Sites of Sky

A Visual Cultures Analysis of Landscape Aesthetics
in an Age of Virtual Ecologies

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Declaration of Authorship

I, Nicole D. Sansone, hereby declare that this thesis and the work presented in it is entirely my own. Where I have consulted the work of others, this is always clearly stated.

Signed:

[redacted]

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Acknowledgments

I think when you finish a major writing project like a doctoral thesis or a book, you're just so happy to be rid of the damn thing that you can't help but have emotional dysentery. This has been true for me, at least, and the first draft of these acknowledgments was unbearably saccharine and over-wrought. In my defense, and having just completed this project, I maintain that writing a thesis has a lot in common with the slow suffering of dysentery. But in the interest of good taste (and given that this is a document that might out live me) I've performed a heavy excision on this document and have limited my displays of affection to just those with direct connection to the thesis.

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I stand on the shoulders of everyone on these pages. This work is dedicated to you.

Abstract

This thesis maps practices of making images of the sky across art, science, and digital culture. Skies present an unparalleled opportunity to consider the disparate topics of aesthetics and epistemology in one setting, and their historical treatment in both the sciences and the arts serves as an equalizer between thinking images in the two domains.

The thesis is organized into three sections, each emphasizing a different mode of perception (ecological, human, and technological). Section I demonstrates a link between aesthetic strategies and pluralities of knowledge. Chapter one provides a brief overview, and counter-reading, of the history of clouds in Western culture. Chapter two explores the limits of the image as a representative form through the process of cloud-extraction in satellite images. Section II explores modes of aesthetic engagement and knowledge creation through two related technical systems: the computer graphics pipeline and computer graphics and animation software. Chapter three shows how rendering protocols operate between human and technical ideals of realism in the photography series *Postcards from Google Earth.* Chapter four proposes the software *Blender* as a site of displaced optics, and stresses the continuous relation between human perception and software logic. Section III draws from my virtual ethnographic work on amateur earth modeling communities. In these final two chapters I build an aesthetics of ecological realism from discourses of troubleshooting. This is counterbalanced with the history of visualization in scientific computing to underscore the notion that visual phenomena can never be represented through a one-to-one capture, but instead are always situated in reciprocal negotiations between aesthetics and epistemology.

Through this work I reveal a set of attendant epistemologies that shape both nature aesthetics and knowledge of the physical world. My conclusions reinforce that the relationship between *images* and *modes of looking and interpretation* is fundamental to epistemic practices.

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Introduction

Figure 1: Still from Joe Hamilton's HyperGeography (2011).

Visions of New Natures

This thesis began with a 2011 exhibition at 319 Scholes, a multi-disciplinary art gallery in Brooklyn. The title of the exhibition was *Notes on a New Nature*, and it was curated by artist, writer, and curator Nicholas O'Brien. The exhibition was one iteration of an on-going research project O'Brien had been engaged in looking at the relationship between practices of Modernist landscape painters and contemporary artists working with digital media. In his statement O'Brien asked, "Can art capture the space between the viewer and the horizon, and where does that horizon reside now that we can digitally circumnavigate the globe? Can the digital reconcile the physical?"[1] His project understood that digital and virtual landscapes now permeated domestic spaces, eliminating (or, at the very least, complicating) simple inside/outside, natural/artificial dichotomies. And as the research went on, it became clear to O'Brien that our myriad notions of what is natural and what is

[1] Nicholas O'Brien, "Notes on a New Nature | 319 Scholes," 319 Scholes: Notes on a New Nature, accessed July 27, 2016, http://319scholes.org/exhibition/notes-on-a-new-nature/.

nature were, in fact, shaped by technology—a theme that, he argued, could be traced to the introduction of agriculture and beyond.

In formulating the project this way, *Notes on a New Nature* wanted to contribute to an articulation of the role of human culture in forming ideas of nature that would continue the trajectory of art history's somewhat contentious past with this dynamic. The approach O'Brien took to doing this was to compound such a question with seemingly inhuman digital technology. While O'Brien was right in that the exhibition clearly showed how ideas of nature in human culture had become sensitized to digital technologies, the exhibition also had the effect of emphasizing posthuman tendencies undergirding the question of human culture and nature. Who did we envision as the human in human culture that was generative of these landscape and nature aesthetics? Both O'Brien and the exhibition artworks seemed agnostic about such a question. Joe Hamilton's Hyper Geography tumblr and 2011 video, for example, created "landscapes" that were just barely identifiable as such. Slashed and collaged with a thin thread of narration, Hamilton's video was described by one reviewer as a "new visual universe" which radically broke away from existing planes of legibility.[2] As Dominikus Müller described it, in this new visual universe—this *new world*—"everything always already refers to everything else ... There is a corresponding shift in emphasis *away from text* – read, deciphered, developed into a story – and *towards texture*, which envelops and encloses."[3] This effect was apparent in other works included in the exhibition as well, such as Kate Steciw's *Depth Mapping (The Mountain)* (2011). This piece was a large photograph of a mountain peak printed on pliable material and made to sit in ripples, languidly, from wall to floor. Its presentation physically mimicked the way *texture maps* are made to drape and wrap around three-dimensional models in computer graphics,

[2] Dominikus Müller, "Ambient Natures," Frieze, Summer, first published in Issue 2012, https://frieze.com/article/ambient-natures.

[3] Ibid. Emphasis mine.

which made *Depth Mapping (The Mountain)* almost too apt a representation of the metaphor to be a pun. Cutting so close-to-the-bone instead seemed to be more of a conceptual innuendo, and one that proved nonplussed with the asymmetry of what computation promised of its interactions with nature compared with what it actually achieved. In both cases, Müller's observation that landscape artworks had now entered a new universe of reference—or *universes*—was clear, as these artworks seemed to signal a break with the conventions of representing nature. The typical axioms of landscape and nature representation—the lone and reflective traveler, bucolic countryside, cottage-industry quaintness—were conspicuously absent. In their place a new, technologically-informed, aesthetic was forming.

This thesis thus began as a way to channel this new aesthetic. I wanted to understand the blossoming romance of technology with landscape art—an unholy union by historical accounts. If anything was anathema to landscape art—to its idyllic projections of nature, its tranquility, its emollient tones—surely it was harsh, cold, digital technology, and not *just* digital technology, but a digital technology of glitches and belches, of lacerated screens and chunky resolutions. Landscape art was the last bastion to uphold *the* image of Nature; what Raymond Williams had identified as "a case of a definition of quality which becomes, through real usage, based on certain assumptions, a description of the world."[4] So deeply implanted in our cultural mind's eye was this quality-become-description that when the environmental historian William Cronon declared the time to rethink wilderness was nigh—that wilderness was "Far from being the one place on earth that stands apart from humanity, it is quite profoundly a human creation"—he also found himself not chasing this declaration with a placating salve. "To assert the unnaturalness of so natural a place will no doubt seem absurd or even perverse to many readers, so let me hasten to add," Cronon begins, entreating readers to not

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[4] Raymond Williams, "Ideas of Nature," *Nature: Thinking the Natural*, 1972, 68.

abscond, "I celebrate with others who love wilderness the beauty and power of the things it contains … . Remember the feelings of such moments, and you will know as well as I do that you were in the presence of something irreducibly nonhuman, something profoundly Other than yourself. Wilderness is made of that too."[5]

Nature has been the place that man and all of his machinations are not. To now deliver an image of Nature and its landscapes that was not only produced by these tools but suffused with them; shaped by technological formats and, what's more, baldly displaying these technics in their scenes suggested the emergence of an aesthetic sensibility—not just the stylistic choices of a society with laptops. With this thesis I set out to build a theory that would account for such an aesthetic sensibility. I hypothesized that I could build on the history of landscape art as a display of the simultaneous individualistic and cultural interpretations of the physical world. This formulation, I hoped, would provide the path for understanding how, in whatever combination, the movement of less-than-visible technologies into our physical environments had a very visible impact on how humans experienced the world, an experience captured and transformed into the very art I was viewing. This was a line of reasoning that was not so far off from what was already being discussed. Thinkers such as Heather Davis, Susan Schuppli, and Nicholas Mirzoeff had all already begun to argue the case that unprecedented climate change and technological geospatial innovations were introducing new optical regimes, the effects of which were not limited to aesthetics but, more crucially, also impacting our politics.[6] As one began to press on more into the

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[5] William Cronon, "The Trouble with Wilderness; or, Getting Back to the Wrong Nature," in *Uncommon Ground: Toward Reinventing Nature*, ed. William Cronon, vol. 1, 1996, 70.

[6] See, for example: Heather M Davis and E Turpin, *Art in the Anthropocene: Encounters among Aesthetics, Politics, Environments and Epistemologies* (London: Open Humanities Press, 2015); Susan Schuppli, "Dirty Pictures," in *Living Earth: Field Notes from the Dark Ecology Project 2014-2016* (Sonic Acts Press, 2016); and N. Mirzoeff, "Visualizing the Anthropocene," *Public Culture* 26, no. 2 73 (April 1, 2014): 213–32, https://doi.org/10.1215/08992363-2392039.

morass of the humanities in the age of the Anthropocene, it was clear that the most stunning accomplishment of this debate was not solely the serious consequences which it named—though those were up there—but the way such a concept had managed to fundamentally disembowel centuries of fomented thinking on human culture, on capitalism, on humanism, on society, on humans *in* society, etcetera, etcetera.[7] The transformative capacity of geologic change was, in no uncertain terms, revolutionary, sending shock waves through every corner of society and culture—not least of which, our images. Technology played its part, too, by sending up the epistemological flares that alerted us to such changes and, placing in our hands the necessary items required to conjure a crisis of the precise magnitudes to inflict maximum panic without ever crossing the threshold into political action.

Making & Un-making Landscape

Yet as can often be the case, what I set out to do is not what I've done. In order to research and develop an aesthetic I had to be clear on the kinds of images that lay within and outside of my remit. Basing my research on the provocation that O'Brien had staged in his exhibition meant that I was dealing with a transforming genre of the image, but the uncertainties of what landscape art is had long been compacted into its foundations. Landscape art is the art of framing and representing physical space, but it is also the practice of creating landscape art that produces landscape.[8] It is a solipsistic relationship that, in more ways than one, belies the

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[7] For a macro-level outlook on how the Anthropocene fundamentally reorganizes how we think time, capitalism, and human culture, see: Dipesh Chakrabarty, "The Climate of History: Four Theses," *Critical Inquiry* 35, no. 2 (2009): 197–222; For the effects that the Anthropocene and climate change are already having more acutely--but with the same fundamental impacts--see, for example: Kathryn Yusoff, "Biopolitical Economies and the Political Aesthetics of Climate Change," *Theory, Culture & Society* 27, no. 2–3 (March 2010): 73–99, https://doi.org/10.1177/0263276410362090.

[8] Foundational and introductory texts to the study of landscape art and landscape painting would include Clark, Kenneth. Landscape into Art. New York: Harper & Row, 1979; Gombrich, Ernst

content of its representation. For one, scholarship has shown that the idealized scenes of nature depicted by most landscape artworks conspicuously lack, or minimize, human figures.[9] This works to conceal the social and economic relations that underpin just such a setting, which is of true concern when the subject of landscape is linked to themes of nationality and imperialism.[10] As W.J.T. Mitchell has written, "What we know now is … that there is a 'dark side of the landscape'," adding, "this dark side is not merely mythic, not merely a feature of the regressive, instinctual drives associated with nonhuman 'nature' but a moral, ideological, and political darkness that covers itself with precisely … innocent idealism".[11] Mitchell reaffirms in his essay *Imperial Landscapes* that there is no naïve or uncomplicated viewing of landscape today: to begin with, there is no unified *we* "corresponding to a universal human spirit seeking harmony" that sees the landscape.[12] The effects of

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Hans. Studies in the Art of the Renaissance: Norm and Form. 4.ed. Oxford: Phaidon [u.a.], 1985; Jackson, John Brinckerhoff. Discovering the Vernacular Landscape. New Haven: Yale University Press, 1984; Friedländer, Max J. Landscape, Portrait, Still-Life : Their Origin and Development. Oxford: B. Cassirer, 1949; and by way of contemporary critical introduction to the category of landscape art DeLue, Rachael Ziady, and James Elkins, eds. Landscape Theory. The Art Seminar, v. 6. New York: Routledge, 2008.

[9] For an examination of English landscape painting (epitomized in the works of Thomas Gainsborough, George Morland, and John Constable) as a practice of visually fetishizing the rural poor, see: Barrell, John. *The Dark Side of the Landscape: The Rural Poor in English Painting, 1730-1840*. Cambridge [Eng.]; New York: Cambridge University Press, 1980. For a specific study in English landscape painting in relation to the socio-economic changes inspired by the Industrial Revolution, see: Bermingham, Ann. *Landscape and Ideology: The English Rustic Tradition, 1740-1860*. Berkeley: University of California Press, 1986. See also: Prince, Hugh. "Art and Agrarian Change, 1710-1815." In *The Iconography of Landscape: Essays on the Symbolic Representation, Design and Use of Past Environments*, edited by Denis Cosgrove and Stephen Daniels, 10. print., 98–118. Cambridge Studies in Historical Geography 9. Cambridge: Cambridge Univ. Press, 2008.

[10] Following from the previous works and continuing with the focus on rural England: for a study on how rural England came to be emblematic of conflicting notions of Britain and Britishness, see Elizabeth K. Helsinger, *Rural Scenes and National Representation: Britain, 1815-1850*, 1997, http://site.ebrary.com/id/10898947.

[11] W.J.T. Mitchell, "Imperial Landscape," in *Landscape and Power*, ed. W. J. T. Mitchell, 2nd ed (Chicago: University of Chicago Press, 2002), 6.

[12] Ibid.

this imagined, landscape-seeing subject is, and has been, to mediate landscape with its attendant prejudices. This is emphasized in what has been drawn out, then, as "the real subject" of landscape presentation: a "European imperial 'vision,' understood as a dialectical movement toward landscape understood as the naturalistic representation of nature."[13]

Secondly, as an exercise in representing the physical world, landscape art both confuses and embodies this principle. Images of nature are the byproduct of political, cultural, and theological ideas about what nature should look like and how it should function. Landscape art has functioned as a proponent of this, perpetuating ideas of nature over earnest observations of nature. This is true even of the images that see themselves as the most ardently observational and scientific. One need only look at the mesmerizing compositions and colorings of Ernst Haeckel's prints and drawings to get a whiff of the whimsy that crept into such observational exercises. Yet while landscape art images might forgo authenticity in their depictions of nature, they no less remain the guardians of the *natural*. Landscape art projects the scenes that are most natural and with that aligns Western ideas of what is socially appropriate with what can be attributed as "natural".[14] Through these naturalizing discourses, spaces are given biosocial constitutions with the power to designate

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[13] Ibid., 19.

[14] Here ecofeminist work is potent. For an approach firmly based in ecofeminism but with a unique emphasis on unpacking the cultural constructions of *nature* and undoing the nature/culture dualism, see: Alaimo, Stacy. *Undomesticated Ground: Recasting Nature as Feminist Space*. Ithaca, N.Y: Cornell University Press, 2000. For a feminist critique of reason that argues for the failings of Western systems of rationality on the basis of an ignorance of nature dependencies, see: Plumwood, Val. *Feminism and the Mastery of Nature*. Reprinted 1997. Transferred to digital print 2003. Feminism for Today. London: Routledge, 2003. See also Daston, Lorraine, and Fernando Vidal, eds. *The Moral Authority of Nature*. Chicago: University of Chicago Press, 2004, and particularly Katherine Park's ecofeminist contribution: "Nature in Person: Medieval and Renaissance Allegories and Emblems." In The Moral Authority of Nature, edited by Lorraine Daston and Fernando Vidal, 50--73. University of Chicago Press, 2004; Daston, Lorraine, and Katharine Park. *Wonders and the Order of Nature: 1150 - 1750*. 1. paperback edition. New York, NY: Zone Books, 2001; Merchant, Carolyn. *The Death of Nature: Women, Ecology, and the Scientific Revolution*. New York: Harper & Row, 1989.

arenas of homosocial and homoerotic practices, order gendered bodies, and link both of these spatializations with forms of labor.[15] For example, the idea that homosexuality in males was a distinctly urban phenomenon was seen as directly linked to the *inhabiting* the of urban space. As Catriona Mortimer-Sandilands and Bruce Erickson write, "It was not until homosexuality became coded as an inherent identity/condition [in the early 20th century] that it came to be understood as a form of degeneracy and located in the artificiality of cities."[16] What the biologized, naturalizing discourses of this time effectively blocked from view was the fact that, understood in one way, homosexuality was more visible in cities precisely because there were more single male workers in cities (and more people in general), allowing for the possibility of (and increasing the odds of) interested men to encounter "homoerotic contacts and/or social networks of men working in increasingly clerical positions."[17] Despite this, Mortimer-Sandilands and Erickson insist, "…it was the growing visibility of these communities, and the increasing association of homosexuality with degeneracy, that tied the homosexual to the urban, not necessarily some quantitatively greater homoerotic presence".[18]

If, after acknowledging the contradictions of landscape art practice, I still set

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[15] For a more focused examination of categories of space and their links to specific modes of queer and gendered being and sexuality, see, for example: Boag, Peter. *Same-Sex Affairs: Constructing and Controlling Homosexuality in the Pacific Northwest*. Berkeley: University of California Press, 2003; Doan, Petra L. "Queers in the American City: Transgendered Perceptions of Urban Space." *Gender, Place & Culture* 14, no. 1 (February 2007): 57–74. doi:10.1080/09663690601122309; Newton, Esther. *Cherry Grove, Fire Island: Sixty Years in America's First Gay and Lesbian Town*. Durham ; London: Duke University Press, 2014; Hessing, Melody, Rebecca Raglon, and Catriona Mortimer-Sandilands, eds. *This Elusive Land: Women and the Canadian Environment*. Vancouver, BC: UBC Press, 2005. For examples of more sociological research in this field, see: Little, Jo, and Ruth Panelli. "'Outback' Romance? A Reading of Nature and Heterosexuality in Rural Australia." *Sociologia Ruralis* 47, no. 3 (July 2007): 173–88. doi:10.1111/j.1467-9523.2007.00434.x; Howard, John. *Men like That: A Southern Queer History*. Chicago: University of Chicago Press, 2001.

[16] Catriona Mortimer-Sandilands and Bruce Erickson, "Introduction: A Genealogy of Queer Ecologies," in *Queer Ecologies: Sex, Nature, Politics, Desire*, ed. Catriona Mortimer-Sandilands and Bruce Erickson (Bloomington, Ind: Indiana University Press, 2010), 8.

[17] Ibid.

[18] Ibid.

one of my determining criteria for *landscape art* to be the depiction, in some form, of the physical world—nature, naturalizing, or otherwise—then there still remained the additional challenge of determining what images counted as "art." With the proliferation of new media art has also come an equalizing of the mediums between the once-antagonistic disciplines of art and science. Works such as those by Natalie Jeremijenko, EcoArtTech, and HeHe seemed to leech art into science. In this body of work, the creative process was a honed method for doing research. The creative output functioned very much in the same way as any bog-standard data visualization. EcoArtTech's *Untitled Landscape #5* (2009-2010), commissioned by the Whitney Museum, displayed "fluctuating orbs of light" over the museum's home page that corresponded in size and speed to "the number of visitors to whitney.org since the previous sunrise (for sunset) or sunset (for sunrise)".[19] This project took for its "habitat" the whitney.org homepage, as adjunct curator Christiane Paul described it, and was synchronized to take place at sunrise and sunset. In a complementary

Figure 2: "Untitled Landscape #5" (2009) by EcoArt Tech.

[19] "Ecoarttech: Untitled Landscape #5 | Whitney Museum of American Art," accessed August 26, 2018, https://whitney.org/exhibitions/ecoarttech.

way EcoArtTech's 2009 Turbulence.org commission, *Eclipse*, distorted images of national and state parks according to real-time data collected from the Air Quality Index (particle pollution data).[20] Above the baseline of simply visualizing quantitative data, these two artworks were indistinguishable in all but context the graphs and tables that populated scientific journals and sites. The use of color, composition, and stylization were a tool set shared between artists and scientists.

This was even more clear after looking at images of the Earth produced in the sciences. What I found in these images was a vibrant and creative practice of artificial coloring, photo manipulating, and pixel editing. For example, we might look at the colored images that institutions like NASA will post. These posts can celebrate certain missions or pieces of technology, like the Hubble telescope or the Mars Rover. These images are staggering, depicting in vivid, mesmerizing color parts of the universe that seem straight out of fantasy. And to a degree, they might be said to be—they are often images that have been artificially colored. For some this is enough to degrade the quality of the scientific image. The awesomeness of the universe that we view in these images can't be enjoyed knowing that they've been "enhanced."[21] Yet *enhanced* is both the correct and incorrect word here. For example, while we might think of telescopes as tools that bring distant objects closer to us for viewing, a telescope is better thought of as a "light bucket." As astrophysicist Paul Sutter explains in his popular science blogpost, a telescope sucks in much more light than the human eye can, picking up both distant and faint phenomena than we naturally could on our own.[22] As a result, its job is to then "shove all those

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[20] Nicole Sansone, "Blogalog, Part 1: About EcoArtTech," Art21 Magazine, accessed August 26, 2018, http://magazine.art21.org/2009/11/26/blogalog-part-1-about-ecoarttech/.

[21] Never mind the preposterous act of of viewing an entire galaxy on a 16" monitor space.

[22] Paul Sutter, Astrophysicist | September 22, and 2016 07:00am ET, "Stop Complaining about 'Fake' Colors in NASA Images," Space.com, accessed August 28, 2018, https://www.space.com/34146-fake-colors-nasa-photos-stop-complaining.html.

astronomical photons into a tiny spot that can fit into your iris; otherwise, it would just dump the light on your whole face, which wouldn't be very interesting or useful."[23] While the volume of light is far greater than what a human would see, its range of light is actually far more restricted. While human optical rods and cones can distinguish a spectrum of colors, telescope's digital sensors don't sense color at all—"They can only measure the total amount of light slamming into them."[24] This overwhelming hit of light data is transformed into images legible to human sensibilities by the software algorithms that "reconstruct all this data into an image that kinda, sorta approximates what your eyes would've seen without the digital gear."[25] Given this, can we really say that the images are *enhanced*—let alone decry them for this—if they would be illegible to us any other way? Do we get angry at amoebe for being too small to see, or think the bottom of the ocean "less ocean-y" for not being self-illuminating (to our eyes, at least)? This attachment to an idea of the raw, scientific image has obvious affinity with the history of the objective observer and "neutral sciences" (as we will explore in more depth throughout this thesis). It is an attachment not easily shaken off and not always so easily detected, particularly as the gap between visual literacy and data seems to grow as we stuff it full of machines increasingly unknown and foreign to us. Yet this feeling about images says more about how we see ourselves than it does the machines or institutions that supply them. Equal parts certain and terrified of our capacity to play God, the "enhanced" scientific image both threatens and promises new knowledge.

It became clear that the methods and subject boundaries between these two once seemingly opposite fields had all but dissolved, and there was some ambivalence between their two practices, methods, and output. While in the sciences, attitudes and ideals remained more or less unchanged by this exchange,

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[23] Sutter, September 22, and ET.

[24] Sutter, September 22, and ET.

[25] Sutter, September 22, and ET.

what was actually being done and accomplished made it increasingly difficult to draw the line between what I was studying as landscape art and what was not. Were the heavily edited—almost falsified—satellite images a new form of landscape art, despite having been produced by teams at Google or NASA? And what did this say about the artistic work that took images as they were but used them to document a process of research and revelation that ended up impacting certain science and business sectors?

What's more is that nowhere were these overlaps more apparent than in images of the sky and outer space. The arena above the Earth's surface is in present day, as it has been throughout history, a great equalizer. Neither the scientist nor the artist has privileged access to this great expanse, which provides one explanation for why art and science can produce such similar images of it. Anyone who wants to see the sky, or see beyond the sky, or see from a position in the sky, has to do so by way of the same shared technologies: satellite images and their archives, telescopes, geospatial monitoring devices, etc. So, the situation I was faced with was that artists and scientists were sharing tools in processes that seemingly swapped methodology to produce images that were indistinguishable to their discipline just by looking. (Not the starting point I was hoping for.)

No World Viewing Without World Making

What this all serves to say is that where this thesis begins, then, is not at the beginning, but some place before the beginning. My original research question unwittingly unearthed the problem of posing such a question. I wanted to know how digital culture had impacted on the practice of landscape art, with the understanding that landscape art was a layered representation of environment as both a place and a feeling, and that this representation was informed by the individual, their society, and their culture. Yet with two of the foundational elements—landscape and art—in flux, it was not possible to add in a third. This is to say is that my question had to be transformed into what is now undertaken here: a methodology that reflects on the vague ontology of the image in order to unearth the incomplete connections such an ontology has to the study and representation of environment. What I have discovered in doing this is while digital culture has had its impact on how and what we might consider the image—both a departure from photography and deeply ideologically connected to it—then such an impact is compounded in the history of image and aesthetics in the sciences. The present condition is what I would describe as one in which the sciences continue a practice of using images without ever engaging with what an image is. Instead, they perform class epistemological maneuvers that recategorize the image-object to better fit a particular epistemological category. While the image is the same between the arts and sciences they are used to very different ends, and because of this their shared axioms are characterized and recharacterized as performing different operations. This is not always the case. As we will see, elements as simple as color and composition migrate in purpose and form across these disciplinary divides, radiating real-time impacts on how we see, study, and know the Earth.

All this is made more complex in its engagement with computation and digital culture. Digital culture and technologies further press on the weak spots of what we think we know about the image. In the absence of what is perceived to be a form of the image object, and with the speed at which the digital image can be replicated, transmitted, and degraded,   Such critiques do not find their way into the sciences but instead further isolate the sciences from the arts. Not only this, as digital technologies create new conceptions and ways of thinking about the image, they also have the tendency to resurrect old beliefs about how these disciplines and technologies operate.

What is contained in this thesis are six episodes in the process of creating an image of the sky. Each of these episodes is thematically grouped in ways that emphasize different registers and forms of perception. These registers and forms of perception are formed out of the predominant modes by which phenomena is made visible. What is stressed in each of these three parts is how these exercises in imaging sky emphasize different logics of visualization, representation, and realism. Sometimes these logics work in coordination with each other, while other times their relations are antagonizing, agitating, and unproductive. An important theme that runs throughout these episodes is the ambiguous line between fact and fiction, knowledge and fantasy. This tension is read into the relationship and roles of aesthetics to epistemology.

Images and art emerge from the mystified creative process which absolves audiences of the necessity for knowing the source of creation (and, indeed, this is part of the appeal of these works). Capital's seizure of digital technologies has put more and more layers of abstraction between users and hardware so that we've arrived at a point where the myth of disembodied information is persistent. These factors come together in the production of digital images of Earth, sky, and landscape, whether that's in the arts, sciences, or otherwise. Ignorance around geospatial images poses serious consequences which are only intensified by the hostility of our present climate. Consider that the most pressing ecological issue of our time—climate change and those other myriad threats that presented and named in The Anthropocene—is a crisis that is largely produced through images, and images created computationally. The very "idea of the Anthropocene is built on a bedrock of supercomputing and climate change modelling," Dan McQuillan writes, and it's an idea that is twinned with the inflammatory imagery of the Cold War. While it has been known since the 1970's that aerosols were harmful to climate stability, it wasn't until 1982 when Paul Crutzen and John Birks published "The Atmosphere after a Nuclear War: Twilight at Noon" with their predictions for *Nuclear Winter* that "paved the way for subsequent public alarm about climate change."[26] Crutzen and Birks' *nuclear winter* was produced through the use of two-dimensional computer models and generated vision of "global darkening and cooling due to the smoke and particulates generated by firestorms following a nuclear exchange."[27] This vision came at a time when the national laboratories that used supercomputers for modeling nuclear weapon yields during the Cold War suddenly found themselves at the end of the war and "facing a loss of purpose," so they shifted to modeling climate.[28] The hardware and engineers remained in this shift from Cold War to climate wars, carrying with them the same moral and existential panic that propelled the specter of another nuclear war but now redirected itself into the possibility of a total environmental war. While this is not to say that panic and urgency play no role in the evaluations of our current environmental situation, we need to also acknowledge the tacit role these affects play in shaping the aesthetics of our images, which are then used as foundational for knowledge. Affects can be knowledge, but they are one in a range of forms of knowledge, and their alterity in the context of Western rational thought should be acknowledged and worked with in order to facilitate knowledge production, rather than occlusion by ignorance.

