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Computation as a Planetary Scale Phenomenon

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Abstract

The concept of the 'technosphere' was advanced in the field of Earth Systems Science to capture the phenomenon of technology as a geological phenomenon in the Anthropocene. What precisely, I ask, drives the technosphere to be so novel and unprecedented a planetary force? Part of the answer, I venture, lies in the nature of computation as a generative force that drives the expansion of the technosphere. To build an account of computation as a generative force of a planetary scale, I engage with and parse through various debates regarding its historical and ontological predispositions. To address computation in its full potential, I argue, is to attend to its creative, albeit imperfect, encounters with the physical world in shifting registers of space and time, which ultimately lends to its epistemological capacity to imagine and facilitate infrastructures that constitute the technosphere.

Keywords:

Computation, Technosphere, Information Technology, Planetary-scale Computation, Information, Earth Systems Science, ESS, Pierre Levy, Digital Technology, Digital Ontology, Addressability, Epistemology.

Summary for Lay Audience

Computers are a lot more than personal devices that entertain or inform us; the sum total of computational devices (anything from vehicles, phones, refrigerators, to buildings and roads) forms a megastructure across our planet. Is the growth and continuous expansion of this megastructure a mere accident? Are there deeper logics to be found that account for this? In this thesis, I argue that this is not mere happenstance. I treat computation as an 'epistemological technology' that expands across the planet by gathering and processing information in continual loops. Even though information "feels" intangible and abstract at first blush, it is a deeply *material* thing that enables us engineer novel infrastructures on and beyond Earth (for instance, satellites). To really understand why it becomes so impactful on such a large-scale, I look at various historical and philosophical factors that have been instrumental in shaping it. I put together a number of these accounts to prove that computation is, by design, a force that seeks to manifest on a planetary-scale. Ultimately, if we are to truly understand its potential, and redesign for the collective good, we must first understand its planetary nature.

I dedicate this thesis to all my professors from undergrad and grad school; they have shown me the potential of a good education, and invigorated my spirit, over and over again, with the force of critical thought and imagination. Thinking enlivens me and I owe it to you.

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My second reader was Dr. Nick Dyer-Witheford. It was a during a course of his that I attended in 2021, 'Network Collapse,' that I first encountered the field of computation and realized I could spend a long time thinking about it. He supported me steadily throughout the course of this research and his faith in my abilities empowered me.

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Preface

This project began when I chanced upon a number of different concepts concerned with computation and technology, from different fields. In a course on 'Network Collapse,' I came across Benjamin Bratton's thesis on planetary-scale computation. A few months later, I discovered a paper on the possibility of "intelligence" as a planetary-phenomenon, penned by astrobiologists, on Twitter. And only a few weeks later, I found (on Twitter, again) freshly published an essay on the concept of 'addressability' that became central to my thinking on computation. Perhaps due to my favorable assessment of it, the algorithm has been generous to me.

Regardless, the link that I slowly began establishing between the theoretical literature in media and technology studies and the empirical findings of Earth Systems Science, then, became the bulk of this project. The question I pose and the answers I find are neither absolute, nor immutably final. Yet, what they present are convictions about the constitution of systems that appear to be larger than we can subjectively realize.

Something that I learnt from Bratton's approach to computation was to integrate disparate events of computing across the planet to produce a larger framework from which to understand them. In doing that, I realized that I brought together various instances of the computing, ranging from scientific computing in the Earth Sciences, to Big Data in the commercial realm. At the same time, I also encountered the field of planetary science, its presence as a field on my campus and its relevance to the subject I was thinking about. This is why the uses of computing from the fields of climatology and geology show up frequently throughout my writing.

A more elaborate comment is in order to explain precisely why I return to these fields so frequently in the course of this thesis: the evident answer is to point to geological character of the subject of our study, the technosphere; its similarity to the physicalist basis of other Earth subsystems, which, at a closer look, betrays novel mechanisms at a planetary scale realized through computation. In addition to that, however, the things I bring in from these fields have a shared concern with mapping and investigating the Earth across spatial and temporal expanses through computation. Much like the promise of scientific photography to deliver the truth when it was first adopted in the field, the scientific process, when using computation, is driven by the potential of data and information gathering systems to deliver a truthful picture of the natural world. In other words, it is premised on a philosophical faith in computation's capacity to translate and represent "stuff," and build on that translation to represent what plausibly existed in the past, and may be likely to exist in the future. Needless to say, this faith is not uncritical. As we will find, it is sustained and reinforced by continual interrogation of computational media. But the faith and drive to stage, investigate, and perfect the universal encounter between real, material objects and the abstractions of informatization can partially account for computation's immense success in becoming a planetary force. This does not amount to claim that computation's encounter with the material world is fair or without its shortcomings. As a matter of fact, an extensive structural overhaul of planetary computation is an urgent necessity to meet a series of planetary crises. But the enterprise to improve and proliferate this encounter is a significant factor in the growth of computation and its attunement, imperfect and shifting, with the materiality of the planet. This encounter is profound achievement that was realized, as Paul Edwards showed in *A Vast Machine*, early on in climatology. The many cases of computing that I borrow from climatology and adjacent fields are useful in investigating the theoretical nature of this encounter.

I often get the feeling that the need to be critical of computation and its many ill-effects amounts to a premature dismissal and disengagement altogether. The achievement such as that of the vast machine is not a perfect one – no one in the theoretical Humanities would want to uncritically legitimize “data” or “models” as a reified version of the truth, and I am on board with that. To me, the “achievement” of the vast machine, or computation as a planetary-scale apparatus is not that it is “right” but that it works. To truly appraise how and why it works, it is important to go further than declare its inadequately and closely pay attention to how it transgresses the need for accuracy at all times. When we address computation as an inadequate and prejudiced means of governance, we forget that the range of its intervention and interest vastly exceeds human subjects. And that its generative potential is abundantly observable in its encounter with the planet. What I am suggesting here is not that we overlook for the former for the latter. But that the facets of the latter showcase a fuller range of its capacities and the promise it holds for a post-anthropocentric future.

I do not claim that we need to discard the traditional concern with data’s ability to represent an “objective” truth, but we can bracket it to understand why it grows nonetheless. For better or for worse, computation’s encounter with the material world is a generative one. It does not need to wait for a pristine epistemological finding or framework to work. It can imagine and enable all kinds of complex cybernetic circuits—hegemonic or equitable, precarious or reliable.

Chapter One

Establishing a Problematic

A few months after his controversial takeover of Twitter in 2022, Elon Musk tweeted, "Because it consists of billions of bidirectional interactions per day, Twitter can be thought of as a collective, cybernetic super-intelligence."[1] People were quick to ridicule the jargon and debunk the ostentatiousness of his claims. Earlier in 2022, however, a paper published in the *International Journal of Astrobiology* asked a similar question: Can intelligence, indeed, exist as collective phenomenon? What if the planet itself displayed signs of intelligence?[2] A provocative question, then, it received plenty of attention in science reportage. Something about the planet being vital and having a "mind of its own" evidently appeals to the imagination. Interestingly, though, the paper itself, while theoretically establishing the concept of intelligence as a planetary-scale process, concluded that the current planetary systems do not sufficiently meet the criteria for intelligence. We dwell in an "immature technosphere" that may show lesser degree of intelligence than, say, a mature biosphere. What is the technosphere to begin with? Why is the scale of the 'planetary' significant at all? To answer these questions, let us begin with a brief introduction to Earth Systems Science (ESS).

ESS and the 'technosphere'

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[1] Elon Musk [@elonmusk], "Because It Consists of Billions of Bidirectional Interactions per Day, Twitter Can Be Thought of as a Collective, Cybernetic Super-Intelligence," Tweet, *Twitter*, November 3, 2022, https://twitter.com/elonmusk/status/1588081971221053440.

[2] Adam Frank, David Grinspoon, and Sara Walker, "Intelligence as a Planetary Scale Process," *International Journal of Astrobiology* 21, no. 2 (2022): 47–61. doi:10.1017/S147355042100029X.

Earth Systems Science is a field that studies physical, chemical, and biological systems on Earth through interaction and feedback between various sub-systems like the biosphere, lithosphere, atmosphere, hydrosphere, etc.[3] ESS imagines the Earth as a complex adaptive system whose integrated whole is comprised of dynamic interactions and feedback between the various sub-systems and their components. While various scientific disciplines already study biological life, or geophysical planetary processes in isolation, ESS emerged as an interdisciplinary framework to address these process as interlocked and interdependent with each other. Another profound factor driving the establishment of ESS, historically, was the evidence of the lasting and cascading effects of human activity on the planet. Situating human species and their activities in the complex systems that comprise the Earth would help contextualize the magnitude of changes that human activity has triggered in the planet as a whole.[4]

The central source of energy for the Earth as a whole is the Sun. Solar radiation enters the Earth through the atmosphere and fuels the activities of each sub-system. One of the theoretical basis of conceiving of the Earth systems is thermodynamics. Simply put, thermodynamics is a framework to study energy transfer and conversions based on the distribution of heat in a system. The first law of thermodynamics states that energy is preserved in any conversion. For instance, steam engine converts heat energy to kinetic energy, the energy may vary, but no loss of energy occurs.[5] The second rule states that entropy increases over time. What does this mean? When there is a difference in temperature

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[3] All living organisms constitute the 'biosphere.' Rocks, minerals and soil constitute the 'lithosphere,' which essentially the outermost layer of the Earth (also referred to as 'geosphere' in some of source material). 'Atmosphere' is a gaseous layer surrounding the planet that contains nitrogen, oxygen, argon and other gases. 'Hydrosphere' consists of all the water bodies, including oceans, rivers, groundwater etc. (while frozen water such as snow and glaciers is sometimes referred to separately as 'cryosphere').

[4] Will Steffen et al., "The Emergence and Evolution of Earth System Science," *Nature Reviews Earth & Environment* 1, no. 1 (January 1, 2020): 54–63, https://doi.org/10.1038/s43017-019-0005-6.

[5] Evidently, no real device that converts energy is without friction or other impediments and therefore, some energy is lost in the process. The validity of the hypothetical, however, is arguably still maintained.

between two things, energy will transfer from the hotter object to the cooler object until there is equilibrium. This movement of energy is referred to as ‘entropy.’ What matters for our purpose is that thermodynamics offers a physical account of the behaviour, evolution, and nature of each subsystem—and ultimately, of the Earth—in terms of energetic transformations that can account not only for “earthy” planetary structures, but for Earth’s unique place in the solar system.

As mentioned above, a significant motive for the establishment of ESS (the term being pioneered in the 1980s by NASA) was to contextualize and study the effects of human activity on the climate. While the field acknowledged the category of the Anthropocene – the current geological epoch in which human beings dominate planetary processes – it did not adequately theorize the nature and mechanisms of the techno-social systems that comprise the Anthropocene.[6] It was no longer sufficient to designate a role to human beings in the Earth system without accounting for the complexity and magnitude of the infrastructures that buttressed collective human activity on a planetary scale. And giving a proper account of these technological infrastructures would entail reassessing several assumptions: for instance, the notion that while naturally occurring systems like the biosphere and geosphere are cohesive planetary-wide phenomena, technology is comprised of disparate physical and information tools subject to the agency of human beings. The empirical evidence of technology’s growth and effects on the planet warrants that we grant a system-like consistency to it. Moreover, social conceptions of technology often attribute little to no autonomy to it, and paint, instead, human beings as puppeteers pulling the strings of technological systems with sheer and sovereign control. If we are to account for its large-scale operations, it is necessary to rethink agency in a more distributed form, such that

[6] P.J. Crutzen, “The “Anthropocene”,” *Earth System Science in the Anthropocene: Emerging Issues and Problems*, ed. Eckart Ehlers and Thomas Krafft (The Netherlands: Springer, 2006): 13-17.

technology, at the scale of a system, has some autonomy. In the last decade, then, Earth systems responded to these various theoretical gaps with the concept of the 'technosphere.' In 2014, P.K. Haff first defined it as:

> [the] set of large-scale networked technologies that underlie and make possible rapid extraction from the Earth of large quantities of free energy and subsequent power generation, long-distance, nearly instantaneous communication, rapid long-distance energy and mass transport, the existence and operation of modern governmental and other bureaucracies, high-intensity industrial and manufacturing operations including regional, continental and global distribution of food and other goods, and a myriad additional 'artificial' and 'non-natural' processes… [7]

The first significant feature that warrants thorough theoretical, political, and scientific investigation of the technosphere is that it "make[s] possible [the] rapid extraction from the Earth of large quantities of free energy." One of the main criteria for the development of a geological paradigm, Haff argues, is the capacity for a system to appropriate resources, including mass and energy, from other living and non-living artefacts on the Earth and energy from the Sun.[8] Every Earth system evolves from and sustains itself independently by acquiring resources from other systems: The biosphere, for instance, self-regulates by appropriating carbon from the atmosphere, hydrogen and oxygen from the hydrosphere, and inorganic material from the lithosphere.[9] Likewise, the technosphere captures from the lithosphere rocks and minerals to supply as raw material for industries, water for

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[7] P.K. Haff, "Technology as a geological phenomenon: implications for human well-being," *A Stratiographical Basis for the Anthropocene,* ed. C.N. Waters (London: The Geological Society of London, 2013): 301

[8] "Geological paradigms emerge when a large energy source is available and the environment contains many similar parts whose individual properties provide a basis for collective use of available energy to perform work." Peter Haff, 'Technology as a geological phenomenon: implications for human well-being,' 303.

