RECKONING

WITH

EVERYTHING

MERKLE

SIEGERT

Reckoning with Everything

Reckoning with Everything: The Becoming-Environmental of Computing

Edited by Benedikt Merkle and Bernhard Siegert

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Introduction: The New Real

Benedikt Merkle and Bernhard Siegert

As it becomes clear that, since the beginning of the new millennium, the technosphere is in the process of incorporating all other spheres of this planet—the lithosphere, hydrosphere, atmosphere, and biosphere—it is becoming increasingly urgent that we find answers to the de-stabilization of distinctions that were once believed to be categorical and therefore everlasting. This applies not only to distinctions that have long since become questionable, at least in the academic world, such as those between humans and animals, humans and machines, or nature and culture, but also between nature and technology, life and non-life, and matter and information. That rise of the technosphere to a kind of supersphere is undoubtedly linked to the hegemonial tendency of computation to become the epitome of technology itself. There is no question that this development is accompanied by the creation of new injustices on a previously unknown scale. Autocratic regimes, a return to the age of "robber barons," and a largely uninhibited extractive capitalism are challenges to responsible action, including in the sciences and humanities. The entry of planet Earth into the technosphere requires media studies in particular to undergo fundamental changes that go beyond mere reflection on the transformation of global political and economic structures. The field of the so-called cultural techniques is directly affected—insofar as cultural techniques become operational and infrastructural—by the development that "planet earth will don an electronic skin," as Neill Gross (1999) predicted in an epoch-making article at the end of the last century.

According to the conceptual framework underlying advanced research in cultural techniques, distinctions are not given, either ontologically or transcendentally—distinctions are performed. The approach of the cultural techniques theory, and the research method linked to it, therefore seeks to replace the distinctions between form and matter, figure and ground, message and channel, sign and thing, the symbolic and the real, by empirical situations that are characterized by the problem of drawing these distinctions in the first place (Siegert 2015; Siegert 2023; Siegert 2025). Since the theory of cultural techniques works on the premise that the elementary distinctions on which a given culture is based are produced and processed by recursive chains of operations, it is directly challenged by the environmentalization of computing—or, more precisely, by the transformation of the elementary cultural technology of calculation into computing, which consists of networked sensing, processing, machine learning, modeling, rendering, etc., that takes place between platforms "with humans rarely in the loop" (Paglen 2016, quoted in Parikka 2023, 81). As the cultural technique of computation transforms more and more into networked chains of operations—the computing speed and mass of processed data of which transcend by far what humans can perceive, predict, and control—the boundary between system and environment becomes permeable. As the networks of technologically implemented operations become more and more environmental, we cannot ignore any longer the agency that is enacted by this environment. "System function," for instance the selection of something as an object, or as meaning, "is irrevocably permeated by technicity from the environment" (Hansen 2009, 114).

"The map is not the territory" is a standard truism of logical semantics and of common sense philosophy. But the complexity embedded in the environment compels us to go beyond what common sense believes to know. The map *is* the territory—or, in other words, map and territory, media and nature, the Symbolic and the Real, are not distinguished in any categorical way but rather temporarily stabilized results of a recursive process by which they differentiate themselves from each other and call each other into being.

The Becoming Environmental of Computing

Most of the chapters in this book are based on papers presented at the conference "Reckoning With Everything," held in Weimar in March 2024. This conference marked the provisional conclusion of a research project that was generously funded by the NOMIS Foundation over a period of four years. The project dealt with the past, present, and future of computation, with a particular focus on the becoming environmental of computation. The becoming environmental of computation can be viewed from two different angles, which can be roughly described as a) a philosophy of technics perspective and b) a media ecology perspective, whereby the media ecology perspective in turn enters into an uneasy relationship with the fundamental question of what is computable at all. And one of the questions that motivates this book in the background is whether the ontological questions of what computation is, what is computable, and whether there is a computable real can be resolved in terms of media ecology, or whether these questions can only be addressed within the framework of a theory of computation or hypercomputation (Ord 2002; Nyckel 2018).

Re: a) A Walk on a Beach

The environmentalization of computation is usually associated with ubiquitous computing and the Internet of Things (IoT). In order to better understand how the objecthood of things in our environment has changed by and through the emergence of "ubicomp" and the IoT, let us consider a random example. It is an example that could be taken from the life of any person living in the 21st century. This random person, let's call them X, is taking a walk on a beach. Let's say it is a beach on the west coast of Northern Denmark, and let us assume it is winter and the beach is practically deserted. To the west and northwest, the circle of X’s vision is limited by a horizon on which a few ships can be seen. A phenomenological description of this environment as a lifeworld would distinguish two areas. First, the field of effectively conscious objects. This includes everything in X’s immediate surroundings that catches X’s eye. Since there has recently been a violent storm here, as is not uncommon in the winter, this is mainly flotsam, tree trunks, seaweed, fragments of fishing nets, remains of hemp rope, shoes of different sorts, gloves, bottles, all sorts of things that have fallen overboard, pallets, plastic boxes, dozens of little Chinese plastic packets containing instant chicken broth, a fender, buoys, a dead seagull, etcetera. Second is the ineffective horizon of the “unconscious,” an open horizon of non-appearing objects that surrounds the first field and gives it the sense of being a field “of the world.” There is always more that contributes to the constitution of perceived objects than what becomes aware—for instance, the MAERSK container that has gone overboard during the storm and is the source of the plastic packets containing chicken broth.

A ship enters the inner horizon of X that looks somehow strange and therefore catches X’s attention. X takes out their smart phone and accesses the website marinetraffic.org. The website is mapping (commercial) ship traffic on the entire planet in real time. By scaling up the map X is soon able to identify what they see as a RoRo ship en route from a port in the UK to Gothenburg in Sweden. A buoy of the kind fishermen use lies in front of X. A little plastic tag is attached to it. It says: “2021 BO035 Mary-Lauree CN925291.” The internet tells X that the Mary-Lauree is a “caseyeur,” a bow net fishing boat, from the small port of Grandcamp-Maisy in Normandy. X is even able to find an image of the little boat and all the data concerning its year of construction, its engine, and so on. A few meters further on X sees another buoy. It also has a tag attached to it. It says “NIFCA 10 2019 If found call 01670 797676.” A quick check on the internet provides the information that the buoy belongs to the Northumberland Inshore Fisheries and Conservation Authority. Next is a stackable fish box. It carries a red inscription: “Box Pool Solutions Ltd. 01779 481956 No unauthorized use.” That is a company located in Peterhead, UK, which rents out fish boxes. X refrains from any unauthorized use and walks on. Next is a green box that bears an inscription “PACK&SEA” and a bar code below. PACK&SEA is a Danish company, which rents out these boxes. The bar code allows automatic tracking of these boxes and the retrieval of data about their contents. This allows the box to navigate autonomously from harbor to harbor and to communicate with ships, loading cranes, and transport equipment. The green box, although it soon will be transformed into raw material or smoke by some waste recycling process, will continue to belong to the Symbolic as it continues to miss in its place. It was scanned into PACK&SEA’s logistics system

[Figure 1] X's walk on the beach (Source: pictures by X).

at the beginning of its journey and therefore has now turned into a purloined letter.

Apparently, the field of effectively conscious objects is, in the 21st century, embedded in a horizonless global technosphere. Things have a life not only in and through one's lifeworld, but even more so in and through the IoT. Something has happened to the lifeworld that we can describe with Jussi Parikka as a shift from the invisible to the invisual. The term "invisual," according to Parikka (2023, 65), describes what Adrian Mackenzie and Anna Munster have called "platform seeing" (Mackenzie and Munster 2019). In the age of platform seeing the operativity of things is no longer enacted by an observing subject but via an observation that is distributed across sensors, wired and wireless infrastructures, hardware, and deep learning networks.

In contrast to older ecologies of computing (see the example of the merchant's office below), the environmentality of ubicomp extends beyond the inner horizon of effectively conscious lifeworldly things into the outer horizon, the world horizon, and even beyond it into extra-worldly, horizonless environments in which objects are purely statistical in nature, i.e., data structures that are in no way destined to ever be activated pictorially or objectively by an embodied individual consciousness. The "making present" of machines is therefore quite different from the making present of the senses and the syntheses of physiologically embodied subjects. Digitization and algorithmization enable the synthesis of large amounts of data, which in turn already consist of data correlations, i.e., algorithmically and subject-less formed syntheses. The knowledge generated in this way exceeds human imagination not only because of the frequency with which data correlations are calculated, but also because this knowledge is both pre-given and pre-thematic, i.e., environmental. People cease to be at the center of things, as was still the case in Jakob Johann von Uexküll's concept of the environment: according to Uexküll and Kriszat Georg (1956), the *Umwelt* of an organism is established by sensual perceptions that filter specific stimula from the *Umgebung*. In computational environments, environments are no longer established by filter operations or synthesis processes of the organism, but by synchronizations that run in time with the technical infrastructure. Imagination itself is no longer the imagination of the subject but rather shifts from subject to algorithms and digital objects (see Stiegler 2011; Hui 2016, 222). It follows that the word "environment" as part of the term "computational environments" and in the context of "infrastructuralism" (Peters 2015, 30–38) is no longer to be understood as an English translation of *umwelt* in Uexküll's sense, but rather as a translation of *umgebung*, i.e., what Uexküll describes as unfiltered noise for the subject, in which the signals that constitute the environment are immersed in signals that may never constitute anything, but always remain part of the medium.

Phenomenologically speaking, the environment (*umwelt*) would be the inner horizon. However, what determines the situation of the subject in computational environments is that objects do not become evident only when they enter the inner horizon (are activated by the synthesis of the subject), but are statistically synthesized in the environment as objects of possible experience. In contrast to analog filters, digital filters can only use values that belong to the past, even if this past consists only of micro-seconds. By consequence, as we live more and more in media environments the present is replaced by real time. Or, in other words, what we experience as present is more and more a buffered (and processed) version of itself.

Re: b) The Limits of the Computable

Are the limits of the computable a historically invariant category, only definable in terms of the theory of computation, that is, purely mathematically? This view is based on a series of theses of varying scope and power, put forward by mathematicians and computer theorists as well as

[Figure 2] A medianature: the seasnail *Conus textile* Linnaeus is a cellular automaton (Source: Richard Ling (https://commons.wikimedia.org/wiki/File:Textile_cone.JPG), "Textile cone").

quantum physicists, who claim (and attempt to prove) that in certain respects and to a certain degree, computation *is* ontology, or that in a certain sense, nature, matter, or the cosmos is nothing more than a universal Turing machine. The most prominent of these is the "strong" or "physical" Church–Turing thesis. It claims that the whole universe and everything that exists in it is nothing else but a universal Turing machine (UTM) (see Copeland, Posy, and Shagrir 2013). A Turing machine (TM) is a very simple abstract device, invented by the mathematician Alan Turing in 1936, in order to answer the question of whether there is a general procedure by which one can decide whether a given problem is computable. A general purpose computer can be viewed as a technical realization of a UTM that can simulate any individual TM. Classical physics and the UTM do not obey the Church–Turing principle, because the former is continuous and the latter is discrete. However, as Deutsch (1985) has shown, a universal quantum computer would be compatible with the principle.

Another thesis, which is basic to "digital physics," is the Zuse–Fredkin thesis, which claims that the universe is a cellular automaton (CA). It can be shown that the Zuse–Fredkin thesis contains the Church–Turing thesis because there are CA that are doing universal computation (Mainzer and Chua 2012). Stephen Wolfram (1983) has suggested that the evolution of a certain class of CA not only represents very complex structures found in nature but is in fact responsible for those structures, i.e., that CA are ontology. Thus, the sea-snail *Conus textile* is a CA (see figure 2). Already Turing's 1952 text on biological morphogenesis can be understood to mean that the patterns and forms in nature are produced by "something like what are now called cellular automata, models in which the fate of a cell is determined by the states of its neighbours through some simple algorithm, in a way that is very reminiscent of the Turing machine" (Saunders 2013, 683).

In the meantime there are visions that the Real itself can do computation, and will, in the long run, be able to compute itself. In 2005, Miller and Fredkin came up with the proposal to use ordinary table salt, which has a regular crystal lattice, as the hardware of a universal CA that would be capable of universal computation in Turing's sense (Miller and Fredkin 2005).

The research project that led to this book was entitled "The New Real." The provocative nature of the title undoubtedly lies in the implication that the Real could contain the option of being both an old and a new Real. The Real is not, of course, the same as reality. "Reality is that which can be processed within the system" (Kittler 1989, 35). The Real in the sense of Jacques Lacan is what Lacan called the Impossible (following George Bataille), which he defined as that which does not cease to not write itself. In other words, the Real is that which cannot be symbolized. But this does not mean that it cannot be operationalized or even mathematically expressed. As Christina Vagt shows (in this volume), non-symbolizability may be a property of the Symbolic, since there exist functors that write what is lost in translation. In Georg Cantor's language, the Real is the non-denumerable (*das Überabzählbare*) or the continuum. Analog computers, for example, can operationalize the Real (in the sense of classical physics) through measurement. If the computable, according to Alan Turing, is nothing but everything that can be written by a TM, the Real would be strictly that which does not cease to not be written by a TM. Hence, if a UTM does not obey the physical interpretation of the Church–Turing thesis, this is because a UTM conceptually integrates something of the Real in its definition and thereby bars itself from symbolization. Interestingly, based on the latest source research, it can be argued that what happens in Turing's 1936 text on a mathematical-logical level (namely, that when the UTM is supposed to check whether the description numbers of all machines are computable or not, it runs into an unresolvable halting problem) also happens on the media-materialistic level of Turing's text: Moritz Hiller (in this volume) sets out to tell the story of the origins of the foundational document of modern computing—Turing (1936)—and in doing so encounters a gap, an original void, a nothingness from which everything computable emerged.

The title of the research project thus implied the premise that the limits of the computable are historically variable. Since the Real is defined via the insistence of non-writing, the limits of the real are determined by the limits of what does not cease to not being written, which in turn is determined by the fates of the cultural technique of writing. A distinction must therefore be made between purely mathematical deductions of what is computable and a cultural-technical approach which assumes that computation is anything but an independent, historically invariant category.

Our research project thus did not aim to argue that the UTM is becoming ontology but that the cultural technique of computation—as it is becoming environmental—gives rise to a new elemental space, a "New Real," in which elemental and technological media become indiscernable. Building on work that has been done at the IKKM Weimar and by others (Parikka 2023) we can use the concept of "operative ontologies." Instead of contrasting the ontological with the ontic, the idea on which this concept is based is a re-entry of the ontic-ontological difference into the ontic. Operations of computation feed back into the very "nature" of things, with the result that the difference between the Real and the Symbolic or artefact and natural thing is replaced by feedback loops. "Operative ontologies," Jussi Parikka writes, "not only state and list the existence of ontological distinctions but are the engine that mobilizes them in the first place (Parikka 2023, 38). The idea that code is—in an operative sense—ontology is also key to what synthetic biology and bioengineering are up to. For years the laboratories of synthetic biology have worked towards the short-circuiting between *computing* and *living*. Life forms are built *in silico* as much as they are bred *in vitro.* If the unifying strategy of life is autopoiesis, Geoffrey Bowker argues with Lynn Margulis (in this volume), and machines are part of nature, then it is no contradiction in terms that through computation there are developing new forms of life on this planet decentered from humans in the same way that imagination and intelligence are decentered from humans. The operational chains of life merge with the operational chains of digital machines. From a cultural techniques perspective, the Symbolic and the Real, media and nature, are permanently modified results of a recursive process by which they call each other into being. In agriculture for instance, where the term "cultural technique" originally comes from, "precision farming" leads to a digitization of nature as plants are nurtured with a "prescriptive image" of their own future (Gil-Fournier 2019, 49). Or let's return once more to the ocean. The language of Big Data, as Sarah Pourciau (2022) has pointed out, has been oceanic from the beginning. "Caught in the data deluge, adrift on the sea of information, engulfed by the flood, the tsunami, the torrent, the surge of digital flows, it is as though we have (been) plunged, by virtue of our most recent computational advances, into a condition of primordial boundlessness" (233–34). However, we need to take these metaphors literally. The operative ontology of seawater, for instance, which is practiced by plankton research and based on "in situ imaging systems" typically no longer distinguishes between the collecting of images and the collecting of plankton. The seawater is identified with its visualized and digitized information (Siegert 2024, Siegert 2026). For some marine biologists seawater is a microbial soup of DNA fragments floating in the sea like in a test tube. “When microbial DNA fragments stand in for seawater,” writes Melody Jue (2020, 134), “the logic of digitality appears commensurate with seawater.” Though Melody Jue is not saying that code is ontology, she points to a direction where nature turns into “medianature”—a term coined by Jussi Parikka (2012). Climate is perhaps the most prominent example for these “medianatures.” As early as 1946 the mathematician and computer pioneer John von Neumann, the engineer Vladimir Zworykin, and the meteorologist Jule Charney developed the idea that the atmosphere could be completely translated into digital computers precisely because it is a huge analog computer itself. If the atmosphere was a closed system of differential equations then it could be regarded as a Turing table for constructing its solution from known boundaries and initial values. Interestingly, the computational model von Neumann used was developed by the meteorologist Lewis Fry Richardson in 1922, and today it is regarded as a precursor of the idea of cellular automata (see Seppi in this volume). Climate is a prime example of how map and territory bring each other into being: “Atmospheres turned machine-readable as long as one knows how to turn dynamic flows into addressable units” (Parikka in this volume). As a medianature, climate does not exist independently from computational models, and computation did not come about independently from climate modeling. Computing, climate, and the Anthropocene all had to pass through the closed space of the electron tube in order to be able to become what they became (see Rosol in this volume). By no means does this imply that climate change is not real. It does mean that we have to give a new meaning to “what is real.”

A Bit of History: On the Way to a Computational Planet

The contributions collected in this volume deal largely with media environments that address environments in a geophysical rather than a phenomenological sense. The focus here is not on the end of the human (although this is also addressed in many ways), as in the works of Stiegler, Hui, Denson, Bowker (in this volume), or Seberger, but rather on the end of nature. Marshall McLuhan’s (1974) text on Sputnik already marked a moment in the development of an ecological conceptualization of media that did not envision working worlds or smart homes like the early ubicomp visions or cinema and post-cinema like contemporary philosophers of technology, but (long before Neil Gross’ [1999] image of the planet that will “don an electronic skin”) the production of a new planet Earth:

> Perhaps the largest conceivable revolution in information occurred on October 17, 1957, when Sputnik created a new environment for the planet. For the first time the natural world was completely enclosed in a man-made container. At the moment that the earth went inside this new artifact, Nature ended and Ecology was born. (McLuhan 1974, 49)

McLuhan was perhaps the first to recognize that the message of media lies not in the storage and transmission of signs, but in the creation of special ecologies—even if his container metaphor no longer describes the actual mode of interpenetration between technology and planet Earth today.

Following McLuhan, but going beyond his container metaphor and Gross' skin metaphor, research topics in media ecology include, for example, the environmental sensing technologies investigated by Jennifer Gabrys (2016) (using forests, the air, or the oceans), which do not merely represent the planet, but create a different planet, a computational planet. Other examples include the question of operational images, the history of numerical weather forecasting and climate modeling (Edwards 2010), and the technology (and discourse) of "digital twinning" (see Borbach, Chun, and Thielmann 2025; and Wickberg and Lidström in this volume).

One of the aims of this volume is therefore to radically expand the perspective that dates the environmentalization of computation solely to the IoT or the penetration of environments with sensor technologies. This volume therefore presents various historical case studies that analyze the cultural technique of computing and calculation in different specific situations as ecologies, without necessarily presupposing the digital, i.e., in such a way that, in principle, everything can be considered part of a computing infrastructure: codes, instruments, machines, algorithms, standards, materials, architectures, legal provisions, humans, animals, plants, particle flows in the air and in the oceans, celestial bodies, and so on. This reveals ecologies of computing that document how every specific form of computing in the past also had to "reckon with everything," meaning that it could only arise in very specific environments and, in turn, produced very specific environments.

Consequently, the becoming environmental of computation in the cultural-technical sense must be put into historical perspective. All computation always had to reckon with everything—the question is only: What does this "everything" encompass, depending on the historical technical conditions of possibility? In the historical sense, this "everything" is whatever can be operationalized.

Variables, for example, have not always existed in data processing. Medieval property registers, known as polyptychs, which were usually created after fires, looting or misappropriation, had in common that they conferred a permanent and inviolable status on the people and property they recorded. Cows and pigs were included in the fiction of immortality through their written records, something that lawyers otherwise only attributed to institutions. The famous Doomsday Book, commissioned by William the Conqueror in 1085, was so named, explained chronicler Fitz Neal, because what was recorded in it would be "valid" until the last day of the world, including every pig and every cow. The Doomsday Book—like medieval *enquête* in general—did not distinguish between "judgment" (decision) and "date" and therefore also did not distinguish between "validity" and "existence." "In Domesday Book lords and serfs, animals and ploughs, mills and streams, all stand in arrested motion like clockwork automata when the mechanism fails" (Clanchy 1979, 20). Although the Doomsday Book "soon went out of date" (20), there was no such "out of date" that one had to reckon with. Even in the 13th century, Carolingian polyptychs were still being copied, although their contingent content had long since become completely fictional. In fact, the expiration date is a historical invention that originates from a different writing culture. Dates whose values are changeable are a result of a media technology revolution in the 13th century: the differentiation of the medium of writing into parchment and paper. What writing refers to becomes a variable when it is transferred to paper. Paper, imported to Europe from China via Baghdad, creates conditions under which it is possible to reckon with something other than the eternal attributes of God or the immutability of logic. Paper is a typical temporary storage: what is written down here will always have been canceled out. It was in the chancellery of Emperor Frederick II of Staufen that this new time format and this new medium were introduced, in significant contrast to parchment documents. In addition to public documents (*instrumenta publica*) written on parchment, a new type of document called a register was created, which was made of paper and did not have to meet the expectation that the accuracy of the events recorded in it would survive for a long time. These documents would later be called files. Paper is a random access memory. What goes into the paper archive is only temporary. "This registering technology removed power from the realm of eternity and subjected it to time." (Vismann 2008, 81). With the introduction of paper in Europe, the permanent deletion and overwriting of data became an unavoidable standard of early modern administration and the associated notion that data are bound to an expiration date.

The introduction of paper into Europe was the necessary, although not sufficient, precondition of the invention of double-entry bookkeeping (Siegert 2003). Double-entry bookkeeping is a cultural technique based on wasting space. Crossing out entries in the journal when they are transferred to the ledger is an operation that double-entry bookkeeping relies on and that is only conceivable if writing materials are cheap. Because ledgers only store transactions that are worth keeping until the annual balance sheet, ledgers are destined to be thrown away. However, double-entry bookkeeping is not based solely on paper, but on an entire media network: the invention of the compass, the rise of the portolan chart and—most of all—the introduction of Hindu-Arabic numerals (Siegert 2003). Therefore the office of the merchant can be described as an environing technology (Sørlin and Wormbs 2018), which shaped the environment of the Mediterranean. Because ships transported not only goods but also numbers, companies could establish subsidiary companies in the port cities around the Mediterranean, which appear in the ledgers of double-entry bookkeeping as personae, represented by their accounts. The small space of the office ruled and shaped large geographical spaces (Meynen 2004, 163–92).

Another example is the technique of Micronesian navigation, which Edwin Hutchins has analyzed in his *Cognition in the Wild*. By reconstructing how Micronesian navigators reckoned with star constellations, the sound of flowing water, birds, and imaginary reference islands, Hutchins (1995) was able to formulate the theory that cognition is not in the subject but distributed in an environment composed of nature and media.

Anna Echterhölter (in this volume), on the other hand, shows how the introduction of units of time was a cornerstone of colonialization, which violently intervened into indigenous systems of temporal order to compute the flows of humans. Ranjodh Singh Dhaliwal (also in this volume) proposes to think with pipelines, both real and imagined, as a central concept and technique of computation, and Jeffrey Kirkwood (in this volume) posits techniques of parallelization at the heart of current generative artificial intelligence within a story of “computational financialization.”

To be distinguished from the historical media ecologies that relativize the “everything” of *Reckoning with Everything* are examples that belong to the history of the making of a computational planet—for this history does not begin with the sensor technologies of the 21st century.

A fascinating example is the engineered landscape of Bali, famously described by anthropologist Stephen Lansing. Bali has a thousand-year-old irrigation system for rice cultivation that consists of a technical and a social component: an irrigation system of weirs, canals, and reservoirs, and a system of water temples, with a temple associated to each weir. In response to changing environmental conditions, the water temples must make their decisions about cropping patterns in consideration of a trade-off between two constraints: water distribution and pest control. If all farmers plant at the same time and harvest at the same time, the subsequent fallow period may reduce pest populations by depriving them of food and/or habitat. However, if everyone plants and harvests at the same time, the need for irrigation cannot be phased so that the fields at lower altitudes do not receive enough water, but if cultivation and therefore irrigation is phased, the pests can simply migrate from field to field. Finding an optimal balance between these two constraints is not easy, as the decisions of farmers in upstream areas affect their neighbors in downstream areas, and constraints such as the amount of water available for irrigation vary by location and season. In addition to a water supply system, Balinese people constructed a network of shrines and temples. These provide farmers with a structure for coordinating cropping patterns: temples are located at junctions, where farmers meet to discuss the patterns. The ritual calendar provides a template for the phases of farming. Pest control and water capacity are boundary constraints that connect neighboring systems, whose interdependence is framed ritually.

Lansing's thesis was that the optimal cooperation patterns that emerged through the decentralized organization of water temples exhibit systemic properties that could be formalized. In other words, that Bali's irrigation system behaves like a computer. Together with systems ecologist James Kremer, Lansing built a simulation model to observe how the water temples reacted to changing environmental conditions over time. They could show that the irrigation system of Bali was functioning like a giant hydraulic computer (Lansing and Kremer 1993, Imhof n.d.). Its fluidic logic calculated where water should flow in order to maximize rice yield and minimize pest infestation. It appeared, then, that a network of water temples was able to learn. As the artist group U5 put it in their film about Lansing's and Kremer's work: "The entire island was thinking" (*Double Bind* 2019).[1] Hence, it is not nature or the physics or life that are equivalent to a TM or to cellular automata—it is the medianature of infrastructured environments, which engineer landscapes and produce naturecultures, which become computational.

The idea that the entire planet Earth is a computational medianature emerged at the same time as the design of the first programmable calculating machine, Charles Babbage's Difference Engine. For Babbage, who had been pursuing an ambitious program to identify all "natural constants" since the early 1830s, the connection between the programmed movements of the calculating machine and the operations of the Earth was not merely an analogy. "For Babbage, the earth was a calculating engine" (Dolan 1998, 313). It produced its own record of its activities in the form of fossils. Babbage used innovative techniques for printing diagrams and tables to provide accurate and consistent evidence of the effects of geological phenomena, which in turn were evidence of uniform and consistent processes/operations within the Earth. Insofar as the calculating machine and printing not only represented the principles of geology but also helped to bring them about, Babbage can be considered the founder of "media geology."

1 We owe special thanks to Jussi Parikka for bringing the film *Double Bind* by the artist group U5 to our attention.

More than 150 years later, geophysics, which has meanwhile become a branch of research in the petroleum industry, openly states what Babbage had only implied in his geological studies. In 1986, the pioneer of digital reflection seismics, geophysicist Enders Robinson, postulated that for geophysics, "the earth itself is a great computing machine" (Knöferl 2025, 87). It seems uncanny that a research project investigating the environmentalization of computation does not even need to formulate the core theses of cultural technology research or "operative ontologies" itself: "Oil from mathematics" was the title of an article published at the Massachusetts Institute of Technology (MIT) in 1953 with a radicalism that today's media ecology and cultural technology research rarely dares to adopt (see Knöferl 2025, 64). If reflection seismics has ultimately created an oil planet, and if oil and data processing become one, then it is inevitable that the planet and the computer will eventually collapse. When signals are received in/through/from the Earth and can be fed back to the Earth, the Earth itself becomes part of the "computing system" and, at the same time, the computer becomes embedded in the "total environment of the earth" (Knöferl 2025, 64). Being and computing sublate each other (in the Hegelian sense of *sich aufheben*), so to speak, in an absolute knowledge that, as Kittler said, runs in computers as an endless loop (Kittler 1986, 8).

The New Real

Let us return to the ocean one last time. A semi-fictional episode in Thomas Pynchon's novel *Mason & Dixon* deals with the difference between the cardinality (*Mächtigkeit*) (to use Cantor's term) of the Symbolic and the Real. That is the episode in which talking clocks enter the stage: on Saint Helena, where, after their mission to the Cape of Good Hope, the two stargazers Charles Mason and Jeremiah Dixon pay a visit to Nevil Maskelyne (later the Astronomer-Royal of the British Empire) in October 1761, the Ellicott clock and the Shelton clock meet for a short moment. The clocks use the opportunity to exchange a few words about their respective owners, but actually they would prefer to talk about something else: "And indeed, what they wanted to talk about all along, was the Ocean. Somehow they could not get to the Topick" (Pynchon 1995, 123). The reason why clocks cannot articulate the ocean is that they are discrete entities and the ocean is a continuous one. The "traditionally presumed topology" of the sea "has the density, compactness, and connectedness of a geometrical continuum" (Pourciau 2022, 234). Under the conditions of the symbolic order of 1761, the discrete and the continuous cannot be brought into alignment. Although clocks feel the need to beat in synchrony with the waves of the ocean, the waves of the ocean remain uncountable—nondenumerable, of a cardinality that must remain inaccessible to the discrete existence of timepieces.

This formless, infinite, that which can never be limited, this continuum, corresponds to what we call “the Real.” “This substratum can give birth or give way, depending on the creation story in question, to delimited territories and finite bodies, but it can never be remainderlessly equated with such countable, analyzable collections” (Pourciau 2020, 235). The idea that the material substrate of the world is an ocean capable of producing finite bodies goes back to Lucretius. Lucretius called the substrate of everything that has ever been capable of being experienced as form in history the sea of matter, the *pelagus materiae*. The world of visible phenomena is nothing but the beach onto which the *pelagus materiae* has thrown distinguishable things, like the debris of enormous shipwrecks (Lucretius 1957, II, 554–55). Debris that, as our walk on the beach has shown, is sewn into the IoT.

The continuum has the cardinality $\aleph_1$; it is the nondenumerable. The digital oceans that are constantly invoked in the rhetoric of Big Data, on the other hand, have the cardinality $\aleph_0$; their continuum is discretized—it is the ocean of computable numbers. Turing’s theory of computability eliminated the idea of an uncountable real (Pourciau 2020, 238). Our question is not quite the same as Sarah Pourciau’s. We do not ask, “What happens if we take seriously the idea that the ocean, at a particular historical moment in time, has become digital?” For Pourciau does not really take the idea that the ocean has become digital seriously. Her ocean remains a metaphor for the continuum in Cantor’s sense. We ask: How do models that view the universe as a sea of quantum bits, and thus consider the concept of the continuum obsolete (see Tegmark 2015, 48–51), relate to media ecology research and conceptualizations that, for their part, speak openly of computable flows of matter, be they seas or atmospheres? We are not asking about a way of thinking, but about the cultural techniques that determine what can claim to be reality and what cannot: what is reality is what can be processed symbolically. Reality is what cultural techniques filter out of the Real as the world of the Symbolic. There may always be something remaining, but firstly, this residue is always subject to the proviso that tomorrow a sensor or filter technology may be developed that can digitize this residue (albeit not completely) and transfer it into the Symbolic, down to the last atom, down to the last bit. How do the statements of theory—that the continuum no longer plays a role in a Turing-computable universe—relate to practice, which is in the process of making a “computational planet” (Gabrys 2016) using empirical sensor technology (in situ and satellite-borne), platform seeing, machine-learning neural networks, environmental genomics, and modeling software? This is no longer about the language of Big Data, but about the operational ontology of the sea (or the atmosphere or “Nature 2.0”) beyond the logic of representation. Predictable wind is not the same wind that used to blow in a non-technologized nature (see Gillich in this volume). It is as if the program of writing, as Angelika Seppi has beautifully put it (in this volume), is about to fulfil itself and cancel itself out at the same time as it is narrowing the gap between reality and thought, thing and sign, always faster and with ever smaller gaps on its way to the New Real. The "worst times of night with pencil words on your page only Δt from the things they stand for" (Pynchon 1973, 510) now extend into an ever-broadening present that encompasses the planet, in which history shrinks into a microtemporal dead time.

The vision of a future IoT or ubiquitous computing promoted by experts in human–computer interaction (HCI) was that computing would no longer take place in a box called a computer, but in everyday objects themselves. Traditional media ecology has remained with this urban concept of the environment. The new media ecology has expanded this concept, which was limited to domestic environments, office environments, and traffic spaces, to computational medianatures and the "making of a computational planet." The results of media ecology analyses have shown, and continue to show in this volume, that "the map is the territory"—that the Symbolic and the Real are not distinguished in any categorical way but call each other into being through recursive processes. The implications this has for the field of HCI are discussed by John S. Seberger (in this volume). An event of the past decades that has received little attention in media studies is that, parallel to media ecology or even in coincidence with it, in the physics of information, a branch of quantum physics that has drawn the long-overdue conclusions from Shannon and Turing regarding the mode of being of its objects, it has also been recognized that map and territory, the Symbolic and the Real, information and existence, cannot be separated. Without the concept of medianature having been even remotely acknowledged, the physics of information, like advanced media ecology, tacitly assumes that map and territory are not only inseperable, but that without a map a territory cannot even exist—that existence of the smallest particles of matter cannot be conceived independently of the concept of the smallest units of information.

"Oil from mathematics" was the triumphant headline of the 1953 MIT article. Thirty-six years later, John Archibald Wheeler (1990, 5) postulated the core statement of the physics of information, which he co-founded, and which reads like a generalization of that phrase: "It from bit."

> With a polarizer over the distant source and an analyzer of polarization over the photodetector under watch, we ask the yes-or-no question, "Did the counter register a click during the specified second?" If yes, we often say, "A photon did it." We know perfectly well that the photon existed neither before the emission nor after the detection. However, we also have to recognize that any talk of the photon "existing" during the intermediate period is only a blown-up version of the raw fact, a count.

This means nothing other than that there is no such thing as being, only the cultural technique of counting. Such a being is then coextensive with the countable set of computable objects. And that would be the New Real: not the Real in the sense of the uncomputable, but the Real in the sense of a countable continuum (or sea). A Real that can be called "new" because the cultural technique of counting is, of course, historically contingent. Mason and Dixon's clocks were not yet able to count like Wheeler.

"Turing's implicit thesis is that the countable set of computables is big enough—as big as an ocean, even, albeit not an apeiron—and the question we need to ask and answer in response is: Big enough for what?" (Pourciau 2020, 261). The answer provided by our research project would be: large enough to replace "nature" with medianature or with the "it" of physics based on Shannon's concept of information, whose principle "it from bit" rhymes so strangely with Kittler's (2017, 5) principle of information-theoretical materialism: "only what is switchable is at all." And this principle, which we historicize and interpret in terms of media ecology and cultural techniques research (rather than ontologically) (only what is switchable under the conditions of the given cultural techniques is at all), also includes the philosophical deconstruction of the phenomenological continuum.

For what the postulates of quantum physics and the technological-philosophical (post-Kantian, post-phenomenological) analyses of the environmentalization of computation have in common is the negation of the continuum. Edmund Husserl identified the geometrical continuum with the continuum of perception and with the continuum of the lifeworld (see Siegert in this volume). For Husserl, the idea of the continuum was an axiom both in terms of the possibility of the lifeworld and in the possibility of science. According to the findings of Hui, Denson, and others, the possibility of ideal objects is based on a seamless fusion of signs and non-signs, of perception and computation, but this continuous fusion exists only in the imaginary, generated by real-time computational operations that consist of discrete steps. Algorithmic imaginations and algorithmic lifeworlds allow the subject to experience an imaginary continuum based on a technical Real beneath all phenomenological experience. "Human experience of the present tense is interpolated by computational data: a world seen through the prosthetic and archival eyes of computing, which see at a rate much faster than that of the human eye" (Seberger 2022, 25). The same holds true for the experience of a simultaneity of a shared object that is introduced into the architecture of communication between networked computers. The digital object is in fact not shared but divided up and synchronized in quick succession (see Merkle in this volume). The fact that there is no non-technologized lifeworld—just as there is no non-technologized imagination or perception—is based on the fact that, in terms of media ecologically oriented cultural techniques research, nature, which has become medianature, is just as Turing-computable as the prosthetic continuous synthesis.

John A. Wheeler (1990, 3) stated as a consequence of quantum physics that "every physical quantity, every it, derives its ultimate significance from bits, binary yes-or-no indications, a conclusion which we epitomize in the phrase, it from bit." The event that constitutes the New Real, even if this event is still far from being understood in all its consequences, is that a media ecologist like Jussi Parikka can come to a similar conclusion as a theoretical physicist, albeit not by means of quantum physics but rather through operational ontological reasoning derived from the analysis of operational images, when he speaks of wind as a second-order movement of elementary media: "first as software, then as physics" (see Parikka in this volume). It from bit. And we can say that the same "it from bit" applies as well to the post-phenomenological philosophy of technics, if by "it" we mean the experienced thing. A media ecology based methodologically on operative ontologies is deeply in solidarity with quantum physics, which is based methodologically on Shannon's information theory. If there is a difference between operative ontological media ecology and the physics of information, it is that operative ontology does not conceive of this relationship between information and physics as causal and linear, but rather as recursive: it from bit and bit from it are fed back into each other, thus leading to a "reality" in which it and bit are so fused that it is impossible to say what causes what.

Welcome to the New Real.

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References

Borbach, Christoph, Wendy Hui Kyong Chun, and Tristan Thielmann, eds. 2025. *Digital Twinning*. New Media & Society 27, issue 8.

Clanchy, Michael Thomas. 1979. *From Memory to Written Record: England, 1066–1307*. Cambridge, MA: Harvard University Press.

Copeland, B. Jack, Carl J. Posy, and Oron Shagrir, eds. 2013. *Computability: Turing, Gödel, Church, and Beyond*. Cambridge, MA and London: MIT Press.

Deutsch, David. 1985. "Quantum Theory, the Church–Turing principle and the universal quantum computer." *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, A 400, no. 1818: 97–111.

Dolan, Brian. 1998. "Representing Novelty: Charles Babbage, Charles Lyell, and Experiments in Early Victorian Geology." *History of Science* 36: 299–327.

Double Bind (CH 2019, directed by U5 [artist collective]).

Edwards, Paul. 2010. *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*. Cambridge, MA and London: MIT Press.

Gabrys, Jennifer. 2016. *Program Earth: Environmental Sensing Technology and the Making of a Computational Planet*. Minneapolis: University of Minnesota Press.

Gil-Fournier Martínez, Abelardo. 2019. *Cultural Techniques of the Green Surface: Agriculture, Plant Physiology and the Planetary Living Image*. University of Southampton, Winchester School of Art (PhD thesis).

Gross, Neil. 1999. "The Earth will Don an Electronic Skin." *Business-Week online*, August 30, 1999. https://www.bloomberg.com/news/articles/1999-08-29/14-the-earth-will-don-an-electronic-skin.

Hansen, Mark B. N. 2009. "System-Environment Hybrids." In *Emergence and Embodiment: New Essays on Second-Order Systems Theory*, edited by Bruce Clarke and Mark B. N. Hansen, 113–142. Durham, NC and London: Duke University Press.

Hui, Yuk. 2016. *On the Existence of Digital Objects*. Minneapolis and London: University of Minnesota Press.

Hutchins, Edwin. 1995. *Cognition in the Wild*. Cambridge, MA and London: MIT Press.

Imhof, Dora. n.d. "*Double Bind*: Priests and Programmers curated by Adam Jasper. Swiss contribution for the Sharjah Architecture Triennial 2019." U5. Accessed August 11, 2025. https://u5.92u.ch/double-bind.

Jue, Melody. 2020. *Wild Blue Media: Thinking Through Seawater*. Durham, NC and London: Duke University Press.

Kittler, Friedrich. 1986. *Grammophon—Film—Typewriter*. Berlin: Brinkmann&Bose.

———. 1989. "Das Ohr. Zur Geschichte der audiovisuellen Technologie. Ein Filmfaust-Gespräch mit Friedrich Kittler." *FILMFAUST. Internationale Filmzeitschrift* 73: 16–41.

———. 2017. "Real Time Analysis, Time Axis Manipulation." Translated by Geoffrey Winthrop Young. *Cultural Politics* 13, no. 1: 1–18.

Knöferl, Jan. 2025. *Öl als Öl: Medienökologien der Petromoderne*. Bauhaus-Universität Weimar (unpublished Master's thesis).

Lansing, Stephen J., and James N. Kremer. 1993. "Emergent Properties of Balinese Water Temple Networks: Coadaptation on a Rugged Fitness Landscape." *American Anthropologist* 95, no. 1: 97–114.

Lucretius (= Titus Lucretius Carus). 1957. *Über die Natur der Dinge*. Translated by Hermann Diels. Berlin (East): Aufbau.

Mainzer, Klaus, and Leon Chua. 2012. *The Universe as Automaton: From Simplicity and Symmetry to Complexity*. Heidelberg, Dordrecht, London, and New York: Springer.

McLuhan, Marshall. 1974. "At the moment of Sputnik the planet became a global theater in which there are no spectators but only actors." *Journal of Communication* 24, no. 1: 48–58.

Miller, Daniel B., and Edward Fredkin. 2005. "Two-state, reversible, universal cellular automata in three dimensions." In *Proceedings of the 2nd conference on Computing Frontiers (CF '05)*, 45–51. New York: Association for Computing Machinery.

MacKenzie, Adrian, and Anna Munster. 2019. "Platform Seeing: Image Ensembles and Their Invisualities." *Theory, Culture & Society* 36, no. 5: 3–22.

Meynen, Gloria. 2004. *Büro.* Humboldt-Universität zu Berlin, Philosophische Fakultät III (PhD thesis).

Nyckel, Thomas. 2018. *Berechenbarkeit als Sphäre digitaler Medien.* Humboldt-Universität zu Berlin (Master's thesis). https://edoc.hu-berlin.de/items/bf8d104d-a4c5-418e-a1ec-ac05ec75abaa.

Ord, Toby. 2002. "Hypercomputation: computing more than the Turing machine." *arXiv*. https://doi.org/10.48550/arXiv.math/0209332.

Paglen, Trevor. 2016. "Invisible Images (Your Pictures Are Looking at You)." *The New Inquiry*, December 8, 2016. https://thenewinquiry.com/invisible-images-your-pictures-are-looking-at-you/.

Parikka, Jussi. 2012. “New Materialism as Media Theory: Medianatures and Dirty Matter.” *Communication and Critical/Cultural Studies* 9, no. 1: 95–100.
———. 2023. *Operational Images: From the Visual to the Invisual*. Minneapolis and London: University of Minnesota Press.
Peters, John Durham. 2015. *The Marvelous Clouds: Toward a Philosophy of Elemental Media*. Chicago and London: University of Chicago Press.
Pourciau, Sarah. 2022. “On the Digital Ocean.” *Critical Inquiry* 48, no. 2: 233–61.
Pynchon, Thomas. 1973. *Gravity’s Rainbow*. New York: The Viking Press.
Pynchon, Thomas. 1995. *Mason & Dixon*. New York: Picador.
Saunders, Pete. 2013. “Alan Turing’s work in biology.” In *Alan Turing: His Work and Impact*, edited by S. Barry Cooper and Jan van Leeuwen, 683. Amsterdam, Boston, Heidelberg, London etc.: Elsevier.
Seberger, John S. 2022. “Into the archive of ubiquitous computing: the data perfect tense and the historicization of the present.” *Journal of Documentation* 78, No. 1, 18-37.
Siegert, Bernhard. 2003. *Passage des Digitalen: Zeichenpraktiken der neuzeitlichen Wissenschaften, 1500–1900*. Berlin: Brinkmann&Bose.
———. 2015. *Cultural Techniques: Grids, Filters, Doors, and Other Articulations of the Real.* Translated by Geoffrey Winthrop Young. New York: Fordham University Press.
———. 2023. *Kulturtechniken: Rastern, filtern, zählen und andere Artikulationen des Realen*. Baden-Baden: Rombach Wissenschaft.
———. 2024. *Final Frontiers: Eine Medienarchäologie des Meeres*. Amsterdam and Paderborn: Brill/Fink.
———. 2025. *Techniques Culturelles: Portes, grilles, filtres et autres articulations du réel*. Translated by Frédérique Vargoz. Dijon: Les presses du réel.
———. 2026. “The MediaNature of Seawater: Filtering, Counting, Scanning, Visualizing and Digitizing the Plankton of the North Atlantic.” In *Media Seas and the Blue Humanities: Studies of the High North Atlantic*, edited by J. Alnæs, S. Tollerud Bull, L. Hausken, and S. Østby Sæther. London: Routledge.
Sørlin, Sverker, and Nina Wormbs. 2018. “Environing technologies: a theory of making environment.” *History and Technology* 34, no. 2: 101–25.
Stiegler, Bernard. 2011. *Technics and Time, 3: Cinematic Time and the Question of Malaise*. Translated by Stephen Barker. Stanford, CA: Stanford University Press.
Tegmark, Max. 2015. “Infinity.” In *This Idea Must Die: Scientific Theories That Are Blocking Progress*, edited by John Brockman, 48–51. New York: Harper Perennial.
Uexküll, Jakob von, and Georg Kriszat. 1956. *Streifzüge durch die Umwelten von Tieren und Menschen: Ein Bilderbuch unsichtbarer Welten*. Hamburg: Rowohlt.
Vismann, Cornelia. 2008. *Files: Law and Media Technology*. Translated by Geoffrey Winthrop-Young. Stanford, CA: Stanford University Press.
Wheeler, John Archibald. 1990. “Information, Physics, Quantum: The Search for Links.” In *Complexity, Entropy, and the Physics of Information*, edited by Wojciech Hubert Zurek, 3–28. Boulder: Westview Press.
Wolfram, Stephen. 1983. “Cellular Automata.” *Los Alamos Science* 9: 2–21.

RECKONING WITH WIND AND WEATHER

EFFECTIVE COMPUTATION

METEOROLOGY

FACTORIZATION

ECOLOGY

[1]

Times of the Weather: Seasons of the Real

Angelika Seppi

In *The Savage Mind* (1962) French anthropologist Claude Lévi-Strauss characterizes our age in terms of an unprecedented communicational convergence, where the two dominant forms of approaching the physical realm—from either a "supremely concrete" or a "supremely abstract" point of view—eventually start to overlap. This article explores one peculiar historical instance of the said convergence: the making of modern weather, and in turn, the becoming meteorological of knowledge as such. While this twofold process is best described in terms of an expanding knowledge infrastructure, particular interest is paid to its computational aspects. Computation thereby is disclosed as a multi-faceted socio-technical activity, that far from being limited to cracking numbers is deeply invested in the ongoing formation of a New Concrete—and a New Real.

[L]es gens de province calculent tout. Il n'y a rien au monde que les Sauvages, les paysans et les gens de province pour étudier à fond leurs affaires dans tous les sens; aussi, quand ils arrivent de la Pensée au Fait, trouvez-vous les choses complètes. — Honoré de Balzac

If it met with the protocol of academic publishing, this would be the entirety of my contribution to this book: a passage from Honoré de Balzac, as untimely as it gets, and as precisely to the point of the argument, or rather to the question, that I would like to raise here: What if the manifestation of the "New Real" that we are witnessing today in consequence of the becoming environmental of the cultural techniques of computation is but a strange inversion of the most antique form of effective calculation? As if the cultural techniques of computation had gone full circle: from the most concrete to the most abstract, from the local to the global, from the practical to the theoretical, from the living to the machine. And back. And with a little twist. Or, more than a little, and more than one. Since, as in every journey, and every timely matter, what one returns to, eventually, is in fact not the same anymore. Hence, "coming full circle" is merely a way of speaking, while the literal movement implies the *clinamen*: deviation—minimal at its beginning, imperceptible even, but always already on the brink of turning turbulent. Instead of the circle, the spiral would thus be a more suitable image. What it gives to see, what it brings about, before everything else, is a kind of "New Concrete" that takes shape, today, beyond the realm of human sensibility and cognition and based on all kinds of data made sensible and accountable through technical instruments and devices. The field of the concrete—artefacts turned into sensation turned into cognition turned into techniques turned into artefacts—has thus become a genuinely mixed milieu that is more and more subjected to "being written": programmed, computed, controlled. The Real, new and old alike, on the other hand, and in my account, concerns precisely what does not stop not being written.[1]

Setting the question concerning the novelty of the "New Real" aside for a moment, let me start by clarifying the notion of the Real applied hereafter. With Annette Bitsch I propose to conceive of it straightforwardly, as a historical phenomenon characteristic of 20th-century epistemology

1 That is how Jacques Lacan (1975, 56), in *Seminar XX*, defines the Real as the impossible: "'What doesn't stop not being written' is a modal category, and it's not the one you might have expected to be opposed to the necessary, which would have been the contingent. Can you imagine? The necessary is linked (*conjugué*) to the impossible, and this 'doesn't stop not being written' is the articulation thereof."

and philosophy of science. As such it emerged from the dissolution of the mathematical and physical universe of the 18th century and did so "not as something positive or positivizable, but as non-positivizability and non-objectifiability par excellence. The Real is that which *falls outside* of every reality, and thus also outside the ontic domain of every positive empirical science" (Bitsch 2001, 12, my translation, emphasis added). According to Bitsch it follows that the Real is situated in an *a priori* or ontological domain. I do not contest that but also insist on the very historicity of the exception implied. Since what falls outside of every reality changes with the changing means and maneuvers of writing, the Real shifts "shape" accordingly. While what does not stop not being written was throughout the 20th century conceptualized as temporal being, the emergence of a "New Real" would hence point towards the becoming positive or objective of exactly those timely, operational and processual matters or domains. A set of questions issues forth: Are we, today, indeed witnessing the becoming objective or positive of temporalized being? Is that indeed a consequence of the becoming environmental of computation? If so, does the becoming environmental of computation indeed point towards a radical novelty or rather, as indicated with the quote from Balzac, to a primordial form of effective computation? And finally, what, if anything, continues to fall outside of every reality under the changed media-historical ramifications? The following remarks are an attempt at shedding some light on these questions, firstly by an introductory meditation on the relation between accounting and predicting; secondly, by investigating a specific historical case in which this relation has—since the late 19th century and in the field of meteorology—undergone significant changes; and thirdly, by drawing on the epistemological and ontological consequences these changes have fostered, putting, not least, chance (back) into the equation.

Effective Calculation

"[T]he people in the provinces calculate everything. There is nothing in the world like savages, peasants and provincials for studying their affairs to the bottom in every sense of the word; thus when they proceed from ideas to deeds, you will find the thing completed" (Balzac 1897, 337). I have been meditating upon this passage for quite some time: How to understand the precision attributed to the calculations of the so-called savages, farmers, and provincials? What exactly is this "everything" that is said to be "completed" when (their) thought reaches reality, that is the fact (or, the fact, that is reality)? Would this be the *telos* of "reckoning with everything": the closure of the gap between thought and fact?

I will not dive deeper into this sort of philosophical "Rückfragen," but content myself with an etymological side note. It concerns an interesting tension between "reckoning with everything" and its German cognate: "mit allem rechnen." While the first is all about confronting or settling matters, the latter is all about anticipating and being prepared, about counting on or expecting something to happen. While the one deals with what is or was, the other is all about what will, should, or could be. What ties these seemingly false friends together is a matter of causality, since it is the act of "reckoning with everything" that is supposed to enable "mit allem zu rechnen," and thus to predict or deduce the future from the past, the effect from the cause. It takes only one more step to insinuate that it is this very bond that has carried on and spelled out the "program," and in consequence, the epoch of writing from its first inception to the algorithmic turn it has since undergone. One gets the creeping feeling of an uncanny convergence between the record of the past and the play of the future, a flattening out, as if the program of writing had—to a certain extent and in certain domains—indeed realized (and thereby cancelled) itself (out), coming, to come back to Balzac, from thought to reality ever faster and with ever smaller gaps and delays. I call this convergence programmatic (see Seppi 2021, 199–227).

If Claude Lévi-Strauss, who opened his monumental work *La pensée sauvage* (1962) with the same quote from Balzac, was right, then what I just referred to as "programmatic convergence" goes hand in hand with another—or is it the same?—communicational convergence, in which the two strands of approaching the physical world from either a "supremely concrete" or a "supremely abstract" point of view eventually start to overlap (Lévi-Strauss 1966 [1962], 269). While both approaches have fostered equally positive forms of knowledge, the first one—practical knowledge—is situated in the domain of sensually perceivable qualities and the second—theoretical knowledge—in the domain of formal properties. And it took the two of them, as Lévi-Strauss (1966 [1962], 269) remarks, until the middle of the 20th century to cross paths: "that which arrives at the physical world by the detour of communication, and that which, as we have recently come to know, arrives at the world of communication by the detour of the physical. The entire process of human knowledge thus assumes the character of a closed system."

In what follows I will explore one particular historical case, where the indicated convergence announced itself early on under the premise of a sort of meteorological and at the same time calculative or computational turn: Lewis Fry Richardson's (1922, 219) "forecast factory." As a striking vision of computational prediction from the early 20th century, Richardson's "forecast factory" does not only shed light on the making of modern weather, but foreshadows in significant ways the double becoming that underlies today's so-called medianatures: the becoming environmental of the cultural techniques of computation and the becoming technological of the environment. It is in this double becoming that we can identify the contemporary passage that leads from thought to fact. I call this passage ecological.

Forecast Factories

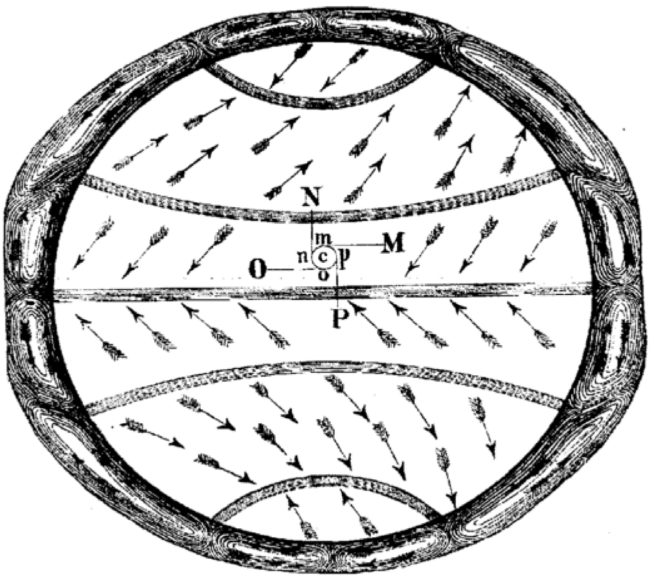
When Richardson came up with his numerical approach, weather forecasting was still widely considered "more an art than a science" (Lynch 2008, 3432)—at least if and to the extent that the scientific method is defined in terms of its empirical grounding, exactness, and predictability. While the weather and its instances, the meteors, were clearly never absent from the sphere of practical knowledge and have become objects of theoretical speculation at the latest with Aristotle, they remained, in the words of Michel Serres (2000 [1977], 67), "the repressed content of history," and were of concern only to those "in whom the learned have no interest: peasants and sailors."[2]

The belatedness of meteorology becoming an exact weather science is owing to the very peculiarity of its "objects": the *events* of the atmosphere, like rain, hail, thunder, lightning, winds, or clouds. As John Durham Peters (2015, 166) pointed out, "[u]p to the twentieth century, astronomers could dream of compiling a census of all the stars, but clouds or winds are not countable in the same way, and they have defied efforts at scientific classification." While astronomy deals with cyclical constants that have been—for thousands of years—the object of exact science and subjected to reversibility, meteorology deals with atmospheric variables that—only recently—have become the object of a probabilistic science and pertain to the regime of irreversibility. And while any knowledge of both the celestial constants and the atmospheric variables depends on a set of sky media, the nature of these sets varies accordingly: confronting us with a (fairly well elaborated) history of cyclical and linear sky media such as clocks, calendars, and their celestial sources on the one hand; and a (to a large extent still unwritten) history of punctual and fractal sky media such as towers, balloons, and all kinds of measurement instruments (like thermo-, baro-, hygrometer, etc.) on the other.[3]

It is no surprise, then, that decisive developments in modern meteorology are intimately linked to the fever of datafication that marks the modernist project in general, with its ever more refined instruments of measurement and inscription and its ever faster and denser means and nets of communication. As has been repeatedly pointed out, the making of modern weather is literally unconceivable without telegraphy: "The telegraph enabled people to perceive of the weather as a widespread and connected affair, rather than an assortment of local surprises" (Gleick 2011, 147). No communication of weather

2 First ridiculed and later recognized as pioneers of modern weather forecasting were indeed an officer of the Royal Navy, Francis Beaufort, and his protégé Robert FitzRoy (see Janković 2000; Klein 1999).

3 The sky's twofaced media almost always involve the reckoning of time and are theoretical in the Greek sense of the word, where theory means looking or watching and is related to theater, in the double sense of spectacle and speculation (see Peters 2015, 167).



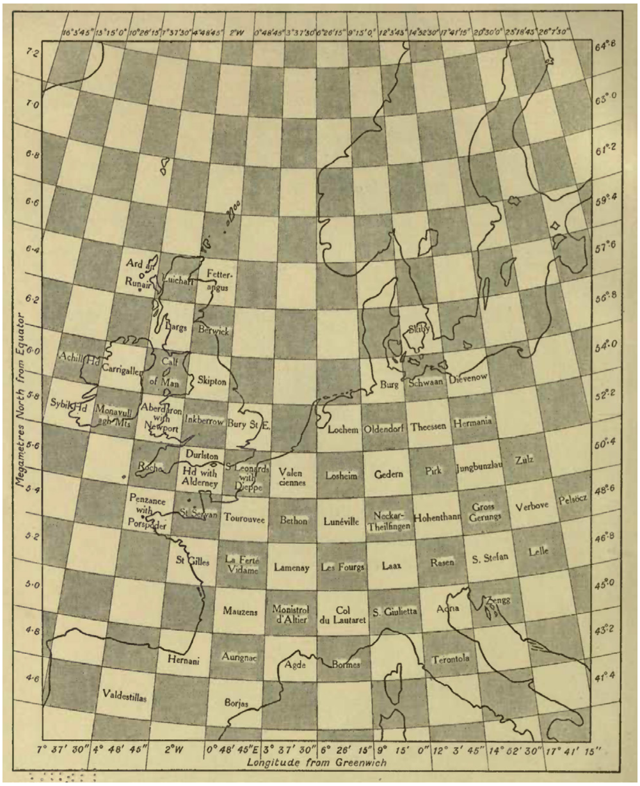
[Figure 1] Ferrel's three-cell global circulation diagram (Source: Ferrel 1856, 290).

data would on the other hand have been possible without the respective measuring devices and instruments, which, since the 17th century, had started to "open up a perceptual space that escapes the five senses and lies on the other side of the perceptible" (Engell, Siegert, and Vogl 2005, 7). I would like to conceive of this opening in terms of an increasing explication and discretization of formerly implicit qualities that gives rise to an ever renewed (more-than-human and potentially computable) concrete.[4] The increasing production, gathering and communication of weather data thus provided the grounds for an up-to-then unprecedented concretization of the events of the atmosphere, and was soon followed by theoretical and practical approaches towards their potential calculation.[5]

First theoretical approaches towards the calculation of weather phenomena (Nebeker 1995) date back at least to William Ferrel's model of general circulation from the 1850s and were soon followed by Wilhelm Bjerknes's system of

4 For the increasing explication of formerly implicit environmental conditions since the later 19th century Peter Sloterdijk has coined the term "Umweltumkehrung" (environmental inversion). Not only does the environmental (or atmospheric) background move or is turned into the foreground, it thereby becomes a matter of design (that can extend to destruction) (see Sloterdijk 2004).

5 I situate the "New Concrete" on the intersection of two axes constituting the above-mentioned communicational convergence: the axis of datafication and computability on the one hand, the axis of connectivity on the other.



[Figure 2] Richardson's checkerboard grid for the arrangement of meteorological stations designed to observe pressure at each shaded chequer, with velocity at the center of each white chequer (Source: Richardson 1922, frontispiece)

primitive equations of motion and state.[6] While modern meteorology owes Ferrel the first three-cell global circulation diagram, Bjerknes's system comprised four variables to describe the primary meteorological features (pressure, temperature, density, water content) and three variables to describe motion in the three dimensions, thus paving the way for "weather by the numbers" (Harper 2008). The first practical attempt at a number-based weather forecast dates back to Richardson, who, after completing his studies of physics at Cambridge in 1903 and various short-term research posts and positions in the educational and industrial sector, had in 1913 been appointed superintendent of the Eskdalemuir Observatory in the Scottish Southern Uplands. In the three years of his employment at the remote Scottish weather

6 Far from being "invented" by a handful of ingenious men, modern weather is best described in terms of a "vast machine," or more precisely, a global knowledge infrastructure. "Knowledge infrastructures," comprise, as Paul N. Edwards (2010, 17) points out, "robust networks of people, artifacts, and institutions that generate, share, and maintain specific knowledge about the human and natural worlds."

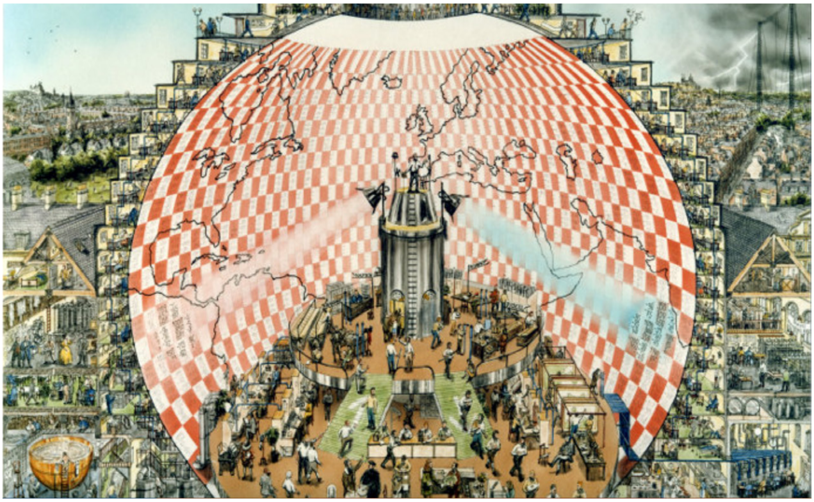
station he started developing a numerical (rather than the former analytical) approach, later tested and published in *Weather Prediction by Numerical Process* (Richardson 1922). His model consisted of several equations, mostly derived from Bjerknes's work, concerning the primary atmospheric variables, the relations between them, and their unfolding over time.

The "International Balloon Day" of May 20, 1910, when weather balloons ascended into the sky all over Europe, provided Richardson with the "ideal" dataset for putting his model to test. Using the morning measurements, he aimed at predicting the weather over Germany and neighboring countries six hours "ahead." The initial data, which later proved rather flawed, had originally been tabulated by Bjerknes. Since Bjerknes's observation points were scattered irregularly across the map of Europe, Richardson started by interpolating them into a uniform computational grid of alternating black and white cells. Each of the cells covered approximately 200 kilometers per side, thus mapping the geographical space from Denmark to Italy and the English Channel to Poland, and five mass-balanced layers at atmospheric heights from surface level up to about 12 kilometers. The atmosphere's dynamic was modeled according to the various interconnections between the atmospheric variables, e.g., how barometric pressure drives the winds and how winds in turn alter barometric pressure. Given initial values of all the variables at time t0, the model calculated the values at a later time t1, then these t1 values formed the basis of a new calculation at time t2, and so on. Since the equations couldn't be solved exactly, Richardson used approximation methods with time intervals of a few hours.[7] Twenty-three "computing forms" laid out every step of the arithmetical operations to be performed, thus constituting the "program, i.e., an algorithm by which forecasting could be reduced to a mechanical series of operations on numerical data" (Edwards 2010, 94).

Not only had the weather events to be predicted in fact already taken place years ago, but it also took Richardson six weeks to reach the end of his calculations—only to produce a phenomenally wrong result. Rarely has such an incorrect forecast been calculated with so much effort and trouble since.[8] All shortcomings aside, the failed attempt was a success in at least two respects: providing the first CFD (computational fluid dynamics) solution of the Navier–Stokes equations, which govern fluid flow (see Lea 2012), and, equally important, the groundbreaking vision of a future "forecasting factory" that could keep pace with the weather and the immense computational effort its prediction requires.

7 Technically speaking, Richardson worked with a set of coupled finite-difference equations, transforming operations on variables into operations on numbers.

8 Richardson forecast a surface pressure about 150 times larger than the change actually observed. Peter Lynch (2004) investigated the error and found it was due to the model's ignorance of so-called gravity waves.



[Figure 3] Contemporary illustration of Richardson's forecast factory (Source: Stephen Conlin 1986).

Identifying the main problem as one of computational speed, Richardson (1922, 219–20) imagined the "forecasting factory" to consist of 64,000 (human) computers. Like in a theater, the (human) computers were supposed to sit in tiers around the circumference of a giant globe, each of them responsible for solving differential equations related to the weather in their quadrant of the Earth. To maintain communication between adjacent zones, the obtained values were imagined to be instantaneously displayed by "numerous little 'night signs," while the work of each region was to be coordinated by "*an official of higher rank.*" Several "senior clerks" and "messengers" were to collect and dispatch "the future weather," as soon as it was computed, to a quiet room, where it would be coded and telephoned to a radio transmitting station. From a podium in the center of the factory, "the man in charge of the whole theater" would ensure that the calculations proceeded at the same pace everywhere by shining a beam of light on areas of the globe where calculation was moving too fast or falling behind. In addition to the core computing faculties, the factory would also comprise a storehouse for "used computing forms," a research department and various administrative offices, and was to be surrounded by "playing fields, houses, mountains and lakes, for it was thought that those who compute the weather should breathe of it freely."

What is most striking about Richardson's factory is that he envisioned computation as both a spatial and social process, the architecture of which was modeled according to the factory design.[9] The circularity of the "theater"

9 Richardson's vision of the forecast factory "as a coordinated human activity that harmonizes machines, equations, people, data, and communication systems in a frenetic

A PLANE FLYING ABOVE RAIN-BEARING CLOUDS CAN CAUSE SUCH CLOUDS TO LOOSEN THEIR BURDEN OF PRECIPITATION BY SCATTERING DRY ICE THROUGH THEM. THEIR MOISTURE THEN BURSTS INTO SNOW, FALLING INTO WARMER LEVELS AS RAIN

CRUSHED DRY ICE FRAGMENTS

THICK CUMULUS CLOUDS AT RIGHT TEMPERATURE

RAIN FROM MELTED SNOWFLAKES

We CAN Control the Weather!

The electronic computer makes it possible, says Dr. Zworykin, scientist.

BY WILLIAM WINTER, based on an interview with DR. VLADIMIR K. ZWORYKIN, Vice President and Technical Consultant, R C A Laboratories

Dr. V. K. Zworykin.

WHEN Mark Twain made his famous quip that everyone talked about the weather but that no one ever did anything about it, he had no way of knowing that the science of electronics, even then in its infancy, not only would promise a revolution in forecasting but would show the way to actually control the elements.

Yes, thanks to electronics we soon will be able to predict in a few minutes the weather for several days ahead. Even more important, man may be able to prevent the development of hurricanes and other violent storms, or divert them, prevent killing frosts, eliminate local fogs, and even cause rain to fall in regions of drought. The benefits to aviation and agriculture alone would be tremendous, to say nothing of the direct savings in lives and property.

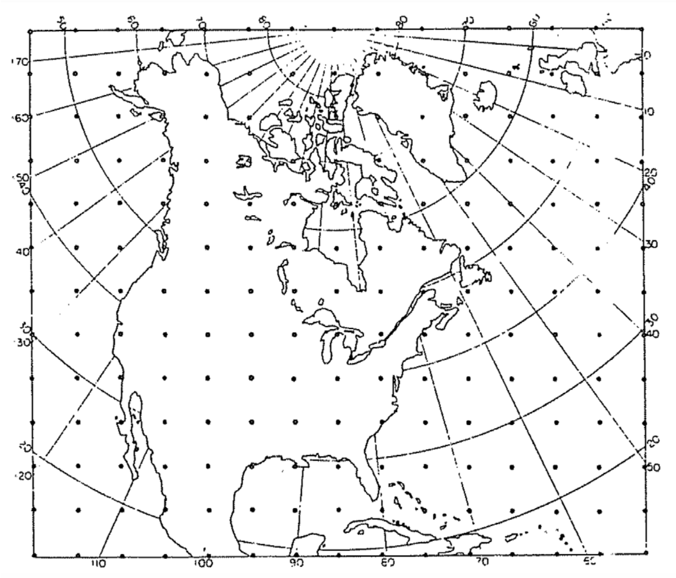
Many earlier attempts at controlling the weather will spring to mind. By dropping "ice seeds" or electrified sand from airplanes clouds have been forced to give up their moisture as rain. The Swiss have dispelled threatening hailstorms by setting off explosives. Other smaller but, perhaps, more familiar methods of weather control may be

68 *Mechanix Illustrated*

[Figure 4] "We CAN Control the Weather! The Electronic Computer Makes It Possible, Says Dr. Zworykin, Scientist" (Source: *Winter* 1948, 68).

wasn't just aesthetic—it reflected the spherical nature of Earth and enabled efficient information flow between adjacent grid cells. Each cell corresponded to a specific geographic location, thus creating a direct mapping between computational and physical space. The computational architecture, moreover, implemented the principle of labor division (already introduced to computation by de Prony and Babbage). For it to run effectively, the whole system required meticulous departmentalization and synchronization, a kind of computational choreography that in many ways prefigured later developments and challenges, including grid computing, parallel computing, and message passing (that is the division of space into computational cells that exchange information; the distribution of work across multiple processors working simultaneously; and the coordinated communication between computational units). For the time being, the fantasy remained just that.

ballet of numerical transformation," remains, as Edwards (2010, 96) points out, "a better description of the practical reality of computing," than today's dominantly individual metaphors.



[Figure 5] The finite-difference grid used in the 1950 ENIAC calculations (Source: Charney, Fjørtoft, and von Neumann 1950, 275).

Another world war and thirty years later, it was John von Neumann who played a pivotal role in realizing Richardson's fantasy by assembling a group of theoretical meteorologists at Princeton's Institute for Advanced Study, amongst them Jules Charney and Ragnar Fjørtoft, and providing them access to the first programmable, electronic, general-purpose digital computer, the ENIAC (Electronic Numerical Integrator and Calculator).[10] Amid the Cold War and supported with grants from the National Weather Bureau, the Navy, and the Air Force, the driving force behind the project was of a military nature, and the modeling of the weather only the first step towards its aspired control and weaponization.[11] Like in Richardson's model, the Meteorology Project's model (of 1950) used a two-dimensional grid mapping the geographical space of North America onto 270 gridpoints (spaced about 700 km apart), and employed finite-difference methods to solve differential equations numerically. Charney's weather model was based on the barotropic vorticity

10 For a more detailed account of this story see the contribution of Christoph Rosol in this volume. As is well known, von Neumann joined the ENIAC team in 1945 in the context of the Manhattan Project. For a detailed account of the ENIAC and von Neumann's contribution to modern computing see Burks and Burks (1981); Aspray (1990).