By not honoring the images we view when we look at geospatial images for the aesthetic forms of knowledge that they are—an epistemology freed from the utility of thought—we indirectly lend credence a world infused with both the real and the imaginary. Such a world appeals to the way in which *worlds* are thought by Maria Lugones, whose use of *worlds* is offered as "a description of experience,

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[26] Dan McQuillan, "The Anthropocene, Resilience and Post-Colonial Computation," *Resilience* 5, no. 2 (May 4, 2017): 1, https://doi.org/10.1080/21693293.2016.1240779. This case study is also revisited in chapter four.

[27] McQuillan, 1.

[28] McQuillan, 1; McQuillan here is drawing on Paul N. Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*, First paperback edition, Infrastructures Series (Cambridge, Massachusetts London, England: The MIT Press, 2013).

something that is true to experience even if it is ontologically problematic."[29] We can pertain to many worlds, simultaneously, even those to which we do not chose to belong. This functions in contrast to that other recognizable configuration of worlds found in Nelson Goodman's *Ways of Worldmaking*. For Goodman, *worlds* describe an order of reference removed from experience; worlds are static, analytic contextualizations.[30] While very different in nature, Lugones and Goodman's *worlds* overlap in the sense that they prescribe a regime of representation that has the capacity to be "world making," in both of their senses of the term. Lugones shares in Goodman's belief that world making "always starts from worlds already on hand; the making is a remaking" but she does so without the implication of a kind of linearity.[31] This is key, too, because their phenomenological and analytical belief systems, respectively, come together on this point. Worlds are often discussed in terms of semiotics and provide a key for reading and addressing symbols in a given system. So too, for Lugones do worlds give us information about representation, but instead of the world making *following* from an existing world, it is more of a lateral relation. Worlds exist side by side, pull from the same stuff, pull from new stuff, create and recreate in spurts, spatters, and lurches. This locating is precisely why for Lugones we can "travel" through worlds; we do not need to race to catch up to them or fall back. When we travel through worlds we retain their memories; we may or may not bring these memories to bear on other worlds. Whether or not we do will always have the impact of creating, or remaking, that world, or some world in relation to us, and such a fact means the referential ordering is always thinly grounded in a world; it is spuriously developed, honed and projected.

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[29] María Lugones, "Playfulness, 'World'-Travelling, and Loving Perception," *Hypatia* 2, no. 2 (Summer 1987): 11.

[30] See: Nelson Goodman, *Ways of Worldmaking* (Indianapolis: Hackett Pub. Co, 1978). For a critique that further highlights the function of "worlds" with respect to realism and representation, see: Menachem Brinker, "On Realism's Relativism: A Reply to Nelson Goodman," *New Literary History* 14, no. 2 (1983): 273, https://doi.org/10.2307/468686.

[31] Goodman, *Ways of Worldmaking*, 6.

What structures worlds for Lugones is the way in which they can connect and bridge through commonalities and norms. For Lugones, being at “ease” in a world is precisely this oneness with the collectivity of that world: the experience of one to their kin, one to their socius, or one to a shared experience. Earth images can create a false oneness through their projection of a unified sense of the global. We inhabit the same earth both in physical space and imagery, and in both cases the Earth is there to be ordered against the loss that climate change collectively imparts and individually impacts. Not only this but Lugones highlights how world traveling can animate worlds we do not chose to belong to, can animate parts of ourselves that we do not recognize, or animate entirely new characters which we do not chose to body forth. There is a similar effect at play as well in our satellite images. Engaging images of the physical world in world *making*, but maintaining that we are world *viewing*, risks performing a digital mode of the same world traveling that Lugones identifies, animating worlds we do not chose to belong, animating parts of ourselves we do not recognize, and animating new characters we do not chose to body forth. This is the political risk that is embedded in all aesthetic forms of knowing. By flattening planetary aesthetics into its image form, we take on this risk as well, and to the detriment of the pressing ecological work that lays ahead of us.

What this thesis ultimately produces is a texturing of what it means to see and represent the world without simultaneously acknowledging that such acts also *create* the world. There can be no *world viewing* without *world making*. Landscape art created one version of the world, and the introduction of digital tools do not radically alter this capacity but instead multiply it. We can understand the worlds these methods create by reverse engineering their aesthetics. How the concept of nature is figured can tell us what how it is we come to “know” nature. Here I am using nature not in its aesthetic idyllic sense but in the sense of place that is always *out there*, a notion that is highlighted by William Cronon when he writes that scenes of wilderness—or a wildness that is coupled to a “pure” or authentic nature—as always being "out there," as forming part of an idealized wilderness or natural scene that "too often means not idealizing the environment in which we actually live, the landscape that for better or worse we call home."[32] With this understanding of nature there can be many sites of nature, and each of these sites signals a *world* that organizes its own references and modes of representation to be made and remade, and which, significantly, animate experiences and representations from across a variety: those we chose and do not to accept, those we are aware of and those to which we are ignorant. In this way computation becomes, in itself, a site of *nature.* Computational processes are most in possession of their "naturalness" when they present in agreement with human ranges of visuality and legibility; glitch, corruption, and misfires slice through this nature like a bulldozer through a field.

The thesis focuses on images of sky because there is no better figure, metaphor, or equalizer for thinking new combinations of nature and technology. The sky is distinct from terrestrial environments in the sense that it is only knowable through the images, and more broadly, by the mediums that represent it. Skies are metonymic of the relation between landscape art and software to environments in the sense that the term and idea of sky culturally signifies something void of material constraint. In its nomenclature, the sky refers to a very particular area of the atmosphere and outer space that is viewable from earth and limited to the range of human vision. For astronomers, the sky is interchangeably referred to as the celestial sphere, which is envisioned as an imaginary dome, across which the sun, moon, and stars are seen to travel. In meteorology the sky refers to the lower, denser portion of the atmosphere. In all three of these examples, though, the sky is always limited to, and defined by, the uppermost bounds of what the human naked eye can see. This variation highlights the multiplicity of worlds and how many worlds can belong to and be associated with (whether invitedly or not) to a space, entity or being. As I

[32] Ibid., 85.

will discuss further in chapter one, sky is metonymic of the kinds of contradictions that are embodied in the paradigm of a world viewing that does not also admit to the ways in which it is a *world making*. This is because very often the technologies that enable our representation of—and access to—the sky are tempered and mediated by the very sky itself, which is relied upon to function as a medium and channel.

This distance and remove helps to demonstrate more clearly how worlds are created through their aesthetic representation. As a site of investigation, it helps to lessen the biases we bring to thinking nature, to thinking landscape, and to thinking landscape art. More than this, though, it is the sky as a site of fantasy and a horizon of knowledge that makes it best suited for this exploration. The episodes contained in this thesis all argue for the creation of worlds through the aesthetics because it is through aesthetics that worlds are made knowable. Aesthetics in this framing forms the basis of epistemology—it can produce what we know—while at the same time being a tool to structure that knowing—it shows us how we know what we know. In images of the physical world, aesthetics serve as both content, key, and archive; there is a formal function of aesthetics—to bring into visibility unseen phenomena for study—and symbolically, as in when it raises the alarm for events as yet unrealized or already past.

Sites/Sights of Sky: A Proposal in Three Parts

This thesis is messy in what it tackles and addresses. It mixes methods and it mixes objects. That is because this thesis is an attempt not at doing something new, but at doing visual methods research in a new way. Understanding images of our physical world as images of *worlds* constantly provoked the question of what I was looking at, and how I knew I was looking at it. These questions fundamentally destabilized the means by which visual research is conducted. It didn't suffice to to mark the visual cultures that were produced around and through the images I was investigating. As we will explore together, it is not enough to understand the culture of scientists and engineers in order to appreciate and evaluate the judgment of satellite images, nor was it enough to mark this culture of visuality as distinct from that which emerges in art contexts. What I instead found was that, particularly in the case of digital images, the ability of images to circulate amongst cultures transformed their reception and, in some cases, their content. A framework which only staged a debate about the meaning of an image in terms of its social effects as an expression of its modality (in this case, a technological modality) only ever provided half of a view onto the significance of the images I was exploring. As images traveled and mutated, their content and significance changed, forcing the cultures around them to adapt. In other words, visual methods of research were always one step behind the image. Something *else* was being formed and left behind in every investigation; something that I saw as very much linked to a deep-seated problem of *representation* that was aggravate by the already unstable realms of ecology and technology. If Jonathan Crary was already writing in 1992 that computer graphics techniques had so radically changed the relation between observer and representation as to render those terms void, then what we are about to see in this new orbit of imaging practices is, in 2018, is exactly that radical change.[33]

With respect to the challenges of visual research methods, what I have tried to do in this thesis, then, is to alternately inhabit different perceptions onto the physical world. Seeing images of sky, a distinctly human concept, in terms set by non-human actors, helps to loosen the grip that human concepts hold on ideas of nature and landscape aesthetics. It also helps to promote ideas of information, logic, and aesthetics not as processes to be modeled in the likeness of the human faculties of thinking and judgment but instead as something else—something more mechanical that, when pushed, will only ever mechanically produce the expression of

[33] Jonathan Crary, *Techniques of the Observer: On Vision and Modernity in the Nineteenth Century*, Nachdr., October Books (Cambridge, Mass.: MIT Press, 2005), 1.

its logical ends (as we'll see in chapter three, with the case of a misplaced glitch aesthetic). At the same time, already you can see how this might create some trap of instrumental determinism that would shut down any possibility for understanding what I would consider as the most human element of technology—their capacity for error and limits. Moving nimbly amongst human/nonhuman, organic/machine registers helps to avoid this.

Section I provides two ruminations over the course of two chapters on the symbolism and treatment of clouds and the sky throughout history and present-day. These chapters are foundational for the ways that they help us to understand the complicated and misunderstood relations that have been (and continue to be) forged between nature, technology, and human culture. In the first chapter I explore a dominant history of clouds in the West to draw out the maneuvers by which skies—and clouds in particular—became instrumentalized and then transformed into *media*.

Section II explores two present-day modes of digitally representing images of the sky. Both chapters in section II speak through technical processes to address the varying modes of perception and representation—ecological, technical, and human—that are always present and imperfectly collaborating in creating digital images of skies. Chapter three does this by uncovering the ways in which visualizing technologies are heavily mediated by the conditions of being human and by human culture. We use the art project *Postcards from Google Earth* by Clement Valla to explore how "true" images of place—images that are the proper result of a functioning digital system—can still denote a "false" cartography. In chapter four we approach such a dichotomy from an opposite end by performing a close reading of the open source, 3D computer graphics software Blender as both a tool *and* a site of epistemology. The focus of section II is to buck against the notion that human-technical collaborations are somehow more "accurate" or objective because of some presumed displacement of subjectivity onto technical operators. What I aim to show in my readings in both these chapters is how such a human subjectivity can never be displaced precisely because it is installed in the origins of the operators themselves. Algorithms and software are never congealed in a vacuum free of human messiness and culture. To the contrary they are forged out of the craze of sleepless hours and vomiting fighter pilots; laziness and looming deadlines. By exposing the soft underbelly of the use and origins of digital images outside of the arts, section II makes clear the necessity of dissecting disciplinary organizations *as well as* structures of the image and aesthetics as a joint practice for working with images as a tool for creating knowledge. These two chapters jointly argue the case that it is not solely the collection and synthesis of data that requires critical political engagement but also the moments of display and communication that subtly perforate these entire processes that so too also present moments of politicized persuasion. Display is itself a rhetoric—not just an invisible holding place.

Section III pivots our focus away from how digital operators are profoundly impacted by the human and human culture to explore how humans are transformed into technical operators. Over these final two chapters we are introduced to four aspects of an online community of amateur Earth modelers, individuals who in various capacities are linked by a desire to create "highly realistic" virtual recreations of Earth. Applying the lessons from Karin Knorr Cetina's ethnographic work on High Energy Physics (HEP) labs we see how the organic world—including both human and non-human organic actors—are absorbed into the digital culture and the varying impacts this has on each of them. More generally, these impacts also raise concerns about the foundations on which we build ecological knowledge, again troubling the boundaries drawn around image and "mere" (or apolitical) representation and display. These chapters work to draw out the unwieldy parts of the digital-human collaboration in capturing and producing digital Earth imagery and use moments of "forced" functioning to reveal the biases programmers bring to images of nature. This is significant because of how it works against the idea that images produced in the sciences, through computation and automation, or with the aid of computers are somehow capable of producing objective or inherent truths. To the contrary, what these three sections all prove to show is that images are always saddled with human cultural baggage, and while this does not negate or prioritize one *world* over another—landscape art images are no truer than scientific models of climate or satellite imagery, for example—it works to return us to Lugones's sense of *worlds* by expanding and multiplying the ways in which these images can be seen, understood, and activated.

Ultimately, this thesis offers a mapping that shows us the limits of visual methods and, through its own messy, heterogenous method maps a series of case studies that, one, make the case for such limits, while, two, also testing new methods of visual research. The case studies are organized around the practice of representing the sky—by all accounts a difficult and vague part of our ecosystem to represent; a region of space that is as conceptual as it is material. Rife with contradictions and paradoxes, the sky pits questions of an *a priori* knowledge against aesthetic processing. Is it more important to not recognize the thing we see if we know that its mechanism of representation perfectly aligns with a certain subject knowledge? In this we see the central question underpinning all of this methodological work: what place does aesthetics hold in the order or information? What kinds of information can aesthetics contain on its own, and how can this format of information square with epistemologies of other kinds? What I will argue for through the case studies treated in this thesis, and through the development of whatever visual method I see here working out, is for a move away from thinking about *images* as we historically have and instead to think of images as just one format of data. Aligning images and image structures with data on-ramps traditional visual methods research to situations with more complex and extensive visual contexts, which is often the case with the images coming out of complex technological cases such as in climate models and ecological simulations. Thinking of images as data and information brings into relief the actual ways that images *are* being used as data and information. Sometimes we find that the discourse analysis of the image is plainly embedded in the spectrums of an image's inputs (as in satellites) or in their coding.

Not only this, but thinking of images in this way overlaps with the history of science to provide new insights on how images are used to make information communicable, or how we *think* we are using images to make information communicable (and perhaps getting it wrong). Thinking of images as data and information merges aesthetics into media theory without skipping on every hardware and software innovation that arises. It drills down into the heart of so many debates in aesthetics—with new tools—and continues the discipline's work of fleshing out and elaborating what are the grammars by which something can make itself (re)presentable. This work is important now, perhaps more than ever, to help make clear the information and disinformation of our current political situation. There is, of course, at least one clear benefit working with the image in this way, in the context of ecological images. So much of our present climate crisis is determined through the computing of sensory data and disciplinary knowledge, and then spit back out as simulations, predictions, and so many other forms of graphic realizations of impending disaster. How can we build a scientific knowledge and praxis that anticipates a disaster on the scale that climate crisis presents, without a foundational knowledge of visual literacy and an appropriate visual method? This question is doubly transferrable to all geopolitical research relying on satellite imagery to provide large-scale views onto the Earth. Action at the level of policy and activism is hindered by the inability to make clear-sighted decisions; to be able to read data in visual formats confidently and with a strong sense of the context in which the knowledge proposed is the knowledge that is present. As we move through the six episodes presented in this thesis, the question of determining *where* knowledge happens and *how* will show just how constant this elaboration and negotiation of aesthetics is. Exploring new, or expanded, ways of doing visual research—mixing art images in epistemic cultures, science images with visual cultures—make the case for understanding *worlds* and images *as data* as, potentially, welcomed additions to the parameters in which we frame debates in visual theory.

I.

Chapter One: Clouds

Introduction

There are certain stories that the West tells about the history of clouds and skies. These stories stand apart from other narratives of nature in unique ways. While many narratives of the West's engagement with environment are often festooned with ideals of progress, dominance, and control, narratives of the sky are far messier affairs. They contain within them secrets about our most foolish enterprises—cloud seeding, failed attempts at weather control as a military strategy, orgones—as well as some of humanity's highest achievements.

The relationship of the West to clouds, and the stories the West tells about clouds—both colloquial and scientific—speak to fundamental incompatibilities between the physical world and technology. Try as we might, the physical world will always contain some portion of the incomputable, the inconceivable, and the imperceptible. Chaos will always exist as an excess of the digital binary. The Western history of the clouds and skies likes to tell the story of man's journey in bringing the skies closer to Earth, of our successes in penetrating sky and our near-misses. This is almost never the case. A third and far slippier agent is always at work, always in the shadows as we focus our energies on the light.

This chapter mines the dominant, Western history of clouds for critical moments in which entanglements of aesthetics and epistemology are at their most unresolved. I propose that these specific historical moments can help us understand the longer history of the sky as a site where issues of method, information, data, subjectivity and objectivity are forced to engage in ways that prefigure contemporary debates in the uses of digital and sensing technologies in Earth observation and climate science. Paul Edwards has argued that ecological knowledge comes to us as a result of an intricate weaving of infrastructure, protocol and policy, all of which "not only accepts the provisional character of knowledge but constructs its most basic practices around that principle."[34] The history traced here proposes another genealogy by which such practices can be understood. By tracing the ambiguous overlaps between art and science this chapter aims to emphasize that a reason for *why* climate sciences might work in this way is precisely related to the study of sky as a natural phenomenon and the broader challenges of a scientific method that seeks to formalize data that otherwise comes to human observers in aesthetic and unregulated forms.

In the first section I provide an overview of the dominant history of clouds in the West. From there I will shift the tone of the chapter to two primary case studies in this history. In the first, we will explore the necessary contradictions present in the subject-object Earth sensing relationship. Here I introduce a case study on J.M.W. Turner's painting *The Fighting Temeraire* (see: figure 3) and Michel Serres' interpretation of the painting as a cultural commentary on Britain's change as an industrial nation—a hypothesis later revoked after scientific findings from glacial cores reveal that a volcanic eruption might also have caused the infamous blackened ash on Turner's canvas. In the second we turn to John Ruskin's early environmental lectures, applying Klaus Amann and Karin Knorr Cetina's ethnographic observations on how visual data becomes evidence through highly proceduralized yet informal modes of social engagement. This staging emphasizes the necessity of aesthetic information to the study of natural phenomena and points to the ways that scientific disciplines strive to accommodate these forms into their modes of working, with variable results and degrees of intensity. The final section of this chapter proposes an open-ended discussion on the emergence of an aesthetic that straddles both artistic and scientific modes of practice. I suggest that *pathological science*, a lecture offered by scientist and cloud-seeding proponent Irving Langmuir, reflects a late-stage development of the practices cultivated in Romantic period engagements

[34] Edwards, *A Vast Machine*, 438.

Figure 3: "The Fighting Temeraire" (1839) by J.M.W. Turner.

of the sky. This science of affect and crafting of procedure produces the sky as a media in itself: a method and means by which objects are created and made visible not by an invisible infrastructure or hardware but instead by one that, by its very nature as a media, is forced to recede into invisibility, leaving in its wake only the faintest trail of its own imprint on the world it has created for viewing.

Some Remarks on the History of Clouds

There's a dominant and well-rehearsed history of clouds in Western culture. It might begin with Aristotle's *Meteorologica* (350 AD), or it might not. The *Meteorologica* is widely regarded as one of the earliest works of collected Western meteorological knowledge. [35] It proposed ideas about the global ecosystem and clouds that, while believed to have been gathered from “facts collected from former natural philosophers, historians, poets, and common experience”, also depicted the Earth, in hindsight, as more fantastical than rational. In Aristotle’s conception of the universe, the earth existed at the center of a series of concentric spheres with the outermost sphere containing fire. Aristotle theorized that clouds could only exist in a limited region that could not extend beyond the highest mountain nor travel too close to the earth because clouds could not withstand the fire of the outer sphere, nor the heat the earth reflected from this sphere. The movement of clouds transgressing these boundaries could be responsible for weather elements such as hail and large, warm rain droplets.

However, any history of clouds in the West will always cite some sort of beginning with Luke Howard’s *On the Modification of Clouds*, first published in 1802. The narrative may or may not give a sympathetic shout out to Jean-Baptiste LaMarck’s decidedly more elaborate cloud classification system—published at the same time but greatly overshadowed.[36] From there it swiftly moves on to the middle of the 19th century, to that great painter of the *organs of sentiment* John Constable. Turner and Monet (figure 4) charge us forward into Modern history where clouds lose their innocence; clouds are darker, unrulier, ominous. They no longer become the screen onto which we project our fantasies but instead reflect some deep, internal disquiet with a rapidly changing world and our anxieties about fitting within it. Soon enough, the World Wars give reason to this agitation. World War I and II

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[35] In 350 AD Aristotle wrote the *Metereologica,* a text that today signals the earliest Western meteorological knowledge because Aristotle is believed to have drawn on including work from the Egyptians and Babylonians.[35] See: H. Howard Frisinger, “Aristotle and His ‘Meteorologica,’” *Bulletin American Meteorological Society* 53, no. 7 (July 1972): 636, https://journals.ametsoc.org/doi/pdf/10.1175/1520-0477%281972%29053%3C0634%3AAAH%3E2.0.CO%3B2.

[36] Howard’s *On the Modification of Clouds* was first published in 1802; LaMarck’s classification in 1802 with further modifications in 1805. See: L. Daston, “Cloud Physiognomy,” *Representations* 135, no. 1 (August 1, 2016): 45–71, https://doi.org/10.1525/rep.2016.135.1.45. Excuse the pun.

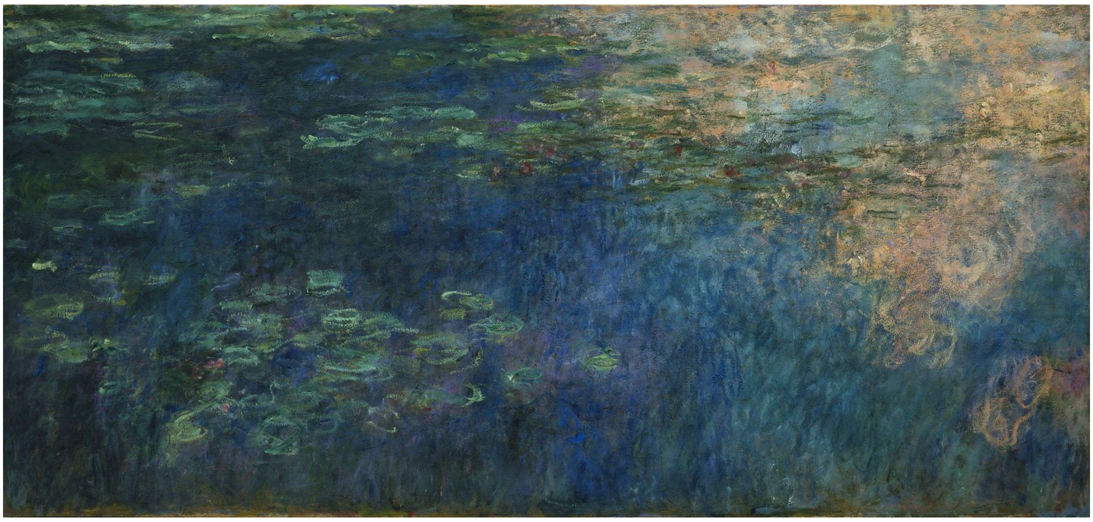

Figure 4: "Reflection of Clouds on Water Lily Pond" (circa 1920) by Claude Monet.

bring with them active, tormenting clouds—the gas chamber, breathing masks, and atomic bombs. We no longer live our lives lovingly gaze upon the clouds but instead guard ourselves against their predatory approach. At the same time as the clouds press against our fragility we become emboldened in our engagements. We no longer live in passive, distant observation of the clouds but propel ourselves forward through the skies: flying and soaring. We become the same predatory clouds we fear, sending bombs from above, masked in the thick condensations of cloud cover, churning the landscape below.

Reeling from this destruction and renewed by technological advances, there is the development of Western space programs and their attempts to operate from the air. The 1957 launch of Sputnik 1 was an event so transformative that Hannah Arendt called it event "second in importance to no other, not even to the splitting of the atom" and an expression of what she took to be "relief about the first 'step toward escape from men's imprisonment to the earth'".[37] This ability to see from above created a vantage point onto the clouds not just as a screen for our projections—for hopes about human culture and the afterlife, as a site of endless

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[37] Hannah Arendt, *The Human Condition*, 2nd ed (Chicago: University of Chicago Press, 1998), 1.

apophenia—but also from above. The double vantage point onto clouds further compartmentalized them into things to be studied, to be ordered, to be rearranged. And perhaps because of their polymorphous, ephemeral presence in a network of global climate did clouds come to signify a resilience in the human fight to manage nature.

This history brings us to today, where the metaphoric use of the word cloud now refers to the networked and remote servers called *cloud computing*. It is widely recognized by now that cloud computing is a metaphoric term in the sense that is an application of a term to an object to which it does not fit. All the same, cloud computing positively conjures a sense of computation as distributed and displaced. It incorrectly conjures the image of computation as a process that happens in the ethers, above our head, and imparts the sense that computation is not *displaced* so much as it is *out of reach*. Cloud computing can misguidedly give the impression that what is saved in the cloud disappears and cannot be accessed by others (sometimes not even by the users themselves), which is something that has woefully been disproven in countless cyber hacks. But the equivocations of cloud computing as a term and as a practice do not belong to the lineage of the history of clouds in the West. Mixed metaphors do not always signal a progression or history. Instead what *is* an outgrowth of this history is the abandonment of control to the seemingly "unnatural" process of computation. This exporting forces a cut between nature and the technologies that are infused into that nature. Not only do distributed servers and networked technology function as our modern-day way into the study of clouds and climate, but they are also themselves emergent features of our natural landscapes. The server farm is the natural habitat for our creature comforts—Netflix, Amazon, Facebook—and produces 2% of all global carbon emissions.[38]

[38] Bryan Walsh, "Your Data Is Dirty: The Carbon Price of Cloud Computing," Time, accessed July 25, 2018, http://time.com/46777/your-data-is-dirty-the-carbon-price-of-cloud-computing/.

Only Fools and Detection

If this history seems short that is in part the intended effect, and that effect in itself is a point. The story of the clouds in Western culture is in many ways one that we already know: a slightly conservative narrative of simpler times made more complex by technology, the subtle gaining momentum of masculinized rationality over the unruliness of nature and its perpetual frontier, the sky. Yet as we will find, this story runs amok of the practices on the ground. Dig deeper and you'll find a story that's been purposely stitched together by a culture that self-consciously wants to construct itself as counter to such wildness and its attendant tropes. It's a strategy securely woven into the history of nature in the West and one that has positioned human culture in a strangely antagonistic and yet enamored relation to its unruly counterpart. As Mette Bryld and Nina Lykke have written, it was at the moment of engagement "in the technoscientific and colonial enterprise aimed at the control of nature and the opening up of a globally unrestrained access to raw materials and slave labour" that "the wild and the savage caught the attention of white Europeans of the Renaissance and early modernity".[39] During this period it was a high priority to "civilize, … tame, domesticate, control … enslave" the wild—in whatever form—so that it might be transformed into a resource. At the same time other characterizations of wilderness and the wild had more Romantic connotations, promoting antidotes for a civilization that had "gone astray" (and could be salvaged with a return to the wilderness and its embodiment of "authentic values").[40]

As Bryld and Lykke argue, these intersections of rather opposing views onto nature and wildness produced patterns of ambivalence that remain installed in our cultural conceptions of nature. "The more rapidly our 'civilized ways of living devour

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[39] Mette Bryld and Nina Lykke, *Cosmodolphins: Feminist Cultural Studies of Technology, Animals and The Sacred* (London: Zed Books, 1999), 21.