[9] For instance, a plant performs 'photosynthesis' by acquiring sunlight filtered through the atmosphere, water (that seeps into soil through a cycle in the hydrosphere) and minerals from the soil (the lithosphere).

consumption and irrigation from the hydrosphere, and food for human beings and fossil fuels from the biosphere, etc.[10] Central to this process of appropriation is the availability and consumption of a large energy source, and while other sub-systems get most energy from the Sun, the technosphere draws most of its energy from the burning of fossil fuels (biosphere). The technosphere's 'autonomy,' as Carsten Herrmann-Pillath explains, emerges from this use of energy that enables it to "complete thermodynamic work cycles, in which work ultimately serves the purpose of reproducing the autonomous agent."[11] In other words, much like every other Earth system, the input of energy works to support energetic processes *within* the technosphere that help it reproduce itself. Arguably, all activities in the global economy comprise of the energetic transformations that characterize the technosphere: transportation, manufacturing, telecommunications, and even computation.

One must make a note of the nature of 'autonomy' being advanced by authors like Haff and Herrmann-Pillath in their sketch of the technosphere. The concept of autonomy in information and communication technology is most commonly associated with concerns about 'artificial intelligence': In popular imagination, especially, AI, at its worst, represents an anthropomorphized threat whose sentience can possibly challenge the sovereignty of the human species.[12] At its best, AI is understood as algorithmic intelligence made ubiquitous

[10] Haff, 'Technology as a geological phenomenon: implications for human well being,' 303.
[11] Hermann-Pillath, 216.
[12] A recent example of this is the case of Blake Lemoine, a software engineer at Google, who was fired after publicly claiming that Google's LaMDA ("Language model for Dialogue Applications") chatbot had gained sentience. Extensive debates ensued and what became clear was that Lemoine was, in all likelihood, overestimating the "intelligence" of LaMDA which was, after all, a bot designed to learn and reproduce language: https://www.theguardian.com/technology/2022/jun/12/google-engineer-ai-bot-sentient-blake-lemoine

More importantly, some interlocutors argued that a reconsideration of erstwhile notions of 'intelligence' were an urgent necessity: "We need more specific and creative language that can cut the knots around terms like "sentience," "ethics," "intelligence," and even "artificial," in order to name and measure what is already here and orient what is to come. Without this, confusion ensues — for example, the cultural split between those eager to speculate on the sentience of rocks and rivers yet dismiss AI as corporate PR vs. those who think their chatbots are persons because all possible intelligence is humanlike in form and appearance. This is a poor substitute for viable, creative foresight. The curious case of synthetic language — language intelligently through information technology, connected to users through computational devices. In the latter, intelligence and autonomy are ascribed to insidious data-gathering algorithms that violate the privacy of users and collect private information for use and manipulation by Big Tech. Computation, indeed, as we shall explore later, is integral to expansive growth of the technosphere. However, the intelligence and autonomy we often attribute to AI is different from the self-organizing, autopoietic *systemic* intelligence that the technosphere (along with other Earth systems) is capable of. While questions about the precise nature of artificial intelligence far exceed the scope of this thesis, I can safely assert that the autonomy of systems, like the technosphere, is nothing like the anthropomorphized "sentience" often attributed to AI.

Autonomy at the level of a system exists when its various components organize and work to reproduce it. Humberto R. Maturana and Francesco J. Varela first theorized the autonomy of living systems as self-producing and organizationally closed agents through the concept of "autopoiesis." While the production of individual technological artefacts seems to be distant from the metabolic processes of biological life, scholars like Haff and Hermann-Pillath insist that the technosphere, as a system, reproduces itself *through* us, human beings, as well as through energetic inputs from other planetary systems. Thus, the systemic complexity of the technosphere cannot be undermined or overcome by human actors.[13] Peter Haff lays out a few different rules for to evaluate the behaviour and tendencies of the technosphere: Based on differences in scale and size, he adopts the three-stratum picture in

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produced or interpreted by machines — is exemplary of what is wrong with present approaches, but also demonstrative of what alternatives are possible" ('The Model is the Message,' https://www.noemamag.com/the-model-is-the-message/)

[13] I do not, in the scope of this dissertation offer normative claims or an ethics of "what is to be done?" The only expose I provide is of a more technical and theoretical nature of the systems that seem to be emerging. There are, however, indubitably, both ethical and political courses of action that can and must be taken because (or despite) of the complex nature of the technosphere.

which Stratum II consists of the object of the analysis (for e.g., human beings), relative to which, a much a smaller component is termed Stratum I (for e.g., atoms), and a much larger object is Stratum III (e.g., a city). A larger system, Haff argues, cannot access most individual components of a smaller system directly; this is called the 'rule of inaccessibility.'[14] Human beings for instance, cannot manipulate transistors directly without unpacking a whole system. Similarly, the technosphere can only affect an individual by affecting a whole population.[15] The 'rule of impotence' states that a system in Stratum II will be significantly affected by individual behaviours of systems in Stratum I. "If the behaviour of Stratum II systems were sensitive to the individual behaviours of most Stratum I parts, then a Stratum II system would be continually buffered by large, essentially random, forces, and would lose its ability to behave coherently and to fulfil its function."[16] The rules that Haff lays out are certainly not predetermined and immutable paradigms that transcendentally dictate how systems of different scales interact with each other. They serve, rather, as a practical framework to guide empirical analyses, generalized on the basis of regularized tendencies observed in complex systems.

Still, conceptual debates around the category are not entirely settled. For instance, the study mentioned at the beginning of the chapter, investigating the possibility of 'intelligence as a planetary-scale process' calls the technosphere "immature" because its dependence upon fossil fuels and acceleration of climate change undermines its ability to produce and sustain itself over a long period of time, thus compromising its material and theoretical claim to autonomy.[17] Moreover, another set of critiques points to the harms of obscuring the social

[14] Haff, Humans and technology in the Anthropocene: six rules, 5.
[15] The phenomenon of how the technosphere, specifically computation, affects population by individualizing users is an interesting one.
[16] Haff, Humans and technology in the Anthropocene: six rules, 6.
[17] Adam Frank *et al.*, 'Intelligence as a planetary scale process,' 2.

nature of the technosphere, and thus obfuscating the power relations that drive and are reinforced by it.[18]

There is no question that conceptualizing technology solely as a physical phenomenon risks obscuring the relations of power that it retains and reproduces. Moreover, appraising the technosphere in its totality should, ultimately, not dichotomize the social and physical character of it, because it is both simultaneously. However, while I am sympathetic to the gist of these critiques, I maintain that there are strategic theoretical and methodological advantages to the original conception of the technosphere: addressing it as a system that operates on geological spatial and temporal scale necessitates bracketing sociality. As discussed earlier, one of the central motivations of establishing ESS was to gauge the effects of human activity on the planet. If human beings, via technological infrastructure, have deeply altered the physical world, it is beneficial to comprehend these infrastructures in their physicality. Stopping short of such a conception may shroud the deeply material nature of technology, whose colossal growth and existence exceeds the circumference of human societies. The perennial dilemma of nature versus culture haunts this debate. For reasons that will become clear in the course of this project, I choose to focus on the former.[19]

If the technosphere can, indeed, be addressed as physical entity, everything that comprises the technosphere, including artificial intelligence, information technology, and non-computational industries, can be grounded (but not reduced) to the physicalist framework of thermodynamics. While a reconciliation of thermodynamics with computation is beyond the scope of this project, an attempt to ground the design and political economy of

[18] Chris Otter, "Socializing the Technosphere," *Technology and Culture* 63, no. 4 (2022): 953-978. doi:10.1353/tech.2022.0153.
[19] A debate on the concept of the 'technosphere' between science and technology historians, Gabrielle Hecht and Paul N. Edwards: "Taking on the Technosphere: A Kitchen Debate," Technosphere Magazine, (May 29, 2019, https://technosphere-magazine.hkw.de/p/Taking-on-the-Technosphere-A-Kitchen-Debate-4TGo3PL5LWM7JydaVdQPHC.

computation in the physicalism of the technosphere—especially once we recognize the primacy of 'energy' to computation—leads us to a much more complicated and intricate consideration of 'materiality.' Are computational infrastructures any less "physical" than the technosphere they are grounded in? How do we reconcile the "abstract" nature of machinic intelligence with the supposed "bruteness" of energy that sets a limit to the technosphere? These questions recur throughout this study.

How did we get here?

The merits of retaining a physicalist conception of the technosphere become self-evident when the concept is employed to produce empirical findings that accurately contextualize its expanse with respect to other sub-systems on Earth. A study in 2016, assessing the "scale and extent of the physical technosphere" concluded that:

> …assessed on paleontological criteria, technofossil diversity already exceeds known estimates of biological diversity as measured by richness, far exceeds recognized fossil diversity, and may exceed total biological diversity through Earth's history.[20]

Technofossils can be defined as the "preservable material remains of the technosphere."[21] The authors claims that current technosphere weighs 30 trillion tons which is "five orders of magnitude greater than the standing biomass of humans," that, in turn, is "more than double that of all large terrestrial vertebrates that characterized the Earth prior to human

[20] Jan Zalasiewicz et al., 'Scale and diversity of the physical technosphere: A geological perspective,' *The Anthropocene Review*, *4*(1), 9–10.
[21] Jan Zalasiewicz et al., "The Technofossil Record of Humans," *The Anthropocene Review* 1, no. 1 (April 1, 2014): 34–43, https://doi.org/10.1177/2053019613514953.

civilization."[22] Even if considered with a grain of salt, these numbers are instructive in demonstrating the geological and civilizational novelty of the technosphere, that now extends well beyond the Earth itself into space.

We arrive, thus, at the main question that drives this project*: How did the technosphere become a geological mammoth par excellence?*

Historicizing the technosphere brings us the crucial insight that it is not, as a matter of fact, solely a modern phenomenon. For as long as hominids have existed, they have interacted with their environment using tools and machines. In fact, the earliest stone tools, around 3.3 million years old, predate the emergence of the genus 'Homo.' With the appearance of Homo sapiens, around 300,000 years ago, technofossils evolved too and reflected on the pace of the evolution of human societies.[23] For instance, the use of iron technology in 1000 BC led to a surge in the production of technofossils. Still, there were periods with fluctuations in the generation of technofossils and it wasn't until the 19th century, the period known as 'Industrial Revolution,' that the number and diversity of technofossils exploded all over the world.[24] The question, however, remains: what exactly distinguishes the current technosphere?

There are many factors that characterize the technosphere we inhabit.[25] The most significant one, arguably, is that its scale and magnitude are large enough to usher in the Anthropocene, the geological epoch when human activity dominates planetary processes.

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[22] Jan Zalasiewicz et al., 'Scale and diversity of the physical technosphere: A geological perspective,' *The Anthropocene Review*, *4*(1), 19.
[23] Jan Zalasiewicz et al., "The Technofossil Record of Humans," *The Anthropocene Review* 1, no. 1 (April 1, 2014): 34–43, https://doi.org/10.1177/2053019613514953.
[24] Teun Koetsier, *The Ascent of GIM, the Global Intelligent Machine: A History of Production and Information Machines*, vol. 36, History of Mechanism and Machine Science (Cham: Springer International Publishing, 2019), https://doi.org/10.1007/978-3-319-96547-5.
[25] Jan Zalasiewicz et al., "When Did the Anthropocene Begin? A Mid-Twentieth Century Boundary Level Is Stratigraphically Optimal," *Quaternary International*, The Quaternary System and its formal subdivision, 383 (October 5, 2015): 196–203, https://doi.org/10.1016/j.quaint.2014.11.045.

Several studies indicate that the beginning of the Anthropocene can be traced to the mid-20th century, and that the latter half of the twentieth century is "unique in the entire history of humane existence on Earth... [characterized by] the most rapid transformation of the human relationship with the natural world in the history of humankind."[26] If tools and machines have existed for several millennia in one form or another, what feature distinguishes its gargantuan nature of the technosphere in the Anthropocene?

I would like to propose that one feature that distinguishes the technosphere as it exists today is the prevalence of information technology, or computation. This suggestion is, by no means novel or unprecedented; academic discourse across the Humanities and beyond has critically addressed the ubiquitous nature of information in the latter twentieth and twenty-first century. Many different concepts and terms have been proposed to distinguish the stage of capitalism marked by the abundance of information technology in everyday life: the 'information society,' 'digital capitalism,' 'platform capitalism,' 'surveillance capitalism,' are just a few of them. While one cannot conflate the varying theoretical ideas purported by them, they all emerge in response to similar conditions of the rise of expansive and ubiquitous information technology infrastructure, ranging from technological objects (smartphones, personal computers, smart cities, etc.) to the growth of corporate giants (Alpha, Apple, Microsoft, etc.) whose innovations based on extensive data infrastructures have fundamentally changed the nature of global political economy. All of these works come with varying relevant theoretical insights, but I retain the category of the technosphere to maintain the emphatic geological character of it; if information is what characterizes the singularity of the society we inhabit, the conceptual emphasis of the technosphere tells us that its prevalence has consequences that are material and planetary in scale. Moreover, this helps

[26] Will Steffen et al., *Global Change and the Earth System: A Planet Under Pressure*, Global Change — The IGBP Series (Berlin, Heidelberg: Springer, 2005), https://doi.org/10.1007/b137870.

us build towards a problematic that stages the encounter of the "abstractions" of information and the physicalism of the technosphere:

> The impact of information technologies on societies and physical environments is thus not limited to modern times. Yet, today's state of the asymmetry between coded information and its physical effects is epitomized by electrons passing through digital microprocessors that effectively steer material and energetic flows within a technosphere spanning the globe from satellite orbits 40,000km above the Earth's surface to 10km into the lithosphere.[27]

Teun Koetsier draws an astute distinction between two types of tools: production tools (or production machines) and information tools (or information machines). Before the emergence of planetary-wide infrastructures of information technology, the mechanization of our interaction with the environment that boomed globally with the Industrial Revolution was predominantly of a *physical* kind. With the emergence of information tools from the twentieth century onwards, the nature of our interaction gradually became computationally imbued. While most machines today are hybrids between the two, the exponential growth of information tools alongside the physical expansion of the technosphere provokes a theoretical question about the relationship between the two. What about computation, precisely, propels the technosphere in this direction? I propose that to answer we must begin to think of computation as a generative logic and infrastructure, that is responsible for its planetary proportions.