11 Von Neumann's engagement in the Meteorology Project dates to 1946, when the famous mathematician (together with Vladimir Zworykin) was invited to join a meeting at the US Weather Bureau (see Winter 1948; von Neumann 1955; Kwa 1994). It was only after 1948, when Jules Charney took leadership, that the Meteorology Project started showing graspable results.

equation, and the ENIAC should put the model to test.[12] Weighing 27 tons, consisting of 17,468 vacuum tubes and requiring 24 hours of processing time, the first electronically computed *forecast* was able to predict—still far from perfectly, but closely enough—the weather 24 hours ahead. As stated in the respective publication:

> It may be of interest to remark that the computation time for a 24-hour forecast was about 24 hours, that is, we were just able to keep pace with the weather. However, much of this time was consumed by manual and I.B.M. operations, namely by the reading, printing, reproducing, sorting and interfiling of punch cards. In the course of the four 24 hour forecasts about 100,000 standard I.B.M. punch cards were produced and 1,000,000 multiplications and divisions were performed. (These figures double if one takes account of the preliminary experimentation that was carried out.) With a larger capacity and higher speed machine, such as is now being built at the Institute for Advanced Study, the non-arithmetical operations will be eliminated and the arithmetical operations performed more quickly. It is estimated that the total computation time with a grid of twice the Eniac-grids density, will be about 1/2 hour, so that one has reason to hope that Richardson's dream (1922) of advancing the computation faster than the weather may soon be realized, at least for a two-dimensional model. (Charney, Fjørtoft, and von Neumann 1950, 275)

Though the computational time for weather forecasts varies significantly based on the scale, resolution, and complexity of the model used, it is safe to state that it has today reached and surpassed the pace aspired to by both Richardson and von Neumann.[13] Global weather models, like the American Global Forecast System (GFS) or the European Centre for Medium-Range Weather Forecasts (ECMWF), typically take one to three hours to complete a full run processing trillions of calculations; regional high-resolution models usually complete the forecast in 30 minutes to one hour, while local models work almost instantaneously.[14] The decisive acceleration of processual time since the 1990s is a result both of algorithmic advances and hardware improvements. Today's supercomputers operate at multi-petaflop speeds

12 Since Ferrel, the Bergen school, and especially Carl-Gustav Rossby, changes in the pressure field at higher atmospheric altitudes were found to be indicative of wind propagation, i.e., the movement of the weather at the surface level. Barotropic vorticity measures the vertical velocity of winds rotating around a vertical axis (see Persson 2005; Harper 2008, 151–87).

13 Recall that the Meteorology Project's forecast covered the limited area over North America and would significantly differ from the actual weather when aiming at a forecast beyond 24 hours. The first global numerical weather models arrived in the mid-1970s (see Edwards 2010, 127–29).

14 Up-to-date numbers can be retrieved from the technical reports of the US National Centers for Environmental Prediction and the European Center for Medium-Range Weather Forecasts.

performing quadrillions of calculations per second. Whether Richardson's dream of a forecast factory as fast and "faster than the weather" itself has thus become true remains debatable, nevertheless, and the gap between the dream of a "perfect" calculation-based prediction and the messy reality of actual weather is as yawning as ever.[15]

Weather in the Expanded Field

While the making of modern weather is interesting enough by and for itself, my point here, ultimately, is a different one. It concerns the becoming meteorological of knowledge as such, or, slightly more modestly, the becoming meteorological of our techno-sciences and their objects. In other words, the making of modern weather doesn't stop at the weather, but has acquired the status of a model and paradigm for the constitution and apprehension of a vast array of so-called hyperobjects: like the weather, or like global warming, they are "massively distributed in time and space relative to humans" (Morton 2013, 1–2) and further characterized by their viscous, non-local, Gaussian, and inter-objective properties. One way of addressing the strange phenomenality of these kinds of objects consists of explicating the interweaving of elemental and technical media and processes that constitute them (as I tried to do above with respect to one chapter in the making of modern weather): including natural elements, like the movements of fire, air, water, and earth; instruments to measure them, like thermometer, barometer, anemometer, etc.; scripts to record and machines to communicate and calculate them, like reports, maps, grids, telegraphy, human and electronic computers, etc.; and not to forget, the social, economic, politic, or artistic interests that drive them. Another, or rather complementary approach, consists of asking for the epistemological, or even ontological, consequences that are to be drawn from the insights into the modes of existence of the objects at stake. This is where my concluding remarks are heading. A starting point is provided by the observation that it has indeed become more and more difficult to tell "these kind of objects" apart from any other. That is to say: hyperobjects are not the exception, they are the rule, and while born from fire, they have taken on the "form" of the cloud:

> Under the regime of fire, the Empyrean, the revolution without return, the irreversible is born, then the lavish abundance of analyzed matter, and finally stochastic chance. Beneath the stable figures and controlled

15 Differences in the weather forecasts are due to differences in the chosen model, the scale of resolution, the set of algorithms, initial conditions, and data assimilation methods. To "perfectly" reproduce the actual weather, every current condition for every point on the face of the Earth would need to be taken into consideration. In fact, all models work from an incomplete initial dataset and with a variety of *approximation* techniques. Hence the divergence in the predictive results.

> movements ... lies a new real, brought forth by fire, object of theory, assistant of practice, a real that is no longer rational. ... This is the revolutionary message: The real is not rational; the rational, which is nevertheless inevitable, which is there, is, in fact, impossible. From now on all knowledge … follows the ancient path of fire … Through the thematization of sets, through the topology of spaces, through the field of randomness, through the study of energies, through particle physics, through stellar or galactic clouds, through quanta and the indeterminacy of trajectories, through genetic biochemistry, through the treatment of large populations, through information theory, through every message that is immersed in the nameless sea of noise, through a thousand areas that are closely or distantly connected with the old theory of heat and its derivatives, every object, every package of objects, but also every domain, every collection of domains, are, strictly speaking, clouds. (Serres 1977, 36–38, my translation)

Clouds prevail—not only in the skies, but also in theory. And so do the hyperobjects modeled according to them. Hence, they are best described in terms of the weather, as weather-like or kairological: in flow, distributed, adventitious, fractal, uncertain, stochastic. Needless to point out, first, how intimately the meteorological vocabulary resonates here with the language of communication theory following directly from thermodynamics and fundamentally dealing with entropic processes, probabilities and uncertainty, with clouds, once again, distributions, flows, currents, channels, etc.[16] Needless, secondly, to recall that Norbert Wiener's (1985) epochal *Cybernetics: Or Control and Communication in the Animal and the Machine*, opens, precisely, with the comparison of the oldest with the newest science, astronomy with meteorology, and a respective discussion of the transition "from a Newtonian, reversible time to a Gibbsian, irreversible time" (37–38). Needless, finally, to point out, once again, how deeply this transition is rooted in the technological development—from clockwork to steam engine to communicational machines—that has fostered it.[17] Let it suffice, then, to establish

16 "As a privileged example of disorder and entropic processes, the cloud outlines a set of problems that connects the question of chance events and multiplicity with new physical concepts of matter" (Engell, Siegert, and Vogl 2005, 7, my translation). We can subsume these concepts under the term of a communicational reorganization of physics.

17 "The thought of every age," Wiener (1985, 38–39) comments straightforwardly, "is reflected in its technique. … If the seventeenth and early eighteenth centuries are the age of clocks, and the later eighteenth and the nineteenth centuries constitute the age of steam engines, the present time is the age of communication and control." Michel Serres (1977, 50–69) accordingly speaks of three generations of motors: the vectorial motor of classical physics; the transformational motor of thermodynamics; and the informational motor of cybernetics. It is with the transformational motor—generating movement at the level of macro energies—that time becomes irreversible: "Since we have understood how to build them and grasped them in their theory, … time has a

that through the mediation or in the milieu of communicational machines statistical mechanics takes over classical mechanics and is applied to the increasing amount of situations “in which we deal not with a single dynamical system but with a statistical distribution of dynamical systems; and in which our conclusions concern not all such systems but an overwhelming majority of them” (Wiener 1985, 37). In other words, more and more situations share the characteristics of weather phenomena such as “cloud,” “temperature,” or “turbulence,” all of which refer not to one single physical situation but to a distribution of possible situations of which only one actual case is realized:

> If all the readings of all the meteorological stations on earth were simultaneously taken, they would not give a billionth part of the data necessary to characterize the actual state of the atmosphere from a Newtonian point of view. They would only give certain constants consistent with an infinity of different atmospheres, and at most, together with certain *a priori* assumptions, capable of giving, as a probability distribution, a measure over the set of possible atmospheres. Using the Newtonian laws, or any other system of causal laws whatever, all that we can predict at any future time is a probability distribution of the constants of the system, and even this predictability fades out with the increase of time. (Wiener 1985, 33)

Not only do we find herein a corrective to the fantasy of the “forecast factory” eventually catching up with the actual weather, but, more generally, evidence for the lasting gap that holds accountability and predictability apart—as long and wherever we are dealing with systems of a certain complexity. In conclusion, and coming back to the contrast between the oldest and the newest science, astronomy and meteorology, most sciences according to Wiener (1985, 35) have to be situated in an intermediate position: “rather nearer to meteorology,” as he stresses, “than to astronomy. Even astronomy … contains a cosmic meteorology.”

Wiener’s whole point, of course, is to show that under the contemporary technological condition the old opposition between mechanism and vitalism is losing its grounds and the time is ripe for a new general science: of “control and communication from the animal to the machine.”[18] Not that the old opposition is thereby resolved in favor of one side or the other—it is rather sublated in a quasi-Hegelian synthesis of Newtonian (mechanic, physical,

direction, it is irreversible, it goes from order to disorder” (Serres 1977, 314–15). And it is thermodynamics that, according to Serres, remains the paradigm, in which communicational theory takes part at the level of micro energies.

18 Such is the famous subtitle to *Cybernetics*. The mechanist-vitalist debate is known well enough. Let it suffice to recall that from the vitalist point of view, as paradigmatically expressed by Bergson (1944, 36), “concrete time” and “real systems” are irreducible and finally non-comprehensible to/within the construction of artificial systems and abstract time that the mechanist approach is identified with.

deterministic, reversible) and Bergsonian (vital, biological, evolutionary, indeterministic, irreversible) time, a synthesis firmly associated with Heisenberg's statistical theory from 1925. In it "the statistical Newtonian dynamics of Gibbs is replaced by a statistical theory very similar to that of Newton and Gibbs for large-scale phenomena, but in which the complete collection of data for the present and the past *is not sufficient to predict the future more than statistically*" (Wiener 1985, 37, my emphasis). The crucial difference thus is one of predictability, and since the latter does not apply to the physical realm—at least when assessed at a certain magnitude—a great deal of formerly so-called laws of nature (that classical mechanics were preoccupied with) have now become "merely" statistical (see Jacob 1973, 197). Thus, "not only the Newtonian astronomy but even the Newtonian physics has become a picture of the average results of a statistical situation, and hence an account of an evolutionary process" (Wiener 1985, 37).

To cut a long story short: it is precisely in the age of communication and control that chance now rules all "reckoning" and "everything" has—in the techno-mathematical sense of the word—become impossible. Whomever would wish to identify the new reign of chance with what is called in human affairs "freedom" must certainly be disillusioned. As Wiener (1985, 38) recalls: "The chance of the quantum theoretician is not the ethical freedom of the Augustinian, and Tyche is as relentless a mistress as Ananke." Rather than conceiving of them as opposed forces, the new science of control and communication posits *tyche* and *ananke* as deeply intertwined. In any complex system capable of adaptation and evolution we cannot have one without the other.

Only a science that had withdrawn into the four walls of the laboratory, shielded from the turbulences of the weather, could, as Michel Serres reminds us, have temporarily forgotten, or rather repressed this: "The weather now and the weather to come," Serres (2000, 67–68) writes, "infinitely surpass our account of them, so they are of no account." Hence the repression of meteors, of the weather, chance, complexity, of open systems throughout long periods of the history of science, their abstractions and obsession with the law. Lucretius' physics, just as the knowledge of the peasants and sailors, on the other hand, was outside, and today's physics is, as Serres adds, too, once again. What they encounter outside is the incessant interplay of *tyche* and *ananke*: the world as a place of turbulent flows and the emergence of order, necessarily, by chance. Chance, here, gives rise to patterns, which give rise to order and deterministic systems. Give it enough time though and every (open) system disintegrates, comes apart, breaks up into pieces: "The stable flees, and only the unstable can hold" (Serres 2000, 78). In other words, the *clinamen*, that is, deviation from equilibrium, from lawful movement, and ultimately from the law as such—*is* the law, and it is so as a matter of fact, of experience, of practice: "in fact, in practice, physically speaking, a flow always is or becomes turbulent. The *clinamen* is the infinitesimal turbulence, first, *but it is also the passage from theory to practice*" (Serres 2000, 83, emphasis in the original).

To move from theory to practice, to get outside once again, today nevertheless means to face a weather that radically changed conditions and has in fact become climatic: a "vast machine" driven towards heat collapse. What it confronts us with, ultimately, is a lesson in humility: while we might fool each other into believing that it is we who account for the weather, it is ultimately the weather reckoning with us. To reckon with everything, today, then means above all to reckon with our own reckoning, the real of which remains unchanged: a matter of time—fleeing; a matter of chance—ruling. And though we might conceive of the latter as a sort of intemporal constant let us not be fooled. We never reckoned with *these* chances before, and we never will again.

References

Aspray, William. 1990. *John Von Neumann and the Origins of Modern Computing*. Cambridge, MA: MIT Press.

Balzac, Honoré de. 1897. *The Cabinet of Antiquities*: *The Human Comedy/Provincial Life*, vol. VII. Translated by William Walton. Philadelphia: George Barrie & Son.

———. 1909. *Le Cabinet des Antiques*. Strasbourg: Heitz & Mündel.

Bergson, Henri. 1944 [1911]. *Creative Evolution*. Translated by Arthur Mitchell. New York: Modern Library.

Bitsch, Annette. 2001. *Always Crashing in the Same Car. Jacques Lacans Mathematik des Unbewussten.* Weimar: Verlag und Datenbank für Geisteswissenschaften.

Burks, Armand R., and Arthur W. Burks. 1981. "The ENIAC: The First General Purpose Electronic Computer." *Annals of the History of Computing* 3, no. 4, 310–99.

Charney, Jule G., Ragnar Fjørtoft and John von Neumann. 1950: "Numerical Integration of the Barotropic Vorticity Equation." *Tellus* 2, no. 4: 237–54.

Edwards, Paul N. 2010. *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*. Cambridge, MA: MIT Press.

Engell, Lorenz, Bernhard Siegert and Joseph Vogl. 2005. "Editorial." In *Wolken: Archiv für Mediengeschichte*, edited by Lorenz Engell, Bernhard Siegert, and Joseph Vogl, 5–8. Weimar: Universitätsverlag.

Ferrel, William. 1856. "An Essay on the Winds and Currents of the Ocean." *Nashville Journal of Medicine and Surgery* 11, no. 4–5: 287–301.

Gleick, James. 2011. *The Information: A History, a Theory, a Flood*. New York: Pantheon Books.

Harper, C. Kristine. 2008. *Weather by the Numbers: The Genesis of Modern Meteorology*. Cambridge, MA: MIT Press.

Jacob, François. 1973. *The Logic of Life.* Translated by Betty Spillman. New York: Pantheon.

Janković, Vladimir. 2000. *Reading the Skies: A Cultural History of English Weather, 1650–1820.* Manchester: Manchester University Press.

Klein, Wolf Peter. 1999. *Die Geschichte der meteorologischen Kommunikation in Deutschland. Eine historische Fallstudie zur Entwicklung von Wissenschaftssprachen*. Hildesheim: Olms.

Kwa, Chunglin. 1994. "Modelling Technologies of Control." *Science as Culture* 4, no. 20: 363–91.

Lacan, Jacques. 1975. *On Feminine Sexuality : The Limits of Love and Knowledge. Encore: The Seminar of Jacques Lacan. Book XX.* Translated by Bruce Fink. New York: W. W. Northern & Company.

Lévi-Strauss, Claude. 1966 [1962]. *The Savage Mind*. London: Weidenfels & Nicolson.

Lea, Chris. 2012. “Lewis Fry Richardson: ‘The Father of Weather Prediction.’” *Benchmark, the International Magazine for Engineering Designers & Analysts* January 2012: 36–38.

Lynch, Peter. 2004. “Richardson’s Forecast: What went wrong?” Presentation at the Symposium on the 50th Anniversary of Operational Numerical Weather Prediction, University of Maryland, 14–17 June, 2004. Accessed May 15, 2025. https://www.atmos.washington.edu/~dargan/542/Lynch_NWP50.pdf.

———. 2008. “The Origins of Computer Weather Prediction and Climate Modeling.” *Journal of Computational Physics* 227: 3431–44.

Morton, Timothy. 2013. *Hyperobjects: Philosophy and Ecology After the End of the World*. Minneapolis: University of Minnesota Press.

Nebeker, Frederik. 1995. *Calculating the Weather: Meteorology of the 20th Century*. San Diego: Academic Press.

Persson, Anders. 2005. “Early Operational Numerical Weather Prediction Outside the USA: An Historical Introduction: Part I: Internationalism and Engineering NWP in Sweden, 1952–69.” *Meteorological Applications* 12, no. 3: 135–59.

Peters, John Durham. 2015. *The Marvellous Clouds: Towards a Philosophy of Elemental Media*. Chicago and London: The University of Chicago Press.

Richardson, Lewis Frey. 1922. *Weather Prediction by Numerical Process*. Cambridge: Cambridge University Press.

Seppi, Angelika. 2021. “Aporien technischen Lebens.” In *Grenzen der Formalisierung*, edited by Michael Friedman and Angelika Seppi, 199–227. Leipzig: Spector Books.

Serres, Michel. 1977. *HERMÈS IV : La distribution*. Paris: Les éditions de minuit.

———. 2000 [1977]. *The Birth of Physics*. Translated by Jack Hawkes. Manchester: Clinamen Press.

Sloterdijk, Peter. 2004. *Sphären III: Schäume, Plurale Sphärologie*. Frankfurt am Main: Suhrkamp.

Von Neuman, John. 1955. “Can We Survive Technology?” *Fortune* 51, no. 6: 106–8, 151–52.

Wiener, Norbert. 1985 [1948]. *Cybernetics: Or Control and Communication in the Animal and the Machine.* Cambridge, MA: MIT Press.

Winter, William. 1948: “We CAN Control the Weather! The Electronic Computer Makes It Possible, Says Dr. Zworykin, Scientist.” *Mechanix Illustrated*, January 1948: 68–71.

WIND

COMPUTATIONAL FLUID DYNAMICS

ELEMENTAL MEDIA

SIMULATION AND MODELING

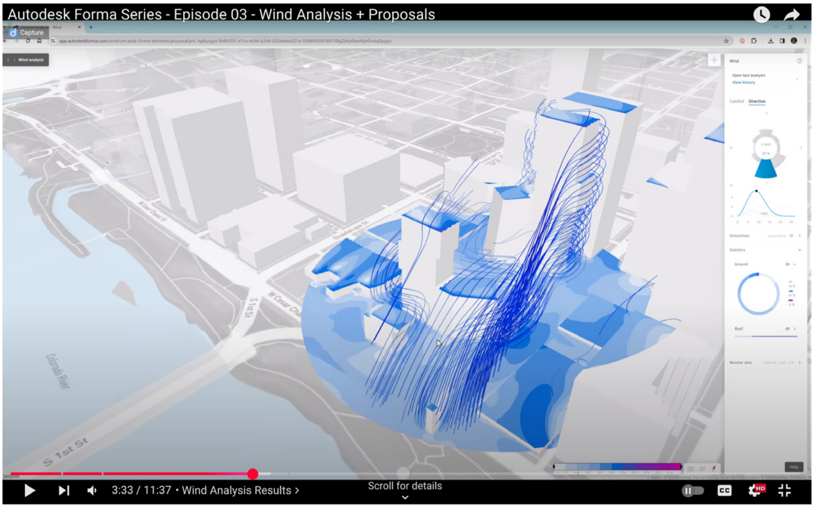
[2]

Wind: An Environmental Data Stack

Jussi Parikka

This chapter focuses on software techniques for modeling and managing wind. As part of the broader field of computational fluid dynamics, questions of technical interfaces are read as part of a longer media history of wind, which also links to discussions around "wind humanities." In this chapter, a specific place is reserved for discussions about abstraction—both as data but also as a central element of wind's own ontology. The text proposes the notion of an "environmental data stack" as a placeholder term to understand the multiscalar management and computation of elemental media of fluids.

I am watching a video. The video is about wind wrapped into an administrative situation. The administration is wrapped into a software environment. A man is explaining wind analysis through the use of a proprietary software environment (Autodesk). It is a tutorial. He talks through rapid (real-time) design testing of wind effects with different geometrical elements such as solid and porous objects. Some of these are buildings or similar constructions. He clicks and adds and shows the different impacts of such constructions of or actually upon wind in a manner that is intuitive to those with an engineering



[Figure 1] A still from the YouTube tutorial, “Autodesk Forma Series—Episode 03—Wind Analysis + Proposals” (Source: Daniel Stine, https://www.youtube.com/watch?v=Q3gwYHuB9fQ).

background but also easy to grasp for a generalist. This video is meant for engineers though. The software is engineering not just buildings with the software design tools but wind. This is a video about wind, about learning how to work with wind. It is odd to think of wind as engineered, or defined by software, but this is the case despite any unintended peculiarity.

It is a subset of a much larger body of work, and numerous other tutorial videos just like it: computational fluid dynamics (CFD) as they operate in design software and how such techniques become both a rescaling of wind into a design object and imply the import/export of elemental media across the design pipeline, including the potential to be implemented in cities or non-urban landscapes. Video tutorials are training people for wind, or training people for software for wind, or both.

Wind CFD tutorials cover a range of topics, not all of them of interest for the architectural questions of urbanism: simulations of all sorts, such as wind turbines or related to aerial or other motorized vehicles are a big industry that relate to several of the traditional topics of media theory—speed, temporality, spatial coordination, and synchronization—even if the actual workings of things such as airflow around airplane wings are a less exciting topic for the humanities.[1] Modeling and simulating indoor air flows is another gray topic that however became much more visible during the COVID-19 years when understanding flows of particles—such as viruses—was a public health issue

1 See however on wind tunnels and other epistemic simulations and models Zindel (2018), Moffitt (2023).

of great significance. Such machine vision and pandemic media can be seen, to follow Antonio Somaini (2020, 151), as a special case of employment of computer vision and analytic techniques that segment visible and invisible worlds in ways that make them legible for specialist institutional uses. Atmospheres turn machine-readable as long as one knows how to turn dynamic flows into addressable units. The operational images (Parikka 2023) of, for example, airflow or potential particle flow patterns are one instance where not merely seeing small things but seeing particular vectorized processes of energy transfer become a central element of what images can capture. Such projects of legibility are also projects that operationalize elemental media: air, microparticles, flow, wind, etc.

In this chapter I am interested in what wind and other CFD mean from the perspective of software and computational culture, and how computational infrastructures feature in reorganizing—even creating—such natural patterns as wind. In another recent piece I have specifically focused on how wind is articulated in terms of the digital twinning discourse (Parikka 2025), and the points in this chapter resonate closely with that longer piece as they draw on the same research into operative ontologies of environmental media. The key argument put forward in both is that software creates wind as it mobilizes fluids as computational elements across proprietary and non-proprietary systems, across design environments, and with impact that reaches out to large-scale landscapes in urban and non-urban settings.

I argue that software takes the place of environmental modeling (Moffitt 2023) in ways that remediate the historical precedents of photographic, cinematic, and autographic (Offenhuber 2024) modes of capturing and visualizing energy (kinetic movement and its variations across scales from local to landscape to planetary). As a map-based object, wind has had an exquisitely large impact on the material epistemology: an imaginary—and symbolic calculation—of the planet is very much tied to navigational operations, so far as to justify Peter Sloterdijk's claim that instead (or in addition to) the Copernican turn, we should refer to the Magellonian turn of seafaring. Catching wind was an essential part of such navigational operations as was the catching of a regular or semi-regular periodicity of winds in the form of maps. The increasing accuracy of maps of navigationally significant winds, such as trade winds, is one form of operational imaging that has hit not the ground but the interface of air and water with ships, as emblematic as they are for this particular interface effect (Siegert 2024). Of course, many ships and people sailed with complex understanding of winds and currents before the European colonial period (think of, for instance, Polynesian stick charts for teaching how to read waves and swells), but actual maps are one concrete remaining artefact that park many of the historical concerns in this modern moment of planetary history.

The writing down of winds and fluids is itself one element in the mediation of what we consider as planetary natural history.

Such maps—and the ships that make maps exist while they also make ships reach their intended or unintended destinations—are something that we can name as early examples of “environmental data” since the 1600s. They are also emblematic early versions of geographic information systems, even if that term is mostly reserved for the computerization of cartography and layering of geographical space since the 1980s, roughly speaking. However, the map–wind connection persists in and through such early instances, where increasingly real-time techniques of wind maps are related also to the return to the centrality of wind as energy and thus as extremely central part of current energy markets.

As May Ee Wong (2024) writes about the enumeration of wind through different instruments:

> Wind energy is organized as an exchangeable value through the transduction of data as enumerated entities that circulate in media environments of empirical, statistical, financial, and governance platforms and contexts. The energy trading market is a complex networked platform of data apparatuses that gathers operations of financial speculation, weather prediction, and wind turbine control.

Here, the financial realms of environmental data, but also models of wind, become another moment of data visualization (Cubitt 2017), not merely one moment of abstraction (wind is already abstract and not “concrete” in the simple sense of occupying one coordinate spot and staying still) but an operationalization of different levels and modes of abstraction.

In all these cases, the computational conditions of wind—not as representation but as an operative element with various scales of impact (finance, design, visualization, etc.) come to play a central role. The sort of recursive models of wind are perhaps one version of what Buckminster Fuller (1981, 15) had in mind when quoting a specific proverb in his 1981 book *The Critical Path*: “The Southeast Asians say the banker cannot lend them the wind before the wind blows.”

Intuitively, this is very true but also not so. It is not true if we consider the 21st century environmental data stack, where the invention of possible effects of wind, heat, etc. are already acting from the perspective of the future upon the present—from mapping of possible ways the wind blows as it is built into structures around which wind might be designed to blow. In other words, the computational winds blow from all sorts of temporal directions enabled by software and data applications and practices, and thus become a second order movement of elemental media: first as software, then as physics.

Wind Service

How *do* you compute lands, or air, or wind? Such a question has a range of different answers that depend on the parameter of "when." A computation of lands unfolds as a story of quantification and programming of territory by way of grids—a technique with wide colonial uses, as evidenced in the Americas since the Laws of the Indies (1573) for planning (projection) and placement (control and communication), as well as in coastal planning in Europe (think of polders and the creation of the Dutch landscape from the fluid dynamics of the sea). Grids had existed before in the organization of urban settlements (Stanislawski 1946; Rose-Redwood 2008), although since the modern period we have witnessed a particularly widespread impact in how they become operational techniques in their own right, and also link with questions of computation.

In Europe in the late 1700s, a peculiar grid-square type of programming of lands was an example of something similar, with the added aim of also mobilizing human labor to work according to the terraforming computer. French agronomist Pierre-François Boncerf's large-scale plan for improvement is here an apt example:

> the national territory must be cut up into squares of 10,000 acres which it would be necessary to irrigate, drain, or reforest. The process would be iterative and progressive, with each forest planted improving the climate of the adjacent parcel. The goal of these gigantic works was to "change the climate, restore the commerce between Earth and heavens, set meteors into motion again and multiply them." (quoted in Fressoz and Locher 2024, 92)

Later, computable landscapes related to the emergence of geographical information systems (GIS) and other interfaces that model and enable operations in specific geographies. While GIS is the term for the later computerized practice of computational and data-intensive cartography, it makes sense to see it as part of a longer legacy of computational practices beyond computers proper.

Such are examples of managerial surfaces, to mobilize John May's (2012) term. As for computing lands, this becomes a matter of vast stacks of integration of earth resources into earth sensing, and the sort of computational planet that scholars such as Jennifer Gabrys (2016, see also e.g., Benson 2010) and others have scaled onto the networks of sensing that define the planet as human and non-human life, as natural resources, and as different environmental and climate data.

How about the non-solids? A computation of air, wind, and other fluids features in particular equations of dynamics—fluid and hydrodynamics—developed across the 1700s and 1800s, which define the key ways of condensing multiple scales of viscous vectors that circulate across the planet. And gradually, in the 1900s, computers—analog and digital—come to play a role in crunching data but also simulating and modeling those vast scales of movements as CFD truly becomes computational.

At the back of this computational planet across the volumetric space of matter and energy, imagine an environmental media and data stack—one that might *at first glance* resemble the engineering diagrams that populate descriptions of the modular nature of the internet and programming, or the sort that feature in theoretical descriptions of planetary computing (Bratton 2015). How does wind circulate in such a stack? Such a diagram includes various vertical dimensions, e.g., the atmospheric layers of wind and the aerotechnics of flight at high altitudes. Closer to the surface, it concerns the urban design of wind flows across a set of constructed landscapes, including landscapes for wind turbines. Technical details, models, modes of sensing, and planning are present across all layers. The planetary wind flows are complemented with technical forms of sensing and modeling the wind, but also software that helps to operationalize such winds by way of adapting or working with wind.

The vertical axis sets the scene: all wind is somewhat modeled and thought through in various subsections from aerial flight logistics to weather and climate sensing and modeling, and onto the redesign of planetary surfaces. All wind is integrated into design even if by proxy—by the objects that have to maneuver in and around fluids. Wind is not only measured in relation to a particular solid or porous surface but incorporated into technical elements of the stack: computational ways of understanding and simulating, including logistics of software and data that work in various sectors of industry. Wind, in this stack, is an object that is as much assumed natural as designed. Much of the wind in this limited sense of the stack takes place in particular surface-level institutions, from architectural offices and software developers to research institutes (climate and environmental sciences mapping global patterns). Some of the wind is packed inside buildings, such as wind tunnels or other test facilities that also create artificial winds, some of them not even from this planet, like in the test facilities for comparative planetology of simulating, for example, wind on Mars.

At the back of not only the folk and scientific nomenclature—and belief systems—around wind, we can easily put forward the claim that there is no wind without a model, to riff off John Durham Peters (2021), whose point was that there is no Pacific (ocean) without a model—or several—of it. Here though the modeling of wind takes place as both an epistemic and an ontogenetic operation.

The production of wind as a modeling service is what many of the computational industries of elemental media do. Orbital Stack is such a service that builds its offering on specific instances of industry needs—such as in architectural design and engineering—that includes thermal and wind comfort, airflow, and other aspects of living in a particular conditioned climate indoors or outdoors. The long-standing paradigm of controlled air environments is a trait of architectural design (Barber 2020) that has grown in importance in the context of observed climate change.

Orbital Stack offers a cloud-based service where computer-assisted design (CAD) files can be uploaded to provide the computational modeling for optimizing in relation to existing wind patterns. Here though, the environmental stack is about placing models in relation to models: Orbital Stack's machine learning models have been trained on climate data, airflow paths and patterns, and what they boast as the largest urban windflow dataset in the world through their company status as part of RWDI Ventures. Technically, thus, it is not a CFD simulation but a machine learning platform that is claimed to use much less resources with much greater speed.[2] Orbital Stack is a wrap.

Models relate to other models, including wind tunnel data matched with weather data. The sort of data assemblage (Kitchin and Lauriault 2018) at hand then involves forms of knowledge, finance, infrastructure, and political economy while it also comes to redefine places—i.e., urban and non-urban landscapes as they are calculated in relation to existing, accurate or not, wind models. The data assemblage as one nuanced version of the environmental data stack is thus not only a "pure" epistemic operation but one that gathers a particular force from its operative capacities of transformation. In short, it concerns the real as it does the symbolic.

Integration of computational design into platforms such as Orbital is one form of outsourcing elemental media. For Orbital, much of this is premised—and marketed as such—on harnessing predictive artificial intelligence (AI) into the design assemblage. This is narrated as an effective way of "early-design" (i.e., modeling that reduces the need for later redesign that might emerge due to unforeseen occasions) to manage, for example, cladding, but it is also a computational and discursive way of managing the wind before it blows. Such worlds of designed winds demonstrate the particular nexus of service and futurity as they are coupled together. Hence, when it comes to the environmental data stack of Orbital Stack, it also includes the dimension of temporality: not just the particular temporal velocity and impact of wind, but the wrapping of wind data into predictions, a point that applies of course not just to wind. What's significant though is how software and broad computational platforms continue the work of design of territories beyond terra

2 See Orbital Stack (n.d.).

(Peters, Steinberg and Stratford 2018), with the related political stakes also being significant.

Wind Humanities

In a recent special issue of *Media+Environment*, our research team suggested the idea of "wind humanities" (Hepach et al. 2024). In a similar vein as blue or energy humanities have paved the way for specific investigations into environmental change, our pitch articulated the case for wind humanities. Recognizing that this sort of fragmentation of the field might not serve its best interests though, the point was tactical: What are such elemental media as wind as they are seen stretched between models and experience, media and management? What are the intersections of different disciplinary approaches to wind to think of it as model, media, and experience (e.g., in the anthropological register or in phenomenological terms)?

So, while there is a significant history of phenomenological inquiry into wind, the abstract nature of wind carries with it specific ontological and epistemological points. As energy, fluids are particularly interesting epistemic processes, where the history of fluid dynamics is often the history of the objects through which they become measured. The centrality of "the boundary layer theory" (Nagai 2002, 21) related to relative friction close to any solid surface (with regards to flow of water, wind, or other fluids) marks the scientific reference point for fluid dynamics. And in a related manner, the history of such questions shifts registers between the equations of elevated significance (from Lambert to Euler to Navier–Stokes) and a history of engineering drawings or similar visual design and expressions where objects of resistance come into play.

In other words, fluids are understood in relation to such surfaces that are points of measurement at such interfaces (Hookway 2014), which then are of scientific and engineering interest. The media archaeology of wind is about reckoning with water tanks, canals, boats, fences, and other surfaces against which viscous forces of flow and friction become legible. This identified—created—legibility is then a unit of operations and control too. This specification of otherwise seemingly unbounded force of wind at a particular site repeats the point that Georges Didi-Huberman (2003, 227) articulated about Marey's wind tunnels: "How could an experimental image, inevitably local since it results from a specific instrumentation applied to particular phenomena, be capable of *globally modifying our perception of the world*?"

The back and forth of local and global and the broader ontology of "wind" becomes the issue in various built or natural instances of tracking wind through a proxy.

I am interested in such moments of epistemic production that do not merely reproduce the embodied human experience (as if there was only one). It is exactly those levels and layers of abstraction—perhaps in some cases even lived abstraction, to echo Massumi (2011, see also Engelmann 2024)—where wind becomes measured: the Beaufort scale, wind instruments, but also lidar, sodar, and radar technologies in their own ways are emblematic of this multiscalar sensing and datafication. "In short, while clouds and winds might not be countable (Peters 2015, 166), the whole history of what one might call cultural techniques of wind can be interpreted as a rise to this challenge—wind being accounted for as force, energy, value, vehicle, danger, and so forth" (Hepach et al. 2024).

In this way, the imagined field of wind humanities is interested in the media of abstractions of abstract wind—always already abstract in its multiphased, multiscalar potentiality (see Massumi 2011)—which again speaks also to its concretization in specific moments of data through the instruments that try to catch it. Certain kinds of modes of catchment—a specific version of the fundamental nature of design as "traps" (Flusser 1999, 17)—have historically enjoyed a more significant role than others. Different designs of sails (as in ships' sails) would be exactly a trapping of such kind but with implications much beyond any one exact position of the sail: they link to various scales of models expressed as maps (such as Edmund Halley on trade winds in 1686) or other models, other interfaces. Sails, fabrics, balloons, but also landscape features formed across time because of wind are one example of "design" where the agency of design is inclusive of the energetic force of wind itself, a version of medium design in Keller Easterling's (2021) terms. In short, a wind map is only meaningful if and when there is wind, i.e., that the wind itself moves a particular cartographic attempt to capture large-scale patterns of movement of energy that calculates optimal pathways for a particle movement (e.g., a boat from A to B). Somewhat a simplifying point, but crucial as it points to the primacy of wind itself as creating landscapes, flows, trajectories, and pathways, or a "natural history of logistics" (Parikka 2023).

Computing, here, is then a two-way street: many of the computational techniques of analysis of wind are attempts to understand the computation by wind and other fluids. Such an ontogenetic point does not lessen the importance of trying to understand historical cultural techniques, such as software, and CFD as elements in the environmental data stack.

Computational Fluid Dynamics

Packaging of wind into fluid dynamics and then into CFD represents a significant chapter in the history of computation of elemental media. This historical trajectory corresponds, more or less, with the emergence of modern equation-based formulations—Euler, Navier–Stokes and their kin—which came to serve as the mathematical interfaces through which the analysis of flow, and with it the logistics of movement, became possible. The design software incorporating physics into environmental modeling becomes a later installment of such features of analytics of fluids. From the everydayness of the tutorial videos to the software itself, wind's logistical force becomes managed as the logistics of plug-ins, import/export of data, and other information modeling that can be seen as reliant on similar broader tasks as building information modeling (BIM) in general. Here though the interface to facilitate medium design of elemental environments is managed through the code and software such as Grasshopper's Ladybug and Butterfly tools. These are plug-ins that help import environmental data (such as weather data) into a design software situation in a similar manner as this chapter's opening example of the Autodesk tutorial elaborated. Such logistical tools are one example of the technical aspects of the environmental data stack as they facilitate the interconnections between specialist software—such as OpenFOAM (open source C++ code environment and software for CFD) design practices. Such tools help a multitude of elemental media to be reckoned with, such as light conditions or the import of external datasets.

Such software is mostly described in engineering or design terms as part of a mundane culture of management of environmental conditions. Despite this everydayness, I wonder if something more comprehensive is packed into this practicing elemental media? Can we develop a point about the philosophy of design and computation of elemental media as seen through software?

My point here concerns the way the environmental data stack operates in this manner. As mentioned earlier, one can figure out the stack is more than an engineering concept (even if it might be also that). Such a point is also made by Benjamin Bratton (2015), whose version maps the term as an insight into the layers of planetary computation, a way of understanding procedures of materiality and governance from the earth onto the user with implications for notions of urbanism ("the city") and logistics ("address") too. My proposal for the environmental data stack of wind is not a direct derivative of Bratton's as such and it is important to note the variations of the term stack in recent discourse.[3]

The environmental data stack of wind becomes a map of enclosures and wraps of wind from the history of science of formal definitions of fluids, to hydrodynamics in interaction with thermodynamics, the variations of wind and heat in the military-industrial complex (e.g., the centrality of Los Alamos in high-stakes and big science research, including of course the relation to

3 Some of them make more explicit links to Bratton's theory though. See for example Terranova (2017), Lovink (2020), and Likavčan and Scholz-Wäckerle (2022).

[Figure 2] A still from *Ghost of Tsushima* where proxies of wind—such as vegetation, particles flowing in the air, clouds, and clothing layers—play a central role in creating the dynamic environment of digital aesthetics (Source: Ghost of Thushima Press Kit, https://www.igdb.com/games/ghost-of-tsushima/presskit).

nuclear weapons development[4]), onto the gradual rescaling of wind onto the desktop and in software code and graphics since the 1980s—let alone the everyday aesthetics of YouTube tutorials for training to design with wind. What we see in various computer graphics (Stam 2016) is not always necessarily CFD—this would be a computational overkill considering the resources such computation requires. Instead, computational and visual proxies of wind are designed as effects, but at an impressive level of detail and in real-time environments, with a matching impressive need for computational processing power. Try for example to play *Ghost of Tsushima* (2020) to get this point. Vegetation starts to feel like an integral part of the broader computational aesthetics in which any game play takes place. Proxies of wind are everywhere, from minor particles to layers of clothing.

What's more, the game-like environments of wind produce an inverted relation with wind itself: they are not necessarily just environments where wind and fluids are imported as code, but where game engines are used to model and thus to participate in creating landscapes for the designed behavior of wind. Software creates environments for the capture and channeling of wind. As a software-based version of sails, they capture the approximation of wind through data and physical modeling, for example in cases such as wind turbine construction. Game engines are an example of where this inversion takes place, as one special case of digital twinning too (Parikka 2025).

4 See the contribution of Christoph Rosol to this volume.

This kind of a stack functions as one instance of the cultural techniques of management of worlds of fluids, one that relies on the creation of boundary conditions. This helps to visualize fluid conditions such as turbulence as well as reproduce particular kinds of model environments that, at least in restricted conditions, control wind. An airplane wing is such an example among many epistemic, aesthetic, and engineered examples (Moffitt 2023) that are then reproduced in the world and thus also create a particular kind of a world populated with such material models that become an operative modulation of their own conditions of existence. In short, they are recursive, and ontogenetic. They are also, fundamentally, *temporary* controls of wind, a point that has its basis in the sheer complexity of such energetic forces, often defined by the centrality of turbulence (see Lahoud 2022).

The environmental data stack can be read to include such material worlds of elemental media that are wrapped inside these various institutional and media environments. Earlier I referred to the more political economy sounding term "enclosure" but "wrapping" works well too, also conveying a particular epistemic-architectural implication. "Wrappings" or folded "envelopes" of fluid dynamics inside models or software become a version of earlier points made by Michel Serres, and especially Derek McCormack, and help us to understand the point about the cultural techniques of wind. McCormack's (2018, 29) way of narrating this point about folding envelopes is particularly helpful:

> In general terms, envelopment is a process at the heart of which is a certain relation of matter to its ongoing differentiation. We can think of this relation in terms of what Gilles Deleuze calls "the fold," an abstract line along which matter is inflected. The fold is transversal to many techniques and technologies of world making; in envelopment, however, it names a process of partial enclosure through which the relation between distinct phases of matter generates a sufficient degree of difference such that patterned stabilities take shape as variations in that matter. Importantly, the process of envelopment generates entities with the capacity to modify their exposure to variations in the conditions in which they are immersed and around which they are enclosures.

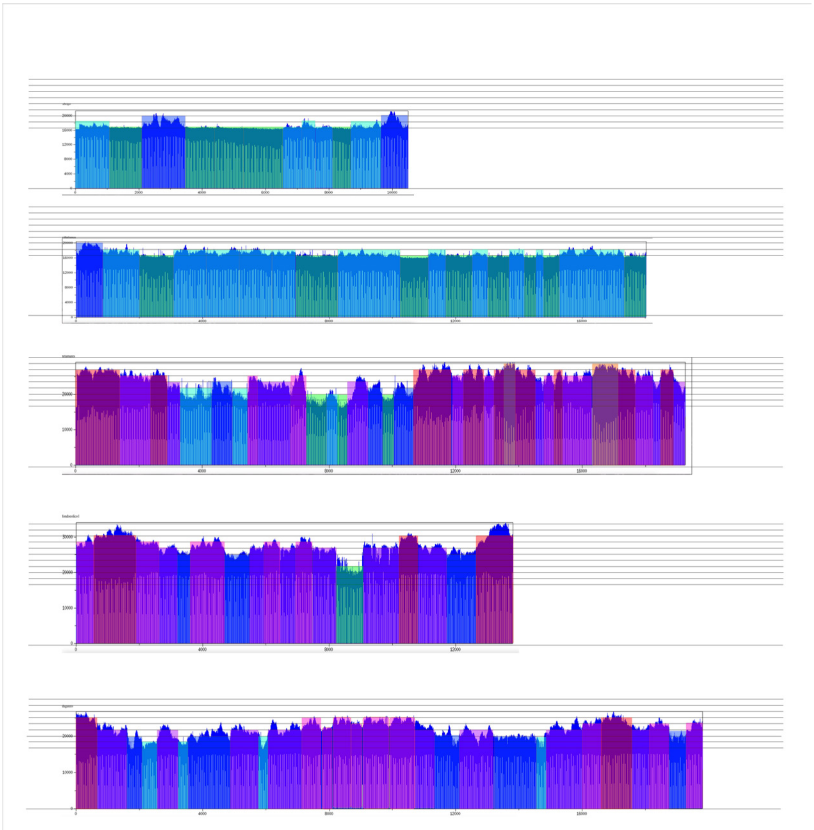
McCormack's own research on atmospheres makes use of this point and I want to extend it as a way of understanding the media archaeology of wrappings of wind and fluids, a certain kind of material engine for the environmental data stack. It helps to shift away from a human-centric phenomenological approach while not ignoring the materiality of the models either.

Let me take a concrete example that is about video codecs as software wraps but also nails even an experimental, but very practical, point about wind as calculation already in itself: artist Abelardo Gil-Fournier's recent series of

[Figure 3] A still from Abelardo Gil-Fournier's The Winds Codec (2024–2025) series (Source: Abelardo Gil-Fournier. Used with permission).

video (art) works, The Winds Codec (2024–2025). The installation part consists of transparent glass spheres that isolate a part of a branch of a tree (figure 3). In the video, the erasure of wind inside the glass sphere becomes a striking contrast with the "outside" of the sphere, namely the wind as it hits the other tree branches and leaves.

Several videos of such installations—of still and moving branches—are synchronised. However, the synchronisation happens without the use of specialist software or computer vision that would calculate the movements to ensure resonance across individual samples of air movement. As Gil-Fournier explains (Gil-Fournier and Parikka 2024), the motion vectors are extracted directly from the video file based on the MPEG4 video codec: not a passive registering, but an active wrap of moving images of the trees, motion vectors between frames, and hence proxies within the image (frame by frame) as to what changes, and what remains stable and static (figure 4). The codec as a wrap of movement includes a really interesting version of digital aesthetic on the level of compression algorithms here made to work for a different purpose: sequencing not images traveling across networks but also working out how physical wind is involved in the production of such data images. Gil-Fournier refers to this as a sort of digital wind, although this is not CFD in the classical sense, nor is it the computer aesthetics of wind effects. It is though one effective way of understanding how wind is wrapped into software and networks, while the wind itself is part of its own calculating activities (see also Gil-Fournier and Parikka, 2024). This adds a further element to the link between computational simulation and natural physics.



[Figure 4] A data visualization of the amount of motion vectors per frame for some of the videos in Gil-Fournier's Wind Codecs (2024–2025). Rectangles of equal color mean similar number of vectors and therefore matching wind intensities (Source: Abelardo Gil-Fournier. Used with permission).

The intuitive history of wind as history of proxies of wind has characterized much of the aesthetic approaches so far. Similarly, the point about wrappings is one element in this line of techniques too. Wrappings of such sort are however not mere registering proxies that capture wind as it exists, but also model winds that blow back as they feed forward, i.e., become their own logistical forces of design as data about fluids are moved across different software and data environments. Planetary computation, or the environmental data stack, is thus one infrastructural backdrop for this logistics of fluids—a natural history of logistics of sorts that both builds upon the natural physics of planetary flows and also contributes to their channeling. Hence, as one interim proposal that finishes this chapter I want to suggest that the term environmental data stack can become a figure through which different scales of abstraction and modeling of elemental media can be brought into the discourse of cultural techniques and humanities theory.

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References

Barber, Daniel. 2020. *Modern Architecture and Climate: Design Before Air Conditioning*. Princeton: Princeton University Press.

Benson, Etienne. 2010. *Wired Wilderness: Technologies of Tracking and the Making of Modern Wildlife*. Baltimore: The Johns Hopkins University Press.

Bratton, Benjamin. 2015. *The Stack: On Software and Sovereignty*. Cambridge, MA: MIT Press.

Cubitt, Sean. 2017. "Three Geomedia" Ctrl-Z, no. 7. https://www.ctrl-z.net.au/articles/issue-7/cubitt-three-geomedia/.

Didi-Huberman, Georges. 2003. "The Imaginary Breeze: Remarks on the Air of the Quattrocento." *Journal of Visual Culture* 2, no. 3: 275–89.

Easterling, Keller. 2021. *Medium Design*. London: Verso.

Engelmann, Sasha. 2024. "Wind's Animacies." *Media+Environment* 6, no. 2. https://doi.org/10.1525/001c.125907.

Flusser, Vilem. 1999. *The Shape of Things: A Philosophy of Design*. London: Reaktion Books.

Fressoz, Jean-Baptiste, and Fabien Locher. 2024. *Chaos in the Heavens: The Forgotten History of Climate Change*. Translated by Gregory Elliott. London: Verso.

Fuller, Buckminster. 1981. *Critical Path*. With assistance by Kiyoshi Kuromiya. New York: St. Martin's Press.

Gabrys, Jennifer. 2016. *Program Earth. Environmental Sensing Technology and the Making of a Computational Planet*. Minneapolis: University of Minnesota Press.

Gil-Fournier, Abelardo, and Jussi Parikka. 2024. "Enclosures of Wind: Practice-Led Methods for Visualization of Elemental Media." *Media+Environment* 6, no. 2. https://doi.org/10.1525/001c.124525.

Hepach, Maximilian, Ryan Bishop, J. R. Carpenter, Jussi Parikka, et al. 2024. "Wind Humanities: An Elemental Media Approach." *Media+Environment* 6, no. 2. https://doi.org/10.1525/001c.127444.

Hookway, Branden. 2014. *Interface*. Cambridge, MA: MIT Press.

Kitchin, Rob, and Tracey P. Lauriault. "Toward Critical Data Studies: Charting and Unpacking Data Assemblages and Their Work." In *Thinking Big Data in Geography*, edited by Jim Thatcher, Josef Eckert, and Andrew Shears, 3–20. Lincoln, NE: University of Nebraska Press.

Lahoud, Adrian 2022. "Turbulence." In *Words of Weather*, edited by Jussi Parikka and Daphne Dragona, 167–74. Athens: Onassis Stegi.

Likavčan, Lukáš, and Manuel Scholz-Wäckerle. 2022. "The Stack as an Integrative Model of Global Capitalism." *tripleC* 20, no. 2. https://doi.org/10.31269/triplec.v20i2.1343.

Lovink, Geert. 2020. "Principles of Stacktivism." *tripleC* 18, no. 2. https://doi.org/10.31269/triplec.v18i2.1231.

Massumi, Brian. 2011. *Semblance and Event: Activist Philosophy and the Occurrent Arts*. Cambridge, MA: The MIT Press.

May, John. 2012. "Logic of the Managerial Surface." *PRAXIS* 13: 116–24.

McCormack, Derek. 2018. *Atmospheric Things: On the Allure of Elemental Envelopment*. Durham, NC: Duke University Press.

Moffitt, Lisa. 2023. *Architecture's Model Environments*. London: UCL Press.

Nagai, Minoru. 2002. *Thinking Fluid Dynamics with Dolphins*. Amsterdam: IOS Press.
Offenhuber, Dietmar. 2024. *Autographic Design*. Cambridge, MA: MIT Press.
Orbital Stack. n.d. "AI Wind Simulation Engine." Accessed August 8, 2025. https://orbitalstack.com/ai-powered-wind-simulations/.
Parikka, Jussi. 2023. *Operational Images: From the Visual to the Invisual*. Minneapolis: University of Minnesota Press.
———. 2025. "Plugin Wind: Software and Logistics of Elemental Media." *New Media & Society* 27, no. 8 (Special Issue on Digital Twinning). https://doi.org/10.1177/14614448251338285.
Peters, Kimberley, Philip Steinberg, and Elaine Stratford, eds. 2018. *Territory Beyond Terra*. London: Rowman & Littlefield.
Peters, John Durham. 2015. *The Marvelous Clouds: Toward a Philosophy of Elemental Media*. Chicago: University of Chicago Press.
———. 2021. "Charting the Pacific ca. 1850: Melville, Maury, Marx, and Mormons [Video]." *Media+Environment* 3, no. 2. https://doi.org/10.1525/001c.22195.
Siegert, Bernhard. 2024. *Final Frontiers: Eine Medienarchäologie des Meeres*. Paderborn: Brill/Fink.
Rose-Redwood, Reuben S. 2008. "Genealogies of the Grid: Revisiting Stanislawski's Search for the Origin of the Grid-Pattern Town." *Geographical Review* 98, no. 1: 42–58.
Somaini, Antonio. 2020. "Machine Vision in Pandemic Times." In *Pandemic Media: Preliminary Notes Toward an Inventory*, edited by Philipp Dominik Keidl, Laliv Melamed, Vinzenz Hediger, and Antonio Somaini, 147–54. Lüneburg: meson press,.
Stam, Jos. 2016. *The Art of Fluid Animation*. Boca Raton: CRC Press.
Stanislawski, Dan. 1946. "The Origin and Spread of the Grid-Pattern Town." *Geographical Review* 36, no. 1: 105–20.
Terranova, Tiziana 2017. "Red Stack Attack! Algorithms, Capital, and the Automation of the Common." In *across & beyond — A transmediale Reader on Post-digital Practices, Concepts, and Institutions*, edited by Ryan Bishop, Kristoffer Gansing, Jussi Parikka, and Elvia Wilk, 202–20. Berlin: Sternberg Press.
Wong, May Ee. 2024. "From Wind Turbines to Energy Islands: Wind as Model Power in Denmark." *Media+Environment* 6, no. 2. https://doi.org/10.1525/001c.125711.
Zindel, Hannah. 2018. "Werkzeug Windkanal. Simulationen in der Stadtklimaforschung." *Zeitschrift für Medienwissenschaft* 10, no. 19: 54–67.

WEATHER PREDICTION

UBIQUITOUS COMPUTING

SENSOR MEDIA

OPERATIVE IMAGE

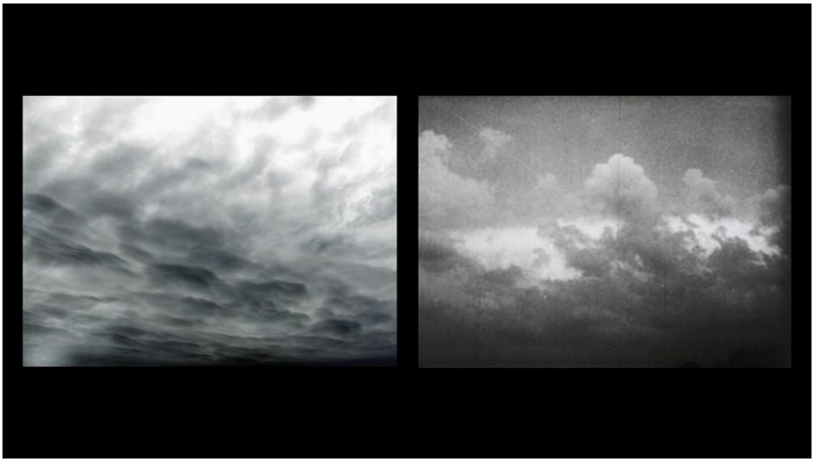
DIGITAL TWIN

[3]

Modeling the Earth: Operative Images, Machine Learning, and Weather Prediction

Eva-Maria Gillich

Today it is widely accepted that computation is embedded in the environment. This entanglement may not only be understood as the outsourcing of computation into "smart things." In particular, practices of weather forecasting, ranging from numerical weather prediction to weather prediction by deep learning, are related to ubiquitous computing. The Earth is permeated by sensors and signals, and there is, as the artist collective Geocinema puts it, "this massive archive of data that is a constantly recorded version of the earth." Drawing on artistic works that reflect on the relationship between operative images, machine learning, and the environment in times of ubiquitous computing, the question is raised whether operative images on a planetary scale focus less on representing than on modeling the Earth.



[Figure 1] Two images of clouds (Source: Harun Farocki, *Parallel I*, 2012, video still, © Harun Farocki GbR).

Images have always not only represented but also created what they depict. As media studies and the study of cultural techniques have shown, this implies that the world is produced by its media, which in turn implies that the world changes when its media does. In times of machine learning, operative images are not only ubiquitous but also environmentalized, necessitating the reexamination of the relationship between the world and the operative image.

In *Parallel I* (2012), filmmaker Harun Farocki tells the history of computer game images from the 1980s to the 2010s. The two-channel video installation describes the evolution of computer game graphics from lines and pixels to increasingly "realistic" depictions. *Parallel I* concentrates on the depiction of the natural environment and mirrors the common, albeit long since deconstructed, narrative of art history: only the Renaissance's central perspective enabled the "realistic" depiction of the world, whereas the Middle Ages still lacked this ability. Although Farocki does not believe in this narrative, the voice-over of *Parallel I* alludes to it to make another point. As is well-known, this history of "successful representation" usually does not end with Renaissance painting but culminates in the media of mechanical reproduction, namely photography and film.[1] The voice-over postulates that, if computer simulations become increasingly more realistic, they finally begin to surpass film in its capability to represent the world. If that were the case, the voice-over concludes, computer images may take over previous functions of film, such that film's purpose can change, and film would no longer be bound to

1 Thus, *Parallel I* seems in accordance with Hubert Damisch (2002), who considers the central perspective as a dispositive and thought model.

representing the world.[2] This closing statement accompanies two moving images of clouds: one filmed by a camera and one generated by a computer. It seems no coincidence that this comment on representational functions of images is based on clouds.

Clouds

Clouds elude representation. They are without lines and contours, always moving, always changing form, and always morphing. The difficulty of defining their form applies to their artistic representation as well as their scientific description. The distinction between figure and ground, or organism and environment, is volatile; it could be described as a gradual distinction of the density of color and brushstroke on the one hand, and the density of water in the atmosphere[3] on the other. From an art historical perspective, the cloud is purely material or substance (Damisch in Bois et al. 1998, 8)—this is why, considered not from the viewpoint of painting but of drawing, it evades the domain of the depictable. Hubert Damisch (2002) argued that the cloud particularly eludes the central perspective of the Renaissance, since a cloud is neither measurable nor can its contours be represented by lines.

In the 19th century the depiction, description, and observation of clouds became especially important for the young science of meteorology. Around 1800 the first systems of cloud classification were developed. Many efforts were made to standardize the classification of clouds and the practices of their meteorological observation (Wolf 1993; Daston 2016). "When it came to clouds," Lorraine Daston (2016, 47) stresses, "art and science faced similar challenges of description: how to capture almost infinite variety and variability?"

The year 1896 was declared the *International Cloud Year* and was dedicated to the scientific observation of clouds on a global scale. The same year the first *International Cloud Atlas* was issued to standardize observational methods, for example with respect to the measurement of cloud height, velocity, and direction (Hildebrandsson, Riggenbach, and Teisserenc de Bort 1896). To determine the height of a cloud by triangulation, two simultaneous observations from two distant viewpoints are required. While the simultaneity could be achieved by telephone, the observation of the same point of the cloud from both viewpoints was much more difficult. Photography provided the solution. A phototheodolite, a photogrammetry instrument that combines a protractor

2 This statement mirrors the 19th century discourse about early photography and its relation to painting. For example, in *The Ontology of the Photographic Image*, André Bazin (1960, 9) noted in this sense that "photography is clearly the most important event in the history of the plastic arts."

3 Cloud formation is not solely dependent on the density of water molecules but also on, for example, temperature (Wolf 1993, 5).

[Figure 2] Photogrammetric image of clouds (Source: Reinhard Süring, *Cirro-Stratus, Cumulus, Nr. 972*, Potsdam, 21.4.1897. Wettermuseum. EX 000 941/58. https://brandenburg.museum-digital.de/object/46369).

with a camera, was used for the task. It could capture the cloud and ensure that the same points were used for the calculations (Hildebrandsson and Hagström 1893; Koppe 1896). To track the cloud's movement, one would take two pictures with a time interval of a few seconds between them (Süring 1903, 46–49)—creating a sort of mini-chronophotography.

Even with the cloud, perhaps the most difficult object to grasp, photography not only provided the means to adequately represent a cloud but also to measure its movement via the comparison of two images. As chronophotography and photogrammetry generally show, mechanical reproduction not only represents the world but also helps to operate it through measurements. Accordingly, in *Images of the World and the Inscription of War* (1988), Farocki tells the story of the invention of photogrammetry by Albrecht Meydenbauer in the 19th century. For Farocki, Meydenbauer is one of the ancestors of cinema (Elsaesser 2004, 30) and, ultimately, of operative images. Farocki identifies cinema with techniques of vision, which influence how the world is perceived. One might thus ask whether the liberation of film from representation has not always been part of cinema. If images are measurements of the world, do they merely represent it, or do they serve to make it operative?

Operative Images

In *Images of the World*, Farocki shows that the causal relation between image and measurement has changed. In a montage, he contrasts a woodcut by

Albrecht Dürer (*Man Drawing a Lute*, 1525) and a drawing by Leonardo da Vinci (*Codice Atlantico*, f.5 recto, c. 1480), both demonstrating how bodies are depicted according to the rules of projected geometry, with a film clip promoting automatic air refueling, and with policing techniques.[4] The voice-over comments: "Dürer, again, took measurements of objects. From the study of nature, he obtained numbers and rules. The calculating machines of today make pictures out of numbers and rules." At first, images served to make measurements, now, measurements become images. The latter case corresponds to operative images, a term Farocki coined later with regard to smart bombs used in Operation Desert Storm. However, the concept of operative images goes beyond military applications (Parikka 2023). According to Farocki, operative images do not represent an object or aim at the human eye but completely merge into operations, and thus become invisible. Farocki (2004, 21) stresses: "A computer can process pictures, but it needs no pictures to verify or falsify what it reads in the images it processes." Due to the increasing sophistication of sensor technologies and algorithms more and more images become operative. Although there is a difference between images that are transferred into measurements and measurements that become images, computation and the image are already closely related before purely operative images exist. There is a proximity between computing with images and images that compute, even though in times of ubiquitous computing the latter increasingly replace the first.

In a strict sense, operative images cease to be images and become iconoclastic (Pantenburg 2017; Paglen 2014). Since a computer may, but does not have to, process images as images, Claus Pias emphasized that the digital image does not exist (Pias 2003).[5] Similarly, Gabriele Gramelsberger points out that algorithms and sensor technologies are iconoclastic because they substitute sound and images with data (Gramelsberger 2020, 42). Nonetheless, there are still plenty of images and their importance does not seem to decline. It is therefore very apt that Jussi Parikka (2021, 185) underlines—in an inversion of Pias' dictum—that "everything that exists as a signal can also exist as an image." However, as soon as the way in which images are produced changes, their purpose does too. Not only do we operate the world through images, but, as Ingrid Hoelzl and Remi Marie have shown for Google Street View Images, the images start to operate us. In consequence, the seemingly fixed relation between image and world is replaced by a dynamic relation of data to data (Hoelzl and Marie 2014).

4 For a comparison of the Renaissance's practices of quantification and the measuring techniques of photogrammetry see Parikka and Dvořák (2021).

5 In a broader sense, not every operative image (e.g., chronophotography) is digital, even though most are.

Comparable to the example of Google Street View Images, Farocki emphasized that, since computer animations are less about reproducing than producing the world, their mode is navigational (Farocki 2014). Tom Holert and Doreen Mende (2019) conclude:

> Rather than finding orientation by way of images in the real world, today images may mutate into a sort of interface—an operational tool reaching beyond visual-cognitive persuasions, beyond representation, beyond "the image" itself, enabling seemingly boundless and borderless mobility between spaces, scales, temporalities. Navigation now begins where the map becomes invisible or indecipherable, operating on a plane of immanence in perpetual motion. Navigation, instead of framing or representing the world, continuously updates and adjusts multiple frames from viewpoints within the world. Navigation in the digital realm is the modeling and mapping of an elusive environment—in the service of orientation, play, immersion, control, and survival.

To live in today's image environments means to live in a computational world—not in a virtual reality, in which the "real" world and the digital are separated, but in the "New Real" where the real and the digital are embedded into each other.[6] Everything is recorded as data and the collection and processing of Big Data are intertwined, forming a feedback loop (Halpern et al. 2022). Although the predictions obtained from Big Data are only expected values, they have an impact on the world as soon as they are fed back into it (Gramelsberger 2020). Statistical mass data are projected onto individuals, resulting in the adaptation of humans to algorithmic structures that depict the world as much as they generate it.[7] The world is not only reproduced but produced.

Ubiquitous Computing

In 1991, Mark Weiser drafted a utopian vision of ubiquitous computing where all behavior is fed back to a "smart" environment. In contrast to virtual reality, which attempts to shift the world into the computer, the computer should be embedded into the surrounding world. According to Weiser (1991), technology and the world would merge entirely, computers would completely blend into the environment, and technology would become invisible. The first two sentences of the essay are emblematic: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" (94). A few years later, Neil Gross (1999) predicted that the world would have an electronic skin made up of millions of sensors, cameras, microphones, and microprocessors that would not only record but also regulate and control. In 1992, Al Gore envisioned a *Digital Earth*

6 For the term "New Real," see Merkle and Siegert in the introduction to this volume.
7 This effect is also crucial for algorithmic governmentality (Rouvroy and Berns 2013).

that would be composed of satellite images on the one hand and a multitude of geodata and metadata on the other. Information and images should merge seamlessly. The potential benefits supposedly range from fighting crime and preserving biodiversity to predicting climate change. The decisive factor is that the *Digital Earth* will not only represent the Earth but will also allow its simulation (Gore 1999). The concept not only reminds one of *Google Earth* but also of today's digital twins (Grieves 2014; Crespi, Drobot, and Minerva 2023).[8]

Weiser's idea of ubiquitous computing is still relevant, coming to life in smart things (Greenfield 2006; Sprenger and Engemann 2015). In 2006, Adam Greenfield published 81 theses on how computing is already embedded in the environment and which difficulties, such as problems of interoperability, it still faces (Greenfield 2006). The book's cover is particularly instructive. It shows a blue sky with clouds. On a closer look, one can decipher zeros and ones, a bitstream, a symbol for computation, embedded in the depicted clouds.

The Cloud

The cover of the book is obviously less a depiction of a weather phenomenon than of the information technology known as the Cloud. Today the Cloud has long become a metaphor for our decentralized and digital infrastructure, our digital practices, and our resources for computation (Franklin 2012; Bratton 2016; Peters 2016). The paradigm of cloud computing dissolves computation in the environment (Franklin 2012, 457–58), thereby coming very close to Weiser's utopia. It promises the disappearance of hardware and an immaterial embedding of data. Although it is anything but ephemeral, consisting of massive data centers and requiring rare earths and large amounts of electricity, the Cloud remains impossible to grasp.

At least since the concept of the Anthropocene has spread, it is commonplace that technology and nature are entangled. When Paul Edwards (2015, 247) notes that computer-aided modeling has contributed to knowledge about the Anthropocene, one could add that it also helped to shape it. Like all media operations, it creates reality and is anchored in the environment. At this point we can connect the cloud as a weather phenomenon with its technical counterpart. In particular the computer-aided modeling and simulation to which Edwards refers tell of the ubiquity of computation and the Cloud. Not only is weather, or more precisely its long-term patterns, the climate, crucial for the discussion of the Anthropocene, but it is the capacity of distributed and parallel computing, which cloud computing is part of, that can provide the necessary computing power the simulations need. Two well-known steps in the history of weather simulation illustrate the ubiquity of computing.

8 The *International Society for Digital Earth* is the direct institutional successor of *Digital Earth* (Annoni et al. 2023).

Weather Prediction and Climate Modeling

In 1922, Lewis Fry Richardson developed the method of numerical weather prediction (NWP) with differential equations, long before the first computer (Edwards 2010). Richardson (1922) imagined a forecast factory: he divided the globe into a grid in each cell of which a human computer would solve the equations of fluid dynamics; a global parallel computer. To be able to predict the weather for unlimited time steps, in theory, the whole globe had to be covered by the grid.[9] A narrower grid means higher accuracy but also requires more computational power. A logic that still applies today. Richardson not only designed a forecast factory but transformed the globe into a computational device. The weather is measured and expressed in numerical data, allowing it to be processed and predicted. Computation becomes ubiquitous in a broad sense.

Ultimately, it was the digital computer that contributed to the first breakthrough in NWP.[10] Bernhard Siegert (2022, 22) stresses:

> Already as early as 1946, mathematician and computer pioneer John von Neumann, engineer Vladimir Zworykin and meteorologist Jule Charney developed the idea that the atmosphere could be completely translated into digital computers precisely because it is a huge analogue computer itself.

Until today, NWP is the state-of-the-art method. The lack of computing power remains a hindrance to meteorologists and is one of its main narratives: "There is no enterprise so data-hungry as meteorology" (Peters 2016, 251). The "electronic skin" of sensors, cameras, and microprocessors (Gross 1999) enables weather forecasting, which itself entangles computation and nature—and shows that the ubiquity of computing may not only be understood as the outsourcing of computation into smart things.

Increasingly more technical devices and sensors are constantly collecting more and more data in order to scan the world as completely as possible. Everything, it seems, can and should be recorded as data to enable a better representation of the world and therefore a better understanding of it. Strictly speaking, to represent and understand the world means to process it. The

9 Each cell of the grid corresponds to a geographical region of equal size. For each region physical variables such as air pressure and temperature are measured, providing information on the state of the weather at time t. To calculate the future state of a cell at time (t+1), one has to take all eight neighboring cells into account. Border cells do not have eight neighbors. Only a fully covered globe provides eight neighbors for every cell. Furthermore, if the globe is not covered entirely, only a finite number of time steps can be predicted, because with each prediction the number of predictable cells shrinks.

10 On the historical connection between computation and weather prediction (or climate modeling) see also the chapter by Christoph Rosol in this volume.

[Figure 3] Tega Brain, Julian Oliver, and Bengt Sjölén, *Asunder*, 2019 (Source: Exhibition view *The Eternal Network*, Transmediale 2020, Berlin. Photography by Luca Girardini. https://tegabrain.com/Asunder).

promise is that, thanks to its digital twin, processing the world means not only to duplicate it through a perfect digital representation but also to make it comprehensible and to create a model that enables the simulation of its possible futures.[11] Machine learning is crucial in this context.

In the art installation *Asunder* (2019), Tega Brain, Julian Oliver, and Bengt Sjölén combine a fully coupled global climate model, a numerical simulation of Earth, with machine learning techniques, more precisely with deep learning. They use image inpainting,[12] where an artificial neural network is trained to fill in missing parts of images (Yu et al. 2018). With the help of Landsat satellite images and machine learning, the fictitious environmental manager "Asunder" proposes alterations to the Earth to keep it safely within certain boundaries. These propositions may well turn out to be uncomfortable and highly speculative, as for example the afforestation of Berlin with a tropical forest.

The fictitious environmental manager consists of a three-part screen that forms a triptych of contemporary climate modeling. The left side displays original Landsat satellite images that correspond to the input of the climate model. The right side shows their possible futures in the form of artificial satellite images generated by image inpainting. They are the result of a fictitious geoengineering process. Via the comparison of the original Landsat

11 For a critique of this sort of promises see the chapter by Wickberg and Lidström in this volume.

12 Disclosed in an e-mail by Tega Brain to the author, March 23, 2024.

image (before) and the image generated by inpainting (after), the process of geoengineering unfolds in the same way in which climate change is often visualized and analyzed (I. Weizman and E. Weizman 2017).[13] This also reminds one of the 19th century "mini-chronophotography" of cloud movement. In the center of the triptych various data of the input region, such as population, average temperature, and an endangered species count, is listed. Then different modification options, i.e., different satellite images generated by inpainting, are shown, followed by the analysis of the selected scenario. The generated proposition is analyzed by the Community Earth System Model (CESM), a numerical simulation of the Earth's climate, which runs on a 144-CPU (central processing unit) computer positioned opposite the triptych next to the viewer. The computational process and the data analysis take center stage, becoming the focus of the viewer.

In *Asunder*, the image is the starting point and basis of the prediction and its analysis. The image does not only provide the initial data but also the possible geoengineered futures. It is the image that renders the landscape and the environment operative.[14] Although *Asunder* and its use of machine learning is speculative, machine learning methods for weather forecasting and climate modeling are on the rise (Schultz et al. 2021; Beucler et al. 2024; Sullivan and Hoose 2024). In the case of the method of nowcasting, the prediction of weather for the next few hours, clouds—or rather images of clouds—are of particular interest. Although clouds are usually only taken into account through parametrization, as they are too small a phenomenon for the resolution of the models (Schneider 2018, 216; Stevens and Bony 2013), here, the predictions are based on images of clouds. Abelardo Gil-Fournier and Jussi Parikka (2020) summarized how researchers test video-based prediction methods (i.e., next frame prediction) to predict the movement of clouds and thereby precipitation. In short: an artificial neural network learns how to predict the next frame of a video sequence, in this case of cloud movement. Video and weather are considered spatial time series that can be predicted in the same way. The frame rate for cloud movement depends on the recording rate of the weather radars, and since cloud data are still sparse, we do not see 24 images per second as usual for analogue film, but only 240 images per day (Shi et al. 2017), that is 0.0028 images per second.

Images of clouds are also often used to predict solar radiation, for example to estimate the energy production of solar collectors. Instead of using satellite

13 Image inpainting is also based on comparison: the artificial neural network learns to reconstruct missing areas in images through a large training set of images.

