen Chung's drawing operations, the robotic arms and machine-learning techniques are not designed to draw. Yet Sougwen sent them through a series of rigorous drawing tests and explored the wildness in these machines. In the end, the robotic arms may not be perfect painters, with their awkward strokes and physical limitations. However, the result is a wild territory that informs a new understanding of human-machine collaboration based on interdependence. Another example is the physical sediment table used in landscape research. By combining sensor arrays, responsive armatures, and a sediment table, a designer may envision strategies based on "cyborg ecology" and real-time feedback.

None of these prototypes can be applied directly in practice. Yet as prototypes, they "support transferable and generative contributions to knowledge, grounded in ad hoc but innovative methodologies" (Arrigoni 2016). The prototypes as physical objects hold innovative techniques. In a way, the value of prototyping research is in exploring technodiversity in a monoculture technological landscape. When prototypes become new objects, they take on a life of their own and withdraw from access. They are inexhaustible and can generate meaning in different situations: others may interpret Sougwen's drawing practices in completely different ways. This interpretational flexibility becomes a way for prototypes to generate knowledge outside the research itself.

There is a growing trend in "lab culture" across landscape and design programs in recent years, such as the Responsive Environmental Artifact Lab at Harvard and the Open Systems Lab at the University of Virginia. These labs promise to conduct design research through prototyping experiments. This emergent “lab culture” raises questions and challenges about research in prototyping. Through which frameworks should these prototypes be documented, discussed, and theorized? How can they be analyzed and reflected on in a manner that transfers and generates knowledge beyond design labs, and is relevant amongst modern disciplines? How does the expertise of these design labs differ from that of science labs? Further research and reflections is needed concerning prototyping research in design practices.

Theorizing Practices

We must abandon the division between theory and practice, and employ a type of non-dualistic thinking. Theorizing is a practice that connects thinking from one realm to another. Design practices, specifically those of landscape design, create theories about the world embodied in built forms and material assemblies.

As landscape theorist Beth Meyer argues, landscape theory’s role is bridging, mediating, and reconciling between thought and action, between a particular project and a general principle, or between a general principle and a specific site (Meyer 2002). The four types of coding practices developed in Chapter Three exemplify how to extract general principles from different environmental sensing practices, so these cases may be viewed as conceptual strategies used to inform new designs.

We should recognize that none of the cases in the four types of coding practices is about landscape design. However, by theorizing about them using different terms – cloning, assembling, rerouting, and physicalization – the conceptual strategies are preserved and highlighted, so that they can be “ported” into landscape design. Here, we deploy the term *porting*, a term used in software engineering. *Porting* refers to the process of adapting software from an older computing environment to a new one, preserving its executing functions. From this perspective, theorizing is about porting ideas from one realm to another, where the interpretative environment differs, but the conceptual functions are upheld. From this perspective, theorizing in design is transdisciplinary by nature.

In the cybernetic environment, trans-disciplinarity becomes important, because cybernetic thinking underpins nearly all modern disciplines. Through prototyping and theorizing, we explore the diversity of thought. Cultivated wildness is a conceptual term to describe one version of cybernetic thinking, which emphasizes a recursive process based on an ontology of non-communicativeness and the uncontrollable nature of beings. It is rooted in a speculative ontology. Thus, cultivated wildness is a theory and speculation that encourages more prototyping research. All modern machines are cybernetic machines. Yet as objects, these machines are also withdrawn and inaccessible, and we can only speculate on different dynamic living relations with them. As we saw in Chapter Three, intelligent machines, such as a DRL agent, may act unexpectedly, and, through objective functions, designers are able only to speculate about the agents' behaviors. Thus, we must remain within a speculative perspective, and explore the wildness of machines by situating them in different conceptual frameworks, and reframing them differently. Machines are also media through which we form living and dynamic relations with other beings.

If modern technology, according to Heidegger, is *enframing,* which turns everything into a standing reserve or resources to be exploited, then "wildness in machines" makes a positive turn on the enframing effect by situating machines within a speculative ontology. Everything may be exploited, but nothing can be completely accessed and thus fully exploited if we begin with the OOO assertion that things, including machines, are withdrawn and can only be speculated upon; exploring wildness in machines is to explore possible relations with beings around us. Only in this way can the cybernetic environment become a reserve of possibility, filled with speculative ecologies between withdrawn objects.