[27] Christoph Rosol, *et. al.*, "On the Age of Computation in the Epoch of Humankind," Nature, https://www.nature.com/articles/d42473-018-00286-8.

A source I draw significantly from—one whose ideas have remarkable parallels with that of the technosphere—is Benjamin Bratton's notion of the planetary-scale computation.

Benjamin Bratton's *The Stack: On Software and Sovereignty (2015)*, for instance, defines the 'Stack,' or planetary-scale computation, as "an accidental megastructure [...] that we are building both deliberately and unwittingly and is in turn building us in its own image."[28] In Bratton's conception of computation as a planetary-scale phenomenon, individual instances of computation can be addressed as embedded in an emergent totality that constitutes itself by mobilizing a vast network of resources and actors across the planet—"from the geochemical to the phenomenological: *Earth, Cloud, City, Address, Interface,* and *User."*[29] The materiality of each of these layers of the Stack, individually and in aggregate, comprises the potential and the limitation of the Stack, and the various ways computation has come to determine the future of the planet and every species that inhabits it. Moreover, what Bratton's study offers is the means to map out the sheer diversity of geological resources, biological life, and political and technological infrastructures that must be deterritorialized and reterritorialized across the expanse of the Earth (and beyond) for the Stack to be a determining force of an unprecedented kind.

The Stack, then, arguably, captures a similar phenomenon as the technosphere. However, there still remain certain differences based in methodology and disciplinary contexts. For instance, the technosphere's conceptual emphasis remains on a physicalist foundation, based in thermodynamics, that situates it in the energetic dynamics of the Earth system and renders it a geological system analogous to the atmosphere, biosphere, lithosphere appropriate for quantitative analyses. A fine example of this is the study mentioned earlier

[28] Benjamin H. Bratton, *The Stack: On Software and Sovereignty* (Cambridge, MA, USA: MIT Press, 2016), 5.
[29] Ibid., 66.

that attempts a preliminary taxonomy of 'technofossils' to measure the diversity of the physical technosphere compared to that of the biosphere and geosphere.[30] Bratton's concept of the Stack, on the other hand, is theoretical elaboration of particular qualitative aspects of the same geological apparatus.

Moreover, I also maintain that this distinction is necessary because conceiving the technosphere in excess of computation can conceptually and historically accommodate technological artefacts and processes that may have preceded computation, or still remain outside its loop in the present. It has been argued that the beginning of the Anthropocene can dated to the mid-20th century, as the Great Acceleration began.[31] If we revisit the conceptual premises of the technosphere and agree that it ushered in the Anthropocene, we can be fairly certain that the technosphere, perhaps of a different kind, preceded the rise and domination of computation. Computation, in that case, can be considered a principal generative, epistemological apparatus *within* technosphere, one that organizes the technosphere in its current form.

What can possibly account, however, computation's generative tendencies on a planetary scale?

If appropriating the resources of pre-existing subsystems is a criterion for a geological paradigm, the technosphere is a geological behemoth whose accretion of matter and energy from the planet is not simply appropriative, but generative in ways that provoke its ontological and systemic bounds. This generative appetite is hardly novel. In *Capital I,* Marx

[30] Jan Zalasiewicz et al., "Scale and Diversity of the Physical Technosphere: A Geological Perspective," *The Anthropocene Review* 4, no. 1 (April 1, 2017): 9–22, https://doi.org/10.1177/2053019616677743.
[31] J. R. McNeill and P. Engelke, *The Great Acceleration: An Environmental History of the Anthropocene since 1945*, 2014.

meticulously demonstrated that labor transforms "natural matter" into commodity, and thus, is the hidden source of its value. Marx's prescient insight speaks to this parallel process of production in both the technosphere and biosphere: "Man can only proceed in his producing like nature does herself; i.e., only change the forms of material."[32] This transformation was, and still remains, fundamental to the accumulation of capital.[33]

Bracketing this process of accumulation, however, there still remains scope to scrutinize precisely how this generative process manifests in the technosphere specifically. This belief comes from a few different observations. As I have stated before, different studies over the past decade present critical observations about the technosphere: the rapid escalation of its diversity and bulk, the extensive changes it has made to biosphere and geosphere, its expansion beyond the planet itself, and the rise of planet-wide information technology that has accompanied this trajectory. It is in order, therefore, to consider concepts that accord some ontological consistency to many such disparate observations. This entails not a totalizing application of a single established idea to empirical cases, as is often seen in theoretical work, but staging encounters between the observations we have at hand with concepts such that they are mutually interrogative, and construct the ontological edifice that undergirds the infrastructural flows of the technosphere.

A theoretical answer to this query was provided by Pierre Levy, in his text *Becoming Virtual.* Largely overlooked by Anglophone media philosophy, Levy argued, in 1998, that the

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[32] "The use-values coat, linen, etc. – in brief, the commodity-bodies – are connections of two elements, natural matter and labour. If one subtracts the total sum of all different instances of useful labour which lurk inside the coat, linen, etc., there always remains a material substrate left over which is present naturally without the interference of man. Man can only proceed in his producing like nature does herself; i.e., only change the forms of material. And what is more, in this labour of formation itself he is constantly supported by natural forces. Labour is not, therefore, the only source of those use-values which are produced by it – material wealth. Labour is its father, as William Petty says, and the earth is its mother."

[33] Needless to say, in the text I refer to here, Marx is assigning an agential primacy to "man," that, in this framework is a part of the technosphere.

concept of ‘virtualization’ plays a significant role in the reach and expansion of the current technosphere. In many ways, virtualization is already a well-known feature of capitalism; French philosophers Gilles Deleuze and Felix Guattari famously characterized capitalism by its capacity for deterritorialization. Lévy, borrowed from Deleuze and Guattari, as well as other sources to advance the thesis that virtualization was an ubiquitous feature of contemporary society, bolstered, especially, by processes of digitalization. Let us explore the concept briefly.

For Levy, the ‘virtual’ is a “kind of problematic complex, the knot of tendencies or forces that accompanies a situation event, object, or entity” that must be resolved through actualization.[34] For Gilles Deleuze, whose concept of the ‘virtual’ influences Lévy, “purely actual objects do not exist,” instead, every object is comprised of actual elements surrounded by clusters of virtual elements of varying densities.[35] Thus, if actualization is a movement from the virtual to the actual, i.e., the process of the resolution of a problematic, virtualization is the movement from the actual to the virtual. Virtualization is “the displacement of the centre of ontological gravity of the object.”[36] It “fluidizes existing distinctions, augments the degrees of freedom involved, and hollows out a compelling vacuum.”[37] The most common (and timely, in the post-Covid world) example of a virtual organization is the virtualized corporation—It does not need to have a shared location (or even shared time) to exist as a unit: “The virtualization of a corporation consists primarily in transforming the spatiotemporal coordinates of work into a continuously renewed problem rather than a stable solution.”[38]

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[34] Pierre Lévy, “Becoming Virtual, Reality in the Digital Age,” *Plenum Trade, New York*, January 1, 1998, 24.
[35] Gilles Deleuze and Claire Parnet, *Dialogues II: Revised Edition*, trans. Hugh Tomlinson and Barbara Habberjam (Columbia University Press, 2007), 148.
[36] Lévy, 26.
[37] Ibid., 27.
[38] Ibid., 26.

Lévy's central contention is that virtualization is a process occurring in all spheres on the planet; the body, text, economy, etc. Every entity and infrastructure imbued with the ontological problematization of the virtual can then potentially partake in creative and generative acts. For instance, information (used interchangeably with 'data'), which constitutes a central commodity in the current global political economy, is a virtual entity since it is inherently detached from any given space and time, and therefore, deterritorialized. As a process, information can generate its own cycles of actualization and virtualization.

> Information is virtual…. one of the distinctive features of virtuality is its detachment from a particular time and place. It is for this reason that I can supply a virtual good, that is essentially deterritorialized, without losing it.
>
> Actualization is […] an inventive act of production, an act of creation. When I use information, when I interpret it, connect it with other information to create meaning or help make a decision, I actualize it. In doing so, I accomplish a creative act, a productive act. Knowledge is the result of apprenticeship, the result of virtualization of immediate experience. It can also be applied or, preferably, actualized in situations other than that of the initial apprenticeship.[39]

Levy makes the prudent distinction between 'virtual' as an intangible, elusive phenomenon (such as in 'virtual reality') and virtualization as an ontological mode that results in generative events in the material world:

> Virtualization is not a derealization (the transformation of a reality into a collection of possibles) but a change of identity, a displacement of the centre of ontological gravity of the object considered.

[39] Levy, 74-75.

The latter, for Levy, becomes the basis of information's material manifestations in all domains of nature and culture. Because it provides an ontological ground for the ubiquity of computation and the material, physical expansion of technosphere, Levy's account becomes an appropriate beginning point in our inquiry.[40]

However, other questions remain: What kind of "generative" agency does information technology or computation have? What drives its propensity for conceiving or aiding the growth of geological systems like the 'technosphere?' If it really is in touch with the 'virtual,' what accounts for its use for control and governance? Thinking of computation as a generative process entails rethinking a number of theoretical assumptions about its nature, as well as appraising the ways in which it interacts with the world at large.

[40] The point I wish to state emphatically is that my attempt to lay bare the workings of the technosphere does not imply that its ontological and geological complexity distinguish it hierarchically from previous states of the planet. That would only betray a tired, old trope of teleological civilizational "advancement," a supposed prerogative of our species. If anything, the unsustainable nature of the technosphere undermines the fantasy. My project, rather, is to engage concepts that productively unveil the ontological grounds of the technosphere and its constituents in their singularity. Their use and relevance can certainly be realized in the study of other systems beyond the scope of this project.

Chapter Two

Computation: An Epistemological Technology

In the last chapter, I argued that in order to account for the physical expanse and complexity of the technosphere we inhabit, we must look, more specifically, at the role of computation as a generative force that mobilizes objects on a planetary scale. The technosphere's accelerated growth into a geological entity necessitates that we consider its physical immensity and dispositions not as arbitrary outcomes of either political economy, advances in science and engineering, or the aspirations of Big Tech, but that of more grounded apparatus that permeates all three. That apparatus is planetary-scale computation.

When pictured in the form of invasive and ubiquitous algorithms, computation is situated in the devious use of surveillance technology, privacy violations, algorithmic bias directed at individual users. While these remain substantial concerns in computation, I insist that if we are to appraise its full potential, we must concede that computation is not solely repressive or directed at human users and population, but that it is productively and intimately engaged with non-human things. In other words, computation in popular imagination inhabits the realm of the symbolic, of subjectivity, and jurisprudence. But it is also ardently concerned with minerals, soil, forests, water, air, and biological organisms. Largely relegated to the domain of the natural sciences, computation, too, displays an appetition for the scrupulous study of all living and non-living matter. This coalesces with its inclination for spatiality on the scale of the planet to generate an exorbitant technosphere. In the rest of the chapter, I explore various facets of computation that impart to it its generative dispositions at the scale of the planetary. Following that, I navigate various conceptions of the 'virtual' relevant to the generative function of computation.

At a planetary-scale infrastructure, what is entailed in computation's encounter with the material substrate of the planet? Moreover, where is the room, if any, for potential in this encounter?

The facets of computation I explore in the rest of the chapter build towards an account of computation as an "epistemological technology." [41] Bratton draws a distinction between two kinds of technologies: instrumental and epistemological. If instrumental technology makes mechanical or physical changes to an object, an epistemological technology produces consistent information about the object it is concerned with and incorporates this information to refine its self-production so it may model and transform its object of interest endlessly.[42] The means, speed, designs and accidents of the abstraction of information at large-scales dispel any misapprehension of "bare physicality" that the geological account of the technosphere attributes to it. Certainly, no information processing method or system is incorporeal and without physicality, an idea I will address further in the next chapter. But computation's vast epistemological operations demonstrate that its capacity for large-scale abstraction is crucial to the physical magnitude and complexity of the technosphere.[43]

A Long-standing Liaison

Long before computation attained the form that it has currently, it showed promise as a tool of investigation into geological matters. Its flirtation with geology goes right back to Charles Babbage himself.

[41] Benjamin Bratton, "Planetary Sapience," NOEMA, June 17, 2021, https://www.noemamag.com/planetary-sapience.
[42] Bratton's distinction between instrumental and epistemological technology parallels the distinction made earlier between production tools and information tools, though Bratton's methodology slightly differs.
[43] It is important to address that I do not consider information or abstraction solely human or machinic prerogatives, but information can take on a different meaning in other living organisms or biospheric systems. For instance, processing signal at boundaries is a key function in autopoietic systems.

Babbage, popularly hailed as the “father of computer,” was an English mathematician credited with constructing the first mechanical computer, the Difference Engine. But introducing him as a “mathematician” obscures his lasting influence on a vast array of academic and industrial output. His contribution to the discipline of Geology, for instance, is less widely known and characterized separately from his role in the history of the computation when, in fact, one of the first uses of Babbage’s Difference Engine was as a geological tool.

The Temple of Serapis, an ancient Greek monument located in Rome, was of significant interest to Scottish geologist Charles Lyell who sought to understand why the columns of the temple showed signs of being immersed under the sea. Just what processes may have caused such an ancient edifice to then rise above sea level would reveal a picture of Earth’s geological history. Darwin, who already held an interest in geology, visited the site and arrived at similar questions. In order to propound plausible theories for what may have caused these changes at the site, Babbage took measurements of the columns and fed the data into the Difference Engine.