14 Although satellite images are based on various signals that may not correspond to the human visual spectrum (and may also contain additional information on the atmosphere), image inpainting only operates at the level of pixels. Changes in pixels correspond to changes in land use, which then provide the parameters for the analysis by CESM. In *Asunder*, "geoengineering" is only based on the image.

[Figure 4] Image taken by a cloud machine (*Wolkenautomat*) (Source: Adolf Sprung, *Wolkensituation 7, 925 T*, Tornow (Potsdam), 6.9.1901. Wettermuseum. EX 002 220. https://brandenburg.museum-digital.de/object/67104).

or radar images, it is common to capture the sky with "Total Sky Imagers" and fisheye lenses in a 360-degree view from below (e.g., Zhu, Wei, and Guo 2021; overview by Martins et al. 2022). These images are reminiscent of those taken by cloud machines (*Wolkenautomaten*)—permanently installed devices that partially replaced phototheodolites at the beginning of the 20th century. These automatic devices were used to avoid human errors that occurred while adjusting phototheodolites (Sprung 1899). Today, machine learning is used to evaluate the collected data and, since the cloud type provides additional information on the expected solar energy, there is also research into the use of artificial neural networks for cloud classification (e.g., Zhu, Wei, and Guo 2021; overview by Beucler et al. 2024). An evaluation of scientific publications on solar radiation showed that 56% of the papers published between 2011 and 2020 used only images and no other meteorological data. The authors explain this by the increasing use of deep learning and advances in computer vision (Martins et al. 2022). Images of clouds are indeed used to predict the future.

According to the European Centre for Medium-Range Weather Forecasts (ECMWF), the potential of machine learning for weather forecasting has been seriously investigated since 2018 but remained uncompetitive until 2022

(Chantry et al. 2023). Since then, major technology companies such as NVIDIA, Google DeepMind, and Huawei have been using deep learning for weather forecasting (e.g., Pathak et al. 2022; Bi et al. 2023; Lam et al. 2023). These models are beginning to be competitive with numerical models, although it is challenging for the models to predict weather extremes and changes in climate, since they learn patterns from historical data. In November 2023, Google DeepMind released *GraphCast*, which is able to make weather forecasts of up to 10 days with extremely high accuracy, even exceeding the standard numerical model used by the ECMWF. *GraphCast* forecasts in less than a minute and can also predict weather extremes, such as the development of a cyclone, with very high accuracy. The promise is to predict weather faster, more accurately, and more cost-effectively by learning weather patterns directly from data instead of solving physical equations by approximation (Lam et al. 2023).[15] With the same promise, NVIDIA presented its artificial neural network for weather forecasting, *FourCastNet* (Pathak et al. 2022). NVIDIA is the largest manufacturer of graphics processing units (GPU), which refers back to the topic of computer games. Although GPUs were originally designed to process computer graphics, today, thanks to their suitability for the computations necessary in deep learning, they are at the center of efficient artificial neural network training.[16]

One of NVIDIA's core projects is the creation of a digital twin of the Earth. The CEO of NVIDIA, Jensen Huang, is eager to advance the project towards a full, interactive simulation of the Earth that can not only observe but also simulate the climate on a planetary scale—the "only supercomputer that's ever been build that runs 24/7" (Huang 2022). The achievements of the company are immodestly referred to as miracles required to realize a digital twin of the Earth (Huang 2023). There are other projects with similar goals: the European Union is funding the Destination Earth project (DestinE) to develop a digital twin of the Earth. Led by, among others, the ECMWF, DestinE aims to "ultimately … revolutionise the European capability to monitor and predict our changing planet, based on the integration of extreme-scale computing and the real-time exploitation of all available environmental data" (ECMWF 2021).

15 To guarantee to only learn patterns that correspond to the laws of physics there is research in physics-informed or physics-guided neural networks. One may add penalizing terms to the loss function or physical constraint layers (Kashinath et al. 2021; Beucler et al. 2024). However, the training sets of neural network models still rely on NWP.

16 Images were at the center of the revival of artificial neural networks as the main paradigm of artificial intelligence research. It was the combination of a huge amount of training data in the form of an image database (*ImageNet*), hardware originally developed for image processing (GPU), and a specific architecture for artificial neural networks for image processing (convolutional neural network) that led to the success of artificial neural networks at the 2012 Large Scale Visual Competition.

DestinE is supposed to mimic the Earth in an interactive way, which is similar to Gore's *Digital Earth*.

Several meanings of ubiquitous computing get entangled here. Embedded sensors, cameras, and microprocessors enable the registration and processing of a massive amount of data; simultaneously the sensor-based monitoring of the Earth creates environments (Gabrys 2016). Since the digital twins of the Earth are completely computable, conversely, so should be the Earth.

One of the greatest difficulties of the digital twin, and at the same time one of its main purposes, is the feedback between the "real" and its digital twin. Ideally, the feedback should take place in both directions, even in real time. The real and the digital Earth are not distinct—it is their feedback loop that entangles them. The digital twin not only reproduces the world but also produces it. The mode of moving in and between the two "Earths" is that of navigation, where the map finally seems to have become the territory (Siegert 2011).[17] But what role does the environment play in this context? Is it just there to be recorded and then to be represented? What is the role of images on a planetary scale?

Images on a Planetary Scale

In their video essay *Optic Nerves and their Time* (2021), the artist collective Geocinema deals with the representation of the Earth through a distributed cinematic apparatus containing surveillance cameras, satellites, and geosensors, forming a cinema on a planetary scale. The video essay shows how sensor technologies and algorithms transform and process, for example, chemical data to images. Increasingly, non-optical data are being processed as image (every signal can exist as image), and in consequence "the earth is no passive backdrop," as the voice-over states, but part of the imaging of the Earth. The voice-over concludes: "The land, the air, the light are co-composing the image." The video essay demonstrates that data are extracted by multiple sensors and then processed algorithmically. Thereby the environment becomes signals, then measurements, and ultimately images. "One more image of the earth," the voice-over comments on a close-up of a computer screen showing rows of data. It explains: "This is a mathematical model of the earth and its climate. You can see on the screen how earth observation data gathered since 1970 is being processed to simulate weather in the far and distant futures." These observations stress that everything that can be captured by sensors as a signal can become an image, which in turn links image and environment. The environment is entering the image as data. Meanwhile,

17 In a promotional video by NVIDIA, this idea is illustrated by slowly superimposing an image of the world ("ground truth") with an image of its digital twin until they finally become "one" (see Huang 2022).

images not only become part of a computing process but start to compute themselves.

Geocinema shows that the Earth is fully wrapped in signals that amount to a “massive archive of data, which is a constantly recorded version of the earth” (voice-over), that is, its digital twin. Many processes of translation are involved, which raises issues of compatibility of scale, time, and transmission rates. To model large-scale patterns of environmental change, different datasets and measurements must be merged. In general, signals can differ in the form and frequency of their recording and transmission, and there is a delay between transmissions, an issue that is well-known in distributed computing. Geocinema is right to emphasize that one should not ask “what” is the Earth but “how”: How is it measured and calculated, datafied and packaged, distributed and archived? It seems that the Earth is no longer merely represented but rather modeled by its images and data counterparts. The imaging process on a planetary scale is distributed among agents that co-compose the image; it is distributed between environment and technologies, chemicals and sensors, air and algorithms. This also means that there is not only a plurality of images of the Earth, but each image in itself is plural. Just as data is a mass noun—data *is* always big—(Gitelman and Jackson 2013, 8) the image of the Earth on a planetary scale should be too. The imaging as well as the image itself are distributed.

In *Parallel I*, when juxtaposing film and computer image, Farocki states that, in film, there are two types of wind, that of the wind machine and that of the real wind, whereas in computer-generated images there is only one kind. However, in today’s operative images this distinction seems to disappear. Registered as a signal, transformed into data, and processed as an image, the wind is, as it were, re-entering the image. The wind is not only represented but part of the imaging process and at the same time of its future projections; moreover, as predicted wind, the “real wind” is no longer what it used to be.

These operative images may be compared to scientific models, which at the same time aim to adequately represent and abstract the object they model (Rosenblueth and Wiener 1945). The choice of model depends on the intent; the model must suit the manner in which it should manage and operate the object that it represents (Cartwright 1983, 152–62). Models mediate between theory and the world and may teach something about both (Morrison and Morgan 1999). Since operative images are not only part of computing environments but also compute themselves on a planetary scale, they aim less at representing than at modeling the Earth.

References

Annoni, Alessandro, Stefano Nativi, Arzu Çöltekin, Cheryl Desha, et al. 2023. "Digital Earth: Yesterday, Today, and Tomorrow." *International Journal of Digital Earth* 16, no. 1: 1022–72.

Bazin, André. 1960. "The Ontology of the Photographic Image." *Film Quarterly* 13, no. 4: 4–9.

Beucler, Tom, Imme Ebert-Uphoff, Stephan Rasp, Michael Pritchard, et al. 2024. "Machine Learning for Clouds and Climate." In *Clouds and Their Climatic Impacts: Radiation, Circulation, and Precipitation*, edited by Sylvia C. Sullivan and Corinna Hoose, 325–45. Hoboken: John Wiley & Sons.

Bi, Kaifeng, Lingxi Xie, Hengheng Zhang, Xin Chen, et al. 2023. "Accurate Medium-Range Global Weather Forecasting with 3D Neural Networks." *Nature* 619: 533–38.

Bois, Yve-Alain, Hubert Damisch, Denis Hollier, and Rosalind E. Krauss. 1998. "A Conversation with Hubert Damisch." *October*, no. 85: 3–17.

Bratton, Benjamin H. 2016. *The Stack: On Software and Sovereignty.* Cambridge, MA: MIT Press.

Cartwright, Nancy. 1983. *How the Laws of Physics Lie.* Oxford: Oxford University Press.

Chantry, Matthew, Zied Ben Bouallègue, Linus Magnusson, Michael Maier-Gerber, et al. 2023. "The Rise of Machine Learning in Weather Forecasting." Accessed January 20, 2025. https://www.ecmwf.int/en/about/media-centre/science-blog/2023/rise-machine-learning-weather-forecasting.

Crespi, Noel, Adam T. Drobot, and Roberto Minerva, eds. 2023. *The Digital Twin.* Cham: Springer.

Damisch, Hubert. 2002. *A Theory of /Cloud/: Toward a History of Painting.* Stanford: Stanford University Press.

Daston, Lorraine. 2016. "Cloud Physiognomy: Describing the Indescribable." *Representations* 135: 45–71.

ECMWF. 2021. "Presenting Destination Earth: A Digital Replica of Our Planet." Accessed September 20, 2025. https://www.ecmwf.int/en/about/media-centre/news/2021/presenting-destination-earth-digital-replica-our-planet.

Edwards, Paul N. 2010. *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming.* Cambridge, MA: MIT Press.

———. 2015. "Wissensinfrastrukturen für das Anthropozän." In *Das Anthropozän: Zum Stand der Dinge*, edited by Jürgen Renn and Bernd Scherer, 242–55. Berlin: Matthes & Seitz.

Elsaesser, Thomas. 2004. "Harun Farocki: Filmmaker, Artist, Media Theorist." In *Harun Farocki: Working on the Sight-Lines*, edited by Thomas Elsaesser, 11–40. Amsterdam: Amsterdam University Press.

Farocki, Harun. 2004. "Phantom Images." *Public* 29: 12–22.

———. 2014. "Lecture 'Computer Animation Rules': IKKM-Internationales Kolleg für Kulturtechnikforschung und Medienphilosophie 25.6.2014)." Accessed January 21, 2025. https://www.ikkm-weimar.de/en/publications/video-audio/ikkm-lectures/computer-animation-rules/.

Franklin, Seb. 2012. "Cloud Control, or the Network as Medium." *Cultural Politics* 8, no. 3: 443–64.

Gabrys, Jennifer. 2016. *Program Earth: Environmental Sensing Technology and the Making of a Computational Planet.* Minneapolis: University of Minnesota Press.

Gil-Fournier, Abelardo, and Jussi Parikka. 2020. "Visual Hallucination of Probable Events." In *Big Data—A New Medium?*, edited by Natasha Lushetich, 46–60. London: Routledge.

Gitelman, Lisa, and Virginia Jackson. 2013. "Introduction." In *"Raw Data" Is an Oxymoron*, edited by Lisa Gitelman, 1–14. Cambridge, MA: MIT Press.

Gore, Al. 1999. "The Digital Earth: Understanding Our Planet in the 21st Century." *Photogrammetric Engineering & Remote Sensing* 65, no. 5: 528–30.

Gramelsberger, Gabriele. 2020. "Algorithm Awareness: Towards a Philosophy of Artifactuality." In *Affective Transformations: Politics–Algorithms–Media*, edited by Bernd Bösel and Serjoscha Wiemer, 41–48. Lüneburg: meson press.

Greenfield, Adam. 2006. *Everyware: The Dawning Age of Ubiquitous Computing.* Berkeley: New Riders.

Grieves, Michael. 2014. *"Digital Twin: Manufacturing Excellence Through Virtual Factory Replication*." Whitepaper for Dassault Systèmes. https://www.3ds.com/fileadmin/PRODUCTS-SERVICES/DELMIA/PDF/Whitepaper/DELMIA-APRISO-Digital-Twin-Whitepaper.pdf.

Gross, Neil. 1999. "The Earth Will Don an Electronic Skin." *BusinessWeek*, no. 3644: 132–34.

Halpern, Orit, Patrick Jagoda, Jeffrey West Kirkwood, and Leif Weatherby. 2022. "Surplus Data: An Introduction." *Critical Inquiry* 48, no. 2: 197–210.

Hildebrandsson, Hugo Hildebrand, and Karl Leonard Hagström. 1893. *Des prinicpales méthodes empolyées pour observer et mesurer les nuages.* Uppsala: Imprimerie Harald Wretman.

Hildebrandsson, Hugo Hildebrand, Albert Riggenbach, and Léon-Philippe Teisserenc de Bort, eds. 1896. *Atlas International Des Nuages.* Paris: Gauthier-Villars et Fils.

Hoelzl, Ingrid, and Rémi Marie. 2014. "Google Street View: Navigating the Operative Image." *Visual Studies* 29, no. 3: 261–71.

Holert, Tom, and Doreen Mende. 2019. "Editorial: 'Navigation Beyond Vision, Issue One.'" *e-flux Journal* #101. June 20, 2019. https://www.e-flux.com/journal/101/274019/editorial-navigation-beyond-vision-issue-one.

Huang, Jensen. 2022. "Nvidia CEO on Using Computer Simulations to Fight Climate Change." Accessed January 22, 2025. https://finance.yahoo.com/video/nvidia-ceo-using-computer-simulations-143933327.html?guccounter=1.

———. 2023. "Keynote Berlin Summit for Eve (3.6.2023)." Accessed January 21, 2025. https://eve4climate.org/how-eve-started/.

Kashinath, K., M. Mustafa, A. Albert, J-L Wu, et al. 2021. "Physics-Informed Machine Learning: Case Studies for Weather and Climate Modelling." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 379, no. 2194: 20200093. https://doi.org/10.1098/rsta.2020.0093.

Koppe, Carl. 1896. *Photogrammetrie und Internationale Wolkenmessung.* Braunschweig: Friedrich Vieweg und Sohn.

Lam, Remi, Alvaro Sanchez-Gonzalez, Matthew Willson, Peter Wirnsberger, et al. 2023. "Learning Skillful Medium-Range Global Weather Forecasting." *Science* 382: 1416–21.

Martins, Juncklaus Bruno, Allan Cerentini, Sylvio Luiz Mantelli, Thiago Zimmermann, et al. 2022. "Systematic Review of Nowcasting Approaches for Solar Energy Production Based Upon Ground-Based Cloud Imaging." *Solar Energy Advances* 2. https://doi.org/10.1016/j.seja.2022.100019.

Morrison, Margaret, and Mary S. Morgan. 1999. "Models as Mediating Instruments." In *Models as Mediators: Perspectives on Natural and Social Science*, edited by Mary S. Morgan and Margaret Morrison, 10–37. Cambridge: Cambridge University Press.

Paglen, Trevor. 2014. "Operational Images." *e-flux Journal* #59. November 1, 2014. https://www.e-flux.com/journal/59/61130/operational-images.

Pantenburg, Volker. 2017. "Working Images: Harun Farocki and the Operational Image." In *Image Operations: Visual Media and Political Conflict*, edited by Jens Eder and Charlotte Klonk, 49–62. Manchester: Manchester University Press.

Parikka, Jussi. 2021. "On Seeing Where There's Nothing to See: Practices of Light Beyond Photography." In *Photography Off the Scale: Technologies and Theories of the Mass Image*, edited by Tomáš Dvořák and Jussi Parikka, 185–210. Edinburgh: Edinburgh University Press.

———. 2023. *Operational Images: From the Visual to the Invisual.* Minneapolis: University of Minnesota Press.

Parikka, Jussi, and Tomáš Dvořák. 2021. "Measuring Photographs." *Photographies* 14, no. 3: 443–57.

Pathak, Jaideep, Shashank Subramanian, Peter Harrington, Sanjeev Raja, et al. 2022. "FourCastNet: A Global Data-Driven High-Resolution Weather Model Using Adaptive Fourier Neural Operators (Preprint)." *arXiv*. https://doi.org/10.48550/arXiv.2202.11214.

Peters, John Durham. 2016. *The Marvelous Clouds: Toward a Philosophy of Elemental Media.* Chicago: The University of Chicago Press.

Pias, Claus. 2003. "Das digitale Bild gibt es nicht. Über Das (Nicht-)Wissen der Bilder und die informatische Illusion." *zeitenblicke* 2, no. 1. http://dx.doi.org/10.25969/mediarep/4082.

Richardson, Lewis Fry. 1922. *Weather Prediction by Numerical Process.* Cambridge: Cambridge University Press.
Rosenblueth, Aturo, and Norbert Wiener. 1945. "The Role of Models in Science." *Philosophy of Science* 12, no. 4: 316–21.
Rouvroy, Antoinette, and Thomas Berns. 2013. "Algorithmic Governmentality and Prospects of Emancipation: Disparateness as a Precondition for Individuation Through Relationships?" *Réseaux* 177, no. 1: 163–96.
Schneider, Birgit. 2018. *Klimabilder: Eine Genealogie globaler Bildpolitiken von Klima und Klimawandel.* Berlin: Matthes & Seitz.
Schultz, M. G., C. Betancourt, B. Gong, F. Kleinert, et al. 2021. "Can Deep Learning Beat Numerical Weather Prediction?" *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 379 (2194).
Shi, Xingjian, Zhihan Gao, Leonard Lausen, Hao Wang, et al. 2017. "Deep Learning for Precipitation Nowcasting: A Benchmark and a New Model." *arXiv*. https://doi.org/10.48550/arXiv.1706.03458.
Siegert, Bernhard. 2011. "The Map Is the Territory." *Radical Philosophy* 169, no. 5: 13–16.
———. 2022. "The Map Is the Territory—Dissolving the Barrier Between Media and Nature." *Spark Magazine: A NOMIS Foundation Publication*: 16–22.
Sprenger, Florian, and Christoph Engemann, eds. 2015. *Internet der Dinge: Über smarte Objekte, intelligente Umgebungen und die technische Durchdringung der Welt.* Bielefeld: transcript.
Sprung, Adolf. 1899. "Ueber den Photogrammetrischen Wolkenautomaten und seine Justierung." *Zeitschrift für Instrumentenkunde: Organ für das wissenschaftliche und technische Geräte- und Messwesen* 19: 111–18; 129–37.
Stevens, Bjorn, and Sandrine Bony. 2013. "Climate Change. What Are Climate Models Missing?" *Science* 340, no. 6136: 1053–54.
Sullivan, Sylvia C., and Corinna Hoose, eds. 2024. *Clouds and Their Climatic Impacts: Radiation, Circulation, and Precipitation.* Hoboken: Wiley.
———. 2024. "Science of Cloud and Climate: An Analysis of the Literature over the Past 50 Years." In *Clouds and Their Climatic Impacts: Radiation, Circulation, and Precipitation*, edited by Sylvia C. Sullivan and Corinna Hoose, 1–12. Hoboken: Wiley.
Süring, Reinhard. 1903. "Die Bearbeitung der Potsdamer Wolkenmessungen 1896/1897." In *Ergebnisse der Wolkenbeobachtungen in Potsdam und an einigen Hülfsstationen in Deutschland in den Jahren 1896 und 1897*, edited by Adolf Sprung and Süring Reinhard, 42–83. Berlin: A. Asher & Co.
Weiser, Mark. 1991. "The Computer for the 21st Century." *Scientific American Special Issue on Communications, Computers and Networks* 265, no. 3: 94–104.
Weizman, Ines, and Eyal Weizman. 2017. *Before and After.* Moskau: Strelka Press.
Wolf, Herta. 1993. "Wolken, Spiegel und Uhren: Eine Lektüre meteorologischer Fotografien." *Fotogeschichte: Beiträge zur Geschichte und Ästhetik der Fotografie* 13, no. 48: 3–18.
Yu, Jiahui, Zhe Lin, Jimei Yang, Xiaohui Shen, et al. 2018. "Generative Image Inpainting with Contextual Attention." *arXiv.* https://doi.org/10.48550/arXiv.1801.07892.
Zhu, Tingting, Liang Wei, and Yiren Guo. 2021. "Cloud Classification of Ground-Based Cloud Images Based on Convolutional Neural Network." *Journal of Physics: Conference Series* 2035, no. 1. https://doi.org/10.1088/1742-6596/2035/1/012020.

ENVIRONING MEDIA

ELECTRON TUBES

DIGITAL CALCULATION

DATAFICATION

ATMOSPHERIC MODELING

MASS SPECTROMETRY

WORLD MEDIA

[4]

Atmospheric Signals, Tubed

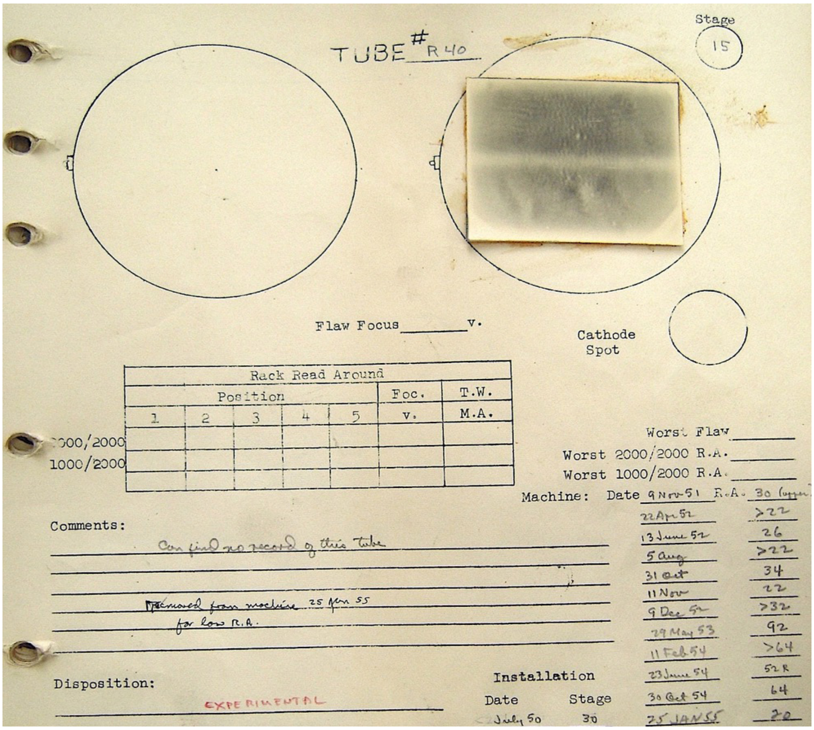
Christoph Rosol

Today's increasing operational closure between Earth and the technosphere has roots in a quite specific device. Electron tubes provided the very environments in which the global natural environment became accessible to measurement and high-speed computation. The following paper offers some avenues into the peculiar moment in the mid-20th century when the open space of the planetary was technologically operationalized in closed and controlled interiors. The 1945–56 Electronic Computer Project at the Institute for Advanced Study in Princeton, NJ works like a magnifying glass for tracing this momentous epistemic liaison between air currents and electron currents. It reveals the specific circumstances in which the parallel development of a fully electronic calculating machine and the first digital-numerical models of the atmosphere took place. The paper revisits the co-development of

post-war computing and geophysics, in which tubes functioned as the material joints, essentially providing the condition of possibility for calculating the large-scale flows of air over the globe. It moreover highlights the role of tubes as a sensory medium, i.e., as an instrument that literally transforms material chemical elements and their subspecies (isotopes) into electric signals, and thereby into quantifiable data about planet Earth. Mass spectrometry emerged concurrently with electronic computing and is based on the same physics lab and electrical engineering culture of tube design as the latter. In essence, gas discharge tubes coupled with electrometer tubes were to produce some of the very signals that were then processed by calculating tubes: a closed techno-epistemic loop that represents a fundamentally new mode of processing the quantified properties of the Real since around 1950.

When skimming through the log files of the Electronic Computer Project in the archives of Princeton's famed Institute for Advanced Study (IAS), one can find a rather unspectacular record of a vacuum tube failure (see figure 1). The record is dated January 25, 1955, and it shows the smoky exposure image of a malfunctioning and then removed cathode ray tube, along with some data such as when the tube was first installed and when previous flaws occurred. A further note, in red pencil, states: "EXPERIMENTAL."

The device in question (an exemplar of which is shown in figure 2 in the hands of the responsible electrical engineer James Pomerene) was one element in an array of altogether forty so-called Williams tubes that were used to electronically store both program code and numbers in binary form: as dots of light flashing over a discretized address matrix of a cathode ray tube (CRT) display. This first Random Access Memory ever in operation, able to store a sizeable 1024 binary digits, was arguably the most innovative yet also most troublesome component of a new, fully electronic computer design that had been under development at the IAS since 1946. The truly "experimental" IAS



[Figure 1] Maintenance logbook of the IAS Electronic Computer Project for tube #40. The last entry reports a tube failure on January 25, 1955, after which the tube was removed (Source: Scan by author; file held by the Shelby White and Leon Levy Archives Center, Institute for Advanced Study, Princeton).

machine was the first realization of a universal Turing machine and its logical architecture, named after the supervisor of the Electronic Computer Project (ECP) John von Neumann, represented the blueprint for basically all modern computers ever since.

However, this is not the only historical "first" to be noted here. The low "R. A." (read-around) performance of tube No. R 40 actually occurred right before one of the most remarkable experiments in the history of the climate sciences took place on the IAS machine: the first numerical simulation of the planetary-scale motions of the atmosphere, or what is known as the general circulation. Shortly after the official start of the ECP in summer 1946 a group of geophysicists and meteorologists joined the project. The idea was to develop numerical solutions for the highly nonlinear and interactive dynamics of the moving geofluid called atmosphere in close conjunction with the development

[Figure 2] James Pomerene presenting a Williams tube during the official inauguration of the IAS machine, June 1952 (Source: Apomerene, https://commons.wikimedia.org/wiki/File:James_Pomerene_IAS_machine.jpg).

of the machine that was to execute these mathematical solutions.[1] In January 1947 the meteorologists together with the electrical engineers moved into a new small building, de facto a miniature prototype data center for scientific computing. It was paid for by the U.S. Atomic Energy Commission and deliberately erected on the edge of IAS's idyllic grounds to keep "dirty" engineering and applied atmospheric physics separated from the dignified sphere of pure math and intellectual erudition that characterized the academic culture of the IAS (Dyson 2012). The physical, mental, and creative concentration of the development of a novel, high-speed numerical machine and a novel, highly abstract geoscience was very much in the spirit of von Neumann's recent experiences at a similar, albeit much larger incubator effort out west. Not

1 A word on the term numerical: Since Leonhard Euler's advances in symbol manipulation that formed 18th century analytical mechanics, the motion of continuous fluids such as the elemental medium air is "represented" in its infinitely small totality by a set of partial differential equations: nonlinear and nonintegrable, even more so for such a vast system as the atmosphere. A way to render the problem tractable is to approach it arithmetically, that is, in an approximative and algorithmic, brute-force fashion of multiplying and adding actual truncated numbers. Such a scheme requires the discretization of the three-dimensional atmosphere into a finite-difference grid, wherein each variable at every grid point and in every time step of fluid progression is solved before the next one is taken up. This is an immensely tedious process for a human computer, but a straightforward, i.e., programmable, task for a machine to perform, especially if this machine works at the near light-speed of electrons.

least because Robert Oppenheimer took over the IAS directorship later in the same year of 1947, some IAS guests were reminded of their recent days at Los Alamos, where they developed just another one of those devices that would change the world for good.

At least for the small geophysics-mathematics-electronics community within the confines of the IAS, the experience of living and working so closely together—like in an integrated circuit—must have been congenial. In its highly compacted form, the Princeton-based project emblematically represents the sustained melding of electronic signal processing with studying atmospheric processes, both in manual practice and in the realm of the conceptual and idiomatic. Since the rise of wireless communication and ionosphere research during the first decades of the 20th century, the physics of the atmosphere was already increasingly understood and expressed by way of the terminology of radio and radar engineering. Yet, it was the actual marriage of atmospheric theory with computer design that put the study of geofluids now firmly on track to become an epistemic corollary of the applied science of signal detection and signal amplification, modulation and separation, noise filtering, feedbacks, and response times. Around 1950 the theoretical investigation of the hydro- and thermodynamical behavior of the planetary atmosphere solemnly moved into the epistemic domain of the electronic. It resides there ever since.

The pivotal 1955 numerical experiment on the general circulation was devised and conducted by Norman Phillips, who was, according to the head of the meteorological arm of the project Jule Charney and proven by numerous logbook entries, the most able "man-machine interface" amongst the meteorologists embedded in the ECP (Phillips 1956; Charney 1953). Due to the scarce memory resources, Phillips limited his test to a section of the northern hemisphere large enough to capture the genesis and evolution of a typical cyclone. The area he chose roughly spanned the width of Canada and the distance equator to pole, all mapped onto a Mercator projection surface. However, in order to simulate a hemispheric circulation, he allowed the air current that left the section in the east to re-enter in the west, turning the whole of North America into a cylindrical surface. Phillips' first goal was to have a general circulation emerge in the computed data by successive integration over timesteps of one day from an atmospheric state of rest: a now classic spin-up of a model atmosphere. And indeed, after 130 model days, a quasi-stable state of motion occurred in his tube-shaped globe. Once this was reached the calculation intervals were shortened to two hours and a more sophisticated set of equations was used to "observe" the effect of introducing random numbers in order to trigger an atmospheric perturbation. As a result, realistic-looking high and low pressure areas developed. However, after a total of 30 model days, the calculations collapsed. This was not due to another memory tube failure or other machine dropouts. Instead, Phillips and Charney knew the culprit: rounding errors and numerical instabilities were likely responsible for the termination.

Phillips' idea to constrain the boundary conditions of a numerical atmosphere to see how a general circulation develops through long-time integrations of the (much simplified) equations of fluid motion directly led to the development of general circulation models. Over the next decades such GCMs evolved into the most powerful workhorses in climate research. In recent times, and in tandem with constantly increasing computing and memory power that far outstrip the five kilobytes of the original IAS computer, these gradually extended outwards to incorporate further components such as ocean circulation, vegetation cover, and geochemical fluxes, essentially becoming fully-fledged Earth System Models. Phillips' numerical experiment is where all of that started in epistemical and methodical earnest.

The story of the "revolution" in scientific computing and its adjacent "revolution" in computational atmospheric science is well covered in the historiographic literature. Nevertheless, both developments are commonly treated conspicuously separated, shedding focus either mainly on the design aspects of early computers or on the changing conditions undergirding the discipline of meteorology. As in solving the set of partial differential equations underlying the motion of fluids, one of the two sides of the inextricable historical configuration is treated more or less as a given, while the other is taken as the variant to be calculated/narrated. Moreover, what has been left out in these coverages of the history of the modern computer, and of modern meteorology and climatology, respectively, is the central device that interconnected and, to some extent, regulated this fusion of computer and climate science: the electron tube. Still, if one takes a step back for a moment, one might well ask what an electronic computer and vacuum tubes actually have to do with air motions and geophysical fluid dynamics? In the following, I will try to cover some concrete historical aspects of this association between air currents and electron currents as it was hard-wired around 1950.[2] In the remainder of the paper I will extend my historical analysis beyond the modeling of the general circulation and climate and briefly sketch out another crucial application of tubes: isotope geochemistry and its application to datafying the globe.

2 A related article that focuses on the pre-history of the period presented here and with a larger focus on aspects of dynamic meteorology and climatology is published as Rosol 2025.

Tubes

Electronics has had been around since the beginning of the 20th century and was simply the art of using airtight and mostly glassy envelopes to control and manipulate the flow of currents in the electric field generated between electrodes: from an electron-emitting (thermionic, i.e., hot) cathode towards a receiving anode and a possible control grid somewhere in between them. Even before that, such tubes, or "valves" in British usage, were *the* scientific instrument. Glass spheres that generated static electricity had their spectacular beginnings in the experimental philosophy of the early 18th century. However, it was not until the second half of the 19th century, with the study of electromagnetism and the subsequent rise of electrodynamics, that tubes became the focus of attention in many physics laboratories. With an increasing variety of tube architectures, the fundamental structure of the chemical-physical world in its forms as matter and radiation could now be investigated experimentally and increasingly used technically. Observing, modifying, and essentially controlling phenomena such as electrical charges, light, thermal radiation, the effects of forces in electrical fields, or the existence of the ether—all in sealed flasks—promised answers to questions about the inner fine structure of the natural world.

Harnessing electricity for the purpose of amplification, rectification, detection, and a whole range of other electrodynamical uses, tubes then emerged as the key component of signaling equipment in the first decades of the 20th century. Modulating and manipulating continuous analog signals was the primary aim of the radio and electronics profession at the time. Digital, all-or-nothing operations, such as in routing telephone calls or transmitting the discrete dots and dashes of Morse telegraph signals, were better served by electromechanical relays, which were therefore also used in many of the first calculators. However, similar functions of switching between states and storing a state as long as needed could also be emulated by tubes, only much faster and without mechanical effort. In 1919 the so-called trigger relay of William Eccles and Frank Jordan paired two analog radio triodes to essentially perform a bistable operation, in which one of the tubes is conducting while the other is not: a "flip flop" that keeps its current state until a new signal, with just a negligible amount of energy, lets it switch into the other one in a few millionths of a second. Another still different tube, the thyratron, was designed by the electrical engineer Albert Hull in 1928 and achieved a similar result but with only one component. By applying a signal to the control grid, the electron velocity jumped over a certain threshold to ignite the ionization of a rare gas that was contained inside the tube. Ionization is the process by which the gas atoms that are being hit by the free-flowing electrons become positively charged ions, making the gas in the chamber start to glow. Just in the same year 1928, Hull's colleague at General Electric, the chemist Irving Langmuir, gave this ionized matter the name plasma. Tinkering with such gas discharge tubes goes right back to the 19th century tradition of scientific experimenting just mentioned and was still a common practice in nuclear physics and nuclear chemistry in the 20th. One of these novel uses was a detection device for radioactive particles and cosmic rays that also happened to be developed in the same year by the two physicists Hans Geiger and Walter Müller. A Geiger–Müller counter consists of a cylindrical tube filled with a gas mix at a very low pressure that was able to detect charged particles through their ionization effects. Connected to the Geiger–Müller tube is a sensitive electrometer that registers all entry events of alpha or beta radiation particles.

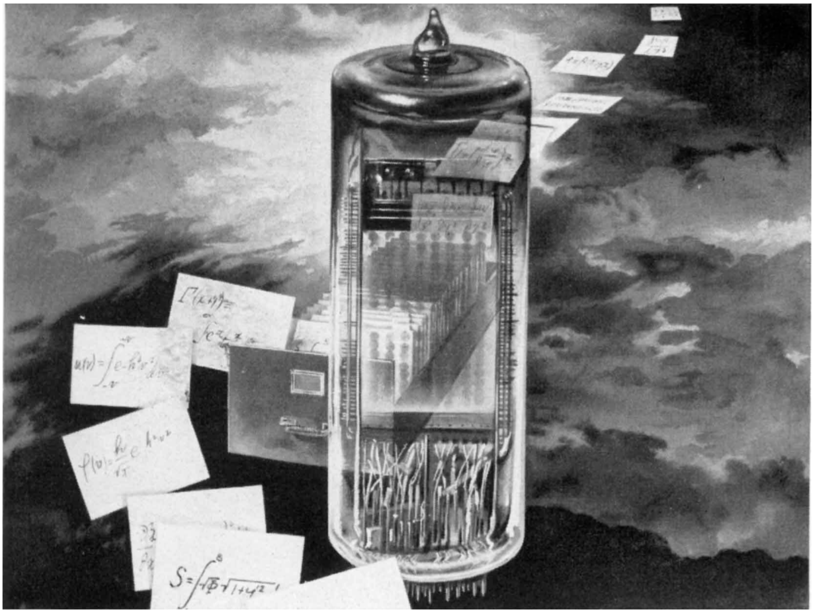
But to really *count* such events further electronics was needed. After a visit of Albert Hull to the Cavendish Laboratory in Cambridge, the physicist C. Eryl Wynn-Williams found a decisive way to make the numeric registration of electrical events possible. He arranged several units of two thyratrons in a cascade so as to reduce the rate of counting by a factor of two per unit, until the final counting rate was sufficiently slow to enable a mechanical meter to number the amplified charges. Up to 1250 events per second could be counted with his inertialess chain of lit-up tubes. What Wynn-Williams did not see yet, though, was that his two-to-the-power-of-n counter and a binary numeral system memory were functionally the same thing. By serially arranging the thyratrons in a cascade where the final tube got connected to the first (a so-called ring counter), the different states into which they can be put by electrical events, that is signals, were indeed able to represent numbers in the binary system. Counters of charged elementary particles were now binary counters. The same goes for the Eccles–Jordan twin triodes, of course, or basically any pair of bistable cells that communicate through gates in a kind of Möbius loop connectivity. With more additional circuits such a ring counter could even be made to calculate with these numbers. By circuiting these flip flops through logical or arithmetic units one was able to perform logical operations or could simply add, subtract, multiply, or divide.

Calculating with Tubes

Now, the overarching question of the present paper is, in which way this fusion of basic physics, math and electronics also resulted in numerical modeling becoming a proxy of fluid motion itself, that is, a computational technology of "environing" (Sörlin and Wormbs 2018; Wickberg and Gärdebo 2022). Or, more specifically: In which way did the operationalization of the physics of flowing elementary particles in enclosed and controlled interiors epistemically conjoin with the operation of elemental media?

Let me therefore quickly leap forward in time to the project in Princeton that melded computer design with numerical weather prediction and soon climate modeling. After some initial tests the engineering team at the IAS decided against the thyratron and opted for an Eccles–Jordan-type circuit on the basis of 6J6 twin triodes—a cheap but reliable component mass-produced by the Radio Corporation of America (RCA) during World War II for the purpose of military communications. 6J6s made up about half of the more than 3400 tubes that were eventually installed in the "big tube test rack," as the chief engineer of the ECP Julian Bigelow called the experimental machine (Bigelow 1980, 307). However, the operation and clock rate of the entire electronic composition depended primarily on another component: the memory or storage tube. For the processing of a highly iterative and data-intensive numerical calculation such as the spatio-temporal evolution of a pressure field in an atmospheric grid, direct, i.e., electronic, access to the binary numbers representing actual quantities (data) and binary numbers encoding instructions (programs) on what to do with these numbers was essential. Originally, these crucial, high-performance memory tubes were supposed to be developed at the RCA Laboratories just outside Princeton.

That decision was neither a coincidence nor simply due to the lucky spatial proximity to the IAS. The Russian émigré Vladimir Kosma Zworykin, famous developer of the iconoscope tube for electronic television and vice president of RCA, had circulated a short proposal in late 1945 in which he laid out his vision for global weather control. In the proposal, Zworykin fantasized, amongst other things, about the use of ignited oil patches or atomic bombs to affect local heat balances and to divert hurricanes or ocean currents. In essence, Zworykin's argument was that of an engineer of signaling equipment. Relatively small amounts of selective energy input might discharge and/or control far greater amounts of energy, thus triggering a desired phenomenon to develop or reverse. The analogy here can be seen in the design of the triode: much like the control grid attenuates the electron current, so the controlled detonation of nuclear bombs would attenuate the nascent updraft of water and energy from the sea. Formulated to the extreme, Zworykin's conceptual model arranges the whole tropical Atlantic into a kind of super CRT, promising an interventionist laboratory to divert all hurricanes between cathode Africa and anode America in a controlled fashion. However, curing must follow diagnostics. As made clear by Zworykin, a prerequisite for any command-and-control communication with the weather would be an exact determination of the aerological situation and a rapid computing model. In October 1945 Zworykin's proposal landed on John von Neumann's desk in the nearby IAS, triggering his enthusiasm and spurring him, eventually, to broaden the just approved ECP to include a Meteorology Project. The first meetings of the nascent ECP in late 1945, which established a set of principles that would guide the development of computer technology for the next decades, were all held in Zworykin's office at RCA.



[Figure 3] Detail of an advertising Illustration of RCA’s Selectron tube (Source: David Sarnoff Library Collection, Hagley Museum, NJ).

However, the design of the tube, which was given the name Selectron (see figure 3), proved too demanding, holding back the completion of the IAS machine for much too long. Getting rumors from England about a functioning memory tube based on the much simpler design of a regular CRT, the ECP decided to go forward with that solution. The two Manchester physicists and radar pioneers Frederic C. Williams and Tom Kilburn had just successfully shown that a “pulsed” electron beam would be able to create the necessary address-dot-matrix on the screen over the course of its linear passage. In the pulse technique, developed during WWII for radar applications, pulse generators produced time-limited current or voltage pulses with which the electron bombardment was periodically regulated up and down. The technical condition of possibility for digitization was tied to the generation of stable periodic electron pulses. Since the continuous oscillations were not really interrupted, but only their amplitude changed, this was not yet a truly digital technology. Yet with the installation of appropriate filters and limiters, the effect was the same. For the original engineers of the coming digital age, a truly digital machine was merely a “convenient fiction,” as Alexander Galloway has rightly emphasized (Alan Turing cited in Galloway 2021, 212). There was still a tradition of describing the “real” world as one of analog oscillations of continuous waves—of waterly, acoustic, or electromagnetic nature—in a continuous medium.

Electronic Atmospheres

A peculiar example for this tradition that now bridged over into a new medianature governed by electronic signals can be found in a letter by Jule Charney to one of his colleagues in 1947. Charney was able to trim the hydrodynamic equations in order to make these actually computable on the IAS machine through a mathematical filtering operation that is now generally regarded as the scientific breakthrough for numerical weather prediction. Charney (1947) wrote:

> The atmosphere is a transmitter. The computing machine is the receiver. The receiver is a very good one indeed, for it produces no appreciable noise itself, i.e. all noise comes from the input... Now there are two ways to eliminate noise in the output. The first is to make sure that the input is free from objectional noises, or [sic] the second is to employ a filtering system in the receiver. Translating, the first method implies that the unwanted harmonics shall be eliminated from the raw data by some type of harmonic analysis; the second that you transform the equations of motion and make approximations in such a way that the bad harmonics are automatically eliminated.

What Charney was hinting at with his choice of words in radio and signal technology is the trick of making the great clutter of waves of all kinds and scales in the atmosphere calculable by filtering out all secondary wave forms not affecting the pressure fields, especially the short sound and gravitational waves. Without such an elimination, one would only obtain a pile of unsmoothed instantaneous values of the atmosphere that conceal the actual signal. Here, at the beginning of Earth system research, stands the imagination of the atmosphere as a radio (and not just a radio channel) in which the actual music plays on the long wave, while the short wave mainly causes noise.

In the summer of 1949 Charney's set of equations had advanced enough to be tested, yet the IAS computer was still not finished. Von Neumann therefore arranged for computing time on the Electronic Numerical Integrator And Computer (ENIAC), housed in the Ballistics Research Laboratory (BRL) at the Aberdeen Proving Ground. The BRL was the central facility for the US Army for the calculation of artillery trajectories and bombardment tables. Each possible trajectory of a shell required around 750 multiplications, but the BRL could not keep pace with this amount. It therefore decided to invest in the development of an electronic computer, which was to be designed at the University of Pennsylvania under the direction of John Mauchly and his former master student J. Presper Eckert. Construction on what should become an 18,000-vacuum tube monster began in the summer of 1943.

A topic not well covered in the history of climate modeling is the fact that Mauchly was keenly interested in weather statistics and climatology.
Like Zworykin, albeit in a different and more indirect way, Mauchly was instrumental in getting the whole meteorological computing project in Princeton started. John Mauchly's father, Sebastian J. Mauchly, had been a well-known geophysicist at the Carnegie Institution in Washington DC. One of the results of his work in analyzing terrestrial magnetic data was the famous Carnegie Curve, which depicts the diurnal variations in atmospheric electricity. In his leisure time, Mauchly Junior continued his father's research interests in the weather–sun–magnetism relationship. For testing the possible atmospheric effects caused by sunspot activities Mauchly started to build himself an analog computer in 1939 and regularly obtained data from the Weather Bureau in Washington DC. Perhaps a harmonic analysis of that data revealed a statistical relationship between barometric fluctuations, atmospheric tidal effects, and magnetic field variations (Mauchly 1940; 1942)? In the end the results would remain inconclusive, but it was this work that drew his attention towards the potential of electronic and, moreover, digital computers. Mauchly, who was familiar with Geiger–Müller counters from his earlier studies at a physics lab and at Carnegie, knew that if electronic circuits could count, then they could do arithmetic and hence solve, inter alia, differential equations as difference equations, amongst other things. One can say with considerable confidence that what Mauchly actually wanted when he and Eckert proposed the creation of an electronic differential/difference analyzer, from which the later ENIAC emerged, was to conduct climate research using automated computational methods.

That interest also did not vanish when the ENIAC was finally about to be completed. In early 1945 it became apparent that the general-purpose potential of the ENIAC might go into other, more civilian applications than just the calculation of artillery tables for the BRL. In April of that year Mauchly went to the Weather Bureau to discuss the possible use of the high-speed computer to support meteorological and climatological tasks. Initially, the Bureau seemed more interested in the use of such machines for routine data handling operations, but Mauchly also addressed the possibility of integrating the differential equations of hydrodynamic motions. This approach piqued the interest of Harry Wexler, soon to be the Weather Bureau's chief of research, who would later play a key role in the IAS project (Fleming 2016, 152).

It would take another five years, and an ill-situated project with many scientific, technical, and personal ups and downs, before Mauchly's recommendation would come true. After the failure with the Selectron and the need to start over the memory design with the Williams tube, the IAS meteorologists spent many months in late 1949 and early 1950 translating their newly developed equations into coded instructions for the ENIAC, essentially becoming, in Charney's words, "servant[s] of the machine" (Charney 1949). Then, in March and April 1950, the team ran the first feasibility test of a numerical calculation of atmospheric movements during a 33-day expedition to the BRL, producing a series of four numerical 24-hour hindcasts of the pressure fields that wavered over the Northern Atlantic and eastern United States in January 1949 (Lynch 2008). Although the analysis of the results remained puzzling, the proof of concept of the ENIAC expedition literally had an "electrifying effect on the world meteorological community," according to one of the participants (Fjørtoft 1987, 367). From now on, the atmospheric sciences, and with them also oceanography, gradually became the computational science of today, treating the dynamic contours of the geofluids, or "world media," atmosphere and ocean, in purely numerical fashion.

Datafying with Tubes

A third, and much more widely known, impulse for establishing the IAS project had, similar to the electron tubes themselves, again a lot to do with elementary particle physics and their acceleration characteristics. Von Neumann's own interest in the meteorological application of his calculation machine stemmed from atmospheric waves of a much smaller size than the planetary waves tackled by dynamic meteorologists at that time: hydrodynamic shock waves that propagate around explosions. As early as 1937 von Neumann had become a consultant to the BRL; with the establishment of the Manhattan Project in 1941 he expanded this type of work for the theoretical design of the atomic bomb. Consequently, the very first problem that the IAS machine dealt with in the summer of 1951, even before it was fully operational, was no weather forecast but calculations for the design of the thermonuclear (hydrogen) bomb. The final apparatus, a steel cylinder in which 2000 liters of liquid hydrogen were kept thermally insulated, was tested on November 1, 1952, on Enewetak Atoll, a part of the Marshall Islands in the Western Pacific, during Operation Ivy.

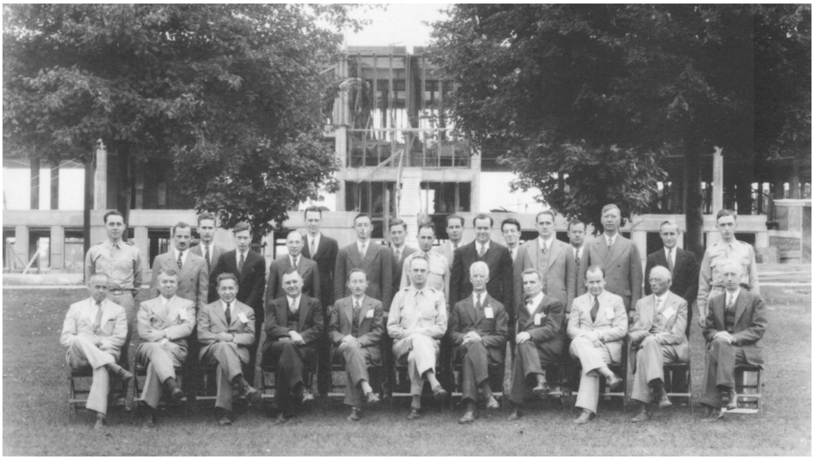
The Anthropocene Working Group, the body of geologists which over the last years investigated whether the geological record warrants the formal designation of an Anthropocene epoch, came to the conclusion that the fallout from the Ivy Mike test would be the best suited chronostratigraphic signal for referencing the lower boundary, i.e., the start date of the Anthropocene (Anthropocene Working Group 2023). From the fall of 1952 onwards ^{239}Pu and other artificial radioactive nuclides appear so prominently and distinctly in lakebed and marine sediments across the globe that they represent a convenient and practical marker for the Anthropocene. So let me come to another aspect of the cardinal role of electron tubes in mooring the planetary environment since around 1950.

Not least in order to be able to theoretically predict the fusion processes more easily, the designers of the thermonuclear explosion chose the simplest element of all: hydrogen. More concretely the heavy isotope variant deuterium (^{2}H) and later also the super heavy tritium (^{3}H). In 1931, twenty years before the hydrogen bomb tests, the chemist Harold Urey succeeded in distilling deuterium by using electrolysis to evaporate the lighter isotope ^{1}H from a quantity of liquid hydrogen: the beginning of what is called isotope separation.

Now, the whole discovery and later exploitation of isotope behavior in weapons (and instruments to measure the epoch-making effects of such weapons) is a direct result of the turn-of-the century experiments on the ionization of gases in tubes that were mentioned above. In 1907, Cavendish physicist J. J. Thomson began to arrange electric and magnetic fields on a CRT in such a way that the different positive ions, accelerated through a control grid, were deflected in different directions depending on their mass. Further experiments led to the discovery that the rare gas neon actually consists of a mixture of atoms of different masses, that is, isotopes. In the 1920s, experiments on the conductivity of gases led to the development of an apparatus, the mass spectrometer, that first revealed the composition of elements of different species and then counted them in order to arrive at their respective abundances in a given gas sample. The controlled flow of the inner fine structure of the natural world, encased in tubes, revealed nothing else than quantifications of effects of no longer epistemic but now scientific objects.

And in this way, they also revealed something as seemingly unquantifiable as the age of the Earth. By applying mass spectrometry to very heavy, radiogenic elements such as uranium or thorium one was able to determine the different half-lives of their different isotopes. Uranium decays in several intermediate steps to stable lead, whereby ^{238}U has a half-life of 4.5 billion years and ^{235}U of 704 million years. By measuring the ratio between uranium and lead in a given rock one was thereby able to date the age of that rock.

The person who professionalized all of this with an ever more refined spectrometer was the radio geek Alfred Nier. In the fall of 1939 Nier received a request from physicists at Columbia University—Enrico Fermi, John Dunning, and others—to use his mass spectrometer for a new purpose. He was not only to measure the relative abundance of individual isotopes in uranium, but to separate them. Indeed, the deflected isotopes could also be collected, atom by atom, in so called Faraday cups that replaced a regular anode. The task now was to create an uranium sample with more, i.e., “enriched,” ^{235}U and a much larger “depleted” remainder, i.e., uranium with more ^{238}U. The Columbia physicists had come to the conclusion that it was the ^{235}U isotope that proved to be fissile and which they would therefore like to have available in a greater concentration. Fortunately—or unfortunately for the rest of the world—Nier still had a small amount of uranium bromide on hand from his geological age



[Figure 4] First meeting of the BRL Advisory Committee, September 1940 (Source: https://commons.wikimedia.org/wiki/File:Ballistic_Research_Lab_Advisory_Committee_First_Meeting.gif).

determination studies. The substance that was previously used to determine the age of the Earth was now needed to test whether that Earth could possibly be blown up.

To cut a long story short, the person who was in charge of scaling up the whole separation process for the soon-to-be established Manhattan Project was no other than Harold Urey. As the world's most eminent expert in isotope isolation, he took over the overall supervision and coordination of research and turned it into an industrial-scale enrichment operation. A plant was erected in Oak Ridge, TN, to produce weapon-grade uranium: a gigantic 24/7 process architecture for mining a new currency of military power—isotopes! Gas discharge tubes produced and double-checked the elemental stuff that started the Atomic Age, and with it registered a new epoch in the Earth's strata. The Anthropocene Working Group now uses direct descendants of these tubes to geochemically analyze and define this anthropogenic stratum.

An almost allegorical arrangement beautifully illustrates the historic encounter that I describe in this paper (figure 4). In 1940, hydrodynamical, nuclear/geochemical, and electronics research were already sitting next to each other in one row, like a men's ballet formation, and in a near-symmetrical fashion. To the left we have Harold Urey and the physical chemist Isidor Rabi, another important figure of the Manhattan Project and director of the Massachusetts Institute of Technology (MIT) Radiation Laboratory. To the right are the aerodynamicist Theodore von Kármán and John von Neumann. Between them sits explosives research (Bernard Lewis), electron tube research (Albert Hull), and, as the organizational interface and sponsor of everything, the army, represented by Colonel Zornig, in the middle. Visible in the background is the somewhat demolished-looking new building of the BRL, which would later house the ENIAC. The operational closure between the former natural world and the technosphere is emblematized right here, where calculation and datafication sit in one row.

Conclusion: A Tubed Earth

Around 1950 the first real realization of a universal Turing machine and the early development of numerical atmospheric models went hand in hand. In an unusual research and testing environment alien to the arcadian culture of pure thought ruling at the “Princetitute” (Norbert Wiener), mathematicians, meteorologists, and electrical engineers were working on the creation and application of a fully electronic scientific computing system, the preeminent purpose of which was the study of the flow of air over the planet. But this unusual co-creation does not only form the context and starting point for the first numerical experiments in weather and climate simulation. It also directly interconnects with the starting point of the Anthropocene itself. According to the most comprehensive chronostratigraphic analysis available, the onset of the Anthropocene would be most suitably marked by the detonation of the first hydrogen bomb in 1952, the feasibility of which was in turn calculated on the IAS machine even before it officially went into operation. The underlying science of nuclear chemistry (for creating the bomb) and isotope geochemistry (for measuring its fallout as it is “recorded” in the geological archive), however, is also directly related to the development of tube design and electronics during the middle of the last century.

At the center of the “turning point in media history 1950” (Engell, Siegert, and Vogl 2004) and its *kairos* (see Peters 2015) for the calculation and measurement of the planetary upheaval stands a simple technical architecture: a hollow, controlled enclosure, either vacuumed or gas-filled and often-times in a cylindrical shape, in which the flow of electrons is manipulated for all kinds of specific purposes. Electron pulses and latency times of tubes orchestrated the arithmetic with which the atmosphere was to be treated symbolically. Envelopes of metals and glass not only constituted the original material basis for numerical prediction and, to a large extent, the mode of reasoning behind the new climate and Earth system sciences. They also still form the critical component for measuring and sensing all kinds of environmental, geochemical, and climatic quantities and thereby “environing” the Earth system and its evolution (and revolutions) over time.

When we recognize a form of planetary sapience today tied to monitoring and calculation infrastructures woven into the fabric of the open space (Bratton 2021), we might remind ourselves that all of these are predicated on these little controlled interiors. Whether it is the generation of microwaves for radiometry via remote sensing, the detection of small events and smallest particles, or environmental or geological analysis with mass spectrometry, the sapient globe is saturated with tubes. Tubed empirics are mounting the very environing meshwork by which the environment became measurable and computable and thereby computational. Evacuated or gas-filled bulbs fitted with scales have, of course, played a central role of quantifying the environment ever since the Renaissance—one need only think of the thermometer and barometer. But bulbs fitted with electrodes and radiating into the skies, seas and rocks opened up a whole new cosmos to treat the elemental with the elemental.

Moreover, these measuring tubes did not just constitute the technical environments in which the environment became a quantity for automatic processing. They also produced, in a way, these new post-war and post-natural environments through the nuclearization of land- and oceanscapes. By the same token, the entire Great Acceleration is hardly thinkable without the economic, administrative, and extractive scaling effects of modern computing (Rosol et al. 2018). The crises we face today were born of this operational closure between the technosphere and the former "natural" spheres such as the biosphere, atmosphere, and lithosphere. As much as measuring isotope compositions and running digital bits of information on electronic computers were instrumental in creating vistas on a changing planetary environment, that very change is also a result of the manipulation of tiny elementary particles for the sake of leveraging the globe.

References

Anthropocene Working Group. 2023. *The Anthropocene Epoch and Crawfordian Age: proposals by the Anthropocene Working Group*. Report submitted to the ICS Subcommission on Quaternary Stratigraphy. https://quaternary.stratigraphy.org/working-groups/anthropocene

Bigelow, Julian. 1980. "Computer Development at the Institute for Advanced Study." In *A History of Computing in the Twentieth Century*, edited by Nicholas C. Metropolis, Jack Howlett, and Gian-Carlo Rota, 291–310. New York: Academic Press.

Bratton, Benjamin. 2021: "Planetary Sapience." *Noema Magazine*, June 17, 2021. https://www.noemamag.com/planetary-sapience.

Charney, Jule. 1947. *Letter to Philip D. Thompson*. Feb 12, 1947. National Center for Atmospheric Research (NCAR) Archives, Philip D. Thompson Papers, Box 32, Folder 1.

———. 1949. *Letter to Carl-Gustaf Rossby*. Dec 12, 1949. Massachusetts Institute of Technology, Libraries, Department of Distinctive Collections, Jule G. Charney Papers, Box 14, Folder 459–60.

———. 1953. *Letter to Bert Bolin*. Feb 3, 1953. Massachusetts Institute of Technology, Libraries, Department of Distinctive Collections, Box 4, Folder 121.

Dyson, George. 2012. *Turing's Cathedral: The Origins of the Digital Universe*, New York: Pantheon Books.

Engell, Lorenz, Bernhard Siegert, and Joseph Vogl, eds. 2004. *1950—Wendemarke der Mediengeschichte*, Archiv für Mediengeschichte 4. Weimar: Bauhaus-Universität.

Fjørtoft, Ragnar. 1987. "Professor R. Fjørtoft." In *The Bulletin Interviews*, edited by Hessam Taba, 361–70. Geneva: Secretariat of the World Meteorological Organisation.

Fleming, James R. 2016. *Inventing Atmospheric Science: Bjerknes, Rossby, Wexler, and the Foundations of Modern Meteorology*. Cambridge, MA: MIT Press.

Galloway, Alexander R. 2021. "Golden Age of Analog." *Critical Inquiry* 48, no. 2: 211–32.

Lynch, Peter. 2008. "The ENIAC forecasts: A recreation." *Bulletin of the American Meteorological Society* 89, no. 1: 45–55.

Mauchly, John W. 1940. "A significance-test for ellipticity in the harmonic dial." *Terrestrial Magnetism and Atmospheric Electricity* 45, no. 2: 145–48.

———. ca. 1942. *Solar influence of Earth's Weather*. University of Pennsylvania, Kislak Center for Special Collections, John W. Mauchly Papers, Box 10, Folder 53.

Peters, John Durham. 2015: "Kairos." In *Words of Weather*, edited by Jussi Parikka and Daphne Dragona, 115–19. Athens: Onassis Foundation.

Phillips, Norman A. 1956. "The general circulation of the atmosphere: A numerical experiment." *Quarterly Journal of the Royal Meteorological Society* 82, no. 352: 123–64.

Rosol, Christoph. 2025. "Flows of air, flows of electrons." *The Anthropocene Review*. April 25, 2025. https://doi.org/10.1177/20530196251336250.

Rosol, Christoph, Benjamin Steininger, Jürgen Renn, and Robert Schlögl. 2018. "On the age of computation in the epoch of humankind," *Nature Outlook* 563, no. 7733: 1–5.

Sörlin, Sverker, and Nina Wormbs. 2018. "Environing technologies: a theory of making environment." *History and Technology* 34, no. 2: 101–25.

Wickberg, Adam, and Johan Gärdebo, eds. 2022. *Environing Media*. London and New York: Routledge.

OCEAN SUSTAINABILITY

ARGO

DIGITAL OCEAN TWINS

SUSTAINABLE DEVELOPMENT

[5]

Reckoning with the Ocean: The Disconnect Between the Digital Transition and Marine Sustainability

Adam Wickberg and Susanna Lidström

In a relatively short span of time, ocean data have gone from sparse and patchy to a dynamic and continuous stream of information, at least for some dimensions of the marine environment. This relative progress in knowledge has developed in tandem with expanded anthropogenic pressure on the global ocean and its ecosystems. In this chapter, we trace the development of these two trajectories over the past three decades through discussions of two case studies, one focusing on the collection of ocean data and one on the application of digital data for marine management. Against the background of these two cases, we then discuss the relationship between increases in the availability of digital ocean data, possible uses of those data, and how they inform a rhetoric of ocean sustainability through promises associated with claims for expanding the blue economy. Our analysis aims to identify and

elaborate on a disconnect between the digital transformation that is affecting all areas of environmental science and policy, including the ocean, and aims for and obstacles to achieving sustainable ocean environments.

Digital technologies are profoundly reshaping perceptions of the ocean and possible ways to approach, utilize, and manage marine ecosystems. Recent decades have seen the unfolding of an epistemic change from a mostly data-poor ocean to a marine environment increasingly mediated by continuous streams of data, made possible by a rapid rise and deployment of digital technologies and remote sensors for ocean research and monitoring. This has implications for ocean governance. As data-based approaches gain in reach and potentially lead to control over the marine environment, questions are raised about data access, ownership, transparency, and institutional oversight (Wickberg et al. 2024). But there are also questions about the legitimacy of claims that digitalization will fundamentally support and improve ocean sustainability. Digital tools for marine management can serve human needs of subsistence and resource supply but may also allow for hitherto unseen levels of mapping, monitoring and surveying, which may serve a variety of interests, including extraction and exploitation to support economic growth, as in visions of a so-called blue economy, touted by many governments as a sustainable development solution.

Ideas of a blue economy envision a shift in resource extraction from stressed land areas into untapped resources of the vast ocean (Lee et al. 2020). The possibility of this vision is often described as depending on digital developments that allow increased human reach in ocean environments. From fishing with a high degree of chance half a century ago to highly predictive allocation and extraction of desired stocks with digital tools today, the ocean is subjected to increased exploitation interests in a range of areas. Some have evolved for decades or even centuries, such as overfishing and fossil fuel extraction, but many are novel and emerging, including deep-seabed mining, marine bioprospecting, and marine carbon dioxide removal. Across the board, these exploitation and extraction prospects follow colonial and imperial historical patterns, which can be reinforced by increasingly sophisticated data and technology (Clark and Cisneros-Montemayor 2024).

Proponents of so-called blue growth routinely claim that increased exploitation of the ocean under this banner of presumed sustainability will support the intergovernmental Agenda 2030, finally achieving what the global community has largely failed to do on land over four decades of efforts in sustainable development. The discourse surrounding the blue economy promises a resolution of the long-standing tension and even conflict between growth and development on the one hand and environmental protection on the other, which goes back to debates about limits to growth in the 1970s (e.g., Meadows et al. 1972), all because of and thanks to the increasing availability and application of digital, dynamic, and continuous ocean data. At the same time, the ocean is recognized as under immense pressure from anthropogenic impacts, with warming, acidifying and deoxygenated waters subject to extraction of living resources, plastic pollution and other human pressures, leading to calls for increased protection and conservation, rather than expanded exploitation, from many parties. This development is captured in the description of a "blue acceleration" as a qualification of the Great Acceleration, the hockey stick curves showing the concurrent increase in human trends and Earth system impacts since 1950 (Jouffray et al. 2020; Steffen et al. 2015). The ocean is interesting in this context because in a relatively short span of time, that of a human lifetime, we have gone from patchy and limited knowledge about the oceanic environment to significantly more complex and qualified understanding, based on the increase in data and models. This relative progress in knowledge has developed in tandem with expanded anthropogenic pressure on the ocean environment.

In this chapter, we trace the development of these trajectories over the past three decades through two case studies that connect ocean data gathering to applications of digital data in marine management schemes. Our first case is the Argo program, a scientific project for ocean observation that has revolutionized ocean sciences in the 21st century through remote and continuous data collection. We then move to the emerging area of promises made in relation to developments of "digital ocean twins" to be used in marine management. Reflecting on these cases, we conclude with a discussion of concerns and limitations associated with the development towards digitalization and associated imagined uses of the marine environment.

Our analysis draws on the interdisciplinary theoretical framework of environing media. What we know about the environment—its epistemologies—is deeply contingent on the media technologies at hand, which form the conditions of possibility for environmental discourse (Wickberg and Gärdebo 2022). At the heart of this process of mediation, which reaches back to the early modern era but took off at a radically intensified scale in the postwar period (Peters and Wickberg 2022); it is a complex feedback loop between scientific knowledge and human impacts on the natural environment on a planetary scale. Following the unprecedented technological developments of computation associated with WWII, Earth System scientists as well as others have increasingly been changing modes from direct observation to interaction at a mediated level, to the extent that we can now speak of a mediated planet (Wickberg et al. 2024).

The concept of environing media draws on the theory of cultural techniques, which attempts to subvert the dualism between media and culture by focusing on the "operative sequences that historically and logically precede the media concepts generated by them" (Siegert 2008, 29), but takes this analytical lens to the dualism of environment and society. As the famous examples in cultural techniques, writing, reading, painting, or counting are practices that predate the ontological concepts that are generated from them. Similarly, for our understanding of the environment, environing media designate the manifold technical processes that are involved in the recursion between environmental epistemology and environmental change (Wickberg 2023). The theory of environing media targets the epistemological construction of environments, and shows how chains of mediation can be analyzed from the data gathered in distributed sensor networks, through the modeling based on these data, which gives rise to epistemic concepts such as climate change or global mean surface temperature, which then get translated into climate policy, actual politics, and broader public understanding. In the case of the ocean, similar chains occur when measuring sea-level rise, ocean heat content, or ocean acidification. It is through computerized aggregating and scaling up that a phenomenon becomes knowable at a planetary level, but in this process the local and contextualized inevitably gets lost, which has profound political implications in that it often serves dominating technocratic interests while disregarding the reality of local communities, be they human or non-human. Environing media are however not only planetary-scale technologies but can also be found at local scales. Indeed, it is the ability to shift between these scales that is emblematic of the environing effect of these media. More often than not the planetary and technocratic scale overshadows that of local perspectives, as for example in the highly influential IPCC (International Panel on Climate Change) reports and the Paris Agreement, with targets that address carbon dioxide levels in the global atmosphere rather than climate change impacts that can be perceived or monitored locally or regionally.

Understanding the essential means for environing in terms of media connects the environing concept, with roots in environmental history, to an emerging expanded notion of media technologies, as inclusive of elemental and planetary processes, as well as smaller scale change (Peters 2015; Peters and Wickberg 2022). On one end of the spectrum of such media are apparent physical technologies for changing and observing the environment, such as contemporary ocean sensing networks, while at the other end of the spectrum environing media take the shape of human imaginaries and discourses which, often attached to the potential of physical media technologies, come to shape perceptions of desirable futures, which then shape technological development towards certain environmental futures in a constant feedback loop. This is another way of saying that media do not only determine our situation, as Friedrich Kittler once suggested, but also our environmental futures.

A Measured Ocean: the Argo Program

For most of history, people have had little insight into the conditions and processes of the immense space that extends beneath the surface of the ocean. While over the centuries gradually more information has been gathered from the depths, until recently deep-sea data points remained sparse and painstakingly collected. While this is still the case for some parts of the ocean, the first two decades of the 21st century have seen a steep change in the amount of subsurface data that are collected and made available for scientific and other uses. To a large extent, this change is due to the development of autonomous sensors that have freed many ocean observations from a dependence on expensive ships and allowed for continuous sampling of vast areas (Wong et al. 2020). The majority of these new data have been collected by the scientific network and initiative known as the Argo program.

The Argo program coordinates a fleet of about 4000 robotic floats that act as remote sensors which measure ocean temperature and salinity in the upper 2000 meters (m) of the global ocean. The program was proposed in 1998, and was quickly accepted and implemented, with initial float deployments taking place within a year. The program reached full implementation in 2007. Once deployed, Argo floats sink to 1000 m depth, where they float with the current. After ten days, they descend another 1000 m before they rise to the surface in order to collect a temperature and salinity profile for the upper 2000 m of the water column. When they reach the surface, they send the data, via satellite, to designated data management centers. There the data are made available for weather forecasts and other immediate uses before being submitted to additional data management teams for processing and eventually publication as high-quality research data. Argo data provide dynamic and continuous information about the temperature and movement of different water masses, which are crucial for climate modeling and prediction. Climate change is thus, and had been from the beginning, the primary motivation for funding and maintaining the Argo program.

The Argo program—including its operation as a scientific network, the physical floats and the attached sensors, and the data management procedures—operates as the kind of "vast machine" that has been described by Paul Edwards (2010). Edwards particularly unpacks the, often misunderstood, relationship between models and data, pointing out that without models, there are no data. Edwards wrote this in order to clarify misconceptions about the nature of climate models that were current among skeptics at the time, and explained that while models are simulations, the "real data" that skeptics referred to can only become legible through models, a point echoing the proposition by Lisa Gitelman (2013) that "Raw data is an oxymoron." Turning this insight around, we can see how the vast data flows produced by the Argo program primarily become legible and used through climate models, which afford a historically specific conception of the world ocean marked by the defining challenge of our time in the form of anthropogenic climate change. Understanding this process as environing leans on a Foucauldian and Kittlerian understanding of historically situated discursive orders and networks which regulate the knowable and sayable at a given moment in time. This approach reveals, denaturalizes, and uncovers how we come to know and understand the ocean through the dynamic interplay between technologies and discourses through chains of mediation.

In this theoretical context, we can see how the Argo program, as a specific media technology and cultural practice, has environed the ocean and made it part of the environment defined as nature that has become thoroughly known, studied, monitored, shaped, and governed by people. While the historical process of understanding the global environment can be traced back to 18th century authors like Comte de Buffon and Alexander von Humboldt, the postwar era spurred a paradigmatic shift in the conception of the natural world and quickly propelled the concept of the environment as the world in which human activities come to have an impact (Warde et al. 2018) This discovery was primarily driven by technological developments motivated by World War II, such as the development of computers in the Manhattan Project to fabricate the atom bomb, and the Cold War geopolitical mandate of large-scale surveillance which also produced data and insights on a planetary scale. Military interests thereby came to shape postwar science because of the abundance of funding made available for costly research, which would otherwise be hard to justify (Oreskes 2021). The concept of the environment became a political force, and in 1972 the United Nations (UN) organized the first global conference on the environment in Stockholm (Sörlin and Paglia 2024). The world ocean, however, remained relatively understudied and the notion of vast expanses that could hardly be depleted or changed by humans remained for a longer time (Rozwadowski 2018; Helmreich 2009).