3. What is Cybernetic Environment?

3.1. Cybernetic System versus Cybernetic Environment

"Cybernetic environment" is not "environmental cybernetics”. The latter merely establishes a larger box around phenomena that were in the environment, transforming them into a new cybernetic system or “environmental system”. Doing so constructs another exterior environment. Instead, the cybernetic environment endeavors to highlight the reverse of the cybernetic system. It signifies a different paradigm in cybernetic thinking, which turns our attention from the inside of the black box – the system – to the outside environment. It applies cybernetic thinking to a seemingly empty space and re-conceptualizes the environment. To certain extent, the cybernetic environment is a reflection of systems thinking in understanding the environment.

Cybernetics defines not merely a system, but an environment, as well. By delineating a box, cybernetic thinking establishes a system-environment dualism that becomes the basis of feedback mechanism – that which is outside the black box becomes the system's environment, reduced to flows of input and output. Thus, one may say that cybernetic thinking has always dealt with cybernetic systems; in this construction, the environment represents a homogeneous backdrop. In turn, the environment – a homogeneous space – defines how we individualize an agent, whose agency and intelligence become localized capacities bounded by the black box. The "cybernetic system" paradigm is incompatible with distributive agency and intelligence with regard to contemporary posthumanist concerns.

In contrast, the "cybernetic environment" paradigm emphasizes that the environment outside a system is not a homogeneous space, but a meshwork of objects, assemblages, and mental processes that are withdrawn and reserved from human access. Defining the environment as a type of space thus becomes problematic, because it renders the environment as an inactive backdrop as if nothing occurs there, and our attention focuses then on the system. From this perspective, if we remove all the objects, assemblages, and mental processes within the "environment", there will be no "environment" left, due to the lack of input to nor output from the system. A system cannot interact with a void, but only with other objects. Thus a cybernetic environment speaks to the totality of the meshwork of different assemblages and objects. On this level, the cybernetic environment attempts to redefine what "environment" entails – it is lively, not empty. It is made of objects with feedback mechanisms and different forms of mental processes.

The "cybernetic environment" paradigm defies inside-outside and system-environment dualisms. The important factor is to overcome systems thinking itself and surpass the urge to draw another, enlarged box that may include more objects into a cybernetic system, while producing yet another exterior realm as a new environment. As Harman argues, this way of thinking is still human-centered, no matter how many nonhuman objects we summon to mold the human world – a systemic construction. We must overcome the tendency to view a collection of processes as a cybernetic system that provides motivation for communication and control.

Perhaps the "cybernetic system" paradigm – a combination of systems thinking with cybernetic thinking – is useful in designing and building powerful machines. However, systems thinking leads us only so far with regard to the environment. This research suggests there may be alternative ways to understand the environment as a cybernetic environment rather than a cybernetic system.

3.2. Cybernetic Environment and Landscape Architecture

From this vantage, many concepts, such as adaptive management, responsive landscapes, cyborg ecologies, and smart cities, are "environmental cybernetics”. They operate within the paradigm of the cybernetic *system*, but not in the paradigm of the cybernetic *environment*. They imagine the environment as systems and apply cybernetic thinking to optimize and control them. A smart city constructs a larger black box; that which is exterior to it becomes a new environment, which then presents the system with a new set of uncertainties. We are challenged to reduce uncertainty with feedback mechanisms, and are trapped in this cycle of using another, larger box to replace the previous one – a continuation of progress narratives that extend the imagined human agency through a systemic construction.

Many of these ideas avoid terms such as *control*; instead, they embrace concepts such as emergence and open-endedness to emphasize a "lack of control”. However, they cannot do so without first articulating the environment as an open system, and then regarding feedback mechanisms as means to achieve emergent behaviors.

Over the past two decades, the discipline of landscape architecture has developed a process-based design framework, articulating landscapes as open systems that evolve, unfold, and thus become open-ended. This conceptualization undergirds today's landscape theory and practice. However, process-based frameworks do not overcome the "cybernetic system" paradigm; they perceive landscapes as a collection of objects in an evolving system that communicates with its outside environment. This is why contemporary process-based landscape design struggles with the idea of open-endedness. The irony is that feedback mechanisms become yet another control strategy to intentionally produce run-away behaviors in a framework of emergence.

Designers still control the system towards an open-ended direction, and system emergence is instrumentalized as a means to another end.