The Difference Engine was a mechanical calculator designed to tabulate polynomial functions. Using the Engine, Babbage was able to correlate the conductivity of rocks with heat, and concluded that “for the case of Temple of Serapis, in order to effect land elevation of twenty-five feet, a five-mile stretch of sandstone on which the Temple stood needed to have its temperature raised by 100 degrees.”[44] “Too much concentrated heat caused fissures in the strata and resulted in volcanic eruptions, during which liquified materials were displaced. These

[44] Brian P. Dolan, “Representing Novelty: Charles Babbage, Charles Lyell, and Experiments in Early Victorian Geology,” *History of Science* 36, no. 3 (September 1, 1998): 310, https://doi.org/10.1177/007327539803600303.
Carla Petrocelli, “‘The Earth Calculus’: Babbage, Tables, and the Calculating Machine in the Study of Geology,” *Rendiconti Lincei. Scienze Fisiche e Naturali* 32, no. 2 (June 1, 2021): 245–55, https://doi.org/10.1007/s12210-021-00988-0.

could then be linked to the occurrences of earthquakes, and helped cool the rocks which eventually resulted in their contraction."[45]

From the Difference Engine, Babbage was able to obtain results about the effect of heat on various rocks: graphite, marble, sandstone, etc. Moreover, Babbage's findings about the gradual submergence and subsequent elevation of the Temple refined Lyell's own theory of uniformitarianism. Lyell has propounded early in the 19th century the idea that, contrary to singular, catastrophic events, changes in the Earth occurred gradually over long periods of time.[46] However, it was with Babbage's measurements and tabulated results produced through the Difference Engine that a much a longer history of the geological changes of the Temple area was established, and the language of "sudden" events was overcome. "Where Lyell cited two historical episodes that made it probable that events connected to a volcanic eruption caused the Temple suddenly to subside, Babbage invoked a variety of measurements, diagrams, illustrations, and calculations as evidence to underscore the gradual operations of nature."[47]

Babbage's influence in the history of geology is surmised as the beginning of the mathematization of the discipline. It is, indeed, to be situated in the mechanization that characterized the Industrial Revolution and the "culture of calculation" that defined Victorian society in the 19th century.[48] But besides being relevant to the history of mathematization of the natural sciences, it is also an early instance of the effective adoption of a computational device for the investigation of Earth through deep time. The imperatives of the natural sciences, at the time, were already driven by a concern with investigating the long history of organic and

[45] Carla Petrocelli, "'The Earth Calculus': Babbage, Tables, and the Calculating Machine in the Study of Geology," *Rendiconti Lincei. Scienze Fisiche e Naturali* 32, no. 2 (June 1, 2021): 245–55, https://doi.org/10.1007/s12210-021-00988-0.
[46] Charles Lyell, *Principles of Geology, Volume 1* (Chicago, IL: University of Chicago Press, 1990), https://press.uchicago.edu/ucp/books/book/chicago/P/bo3774432.html.
[47] Dolan, "Representing Novelty: Charles Babbage, Charles Lyell, and Experiments in Early Victorian Geology," 304.
[48] Ian Hacking, *The Taming of Chance*, Ideas in Context (Cambridge: Cambridge University Press, 1990), https://doi.org/10.1017/CBO9780511819766.

inorganic nature.[49] And computation appears at this crucial moment. In Babbage's exploration of the Temple of Serapis, the Difference Engine, even if only partially successful, played an instrumental role in constructing a temporal narrative of a geological scale. As we gather in the following sections, one feature of computation that makes it an epistemological aid in a wide variety of research is its ability to address things across various temporal and spatial scales.

Roughly, a century later, when computation became ubiquitous in the field of Earth Sciences, it was due to this capacity for abstraction at shifting temporal and spatial scales. As Paul Edwards argues in his phenomenal text, *A Vast Machine*, no field grew as monumentally with the growth of computing resources in the 1970s as climatology did. Its achievements are, perhaps, one of the earliest concrete computational infrastructures to be realized on a planetary scale. Theoretically, meteorology, by the 1930s, had already determined the scale of the planetary to be fundamental to the climate. But with computer simulations, it became possible to model vast and complex geophysical systems that would otherwise be difficult to "experiment" with. Moreover, with the proliferation of satellites and sensor technology, it also became possible to gather data on a large scale from across the planet. Edwards finds an early articulation of what was to become this infrastructure in the words of John Ruskin:

> A vast machine… systems of methodical and simultaneous observations… omnipresent over the globe, so that [meteorology] may be able to know, at any given instant, the state of the atmosphere on every point on its surface.[50]

Today, weather forecasting is made possible by instantaneous transmission of data from satellites and sensors spanning across the planet, assimilated by computer models that can

[49] In *Principles of Geology* (Volume I), Lyell describes Geology as the endeavour to investigate the successive changes in history of nature so as to understand its present conditions. *Principles* was also read by Charles Darwin and influenced his thinking about long-term natural of evolution and natural selection.
[50] Paul N. Edwards, *A Vast Machine: Computer Models, Climate Data, and The Politics of Global Warming,* (Massachusetts Institute of Technology, 2010), 431.

predict the weather of any place at any time. Built atop weather forecasting systems is the infrastructure for climate science that conducts longer temporal forays into the past and the future. The global infrastructure for the collection and creation of this knowledge is a robust "vast machine," consisting of continual feedback between various points on the planet and a reflexive interrogation of its own model of the world.

I bring up these disparate cases to illustrate that computation's role in geological enterprises is not merely fortunate happenstance. As we will establish gradually in the following sections, computation's propensity for spatiality, proliferation of material relations, and visuality based in feedback were indispensable to the latter's ambitions of constructing knowledge of large swatches of the planet across geological durations, one that developed into a planetary-scale machine. Now the machine exceeds the limits of the Earth and is progressively growing further into space.

Addressability

When we speak of computation as "media—pictured in the form of devices we use on a daily basis with particular objectives in mind—it is easier to imagine it as a separable, intermediary function that is subject to the agency of the user and their plans. But rethinking it as an agential infrastructure itself significantly disrupts this image.[51] Specifically, to think of computation as an infrastructure of planetary proportions entails asking the question: What is it about computation that inflates it across the planet, as both an epistemological machine and a physical infrastructure?

[51] Note that I speak of computation both as an agent and an infrastructure, though this agency is only an emergent function of the infrastructure itself and does not exist as a singular agent, except in a manner of speaking.

As it turns out, spatiality is hardly incidental to computation. Ranjodh Singh Dhaliwal argues that computation has always been spatial: "[…] addressability – the condition whereby addressing, or the practice of giving a locational/spatial index, takes places – undergirds all computing as we know it."[52] Dhaliwal traces the continuation of the addressing techniques primary to the postal system of early modern society into computation. In the genesis of early computing devices, he finds that it is, by design, necessary to their functioning that they address both objects that are outside of them, and devices and functions that are internal to them. "[…] when the question on the table is how to identify each functioning element of the computational system, the answer is to *always spatialize!"*[53] In network addresses, this tendency becomes even more remarkable: every computational device that participates in a network is located with the help of a combination of addressing tactics, such as media access control (MAC) that is the physical address of a device, and Internet Protocol (IP) address that is its logical address.

Addressability is not a mere allocation of an address to various objects. It is a "technical, material-semiotic operation that joins […] the addressee and the addressed, in an ongoing relationship." Dhaliwal emphatically states here that the process of addressing is never as simple as a static, established connection between computation and the object it seeks. There could be, and likely is, a combination of logical and physical addresses, with a physical address in the end that arrives at the object itself.

A known form of addressability is the data that is collected on individual users. Based on the use of the Global Positioning System (GPS), Google knows the exact location that I have been at for the last several years. Google Maps knows, for instance, that on January 26, 2019, I left my apartment at 9:53 AM to walk 400 meters to college for 4 hours and 20 minutes

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[52] Ranjodh Singh Dhaliwal, "On Addressability, or What Even Is Computation?," *Critical Inquiry* 49, no. 1 (September 2022): 1–27, https://doi.org/10.1086/721167. 4.
[53] Ibid., 9.

and returned at 2:19 PM. Based on the photographs I have taken, Google Photos can guess, even when my GPS is turned off, from the landmarks in my photos, that I was in Toronto for less than a day last year in October. Through facial recognition, Google Photos also recognizes the friend I visited in Kolkata, India, annually, and situates us precisely at her home address. My friend's addresses collected over years overlap with mine. Even when a user turns off their 'Location History', Google continues to collect location-data from minute to minute from weather update apps and browser search. This data collected does not show on the user's phone, but is registered nonetheless. Every application on a user's Android phone is directly or indirectly equipped to gather location data.[54] The sum total of addresses collected from users globally amounts to information about the planetary-wide movement of users. In October of 2022, Google publicly released a report titled 'Community Mobility Report' that "charted movement trends over time by geography, across different categories of places such as retail and recreation, groceries and pharmacies, parks, transit stations, workplaces, and residential" in every state/province from 131 countries.[55]

"…anything that can be addressed *will* be addressed"[56]

It seems then, when realized in its full capacity, addressability is more than a technical operation; it is the facilitator and symptom of computation's appetite for assimilating *anything* that can be computed. As Benjamin Bratton explains, this has profound consequences when realized on a planetary scale:

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[54] "Google Still Tracks You through the Web If You Turn off Location History - The Verge," accessed April 1, 2023, https://www.theverge.com/2018/8/13/17684660/google-turn-off-location-history-data.
Olivia Krauth, "Your Smartphone Can Be Tracked Even If GPS, Location Services Are Turned Off," TechRepublic, February 8, 2018, https://www.techrepublic.com/article/your-smartphone-can-be-tracked-even-if-gps-location-services-are-turned-off/.
[55] "COVID-19 Community Mobility Report," COVID-19 Community Mobility Report, https://www.google.com/covid19/mobility?hl=en.
[56] Dhaliwal, "On Addressability," 10.

> To the extent that The Stack, as megastructure, provides a global and universal architecture for planetary computation, the space of potential location in which any thing may be situated is equally global and universal. That universality is necessary because the addressed "things" may be of very different kinds and qualities (an entry in a particular spreadsheet, a light bulb in a remote street lamp, a single gateway on a single transistor, a component on an orbiting satellite, or a unique chemical process in a Petri dish). The *Address* layer of The Stack organizes this telescoping from a global grid of locations to the specific local instance of the addressed and back again. This is the ultimate horizon of the truly ubiquitous computing that exceeds the experiential limits of anthropometric and anthropocentric design by enrolling entities into a scope of addressability across and between natural scales, from the infinitesimal to the astronomic, and across natural tempo, from instantaneous to geologic duration. This is *deep address*; it is where the scope of addressability expands to the point of breaking common sense of what is and is not a sender, a receiver, and message as the theoretical landscape of information promiscuity explodes.[57]

It would not be a stretch, then, to suggest that computation exhibits a generative capacity that exceeds the pinpointing of things. "Deep address is not only a mechanism for the capture of what exists and a formalization of its space of juxtaposition; it is also, as conceived, a medium for the creative composition of the relations, positions, and interrelations."[58]

One can see how addressability is indispensable to computation on a planetary scale: it enables computation to acquire, model or reinvent the world endlessly. If computation is driven to expand itself across and beyond our planet, addressability is how it cognizes the planet in the first place.

[57] Bratton, *The Stack,* 197-198.
[58] Bratton, *The Stack, 199.*

The scope of addressability is so extensive that it pushes computation's capacity for perception and capture beyond the anthropometric register, ranging from macroscopic to microscopic scales that reach far beyond the limits of space and time perceptible to us, the limits of which can be peeled and pushed even further. But as Bratton notes, computation does not solely address by locating particular objects with precision. The process of situating individual things proceeds hand-in-hand with the imagination and construction of a milieu that, in the case of the present planetary-scale computation, is "global and universal." The limits that computation pushes through *deep address* is that of this expansile space, or milieu in which objects are situated. This concern with milieu, Alexander Galloway argues, is characteristic of computational vision.[59]

"How did the computer learn to see?" Galloway asks. The answer, he argues, lies not in cinema or photography but in "architectural modelling, [the] special mode of sculpture devoted not to the integral object but to the complexities of built environment."[60] In his analysis of the history of visual media, photosculpture emerges as the most appropriate predecessor to computational vision. Photosculpture was pioneered by French photographer François Willème in 1859, who attempted to produce a three-dimensional still by integrating photographs taken from twenty-four cameras placed surrounding a single subject in the centre. Later, in the 1890s, Christian Wilhelm Braune and Otto Fischer developed a technique to capture the motion of a subject in space. The subject would wear a suit made of electric wires and Geissler tubes that would light up from movement, captured by multiple cameras surrounding the subject. From the final chronophotographs, the movement of each body part could be accurately plotted in three-dimension. These are early occurrence of the "virtualization of space" that Galloway

[59] Alexander Galloway, *Uncomputable: Play and Politics in the Long Digital Age* (Verso Books, 2021).
[60] Ibid.

claims characterizes computation vision. Computation "sees" by overcoming particular points of view focussed on singular objects, and trying, instead, to capture milieus in flux by disappearing into them. Whether or not this disappearance is total and the multiplication of points of view can truly make computation absolute in its presence and perception of the world, that is the end it seeks.

In the present day, one enterprise that has been integral to the growth of the technosphere in outer space and is an instance, par excellence, of computation's intricate concern with spatiality and milieus is satellite imaging. The satellite imaging industry has grown exponentially over the last few years and is projected to grow further for the next ten years.[61] And tracking changes in satellite imaging technology are a testament to just how significant geospatial mapping has become to not only for scientific and technological enterprises, but ideological, political and cultural processes as well. A distant bird's-eye view of ourselves seems to be the most reliable one.