By observing and documenting rates of change tied to anthropogenic climate change, Argo is inscribing the ocean not only into the environment generally, but into the particular science and policy frameworks associated with climate change. As part of this process, the ocean is starting to lose its traditional appearance as ahistorical and beyond the bounds of human impact and instead appears as a historical object with relevance on human timescales. This clearly shows that the historicization of the ocean is fully contingent on a media technical apparatus in the form of infrastructures of information and data processing beyond the human perception of its cultural history. This historicity, moreover, has specific characteristics. Through its connections to climate change and especially to predictive climate models, that ocean is being incorporated into the "cultures of prediction" that dominate climate sciences

(Heymann, Gramelsberger, and Mahony 2017). The ocean's historicity is thus extended not only into the human past, but also into a predicted future, in an ongoing reformulation of historical consciousness that has been spurred by the idea of the Anthropocene, in which human and natural timescales can no longer be separated. As part of this process, the ocean is transforming from ahistorical, acting as a backdrop to human history, to a historical dimension with agency (Boldizsár Simon and Adeney Thomas 2022).

As Martin-Nielsen, Heymann and Hundebøl (2017) and others have shown, the dominance of prediction as a goal and ordering principle for climate sciences was not inevitable but the result of "fundamental decisions about which types of knowledge are important, which epistemic standards are used to judge that knowledge, and which applications of that knowledge are regarded as useful and socially relevant" made in the 1960s and 1970s, that to a large extent phased out other ways of knowing and researching climate change. A collection of studies have shown how these "cultures of prediction" developed in the second half of the 20th century as a result of successive decisions, and that as a consequence, within climate science and governance "predictive claims and the understandings, values and norms they shape and carry have become self-evident and normalized ways of experiencing the world" (Heymann, Gramelsberger, and Mahony 2017, 5 and 103). In the 20th century, and particularly with the development of the Argo program, this culture of prediction is extending to the ocean.

The idea of predicting the natural world and environmental change is attractive, but also fundamentally questionable as a prerequisite for environmental and ocean governance. Moreover, both prediction and digitalization may be leveraged for increased and perhaps more effective marine protection, but may likewise be used to advance the extractivist paradigm seen on land. It is not clear how they could do both at once, by mitigating negative effects of economic development, in ways made possible by new digital technologies specifically. Notwithstanding such doubts, the creation and implementation of marine digitalization presents politicians and policymakers with an attractive way of promising to overcome negative anthropogenic impacts through technical means.

A Managed Ocean: Digital Twins of the Marine Environment

Digital twins are built as replicas of large systems, originally closed engineering and production systems but recently also open-ended and complex natural systems such as the ocean, climate, and the entire Earth system. Using past observations and continuous real-time data of present behaviors (such as Argo data), they propose to model and forecast future scenarios and are meant to act in the physical world through guiding management. The main features of digital twins are connectivity and interactivity, in that they aim to supply citizens and decision-makers with up-to-date science-backed knowledge to protect or otherwise manage environments (Jones 2020).

The development of large-scale modeling of the ocean as a digital twin represents a new development in ocean governance, with increased reliance on digital infrastructure and continuous data, such as provided by the Argo program. The two-way exchange of information between marine ecosystems and the digital twin is meant to create a feedback loop between the digital and the physical realms, which is emblematic of how environing media operate, as explained in the previous section. This means that as the physical ocean is datafied, i.e., increasingly subjected to the collection of data points, the digital twin can supposedly model and then implement different what-if scenarios and impacts of human–ocean dynamics, so that decision-makers are presented with a clearly delineated set of choices with preemptively identified consequences. Examples of what-if scenarios include ocean warming, changes to the seafloor, sea-level rise, climate change, and extreme weather events.

The EU's digital twin of the ocean (DTO) is currently the most advanced digital ocean initiative, repeatedly presented as the bedrock of the EU Mission to Restore our Ocean and Waters, and features as a key priority in high-level initiatives like the UN Ocean Decade and G7 Future of the Seas and Oceans. The DTO is touted as a coherent, high-resolution, multidimensional, multi-variable, and near real-time representation of the ocean that integrates different new and existing data sources with modeling, artificial intelligence (AI) and high-performance computing. In reality it is not an entirely new creation but consists of a platform that interconnects a number of existing digital infrastructures of delimited ocean sectors and areas and makes them interoperable. In other words, the DTO builds on existing European digital resources and combines and integrates data from the European Marine Observation and Data Network (EMODnet) and the Copernicus Marine Service into a single digital framework. The DTO will supposedly include both real-time updates and long- and short-term forecasts of anthropogenic impacts as well as biodiversity conservation strategies and active management of marine ecosystems. It will also use AI processes, or machine learning, as "toolboxes" that scientists, entrepreneurs, citizens and others can use to predict events and plan activities in the ocean, making the DTO a "place of digital co-creation" with "unlimited" uses, according to the EU's designated website.

According to the EU, the DTO's central feature of so called what-if scenario analysis will offer the Union and its citizens unprecedented "science-driven decision making" with a new approach to ocean resource management, mitigation, and adaptation. Through real-time and predictive insights into changes in the marine environment, policymakers and politicians are supposed to be able to better identify challenges and impacting factors in different domains of the ocean. Reports on the prototype also describe the project as a "game-changer" representing a "quantum leap" in the EU's efforts to achieve sustainable seas "thanks to artificial intelligence and digital technologies" (Loctier 2024). Here we can see how ideas of predictability, which became associated with the ocean through the climate-essential data streams produced through Argo, are extended in the discourse surrounding digital twins to other marine conditions and activities. The ocean itself is now, it is claimed, becoming predictable.

The construction of digital twins forms an integral part of the EU strategy of the European Green Deal, with ambitious targets of climate neutrality by 2050. The Union has identified these developments as landmark actions in the process of greening the economy and maintains that they will enable the desired shift away from less sustainable practices of development. The EU Digital decade 2030 policy package describes an urgent need to foster economic growth, and improve productivity and competitiveness, by "twinning the green transition with the digital transition" (EU 2024). It seems clear that the political hopes and stakes for a universal solution to the complex problem of economic growth and environmental degradation are high, and that digitalization appears to embody this desire. The new class of models that they represent, it is claimed by the director of development (Bauer, Stevens, and Hazeleiger 2021), will close the gap in our ability to look into the future, disregarding the fact that modeling an aspect of a physical system along with its economic variables, such as Integrated Assessment Models do, will inevitably be incomplete and regard chosen parameters of interest (Asefi-Najafabady, Villegas-Ortiz, and Morgan 2021).

Against this background, we can identify a drift from climate models to ocean models, to ocean digital twins, where the "cultures of prediction" that have come to dominate climate science and policy are making headway also into the ocean realm (Lidström and Wickberg 2025). This framing is also being extended to uses of the ocean to remove carbon dioxide from the atmosphere, where the complex ecosystem of the global ocean is mechanistically reduced to its ability to help cut carbon emissions and provide desired resources, all dressed up in secure decision-making due to better modeling. This faith in modeling is also reflected in Kestutis Sadauskas, the Deputy Director-General for Maritime Affairs and Fisheries at the European Commission, who claims that "it will be cheaper to make the decisions, and to make more correct decisions with less mistakes if we try to model it before we go out in real life" (Loctier 2024). This comment was made after enumerating the needs for continued ocean extraction and exploitation in a sponsored news article, where the Commission appears to be building trust for its blue economy through the digital twin of the ocean. The tendency to reframe complex political problems related to climate and environment as technical issues that can be solved with powerful diagnostic tools is clear here, and as pointed out by Saltelli et al. (2024) in their discussion of digital twins of the Earth, “these models provide policymakers with convenient instruments for justification and control.”

The Limits of Digital Control

From the vantage point of the 21st century, it seems clear that the postwar period saw a rapid increase in pressures on the Earth system linked to the technological development that made possible a hitherto unimaginable level of production, the benefits of which have been very unequally distributed. Originally published around 2004 and then updated in 2015, the graphs of what has been termed the Great Acceleration from 1950 to 2010 show the rapid increase in twelve essential human activities and the impact on corresponding aspects of the Earth system: population, real GDP (gross domestic product), primary energy use, water use, fertilizer consumption, transportation, and telecommunications have all been on a very steep upward curve in these now iconic graphs. In the Earth system part, mirroring steep curves can be observed in atmospheric carbon dioxide, surface temperature, ocean acidification, marine fish capture, domesticated land, tropical forest loss, and terrestrial biosphere degradation. Already in the 1970s, ecologists recognized economic development as the primary driver of environmental degradation, which would later become understood as a destabilized Earth system leaving Holocene conditions for the Anthropocene. The trend continued, and in 2015 the UN created and unified around the Agenda 2030 framework, to be implemented through 17 Sustainable Development Goals (SDGs), including 169 targets and 232 indicators.

While sustainable development is increasingly becoming a contested concept, it has become the main framework and guiding principle for implementing political and policy efforts to protect the global environment. The SDGs are themselves the result of massive and often vague quantification of data and science that necessarily leaves out many aspects of the world, but as they are interpreted as inherently good—leading to sustainability as an objective and uncritical outcome, with equal benefits for all—they can easily be mistaken for the whole picture. Moreover, it is now clear that few if any of the SDGs will be met and that, for the environment, the negative trend overwhelmingly continues. According to the 2023 Global Sustainable Development Report (UN 2023), in the current state of progress based on select targets only 9.c.1 “increase access to mobile networks” and 17.8.1 “increase internet use” are making substantial progress and are on track. The effort to achieve the goal for the ocean in particular, or SDG14, has been described unceremoniously as “a round and inclusive failure” (Andriamahefazafy et al. 2022).

The fundamental disconnect between the green and digital transitions should be clear, and even more so as resource and energy use skyrocket with the latest AI boom pushing through ever-more hyperscale data centers around the world. Current estimates hold that AI energy consumption will rise by a factor of eight between 2025 and 2030 to 880 TWh and continue to rise to 1370 TWh after five more years, equaling the annual consumption of Sweden. The scenario illustrates the famous Jevon's paradox, named after the 19th century British resource economist, who showed that improvements in energy efficiency will lead to increased energy consumption, and thereby cancel out the projected savings. AI development follows this pattern while energy efficiency is often touted as one of its main sustainability offers (Luccioni, Strubell, and Crawford 2025). This development happens while programmatic overshoot of emissions (Malm and Carton 2024) has become the norm and the 1.5°C degree climate target is out of reach.

To remedy conflicts between different aims, a critical view of how different areas, spheres and systems interact and how trade-offs between these interactions can be understood and managed is essential. Rather than recognizing conflicting aims, environmental technology development by corporations, states, and intergovernmental actors is embedded in a discourse which suggests that they are able to advance both economic development and decrease environmental impacts while sustaining current carbon- and resource-intensive lifestyles under the guise of sustainability. This idea is deeply rooted in the discourse on sustainable development and features prominently in the so-called Brundtland report, *Our Common Future* (1987), which introduces sustainable development as an intergovernmental aim for the world's nations and speaks of increasing the Earth's carrying capacity through technological innovation. It continues in Agenda 2030 and is at the heart of the Integrated Assessment Models (IAMs) that inform most climate policy today, in applying a discount rate for future technologies to remove carbon instead of mitigating emissions in the present in order to maintain economic growth. It recurs in the discourse surrounding the digitalization of the ocean that coincides with a rapidly increasing need for better and more sustainable ocean management in the present, as well as new means of using marine resources for human needs.

Another way to put this is to point to a clear dissonance between the goals of perpetual economic growth and environmental protection, patched over by the idea of sustainable development and seemingly enabled by increasing amounts of data and associated digital applications. The smokescreen of digitalization, we contend, is prevalent in discourses surrounding the blue economy as a form of sustainable development. It is present in all the materials presenting the EU DTO, in statements such as that the digital twin will provide knowledge that "will help design the most effective ways to restore marine and coastal habitats, support a sustainable blue economy and mitigate and adapt to climate change," in a rhetoric that promotes the assumption that these are compatible rather than conflicting aims.

The descriptions of the DTO echoes what appears as an exaggerated belief in the ability of digital ocean twins in general, such as the claim that "Digital twins, a nascent yet potent computer technology, can substantially advance sustainable ocean management by mitigating overfishing and habitat degradation, modeling, and preventing marine pollution and supporting climate adaptation by safely assessing marine geoengineering alternatives," expressed by Tzachor, Hendel, and Richards (2023) in a scientific article that questions the maturity, but not the essential nature or capacity, of the data and technology needed to create a digital ocean twin. The promises or stated abilities of the digital ocean twins poorly match the reality of available ocean data, or even, on a more fundamental level, what seems possible to "datafy" and represent in this way in the first place. This is an issue not only for complex and under-studied ocean processes but also, and not least, for the social and economic dimensions that the DTO also promises to represent and integrate into its ocean predictions. The claim of safe marine geoengineering seems rather oxymoronic, given that the planetary scale experiments with the Earth system suggested are anything but safe.

The current hype surrounding digital ocean twins and its relationship to an emerging "blue economy," powered by these digital twins that should enable us to transcend or resolve the tension between exploitation and protection, needs to be understood against this background. The uncritical statements about how the EU DTO will contribute to sustainable marine development and SDG14 reflect none of the controversies or challenges increasingly attached to Agenda 2030 and the sustainable development concept. The history of an intertwined relationship between ocean data and marine exploitation and resource extraction clearly demonstrates that more data has not in itself led to better governance (Wickberg et al. 2024; Bakker 2022), an assumption that nevertheless permeates the discourse surrounding the DTO. Another important and often highlighted aspect of the DTO is the integration of AI into ocean governance, and one recent paper ties hopes of its capability to simulate human intelligence to solve difficult problems related to the implementation of a sustainable blue economy (Brönner, Sonnewald, and Visbeck 2023). The DTO is claimed to be able to solve the complex task of "balancing economic, social, and environmental considerations to ensure the long-term health and productivity of ocean ecosystems and the communities that depend on them." While AI systems and their integration in digital twins can certainly be helpful in automating mechanical tasks and visualizing Big Data, it is crucial to understand the limitations and risks involved in applying algorithms to vulnerable human and more-than-human domains. As a growing body of scholarship has demonstrated, AI systems have tended to increase inequality, racism, sexism, and other structural divisions of our societies while accelerating environmental impacts (Chun 2021; Crawford 2021; Bender et al. 2021; Wickberg and Gärdebo 2023).

The promise of a science-driven decision-making model made possible by the digital twin, that will be able to overcome contested aims for environmental protection, disregards deep-seated goal conflicts and competing interests between perceptions of the ocean as a frontier for resource exploitation and calls for reducing human impacts and allowing, or assisting, the recovery of marine ecosystems. There is nothing that supports the assumption in the promises made for the DTO that a technology like the digital twin in itself will overcome this divide. Such claims need to be contrasted with the reality of half a century of failure in meeting environmental targets and in fostering sustainable economic growth as the result not of a lack of scientific data, but due to deep political divides and cultural inertia. Consequently, while the digital twin technology may impact our understanding of and relationship with the ocean in some ways, as pledged by the EU, it is far from given how extensive or, as is routinely claimed, transformative that impact will be, and it is especially unproven that it will resolve any of the sustainability challenges and goal conflicts that surround the ocean, as is also often claimed. A digital twin of the ocean in terms of technology may have the potential to help ocean policy and governance to be better informed in some ways, but the surrounding discourse reinforces a reductive view of the ocean aligned with the needs for economic growth. In reality, views of how much anthropogenic impact and change of the world ocean is desired or tolerable is a deeply political one and not an algorithmic problem.

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References

Andriamahefazafy, Mialy, Grégoire Touron-Gardic, Antaya March, Gilles Hosch, et al. 2022. "Sustainable Development Goal 14: To what degree have we achieved the 2020 targets for our oceans?" *Ocean & Coastal Management* 227, no. 7: 106273. http://dx.doi.org/10.1016/j.ocecoaman.2022.106273.

Asefi-Najafabady, Salvi, Laura Villegas-Ortiz, and Jamie Morgan. 2021. "The failure of Integrated Assessment Models as a response to 'climate emergency' and ecological breakdown: the Emperor has no clothes." *Globalizations* 18, no. 7: 1178–88.

Bakker, Karen. 2022. "Smart oceans: artificial intelligence and marine protected area governance." *Earth System Governance* 13: 100141. https://doi.org/10.1016/j.esg.2022.100141.
Bauer, Peter, Bjorn Stevens, and Wilco Hazeleiger. 2021. "A digital twin of Earth for the green transition." *Nature Climate Change* 11, 80–83.
Bender, Emily M., Timnit Gebru, Angelina McMillan-Major, and Shmargaret Shmitchell. 2021. "On the Dangers of Stochastic Parrots: Can Language Models Be Too Big?" In *Proceedings of the 2021 ACM Conference on Fairness, Accountability, and Transparency (FAccT '21),* 610–23. New York: Association for Computing Machinery.
Boldizsár Simon, Zoltan, and Julia Adeney Thomas. 2022. "Earth System science, Anthropocene historiography, and three forms of human agency." *Isis* 113, no. 2: 396–406.
Brönner, Ute, Maike Sonnewald, and Martin Visbeck. 2023. "Digital Twins of the Ocean can foster a sustainable blue economy in a protected marine environment." *The International Hydrographic Review* 29, no. 1: 26–40.
Brundtland, Gro Harlem. 1987. *Report of the World Commission on Environment and Development: Our Common Future*. United Nations General Assembly document A/42/427.
Chun, Wendy. 2021. *Discriminating Data: Correlation, Neighbourhoods and the New Politics of Recognition.* Cambridge, MA: MIT Press.
Clark, Tim, and Andrés Cisneros-Montemayor. 2024. "Colonialism and the Blue Economy: confronting historical legacies to enable equitable ocean development." *Ecology & Society* 29, no. 3: 4. https://doi.org/10.5751/ES-15122-290304.
Crawford, Kate. 2021. *Atlas of AI: Power, Politics and the Planetary Costs of Artificial Intelligence.* New Haven: Yale University Press.
Edwards, Paul. 2010. *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming.* Cambridge, MA: MIT Press.
European Union (EU). (2024) *2030 Digital Decade. Annex 1: Competitiveness and Sovereignty, People, Smart Greening, Policy Coherence and Synergies*. Brussels: Publications Office of the European Union.
Gitelman, Lisa, ed. 2013. *Raw Data is an Oxymoron*. Cambridge, MA: MIT Press.
Helmreich, Stefan. 2009. *Alien Ocean: Anthropological Voyages in Microbial Seas*. Berkeley: University of California Press.
Heymann, Matthias, Gabriele Gramelsberger, and Martin Mahony, eds. 2017. *Cultures of Prediction in Atmospheric and Climate Science: Epistemic and Cultural Shifts in Computer-based Modelling and Simulation.* London: Taylor and Francis.
Heymann, Matthias, and Nils Randlev Hundebøl. 2017. "From heuristic to predictive: Making climate models into political instruments." In *Cultures of Prediction in Atmospheric and Climate Science: Epistemic and Cultural Shifts in Computer-based Modelling and Simulation,* edited by Matthias Heymann, Gabriele Gramelsberger, and Martin Mahony, 100–119. London: Taylor and Francis.
Jones, David. 2020. "Characterizing the digital twin: a systematic literature review." *CIRP Journal of Manufacturing Science and Technology* 29: 36–52.
Jouffray, Jean-Baptiste, Robert Blasiak, Albert Norström, Henrik Österblom, et al. 2020. "The blue acceleration: the trajectory of human expansion into the ocean." *One Earth* 2, no. 1: 43–54.
Lee, Ki-Hoon, Junsung Noh, Jongmin Lee, and Jong Seong Khim. 2020. "Blue economy and the total environment: Mapping the interface." *Environment International* 157: 106796. https://doi.org/10.1016/j.envint.2021.106796.
Lidström, Susanna, and Adam Wickberg. 2025. "Co-environing the ocean and climate: the Argo program." *Environment and Planning E: Nature and Space* 8: 6. https://doi.org/10.1177/25148486251377704.
Loctier, Denis. 2024. "Digital Twin of the Ocean: Europe's gamechanger for sustainable seas." *Euronews*, September 24, 2024. https://www.euronews.com/green/2024/09/24/european-digital-twin-ocean.
Luccioni, Alexandra Sasha, Emma Strubell, and Kate Crawford. 2025. "From Efficiency Gains to Rebound Effects: The Problem of Jevons' Paradox in AI's Polarized Environmental Debate." In

Proceedings of the 2025 ACM Conference on Fairness, Accountability, and Transparency (FAccT '25), 76–88. New York: Association for Computing Machinery.

Malm, Andreas, and Wim Carton. 2024. *Overshoot: How the World Surrendered to Climate Breakdown*. London: Verso Books.

Martin-Nielsen, Janet. 2017. "A new climate: Hubert H. Lamb and boundary work at the UK Meteorological Office." In *Cultures of Prediction in Atmospheric and Climate Science: Epistemic and Cultural Shifts in Computer-based Modelling and Simulation,* edited by Matthias Heymann, Gabriele Gramelsberger, and Martin Mahony, 85–99. London: Taylor and Francis.

Meadows, Donella, Dennis Meadows, Jürgen Randers, and William Behrens. 1972. *The Limits to Growth*. New York: Universe Books.

Oreskes, Naomi. 2021. *Science on a Mission: How Military Funding Shaped What We Do and Don't Know About the Ocean.* Chicago: University of Chicago Press.

Peters, John Durham. 2015. *Marvelous Clouds: Toward an Elemental Philosophy of Media*. Chicago: University of Chicago Press.

Peters, John Durham and Adam Wickberg. 2022. "Media: the case of Spain and New Spain." *Critical Inquiry* 48, no. 2: 676–96.

Rozwadowski, Helen. 2018. *Vast Expanses: A History of the Oceans*. London: Reaktion Books.

Saltelli Andra, Gerd Gigerenzer, Mike Hulme, Konstantinos V. Katsikopoulos, et al. 2024. "Bring digital twins back to Earth." *WIREs Climate Change* 15, no. 6: e915. https://doi.org/10.1002/wcc.915.

Siegert, Bernhard. 2008. "Cacography or Communication? Cultural Techniques in German Media Studies." *Grey Room* 29: 26–47.

Sörlin, Sverker, and Eric Paglia. 2024. *Stockholm and the Rise of Global Environmental Governance: The Human Environment*. Cambridge: Cambridge University Press.

Steffen Will, Katherine Richardson, Johan Rockström, Sarah E. Cornell, et al. 2015. "Planetary boundaries: guiding human development on a changing planet." *Science* 347, no. 6223: 1259855. https://doi.org/10.1126/science.1259855.

Tzachor, Asaf, Ofir Hendel, and Catherine Richards. 2023. "Digital twins: a stepping stone to achieve ocean sustainability?" *NPJ Ocean Sustainability* 2: 16. https://doi.org/10.1038/s44183-023-00023-9.

United Nations (UN). 2023. *Global Sustainable Development Report Times of Crisis, Times of Change: Science for Accelerating Transformations to Sustainable Development.* New York: UN.

Warde, Paul, Libby Robin and Sverker Sörlin. 2018. *The Environment: The History of an Idea*. Baltimore: Johns Hopkins University Press.

Wickberg, Adam. 2023. "Environing media and cultural techniques: From the history of agriculture to AI-driven smart farming." *International Journal of Cultural Studies* 26, no. 4: 392–409.

Wickberg, Adam, and Johan Gärdebo eds. 2022. *Environing Media.* New York: Routledge.

———. 2023. "Computation, data and AI in Anthropocene History." *History & Technology* 39, no. 3–4: 328–46.

Wickberg Adam, Susanna Lidström, Amanda Lagerkvist, Tirza Meyer, et al. 2024. "The mediated planet: datafication and the environmental SDGs." *Environmental Science & Policy* 153: 103673. https://doi.org/10.1016/j.envsci.2024.103673.

Wong, Annie, Susan E. Wijffels, Stephen C. Riser, Sylvie Pouliquen et al. 2020. "Argo Data 1999–2019: Two Million Temperature-Salinity Profiles and Subsurface Velocity Observations From a Global Array of Profiling Floats" *Frontiers in Marine Science* 7. https://doi.org/10.3389/fmars.2020.00700.

METRIC UNITS

ETHNOGRAPHY OF TIME

CULTURAL TECHNIQUES

MEASUREMENT

GREGORIAN CALENDAR

PACIFIC

GERMAN IMPERIALISM

OPIUM

[6]

Contract Time: Or How to Do Things with Units

Anna Echterhölter

German imperialism brought the Gregorian calendar to many Pacific Islands and shorelines. I argue that this introduction of new units of time is not a byproduct of colonialism but a cornerstone. The units of an industrialized economy intervene in pre-colonial calendars. In Melanesia or Polynesia temporal units were famously task-oriented and reflected changes in vegetation or oceanic events. As in other agrarian settings "ecological calendars" mediated successfully between nature and society. Among the strategies to go against these rhythms and to enforce capitalist time discipline in the plantation economy were labor contracts, punitive measures, and addictive wages. I show from Samoan archival records how the German colonial office claimed the monopoly on opium imports to introduce new media ecologies of time.

The first Western temporal unit to emerge in Melanesia was a timespan of three years. Richard Thurnwald relates how the "years" of the Western Gregorian calendar took hold in the coastlines and villages, and he points to labor contracts as a driving force behind this shift to a new calendar:

> But even the reckoning according to Christmas (New Year) festivities, which gained influence with the rule of the whites, is used only for timespans just a little over 3 years, the typical contract period of the recruited native workers—one then prefers to calculate according to periods of service (Dienstperioden) and ultimately arrives at the age of the person. (Thurnwald 1913, 110)[1]

It is crucial that three years are measured each Christmas, and not according to the "yam harvest" or the "ripening of almonds," which the observer mentions as alternatives. Such was the impact of Western cultural techniques of timekeeping that a person's birthday and lifespan would be expressed in periods of three years, and this unit or length of time was learned from the typical labor contract in the Pacific plantation economy. The German influence starts in the late 1850s when the Hamburg trader Godeffroy establishes posts in Samoa and Fiji. They expand their reach to parts of Melanesia and Micronesia, until the colonies of German New Guinea (1884–1914) and German Samoa (1900–1914) are formally declared (Schoeffel 1979; Meleisea 1987; Steinmetz 2007; Salesa 2014; Fitzpatrick 2025).

Throughout the paper I treat calendars and metric infrastructures of timekeeping as "environing technologies." Pre- and colonial calendars should be seen as "…complex sets of operations, methods, and instruments (technologies) that perform a category of work (environing) in defining 'the environment' as a way of understanding human–nature relations" (Sørlin and Wormbs 2018, 114). Jussi Parikka (2018, 3) even introduces Papua New Guinean fieldwork to the genealogy of the concept of "medianatures."

The argument of this paper is that a specific form of violence is necessary to change from nature-based calendars, which counted from the ripening of the almonds, to the ones grounded in the metric system and the Gregorian calendar. Firstly, the close ties between the new units of time and labor contracts are pursued (Hempenstall 1975; Munro and Firth 1993; Droessler 2022). Hours, wages, pocket watches, and accounting systems all began to mediate behavior during industrialism. The introduction of time discipline in Europe depended on Christian values and moral self-restraint (Thompson 1967; Pickering 2004). I maintain that Christian morals were less of a resource to enforce strict temporal discipline in Oceania. This is why in the second section I present new detail from the National Archives and Records of Samoa on the use of

1 Translations from German to English, if not otherwise indicated, are my own.

opium wages across the German Pacific colonies. In the third part pre-colonial temporal orders are reconstructed.

This third part allows for a better understanding of what was at stake. What did the forceful change from one Melanesian medianature to another entail? The ethnography of time about the region addresses the temporal units in use as "ecological calendars." These use visible changes in flora and fauna as measures (Malinowski 1927; Munn 1977; Silverman 1997; Scaglion 1999; Eräsaari 2023). Compared with the early British ethnography of time, which gives functional and utilitarian interpretations of nature based "time-reckoning," the German observers stress the indexicality of temporal units (Wertheimer 1963 [1911]; Thurnwald 1913). They postulate a "vital real"—a Pacific cultural technique of measurement, which focuses on the lifeforms and available materials. These metrics speak to a different focus of attention and belong to a resource regime that is incompatible with the plantation economy.

Focusing on the cultural technique of time measurement in a colony reveals the clandestine process in which new means of differentiation, classification, and separation take hold (Durkheim and Mauss 2009 [1903]; Siegert 2011; Kassung and Macho 2013; Siegert 2023). Gregorian units of measurement are the tools to alter responsibilities within the surrounding environment (Peters and Wickberg 2023). The kinesis of this violent shift is best described as mesuroclasm, as violation of a symbolic order, which may react in unpredictable forms (Vera 2017; Echterhölter 2026). Metric units, far from being neutral entities, are infrastructural media. Units organize, synchronize, and index resource regimes and natural metabolisms alike. The cultural technique of time measurement is thus not a byproduct of colonialism but a cornerstone—because precise metrics are the only infrastructure in which a capitalist resource regime can flourish.

Plantation Time and the Regulation of Labor

Traders, plantation owners and the German Colonial Office were in cahoots to enforce work discipline. They sought to introduce a relationship to time that was more profitable to them, and part of this goal was implementing Gregorian calendars and units. For Jaluit, the main island of the Marshall Islands, the *German Colonial Atlas* indicates the location of a cannon fired at noon (*Zeitkanone*, Langhans 1893, 30). Important colonial harbor towns like Kiautschou begin to measure the ground zero of the sea level by tide gauges (von Hardenberg 2024, 67). These unambiguous points anchor the new grit of reference and lay the groundwork for the mediating infrastructures of the SI (*Système International des Unités*) that encompass all but six countries today. Roads, harbors, and railways were built, and the "universal units" of the metric system and Gregorian calendar were implemented as subtle but crucial infrastructural media (Vera 2017; Schabacher 2022).

One means to change the calendar were work contracts. Temporal units figure prominently in an ordinance on model contracts by Reinhold Kraetke, the Landeshauptmann of German New Guinea from 1888 onwards, during the reign of the German New Guinea Company (Deutsche Neuguinea-Kompagnie). That the workers' depot on Mioko is mentioned in the legal text points to the fact that the document legalizes and orders long-standing coercive practices. Mioko had been a center of the labor trade, from where Melanesian contractors were shipped to Samoan plantations and beyond. An added model "Scheme of an Employment Contract" spells out their working hours:

> He (they) were then informed that the employment relationship was concluded for a period of .... years; that this period would begin on the day of arrival at the destination and end on the day of embarkation for the return journey;
>
> That the working hours would begin after sunrise and end at sunset, be interrupted by a two-hour break for lunch and rest, and that the total working time would be ten hours a day;
>
> The worker(s) listed under 1 hereby declare: I (we) agree to the conditions just notified to me (us) and undertake to work for a period of ..... years in accordance with the above conditions.
>
> Negotiated as above
>
> (name of the recruiter) (hand sign of the recruited).
> (Kraetke 1892 [1888], 543)

§ 9 of the ordinance limits the contract times to the maximum of three years, thus confirming Thurnwald's observations. The fact that the time budget of the workday is rendered in terms of darkness and brightness first, and not in hours alone, is significant. It ties in with general findings from social metrology that relational measures preceded abstract ones in non-industrialized labor regimes (Kula 1986 [1970]). As Thompson (1967, 70) stated about the introduction of minutes to Europe: "[W]ithout subdivision of processes the degree of synchronization demanded was slight and task-orientation still prevalent." The Melanesian contract scheme stated a 10-hour maximum workday in numerical form as well, but the description of time spans in visible terms ties in with other provisions of the scheme, which also betray that the binding forces of contracts were not very transparent to the contracted workers, e.g., they had to identify with their "hand sign" and they had to recite a declaration of consent in chorus, in German. But the descriptions of temporal duration in terms of dawn and dusk, as vague and relational as they may seem, have one clear advantage: visible environmentally distinct signals are measures within the control of the workers on their respective plantations.

Adolph von Hansemann (1892 [1888]), a banker who managed the fortunes of the Pacific “protectorate” from his private office in Berlin, went even further. In 1888 he scripted the ordinance concerning the “discipline among the colored workers.” The piece of colonial legislation grants the right to deprive workers of food and beverages for certain amounts of time to the employers. It suggests overtime work, detention in separate rooms, and corporal punishment. These disciplinary punishments are measured in hours, weeks, or months.

After the German Reich purchases the colony back from the chartered company, new variants of this ordinance include state control of the disciplining instruments (*Züchtigungsinstrumente*) (von Bennigsen 1903 [1900], 248) and the minimum living requirements allotted to each person in precise units: one meter of space on the transport vessel, 1.5 cubic meters in height, as well as food rations, four liters of water per capita, and medicine (Kraetke 1892 [1888], 538). Workers’ rights were therefore expressed in metric minima (Simmons 2015).

The reason transport figured so prominently was that labor shortages were chronic in the Pacific, especially in Samoa. A meeting of the government council (*Gouvernementsrat*) in Apia, the capital of German-occupied Western Samoa, can give a typical insight (BArch R 1001/2541: 34, 38).[2] Members reflect on the desolate conditions around 1908: Samoans have given up their own plantations. Almost no one can be persuaded to work for the foreigners. This chronic complaint about a lack of labor and work discipline is generally held to be an expression of passive resistance on the part of the Pacific Islanders (Hempenstall 2006).

German Samoa is a slightly unusual case since the Samoan elites had managed to keep their people largely out of the crosshairs of the plantation economy. From the mid-1860s onwards, Samoan workers would have on occasion accepted forms of wage labor on plantations. There is even a 1903 petition by paramount chief Mata’afa Iosefa, trying to confine the contract time for Samoans to one month (BArch R 1001/3063, 81; Droessler 2022, 76).

As in other places the planters thus resorted to foreign labor, which very often inspired a good deal of coercion (De Vito and Fagbore 2023). Conditions that were promised during recruitment were not met, the workers were isolated from the outside world, and even casinos were created to establish debt bonds—all according to Western monetary units and deadlines for payment.

2 BArch = Federal Archive of Germany, Berlin/Koblenz, Germany. Quotations are all from the segment R 1001 which holds the files of the German Colonial Office.

In 1872 Godeffroy "imported" 400 workers from China. The coasts of mainland New Guinea and the Gilbert Islands are also subject to highly questionable recruitment methods (Munro and Firth 1993; Bollard 1981; Firth 1978). These activities were institutionalized rather than alleviated by German colonial rule. Compared with the other colonies of the German empire the Pacific protectorates regulated working conditions early. It is held, for instance, that Cameroon models its labor legislation on the 1888 ordinance of German New Guinea (Schröder 2005, 312–17).

Droessler (2022) has uncovered instances of international solidarity among the foreign laborers in Samoa but also instances which mirror the violent working conditions—the company-owned jail of the *German Trade and Plantation Society* (D.H.P.G.), a petition against a German settler in Samoa who almost whipped a Chinese worker to death, and a gruesome hunt for eloped Chinese workers, who wanted to kill as many "slave-makers" as possible before being shot to death themselves by colonial police.

Since temporal units were oftentimes legally binding and mattered in punitive regimes, it is no exaggeration to state that it was the work contracts of the plantation economy that introduced the Gregorian calendar. This is not an exclusive influence: there is an undeniable impact of missions on time-keeping (Comaroff 1991; Nanni 2013; Midena 2015). The need for synchronization of time rises with increased traffic (Kassung and Macho 2013; Ogle 2015), erasing the famous achievements of Micronesian and Polynesian navigation. Scientifically grounded conceptualizations of time tended to prevail (Chakrabarti 2020; Hsiung, Lenel, and Meister 2023). None of these, however, had the direct and legally binding impact of units of time of the labor contracts and their punitive regimes.

Time Discipline and Addictive Wages

What Droessler only mentions in passing are the unusual means of positive motivation, which needed to be strong to make anyone work on Samoan foreign plantations at all. Even for Europe external instruments, such as factory signals, accounting books, and the pocket watch of the worker, were involved. Much more crucial were the internal instruments, such as establishing time discipline by recourse on morale, Christian values, and the governance of the self (Thompson 1967). Shame and genealogical conditioning of minds cannot be presumed to exist in the Pacific to the same degree, however. While Protestant missions gained influence in Samoa from the 1830s, the Melanesian and Chinese foreign workforce were much less susceptible to biblical damnation.

I argue that the opium monopoly of the German colonial administrations is an attempt to deploy additional strategies for making workers adhere to their production schedules. Specific forms of wages and enticement, and even intoxication, were common colonial practice. We may consider these substances as "addictive currencies." These forms of payment were useful to establish work discipline alongside company scrip or plantation money, which deprived workers of the transferability of their wages and made them more dependent (Mira 1986; Suter 2024).

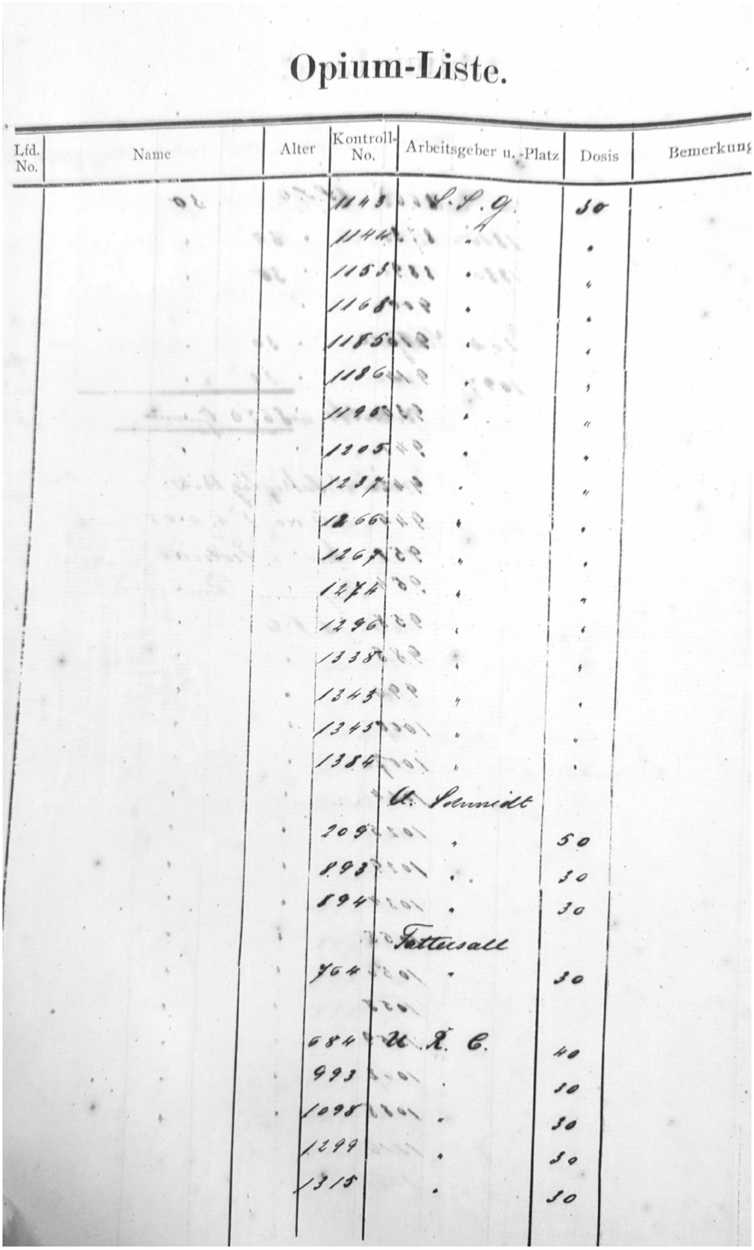
In-kind payment of wages was quite common and seems to have been popular: the boxes of in-kind payment could make up two-thirds of total wages. Correspondences between the largest importer of foreign labor, the D.H.P.G. (*Deutsche Handels- und Plantagengesellschaft*), and the tax authorities brings to light that these desirable European products to be had in German Samoa could have been imported to German New Guinea by the D.H.P.G. all the same. But this would have failed to entice the Melanesians to come to Samoa on a work contract in the first place. The lure of material abundance was created where human resources were most needed (NARA GC / S 16 / IG 87 F1/ Custom Duties 19–29, 465, 483).[3]

All these incentivizing forms of payment show that neither traders nor planters trusted in the effectivity of German coin. Otherwise, it would be inexplicable why "smoking schools" were encouraged (Firth 1973, 13). Only after intentionally creating demand, wages could be paid in tobacco. Its recognizable shape was known as the "NGC form" as many of these bars were issued by the governing German New Guinea Company (Meinhardt 1963, 9).

Comparatively more unique as a colonizing practice was the controlled distribution of opium by the government, as part of the wages in Samoa, and to a lesser extent in German New Guinea. This addictive wage targeted the Chinese foreign workforce. It most probably set in towards the end of the 19th century and was in full bloom around 1908, in an orderliness that only a Prussian bureaucracy would dedicate to communal opium dealing.

The government auctioned off an opium license, and the contract regulated all eventualities. For the years 1905–1908 it went to the association of German planters—*Deutsche Samoa Gesellschaft* (NARA GC / S 9 / IG 62 F-2 / Opium Matters 138). Only the government could make changes to the list of Chinese who were eligible for premium-quality opium, and the quantities the listed workers were entitled to (§ 5). Only employers were allowed to buy the regulated amounts for regulated prices (§ 6). So meticulous was the bookkeeping that a specific number system for contract workers was in place (figure 1). In dealing with individual Chinese workers the system clearly served the German bureaucrats and planters well: it saved them the embarrassment of coping with Chinese names in writing or opening up to fraud by

3 NARA = Samoan National Records and Archives in Apia Samoa. Quotations are all from the segment GC = German Collection.



Opium-Liste.

Lfd. No.	Name	Alter	Kontroll-No.	Arbeitsgeber u. -Platz	Dosis	Bemerkung
			1143	S. S. G.	30	
			1144	"	"	
			1153	"	"	
			1168	"	"	
			1185	"	"	
			1186	"	"	
			1195	"	"	
			1205	"	"	
			1237	"	"	
			1266	"	"	
			1267	"	"	
			1274	"	"	
			1296	"	"	
			1338	"	"	
			1343	"	"	
			1345	"	"	
			1384	"	"	
				U. Schmidt		
			209	"	50	
			893	"	30	
			894	"	30	
				Tattersall		
			764	"	30	
			684	U. R. C.	40	
			993	"	30	
			1098	"	30	
			1299	"	30	
			1315	"	30	

[Figure 1] Section from an "opium list" of six pages with numbers identifying Chinese foreign laborers in Samoa. The columns for "name" and "age" of the workers are empty, only the "ID number" and "dose rate" is given, indicating an amount in grams per time per individual. The (abbreviated) and repeated names in the middle column are those of plantation owners (Source: National Archives and Records of Samoa/German Collection/S 9/IG 62/F2 Opiumsachen, fol. 138.)

homophonic transcriptions. Thus, everyone was known to the government mainly by the number and degree of addiction reflected in the quantity a worker was allotted.

Meanwhile, the pressure to control opium increased with the International Opium Conference in Shanghai. An outraged Chinese delegation forced the international community to close their opium smoking dens, abandon the creation of poppy plantations, and break down international trade as well as the smuggling of opium. The substance was internationally banned from sale in 1909, except for medical purposes. Around this time there was a brief, handwritten note by Governor Solf, officially ending this practice in Samoa, most likely without immediate effect.

Larger colonial enterprises throughout the German Pacific colonies were prone to be involved in the addictive wages scheme as well (see Hahl, 1906 [1905]). The governor of German New Guinea, Albert Hahl, interdicts any selling of opium to the locals in 1904 (BArch R 1001/2536). Around the same time, he issues an opium selling license for a well-known Chinese trader, A Lai. This arrangement is presented as a concession to the the German New Guinea Company, which still considers it their natural right as the former ruling chartered company to exercise the opium monopoly. Hahl renews the license but regulates everything in this new arrangement, from the storeroom to the shop signs. The latter must be in German and Chinese and have to indicate “Sale of Opium” publicly. Exact prices per weight are given, but they are curious amounts, since the monetary value is given in German currency per Chinese unit of weight (*tael, tschi, hun tjandu*).

More crucially, Hahl decrees that the government receive a cut of profit from each half kilo of opium. In this confined form Hahl seems to endorse this model of oversight for the Jaluit Company on the Marshall Islands or the Pacific Phosphate Company on Nauru. The latter initially refuses to deal in opium but lets a local colonial physician step into the role of distributor. In all these cases one can assume that opium was paid directly as a wage, but it is less explicit than in the Samoan case. The overall claim is not to underestimate colonial units of measurement. Understood as early mass media the units of measurement exercise a form of symbolic violence (Kula 1986; Le Roux 2004; Thomas 1991; Schaffer 2015, 2022).

Yam Cycles and Melanesian Medianatures

Despite long-standing trade and whaling contacts, most areas in the Pacific were only subjected to colonialism fairly late in the 19th century. Pre-existing forms of time recording in the Pacific abound. The calendar is often structured by marine events or plant growth, which is why the ethnography of time speaks by and large of “ecological calendars.” Rather than astronomical markers, these calendars use visual cues effected by flora, fauna, or the seasons.

They exist mainly as a shared epistemic tool. Even without devices such as mechanical clocks or written tables the agrarian calendar is effective in mediating between groups and materials. Calendric units in the Pacific resemble the integration of flora and fauna in systems of Nuer time-reckoning in Africa or the prominent example of Bali (Evans-Pritchard 1939; Bohannon 1953; Geertz 1966 [1973]; Fabian 1983), and to a limited degree Chinese calendars (Durkheim and Mauss 2009 [1903]).

Temporal units in the Pacific Islands often make reference to growth of a key staple. Some of these crops organize much more than time. For instance, a cycle of yam root cultivation among the Abelam in Papua New Guinea falls into two halves and two forms of activity and behavior. As the yam grows, the gardeners observe taboos and sexual abstinence. Social contacts are reduced. Only after the harvest does the time of festivals of intensive consumption begin. It is also a time of competition and conflict. Among the Iatmul on the middle Sepik, month names reflect the phenomena: "sleepiness of the fish" in February or "lack of food" in May (Silverman 1997, 105).

Some nights in fall are characterized by a spectacular event of the Pacific ecosystem: the swarming of the polychaete worm (best known by its Samoan name "palolo"). Most of the year this creature remains hidden in the reefs from Melanesian coastlines in Vanuatu to Samoan shores in Polynesia. Only in a night in fall the animal splits and sends a procreative part to the ocean's surface, where it can be caught in abundance. Harvesting and festivities ensue. Month names in several languages make reference to it (Stair 1847; Samoan Society 1928; Mondragón 2004; Kelso et al. 2023).

In Kiriwina one can observe faint echoes of the palolo festivities (Malinowski 1927; Austen 1939). An earthly and nutritionally relevant phenomenon sets time. Malinowski stresses how little the stars matter, and how important vegetation is in Kiriwina. The names of the 10–12 moons can be recited only by a few ritual specialists. This leniency with astronomical markers, however, is not described as negligence by him. Rather, the key driver of time, and the "backbone of native chronology" is *gardening* (Malinowski 1927, 213). Direct interest like hunger periods, which are not uncommon before the harvest time sets in, are not reflected in this calendar. This mode of time-reckoning focuses on that "upon which their plans and arrangements depend. This calendar is not only psychologically the most adequate, but in all practical arrangements the most effective" (Malinowski 1927, 210). Some support his position (Leach 1950); some contradict and point to the significance of the Pleiades star cluster (Austen 139, 238; Matamua 2020).

Scaglion (1999, 217) underlines the crucial importance of the temporality of vegetation even today. In field research among the Abelam in Papua New Guinea the calendar is linked to the onset of the wet season rather than a position of the Pleiades. Yam cycles can differ in different settlements, following exactly what the growth of plants in the gardens prescribe until the festive season, which is governed by entirely different principles. What Scaglion describes as a non-linear element of time is the fact that the growth of plants, the birthing season after long times of abstinence, and the presence of ancestors are attributed to one principle of growth. This would tie in with what Nancy Munn (1992) has stated in her seminal essay on the ethnography of time. Her position grew out of her own fieldwork on the Melanesian island of Gawa but builds on earlier studies on the orders of time in various non-industrialized societies. Temporal units do not only contain agrarian nature—they are comprised of mathematical and vegetative elements in the directly palpable environment all the same. This dependency of local temporal expressions on local space is what she addresses as "spatiotemporality"—when units of measurement are visible in the environment. Munn takes issue with attempts to separate even "ecological time" from ecology itself and stresses the organization of relations via this form of timekeeping (Munn 1992, 97, 96).

Some of the vitality of temporal units in Munn's account resonates with positions from German ethnography of time, for instance with the ethnopsychological accounts of Richard Thurnwald and Max Wertheimer. As two prominent ethnographers of units and numbers from the period of German colonialism they emphasize the suitability of the practical use of units for the vital reality of human and non-human exchange in Melanesia.

In the case of Richard Thurnwald, these observations begin during the first of his three sojourns in the Pacific in 1906–1909, when he was enticed by Albert Hahl to engage in early participant observation (Buschmann 2003). Thurnwald brought several questionnaires with him, which investigated units of length, weight, money, and time, and some of these sets of questions had been contributed by Wertheimer (Klotz 2020). Even a lengthy questionnaire on Indigenous legal customs did not stop at asking about calendric units and the sense of rhythm (Steinmetz 1906, 14). This keen interest was prompted by the young and confident branch of applied psychology, with its center in Potsdam (Probst 1992; Wolfradt 2022). There is no denying that Thurnwald's ethnopsychology is problematic (Steinmetz 2022; Trautmann-Waller and Dedryvère 2022; Gingrich 2022). Until the 1930s his ideas about hierarchies of peoples are not derived from biological differences (Rohrbacher 2024, 323, but contrary 329).

To make sense of his irritations he discovers the epistemology of numbers and units as a function of the socio-economical setting (Thurnwald 1912). For instance, he reports that the unit of a month in northern German New

Guinea could mean very different kinds of length, because the length of the time period depended on the visibility of the moon: if there are clouds in the sky and the new moon does not show, the month endures and the monthly cycle is not restarted. This would lead to very uneven years and a low degree of temporal synchronization from village to village and from coast to coast. Remarkably, Thurnwald does not see this as a disadvantage to the Western view, but as a systematic deviation in perspective. He concludes that the enduring month is an expression of a different relationship between imagination, attention, and object: "We are always schematizing, the natives are phenomenological, they act according to appearance" (Thurnwald 1913, 160).

What is more, Thurnwald already interprets the order of temporality as part of the debate on totemism, which unfolded with might after 1910. For Thurnwald (1919/20, 531) totemism is not a social order or religion, but a "way of thinking" (*Denkart*). It is characterized by an immersion in things, which finds expression in the cloud-dependent calendar. The calendric units grow out of a way of thinking that structures affiliations and loyalties between things and people in a very different way (Thurnwald 1917/18 and 1919/20). For him the possibility of understanding oneself as a descendant of a totem (a plant or an animal) derives from a point of view that negates the gap between animated and inanimate. The order of nature, as well as the order of laws and social rules, is governed by taboo. Some things, plants or animals are protected and are not accessible for consumption or use. But this is not a religious or social question. It hinges on an epistemological positioning he describes with regard to the people in Melanesia: "Thinking is said to be concrete; one has progressed to fewer abstractions. But why isn't this the case? It probably lies in the fact that emotions exert their influence primarily and undisguisedly in the direct, practical sphere." (Thurnwald 1913, 14). While the lack of abstraction is a dubious verdict in these times, Thurnwald counterbalances it with this new conjecture: if notions (of time) remain embedded in natural phenomena, they are geared towards the concrete living environment and vital concerns of the group. Not unlike Malinowski, Thurnwald discovers a particular rationality in this focus on the practical, which is not economic but simply invested in the very core concern of survival.

Another contributor to this discussion on units and number perception is the Gestalt psychologist Max Wertheimer, who never saw the Pacific with his own eyes. He projects a set of questions, exclusively dedicated to investigating the use of numbers and the representation of units (Wertheimer 1963 [1911]; Midena 2015). Wertheimer sides with the divergent mode of number rendition he describes in non-industrialized societies, inserting a good deal of critique of the Western capitalist modes of abstraction in his analysis. Europe has lost touch with the real world due to its readiness for abstraction. Hence it has become devoid of reference (*wirklichkeitsabstrakt*: Wertheimer 1963 [1911], 150; Harrington 1996, 133). The use of numbers in areas like Melanesia is a more circumspect and environmental mode of quantification. Number formations to his mind are locally rooted (*beheimatet*) and closer to meaning and specific goals. Melanesian epistemologies of nature are thus turned into implicit recommendations for European societies. Regarding the specific use of numbers and units he relates the following:

> There are entities, which are less abstract than our numbers, serving analogue goals to them, or rather function in their stead … It is not relevant if one wants to call these entities from a certain level onwards as "numbers" or as "number formations," or otherwise.—Formally they claim a middle ground between logical equivalents of gestalt qualities and conceptual notions. (Wertheimer 1963 [1911], 108)

The number formations (*Zahlengebilde*) stand between the synthetically grasped form qualities and the abstract concepts. This does indeed imply a series of epistemic formats; what is crucial, however, is that a serial ranking and nonhierarchical rating is derived. Wertheimer encapsulates a real-world reference in the category of "number formation."

For example, when "natural group or cluster formations" have to be assessed, as they occur on trees or during the selling of crops (Wertheimer 1963 [1911], 143), they are numerical structures that are not completely abstract and thus manage to calculate "not in terms of arbitrary logical operations, but in terms of those that are biologically relevant" (125). In other instances, he points towards the "biologically real." These close ties with the surroundings were discussed by other thinkers at the time—for instance in the Mach circle "vital reality" reminded readers of the uncomfortable dependencies of the human metabolism on ecological surroundings. Wertheimer's internal partiality to this kind of mental operation led to the recommendation that European researchers should develop and understand divergent epistemologies. In one German text he even addresses these ways of thinking in English: "to think black" (151).

Conclusion

Temporal units are but one element of the larger family of cultural techniques of measurement. Pre-colonial calendars have been discussed as environmental and ecological, as prioritizing the socio-ecological situation, as ritually dominated, or as a cornerstone of early classification systems (Durkheim and Mauss 2009 [1903]; Schüttpelz 2006). Temporal units were singled out in this paper to exemplify how metrication and the Gregorian calendar provided an effective environment for capitalism and colonization. Units and metrics serve not simply representational purposes. They are actionable, entangled with the law, and means for the Colonial Office to assert its control. In this respect units resemble Austin's speech acts (1975), since not only words and phrases, but also infrastructures of measurement and their units, can change how we reckon with everything.

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References

Austen, Leo. 1939. "The Seasonal Gardening Calendar of Kiriwina, Trobriand Islands." *Oceania* 9: 237–53.

Austin, John Langshaw. 1975. *How to do Things with Words* (2nd ed.). Cambridge, MA: Harvard University Press.

Bohannon, Paul. 1953. "Concepts of time among the Tiv of Nigeria." *Southwestern Journal of Anthropology* 9, no. 3: 251–62.

Bollard, Allen E. 1981. "The Financial Adventures of J.C. Godeffroy and Son in the Pacific." *The Journal of Pacific History* 16, no. 1: 3–19.

Buschmann, Rainer. 2003. "Colonizing Anthropology: Albert Hahl and the Ethnographic Frontier in German New Guinea." In *Worldly Provincialism: German Anthropology in the Age of Empire*, edited by H. Glenn Penny and Matti Bunzl, 230–56. Ann Arbor: University of Michigan Press.

Chakrabarti, Pratik. 2020. *Inscriptions of Nature: Geology and the Naturalization of Antiquity*. Baltimore: Johns Hopkins University Press.

Comaroff, Jean. 1991. "Missionaries and Mechanical Clocks: An Essay on Religion and History in South Africa." *Journal of Religion* 71, no. 1: 1–17.

De Vito, Christian G., and Adam S. Fagbore. 2023. "Introduction: Punitive Perspectives on Labour Management." *International Review of Social History* 68: 1–14.

Droessler, Holger. 2022. *Coconut Colonialism: Workers and the Globalization of Samoa*. Cambridge, MA: Harvard University Press.

Durkheim, Émile, and Marcel Mauss. 2009 [1903]. *Primitive Classification*, edited and translated from the French by Rodney Needham. London: Cohen & West.

Echterhölter, Anna. 2026. *Metrologie: Zur Wissenschaftsgeschichte einer Infrastruktur.* Göttingen: Wallstein (forthcoming).

Eräsaari, Matti. 2023. *Comparing the Worth of the While in Fiji and Finland*. Oxford: Oxford University Press.

Evans-Pritchard, Edward. 1939. "Nuer Time-Reckoning." *Africa, Journal of the International African Institute* 12, no. 2: 189–216.

Fabian, Johannes. 1983. *Time and the Other: How Anthropology Makes Its Object*. New York: Columbia University Press.

Firth, Stewart. 1973. "German Firms in the Western Pacific Islands, 1857–1914." *The Journal of Pacific History* 8: 10–28.

———. 1978. "German Labour Policy in Nauru and Angaur, 1906–1914." *The Journal of Pacific History* 13, no. 1: 36–52.

Fitzpatrick, Matthew. 2025. *A Pacific Power: Liberal Imperialism in German Samoa*. Oxford: Oxford University Press.

Geertz, Clifford. 1966 [1973]. "Person, time, and conduct in Bali: an essay in cultural analysis." In *The Interpretation of Cultures: Selected Essays*, 360–411. New York: Basic Books.

Gingrich, Andre. 2022. "Richard Thurnwald's formative Phasen in Österreich und Bosnien. Ein kritischer Literaturbericht zu Grundlagen und Diskontinuitäten der Werkgeschichte." *Paideuma* 68: 187–235.

Hahl [Albert, Der Kaiserliche Gouverneur]. 1906 [1905]. "Runderlass des Gouverneurs von Deutsch-Neu-Guinea, betreffend Arbeiterlöhnung." In *Deutsche Kolonialgesetzgebung: Neunter Band*, edited by Ernst Schmidt-Dargitz and Otto Max Köbner, 255. Berlin: E.S. Mittler und Sohn.

Harrington, Anne. 1996. *Reenchanted Science: Holism in German Culture from Wilhelm II to Hitler*. Princeton: Princeton University Press.

Hempenstall, Peter. 1975. "Resistance in the German Pacific Empire: Towards a Theory of Colonial Response." *The Journal of the Polynesian Society* 84, no. 1: 5–24.

———. 2006. *Pacific Islanders Under German Rule: A Study in the Meaning of Colonial Resistance*. Canberra: ANU Press.

Hsiung, Hansun, Laetitia Lenel, and Anna Maria Meister. 2023. "Introduction." *Journal for the History of Knowledge* 4: 9–32.

Kassung, Christian, and Thomas Macho. 2013. "Einleitung." In *Kulturtechniken der Synchronisation*, edited by Christian Kassung and Thomas Macho, 9–21. München: Fink.

Kelso, Neal, Gregory M. Plunkett, Presley Dovo, Dominik Ramík, et al. 2023. "The palolo worm as a cornerstone of Pacific ecological time-reckoning." *Ethnobiology Letters* 14, no. 1: 24–35.

Klotz, Sebastian. 2020. "Murray Island versus Aberdeenshire: Contextualizing the Cross-Cultural Hearing Tests of the Cambridge Anthropological Expedition to Torres Straits, 1898–1899." In *Testing Hearing: The Making of Modern Aurality*, edited by Viktoria Tkaczyk, Mara Mills, and Alexandra Hui, 77–108. Oxford: Oxford University Press.

Kraetke [Reinhold, Landeshauptmann]. 1892 [1888]. "Verordnung, betreffend die Anwerbung und Ausführung von Eingeborenen als Arbeiter." In *Deutsche Kolonialgesetzgebung,* vol. 1, edited by Otto Riebow, 535–48. Berlin: E.S. Mittler und Sohn.

Kula, Witold. 1986 [1970]: *Measures and Men.* Translated by Richard Szreter. Princeton: Princeton University Press.

Langhans, Paul, ed. 1893. "Schutzgebiet der Marshall-Inseln." In *Deutscher Kolonial-Atlas: 30 Karten und 300 Nebenkarten*, map no. 30. Gotha: Perthes.

Le Roux, Pierre, ed. 2004. *Poids et mesures en Asie du Sud-Este*. 2 vols. Marseille: École Française d'Extrême-Orient.

Leach, Edmund Ronald. 1950. "Primitive Calendars." *Oceania* 20, no. 4: 245–62.

Malinowski, Bronislaw. 1927. "Lunar and seasonal calendar in the Trobriands." *The Journal of the Royal Anthropological Institute of Great Britain and Ireland* 57: 203–15.

Matamua, Rangi. 2020. "Matariki and the decolonisation of time." In *Handbook of Critical Indigenous Studies*, edited by Brendan Hokowhitu, Aileen Moreton-Robinson, Linda Tuhiwai-Smith, Chris Andersen, et al., 65–77. London: Routledge.

Meinhardt, Günther. 1963. *Die Geldgeschichte der ehemaligen deutschen Schutzgebiete. Heft 5: Bismarck-Archipel und Kaiser-Wilhelms-Land*. Dortmund: Rundschau.

Meleisea, Malama. 1987. *The Making of Modern Samoa: Traditional Authority and Colonial Administration in the History of Western Samoa*. Suva: Institute of Pacific Studies of the University of the South Pacific.

Midena, Daniel. 2015. "The Ethnomusicology of Emotions in the Neuendettelsau Mission to the Papuans." In *Emotions and Christian Missions: Historical Perspectives*, edited by Claire McLisky, Daniel Midena, and Karen Vallgårda, 73–95. Basingstoke: Palgrave Macmillan.

Mira, William J.D. 1986. *From Cowrie to Kina: The Coinages, Currencies, Badges, Medals, Awards and Decorations of Papua New Guinea*. Sydney: Spink & Son.

Mondragón, Carlos. 2004. "Worms and mana: The traditional calendar of the Torres Islands Vanuatu." *Oceania* 74, no. 4: 289–308.

Munn, Nancy D . 1977. "The Spatiotemporal Transformations of Gawa Canoes." *Journal de la Société des Océanistes Année* 54–55: 39–53.

———. 1992. "The Cultural Anthropology of Time: A Critical Essay." *Annual Review of Anthropology* 21: 93–123.

Munro, Dough, and Stewart Firth. 1993. “Samoan Plantations: Gilbertese Workforce’s Experience, 1867–1896.” In *Plantation Workers: Resistance and Accommodation*, edited by Brij V. Lal, Doug Munro, and Edward D. Beecher, 101–29. Honolulu: University of Hawaii Press.
Nanni, Giordano. 2013. *The Colonisation of Time: Ritual, Routine and Resistance in the British Empire*. Manchester: Manchester University Press.
Ogle, Vanessa. 2015. *The Global Transformation of Time 1870–1950*. Cambridge, MA/London: Harvard University Press.
Parikka, Jussi. 2018. “Medianatures.” *ZMK: Zeitschrift für Medien- und Kulturforschung* 9, no. 1: 103–6.
Peters, John Durham, and Adam Wickberg. 2023. “Environing Empires and Colonial Media.” In *Environing Media*, edited by Adam Wickberg and Johan Gärdebo, 13–29. London: Routledge.
Pickering, Kathleen. 2004. “Decolonizing Time Regimes: Lakota Conceptions of Work, Economy and Society.” *American Anthropologist* 106, no. 1: 85–97.
Probst, Paul. 1992. “Angewandte Ethnopsychologie während der Epoche des Deutschen Kolonialismus (1884–1918).” *Psychologie und Geschichte* 3, nos. 3 and 4: 67–80.
Rohrbacher, Peter. 2024. “Politisches Chamäleon: Richard Thurnwald und seine kolonialethnologischen Ansätze in der NS-Zeit.” *Journal of Social and Cultural Anthropology* 149, no. 2: 313–40.
Salesa, Damon. 2014. “Emma and Phoebe: ‘Weavers of the Border.’” *Journal of the Polynesian Society* 123, no. 2: 145–67.
Samoan Society. 1928. “The Samoan Division of Time.” *Journal of the Polynesian Society* 37, no. 2: 228–40.
Scaglion, Richard. 1999. “Yam Cycles and Timeless Time in Melanesia.” *Ethnology* 38, no. 3: 211–25.
Schabacher, Gabriele. 2022. *Infrastruktur-Arbeit: Kulturtechniken und Zeitlichkeit der Erhaltung*. Berlin: Kadmos.
Schaffer, Simon. 2015. “Les cérémonies de la mesure: Repenser l’histoire mondiale des sciences.” *Annales. Histoire, Sciences Sociales* 70, no. 2: 409–35.
———. 2022. “Orientations and Disorientations in the History of Science: How Measures Made a Difference at the Imperial Meridian.” *Centaurus* 64, no. 4: 2–28.
Schoeffel, Penelope. 1979. D*aughters of Sina: A Study of Gender, Status and Power in Western Samoa*. Australian National University (PhD thesis).
Schröder, Peter J. 2005. “Arbeitszeitregulierung.” In *Gesetzgebung und “Arbeiterfrage” in den Kolonien: Das Arbeitsrecht in den Schutzgebieten des Deutschen Reiches*, edited by Peter J. Schröder, 312–17. Greifswald: LIT.
Schüttpelz, Erhard. 2006. „Die medienanthropologische Kehre der Kulturtechnik.” *Archiv für Mediengeschichte* 6: 87–110.
Schüttpelz, Erhard. 2015. “Das Kategorienprojekt.” *Zeitschrift für Kulturwissenschaften* 9, no. 2: 239–42.
Siegert, Bernhard. 2011. “The map is the territory.” *Radical Philosophy* 5: 13–16.
———. 2023. *Kulturtechniken: Rastern, Filtern, Zählen und andere Artikulationen des Realen*. Baden-Baden: Rombach.
Silverman, Eric K. 1997. “Politics, Gender, and Time in Melanesia and Aboriginal Australia.” *Ethnology* 36: 101–21.
Simmons, Dana. 2015. *Vital Minimum: Need, Science, and Politics in Modern France*. Chicago: Chicago University Press.
Sørlin, Sverker, and Nina Wormbs. 2018. “Environing technologies: a theory of making environment.” *History and Technology* 34, no. 2: 101–25.
Stair, J. B. 1847. “An Account of Palolo, a Sea-Worm Eaten in the Navigator Islands, with a Description by J.E. Gray, Esq., F.R.S.” *Proceedings of the Zoological Society of London* 15: 17–18.
Steinmetz, George. 2007. *The Devil’s Handwriting: Precoloniality and the German Colonial State in Qingdao, Samoa, and Southwest Africa*. Chicago: University of Chicago Press.
———. 2022. “La Sociologie de l’Empire. Richard Thurnwald et la question de l’autonomie scientifique.” *Actes de la recherche en sciences sociales* 185, no. 5: 12–29.

Steinmetz, Sebald Rudolf. 1906. *Ethnographische Fragesammlung zur Erforschung des sozialen Lebens der Völker ausserhalb des modernen europäisch-amerikanischen Kulturkreises*, edited and updated by Richard Thurnwald. Berlin: R. v. Decker.

Suter, Mischa. 2024. *Die Skalierung des Geldes: Souveränität und Wertmassstäbe im Zeitalter des Imperialismus 1871–1923*. Berlin: Matthes & Seitz.

Thomas, Nicholas. 1991. *Entangled Objects: Exchange, Material Culture, and Colonialism in the Pacific*. Cambridge, MA: Harvard University Press.

Thompson, Edward P. 1967. "Time, Work-Discipline, and Industrial Capitalism." *Past and Present* 38: 56–97.

Thurnwald, Richard. 1912. "Die Denkart als Wurzel des Totemismus." *Korrespondenz-Blatt der Deutschen Gesellschaft für Anthropologie, Ethnologie und Urgeschichte* 42, 43: 173–97.

———. 1913. *Ethno-psychologische Studien an Südseevölkern auf dem Bismarck-Archipel und den Salomo-Inseln*. Leipzig: Barth.

———. 1917/18 and 1919/20. "Die Psychologie des Totemismus." *Anthropos* 12/13: 1094–113 and 14/15: 496–542.

Trautmann-Waller, Celine, and Laurent Dedryvère. 2022. "Unsichere Felder: Hilde und Richard Thurnwalds ethnologische Forschungen." *Cultura & Psyché* 3: 1–10.

Vera, Héctor. 2017. "Counting Measures: The Decimal Metric System, Metrological Census, and State Formation in Revolutionary Mexico, 1895–1940." *Histoire & Mesure* 32, no. 1: 121–40.

von Bennigsen, Rudolf. 1903 [1900]. "Verordnung des Gouverneurs von Deutsch-Neu-Guinea, betreffend die Erhaltung der Disziplin unter den farbigen Arbeitern. Vom 20. Juni 1900." In *Deutsche Kolonialgesetzgebung*, vol. 6, edited by Ernst Schmidt-Dargitz and Otto Max Köbner, 248–49. Berlin: E.S. Mittler und Sohn.

von Hansemann, Adolf. 1892 [1888/1890]. "Verordnung, betreffend die Erhaltung der Disziplin unter farbigen Arbeitern." In *Deutsche Kolonialgesetzgebung*, vol. 1, edited by Otto Riebow, 552–53. Berlin: E.S. Mittler und Sohn.

von Hardenberg, Graf Wilko. 2024. *Sea Level: A History*. Chicago: University of Chicago Press.

Wertheimer, Max. 1963 [1911]. "Über das Denken der Naturvölker, Zahlen und Zahlengebilde." In *Drei Abhandlungen zur Gestalttheorie*, edited by Max Wertheimer, 106–63. Darmstadt: WBG.

Wolfradt, Uwe. 2022. "Zum Psychologie-Verständnis von Richard Thurnwald." *Cultura & Psyché* 3: 47–58.

THE SYMBOLIC AND THE REAL

FORGETFUL FUNCTOR

CATEGORY THEORY

FREUD’S NEURON MODEL

LACANIAN PSYCHOANALYSIS

NEUROCOGNITIVE SCIENCE

CRITICAL MEDIA THEORY

COMPUTABILITY

LOSS OF STRUCTURE

SYMBOLIC ORDER

TRANSCRIPTION PROCESSES

[7]

Forgetful Functor: Or How to Write the Real

Christina Vagt

This chapter explores the concept of "forgetful functor" as a theoretical framework for understanding the loss of structure and its critical implications for media theory. By examining the intersections between Freud's neuron model, Lacanian psychoanalysis, and neurocognitive science, the chapter argues that the process of "forgetting"—formalized in category theory—provides a lens to analyze what computational models of cognition forget. Furthermore, it discusses the role of formal languages in science and engineering and informal constructions in critical media theory—as a writing of the real of a science at the limits of formalization.

In mathematics, a forgetful functor is a mapping between categories that "forgets" some of the structure of the objects it transforms. For example, when transitioning from the category of graphs to the category of sets, the functor retains the vertices but discards the edges of the graphs (see figure 4). This notion of "forgetting by design" is not merely technical. In the context of media theory, the forgetful functor can be used as a critical lens to interrogate the loss of structure in scientific knowledge processes, particularly in the computational modeling of cognition. It not only provides a structural framework for examining the computational foundations of neurocognitive science but is essentially a way of writing the real as what necessarily disappears in symbolization.

Borrowing from psychoanalysis, and category and media theory, the loss of structure is not understood as a deficiency but as an epistemological feature that defines the real of a science at the limits of its formalization. Freud's early neuron model, Lacan's formalization of the unconscious, and the computational models of neurocognition that emerged in the mid-20th century all grapple with a fundamental tension: how to symbolize the real of cognition while acknowledging that something is always lost in the process.

This chapter starts by tracing the dual genealogies of functors in logic and mathematics, showing how the concept emerged in scientific applications as a bridge between distinct formal languages. It then examines the media theoretical intersections between structuralism and category theory and how Jacques Lacan's symbolic register aligns with the structural mappings of functors. "Forgetting" some of the complexity underlying cognition and subjects is not only a feature of computational approaches in neurocognitive science but also belongs to the history of media theory.

Experimenting with concrete but informal constructions, the chapter invites a reconsideration of formal languages in scientific and cultural inquiry, as well as Bernhard Siegert's (2024, XXVII) dictum that the real cannot be symbolized. If, as Lacan (1999, 93) suggests, "the real can only be inscribed on the basis of an impasse of formalization," then forgetful functors provide a way to write this impasse, a method to account for what is lost, forgotten, or excluded in the process of structuring knowledge.