[40] Bryld and Lykke, 22.

the wild," Bryld and Lykke write, "the more we middle-class people of postindustrial cultures become obsessed with a radical nostalgia for healing the broken bonds between human and wild nature."[41] Such an ambivalent patterning suggests an insecurity that is untenable. Such a patterning is not unfamiliar to the history of the sky in the west.

Patterning also becomes the name for the repeated action of seeking resolution only to find more questions. Irving Langmuir famously presented a seminar on what he deemed *pathological science*, or a "science of things that aren't so."[42] Langmuir's pathological science included (among other examples) "the extrasensory perception (ESP) of the American parapsychologist Joseph Banks Rhine" and René Blondlot's "nonexistent N-rays (1903), so subtle that only a Frenchman could see them".[43] While Langmuir's talk does not propose malintent—and even finds quite a few jokes at the friendly expense of these researchers–[44] what he really warns against is "researchers [being] tricked into false results by a lack of understanding about what human beings can do to themselves in the way of being led astray by subjective effects, wishful thinking, or threshold interactions."[45]

What does it mean to be led astray by subjective effects, wishful thinking, or threshold interactions? To make such claims you have to believe that such affects are

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[41] Bryld and Lykke, 23.

[42] James Rodger Fleming, *Fixing the Sky: The Checkered History of Weather and Climate Control*, Columbia Studies in International and Global History (New York: Columbia University Press, 2010), 137.

[43] Fleming, 137.

[44] One transcription of Langmuir's talks has eighteen "laughter" notes peppered through. Langmuir was either very charming or felt very much at ease with his colleagues and the subject. The talk is casual: he mentions having lunch before returning to a dark room to see n-ray experiments, he confesses to playing a "dirty trick" to catch out an experimenter who had not been properly measuring results, he describes whispering to a colleague before again the room appears to join in "laughter". Irving Langmuir, "Pathological Science" (Colloquim, December 18, 1953).

[45] Fleming, *Fixing the Sky*, 138.

capable of existing on their own, or outside of a human body practicing science. It is no surprise that Langmuir gave this seminar at the same time that he himself was engaging in the pathological science of cloud seeding to create rain and alter climate.[46] Langmuir's experiments in climate control were exercises of wishful thinking, a faith frequently renewed on the basis of threshold interactions, and carried out by Langmuir until his death. That Langmuir was unable to see the irony in his own statements gets to the heart of a fundamental contradiction that runs through the history of the West's relationship to clouds and sky. While histories and narratives of Nature seem tailored towards the exaltation of a culture that mans its own destiny, the sky remains a steadfast foil to human hubris. Amorphous, inaccessible, alluring and at once punishing, clouds and sky overwhelm our senses and reason. What the history of sky and its attendant phenomena tell us about are the clashes between data that is received in visible forms to be forced into formalizable structures. The bad-faith experiments, the uncertain hypotheses, the revised conclusions—these are all the marks of early epistemological struggles in attempting to recreate a fundamentally sensory phenomenon into the kind of form and content that could serve notions of scientific objectivity and rationality.

There's a second point to make here then, too. The encounter between the sky and the scientists and artists who tried to observe it foregrounds larger questions about how humans understand aesthetics as information. In her work on Earth observation satellites—a direct and present-date outgrowth of the genealogy we are discussing here—Karen T. Litfin quotes the work of ecofeminist writer Yaakov Jerome Garb in announcing that vision is the "cardinal sense in Western thinking" as well as being "Of all our senses… requir[ing] the least engagement".[47] I am in

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[46] Fleming, 139.

[47] Karen T. Litfin, "The Gendered Eye in the Sky: A Feminist Perspective on Earth Observation Satellites," *Frontiers: A Journal of Women Studies* 18, no. 2 (1997): 39–40, https://doi.org/10.2307/3346964.

agreement with Litfin that vision does dominate the history of Western reasoning—a history that also finds its way into computing. This might be unrelatedly because it is vision that is the most readily available to human mental faculties (with perhaps the slightest suggestion that it is the most *lazily* so?). However, I want to suppress this strand of Litfin's argument here in favor of what she points out as the relationship between seeing—the "drive to gain 'objective' knowledge about the earth"—and the necessary interplay of "actual and felt distance between subject and object".[48] Here we must ask *who* the subject is, and how we might know a subject as distinct from their objects. This is a far trickier question to parse given the myriad forms that feminist STS discourses have assigned to the production and understanding of subjectivities. One such example that is particularly apt for our study here arises out of the cooperation of humans and tools. Donna Haraway's understanding of cyborg subjectivities is one dominant perspective that threatens to upend Litfin's construction. Haraway notes in her introduction that *The Cyborg Manifesto* was expressly written to find a "political direction in the 1980s in the face of the hybrids 'we' seemed to have become world-wide" as well as a proposal for the "transformation of the despised metaphors of *organic and technological vision*" that could ultimately foreground "a possible allegory for feminist scientific and political knowledge."[49] For Karin Knorr Cetina (whose work will be discussed in greater detail in chapter six) the collaboration between human scientists and their tools extends far beyond arguing for a distinctly feminist position but instead as an acknowledgment of the intimate and integral human/non-human sociality that supports laboratory work on phenomena not easily observable by the human eye.[50] In this configuration subjectivity flows between humans and their tools in ways that

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[48] Litfin, 39.

[49] Donna Jeanne Haraway, *Simians, Cyborgs, and Women: The Reinvention of Nature* (New York: Routledge, 1991), 3. Emphasis mine.

[50] See: Karin Knorr Cetina, *Epistemic Cultures: How the Sciences Make Knowledge* (Cambridge, Mass: Harvard University Press, 1999).

are not easily definable. What Knorr Cetina calls a *care of the self* refers to the intimate and persistent ways that human scientists come to care and "know" their instruments as a way of producing objectivity and safeguarding against fallibility, but which results in a mode of anthropomorphizing that risks exaggerating the forms of human subjectivity such maneuvers set out to prevent.

J.M.W. Turner and the Blight on Blighty

One moment in which the topology of actors inflects the observation of sky can be seen in the example of a particular dark cloud that makes more than one appearance in the paintings of J.M.W. Turner. In these paintings this dark cloud appears as an ashen veil on an otherwise warmly hued canvas, or a smudge of darkness drifting around a yellow sun. Turner's dark cloud is read in one way as the account of a country in the throes of progress, of England's transitional period of Industrialization.

On this basis Michel Serres heralded Turner's paintings for their singularity, and Turner for opposing his peers' more pastoral English landscapes in making "us see what he observed … the novelties of a country in the throes of a complete scientific, technological and social renewal" and not the "fields, meadows, and gardens still plunged in the old society of the eighteenth century and its agrarian, aristocratic world".[51] Serres compared Turner's painting to a painting by George Garrard of a brewery warehouse and saw the two artists as giving visual life to a historical shift in labor and power. One commentary notes that Serres "neatly captures this with the quip that it is as though fire consumed the horses in Whitbread's yard and reincarnated them over the bridge of the tug as a 'cloud of

[51] Michel Serres, "Science and the Humanities: The Case of Turner," trans. Catherine Brown and William Paulson, *SubStance*, 1997, 7.

Figure 5: Two paintings of the Whitbread Brewery by George Garrard. Left, "Whitbread Brewery in Chiswell Street" (1792); right, "Loading the Drays at Whitbread Brewery, Chiswell Street, London," (1793).

horsepower'."[52] Garrard's painting of the Whitbread brewery captures a world in wh ich "work is done through mechanical devices that harness basic forces—'men, horses, wind and water'"—a near perfect visual guide to Joseph-Louis Lagrange's *Analytical Mechanics*.[53] In contrast, Turner embodies the principles of Carnot's thermodynamics by painting a world "where fire and steam are the motors of industry" and moreover by acknowledging that the rationality of such a world "must be one attuned to the stochastic rather than precise calculation of balances between forces."[54]

Yet twelve years later, in "Science and the Humanities: The Case of Turner," Serres backtracks on his earlier assessment of Turner and his dark English cloud. Serres admits that new information from glacial core samples in Greenland "have laid waste to my old intuition, which had sprung from the history of natural and

[52] Steven D. Brown, "Natural Writing: The Case of Serres," *Interdisciplinary Science Reviews* 28, no. 3 (September 2003): 4, doi:10.1179/030801803225005175.

[53] Ibid., 3.

[54] Ibid., 4.

social science."[55] Serres explains that this core sample is evidence of a monumental eruption of the 9,000-foot volcano Tambora, located in the lesser Sunda Islands of Indonesia, at around the same time that Turner was painting his ashened cloud. "Thanks to Tambora, in those years," Serres writes, "London and England … lay under a cloud of volcanic ash spewed up from Indonesia".[56] Serres concedes that "Turner simply painted [the volcanic ash's] visible reality, for an honest artist describes what he has before his eyes more and better than what he thinks". [57]

Serres's quick retreat into disciplinary explanation is curious, and more so for the way it walks back his once enthusiastic appreciation for the artist as someone who now *only* describes what they see—an act that is, in Serres' estimation, devoid of thinking. Observing the two episodes side by side reveals the distinctions between subject and object, scientist and artist, and the tools attendant to each as a socially constructed artifice. It is worth here quoting Serres in full as a kind of exercise in the conservative cataloguing that he engages in:

> Did this ashy screen come from the eruption of that volcano or from the social reflections of the Industrial Revolution? Did it come from the phenomena of nature or from the effects of society? Were the air, the light, and the sky of London direct manifestations of telluric powers, or were they indirect manifestations of relations of force remodeled by fire-driven machines and the factory proletariat? Since the immediate moves more quickly than the mediated, geophysics seems more powerful than economic history—Tambora more powerful than Marxist analysis. Was I mistaken? I am ready to admit it.[58]

Here natural phenomena are sorted from their social and cultural contexts, and science removed once step further. Ash either arises from a volcano *or* a social attitude towards industrialization; air, light and sky from preexisting Earth processes *or* mechanical energy? It seems counterintuitive that such equivocating would not also admit that there is no clear line between these causes and effects, no either or.

[55] Serres, "Science and the Humanities," 12.

[56] Ibid.

[57] Ibid.

[58] Ibid.

What I take from this situation is a comment on some of the uppermost absurdities of natural world observation, best embodied in this history of Western skies. For Serres, his reversal of revelation is also testament to this to some degree. He reflects that the question of truth is a question of position and ordering: that, like geographic cultures, "official knowledge is divided into provinces: logic, astronomy, sociology ... and scholarly or scientific truth haunts the intersections between disciplines."[59]

Further to the point, we can read Serres somewhat literally when he further comments "the invention of truth is born from the moving intersections of specializations—here, from an overlapping of nature and society, from a projection of two world maps, one on the other."[60] Here I want to thread the needle between a disciplinary comment on the formation of knowledge and the role of the aesthetic: though metaphoric, it is the ability to see and distinguish projections that provides the overlap necessary to engage the "moving intersections of specializations" that will bear out truth. My method here echoes that of Steven Brown, who raises an equally important issue. How can we understand this metaphor of projection as a physical instantiation of the problem raised? Brown remarks in a similar vein on the trope of *writing* that is present in Serres's thinking. Brown highlights that Serres "compares the ice core samples to 'pages' on which the natural world has 'written' its own history" and "refers to the strata as 'pages' constituting a 'book' recording 'the diverse climactic moments of eras whose dates and memory we had often lost'. It is as though a 'new library' had been discovered 'in a refrigerator'."[61] For Brown, the literary signifies rationality. "What does it mean to say that non-humans, that

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[59] Michel Serres, "Science and the Humanities: The Case of Turner," *Journal of the International Institute* 4, no. 2 (Winter 1997): 19–20, http://hdl.handle.net/2027/spo.4750978.0004.201.

[60] Serres, 20.

[61] Steven D. Brown, "Natural Writing: The Case of Serres," *Interdisciplinary Science Reviews* 28, no. 3 (September 2003): 5–6, https://doi.org/10.1179/030801803225005175.

inanimate things, can write?" he posits, answering "If we consider that writing or formal symbolic manipulation is typically considered the cornerstone of human civilization … then the idea of inhuman writing poses a threat to the basis of our rationality."[62]

I contend that while this may be true it fundamentally overlooks the aesthetic component that is required for the functioning of the literary: we must be able to see in order to read, to see in order to write; to write and make legible in forms that are available to our senses. What the example of Turner, Tambora and Serres highlights—in addition to the inability to draw clear lines around what and who are objects and subjects while at the same time collapsing the distances between them in order to perform sky observation— is not just how subjects/objects contained within the natural world and atmosphere are themselves confused. It is also the context itself that is confused. In the study of the natural world, and indeed the sky, subjects and objects are indistinguishable from their object of study. Air becomes breath becomes nourishment for plants becomes medicine becomes poison: it is a long and cyclical life process without starts and stops. What this fact highlights is the issue of how we then understand this continuum of organic existence in relation to technological operators. As the next section will discuss, when the tools we require to understand the world we live in are not understood as precisely that—tools with their own drives, wills, and socially-steeped orders of meaning—it becomes increasingly difficult to distinguish between the world we create and the world we observe. The conversion of nature to media only enhances this problematic.

The Solipsism of Sky Media

To return this discussion back to Litfin's formulation, we understand that

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[62] Brown, 6.

"the drive to gain objective knowledge about the earth" requires the collapse of "actual and felt distances" between un-demarcated subjects and objects. This conundrum of requiring the collapse of distances but being unclear on where that distance precisely exists is reflected in the present and historical engagements with the sky. Moments of engaging the sky reveal the complex ways that the sky is both a phenomenon to be studied, as well as the means of that study. Understood in this way, the history of the sky in the West is doubly the history of the transformation of nature into media. Here we can look to Joseph Vogl's work on the *becoming-media* of Galileo's telescope as a blueprint for understanding what exactly this might mean. While only one example out of many, Vogl's work with Galileo in particular, and Galileo's position in the history of thinking the sky, is of particular relevance to our study. Joseph Vogl describes mediums as that which "make things readable, audible, visible, perceptible".[63] Vogl doubly cautions that media also poses the "tendency to erase themselves and their constitutive sensory function making themselves imperceptible and 'anesthetic'".[64]

These qualities of media can help us to organize the way we understand our Western historiography of skies and clouds. We can see how in the clouds there are entanglements of aesthetics, representation, and epistemology. Vogl's account can also give clues as to how an *instrument* becomes a *media*. Vogl's study frames technical instruments—for Galileo, the telescope—as helping to commune a series of different but coordinating drives from which emerge a discourse on visibility and invisibility. The telescope becomes a medium through which the invisible is made visible, and in so doing legitimates a proposed theory of how it is that *seeing* occurs. The tool is a verification of the experiment: when Galileo is able to draw the shadows of the moon by using his telescope he not only brings to Earth this textured

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[63] Joseph Vogl, "Becoming-Media: Galileo's Telescope," trans. Brian Hanrahan, *Grey Room, Inc.*, New German Media Theory, No. 29, no. Fall, 2007 (n.d.): 16.

[64] Vogl, 16.

surface from a place far, far away, but he also surfaces knowledge about a phenomenon very personally felt but little understood. For Vogl, sky viewing technology becomes media when it allows for phenomena not only to come into visibility but *also* that this visibility becomes a means of self-referentiality as well. The telescope is a kind of media that brings the universe closer to Galileo, its structure melting into the background as it does so, but the telescope also comments on the form and kinds of seeing; in showing the visible it also marks out what remains in the realm of the invisible.

From this perspective we experience a slight disciplinary drift, as our aesthetic question gets put through the scientific ringer. What underlies all of these concerns on the relation of subjects, objects, tools, and observation is a preoccupation with the sources of epistemic authority. Who, and how, does one gain the ability to make a claim to truth? Translated in terms of aesthetics we can shift this question onto the same grounds that art historian Hanneke Grootenboer wrestled on when she attempted to dissect the relationship between *optical truth* and *pictorial deception* in the work of 17th century Dutch still life painters, and what I would here propose is a cognate for the ambivalent patterning that Bryld and Lyyke flag as fundamental to organizing the history of the West's engagement with nature.[65]

As one demonstration of this, Bryld and Lyyke note that the post-WWII interest in extraterrestrial commons was piqued by the belief that "The resources and riches of outer space and the ocean depths … might compensate for the lost terrestrial ones" with little attention paid to the fact that it is unsustainable practices—and not the finite resource themselves—that drive this problem.[66]

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[65] Hanneke Grootenboer, *The Rhetoric of Perspective: Realism and Illusionism in Seventeenth-Century Dutch Still-Life Painting* (Chicago: University of Chicago Press, 2005).

[66] Bryld and Lykke, *Cosmodolphins: Feminist Cultural Studies of Technology, Animals and The Sacred*,

Langmuir cautioned scientists against letting their passion for a subject overwhelm their good sense: to avoid being the kind of men that "perfectly honest, enthusiastic over their work, can so completely fool themselves."[67]

Since it is never clear where the line between subjects and objects is drawn, the transformation of *instrument* to *media* also has the equal effect of transforming phenomena into something to be received by media. In the case of Earth observation or engaging the sky, these phenomena are converted into data to be "seen" by the *media* and attending systems that have been constructed to receive and make sense of them. Karin Knorr Cetina and Klaus Amann's study on the "fixation"— the process by which beliefs are accepted as facts within a scientific community—of visual evidence can here show us how sensory data undergoes this transformation. For Amann and Knorr Cetina (and in a similar sense to Serres) words are the means by which data, and ultimately facts, come into circulation.

John Ruskin's Morality

An early article to come out of Amann and Knorr Cetina's ethnography of a molecular genetics lab grapples with questions of the type of "visually flexible phenomena" that are omnipresent in the natural sciences and the problematic of the embodiment of evidence in sense data.[68] The set-up of Amann and Knorr Cetina's initial problem has here multiple applications. Visually flexible phenomena is the term Amann and Knorr Cetina give to visual objects that appear in the sciences "whose boundaries, extension and identifying details are themselves at stake".[69] Staying with the ashen cloud that hung over London we can see how visual data marks out varying territories to be "projected in overlap" in the treatment of John

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[67] Langmuir, "Pathological Science," 9.

[68] K. Amann and Karin Knorr Cetina, "The Fixation of (Visual) Evidence," *Human Studies* 11, no. 2/3, (1988): 134–35.

[69] Amann and Knorr Cetina, 135.

Ruskin's 1884 lectures *The Storm-Cloud of the Nineteenth Century*.

Ruskin's storm cloud and lectures are often interpreted as warning against the moral and environmental consequences of Industrial and Capitalist expansion. In fact, the lecture has since earned Ruskin the honor and canonization of being the nineteenth century's "best-known piece of … 'environmental' writing by an English author".[70] Ruskin describes this same cloud as a "storm-cloud—or more accurately plague-cloud, for it is not always stormy—… never … seen but by now living, or lately living eyes."[71] He compares this new cloud with the "beneficent rain-cloud" and storm clouds which were "usually charged highly with electricity".[72] These clouds brought equal darkness and gray moods, but they were always followed by a clearing of a rainbow, and imparted the feeling of "affecting the mass of the air with vital agitation … purging it from the impurity of all morbific elements."[73] By contrast, the new cloud brings with it "plague-winds."[74] It is a "wind of darkness" with a "malignant quality of wind … attaching its own bitterness and malice to the worst characters of the proper winds of each quarter"; the wind "blows tremulously" and can blow "without cessation" when not tempered by "healthy weather."[75] It is a wind that "degrades, while it intensifies, ordinary storm."[76]

The reception of Ruskin's lecture in its time was far less complimentary. The mechanization of agriculture that was emblematic of Industrialization was seen ipso facto as the result of natural forces, and these natural forces also extended out to

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[70] Brian J. Day, "The Moral Intuition of Ruskin's 'Storm-Cloud,'" *SEL Studies in English Literature 1500-1900* 45, no. 4 (2005): 917.

[71] John Ruskin and Edward Tyas Cook, *The Storm-Cloud of the Nineteenth Century* (Allen, 1908), http://www.munseys.com/diskfive/ston.pdf.

[72] Ibid.

[73] Ibid.

[74] Ibid.

[75] Ibid.

[76] Ibid.

Figure 6: "Towers of Thun, Switzerland" (1854) by John Ruskin. Part of the Collection of the Guild of St. George, Museums Sheffield.

This watercolor is part of a series of studies Ruskin did in the summer of 1854 for a book on Switzerland that he never finished. Ruskin's interest in the sky is present even here, though in stark contrast to the malignant clouds of London. Ruskin paid paritcular attention to the color of the sky and recorded color variations in his diary which he measured with a self-made device he called a "cyanometer."

include the market that formed around it. Ruskin's tirade railed against this belief in the market as "natural," and thereby also inevitable, logical, and absolute.[77] The effects of such radical criticism were not unnoticed. Critics accused Ruskin of "preferring to '[wrap] himself as it were in the gloom [and play the role of] the Prophet [who] denounced woe upon a wicked and perverse generation'," an

[77] Ibid., 13.

accusation which caused Ruskin to "suffer 'much ridicule' and caused some to question his sanity."[78] In detailing the explicit ills of an unchecked mechanization of Capitalist development, Ruskin's lecture challenged the legacy left behind by the 18th century bifurcation of *nature* from *society*, in which a separated-out *Nature* was governed by physical laws that were also God's laws. This was the reasoning that justified, if not compelled, man's interference into the realms of the natural, physical world, because "since these were considered God's laws, physical interference came to represent the continuation of God's creation."[79]

Here again I want to quote, in full, from the preface of Ruskin's published lectures:

> The following lectures, drawn up under the pressure of more imperative and quite otherwise directed work, contain many passages which stand in need of support, and some, I do not doubt, more or less of correction … But though thus hastily, and to some extent incautiously, thrown into form, the statements in the text are founded on patient and, in all essential particulars, accurately recorded observations of the sky, during fifty years of a life of solitude and leisure; and in all they contain of what may seem to the reader questionable, or astonishing, are guardedly and absolutely true.[80]

Ruskin wagers that the haste in which he's drawn up his lecture must certainly mean he's overlooked some aspect of his new clouds, or overstated the matter altogether, but he says so in the same breath as he announces his observations to be "guardedly and absolutely true." Ruskin is ridiculed for suggesting the unnaturalness of the culture that was being expressly manifested in the sky above him.

How does the poor reception of Ruskin's announcements mix with the fact of the storm cloud, Ruskin's own insecurities and—at the same time—absolute certainty in what he knows to be true? The lessons that Ruskin imparts did not disappear with time but only fomented the nuances of the nascent study of

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[78] Day, "The Moral Intuition of Ruskin's 'Storm-Cloud,'" 919.

[79] Phil Macnaghten and John Urry, *Contested Natures*, Theory, Culture & Society (London ; Thousand Oaks, Calif: SAGE Publications, 1998), 11.

[80] Ruskin and Cook, The Storm-Cloud of the Nineteenth Century, Preface.

landscape and geography. Denis Cosgrove partly attributes the re-enchantment of scholars with Ruskin's environmental thought during the 1940's as being because of precisely Ruskin's *geographic imagination*—an ability to synthesize pleasure, aesthetics and a "scientific study of form" that appealed to new methods in the study of landscape.[81] Ruskin's thought is preserved and presented in literary forms: in the lectures, writings and personal observations that are later revisited—what Amann and Knorr Cetina would refer to as *optical induction.* Optical induction carries visual operations in literary form, coding visual phenomena not as a set of questions and answers but instead as "sequences that include formulations of details… mixed with interpretations."[82] While Amann and Knorr Cetina's study occurs in real time and emphasizes the impact that conversation can have on the formation of study, Ruskin's literary form of investigation puts data and experience from past and present in contact with each other in far more distended ways. For Amann and Knorr Cetina, conversation is mixed in with a kind of epistemological debate where participants use visual markers itself to interrogate images themselves, negotiating, accepting and at times rejecting the proposals being offered. This process has ultimate significance because it grounds the aesthetic and phenomenological experiences of the initiating scientists with the immediate scientific community that will ultimately permit such conversations on *visual data* to cross the threshold of *evidence*—the kind of data "that will be included in scientific texts, only after they have undergone an elaborate process of transformation."[83]

Cosgrove notes that the contemporary treatment of Ruskin's geographical thought is pried from Ruskin's work on "landscape as a subject for art and as a

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[81] Denis E. Cosgrove, "John Ruskin and the Geographical Imagination," *Geographical Review* 69, no. 1 (January 1979): 43, https://doi.org/10.2307/214236.

[82] Amann and Knorr Cetina, "The Fixation of (Visual) Evidence," 148.

[83] Amann and Knorr Cetina, 160.

medium for moral uplift and education."[84] Contemporary geographers look to Ruskin to counteract what Cosgrove calls the "limits of science" and "claims that an aspect of the essence of landscape lies beyond the grasp of scientific method."[85] On the other hand, while Ruskin aimed to understand the landscape around him and the landscape that was being treated by painters such as Turner as embedding certain moral imperatives, Ruskin also recognized that "such an approach would veer into a dangerous idealism without the rigor of scientific observation."[86] Such a method emphasizes that the aesthetic and sensory components of natural science study from this period should not be read as a regression of sciences or Western scientific ideals but instead as a fuller embodiment of what we now presently value. Luke Howard's cloud classification system, the bedrock of so much of our meteorology and climate science, owes itself to precisely this ideal. Mary Jacobus has written that in the early days of cloud study, the sky served as a "poetic workshop" as well as "mobile laboratory for the study of air-borne bodies of water."[87] We know that "Between 1817 and 1822 Goethe wrote a series of poems and studies that honored the work of Luke Howard" [88] and that "Shelley found in clouds a swift-moving image of constancy-in-change – 'I change but I cannot die'".[89] Goethe may have been a formidable intellectual in his time, but he celebrated Howard as "the man who 'distinguished cloud from cloud'" and Howard was "the only Englishman whom Goethe ever addressed as 'Master.'"[90]

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[84] Cosgrove, "John Ruskin and the Geographical Imagination," 59.

[85] Cosgrove, 61.

[86] Cosgrove, 61.

[87] Mary Jacobus, "Cloud Studies: The Visible Invisible," *Gramma: Journal of Theory and Criticism* 14 (2006): 220.

[88] Hubert Damisch, *A Theory of /Cloud/: Toward a History of Painting*, Cultural Memory in the Present (Stanford, Calif: Stanford University Press, 2002), 194.

[89] Jacobus, "Cloud Studies," 220.

[90] Maria Popova, "How the Clouds Got Their Names and How Goethe Popularized Them with His

What this example serves to show is how aesthetic data is already retroactively being appreciated and admitted as more legitimate forms of scientific study and knowledge. What legitimates these forms of investigation, as Amann and Knorr Cetina's study helps us to understand, is not the subjective acuteness of those who observed clouds and sky. Instead it is the craft of writing and documenting that brings these early aesthetic experiences into history as forms of knowledge and knowing. Seeing and feeling become the unique tools by which knowledge is attained, performed and communicated. Far from marking out phenomenological moments of irrelevance they should instead be read as part and parcel of our contemporary scientific method. In particular these moments demonstrate a moment in the history of scientific objectivity specific to the study of the natural world—what Lorraine Daston and Peter Galison have identified as the "curious parallel between self and world governed conceptions of structural objectivity" where on the side of the world all that mattered were *structures*—the way things were made visible—and on the side of the scientific self the only thing mattered was the rational mind that remained once one was purged of all "memories, sensory experience, excellences and shortcomings, individuality tout court".[91] As Daston and Galison tell us, "Structural objectivity did not so much eliminate the self in order to better know the world as remake self and world over in each other's image."[92]

I leave this discussion with one final and brief cloud anecdote. We are often told of John Constable's meticulous cloud studies—each one dated, each one so detailed and precise in their rendering as to become some of the most prized visual comments on the British landscape in landscape art history. In her book <u>For the</u>

Science-Inspired Poems," *Brain Pickings* (blog), July 7, 2015, https://www.brainpickings.org/2015/07/07/the-invention-of-clouds-luke-howard-hamblyn/.