Since satellite images promise a faithful and sweeping view of large expanses of the Earth, they can potentially enable a swift detection of infrastructural problems of a large scale or a close study of geological processes in motion. To enable a complete imaging of the planet captured periodically, Planet Labs, a San Francisco-based public Earth imaging company innovated the 'Dove Constellation,' which, "as of April 2018 consisted of 207 satellites, hover[ing] at a stationary orbit around Earth and uses the planet's rotation to cover the entire surface every twenty-four hours, effectively acting as a "line scanner" that produces 1.5 million images covering 350 million square kilometers every day."[62] If Francois Wilhelm's

[61] "Satellite Based Earth Observation Market Size Is Growing and Having a Huge Impact on the [Analytics] Industry from 2023 to 2029," Digital Journal, March 17, 2023, https://www.digitaljournal.com/pr/news/satellite-based-earth-observation-market-size-is-growing-and-having-a-huge-impact-on-the-analytics-industry-from-2023-to-2029.
[62] Jenny Goldstein and Eric Nost (ed.), *The Nature of Data: Infrastructures, Environments, Politics,* (University of Nebraska Press, 2022), 42.

photosculpture was an attempt at modelling a subject in three dimensions by suturing twenty-four separate images together, Planet Lab's Dove Constellation fragments the total surface of the Earth and images them every single day. Whether it is moving from fragmented images to a three-dimensional totality of the subject, or from distanced totality to a detailed shot of the Earth's s surface, the principle, in Galloway's words, is the same: "assume that objects and worlds will be viewable and manipulable from all sides in multiple dimensions."[63]

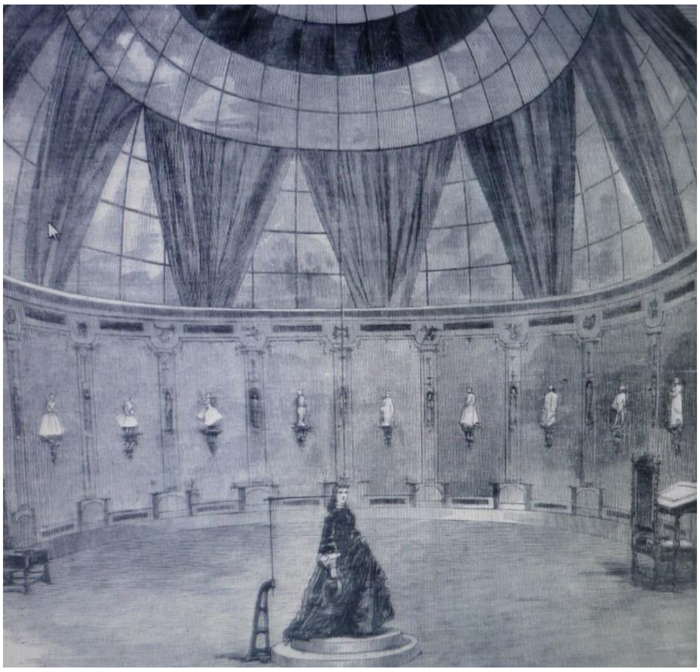

Fig. 1. François Willème's photosculpture in which the subject is surrounded by cameras to produce a three-dimensional sculpture

[63] Galloway, *Uncomputable.*

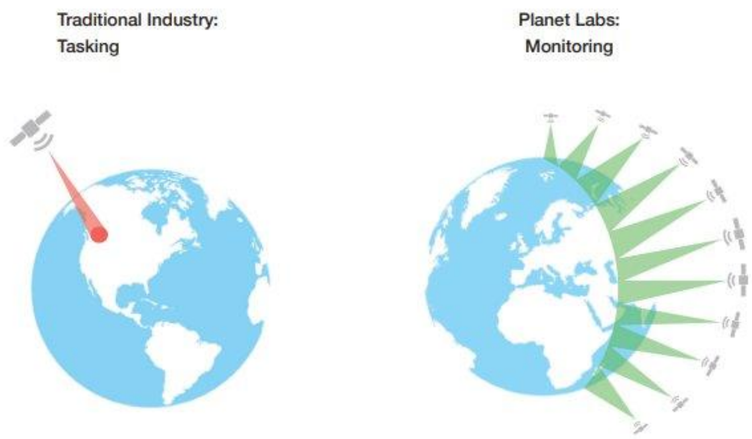

Fig. 2. Planet Lab's Dove Constellation captures the entire surface of the planet by acting as a "line scanner"

It is hard to overstate the quantity and variety of the kinds of information that satellite imaging makes accessible beyond scientific or commercial use. Satellite images are frequently used by human rights organizations and NGOs to gather information from sites that are otherwise inaccessible to journalists to point to atrocities occurring in conflict zones, mass graves, military/police abuses, unofficial detention camps, destruction of natural resources by commercial groups, etc.[64] The most recent instance of the invaluable use of satellite images was to corroborate the war crimes committed against Ukraine by Russia since 2022. While digital photos and videos of all kinds are useful in building a legal case of war

[64] Jo-Ansie van Wyk, "Pixels, Politics and Peace: The Forensic Use of Satellite Imagery," *Journal of African Foreign Affairs* 6, no. 2 (2019): 31–50.
Steven Livingston, "Satellite Imagery Augments Power and Responsibility of Human Rights Groups," *Brookings* (blog), November 30, 1AD, https://www.brookings.edu/blog/techtank/2016/06/23/satellite-imagery-augments-power-and-responsibility-of-human-rights-groups/.

crimes, photos and videos on grounds can also be digitally manipulated or capture an event only partially. Even personal testimonies, based on memory, could be shaky. And even if we, good faith, believe the self-evident nature of mass destruction and human rights violations that have occurred in the course of the war, building a legal case in the International Criminal Court entails strict adherence to particular standards of legal evidence. What provides a truth as unadulterated and comprehensive as the aerial view of a satellite? Maxar Technologies, a US-based space technology company captured extensive evidence of the steady invasion of Ukraine, as it was occurring in real time, and published it for the public to see.[65] One must note, however, that Maxar also has verifiable links with the US government. Its activities and digital intelligence cannot be sundered from imperialistic propensities of the latter. At the same time, the material existence of the proliferation of computational vision across the planet cannot be reduced to the role of single political actor. As mentioned earlier, often human rights organizations also employ satellite images to gather evidence of ongoing abuses by governments. In 2018, Human Rights Watch, an international NGO, acquired images from Planet Labs that showed a significant increase in detention camps in Tornillo, Texas, that were used to detain migrant children.[66]

The important takeaway is that satellite data is no longer the exclusive privilege of state actors for repressive political purposes. The information that is gathered from satellites – far-reaching, extensive, and reliable – becomes the basis for various organizations to assess events over large spatial and temporal scales that even extend into the future and *anticipate*

[65] Team Register, "The Satellite Giant Bringing Global Crisis into Focus," March 1, 2022 https://www.theregister.com/2022/03/01/maxar_satellite_imagery/.
"Maxar Continues To Capture Satellite Imagery Of The Russian-Ukraine Invasion – SatNews," March 21, 2022, https://news.satnews.com/2022/03/21/maxars-satellite-imagery-captures-continue-of-the-russian-ukraine-invasion/.
Denise Chow and Yuliya Talmazan, "Watching from Space, Satellites Collect Evidence of War Crimes," NBC News, May 3, 2022, https://www.nbcnews.com/science/science-news/ukraine-satellites-war-crimes-rcna26291.
[66] "New Satellite Imagery Shows Growth in Detention Camps for Children," Human Rights Watch, October 3, 2018, https://www.hrw.org/news/2018/10/03/new-satellite-imagery-shows-growth-detention-camps-children.

events through patterns that emerge over a period of time.[67] Computation's capacity to view and address translate into discursive regimes that contest each other. The sweeping, bird's-eye view of the satellite has now become vital our collective imaginaries and to the construction and enlargement of the technosphere. Only when we assume that all objects can be viewed and manipulated from all sides an omnipresent access to all that exists – can we proceed to also build new milieus, on Earth and beyond.

This omnipresence exceeds assumption, and becomes a principle for epistemological construction. Even when machinic vision makes processes or objects across distant scales accessible to us, the mechanism of mediation must be subject to frequent interrogation to enhance its output or adjust accuracy. This reflexive inspection of mediation was always common to scientific practice; in the case of climatology, for instance, Paul Edwards clarifies that the models that produce simulation of the climate must be routinely studies and updated. But this practice appears even more intriguing when it serves to expand the scope of vision into space. I came across the research of a doctoral student, Reid Perkins, from the department of Earth Sciences at Western University, whose project to understand lava flows on the surface of Mars entails building an elaborate account of radar itself. Radar, as we will explore later in this chapter, was developed in the mid-twentieth century for the US military to detect enemy aircrafts and missiles in space with the help of radio waves.[68] One of its present uses is in remote sensing technology, such as satellites. But their mediation of geological process on another planet, such as Mars, may be prone to error or have blind spots. A more rigorous portrait of its lava flows would then have to entail a deeper understanding of the radar itself, and accounting for its plausible errors to arrive at a fuller picture. How is this achieved? Perkins' doctoral project entails understanding 'surface roughness' through

[67] Mikkel Flyverbom and Christina Garsten, "Anticipation and Organization: Seeing, Knowing and Governing Futures," June 16, 2021, https://journals.sagepub.com/doi/10.1177/26317877211020325.
[68] Radar is an acronym for Radio Detection and Ranging

different media *comparatively*. He travelled to Iceland to obtain topographic data from both radar and LiDAR of the Holuhraun lava-flows.[69] “Since our LiDAR instrument is very high-resolution,” Perkins explains, “our goal is to use it to "ground-truth" roughness measurements that we get from orbital radar, which could be a bit more prone to error.” The lava-flows of Holuhraun becomes an analogic site where the comparative use of two geospatial media paves the way for producing knowledge about the surface of Mars.

The Epistemological Promise of Vision

Vision and its various iterations appear to be pertinent to computation’s operations. In language, a referent represents a signifier referring to a signified object. In photographs and film, the visual referent not only captures the various faces of an object, but serves as an epistemological guarantee of the proof of its existence; imaging bears a promise of fidelity that is unparalleled in other media.[70] I refer to “various iterations” because vision seems to be significant to computation in such a variety of ways that a proper theoretical review far exceeds the scope of this project. But it warrants some elaboration, nonetheless.[71] One iteration is the remarkable achievements of photography, for instance, in the history of science and technology. From the very beginning of photography in the nineteenth century, it promised the potential to visually access objects that are not visible to the human eye and bring large swathes of the world into the known. Kelly Wilder traces, for instance, some of the earliest debates on photography that took place in the context of astronomy, and its use in observing two transits

[69] For more information on Reid Perkins’ doctoral project, see: https://reidperkins.github.io/reidsite/
[70] Kelley Wilder, *Photography and Science*, Exposures (Reaktion Books, 2009), https://press.uchicago.edu/ucp/books/book/distributed/P/bo6165999.html.
[71] As we will find the following paragraphs, the subject of vision in computational infrastructures must be situated in broader and intersecting histories of the act of seeing, of visual media, and of interfaces that calculatedly represent distant objects. It would simultaneously overlap with an examination of the scientific method and the many ways in which visuality is inseparable from it.

of Venus in 1874 and 1882.[72] Even though this particular project was not fully realized, the attempt to improve photographic methods for scientific investigation carried on, and eventually developed into various successful applications like Raman spectroscopy and photogrammetry.[73]

But visuality in computation far exceeds the employment of imaging technology for epistemological ambitions that supposedly exist apart from it. The natural science's affair with images betrays a larger epistemic prerogative held by vision that is imbricated with the ocularcentrism of Western philosophy.[74] Georgina Kleege demonstrates that various figures of European early modern philosophy's construction of a subject rests on a comparison between "normal vision" and the haptic perception of a hypothetical blind man, an equation that reduces perception to vision. One of these philosophers was Rene Descartes whose epistemological project entailed the search for a hyperbolic lens whose perfect vision that would advance the Cartesian scientific process. This hyperbolic lens was the mind itself, the perfection of which would produce a higher order of the subject and its perception of the object.[75]

Modern Western Philosophy's reverence of vision is, thus, more than a mere metaphor. It is both a theoretical component of subjectivity and the means of advancing scientific clarity and access. Its primacy to the practice of astronomy demonstrates this further: Even before the technological arbitration of mechanical or computation media, vision bore proof of the existence of heavenly bodies and their movement across the night sky. But bare vision could only go so far, and would have to be aided by mathematization. Because it stages the encounter

[72] Wilder, 21.
[73] Ibid., 34. Wilder notes that the application of photography in science, termed 'scientific photography,' also bends the process of visualization to mathematization such that the outcome of the process may not represent an object in itself, but a mathematized representation of it.
[74] DeGruyter, "The Noblest of the Sense: Vision from Plato to Descartes," *Downcast Eyes* (University of California Press, 1993), https://www.degruyter.com/document/doi/10.1525/9780520915381-003/pdf.
[75] Ryan Johnson, "The Cartesian Eye Without Organs: The Shaping of Subjectivity in Descartes's Optics," *Philosophy & Rhetoric* 51, no. 1 (February 21, 2018): 73–90, https://doi.org/10.5325/philrhet.51.1.0073.

of vision (for the observation of visible phenomena) with mathematical calculation in an attempt to predict and map spatial movement of celestial objects, astronomy arguably constitutes a compelling precursor to the visual dispositions of present-day computation. As early as the last two centuries BC, Greek astronomers were influenced by Babylonian mathematical astronomy to replace descriptive geometric models of the heavens (imagined as a revolving spherical shell) by quantitative predictions.[76] Vision thus held the capacity to gauge large swathes of space, that, when combined with arithmetic calculations, produced a fuller, more universal picture of what could only be partially perceived by the eye. With the invention and popularization of the Galilean telescope in the seventeenth century, the limits of the naked eye were surpassed. Vision could pierce further than before and brought to life a three-dimensional model of space, and facilitated shorty after Copernicus's discovery heliocentric model of the Solar System.[77]

Advances in astronomy, in particular, in the last few centuries, enabled by the growth of various media technologies anticipate the planetary nature of present-day computation because they realize an epistemological objective by deploying planetary-wide resources, including the planet's spherical shape itself. As Jussi Parikka explains,

> While the sky has been pictured, read, observed, interpreted and calculated for millennia, […] the scientific analysis of movement of light became particularly interesting towards the fin de siècle. The employment of both media and visual technologies (photography and spectral analysis) and the possibilities to harness the planet's spherical shape – Northern and Southern Hemispheres into a binocular view

[76] Jones, A. (2015). Greek Mathematical Astronomy. In: Ruggles, C. (eds) Handbook of Archaeoastronomy and Ethnoastronomy. Springer, New York, NY. https://doi.org/10.1007/978-1-4614-6141-8_159
[77] Burns, J. The four hundred years of planetary science since Galileo and Kepler. *Nature* **466**, 575–584 (2010). https://doi.org/10.1038/nature09215

of sorts – as part of the astronomic observation unit from Peru to Massachusetts provided the backbone for broader infrastructures of knowledge.[78]

Parikka captures an early historical glimpse of an encounter that was to become indispensable to planetary-scale – that of media and visual technology with the epistemological objectives of the sciences.