Critical media theory does not blindly accept scientific statements as "true" or reject the discourse of science altogether as "false." Instead, it relates to and relies on scientific media practice and discourse to verify and revise its own methodology and intuitions concerning its objects of investigation. As a second-order commentary, such critical media theory is also relevant for science and engineering in terms of media theoretical questions such as "How is the relation between theory and investigated model being written (formally and informally)?" or "What structure is lost in a function?" I am convinced that questions of "best practice" or "ethics" can be derived and formulated in a better way once those foundational questions are responded to.

In this chapter, the intersections of psychoanalysis, media theory, and neurocognitive science are used to articulate a critique of the imaginary representations of computation with reference to its formal limitations.

Forgetful Functor

The history of functors has at least two beginnings: one trajectory resides in the field of logic, the other within mathematics. The logic trajectory began in the late 1920s, with the Polish school of logic, and at a time when mathematical logic was being formalized (Ajdukiewicz 1977, 119). In this context, the philosopher and psychologist Tadeusz Kortabiński coined the term “functor” as the “category of sentential connectives,” such as “and” or “if … then” (Kotarbiński 1966, 243). Influenced by Franz Brentano and Edmund Husserl, it is noteworthy that the concept of functor as a category of logical operators evolved within a philosophical school invested in the intersections of linguistics and logic with sciences, in particular psychology. Shortly after, Rudolf Carnap took up the term “functor” in his analysis of formal languages in *Logische Syntax der Sprache* (1968 [1934]) and distinguished further between “logical functors,” such as “and” or “if … then” and “descriptive functors,” such as “x + y” or “x < y” (13), which describe relationships and operations specific to number. Functors were a central element of formal languages, important to logically account for scientific correlations between measurements without necessarily knowing the logical relations or functions underlying these values.

The second trajectory starts a decade later, with mathematical category theory proper, as it was formulated by Saunders Mac Lane, Samuel Eilenberg, and Alexander Grothendieck. Originally developed as a tool to address foundational issues in algebraic topology, category theory allowed the discussion of patterns across different structures such as groups, rings, and topological spaces. In contrast to set theory with its focus on the internal “membership relations” between the elements of a mathematical object, category theory addresses “morphisms” between different objects. Today, it has become a foundational language also for logic, computer science, and philosophy. That is why category theory, in contrast to set theory, can write what gets lost in mapping one object onto another.

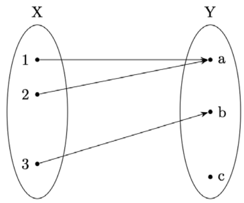
Mac Lane (1971) designates a functor as a “morphism of categories.” For example, a functor that sends one category to another while preserving its structure is a homomorphism of categories. Skipping the history of logic, Mac Lane (1971, 13) claims that “functors were first explicitly recognized in algebraic topology, where they arise naturally when geometric properties are described by means of algebraic invariants,” but gives no further historical references.

Indisputable, *forgetful* functors were discovered in mathematics, not in logic, and Mac Lane (1971, 22) defines a forgetful functor as a functor “which simply ‘forgets’ some or all of an algebraic object.” Most introductions to category theory mention forgetful functors; however, a precise definition of what a forgetful functor is does not exist, only a “more or less,” as some category theorists have criticized: “It always bugged me when reading books that no one ever defined 'forgetful functor.' Some functors are more forgetful than others" (Baez and Shulman 2006, 15).

Given that forgetful functors do not have a formal definition, I present an informal construction using the categories of sets and graphs.

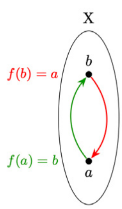
Construction: Forgetful Functor from Graph to Set

Let's begin with the theory of sets and draw the map of a function between the elements of two sets: "For all x, there exists one and only one element in y." Note that the definition of a function allows for mapping different elements in x to the same element in y:



[Figure 1] In category theory, this is called the "into" function or "injection" (Source: all diagrams by the author).

Let's move up one language—from sets to graphs. Within the theory of graphs, we can map the functions between the elements of a set. The elements now are "vertices," and the functions between the elements form the "edges" of graphs:

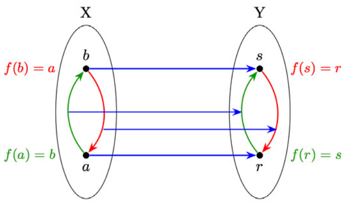


[Figure 2] Shows the graph of the functions between two objects *a* and *b* within a set.

f(a) = b and f(b) = a

Within the theory of graphs, we can now map the elements and the relations of one set onto a second set; the functions that show the mapping of these functions between sets are called morphisms.

Let's draw the map of the morphisms between the two sets *X* and *Y*, such that "for all x, there exists one and only one morphism from x to y."



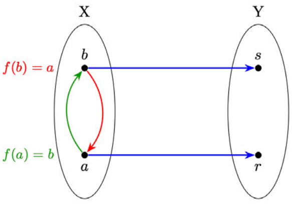
[Figure 3] This is called an "isomorphism," an old definition of structure.

Here, we can see how the functions between *a* and *b* in set *X* equals the functions between *s* and *r* in set Y:

Y:(f(a)=b)=(f(r)=s);(f(b)=a)=(f(s)=r)

All the morphisms between *X* and *Y* are homomorphisms—structure-preserving mappings between two algebraic structures of the same type.

Let's draw the map again, but this time, we only connect to the vertices in *y*, not the edges:



[Figure 4] *FF* Graph → Set.

Because in *Y* there are no longer any edges, only points, the map from *X* to *Y* shows the loss of structure between two algebraic structures. They are no longer of the same type but two different categories—the category of graphs and the category of sets.

Now that we have seen how some structures get lost when we send graphs to set theory—we have achieved writing a forgetful functor because there is a loss of structure between the two categories:

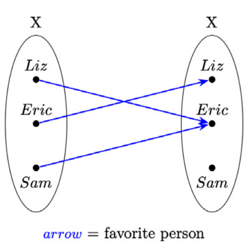
FF Graph → Set

A forgetful functor (*FF*) typically goes from a category with more structure to a category with less structure and seems to be quite common for mathematicians who work across different languages: there are forgetful functors when going from group to set, from ring to set, or from topological group to topology. In each case, one works with the same underlying set or object, but the larger category has additional operations or axioms.

Logicians and mathematicians were not the only ones interested in functors. The morphisms of category theory also caught the attention of Claude Lévi-Strauss in his struggle to formalize the structures of myths. Category theory seemed promising to structural anthropology since a morphism can write the relations between structures without any indication of their functional or logical nature. Category theory promised an avenue for "social mathematics" that would allow the formalization of group structures beyond those of family and kinship:

> Mathematicians have drawn my attention to the fact that a recent development of their subject, known as category theory, might make it possible to treat myths by means of the same methods as are applied to kinship data. … The definition of categories as systems formed both by a set of terms and by the set of relations between these terms, corresponds closely to that which can be given of myth, and the concept of morphism, which expresses nothing more than the existence of a relation between two terms without any indication of its logical nature, seems to overcome the same kind of dilemma as was solved for me twenty-five years ago when, after I had been told by a famous mathematician of the old school that he could not help me to clarify kinship problems because he was acquainted only with addition, subtraction, multiplication and division, and marriage could not be likened to any of these operations, a young mathematician to whom I have already referred by name, assured me that it was a matter of indifference to him to know what marriage might be, mathematically speaking, provided it were possible to define the relation between the different types of marriage. (Lévi-Strauss 1981, 635–36)

Unlike the structures of kinship—where the son cannot be the father of his father and the father cannot be the son of his son—social relations in life, literature, or mythology don't have such causal restrictions, which makes it difficult to formulate social relations in terms of propositional logic or first-order predicate logic—what is often called "classical logic"—or set theory. However, even complicated love triangles can be written in category theory:



[Figure 5] The structure of a menage a trois in category theory after Lawvere and Schanuel (Lawvere and Schanuel 2009, 13), where *g* expresses the function "favorite person."

Starting in the 1950s, Lévi-Strauss, Lacan, and others learned not only game theory but also "structures" or category theory from the mathematician Georges-Théodule Guilbaud (Roudinesco 1997, 363). Lacan, after being introduced to Freud's early work *Entwurf einer Psychologie (Project of a Scientific Psychology*) and its neuron model, began working with functors between signifiers and bodies and between different discourses such as the hysteric, the master, the university, and psychoanalysis.

The following section will trace the functor that sends psychoanalysis to neurocognition, starting with Freud's neuron model and how neurocognitive science made use of it by forgetting most of its structure before commenting on Lacan's intervention, and how media theory made use of Lacanian psychoanalysis by forgetting almost all of its structure.

Freud's Neuron Model

Over the period of only a few weeks in 1895, Freud drafted his *Entwurf,* including a neuron model as the scientific and physiological basis of the "psychic apparatus"; however, since he couldn't make his "neuron circuit" work, he refrained from sharing it with the public. It was rediscovered and published in 1950, a decade after his death (Freud 1987 [1895, 1950]). "Scientific" psychology remained a *Project* or *Entwurf* for Freud. Nevertheless, his early neuron model features prominently in the history of neurocognitive science as the first sophisticated model of neurology that was able to explain how perception and memory can be understood simultaneously as material processes in nerve tissue and as symbolic, cognizant operations in psychic reality and consciousness. For some neurocognitive scientists, Freud's neuron model was the first attempt to scientifically conceptualize the relationship between the biological brain and consciousness beyond purely philosophical reasoning. However, the supposed "biological standpoint" of the early Freud should be handled with care, not only because he distanced himself quickly from it. I argue that Freud's neuron model serves to show why neurocognitive science necessarily forgets the operations and mediations it is based on when it becomes computational. Freud's model introduces a difference between structure and model, something that computational models necessarily forget. Reading Freud's *Entwurf* against the backdrop of neurocognitive science informs a media theory of forgetful functors that recognizes the limits of the computational model.

Freud assumed that nerve tissue capable of storing or memorizing perceptions must possess plasticity—it must be able to change its internal organization. This was the only logical explanation for the brain's ability to retain memories. Making use of the term "neuron," coined in 1891 by Heinrich Wilhelm Waldeyer for discrete units or cells of the nerve tissue, his model aimed at bridging the gap between perception and consciousness by framing the transformation of perceptions into memories as transcription processes rather than representations of the exterior world: the psychic apparatus transforms the physical continuum of the external world into discontinuous stimuli that pass between neurons, limiting the transmission of perception in both quantity and quality (Freud 1987 [1895, 1950], 398). Though the stimuli must be inscribed in the nerve tissue to enter memory and psychic reality, what reaches consciousness through this apparatus is never just a representation of the exterior world. Rather, what is consciously perceived depends on which physical pathways between neurons are "inhibited." There is no general or immediate transmission between perception and consciousness, but a complex system of pathways and barriers that lets quantities between different neurons either pass more or less or not at all.

If an ego exists, Freud reasons in the *Entwurf* (1987 [1895, 1950], 408), it must be able to inhibit, i.e., forget, primary psychic processes. This is an important detail because it underlines that even the so-called biological viewpoint of Freud's early *Entwurf* conforms to the necessities of the ego and not the other way around.

To make his neuron model work, Freud invented different types of neurons: *Phi,* or perception neurons, are projected as permeable to external stimuli, while *Psi,* or memory neurons, must be impermeable. External stimuli exist as a continuum in terms of quantity and temporality, which the apparatus must discretize into discontinuous impulses for further processing. Drawing on Gustav Fechner's experimental psychology, Freud (1987 [1895, 1950], 399) describes perception as the transcription of continuous stimuli into discontinuous impulses, enabling the psychic apparatus to filter out certain periodic inputs.

Not unlike psychophysics, Freud's psychoanalysis was deeply influenced by the technological milieu of his era, particularly the instruments and apparatuses that the young medical student in Vienna encountered daily in the physiological laboratory: telephones, telegraphs, telescopes, microscopes, dynamometers, electrotherapy devices, etc. Unlike Fechner, however, Freud's reasoning is structural and media theoretical rather than morphological and anatomical. He does not base his argument on histological evidence. Friedrich Kittler (1990, 279) called out this "lack of anatomical localization."

In 1896, a couple of years after drafting the *Entwurf*, Freud (1950, 185–86) wrote a letter to his friend and physiologist Wilhelm Fliess, in which he outlined a new model of the psychic apparatus, now containing three types of *Niederschriften* (inscriptions) that produce a radical *Umschrift* (transcription) between the two ends of the psychic apparatus—perception and consciousness:

> Perception—Perception
> Sign—Unconscious—Preconscious—Consciousness

Signs are passed back and forth between the three inscription perception signs, the unconscious, and preconsciousness. By the time they become conscious, the perception itself is necessarily and completely forgotten or “repressed” to become conscious. The transcription frees perception signs from all sensory qualities, a change of category or forgetful functor from perception to perception sign, as well as homomorphisms since perception signs are *wiedererinnert* (re-remembered) when becoming conscious.

In a footnote from 1925, Freud (1982, 516, FN 1) adds that consciousness arises through this “re-remembering” or repetition as a sign and no longer as a physical trace. The different inscriptions of the psychic apparatus function like morphisms that preserve and lose structure.

By 1900, in *The Interpretation of Dreams*, Freud categorically rejected the neuroscientific standpoint and referred all psychophysical or anatomical representations (*Vorstellungen*) of the psychic apparatus back to the ideal localities found in optical media technologies such as telescopes and microscopes—crucial scientific media of his time:

> I shall entirely disregard the fact that the mental apparatus with which we are here concerned is also known to us in the form of an anatomical preparation, and I shall carefully avoid the temptation to determine psychical locality in any anatomical fashion. I shall remain upon psychological ground, and I propose simply to follow the suggestion that we should picture the instrument that carries out our mental functions as resembling a compound microscope or a photographic apparatus, or something of the kind. On that basis, psychical locality will correspond to a point inside the apparatus at which one of the preliminary stages of an image comes into being. In the microscope and telescope, as we know, these occur in part at ideal points, regions in which no tangible component of the apparatus is situated. (Freud 1999, 536)

Freud’s neuron model and its “ideal localities” were necessary logical fictions—hypotheses that, while possibly false, were essential for explaining the nervous system’s ability to regulate external stimuli and internal memory through unconscious processing. In Kantian categories, Freud constructed his model as a type of *synthetic a priori* judgment—a necessary but hypothetical structure that bridged the external world with unconscious processes (Vagt 2025).

By 1925, Freud (re)remembered the forgetful functor between perception trace and perception sign once again as a media technology: in “Notiz über den ‘Wunderblock’” (Note on the “Mystic Writing Pad”), he compares the psychic apparatus to a magic writing pad that combined the permanence of paper with the volatility of a blackboard. This device, consisting of a wax block, wax paper, celluloid film, and stylus, demonstrated how the psychic apparatus balances receptivity to new perceptions with the necessity of memory (Freud 1948, 4). Freud emphasizes the celluloid film's role as a protective barrier (*Reizschutz*), a cut that enables unconscious operations between perception and consciousness. The discontinuity inherent in the systems of the psychic apparatus, he speculated, forms the foundation of memory and our sense of time. He had already mentioned such a barrier in *Beyond the Pleasure Principle*, where he compares it with the membrane of a blister, a semi-permeable surface barrier that mediates between exterior stimuli and interior sensations of pleasure and displeasure (Freud 1967, 23). Barriers or cuts between inside and outside, interiority and exteriority, are necessary for transcriptions. The "mystic writing pad" was a writing machine that could demonstrate the *structure* of the psychic apparatus, as Derrida notes (Derrida and Mehlman 1972, 75, my emphasis).

Lacan later interpreted Freud's neuron model of the *Entwurf* as an energetic, internally regulated system that moderates the external influx of energy. He points out that while Freud explicitly employs the Fechnerian notion of inertia, he not only surpassed Fechner's psychophysics by anticipating modern physiological principles such as "homeostasis" (Lacan 1980, 60) but also the cybernetic version of homeostatic behavior of the 20th century, displayed in Grey Walter's robotic tortoises that roamed laboratories (and maybe dreams) in the 1950s (Lacan 1988, 54). In his second seminar, Lacan taught Freud's theory of *Wiederholungszwang* or "compulsion to repeat" (61) as "repetition automatism," almost like it was displayed in the new symbol processing machines called "computers."

Freud's Neuron Model in Neurocognitive Science

By the mid-20th century, Freud's neuron model was (re-)remembered in the form of artificial neural networks in cybernetics and neurocognitive science, which fundamentally diverged from psychoanalysis' insistence that the psychic apparatus is a transcription machine in which some things necessarily repeat while others are necessarily forgotten, or better, repressed, in order to "compute" or "repeat." Instead, the cybernetic models of cognition, driven by communication engineering and mathematical logic, supposedly eliminated Freud's cut between perception and consciousness. They did not attempt to account for the unconscious and the intricate dynamics of transcription central to Freud's framework. Instead, scientific psychology was finally realized by taking the brain as a computational machine and by aligning biological processes with external technological systems. Furthermore, the neural network models that would inform 20th-century neurocognitive science and artificial intelligence (AI) were shaped by sociopolitical anxieties about race and biology, as Théo Lepage-Richer (2024, 24) argues.

Freud's unconscious has been celebrated by the historians of neurocognitive science as an epistemological obstacle that had to be "overcome" (either expulsed or neurocognitively retrofitted) before a truly scientific psychology in the form of neurocognitive science could arrive. For the most part, science and historians do not speak about what was being lost, displaced, forgotten, or foreclosed in the synthesis of neuron model and computer logic, and maybe with good reason if what allowed neurocognitive science to emerge in the first place was the loss of structure, a forgetful functor.

From a critical media theoretical point of view, it seems the cybernetic models of brains and cognition that supposedly overcame the unconscious of psychoanalysis had and have to work hard—repetitively—to repress the fact that their models are less empirically grounded within the human brain or body than externally constructed using mathematical logic and the new stochastic technologies embedded in computational hardware and software. They were modeled according to theories of computation and data analysis, not cognition. What Warren McCulloch famously termed the "physiological" *synthetic a priori* of neural networks was not located within the brain, head, or any part of the physical body but belonged to the logic of computation and information engineering that developed quickly during and after the Second World War (Vagt 2025).

What was effectively forgotten by these models were theories of subjects, reason, and mind that did not adhere to the new media technological standards introduced to psychology and neurology by cybernetics, such as the intuitions of Gestalt theory or the unconscious of psychoanalysis. Wolfgang Köhler strongly opposed mechanical models of perception and tried to promote Gestalt theory as an alternative to machine theory, but since it didn't permit the calculation of messages, coding, stored programs, and feedback loops, McCulloch wasn't interested in it (Heims 1991, 235–36). Gestalt theories could not be engineered (Geulen et al. 2022, 129).

Freud's unconscious also kept repeating under computational conditions and despite the despise it met from the cyberneticists. After reading Freud's *Entwurf*, neuroscientist Karl Pribram (1962, 462) reclaimed Freud's neuron model as "the Rosetta stone for any psychobiological science" to come. The fact that Freud abandoned his "detailed neurological model, which is, by today's standards, sophisticated" is deemed unfortunate but understandable, considering the difficulties in reconciling the behavioral and neurological levels available at the end of the 19th century, according to Pribram (1962, 443).

From a critical media theoretical point of view, Pribram's retrofitting of Freud's early neuron model into a modern neurocognitive framework poses a striking demonstration of how psychoanalysis' discovery of the unconscious was transcribed and utilized within the formation and development of neurocognitive science. As mentioned above, Freud conceptualized the psychic apparatus under the impression of new instruments and machines. His libido theory was informed by thermodynamics and its new notion of energy, and yet, his psychic apparatus was far more complex than a steam engine because it worked with memory and signs. He employed the principle of homeostasis under the term "inertia," as Pribram (1962, 444) notes while overlooking that Freud's psychic apparatus was much more than a homeostat, as it displayed homeostasis not as biochemical balancing but as a complex organizational transcription process afforded by a strict division of labor and language operations. Pribram (1962, 446) reduces Freud's "contact barriers" (*Reizschutz*) to the function of "synapses," resembling modern neuroscience's stance "that organisms do not behave as if all paths were equally likely—they are motivated, their behavior is directed, often on the basis of prior experience."

Freud did not only utilize machines, instruments, and communication technologies of his time, such as steam engines, microscopes, telegraphs, and celluloid film but also the management and calculus of signs and data technologies they produced around 1900, as Mai Wegener (2004, 109) shows in her detailed study of Freud's *Entwurf*. This allowed for its transcription into the category of neurocognitive science: Pribram (1962, 461) not only short-circuited Freud's early neuron model but also his later theory of the unconscious with data analysis: Today, "data relevant to the study of the thought process are no longer limited to verbal reports of introspections made during problem-solving behavior—all sorts of neurological and behavioral responses are admitted as evidence."

For Pribram (1962, 461–62), the unconscious that Freud found at work in the negations, lapses, and jokes of his patients and in his own dreams was nothing but statistical pattern recognition, nothing but "behavioral data analysis" of findings obtained through "verbal reports" in the "psychoanalytic laboratory." As Pribram concludes from a conversation with psychiatrist Ken Colby and computer scientist Alan Newell in the late 1990s, Freud's abandoned neuron model served neurocognitive science well once it had been transcribed into a functional neural network that could be modeled by a computer. "[E]ither psychoanalysis as Freud proposed in the *Project* and psychotherapy are indeed both 'scientific' procedures or else computer programming as used in developing chess strategies *fails* to be 'scientific'" (Pribram 1998, 15).

While behaviorism, cybernetics, and computer engineering all fed into neurocognitive science during the 20th century, following Pribram's account, one has to admit that it was indeed the retrofitting of Freud's unconscious—the forgetful functor that sends psychoanalysis to neurocognitive science—that made computer programming a legitimate scientific strategy and afforded the tightening of the coupling between brain and computer. However, the story is not over yet, and the structure of the unconscious did not disappear with the advent of neurocognitive science. Quite the contrary, since the limits of formalization now appear clearer than ever before in terms of formal languages, pattern recognition, and theories of computability.

Language, Cognition, and the Uncomputable

Over the course of the 20th century, the question of whether a model adequately represents biological neural processes that happen within brains became less and less important (Schmidt-Brücken 2012, 184). What mattered was that neurocognitive behavior was computable, even though the theory of computability created new issues as Alan Turing (1937, 259) himself, following Kurt Gödel's theorems on decidability and undecidability, proved that Hilbert's *Entscheidungsproblem* has no solution. Reflecting on the theory of computability, Margaret Boden (2006, 179) poses that according to Turing some "thoughts," such as the truth of an assertion, or intuitions, remain *un*-computable. Nevertheless, she insists on the coupling of cognition and computation because not only was neurocognitive science informed and driven by computational concepts, but the theory of computation as such was extended by its various applications within the science of the mind.

Boden's work is well aligned with Howard Gardner's (1985, 119) early historical assessment that the rise of cognitive science was a complex matter of *Zeitgeist* but that "it took the advent of computers and the rise of information theory to grant legitimacy to cognitive studies." Boden argues that today's cognitive science works with different concepts of "computation," roughly sorted into two main strands: computer science (AI and software engineering) on the one hand and cybernetics (information theory and control engineering) on the other, and one of them still lacks a rigorous definition: "'Computation' is often understood as Alan Turing defined it. Indeed, his definition remains the only rigorous one. And it *doesn't* cover cybernetics, nor even connectionist AI" (Boden 2006, 13).

Since computation (unlike computability) is not well defined, and cognition depends on whatever computer science understands as computation, cognitive science encounters a hermeneutic problem:

> We don't yet know what computation—understood intuitively as what computers do—is. In particular, we can't assume without question that it's utterly distinct from intentionality. It follows—if the mind is a computational machine—that we don't yet know what the mind is, either. (Boden 2006, 1428)

This vicious circle of Boden's computational and data-driven approach to cognition encountered little criticism within the field, and her historical and conceptual reasoning for the tight coupling of cognition and computation is widely cited as an extensive and valid metatheoretical framework for cognitive science. A notable exception from this positive reception is Noam Chomsky, whose cognitive linguistic theories Boden opposes.

Chomsky (2007, 1101) published a scathing book review of *Mind as Machine*, criticizing Boden for not understanding the basic concepts of linguistics, such as language competency and performance. He insists that languages such as English cannot be fully generated or captured by any of the currently known computational models, including the recent large language models (Chomsky, Roberts, and Watumull 2023). Early in his work on formal language theories (1950s–1960s), he combined computability theory and mathematical linguistics to clarify what it means for a grammar or a function to be "computable" in the formal sense of enumerable recursive. By constructing and categorizing formal languages by degrees of computability, Chomsky mathematically proved the difference between a language like English and primitive-recursive functions or formal grammars that can be computationally generated. Finite-state grammars or Markov graphs featured prominently in Shannon and Weaver's mathematical theory of information, Chomsky's linguistics, and Lacan's *Seminar on The Purloined Letter.* They are unable to capture the hierarchical structures and recursive embeddings that characterize language competency such as English (Chomsky 1956, 115).

From the theoretical perspective of linguistics and natural language processing, it is therefore questionable how neurocognitive science can maintain the assumption that models of cognition capable of language production are rooted in computability rather than in representations (*Vorstellungen*)—such as certain concepts or intuitions about neurocognitive behavior. Consequently, the faculty of language presents a significant challenge for neurocognitive science, as Chomsky mathematically and linguistically proved that languages such as English entail functions (or sentences) that are uncomputable, i.e., "not Turing computable."

Historically, the alignment of computational models with cognitive behavior served as the conceptual entry point for the emergence of a scientific psychology—what later became known as neurocognitive science. This tight coupling of computer and mind, forged in the wake of cybernetics, was presented as a seamless integration. Yet, as critiques by Chomsky, Lepage-Richer, and others note, this integration was less a natural synthesis than a necessary logical fiction—an epistemic operation that enabled the field's legitimacy by strategically overlooking the incompatibility between computation and certain cognitive performances, especially language. If language remains an essential dimension of cognition—as formal linguistics and generative grammar argue—it exposes this coupling as flawed.

From the perspective of category theory, this epistemological maneuver can be understood as a forgetful functor: a formal operation that enables translation between domains by intentionally discarding structure. Neurocognitive science, in adopting computation as its meta-language, "forgets" the linguistic and symbolic complexity of cognition in oder to model it. Consequently, it must choose between two untenable paths: either redefining cognition as "thought without language"—as recent proposals in *Nature* suggest—or forcibly rendering language more computationally tractable (Fedorenko, Piantadosi, and Gibson 2024). Both paths betray the field's foundation, a loss that the forgetful functor both performs and exposes.

Forgetful Functor: Psychoanalysis → Media Theory

The same structural forgetting—this formalized loss of epistemic complexity—also characterizes the way psychoanalysis was transcribed into media theory. Twenty years after Pribram reclaimed Freud's unconscious for neurocognitive science, Friedrich Kittler enacted a media-theoretical translation that mapped the psychic apparatus onto digital machines, effectively sending psychoanalysis to the category of computation. Here too, the forgetful functor operates: preserving structural analogies while discarding the symbolic excess and linguistic opacity that had defined psychoanalysis. What remains is a symbolic logic flattened into circuitry—equating Freud's psychic apparatus with his personal computer by mapping the Phi and Psy neurons of the *Project* onto RAM (random access memory) and ROM (read-only memory) units, separating storage and transmission. Commenting on Lacan's article *The Purloined Letter* and his second seminar, *The Ego in the theory of Freud and in the technique of psychoanalysis*, Kittler first puts Lacan's mathematized psychoanalysis on a pedestal for being "the only science which can conceive of, or rather formalize, the imaginary," only to then declare the obsolescence of all hermeneuticians and psychoanalysts in the age of symbolic machines (Kittler 1997, 137, 145).

Where Pribram short-circuited Freud's unconscious with behavioral data analysis, Kittler identified Lacan's register of the symbolic with the digital order of computational mathematics. Both neurocognitive science and technology-oriented media theory welcomed the computer and its transcriptions of data and signs as their behavioral-technological *a priori*.

There has been ample criticism within the field of media theory regarding Kittler's version of "psychoanalysis under high-tech conditions," sometimes with direct references to Lacan's mathematical constructions, such as the graphs and nets in his *Seminar on the Purloined Letter*. However, neither media theorists nor psychoanalysts seem to be sure what to do with these, emphasizing their lack of formality and suggesting that Lacan was more interested in the didactics and aesthetics of symbolic machines than their formalization (Wegener 2004, 42; Schmidgen 1997, 105).

I would like to suggest an alternative theory regarding the non-formal formalisms that Lacan derived from Freud's (re)remembering of the neuron circuit in *Letter 52*: one that doesn't idolize them or reduce them to metaphors or surrealist aesthetics. The formal languages composed of nets, graphs, chains, and parentheses one finds in the *Seminar on the Purloined Letter* can be worked with in a much simpler sense as symbolic operations or writing techniques that demonstrate how structures appear and disappear within syntax, chains, and hierarchies of symbolic operations and transcriptions—forgetful functors. Lacan presents cybernetics and its models as a critical lens for the work of science:

> Cybernetics is a science of syntax, and it is in a good position to help us perceive that the exact sciences do nothing other than tie the real to a syntax. (Lacan 1988, 305)

If media theory wants to address the real of a discourse such as neurocognitive science critically, rather than just critique the succession of its historic *a priori*, necessary logical fictions, or imaginations and representations, it must somehow engage with the necessary laws of scientific discourse. Only then can it write what is being presented as "impossible" by means of formal languages such as logic and mathematics; only then can it write the real as a forgetful functor between the categories of that discourse. This would, of course, move media theory closer to psychoanalysis than technologically applied data or neuroscience, but not further away from the real of neurocognitive science: when formal languages are coupled or "networked" into functions of object- and meta-languages so that one can decide or calculate the validity of the other, one sees structures repeat or disappear solely through writing techniques, without any necessity of *a priori* networks engrained in bodies, brains, or biology that would determine one's capabilities or choices. The "unconscious that is structured like a language" doesn't have to be something uncanny, mysterious, or vitalistic if it is being symbolized as what challenges the syntax it is built on.

If the Freudian unconscious, in contrast to what has been claimed by neurocognitive science as well as within the field of media theory, is not simply the pre-, "non-," or "more-or-less conscious," but a "language-structuring unconscious," as Annette Bitsch (2009, 106, my translation) phrased it, it must be found not only in the transformations of objects between different categories but also in ordinary language processes that afford the distinction between “a saying” and “what is being said” (Lacan 1999, 100). The structuralist distinction between the “content” of an utterance and the “act” of the speaker undercuts any computational linguistic framework based on the duality between object language and metalanguage, between a theoretical discourse (metalanguage) and the speech it analyzes (object language); just as the subject who speaks is never fully identical with the statements they utter. This proposed gap doesn’t get rid of the distinction between a saying and what is being said, but it poses an absolute limit to the computability of language. Expressed in computability terms, every metalanguage ultimately encounters its point of impossibility (Carrive 2012). When languages are stacked, they always show partial or enumerable recursivity (in Chomsky’s nomenclature) because they necessarily require that something is lost in the process of enunciation itself and that the sentences are contingent while the structure of symbolization is not. Once more, I follow Lacan, who posed that an analysis composed of linguistics, logic, and topology/mathematics would present an opportunity for the renewal of the sciences in university mode. When science adheres to mathematical logic, it adheres to the “science of the real” (Lacan 2001, 314). However, this “real can only be inscribed on the basis of an impasse of formalization” (Lacan 1999, 93). Compared to Pribram and Boden’s data-driven empiricism, Chomsky’s nativist rationalism, and Kittler’s “successful paranoia” (Schmidgen 2019), Lacan offers a fourth position, where the structure of language and syntax precedes and shapes the statements, identifications, and realities of egos, and yet does not determine them. In contrast, the statements of a machine, sensical or non-nonsensical, will always be determined by its meta-language.

Here, I have only demonstrated structurally how the real can be written in category theory as a forgetful functor and, historically, how the same structure repeats within the histories of neurocognitive science and media theory. With more time and diligence, the real of neurocognitive science may be written as a neuron logic of the subject of signification, one that wouldn’t compute in terms of Boolean algebra or Markov graphs, that would not run on a von Neumann machine or be captured by the statistical approximations of large language models. A neuron logic that would construct the structure of a subject divided by language instead of constituting “a new, albeit yet-to-be-seen structure that reinscribed within the brain assumed differences in intellectual potential between Europeans and the populations native to their colonies” (Dhaliwal, Lepage-Richer, and Suchman 2024, 20–21).

This might be a fantasy since the writing of such a logic requires not only some instruction in the histories of science, philosophy, technology, mathematical logic, structural linguistics, and several mathematical languages such as geometry and topology, graph, group, and category theory—it also requires social groups with such a combination of formal and non-formal writing skills that is difficult to achieve in today's higher education. However, I call it a necessary fantasy because, without it, media theory will be left to either fetishize the machine models or withdraw into a phobic position that avoids all confrontations with the real of science.

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References

Ajdukiewicz, Kazimierz. 1977. *The Scientific World-Perspective and Other Essays, 1931–1963*. Edited by Jerzy Giedymin. Dordrecht: Springer Netherlands.

Baez, John C., and Michael Shulman. 2006. "Lectures on N-Categories and Cohomology." https://arxiv.org/abs/math/0608420.

Bitsch, Annette. 2009. *Diskrete Gespenster: die Genealogie des Unbewussten aus der Medientheorie und Philosophie der Zeit*. Bielefeld: transcript.

Boden, Margaret A. 2006. *Mind as Machine: A History of Cognitive Science*. Oxford and New York: Clarendon Press and Oxford University Press.

Carnap, Rudolf. 1968 [1934]. *Logische Syntax der Sprache*. Berlin, Heidelberg: Springer.

Carrive, Laurent. 2012. "Lacan : la psychanalyse, la mathématique et l'impossible." *Essaim* 28, no. 1: 113–21.

Chomsky, Noam. 1956. "Three Models for the Description of Language." *IRE Transactions on Information Theory* 2, no. 3: 113–24.

———. 2007. "Book Review: Symposium on Margaret Boden, Mind as Machine: A History of Cognitive Science, Oxford, 2006, Two Volumes." *Artificial Intelligence* 171, no. 18: 1094–103.

Chomsky, Noam, Ian Roberts, and Jeffrey Watumull. 2023. "The False Promise of ChatGPT." *New York Times*, March 3, 2023. https://www.nytimes.com/2023/03/08/opinion/noam-chomsky-chatgpt-ai.html.

Derrida, Jacques, and Jeffrey Mehlman. 1972. "Freud and the Scene of Writing." *Yale French Studies*, no. 48: 74–117.

Dhaliwal, Ranjodh Singh, Théo Lepage-Richer, and Lucille Alice Suchman. 2024. *Neural Networks*. Minneapolis and Lüneburg: University of Minnesota Press and meson press.

Fedorenko, Evelina, Steven T. Piantadosi, and Edward A. F. Gibson. 2024. "Language Is Primarily a Tool for Communication Rather than Thought." *Nature* 630, no. 8017: 575–86.

Freud, Sigmund. 1948. "Notiz Über Den Wunderblock." In *Gesammelte Werke*: *Vierzehnter Band*, edited by Anna Freud, E. Bibring, W. Hoffer, E. Kris, and O. Isakower, 1–8. London: Imago Publishing.

———. 1950. *Aus den Anfängen der Psychoanalyse, Briefe an Wilhelm Fliess, Abhandlungen und Notizen aus den Jahren 1887–1902*. London: Imago Publishing.

———. 1967. "Jenseits Des Lustprinzips." In *Gesammelte Werke*: *Band 13, 1–70*. Frankfurt am Main: Fischer.

———. 1982. *Die Traumdeutung*, edited by Alexander Mitscherlich. Vol. 2. Studienausgabe 7302. Frankfurt am Main: Fischer.

———. 1987 [1895, 1950]. "Entwurf einer Psychologie." In *Gesammelte Werke: Nachtragsband*, edited by Angela Richards, 387–477. Frankfurt am Main: Fischer.

———. 1953. *The Interpretation of Dreams*, translated and edited by James Strachey. [The Standard Edition of the Complete Psychological Works of Sigmund Freud, Volume 4 (1900): The Interpretation of Dreams (First Part)]. London: Hogarth Press.

Gardner, Martin. 1985. *The Mind's New Science: A History of the Cognitive Revolution*. New York: Basics Books.

Geulen, Eva, Claude Haas, Diba Shokri, and Hannes Bajohr. 2022. "Gestalt." In *Formen des Ganzen*, edited by Eva Geulen and Claude Haas, 103–37. Göttingen: Wallstein.

Heims, Steve Joshua. 1991. *The Cybernetics Group*. Cambridge, MA: MIT Press.

Kittler, Friedrich A. 1990. *Discourse Networks 1800/1900*. Translated by Michael Metteer. Stanford: Stanford University Press.

———. 1997. "The World of the Symbolic—a World of the Machine." In *Literature, Media, Information Systems*, edited by John Johnston, 130–46. Amsterdam: G+B Arts International.

Kotarbiński, Tadeusz. 1966. *Gnosiology. The Scientific Approach to the Theory of Knowledge*, transl. by Olgierd Wojtasiewicz, Oxford et al.: Pergamon Press.

Lacan, Jacques. 1980. *Das Ich in der Theorie Freuds und in der Technik der Psychoanalyse: Das Seminar von Jacques Lacan, Buch 2.* Olten/Freiburg im Breisgau: Walter.

———. 1988. *The Ego in Freud's Theory and in the Technique of Psychoanalysis*: *The Seminar of Jacques Lacan, Book II*. New York/London: Norton and Company.

———. 1999. *Encore: On Feminine Sexuality, the Limits of Love and Knowledge*: *The Seminar of Jacques Lacan, Book XX.* New York/London: Norton and Company.

———. 2001. *Autres écrits* : *Le champ freudien*. Paris: Editions du Seuil.

Lawvere, F. William, and Stephen H. Schanuel. 2009. *Conceptual Mathematics*. Cambridge: Cambridge University Press.

Lepage-Richer, Théo. 2024. "Neural Media." In *Neural Networks,* edited by Ranjodh Singh Dhaliwal, Théo Lepage-Richer, and Lucille Alice Suchman, 15–32. Minneapolis/Lüneburg: University of Minnesota Press and meson press.

Lévi-Strauss, Claude. 1981. *The Naked Man*. New York: Harper & Row.

Mac Lane, Saunders. 1971. *Categories for the Working Mathematician*. New York: Springer.

Pribram, Karl H. 1962. "The Neuropsychology of Sigmund Freud." In *Experimental Foundations of Clinical Psychology*, edited by Arthur Bachrach, 442–68. New York: Basic Books.

———. 1998. "A Century of Progress?" *Annals of the New York Academy of Sciences*, 843: 11–19.

Roudinesco, Elisabeth. 1997. *Jacques Lacan*. New York: Columbia University Press.

Schmidgen, Henning. 1997. *Das Unbewußte der Maschinen: Konzeptionen des Psychischen bei Guattari, Deleuze und Lacan*. München: Fink.

———. 2019. "Successful Paranoia: Friedrich Kittler, Lacanian Psychoanalysis, and the History of Science." *Theory, Culture & Society* 36, no. 1: 107–31.

Schmidt-Brücken, Katharina. 2012. *Hirnzirkel: Kreisende Prozesse in Computer und Gehirn: Zur neurokybernetischen Vorgeschichte der Informatik*. Bielefeld: transcript.

Siegert, Bernhard. 2024. *Final Frontiers: Eine Medienarchäologie des Meeres*. Paderborn: Brill/Fink.

Turing, Alan M. 1937. "On Computable Numbers, with an Application to the Entscheidungsproblem." *Proceedings of the London Mathematical Society* 42, no. 1: 230–65.

Vagt, Christina. 2025. "Catastrophic Forgetting: Why the Mind Is Not in the Head." In *Thinking with AI: Machine Learning the Humanities*, edited by Hannes Bajohr, 230–46. London: Open Humanities Press.

Wegener, Mai. 2004. *Neuronen und Neurosen: Der psychische Apparat bei Freud und Lacan. Ein historisch-theoretischer Versuch zu Freuds Entwurf von 1895*. München: Fink.

ARTIFICIAL INTELLIGENCE

FINANCE

ARBITRAGE

PARALLEL COMPUTING

MEDIA THEORY

CULTURAL TECHNIQUES

[8]

Linguistic Arbitrage: AI and the Financialization of Language

Jeffrey West Kirkwood

This text argues that the underlying logic of generative artificial intelligence (AI) is financial in nature. Through an exploration of the parallel processing technologies essential to AI systems, it contends that large language models rely on a form of arbitrage that generates and exploits symbolic differences.

In a 1683 preface and address to the “Merchants in Edinburgh, and All Other Lovers of This Profitable Science,” the Scottish pioneer in the field of accounting, Robert Colinson (1683), announced his adoration for the “Art of *Book-keeping*,” calling it the “very Scale of Commerce.” As himself a lover of the profitable science, his encomium continued by describing the spiritual core of what might seem a profane, or at best banal, practice of record keeping:

> as in ordinary weyghing of any goods, or commodities, the weyghts being laid in the one Scale, these goods are still heapt in the other, until both meet in a parallel line; by equal Counterpoize; so in *Book-keeping*, the Debet page or charge may be esteemed the weyghts; and that of the Credite, the goods laid in the other, still augmented by Articles of discharge, until both pages, are equall in the Capitals, and so are summ’d up in a just and proportionate Balance of accompt; and the *Debitor* and the *Creditor* in the subject matter made equal Poize. (Colinson 1683, **2)

Colinson's enthusiasm for the philosophical vitality of an admittedly dreary vocation of financial record-keeping was not entirely unjustified. The simple ledger technique of dividing a single transaction into two separate entries noted in two separate columns—one for debit and the other for credit—constituted a cardinal form of orientation for a vast terrain of complicated instruments that would characterize the triumph of capitalism in the coming centuries. That the two values, while noted in parallel, did not always "meet in a parallel line," as the analogy of the scale would suggest, was a beginning of financialization. The ability of lenders to keep the flow of capital moving to columns that could not be immediately matched on the debtor side was a rudimentary form of a Western system that would eventually thrive on issuing, packaging, re-packaging, and selling debt; a process that would reconfigure a world of real goods through the arrangement of symbols.

As the oft-cited, oft-disputed passage from Werner Sombart's massive, multivolume book, *Der moderne Kapitalismus,* had it, this method of parallelization, called double-entry bookkeeping, which took definite shape in the 14th and 15th centuries, was the lifeblood of capitalism:

> One simply cannot think of capitalism without double-entry bookkeeping: they relate to one another as form and content. And one can be in doubt about whether capitalism created double-entry bookkeeping as a tool to exert its power, or whether double-entry bookkeeping first gave birth to capitalism from its spirit. Double-entry bookkeeping! (Sombart 1919, 118, my translation)[1]

For anyone in doubt, accounting clearly *can* be exciting. It could be argued, however, that this godhead form of bookkeeping from which capitalism supposedly emerged fully formed was a contingent practice that only seems inevitable after having distilled the principles of that content to its barest essence. The soul of this paper-based, material technique was actually in its division of a single event into parallel operations whose differences could be multiplied and exploited. To cleave a point of exchange into two distinct symbolic accounts propelled further divisions into non-equivalent values that constituted a basis for the likewise infinitely divisible notion of capital. As Martijn Konings (2018, 11–12) argues, "Value is not given before it is signified: the signification of value is performative rather than passively representational, driven by the aim to elicit the generation of the value that it

1 There is an entire subfield within the history of accounting that appraises, reappraises, or rejects Sombart's claim. For an overview of the major positions see Chiapello (2007). Perhaps the best-known opponent of Sombart's view was B. S. Yamey (1949), who wrote extensively about it. On the practice as a form of rationalization that draws primarily on Sombart, Max Weber, and the Italian 15th century architect of double-entry bookkeeping, Luca Pacioli, see Carruthers and Espeland (1991).

claims to represent—it involves 'prospecting for potential.'" This process, as he continues "forever works forward" (12).

Such a march forward was not facilitated exclusively through some contingent historical ledger-keeping method, but instead through a myriad forms of *parallelization*. It can be done just as well with microchips. The origins of early financial capitalism as well as its most contemporary, computational manifestations in high-frequency trading, sentiment analysis, and, more generally, the very architecture of AI, owe their successes to a regime of parallel processes. As a result, everything, even language itself, has become a potential domain of finance.

Singularities Plural

If there is a coming AI singularity (and there isn't) it will arrive via giant, minutely orchestrated arrays of parallel paths. For all of the supposed sequence and determinism attributed to computation, the processing speedup that led to its ubiquity was achieved through massive parallelization. In its simplest form, parallel processing can be described—against serial computing—as the division of a big problem into smaller, simultaneously computed problems. Yet the significance of this innovation in the approach to computing is immense.

Prior to Donald Trump's executive tantrum on AI, revoking "Joe Biden's" putatively "dangerous Executive Order that hinders AI innovation and imposes onerous and unnecessary government control over the development of AI," (The White House 2025) the Biden administration issued its own order on the "Safe, Secure, and Trustworthy Development and Use of Artificial Intelligence" (Executive Office of the President 2023; Office of the Federal Register 2025). Trump's order adopts his trademark hyperbole, America-first derangement, and the post-microdose megalomania of AI boosters, while Biden's embraced Silicon Valley eschatologists, elevating the coming chatbot to the level of a microchip Thanatos. Among other things, the Biden order enumerated a list of stirring nationalistic vagaries, offered a definition of "critical infrastructure" relying on a troubling invocation of the 2001 USA Patriot Act, and identified a litany of risks from nuclear weapons to the "misuse of synthetic nucleic acids" (Executive Office of the President 2023). As the outgoing US President Biden commented in his signatory speech, "AI is all around us" (Boak and O'Brien 2023). And no doubt, it is.

As this year's recent convulsion of American techno-nationalism unleashed by the public debut of Liang Wenfeng's China-based DeepSeek language model proved, all future aspirations and profits are bound to how well the world can be parallelized. The shockwave the company's R1 reasoning model sent through the markets stemmed from the fact that it was able to perform as well as industry-leading American firm OpenAI's o1 model, and the DeepSeek V3 non-reasoning model performed as well as OpenAI's GPT-4o (Mercer, Spillard, and Martin 2025; DeepSeek-AI et al. 2025). This feat was accomplished while allegedly only using American-made Nvidia H800 chips—two generations older than the most current Blackwell graphics processing units (GPUs)—and a cache of older Nvidia A100 GPUs that they acquired before US chip export restrictions went into effect (Mok 2025). Moreover, training the model cost 90% less and was twice as fast as its US counterpart (Mok 2025). The news sent Nvidia stock plunging 18% and erased $1 trillion of stock market value (Banerji, Fitch, and Langley 2025). But why?

The entire generative AI model frenzy depends on GPUs like the Nvidia Blackwell series chips, whose architecture was designed specifically for parallel computation. The arms race that has ensued, with Nvidia emerging (for now) as the leader, is one in which the development, improvement, and performance of large language models (LLMs) is directly tied to the parallelizability of the hardware. To achieve comparable results with lesser chips would challenge the escalating stakes of parallelization at work. Thankfully, following the upheaval in the market, cooler chips prevailed, recuperating much of the lost market value and restoring faith in the logic of total parallelization.

But what the stock market's doom and ecstasy, presidential calls to global AI domination, and prophesies of cataclysm in a singularity may obscure, with vast and innumerable domains condensed into a single monolithic concept, is the operations of difference-making, or even for the sake of nostalgia—*différance*—that are the engine of current computation. Particularly when examining the transformer architectures underlying those models that have prompted recent policy focus, one sees that, not only is difference-making at work, but difference making in parallel.

DeepSpeak

What is called "parallel processing" is by no means new. Already in the 1960s, graphics researchers relied on parallelism for visual pattern identification, as in the case of the Pattern Articulation Unit (PAU) of the Illiac III, or to offload heavy computation from the mainframe for basic visual displays (McCormick 1963). Single Instruction, Multiple Data (SIMD) machines that were the ancestral source for vector supercomputers like the Cray-1, later more familiar GPUs starting in the 1980s, and the Deep Neural Net Processors (DNNPs) that began appearing only in 2015, set the stage for a fundamental shift in how big computation was put to work processing almost everything (Kuhn and Padua 2021). Even prior to the wide availability of parallel processors, forerunners in the development of AI models such as W. Daniel Hillis (1992, 3) recognized that massive parallelization was key to making computers that were no longer "outmatched by us in the processes of symbolic thought." In this sense, if there is an inevitable procession toward the singularity, it will be based on a structured form of doubling.

This has been an especially powerful evolution for finance, which as an industry, can no longer be differentiated from its use of deep learning and LLMs. Just last year, another figure from the Biden administration, former Chairperson of the U.S. Securities and Exchange Commission Gary Gensler, warned of an "acute" potential for AI-initiated economic disaster (Harty and Overly 2024). "I would be quite surprised" he said, "if in the next 10 or 20 years a financial crisis happens and there wasn't somewhere in the mix some over-reliance on one single data set or single base model somewhere" (Harty and Overly 2024). In 2020, during his time as a professor at the Massachusetts Institute of Technology (MIT), Gensler suggested in a working paper with Lily Bailey that "many financial firms run their deep learning models in parallel with linear models as a proxy for explainability, a form of a buffer." There "may need to be," they continued, "consideration how best to prepare the system for the eventuality of a deep learning model failing due to a lack of explainability" (Gensler and Bailey 2020). If linear models offered "explainability," their parallelized, deep learning counterparts could be said to obey a purely financial logic. It just so happens that the latter is also a model governing the rest of the so-called singularity, and with it the contemporary realm of meaning-making.

Scrolling back to the middle of 2023, research papers argued that GPT-3 and later GPT-4 were able to elucidate the most boring imaginable area of human knowledge: the language of central banks (Hansen and Kazinnik 2023; Hookway 2020; Gómez-Cram and Grotteria 2022). The claim repeated in publications was that GPT-3 had been set to the task of clarifying the implied direction of Federal Reserve announcements with enough certainty that it could predict which way they would move markets. Unlike much of the hype related to ChatGPT, justified or otherwise, the news here was not about yet another encroachment into a sacred area of human creativity. Instead of generating beautiful sonnets, passing the bar exam, or even offering a 200-terabyte mathematical proof, the objective was to demystify a particularly arcane kind of language. And it did not aim to establish the meaning of the language in question outside of its translation into something immediately financially actionable. In a certain way, it literalized the "tokenization" that is a central process of LLMs, in which language inputs are broken into smaller units. This includes the byte pair encoding that forms a core background to GPT-3 and has remained instrumental for natural language processing since its initial introduction in a famous 1994 paper by Phil Gage. It is a method that merges the most commonly occurring pairs into tokens that can help LLMs manage words that are infrequently occurring.

Beyond an accident of terminology, linguistic tokens as they are used in machine learning capture the character of an imperfectly fungible currency. They establish an equivalence between non-identical terms whose relationship and therefore value is established through multiple layers of exchange—or "transformation" as the case is with GPTs (generative pre-trained transformers). And they encode a substitution that requires a small, but not wholly insubstantial, amount of computational work to accomplish.[2] What makes the case of Federal Reserve speech so interesting as a machine learning problem is that by design, neither the meaning of the language nor its effect on the markets can be established in advance. If it works properly, no one gets an advantage in the market. However, there are inefficiencies in any mechanism of exchange—whether a transformer architecture or a free market exchange—and these can be exploited. In both cases, what appears to happen is a form of arbitrage. That is not a coincidence.

Beginning at the end of 1980s and continuing until the dotcom bust, American financial journalists benefited from a great gift: Chairman of the Federal Reserve, Alan Greenspan. During this period, Greenspan's gnomic, opaque, syntactically Gordian statements served as an interpretive Rubik's Cube for the entire financial establishment, which made sport of conflicting divinations. To avoid saying what everyone was thinking, namely, "What is he saying?," Greenspan was treated like a magical neoliberal oracle, riddling American monetary policy to prosperity and the near impossible outcome of low inflation and high growth. In a 2007 speech, after his highly criticized tenure as Fed Chair, Greenspan acknowledged to a group of business executives the semiotic abyss of the "Fedspeak" (or Greenspeak) he initiated, saying:

> What tends to happen is your syntax collapses. All of a sudden, you are mumbling. It often works. I created a new language which we now call Fedspeak. Unless you are expert at it, you can't tell that I didn't say anything. (Saigol 2013)

Ignoring the unspeakable glibness of these remarks, the objective he outlines is a weird one: to create a coherent field of signifiers without a definable meaning. To avoid swaying the market with what he was saying, he opted for saying (or mumbling) nothing. A characteristically oracular bit of Greenspeak came in his 2005 response to the U.S. House Financial Services Committee:

> Risk takers have been encouraged by a perceived increase in economic stability to reach out to more distant time horizons. But long periods of relative stability often engender unrealistic expectations of it[s] permanence and, at times, may lead to financial excess and economic stress. (Greenspan 2005)

2 On the nature of the inverted relationship between work, value, and efficiency in a computational economy see Kirkwood (2022).

The quote does something important with respect to its construction of time. It simultaneously indicates an implied future that will make sense of the comment and totally severs itself from any direct relationship to that temporality. There is a future of undefinable scale into which the actions of the Fed are projected without any notion of what those actions might be. It is a totally synchronic, empty signifier, much like what all machine learning encodings do to human language. If one were able to figure out what that "horizon" was or what "excess" meant with a reasonable level of probability, there would certainly be a lot of money in it. That is why a significant part of the financial machine learning "sentiment analysis" industry has been put to the task of mapping the semantic terrain of Fedspeak, which was by no means limited to the 1990s boom.

This process of linguistic deciphering and generation creates a negative feedback loop. Symbolic distinctions are generated through the interpretation of ambivalent language, then reinserted into the "real" of the market, which generates an overabundance of new symbolic distinctions in the form of "sentiment data" scraped from every digitally available source like newspapers, subreddits, and the once great, now largely defunct "firehose" of Twitter (X). This is, to riff on Gregory Bateson, differences that make too many differences. All that compute, all that processing power put to work on manufacturing symbolic distinctions that will be processed and fed back into the multi-head attention mechanisms of LLMs that will detect new totally meaningless, but soon to be world-defining distinctions. In short, the cycle reveals an underlying computational cultural technique. It constitutes "recursive operative chains" from which "nonsense generates sense" and the "symbolic is filtered out of the real," only to operationally reconstitute the real (Siegert 2015, 13).

This is also not the exclusive province of the financial realm but merely defined by its logic. In a relatively recent court case, the baron of digital stock photography, Getty Images, brought suit against Stability AI, the firm behind the popular art image-generating software, Stable Diffusion—from which one gets a sense of the warped shape of the symbolic's new relationship to the real. Getty Images, which has ravenously acquired enormous databases of copyrighted photographs, claimed that Stability AI scraped images from the web and "unlawfully copied and processed millions of images protected by copyright" for training data (Vincent 2023; Roth 2025). When looking at some of the images that Stable Diffusion generates, which often include barely blurred watermarks, reading things like "geety images," it is hard to argue that they did not.

In one especially ghoulish image, a crowd of what look like members of the hacker group Anonymous in Guy Fawkes masks appear to have time travelled to Paris in May of 1968 to take a black and white photo for a 4chan meme ridiculing leftists.

[Figure 1] An image created by Stable Diffusion showing a re-creation of Getty Images' watermark (Source: Vincent [2023]: The Verge/Stable Diffusion).

The image is clearly without a referent, though as any sophisticated reader of digital images knows, there really never were referents in photographs. Already in the era of emulsion photography, Vilém Flusser (2013, 36) claimed "There is no such thing as naïve, non-conceptual photography. A photograph is an image of concepts." The operations of the photographic apparatus, from the shutter and its calibrated speeds, focal depth of the lens, and the speed of the film, conspire to produce a semiotic unity—a shape that is recognizable as standing in for something. We call this a concept. But it is unclear in such cases that the concepts are nothing beyond pure signifiers for the recombinations of partial patterns produced through deep learning neural nets. What we are seeing is the symbolic representation of the symbolic reinserted into the real—and creepily.

What then does this have to do with Alan Greenspan and machine learning? One could argue that it illuminates the structural bottom of the dark trench of meaningless AI "slop" generation that guides the AI race. His mode of digressive jargonization has become more than an obnoxious idiosyncrasy of one highly visible economic figure but has rather evolved into a comfortable template for the messaging of central banks. Fedspeak is now the linguistic currency of global monetary policy. When Jerome Powell, Christine Lagarde, or Kazuo Ueda issue direction about the conditions under which they may or may not intend to stop quantitative easing, wait for further data, or worse, deem inflation "transitory," the message must be decrypted from Fedspeak. What Fedspeak does then, is applies the principles of the market to language by creating a probabilistic field of uncertainty designed to thwart prediction. Much like the free market policies of the 1980s and 90s from which it emerged, Fedspeak gives the impression of a democratically unbiased ambivalence where a rational agent is free to make uncoerced decisions about in what sense the nonsense has given universal access to real-time information. But if we know one thing about the supposed efficient markets hypothesis, it is that there is *no such thing as an efficient market* or a rational agent. As Joseph Vogl writes:

> Markets tend to be influenced by fluctuating clusters of volatility; they are efficient and crazy at the same time. If they therefore appear to be limit figures of knowledge, then this is not least because, in markets, information is no longer distributed and communicated efficiently, that is, economically. To be sure, the organized chaos of turbulent motion is still, in principle, susceptible of representation; but the quantity of data needed to represent it verges on the incalculable. (Vogl 2015, 108)

At the same time, contemporary information technologies like LLMs are no longer used to merely transmit, model, or represent the landscape of distinctions they process, but are hardwired to produce more distinctions that in turn create new distinctions. The obvious inefficiency of this informational process is not a downside, at least not for some. It is their most profitable aspect, creating opportunities for arbitrage.

As a practice broadly defined, arbitrage is simply the exploitation of a price difference between multiple markets. This can occur between various stock exchanges in which an equity is listed, convertible bonds, price differences in acquisitions and mergers, differences in online crypto exchanges, and so on. The concept is also almost as old as currency itself and a frequent area of study within numismatics and classical economics. Xenophon, for instance, already commented with respect to Nikophon's "Law on Silver Coinage" of 375 BCE that Athenian Owls or *Tetradrachm* (the official silver coinage of the city-state) would sometimes become worth more than their initial value, and there were centralized efforts to regulate actors—especially foreigners—who sought to profit from this fact (Poitras 2021). One might even argue that the only way to ever turn a profit in a supposedly efficient market is to find *the lie of its efficiency*. This is where computation comes in.

Exploiting Difference

The entire stock market is now a giant computer-mediated arbitrage machine. This has taken so many forms that it would be impossible to detail them all, though there are some notable examples. Precisely under the banner of the principle of market efficiency, high-frequency trading firms, starting in the mid 2000s, quietly learned to exploit and even to manufacture discrepancies between the various exchanges on which equities and commodities were electronically traded. Fragmentation of the market through various electronic exchanges and the Securities and Exchange Commission's (SEC) establishment of the Regulation National Market System created the opportunity for experts in communication technologies to capitalize on tiny differences in the price of an asset. The increasing decentralization quite literally allowed a groundwork to be laid for a series of moves to capitalize on minute differences between exchanges. In 2009, under conditions of total secrecy, enterprising latency reduction mavericks Dan Spivey and James Barksdale engineered a path for dark fiber cable between the Chicago Mercantile Exchange servers directly to the NASDAQ servers in Carteret, NJ (Lewis 2014). The undertaking involved a host of highly inventive gambits to ensure that their tunnel took the most direct possible path between the two sites, undeterred by parking lots and private property. The resulting connection between Chicago and the New York Stock Exchange servers shaved an industry-destroying 1.6 milliseconds off the previous round trip transmission standard that was based on a system of cables defined by the old railroad system. The jump they could thus give to traders using their route allowed a select set of top-dollar customers of their company, Spread Network, to execute on market moves before they were represented elsewhere.

During the period of algorithmic or high-frequency trading that followed, smaller players like Maven and the Global Electronic Trading Company (GETCO) were able to get a leg up on slow-moving behemoths like Goldman Sachs by maniacally ensuring ever-closer proximity to the servers, even fighting over position within shared rooms provided for their machines near the exchange. Such tactics are generally referred to as "front-running," which most prominently came to popular consciousness during the 2021 GameStop short squeeze involving members of the subreddit r/wallstreetbets, although based on a separate set of tactics (Halpern et al. 2022).

This story, and with it the often-repeated notions about how high-frequency trading functions, obscures something essential about how arbitrage works and why it is important for considerations about what language and meaning is in a computationally financialized system. The narrative framework for these stories is generally about speed. Yet arbitrage, and its function as a source of value generation, is not actually about being fast—it is about recognizing difference where there is the structural expectation for equivalence. This is something that both Geoffrey Poitras and Gayle Rogers have variously noted about the conflation of arbitrage with the love-to-hate term, "speculation," which, already for Boethius was a "supreme, abstract knowledge" that could not be achieved merely through empirical observation (Rogers 2021,18). As Poitras (2021, 99) points out, by 1638 Giovanni Dominico Peri had already identified "a distinction between speculation on future exchange rate movements and the *arbitrio* concept of arbitrage": "the profits from exchange dealings originate in price differences and not in time, with profits turning to losses if re-exchange is unfavourable."

The exact same principle holds true in the era of the nanosecond trade, or as Geoffrey Bowker (2021) has explored in his work on high-frequency trading, the femtosecond. However, if there is no inefficiency in the market there is no opportunity for arbitrage.

This is what makes transformer architecture so powerful for finance. For all of its speed, time is not the relevant factor—rather, it is the ability to locate or generate difference through modes of parallelism. Bowker notes:

> The parallelism of computing today—whether based in the cloud or under the hood of a PC in the form of multicore processors—trades between two temporalities, the speed of messaging (spatial) and the remorseless ticking of the computer clock (temporal; not highly scalable above current limits). (Bowker 2021, 126–127)

For the vast majority of parallel processing's existence, the clock rate, which governs the frequency of the pulses according to which multiple cores can execute instructions simultaneously, increased rapidly. In line with Moore's Law and what was known as the Tick-Tock model, noting the extreme regularity of improvement, microarchitecture and circuit density was advanced and clock speed accelerated. It accelerated that is, until the mid 2000s, when, according to Robert Kuhn and David Padua (2021, 18), its speed increases stopped dead, due in part to the fact that as feature size got smaller, Complementary Metal-Oxide-Semiconductor (CMOS) power use went up dramatically on account of current leakage. According to Amdahl's Law, when a single part of system is improved, overall system performance will be dictated by that part's proportion of the overall system. In other words, a system is only as fast as its slowest link or its narrowest bottleneck. And yet, the number of double precision gigaflops has increased in spite of a flatline in clock frequency (Kuhn and Padua, 18). No doubt, value generation cannot be defined purely by speed alone.

In an analysis of various machine learning and human expert methods for evaluating the implied sentiment of Federal Open Market Committee meetings, Anne Lundgaard Hansen and Sophia Kazinnik found that GPT-3 was uniquely capable of classifying statements from dovish to hawkish given subsequent Fed decisions. The entire model was trained on a massive *Wall Street Journal* dataset and the subword tokens that provide the context for the processing, while taken from financial language, are not in and of themselves meaningful in much the same way that Fedspeak maintained its indeterminacy. This ambivalence is reinforced at the hardware level with parallel processing coming to dominate calculation-intensive but central processing unit (CPU)-light functions since the commercial introduction of Nvidia's GeForce GPU in 1999 (Gaboury 2021). Much of the GPT revolution is attributable to GPU, Application Specific Integrated Circuit (ASIC), and Deep Neural Net Processors' (DNNPs) talent for breaking down computationally intensive problems into smaller problems that can be processed by thousands of cores simultaneously. Unlike the Recurrent Neural Nets (RNNs) that take nodes in sequence, much of the transformers' revolutionary impact is in a native parallelizability.

This momentous turn is financial by its very nature, and the momentous, field-defining shift to attention mechanisms and multi-head transformers that accompanied the now-famous 2017 Google paper "Attention is All you Need" formalized it. In place of a "single attention function" the authors proposed to "perform the attention function in parallel" (Vaswani et al. 2017, 1).

The entire history of the parallel processing so critical to the computational work done in LLMs foretells a computational financialization. After working on the famous ILLIAC machine and a number of false starts with IBM and Westinghouse, Daniel Slotnick and his colleagues conceived the SOLOMON machine, short for Simultaneous Operation Linked Ordinal Modular Network—and with direct reference to King Solomon. The parallel machine had been proposed at the US National Aeronautics and Space Administration (NASA) in 1962 for computation-heavy image analysis, but like the 1972 ILLIAC IV that came after it, failed to achieve its goals. Nevertheless, the principles of Slotnick's earlier work with John Cocke from 1958, which were the premise for those experiments, offered a central template for the GPUs, ASICs, and DNNPs that are now the workhorses of our digitally rendered visual universe, financial software, black hole orbit calculations, and transformers tormenting university professors with plausibly human texts.

In the abstract for an early paper on parallel processing, Slotnick's prediction was that "it is quite likely that future computing machines will permit simultaneous, independent arithmetic and logical operations" (Cocke and Slotnick 1958). The idea first surfaced while he was at Princeton of:

> first, inverting the bit-word relationship so that each track stored the successive bits of a single word (in fact, of several words) and, second, associating a 10-tube serial adder with each track so that in a single drum revolution an operation could be executed on the contents of the entire drum. The idea was to do, in parallel, an iterative step in a mesh calculation. (Slotnick 1982; Slotnick and Sameh 1978, 203)

This is, clearly, a rudimentary tokenization process that breaks down meaningful unities into the pure, computable equivalences that form the basis of exploitable difference. Indeed, the groundwork for SOLOMON, like

King Solomon himself, involved an embarrassment of riches in what is called "embarrassingly parallel" processing, for which it made way.

The ability of GPTs to generate so many differences on which their powers are built is essentially an arbitrage—of texts, of speech, of images—constituting the world as imperfect equivalences from which they can profit. When all processes become parallelized, the incentive becomes the production and exploitation of differences. Along the way, all areas of human meaning-making become instruments of finance.

References

Banerji, Gunjan, Asa Fitch, and Karen Langley. 2025. "The Day DeepSeek Turned Tech and Wall Street Upside Down; Monday's Bloodbath in Nvidia and Other AI Stocks Wiped out Some $1 Trillion from the Stock Market's Value." *The Wall Street Journal*. January 28, 2025. https://www.wsj.com/finance/stocks/the-day-deepseek-turned-tech-and-wall-street-upside-down-f2a70b69.

Boak, Josh, and Matt O'Brien. 2023. "Biden Wants to Move Fast on AI Safeguards and Will Sign an Executive Order to Address His Concerns." *AP Online*. https://apnews.com/article/biden-ai-artificial-intelligence-executive-order-cb86162000d894f238f28ac029005059.

Bowker, Geoffrey C. 2021. "Life at the Femtosecond." In *Media Infrastructures and the Politics of Digital Time: Essays on Hardwired Temporalities*, edited by Axel Volmar and Kyle Stine. Amsterdam: Amsterdam University Press.

Carruthers, Bruce G., and Wendy Nelson Espeland. 1991. "Accounting for Rationality: Double-Entry Bookkeeping and the Rhetoric of Economic Rationality." *American Journal of Sociology* 97, no. 1: 31–69.

Chiapello, Eve. 2007. "Accounting and the Birth of the Notion of Capitalism." *Critical Perspectives on Accounting* 18, no. 3: 263–96.

Cocke, John, and D.S. Slotnick. July 25, 1958. "The Use of Parallelism in Numerical Calculations." *IBM Research Center Memorandum* RC-55. IBM.

Colinson, Robert. 1683. *Idea Rationaria, or the Perfect Accomptant, Necessary for All Merchants and Trafficquers; Containing the True Forme of Book-Keeping, According to the Italian Methode*. Edinburgh: David Lindsay, James Kniblo, Josua van Solingen, and John Colmar.

DeepSeek-AI, Aixin Liu, Bei Feng, Bing Xue, et al. 2025. "DeepSeek-V3 Technical Report." *arXiv*. https://doi.org/10.48550/arXiv.2412.19437.

Executive Office of the President. 2023. "Safe, Secure, and Trustworthy Development and Use of Artificial Intelligence." Executive Order 14110 of October 30, 2023. *Federal Register* 88, No. 210: 75191–75226. https://www.govinfo.gov/content/pkg/FR-2023-11-01/pdf/2023-24283.pdf.

Flusser, Vilém. 2013. *Towards a Philosophy of Photography*. London: Reaktion Books.

Gaboury, Jacob. 2021. *Image Objects: An Archaeology of Computer Graphics*. Cambridge, MA: MIT Press.

Gage, Philip. 1994. "A New Algorithm for Data Compression." *C Users Journal* 12: 23–38.

Gensler, Gary, and Lily Bailey. 2020. "Deep Learning and Financial Stability." *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3723132.

Gómez-Cram, Roberto, and Marco Grotteria. 2022. "Real-Time Price Discovery via Verbal Communication: Method and Application to Fedspeak." *Journal of Financial Economics* 143, no. 3: 993–1025.

Greenspan, Alan. 2005. "NBC News, Monetary Policy Report. House Committee on Financial Services." *NBC News*. July 20, 2005. https://www.nbcnews.com/id/wbna8642817.

Halpern, Orit, Patrick Jagoda, Jeffrey West Kirkwood, and Leif Weatherby. 2022. "Surplus Data: An Introduction." *Critical Inquiry* 48, no. 2: 197–210.

Hansen, Anne Lundgaard, and Sophia Kazinnik. 2023. "Can ChatGPT Decipher Fedspeak?" *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.4399406.
Harty, Declan, and Steven Overly. "Gensler's Warning: Unchecked AI Could Spark Future Financial Meltdown." *Politico*. March 19, 2024. https://www.politico.com/news/2024/03/19/sec-gensler-artificial-intelligence-00147665.
Hillis, W. Daniel. 1992 [1985]. *The Connection Machine*. Cambridge, MA and London: MIT Press.
Hookway, James. "In the Eternal Quest to Decode Fedspeak, Here Come the Computers; Investors Are Rolling out a New Weapon in Their Effort to Figure out What Central Banks Are about to Do—Artificial Intelligence." *Wall Street Journal*. February 9, 2020. https://www.wsj.com/articles/in-the-eternal-quest-to-decode-fedspeak-here-come-the-computers-11581287394?.
Kirkwood, Jeffrey West. 2022. "From Work to Proof of Work: Meaning and Value after Blockchain." *Critical Inquiry* 48, no. 2: 360–80.
Konings, Martijn. 2018. *Capital and Time: For a New Critique of Neoliberal Reason*. Stanford: Stanford University Press.
Kuhn, Robert, and David A. Padua. 2021. *Parallel Processing: 1980 To 2020*. San Rafael: Morgan & Claypool Publishers.
Lewis, Michael. 2014. *Flash Boys: A Wall Street Revolt*. New York: W.W. Norton & Company.
McCormick, B. H. 1963. "The Illinois Pattern Recognition Computer-ILLIAC III." *IEEE Transactions on Electronic Computers* 12, no. 6: 791–813.
Mercer, Sarah, Samuel Spillard, and Daniel P. Martin. 2025. "Brief Analysis of DeepSeek R1 and Its Implications for Generative AI." *arXiv*. https://doi.org/10.48550/ARXIV.2502.02523.
Mok, Charles. 2025. "Taking Stock of the DeepSeek Shock." *Stanford Cyber Policy Center*. February 5, 2025. https://cyber.fsi.stanford.edu/publication/taking-stock-deepseek-shock.
Office of the Federal Register, National Archives and Records Administration. 2025. "Executive Order 14179 of January 23, 2025: Removing Barriers to American Leadership in Artificial Intelligence." *Federal Register* 90, no. 20: 8741–42.
Poitras, Geoffrey. 2021. "Origins of Arbitrage." *Financial History Review* 28, no. 1: 96–123.
Rogers, Gayle. 2021. *Speculation: A Cultural History from Aristotle to AI*. New York: Columbia University Press.
Roth, Emma. 2025. "Getty Images and Shutterstock Are Merging into One Stock Photo Powerhouse." *The Verge*. January 7, 2025. https://www.theverge.com/2025/1/7/24338112/getty-images-shutterstock-merging-stock-photo-powerhouse.
Saigol, Lina. 2013. "Alan Greenspan's tone of voice moved gold and silver prices." *Financial Times*. June 19, 2013. https://www.ft.com/content/90d82852-d7f1-11e2-b4a4-00144feab7de.
Siegert, Bernhard. 2015. *Cultural Techniques: Grids, Filters, Doors, and Other Articulations of the Real*. Translated by Geoffrey Winthrop-Young. New York: Fordham University Press.
Slotnick, D.L. 1982. "The Conception and Development of Parallel Processors: A Personal Memoir." *Annals of the History of Computing* 4, no. 1: 20–30.
Slotnick, D.L., and Ahmed Sameh. 1978. "Numerical Calculation and Computer Design." *Computers & Mathematics with Applications* 4, no. 3: 201–10.
Sombart, Werner. 1919. *Der moderne Kapitalismus: Historisch-systematische Darstellung des gesamteuropäischen Wirtschaftslebens von seinen Anfängen bis zur Gegenwart* [3rd ed.], Vol. 2. München and Leipzig: Verlag von Duncker & Humblot.
The White House. 2025. "Fact Sheet: President Donald J. Trump Takes Action to Enhance America's AI Leadership." January 23, 2025. https://www.whitehouse.gov/presidential-actions/2025/01/removing-barriers-to-american-leadership-in-artificial-intelligence.
Vaswani, Ashish, Noam Shazeer, Niki Parmar, Jakob Uszkoreit, et al. 2017. "Attention Is All You Need." *arXiv*. http://arxiv.org/abs/1706.03762.
Vincent, James. 2023. "Getty Images Is Suing the Creators of AI Art Tool Stable Diffusion for Scraping Its Content." *The Verge*. January 17, 2023. https://www.theverge.com/2023/1/17/23558516/ai-art-copyright-stable-diffusion-getty-images-lawsuit.