Cantrell and Holtzman asked, "At what point are goals, scaffolds, and protocols actually open-ended?" This question cannot be resolved, because as long as we draw a box, we will construct an environment outside. Whatever lies outside this "landscape system" and undermines its emergent behaviors becomes a new uncertainty that challenges designers' urge to control. Only when we shift our attention from the "cybernetic system" may we begin to develop alternative ways of reasoning. Contemporary landscape theory and practice, rooted in process-based strategies, have sought to explore an alternative way of reasoning. However, this exploration will not bear fruit unless one takes on an ontological and epistemological reconfiguration that surpasses the "cybernetic system" as the only framework to understand cybernetic thinking. On this level, the cybernetic environment not only signifies a concept, but also prizes other ways of reasoning rooted in contemporary posthumanist concerns on nonhuman agency, intelligence, and inaccessible "surplus" in objects.

3.3. Cybernetic Environment and Design

Once we conceptualize the environment as a cybernetic environment – a meshwork of different assemblages and objects interacting with each other through feedback mechanisms and recursive processes – we may understand that this cybernetic environment results from an amalgamation of different goals, mental processes, and objective functions distributed across it. How, then, might designers participate in a cybernetic environment comprised of non-communicative and uncontrollable objects and assemblages? What does design mean in a cybernetic environment? Many landscape architects and theorists, such as Brian Davis, endeavor to answer these questions by articulating a space between a designer's intention and the reality co-produced by more than human beings. The environment becomes a place with different levels of human intent.

However, this reasoning pushes the process-based landscape framework too little to surpass the "cybernetic system" paradigm. One may still conceptualize what is influenced by the designer's intentional decisions as a cybernetic system, unfolding and evolving under the designer's control, while the uncontrollable poses challenges to designers' goals, even if the aim is to promote open-endedness and emergent behaviors. Thus, the liminal space between intention and reality leaves a great deal for designers to articulate, expounding on their intentions and agency. This is why present-day landscape theory and practice still prioritize knowing, particularly human knowing, as the foundation of design. This urge to know motivates designers to draw a larger box and conceptualize a new cybernetic system. This becomes the most profound irony and predicament in today's landscape discipline's nonhuman turn. Even though designers wish to embrace a posthumanist framework, one that de-centers designers from the source of agency, the "cybernetic system" paradigm challenges designers only to summon more nonhuman objects to participate in our stories of controlled emergence.

The predicament in contemporary landscape theory and practice is viewing intentionality and unintentionality as mutually exclusive, with shades of gray in between. Instead, the "cybernetic environment" paradigm offers a different picture. When engaging with a cybernetic environment, we must not understand intentionality by percentage. Because the environment is a collection of non-communicative and uncontrollable objects that occasionally synchronize and attune to each other, we cannot hope that designers' intentions can be actuated. Objects constantly reduce each other within their own system operations, and respond in their own ways. The important element is to recognize that designers' intentional decisions may be modified, amplified, dampened or canceled by other beings. Designers' intentional decisions constantly create unintended consequences – *cultivated wildness* becomes the metaphor for designers' work in a cybernetic environment. The so-called intentional outcomes – those situations in which we believe we are in control – are mere flickering moments when things outside ourselves accidentally synchronize and align. Consequently, design becomes a constant effort to cultivate attunement between things.

4. Future Research

This research generates two areas of further investigation – prototyping and theorizing. The cybernetic environment paradigm suggests that design requires constant engagement, through which designers attune themselves to other beings. This requires a reworking of the mainstream design workflow that perceives a designed landscape as a product. Instead, landscape designers must focus on maintenance as a preeminent strategy. Maybe landscape designers should return to one of the discipline's traditions, and reflect on the importance of *landscaping* and *gardening* in contemporary landscape theory and practice. Maybe the discipline must explore theories that support this concept. Ideas such as phasing and maintenance offer an initial point with which to envision a landscape as a place where constant engagement occurs. Here, maintenance entails more than human and machine labor invested in the landscapes; it includes land-use policies, funding, organization, and the agencies behind a landscape project. In this way, we may begin constructing narratives of a landscape as a territory where strategies, protocols, and goals are open-ended.

This workflow will require the development of new tools and techniques, with which designers may continuously code, choreograph, and attune to objects that compose the cybernetic environment. Environmental sensing, machine learning, and cyberphysical infrastructures may be incorporated into "landscaping" practices. Thus, the proposed theoretical framework may be greatly enhanced by prototyping research with machines. The key is to bypass the "cybernetic system" paradigm that sees machines as a layer of infrastructure chosen to regulate and control "environmental systems”. Instead, we should take on the "cybernetic environment" paradigm, in order to understand machines as agents deeply embedded in the landscape and interacting with other human and nonhuman beings. Prototyping is also concerned with exploring the "wildness" in machines and embracing a sense of "machine perspective" – that is, the unexpected outcomes that lie outside designers' goals and challenge their conceptions of the cybernetic environment.

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