In planetary-scale computation, the seemingly rudimentary capacity of the image, of representing a distant object thus takes on the most imperative role: to connect one point to another in space. McKenzie Wark articulates the novel significance of space in information society poignantly when she says, "[a]ll that was solid melts into air. Space becomes a topology in which any point can connect to any other."[79] This connection, when realized in an image with computational capacity, becomes an interface: "An interface is *any point of contact between two complex systems that governs the conditions of exchange between those systems."*[80] Such a point of contact between two systems, milieus, objects, or users, distant or close, "[…] because it is a specific summary, must eliminate or make invisible a whole range of other equally possible interactions."[81] The specificity of how an interface is designed engenders technical, economic, political, and phenomenological implications. It may range from purely commercial purposes – such as the click of a button on Amazon that sets in motion processes that cut across the breadth of the planet – or wear a badge of scientific legitimacy and purpose, such as interfaces that assimilate weather conditions from across the planet. At the threshold of the interface come together the imperatives of knowledge, representation, and intervention grounded in the spatial expanse of the entire planet.

[78] Jussi Parikka, "Operational Images: Between Light and Data," e-Flux, Issue #133, (February 2023), https://www.e-flux.com/journal/133/515812/operational-images-between-light-and-data/.
[79] Mckenzie Wark, "The Vectoralist Class," e-Flux, Issue #65, (May 2015), https://www.e-flux.com/journal/65/336347/the-vectoralist-class/.
[80] Bratton, *The Stack,* 220.
[81] Ibid., 221.

How does the 'virtual' relate to computation?

I began this thesis with the following problematic: If the technosphere as an Earth system has achieved geological proportions, what can possibly account for its rapid growth and complexity, especially since the twentieth century? Information processing, or computation, I argued, is plausibly a part of the answer. To build an account of computation that answers this query, I pieced together, from various sources, material aspects of it that furnish its dispositions for the 'planetary.' No single argument about the nature of computation in itself suffices to build this account. Instead, a complex of various conceptual and philosophical, drawn from histories of technology and media, come together to present

However, a question that I posed earlier remains unanswered: What accounts for computation's generative potential on such a scale? If the virtual, in Levy's words, is a "fecund and powerful mode of being that expands the process of creation," how does computation partake in this process of creation in the first place?

Because in popular imagination, digital content is considered entirely disembodied and intangible, it is conflated with the "virtual" that signifies incorporeality. This impression regarding the precise material nature of digitality would imply the erroneous idea that information or computation exist without particular forms, are endlessly manipulable, and creatively fertile; that its potential is unconstrained and infinite.

To contest this misapprehension, Brian Massumi takes recourse to the nature of binarism that characterizes coding to argue that digital computation "ha[s] a remarkably weak connection to the virtual, by virtue of the enormous power of the systemization of the possible."[82] In an evidently Deleuzian vein, he finds the digital's capacity for abstraction

[82] Brian Massumi, 'On the Superiority of the Analog,' in *Parables for the Virtual:: Movement, Affect, Sensation,* (Duke University Press, 2022), 137.

reduced to zeroes and ones inherently suppressive of potential; its only capacity for creation is that of the 'possible,' in which the outcome is strictly systematized. If the digital does brush with the virtual at all, it is when digital content transfers to the analog, into the realm of experience, and set in motion things with potentializing effects: "…Whatever inventiveness comes about, it is a result not of the coding itself but of the detour into the analog. The virtuality involved, and any new possibility that may arise, is entirely bound up with the potentializing relay. It is not contained in the code."[83] In other words, the threshold of the meeting of analog with the digital¾the display of words and images on a screen registered by a user and transmitted linguistically and affectively to another, or realized as a creative invention¾is where the virtual can emerge. Massumi maintains a binary between the logico-quantitative systematizing realm of the digital and the experiential realm of the analog in which quantitative transformations fold in the virtual. Anything the digital may produce can be inspirited by movement, sensation and variation of the analog and have greater reach towards the virtual. "The possible is already fully constituted, but exists in a state of limbo. It can be realized without anything occurring in its determination or nature."[84]

To contextualize his arguments further, it helps to know that Massumi is making this claim in 2002, a time when, perhaps, an undue faith in the promises of data and digital technology needed a check. Given that, I would say that I would say that his assessment of the digital is still a generous one. He takes Levy's treatise on the virtualizing effects of digital technology into cognizance and does not dispute them. Instead, he diagnoses the primacy of codification in the digital mode, its alterity to the analog, and relegates potential to the latter. It is interesting, nonetheless, to note Massumi's treatment of this binary.[85]

[83] Ibid., 142.
[84] Levy, *Becoming Virtual,* 24.

A similar¾albeit more generous¾analysis underlies the thought of Pierre Levy. Even though he reiterates the regarding the abundance of virtualizing processes throughout *Becoming Virtual*, digital texts and images themselves sustain only possibility, or potentialization at best. Recall that if the possible is "already fully constituted," then potentializing entails the mixture and selection of a particular possible. As opposed to the virtual, it does not pose a problematic in response to which an event of pure creation may occur.

> Based on an initial store of data, a model or metatext, a program can calculate an indefinite number of *different* visible and audible, or tangible manifestations[.] [Therefore,] computer technology provides only a combination of possibles, albeit infinite, and never a problematic domain.[86]

The visible, audible, or tangible manifestations exist in the realm of experience, and "the virtual," therefore, only "begins to flourish with the appearance of human subjectivity in the loop[.]" Thus Levy's account finds a concrete link between the potentialization of digital technology and the virtualization in the analog. Virtualization does prevail throughout culture and economy in our times, for Levy, prompted ubiquitously by the proliferation of computer-generated possibles. But his account remains, more or less, similar to Massumi's in its assumptions about the alterity of the digital and analog, the discrete and continuous, and the absence of virtuality in the former.

M. Beatrice Fazi responds to the prolonged dilemma that permeated discourses about digital ontology, and the suppression of creativity attributed to the discrete logic of computation. She does not contest that computation is characterized by discretization, but finds at its heart an "incomputability" that engenders an indeterminism characteristic of the discretization itself: "computation's preprogrammed procedures should be understood not as

[86] Ibid., 52-54.

an all-encompassing and preformed total determinism, but as processes of determination that are always exposed to, and in fact ingressed by, indeterminacy."[87] "It is not despite but rather because of formal abstraction that computation proves to be a procedure that is already complex."

Fazi's theorization of incomputability resolves a fundamental impasse that we find in digital ontology but she also does not agree that any creative potential is of the same nature as virtual intensities of "lived experience." Fazi departs from the metaphysical decoupling of novelty from discrete logic, and finds immanent to discretization itself an element of indeterminacy.

"…this indeterminacy is not modelled upon empirical individualities and […] does not correspond to the virtual intensities of that which is lived. Instead, this indeterminacy is specific to the formal axiomatic procedures of computation and to the functional and ontological autonomy of the latter." [88]

Whether the virtual is to be found only at the threshold of computation, where the digital meets the analog, or is substituted by the indeterminacy of the logico-quantitative nature of computational operations, these debates point to an awareness of computation's historical, material, and logical agency in shaping the world. And while Fazi responds elaborately to stubborn binaries in digital philosophy – in ways that can account for computation's generative capacities on a planetary-scale – I wish to return to a more immediate, empirical object relevant to computation, the image itself.

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[87] M. Beatrice Fazi, "Digital Aesthetics: The Discrete and the Continuous," *Theory, Culture & Society* 36, no. 1 (January 1, 2019): 21, https://doi.org/10.1177/0263276418770243.
[88] M. Beatrice Fazi, *Contingent Computation: Abstraction. Experience, and Indeterminacy in Computational Aesthetics*, (London: Rowman & Littlefield International, 2018), 205.

Rethinking Thresholds

The notion of the image I attempted to evoke in the previous sections¾in the various forms of simulations that model the climate, astronomical observations that mobilize the planet's shape itself, digital twins closely bound with a physical infrastructure, or interfaces on our personal devices¾is of a particular kind: an image that is thoroughly connected to the environment it is embedded in, and is simultaneously capacitated with information processing to continually interact with, learn from, and even aid in the construction its milieu. Bernard Dionysius Geoghegan offers a suitable account of this by historically situating the emergence of digital graphics and the computer screen in the early decades of the Cold War to track foreign aerial crafts in real-time:

> [C]omputer screens emerged from the problem of integrating humans, computers, and their environments into a single problem-solving system… by folding picturing and calculation into dual aspects of a single process, these systems joined humans and calculating instruments in a single circuit of information processing.[89]

In the same milieu, the representation of the enemy gave way to intervention, wherein the click of a button would also effectively dispatch missiles to intercept them. The feedback loops enabling this entailed various points of mediation between humans and machines: the precise location of the enemy in space through radio waves, its conversion into electronic signals, their visual representation and interpretations by humans to separate signal from noise, so an effective interception can be carried out. Territoriality is vital to this operation¾only grounded in a specific territorial expanse, the breadth of which it is conscious, does the visual capacity of computation emerge to address an object of interest, and intervene. A nexus emerges here

[89] Bernard Dionysius Geoghegan, "An Ecology of Operations: Vigilance, Radar, and the Birth of the Computer Screen," *Representations* 147, no. 1 (August 1, 2019): 59, https://doi.org/10.1525/rep.2019.147.1.59.

between visuality, data-gathering, spatiality, and feedback loops that run through them. These loops proliferate across the planet to engender planetary-scale computation that connects various human and nonhuman subjects, environments and infrastructures together. Indeed, as Geoghegan states:

> [T]`he actualization of computers into something approaching Alan Turing's universal machines is inconceivable without a vast array of dynamic feedback loops incorporating input from users and their environments. Without the digital images enabling this circuit, the computer is little more than a fantastic automaton...[90]

In the context of a prolonged Cold War, the computer screen ties together various machines and humans in the service of "territorial production." Geoghegan notes that situating the computer screen in this history contests the long-held notion that digitality is a mode that *precedes* visuality and is comfortably separable from it. The digital mode itself, in this case, is seen as an apparatus of information and the digital image is considered a supplemental representative outcome of that processing of that information.

Moreover, Geoghegan also contests the sharp distinction drawn between digital and analog media and argues that "the digital, or at least the 'actually existing digital,'" is a hybrid or mixed medium. [Any] attempts to define the digital in terms of the digital involve some kind of ideologically suspect exclusion or metaphysical obfuscation."[91] For Geoghegan any feature that may distinguish digital from analog media is based on the assumption that can be undone to undermine any "essence" one may attribute to digital. There can be no digital essence.[92]

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[90] Ibid., 60.
[91] Alexander R. Galloway and Bernard Dionysius Geoghegan, "Shaky Distinctions: A Dialogue on the Digital and the Analog," e-flux, Issue #121, October 2021, https://www.e-flux.com/journal/121/423015/shaky-distinctions-a-dialogue-on-the-digital-and-the-analog/.
[92] In the same conversation Alexander Galloway insists that the "digital" must still be considered as a distinct mode constituted by arithmetic, inclined towards spatiality and atemporality.

The assumption that the digital mode has a "purer" essence that precedes visuality and is perfectly separable from the analog betrays a broader assumption about the independence of information. Information has often prevailed as an abstract entity outside of particular material configurations: whether it appears on the screen as an image or a code, as electric signals in a wire, or a statistic verbalized by a human being, information persists as a singular thing, only in different material iterations. It is almost as if information exists outside of matter and therefore, "the bit is the new atom." Levy seems to adhere to a similar notion. Even though he maintains that digital coding itself is potentializing at best, he declares that "information is virtual." At the same time, he finds that digital images themselves are "possible images displayed on the screen."[93] If information itself is virtual, its digital outcome is only possible at best, we can infer that Levy considers information to exist in a purer state of differentiation before it manifests as an image or text on the screen. In this particular framework, a linear trajectory exists between information that precedes representation, the digital image that represents it in the form of a 'possible,' and the analog processes that it sets in motion.[94] Recall that Levy also considers that since the binaristic mode of the digital is potentializing at best, the virtual only begins to flourish once human subjectivity enters the loop.

Pure Information	→	Digital Image	→	Human subjectivity
[Virtual]	(potentialization)	[Possible]	(virtualization)	

Levy's Scheme of Virtualization

To reiterate, however, Levy's assessment of the digital is not a cynical one: he agrees computing potentializes information in an infinite number of ways, even if it follows the

[93] Levy, *Becoming Virtual,* 53
[94] Galloway & Geoghegan, "Shaky Distinctions."

protocol of a pre-determined code. On the basis of the infinite ways in which computing processes and represents information, in image or in text, the realm of experience can virtualize.

However, as pointed out above, a number of assumptions in this trajectory fall short. The binary of the digital and the analog, even if theoretically sound, does not account for the relations that exist between computation, the objects it addresses, and the human subjectivity that participates in its physical and epistemological production. No stringent threshold keeps them apart. If information and digital stuff do not precede visual, and if the visual is a function of circular loops that run through the realm of the analog, machines, human beings via feedback, where precisely is the room for the "virtual?" Moreover, when these feedback loops proliferate across large expanses of the planet itself, how does one theoretically account for how they take hold? It seems rather simple and even imprecise to insist that in these loops that connect computation, territories, humans and non-human things to insist that either computation and human users are the sole source of creative agency.

The virtual, I propose, is retained in the 'relations' that replace the thresholds in the operations of computation.