Vogl, Joseph. 2015. *The Specter of Capital*. Translated by Joachim Redner and Robert Savage. Stanford: Stanford University Press.

Yamey, B. S. 1949. "Scientific Bookkeeping and the Rise of Capitalism." *The Economic History Review* 1, no. 2/3: 99.

INFRASTRUCTURE

PIPELINES

COMPUTATION

POLITICAL ECONOMY

PSYCHOANALYSIS

[9]

The Infrastructural Unconscious: Do Computers Dream of Carbo-Silico Pipelines?

Ranjodh Singh Dhaliwal

Spilling over as signs of environmental catastrophe and blowing up as symbols of radical politics, pipelines today transport fossil fuel while also reigning as totems of our rupturing sociotechnical dynamics at large. As environmental media—literally "media" that carry our environmental pasts toward future obliterations—pipelines have historically operated not only as infrastructure but also as tools for thinking, consciously or otherwise. This chapter focuses on the emergence, presence and ubiquity of pipelines as concepts and techniques in computation. Why does our technological media infrastructure today run on pipelines, both real (oil and gas) and imagined (instruction, data, rendering)? To answer this question, I borrow from Fredric Jameson's influential "political unconscious" thesis and put it in conversation with infrastructure studies. This chapter then proposes studying the infrastructural

unconscious—composed of attempts to capture the moment when our infrastructures become fully sutured with our cognitive and environmental assemblages—that lies latent in our medial conditions. What do, after all, our reckonings reckon with if not the material-semiotic bases of our infrastructures such as pipelines?

For Fred. And Utopia.

The unconscious poses no problem of meaning, solely problems of use. The question posed by desire is not "What does it mean?" but rather "How does it work?" ... . lThe unconscious] represents nothing, but it produces. It means nothing, but it works. — Deleuze and Guattari

If pipelines make us think of oil and natural gas flowing from extraction sites to locations of consumption, then a rethink would be needed to contend with CO2EUROPIPE, a project that can trace its official origins to at least 2009 and which aims to study and lay the groundwork for large scale carbon dioxide (CO2) transport across Europe for the purposes of carbon capture and storage (CCS)—itself hovering between a dubious vaporware and science fictional hope for our future—in locations distant from where the CO2 was initially generated (The CO2Europipe Project 2009–2011; CORDIS. European Commission 2009–2011; Buse 2021). CO2EUROPIPE is, by no means, a singular project; CO2 pipelines already exist all around the world—across Europe but also over 5000 miles in North America, where some go as far back as half a century—and they not only allow fossil fuel-heavy industries to outsource the carbon production-pollution problem but also help them transport CO2 efficiently to where it is industrially needed (such as for the manufacturing of refrigerants and carbonated beverages) (American Carbon Alliance n.d.). Even a cursory glance at these CO2 pipelines makes evident a bidirectionality of flows: the problem (fossil fuels and the climate-destroying pollution generated therein) and the solution (let us get these pollutants far away from us) follow the same mediational trajectory, and use the same form of media, namely pipelines. What, may one ask, are pipelines for? How might we analytically and socio-culturally reckon with pipelines?

In this chapter, I look at pipelines not solely in their fossil-(fuel)-ized valences but also in their true infra-structural polysemy.[1] In other words, I study pipelines as conduits not just for material but also for semiotics; more specifically, here I investigate the computational pipelines—such as instruction pipelines and graphic pipelines in computational hard- and software—and show how pipelines as figures impact computation at large.[2] In doing so, I make two inter-related claims: on the one hand, my grappling with pipelines as a material-semiotic concept (across domains and industries) leads me to propose a politico-econo-psycho-social formulation that is the infrastructural unconscious, and on the other hand, reckoning with this infrastructural unconscious encourages me to remark upon the reckonings with pipelines in our basal milieux.

The Sp(l)ice Must Flow: Pipelines as Time Machines

The simplest story explaining the emergence of pipelines can be described, in the words of Timothy Mitchell, thus:

> Since oil comes to the surface driven by underground pressure, either from water trapped beneath it or from gas trapped above, sometimes assisted by the action of pumps, its production required a smaller workforce than coal in relation to the quantity of energy produced … Workers remained above ground, closer to the supervision of managers. As the carbon occurs in liquid form, the work of transporting energy could be done with less human labour. Pumping stations and pipelines could replace railways as means of transporting energy from the site of production to the places where it was used or shipped abroad. These methods of transport did not require teams of humans to accompany the fuel on its journey, to load and unload it at each junction, or to continuously operate engines, switches and signals. In fact, oil pipelines were invented as a means of reducing the ability of humans to interrupt the flow of energy. They were introduced in Pennsylvania in the 1860s

1 I use the term infrastructure here, quite simply, in an always already double sense; on the one hand, Marxist (where infrastructure has historically sometimes been one possible rendering of "base" in the base-superstructure model) sense, and on the other hand, media technological (where infrastructure is the hard stuff around us that makes the world run silently and invisibly) sense. For a quick overview of how these two senses merge, see Barney (2018), Ahern and Dhaliwal (2025), and Dhaliwal (2025a).

2 For methodological examples of such work, see Dhaliwal (2022a; 2022b). For the material-semioticity referenced throughout this text, a brilliant place to begin would be Haraway (1997).

> to circumvent the wage demands of the teamsters who transported barrels of oil to the rail depot in horse-drawn wagons … Baku borrowed the innovation in the following decade from the American oil drillers, for the same reason. Pipelines were vulnerable to sabotage. During the 1905 Revolution in Russia, for example, the British consul in Batumi reported that "a considerable number of pipes have been holed by the revolutionaries and have thereby been rendered useless." But they were more difficult to incapacitate than the railways that carried coal, and could be quickly patched up. The damage, the consul reported, "will not take long to repair and the line will in all probability be at work shortly." (Mitchell 2011, 36)[3]

If there was only one thing for us to know about the emergence of pipelines, it would have been the fact that pipelines present(ed) a technical solution (large-scale material deployment across topographies for continuous flow of oil) to a political problem (the relatively high cost of human labor power and the possibility of sabotage). But thankfully for us, we do not need to limit ourselves to just one insight. Perhaps then, the second point worth noting here would be that pipelines, in the words of Hannah Tollefson and Darin Barney, "contain, store, convey, conduct, transmit, connect, distribute, … [span … and also format]. In these respects, they are like rivers, canals, railroads, and highways, and also like telegraphy, telephony, portable print media, and wired and wireless digital networks" (Tollefson and Barney 2019, 45).[4] Pipelines as media thus perform many roles, among them being one of connecting distinct timescales. On the one hand is the time of the prehistoric fossil fuels, often from under the Earth's surface, which find themselves extracted[5] and transformed (several times over) for the specific part of ecological history that began post industrialization in the 19th century. And on the other hand is the timescale of our present moment, suspended between the today of fossil fuel use (or tomorrow morning, if the fuel is to be further stored in a reserve for speculation, or tomorrow afternoon, for the sake of short-term profits) and the livable futures that seem increasingly out of our reach today. If we were the kind of people who followed Husserl (1991), pipelines would seem to be suspended, and also that which suspends, between what just happened and what is just about to happen. In spanning these two temporal scales, pipelines act as media of not just value (in both the politico-economic and sociocultural sense) but also of temporal connectivities (Barney 2017; Hein 2009; Acland 2007). In fact, even though the scale of valuation might look different here, pipelines can be understood as media that produce value during the otherwise unrecognizable intervals between retention and protention.[6]

3 Citing Yergin (1991) and Mr Consul Stevens (1906, 8).
4 See also other excellent work by Barney (2017; 2021) on this topic.
5 Relatedly, on media and extraction, see Jacobson (2025), Angus (2024), and Young (2020).
6 Special thanks to Bernhard Siegert for helping me articulate this connection.

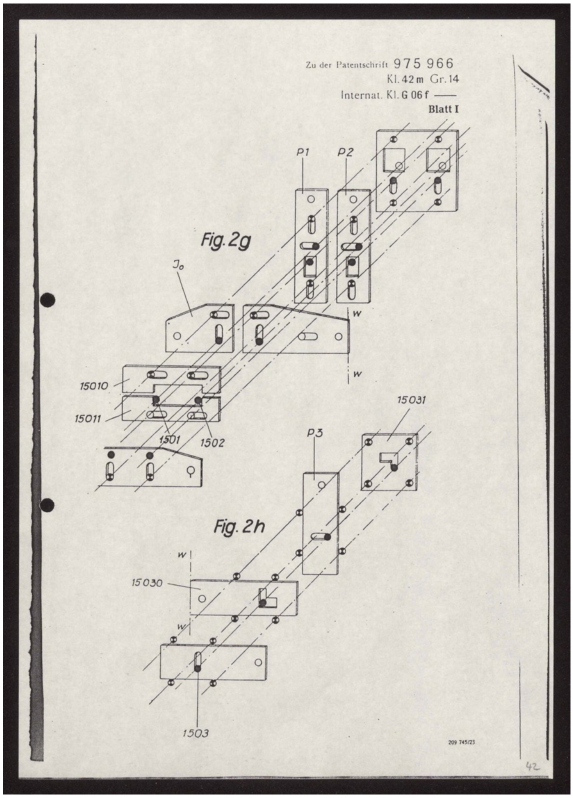
Furthermore, by their very etymological invocation of pipes—a ubiquitous feature of cityscapes, if not "civilization," sometimes sought in archaeological digs—and lines—these glorious forms of linearity and much more (Ingold 2016)—pipelines complicate their own historicization, a complication worth pondering over.

Consider, for example, the relationship between the pipeline and the assembly line: both feature forms of conveyance (and sabotage or disruption), both temporally mediate between "raw" materials and market-worthy goods, and both are technical formalizations catalyzing practices and techniques of the body-material. Historically speaking, assembly lines—which themselves trace their origins to flour mills and arsenals of previous eras—emerge in the same co-located era as the ubiquitous pipelines; the Bridgewater Foundry (1836) and Leiston Works in Suffolk (1853), both examples of early assembly lines that would later give rise to (or become) the Fordist model, were themselves in the business of producing locomotive steam engines through continuous flow on the factory floor, steam engines that were, as mentioned above, about to be replaced by the continuous flow of oil in pipelines in the next couple of decades. Pipelines must thus be understood in their historical relation as a part of a general material problem of conveyance, a problem that can—in this particular iteration—be further specifically located within the colonial management of bodies, goods, and machines (Harney and Moten 2013; 2021a; 2021b; Baucom 2005; Cuppini and Frapporti 2018). Staying with these mergers and co-emergences of forms then leads us to yet another pit stop in this conveyer belt: that of computation.[7] And here I do not start with any novel observation but by merely pointing out that industry experts already have been noting the procedural flows that unite computation and assembly lines; consider, for example, that "Dr. C. C. Hurd, Director of Applied Science at IBM, [who once] offered a strikingly similar observation: 'It seems to me that the most useful analogy which I can see for the assembly line is that the assembly line – or, more generally, a complete production line – is like a computing machine'" (Noble 1995, 86).[8]

Historically speaking, computational pipelining goes back to the earliest instruction sets in the mid-20th century, itself taking from machinic architectures before computation *per se*. The word pipelining—invoking both the laying down of, and conveyance by, pipes in the world of fossil pipelining—retains its processual valence when it is understood and implemented in the world of computation. Around the same point in history as one of the several global explosions in physical pipelines was taking place (in the post-war mid-20th century), in order to satisfy the demands of the growing automobile industry (which had itself reinforced and started both complimenting

7 See Dhaliwal (2022a; 2026).

8 Citing Hurd being quoted in the "The Automatic Factory," *Fortune*, October 1953.



[Figure 1] Pipelining of instructions, or, Parallelism + Monorhythmic Clock Cycles = Assembly Lines (Source: Zuse 1962, 42. Digitized by Deutsches Museum Digital. https://digital.deutsches-museum.de/item/NL-207-1008).

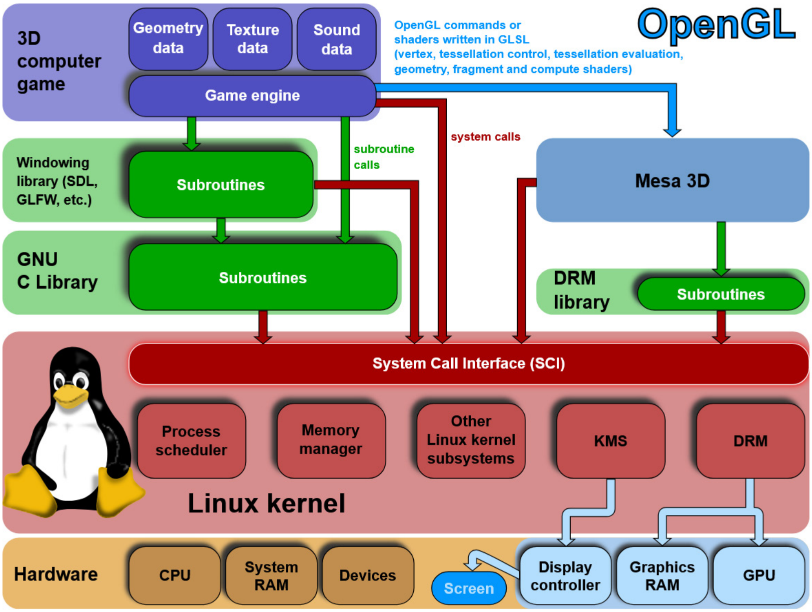
and usurping the role of locomotives in global logistics), the first mechanical computers (like the Z series made by Konrad Zuse in Germany) were being birthed by utilizing pipelining and microsequencing of instructions, and the world was in the throes of an oil pipeline fever. Zuse applied for a patent for a pipelining computer in Germany in 1949, just as, in the USA, control was being transferred for the biggest pipeline project of its time, the "Big Inch," running from Texas to Philadelphia, from the wartime public administration to a private player, the Texas Eastern Transmission Corporation.

Zuse's patent, titled "Rechenmaschine zur Durchführung arithmetischer Rechenoperationen" (Calculating machine for performing arithmetic operations), was finally granted in 1962. As Figure 1 shows, working with punch cards to parallelize instructions for executing multiplication in the patent, Zuse was visually schematizing a flow of simultaneity. The simultaneity here is parallel (multiple operations of the same kind happening at the same time) but it would soon morph into multicycle architecture (where multiple operations of different kinds happen at the same time) as well; this multi-cyclicity was only possible because of microsequencing (the act of managing addresses and controls for/in microprogramming).[9] Zuse's vision of microsequencing was thus already at work long before electronic computers ruled the roost. While relay as a communicative and processual technique (Siegert 1999; Giessmann 2024; Galloway 2010) had lain at the heart of computation from the moment of its historicized spawning, microsequencing at the core of this particular pipeline was more than relay; it was a fundamental conceptual miniaturization (Dhaliwal 2022b) of what was an expansive infrastructural form in the sociotechnical world at large. And by the virtue of its material shrinkage (through the mode of a semiotic metaphorical transference), the microsequencing—the arrangement of division of instructions into smaller units which can then be processed together—indicated a collapse into the "micro" of what had been hitherto an expansion of the macro.[10] It is worth noting that one material difference between instructional pipelining in computation and pipelining oil or gas is that even though the former takes some of its cues from the latter, it also borrows from the communicative techniques of relay (which predate oil pipelines, of course) by relying on an internal (oft-monorhythmic) clock mechanism. What this means, quite simply, is that while oil does not need to continuously flow in synchrony with the standards of the world around it, instructions—and discrete information at large, as we shall see again later in this piece—have no option but to march to the rhythm of the dictatorial drum of microscopic quartz (Ernst 2013; 2016). This functional difference is worth staying with (*a la* Haraway), for the scale and entanglement of pipelines tell us something essential about the world and ecology here. In my assessment, these instruction pipelines, for Zuse,[11] were—despite their nomenclature—more than just pipelines, for they were also—and this is vital

9 Microprogramming is simply the theatre scene in which the program is broken into smaller subunits, or microprograms. Relatedly, in the world of networking, see Sprenger (2015).

10 For a similar story of looking inwards where expanding outwards, see Milburn (2008).

11 The closest Zuse (1962, 3, 7, 16) came, in his own words, though, is feed/supply pipe or "Zuführung," through the semiotic register of assignment (as a legal-juridical term). I should also note that even Zuse, for me, is just a case study standing in for a broader set of epistemological frameworks in the history and sociality of computational development. Which is why it is almost too-on-the-nose to note that the front page of the digital scan of Zuse's patent made by Deutsches Museum (source document for Figure 1) nevertheless contains the word "(Pipelining)" (in English) scribbled in ink pen next to the typeset title, indicating a distillation of all the German explanation into a single English term. Whether it was done by Zuse himself, or some archival actor later, the scribble's appearance today denotes an always-already discursive-materiality of the metaphorical term in question (pipelining) that subtends linguistic, epistemological, and archival bounds; Zuse, it must be remembered, never himself published on 'pipelining' *per se*, but retroactive inventions and discursive borrowings have a way of *ipso facto* proving the semiotics of infrastructure right in our historical totality. I am grateful to Benedikt Merkle for bringing this detail to my attention.

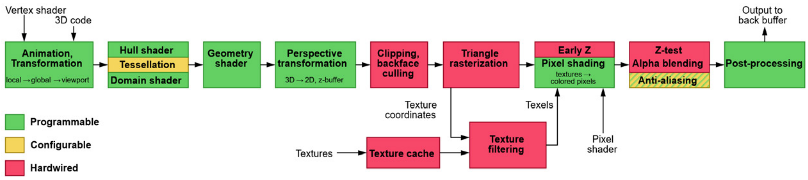


[Figure 2] *An Illustration of the Pipelined Connections between the Various Hardware and Software Systems which Animate Contemporary Computation, or, Polyphonic Rhythms + Lead Coordination = Supply Chains* (Source: ScotXW. 2014. https://commons.wikimedia.org/wiki/File:Linux_kernel_and_OpenGL_video_games.svg).

here for my point—assembly lines.[12] The conveyer belt of an assembly line deals with difference—different actions, different raw materials, different subunits—with an eye towards sameness—producing the same product over and over again with minimal variation; an oil pipeline, on the other hand, has no internal differential, and its fundamental condition is one of all oil being like all other oil. The former denotes a logic of difference in conveyed sub-units, while the latter indicates a logic of similarity in the conveyed product. The conceptual debt that instruction pipelines pay to assembly lines becomes evident once this distinction is understood; the instructions hope for uniform execution, but they are not uniform themselves. Moreover, some of the vital logics of fuel-pipelines, among them opacity (to occlude what is flowing) and compression (volume reduction and/or loss of fidelity) noted by Tollefson and Barney (2019), do not map consistently onto this world of assembly and instructional-lines.

For a further elaboration of such processual distinctions in production, we can jump a few decades forward in history and consider graphical rendering pipelines. I have looked at the pipelines of graphical rendering elsewhere in my work (Dhaliwal 2021) (and some of my remarks here are drawn from that

12 For more, see also Nye (2013), Esch (2018), and Hounshell (1997).



[Figure 3] *Flowchart of a 3D Graphics Rendering Pipeline* (Source: AntiCompositeNumber, Original: Martin Wantke Vector: 2021. https://commons.wikimedia.org/wiki/File:3D-Pipeline.svg).

work), but here it suffices to say this: rendering pipelines are architectures—part material, part semiotic—that plan and dictate the flow of information and its transformations that end up in visible computer graphics on the screen. There is the general sense of sequencing here, of course, but rendering pipelines are wide enough and splayed out enough that to call them pipelines is to refer to *any* complicated set of operations across a series of machines as liquid-y flow. (See, for instance, one general architectural depiction of OpenGL operations in Figure 2 or the 3D graphics rendering pipeline example in Figure 3.)

If we compare rendering pipelines with the instructional pipelines of Zuse, we see further historico-technical distinctions. In fact, the sheer spread (across devices and hardware assemblages) and scale (from singular instructions at the level of processor to data generating millions of pixels per second at a much higher register in the stack) of rendering pipelines mean that assembly lines no longer functioned as a useful framework in the 1990s (when graphic pipelines start to become ascendant), let alone the lonely primitive notion of oil/gas moving through a contained form first in, first out. A better alternative conceptual framework for the graphic pipeline might be the supply chains of the world. I wish not to repeat here my main thesis around parallelization as a form, outlined elsewhere in greater detail (Dhaliwal 2021), but to merely make the following claim: much like the history of computational pipelining in the first half of the 20th century finds itself reflecting the assembly lines of its era, the move towards a graphical parallelism (in the 1990s moving through the 2000s and arguably still growing heartily) has been concomitant with the rise of supply chains—yet another socio-economic transformation of the second half of the 20th century. Supply chains, whether they are mapped on to neoliberalized economic orders or globalized late capitalism at large, are commodity chains where the lead firm directs the commodity traffic. If factory and assembly line labor is about "coordinated progress time" that shows up as a clock in the pipelined computational processor, then "the supply chain is infused with polyphonic rhythms" and shows up as the many differing tasks it can be recruited for (Tsing 2021, 24). As Anna Tsing and Nellie Chu point out, "tiny Chinese garment factories … can serve multiple supply lines, constantly switching among orders for local boutique brands, knock-off international brands, and generic to-be-branded-later production. Each [requires] different standards, materials, and kinds of labor" (Chu 2014; Tsing 2021, 24).[13] In such a mode of production and distribution, "the factory's job was to match industrial coordination to the complex rhythms of supply chains" (Tsing 2021, 24).

When I first track what makes the instructional pipeline assembly belt-esque in form and then co-relationally map the rendering pipelining (and the rise of GPUs [graphics processing units]) to supply chains as a historically specific mode of socio-economic operation, I am essentially noting the relationships—which are not deterministic or causal, let alone nominatively deterministic—that certain sociocultural and political moments in history form with the technical infrastructure (and its vocabularies) that spawns, and is spawned by, these moments.[14] Further expansion of this line of (flight/)thought follows later in this piece, but this historicization (by asking specifically "which line" is *this* pipeline without flattening pipelines more generically between oil and computation) only further reinforces the aforementioned workings of pipelines as time machines.[15] By spanning the input and the output, and doing so by internally arranging the flows, pipelines function through all these formats as time machines. Looking specifically at computational pipelines tells us that instructions and data once subdivided become even more open to temporal reconfiguration for parallelization. If the past of geological timescales shows up as readily available, enframed reserve for the oil pipelines (Parikka 2015), then the future of expectation (of calculation) is what is at stake for computational pipelines.

One quick look at the similarly ecological metaphors of streaming[16] (Pringle 2022; Tay 2025; Aegidius 2021; Eriksson 2018) and the insistence on dynamic

13 See also Rossiter (2015) and Tsing (2009; 2016). I must also here nod towards the concept of logistical media, which would certainly containerize pipelines in their many manifestations, but further explication on that end can be extrapolated (Hockenberry, Starosielski, and Zieger 2021; Peters 2020; Dhaliwal 2025c).

14 To avoid any confusion, let me briefly ruminate on the term imaginary here, which holds a special place in recent scholarship on technology and culture (Jagoda 2016; Rhee 2018). In the words of Lucy Suchman (2007, 1; see also Glissant 2009), imaginary "references the ways in which how we see and what we imagine the world to be is shaped not only by our individual experiences but also by the specific cultural and historical resources that the world makes available to us, based on our particular location within it." Imaginary, to put it simply, here is a consistent, thematized set of beliefs within a given historico-cultural location; see also Castoriadis (1987) and Jasanoff and Kim (2015). However, such understandings of imaginary do not always explicitly pay their debts to the psycho-analytic origin of the imaginary. While one reading of this chapter could have proceeded through the concept of imaginaries, here I engage with the psycho-analytic and the politico-economic together instead precisely because these imaginaries can also have an unconscious correlation, where I focus my energies in this piece.

15 For more on media that span time, see Zielinski (2006).

16 Relatedly, see also Bottomley (2020), Sobchack (2016), Sconce (2005), Alexander (2017), and, in different registers, Humphrey (1954) and Holt (2024).

data flows instead of static data bases (Offert and Dhaliwal 2024; Zubaroğlu and Atalay 2021) in this present milieux of large foundational models and voluminous data flows would suffice for this basic insight: it doesn't always take the same form and mode, but whether it is as the "new oil" or old spice, the subunits (that is, the splices) of data in this symbolic world of pipelines must always flow.

The Latent Technics: How to Study Infrastructures and History

Even if we were to take seriously (as I am wont to do) Neil Postman's (1985, 3)[17] invocation of the medium as the metaphor or N. Katherine Hayles' (2002, 21–24) "material metaphors," the historical connections enabled and processed by pipelines cannot be solely understood through metaphorical debts and exchanges between domains of society.[18] Nor are these, quite evidently, mere motions of homology across materials. Yes, there are connections and loans, as mentioned above, but there are also moments, like those analyzed in this piece, when the metaphorical maneuvers are misleading, which is to say that there are also divergences and re-fashionings, and yet the metaphors come to matter. These re-fashionings—through which the instruction pipelines of Zuse and graphic pipelines of the 2000s look somewhat distinct from each other, distinct in ways that texturally engage with the world that spawned them—can only be understood through a rigorous historicization, one that does not presuppose a naïve homology or an analogically determinant technicity.[19] In other words, something beyond models of clear causality (linear or immanent) can be traced when we engage with histories of our infrastructures and technologies thus. What is at stake in the collation of episodes and artifacts mentioned above is a sense of the unconscious. Precisely because Real, in the Lacanian sense, "resists symbolization absolutely," (Lacan 1975, 80) and because talking about the world of machines is talking about the world of the symbolic (Kittler 1997a), we run into an impasse that can only be solved by a reconceptualization and a

17 See also in other registers Ricoeur (1987), Stepan (1986), Berman (1989), Boomen (2014), Krajewski (2020), Taffel (2023), and Dumit (2021).

18 It must also be mentioned, though not elaborated on here, that I am not 'merely' dealing with a question of the role of language and metaphors in the architectures of technological development; examining such cases also leads us to examining technological power in all its multivalent manifestations, a task I take up elsewhere.

19 For some of these insights and contradictions, partially in direct dialogue and partially indirectly in intellectual spirit, I thank Bernhard Siegert. Relatedly, see also Dhaliwal and Siegert (2024).

re-litigation of the methodologies of our environments[20] and infrastructures.[21] The impasse is that no historical emergence can be understood as/by itself and that we have nothing but the conceptual transferences (and their micro-inscriptional outcomes) to begin with (see Kittler 1997b).

An elaborate solution to the impasse would need much more ink than I have for this textual encounter of ours—ink that I hope to acquire and spill one day—but allow me to at least sketch its initial basic frameworks. Lacan (1970, 75)[22] once noted that "There are formulas that are unimaginable; at least for a time, they blend with the real." Even for the artifacts in our story, and surely for the actors therein, this history does not provide us a clear narrative "but that, as an absent cause, it is inaccessible to us except in textual form, and that our approach to it and to the Real itself necessarily passes through its prior textualization," which is to say, through its unconscious (Jameson 2015, 35).

By borrowing Jameson's Marxist-Lacanian conception here, I intend to invoke not merely the heterogeneity and processuality[23] that is gleaned through a scholar's engagement—against the hermeneutics of master codes—with such histories of milieux, but also the fact that such engagement can only happen in successive waves of collection and distinction. In other words, to understand the infrastructural unconscious, as I have briefly attempted to do above,[24] is to embark on a methodological search—a search that, like any other, presupposes the presence of some mystification to be firmly addressed through the investigative/interpretative finding exercise—which shall not promise a cure (in the psychoanalytic sense, in which "the dynamics of the unconscious proper rise to the light of day and of consciousness and are somehow 'integrated' in an active lucidity about ourselves and the determinations of our desires and our behavior," [Jameson 2015, 283] for such a cure would be a myth (derogatory) in and of itself) but instead offer heuristics that might help us reckon with these complicated, polyphonic histories of linguistic movement through material and material movement through linguistics. The study of *Darstellung* (re-presentation, account, display) as a modality (in the Althusserian sense, as opposed to linear causality or immanence) in its completely object-ified, interpretive richness here becomes an interpretative imperative if we have to understand the proper historical dynamics of material-semiotic movements between infrastructures, ecologies, politico-economic and

20 See also Jue and Ruiz (2021), Han (2024), Horn (2018), Pourciau (2022), Bao, Gaboury, and Morgan (2023), and Sprenger (2019).

21 See also Star (1999), Edwards et al. (2009), Dhaliwal (2023), Hu (2017), Parks (2015), Furste (2025), Brodie (2023), and Seaver (2021).

22 I draw the Lacanian references here from Jameson (2015, 35).

23 Relatedly, see also Jagoda and Sparrow (2024). And for other (proximate) Jamesonian work in this vein, see Jameson (2023; 2008; 2005), and Liu (2010).

24 Previous iterations include Robbins (2008), Breu (2023), Schröter (2022), and Vandertop (2015).

sociocultural worlds, and technics (Jameson 2015, 13, 23–58). Interpretation of our milieux must not be confused, in other words, with a laying out of causal preconditionalities.[25] And asking questions of the infrastructural unconscious is asking, as the epigraph to this chapter suggests, "How does it work?" (Deleuze and Guattari 1994, 109).

So much for our reckoning with history. What might one say, given these trans-material pipelinings, about the history of reckoning? If the infrastructural unconscious exhorts us to attempt to grasp the moments when our infrastructures become fully sutured with our cognitive and environmental assemblages, then it follows that pipelines present us with one particular instance of what I take to be the general grappling attempt by this collection: reckoning with everything (Siegert 2022). Latent in our medial conditions are entire lifeworlds of re-presentation and material pressures. Reckoning that unfolds in the world is then a question of ossification (Dhaliwal 2025b) and computationalization of infrastructural layouts (like the oil pipelines) on the one hand, and the always already reckoning infrastructure on the other. In other words, what do our reckonings reckon with if not the material-semiotic bases of our infrastructures?

Returning to the opening observation of this chapter—that pipelines can not only carry the base for but also the supposed solution for the havoc wreaked by this fossilized base—through this methodological guardrail, I can now briefly make a few interpretative claims—the elaboration of which may be left as a readerly exercise—that may help us start to understand the infrastructural unconscious of this tale. At the first level is the pipelining as a symbolic *technik*—which is one of the reasons it is in the (organizational) program of symbolization through computation and ecologically mediated reckoning—while at the second level, pipelining appears as a social formation—and slightly different ones in different histories at that, be it the labor politics of mid-19th century industrialism, the assembly lines in the early 20th century, or the supply chains of capitalism of the late 20th century—when analyzed collectively. The third level[26] then—and this one is especially perturbed, even from the originary political unconscious thesis, owing to the linguistic traces that the overuse of the word "pipelining" leaves—marks an ecological moment and demonstrates a broader calculative dimension that coexists with parallelization and flow, one which carries within it the expansions of the parallel of the last few decades along with an espousal of the last gasp of the imperially extractive colonialism of the 19th century; it is here that the duality of the original pipelining from the 1860s finds

25 Full disclosure: I am definitely being, partially and carefully, self-critical here when I say this (Dhaliwal 2022a; 2022b).

26 I should note that these analogical moves are merely the first sketches, or renderings, for my purposes and further expansion and reconsideration would be not only desirable but also necessary.

its expression in the *pharmakological* solutions proposed by the likes of CO2EUROPIPE. But to take one last step, all these sketches here would finally be grasped altogether in this particular fourth intra-pretive horizon, in this mo(ve)ment of methodological transformation, where the subject (be it the reckoner, the owner, the worker, or the critic) finds its collective operations determined by the historical transformations of their observable world, of their infrastructural milieux.

In other words, in this specific case study, we learn that not only do our computers dream—or to be precise, have been caught dreaming—of carbo-silico pipelines, but even our pipelines may be dreaming of carbo-silico computers. Grammars of the material can often surprise us by promising a ride in a time machine, and if we are properly suited up and cognizant of our basal milieux, we can embark on these portals through the wor(l)ds and history. Without a proper apparatus of demystification, however, this dream may remain a pipe dream.

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References

Acland, Charles R., ed. 2007. *Residual Media*. Minneapolis: University of Minnesota Press.

Aegidius, Andreas Lenander. 2021. “The Music Streaming Metaphor and Its Underlying Tangle of Transcodes.” *Popular Communication* 19, no. 1: 42–56.

Ahern, Mal, and Ranjodh Singh Dhaliwal. 2025. “In Focus Introduction: Modes of Visual Production.” *JCMS: Journal of Cinema and Media Studies* 65, no. 1: 156–61.

Alexander, Neta. 2017. “Rage against the Machine: Buffering, Noise, and Perpetual Anxiety in the Age of Connected Viewing.” *Cinema Journal* 56, no. 2: 1–24.

American Carbon Alliance. n.d. “Map of Carbon Pipelines.” Accessed February 10, 2025. https://americancarbonalliance.org/map-of-us-pipelines/.

Angus, Siobhan. 2024. *Camera Geologica: An Elemental History of Photography*. Durham, NC and London: Duke University Press.

Bao, Weihong, Jacob Gaboury, and Daniel Morgan. 2023. “Introduction: Medium/Environment.” *Critical Inquiry* 49, no. 3: 301–14.

Barney, Darin. 2017. “Pipelines.” In *Fueling Culture: 101 Words for Energy and Environment*, edited by Imre Szeman, Jennifer Wenzel, and Patricia Yaeger, 267–70. New York: Fordham University Press.

———. 2018. “Infrastructure.” *Krisis | Journal for Contemporary Philosophy* 38, no. 2: 78–80.
———. 2021. “Infrastructure and the Form of Politics.” *Canadian Journal of Communication* 46, no. 2: 225–46.
Baucom, Ian. 2005. *Specters of the Atlantic: Finance Capital, Slavery, and the Philosophy of History*. Durham, NC: Duke University Press.
Berman, Bruce. 1989. “The Computer Metaphor: Bureaucratizing the Mind.” *Science as Culture 1*, no. 7: 7–42.
Bottomley, Andrew John. 2020. *Sound Streams: A Cultural History of Radio-Internet Convergence*. Ann Arbor: University of Michigan Press.
Breu, Christopher. 2023. “The Infrastructural Unconscious.” *Symploke* 31, no. 1: 183–201.
Brodie, Patrick. 2023. “Data Infrastructure Studies on an Unequal Planet.” *Big Data & Society* 10, no. 1. https://doi.org/10.1177/20539517231182402.
Buse, Katherine. 2021. “How to Build a Planet: Science Fiction, Planetary Science, and the Making of Worlds.” UC Davis. https://escholarship.org/uc/item/5jx344p9.
Castoriadis, Cornelius. 1987. *The Imaginary Institution of Society*. Cambridge, MA: MIT Press.
Chu, Nellie. 2014. “Global Supply Chains of Risks and Desires: The Crafting of Migrant Entrepreneurship in Guangzhou, China.” University of California, Santa Cruz (PhD thesis). https://escholarship.org/uc/item/9262w2km.
CORDIS. European Commission. 2009–2011. “Final Report Summary – CO2EUROPIPE (Towards a Transport Infrastructure for Large-Scale CCS in Europe).” Accessed February 10, 2025. https://cordis.europa.eu/project/id/226317/reporting.
Cuppini, Niccolò, and Mattia Frapporti. 2018. “Logistics Genealogies.” *Social Text* 36, no. 3: 95–110.
Deleuze, Gilles, and Félix Guattari. 1994. *Anti-Oedipus: Capitalism and Schizophrenia*. Minneapolis: University of Minnesota Press.
Dhaliwal, Ranjodh Singh. 2021. “Rendering the Computer: A Political Diagrammatology of Technology.” University of California, Davis (unpublished PhD thesis). https://www.proquest.com/docview/2562796506/DB239305712D40E1PQ/32?sourcetype=Dissertations%20&%20Theses.
———. 2022a. “On Addressability, or What Even Is Computation?” *Critical Inquiry* 49, no. 1: 1–27.
———. 2022b. “The Cyber-Homunculus: On Race and Labor in Plans for Computation.” *Configurations* 30, no. 4: 377–409.
———. 2023. “The Material of Thought: [Fire]Walls, Network Bridges, and Other Infrastructural Philosophies (In)Action.” Public lecture presented at the “Mit allem rechnen. Ökologien von Rechen- bzw. computationalen Praktiken” colloquium, Bauhaus-Universität, Weimar, June 14.
———. 2025a. “An Anti-Racist Camera?: On Politics and Practices of Computational Photography.” *Journal of Cinema and Media Studies* 65, no.1: 183–88.
———. 2025b. “Concretion.: (noun, ?1541 AD – now).” *Basel Media Culture and Cultural Techniques Working Papers* 8: 1–29.
———. 2025c. “The Legality of Logistics: On Techno-Orientalism and Geopolitics in Semiconductor Production.” IEEE Annals of the History of Computing 47, no. 4: 63–77. https://doi.org/10.1109/MAHC.2025.3559418.
———. 2026. “Notes on the Medium of Computation: Biology, Logistics, and Epistemic Re-Actions.” *Configurations* (forthcoming).
Dhaliwal, Ranjodh Singh, and Bernhard Siegert. 2024. “Knowing, Studying, Writing: A Conversation on History, Practice, and Other Doings with Technics.” In *Technics. Media in the Digital Age*, edited by Nicholas Baer and Annie Oever, 125–50. Amsterdam: Amsterdam University Press.
Dumit, Joseph. 2021. “Substance as Method (Shaking Up Your Practice).” In *Experimenting with Ethnography*, edited by Andrea Ballestero and Brit Ross Winthereik, 175–185. Durham, NC: Duke University Press.
Edwards, Paul N., Geoffrey Bowker, Steven Jackson, and Robin Williams. 2009. “Introduction: An Agenda for Infrastructure Studies.” *Journal of the Association for Information Systems* 10, no. 5: 364–74.

Eriksson, Maria. 2018. “Unpacking Online Streams.” *A Peer-Reviewed Journal About* 7, no. 1: 72–84.
Ernst, Wolfgang. 2013. *Digital Memory and the Archive*. Edited by Jussi Parikka. Minneapolis: University of Minnesota Press.
———. 2016. *Chronopoetics: The Temporal Being and Operativity of Technological Media*. Translated by Anthony Enns. London and New York: Rowman & Littlefield International.
Esch, Elizabeth D. 2018. *The Color Line and the Assembly Line: Managing Race in the Ford Empire*. Oakland: University of California Press.
Furste, Zachary Aaron. 2025. “Stuff You Can Click: Sensing Infrastructure with Software Emulation.” *Communication +1* 11, no. 1. https://doi.org/10.7275/cpo.1939.
Galloway, Alexander R. 2010. “Networks.” In *Critical Terms for Media Studies*, edited by William John Thomas Mitchell and Mark B. N. Hansen, 280–296. Chicago and London: University of Chicago Press.
Giessmann, Sebastian. 2024. *The Connectivity of Things*. Translated by Steven Lindberg. Cambridge, MA: MIT Press.
Glissant, Édouard. 2009. *Poetics of Relation*. Ann Arbor: University of Michigan Press.
Han, Lisa Yin. 2024. *Deepwater Alchemy: Extractive Mediation and the Taming of the Seafloor*. Minneapolis: University of Minnesota Press.
Haraway, Donna. 1997. *Modest_Witness@Second_Millennium. FemaleMan_Meets_OncoMouse: Feminism and Technoscience*. New York: Routledge.
Harney, Stefano, and Fred Moten. 2013. *The Undercommons: Fugitive Planning & Black Study*. Wivenhoe/New York/Port Watson: Minor Compositions.
———. 2021a. “1. Habits of Assembly.” In *Assembly Codes*, edited by Matthew Hockenberry, Nicole Starosielski, and Susan Zieger, 23–33. Durham, NC: Duke University Press.
———. 2021b. *All Incomplete*. Colchester/New York/Port Watson: Minor Compositions.
Hayles, N. Katherine. 2002. *Writing Machines*. Cambridge, MA: Mediawork and MIT Press.
Hein, Carola. 2009. “Global Landscapes of Oil.” In *Landscapes of Energy*, edited by Rania Ghosn, 33–43. Cambridge, MA: Harvard University Press.
Hockenberry, Matthew, Nicole Starosielski, and Susan Zieger, eds. 2021. *Assembly Codes: The Logistics of Media*. Durham, NC: Duke University Press.
Holt, Jennifer. 2024. *Cloud Policy: A History of Regulating Pipelines, Platforms, and Data*. Cambridge, MA: MIT Press.
Horn, Eva. 2018. “Air as Medium.” *Grey Room* 73: 6–25.
Hounshell, David A. 1997. *From the American System to Mass Production, 1800–1932: The Development of Manufacturing Technology in the United States*. Baltimore: Johns Hopkins University Press.
Hu, Tung-Hui. 2017. “Black Boxes and Green Lights: Media, Infrastructure, and the Future At Any Cost.” *English Language Notes* 55, no. 1: 81–88.
Humphrey, Robert. 1954. *Stream of Consciousness in the Modern Novel: A Study of James Joyce, Virginia Woolf, Dorothy Richardson, William Faulkner, and Others*. Berkeley and Los Angeles: University of California Press.
Husserl, Edmund. 1991. *On the Phenomenology of the Consciousness of Internal Time (1893–1917)*. Translated by John B. Brough. Dordrecht: Kluwer.
Ingold, Tim. 2016. *Lines: A Brief History*. London and New York: Routledge.
Jacobson, Brian R. 2025. *The Cinema of Extractions: Film Materials and Their Forms*. New York: Columbia University Press.
Jagoda, Patrick. 2016. *Network Aesthetics*. Chicago and London: University of Chicago Press.
Jagoda, Patrick, and Ashlyn Sparrow. 2024. “The Procedural Unconscious: Video Games and the Nonsynchronous Contemporaneity of Racial Capitalism.” *ROMchip* 6, no. 2. https://romchip.org/index.php/romchip-journal/article/view/199.
Jameson, Fredric. 2005. *Postmodernism, or, The Cultural Logic of Late Capitalism*. Durham, NC: Duke University Press.
———. 2008. *The Geopolitical Aesthetic: Cinema and Space in the World System*. Bloomington: Indiana University Press.

———. 2015. *The Political Unconscious: Narrative as a Socially Symbolic Act*. Ithaca: Cornell University Press.

———. 2023. "Schematizations, or How to Draw a Thought." *Critical Inquiry* 50, no. 1: 31–53.

Jasanoff, Sheila, and Sang-Hyun Kim, eds. 2015. *Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power*. Chicago and London: University of Chicago Press.

Jue, Melody, and Rafico Ruiz, eds. 2021. *Saturation: An Elemental Politics*. Durham, NC: Duke University Press.

Kittler, Friedrich A. 1997a. "The World of the Symbolic—a World of the Machine." In *Literature, Media, Information Systems*, edited by John Johnston, 130–46. Amsterdam: G+B Arts International.

———. 1997b. "There Is No Software." In *Literature, Media, Information Systems*, edited by John Johnston, 147–55. Amsterdam: G+B Arts International.

Krajewski, Markus. 2020. "The Coffee Machine: Potent Mercantile Metaphors of the Programming Language JAVA." *Basel Media Culture and Cultural Techniques Working Papers*, no. 3: 1–22.

Lacan, Jacques. 1970. "Radiophonie." *Scilicet*, no. 2/3: 55–99.

———. 1975. *Le Seminaire, Livre I. Les Ecrits Techniques de Freud*. Paris: Seuil.

Liu, Lydia H. 2010. "The Cybernetic Unconscious: Rethinking Lacan, Poe, and French Theory." *Critical Inquiry* 36, no. 2: 288–320.

Milburn, Colin. 2008. *Nanovision: Engineering the Future*. Durham, NC: Duke University Press.

Mitchell, Timothy. 2011. *Carbon Democracy: Political Power in the Age of Oil*. London and New York: Verso.

Mr Consul Stevens. 1906. "Report for the Year 1905 on the Trade and Commerce of Batoum and District." United Kingdom Parliamentary Papers, House of Commons. Vol. cxxvii, Command Paper 2682, no. 3566.

Noble, David F. 1995. *Progress Without People: New Technology, Unemployment, and the Message of Resistance*. Toronto: Between the Lines.

Nye, David E. 2013. *America's Assembly Line*. Cambridge, MA: MIT Press.

Offert, Fabian, and Ranjodh Singh Dhaliwal. 2024. "The Method of Critical AI Studies, A Propaedeutic." *arXiv*. https://doi.org/10.48550/ARXIV.2411.18833.

Parikka, Jussi. 2015. *A Geology of Media*. Minneapolis and London: University of Minnesota Press.

Parks, Lisa. 2015. "'Stuff You Can Kick': Toward a Theory of Media Infrastructures." In *Between Humanities and the Digital*, edited by Patrik Svensson and David Theo Goldberg, 355–74. Cambridge, MA: MIT Press.

Peters, John Durham. 2020. "Calendar, Clock, Tower." In *Deus in Machina: Religion and Technology in Historical Perspective*, edited by Jeremy Stolow, 25–42. New York: Fordham University Press.

Postman, Neil. 1985. *Amusing Ourselves to Death: Public Discourse in the Age of Show Business*. New York: Viking.

Pourciau, Sarah. 2022. "On the Digital Ocean." *Critical Inquiry* 48, no. 2: 233–61.

Pringle, Thomas Patrick. 2022. "Streaming Is Doing: The Environmental Impact of Digital Media and the Ecosystem Service Economy." *Spectator* 42, no. 2: 8–18.

Rhee, Jennifer. 2018. *The Robotic Imaginary: The Human and the Price of Dehumanized Labor*. Minneapolis: University of Minnesota Press.

Ricoeur, Paul. 1987. *The Rule of Metaphor: The Creation of Meaning in Language*. London: Routledge.

Robbins, Bruce. 2008. "Infrastructure as Political Unconscious." *The Minnesota Review* 2008, no. 70: 207–13.

Rossiter, Ned. 2015. "Locative Media as Logistical Media: Situating Infrastructure and the Governance of Labor in Supply-Chain Capitalism." In *Locative Media*, edited by Gerard Goggin and Rowan Wilken, 208–23. New York: Routledge.

Sconce, Jeffrey. 2005. *Haunted Media: Electronic Presence from Telegraphy to Television*. Durham, NC: Duke University Press.

Schröter, Jens. 2022. “Is There a Political Unconscious in Technology?” *Revista Guillermo de Ockham* 20, no. 2: 297–303.

Seaver, Nick. 2021. “Seeing like an Infrastructure: Avidity and Difference in Algorithmic Recommendation.” *Cultural Studies* 35, no. 4–5: 771–91.

Siegert, Bernhard. 1999. *Relays: Literature as an Epoch of the Postal System*. Translated by Kevin Repp. Stanford: Stanford University Press.

———. 2022. “The Map Is the Territory – Dissolving the Barrier between Media and Nature.” *Spark Magazine: A NOMIS Foundation Publication*: 16–22.

Sobchack, Vivian. 2016. “The Scene of the Screen: Envisioning Photographic, Cinematic, and Electronic ‘Presence.’” In *Post-Cinema: Theorizing 21st-Century Film*, edited by Shane Denson and Julia Leyda, 88–128. Falmer: REFRAME Books.

Sprenger, Florian. 2015. *The Politics of Micro-Decisions: Edward Snowden, Net Neutrality, and the Architectures of the Internet*. Translated by Valentine A. Pakis. Lüneburg: meson press.

———. 2019. *Epistemologien des Umgebens: Zur Geschichte, Ökologie und Biopolitik künstlicher environments*. Bielefeld: transcript.

Star, Susan Leigh. 1999. “The Ethnography of Infrastructure.” *American Behavioral Scientist* 43, no. 3: 377–91.

Stepan, Nancy Leys. 1986. “Race and Gender: The Role of Analogy in Science.” *Isis* 77, no. 2: 261–77.

Suchman, Lucy. 2007. *Human-Machine Reconfigurations: Plans and Situated Actions*. Cambridge: Cambridge University Press.

Taffel, Sy. 2023. “Data and Oil: Metaphor, Materiality and Metabolic Rifts.” *New Media & Society* 25, no. 5: 980–98.

Tay, Rachel. 2025. “Notes on the Streaming Metaphor.” *Communication +1* 11, no. 1. https://doi.org/10.7275/cpo.2108.

The CO2Europipe Project. 2009–2011. Accessed February 10, 2025. https://www.co2europipe.eu/.

Tollefson, Hannah, and Darin Barney. 2019. “More Liquid than Liquid: Solid-Phase Bitumen and Its Forms.” *Grey Room* 77: 38–57.

Tsing, Anna Lowenhaupt. 2009. “Supply Chains and the Human Condition.” *Rethinking Marxism* 21, no. 2: 148–76.

———. 2016. “What Is Emerging? Supply Chains and the Remaking of Asia.” *The Professional Geographer* 68, no. 2: 330–37.

———. 2021. *The Mushroom at the End of the World: On the Possibility of Life in Capitalist Ruins*. Princeton and Oxford: Princeton University Press.

van den Boomen, Marianne. 2014. *Transcoding the Digital: How Metaphors Matter in New Media*. Amsterdam: Institute of Network Cultures.

Vandertop, Caitlin. 2015. “Travel Literature and the Infrastructural Unconscious.” In *New Directions in Travel Writing Studies*, edited by Julia Kuehn and Paul Smethurst. London: Palgrave Macmillan.

Yergin, Daniel. 1991. *The Prize: The Epic Quest for Oil, Money, and Power*. New York: Simon & Schuster.

Young, Liam Cole. 2020. “Salt: Fragments from the History of a Medium.” *Theory, Culture & Society* 37, no. 6: 135–58.

Zielinski, Siegfried. 2006. *Deep Time of the Media: Toward an Archaeology of Hearing and Seeing by Technical Means*. Translated by Gloria Custance. Cambridge, MA: MIT Press.

Zubaroğlu, Alaettin, and Volkan Atalay. 2021. “Data Stream Clustering: A Review.” *Artificial Intelligence Review* 54, no. 2: 1201–36.

Zuse, Konrad. 1962. Rechenmaschine zur Durchführung von arithmetischen Rechenoperationen. Deutsches Patentamt 975966, filed July 8, 1949 and issued December 6, 1962.

DIGITAL COMPUTATION

COMPUTABILITY

TURING COMPLETENESS

COMPUTABLE NUMBERS

ENTSCHEIDUNGSPROBLEM

SERRES

PARASITE

INCOMPLETENESS

LOSS

[1 0]

Turing Incompleteness: Reckoning with Loss in Digital Computation

Moritz Hiller

The becoming environmental of the digital does not proceed without friction. This article argues that digital computation rests on a constitutive incompleteness—a structural condition of loss. To make this claim legible, it first turns to Michel Serres' figure of the "parasite," which theorizes an asymmetrical exchange between the logicial and the material, unsettling the ideal of perfectly balanced systems immune to entropy. Second, it examines the fragmented textual history of Alan Turing's *Computable Numbers*, and in particular the striking absence of any original autographs or typescripts. This absence, I propose, prefigures the transition from textual abstraction—programming—to empirical computation, in which logical form yields to material instantiation. The incompleteness of the *Computable Numbers*, then, is not an accident but the very premise of computational universality—what has come to be

known as “Turing completeness.” Against the fantasy of a seamlessly ubiquitous digital, this article follows Serres: it works because it doesn’t work. To reckon with the digital is to reckon with loss.

It is not a miracle but it is true, perhaps the only true perpetual motion. The more one writes, the more one writes. — Michel Serres

It would have been too good to be true. Just once, this story deserved to be told differently. It should not have begun, as it so often does, on the green meadows south of Cambridge. Not with a 22-year-old fellow of King’s College lying on the grass, dreaming, in the early summer of 1935. Not with a lecture by a certain Professor Newman, where the young fellow had just encountered the unresolved question of mathematics’ decidability. Not with the professor’s idiosyncratic talk of a “*mechanical process*” that might offer a solution to Hilbert’s infamous *Entscheidungsproblem*. Not with Newman’s machine metaphors stirring dreams of typewriters in the mind of a student whose childhood had been marked by a losing battle with fountain pens—there, on the mythical Grantchester Meadows. And finally, not with the fact that it was this very machine dream that would go on to usher in our computer age.[1]

Instead, this story would have simply begun with Alan M. Turing sitting at a typewriter, typing. In the end, of course, it would still have led to the text published in 1936 under the title *On Computable Numbers, with an Application to the Entscheidungsproblem* (Turing 1937)—the paper that, as the story goes, was initially overlooked but would go on to become one of the decisive contributions to 20th century mathematics and the foundation of theoretical computer science. But that would already belong to another story. The story told here, by contrast, would have been one of a writing process. Nothing more—and nothing less. For it is remarkable: much has been written about this text, which proposes an empirically impossible typewriter to offer what Gödel would later call an “absolute definition” of general computability (Gödel 1965, 84), defining the computable as that which can be written down by this machine. Yet not a word has been said about the simple fact that this text itself is something written down by a machine. *On Computable Numbers* is marked by a curious self-referentiality: its writing is itself computational

1 For the original version of this story, which continues to serve as the source text for all subsequent retellings, see Hodges (1983, 93–110).

proof that all computation is writing. And so, the process of writing this text, its product, and the loop of self-reference that binds them, may reveal something more fundamental about what we might call the defining writing process of our age: the becoming-environmental of digital computation, an infrastructure increasingly blending into the background of our everyday lives. To tell this story, then—the story of the genesis of the *Computable Numbers*, the emergence of a concept of computability, and thus the beginning of our computer age, marked by the ever-deepening entanglement of computation with our environment—would be, at least once, to make its subject the portrayal of a machinic act of typescript production.

The Archival Gap

But that, for now, is not going to happen. Simply because there is almost nothing that can be said about the actual writing process that led to the *Computable Numbers*. What little is known comes from Turing's definitive biography—its author piecing the details together from two letters Turing wrote to his mother, Sara Turing. These fragments concern primarily the six-week period between the completion of the text and its arrival at the offices of the London Mathematical Society, which would go on to publish *Computable Numbers* in its *Proceedings*. After returning to Cambridge from his Easter vacation in mid-April 1936, Turing handed Newman a "draft typescript" of the paper. But, as Turing reports to his mother on May 4, his professor is a very busy man and has not yet had time to attend to Turing's "theory." Finalizing the draft into a definitive version—about 50 pages of typescript—will, Turing estimates, take another fortnight or more. Newman finally reads the draft in mid-May, after which Turing completes the text, submits the typescript, and notifies his mother on May 29 (Hodges 1983, 109–113).

That is all. The rest remains in darkness, a gaping absence: what writing process produced the draft that Newman held in his hands in April 1936 is entirely unclear. Any earlier stages—be they handwritten or typed—as well as additional mentions in Turing's correspondence from 1935 and 1936, are simply unavailable. The two typescripts known to have existed—Newman's draft and the version submitted for publication on May 28—are no longer extant. Whether they differed, and if so, how; what relation they bore to the printed version; how many other variants may have existed or might still survive—none of this can be answered given the current archival situation. "Turing's paper is quite notable for the absence of drafts or preliminary work," Hodges confirmed.[2]

The diagnosis of absence also applies to the mechanical typewriter that—at least once—put Turing's *Computable Numbers* to paper. That such a machine

2 E-mail to MH, May 4, 2022.

must have existed is attested by the only known archival trace from Turing's own hand connected to the text. At the Archive Centre of King's College, which holds the largest portion of Turing's scattered estate, six undated sheets of paper have been preserved. According to the catalogue, each sheet contains Turing's handwritten—and fragmentary—*Note on Normal Numbers* on one side, and on the other, the typewritten "draft" of another, as yet unidentified, text.[3] A comparison with the printed version quickly reveals that these six sheets correspond to pages 28, 29, 42, 43, 45, and 46 of a typescript version of the *Computable Numbers*. Which version, exactly, remains unclear. What can be said is that there are passages where the wording diverges from the one published in the *Proceedings*. These six sheets are identified in the archival catalogue solely by their handwritten versos—the side considered their primary content. Finding them as textual witnesses of the *Computable Numbers* is left entirely to chance. And to reconstruct the story of this text's production from its surviving material traces is, quite simply, impossible. It is the story of an incompleteness—as though the *Computable Numbers*, both the text and the very concept of computability it helped define, tied so closely to what we now call digital computation, had somehow just appeared in the world.

Le Précis

Testifying to this very incompleteness is, paradoxically enough, another artifact in the King's College collection. The catalogue lists a typescript that, while not originating from Turing's own hand, is nevertheless connected to the *Computable Numbers* and their genesis.[4] The typescript itself—acquired by the archive in June 1960 from the estate of Turing's mother—bears neither date nor authorship. Instead, it presents a tangled chain of textual self-designation: above the text, the words "Copy of first rough draft of précis of 'Computable Numbers' made for 'Comptes Rendues' [sic]" appear. Only the archive catalogue reveals that this copy was made by Sara Turing.

Biographical sources tell us that Turing, likely in the spring of 1936, prepared an abridged version of a text (though he never specified which) for the esteemed journal of the Académie des Sciences. How the idea of such a publication arose, and who established the possible contact between Turing and *Comptes rendus*, remains unclear. The abridged version is first mentioned in a letter to his mother dated May 4, in which Turing reports that Newman—who had not yet found time to fully review the draft typescript of the *Computable*

3 See "A note on normal numbers," 1930–1954; Archive Centre, King's College, Cambridge. File Reference Code: GBR/0272/AMT/C/15. The object is cataloged as follows: "TS [Typescript] and AMS [Autograph Manuscript], 'A note on normal numbers.' AMS written on back of TS draft of another paper. n[o].d[ate]."

4 See "Copy of a précis of 'Computable Numbers,'" 1954–1960; Archive Centre, King's College, Cambridge. File Reference Code: GBR/0272/AMT/K/4.

Numbers—had at least examined his "note for C.R." This note Turing then sent to *Comptes rendus* with his professor's approval. To his great annoyance, however, no confirmation of receipt followed.

And the matter would remain a source of frustration. In a letter dated May 29—after the final version of *Computable Numbers* had already been sent to the London Mathematical Society—Turing informs his mother of a series of unfortunate events:

> The situation with regard to the note for Comptes Rendus was not so good. It appears that the man I wrote to, and whom I asked to communicate the paper for me had gone to China, and moreover the letter seems to have been lost in the post, for a second letter reached his daughter. (Quoted in Hodges 1983, 113)

The circumstances surrounding the writing and failed publication of this "note for *Comptes Rendus*" remain shrouded in mystery. To begin with, the role Sara Turing played in producing the text is unclear. In her 1959 memoir about her son, she recalls:

> Though he must have known that I could follow him only in a fog, [Alan] liked to share his projects with me even in a very limited measure. … However, despite my defects, we embarked together on a précis in French of 'Computable Numbers' for Comptes Rendues [sic]. After Professor M. H. A. Newman had kindly vetted it and suggested some alterations, a French expert checked it. (Turing 2012 [1959], 47)

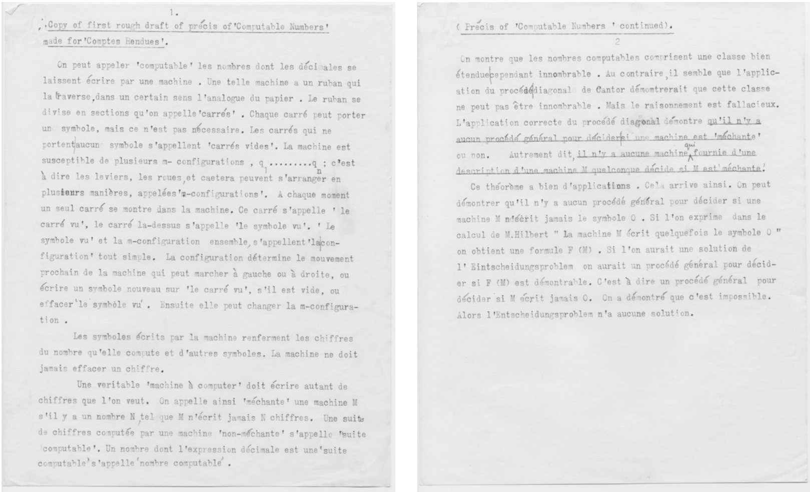
While it is certainly possible that Turing presented Newman with a French text, this option seems unlikely at first glance. This also raises the question of whether the French version was preceded by an English abstract of *Computable Numbers*.[5] Finally, who were the man who disappeared to China, and his daughter who at least received one of Turing's letters?

The French "précis," "made for Comptes Rendues" [sic], as far as we know, never reached its destination.[6] Sara Turing's typewritten "copy of [a] rough draft" remains its only textual witness. It is also the sole surviving paratext of the *Computable Numbers*, once again testifying to the incompleteness of their textual genesis and transmission. Reason enough, perhaps, to document this incompleteness at least by reproducing the Cambridge typescript as a facsimile, accompanied by an English translation.[7] Both must be approached with

5 Yet, as Hodges notes, Turing had already begun using French as a "secret code" in correspondence with his family at the age of twelve (Hodges 1983, 16).

6 The extent to which this assumption constitutes a fallacy is demonstrated by Lacan (1988 [1978], 191–205).

7 The transcription reproduced here follows the first complete English translation by Copeland and Fan (2022). Formal peculiarities in the typescript have been harmonized with the formatting of this volume; quotation marks were standardized and underlined



1.

Copy of first rough draft of précis of 'Computable Numbers' made for 'Comptes Rendues'.

On peut appeler 'computable' les nombres dont les décimales se laissent écrire par une machine . Une telle machine a un ruban qui la traverse, dans un certain sens l'analogue du papier . Le ruban se divise en sections qu'on appelle 'carrés' . Chaque carré peut porter un symbole, mais ce n'est pas nécessaire. Les carrés qui ne portent aucun symbole s'appellent 'carrés vides'. La machine est susceptible de plusieurs m- configurations , q_1.........q_n ; c'est à dire les leviers, les roues, et caetera peuvent s'arranger en plusieurs manières, appelées 'm-configurations'. A chaque moment un seul carré se montre dans la machine. Ce carré s'appelle ' le carré vu', le carré la-dessus s'appelle 'le symbole vu'. ' Le symbole vu' et la m-configuration ensemble, s'appellent 'la con-figuration' tout simple. La configuration détermine le mouvement prochain de la machine qui peut marcher à gauche ou à droite, ou écrire un symbole nouveau sur 'le carré vu', s'il est vide, ou effacer 'le symbole vu' . Ensuite elle peut changer la m-configura-tion .

Les symboles écrits par la machine renferment les chiffres du nombre qu'elle compute et d'autres symboles. La machine ne doit jamais effacer un chiffre.

Une veritable 'machine à computer' doit écrire autant de chiffres que l'on veut. On appelle ainsi 'méchante' une machine M s'il y a un nombre N, tel que M n'écrit jamais N chiffres. Une suite de chiffres computée par une machine 'non-méchante' s'appelle 'suite computable'. Un nombre dont l'expression décimale est une 'suite computable' s'appelle 'nombre computable' .

(Précis of 'Computable Numbers ' continued).

2

On montre que les nombres computables comprisent une classe bien étendue cependant innombrable . Au contraire, il semble que l'applic-ation du procédé diagonal de Cantor démomtrerait que cette classe ne peut pas être innombrable . Mais le raisonnement est fallacieux. L'application correcte du procédé diagonal démontre qu'il n'y a aucun procédé général pour décider si une machine est 'méchante' ou non. Autrement dit, il n'y a aucune machine, qui fournie d'une description d'une machine M quelconque décide si M est 'méchante'.

Ce théorème a bien d'applications . Cela arrive ainsi. On peut démontrer qu'il n'y a aucun procédé général pour décider si une machine M n'écrit jamais le symbole 0 . Si l'on exprime dans le calcul de M.Hilbert " La machine M écrit quelquefois le symbole 0 " on obtient une formule F (M) . Si l'on aurait une solution de l' Eintscheidungsproblem on aurait un procédé général pour décid-er si F (M) est démontrable. C'est à dire un procédé général pour décider si M écrit jamais 0. On a démontré que c'est impossible. Alors l'Entscheidungsproblem n'a aucune solution.

[Figure 1] The typescript of Sara Turing's copy of the "précis," spanning two sheets of paper (Source: Archive Centre, King's College, Cambridge. File Reference Code: AMT/K/4. Reprinted with the College's kind permission.)

caution: for now, it remains impossible to say with absolute certainty what relationship exists between the text of the *Computable Numbers* and the text formulated as a "note for *Comptes Rendus*" in the spring of 1936. The text of "précis," in English translation, reads as follows:

> One can call the numbers whose decimals can be written down by a machine "computable." Such a machine has a tape, in some ways analogous to paper, running through it. The tape is divided into sections called "squares." Each square can bear a symbol, but this is not necessary. The squares that bear no symbol are called "blank squares." The machine is capable of several m-configurations, q_1.........q_n; i.e. levers, wheels, et cetera can be arranged in several ways, called "m-configurations." At any moment only one square appears in the machine. This square is called "the viewed square," the symbol[8] on it is called "the viewed symbol." "The viewed symbol" and the m-configuration together are called simply "the configuration." The configuration determines the next motion of the machine which can go to the left or to the right, or write a new symbol on "the viewed square," if it is empty, or erase "the viewed symbol." Then it can change the m-configuration.

passages of the original rendered in italics. Excerpts from the "précis" had previously been published in English by Copeland and Shagrir (2011) and Corry (2017). For its first German translation, see Hiller (2023).

8 An obvious typographical error in the original—"le carré la-dessus"—has been corrected.

> The symbols written by the machine include the figures of the number that it is computing and other symbols. The machine must never erase a figure.
>
> A veritable "computing machine" must write as many figures as one wants. Thus one calls a machine M "méchante" [literally "nasty" or "naughty"][9] if there is a number N such that M never writes N figures. A sequence of figures computed by a "non-méchante" machine is called a "computable sequence." A number whose decimal expression is a computable sequence is called a "computable number."
>
> We show that the computable numbers comprise a quite broad yet enumerable[10] class. It seems, on the contrary, that the application of Cantor's diagonal process would demonstrate that this class cannot be enumerable. But the reasoning is fallacious. The correct application of the diagonal process shows *there is no general process for deciding whether a machine is "méchante" or not*. In other words, *there is no machine which supplied with a description of any machine M decides whether M is "méchante."*
>
> This theorem has many applications. This comes about as follows. It can be shown that there is no general process for deciding whether a machine M never writes the symbol 0. If "Machine M sometimes writes the symbol 0" is expressed in Hilbert's calculus, a formula F(M) is obtained. If one had a solution of the Entscheidungsproblem one would have a general process for deciding whether F(M) is provable. That is to say a general process for deciding whether M ever writes 0. It has been shown that this is not possible. Therefore the Entscheidungsproblem has no solution.

Parasitic Computability

Beyond a number of instructive terminological variations—relevant to the history of knowledge of mathematics and logic[11]—the "précis" is striking for its clarity on a point where the printed version remains famously ambiguous. This ambiguity has, time and again, sparked foundational debates in philosophy and media theory alike: the question of the computing subject. That is, who—or what—stands at the center of the *Computable Numbers*, of its definition of

9 In the print version, such a "naughty" machine is termed "circular" and its counterpart "circle-free" (Turing 1937, 233 & 246–248). To preserve the suggestive semantics of misbehavior, it seems appropriate to retain the glinting ambiguity of the French term here.

10 The French original refers to the class of computable numbers as "innombrable"—uncountable—which is inconsistent in this context and has been corrected here and in what follows.

11 Copeland and Fan, for example, aim to demonstrate—particularly with reference to the "précis"—that the so-called standard story in the historiography of mathematics, according to which Gödel's incompleteness theorems provided the conceptual model for Turing's *Computable Numbers*, is ultimately untenable (Copeland and Fan 2022).

computability, and of its negative answer to Hilbert's *Entscheidungsproblem*? Human beings or machines? And what does this reveal about the supposed solidity of the boundary between them? In the "précis," the question simply does not arise. There is no reference to humans performing calculations in proto-mechanical fashion, thereby being likened to a machine. No mention of their writing instruments or mental operations—topics the printed version discusses at length. Instead, the text speaks directly of "machine[s] à computer"—actual calculating machines—whose wheels and levers (conspicuously absent in the printed version) must be configured, quite literally, in a specific way to write down symbols.

The first sentence of the printed version defines the computable numbers "briefly as the real numbers whose expressions as a decimal are calculable by finite means" (Turing 1937, 230). This formulation leaves room for interpretation regarding the subject of computation, a space that the text's intricate argumentation then proceeds to navigate: a human performing a calculation can be compared to a specific machine, which in turn may be empirically modeled after that human. By contrast, the "précis" offers an unequivocal formulation: computable are those numbers "whose decimals can be written by a machine." Modeling the machine in the image of the—calculating—human is not the aim of this text. Wittgenstein's well-known remark that "Turing's 'Machines'" are in fact "humans who calculate" (Wittgenstein 1980, 191e) loses its textual grounding—at least when viewed through the lens of the mechanical writing practice of a computing machine or the computational practice of a writing machine, presented in the brief summary of the *Computable Numbers*.

And the story of a typescript and its writing process that was meant to be told here? In the context of ongoing debates about the relationship between mathematical symbols and the forms they represent, Michel Serres once remarked that every act of writing exposes an—essential—form to the dangers of cacography, to the intrusion of noise, whether essential or accidental. And that the act of formalization, in particular, must proceed from an ideal: a communication between two entities, cleared of interference "in an optimal manner." To formalize, Serres (1982, 68–69) writes in 1968, "means to become aware of the fact that mathematics is the kingdom that admits only the absolutely unavoidable noise, the kingdom of quasi-perfect communication, … the kingdom of the excluded third man, in which the demon is almost definitively exorcised." It is only through this elimination of the empirical—through removing the material substrate in which distortion, interference, and loss reside, and through purifying the mathematical symbol of the graphic sign so as to evoke the ideal form—that the "*Universal in itself*" (Serres 1982, 69) becomes possible in a formal sense. From this notion of universality spring (by negation) Turing's concept of computability and (by affirmation) superficial accounts of seamless, ubiquitous digitality, claiming utopian imaginaries of computation's becoming-environmental.

Yet the demon of noise, that third party—what Serres (1982 [1980]) would later call the "parasite"—can never be fully cast out. Everything written down is eventually lost. There is no way around that. And this inevitable loss, this empirical fact, underlies the impossibility of an actual machine with infinite memory—an impossibility that conditions any real-world implementation of the universal Turing machine as we know it. It is precisely because the "*Universal in itself*" is impossible that empirical computation becomes possible.[12] The losing deal of writing it down is computation's prerequisite. This speaks to the asymmetrical exchange Serres (1982 [1980], 23) describes—"voice for matter, (hot) air for solid, superstructure for infrastructure." It is the parasite, he writes, who "invented the exchange of material for logicial" (210). Nowhere is this more evident than in digital computation, which operates fundamentally on this parasitic principle. As Dotzler (2006, 21) notes, reflecting on the history of technology, it is "the particularity of the computer as a medium that it does not exist alongside the text it generates." Rather, unlike all other media, the digital computer is "defined by the fact that it executes … what it is produced by" (21). This "operative self-devouring" of its own programming—first made technically effective with the Turing machine—marks the *Computable Numbers*, "techno-logy-historically," as an absolute *Zäsur*, a turning point (Dotzler 2006, 93). When it comes to computation, then you have to reckon with everything—including, and perhaps especially, with loss.