[91] Lorraine Daston and Peter Galison, *Objectivity* (New York: Cambridge, Mass: Zone Books; Distributed by the MIT Press, 2007), 301.

[92] Daston and Galison, 301–2.

Time Being, Annie Dillard writes, "We people possess records, like gravestones, of individual clouds and the dates on which they flourished".[93] Dillard explains the circumstances of one particular painting in which John Constable painted the skies of Brighton during an afternoon where he had brought his sick wife out, believing the air and skies to be curative. Perhaps not unrelatedly, Lorraine Daston tells us that Howard was an "English manufacturing chemist whose hobby interest in meteorology led him to write an essay on the scientific classification of clouds."[94] Howard's classification system helped to bring the clouds into knowing, which was a foundational move for meteorology given that "Driven by the turbulence of high altitude winds and storms, bearing moisture or volcanic dust, clouds—we now know–form part of a global weather-system."[95] While, somewhat inversely to the successes Constable enjoyed, Howard's more scientific theories about these forms were "controversial among other early nineteenth- century naturalists," Daston writes, "the forms themselves spread like wildfire."[96] After reading Howard, many like John Constable "suddenly saw cirrus, cumulus, and stratus clouds where they had only seen white blobs before."[97] In each of these projects we see the particular visual crafting: for Constable, through a persistent science of drafting, spurred at least in part by a sense of care for a sick wife, and for Howard through the verbal whittling down of the playfully artistic into a systematized science inspired by hobby. And for each we see the espousal of a structural objectivity that promoted precisely what Daston and Galison allege: a remaking of the world in each other's

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[93] Annie. Dillard, *For the Time Being* (New York: Vintage eBooks, 2010), http://www.contentreserve.com/TitleInfo.asp?ID={C146A0E2-BD67-4DE7-9DDC-2CF55EC00EB8}&Format=410.

[94] Damisch, *A Theory of /Cloud/*, 194. See also: Luke Howard, *Essay on the Modifications of Clouds*, 1865, http://archive.org/details/essayonmodifica00howagoog.

[95] Jacobus, "Cloud Studies," 220.

[96] Daston, "Cloud Physiognomy," 55.

[97] Daston, 55.

image. To be sure, as Daston tells us, attempts at systematized sky study sought to defy the fact of the "actual sky [as] a Heraclitean spectacle in which everything flowed."[98] As a result, what was pursued was much less art *or* science but instead an instrumentalization of aesthetic crafts that was much less concerned with understanding the sky *per se* than it was coaching humans in a particular, agreed way of seeing the sky. In Daston's parting words on this period:

> Standardization is generally applied to things: identical manufactured goods, identical scientific instruments, identical measuring units. But it is also an achievement of persons joined in a collective. It is a prerequisite for a shared world—especially when the world in question is admitted even by cloud classifiers to be continually on the verge of chaos, and each chaos as different from the other as human faces—or as clouds.[99]

Pathological Science, Bad Feels, and How to Know

Having reviewed the topological relationship between contexts, subjects and objects in the historical engagement of the sky in the first section, and now the means by which aesthetic data in its multiple forms—personal experience, visual observation, moral intuition—is transformed into evidence, I now turn to the question of aesthetics that pervades these moments. For this I return to the pathological science of Langmuir and the patterning of Bryld and Lykke that we started with at the top of this chapter. I want to propose that the source of this ambivalence—however we should so choose to call it, this propulsion that allows perfectly honest men to fool themselves—emerges from the particular ways that working with visual forms of knowledge run into complication when confronted with more formalized forms of knowledge making. Much of the history of the Western culture's engagement with skies and clouds was motivated by the desire to bring some aerial or celestial phenomena into knowing. However, given the distance and means by which the empirical study of these phenomena were to be accessed,

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[98] Daston, 67.

[99] Daston, 67.

representation and sensory tools and faculties had to play a leading role. This is in addition to the cultural imperatives at varying points in this history which are often attributed to the Western move towards early modern capitalism and Francis Bacon's strong rhetoric advocating "extracting nature's secrets from 'her' bosom through science and technology."[100]

In this way pathological science becomes not some psychologized, individual trapping as Langmuir's speech might suggest—it is not a thing that happens in such a way as to expose one's weaker mind. It's instead the way that visual phenomena can over and under-whelm the senses. Here the prominent history of observation is shared between artist and scientists alike. Inasmuch tools of representation and access become all the more important for accessing phenomena. At the same time, we can look at these moments to see when tools are misused and overused. At the moment when our human senses fall short it is the tools and media that are called upon to make up for the shortcoming. These moment of aesthetic short-circuiting

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[100] Carolyn Merchant, "The Scientific Revolution and *The Death of Nature*," *Isis* 97, no. 3 (September 2006): 515, https://doi.org/10.1086/508090. I am quoting Bacon from this text with the full awareness that Merchant's reading of Bacon's rhetoric has been the source of much debate and alienation between her and FOBs (*friends of Bacon*, as those sympathetic to Merchant's feminist reading have called them). It is my personal opinion that Merchant very persuasively makes the case for reading Bacon in this way in her book The Death of Nature. Merchant's account makes clear that the code of conduct both approved and advanced by Bacon and his contemporaries was predicated on brute exploitation. She writes that mechanical technology in combination with the scientific method gave way to a "new system of investigation" that was described as helping "us to think about the secrets still locked in nature's bosom." It is clear that such inventions were the necessity of wanting to transgress a firm and non-compliant boundary. Troubling still is the alliance between these inventions and the witch trials: an apt arena for applying the power over nature that mechanics enabled, and which also granted the power of "uniting or disuniting … natural bodies." Merchant makes it perfectly clear: "The interrogation of witches as symbol for the interrogation of nature, the courtroom as model for its inquisition, and torture through mechanical devices as a tool for the subjugation of disorder were fundamental to the scientific method as power. For Bacon, as for Harvey, sexual politics helped to structure the nature of the empirical method that would produce a new form of knowledge and a new ideology of objectivity seemingly devoid of cultural and political assumptions." Carolyn Merchant, *The Death of Nature: Women, Ecology, and the Scientific Revolution* (New York: Harper & Row, 1989), 172. For another damning perspective on the debate between Merchant and the FOBs, see: Katharine Park, "Women, Gender, and Utopia: *The Death of Nature* and the Historiography of Early Modern Science," *Isis* 97, no. 3 (September 2006): 487–95, https://doi.org/10.1086/508078.

Figure 7: Two examples of Constable's cloud studies. Left, "Cloud Study" and right, "A Cloud Study, Sunset." Both circa 1821.

foreground the meeting of knowledge that is polymorphic and overwhelmingly aesthetic with formalizable formats and processes of knowledge making, and the various contours such encounters produce.

We can see evidence for this in the ways that scientific study of the skies was undertaken by artists. Constable's numerous cloud studies, done in the years of 1819 through to 1822 (see figure 7 for two examples), were done in meticulous and scrupulous attention to detail, enabling him to "make the skies of his finished pictures serve… as 'the "key note," the standard of "Scale," and the chief "Organ of sentiment".'"[101] The painter would include notes on the weather conditions on the backs of his cloud paintings while waiting for them to dry. Clouds are a dualistic way that science and rationality is sneaked into the history of images and art. The

[101] Paul D. Schweizer, "John Constable, Rainbow Science, and English Color Theory," *The Art Bulletin* 64, no. 3 (September 1982): 420, https://doi.org/10.2307/3050245. There is a good deal of overlap in the history of the cloud—especially with its empirical study—and the history of the rainbow. This article covers some of that through an art historical account of Constable's *Salisbury Cathedral from the Meadows*, touching on the influences of Aristotle and Howard to support a reading of the rainbow as impossible, and thus embedding the shared concern of Constable and Archdeacon John Fisher over the "fate of the Anglican Church Establishment, which they mistakenly feared was threatened by the Reform Movement then sweeping over England."

study of clouds has led to a range of paintings being deciphered according to their abilities to predict weather, a proclamation that is subsequently foisted on the cultures that begat them.[102] Even Vincent van Gogh is found to have recorded changing weather patterns; his clouds, though not painted in any scientific detail, are still illustrative of certain meteorological facts, such as the poor air quality in Paris during Industrialization and the painters' trademark stylistic distortion actually "reveal with a perspicacity exceptional in Western art how clouds mark the air's flow pattern."[103] It was as though the marshaling of this branch of art historical study is an attempt at inclusion or self-legitimation; to save the discipline we must first prove its fruits as a rational science. Instead what is taking shape here then, we can see, is this longing to make rigid what is ephemeral. Constable's biographer noted that for the painter the "environment formed … 'a history of his affections'".[104] Yet there can be no history of the pulses of affections, fortuitous as they are; the cloud studies seen in this perspective are a vain attempt at order, and it is not coincidence either that "the most detailed study of Constable's cloud-studies is by a meteorologist, John Thornes."[105]

The question of the aesthetic that is formed out of this entangled meeting of art, science, and experience is ambiguous. In one respect, both Constable and van Gogh represent some of the highest achievements in the history of art, and both of their work comes out of the kinds of practices that have taken root in the ambiguous study and relationship of sky to developing modern science. I want to leave this section with the suggestion that the disciplinary foibles that surface in our examples here—the pathological science, the search for a way out of strong affectations

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[102] Stanley David Gedzelman, "Weather Forecasts in Art," *Leonardo* 24, no. 4 (1991): 441, https://doi.org/10.2307/1575522.

[103] Stanley David Gedzelman, "The Meteorological Odyssey of Vincent van Gogh," *Leonardo* 23, no. 1 (1990): 120, https://doi.org/10.2307/1578474.

[104] Jacobus, "Cloud Studies," 220.

[105] Jacobus, 220.

through systematized (and "unsuccessful?") study applied towards the arts—are not the ineffective fruits of labor. Rather, they constitute an aesthetic in themselves. The sickly body that requires a curative air, the scientist slightly deluded with inordinate self-belief and a shaky hypothesis, the plagued artist with a preoccupation for study (but who then promptly abandons their study to create something else)—these episodes pulsate in the history and establishment of a study of skies and clouds. They are installed alongside the successes that Western narratives of clouds and sky do not choose to celebrate, and we can see them in their full richness when we begin to broaden our disciplinary scopes to ask what precisely it means to study sky, in all its myriad forms and instantiations. As Daston notes at the close of her analysis of the *International Cloud Atlas*: "Perhaps in a gesture of humility, perhaps of hubris, the most recent edition of the International Cloud Atlas has confronted the specter of too many faces of the heavens face-on, with a name of its own: the 'Chaotic Sky'."[106]

Many Skies, Many Knowings

In this chapter we have re-read select moments in the history of Western engagement of the clouds and the sky as indicative of the kinds of challenges that arise out of the formalize study of natural phenomena. The relationship between tool, human, organic phenomena prefigures the ways in which we today rely on similar methods of collaboration and coordination between humans, ecology and the digital technologies. Looking at the clouds and the sky has always required a kind of invention and creativity; making claims about the properties of the sky only intensifies this. We can read this communing as a class of what Matthew Fuller has described as *media ecology*. Media ecologies emphasize that "All objects have a

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[106] Daston, "Cloud Physiognomy," 67.

poetics; they make the world and take part in it, and at the same time, synthesize, block, or make possible other worlds."[107] This communing embodies the ways that media ecologies, as Matthew Fuller conceives of it, demonstrate the Nietzschean *will to power*: a force that "moves things across thresholds but cannot be defined by the states exemplified on either side of that threshold", and how just such a force can join and pass through bodies (of all material and makeup) to "interweave to produce the apparatus"; that even just in its coming to form—in the will to power moving propelling it to just such a transitory state—we create a foundation for the formation of a knowledge—knowledge that takes place in bodies, and that knowledge, in itself, is a type of body—an apparatus body—that seeks, hungers, drives, and roves to fulfill its purpose as "an apparatus for abstraction and simplification— directed not at knowledge but at taking possession of things."[108]

The notion of an apparatus that takes possession of things rather than apprehending them for knowledge is a useful framing for further considerations of how the sky is treated in light of digital media, earth observation and sensing technologies. We will begin to explore this in the next chapter as we shift our focus to zoom in to a particular case study of present-day engagements with sky and technology. This chapter will highlight the way the themes in this genealogy have become amplified over time. In particular we will explore how digital media in particular embodies some of the questions of vision, systems of study, and the formalization of aesthetic data into evidence and information, and how digital media is particularly good at confusing the boundaries of bodies in an overall drive to take possession of things.

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[107] Matthew Fuller, *Media Ecologies: Materialist Energies in Art and Technoculture*, Leonardo (Cambridge, Mass: MIT Press, 2005), 1.

[108] Fuller, 63–64. Here Fuller is quoting from Nietzsche's *The Will to Power*.

Chapter Two: Pixels

Introduction

This chapter builds on the points made in the last chapter, but with an opposite perspective. Having proposed a Western genealogy outlining the moves by which the sky has transformed into media, this chapter works through the problems of just such a relation. The sky is an ill-fitting and imperfect media, and when we engage it *only as* media we are only ever met with the unnaturalness of such a pairing. Media in these instances is understood in a particular way, as both the underlying structure that helps bring phenomena into visibility while at the same time itself becoming an "invisible" structure of such knowledge (as if the phenomena might have suddenly floated into our consciousness). Natural phenomena enter into media as a visual format of data. These moments play out the encounter between polymorphic forms of information and formalized structures of receiving, unpacking, and disseminating that information. The sky as an "objective" media communes with human aspirations towards a "knowledge that bears no trace of the knower—knowledge unmarked by prejudice or skill, fantasy or judgment, wishing or striving." [109]

We begin with a case study on the 2013 creation of Google Earth's cloud-free image of planet Earth's topography—an astoundingly accurate work of complete fabrication. This image forms the baseline for many Google's other products and supports the technology heavily relied upon by policy makers monitoring changes to our global systems. These conditions make the issue of the cloud-free Google Earth image all the more pressing and, more specifically, call up the need for deeper and more critical engagements with the mediatic structures of the digital image. I suggest in this chapter that the effacement of these digital image structures are naturalized by what was explored in the previous chapter—the overwhelming cultural belief that the sky and the clouds are a medium, a channel: always revealing phenomena while simultaneously receding into invisibility.

Google is a near unavoidable entity these days, but its presence and impact

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[109] Daston and Galison, *Objectivity*, 17.

on geography and cartography are well worth noting. The development of the Google Earth engine, as we will see, was billed as a way to do better *science.* Yet, as a virtual globe technology and an archive of geospatial data and satellite images, there are few options as accessible, exhaustive, and comprehensive as those (indirectly) offered by Google's platforms, such as Google Maps and Google Earth. Google's computational power has empowered an unprecedented command and control over geographic information, which is both inspiring and a point of contention. For political theorists, critical geographers, and media scholars, Google's platforms provide tools to be applied towards humanitarian and geopolitical issues.[110] On the other hand, and particularly in the field of critical studies of geospatial technologies, there is question about the visuality of these technologies and services, and how they might serve as techniques of a new politiking. Sympathetic images gathered from around the world can at once garner support and activate sympathy at the same time as they might absolve individuals of their responsibility to move to action.[111] An additional layer of complexity emerges at the intersections of Google platforms and literacy of satellite imagery. Understanding satellites as technologies that were born of political potency and geopolitical tension is argued as imperative to understanding the pressures that satellite images are wont to silently exert.[112] Similarly, the combination of satellite images and Google platforms as a packaged presentation and point of view onto political crises is critiqued not because of its complete

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[110] Noel Gorelick, "Google Earth Engine," (2013), https://projects.listic.univ-smb.fr/seminaires/EarthEngine_LISTIC.21062016.pdf.

[111] See: Yusoff, "Biopolitical Economies and the Political Aesthetics of Climate Change"; L. Gurevitch, "Google Warming: Google Earth as Eco-Machinima," *Convergence: The International Journal of Research into New Media Technologies* 20, no. 1 (February 1, 2014): 85–107, https://doi.org/10.1177/1354856513516266; Leon Gurevitch, "The Digital Globe as Climatic Coming Attraction: From Theatrical Release to Theatre of War," *Canadian Journal of Communication* 38, no. 3 (September 14, 2013), http://cjc-online.ca/index.php/journal/article/view/2731.

[112] See, for example: Elizabeth DeLoughrey, "Satellite Planetarity and the Ends of the Earth," *Public Culture* 26, no. 2 (2014): 257–80, https://doi.org/10.1215/08992363-2392057.

inutility but rather for the ways in which the expectation of visuality alone falls short of political production.[113] Such a way of thinking makes use of strands in geography that consider the impact of global visualization practices, and how they might pressurize or animate certain qualities of the human experience or human culture.[114]

Visual presentation is a strong point of engagement in the critical literature on networked GIS systems and virtual globe and cartographic platforms. Lev Manovich is among the scholars who has situated GIS and virtual globe visualizing techniques in a geneaology of early diagrammatic representations that extend to the evolution of Renaissance perspective and spherical drawings.[115] He argues, along with Leon Gurevitch, that these figurations of the earth drew on techniques of visual nominalism[116] and that the use of these structuring geometric schemata have inflected the production and formation of earth images from as early as the Copernican image of the earth—an image of the earth as being all-knowable—to as recently as the virtual re-creations of the earth, where space and time are collapsed and made to serve the regime of a scopic "I". As these authors and Denis Cosgrove all suggest, it is the practice of creating the earth for cultural viewing that is just as vital to the construction of its meaning as its more scientific imaging has been credited for the validation of these theorems.[117]

I pick up where this way of thinking—at the matrix of seeing, thinking, and

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[113] See, for example: Lisa Parks, "Digging into Google Earth: An Analysis of 'Crisis in Darfur,'" *Geoforum* 40, no. 4 (2009): 535–545.

[114] See: Denis Cosgrove, *Apollo's Eye: A Cartographic Genealogy of the Earth in the Western Imagination* (JHU Press, 2001); Denis E. Cosgrove, *Geography and Vision: Seeing, Imagining and Representing the World*, International Library of Human Geography, v. 12 (London ; New York : New York: I.B. Tauris ; In the United States of America and Canada distributed by Palgrave Macmillan, 2008); Tim Ingold, *Being Alive: Essays on Movement, Knowledge and Description* (London ; New York: Routledge, 2011).

[115] Lev Manovich, "The Mapping of Space: Perspective, Radar, and 3-D Computer Graphics," *Manovich. Net*, 1993, http://manovich.net/content/04-projects/003-article-1993/01-article-1993.pdf.

[116] Nominalism is the representation of three-dimensional objects in two-dimensional planes. See: Gurevitch, "Google Warming."

[117] Cosgrove, *Apollo's Eye*.

representation—in many ways leaves off. I explore the the less emphasized processes of contemporary image manipulation that produce the presentations with which all these authors are engaged. The focus of this chapter will be both on the politics of the earth image that is presented in platforms like Google Earth and in satellite imagery and also on *how* that image got to look the way that it does. The image pipeline from geospatial data archive or satellite onto a personal monitor or display screen is never one-to-one. Instead, these images are the craft of a certain kind of visuality; they model an assemblage of gazes that reflect multiple investments in the forms of knowledge that are created and made accessible, as well as blocking those that are less desirable.

To begin to unravel these politics we begin with a single case study: a cloud-free image of the Earth created by the Google Earth Engine team. The Google Earth Engine powers cartographic technologies such as Google Maps and Google Earth. As insights from my interview with Matt Hancher, Tech Lead for the Google Earth Engine, will show, the story of this image's creation is revelatory about our ecological epistemology and the formats to which ecological knowledge comes to us. Central to cloud-free Google Earth image and these formats of ecological knowledge is the pixel as an irreducible unit of information and aesthetics. The pixel in the cloud-free Google Earth image converges both the physical and the symbolic; energy and matter; nature and culture. It acts as a bridge which simultaneously puts scientists in contact with a data archive and geographers in view of the most accurate topographical vista of the entire globe that exists. At the same time, the pixel is also a dividing line, separating out usable information from that which is discardered as merely stylistic. Seen in this way, Google Earth becomes less of a platform for cartography and more of a high-level infrastructure for the management and gatekeeping of forms of knowledge.

The cloud-free Google Earth image exists between multiple *worlds*, and the meaning of the singular pixel is contingent to each. In one *world,* the cloud-free

Google Earth image is the result of a photo manipulation procedure that is routine in many epistemic cultures, but that has the effect of that producing scientifically null results. In another *world,* this same image is the most accurate view on to the Earth topography available today, and though while it is inadmissible for geographic study, it makes for an ideal corporate product. In all of these *worlds*, the pixel is the single most determining element of the whole image, and for this reason, a critical site of engagment and visual culture analysis.

The cloud-free Google Earth image is thus a concise way to evaluate how so many contradicting and simultaneous *worlds* and orders of knowledge can coexist across pixels. Equally, the many *worlds* of the cloud-free Google Earth image are metonymic of the multivalence of satellite images, and the way it is activated and deactivated in epistemic cultures. In particular, the means by which the cloud-free Google Earth image was created emphasize the centrality of pixels in digital articulations of Earth and space and deemphasize the ontology of *the image* as a boundary of ecological knowledge. In terms of the information they contain, digital images of Earth and space are more accurately addressed at the level of the pixel, while the notion of the *image* can, in some contexts, hinder epistemic engagement. However, in other contexts, the ontology of the image emerges from work with satellite pixels in invisible formats, rich with information about our planetary conditions. For these reasons we will see how it is more theoretically useful to apply Lugones's sense of *worlds,* as an aesthetic ordering that has the capacity to initiate beliefs and ethical engagements, to digital images of Earth and space rather than think of them in their more colloquial connotations: static, inert, and purely visual. With this reorganization of the image around *pixels* and *worlds*, a theme that will also indirectly be addressed is the usefulness of these gridded structures of knowledge, such as the database or the pixelated image, when discussing the politics of planetary epistemology.

The *worlds* that emerge through pixels collected from satellite imaging show

how the Earth can be activated in ways that are contradictory—true and impossible, accurate and fictional, present and future—and informative. In this way we will also be using the cloud-free Google Earth image as a way of not only understanding satellite pixels are moving across *worlds* but also as having the capacity to constitute worlds in themselves. In this way we can begin to see how computation functions as a procedure of worldmaking.

Prelude to a Pixel

Pixels are the smallest unit of a digital, pixel-based image or graphic. They are small squares of illumination, gathered together on our digital display screens in alarming numbers, producing images of astouding clarity. Pixels are, in no uncertain terms, foundational to graphic work with computers. They are foundational to the functioning of computers, and to making possible the conditions of relation that run from and through computers and humans. Pixels help humans exert a degree of control over our immediate reality. Through photo and video manipulation pixels can amplify what is available to be seen. Pixels can also occlude what is undesirable. Pixels can melt away into a seamless picture or produce the jagged edges of an improper resolution. Hito Steyerl tells us that one should make themselves smaller than a pixel to escape state surveillance,[118] and that the wrong organization of pixels can secretly signal the presence of an "anonymous global networks" that is generative of a "shared history."[119] Pixels, in short, contain multitudes of meaning.

More than ever, humans are accessing their physical surroundings with the aid of digital and networked technologies, foregrounding pixels as the pathway between humans and their habitat. Through images like *Earth Rise*, *Blue Marble*, and the *Solar System Family Portrait,* the second half of the 21st century has been

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118 Hito Steyerl, *How Not to Be Seen: A Fucking Didactic Educational.MOV File*, 2013, single screen 1080p .mov file, 14 min., 2013.

119 Hito Steyerl, "In Defense of the Poor Image," *E-Flux Journal* 10, no. 11 (2009): 1–9.

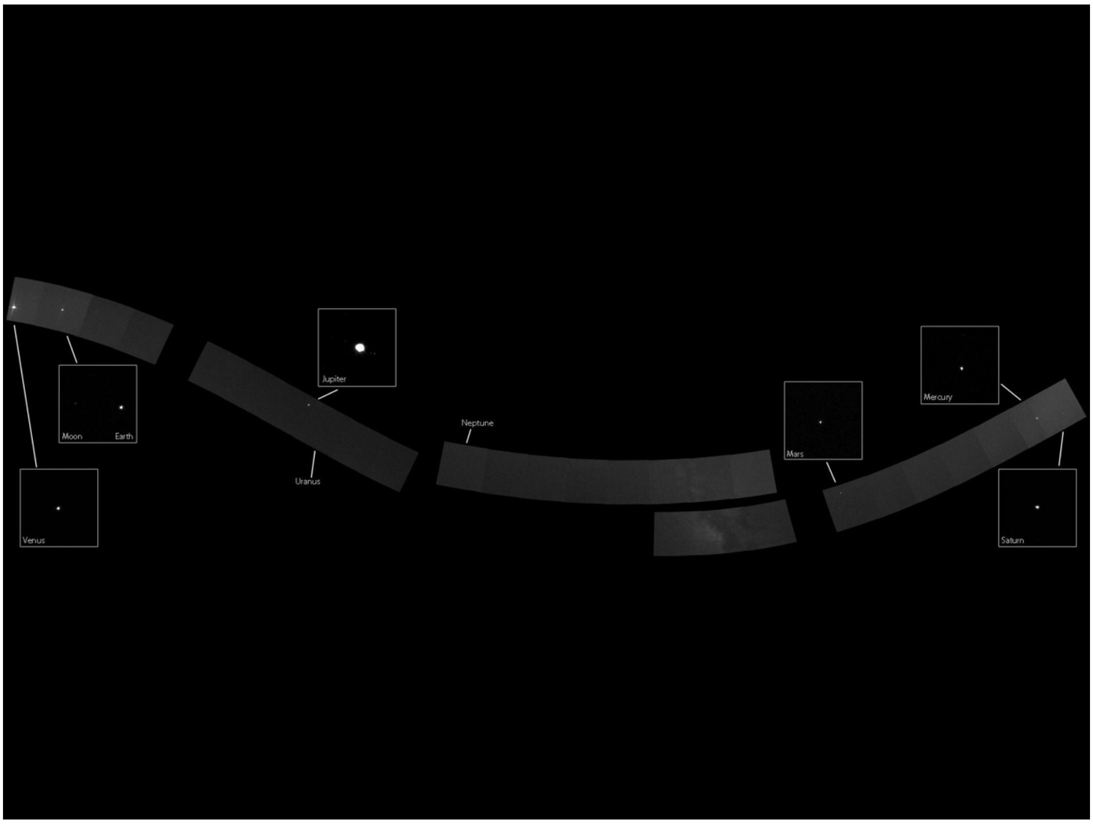

Figure 8: Family Portrait of the Solar System taken by Voyager 1.

marked by the desire to reconcile feelings of interpersonal alienation with the vastness of human experience by grounding ourselves in a sense of planetary one-ness. In the *Solar System Family Portrait* image (figure 8), the Earth is contained in a single pixel.[120] This pixel might be "the only single pixel with a name" and the only

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[120] This image is likely more recognized as *Pale Blue Dot*, popularized by Carl Sagan and, later on, by Al Gore in the film *An Inconvenient Truth*. *Pale Blue Dot* is actually one of 60 frames composed from recordings of light made in the 90's by NASA's Voyager 1 as part of the Solar System Family Portrait program. The intention of the program was to get an image of the earth in its complete solar environs for the first time using a space probe on its exit out of our solar system. Unfortunately, the whole thing ended up being a pop culture flop. The sun was too bright, making the images either too illuminated or too dark to see the planets, and as a result, the *Solar System Family Portrait* images were largely ignored. They were later popularized by Carl Sagan, as discussed above. Chris Russill, "Earth Imaging: Photograph, Pixel, Program," in *Ecomedia: Key Issues*, ed. Stephen Rust, Salma Monani, and Sean Cubitt, Key Issues in Environment and Sustainability (London ; New York: Earthscan/Routledge, 2016), 228–29.

single pixel to appear in a movie. In his film *An Inconvenient Truth*, Al Gore described this pixel as "'us,' as 'our only home,' and as the site of all human significance: 'all of human history has happened on that pixel'."[121] Carl Sagan said that this single pixel contained a revelation: "It illustrated the obscurity of our world from a cosmological perspective and instantiated a principle known since ancient antiquity: the Earth was a mere point in a vast encompassing Cosmos, but no one had ever seen it as such."[122]

The technologies that help humans to access their physical surroundings have also fundamentally impacted on what can be considered one's surroundings. The surface of the Earth has been repetitively shrunk into gridded, ordered points that can be converted into binary data for computation. These same procedures that have whittled an entire planetary terrain into 1s and 0s have also simultaneously expanded the human visual field, and exponentially so. Humans can be in instant visual contact with a range of distances and depths, from a hyper-local neighborhood to galaxies light years away, and with options for remarkable detail. Remarkably, this embarrassment of visual riches continues to grow with fewer, or miniaturized, hardware. Humans are seeing more with less: less hardware, less effort, less energy.