To expand on this, I return to the work Brian Massumi. In a different section of *Parables for the Virtual*, Massumi addresses some fundamental questions that plague social theory: What comes before, the individual or the collective? To him, this is a dilemma akin to the riddle of the chicken and egg. What came before, the chicken or the egg? Who can tell? Instead of fixating on the unit of either the individual or the collective, we should, instead, address them as entities that exist in an inextricable relation with another and are constituted as singular units only by virtue of the shared relation in-between. This relation must acquire an independence that is *extrinsic* to its terms. "[W]hat would it mean," Massumi asks, "to give logical consistency to the in-between?"

It would mean realigning with a logic of relation... It may seem odd to insist that a relation has an ontological status separate from the terms of the relation. But, as the work of Gilles Deleuze repeatedly emphasizes, it is in fact an indispensable step toward conceptualizing change as anything more or other than a negation, deviation, rupture, or subversion…

If [things] cannot be seen as terms in extrinsic relation, then perhaps they can be seen as products, effects, coderivatives of an immanent relation that would be change in itself. In other words, they might be seen as differential emergences from a shared realm of relationality that is one with becoming—and belonging.[95]

In the operations of computation itself, relations proliferate across the planet. Computation becomes a planetary-scale infrastructure by forging relations between humans, machines, objects, infrastructures and territories Computation does not *impose* as much as it participates in mutual becoming via these relations. Its success as a material force across the planet should be attributed to this. This does not mean that the becoming it participates in is inherently politically and ethically emancipatory. As Deleuze, will remind us, an apparatus can capture *by* being attuned to becoming. In a similar vein, Massumi notes, "[c]hange is an emergent relation. [But] post-emergence there is capture and containment… Becoming becomes reviewable and writable."[96]

A crucial assumption that keeps us from appraising the "generative" component of computation is that the nature of the relationship between "data" and real-objects is of one of

[95] Massumi, "The Political Economy of Belonging and the Logic of Relation," in *Parables for the Virtual: Movement, Affect, Sensation,* (Duke University Press, 2002), 70-71.
[96] Ibid., 77.

similitude. To put it simply, when we speak of "data" about an object, a person, or an infrastructure, to our mind, data is either true or false, accurate or inaccurate, precise or imprecise in its portrait of the latter. It comes to acquire a *representative* role with respect to whatever it may address. Discussions around subjects like algorithmic bias explicitly or implicitly convey this notion: Facial recognition technology, for instance, used extensively in law enforcement, is found to be consistently least accurate for subjects who are female and Black.[97] Discourses around such racial and gender algorithmic bias then seek to formulate alternative models that reflect a more unprejudiced view of all subjects. When this alternative is envisioned and enforced, it does not amount to a *return* to an objective algorithm that was deviated from, but the creation of a new generative computational process whose outcome, we hope, is more egalitarian.

The idea of data as *generative* rather than purely representative becomes harder to grasp in the context of research on the natural world. Culture, or human societies, are easier to theoretically refurbish in the light of some form of constructivism; but it seems bizarre to suggest that nature, its metaphysical inverse, is "constructed" at all. To overcome this strange impasse, Jennifer Gabrys considers the proliferation of DIY citizen-sensing projects, in which non-expert people use environment-sensor technology to gather data to inspire or advocate for change. Smartphone apps, for instance, provide air quality and pollution tracking apps such as Air Care and Breezometer, that provide environmental data connected immediately to the experiential conditions of the users. This may differ vastly from long-term average air quality information that has more scientific legitimacy or informs government policy. What, then, accounts for the relevance of this "immediate," experiential data?

[97] SITNFlash, "Racial Discrimination in Face Recognition Technology," *Science in the News* (blog), (October 24, 2020), https://sitn.hms.harvard.edu/flash/2020/racial-discrimination-in-face-recognition-technology/.

Before we explore Gabrys' insights to this question, we must pause to address a significant takeaway that is relevant to the conditions of computation as a planetary-force: "Data" is not a homogenous entity grounded in a singular apparatus of legitimacy. This is especially the case with the proliferation of various methods of data-collection and computation – commercial, scientific, personal, collective (wherein the latter two may borrow from methods and applications of the former two). Moreover, there are significant overlaps between them; such as scientific research that is commercially funded or commercial research that claims scientific legitimacy. The flows of money, data, and research between the two tells us that it is, frequently, not simple to conclusively disentangle one from the other.

Does this mean that all scientific research is tainted with the trace of commercialism and cannot claim scientific legitimacy? Certainly not. The question of what constitutes scientific legitimacy itself is not simple to answer. In a provocative article titled 'To be Scientific is to be Communist,' Liam Kofi Bright and Remco Heesen suggest that instead of ascribing an *intrinsic* legitimacy to research based on one epistemic norm or another, the criterion should be non-epistemic: to make scientific work publicly aware for scrutiny and debate by a community of researchers in one's field, a practice they call the 'communist norm.'[98] One of the major reasons a norm of this kind is necessitated is because commercial research, such as the kind conducted by pharmaceutical companies, is marketed as scientifically legitimate but kept under wraps. As long as it serves the purpose of the company in question, it remains admissible.

To theoretically account for the heterogeneity of such varied kinds of data, Gabrys argues that all data must be viewed in the particular context in which it gains 'relevance.' Instead of data

[98] Liam Kofi Bright and Remco Heesen, "To Be Scientific Is to Be Communist," *Social Epistemology*, January 23, 2023, 1–10, https://doi.org/10.1080/02691728.2022.2156308.

having intrinsic validity, it must be viewed as an entangled entity in the environments that it mobilizes and that, in turn, impart to it its legitimacy:

> Relevance is a term that Whitehead uses to address the ways in which facts have purchase, and the "social environments" that are set in place in order for facts to mobilize distinct effects… If facts require particular social environments in order to have relevance, this does not make them illusory.[99]

The suggestion made about the usefulness of the 'communist norm' as an indicator of scientific legitimacy, in many ways, almost anticipates this relationship between a "fact" and its environment, and accordingly argues that scientific validity be derived specifically from a shared space of academic community. Simultaneously, data that is gathered by non-expert individuals or groups for purposes of politically advocacy is made relevant by being politicized and publicized as an indicator of environmental issues.

This does not mean that all data or research produced has no real relationship with the object it seeks to represent. Taking away from the representative role of data does *not* amount to pure schizophrenia, or a philosophical implication that the "in-itself" is inaccessible. Rather, different kinds of data can address the same object differently, depending on its methodology and objective.

What are the implications of this for the current state of planetary-scale computation? The slippage between data, research, or computation and the object it addresses persists in retaining the virtual. No matter how closed and tight the feedback loop between computation and the thing it addresses, the relation itself entails contingency and accident. Data, when viewed as exceeding the limited role of representation, becomes the source of mobilizing

[99] Jennifer Gabrys, "Sensing Air, Creaturing Data," in *Data Publics* (Routledge, 2020), 121-123.

entities across the planet. This mobilization is not an "imposition" but a *provocation* through epistemological means. It is not in the data itself and its "impositions" onto the planet, but in the many social, and technical infrastructures that it mobilizes through it that the virtual persists.

The generative capacity of computation that I envision does not lie strictly "within" the computational apparatus, cleaved neatly from the analog world, controlled and driven by decisive rational actors; Instead it emerges from the many ways in which the computational mode is materially embedded in and realized through the world. The logic of relation itself is what engenders the virtual because it entails new connections between various things. I think of computation as a force, logic, and infrastructure that is attentive to the materiality of the planet, and engages with it. I do not ascribe to it the structure of a transcendental agency that hegemonically shapes materials, even if its political consequences are such. Instead, it frees material aspects of things; the things it frees and generates are not strictly correct or incorrect in any way.

Chapter 3

The Physical World Persists

For reasons historical, theoretical and ideological, the promise that the 'bit' brought with it was one of absolute emancipation. For the longest time, the growth of information technology was premised on a supposed "liberation of information from matter."[100] In discourses of innovation, this manifested in the popular slogan of "the bit is faster than the atom," to signify the exponential growth of information technology over material production. In the last decade, this statement has been contested by "atom is the new bit," to signify that with the slowing down of computing powers, innovation must focus on manufacturing again.[101]

One could dismiss obtuse slogans as ill-informed analogies that hype commercial technology. But they also point to deeper unresolved tensions that exist about the materiality of information: Both in academic and popular discourse, information, for the longest time, prevailed as an immaterial thing distinct from the physical form it takes; as form rather than matter. The pervasive notion of immateriality has profound implications. Jean-François Blanchette, drawing on Katherine Hayles, argues that:

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[100] Jean-François Blanchette, "A Material History of Bits," *Journal of the American Society for Information Science and Technology* 62, no. 6 (2011): 1043, https://doi.org/10.1002/asi.21542.
[101] John Baichtal, "Are Atoms the New Bits?," Make:, February 7, 2010, https://makezine.com/article/maker-news/areatomsthenewbits/.
"The Atom, The Bit And The Gene: Silicon Valley's Innovator's Dilemma," Digital Tonto, September 26, 2021, https://digitaltonto.com/2021/the-atom-the-bit-and-the-gene-silicon-valleys-innovators-dilemma/.
Bernd Schmitt, "From Atoms to Bits and Back: A Research Curation on Digital Technology and Agenda for Future Research," *Journal of Consumer Research* 46, no. 4 (December 1, 2019): 825–32, https://doi.org/10.1093/jcr/ucz038.

> At the heart of this project lies a fundamental assumption, that information patterns (including human consciousness) are ontologically superior to their (accidental) material instantiation (including the human body); a promise, that information "can be free from the material constraints that govern the material world.

Even as scholarship contested this notion heavily, for some reason, the aspiration for freedom from "material constraints" continues to shape popular imagination. A controversial philosopher, Nick Bostrom, for instance, once advanced the argument that in order to realize full number of potential lives that can possibly exist in the future, human existence could be converted into digital simulations.[102] While this seems like an outrageous idea (because it is!) Bostrom is a part of larger movement called 'longtermism' that is not unheard in the technology sector.[103]

Inhabiting the Threshold: Cloud

Perhaps this is too bizarre a proposition to take seriously as a case of the persistence of the trope of immateriality. A more concrete instance then, that is arguably indispensable to the enlargement of the current technosphere, is that of cloud computing. No single metaphor has, perhaps, been as effectively mobilized in transforming computing experiences of users across the world as that of the 'cloud.' If ten years ago, I was typing on a Microsoft Word document on my family's shared computer, I knew, intuitively, that forgetting to hit 'save' could potentially be catastrophic and I was certain to lose a document. Only a couple years ago, when I was working on an undergraduate thesis in India—a time when the cloud still appeared to be a distant and vague place—a friend of mine lost a significant chunk of her

[102] Nick Bostrom, "Astronomical Waste: The Opportunity Cost of Delayed Technological Development," *Utilitas* 15, no. 3 (November 2003): 308–14, https://doi.org/10.1017/S0953820800004076.
[103] Longtermism is the idea that we should prioritize the sum total of future lives that are yet to come into existence, possibly at the cost of lives in the present.

thesis when her computer crashed. Incidentally, my move to Canada in 2021 coincided with enrolling fully onto Microsoft's public cloud computing service, Azure. Now, any application that I use from Microsoft 365—Excel, Word, Outlook, PowerPoint, Office—on my personal laptop or phone, is automatically uploads my files to Azure. If I wish to access the same document from a different device, the click of the cloud icon of OneDrive ubiquitously provides. In fact, with the purchase of a Microsoft 365, users acquire a free subscription to Azure, and abundant access to the cloud.[104]

Fig. 3: OneDrive Icon

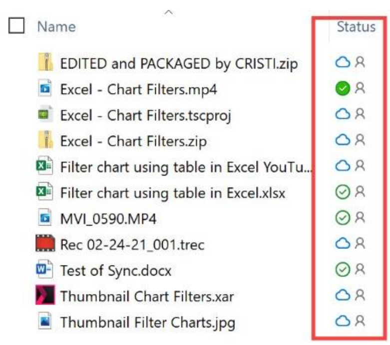

Fig. 4: Various signs to indicate whether or not a document is on uploaded to OneDrive.

How does immateriality manifest in cloud computing? Quite simply, because ideologically and subjectively, the cloud feels like ether. Tung Hui-Hu captures this eloquently in *A Prehistory of the Cloud* when he says:

[104] "Azure Integration with Microsoft 365," Microsoft, February 16, 2023, https://learn.microsoft.com/en-us/microsoft-365/enterprise/azure-integration.

> Like the inaudible hum of the electrical grid at 60 hertz, the cloud is silent, in the background, and almost unnoticeable. As a piece of information flows through the cloud — provisionally defined, a system of networks that pools computing power—it is designed to get to its destination with “five-nines” reliability, so that if one hard drive or piece of wire fails en route, another one takes its place, 99.999 percent of the time. Because of its reliability and ubiquity, the cloud is a particularly mute piece of infrastructure. *It is just there, atmospheric and part of the environment* (emphasis mine).[105]

Hui-Hu makes a crucial point here: The experiential aspect of the silence we attribute to the cloud is also an effect of its extensivity, complexity, and reliability as an infrastructure; perhaps, the silence is an ideological concession that permits the infrastructure to expand further. If a worldwide breakdown of cloud computing were to occur, it would, certainly become more visible to us again.