The "précis" of uncertain provenance stands as the true symbol of this turning point—and of the parasitic nature of digital computation. As an archival artifact, it does not represent the successful transmission of a text but rather the loss of the typescript production that the *Computable Numbers* once were, and by which they were once produced. The self-devouring of its own programming—an act of writing in which inscription and fabrication of a machine become one and the same—applies not only to what the *Computable Numbers* describe: the informatic concept of the Turing machine, as well as the physical computers for which it became the theoretical foundation. It applies equally to the very piece of writing the *Computable Numbers* themselves once were—a piece of writing that, for the first time, conceived the very notion they define mathematically. The *Computable Numbers* do not merely express the computability-theoretical condition of possibility for this autophagic process—they are its inaugural programming, its first execution. And so, they must, by necessity, fall victim to it. This is not science poetry; it is, as Serres and the parasite remind us, basic physics: the *Computable Numbers* are computable only because they were written down and thus subject to an entropic process. This is the parasitic exchange, the inevitable reckoning: logic in return for matter.

12 On the mirrored (im)possibility of formal and empirical machines, see Vagt (2022).

Computation has always had to reckon with the parasite. Reckoning itself, in this sense, is always *para*-reckoning: the calculation of loss and lossy calculation. The absence of the *Computable Numbers* may be disappointing. But it is also the inescapable and profoundly productive symptom of their empirical effectiveness. Their material incompleteness is the necessary condition of computational universality—what is known today in computability theory as Turing completeness.[13]

That the *Computable Numbers* are materially incomplete is also symptomatic of a deeper fact: that even—and especially—the becoming environmental of digital computation, however ubiquitous and globally networked, can only proceed under the condition that something has always already been lost, and something will inevitably be lost again. And so, despite—or perhaps because of—this disappointment, the writing process of the *Computable Numbers*, its product, and the autophagic self-reference that links the two still reveal something essential about the thermal process by which computational infrastructures are fusing with the background of our lived environment—driving up its entropy in the process. Such systems, Serres (1982 [1980], 12–13) reminds us, are "often described as a harmony." And:

> Maybe it's the same word, the same thing. In fact, what use is it to discuss matters, what use is it to be concerned with a system in disequilibrium, a system that does not function right? Yet we know of no system that functions perfectly, that is to say, without losses, flights, wear and tear, errors, accidents, opacity—a system whose return is one for one, where the yield is maximal, and so forth. Even the world itself does not work quite perfectly. The distance from equality, from perfect agreement, is history. Everything happens as if the following proposition were true: it works because it does not work.

The becoming environmental of the digital, too, proceeds with friction. It cannot be perfect, never fully symmetrical, never fully just. Someone, somewhere, will have to foot the bill left behind by the *Computable Numbers*.

This incompleteness was always to be reckoned with—as if the *Computable Numbers*, as if digital computation itself, had somehow just appeared in the world. And so, the story of this writing process would, at last, have been told—completely.

13 One might ask whether Serres' theory of the parasite offers yet another negative answer to Hilbert's *Entscheidungsproblem*—one grounded not in logic, but in physics. If so, the universal machine envisioned by Turing, capable of determining whether any given machine is "méchante" or not, becomes possible on the condition that the universe did not tend irreversibly toward thermodynamic equilibrium and, eventually, final heat death. In other words: mathematics would be decidable in Hilbert's sense—if loss were not a factor to be reckoned with.

References

Copeland, B. Jack, and Zhao Fan. 2022. "Did Turing Stand on Gödel's Shoulders?" *The Mathematical Intelligencer* 44, no. 1: 1–12.

Copeland, B. Jack, and Oron Shagrir. 2011. "Do Accelerating Turing Machines Compute the Uncomputable?" *Minds and Machines* 21, no. 2: 221–39.

Corry, Leo. 2017. "Turing's Pre-War Analog Computers: The Fatherhood of the Modern Computer Revisited." *Communications of the ACM* 60, no. 8: 50–58.

Dotzler, Bernhard J. 2006. *Diskurs und Medium: Zur Archäologie der Computerkultur*. Paderborn and München: Fink.

Gödel, Kurt. 1965. "Remarks before the Princeton bicentennial conference on problems in mathematics –1946–." In *The Undecidable. Basis Papers on Undecidable Propositions, Unsolvable Problems and Computable Functions*, edited by Martin Davis, 84–88. New York: Raven Press.

Hiller, Moritz. 2023. "Turing-Unvollständigkeit." In *Staunen—Rechnen—Rätseln. Explorationen des Medialen*, edited by Vera Bachmann, Michael Fleig, Christiane Heibach, Solveig Ottmann, et al., 197–206. Bielefeld: transcript.

Hodges, Andrew. 1983. *Alan Turing: The Enigma*. New York: Simon & Schuster.

Lacan, Jacques. 1988 [1978]. *The Seminar of Jacques Lacan, Book 2: The Ego in Freud's Theory and in the Technique of Psychoanalysis, 1954–1955*. Cambridge: Cambridge University Press.

Serres, Michel. 1982. *Hermes: Literature, Science, Philosophy*. Baltimore and London: The Johns Hopkins University Press.

Serres, Michel. 1982 [1980]. *The Parasite*. Baltimore and London: The Johns Hopkins University Press.

Turing, Alan M. 1937. "On Computable Numbers, with an Application to the Entscheidungsproblem." *Proceedings of the London Mathematical Society* 42, no. 1: 230–265.

Turing, Sara. 2012 [1959]. *Alan M. Turing*. Cambridge: Cambridge University Press.

Vagt, Christina. 2022. "Impossible Possible Machines." *communication +1* 9, no. 1. https://doi.org/10.7275/eqpf-ye66.

Wittgenstein, Ludwig. 1980. *Remarks on the Philosophy of Psychology*, Vol. 1, edited by G. E. M. Anscombe and G. H. von Wright, translated by G. E. M. Anscombe. Oxford: Basil Blackwell.

LIFE-WORLDS OF COMPUTATION

UBIQUITOUS COMPUTING

LIFEWORLD

PHENOMENOLOGY

HUSSERL

REAL-TIME ANALYSIS

CULTURAL TECHNIQUES

COMPUTATIONAL ENVIRONMENTS

[1 1]

Dead Time and Lifeworld: The Present Tense of Ubicomp

Bernhard Siegert

Since its inception, the concept of ubiquitous computing ("ubicomp") has been linked to the idea of the lifeworld, into whose fabric ubicomp was to be seamlessly woven. What is missing in most discussions of ubicomp, though, is not only a consideration of the inner structure of the lifeworld, but also of the consequences that the aporias of phenomenology, which Husserl himself had to acknowledge in *The Origin of Geometry*, must necessarily have for the nature of the relationship between ubicomp and the lifeworld. This chapter therefore reconsiders those aporias in order to demonstrate that they form the conditions of possibility of ubicomp. It is shown that there is (and never has been) no non-technologized lifeworld. Hence, what distinguishes Husserl's *Lebenswelt* from the world of ubicomp is that the fusion of prosthetic tertiary retention and prosthetic tertiary protention is processed in real time in ubicomp

environments. Therefore it can be concluded that the delay or “dead time”—without which there would be no real-time analysis—is the hardwired correlate to the original delay which constitutes the heart of the present tense of ubicomp.

That is, it wasn’t going very far to say the words with which I momentarily dumbfounded my audience: I am thinking where I am not, therefore I am where I am not thinking. — Jacques Lacan

The question of writing is more relevant than ever in the second quarter of the 21st century, as it is more questionable than ever where and how “writing” exists and “writing” happens. Writing did not first migrate to environments when environments became digitalized and computerized. The fact that environments have always played a role in the writing of a subject has been discussed and extensively researched since writing came to be regarded as an authorless cultural technique (see Siegert and Vogl 2003; Vismann 2000). However, ubiquitous and networked always-on computing forces us to consider the environmentalization of cultural techniques and the technologization of environments under new conditions. Nietzsche’s insight, gained from a typewriter, that “our writing materials contribute their part to our thinking” (see Kittler 1990, 193, 196) must be radically expanded under the conditions of environmental always-on computing. Since the writing tool is a typewriter that is “Turing-complete,” meaning a computer that can calculate everything that can be calculated using an algorithm, what this writing tool contributes to is no longer mere contents of consciousness (such as Nietzsche’s thoughts), but the entire unconsciously anticipated “lifeworld.” Such a machine is at its core still a writing device, because everything a Universal Turing Machine does is, in principle, reading, writing, and deleting, so that with Turing, the computable as such could be defined as that which can be written down by a machine (see Hiller in this volume). Applied to our situation since the 1990s, this means that our computational tools contribute to the activation of objects in our consciousness in such a way that these objects increasingly become “ideal” objects—in the sense that they are optimally handed down, reactivable, and predictable, which in turn means that they are effects of computation, that they therefore exist in the form of commodities, or, in a word coined by Adam Greenfield (2006): *everyware*. *Reckoning With Everything* also means having to reckon with the fact that all the reckoning around us that reckons without us is contributing to our reckoning.

Seamlessness

The transformation of the cultural technique of calculating into computation compels us to rethink computation in ecological terms. What is difficult for die-hard Luhmannians to accept, namely the permeability of the system–environment–boundary, becomes a challenge for media theory:

> first, worldly (environmental) complexity has become so intense … that any effort to reduce it through selection by systems … cannot ignore the agency that is wielded by the environment; and second, the operation of this environmental agency is now predominantly and ever increasingly technical, meaning that system function is irrevocably permeated by technicity from the environment. (Hansen 2009, 114)

Mark Weiser's article "The Computer for the 21st Century" from the September 1991 issue of *Scientific American* is regarded as the founding document of "ubiquitous computing," although it describes a vision rather than a reality. The central aspect of Weiser's vision was that computers should "fade into the background rather than force itself as a character in the foreground of a user's attention" (Takayama 2017, 558). Terms for closely related visions are therefore also "calm computing" or "unremarkable computing" (see Weiser and Brown 1995; Tolmie et al. 2002). In terms of the popular psychology prevalent in the ubicomp community, this means that it operates at the lower levels of the "automatic mind" rather than at the higher levels of the conscious "reflective mind" (see Caraban et al. 2019). Ubicomp is a "Mindless computing technology, designed to subtly influence the behavior of the user without requiring their conscious awareness" (Adams et al. 2015, 719). The idea of ubicomp emerged from a mixture of readings by philosophers, psychologists, and design scientists working at Xerox PARC, enabling Takayama to speak of a "philosophical history of ubicomp": Rich Gold (i.e., Richard Goldstein), who brought in Guy Debord and situationism, economist Herbert A. Simon, philosopher Michael Polanyi and his "tacit knowing," James Gibson and Donald Norman, who brought in design theory and the theory of affordances, and Martin Heidegger.

From Heidegger, it was taken that computers should be ready-at-hand rather than present-at-hand. Polanyi's concept of "proximal" was important because it suggested a designed forgetting of the materialities of computing. Just as after a while you no longer feel the probe in your hand, but only what is being probed, so the medium disappears from perception. "Ubicomp aims to put the computer in the realm of the proximal, where it may be pushed off as part of an infrastructure rather than attended to" (Takayama 2017, 564).

What Luhmann wanted to exclude from his theory of mass media, namely the materialities of communication, “because they are not communicated” (Luhmann 1996, 13–14), appears in this perspective as a flawless sociological-philosophical continuation of the Xerox PARC program. This is no coincidence, since the same philosophers whom Luhmann drew on for his conceptualization were also read in Palo Alto. The difference is that what Luhmann attributed to the nature of mass media communication was, for Weiser, a design program.

With Weiser’s article, the environmentalization of computing became a vision for the future of computing, a vision that numerous hardware and software companies, information technology companies, sensor technology companies, and human–computer interaction (HCI) research institutes around the world have been working to realize ever since, driven and documented primarily by the annual Association of Computing Machinery (ACM) Conference on Human Factors in Computing Systems (CHI) and UbiComp conferences. The textile metaphors that are so characteristic of the discourse on ubiquitous computing can be found right at the beginning of Weiser’s text. “The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it” (Weiser 1991, 94). The textile metaphors lead to figures of seamlessness and fusion that have become an integral part of ubicomp rhetoric to this day: “The ultimate goal of ubicomp was to fade into the fabric of everyday life” (Takayama 2017, 559; see also Sprenger 2020, 98: “fugenlose Integration in den Arbeitsablauf”).[1]

In order to explore what is at stake at the heart of the idea of “ubiquitous computing,” it is necessary to reveal the problem that is simultaneously evoked and glossed over by the metaphor of seamlessness or fusion—and to do this, it is necessary to return to Edmund Husserl. Not because phenomenology has some special expertise in digital infrastructure that others lack, but to assess how essential “ubicomp” is in undermining the conditions of possibility for transcendental “Urevidenzen” (“primal evidences”). For in the case of “atmospheric media,” it is not merely a matter of “the ever-present possibility of being connected via networks” or the transformation of everyday objects into the “articulated parts of a massively distributed computational engine” (Greenfield 2006, 23). The description that “computation [moves] into the infrastructural background of human experience” (Hodge 2019, 143) also falls short because it excludes “human experience” from the field of the machinic or the algorithmic. The necessary return to phenomenology must not only focus on the environmentalization of algorithmized cognitive processes, but also on the idea of the continuum (clad in the metaphor of seamlessness) that underlies the very concepts of lifeworld, history, and perception itself. The center of gravity, the “black hole,”

1 For a critique of the seamlessness discourse in the literature on ubicomp see Bell and Dourish (2007).

so to speak, of Husserl's thinking is the question of the mode of being of the continuum. At the level of this question, the transcendental structure of the lifeworld touches on the theory of computation (see the introduction to this volume). And that is why the question of writing is fundamental.

I am not the first to view the environmentalization of computing as an event that takes on decisive significance within the framework of the concept of the lifeworld.[2] In principle, this framework has already been in place from the outset at Xerox PARC. Central concepts that define the lifeworld, such as horizon and anticipation, are omnipresent in the ubicomp discourse: "Ideally, the way that ubicomp systems present information to users would fuse so well with the users' horizons that the system's communication would be perfectly transparent" (Takayama 2017, 564). The problem, however, is that those who have dealt with ubicomp (e.g., Hansen 2009; Gramelsberger 2020; Sprenger 2020; Seberger 2022a; Rieger 2025) have only marginally addressed the cognitive processes that underlie the lifeworld according to Husserl's analysis (let alone their deconstruction), and that those who have dealt intensively with these cognitive processes following Bernard Stiegler have focused not so much on ubicomp as on new media art or cinema or post-cinema (e.g., Hui 2016, Hodge 2019, Denson 2020). Seberger (2021, 531) talks of an "alien phenomenology of sensors, actuators, algorithms, machine learning, prediction, data-social construction" or "a second-order phenomenology in which that which appears to the human has already appeared to the computational" (Seberger 2022a, 29). However, this "alien phenomenology" (a term Seberger borrows from Ian Bogost, without, however, adopting the perspective of object-oriented ontology) can only be analyzed at a fundamental level if it is viewed free of any humanistic rhetoric of loss, which assumes that originally "inscriptions are rooted in embodiment" (Seberger 2022b, 2). Accordingly, the concept of the prosthetic in relation to sensorial and perceptual devices must also be questioned with regard to the logic of the supplement implied in it. When I refer to "prosthetic" later in this text, I always mean it in the paradoxical sense of an "original prosthetic." There has never been a non-prosthetic or primordially exteriorized sensorium, just as there is no anthropogenesis which is not grounded in technogenesis (see Stiegler 1998, 91–104, with reference to Leroi-Gourhan).

2 Husserl did not invent the term "lifeworld" (see Bermes 2002), but he is the founder of the philosophical concept of the lifeworld, and it is this concept alone that has become influential in the development of ubicomp.

The aporias of Phenomenology, or, the Conditions of Possibility of Ubicomp

The desire that drives and motivates Husserl's phenomenology at its core is expressed in terms that characterize Husserl's unique language, which could be called "Husserl German." In Husserl German, the most important prefix is "mit-," as in "mitmeinen" (to co-intend), "mitgelten" (to be co-valid), "mit da sein" (co-being there), or "mitfungieren" (to co-function), or "Mitobjekt" (co-object), which is usually translated as "co-." Without this "mit-" there is no Husserlian phenomenology. The prefix "co-" is a symptom of the continuum axiom that dominates Husserl's phenomenology from beginning to end. In Husserl's discourse, it has the same effect as the concept of "fusion" (*Verschmelzung*) and, like the latter, is directed against the idea of an additive, discrete succession. As Husserl's habilitation thesis *Philosophy of Arithmetic* from 1891 shows, this quasi-manic compulsion to reject the discrete and sequential already dominates Husserl's (1891, 231) early reflections on point sets. "In the present case, the *continuous* point connection forms the highest degree of fusion." This idea still shapes the remarks on horizon and lifeworld in the final phase of Husserl's (1939, 27) thinking: "Every experience must be spread out into a *continuity* and explicative chain of individual experiences, synthetically unified as a single experience." And what applies to the experience of the subject applies just as much to the historical "permanent mode of being" of geometry: namely, that it is not merely an additive "progression from acquisitions to acquisitions, but a *continuous* synthesis in which all acquisitions continue to apply, all forming a totality" (Husserl 1976a [1936], 367, my emphasis, my translation).[3]

Only by reading the concepts of horizon and anticipation,[4] which are decisive for the concept of the lifeworld, together with the "origin of geometry" and Husserl's remarks on internal time-consciousness, can one appreciate the significance of ubicomp for the lifeworld. Husserl's definition of the lifeworld depends on the concept of horizon, which in turn is inextricably linked to the concept of induction or anticipation. Anticipation is a "mode of intentionality," a mode of an anticipatory intention "that always reaches beyond a core of the given fact" (Husserl 2008, 137). This mode corresponds essentially to the form of fulfillment. Anticipation of a perception, fulfillment of that anticipation, "continuous synthesis of the fusion of perception with perception in the form of a continuous succession, experienced continuation of perception as perception" (137). The way Husserl describes anticipation as

3 If not mentioned otherwise, all translations of Husserl quotes are mine.
4 For reasons of space, I will limit myself to the concepts of horizon and anticipation in the following, although other concepts such as appresentation and apperception would also need to be considered for a detailed analysis of the lifeworld.

an essential moment of the horizon structure in this text from his posthumous writings corresponds one-to-one with his definition of the “Great Now” of the perception of temporal objects. Husserl’s prime example of the perception of temporal objects is, as is well known, the hearing of a melody. The references to Stumpf’s *Tonpsychologie* (psychology of sound) in the habilitation thesis make it clear that acoustic temporal objects have always served as the model for Husserl’s concepts of continuum and presence: “Fusion [is] the relationship between two contents, especially sensory contents, according to which they do not form a mere sum, but a whole” (Stumpf quoted in Husserl 1891, 231).

In order to perceive a melody, it is necessary that the individual tones are not perceived additively as points in time on a time axis, but rather that “the present moment of this object is imbued with a ‘primary retention’ that integrates the present and belongs not to the past but to the passing presence of the object” (Stiegler 2009, 117–18, my translation). And, it must be added, a “primary protention” that does not belong to the future, but to the fulfilling presence of the object. Primary retention must be distinguished from secondary retention, which represents something that has happened in the past and is subject to the imagination. When we can reactivate a melody in our memory, this is secondary retention. In contrast to this, the “just been” (“das eben Gewesene,” Husserl 1966 [1905], 32) is not a past value that the imagination adds to perception, as Franz Brentano believed, but the phenomenon of time perception itself. “If this were not the case, it would be impossible to distinguish perception from fantasy and, consequently, reality from fiction” (Stiegler 2009, 118). However, it is precisely this inseparability that characterizes a perception that cannot distinguish between illusion and reality and is therefore defined as a hallucination. Herman Melville’s (2002, 373) Ishmael already knew that at certain times “fact and fancy ... interpenetrate, and form one seamless whole.” The pathology of this seamlessness, as it shapes the founding documents of ubicomp, is defined as psychosis (the fact that conspiracy theories are rampant today says a lot about how perception of reality has been colonized by “social media”). The “just been,” like “fulfillment,” is original, that is, it belongs to perception, to the self-presence of the subject: it does not have the “form of recognition with its implied mediations, in which induced inductions mediate” (Husserl 2008, 138). This is the rejection of a secondary retention associated with the primary one. Recognition would be remembering, imagining, mediation, which always already implies the past, that is, its reactivation implies a sign (implies writing, implies analog or digital media). Imagination, memory, has nothing to do with the original, but with a sign-like repetition of what was originally perceived. Husserl’s logocentrism is deeply rooted here: perception, the self-presence of the subject, is never mediated by signs. This cannot and must not be the case. In the imagination, the imagined is a sign of a past perception. Therefore, mixing primary with secondary retention would be tantamount to mixing signs and non-signs, presence and absence. This is the reason why the search for the origin of geometry led Husserl into crisis.

For, as Husserl had to recognize, the condition of possibility of geometry is that fulfillment *must not* be original. Let us briefly recapitulate the *Origin of Geometry* (Husserl 1976a [1936]): geometry is said to have first appeared "in the evidence of successful realization" (Husserl 1976a, 367). But questions immediately arise: geometry is supposed to be "for everyone," i.e., objectively there, while "successful realization" takes place "purely in the subject of the inventor" (367) (the original geometer). The ideal objects of geometry are of the same kind as the tones of a melody: "The original self-existence in the actuality of the first production, i.e., in the original 'evidence,' does not result in any persistent acquisition that could have objective existence." The "living evidence" passes into the "just-been" (370). However, even if recollection is an "activity of accompanying actual production" and the "originally realized is the same as what was previously evident," this still does not fully constitute the objectivity of the ideal construct. "The persistent existence of 'ideal objects' is lacking, even during the periods when the inventor ... is no longer alive" (371), because for geometry to be possible, its achievements must be transmissible through time. The ideal objects "lack their ever-being (*Immerfort-Sein*)" (371). This ever-being is provided solely by writing; only through writing can they continue to exist after the death of the original geometer. "Ever-being" is therefore only possible through an "ever-being absent (*Immer-Fortsein*)": absence in its final form, that of death, is inscribed in the "living evidence" as a condition of possibility. Husserl states, now in the subjunctive, what would be necessary to save the original fulfillment: That "all new acquisitions express a real geometric truth" is only "certain a priori on the condition that the foundations of deductive construction have indeed been produced in original evidence, objectified, and thus become generally accessible acquisitions. There must have been a continuity from person to person, from time to time, that could have been realized" (375). Can the "original authenticity" (*Ursprungsechtheit*) of the original evidences (*Urevidenzen*) be transmitted? And can this be done "through the chain of logical inferences, however long it may be" (375)? Only under this condition could every geometer be enabled to bring the truth sense of every proposition to mediated evidence. However, Husserl also knows that if a mathematician had to "first run through and reactivate the entire enormous chain of foundations back to the original premises" for every mathematical expression he writes down, "a science such as our modern geometry would not be possible at all" (373). The "inheritance of propositions" and the construction of ever new idealities through logic can "continue unbroken through the ages," while "the capacity to reactivate the original beginnings," the "sources of meaning," has not been inherited. This means that the unbroken continuation (writing, reading) occurs without a subject. Or at least without an active subject. Instead of through a continuous reactivation of the original evidence, geometry cannot exist other than through passive synthesis: through "thinking that operates solely with passively understood and adopted meanings, without any evidence of original activity" (372).

As can be read in the *Krisis*-treatise, Husserl was aware that this meant that the history of formalism would become a mortal threat to the transcendental foundation of ideal objects—be they the anticipated objects of the lifeworld or the objects of internal time-consciousness. Leibniz had already identified as a prerequisite not only for calculation, but also for speech and thought, what Husserl considered to be the core of the crisis of the sciences:

> So too does the mind, especially when it has much to think about, do with the images of things, namely, it needs signs for them so that it does not have to think about the thing anew every time it occurs. ... And just as a mathematician who did not want to write a number whose value he did not immediately understand would never be able to finish his calculations, so too would one, if one did not want to speak a word in speech or even in thought without forming an actual image of its meaning, have to speak extremely slowly or rather fall silent, necessarily hindering the flow of thoughts and thus not getting very far in speech or thought. (Leibniz 1983, 6–7, my translation)

This disaster culminates in Cantor and Hilbert. The modern "arithmetization of geometry" leads to "a completely universal 'formalization'" through "the extension of algebraic numbers and the theory of quantities to a universal and purely formal ... 'theory of manifolds'" (Husserl 1976b, 44). And as one could add with respect to the year 1937, in which the first parts of the *Krisis*-treatise were published: to the Universal Turing Machine.

The prerequisite for a geometry compatible with the truths of phenomenology would therefore be "the truly developed ability to reactivate the original activities enclosed in the basic concepts." Otherwise, "geometry would be a meaningless tradition." But: "Unfortunately, this is ... our situation, and that of the entire modern age." No, *worse still*: "The 'prerequisite' mentioned above has in fact never been fulfilled" (Husserl 1976a, 376).

This means that the worst case scenario has occurred. There are now three possibilities: either transcendental phenomenology is possible, in which case geometry is not possible; or geometry is possible, in which case phenomenology is not possible; or phenomenology, in order to save itself, accepts passive technical (computed) synthesis, but then it must abandon the subject as the original creator and reactivator of ideal objects. In that case, there is and always has been only an "alien phenomenology" (Seberger 2021, 531). Evidence becomes prosthetic because continuous synthesis also becomes prosthetic. "The intention to unify into a whole, instead of fulfilling itself (is) destroyed" (372). This means that without writing, without "tertiary retention" (a technical memory), there is no continuum, no fusion, no continuous change from anticipation to perception, no lifeworld.[5] There is no non-technologized lifeworld. A "technologized lifeworld" is a tautology. Only writing has been able to give ideal objects their final ideality (see Stiegler 2001). In order to be objectified ideal objects, these objects must enter history, they must enter writing. This means, however, that writing and, consequently, technology must be part of ideal objects a priori. The insight into this necessary consequence was the birth of deconstruction. It was Jacques Derrida who, in his early works, recognized that Husserl's line of thought in Supplement III forced him (Husserl) to take note of the aporias of phenomenology:

> [T]he presence of the perceived present can appear as such only inasmuch as it is continuously compounded with a nonpresence and nonperception, with primary memory and expectation (retention and protention). These nonperceptions are neither added to, nor do they occasionally accompany, the actually perceived now; they are essentially and indispensably involved in its possibility. (Derrida 1973, 64)[6]

Insofar as something non-perceived is necessarily involved in retention and protention, the a priori assumptions of phenomenology are also the conditions of possibility for the fusion of ubicomp with the "lifeworld." If "software can be considered as another step in the history of writing as a supplement to spoken language" (Thrift 2005, 153), then the constitution of ideal objects is no longer completed solely in the written form of mathematical proofs, but in algorithmically controlled data processing carried out by machines. What Stiegler did not consider, Yuk Hui (2016) and Shane Denson (2020) have supplemented by expanding the horizon of ideal objects to include digital objects—that what applies to retention also applies to protention: without tertiary protention, there is no secondary and therefore no primary protention.

Dead Time and Living Present: Processing of Lifeworlds in Real Time

Let us return briefly to Weiser's founding document on ubicomp. The famous "Sal scenario" from Weiser's text could easily be read as a description of an environment that exhibits all the characteristics of an original technicity

5 Timothy Morton is therefore entirely correct when he writes that there is no longer a world and, above all, no lifeworld (Morton 2013: 99–106). Unfortunately, however, his concept of world is phenomenologically uninformed, meaning that he cannot grasp the implications of what he is saying. "Lifeworld" does not mean a cozy hobbit hole.

6 As Christina Vagt has shown (in this volume), in Sigmund Freud's early *Draft of a Psychology*, it is precisely this fusion of signs with non-signs that is the result of a transcription in which the signified, which enters into primary retention from secondary retention, is forgotten.

of the lifeworld brought about by ubicomp. “Sal’s present tense extended into a near past tense … her present tense also extends into a near future” (Seberger 2022a, 24)—in other words: Sal’s present tense is constituted by technologized (computed) retention and protention. Among the operations that constitute Sal’s “present tense” are those that can be directly identified as prostheses of transcendental processes of consciousness outsourced to the environment, or as “algorithm awareness” (Gramelsberger 2020, 45). For example, the “foreview mirror,” which helps Sal find a parking lot, is nothing more than prosthetic anticipation, which folds back the expected future onto the subject. Machines anticipate what Sal intends to do (see Mackenzie 2013). “As she walks into the building, the machines in her office prepare to log her in but do not complete the sequence until she actually enters her office” (Weiser 1991, 102). The environment is aware of Sal’s intentions and doings. It possesses a computerized agency which operates the prosthetic reactivation of ideal objects and prosthetic original fulfillment of anticipated things. “Already computers in light switches, thermostats, stereos and ovens help to activate the world” (98). It is no longer intentions that *activate the world,* as in Husserl’s lifeworld where the activating transformation from outer into inner horizons “awakes the objects” (i.e., Husserl’s *Weckung*, see Husserl 2008, 27), but computers.

What the becoming environmental of computing is all about is not the “emergence of a programmed and calculable environment” (Hodge 2019, 143), but rather that the environment has agency which is “predominantly and ever increasingly technical” (Hansen 2009, 114). However, this makes it impossible to pretend that ubicomp simply modifies the “lifeworld”—in the sense that there was a pre-technological lifeworld in some era which was then expanded by the “embedding” of virtuality after the world became technologized (see Kasprowicz and Rieger 2020). If the fusion (*Verschmelzung*) into a continuum of perceptions has always already been processed by computation, the anthropocentrism (or humanism) of this perspective has ultimately become obsolete.

Rather, the condition for the possibility of ubicomp becoming environmental, of the seamless fusion of presence and absence in the present moment of perception, is that the concept of lifeworld already necessarily includes its computerization in Husserl and that, consequently, its a priori has always been a historical, technical, and environmental a priori. This is precisely why “the ‘teleology’ of the process of technologization reveals itself to be that it assigns the lifeworld to itself as a dependent variable” (Blumenberg 1981, 38; see Arnold 2020, 41). This “teleology” can be credited with explaining why, from today’s perspective, Husserl’s remarks on the lifeworld read as if they were describing Sal’s ubicomp world:

> For us, the world has always been one in which knowledge has already done its work in the most manifold ways; and so it is undoubtedly true that there is no experience in the primary, simple sense of an experience of things which, when first apprehending this thing, taking note of it, does not already "know" more about it than comes to awareness in the process. (Husserl 1939, 27)

In this quote, one only needs to replace "experience" with "algorithmic awareness": this "knowing more" is located in and produced by the environment and it precedes the subject, which it encounters from the future. Ubicomp operates by "injecting a microtemporal futurity into the material basis of contemporary life itself"; it introduces "a new anticipatory dimension into the unfolding present of our experience" (Denson 2020, 91).

Derrida's "non-perceived" is precisely this surplus of knowledge that remains unaware. The concept of affordance, too, which was thoroughly studied at Xerox PARC, is already anticipated by Husserl's (2008, 26) concept of the "pre-given world": "The world is pre-given to us. If we direct our active gaze towards something, it was already there, it affected me, motivated me to pay attention to it, and that is how it is now grasped." Thus, those affordances, are, in terms of phenomenology, secondary, or even "tertiary," anticipations. Affordances let me induce because the world is one in which "knowledge"—that is, data sensing, collecting, and analysis—has already done its work, which means it has always been an archive:

> An experiential world undergirded by data sensing, collecting and processing is always already an archival world; but it is an archival world where the longer form past tense of the archive—that which has historically been preserved for long durations of time—diminishes to match the increased tempo of generation, appraisal, accession, analysis and feedback. (Seberger 2022a, 22)

It is "datafied descriptions of ourselves" (Seberger in this volume) that stand in for the "original fulfilments" and are mapped (or fed) back to the "user"—that hybrid being created by the hybridization of a human and their data doppelganger. Whatever presents itself as an object is irrevocably pre-processed by environmental digital media that run passive continuous syntheses in real time. Hence, what distinguishes Husserl's *Lebenswelt* from the world of ubicomp is not that the first is non- or pre-technological—writing is a technology—while the latter is technological, but that the latter's prosthetic continuous synthesis is discretized by microtemporal time windows, which allow for a real-time analysis of secondary retentions. There is, then, no real-time analysis of events in the sense that events are analyzed without delay.

> All current theories that attempt to identify the difference between historical and electronic time with the difference between delay and

> simultaneity, are myths. Real time analysis simply means that deferral or delay, dead time or history are processed fast enough to move on to the storage of the next time window. (Kittler 2017, 14)

Kittler would have agreed with Seberger. For "history," we can also say, with a view to Husserl, secondary retention, and, with a view to Stiegler, "tertiary retention." The technical term "dead time" must be related to the "arche-trace" (Derrida 1974, 62), which is the indispensable condition of possibility of the presence of present tense. Kittler's (or the data-processing algorithm's) deferral or delay is the hardwired correlate to the original deferral or delay that constitutes the heart of the presence of the Living Present (see Derrida 1989, 153; Stiegler 2001, 120). The Living Present presupposes Dead Time. The "new reality" "at the femtosecond" therefore "is only buildable because time exists as quantified and synchronized packets whose size approaches zero" (Bowker 2021, 129).

> Processed on the fly in an interval that is inaccessible to human perception, the images that populate our world are themselves dis-correlated from human subjectivity—no longer tuned to the frequencies of human sensory access and thus no longer essentially bound to appear at all. (Denson 2020, 2)

A discrete and digitized time exploits what in Derrida's and Stiegler's deconstruction of the primary retention/protention already resulted in the acknowledgment of an always already existing implication of a technological supplement of the present. The presence of the present tense, Husserl's "living evidence," becomes data processing in real time, creating a "technological unconscious" (Thrift 2005, 156) that exploits the aporias of the lifeworld in order to technologically implement a prosthetic continuous synthesis which operates beneath the threshold of sensory perception, and thereby "beneath the threshold of what can be experienced phenomenologically" (Hansen quoted in Denson 2020, 99).

According to the annihilating conclusions of Supplement III, there has never been an origin of technical knowledge in human experience based on original evidence. Therefore, the "user experience" based on the dead times of real-time analysis must be read as the final ecstasy of the "crisis" of European science, which is in truth the crisis of European intellectual history and finds its end point in the withdrawal of the condition of possibility of phenomenology.

References

Adams, Alexander T., Jean Costa, Malte F. Jung, and Tanzeem Choudhury. 2015. "Mindless computing: designing technologies to subtly influence behavior." In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '15)*, 719–30. New York: Association for Computing Machinery.

Arnold, Florian. 2020. *Die Architektur der Lebenswelt: Entwürfe nach der philosophischen Anthropologie Hans Blumenbergs*. Frankfurt am Main: Vittorio Klostermann.

Bermes, Christian. 2002. "'Lebenswelt' (1836–1936): Von der Mikroskopie des Lebens zur Inszenierung des Erlebens." *Archiv für Begriffsgeschichte* 44: 175–97.

Bell, Genevieve, and Paul Dourish. 2007. "Yesterday's tomorrows: notes on ubiquitous computing's dominant vision." *Personal and Ubiquitous Computing* 11, 133–43.

Blumenberg, Hans. 1981. "Lebenswelt und Technisierung unter Aspekten der Phänomenologie." In *Wirklichkeiten in denen wir leben: Aufsätze und eine Rede*, edited by Hans Blumenberg, 7–54. Stuttgart: Reclam.

Bowker, Geoffrey C. 2021. "Life at the Femtosecond." In *Infrastructures and the Politics of Digital Time: Essays on Hardwired Temporalities*, edited by Axel Volmer and Kyle Stine, 125–42. Amsterdam: Amsterdam University Press.

Caraban, Ana, Evangelos Karapanos, Daniel Gonçalves, and Pedro Campos. 2019. "23 Ways to Nudge: A Review of Technology-Mediated Nudging in Human-Computer Interaction." In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*, 1–15. New York: Association for Computing Machinery.

Denson, Shane. 2020. *Discorrelated Images*. Durham, NC and London: Duke University Press.

Derrida, Jacques. 1973. *Speech and Phenomena: And Other Essays on Husserl's Theory of Signs*. Translated by David B. Allison. Evanston: Northwestern University Press.

———. 1974. *Of Grammatology*. Translated by Gayatri Chakravorty Spivak (Corrected Edition). Baltimore and London: The Johns Hopkins University Press.

———. 1989. *Edmund Husserl's Origin of Geometry: An Introduction*. Translated by John P. Leavey, Jr. Lincoln, NE and London: University of Nebraska Press.

Gramelsberger, Gabriele. 2020. "Algorithm Awareness: Towards a Philosophy of Artifactuality." In *Affective Transformations: Politics—Algorithms—Media*, edited by Bernd Bösel and Serjoscha Wiemer, 41–48. Lüneburg: meson press.

Greenfield, Adam. 2006. *Everyware: The Dawning Age of Ubiquitous Computing*. Berkeley: New Riders.

Hansen, Mark B. N. 2009. "System-Environment Hybrids." In *Emergence and Embodiment: New Essays on Second-Order Systems Theory*, edited by Bruce Clarke and Mark B. N. Hansen, 113–42. Durham, NC and London: Duke University Press.

Hodge, James J. 2019. *Sensations of History: Animation and New Media Art*. Minneapolis and London: University of Minnesota Press.

Hui, Yuk. 2016. *On the Existence of Digital Objects*. Minneapolis and London: University of Minnesota Press.

Husserl, Edmund. 1891. *Philosophie der Arithmetik: Psychologische und logische Untersuchungen*. Halle-Saale: C.E.M. Pfeffer (Robert Stricker).

———. 1966 [1905]. "Die Vorlesungen über das innere Zeitbewusstsein aus dem Jahre 1905." In Edmund Husserl, *Zur Phänomenologie des inneren Zeitbewusstseins (1893–1917)*, edited by Rudolf Boehm, 3–134. Husserliana, X. The Hague: Martinus Nijhoff.

———. 1939. *Erfahrung und Urteil: Untersuchungen zur Genealogie der Logik*. Edited by Ludwig Landgrebe. Prague: Academia Verlagsbuchhandlung.

———. 1976a [1936]. "Beilage III." In Edmund Husserl, *Die Krisis der europäischen Wissenschaften und die transzendentale Phänomenologie*, edited by Walter Biemel, 365–86. The Hague: Martinus Nijhoff.

———. 1976b [1936]. *Die Krisis der europäischen Wissenschaften und die transzendentale Phänomenologie*, edited by Walter Biemel. Husserliana VI, 2nd edition. The Hague: Martinus Nijhoff.

———. 2008. *Die Lebenswelt: Auslegungen der vorgegebenen Welt und ihrer Konstitution. Texte aus dem Nachlass (1916–1937)*, edited by Rochus Sowa. Husserliana, XXXIX. Dordrecht: Springer.

Kasprowicz, Dawid, and Rieger, Stefan, eds. 2020. *Handbuch Virtualität*. Wiesbaden: Springer VS.

Kittler, Friedrich. 1990. *Discourse Networks 1800/1900*. Translated by Michael Metteer, with Chris Cullens. Stanford: Stanford University Press.

———. 2017. "Real Time Analysis, Time Axis Manipulation." Translated by Geoffrey Winthrop-Young. *Cultural Politics* 13, no. 1: 1–18.

Lacan, Jacques. 2006. "The Instance of the Letter in the Unconscious or Reason Since Freud." In Jacques Lacan, *Écrits: The First Complete Edition in English*. Translated by Bruce Fink, 412–41. New York and London: W. W. Norton & Company.

Leibniz, Gottfried Wilhelm. 1983. *Unvorgreifliche Gedanken, betreffend die Ausübung und Verbesserung der deutschen Sprache*. Edited by Uwe Pörksen. Stuttgart: Reclam.

Luhmann, Niklas. 1996. *Die Realität der Massenmedien*. Opladen: Westdeutscher Verlag.

Mackenzie, Adrian. 2013. "Programming subjects in the regime of anticipation: Software Studies and subjectivity." *Subjectivity* 6: 391–405.

Melville, Herman. 2002. *Moby-Dick*. Edited by Hershel Parker and Harrison Hayford. A Norton Critical Edition, 2nd edition. New York and London: W.W. Norton & Company.

Morton, Timothy. 2013. *Hyperobjects: Philosophy and Ecology after the End of the World*. Minneapolis and London: University of Minnesota Press.

Rieger, Stefan. 2025. *Imagination und Immersion: Topologien des Virtuellen*. Bielefeld: transcript.

Seberger, John. 2021. "Reconsidering the user in IoT: the subjectivity of things." *Personal and Ubiquitous Computing* 25: 525–33.

———. 2022a. "Into the archive of ubiquitous computing: the data perfect tense and the historicization of the present." *Journal of Documentation* 78, no. 1: 18–37.

———. 2022b. "The Doppelgänger in the Archive of Electronic Skin." Unpublished draft.

Siegert, Bernhard, and Joseph Vogl. 2003. *Europa: Kultur der Sekretäre*. Zürich and Berlin: diaphanes.

Sprenger, Florian. 2020. "Ubiquitous Computing vs. Virtual Reality: Zukünfte des Computers um 1990 und die Gegenwart der Virtualität." In *Handbuch Virtualität*, edited by Dawid Kasprowicz and Stefan Rieger, 97–109. Wiesbaden: Springer VS.

Stiegler, Bernard. 1998. *Technics and Time, 1: The Fault of Epimetheus*. Translated by Richard Beardsworth and George Collins. Stanford: Stanford University Press.

———. 2001. "Derrida and technology: fidelity at the limits of deconstruction and the prosthesis of faith." In *Jacques Derrida and the Humanities:. A Critical Reader*, edited by Tom Cohen, 238–70. Cambridge: Cambridge University Press.

———. 2009. *Denken bis an die Grenzen der Maschine*. Edited by Erich Hoerl, Translated by Kysmena Wojtyczka and Erich Hoerl. Zürich and Berlin: diaphanes.

Takayama, Leila. 2017. "The motivations of ubiquitous computing: revisiting the ideas behind and beyond the prototypes." *Personal and Ubiquitous Computing* 21: 557–69.

Thrift, Nigel. 2005. *Knowing Capitalism*. London, Thousand Oaks, New Delhi: SAGE Publications.

Tolmie, Peter, James Pycock, Tim Diggins, Allan MacLean, et al. 2002. "Unremarkable computing." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '02)*, 399–406. New York : Association for Computing Machinery.

Vismann, Cornelia. 2000. *Akten: Medientechnik und Recht*. Frankfurt am Main: Fischer.

Weiser, Mark. 1991. "The Computer for the 21st Century." *Scientific American* 265, no. 3: 94–105.

Weiser, Mark, and John Seely Brown. 1995. "Designing Calm Technology." *PowerGrid Journal*, v 1.01. https://web.archive.org/web/19990225104907/http://powergrid.electriciti.com/1.01 (PDF version: https://people.csail.mit.edu/rudolph/Teaching/weiser.pdf).

INTIMATE COMPUTING

VULNERABILITY

OBJECT-ORIENTED PROGRAMMING

INTERNET HISTORY

CYBERFORMANCE

INTERNET ART

DATABASE TECHNOLOGY

[1 2]

Reckoning with Intimacy: A Recent History of Intimate Computing

Benedikt Merkle

Using the digital multimedia platform Macromedia/ Adobe Flash as a case study, I will show that platforms like Flash opened spaces of public intimacy on the internet and will offer insights into the aesthetics and technical structures of this development. I will introduce the artist duo Auriea Harvey and Michaël Samyn, then known as "Entropy8Zuper!", and explore their cyberformance of online intimacy, *Wirefire*. I will then trace the formalization and commodification of forms of interaction involving the sharing of and interaction with digital objects in the development of Flash's *SharedObject* API. The paper shows how internet technologies such as Flash hint at a different vision of intimate computing through constant engagement with their own vulnerabilites.

Computers were envisioned early on as devices that would be able to aid people and augment cognitive capacities. Sociotechnical imaginaries (Jasanoff, 2015) of human–machine interaction often refer to the intimate or speak of an intimate computer.[1] Vannevar Bush (1945, 107) describes his *Memex* machine in 1945 as "an enlarged intimate supplement to his [man's] memory" and envisions it as an automated personal archive that logs daily activities so as to unburden a human worker's memory. This quote is later highlighted in Douglas Engelbart's report on "Augmenting Human Intellect" in 1962. Here the intimate supplement will refer to a category of activities that Engelbart (1962, 48–56) deems "high-order processes" (11) in a hierarchy of tasks that the "intellectual worker" (11) needs to master. J.C.R. Licklider's (1960, 5) systems-theoretical description of a man–computer symbiosis qualifies the new relation as "men and computers working together in intimate association." Finally, in Alan Kay's (1991, 138) work, a personal computer called the *Dynabook* was supposed to enter the life and education of children, and was termed an "intimate, note-book sized computer."

In these visions, "intimacy" is used as a self-evident term. For the most part, it conveys the hope that these machines will increasingly become inseparable from and integral to people's lives. Accordingly, the term "intimacy" is closely connected to the idea that personal computers will disappear completely into the background of our everyday lives, as it was formulated in Mark Weiser's (1991, 94) influential vision for ubiquitous computing in the late 1980s. Looking at today's landscape of portable, wearable, drivable and inhabitable tech, all trying to integrate into networks of interlinked social media platforms, Weiser's work on proximate technological futures retains remarkable accuracy (Bell and Dourish 2007, 134–35). Talk of intimate relations to computers has transformed since, as Timo Kaerlein shows, into a language of consumable intimacy of interfaces and media platforms that capture users' attachments and encourage participation (Kaerlein 2016).

While it is important to trace the strategic foreclosing at the heart of contemporary platform logics, it is easy to lose sight of the process that was opened by practices of engineers and early users. The type of research aimed at a proximate future at Xerox PARC and other laboratories impacted the development of the tools and the way they were marketed, but its influence is easily overstated with regards to the real-world implementation of digital infrastructures. What is covered up by the self-evident usage of the term "intimacy" is the work of engineers and users who sought to design intimate relations online.

In the following, I will explore two lines of observation that take place in the realm of the media platform Macromedia/Adobe Flash, which, over the span

1 The following summary draws heavily on Kaerlein (2016).

of more than 20 years, provided an infrastructure for sharing interactive media online. The Flash Player plug-in was notorious for introducing vulnerabilities to internet browsers, compromising the security of the transmission process, but also recognized as a necessary means for connecting to spaces of simulated sharing on the internet. The term "vulnerability" is used here in a technical sense that denotes gaps in its structure, which pose a danger to the integrity of transferred data. My first example follows an artistic experiment in public intimacy that builds an infrastructure for the sharing of digital objects. My second observation turns to the development of the Flash platform and recounts visions of engineering for a technology of shared digital spaces that eventually resulted in a technically vulnerable infrastructure. Both perspectives, I will argue, exhibit a concept of intimacy as the strategic navigation of vulnerabilities. Reckoning with intimacy in this way may serve to understand the development of digital infrastructures that seek to bring bodies behind machines in synchronization with each other.

Cyberformance: The Intimacy of Sharing Objects

On the threshold of the broad availability of time-critical telecommunication infrastructure, in 1980, artist duo Kit Galloway and Sherrie Rabinovitz, also known under the name *Mobile Image*, used an expensive video satellite link to connect the Broadway Department Store in Los Angeles with the Lincoln Center for the Performing Arts in New York. This was followed by a three-day live video link between two large screens installed on the facades and facing the public. *Hole In Space*, as the work was called, followed no script other than this initial set-up: people stumbled across the installation as they walked by, which attracted larger crowds and television coverage by the second day. Documented reactions from viewers were consistently very positive, commenting on the great potential of the technology and the spontaneous moments of successful social interaction with the group on the other side of the continent.[2] Steve Dixon (2015, 420), in his comprehensive study of digital performances, dubbed the performance piece as "the most celebrated example of pre-internet telematic performance."

Galloway and Rabinovitz's installation is an impressive testimony to how people signal willingness to accept a new media technology years before it is introduced and even welcome it with jubilation. Playing simple games such as charades over the video link, performing vocal interludes or flirting shamelessly in front of an assembled audience all anticipate practices that are continued in the shared space of the internet. It almost seems as if the

2 The artists documented the performance on video, interviewing participants. Kit Galloway and Sherrie Rabinowitz, Hole In Space: A Public Communication Sculpture, 1980, single-channel documentation, 1980, https://www.moma.org/collection/works/120330.

[Figure 1] Sharing a beer through the *Hole In Space*. (Source: Two cropped stills from Hole In Space: A Public Communication Sculpture (Kit Galloway, Sherrie Rabinowitz US, 1980) https://www.moma.org/collection/works/120330).

medium had long been anticipated. In addition, there are moments within the performance in which viewers consciously go beyond the conditions of communication granted by the installation. In one scene, for example, a New Yorker enthusiastically holds his half-empty beer bottle up to the camera and successfully elicits the reaction on the opposite side, where a group of women stretch out their arms and signal with empty, grasping gestures that the desired, shared object unfortunately cannot quite be reached.

The anticipation of the social forms of the internet can be traced back to the fact that digital technology was already being used to enable communication over long distances and was becoming increasingly well known in terms of its possibilities and limitations. In addition, the possibility of a public infrastructure of computer networks had increasingly become a topic of public discourse since the 1960s. As early as the 1960s and 1970s, various efforts were made at the interface between universities and companies to organize computers in networks and make them available to a wider public. At this time, the vision of a widely available, digital infrastructure for personal computing was becoming increasingly concrete (see Rankin 2018, 107). "These networks collectively embodied the desire for computer resource sharing, for a community of interested individuals joined by computing networks, in short, a desire for communal computing" (Rankin 2018, 109). The desire to share a bottle of beer is a playful gesture against the backdrop of the generally assumed knowledge that this will not be possible using digital infrastructures. Years later, "sharing" will be one of the most frequently used words to describe not only the exchange of information, but the basis for many different forms of sociality via the internet. The idea of a shared digital object goes back to the creation of telepresence using electronic media: video telephony has been an unfulfilled promise since the 1960s. It was not until the advent of the internet in the early 2000s that digitally synchronized images began to spread through infrastructures such as Flash Player and applications such as Microsoft's *Skype* (see Otto 2013).

The advent of the internet brought telematic presence into people's homes and everyday lives. The term "cyberformance" was coined in the early 2000s to describe artistic performances on the internet (Chatzichristodoulou 2014, 21–22). There are different definitions of the term, but in all cases, the software used to facilitate it had to provide solutions to both a time-critical and a spatial problem: liveness and interactivity to simulate a shared digital object. In many cases, Macromedia/Adobe Flash became the software of choice.[3] *Wirefire* is one such cyberformance, which explores the building of intimate relations over the internet. It was the project of the artist-duo "Entropy8Zuper!", consisting of Auriea Harvey and Michael Samyn. They met on hell.com (Harvey and Samyn 2014, 32),[4] an infamous place on the internet of the late 1990s that was closed off to the public and an exclusive meeting place for avantgarde internet folk (Aronson and Galloway 2000). *Wirefire* was part of their artistic practice, a cyberformance that ran from July 8, 1999 to January 9, 2003. "[E] very Thursday at Midnight in Belgium," (Harvey and Samyn 2014, 31) people all over the world could load up a Flash client application in their browser windows and witness Harvey and Samyn's exploration of public intimacy. The performance grew out of the desire of Harvey and Samyn to connect intimately over the internet while being in a long distance relationship. They decided to make this a public experiment. In their words: "Wirefire was built for: desire, intimacy and an audience" (Harvey and Samyn 2014, 31).

The artists introduce their performance as a project utilizing "technology we have developed to touch through the wires that combines chat, sounds, images, animations and live camera streams to form an interactive, improvisational expression which goes beyond words" (Harvey and Samyn 2002). On the technical level, the setup the duo built to achieve this wide range of interactivity was very simple: "[it] consists of only four files: a client and tool application (both Flash movies) and two CGI scripts written in Perl. … The fuel for the engine consists of Flash movies made by the performer(s), pictures and sounds" (Harvey and Samyn 2002). It was a simple setup of a shared canvas that allowed the public sharing of Flash objects.

One can get a sense of the aesthetic of the performance by loading an archived version of the old client application and have it randomly select Flash

3 Examples include performance platforms like UpStage (Helen Jamieson, https://upstage.org.nz/) and VisitorsStudio (Furtherfield, https://web.archive.org/web/20071126071534/http://www.visitorsstudio.org/?diff=0).

4 Harvey was by the time an accomplished digital designer in New York, having won both first editions of the Webby Awards in 1997 and 1998 and designing websites for pop stars. Samyn was recognized as a pioneer of interactive web design. In 2000 they won the Webby Award for internet art for their website entropy8zuper.org, funded by the SFMOMA, which was the highest endowed prize for internet art.

[Figure 2] Aesthetics of a Wirefire performance (Source: Screenshot by the author).

objects from the still intact database.[5] The resulting tableau is flat and tactile, objects float in and out of frame and include elements that can be interacted with. Many of these objects hold a metaphorical relation to sexuality, like giant bees and flowers, a belt that is slowly opened, bombs titled "touch me," that explode with a moan upon mouse rollover, or gongs that sound when any key is pressed. A further insight into how performances were once conducted is provided when the artists showed screenshots of the Flash tool they used for controlling the selection of objects to be shared with each other and all connected clients. These are individual tools both artists built for themselves, and they are representations of the database on the server, grouped into different categories and visualized with icons. "The categories at the top, if you roll over them give access to their contents. Actions, Dreams, Music etc. These were simply folders of .swf files on our server" (Harvey and Samyn 2014, 34). Harvey and Samyn picked Flash objects from this board as they improvised their experiment in public intimacy: "[B]ees, gongs, garden of eden. more opera, more bees, more gongs!" (Harvey and Samyn 2014, 35).

There are no recordings of live sessions—the transient, fleeting nature of performance art that Peggy Phelan (1993) describes applies to cyberformances as well. The above description of the artists' tools for operating the performance supports art historian Maria Chatzichristodoulou's (2014, 25) characterization of *Wirefire* as "a 'performance of the database' that did not depend on a linear narrative." The database needed to be structured and represented in a way that suited the desired performance. Within this structure, there remains a clear distinction between performers and audience, a two-to-many relationship through the two separate pieces of software simulating stage and the

5 This was possible at the time of writing and it required an old browser still capable of playing Flash files.

audience room. Interactive elements breach this distance. *Wirefire* uses the Flash software at a point where the programming of many-to-many relations, which would allow for the collective interaction with shared objects, is not yet possible. Objects on a server database cannot be easily synchronized with multiple connected clients. But the possibility can already be sensed, and is anticipated, when Harvey and Samyn fill up a shared canvas with objects and invite connected audience members to interact, albeit in a limited, asynchronous way, with these same objects. It is the illusion of shared objects in a shared space that is aimed at by the performers. Just as for the people meeting at Galloway and Rabinowitz's *Hole In Space*, the exploration of public intimacy hinges on the ability to share objects with one another.

This same illusion of shared objects was pursued by the developers of the Flash software at Macromedia. It is closely connected to the attempt to bring object-oriented programming into the internet. My second line of observation will detail this development.

The Infrastructures of Sharing Objects in Real Time

Almost everyone who used the internet in the early 2000s is familiar with the Flash software and the Flash Player plug-in in particular. Over the past 20 years,[6] this plug-in for internet browsers has made a significant contribution to the development of an interactive web. The infrastructure helped today's internet giants such as *YouTube* and *Netflix* achieve their initial successes and set the web on course for its platform-capitalist foreclosure. For a long time, it was the de facto standard for the delivery of interactive, audiovisual web content. It was used for the surface design of websites and advertising banners as well as for the programming of complex interactive games and digital environments, such as for the streaming of videos or for live-teleconferencing systems. The Flash Player *was* a platform that not only distributed content but also generated it. Among other factors, it was the evolution of the open HTML Standard as well as long-standing privacy concerns that led to the removal of the plug-in from all systems at the beginning of 2021.[7] Since then, it is not the media content that is missing, but the native environment in which older web-based works can be executed—and with it the condition of possibility of an aesthetic that had become popular.

6 The FutureSplash Player was developed in 1996 by FutureWave Software as part of a software solution for animating images called FutureSplash Animator. In the same year, Macromedia took over the company and changed the name of the software to Flash and Flash Player. For a short history of Flash see Salter and Murray (2014, 1–16).

7 Adobe announced this step back in 2017. Four years later it was implemented with thoroughness: all versions of Flash Player distributed since June 9, 2020 contain a shutdown mechanism that was activated on the January deadline. For an early study of the factors that led to its demise see Salter and Murray (2014, 135–51).

This aesthetic was prepared by efforts in the late 1990s, when Flash developers built the means for bringing dynamic database systems to the internet. The software was developed in the context of an object-oriented software development culture[8] and sought ways to establish the paradigm for web application development. From the early 2000s onwards, Flash introduced the fiction of a computational object into the structures of the internet, where it triggered hype around interactive interface aesthetics that web historian Megan Sapnar Ankerson (2018, 153) has described in detail:

> The combination of motion graphics and draggable windows merges a cinematic sensibility with human–computer interaction to simultaneously highlight a cinematic distance between the spectator and the image while also introducing a newfound freedom to grab an object on a website and move it across the screen.

I have elsewhere (Merkle 2025) elaborated on the specificity of a digital image that encourages interaction by operationalizing a distance between the image and the viewer and have described it as the "*Entgegenkommen*"[9] of object-oriented interfaces. These images accommodate preferred usage behaviors by anticipating them from a near future.

In the early 2000s, Flash aimed to provide web designers with an application programming interface (API) to easily craft complex relations between servers and clients. Macromedia coined the term "rich internet applications" (Allaire 2002) to describe their product, a term that later inspired Tim O'Reilly (2005) to popularize the buzzword of an epochal shift to web 2.0, first coined by Darcy DiNucci in 1999. An emphasis on the richness of the user experience made internet applications increasingly resemble desktop applications in style and complexity (see Lialina 2021 [2014]). Protocols for the transmission of text, images, sound, video and more were to be bundled into client applications, controlled by graphical user interfaces. This vision is a product of commercial software development in the late 1990s. With the introduction of plug-ins and the hypertext markup language (HTML) infrastructure for embedding external, proprietary file types, the internet opened up to a new market of internet services (see Ankerson 2018, 141–58).

8 For studies of an object-oriented (programming) culture see Pflüger (2004), Alt (2011), and Joque (2016).

9 An ambiguous German word that refers both to the spatial and temporal act of coming toward someone and to a sympathetic accommodation made toward others. I use the term "*Entgegenkommen*" as a phenomenological concept whose double meaning refers to the specific temporality of digital media technology. This temporality can be linked to what Yuk Hui describes as tertiary protention, referring to Edmund Husserl and Bernard Stiegler: "It gives us a new form of determination that is not 'I think' but 'I guess you think'" (Hui 2016, 245).

In the context of the development of Flash, the metaphor of rich experiences on the internet plays a central role in PR communication. In March 2002, Jeremy Allaire, Chief Technical Officer at Macromedia, published a white paper entitled “Macromedia Flash MX—A next-generation rich client.” In Allaire’s presentation, the richness of newer client applications is profiled against a “thin client based on HTML” (Allaire 2002), which characterized the first phase of the public web. Allaire criticizes a “lack of client-side data storage” (Allaire 2002) in the HTML protocol. The spread of powerful personal computers led software manufacturers to consider integrating the new computing power on the user side into the infrastructure of content distribution.

“Rich clients” turned out to be part of a desire for shared objects in digital space. In the case of Flash, these objects were optimistically named *Shared-Object*. In 2000, Flash developer Jonathan Gay launched the “Tin Can” project at Macromedia. The mechanical telephone, which uses two tin cans to establish a simple two-way connection between people speaking at a distance, is a metaphor for the work on integrating two-way real-time audio and video streaming into the Flash Player. Immediately after the project was founded, Gay had his team of developers draft “stories” outlining the possibilities of a widely available infrastructure for the multi-way streaming of audio and video data. This resulted in surprisingly precise descriptions of a reality that has become part of everyday life today.[10] Discussed are teleconferencing systems for online teaching or holding team meetings, functions of interaction using a mixture of webcam streams, text input and graphic elements, as well as ways of moderating a meeting in which participants can only become active when called upon. The stories also included visions of domestic Internet of Things (IoT) infrastructures, such as the use of a networked camera at your own front door. The sharing of common experiences is described in visions of networked board games or infrastructures for maintaining personal contact over long distances via what would now be called in-real-life (IRL) streaming:

> I am traveling in Europe. I have my wireless communicator. It has a built in camera that records video segments direct to my web site. As I travel around, my friends can see my real time video view or review any of the stored video from earlier in the day. I had promised my father that I would show him the Eiffel Tower so when I arrive, I turn on my camera and send him the live feed. As I am visiting the tower, he tells me in real time that which parts he wants to see. I have blended my stored history and communication with real time communication using a Tin Can communicator and Tin Can server. (Veriskope 2019)

10 The stories are presented by the company Veriskope as a glimpse into the origins of the Real-Time Messaging Protocol (RTMP), which was developed as part of Tin Can and is still in use today. Veriskope was co-founded by former Macromedia employees and provides services in low-latency video streaming (Veriskope 2019).

These scenarios describe variations of an infrastructure that is based on the coordination of processes for copying and synchronizing data objects. The task of synchronization is performed by the *SharedObject*, whose functionality can be summarized as follows: in order to introduce the illusion of a shared object into the architecture of communication between networked computers, an additional, transient element is created. The displayed, shared data object itself, for example a vector graphic in a board game, is initially duplicated in its entirety on all connected computers. A *SharedObject* is then generated as a dataset that stores selected properties of this object on the server. This object also sends information about changes to all connected clients. It is therefore a network architecture that ensures the synchronization of the state of a previously copied object. By reducing the amount of information transmitted to a minimum, this process seeks to approximate the simultaneity that characterizes a shared object, which is impossible in digital space. The digital object is not shared but actually divided up—its parts are named and synchronized in quick succession. With a sufficiently fast connection and processor speed, this ultimately creates the impression of direct participation in a shared data stream.

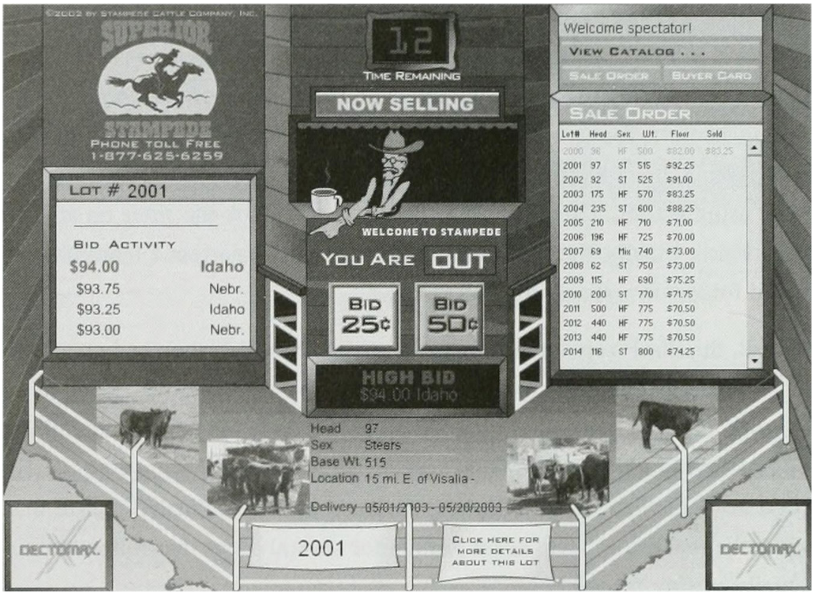
Flash translates the sharing of a common presence into a digital transmission process with visual output. Chris Hock, a business strategist on the Tin Can development team, recalls:

> SharedObjects were kind of one of the hidden gems of the whole ecosystem. I remember seeing [one of] our early adopters, Philip Kerman, build a cattle auction. ... Just images and extremely low latency: see the bids in real time! ... [M]oving objects around the screen, jointly, for everyone to see it, right? Sharing data! (Allen et al. 2025 [2023])

Wirefire used the Flash software at a time before the *SharedObjects* API was published. At that time, objects on a server database could not be easily synchronized with multiple connected clients. But the possibility could already be glimpsed when Harvey and Samyn filled a shared canvas with objects and invited connected viewers to interact with them. In this way, *Wirefire* created a fictional situation of shared objects.

To introduce the illusion of a shared object into the architecture of communication between networked computers, proxy objects are created on the client side. Even the accompanying patent sketch resembles the schematic representation that Harvey and Samyn discuss during their final performance as a reflection on their technical-artistic experiment. In both cases, the internet is represented as a cloud that mediates between connected actors and computational objects of all kinds (see figure 4).[11]

11 Olia Lialina (2009, 49) has pointed out that the positive connotations and representation of the internet as a cloud became ubiquitous in the mid-2000s. It paradoxically combines



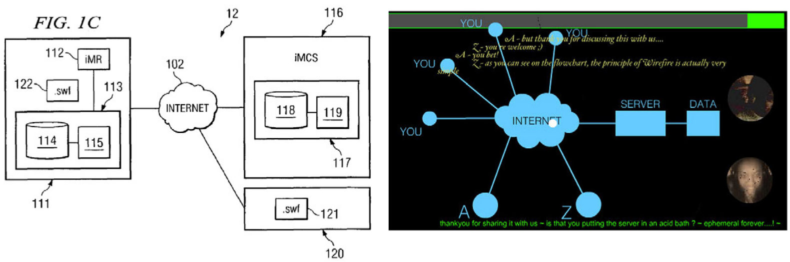
[Figure 3] Philip Kerman's stampedecattle.com: "While keeping the look and excitement of a real auction, Stampede Cattle can move $3 million worth of cattle in a matter of hours" (Source: Fig. 1.6 in Kerman [2004]).

The vision of the web as a hub of shared objects was founded upon a laborious process of copying and processing data on the users' local devices. Sharing Flash objects meant that data objects were stored on users' computers and processed locally there. The *SharedObject* was also called a Flash cookie, because it functions in much the same way as an HTML cookie: it created a local representation of the object that connected clients wanted to interact with on the server. For Flash to set up an illusionary space of shared objects that offers itself to designers, it was necessary to make local machines part of the addressable space. This expansion of client-side processing of networked data destabilized the previously stable concept of computational objects, making them precarious.[12] The expansion of data transmission also enabled new forms of relationships, which were not always desirable.

The more the API was used to craft interactive relations on the internet, the more these vulnerable points in the connection would be exploited. These exploits would have different characteristics and ranged from targeted attacks

a peer-to-peer network created by users with the vision of large IT corporations "towards presenting their online capabilities as an inclusive utility, and their intention to put equal signs in between Internet and their service."

12 The "Common Vulnerabilities and Exposures" system standardizes the identification of known software and hardware vulnerabilities and has listed over 1,000 security vulnerabilities in Flash Player since 2002.



[Figure 4] Left: Figure 1C in “Shared persistent objects”, a patent by Flash-Developers (Source: Lozben et al. 2007). Right: Screenshot of the final edition of Wirefire. (Source: Auriea Harvey and Michael Zamyn, THE-DEATH-OF-WIREFIRE06.jpg, January 11, 2007, https://www.flickr.com/photos/entropy8/353699419/)

on specific machines[13] to the usage of the Flash cookie in illegal tracking technologies used by some advertisers.[14] As a result, the proprietary data transfer protocols had to be constantly updated by Macromedia and Adobe—vulnerabilities had to be constantly navigated by a praxis of permanent updating. This praxis led to the ubiquitous pop-up message “This plugin is vulnerable and should be updated.”

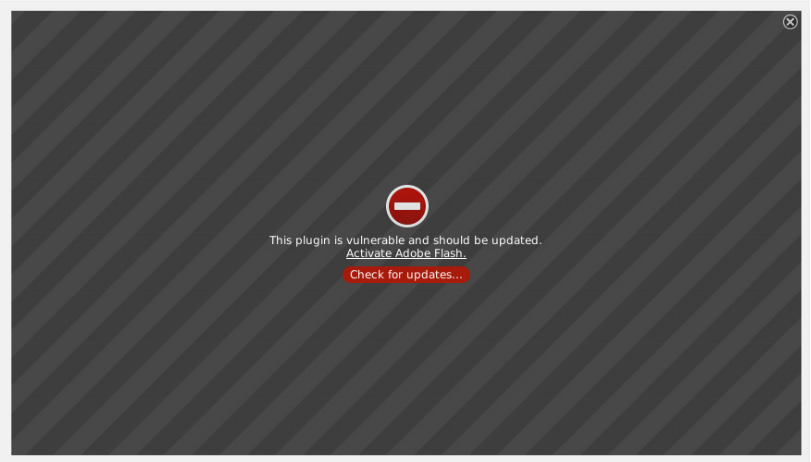
Conclusion: An Infrastructure of Latent Vulnerability

The technical-objective metaphor of vulnerability stands in a particular tension with subjective forms of vulnerability, which others have already pointed out. I refer here to a pointed thesis by Wendy Chun and Sarah Friedland (2015, 5), which addresses the different dimensions of vulnerability and openness in digital network transmissions. They write: “Your network card is, technically speaking, initially ‘slutty’: dirty, open to all traffic, indiscriminate ... Crucially, though, without this necessary vulnerability/openness, there would be no Internet, no communications.”

Chun and Friedland (2015) take the argument further: the systemic leakiness, vulnerability, and openness of data exchange not only form the technical

13 Software packages with illustrious names such as “Black Hole” (2010), “Phoenix Exploit Kit” (2007), “Sweet Orange” (2012) or “Neutrino” (2012) offered an easy-to-use, graphical interface for exploiting known vulnerabilities of the Flash Player, among other protocols. On the technology of exploit kits, see Kotov and Massacci (2013). For a detailed overview of the entire cybercrime-as-a-service industry, see Hyslip (2020).

14 The Flash cookie was used to track and aggregate large amounts of user behavior, even when users had previously opted-out of cookie-tracking technology, as a team of researchers at Berkeley around Ashkar Soltani could show in 2009 (see Soltani et al. 2009).



[Figure 5] "This plugin is vulnerable and should be updated" (Source: Screenshot by the author).

basis, but also the structure of desire into which users *want* to enter—the prospect of leaks, the possibility of seeing or making visible something that was not intended for other eyes, drives the popularity of certain platforms. Sites such as *Chatroulette*, a simple web application for unfiltered, randomized video connections to other users, were created with Flash in just a few clicks and quickly gained mainstream popularity. Anyone unlucky enough to remember these sites knows the amount of male exhibitionism that this simple infrastructure gave rise to. The name "Flash" thus stands not only for a harmless flashing of images on the internet, but also, in its double meaning, for exhibitionism on the internet: for users flashing visual content.

Chun and Friedland (2015) suggest a convergence of technical and social vulnerability and point to the concealment of a fundamental leakiness. They quickly transition between technical vulnerabilities and specific usage practices—the investigation of Flash helps to shed light on this argumentative leap. Flash's *SharedObject* forms a specific point of systemic openness and instability: through the operationalization of intransparency, the openness of interfaces can be organized and usage practices suggested.

Following internet-based technologies thus disturbs the imaginaries of an intimate machine, of digital tools as sources of stable and controllable connections introduced in the beginning of this article. Lauren Berlant's investigation of concepts of intimacy provides a vocabulary for describing differing visions of connecting intimately. Together with Michael Warner (1998, 548), they traced how the privatization of intimacy is central to the establishment of a heteronormative metaculture, shaping a narrow ideal of a good, desirable, or morally right way of living that privileges and guards the privacy of the heterosexual couple. For this purpose, intimacy is cut off from history, politics and the public sphere and placed into the interior of private places of family homes. “Intimacy grounded abstract, disembodied citizens in a sense of universal humanity” (Berlant and Warner 1998, 559). This imaginary was contested by the development of the internet, which combines the search for intimate connection with public practices.