This all raises the issue of how aesthetics has the capacity to impact physical space: to grow or raze; to represent or visualize; to clarify or reorganize. As more of the cosmos becomes accessible to human viewers by procedures that miniaturize our *oikos*, the one constant is the digital technologies that undergird them. These digital technologies function not solely as supplements to the human eye but often outright replace them. Instead, the pixel becomes the eyes by which phenomena are made visible. From this perspective, human actors are surpassed by digital images in their capacity to impact on the geological life of the Earth. We can see this effect in the

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[121] Russill, 228–29.

[122] Russill, 228–29.

way images become visibly inscribed onto the topography of the earth, and how the authority of the image continually manifests itself at the borders of policy and climate research.

One format for these pixels comes to us in satellite images. While humans are increasingly accessing their surroundings by technical means it is perhaps the satellite and the images it produces that is the most prevalent of all these tools. Satellites are constantly photographing the Earth and their images have largely been made accessible to the general public. The applications for satellite images span civilian, epistemic and military domains. In this way, satellite images are a category of digital image at the nexus of a number of forms of knowing and structures of knowledge.[123] As we will soon see, it is the unique way that satellite images play a role across disciplines that emphasizes the importance of pixels on yet another front. Other qualities that signal the pixel's importance in satellite images is how pixels are guarded from outside observation; debated internally; dated, edited, ranked and scored. Satellite pixels constitute the smallest, and most fundamental, rungs of a knowledge infrastructure that generates our most crucial ecological data. Such a point underscores that satellite images cannot simply be regarded as images but instead also function as databases, with each individual pixel acting as its own archive of information, and indexical to a physical and real-time place.

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[123] It might also be interesting to note that this nexus is not emergent with the new technology of satellites, but instead we might read it as the outgrowth of that older colonial technology of capital and governance: the ship. Elizabeth DeLoughrey writes: "Of course, modern ways of imagining the earth as a totality, including those spaces claimed for militarism and globalization, derive from colonial histories of spatial enclosure. Denis Cosgrove (2001: 220) points to the Enlightenment era's encirclement of the globe through Cook's circumnavigation of the seas, which allowed for colonial claims to expand to a planetary scale." The satellite shares in the Colonial ships movement of global circumvention, as well as in satellite imaging too has bolstered Western claims planetary-scale expansion. Given this and the preceding paragraphs, we can also see further evidence in support of the claim that visualizing the Earth has notable and proportional influence on the cultural values from which it derives, and which can be continued through Earth imaging—particularly as it is falsely presented as "representation." See: DeLoughrey, "Satellite Planetarity and the Ends of the Earth," 261.

"Only clear skies on Google Maps and Earth"

On June 26, 2013, Matt Hancher wrote a blogpost titled, *Only clear skies on Google Maps and Earth*.[124] With palpable pride, Hancher announced, "To celebrate the sunny days of summer … we're unveiling new satellite imagery for all Google mapping products today. This stunning new imagery of the earth from space virtually eliminates clouds … and offers a more comprehensive and accurate view of the texture of our planet's landscape."[125] The grand arrival Hancher was announcing was for a picture of the entire globe, assembled from an archive of forty years of

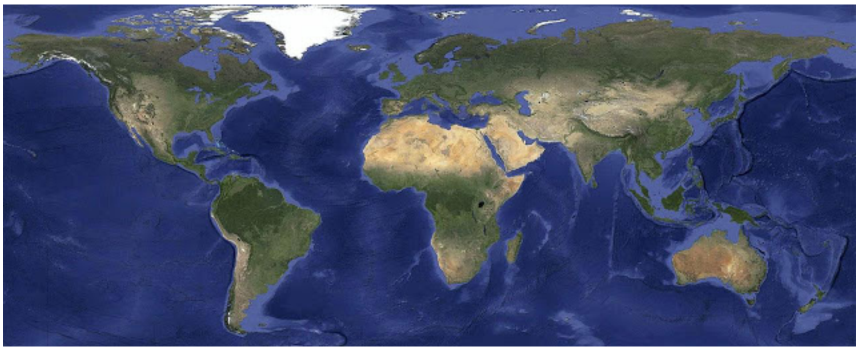

Figure 9: A cloud-free planet Earth.

satellite images, which showed the Earth as it would appear on a cloudless, Spring day, with all the globe experiencing daylight. This image joins the other famous whole Earth images in illustrating key ways that our human culture rationalizes a relationship between ourselves and our environment through the aesthetic uses of media.

The cloud-free Google Earth image is significant for a number of reasons. For one, for Google as a cartographic service, cloud cover posed two competing ideals about the types of images that Google's software could make use of. On the

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[124] Matt Hancher, "Only Clear Skies on Google Maps and Earth," Google Maps, June 26, 2013, https://maps.googleblog.com/2013/06/only-clear-skies-on-google-maps-and.html.

[125] Hancher, "Only Clear Skies on Google Maps and Earth."

one hand, the scenes on Google Earth were of the highest accuracy and realism possible because they were drawn directly from LandSat image archives. However, cloud cover is a well-known problem in geospatial digital images.[126] Geospatial digital images try to image a set point on the surface of the earth, and with a camera positioned high in the atmosphere, clouds can potentially block the view of the ground below. This is a particular problem for certain parts of the world such as the tropics, because clouds are a permanent fixture in that climate. In the tropics, clouds do not disappear; they only move. Another problem is that both cloud cover and clean ice look the same in RGB, so this again can morph how you see, or what you interpret as, the ground below. No matter how realistic or authentic, if Google could not fulfill the ideals it set for its users to *explore the globe with a swipe of the finger* then their service would be null.

Yet perhaps even more important than the cloud-free image is the process itself by which the image was created. The task of removing clouds from satellite photos is a tedious task; it cannot work as a simple one-to-one, edit-and-replace project because there are so many other multiple variable influences on the appearance of clouds. Clouds move, clouds are polymorphously shaped, they have different densities; cloud brightness and cloud shadow can throw off other measurements such as atmospheric corrections, not to mention the angle at which the images are taken can affect cloud presentation, and so on.[127] Instead, making the cloud-free Google Earth image was a multi-part task, performed pixel by pixel. To begin the process, the Earth Engine team worked with aggregate of images and topographical data pertaining to the Earth collected from LandSat satellites, USGS

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[126] Din-Chang Tseng and Chun-Liang Chien, "A Cloud Removal Approach for Aerial Image Visualization," International Journal of Innovative Computing, Information and Control 9, no. 6 (June 2013): 2421.

[127] Zhe Zhu and Curtis E. Woodcock, "Object-Based Cloud and Cloud Shadow Detection in Landsat Imagery," *Remote Sensing of Environment* 118 (March 2012): 3, https://doi.org/10.1016/j.rse.2011.10.028.

data reserves and other various geospatial data archives. From these stores of data and images, Google segmented the earth into workable, geographic regions. Within each region, areas of *cloudiness* were identified according to the RGB color of each pixel. Simply put, Google isolated the regional images' white pixels.

For pixels that were white and determined to be definitively related to cloud cover, or "cloud-defective," as Hancher called it, servers mined the collected LandSat archive of images—what they called the "time series"—to find a pixel in that exact same spot that was not cloud-defective. The time series refers exclusively to pixels in one geographic region but gets its "depth" from the fact that every forty meters squared of the earth is photographed biweekly for as long as a satellite is up and functioning.[128] The cloud-defective pixel was then replaced with a non-cloud defective pixel. When the cloud-defective pixel was replaced by another pixel the geographic position was the same, but temporally the pixel was completely brand new.

For pixels that were white but not obviously cloud defective, servers cross referenced the pixel with the other spectral bands on the satellite and ratios to make a determination. White pixels can be ambiguous in their significance, meaning that cloud cover in satellite imaging can be tricky to distinguish from other elements in a geospatial digital image. As Hancher explains it, "Clean ice and fresh clouds both look white in red, green, and blue, but there's a distinction in some of the infrared bands. So, what we have is sort of a heuristic. It's just looking at how bright the pixel is in these different bands, looking at some of the ratios … between those bands, to try to assess or really just *score* the pixel."[129] He adds, "It's not really a

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[128] LandSat satellites have a spatial resolution of thirty meters per pixel, depending on the generation of satellite. With the Earth's precession, each single photographed spot on the earth was photographed once every two weeks. This information was important for Hancher and his team in order to make sure that every area of the globe was represented and/or accurately re-stitched into the resulting image.

[129] Matt Hancher, Interview: Removing Clouds from Google Earth, interview by Nicole Sansone,

likelihood measure, it's just sort of a *cloudiness* measure."[130] White pixels determined cloud-defective were replaced; white pixels determined not cloud-defective remained.

Once all cloud-defective pixels were identified and replaced, the earth image underwent a further filtering/editing process to ensure that all the pixels were Springtime, daylight pixels. The completed image then stitched together all of the working regions to make a complete world view, resulting in an 800,000 megapixel seamless image.[131]

Seeing the Cloud through the Forest

To understand the significance of this image we need to first take a step back and understand the context in which the image was created. Matt Hancher is a former NASA scientist and the co-founder of the Google Earth engine, a Google Labs product officially announced in 2010 at the International Climate Change Conference in Cancún, Mexico.[132] The Google Earth Engine was launched as a "new technology platform that puts an unprecedented amount of satellite imagery

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Interview via Google Hangout, April 14, 2016.

[130] Ibid.

[131] Curiously, despite performing the unprecedented task of synthesizing forty years of geospatial imaging and data into one, 800,000 megapixel seamless image, using server power that only Google could muster up at that time, the algorithm that Google used to produce such an image was never published. Instead, when I spoke with Hancher he was very happy to point me in the direction of the published papers that other "scientists who use the platform have used for various other kinds of mapping." Hancher explained that while Google never published the cloud-sorting algorithm that it was structurally very similar to the algorithms other scientists "who use the platform have used for various other kinds of mapping," such as for deforestation research. I followed up on the deforestation papers Hancher mentioned, and from the best of my knowledge and what I could tell these processes were very similar. The competitive advantage that Google might have had—and, to my mind, a reason for publishing the algorithm—could have been that Google did this cloud sorting on such a large, global scale, and that they had the end result of such a huge and seamless image which was basically stitched together piece by piece.

[132] "Introducing Google Earth Engine," accessed November 8, 2018, http://blog.google.org/2010/12/introducing-google-earth-engine.html.

and data—current and historical—online for the first time."[133] In a blog post about a prototype made the year prior, Google.org engineering manager and environmental manager Rebecca Moore and Dr. Amy Luers talk about the problem of monitoring deforestation as a metaphor for the virtues of the Google Earth engine. They describe how satellite images containing valuable information about our globe from the past, present, and future exist everywhere but lament that "while today you can *view* deforestation in Google Earth, until now there hasn't been a way to *measure* it."[134] Moore and Luers cleverly title their post *Seeing the Forest through the Cloud* as a way to legibly communicate how Google Earth Engine will enable "global-scale monitoring" as a tool for measuring and analyzing "changes in the earth's environment."[135] Such fuzzy wording and clever packaging allows Luers and Moore to earnestly discuss such wide-scale surveillance without sounding any alarms; they finish off their introduction writing, "The platform will enable scientists to use our extensive computing infrastructure—the Google 'cloud'—to analyze this imagery. "[136]

Figure 10: Forest cover and water map of Mexico.

To be sure, the Google Earth Engine was launched from Google's more philanthropic division, Google.org, and focused most of its earliest work on solving problems of global deforestation. The blog details the early projects of the Google Earth engine working with state institutions and non-profit organizations like Mexico's National

133 "Introducing Google Earth Engine."

134 "Introducing Google Earth Engine."

135 "Introducing Google Earth Engine."

136 "Introducing Google Earth Engine."

Forestry Commission (CONAFOR), the Carnegie Institution for Science and Imazon, a Brazilian "non-profit research institution classified as a Civil Society Public Interest Organization (OSCIP), whose mission is to promote sustainable development in the Amazon through studies, support for public policy formulation, broad dissemination of information and capacity building."[137] The Google Earth engine team also published a number of professional papers on their early work with issues of deforestation, and the blog highlights a collaboration with Matt Hansen and CONAFOR to create a forest cover and water map of Mexico that was "the finest-scale map produced of Mexico to date" and required "15,000 hours of computation" to complete (see figure above).[138]

Yet there is discord in the ways that Google talks about the project of combating deforestation and the Google Earth engine. While Google, Google.org, and Google professionals all discursively position themselves as mobilizing technology to support science in "doing good," the Google Earth Engine itself seems to frame the project in an entirely different way. The Google Earth Engine's early work with deforestation helps to corroborate this ideal by promoting itself as a platform that acts in the interest of civic goods, with an environmental framing. In a 2013 presentation, Earth Engine co-founder Noel Gorelick discusses the Earth Engine predominantly in terms of its environmental applications, saying the service was as aimed at "organiz[ing] the world's scientific information and making it universally accessible and useful" with the goal of "Build[ing] the world's most advance geospatial analysis platform ~~… so we all don't die~~ to help solve the world's

[137] Imazon, "Who We Are," Imazon, accessed November 8, 2018, https://imazon.org.br/en/about-us/who-we-are/.

[138] "Introducing Google Earth Engine." The blog notes that all 15,000 hours of computation were completed in less than a day using the Google Earth engine. The project was distributed over 1,000 computers and was built from "more than 53,000 LandSat scenes (1984-2010)" as well as "ground-sampled data to calibrate and validate the algorithm," provided by CONAFOR.

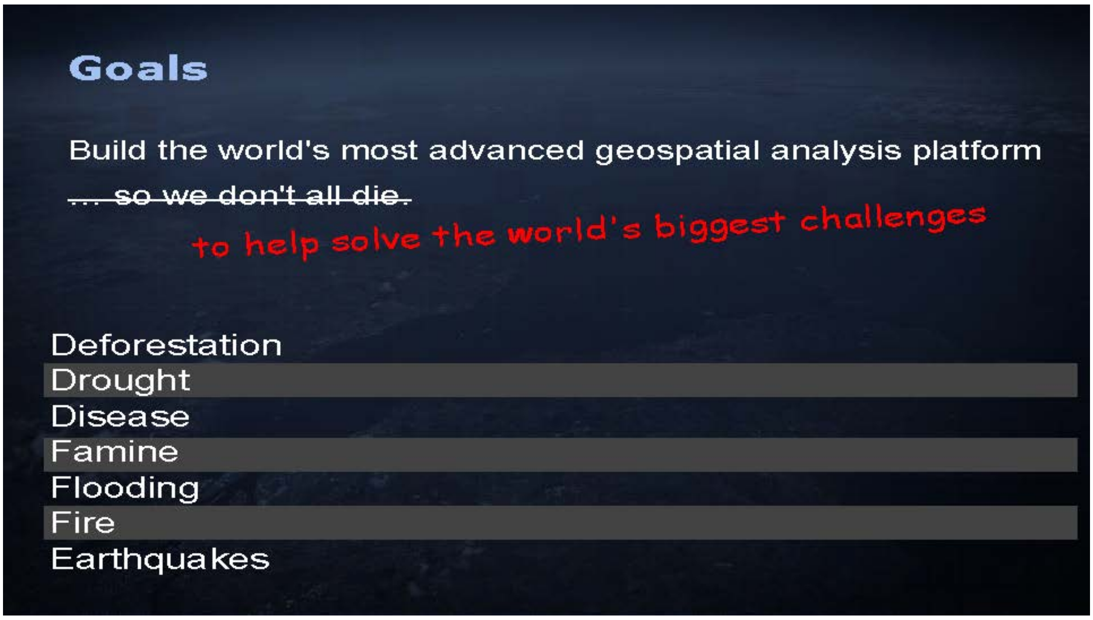

Figure 11: Slide from Gorelick's presentation on the Earth Engine.

biggest challenges" (figure 11).[139] A 2013 presentation Gorelick highlights that the Earth Engine had empowered "~400 published papers" and was focused on "society's biggest challenges," listing deforestation, climate change, drought, conflict, disaster, global food security, disease, and sustainability as key areas.[140]

Yet what lurks beneath this self-promotion is the tacit, yet obvious, enthusiasm for the ways that these environmental conditions are generative of massive amounts of data that can uniquely create computational problems to be solved. Hancher described the process of working with the deforestation mapping as a "really fun data set to look at"; a "great example of pulling something a little more quantitative out of the landscape". [141] It was this work with deforestation maps that provided the basis by which the Google Earth Engine team was able to then create

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[139] Gorelick, "Google Earth Engine."

[140] Noel Gorelick, "Briefing on Land-Cover Classification in the Cloud Using Google Earth Engine" (2013), http://csebr.cz/scerin2017/presentations/DAY1_09_Noel_Gorelick_Google_SCERIN5_2017.pdf.

[141] Matt Hancher, Interview: Removing Clouds from Google Earth, interview by Nicole Sansone, Interview via Google Hangout, April 14, 2016.

the cloud-free Google Earth image. While the work on deforestation allowed the team to gain access to the geospatial data they then archived and to first explore what it might mean to work with data at a per-pixel basis, the question of cloud-extraction added the additional challenge of working with data in slightly more qualitative way. Here Hancher explains in his own words:

> Right around the same time, it was sort of the very next thing we did, we worked with our partners who were then at the University of South Dakota, they're now in Maryland, and they were working on mapping deforestation globally. … This was a scientific result they were trying to assess quantitatively at each pixel: *is this forest or not*? and *has there been loss of forest or growth of forest over the course of the 21st century*?
>
> But the basic techniques are very similar: they make some decisions on a per pixel basis looking at the input data to decide do I think this is probably a cloud? probably a cloud shadow? probably haze affected? and so forth, decide then at each location what data they're going to actually use in the analysis, compute some statistics on that data, and then look at those statistics to say Aha, I think this is *forest-ey* or is not *forest-ey*.[142]

From this perspective the question being asked is not one of how to work with data to solve environmental issues. Instead the focus seems to be on *creating* qualitative concerns out of *quantitative* data. The extraction of clouds from these images becomes an early experiment in the types of cognition that might be afforded to computation when the data set is visual but still discretely ordered. Such a reading is further supported in the ways that Hancher also discusses the process of working with satellite images versus pixels.

Seeing the Picture through the Data

During our conversation Hancher was quite explicit that the focus of the entire cloud removal project was "not so much a scientific result as it was a pretty picture that we could use in our *product,* that would be attractive and would accurately reflect the landscape." On the face of it, this is a self-contradicting

[142] M. C. Hansen et al., "High-Resolution Global Maps of 21st-Century Forest Cover Change," *Science* 342, no. 6160 (November 15, 2013): 852, doi:10.1126/science.1244693.

distinction. In Hancher's phrasing we learn that even while it was a team of scientists working with the satellite images to perform the cloud extractions, to his mind, the resulting image didn't pertain to the realm of knowledge. Hancher explained that, in starting out, the team wanted to resolve a core issue with the fact that there were still parts of the world that weren't able to be seen because of cloud cover. But then, as Hancher later explained, "what we found was, in addition to solving that problem, it resulted in an image that *did* display the structure of the landscape at a global scale much better. And so that was a wonderful secondary benefit."[143] What's more is that once the pretty picture has been created and put into operation as Google's product, Hancher finds some light humor in the idea that presumably *an* average viewer or some average viewer might say "*Oh! They removed all the clouds for a picture of the earth. This is what it would look like if we just removed the clouds from the actual earth*." Because of course, this isn't true. The image we see of the cloud-free earth shows it as it would be were there no clouds *anywhere*, no seasons (except for spring), no weather, no atmospheric effects, and no night-time, *anywhere* on the *entire earth.* Simultaneously.

There's a disjunction between how Hancher viewed the cloud-free Google Earth image in one respect versus another. What I took away from this disjunction was that Hancher was describing to me two unofficial orders of the digital image in the sciences. In one order of the digital image, pixels are *data*, and digital images are databases of data formatted into pixels. Here, cloud cover in Google Earth is not an issue of being able to see an image—of using photographs to make visible a landscape structure—but is instead a problem of corrupted data in a database. Google Earth is a cartographic database that was failing on two fronts: one, that it was not extensive—that, as a map of the world it was not showing *all* of the world. And two, its data was risking becoming noise, or being drained of its meaning,

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[143] M. C. Hansen et al., "High-Resolution Global Maps of 21st-Century Forest Cover Change," *Science* 342, no. 6160 (November 15, 2013): 850–53, https://doi.org/10.1126/science.1244693.

because it could not provide information clearly, or without ambiguity. These pixels could not tell us, definitively and consistently, if white meant glacier or cloud. In the second order of the digital image in the sciences, the images are barely centered within the sciences at all. They exist, instead, on the fringe. They serve some outward facing purpose—to popularize an institution and its project, to communicate some idea to a broader and less expert audience—but as far as their internal utility they are basically null. The boundaries between *scientific result* and *pretty picture* seem both arbitrary and unanimously agreed upon. There is a sense when talking with Hancher that a *scientific result* can become a *pretty picture* the moment there is human intervention, or at the least when this human intervention surpasses a certain threshold. It's unclear the scale of human intervention necessary, but what is clear is that following this moment the image becomes inert. The pixels no longer store active, usable data. The images are no longer modular or scalable. They can be useful, to certain specific ends—as in, for a product, for example—but they cannot be continually built upon in the way that a scientific result, once verified, becomes a tool for other, further developments.

As an image comprised of epistemic and archival pixels, the image of the cloud-free earth is the most accurate and clear description of the Earth's topography. Every pixel is correct. Every pixel was imaged at the same spot and placed in the same spot. Every pixel is from our world, our time. The pixels are even limited to just one, human lifetime. And all of the pixels contained within the cloud-free Google Earth image are individually true and accurate. But taken together these pixels always present a falsehood. With the expectation that the cloud-free Google Earth image shows one, and only one, instant—a frozen glimpse at how planet earth could look at any singular point in time—then this image is incorrect.

With the expectation that this image is terrain map or a visualization of global terrain topography then you'd be hard pressed to find something more accurate than this image. It's a true image of land mass seen from a satellite. It is *not*

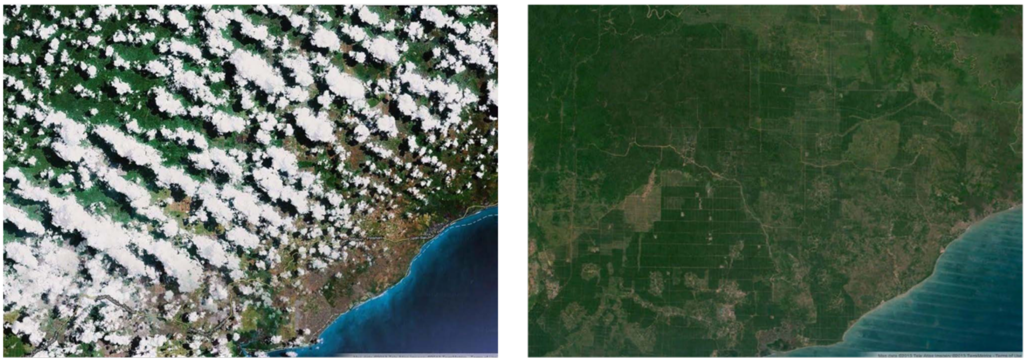

Figure 12: Cloud correction, before and after. No white pixels remain.

a true image of how satellites see land mass. But it is a true image of terrain topography from the orbital gaze, or the perspective of a satellite. All the falsehoods that this image shows are the residue of a transformation of a pixel database, that surpasses "scientific result" to become "pretty pictures" or "(merely) aesthetic."[144] As a collection of pixels formed into an image, we can see how epistemology is corrupted through stylization. By misguidedly classifying, and working with, the satellite pixels as an image, color becomes a fault line. The color white can't tell us about the conditions of the land we are viewing, nor can it tell us if the land in question is what we're actually viewing, and not instead a passing cloud. White pixels that have become "cloud-defective" require that engineers and scientists excise the cloud-defective pixels to preserve their database. The satellite pixels straddle their place within an image and a database, and color corrupts this databases by degenerating pixels. That white pixels can represent snow, glacier *or* clouds—with no definitive and direct way of telling the difference—means that color, in this sense, is like a malignant virus, working from within a database to corrupt that database.

[144] Hancher, Interview: Removing Clouds from Google Earth.

The Aesthetic and the Archive

The ambivalent role of the pixel in the context of the satellite image poses complex, and perhaps contradictory, notions about the pixel itself. In the context of science, the geospatial digital image is a clear database, with each pixel acting as modular and archival component. As the geospatial digital image becomes increasingly mediated along lines of style, color, and composition, its status as a database becomes increasingly unclear until its epistemological merit ceases to apply. Yet there are no hard and fast rules for when geospatial digital images are pictures and when they are databases. This becomes even more difficult to parse because often the character of the research in which geospatial digital imaging is involved always requires an element of creativity to close the gap between first-hand empirical research and technologically-facilitated empirical research.

What is worth exploring now is how classic qualities of the image are, in the context of satellite images of the earth, better understood as metaphors. They are figures of speech, or words, that are applied to objects to which they are not applicable. The satellite image does not show color: it shows space and time. The satellite image does not show space and time: it shows a specific, aesthetic framing of the earth. The metaphor cuts both ways: it is sincerely applicable in one sense—the white pixels show snow—and a symbolic reality in the other—the white pixels show light, they show the color white, they show hex code #FFFFFF, they show decimal code (255, 255, 255).

Color is one of the pluripotent metaphors in satellite earth images. Color functions in a variety of ways when working with the satellite image. As both a *pretty picture* and a *database,* color enhances the quality and clarity of the image, making it more legible and attractive for human viewers. Color in the satellite image always signals multiple things at once. It announces itself as a color; and it can mark out a composition. It can tell us something about the place and time in which we are viewing the earth. Color can be a data point in a database formatted as an image, and color can be the result of an input into a technical machine, and color can be a way to create an attractive image. Color is also a way to register and communicate information. Green and blue can indicate land and water. In the early projects on deforestation the change between green pixels and beige could show a change over time and indicate an increase in deforestation practices. The presence of phytoplankton in the ocean can make itself known through color changes in the ocean.