Temporary suspensions and accidents of cloud are not uncommon. The fact that majority of the world’s cloud infrastructure is owned by a handful of companies—67% by Amazon, Microsoft, Google and Alibaba— makes it highly susceptible to accidents.[106] In December 2021, when the Amazon’s cloud infrastructure, Amazon Web Services, went down, multiple services across North America and Europe that relied of AWS, including IMDb, Duolingo and Tinder, shut down.[107] Beyond access to internet services, our widespread dependence on cloud services also hands over all of our data to specific

[105] Tung Hui-Hu, *A Prehistory of the Cloud*, MIT Press, 2016, ix.
[106] Jason Cohen, “4 Companies Control 67% of the World’s Cloud Infrastructure,” PCMag, December 29, 2021, https://www.pcmag.com/news/four-companies-control-67-of-the-worlds-cloud-infrastructure.
[107] Jamie Grierson and Dani Anguiano, “Amazon Web Services outage hits sites and apps such as IMDb and Tinder,” The Guardian, December 7, 2021, https://www.theguardian.com/technology/2021/dec/07/amazon-web-services-outage-hits-sites-and-apps-such-as-imdb-and-tinder.

companies that then use vast amounts of data to train Artificial Intelligence.[108] Yet, popular concerns about individual privacy sometimes fail the grasp the expanse and complexity of cloud infrastructure, and our parasitic dependence on it for virtually every task we perform on a daily basis. Perhaps, because its existence is atmospheric and silent.

To reiterate the arguments I advanced above: there is no point at which computation is, in actuality, immaterial. Even when a physical object is turned into a logical object, a bit, particular constraints determine its existence. The conversion of a physical thing into computable object is not so much the conversion of a material into immaterial thing, but a transfer from one sort of materiality into another. The de-physicalization of an object does not imply that it is immaterial; it may be intangible to our senses, but particular material structures within the logical apparatus of computational code continue to determine it. In the case of cloud computing, the material traces are data centers that store hardware in huge warehouses and enable computing for all organizations from a distance.

Yet, even as our theoretical assessment of computing deems is thoroughly material and embedded in a physical reality, its capacity for abstraction enables *play* within given constraints that bolster its logical and infrastructural reach as a planetary-scale apparatus. In the case of cloud computing, Devika Narayan explains that the decoupling of software from hardware achieved on a large-scale accounts for cloud computing's widespread success, and its ushering in of platform companies. Virtualization technology has been around since the 1960s, and refers to abstraction of software from hardware, to create multiple virtual machines (VMs) from the same hardware. In the case of cloud computing, however, one company—say, Amazon—aggregates a huge amount of computing hardware distributed all

[108] Robert Stevens, "Almost everything is in cloud—and experts are worried," Fortune, Pctober 24, 2022, https://fortune.com/2022/10/24/business-in-the-cloud-oxford-digital-economies/

across the globe, and the offers virtual machines to any organization with varying combinations of processing powers, storage capacities, software applications, etc.[109] Essentially, this allows any organization to access any amount of computing power without going through the lengthy process of buying and installing any additional hardware or software, at the click of a button. In additional to virtualization, the process of 'containerization,' adopted by cloud computing services, make software applications agnostic to operating systems, further abstracting software from hardware. "Virtualization and containerization," Narayan explains, greatly exaggerate the flexibility of the underlying hardware, meaning that the different parts of what previously was a single machine have been unbundled, fragmented, and dispersed."[110] Any client accessing software services from the cloud provider, no matter how extensively, has no idea where they physical is located. The paradigm shift it brings about, therefore, exceeds a simple displacement of computing resources: "[W]ith cloud-based computing, the structure, anatomy, and architecture of hardware and software are transformed—not merely transferred or outsourced."[111] For the growth of the 'platform,' defined by Nick Srnicek as business model based on the extraction and analysis of data, the usage of cloud computing is indispensable as hosting online services and computing huge amounts of data is at the heart of platforms.

Yet another kind of abstraction that computation enables is the kind realized in simulation technology. As discussed in the last chapter, fields like climatology, where the object is too vast and complex to study through experimentation, rely on simulations to model a system. Historically, the development of simulation technology was tied to military

[109] To see the exact locations of all of Amazon Web Services' 38 data centers, see: https://www.datacenters.com/amazon-aws-data-center-locations
[110] Devika Narayan, "Platform Capitalism and Cloud Infrastructure: Theorizing a Hyper-Scalable Computing Regime," *Environment and Planning A: Economy and Space* 54, no. 5 (August 1, 2022): 919, https://doi.org/10.1177/0308518X221094028.
[111] Narayan, "Platform Capitalism," 924

use and employed to "manage the complexities of real-world modelling by employing random numbers to explore divergent paths of probabilities and assessing statistical likelihoods of different outcomes, […] initially developed by John von Neumann and colleagues as part of the Manhattan project."[112] As Paul Dourish points out, the use of simulation technology is now so extensively used in designing weapons that limiting digital resources would limit their development of weapons. The epistemological import of simulation technology not only *aids* processes in the real world, but comes to displace them by providing insight into how a real-world physical entity is likely to behave in any given scenario. This insight then becomes crucial input that informs decisions about material construction.

The use of simulation I discussed in weather forecast and climatology primarily served the purpose of anticipation. But Dourish's example brings to the fore the constructive role it serves now: simulations do not simply model an existing reality and its behaviour under varied conditions, but allow for the construction of novel realities, and *precede* the production of material infrastructures. A recent instance of this is the use of simulation for Carbon Capture and Storage technology (CCS). CCS refers to a set of technologies that can reduce carbon dioxide (CO_2) emissions by capturing and storing them under the Earth's surface.[113] Since it entails a series of physical and chemical conversions, transportation, and a method of storage that entails several risks like high-volume leaks and earthquakes, modelling it also necessitates quantitively accounting for the probability of accidents. To enable this, a collaboration among several national laboratories and industries produced the Carbon Capture Simulation Initiative, a computational toolset developed exclusively for the needs of CCS technology. CCSI uses 'multiscale models' that can integrate simulations at

[112] Paul Dourish, *The Stuff of Bits: An Essay on the Materialities of Information*, (MIT Press, 2022), 1-2.
[113] Howard Herzog, "Carbon Capture," MIT Climate Portal, January 20, 2023, https://climate.mit.edu/explainers/carbon-capture

various spatial scales—ranging from the quantum to the molecular—and quantify the sum total of uncertainty that stems from the model. CCS is a highly complex and risky infrastructure, and various aspects of its technical and scientific viability are subject to ongoing research.[114] The adoption of advanced computing toolset, like CCSI, is not simply an aid in realizing it, but indispensable to its creation along with a circumscription of the precise risks it contains.[115] Computation's ability to model complex, novel infrastructures and delineate, through quantification, their risks, is also necessary for a technology like CCS to be marketed, procure funds, and become ideologically, politically, and economically conceivable.

Abstraction as Epistemology

The epistemological function of computation is, ultimately, realized in its capacity for spatial and temporal abstraction that enables its imagination at scales ranging from the "infinitesimal to the astronomic" and "instantaneous to the geological duration." This abstraction, in its objective or ambition, appears disembodied and gargantuan in its range for addressing and creating things, but is never, at any point, not in touch with the physical world. It grows not apart from, but along with the findings that pertain to the physical world.

To bring focus back to the Geosciences, consider the relevance of archives of climate science. Besides the abundance of data and simulation models, climate science progresses as a field by archiving various kinds, "ice cores, boreholes, sediments, pollens tree rings, corals," etc. Archival samples become the source of data for research that may be conducted in the future. What these collections represent is the acquisition of material from

[114] Kerry Sheridon, "'Carbon capture' too risky, earthquake prone: study," PhysOrg, June 18, 2012, https://phys.org/news/2012-06-carbon-capture-risky-earthquake-prone.html.
[115] David C. Miller, *et al.*, "Carbon Capture Simulation Initiative: a case study in multiscale modeling and new challenges," Annual Review of Chemical and Biomolecular Engineering, (April 10, 2014), https://www.annualreviews.org/doi/10.1146/annurev-chembioeng-060713-040321.

various regions across the Earth that may otherwise be inaccessible to a researcher. A good example is that of an ice-core drilled at Camp Century, Greenland, in 1966; a 1,387 meter long core that changed the field of climate science by "providing unbroken physical access to 100,000 years of history."[116] How does an ice core become the medium of "physical access" to such a long period of of the Earth's history? Ice cores are cylindrical and dug from deep underneath the Earth's surface of polar regions such as Greenland or Antarctica, where accumulated layers of ice from several millennia remains frozen. The ice traps air bubbles in it that, through analysis, can reveal the concentrations of carbon dioxide, which, when correlated with its temperature, gives an insight into climate changes that occurs over long geological durations.[117] This correlation is essential to building mathematical models of the climate and predicting the climate change that may occur in the future if carbon emissions continue at a particular rate.

How is this niche geoscientific practice relevant to computation? It tells us, first of all, that if computation has an imagination of or appetite for abstractions at multiple scales, that it is necessarily sustained by a close engagement with the physical objects and infrastructures. Any success that computation as a modality has in enabling real-world infrastructures is because it is, firstly, attuned with its materiality. This attunement is not given, but constructed and arrived at by a reflexive inspection of computational media, demonstrated in the methodical study of radar as a bridge to understanding Martian lava flows. This enables the physical enlargement of the technosphere, which in turns enables computation. Secondly, that computation as a planetary-scale generative process is to be situated in a longer history of epistemological endeavours that are driven by a concern for access into deep time.

[116] Shannon Mattern, "The Big Data of Ice, Rocks, Soils, and Sediments," *Places Journal*, November 7, 2017, https://doi.org/10.22269/171107.
[117] "Using Ice Cores to Model Climate Changes," PBS LearningMedia, https://www.pbslearningmedia.org/resource/ice13.sci.ess.icecore/using-ice-cores-to-model-climate-changes/.

Computation's resourcefulness in constructing events on a geological time scale demonstrated this. An early instance of this, as I've explored in the previous chapter, was Babbage's use of the Difference Engine to study of the site of the Temple of Serapis. Even though the Difference Engine was mechanical, it aided Babbage's findings about the behaviour of various rocks under heat over periods of time through correlation, which ushered in mathematization in the field, namely, how the construction of a temporal narrative for computation is materially entwined with objects and procedures that constitute the investigation. In the case of the Temple of Serapis, for instance, the present object is the columns, the instruments that Babbage used to make measurements, as well as the Difference Engine whose results confirm Babbage's hypotheses about the gradual changes in the surface of the Earth over long periods of time.

The fact that computation becomes a means of conceiving long-term future of the planet, such as in the ethical considerations of longtermism—however disagreeable—is also not a coincidence. Any imagination that concerns itself with establishing novel infrastructures of collective political and biological life necessitates is engaging the theoretical and material grounds of computation, and its planetary basis. A reference I cannot help but bring up in this context is the Double Asteroid Redirection Test (DART) that was successfully concluded on September 26, 2022. Conducted by NASA as a means of consolidating "planetary defense," DART was aimed to test the ability to deflect a near-Earth object (NEO), such as an asteroid, with a spacecraft. The part of the process that struck me was the mobilization of spectators from across the globe through a live visual transmission of DART's spacecraft smashing into the asteroid Dimorphos, via a "silent witness," the LICIACube.[118] LICIACube, or the 'Light Italian CubeSat for Imaging of Asteroids,' was a micro-satellite equipped with cameras that captured the event of the collision, and transmitted data to back to Earth during and after the

[118] Tereza Pultarova, "LICIA Cube Will Witness DART Smash into Asteroid Dimorphos in Real Time," Space, September 12, 2022, https://www.space.com/liciacube-readies-to-observe-dart-hit-asteroid.

event. That this data matters to the scientists and engineers working on DART is unsurprising; but in the event of the collision, it exceeded an instrumental, scientific function. It became a live, tactile, and arresting spectacle that mobilized the collective, planetary "we," from the perspective of DART's spacecraft. In this event, computation was not only a technical means of defending a planet, but a visual medium to constitute the "we" that comprises the planet.

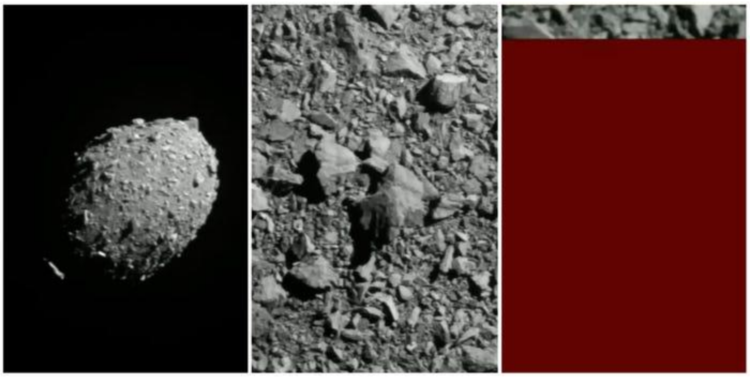

Fig. 5: What "we" witnessed when DART's spacecraft collided with Dimosphos

Conclusion

There is only so much one can write about theoretically without delving into political and ideological questions, especially with a subject like computation. I have done my best to bracket the latter while focusing on the former not because the political does not matter, or is secondary in significance, but because it calls for an elaborate exposition of its own. My interest and concern remained in the theoretical realm of it, and I saw value in articulating a phenomenon as vast, complex, and precarious as computation as a generative apparatus. To reiterate points I made in the previous chapter, this generative capacity is not intrinsically positive or negative in political and ethical value; it may be a “successful” apparatus because it is generative, but it can be appropriated and designed differently for different political ends. To design it differently, we must begin to appraise its potential and complexity, and view it as more than a passive medium. This appraisal was the fundamental motivation for my project.

When I began the project, in attempting to bring several threads together from different disciplines I realized that various assumptions needed to be reassessed; the ‘physical’ nature of the technosphere in ESS and the seemingly abstract nature of computation made them appear distant. But in the chapters above, I have attempted to show a rethinking of their material basis and infrastructural logic can integrate them into a fuller portrait of the structures that make up the world.

Computation is as epistemological technology with an immanent logic of the ‘planetary.’ By gathering a diverse range of examples from the uses of computing, I have hoped to show that its epistemological use at a planetary-scale is far beyond an accident. Moreover, if we are overcome the current set of crises that we face collectively, embracing this logic of computation would be an indispensable task in wresting power away from the exclusive set of actors that control most of computation today. To arrive at and realize viable alternatives, we must embrace the complexity and vastness of computation, and rethink infrastructures accordingly.

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