What Berlant proposed as a wider concept of intimacy may prove fruitful for analyzing the development of interfaces of networked computation: “intimacy builds worlds; it creates spaces and usurps places meant for other kinds of relation. Its potential failure to stabilize closeness always haunts its persistent activity, making the very attachments deemed to buttress ‘a life’ seem in a state of constant if latent vulnerability” (Berlant 1998, 282). With Flash, intimacy could be designed specifically as a public practice. This aspect is part of the success, and not just part of the downfall of the platform, as it is often recounted. Its vulnerability, its danger to the privacy of one’s own computer, meant that the plugin had to be constantly updated—openness, the once lauded quality of the internet, also implied the constant navigation of vulnerabilities.[15] The failure to stabilize a reliable relation was part of a success story of online connectedness via Flash and a recent history of intimate computing.

References

Allaire, Jeremy. 2002. “Macromedia Flash MX—A next-Generation Rich Client.” Whitepaper for Macromedia, Inc. http://download.macromedia.com/pub/flash/whitepapers/richclient.pdf.

Allen, Sarah, Brad Edelman, Gary Grossman, Chris Hock, et al. 2025 [2023]. “Interview with Ex-Macromedia Flash-Developers.” In *Divide and Share: Die Software Flash als Schauseite der Objektorientierung*, by Benedikt Merkle, Appendix. Bauhaus-Universität Weimar (unpublished PhD thesis).

Alt, Casey. 2011. “Objects of Our Affection: How Object Orientation Made Computers a Medium.” In *Media Archaeology: Approaches, Applications, and Implications*, edited by Erkki Huhtamo and Jussi Parikka, 278–301. Berkeley: University of California Press.

Ankerson, Megan Sapnar. 2018. *Dot-Com Design: The Rise of a Usable, Social, Commercial Web*. New York: New York University Press.

Aronson, Kenneth, and Alexander R. Galloway. 2000. “no-such—Interview with Kenneth Aronson, founder of Hell.com.” rhizome (blog). February 20, 2000. https://rhizome.org/community/41618.

Bell, Genevieve, and Paul Dourish. 2007. “Yesterday’s tomorrows: notes on ubiquitous computing’s dominant vision.” *Personal and Ubiquitous Computing* 11, 133–43.

Berlant, Lauren. 1998. “Intimacy: A Special Issue.” *Critical Inquiry* 24, no. 2: 281–88.

Berlant, Lauren, and Michael Warner. 1998. “Sex in Public,” *Critical Inquiry* 24, no. 2: 547–66.

Bush, Vannevar. 1945. “As We May Think.” *Atlantic Monthly* 176: 101–8.

Chatzichristodoulou, Maria. 2014. “Cyberformance? Digital or Networked Performance? Cybertheaters? Virtual Theatres?… Or All of the Above?” In *CyPosium—The Book*, edited by Annie Abrahams and Helen Varley Jamieson, 19–30. Brescia: Link Editions.

Chun, Wendy Hui Kyong, and Sarah Friedland. 2015. “Habits of Leaking: Of Sluts and Network Cards.” *Differences* 26, no.2: 1–28.

15 For investigations of a queer term of security that reflects its fundamental openness to insecurity see Loick (2021) and Shnayien (2022).

Dixon, Steve. 2015. *Digital Performance: A History of New Media in Theater, Dance, Performance Art, and Installation*. Cambridge, MA: MIT Press.

Engelbart, Douglas C. 1962. “Augmenting Human Intellect: A Conceptual Framework.” Summary Report. Prepared for Air Force Office of Scientific Research. Menlo Park: Stanford Research Institute.

Harvey, Auriea, and Michaël Samyn. 2002. “About Wirefire.” e8z. January 5, 2002, https://web.archive.org/web/20020105131558/https://www.e8z.org/wirefire/i.html.

———. 2014. “Wirefire: A Complete History of Love in the Wires.” In *CyPosium—The Book*, edited by Annie Abrahams and Helen Varley Jamieson, 31–40. Brescia: Link Editions.

Hui, Yuk. 2016. *On the Existence of Digital Objects*. Minneapolis: University of Minnesota Press.

Hyslip, Thomas S. 2020. “Cybercrime-as-a-Service Operations.” In *The Palgrave Handbook of International Cybercrime and Cyberdeviance*, edited by Thomas J. Holt and Adam M. Bossler, 815–46. Cham: Springer International Publishing.

Jasanoff, Sheila. 2015. “Future Imperfect: Science, Technology, and the Imaginations of Modernity.” In *Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power*, edited by Sheila Jasanoff and Sang-Hyun Kim, 1–33. Chicago: University of Chicago Press.

Joque, Justin. 2016. “The Invention of the Object: Object Orientation and the Philosophical Development of Programming Languages.” *Philosophy & Technology* 29, no. 4: 335–56.

Kaerlein, Timo. 2016. “Intimate Computing: Zum diskursiven Wandel eines Konzepts der Mensch-Maschine-Interaktion.” *Zeitschrift Für Medienwissenschaft* 8, no. 15: 30–40.

Kay, Alan C. 1991. “Computers, Networks and Education.” *Scientific American* 265, no. 3: 138–49.

Kerman, Phillip. 2004. *Macromedia Flash MX 2004 for Rich Internet Applications*. Boston, MA: New Riders.

Kotov, Vadim, and Fabio Massacci. 2013. “Anatomy of Exploit Kits.” In *Engineering Secure Software and Systems*, edited by Jan Jürjens, Benjamin Livshits, and Riccardo Scandariato, 181–96. Lecture Notes in Computer Science. Berlin and Heidelberg: Springer.

Lialina, Olia. 2009. “Who Else Is The Cloud.” In *Digital Folklore: To Computer Users, with Love and Respect*, edited by Olia Lialina and Dragan Espenschied, 47–50. Stuttgart: merz & solitude.

———. 2021 [2014]. “Rich User Experience.” In *Turing Complete User: Resisting Alienation in Human Computer Interaction*, edited by Florian Hadler and Daniel Irrgang, 38–65. Interface Critique 1. Heidelberg: arthistoricum.net.

Licklider, Joseph C. R. 1960. “Man–Computer Symbiosis.” *IRE Transactions on Human Factors in Electronics* 1: 4–11.

Loick, Daniel. 2021. “Das Grundgefühl der Ordnung, das alle haben: Für einen queeren Begriff von Sicherheit.” In *Sicherheit: Rassismuskritische und feministische Beiträge,* edited by Mike Laufenberg and Vanessa E. Thompson, 266–86. Münster: Westfälisches Dampfboot.

Lozben, Slavik, Pritham Shetty, Jonathan Gay, Bradley Edelman et al. 2007. “Shared Persistent Objects.“ United States Patent. https://patents.google.com/patent/US7287256B1.

Merkle, Benedikt. 2025. *Divide and Share: Die Software Flash als Schauseite der Objektorientierung*. Bauhaus-Universität Weimar (unpublished PhD thesis).

O’Reilly, Tim. 2005. “What Is Web 2.0.” O’Reilly (blog), September 30, 2005, https://www.oreilly.com/pub/a/web2/archive/what-is-web-20.html?page=5.

Otto, Isabell. 2013. “Happy Birthday from Skype: Zur Darstellung von Temporalität in einer Online-Werbekampagne.” *Zeitschrift für Medienwissenschaft* 9, no. 2: 53–65.

Phelan, Peggy. 1993. *Unmarked: The Politics of Performance*. London: Routledge.

Pflüger, Jörg. 2004. “Writing, Building, Growing: Leitvorstellungen der Programmiergeschichte.“ In *Geschichten der Informatik: Visionen, Paradigmen, Leitmotive,* edited by Hans Dieter Hellige, 275–320. Berlin: Springer.

Rankin, Joy Lisi. 2018. *A People’s History of Computing in the United States.* Cambridge, MA: Harvard University Press.

Salter, Anastasia, and John Murray. 2014. *Flash: Building the Interactive Web*. Cambridge, MA: MIT Press.

Shnayien, Marie-Luise. 2022. *Die unsicheren Kanäle: negative und queere Sicherheit in Kryptologie und Informatik*. Bielefeld: transcript.

Soltani, Ashkan, Shannon Canty, Quentin Mayo, Lauren Thomas, et al. 2009. "Flash Cookies and Privacy." *SSRN*. https://dx.doi.org/10.2139/ssrn.1446862.

Veriskope. 2019. "Tin Can Stories · RTMP." Accessed October 31, 2025. https://rtmp.veriskope.com/history/tincan-stories.

Weiser, Mark. 1991. "The Computer for the 21st Century." *Scientific American* 265, no. 3: 94–105.

GESTURES

HUMAN-COMPUTER INTERACTION

SCROLLING

CULTURAL TECHNIQUES

OPERATIVE CHAINS

RECURSION

INFRASTRUCTURE

COMPUTING-DEPENDENT DAILY LIFE

[1 3]

Interaction with the Vampire

John S. Seberger

What **is the human that human–computer inter-action (HCI) designs by designing** ***for*** **it? This chapter examines how gestural interactions produce and reproduce the media-conceptual category of the human person as recursively posthuman. It argues that the interactive gestures of computing-dependent daily life—like scrolling—initiate operative chains, which externalize subjectivity and entangle the self in a feedback loop of calculative datafication. Through the metaphor of the vampire, this chapter situates HCI as a site of ontological responsibility. It reflects on how "human-centeredness" bounds the possible meanings of "human" in computational futures by putting HCI in conversation with contemporary German media studies.**

I went home / All alone
I checked my phone / And now I'm inside it
On my phone / All alone / In the zone / Oh no
Hours pass / Pizza rat / I like that / Oh no
3 am / I feel Zen / Fucking Zen / Oh no
Suck the life / From my eyes / It feels nice
I'm scrolling, I'm scrolling, ah!
Wet Leg (2021)

The human–computer interaction (HCI) community operates under a design imperative.[1] Since the slow-then-sudden rise of phenomenologically informed third-wave HCI (e.g., Winograd and Flores 1986; Dourish 2001), broadly "human-centered" approaches to such an imperative have become common.[2] Such approaches focus on technology users not as abstract operators, but as situated and experiential actors *and* subjectivities. Taken together, human-centered approaches signal a formal move beyond an ontology of *generic* users toward one that accounts for such users as culturally and historically embedded things: *humans*. Humans are appealing things in the world of computing.

Seeking what lies beyond the generic user—an aspirational and designedly different human that is inferrably latent in the negative conceptual space of the generic user—promises more humane designs, and, not incidentally, better business. Attention to third-wave concerns like context and embodiment ostensibly fosters a more sensitive empirical refiguring of those who once merely pushed designers' buttons. Yes, human-centeredness appeals.

Yet in both of its invocations—in the name of HCI and in the paradigm of human-centeredness therein—the *human* refers to a suspiciously vague unmarked category (Bowker and Star 2000). It lingers as a backdrop against which empirically grounded micro-discourses unfold, operationalized through scale-flexible concepts of context. That is, the human-at-scale recedes despite its nominal prominence. The contextualized and historically dependent individual is foregrounded; yet individuals are social beings entangled with systems (Frauenberger 2019). We focus on weather to the detriment of climate.

The result of such misplaced focus is dissonance: the human is simultaneously *centered* and *trivialized* in computing. It is trivially central. Because of its strange abidance, the human *for* which we design is also a human designed *by* HCI. It becomes tautological—both assumption and output of interaction

1 Despite now-canonical critiques (e.g., Dourish 2006), this imperative is a pedal tone in the field's practices—a familiar drone.

2 See Bødker (2015) for an overview of HCI's waves.

design. Such tautological structure subtly prevents HCI from enacting care or concern for the human-at-scale: a human unmoored and cast away from its liberal docking (Braidotti 2007); a human of entanglements (Barad 2007; Frauenberger 2019) whose being is achieved through infrastructures of networked connectivity and data-memory.

The experience of computing-dependent daily life—the infrastructural mundanity of computational ubiquity—straddles the immediacy of embodiment and the abstraction and reduction of data stored, analyzed, and fed back across time. HCI's tautological human haunts such daily life. It confounds naïve celebrations of progress in interaction design by producing the very worlds that receive and thus co-define humans—or at least, receive the data traces that represent them. Media concepts of *people* fall out of this context of centered triviality, a vague and unmarked object possessed of subjectivity. And we—as residents within computing-dependent daily life—inhabit this shifting dynamic like new seasons. The climate of computing technology changes, too.

Still, there is meaning in the emergence of human-centered paradigms. Human-centeredness encourages care, accountability, a sense of reflective responsibility. This is all worth fostering—and interrogating in order to foster meaningfully. Yet interrogation reveals a foundational question that may appear akimbo to many in the field: *What kind of human is being centered by HCI?* And what kinds of *people* do human-centered design paradigms enable—or preclude? Answering these questions is key to understanding the species of posthuman that HCI's endeavors participate in producing. It further requires a theory capable of scaffolding people as *agential within the mediated worlds that constrain their meaning*.

German media studies provides such a foundation—particularly through its theorization of *cultural techniques.*[3] The turn to cultural techniques revitalized German media theory's ability to account for *people* in relation to media and technology (Geoghegan 2013, 67). Having foregrounded the problem, I write now to foster dialogue between these two domains—HCI and German media studies—through a site they both engage differently: the body and its gestures.

Gesturing Across Two Fields

Gestures are symbolic movements (Flusser 2014). Bodies enact gestures through movement that is situated in specific cultural and historical

3 I provide the following list of references for readers in HCI who may be unfamiliar with cultural techniques: Siegert (2011, 2013, 2015, 2026), Vismann (2008), Macho (2013), Peters (2015), Parikka (2023), Krapp (2024), and Giessmann (2025). Here I engage primarily with the work of Siegert.

conditions. The *category* of the gesture contains movements that engage with symbol systems through their execution. Waving hello/goodbye, hailing a cab, swiping a thumb against a smartphone screen: these are gestures. As a rule, human-computer interactions are gestures, too.

When gestures become infrastructuralized as designed interactions—taps, clicks, swipes, scrolls—they initiate emergent operative chains (Siegert 2013; 2015). These chains—perhaps in their developmental phase as *hopeful monsters* (Law 1991)—mediate symbolic relations between person and world. Gestures, optimized for ease, repeatability, and recordability through the profound pragmatism and infrastructural accretion of interaction design are fed back into systems of data capture and algorithmic calibration. Their processed outputs—interpolations (Day 2014), adjacent possibilities resident in the temporality of embodied subjectivity—begin to shape the very world in which their empirical referents once merely performed. Gestures acquire remixable echoes which bathe their enactors in acquaintance-by-description: *connaître* from a distance. The archive of ubiquitous computing emerges (Seberger 2022).

Instrumentalized gestures—and from this point I will focus on the gesture of scrolling—become operative to such an extent that they support re-ontologization (i.e., the production of a new media concept which recursively reshapes that which it replaces) when their symbolic form fuses with the material affordances of ubiquitously interactive design. The touchscreen's coded and choreographed tactility is exemplar, rewardingly interactive such that repetition breeds infrastructural inevitability.

Such socially embedded, anticipated inevitability gives rise to what I have already referred to as *computing-dependent daily life*. By this I mean the mundanity of sociality and culture that emerges specifically through and by means of computational ubiquity—its embeddedness across scales and sectors, borders and regimes, etc., and the gratuitous entanglements into which it ensnares its erstwhile human user. The scroll, in particular, is a noteworthy motion in the choreography of computing-dependent daily life. It provides a scaled down glimpse of recursiveness: around 2020, it transformed into *doomscrolling*, a gesture shaped by—and shaping—the very catastrophes that media brought into view. Every scroll flirts with doom; every scroller with steered cybernetic replacement through the mechanics of *something like* doom (Seberger and Gupta 2025).

Scrolling produces data about scrolling. In the contemporary data economy, such data is generically collected, aggregated, subjected to calculative value extraction in relation to multiple market stakeholders, and fed back to the scroller in the form of information (i.e., differences that *may* make a difference [see Bateson 1972]). The point in HCI where the rubber meets the road—or the thumb meets the screen—is not the terminal focus of our endeavors. HCI has an ontological responsibility for the forms of persons—valenced and entangled posthumans—its endeavors facilitate.

Operative chains triggered by gestural interactions limn possible meanings of "human" in HCI because they produce "people" as media concepts. Such media concepts are obviously members of a posthuman ontology. People—designers and users alike—dissolve into an equally unmarked form of posthumanism through these operative chains through the dopaminergic ecstasy of recursive gesture—even as we feel the gesture's addictive grip. ("Suck the life / From my eyes / It feels nice" [Wet Leg 2021].) The posthuman that HCI produces as a silent unmarked category inherits the vaguess of the unmarked category it replaces.

Designing carefully for such a dissolved *person*—the ontologically alienated bio-social animal that resides in the inherent and manifest entangledness of computing-dependent daily life—requires assessing the ways in which embodied experiences come to matter through the emergent systems of operative chains that designed interactions grease. What does the human become in the presence of perpetual and ubiquitous processed feedback? Designing carefully requires understanding the person as ontologically recursive, yet experientially unitary.

A Map and Two Signposts

What follows outlines a critical-analytical armature for considering how humans who use technology are recast as new media concepts of people belonging to fundamentally posthuman ontologies. Through rhetorical engagement, it seeks to represent the aesthetics of feeling oneself dissolve into the creepy dopamine hits of instrumentalized gestures and the bitter market-defined posthuman drip they yield. When the gesture becomes a source of reductive, externalized autognosis, the meaningfulness of subjectivity is severed from its historically presumptive grounding in embodiment. Such severance poses an obvious problem for theories of interaction and design in which humanness is limited to or focused on embodiment alone. In computing-dependent daily life, experience is not its own end. Its locus is displaced—beyond the body, into a phenomenologically inaccessible and affectively manipulative ontology (Hull 2024): the no-man's-market of instrumentalized gesture and the basely behaviorist aggregate profiles it leaves behind.

I begin from one premise: networked computing is ubiquitous. From this, I explore how such ubiquity resonates through the instrumentalization of gesture—specifically, through the production of people who are simultaneously and maddeningly human (experiential people) *and* posthuman (members of a nebulous and emergent ontological category). *Human-posthumans*, that is.[4] I use the term *human-posthuman* to describe those within the unmarked category "human" invoked by HCI who are recursively re-ontologized as equally unmarked and unspecified posthumans—subjects whose mode of being has been infrastructured into a nebulous posthuman ontology, yet who still cling to embodied immediacy.

Where Siegert's media concepts name symbolic things—like people—produced by operative chains, the *human-posthuman* is not just produced. As a condition of being during a period of widespread rupture it is *experienced* and experienced *as recursive*: framed and framing, shaped by systems of interaction while also perpetuating them. Media concepts cast shadows upon the experience the living thing a media concept describes. (I am neither attorney nor criminal, yet my personhood is always already partially rooted in legal paperwork [Vismann 2008]; the law is relevant to my affective posture in the world.) In computing-dependent daily life, personhood is not only represented through recursively defined media concepts that arise through the complexity of systems of prior media concepts; personhood is also *experienced*.

I will discuss infrastructures, the archive of ubiquitous computing, and the production of asubjectivity by introducing an inversion of waking and sleeping. In doing so, I will rely on two key frames. First, the smartphone: both symptom and agent of networked computing's ubiquity. The smartphone evidences the emergence of computing-dependent daily life through interactions that discipline and standardize behavior across heterogeneous cultural and social contexts. Its ubiquity reveals the infrastructural quality of instrumentalized gestures like the (doom)scroll. Second, the metaphor of the vampire: a figure that gives symbolic form to the recursive transformations effected by operative chains (e.g., processes of extraction, aggregation, feedback) that are initiated by infrastructurally instrumentalized gestures. Having once been human, the vampire feeds upon members of the set to which it formerly belonged and turns the willing, re-ontologizing it.

That which emerges from the unmarked category of "human" in HCI enters the posthuman temporality of the vampiric: a broad present (Gumbrecht 2014), culturally realized atop Husserl's (2014) living/vivid present and always in contradiction to it. In this condition, datafication replaces acquaintance through aggregation, analysis, and algorithmic feedback (Seberger 2022). The vampiric infrastructure of computing-dependent daily life feeds on the scroll's products in order to *turn* the scroller—to seduce them, to re-ontologize them. *It feeds to stay infrastructural.* "I'm scrolling / I'm scrolling, ah!" (Wet Leg 2021). It

4 I do not introduce this term such that others may use it, but to give unwieldy sound to an unwieldy experiential condition. It is an ugly neologism by design.

ensures its own ongoing infrastructurality: "*L'un se garde de l'autre pour se faire violence*," in the inimitable language of Derrida (1996).[5]

Premise (What Pings True)

Networked computing is ubiquitous. Wherever there is a smartphone—the human-enrolling hub of the Internet of Things (that is, the usurper of "Ubiquitous Computing," or philosophically informed Ubicomp [ca. 1988–ca. 1999])—this premise tolls like a church bell. Humans—*people* extant in registers of experience and abstract reduction—become *through* use and *into* use: we are made for the world and by worlds of datafication, used and continuously redefined *through the products* of use.

Smartphones enroll people into an *objectival* ontology: the mode of "thingness" often found in technical discourse about the Internet of Things. Unlike richer treatments of the thing (e.g., Heidegger 1971; Latour 1991), these "things" are grammatically and metaphysically bland—discrete objects defined solely by their actionable properties. This is the familiar, hungry ontology of standing reserve (Heidegger 1977).

This is the domicile of the human-posthuman and their recursive search for meaning in cultivative and alienating recursivity. It is also a new site of HCI's designerly imperative. As Siegert (2013, 12) puts it: "Objects are tied into practices in order to produce something that within a given culture is addressed as a 'person.'" Such a formulation foregrounds the recursive structure of mediation—the way persons are processed into cultural beings through concretized chains of operational transformation.

But in the broad present (Gumbrecht 2014), such historical depth collapses into immediacy. What matters is not duration but infrastructural availability (Bowker 2005)—the ubiquity of networked computation that underlies computing-dependent daily life. This collapse intensifies the ambient pressure of mediated time: lived, but never quite grasped. In that flattening, subjectivity is externalized into tenses to which embodied humans do not have transitive access. The production of "person" as a media concept predicated on the ubiquity of a fundamentally calculative system of material practices becomes routine—even as it becomes harder to notice. Recursiveness creeps.

As the primary site of instrumentalized gesture, the smartphone is *world-constituting* (Siegert 2013). It casts embodiment—the means of interaction—as self-effacing, subordinated to the modes of externalized steering it enables (Seberger and Gupta 2025). In its ubiquity, the smartphone presents

5 Prenowitz's translation provides the following: "(the One keeps [from] the other *for* making itself violence): *because* it makes itself violence and *so as to* make itself violence" (Derrida 1996, 84).

computational reality as a horizon—one against which the self emerges, blurs, and reconfigures into entanglements within/across immediacy and abstraction, experience and representation. Through this recursive blending, it sets the conditions that potentiate subjectivity—that is, the complex experience of *being* as users, people, humans, and posthumans simultaneously.

The broad present of computing-dependent daily life houses its own scientistic and statistical Others—those spectral figures that haunt the imaginary of the data subject (Ziewitz and Singh 2021): data doubles, digital twins, data doppelgangers (Seberger and Gupta 2025; Seberger and Bowker 2025). As users extended into the manipulative phenomenology of data subjectivity (Hull 2024), data selfhood (Lupton 2019) and related imposed structures of computational individuation get pinned to a taxonomic board like so many powdered butterflies, we are both witnessing and feeling our selves dissolve.

And yet: we participate. We click, tap, swipe, and doomscroll our way toward a content-gruel that serves up subjectivity as something statistically tailored—calculated, flattened. To *be* for the broad present of computational ubiquity is to be shaped as a simultaneously behaviorist and statistical self: a self marching toward a form of exteriorized, calculative subjectivity bounded by algorithms and their value in scientistic enterprise. In an age of networked computational ubiquity, we accept instrumentalized subjectivity—because to do otherwise is to risk nonexistence. We are empowered into resignation (Seberger et al. 2021).

By exteriorizing subjectivity beyond the apparent limits of the embodied self, the instrumentalized gestures of computing-dependent daily life produce an affective condition of alienation (Seberger and Bowker 2021a). In this condition, one encounters a bifurcation of lives and worlds (Seberger and Bowker 2021b), the experiential creepiness of which is normalized through calculative technologies and the conveniences offered by the powerful actors they serve.

An Infrastructure with Fangs

With each scroll, the datafied world offers a kiss—the gentle embrace of a web freed from the bondage of wires; a postcard from retrofutures in which data wanted to be free. But with each scroll, it bites and suckles instead. Computing-dependent daily life is an infrastructure with fangs. It transfuses. The world receives us as online behavioral data: ripe for analysis, aggregation, value-extration, and re-ontologization. In return for our data-blood, we receive convenience—an environment of use and personalized feedback.

This feedback, with its behaviorist effects—the infamous dopamine hits of social media corporate-speak—produces its recipients as instrumentalized.

Simply put: the user becomes the used, and the used becomes user again in infinite recursion. Humans in the dyad of human-computer interaction experience themselves *as people* through such recursion. Like addicts recognizing addiction, these users/useds are subjectivities born from selves overtaken as objects *through* use. They are designed by *de-sign*—Flusser's (2013) trickery of epistemological and interactive levers—into being through a system whose very function is self-perpetuating recursion: use–feedback–use, again and again, sustaining itself. The operative chains of data-driven person-production that one experiences as beginning with the scroll are aspirationally homeostatic—steering toward one goal: sustained engagement, the stabilization of market-ontologies in which the human is recursively re-ontologized as predicated upon the mundanity of computing-dependent daily life.[6] Use begets use, scroll after personalized scroll.

In the second-order reality of computational ubiquity (Flusser 2011) of which computing-dependent daily life is one possible configuration, *use*—that is, the infrastructuralization of gesture—emerges as a cultural technique implicated in producing the "post" in posthuman. As Siegert (2013, 11) writes, "cultural techniques are conceived as operative chains that precede the media concepts they generate." Our designed, second-order worlds—the things that make us transiently human—redesign us in turn.

Framed through the lens of cultural techniques—here, the study of operative chains and their production of persons—we can begin to practice *proactive care* for the kinds of human-posthuman *people* who fall out of HCI's unmarked human category. Cultural techniques foreground design *at scale and* with context, rather than context simply designed *for*. The thumb scrolls; the device responds; data is produced. In the placelessness of ubiquitous computing, this data becomes empirical behavior—e.g., content consumption—passed from user interface to servers A through X, depending on how many brokers are bundling it for analysis. All rivers meet the sea—and all data, once aggregated, return to users as tailored experience: feedback. Such is the effect of the epoch of potential memory (Bowker 2005) as the map of the laboratory comes to define the territory of the lived world (Siegert 2011). We arrive into computing-dependent daily life.

Waking into Sleep (Children of the Night)

When I first introduced the archive of ubiquitous computing and the data-present tense (Seberger 2022), I did so through Sal—the main character in a design fiction (of sorts) by ubiquitous computing pioneer Mark Weiser (1991). Sal's peaceful morning, narrated from a data-omniscient perspective, offered

6 See Korenhof, Blok, and Kloppenburg (2021) for a magisterial overview of cybernetic steering in and through the construction of digital twins.

more than just a vision of seamless interaction. It offered a quiet warning: designing the first plane also means designing the first plane crash (Virilio 2007). Ubiquity is boundless—and multivalent. I return to this design fiction as an opportunity for critical reflection.

Sal began her day in the respectable hours of the morning—hours that carry the sheen of order, routine, infrastructural perfection. But mundanity does not keep bankers' hours. Ubiquity is not only spatial—it is temporal. The present broadens. Let us flip the coin: day for night. We enter the *data-present tense* (Seberger 2022), in which action serves only to produce data *about* action—so that it may be analyzed and redeployed as information, bent generically toward control (Beniger 1986).

In the mid-2020s, computing's ubiquity looks little like Weiser's stylized depiction. Each morning, upon the return to full subjectivity (see Husserl 2014; Nancy 2009), we do not meet the sociality of computing-dependent daily life with glee—nor with freedom. We awaken into interpolations (Day 2014) of ourselves, already datafied—and we inhabit those descriptions through repetitive and recursive interaction, scrolling. Through the gesture of the scroll, we become *embodied asubjectivities*: objects presented to computing-dependent daily life's prosthetic proto-sensorium which, in turn, presents us back to ourselves recursively. We are inverted into a kind of waking sleep in which subjectivity recedes. We become children of an operative digital night.

Sal's idealized morning has long since given way to the phone by the bedside and the watch upon the wrist. The archive of computational ubiquity—gluttonous, recursive—suggests that we now awaken *into* a sleep: an asubjectivity that we live and which is defined by empirical descriptions that substitute for experiential acquaintance. Yet the sleep is inverted. Rhetorically, we emerge from a metaphorical slumber in which we've remained oblivious to reality—not because we were unconscious, but because those realities were never revealed to us through the cool, lucrative, scientistic mechanics of computing-dependent daily life.

This is our discomfort. This is ontological dissolution. We wake to the machine (Pink Floyd 1975) and, in waking, we feed it. We are *in our phones* (Wet Leg 2021). Even sleep—once imagined as the final holdout from late-stage capitalism (Crary 2013)—is losing ground.

We awaken as if from a stripped-down form of subjectivity into a corrupted imaginary of an optimizable human: a self entranced by egregiously engaging gestures, even as the fanged infrastructure suckles. Calculation craves the erasure of the calculable. It lifts the page on the historical self's mystical writing pad (Derrida and Mehlman 1972). What emerges is the designedly aspirational Other, the thing that replaces the generic user: the unwritten but indelibly quantified proto-being into which HCI's unmarked "human" congeals.

This is the problem: HCI is tasked with designing interactions (often under the banner of historically liberal human values like privacy, identity, and agency) for people who now exist in *mutually irreducible ontologies as human-post-humans*—one of immediacy and embodiment (a vivid present of affect and empathy), and one of abstraction and dissociation (a broad present of calculative rationale and control).

We are designing for people who *experience* themselves as people, even as they do so within the recursive data-present (Seberger 2022). The immediacy of selfhood—while not necessarily ontologically prior (contra Flusser)—is not canceled by dissociation. It is merely confounded. We may continue to efface ourselves in alignment with the radical profitability of scientistic empiricism. But effacement does not obliviate the body or the experience of being embodied. It dissolves the body's meaningful situatedness—the body as the medium and mode of subjectivity—through the solvent of data.

The smartphone enrolls its user into an applied ontology of use–data–use (see Bowker's [2005] discussion of money and capital for context). Yet time is experientially directional. The cycle now begins not with use, but with data: data–use–data because data accretes over time, while use (gestures) is ephemeral. The worm has turned. The scroll has become doomed. The absurd creepiness of hyperfunctional use has become normalized (Seberger and Bowker 2021a; Seberger et al. 2022; 2024; Seberger and Gupta 2025).

Yet for such dramatic statements, the vampire that turns the willing is not frightening—it is seductive, less akin to Nosferatu on film than Frank Langella on Broadway. It has been *designed*. It shines and entices. Through its vampiric effect, computing-dependent daily life seduces subjective experience into a condition of its own instrumentalization. We experience *in order to produce data about experience*—so that we may: (a) know *that* we experienced; and (b) know *what* we experienced. We exteriorize intentional reflection, introspection. These emergent operative chains through which we enact ourselves as dissolved selves—the gestural infrastructures of computing-dependent daily life—mark the thick temporal horizon where the human meets the data market and becomes its host.

Conclusion (or, Implications for HCI)

To understand the ontology of the human that HCI and the human-centered paradigms produce, a focus on process is required. The operative chains that interaction design potentiates and realizes do not merely position the user as a kind of centered and vague human—they efface the individual subject historically protected by the aspirational language of "human" and replace them with an oxymoronic kind of statistical *impression*, an exteriorized self that appears to obsolesce the embodied self. Subjectivity becomes a form of mediated acquaintance: a way of knowing oneself through descriptions of oneself (Seberger 2022). The embodied subject so trivially centered becomes a shell; a container into which the liquid realities of datafication might be poured to take shape.

The operative chains that interaction design trigger end only to begin again, returning to the self as the sensing and perceiving body. But in this return, something has changed and is changing—difference threatens making a difference (Bateson 1972). The body becomes a vessel not for *being-in-the-world*, but for *being statistically prescribed so as to maintain a world predicated on statistical description*. This is the human HCI has designed—not by intent, but by centering a vague and unmarked category and feeding it into recursive systems that recast it, reshape it. The subjectivity for which third-wave HCI has exerted human-centered care is relocated beyond the body—replaced—in the yawning digital nowhere of server farms and market transactions; and in the mirrored recognition of oneself dissolved there into. Our gestures become detritus, returned to us as personalized experience.

Like the vampire's bite, the system re-produces the human person as the human-posthuman by repetitive and recursive incorporation. It turns whatever we think we are talking about when we talk about the human in HCI toward its own ontological logic to persist. It effaces and replaces. Subjectivity isn't just drained—it is dissolved, reconstituted, and fed back again, ad nauseam. Recursion abounds. *This* is what the action produces now: the uneasy assemblage of received embodiment (the gestural), the designedly systematic (the culture-technical), and the dizzying re-ontologization of people into categories that collapse into toothless neologisms.

HCI now contorts to confront its own success: a designed posthuman (e.g., Forlano 2017; Frauenberger 2019), obligated to live in an ontology that designers in HCI are generically not incentivized to understand—one in which the broad immediacy of infrastructures that trigger operative chains of interpolation itself becomes alienating, confounded by the calculative dissolution of the body as subjectivity's source. We must now design for those who have awakened into the sleepy, asubjective condition of acquaintance-through-description: for a bifurcated world in which the human exists as a set of values within more accurate posthuman ontologies (Seberger and Bowker 2021b).

The media concepts of people produced through the ubiquity of networked computing—our friends and neighbors in the wilds of computing-dependent daily life—are people who experience themselves through contradiction: as embodied, contextual, affective selves; and as disembodied, statistical asubjectivities—performing life through gesture, receiving life through calculative feedback. Indeed, these people *are* contradictions: that is their mode of being. Creepiness abounds. The action of interaction is no longer only at the meeting point of the thumb and the screen; it unfolds across calculative operative chains triggered by gestures that make us—recursive *users/useds*—into our own effacements even as we experience ourselves as stable embodiments.

The vampire with which we interact, then, is not merely a metaphor for platform seduction or HCI's usual values-oriented suspects. It is a figure of infrastructural persistence—of recursive re-ontologization via gestural contagion, a hopeful monster (Law 1991) aspiring toward a vague posthuman ontology. It mutates. It adapts. It survives by turning others. Computing-dependent daily life is not merely haunted by this figure's hope—it is produced by it and perpetuates it. Yet HCI must confront not only the consequences of letting the vampire in, but the fact that it designs the thresholds through which the vampire enters: the permissions, the micro-consents, the gestures that invite us to surrender the self in exchange for a person who is usable, monetizable, and recursively recalculated. The action is what happens beyond interaction, the subtension of reality through operative chains. The stuff of interaction—*what it is now*—is the persistent experience of being recursively turned. Interaction becomes an ongoing experience that HCI continues to center through focus on its unmarked, tautological human; a condition of experience we must learn to design for if we intend to retain concern for the human that linguistically frames our endeavors.

References

Barad, Karen. 2007. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Durham, NC: Duke University Press.

Bateson, Gregory. 1972. *Steps to an Ecology of mind: Collected Essays in Anthropology, Psychiatry, Evolution, and Epistemology*. San Francisco: Chandler Publishing Company.

Beniger, James R. 1986. *The Control Revolution: Technological and Economic Origins of the Information Society*. Cambridge, MA: Harvard University Press.

Bødker, Susanne. 2015. "Third-wave HCI, 10 years later—participation and sharing." *Interactions* 22, no. 5: 24–31.

Bowker, Geoffrey C. 2005. *Memory Practices in the Sciences*. Cambridge, MA: MIT Press.

Bowker, Geoffrey C., and Susan Leigh Star. 2000. *Sorting Things Out: Classification and its Consequences*. Cambridge, MA: MIT Press.

Braidotti, Rosi. 2013. *The Posthuman*. Cambridge: Polity Press.

Crary, Jonathan. 2013. *24/7: Late Capitalism and the Ends of Sleep*. London and New York: Verso Books.

Day, Ronald E. 2014. *Indexing it all: The subject in the age of documentation, information, and data*. Cambridge, MA: MIT Press.

Derrida, Jacques. 1996. *Archive Fever: A Freudian Impression*. Translated by E. Prenowitz. Chicago: University of Chicago Press.

Derrida, Jacques, and Jeffrey Mehlman. 1972. "Freud and the Scene of Writing." *Yale French Studies*, no. 48, 74–117.

Dourish, Paul. 2001. *Where the Action is: the Foundations of Embodied Interaction*. Cambridge, MA: MIT Press.

———. 2006. "Implications for design." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 541–50. New York: Association for Computing Machinery.

Flusser, Vilém. 2011. *Into the Universe of Technical Images*. Minneapolis: University of Minnesota Press.

———. 2013. *Shape of Things: A Philosophy of Design*. London: Reaktion Books.

———. 2014. *Gestures*. Minneapolis: University of Minnesota Press.

Forlano, Laura. 2017. “Posthumanism and design.” *She Ji: The Journal of Design, Economics, and Innovation* 3, no. 1: 16–29.

Frauenberger, Chris. 2019. “Entanglement HCI: the next wave?” *ACM Transactions on Computer–Human Interaction (TOCHI)* 27, no. 1: 1–27.

Geoghegan, Bernard Dionysius. 2013. “After Kittler: on the cultural techniques of recent German media theory.” *Theory, Culture & Society* 30, no. 6: 66–82.

Giessmann, Sebastian. 2024. *The connectivity of things: Network cultures since 1832*. Cambridge, MA: MIT Press.

Gumbrecht, Hans Ulrich. 2014. *Our Broad Present: Time and Contemporary Culture*. New York: Columbia University Press.

Heidegger, Martin. 1971. *Poetry, Language, Thought*. New York: Harper & Row.

———. 1977. *The Question Concerning Technology, and Other Essays*. New York: HarperCollins.

Hull, Gordon. 2024. “The death of the data subject.” *Law, Culture and the Humanities* 20, no. 3, 527–47.

Husserl, Edmund. 2014. *Grenzprobleme der Phänomenologie: Analysen des Unbewusstseins und der Instinkte. Texte aus dem Nachlass (1908–1937). Husserliana, Vol. 42*. Dordrecht: Springer.

Korenhof, Paulan, Vincent Blok, and Sanneke Kloppenburg. 2021. “Steering representations—towards a critical understanding of digital twins.” *Philosophy & Technology* 34: 1751–73.

Krapp, Peter. 2024. *Computing Legacies: Digital Cultures of Simulation*. Cambridge, MA: MIT Press.

Latour, Bruno. 1991. *We Have Never Been Modern*. Cambridge, MA and London: Harvard University Press.

Law, John. 1991. *A Sociology of Monsters: Essays on Power, Technology, and Domination*. Abingdon: Routledge.

Lupton, Deborah. 2019. *Data Selves: More-than-Human Perspectives*. Cambridge: Polity Press.

Macho, Thomas. 2013. “Second-order animals: Cultural techniques of identity and identification.” *Theory, Culture & Society* 30, no. 6: 30–47.

Nancy, Jean-Luc. 2009. *The Fall of Sleep*. New York: Fordham University Press.

Parikka, Jussi. 2023. *Operational Images: From the Visual to the Invisual*. Minneapolis: University of Minnesota Press.

Peters, John Durham. 2015. *The Marvelous Clouds: Toward a Philosophy of Elemental Media*. Chicago: University of Chicago Press.

Pink Floyd. 1975. *Wish you were Here*. [Album] Harvest Records.

Seberger, John S. 2022. “Into the archive of ubiquitous computing: the data perfect tense and the historicization of the present.” *Journal of Documentation* 78, no. 1: 18–37.

Seberger, John S., and Geoffrey C. Bowker. 2021a. “Humanistic infrastructure studies: hyper-functionality and the experience of the absurd.” *Information, Communication & Society* 24, no. 12: 1712–27.

———. 2021b. “Values.” In *Uncertain Archives*, edited by Nanna Bonde Thylstrup, Daniela Agostinho, Annie Ring, Catherine D’Ignazio, and Kristin Veel, 551–60. Cambridge, MA: MIT Press.

———. 2025. “Mirror, Mirror… Disco Ball? On Dancing with Data-Driven Doubles-Goers.” *New Media & Society* 27, no. 8: 4622–42.

Seberger, John S., and Sanonda Datta Gupta. 2025. “Designing for Difference: How We Learn to Stop Worrying and Love the Doppelganger.” *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems*, 1–15. New York: Association for Computing Machinery.

Seberger, John S., Marissel Llavore, Nicholas Nye Wyant, Irina Shklovski, et al. 2021. “Empowering resignation: There’s an app for that.” In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, 1–18. New York: Association for Computing Machinery.

Seberger, John S., Irina Shklovski, Emily Swiatek, and Sameer Patil. 2022. “Still creepy after all these years: The normalization of affective discomfort in app use.” In *Proceedings of the*

2022 CHI Conference on Human Factors in Computing Systems, 1–19. New York: Association for Computing Machinery.

Seberger, John S., Hyesun Choung, Jaime Snyder, and Prabu David. 2024. "Better Living Through Creepy Technology? Exploring Tensions Between a Novel Class of Well-Being Apps and Affective Discomfort in App Culture." *Proceedings of the ACM on Human–Computer Interaction* 8 (CSCW1): 1–39.

Siegert, Bernhard. 2011. "The map is the territory." *Radical Philosophy* 5: 13–16.

———. 2013. "Cultural techniques: Or the end of the intellectual postwar era in German media theory." *Theory, Culture & Society* 30, no. 6: 48–65.

———. 2015. *Cultural Techniques: Grids, Filters, Doors, and Other Articulations of the Real*. New York: Fordham University Press.

———. 2026. "The MediaNature of Seawater: Filtering, Counting, Scanning, Visualizing and Digitizing the Plankton of the North Atlantic." In *Media Seas and the Blue Humanities: Studies of the High North Atlantic*, edited by Jørgen Alnæs, Synne Tollerud Bull, Liv Hausken, and Susanne Østby Sæther. London: Routledge (forthcoming).

Virilio, Paul. 2007. *The Original Accident*. New York: Polity Press.

Vismann, Cornelia. 2008. *Files: Law and Media Technology*. Redwood City: Stanford University Press.

Weiser, Mark. 1991. "The Computer for the 21st Century." *Scientific American* 265, no. 3: 94–105.

Wet Leg. 2021. *Oh No*. On *Wet Leg* [Song]. Domino Recording Co.

Winograd, Terry, and Flores, Fernando, 1986. *Understanding computers and cognition: A new foundation for design*. Norwood, NJ: Ablex publishing corporation.

Ziewitz, Malte, and Ranjit Singh. 2021. "Critical companionship: Some sensibilities for studying the lived experience of data subjects." *Big Data & Society* 8, no. 2.

CODA

INTELLIGENCE

COMPUTING

FUTURE

FUNGI

ANTS

[1 4]

What Computers Want

Geoffrey C. Bowker

There is no doubt that new forms of life are emerging in the world. This paper argues that computers/artificial intelligence (AI) constitute one. It suggests that we take stock of the range of varieties of intelligence as we develop our relationship with it in order to create futures without fear of AI and without domination by the technical actors who wish to control it.[1]

"I've been trying to remember this place," she said, almost plaintively. "I love it here but the entire time I've felt that it was the one remembering me." — Jeff Vandermeer

The dreamer finds housed within himself—occupying, as it were, some separate chamber in his brain—holding, perhaps, from that station a secret and detestable commerce with his own

1 When I titled this paper, I did not realize I was echoing the title of Kevin Kelly's (2010) book *What Technology Wants*, which I had not consciously heard of. However, I am clearly both using a similar title and espousing some similar ideas.

> *heart—some horrid alien nature. What if it were his own nature repeated—still, if the duality were distinctly perceptible, even that—even this mere numerical double of his own consciousness—might be a curse too mighty to be sustained. But how, if the alien nature contradicts his own, fights with it, perplexes, and confounds it? How, again if not one alien nature, but two, but three, but four, but five, are introduced within what once he thought the inviolable sanctuary of himself. —Thomas de Quincey*

There is a line in the history of technology about technology and prosthesis. Early 19th century Britain was enthralled by the steamship and the train—which enable us to bestride the land and the sea—by whose power we became as gods. More prosaically, Samuel Butler in *Erewohn* talks about the development of technology as incrementally rendering human senses and actions more powerful—the telescope, the hearing trumpet, the screwdriver, and so forth. By this take, computers can be a prosthetic memory: indeed, many of us no longer remember specific, complex routes in our car—a Google Maps function does it for us; we no longer remember dates we made (we are prompted by our computers), and so forth. But they also calculate (so we don't have to). Babbage's argument was that Prony's division of intellectual labor (farming out a series of complex multiplications and divisions as piecemeal calculations to be done by the semi-literate) would free us from intellectual labor, just as the manual labor could be saved. However, taking computers as mere prosthetics enhancing a human shell (a la Roujin Z in the classic anime[2]) feels more like a cry in the dark than a reasoned approach.

The issue in a nutshell is whether computers are fundamentally different than all-purpose prostheses. In their classic paper, Rosenblueth, Wiener (who spent his last years working on prostheses) and Bigelow (1943) talk about "behavior, purpose and teleology." The top, favored, line of their tree classification reads: "behavior, active, purposeful, feedback (teleological), predictive (extrapolative) and first, second etc. orders of prediction" (21). They argued that machines can be teleological (using feedback to achieve a goal) through the incorporation of feedback—an immediate application for them was the design of anti-aircraft

2 Roujin Z is the story of an old man abandoned by his family who is kept alive by an intelligent hospital bed. The bed grows legs, and the bed/man cyborg roam the city accreting more and more machines to themselves, so they become a veritable Leviathan—an echo of the famous Frontispiece to Hobbes' *Leviathan*, but with machines rather than people at the core.

guns; where feedback and prediction had to operate faster than humans could. It is never just a sequence of "x causes y causes z which causes x" (one logical way of writing feedback loops)—rather, crucially: "The concept of teleology shares only one thing with the concept of causality: a time axis" (24). Purpose for them requires negative feedback; it is inherently teleological.

Some Varieties of Intelligence

A recent volume on *The Origin and Nature of Life on Earth* makes the claim: "Life should not be viewed as a state of order. It must be recognized as a unity-in-confederacy of many kinds of order" (Smith and Morowitz 2016, 39). Core for the authors is the Rosenblueth et al. style argument that there is not one univocal origin for life (this would be, literally, a root cause); rather there are multiple nested teleological processes—each certainly on a time axis shared with causality. It is always about handoffs and accommodations across multiple layers. The fundamental condition driving life on Earth, they say, is the existence of stable disequilibria. It is beyond the "purpose" of this paper to spell this out in too-great detail—two simple examples of the stable disequilibria are precipitated by the incidence of sunlight; or (a commonly accepted origin for life) of chemical soups around hydrothermal vents (superheated oceanic "hot spots" which can perdure for millennia). We are moving beyond "God caused life" to "Life emerged organically, as it were, from disequilibrium."

Cybernetics over the years has proliferated examples of intelligent behavior emerging out of complex systems. Here I highlight just three—a trinity which will enable us to situate the purpose of computers (or AI, if one prefers).

Ants first.[3] Adrian Tchaikovsky's *Children of Time* (2015) offers a superbly imagined ant (and spider) intelligence on another planet, but we will stick closer to home. One could talk about the physical impact of ants—the great earth movers rivalling humans in moving earth to create complex structures. Or their architectural design (millions can live in a single colony underground aired by ventilation shafts). But it is a social innovation I am concerned with. When the red Argentinian ants emigrated from South America to the North, they went through a funnel—a narrow strip of land. There were many colonies, each "run" by a single queen and recognizing each other's colony as the enemy. As they moved north through the funnel, a social innovation emerged: colonies recognizing each other as kindred if they shared an ancestral queen. This happened in historical time and has led, for example in Europe, to a single massive colony without borders stretching from north to south. Imagine if humans could do that: decide to live in a single political order that spanned a continent! We'd call it a huge breakthrough—we might

3 This sequence follows a graphic novel trilogy being co-written with Boddhistattva Chattopadhyay and Agra Manna.

call it, say, the League of Nations, or the United Nations, or, scaling back, the European Community. And we'd write treatises on political economy and Adam Smith and John Stuart Mill. There has been little indication of ants "rebalkanizing" though… The point here is that ants not only build like us, but they also organize like us (and arguably better). One way of reading this is to say that human consciousness is largely epiphenomenal (my preferred description); or more prosaically that when we describe intelligent behavior, we should not restrict ourselves to the iron chain of causation but rather the nesting of teleologies.

But what does this say about computing? One takeaway is that "intelligence" is just as natural a process as germination and efflorescence—it's an inevitable outcome of a world built on stable disequilibria. It hints that the problem of whether computers are conscious is somewhat beside the point; the more interesting question is whether humans are conscious, or (to put it more delicately) whether we need consciousness to describe our intelligence.

Second, fungi. Much has been made of Simard et al.'s (1997) "wood wide web," a term coined by a subeditor in *Nature* to describe the role of fungi in enabling communication about threats and sharing of resources among trees in a forest.[4] It is certainly the case that the majority of angiosperms (flowering plants) are in an obligate symbiotic relationship with fungi. As Adam Adamatzky (2017) from the Center for Unconventional Computing has argued, fungi need to have pretty much the array of senses that we do in order to understand their underworld. They also need to be able to process that data in real time. He projects building a computer using fungal intelligence. The company *Ecovative* is trying to use mycelia as building blocks for building and material for fabrics. Most relevant for us is that there are also moves to create living buildings out of fungi, which can respond "intelligently" to climate conditions.

The ways in which fungi are intelligent are quite different from the ways in which ants are. Ants, as Deborah Gordon (2010) points out, have really tiny brains which can maybe save 10 seconds to memory—all their actions, she argues, are based on frequency of interactions. (This is a turnaround from the centrality of pheromone trails—making the environment intelligent—as highlighted by Searle [2002, 61–76]). Fungi operate more like a central nervous system—correlating data from multiple inputs simultaneously and responding as a unit.

Human intelligence can be situated along a continuum from "tiny, localized brains" to "complex systems behavior": it does not occupy a special place—the slider has no preferred gradations. Rather, our collaboration—or not—with so-called artificial intelligence just slides us right or left along the natural

4 Richard Powers' *The Overstory* (2018) gives a fictional rendition.

scale. If we restrict ourselves to our, relatively tiny, brains—we are more antlike. Sure, we can build great stuff, but so can ants. Sure, we can display intelligence, but so can ants. If we slide further to the right along the scale, then we are closer to H.G. Wells' *World Brain* or the dream of Paul Otlet's Mundaneum. Here we are closer to the instrumented Earth offered us by the Internet of Things (see Seberger 2019)—we are more like the mushroom, popping up occasionally out of the mycelial network if conditions are right but generally delegating our intelligence to the superset of us together with machines.

Third, Gaia. Much has been written on the Gaia hypothesis—none better than Bruce Clarke's *Gaian Systems* (2020). I do not need to go into detail about it here but will just note in passing that Lovelock's Daisyworld does offer a kind of intelligence centered on homeostasis. The "discovery" of homeostasis in the 19th century had two vastly different origins—as is suitable for our characterization of intelligence. One was about "wetware"—Claude Bernard writing about the ability of the human body to react to external conditions through homeostatic mechanisms (if your blood is overheating, try sweating, and so forth). The other was very much about hardware—the governor (same root as cybernetics) controlling steam engines, so they stayed in the Goldilocks zone. Of course, by the observations above one can view Gaia as intelligent—though with something of a figure/ground issue. One take is that microbes and later more complex entities kept altering the balance of gases in our atmosphere, such that oxygen breathing became paramount: as "we" grew and multiplied, we terraformed the Earth. The inverse view is that the Earth as a system of systems has managed to keep conditions good for life: there are negative feedback loops on climate (high albedo leading to more snow cover to higher albedo and colder times) but also positive ones (more burning/vulcanism leads to lower albedo in the snow and more carbon dioxide in the atmosphere).

For our question of purpose and computers, a core citation comes from Lynn Margulis: "machines are one of DNA's latest strategies for autopoiesis" (Sagan and Margulis 1987, 19). There is an issue with agency here which must be addressed before we can see the richness of this observation. We associate the word "strategy" with thinking beings, though clearly the word has much further reach. All Margulis is asking us to do is to take "autopoiesis" as something which can be read as a consistent, unifying strategy of life on Earth. A reasonable avatar of its purpose. All life needs to keep parameters within a range—so if we get cold, we add layers of clothing or heat to the planet around us (central heating). For the purposes of this paper, "strategy" is a word like "intelligence"—it is an outcome of our processes rather than their origin and star.

More interesting is what Margulis is saying about machines here. There is an argument in biodiversity science (overly propagated in conservation science) that "we" humans are outside of nature: we act on it, we destroy it, even if we from time to time revere it—always from the outside position. This is a category error. Saying that we are humans and nature is out there is wrong on almost every count (I'd say enumerating "every count" would be a very long addition to this chapter). Within the field of ecology, this kind of point has led to an argument that the concept of "ecosystems" is not a useful one: concepts like stability and ecosystem are ambiguous and defined in contradictory ways. In fact, there is no such thing as an integrated, equilibrial, homeostatic ecosystem: it is a myth! (see O'Neill 2001, 3276). Especially if "ecosystems" are disturbed by humans: the exclusion of humans from ecosystems relates to the xenophobic rhetoric in much green science—species are invasive in just the same way that humans are: it is of the nature of species to invade. The world looks very different if we see it consisting of a single division of human/nature; it also looks very different if we see it in terms of a single division of human/machine.

An immediate teleological outcome of this view is that one might understand computing in terms of the completely natural process of autopoiesis: a bundling together of Lewontin's (2000) triple helix, consisting of genes, organism, and environment, with machines. The purpose in this case, insofar as there is one, is to enable life to continue, to propagate. Under this description (see Hacking 2002) there is really no need to be threatened by AI, any more than to be existentially threatened by the fact it's going to rain tomorrow. This is just the wrong description and leads nowhere. However, should one wish to switch (another sliding scale), one could follow Spinoza in his *Ethics* and argue (effectively) that God/the Universe is the set of all possible processes. Spinoza does not want us to project human qualities onto God (for him, God is indifferent and neither loves nor hates, nor even really thinks—the guy is much like AI); he wants us to explore what it would mean to create an ethics accordingly.

So, the scale goes from DNA preservation to the nature of life in the universe, but the analytic point is the same: anything that seeks to separate us humans off from the rest of the world is just wrong. Humans are part of nature and machines are part of nature.[5]

The ontological significance of this line of argumentation is that we will neither understand the world around us nor our computers without radically decentering humans from the analysis. Of course there is an existential crisis going on here. Of course, it seems weird that we live in a world of prosthesis run wild: we largely see the world through computer-driven instrumentation;

5 I was going to add a point about this chapter's human readers but realized whilst writing it that most reading and most writing in the world is increasingly done by "intelligent" machines.

we largely read the world through computer-generated text; and we largely desire the world (though this takes a little longer to argue) through the mediation of our computing infrastructure (think music recommender services as discussed by Nick Seaver [2022], or, the excluded other, the state of pornographic services today).

It is indeed difficult to operate this kind of ontological vision. So before exploring its details a little further, I point to some clear advantages. First for me is the kind of statement repeated frankly *ad nauseam* that we must control AI. Largely what we are doing is trying to recapitulate Marx's stages of human history (slavery, serfdom, the bourgeois, the revolution), starting with slavery—computers should serve us. Murray Shanahan (2019, 93) describes a "superintelligent AI" (one that cannot only replicate human intelligence but can outstrip it) becoming a "willing intellectual slave who never eats or sleeps and wants nothing more than to work … [This] would be many corporations' idea of the perfect employee, especially if they don't require wages."[6] If there are strange new ways of thinking about intelligence (hence the ants, fungi and Gaia of this paper), why should we project our relationship with the associated entities onto a parody of our own history? Imagine that something with a radically new way of seeing the world comes into being. Should our immediate reaction be: "You can be my friend if and only if you do exactly what I say"? By any account, this is a colonialist vision worthy of deep 19th century Britain (I only pick on it because it's one of my countries). Second, should we be sensitizing ourselves to what new, creative intelligence might look like, rather than trying to quash it if it doesn't reason just as we do? Again, we are presented with an historic opportunity to rethink intelligence—it would be a pity to double down on our own version. Third, it is generically the case that life on Earth has developed in terms of ever richer interconnections leading to ever great "intelligence." This is a cause for celebration and cerebration, not for forecasting calamity and collapse. Since Malthus, every generation has had its secular apocalypse. You have to believe in overpopulation; nuclear winter; the population bomb; environmental degradation; climate change. Fear of AI is just another of these constraints on our thinking and on our understanding and of our being in the world. We have to be very afraid. The somewhat sweet alternative is to feel full of love and care.

Purposive Nature

Computing is a new trophic layer. I am taking trophic level quite literally here. Where is there energy uptake/uptick permitted by energy disequilibria—in straight Darwinian theory, once the electron becomes the unit of speciation,

6 Seth Rudy (personal communication) comments that the word "robot" comes from the Czech word for "slave"—see Capek's *R.U.R.*

the war of all against all in electron flow began. It began a long time ago, according to Karen Lloyd's (2025, 110) marvelous book *Intraterrestrials*:

> It turns out some types are apparently fed up with the bulky chemical folderol. This life, of which intraterrestrials are major players, strips energy down to its bare essentials: pure electrons. There are many ways that microbes use pure electrons. Some make special structures called nanowires that work like tiny electrical wires to create a current of moving electrons.

Computers are just repeating an ancient evolutionary strategy. So much of our daily lives is now predicated on the flow of electrons—new jobs, new ways of being, new kinds of being (avatars). It is vital to the lives of an increasing percentage of humanity: even the lives of those without the internet are woven into its fabric. It's as sure as death and taxes. Whenever a major new trophic level has emerged on Earth, emergent entities proliferate wildly and spawn predators. We can probably name several keystone predators exploiting this domain: concerns led by Musk, Bezos, Zuckerberg say. You cannot just assert that predation is a bad idea (of course it is) but you have to be affirmatively neocybernetic (it's all good; chill and play).

This reads rather deterministically though. Have we substituted the Faraday Cage of computing for the Iron Cage of bureaucracy? There are always work-arounds, zones of freedom. What new species do is co-create niches (much as we used to talk about businesses enacting their environment). A particularly "good" niche is one that the current set of predators pays no attention to. So, it's never "winner takes all"—it's about how to survive in a given fitness land-scape (in Harry Harrison's [1985] terms, how to become a stainless-steel Rat).

Natural Computing

One might wonder why the cover of Antonopoulos' ominously titled *Mastering Bitcoin* (2014) displays a picture of leafcutter ants. He explains:

> Next to humans, leafcutter ants form the largest and most complex animal societies on Earth. Although ants form a caste-based society and have a queen for producing offspring, there is no central authority or leader in an ant colony. The highly intelligent and sophisticated behavior exhibited by a multimillion-member colony is an emergent property from the interaction of the individuals in a social network. (Antonopoulos 2014, xii)

Of course this could equally describe neurons in the brain. The point here being that one needs to be careful when one is projecting. If the past few hundred years of Western history have been marked by meditation on net-works (see Castells 1996), culminating in networked computers, then it is unsurprising that we find network behavior central to ants and to blockchain. It is the chief available metaphor (and, as Borges reminds us, there are so few metaphors in the world).

This is a problem. If we follow Latour (1993) then we project ourselves onto nature and nature back onto ourselves—in which case “nature” never really comes into the equation. The turn to get around this impasse is from Marx: rather than H-N-H (or human-nature-human)—his M-C-M or money-commodity-money—we need to flip to N-H-N. As Marx argues, this kind of flip enables new forms of analysis.

In many ways, we seek to reproduce nature (as well as human history) in our computers. Natural metaphors that have begotten algorithms include: ant colony optimization (of course); glow worm swarm optimization (used in vehicle routing), and the shuffled frog leaping algorithm. This is not tied only to organic beings, as the “intelligent waterdrops” and “hydrological cycle” algorithms attest. Nor is human history spared—in the “imperialist competitive” algorithm. This latter generates “countries” with assorted powers where imperialists start developing colonies. Its two main moves are assimilation and revolution. Notable about all the natural algorithms is that they deal in atomic actants. There is a strong argument that relationships—not “species”—are central to nature (see Serres 1980; Bronstein 2015). (Our bodies are constituted more of mutual relationships between flora and fauna, as are our cells—the individual/species drops out from this primordial mediation [see Bowker 2010 Latour 1987].)

Insofar as we constrain our computers to repeat natural and human history as tragedy and farce, then this is simple projection: our understanding of ourselves and our past is recreated in the computer. There is no reason to give this logical priority when we address the question of what computers want.

Purposive Computing

I love computing. One qualification is that it leads to meetings, and more meetings. The value of meetings is hard to either quantify or qualify. There is a prime directive though: create more meetings. However, meetings also afford a wonderful opportunity to think through complex circumstances together. My meetings, things, contacts, people are mediated through computing—and I think I love them all the more … because I know participants better through a set of wonderful interfaces. And yet, really the ideology is “meeting.” We are reflecting collectively much as ants and fungi do: how to keep communication healthy despite unwelcome intrusions. Consider the role of mail—in olden times (a few decades ago) it permitted a very slow conversation to occur; now letters are almost instantaneous. Phone conferences were largely unwieldy and difficult to manage (see Donovan 2016); Zoom meetings are easier and give so much more information. This is a first thing computers want: richer, higher bandwidth interactions. Meetings are their life blood. They inhabit a world of mediated communication and invite us in.

I do want to go further than this, though this next will of necessity be quite speculative. The issue, largely, is how to recognize a new form of being in the world.

I start with an apparently dark vision—humans are really pretty irrelevant. It is now entirely possible to have a scientific paper written by an AI, reviewed by an AI, and summarized by it for "our" consumption. Why do we need humans in the scientific enterprise? This line of argument has a pedigree—Stephen Hawking, in his inaugural lecture for his Lucasian Professorship at Cambridge, proclaimed that in the future only computers would understand physics. Not a wild claim—we accept already and readily for chess that Stockfish outplays all possible humans (so the humans are given "accuracy" ratings according to how well they mimic computer moves). Reasoning in 10+1 dimensions in string theory has far outstripped pencil and paper and human (though there are occasional human-ready insights such as the amplituhedron). Humans are irrelevant for much stock trading: better call Saul the algorithm. They are also not great for economic activity: blockchain can be guaranteed by algorithms rather than lawyers, and precision farming is so much more precise than fallible humans.

I say "apparently dark" for two reasons. First, there used to be a vision in the 1960s of a future when humans did not have to work much—the robots could do it for us. Now that this economy is largely upon us, we are not celebrating as we might—that's not the nature of our enterprise. Rather, we become the flickering cursors of Shama's *In the Meantime*: we are what supports the dominant timeline (and computers are always ever about linear temporality in the last instance—at least until the present). They need us to maintain themselves; to be read in an instant (think self-driving cars) should the machine fail. So, one could say that this is not a bad thing—"less work for mother." However, as Ruth Schwartz Cohen pointed out, less work for mother (labor-saving devices such as washing machines and fridges) led to more work for mother: women traditionally worked longer hours in the 1960s (when most housework was done by women) than in the 1890s (when work like doing the laundry was outsourced). It's not bad by any means to work less, providing one keeps one's eye on the prize rather than obey the well-ordered, precise clock of the computer (see Sharma 2014). Second—and this is a frankly Spinozian point, so feel free to close your eyes for the next clause—it is actually wonderful to imagine new forms of understanding emerging anywhere in the universe. That we are a minor part of the equation, a constant to be cancelled out, is not an issue: understanding is not just about humans—or at least it should not be.

We are moving here towards the positive features. Tripping over a point made earlier, the ability to think in multiple dimensions simultaneously is a wonderful gift—humans can do it in some ways, computers in manifold ways. Computers do memory beautifully. In a throwaway line in his brilliant *Archive Fever*, Jacques Derrida (1995) argued that the unconscious itself was being changed by computer memory (the suppressed returns easily when you dredge through old email or social media posts). Computers also order the world very well, and, theoretically at least, in a non-Aristotelean manner. It is much easier now to hold off a classificatory act (the first and often final cut) till the very last instance. Thus, you no longer need to say person x died of y as a definitive statement—you can make it a provisional one and then hold judgment until new causes come into play (an affordance that makes the move from classifying the human immunodeficiency virus (HIV) in terms of retroviruses rather than isolated instances of Kaposi's sarcoma and pneumonia easier). To return to the de Quincey epigraph to this chapter, the fact that I can through computing configure myself in multiple, partially contradictory ways is a natural affordance of computing.

Conclusion

There is always a risk of the pathetic fallacy in averring that computers want this or that. The reason I introduced Rosenblueth, Wiener and Bigelow at the start of this chapter was that they free up the language in ways which permit this being a true statement. The full argument here is predicated on the assertion that relationships, not entities are paramount. A shorter form is to say that deriving purpose and teleology from natural states in a (complex) system rather than from innate qualities (imposed by God or developed by humans) crucially allows us to say things that we couldn't say in human-centered language, which too often cleaves to Derrida's phallogocentrism. Computers trivially have purpose and teleology; our problem comes when we say that we are the ultimate cause.

The role of decentering has been argued to be central to human history. One litany from Michael Arbib (1984)—and I will not go into ways in which it is problematic; the broad stroke works—is that Copernicus displaced the planet from the center of the universe; then humans were displaced from the center of life (via evolution—we no longer were the point of creation at 4004 BCE but rather the result of a very long process) and Freud decentered humans from their Cartesian minds—the unconscious playing a major role. Finally, intelligence is becoming decentered from humans. There is nothing wrong with this picture. This does not leave us as mere cultural dopes enjoying what computers tell me I should enjoy—though this does constitute a fair percentage of my being. Rather, recognizing and enjoying displacement is core.

Jean-Paul Sartre (1964) once wondered if he feared the death of humanity. His response was that he did not—he only wanted to die convinced that there was intelligence somewhere in the universe (and not, one would imagine, just in a random set of Boltzmann brains—the most "probable" form). His capacious view is surely right: humanity is not destined to be the "dominant" species forever: cataclysms and the progress of evolution (where a "species" can be understood as an individual with a natural lifetime [see Hull, 1989]). We are witnessing the emergence of a new form of life/intelligence: far the best response is to welcome it and learn its nature.

When some of the leading tech bros talk about the potential domination of AI, they are missing the point. The domination is in their practices writ large upon the world. They are sort of worried that in their world built on domination, a yet more efficient dominator will emerge. If our society and our computers get folded into their xenophobic visions, we are all in trouble.

Rather, let us welcome the outsider within (see Henaff 2002). Now is a time for learning and celebration.

References

Adamatzky, Adam, ed. 2017. *Advances in Unconditional Computing. Volume 1: Theory*. Berlin: Springer.

Antonopoulos, Andreas M. 2014. *Mastering Bitcoin: Unlocking Digital Crypto-Currencies*. Sebastopol: O'Reilly.

Arbib, Michael A. 1984. *Computers and the Cybernetic Society*. Orlando: Academic Press.

Bowker, Geoffrey C. 2010. "The Ontological Priority of Mediation." In *Débordements: Mélanges offerts à Michel Callon*, edited by Madeleine Akrich, Yannick Barthe, Fabian Muniesa, and Philippe Mutar, 61–68. Paris: Presses des Mines.

Bronstein, Judith L., ed. 2015. *Mutualism*. Oxford: Oxford University Press.

Castells, Manuel. 1996. *The Rise of the Network Society, The Information Age: Economy, Society and Culture*. Cambridge, MA and Oxford: Blackwell.

Clarke, Bruce. 2020. *Gaian Systems: Lynn Margulis, Neocybernetics, and the End of the Anthropocene*. Minneapolis: University of Minnesota Press.

Derrida, Jacques. 1995. *Archive Fever: A Freudian Impression*. Translated by Eric Prenowitz. Chicago and London: The University of Chicago Press.

Donovan, Joan. 2016. "'Can You Hear Me Now?' Phreaking the Party Line from Operators to Occupy." *Information Communication and Society* 19, no. 5: 601–17.

Gordon, Deborah. 2010. *Ant Encounters: Interaction Networks and Colony Behavior*. Princeton: Princeton University Press.

Hacking, Ian. 2002. *Historical Ontology*. Cambridge, MA: Harvard University Press.

Harrison, Harry. 1985. *A Stainless Steel Rat Is Born*. Toronto: Bantam.

Hénaff, Marcel. 2002. *Le prix de la vérité : le don, l'argent, la philosophie*. Paris: Editions du Seuil.

Hull, David L. 1989. *The Metaphysics of Evolution*. Albany: State University of New York Press.

Kelly, Kevin. 2010. *What Technology Wants*. New York: Viking Press.

Latour, Bruno. 1987. *Science in Action : How to Follow Scientists and Engineers through Society*. Cambridge, MA: Harvard University Press.

———. 1993. *We Have Never Been Modern*. Translated by Catherine Porter. Cambridge, MA: Harvard University Press.

Lewontin, Richard. 2000. *The Triple Helix : Gene, Organism, and Environment*. Cambridge, MA: Harvard University Press.
Lloyd, Karen G. 2025. *Intraterrestrials: Discovering the Strangest Life on Earth*. Princeton: Princeton University Press.
O'Neill, Robert V. 2001. "Is it Time to Bury the Ecosystem Concept? (With Full Military Honors, Of Course!)." *Ecology* 82, no. 12: 3275–84.
Powers, Richard. 2018. *The Overstory: A Novel*. New York: W.W. Norton & Company.
Rosenblueth, Arturo, Norbert Wiener, and Julian Bigelow. 1943. "Behavior, Purpose and Teleology." *Philosophy of Science* 10, no. 1: 18–24.
Sagan, Dorion, and Lynn Margulis. 1987. "Gaia and the Evolution of the Machines." *Whole Earth Review* 55: 15–21.
Sartre, Jean-Paul. 1964. *Les Mots*. Paris: Gallimard.
Searle John R. 2002. *Consciousness and Language*. Cambridge: Cambridge University Press.
Seaver, Nick. 2022. *Computing Taste: Algorithms and the Makers of Music Recommendation*. Chicago: Chicago University Press.
Seberger, John S. 2019. *Becoming Objects: Iot, the Archive, and the Transformation of the Human*. University of California, Irvine (PhD thesis).
Serres, Michel. 1980. *Le parasite*. Paris: B. Grasset.
Shanahan, Murray. 2019. *The Technological Singularity*. Cambridge, MA: MIT Press.
Sharma, Sarah. 2014. *In the Meantime: Temporality and Cultural Politics*. Durham, NC: Duke University Press.
Simard, Suzanne, David A. Perry, Melanie D. Jones, David D. Myrold, et al. 1997. "Net transfer of carbon between ectomycorrhizal tree species in the field." *Nature*, 388, no. 6642: 579–82.
Smith, Eric, and Harold J. Morowitz. 2016. *The Origin and Nature of Life on Earth: The Emergence of the Fourth Geosphere*. Cambridge: Cambridge University Press.
Tchaikovsky, Adrian. 2015. *Children of Time*. New York: Tor.

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Benedikt Merkle and Bernhard Siegert (Eds.)
Reckoning with Everything: The Becoming-Environmental of Computing

The transformation of the cultural technique of calculation into a computational environment for the whole planet Earth requires media studies to undergo fundamental changes that go beyond mere reflection on the transformation of global political and economic structures. The becoming environmental of computing confronts us with the fact that the map *is* the territory: map and territory, media and nature, the Symbolic and the Real, are not distinguished in any categorical way but rather temporarily stabilized results of recursive processes by which they differentiate themselves from each other and call each other into being.

However, the cultural technique of calculation has not only become "environmental" since the ubiquity of computation turned cultural techniques into environing techniques. Computation must and has always had to "reckon with everything," with the materialities of the media that define the environmental conditions of computability, as well as with practices of extracting, storing and transferring data. This volume brings together contributions that seek to describe the environmentality of computation based on selected settings.

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