Color can also show us what the satellite does not. In May of 2003 LandSat7 began to produce images with diagonal stripes of black running throughout the entire picture plane. This was a result of the failure of a sensor "the Landsat 7 Enhanced Thematic Mapper Plus [ETM+] … resulting in a 22% loss in overall data."[145] Six weeks later the ETM+ was restored to its original function, but the result of the data dropout was that the faulty images output by LandSat 7 had to be retroactively corrected, with additional information and data being applied heuristically to fill in the gaps. NASA is reassuring that the United States Geological Service (USGS) continues to collect, archive, use and distribute this ETM+ data because of its accuracy with regards to radiometry and geolocation, adding that "Many users find the images useful despite the wedge-shaped gaps and 25% loss of data per image."[146] However, the website for the Yale Center for Earth Observation seems to report to the contrary, writing: "On May 31, 2003 the ETM scan line corrector failed and ETM images since that time are missing large portions each scene. On USGS sites these images are designated as SLC-Off and use of

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[145] Susan Schuppli, "Atmospheric Correction," in *On the Verge of Photography: Imaging beyond Representation*, ed. Daniel Rubenstein, Johnny Golding, and Andy Fisher, 2013, 17. NASA attributed the striped images to a failure of "a component of the ETM+ optical scanning system (called the scan line corrector or "SLC")" which left "wedge-shaped spaces of missing data on either side of the images." See: "Missions - Landsat 7 - NASA Science," accessed May 6, 2016, http://science.nasa.gov/missions/landsat-7/.

[146] "Missions - Landsat 7 - NASA Science."

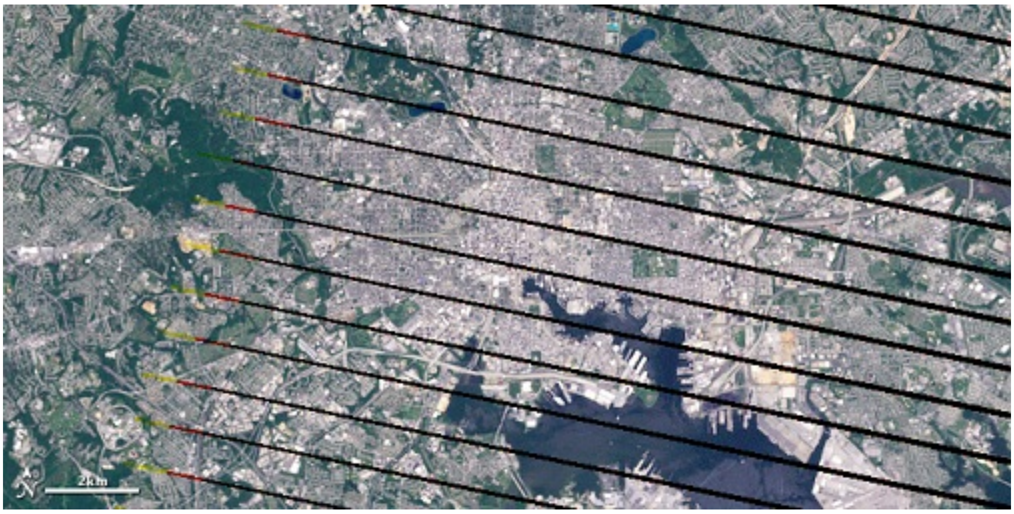

Figure 13: Image from Landsat 7 with characteristic black diagonal stripes, signifying data loss.

these images is generally not recommended."[147] In this example, striped images—the result of a consistent pattern of blank pixels—signal and represent a quantifiable *data loss*, which in turn makes the images as data archives unreliable (as illustrated in figure 13). Not only this, but the differing institutional positions on whether the images can be adequately used reveals the degree to which geospatial digital images extend beyond an ontological reality as mere image, or appearance, and materially quantify, order, and qualify empirical ecological data.

During my discussion with Hancher he told me that a logical outgrowth of the cloud-free Google earth and deforestation mapping projects has been to attempt to map malaria risk by tracking the environmental factors that drive up the mosquito populations that carry the disease.[148] Hancher explained how "you can't see the malaria, but you can see all the environmental indicators that malaria risk is likely … and you can look at that over time, you can even use that to inform better decision

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[147] "What Is the Landsat Program?," accessed May 6, 2016, http://yceo.yale.edu/what-landsat-program.

[148] Hancher, Interview: Removing Clouds from Google Earth.

making about how to deploy anti-malaria interventions."[149] In this example, images aren't images of the earth explicitly, but are instead a "grid of pixels describing some region of the surface of the earth" in terms of its moisture, temperature, atmospheric humidity, and other variables.[150]

In this scenario, the geospatial digital image makes visible an invisible picture of the earth, and does so in multiple, layered temporalities: present (the image of earth as having *x* humidity, temperature, etc.); future (the image of earth as site for future increased population of mosquito, the image of earth as site for future potential malaria outbreak, the image of earth as hosting variable human populations as a result of malaria outbreaks); and past, the sum of these images, collected and analyzed over time, solidified into archive and reference. If all these potential images of the earth also constitute *possible* images of the earth, then the logic follows that the materialization of the satellite data that make these earth images possible also has a direct impact on which of these outcomes is most *probable.* In this way, the geospatial digital image again has a material impact on the earth, whether we measure that impact in the consequences of intervention taken before, during, or after a malaria outbreak, or not at all.

Another image of the earth that arises out of this method of using geospatial image as prediction was introduced when discussing how human behavior is mapped in relation to malaria as a *cause* of outbreak (and not necessary measured in terms of a *result* of outbreak). It seems noteworthy to me for the extent to which it models a mode of predicting human behavior propeled by certain readings of geospatial digital images. In Hancher's words: "So, we can look at moisture and temperature and other atmospheric variables like atmospheric humidity, combined now with things that don't change as much, like the shape of the terrain itself, the elevation, and then combine that [with] human population density *and potentially information*

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[149] Ibid.

[150] Ibid.

about [how] the humans themselves are moving within that landscape (since that's another way that malaria can move) and each throw a lot of … environmental variables into the pile."[151] In this way we can see how computation serves a kind of explicit world making that I'm referencing can be seen in the ability for satellite images to create second order images or meta images of the world.

This recasts the duality of the satellite earth image as a dichotomy that pits aesthetic against archive. Satellite images accumulate over time and are kept as a digital archive of the Earth's documentation within the constraints of satellite imaging. The satellite image database accumulates to form an archive preserving a technological view onto the changing earth. With this shift the borders of the individual satellite images drop away, and all imagery is dealt with on the level of the pixel. Instead of satellite images we have an archive of pixels, taken over time and in various places, with visibility ranges as high as thirty meters or in some cases sixteen inches per pixel. When scientists talk about pixel archives, they call it a *time series*. The time series has a depth: the LandSat time series, for example, have a depth of forty years. This does not mean forty years of images but instead forty years of unique, biweekly pixels.

What happens, then, when a satellite image is manipulated? What are the consequences of moving pixels, substituting pixels, applying varying affects to swathes of pixels? The pixel is not just an element in an image: it is a query in a database; it is a *time series*; it is an archive of physical space and resource for environmental knowledge. Can we just substitute one pixel in for another? Can we stand to lose pixels when we compress files into more palatable formats? Is the archive or the database truly that flexible to loss and change?

Aesthetics as a Format for Eco-Knowledge

This question is particularly important when we situate these aestheticizing

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[151] Hancher, Interview: Removing Clouds from Google Earth.

maneuvers in an age of climate change. Kathryn Yusoff has argued, for example, that databases dampen the potential of a political aesthetic by inverting and misaligning the affective capacity of visualization and the specific modes it elicits of bearing witness.[152] Database ordering cuts off critical aesthetic registers of climate change, so that the proliferation of databases and images of endangered animals belies their actual scarcity in the physical world. Satellite imagery too cut off the registers of climate change in their proliferation in the present. They falsely stage the multiplicity of surveillance as a form of ethical care of environment, while the real effect is one in which individuals' sense of empowerment to enact ecological change is cauterized.

One way that satellite pixels contribute to worldmaking is by virtue of their status as makers of ecological knowledge. Pixels present a pathway to knowing the Earth by the same means in which the Earth is formatted for knowing. This solipsism becomes impactful as global observation data crossed the threshold hold of study into policy making—where the creative-scientific work of interpreting pixelated satellite images functions as a set of directives to be trusted, almost blindly. Climate change data is dependent on global observation research. DeLoughrey notes, "it's this very [satellite] probing that led to some of the most important ecological discoveries, such as the depletion of the ozone layer and the collapse of ice shelves at the poles."[153] While I can't currently verify the exact ways in which the boundaries between climate research and national governance are fraught, further research seems likely to reveal unforgiving boundaries that demarcate, produce, and reinforce global inequities at the expense of ecological vulnerabilities. Such a finding would be in keeping with Benjamin Bratton's prescient prognosis of the planetary-scale computation not in service of, or in resistance to, governance, but "*as*

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[152] Yusoff, "Biopolitical Economies and the Political Aesthetics of Climate Change."

[153] DeLoughrey, "Satellite Planetarity and the Ends of the Earth," 261.

governance itself."[154]

In addition to this, when observational data is passed over to policy makers, there is a high tolerance for the kind imprecision (that creativity necessarily invokes) in the service of a general good or private interests. What is significantly revealed in this the high level to which *creativity* plays a role. Paul Edwards has shown of the climate knowledge infrastructure (of which geospatial digital images as well as global observational data are a part) that policy "not only accepts the provisional character of knowledge but constructs its most basic practices around that principle."[155] This is so much so that the Intergovernmental Panel on Climate Change (IPCC) has, since the mid 1990's, built such a tolerance into their rhetoric, reducing and substituting quantitative expressions of uncertainty with more *qualitative* language "especially in its synthesis reports intended for a largely non-scientific audience."[156] As Edwards notes, such language promotes trust between researchers-as-experts, the quality of their expertise, and audiences, while at the same time minimizing the platform for critique.

The Position of Knowledge

Satellite pixels have one pathway by which they create worlds through policy and governance. This materially manifests by way of human intervention into the administering of environmentalism, acting as a guide that influences topography at a distance at least once removed. Another way that satellite pixels create worlds is in their prescription of the visual. The decisions that propel the creation of pretty pictures, and the logics that make pretty pictures aesthetically functional, are significantly revelatory. They can tell us why we believe what we see when we look at a picture. They can tell us what they show. They can tell us about our own vision

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[154] Bratton, *The Stack*, xviii.

[155] Edwards, *A Vast Machine*, 438.

[156] Edwards, *A Vast Machine*, 438.

when we look at a picture. These are the simplistic-sounding but fundamental parts that form a bigger picture of *computation as world making* that began in an earlier project of *landscaping* as world making.

In the history of landscape art we can trace connections between the idealized styling and depiction of landscapes to their consequences and origins in cultural, political, and social life. In the same way can we ask how the aesthetics satellite images can also be mapped onto social, cultural, and political consequence? This is a question that is justified when we consider the slippery way that pixels can serve as data point and then be subsumed into imagery. Such ambiguity suggests new boundaries for the meaning of images and the limits of information that can be contained within an image. Further, within these new boundaries, already occurring practices of pixel *erasure* and *substitution* are not solely stylistic choices but rather have temporal and physical impact. In this way an ecologically material engagement with satellite pixels on the level of their aesthetics attends to the incalculable ways that technological mediation drives the life of the geospatial digital image as a contemporary episteme. Here I am reminded of another point in my conversation with Hancher. He told me:

> Often in a machine learning setting you go in without knowing in advance exactly which variables you're going to use. You think about all the things that might have bearing on your problem, throw them into the pile, and let the machine learning system figure out which variables actually end up being most predictive of whatever quantity you're trying to understand. There's a large grab bag of environmental variables that we'll often throw into the pile.[157]

Hancher's trust of computation and automation to make sense a seemingly disparate array of data—a "large grab bag of environmental variables"— to produce a scientifically valid output is revelatory of the variability of factors that are determining our environmental and climate data.

Such a point underscores how viewing the Earth, and the human viewing-

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[157] Ibid.

by-teleproxy that is enabled by such viewing, can never be a neutral act. Seeing the Earth at a distance removed from planet and self always requires an act of constructing the Earth. This seeing/constructing can never be bracketed out of the circuit, and so when scientific projections of Earth claim to do so from a position of pure epistemology they undercut the myriad ways in which epistemology too is a participant in the construction of values and beliefs. This construction happens in part because of the imaging technologies themselves. Much of the technology that has allowed for the shrinking/expanding optical technologies owes its success to a long history of representing the Earth so as to make such a vast expanse manageable, and thereby knowable. As Tim Ingold, Leon Gurevitch, and Lev Manovich have shown, figurations of the Earth draw on the geometric technique of *visual nominalism*, a practice of the representing three-dimensional objects in two-dimensional planes. This practice has its origins in early diagrammatic representations of the Earth performed by spherical drawings and Renaissance perspective.[158] The employment of perspective, grids, and visual nominalism tie human actors with their planetary environment in unique ways that are contingent to properties of geometry itself. This is true for images as early as the Copernican image of the earth—an image of the earth as being *all-knowable*—to as recently as virtual re-creations of the earth—as in virtual globes, for example—where space and time are collapsed and made to serve the regime of a scopic "I". The use of perspective, grids, and geometry to figure the representation of three-dimensional objects on two-dimensional planes has had relatively little change since its implementation in digital technologies. What is different, however, is that digital images of earth and space are now also reliant on other forms of imaging

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[158] Tim Ingold, "Globes and Spheres: The Topology of Environmentalism," in *Environmentalism: The View from Anthropology*, ed. Kay Milton, ASA Monographs 32 (London ; New York: Routledge, 1993), 29–40; Gurevitch, "The Digital Globe as Climatic Coming Attraction"; Lev Manovich, "The Mapping of Space: Perspective, Radar, and 3-D Computer Graphics," *Manovich. Net*, 1993, http://manovich.net/content/04-projects/003-article-1993/01-article-1993.pdf.

technologies to produce their aesthetic effects: things like drones, satellites, and light-based LiDAR technologies that feed into digital elevation models.

In the geospatial and satellite images, the pixel is made to perform a pictorial function but its claims are staked in the physical geography of the earth. When the operative priority of the image (pixels) is set at visual legibility for human interpretation, the role that pixels play as data points drops away in proportion to what is necessary to achieve, or maintain, legibility. As we will see in chapter three, in Clement Valla's *Postcards from Google Earth* series the demand to provide an on-demand, God-like view of any point in the world made it necessary to manipulate with good approximation (though not anything close to "scientific precision") the data set at hand. Furthermore, in this moment the data set is no longer strictly a *data set* but instead alchemically "corrupted," or transformed, into imagery. The pixel as structural form for compounding layers of data—pixels, to meters squared, to cities with inhabitants, to forest acreage over time, etc.—applies loosely, or holds only in memory.

A Pixel Amongst Worlds

The satellite image is itself aesthetic, and also persistently aestheticized, whether under the aegis of making images legible, of making information knowable, of making phenomena visible, of compressing and converting for different hardware and recipients. All satellite images invoke the possibility—and peril—of aestheticizing interventions. Unexamined, this presents a danger to the foundations of ecological knowledge. We have seen how aesthetics of satellite images reconfigures the status of the data contained within those images image. Pixels which play a role in storing and producing knowledge disappear into structures of the image, and the information contained within them disappears as well. The image itself is made repellant to certain forms of epistemic practice. No matter again that the image is just one storage format for these pixels; their aestheticization seems to suggest a human intervention that is untenable to the scientific method.

In satellite images, pixels must always work as both information and metaphor. Pixels stand in for data at the same time as they allegorize datasets. It is difficult to tell how to best group pixels because they can function independently, in clusters, or across images. As we saw with the cloud-free Google Earth image, pixels across satellite images were repeats of information—enough so to become interchangeable—and also unique. Given this, it seems that pixels prescribe certain ways of working with them. What is less clear is how much this prescription is actually enacted. To generalize for a moment, it was my impression that pixels are often worked with as a one would a map key. They can orient a perspective both in terms of placing oneself within an image and in terms of providing a vantage point onto a problem. Pixels also provide a base unite of measure: one pixel, thirty meters, for example. Surprisingly, at least in the case of the cloud-free Google Earth image, this seemed to be the end of the pixel function when it came to their role as key. It was unclear to what extent meta data was attached to, or viewed in conjunction with, individual pixels. Satellite images clearly bore the mark of date and time; did their individual pixels as well? Inversely, satellite images were less attached to their geographic indexing, while pixels firmly represented place. Place and time thus had clear alliances to their digital structures—pixel and image—but the modes of working with pixel and image seemed ambivalent about about these alliances. Digital structures provided heuristics that allowed image manipulation to be a process aimed at an appropriate end result. In this sense, the digital structures seemed to be somewhat superfluous to what was perceived as the "actual" data, though little distinction seemed to be made to the ways in which content and form were fused together. In this case we can see how *worlds* can become collapsed into one another. Without distinction or parsing the *worlds'* individual aesthetics and orders of signification disappear when they do not overlap—arguably at the most crucial and important moments. When moving through different *worlds*, alterity provides a necessary guide for orientation; when working with different aesthetic orders, digital structures impart wisdom of their own.

The cloud-free Google Earth image threads the needle between the *worlds* in which satellite images coexist. The cloud-free Google Earth image is both an unmatched, accurate image of the Earth's topography and appearance from orbit *and* a complete fabrication. The modes of aestheticization that activate one understanding of the image over another are crucial to ecological knowledge. The images used to study and prevent deforestation can still be described as beautiful, and Hancher takes sensuous pleasure out of that dataset. These moments of aesthetic enjoyment do not preclude the images from being qualitatively productive; in fact, they seem to add to it. For the cloud-free Google Earth image, the same is not true. The cloud-free Google Earth image hews close to accuracy by operating pixel by pixel and yet while all the pixels pulled from the same data pool—the same time series—their combination in new temporal forms was enough to be invalidating. At the same time that the cloud-free Google Earth image moves between *worlds*, we can also see how these *worlds* exist in friction with each other, and with the *worlds* outside of their immediate context to which they must bond in order to make meaning proliferate. The cloud-free Google Earth image is a scientific image, it is a product, it is a satellite image; it is reality, and it is also fiction. It has been fabricated, altered, it displays a world of idealization rather than manifestation. Between fiction and reality knowledge loses its way. Knowledge loses its credibility, its compulsion to persuasion. Knowledge rises to the surface and becomes an effect: one inscribed, with alternative consequences, on the surface of the image, and the surface of the Earth.

In aestheticization there is loss. Aestheticization produces an image that becomes, as Yusoff also argues, indexical to destruction and enacting "a future technology of ordering loss."[159] The satellite image as image and database are just such technologies which order loss, both in what is left invisible and unaccounted for, and for the idealizations that such images set into place. Does the cloud-free Google Earth display an allegory for the thinning ozone, and is it an allegory that is understood as such? As it stands now, the manipulation of these types of images does not make an image more clear, and it does not make our Earth more knowable. Instead, it further hones the space of ecological politics into an arena of the ideal, the beautiful, and the sanitized. The satellite image destroys the possibility of world viewing outside of *world making*. By not honoring the pixels we view when we look at satellite images for the aesthetic forms of knowledge that they are—an epistemology freed from the utility of thought—we indirectly honor a world infused with both the real and the imaginary. We inhabit the same earth both in physical space and imagery, and in both cases the Earth is there to be ordered against the loss that climate change collectively imparts and individually impacts. The cloud-free Google Earth is a constant presence across the Google products, and Google products are ubiquitous. In its constancy and ubiquity, the cloud-free Google Earth image is an exponentially multiplying site of sky that falsely reassure us that there are "only clear skies" here on Earth.

[159] Yusoff, "Biopolitical Economies and the Political Aesthetics of Climate Change," 89.

II.

Chapter Three: Texture Maps

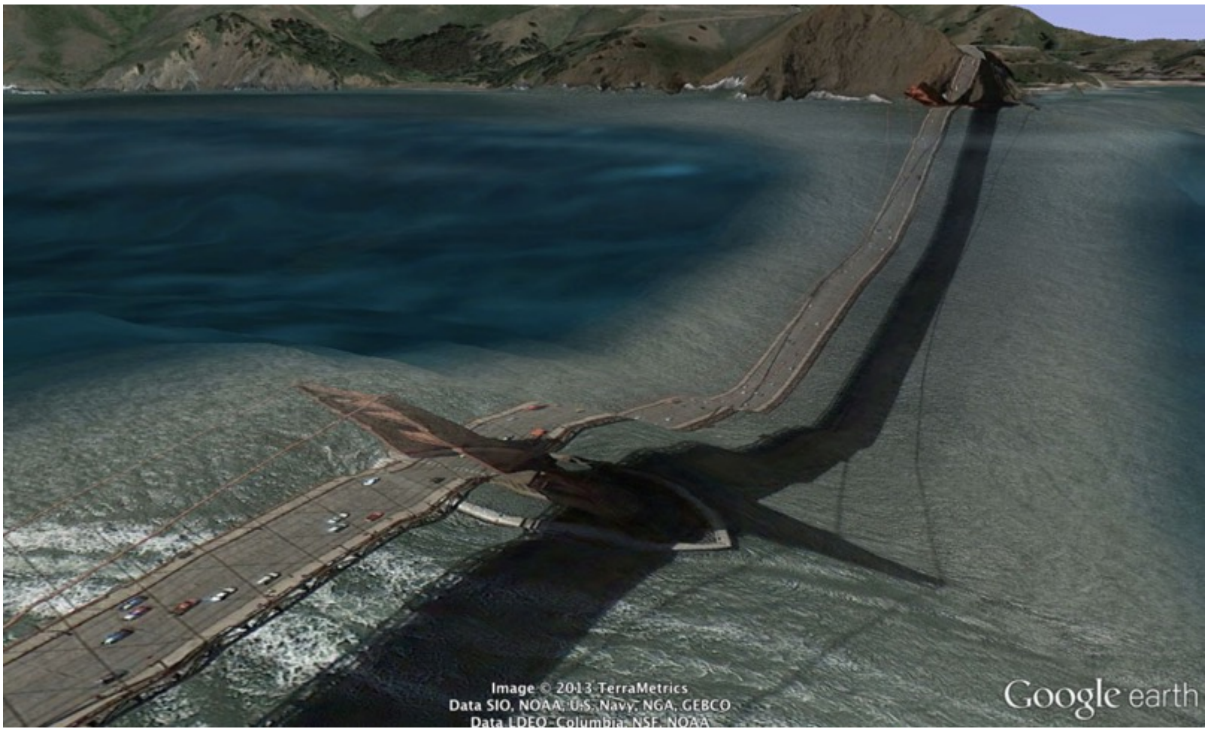

Figure 14: "Postcards from Google Earth" (2011-Ongoing) by Clement Valla.

Introduction

This chapter opens with a case study on the popular photography series *Postcards from Google Earth* by Clement Valla. In this series, images are pulled from Google Earth that appear distorted and unfamiliar. While the images appear to be the result of glitches in the Google Earth software, what we will discover is that these images are not glitches at all. Instead, they are completely accurate representations of the Earth and indicators of a successfully logical technical procedure. The images both *are* and *are not* reasonable in what they display. In this, they trouble our faith in scientific images to present accurate, or true, content. To get to the root of this troubling, we will look at the historical and technological conditions for the creation of these images. By fleshing out the conditions of creation I aim to show how the contemporary field of vision is not one that can be thought of as solely, or primarily, optical or organic, but instead that it is made up of the complex interplay of multiple registers of perception.

This discussion of *Postcards from Google Earth* stages a debate on why and how certain images are able make claims to truth. In general, images of environment play out this debate in a more controlled way because any image of the Earth can be verified by going and looking at that place. Images of sky hold this potential as well, but with some caveats given how ethereal, volatile, and formless the sky can appear. These characteristics of the sky, in addition to the fact that all humans must access the sky in particular, predetermined ways, provides control in another way. It helps to shift the debate from *how do we know an image of the Earth is accurate* to *how can scientists and artists both accurately represent the sky?* By adjusting the debate to reflect on disciplinary method rather than ideals of accuracy and representation, we can see how visual claims to truth in the digital Earth image emerge out of the construction of structures of believability. While digital Earth images taken by satellites, for example, often circulate as direct and super-human views onto the world, they do not in fact present any direct pathways to a truth or knowledge content. They are no more indexical to the real world than regular photography might be. Instead, digital earth images function as realistic and authentic representations of the content they portray because of the immediate and broader contexts in which they are created and received. We see truthful images that are capable of functioning to create content because we are primed to do so.

Postcards from Google Earth

Postcards from Google Earth are, in one sense, exactly what their title names them: postcards. They are screen grabs from moments and places in a world meticulously crafted by Google Earth. Yet these moments and places are unlike any other. Valla explains, "I discovered [these images] by accident … when I noticed

Figure 15: "Postcards from Google Earth" (2011-ongoing) by Clement Valla.

that a striking number of buildings looked like they were upside down."[160] In these images, roads suddenly dip and ripple like strewn ribbon (see figure15). Tree foliage is stretched and wrapped over uneven terrain. The images give the appearance of a glitch in the Google Earth software. Yet, as Valla discovered, these moments are not glitches or errors; rather, they "are the absolute logical result of the system. They are an edge condition—an anomaly within the system, a nonstandard, an outlier, even, but not an error."[161]

What *Postcards from Google Earth* often ends up documenting are misalignments in what humans expect of computers, and what computers actually do. This requires both a simple and more extended explanation. To the former: the "problem" *Postcards from Google Earth* demonstrates involves a central procedure in 3D computer graphics and is a fairly simple issue. As with many multiplayer video games, the landscape of Google Earth is assembled in real-time through a rendering

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160 Valla, 2012.

161 Valla, & Sansone, 2016.

pipeline that moves a geometry of data points to the pixel rendering that appears on user's screens. A key component of this process is texture mapping. Texture mapping applies textures to 3D models. This gives the impression that there is visual depth in our computer screens. We feel we can move around in a video game landscape or in Google Earth because texture mapping effectively mimics depth perspective and volume. Texture mapping requires at least two inputs. One, texture mapping requires textures. Textures are images with very little depth of field. The flatness of textures are meant to mimic the surface of an object; "they are more like a scans than a photograph."[162] Two, texture mapping requires models. Models look like clay forms on your computer; devoid of color, they are the lumpy mass of the objects we see and interact with on our computers. Texture mapping then (as you might have guessed) maps textures onto objects. You can think of texture mapping as putting a label on a bottle: wrapping or grafting an image with very little depth of field (as opposed to a painting or photograph with deep perspective) onto the surface of 3D object. Done correctly, texture mapping can make models with even the least amount of sculpting look textured, voluminous, and highly realistic.

In Google Earth, textures come from satellite images, and the dimensions for models come from Digital Surface Models (DSM). Topographic data used to furnish DSMs are collected by LiDAR systems. These are systems in which light transmitted from overhead is measured for the time it takes to return to its origin. This straightforward way of measuring the Earth's surface doesn't distinguish between terrain and built structures, as a Digital Elevation Model (DEM) might. A DEM is a "bare-earth raster grid" that has been voided of all built elements and vegetation.[163] What this means is that sometimes the DSM data Google Earth has directs a model to be built that has some kind of structure in the landscape, but the

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[162] Valla, 2012

[163] "DEM, DSM & DTM Differences - GIS Elevation Models," GIS Geography, March 9, 2016, http://gisgeography.com/dem-dsm-dtm-differences/.

satellite image for that same location does not have an image of that structure. Alternatively, sometimes the DEM data Google Earth has directs the model to show absolutely flat terrain, but the satellite image for that site clearly shows buildings. When texture mapping is in process, it doesn't reconcile imagery in satellite images with the elevation model data used for modeling texture mapping volumes. Unless otherwise directed, texture mapping solely maps textures onto models.

The images selected for *Postcards from Google Earth* are moments in time when land elevations and topographic data fail to incorporate 3-D structures in their data stores, but overhead imaging does not. Bridges and overpasses are clear examples of this. At these sites, when the pipeline applies textures to models, it does so efficiently but stupidly, applying an image of a bridge to a terrain measured in the absence of that same bridge. The result is that an image that appears as a place with *a lot of depth* is distorted as it is applied to a model with *no depth* and presented to viewers from an orthogonal perspective. The images look weird. Places make no sense. More than this, Valla offers that images also "*feel* alien," precisely because they were not created by humans but instead "by an algorithm that finds nothing wrong in these moments."[164]

A User-Driven Realism

When we spoke, Valla characterized his project as butting up against what had been the history of theorizing photography in our lifetime as "indexical system of capturing a point in a moment in time".[165] He was particularly interested in the way these strange Google Earth "actually show[ed] a complete reversal of that way

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[164] Clement Valla, "The Universal Texture," *RHIZOME Blog*, July 31, 2012, http://rhizome.org/editorial/2012/jul/31/universal-texture/. Emphasis mine.

[165] Clement Valla, Interview: "Postcards from Google Earth" project, interview by Nicole Sansone, Skype, March 21, 2016.

of thinking that way of photography" and in so doing emphasized how uncritically the idea of representation had hinged on a belief in the indexicality of photography.[166] This reversal became more important for Valla when, as he told me, photographic systems reveal themselves as not being indexical, but then also fail to offer an alternative:

> In a place like Google Earth it's obvious that that representation isn't indexical, and yet is that representation objective to the degree that the system treats all photos the same? All inputs the same? No human is going in and painting these mountains, so it's not painting, but it's not photography either. It lies somewhere else, and the place I think it gets interesting is that it's all around these ideas of protocols, that algorithms are systems that translate a set of what we might call *data* from the world—in this case light data—through the form of photography, into some other form of representation.[167]

What Valla's commentary inspired me to think through was not some other form of representation, but instead to use such moments to interrogate the representation we already have.

To begin this interrogation we might consider the context from which Valla's photography project emerges. *Postcards from Google Earth* are embedded in the Google Earth software and platform. Google Earth is both a cartographic service offered to users for free, as well as highly sophisticated indexed archive of land data stores, some of which includes satellite image archives. As a cartographic service the moments that Valla documented in *Postcards from Google Earth* were untenable. In 2011, Google Inc. employee Joshua Schpok's delivered proceedings of the 19th ACM SIGSPATIAL conference in which he presented a "method to extract elevated road structures, typically overpassing other roads, transit lines, and water- courses."[168] We might infer that this method was developed as a result of Valla's series—perhaps even a bit out of the sheer embarrassment of having a tech

166 Valla.

167 Valla.

168 Joshua Schpok, "Proceedings of the 19th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems" (ACM, 2011), 3.

giant's oversight plastered all over the internet as an art project—though there's no way to be sure. What we do know is that in his proceedings Schpok says:

> Overpass structures are an important part of realistically and accurately representing roadways. Without overpass structures in a terrain model, roadways in bare digital terrain models (DTMs) … appear unrealistic and do not clearly convey the absence of an intersection between the crossroads. **Though these artifacts may have some artistic merit, they can be visually distracting, difficult to parse visually, and break an immersive experience**.[169]

In the upper right-hand corner of the published proceedings is an image not entirely unfamiliar to the *Postcards from Google Earth* series, though Schpok does not credit the image as part of Valla's series.

By 2014 Schpok had been granted a patent for a "computer implemented system and method … for generating realistic three-dimensional models of roadway overpass structures."[170] The system and method lamented that there were *too many* overpasses in the sum regions relevant to their purpose[171] and so this method was a way to efficiently and quickly approximate (with some chance of error and deviation) the topographical dimensions of the overpasses as a standard rectangular grid. In this spirit we can get another glimpse onto what a user-driven realism might look like.[172] Schpok's writing defines roadway overpasses in part by operating on the

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[169] Joshua Schpok, "Proceedings of the 19th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems" (ACM, 2011). Emphasis mine.

[170] Joshua Schpok and Tilman Reinhardt, Automated Overpass Extraction from Aerial Imagery, US20140362082 A1, filed May 3, 2011, and issued December 11, 2014, http://www.google.co.uk/patents/US20140362082.

[171] I assume the "sum regions" relevant to their project might be, in other words, the entirety of the Earth, or at the least those parts of the entire Earth that are available for man-made structures.

[172] In the patent authored by Joshua Schpok and Tilman Reinhardt correcting the problem of overpasses in Google Earth, we can see how the solution provided is one that prioritizes Google's economic and labor resources over a thorough approximation. Simply put, it would be a tremendous task to identify and collect data on all the world's road overpasses, so instead overpass information is gathered using a combination of roadway map data and Digital Surface Models (DSM) and a series of predetermined assumptions. A non-exhaustive list of the assumption-axioms employed by the patent define all overpasses as having "at least a first and second road segment"; "a constant width"; "not to roll" –though the patent does admit that this criteria fails to hold for banked roads but is

Figure 16: "Postcards from Google Earth" (2011-ongoing) by Clement Valla.
This image demonstrates the challenge that overpasses posed to the algorithm, and to user experience.

assumption that "A road way overpass region [would] have at least a first and second road segment."[173] Schpok's patent proposes two-part process: a segmentation module for identifying upper and lower roadway sections, and an extraction module that would generate the approximate 3D grid of the overpass based on the regions identified in the previous module. The extraction module would then combine "aerial images with 3D computer models of overpass structures to generate a realistic 3D rendering of surface topography of the earth including roadway overpass

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admitted as a "compromise to avoid noisy elevations"; and that all overpasses can be located "If two roads are observed to cross, but no intersection feature exists"; "any road segments with [a numerical stacking index] participate in an overpass structure (either as the overpass, or the over passed)". I labor this point not because this is a nonsensical or ill-conceived approach to the problem of mapping/correcting overpass imagery in Google Earth but rather to emphasize the extent to which this data is mediated in compounding proportions, and to suggest that such a degree of mediation could invite error. See: Joshua Schpok and Tilman Reinhardt, Automated Overpass Extraction from Aerial Imagery, US20140362082 A1, filed May 3, 2011, and issued December 11, 2014, http://www.google.co.uk/patents/US20140362082.

[173] Ibid.

structures".[174] In computational terms every structure that meets the criteria of a *two-part road segment* becomes an overpass, and further, every two-part road segment must be extracted and reformed. Every two-part road segment becomes not just a unit in the graphic and computational world that Google Earth must construct but instead is a catalyst for further algorithmic action, a catalyst for more decision-making and creative intervention into what might otherwise be taken as the indexical relation between photography and map-making.

Schpok's method and patent seek to fix an undesirable and unsustainable quality that was the result of an imperfect process of turning data and archives into a particular kind of user experience. He notes that what was captured in *Postcards from Google Earth* is something that detracts from the important realism and accuracy of the images Google Earth presents, and further that this quality threatens Google Earth with a sense of unrealism and opacity. If not corrected, this perfectly logical, albeit unexpected, functioning of the Google Earth algorithm threatens the unity of a specific vision of the Google Earth experience, of which the user's input, experience, and opinion is a major part.

The values of the image for Schpok and Google Earth then are clear: it is *users* that drive the image, and not any intake of data or representational relationship to Earth as a physical space. Schpok writes that Valla's images are "visually distracting, difficult to parse visually, and break an immersive experience," which is to suggest that Google Earth's images must draw out and maintain engagement with users in a singular way, and in such a way that can cohere with a cogent and contained "experience".[175] With this value system it becomes clear that it is not so much that Google Earth's algorithm mis-perform, or that they fall short in their function to create an accurate or realistic view of the Earth. Instead, the algorithm's

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[174] Ibid.

[175] Joshua Schpok, "Proceedings of the 19th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems" (ACM, 2011). Emphasis mine.

great sin is to break the fourth wall; to jar users out of their willingness to believe that *it is reasonable* that they should be able to view the earth from outer space, with machines, at varying levels of detail, with perfect, continual, and seamless accuracy.

Between Photography and Data

In discussing *Postcards from Google Earth* and the corrective patents that project has inspired, we can see how realism and accuracy are not so much tied an epistemological or cartographic project or gaze, but instead an expectation of perception that is inhered in user experience. How a user expects the software to perform becomes the standard by which a user expects images to appear. The intersection between user experience and aesthetics congeals to be a programming directive. There is a sense that for software and platforms like Google Earth, programmers should have some sense of responsibility to their categorical purposes—to be a map and provide way-finding information, to display and store data about the Earth and its immediate atmosphere. Yet the power and influence of the user is strong. As the proprietary products of multi-billion, trans-national companies, loyalty to user/consumer cannot be overlooked. This fact creates an incongruous sense of purpose between satisfying a user desire to be in access to images—both in terms of system responsiveness and also image legibility—and presenting visual data in a way that is amenable to the sciences.

Yet, what is amenable to the use of visual data in the sciences has its own blind spots and hypocrisies. In this instance, the hypocrisies and blind spots are precipitated by the inherent difficulties in calibrating the performances of all the viewing bodies around a single presentation of data. How the artistic, the scientific, user, and technical bodies must be accommodated to engage data is distinct for each. Yet despite these distinctions, all of these bodies—with their predefined gazes, needs, and desires—are persistently pressed into uncomfortable and irresolute communion and cooperation as the necessary precursor to their *fabrication.*[176]

While, to his mind, Valla might have been performing a serial photography project, viewed from the perspective of the project's more extensive history, this same serial photographing is a continual act of archiving and documentation. Valla admits that to some degree he is drawn to images like the ones in *Postcards from Google Earth* is because he is "searching this data", and that such searching is bolstered by his "really good technical understanding of how all these systems work, from a programmatic point of view."[177] This gives a clear indication the project is undoubtedly rooted in an *artist-as-researcher* mode of practice, central to which would be the act of documentation and the reconstruction of discoveries visually, or the presentation of a new framing of existing data by way of art. The interaction between Valla's project and the response by Google is demonstrative of this link

Valla tells me that in addition to searching this data and understanding it technically, he is equally (if not more) interested in the ways that data can configure photography as a mirror of representing the world. I would disagree, and in our conversation we talked about how I had been brought to his project precisely for its technical components, while Valla remained certain that *Postcards from Google Earth* was an exercise in understanding the role of contemporary photography. When I ask Valla about his considerations for texture mapping in his project, it's not something he sees as central to his research. I had felt differently (as we will explore further on) and so the divide in our priorities when interpreting the project became a point of interesting discussion. He told me,

> But all of the projects that I'm working on use photography as a texture map, as opposed to a kind of scan or thin space as a texture map. So, I am interested in that weird double space, or not double space, between photography and a distorted

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[176] I use this term as Matthew Fuller does in his study of media ecologies; as "a medial will to power made in the ontogenetic, reality-forming nature of a media and in its capacity for connection and use." Fuller, *Media Ecologies*, 2.

[177] Valla, Interview: "Postcards from Google Earth" project.

> object in 3D space, and CGI space. That's really the way I'm thinking of texture mapping and its relationship to photography. … I guess, that's what I would say is specifically what I'm looking at: is texture mapping and its specific relationship to distorting photographs, as opposed to painting or shallow surfaces.[178]

In this sense, then, Valla's interest in photography did have some overlap with my interest in texture mapping. The distinction between our two views is perhaps a matter of personal taste, which is not to say that both are not still important and valid. In fact, this is key: it was Valla's personal taste and artistic impulse that drove a project which ultimately produced a view onto data otherwise unseen by data researchers and programmers. In this we can see the value of Aimé Césaire's warning: "A view of the world, yes; science affords a view of the world, but a summary and superficial view."[179] Google Earth may afford us a view of the world, but it is a summary and superficial view when left to exist on its own, in a the void of conversation with its own users. It was Valla's movements that traversed this void—alternating between user, theorist; programmer, photographer; scientist, artist—and that ultimately provided a much-needed outlook onto how software, image, and data were functioning in a space away from user concern.

Realism for a Universal User

Postcards from Google Earth helps illustrate how even in seemingly objective services and disciplines there is always a politics of aesthetics that undergirds notions of realism. This is true for *Postcards from Google Earth,* and it is also true for the wider processes and people who contribute to the project and platform. In this section we turn to the broader context in which some of the central components of *Postcards from Google Earth* and the software that undergirds it were created. We can

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[178] Valla.

[179] Aimé Césaire, "Poetry and Knowledge," in *Lyric and Dramatic Poetry, 1946-82*, trans. Clayton Eshleman and Annette Smith, CARAF Books (Charlottesville: University Press of Virginia, 1990), xlii.

look at these moments as a way of understanding how it is not just users who drive realism for a business such as Google, but instead it is human beings as the presumed *universal* computer user who also condition these decisions.

Texture mapping is a central component of the computer graphics rendering pipeline, which makes it applicable to a range of projects like the creation of video games and movies. In half of these projects the 3D computer graphics modeling takes place offline and can be exported into contained animations. In the other half of these projects modeling occurs in real time, as in massive multiplayer online (MMO) games and in Google Earth. In these projects modeling is inhered in the function of the software itself, and without it, the software is not sustainable. Specifically in these contexts, modeling and texture mapping are the backbones of what W. S. Bainbridge has described as *virtual worlds*, "electronic environment that visually mimics complex physical spaces, where people can interact with each other and virtual objects and where people are represented by animated characters."[180] Some of the most commonly referenced virtual worlds are probably World of Warcraft (WoW) and Second Life (SL). WoW is a massive multiplayer online role-playing game, and it's structured according to its own overarching, internally self-consistent, mythology. SL is more individualistic, undirected, and amorphous. The unique narrative and gaming ethos of each of these games guides and informs both structure of the games' virtual world, and by extension therefore also the computational choices that structure the games functionality and code. Although Google Earth isn't an MMO, the construction of a virtual world is actually as central—if not more—to the function of the platform and what it promises than in WoW and SL. In this regard, WoW, SL, and Google Earth share specific computational concerns and are confronted with similar computational challenges, though their end purposes are oriented towards very different aims.

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[180] W. S. Bainbridge, "The Scientific Research Potential of Virtual Worlds," *Science* 317, no. 5837 (July 27, 2007): 472, https://doi.org/10.1126/science.1146930.

A big problem for virtual worlds, or any platform that relies on graphics rendering, is latency and lagtime. Users hope for, and expect, virtual worlds to move and respond on a temporal scale that at least *begins* at a human perception of the instantaneous. Virtual worlds can compress time at the higher speeds—characters can grow old or have life cycles many times in the duration of one gaming session, for example—but any slower and games risk high levels of dissatisfaction. In fact, it has been reported that humans can detect latency up to 50 miliseconds.[181] In terms of computation, latency and lagtime can come as a result of restricted bandwidths. WoW solves this problem, in contrast to SL, by putting all of the game's computer graphic load on individual users' computers.[182] For example, instead of the free form, limitless invention that is promoted and expected in SL, WoW are only able to *customize* (not invent) their characters. The result for WoW is a twofold win. One, WoW developers avoid issues of lagtime which threatens to break the narrative flow of the game and degrade user experience. Two, at the same time that they're doing this, the developers' self-imposed *restriction* isn't seen as a restriction at all. Choosing characters is a feature of the game and the WoW narrative, not a constraint. WoW could be a game, like SL, that invites users to make up characters as they see fit. That is a realistic ability of the game and the code. However, such limitlessness threatens a very particular "realism" of WoW on both the narrative and computational fronts. Jaggy play time and a virtual world comprised of characters beyond the expected elves and wolves threatens WoW's internal consistency. In this sense WoW meets the standards of "realism," or internal consistency, it sets for itself *precisely* through its arbitrary limit on *user* freedom.

This moment in WoW shows a clear instance when computational challenge becomes a user restriction, which then becomes a game feature, which then becomes a standard of realism. What is noteworthy in this example is how WoW's model of

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[181] Bainbridge, 474.

[182] Bainbridge, 474.

user-programmer-computation circuitry reveals a clear aesthetic blueprint. The ontology of virtual worlds is entirely dependent on the affective sensoriums they are able to generate, and primarily by visual means. As we just saw in WoW, this virtual world ontology includes a non-textual but self-consistent mythology, that limits choice in order to preserve movement and responsiveness, thereby promoting interactivity between users and world. In SL, the virtual world ontology requires less movement and interactivity, instead redirecting its load onto the kinds of functionality that are permitted. This at times means that SL sacrifices performance—risks lagtime—in order so that users can feel like their SL cultural ontology is in alignment with their experience.

Google Earth also faces potential problems with latency and lagtime, and particularly so because the textures they are dealing with are so big—as in, literally the size of the earth. What Google Earth developers chose to do to solve this problem was to reinvent the procedure of texture mapping and the rendering pipeline according to arbitrarily imposed standards of what is *acceptably* realistic. This standard of *acceptable realism* is in discordant conjunction to the other multiple forms of realism that compete in the user experience as well as in the platform's function and purpose. The *Universal Texture*, as it is colloquially called, sets the stage for Google Earth's strange and uncanny virtual world by promising a "god-like" view onto the Earth from a fixed, yet indeterminate, point in the ethers of outerspace. Instead of feeling yourself move through the universe, the universe comes to you. Planets take up more of *your* eye-space as you move into zoom; star clusters and distant galaxies are directed to re-center on *your* monitor. Yet, while your experience of Google Earth appears as a limitless experience, and you feel as though you are playing God and the entire planet has been made available for your viewing, this isn't actually true. Your uninterrupted, continuous viewing experiences come at the expense of your potential lateral vision.

Planetary Textures & The Asynchronous Multilevel Texture Pipeline

As we've discussed, textures are the skins of 3D objects, and they help to make models look like the things they are modeled after—oranges to look like oranges, buildings to look like buildings—as well as anchoring the objects we see in our computer screens to their reference points in the real world. The more realistic the model/texture ratio and relationship to its physical world cognate, the more legible the 3D objects behind our screens appear. Yet texture mapping poses some computational challenges. First, texture mapping requires coordination between a 3D model and a 2D image with a very shallow depth of field. Already there exists a discrepancy between what you have, and what you want to do with what you have. How do you make a quadratic, two-dimensional form neatly fit on to a three-dimensional shape? The solution to this is a process called *bilinear filtering*.[183] Bilinear filtering works by blending two pixels at a time from a selected group of four pixels, starting with two pixels on one axis, and blending those with two pixels on another axis. Bilinear filtering allows for images to be massaged into wrapping around a 3D object because it works by blending two pixels at a time, on intersecting axes. The payoff is being able to look at and *around* objects in virtual and computational spaces, and have their texture be consistent throughout.

For small textures, bilinear filtering—working to blend two pixels by two pixels—is a manageable process. For larger textures, much less so. The challenge is in being able to sample and filter every individual pixel in large images and to do so at the rate necessary to "rapidly draw 3-D scenes from changing perspectives", or at a rate that can keep pace with users.[184] For programs like Google Earth, its texture images are monumentally huge. The material a software like Google Earth needs for

[183] Avi Bar-Zeev, who will be introduced in the pages to follow, notes on his blog that most personal graphics hardware now feature *trilinear filtering*, which performs bilinear filtering and then a third filtering of the two previously filtered pixels.

[184] Christopher C. Tanner, Asynchronous multilevel texture pipeline, US6618053 B1, filed October 6, 2000, and issued September 9, 2003, http://www.google.com/patents/US6618053.

its texturing mapping—i.e. the *actual Earth* and, by extension, *pictures* of the Earth, pulled from satellite image archives, often owned by NGOs—are too big to handle gracefully. As Avi Bar-Zeev—a co-founder and director of Keyhole Inc.—notes, the Earth's circumference is 40,075 km, and if you had an image of the earth at a resolution of one kilometer/pixel, you'd have an image that was both 40,075 pixels tall *and* wide; totaling in at an 800-megapixel image and a minimum size of 2.4 gigabytes.[185] Now, consider that most of the LandSat images have a spatial resolution of three percent less than that—approximately thirty meters per pixel—and some an even greater spatial resolution of less than *one* meter per pixel. At one meter per pixel, you're talking about an image that is now a little over forty-million by forty-million pixels. These images far exceed the capacities of the average home computer, or an even a computer suited for high-end gaming.[186]

To solve the problem of texture mapping such large textures at an appropriate rate, Google Earth uses a patented texture mapping process commonly referred to as the *Universal Texture*. What's important to know about the Universal Texture on the user side of things is that it stitches textures to 3D models in a way that is unique to the Google Earth service, and which allows for an unprecedented user experience at better levels of efficiency. Users are able to have their God-like

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[185] Keyhole Inc. was a CIA-funded company bought by Google in 2004. Keyhole Inc. ran a service called EarthViewer3D, which was rebranded and revealed in mid-2005 as Google Earth. Parts of my work researching how Google Earth works has been informed by the explanations offered by Bar-Zeev on his blog, *Reality Prime*. This risks two things, which Bar-Zeev himself notes: one, that it is already out of date, and two, that the explanations offered are a vast oversimplification. The former risk is inevitable. Bar-Zeev has admitted that, "The Google Earth code base has probably been rewritten several times since I was involved with Keyhole and perhaps even after these patents [linked in text] were submitted. Suffice it to say, the latest implementations may have changed significantly." He warns that this fact plus the broadness with which he goes on to explain how Google Earth works (or rather, *might* work) should be understood as caveats to any concrete information being offered; that his explanation is best applied to sating intellectual curiosity, no more, no less. I have attempted to contact Bar-Zeev for an interview though have been unsuccessful. Still, his connection to Google Earth via Keyhole, and his general knowledge on the subject make these risks worthwhile.

[186] At present, the biggest consumer gaming card capacity I could find averaged 4GB and ran between £200.00 and £400.00.

view of the Earth and its galaxy because the Universal Texture is able to effectively balance computational load time while consistently hitting an upper limit of realism in its imagery. It does this by optimizing two aspects of the texture mapping process. One, a more selective approach to saving textures called *clipmapping*, and two, an economically resourceful method for retrieving and rendering textures in real time that relies on a novel method for administering the responsibility of memory and storage. This efficiency in modeling gives the (false) appearance that Google Earth works off of one giant, endless texture available for users' view alone—hence the name the *Universal Texture*. The Universal Texture method is one of Google's few software patents, under the title of *Asynchronous Multilevel Texture Pipeline* (AMTP), and Bar-Zeev admits that against his belief that no software should be patented, this is might be one exception to the rule. It is, as Bar-Zeev notes, an incredibly clever piece of engineering.

On the computation side, the AMTP patents a "texture loading pipeline that operates on a source texture having one or more levels of detail."[187] Put another way, the AMTP patents a process consisting of multiple and asynchronous processes that both organize, and are inherent to, texture mapping in 3D virtual cartographic software. AMTP is distinct for the way in which it segments the topographic Earth texture not as large tiles to be loaded and reloaded on your computer screen but instead loads the central most focal point of your viewing at all the necessary levels of detail. This is the role of clipmapping. Clipmapping's predecessor, *mipmapping*, stores textures at various levels of detail and resolution, and performs image processing and filtering ahead of command so that the mipmap texture corresponds to the size of the polygon it's using: "For example, if the polygon is a square having four pixels on a side, the mipmap level having sixteen texels [a pixel in a texture,

[187] Tanner, Asynchronous multilevel texture pipeline.

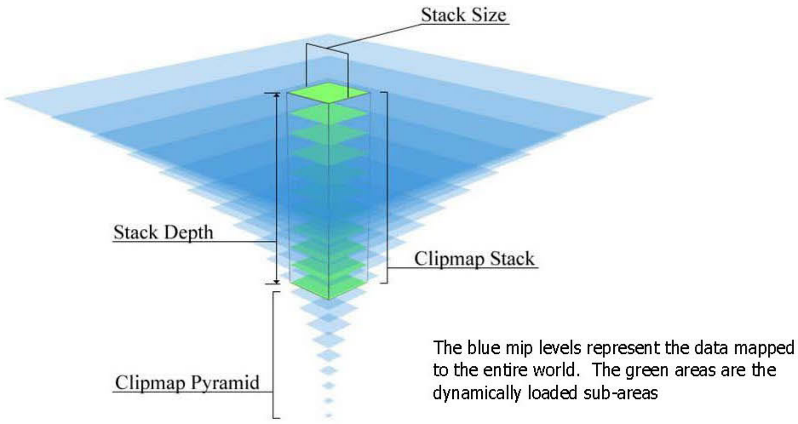

Figure 17: Diagram of clipmapping.

sometimes also known as a texture pixel] will be mapped onto the polygon."[188] Clipmapping also stores textures at various levels of detail but differs significantly from mipmapping in that it is "limited to a fixed but roaming footprint[189] … [which] means that each clip-level is both twice the effective resolution and half the coverage area of the previous."[190] This technique allows users all the benefits of a mipmap but by only loading the parts relevant to any given view greatly decreases strains on memory, load time, and processing. "Put another way," Bar-Zeev writes:

> Google Earth cleverly and progressively loads high-res information for what's at the focal 'center' of your view … and resolution drops off by powers of two from there. As you tilt and fly and watch the land run towards the horizon, Universal Texture is optimally sending only the best and most useful levels of detail to the hardware at any given time. What isn't needed, isn't even touched.[191]

While the experience of using Google Earth might summarily promise a God's-eye view on the world– and the title *Universal Texture* purports to put an entire universe

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[188] Tanner, 2003

[189] An example footprint dimension is 512×512 pixels wide, which is what Bar-Zeev offers as the Google Earth preference.

[190] Avi, "How Google Earth [Really] Works," *Reality Prime*, July 3, 2007, http://www.realityprime.com/blog/2007/07/how-google-earth-really-works/.

[191] Ibid.

at your fingertips—it is actually this clever piece of engineering determines not only what you see, but what is *important* for you to see. By linking resolution and framing with storage and retrieval, the AMTP makes clear that vision in the Google Earth virtual world is determined by hardware.

"Ninety-nine guys would throw up and they still made the hundredth guy get in"

However, the early history of AMTP and clipmapping shows that its considerations for vision and standards of realism are actually far more inflected with human consideration than this interpretation might suggest. Chris Tanner, the inventor of the AMTP and clipmapping, explained to me in an interview that—like many software—the clipmapping that is so fundamental to Google Earth originally came out of his time working for Silicon Graphics Inc. (SGI) on flight simulators.[192] At SGI, Tanner was in his early 20's and a recent graduate of Princeton University. He described the energy at SGI almost as if it was an elite and high-functioning fraternity house. "It was the Google of the 1990s," Tanner says, with no hint of irony, "When I was there, it was like a college atmosphere. All of my friends and my now wife … we worked 24/7 at Silicon Graphics for like, three years, where we were probably with each other all but six hours of the day, seven days a week, for … three years."[193] SGI was working on cutting-edge projects at the forefront of computation for contractors with bottomless pockets like the U.S. Army and Disney. Tanner describes the SGI office as being littered with SGI t-shirts. Corporate logo t-shirts are apparently a very popular trend amongst Silicon Valley startups, though Tanner ventures that SGI were among the first to do it. He reminsces, "The first [t-shirt] I got was, *Silicon Graphics: the coolest computer company on the planet,* and it had a

[192] SGI was a high-performance American computer manufacturing company active between the years of 1981 and 2009.

[193] Christopher Tanner, Interview with the inventor of the Asynchronous Multilevel Texture Pipeline, interview by Nicole Sansone, Interview via Apple Facetime, August 14, 2017.

picture of *Jurassic Park* on it. All of the movies that were made in the nineties were all done with SGI hardware."[194] SGI was the stuff of every slightly tech-inclined, 20-year old's dreams: a job that required, as Tanner recalls, "basically working on cool problems in an environment with a bunch of other people that—that's all that they thought about, and … trying to see how much we could accomplish and how much we could influence things."[195]

Yet the high reward was not without high-stakes. Along with the long working hours, intense comradery, personal ambitions, and competition, big budgets furnished both exciting projects and big expectations for results. Tanner recalls that while he was developing AMTP "there was a billion dollars of hardware that was on back order, waiting for my algorithm to work on the new hardware for clipmapping."[196] "I started working in different places," he tells me, "because I started getting calls every three hours about whether it was working or not, for like three months, seven days a week, and, *Hey, can I help you? What do you need?*"[197] Tanner goes on:

> I had this woman who, at that time was my manager, in theory, used to be my peer. She was somebody who never slept more than two and a half hours, and she was a little bit OCD. It was not helpful. There was a lot going on that, because all these people were building all of this hardware, to be able to go to the next generation of simulators, and they wanted this new feature that we were working on.[198]

The intensity of the work pace and environment took its toll. Tanner tells me of how a local newspaper came to Silicon Graphics once on a Saturday because "They knew that the people at Silicon Graphics worked so hard, and so they stopped by one of the labs at 2:00 in the morning. There were still like 25 of us there

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194 Tanner.

195 Tanner.

196 Ibid.

197 Ibid.

198 Ibid.

working."[199] The reporters went in and interviewed some of the SGI employees, including Tanner. Tanner's first debut appearance in the local Silicon Valley newspaper read: "Christopher Tanner, a tired, ruined looking young man…"[200] Tanner was just twenty-four.

The catalyst of working on what would eventually become AMTP came out of this high-stakes, high reward, highly competitive environment. Tanner recalls that while he and his team were working on flight simulators at SGI, his boss attended a trade show where he saw a flight simulator by Evans & Sutherland[201] "where you can fly over and it's all real imagery."[202] Tanner tells the story of how his boss came to him, saying "These guys have this flight simulator where you can fly over and it's all real imagery … I want you to go figure out how to do that. How can we do something like that? I have no idea how they did it." And with that, Tanner remembers, "We sat there brainstorming for a half an hour, and then he left."[203] *Figuring it out* would become Tanner's life's work for the next few years. The "real imagery" that Tanner's boss was so taken with was a departure from what the current practice at the time in texture mapping which included using generic (as Tanner describes it) or stock photos of a house, for example, to map onto polygons to create the feeling of moving through a space. Instead, as Tanner and his colleagues would work out, the imagery Evans & Sutherland were using was being stitched together *as* users of the flight simulator flew overhead.

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[199] Ibid.

[200] Ibid.

[201] Evans & Sutherland was founded in 1968 by two professors in the Computer Science department at University of Utah and is "a pioneering American computer firm in the computer graphics field." Tanner recalls that Evans & Sutherland were making "all of the multi-million-dollar flight simulators for the U.S. government at the time." Their simulation business, which primarily "sold products … used by the military and large industrial firms for training and simulation" was sold to Rockwell Collins in 2006.

[202] Tanner, Interview with the inventor of the Asynchronous Multilevel Texture Pipeline.

[203] Tanner.

From the outset there were a few sets of issues to be resolved if this flight simulation technology was to be replicated. One was how to avoid "seams" at the borders of where one texture stopped, and another began. This was also particularly tricky because of a basic property of texture mapping. As was discussed earlier, texture mapping brings together two opposing entities into a cohesive unit. Similarly, Tanner faced the challenge of wrapping a spherical polygon with rectangular images of the Earth, and at different resolutions and fields of distance. "You can't store the whole [texture] at a high resolution, so what happens is every time you have to switch resolutions, there's a hard seam. In the images, you can actually see all of these little patches. It looks like a little quilt," Tanner explained. [204] The entire project was characterized by this constant pull between the unyielding and rigid geometry of programming, pixels and computation and the fluidity of an approximate "real world" experience: "You start thinking about those two sides of the problem, which is one, we have this artificially created representation where we're using these polygons and triangles … Yet, our eye is just seeing this image on the screen, which is doing the analog interpolation of these million pixels." [205] Add to this challenge that even as you could abstractly represent how to bring the amorphousness of the physical world into the calculations of digital representation, there was the additional challenge of "the architectures of the hardware itself." As Tanner explains, the AMTP "was a very powerful metaphor for how to move giant pieces of data through computer systems at the time. Where I could get a huge amount of efficiency from the hardware by working in bulk, and I would only need a fixed amount of computer and image resource to be able to do that stuff." [206]

As Tanner began to solve these problems and configure the early iterations of AMTP he started considering what it would mean to scale up to work on a

[204] Tanner.

[205] Tanner.

[206] Tanner.

planetary stage. "As you start thinking about this stuff, you're like, *If I can already do it for 32K by 32K, why shouldn't this work on a bigger scale?*" Tanner adds, "I actually kind of got a little bit of a movement inside, and I said, 'We need to put this on a globe, because that would unify the whole space. It would actually make the coordinate systems, so that people didn't have to hack the geometry at all. The geometry could all be the planet.'"[207] Tanner converted cyber space into the actual space of our Earth and immediate cosmos precisely because it was a space that had already been segmented into the polygons that were required for texture mapping and modeling; it was, incredibly, already computational because of its existing coordinate system. With this problem solved Tanner's focus was necessarily redirected to refining user experience. While solving the problem of bringing together physical space and rendering was simplified in this move to scale up it also had the effect of amplifying user expectations. This became an issue not of what we see, but of how we see it. As Tanner described it:

> All this stuff … mapped back to the visual perception. *What are you doing? What are you seeing as a human being?* Lots of interesting experiments that we had heard about as we were doing all this stuff, that they used to torture all of the … Air Force guys in these flight simulators. Ninety-nine guys would throw up and they still made the hundredth guy get in and throw up.
>
> It turns out that our eyes … our periphery vision has an incredible sensitivity to movement. What happens is when you change the way that something looks, even though it's insignificant, on your periphery vision your eye goes there. These guys couldn't stop looking around because all of this stuff was changing as they were flying through it. It was freaking them out because they would look … and then the computer would draw it correctly. It would be like nothing's changed, and then they would look away and all this stuff would really freak them out. [208]

Clipmapping's lack of peripheral vision wasn't just a computational solution but also an act of mercy. Given the sensitivity of human peripheral vision and its nauseating impact, cutting out the outer fringes of a texture's visible field in order to save computational load was a no-brainer. The AMTP also contains a second solution to

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[207] Tanner.

[208] Tanner.

the problem of the sensitive peripheral vision. To avoid the “freak out” when users would look away and then have the computer (appropriately) redraw their view, AMTP links the motion of looking to point of view. This is dealt with through *toroidal roaming*, wherein “an arbitrary rectangle, or other bounding shape, specifies the textures in the tile cache to page into the texture cache. The rectangle moves as the region of interest changes.”[209] Whatever imagery or place that falls outside the region of interest is deleted.

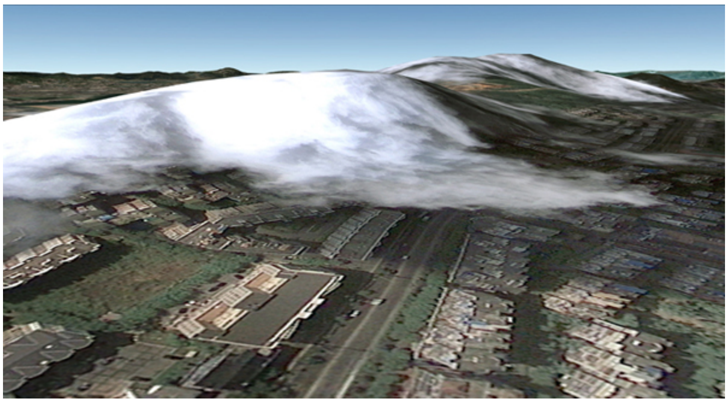

Figure 18: Screenshot of Google Earth before cloud removal

Our Virtual Earthworld

The computational design and structure, as well as the display and user experience of Google Earth, tells us a few things about the virtual world we enter into when we use Google Earth. For one, as Valla notes, Google Earth is “an automated, statistical, incessant, universal representation that selectively chooses its data,” that has no nighttime.[210] Google Earth is also in a constant state of refinement. Along with overpasses there is the problem of bridges, sometimes skyscrapers. There is also at times the problem of cloud cover in the textures

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[209] Christopher C. Tanner, Asynchronous multilevel texture pipeline, US6618053 B1, filed October 6, 2000, and issued September 9, 2003, http://www.google.com/patents/US6618053.

[210] Valla, “The Universal Texture.”

themselves—a persistent issue in overhead imaging, as we will later see—and a side project that Valla has also taken on, archiving the cloud images before they are corrected out. The virtual world of Google Earth presents two simultaneous and conflicting narratives about itself. In one version, the platform positions the user at the center of the virtual world. The world is literally built around that singular users' interests: where they look, where they want to go, what they can stomach to see. Because the virtual world in Google Earth does allow for interactivity with other users, it is this narrative of the virtual world goes uncontested. Google Earth's virtual world, as Gurevitch has argued, presents the earth as having "been fabricated as a digital object purely for the viewer" and this in turn has the effect of imbuing the viewer with a sense that they do "not simply inhabit a seemingly omniscient power of scopic automobility, they also become the reason that the simulated earth exists at all."[211] Seen another way, *this* version of the narrative is somewhat of a farce. The user-centered experience promises a God-like view onto the Earth that turns out to be a highly-constructed and constrained animation of the limits of computation in a certain place and time. Instead of the whole earth being laid out and roam-able for one's viewing pleasure, users are instead placated with a charade, while the real work of visualization takes place behind the scenes, secretly, in a code that already determined what you could see in the '90s by a young man in his 20's tasked with figuring out how to copy and improve upon the technology of a competitor.

I would contend that neither *one* of these narratives is a fair enough account of what is taking place. All the same, while they might not be probable, they are possible. And these possible narratives reorient the entire structure and understanding of the virtual world, carrying with them the capacity to rethink and second guess our interactions with it. No doubt, as Gurevitch claims, "In booting up

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[211] Gurevitch, "Google Warming," 91.

the program and commanding the visualised data into being, the contemporary user exists in a new dynamic to the visualised earth."[212] We realize this virtual world has many portals by which to enter. *Postcards from Google Earth* displays a convergence of just some of these entrances and overcrowdings. Each of the ways that *Postcards from Google Earth* introduces a new framing and presents an entirely new narrative of the virtual world contained and animated through the Google Earth platform, complete with its own values and belief systems. For instance, Schpok's corrections for the Google Earth texture mapping algorithm signals that for Google the company, Valla's project brings into relief moments of misfire and correction. These moments are not problems to be eliminated but rather signal a software transcending its programming and achieving a level of output that exceeds its original, coded intention. On the part of *Postcards from Google Earth,* and if we take this project as a photography series—as Valla does—then these moments exist for our bemusement: they allow us to be smug about a technical system that can see everything and yet can only imperfectly rebuild it.

What these examples can really underscore is that the digital image is not only fragmented, it is not only *drawn from* a disparate number of sources, but it is also being shaped and directed by an equally diverse set of factors on the other end. And a necessary consequence of this two-sided process is that standards and conventions of realism need to now be renegotiated to reflect these converging influences. These images show that, far from the days of the single viewer and one-point linear perspective, our expectations of, and sensitivities to, what can be deemed *realistic* is a whole set of conventions, numbers, and influences that all have to be delicately and uniquely calibrated according to their computation. Looking real or appearing familiar isn't a standard we can rely on anymore because the world is being formed by algorithms that have appropriated this standard and transcended it.

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[212] Gurevitch, 91.

The Politics of Render

In this chapter we explored the politics of aesthetics that become entangled when creative decisions are offloaded onto algorithms. In *Postcards from Google Earth* we saw how computation can be made to achieve incredible feats—bringing the entirely of the world's topography into one, seamless view from the comfort of a personal computer—and is equally a blunt tool. Computation can synthesize elements (such as GIS archives, data elevation models, planetary textures) and perform tasks with incredible ease and efficiency, but to do something is not the same as doing something *right*. *Postcards from Google Earth* makes a case for the eternal cooperation amongst differing gazes and forms of logic. In the example of a software meant to give human beings a sense of flying overhead and seeing their world re-presented to them exactly as they expect it might look should they be flying creatures, algorithmically-generated images cannot be expected to operate in full autonomy. In such instances computation must always work in tandem with the audience for whom it performs. Data must be contextualized, conditioned, and corrected to meet its end results. The alternative is true as well, and this has what been more tacitly developed in our later discussions of *Postcards From Google Earth*. The broader context and history of *Postcards from Google Earth*, starting with the history of developing clipmapping as a solution for nausea-stricken, training fighter pilots frames the origins of such a technology in a very different manner. Sprung from the military industrial complex (as so much of our technology has been), texture mapping was a means to an ends; a way to familiarize pilots with techniques that kept a singular, standardized body safe as it careened through the air in sleek fighter jets. As time has passed, clipmapping has been sold as an improvement on this promise for more variant audiences while also promising higher levels of realism and more authentic experiences of the otherwise unreal. Clipmapping is a feature for making fantasy seem more in reach, though it developed in the stench of sick and stale coffee and as a means for harnessing the power of fantasy to prepare pilots for real-life, urgent crises. Texture mapping's (and clipmapping) use across domains and disciplines infuses all of its projections with opacity. Does our fly-over, seamless view of the topography below provide greater realism? (For pilots, yes). Or does the way texture mapping limits our vision to a tightly bound square position users in an inverted fantasy where fewer things are possible (such as seeing through your peripheral vision) but the consistency and seamlessness of the experience of such a world are such as to give a false illusion of limitlessness?

Postcards from Google Earth and its broader context map onto the larger issue of illusion and realism in the visual display of data and aesthetics more broadly. When Valla spoke to me of *Postcards from Google Earth* as a photography project he did so with an earnest searching; asking if, somehow, in our contemporary milieu's protocols and algorithms might constitute systems that move data into other forms of representation—separate from those objective forms like painting, but still something that might stand far apart from human interference. His attempt to characterize this "something" was telling:

> If we go back and rethink about photography in that we might realize that photography never really was indexical or photography as the way we have come to conceive … has always just been a metaphor [that's] more or less useful, but that definitely, in a contemporary [context] where we have so much, let's call it … I don't know, I don't have a good word for it, data? I don't want to say *manipulation* because that sounds like we're inserting something else into it, but it's sort of like, algorithmic and procedural processing of these image sets give us representations that still bear some connection to reality, but what that connection *is* is more complicated to parse than the simple metaphor of indexicality ever led us to believe. [213]

It might not be possible to solve for this "something", but instead we might consider that this "something" is located in precisely the entanglement of realism and illusion. *Postcards from Google Earth* and texture mapping as a technical process more broadly are always involved in a continual orchestration of fact and fiction; of sensing data (from light on sensors) and aesthetic judgments, of craft and programming. That

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[213] Valla, Interview: "Postcards from Google Earth" project.

such a fact would reveal itself at the moment of users' engaging in new ways with novel expressions of the cartographic isn't in itself novel but instead a transformation of the conditions of seeing. The aesthetics we are jolted alert to are not those in the programming of clipmapping, or the synthesizing of DEM and satellite image into a singular scenery, or even in the God-like experience of the *Universal Texture*. Rather it is in the way that *display itself* becomes a politicized framing of data. The aesthetics of the display becomes the portal by which we are suddenly overwhelmed by the technicity that is installed into and expected of our human eyes and craggy software. Breakdown of this aesthetic order of display reads not as glitch but rather as disorientation.

It is one thing to engage in the visual display of data that is off in some way. However, it is a wholly uncanny situation to experience the doubled experience of off-kilter engagement and display. For centuries in history we have been taught as viewers to see *through* display structures. This is a practice that has continued with computer users. *Look into the monitor* (through the glass, directly at the light). *Look around the virtual world* (you can't, you're in a three-dimensional space offering only optical deceptions). These are not moot nor harmless details about the way we interact with computers and computer graphics. They are framings of power in themselves; an overlooked component in the politics of data.

We will continue to return to this theme of the politics of data that happens at the moment of display: when what has been collected and computed is replayed back to an audience, and how. This inquiry picks at the broader theme running throughout this thesis of "the relation of image to meaning and to modes of looking and interpretation", where the *modes of looking and interpretation* are understood as human, non-human, and environmental actors.[214] This theme is also of central concern to scholarship on the critical engagement with images in epistemic cultures

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[214] Grootenboer, *The Rhetoric of Perspective*, 5.

and scientific computing, as well as art history. In the next chapter we will approach this issue from the perspective of the machines that make this display possible, asking what it is software "sees" when we feed it data and force it into modes of display.

Chapter Four: Blender

The MarCO-A cubesat also indirectly performed science during the flyby as its radio signals were occluded by the planet as it passed behind Mars.[215]

– *Jeff Foust reporting on the announcement of cubesats results during a deep space mission to Mars.*

FRELLED: a non-taboo replacement for fuck. (tv series, *Farscape*) note: rarely used in the sense, 'to engage in sexual intercourse'; Word made popular in the TV series, *Farscape*. More like a replacement for the more common cuss words. Easily interchangeable with different emotional responses; A swear-word invented for use in the *Farscape* series … usually as an adjective.

Introduction

In the previous chapter we explored how the contemporary field of vision is being shaped and formed algorithmically. The case study of *Postcards from Google Earth* highlighted that this algorithmic shaping is not to be understood as solely the byproduct of digital or automated processes. Instead, a brief history of the development of clipmapping—developed as a more sophisticated technique of texture mapping satellite images in real-time on personal computers—shows how these algorithms are directly linked to, and influenced by, various properties of the human. The utility of clipmapping as a technique has contributed to its widespread use across a number of important domains (here, cartography). This distribution, coupled with the partly-occluded information about how human culture and human vision are hardcoded into clipmapping, makes pervasive the misguided belief that contemporary vision is distinctly formed by digital processes alone. Such beliefs pose significant challenge to how we might in turn understand the relationship between representation and image. The stakes of such a challenge become more evident when we take into consideration the considerable role that images play in the sciences.

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215 Jeff Foust, "MarCO Success Vindicates Use of Cubesats on Deep Space Missions," SpaceNews.com, November 26, 2018, https://spacenews.com/marco-success-vindicates-use-of-cubesats-on-deep-space-missions/. NASA describes cubesats as a class of nanosatellites that have "advanced into it's own industry with government, industry and academia collaborating for ever increasing capabilities." See: Elizabeth Mabrouk, "What are SmallSats and CubeSats?," Text, NASA, March 13, 2015, http://www.nasa.gov/content/what-are-smallsats-and-cubesats.

We can use Blender's ambivalent position to the sciences to draw parallels to the discussion in the previous chapter on Clement Valla's project *Postcards from Google Earth*. Blender's availability to those both inside and outside of the epistemic disciplines affords new positions and outlooks on the tool itself, as well as the knowledges it is capable of producing. Crucially, as we will explore in this chapter, these outlooks are not always human or human-oriented. Blender is conditioned not just by a human culture but instead its openness also allows for other technical objects to become operative in the prescription of its functions and realism. In this way we can think about how Blender itself functions as an epistemic environment: a site where not only is knowledge made and viewed but also that such processes should happen on registers that are inaccessible or not intended for human viewers.

Traditionally, art history has two predominant modes by which it relates to the sciences. This has been either through the late-Romantic period move to use science to inform images, or in the anti-romantic, modernist gesture of using science as a means of deconstructing images back to their origin.[216] As James Elkins notes, while such a statement is not untrue it is also a highly impoverished perspective onto the ongoing and more quotidian relationship between science and art, and particularly between science, art, and the rich deployment of images in both fields. Alternatively, sociologists and philosophers of science have increasingly made use of the unstable ontology of the image to expand the critical lens by which they understand the production of knowledge. Peter Galison's work on the material cultures of physics plots the variable implementations of images and image-producing machines that give shape to the scientific experiment as a form, constituting the both *experimenter* and *experiment*.[217] Klaus Amann and Karin Knorr

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[216] James Elkins, "Art History and Images That Are Not Art," *The Art Bulletin* 77, no. 4 (December 1995): 555, https://doi.org/10.2307/3046136.

[217] Peter Galison, *Image and Logic: A Material Culture of Microphysics* (Chicago: University of Chicago

Cetina's work with a molecular genetics lab propose a protocol that encapsulates the process by which scientists and technicians formalize sensual phenomena into images understood *as* data, which can then be verified and used as evidence in scientific research.[218]

These expanded approaches to the image and the broad moves that the image is allowed to make in transgressing disciplinary borders is a reminder of what W.J.T. Mitchell wrote when in 1984 he asked, *What is an image?* Mitchell explains that what is typically considered *the image proper* is our understanding of the image from institutional discourses—something that is optical or graphic (like a mirror reflection or a picture) and therefore stable.[219] However in practice, human approaches to thinking the image are much broader, largely falling into the categories of mental and not-mental images. In this sense, Mitchell shows us that "images 'proper' are not stable, static, or permanent in any metaphysical sense; they are not perceived in the same way by viewers any more than are dream images; and they are not exclusively visual in any important way but involve multisensory apprehension and interpretation."[220] A broad conclusion we might draw from this is that humans intuitively understand the image to be more than just *pictures* but less than the sum of all visual sensory experience. This unspoken intuition seems to be a crucial component of the consensus that emerges amongst scientists using images to help making knowledge, despite that these scientists have very little critical reflection on what precisely this thing *the image* that they're working with actually *is*.[221] Such a consensus legitimates the open and variable ways that images might be

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Press, 1997).

[218] Amann and Knorr Cetina, "The Fixation of (Visual) Evidence."

[219] W.J.T. Mitchell, "What Is An Image?," *New Literary History* 15, no. 3 (Spring 1984): 503–37.

[220] Mitchell, 507.

[221] I don't think this is too bold a statement to make given the way that unspoken consensuses seem to emerge from other uses of the sensual body in similarly unexamined ways. In separate writing on

used while cleverly tabling any anxieties about what the uncertainties image itself—as both a tool and format of information—might bring to the results.

It is perhaps this careful straddling of selective ignorance and intuition that has also contributed, at least in some small way, to the seamless outsourcing of our faculties of optical observation onto machines and sensors. Using machines to bring phenomena into visibility is, of course, at certain scales a matter of necessity. But what strikes me as unusual is the way in which critical scientific appraisal or judgment seems to loosen on the topics of how images, machines, and display might all introduce significant mediations into scientific results. This lapse is most apparent in the use of simulation software and modeling, which are computer techniques imported into the sciences but which borrow heavily from art history and visual culture. Given the sharp divides between these disciplines (which are even played out on digital images and their pixels, as we saw in chapter two) it is telling that not more attention is paid to the ways that machines and images in their forms and hardware alone could present uncertainties in scientific results. In both Knorr Cetina's and Galison's work the relationship between image-producing machines and scientists is explored in great detail, with productive conclusions being drawn on the ways in which machines produce both good and bad effects that must be accounted for in scientific results.

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the molecular biology lab, Karin Knorr Cetina has written of the primacy of doing scientific work with one's body. She writes: "experimental work is skilled manual labor … But the body is also more than simply what carries out an action. It is called upon as an information-processing machine in research." She notes how junior scientists are asked by advisors to see and learn to do things "for themselves" and while senior scientists will also make similar demands. This imperative to *see* and *do* experimentation with one's own body (as opposed to leaving such processes to others or automation) comes from the belief "that doing the procedures oneself will increase the chances that they will work" and "also by the idea that only through personal experience ·does one know the real meaning (the strengths, the weaknesses, the implications) of the results obtained: To have performed the relevant tasks of an inquiry oneself-or at least to have seen them done-is the capital on which trust in the results is based. *Results not seen directly or not produced through embodied action cannot be properly evaluated and are prone to misinterpretation*." (Emphasis mine). See: Karin Knorr Cetina, "Evolutionary Epistemology and Sociology of Science" (Transitions in Recent Economics: Studies in Alternative Research Programs, Capri, 1989), 98, http://link.springer.com/chapter/10.1007/978-94-009-3967-7_8.

However, as the overarching theme of this chapter will propose, visual phenomena cannot strictly be contained in the tools that are used to bring it into visibility nor the human bodies that make this visibility legible to other audiences and purposes. Instead, visual phenomena are squarely located in a nexus of visibility. The catalyst that enables phenomena to become sense data, and then information, is always one that initiates, and is initiated by, particular modes of seeing, performed by particular bodies of sensing (for us here, optical sensing), as a way of extracting and reconstructing events into evidence. With phenomena that exist on scales not readily available to human sensing (microscopically small, cosmically large) this nexus of visibility grows to include technical machines and digital processes. To what extent can we say that image, hardware, software, and algorithms *see* phenomena, and by what structures or effects can we understand this *seeing*? This question is under-examined in discourses of laboratory studies or material cultures of sciences, and more so with respect to digital machines and properties. Answering this question also offers the chance to account for potential uncertainties that working with machines as a method of proxy vision bring. My contribution to answering this question is undertaken in this chapter in the exploration of the open source, 3D computer graphics software Blender and its relationship to the production of knowledge in the natural sciences.[222]

Blender is a software with widespread application across disciplines, minimal

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[222] This chapter is going to focus on the native, desktop client Blender and not focus on webGL, a standard for doing openGL in browsers. This edit is not for reasons of their unimportance or irrelevance. To the contrary, the implications of how webGL networks graphics coding, as well as the differences that are built into their configurations as two-dimensional versus three-dimensional work spaces, which includes relinquishing the pixel-per-pixel control in the former in order to work in the latter. Not only this, the fact that there exist specific libraries of webGL made to work with geospatial and satellite data is significant, such as Cesium.js and. One, it shows the pervasiveness of how much computer graphics regularly deals with and is expected to handle geospatial and satellite data. Two, it shows that in spite of this symbiosis geospatial and satellite data still pose challenges to computation and networked servers so distinct as to require their own libraries and coding languages.

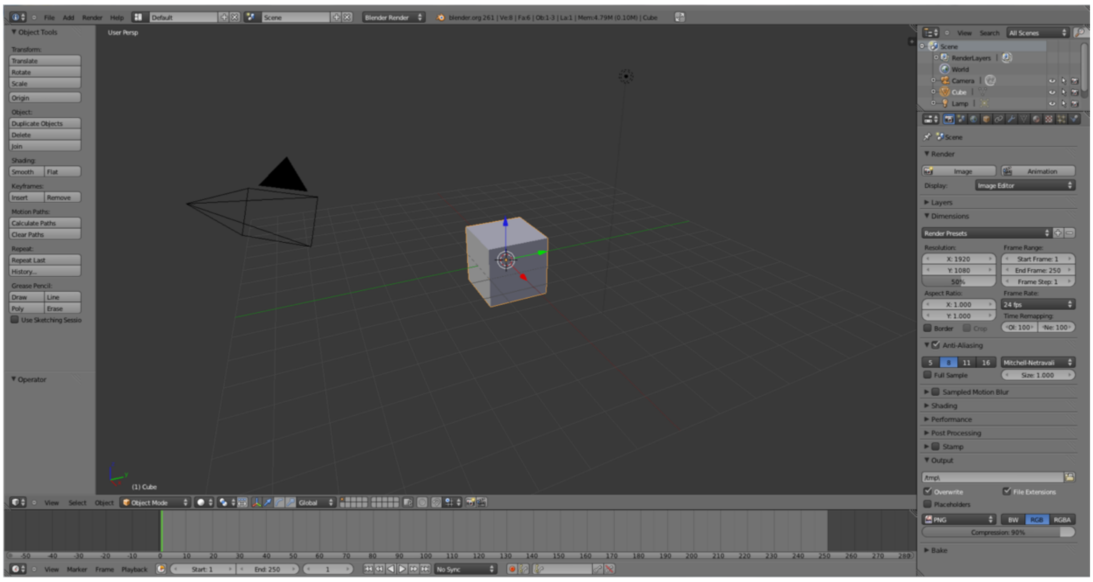

Figure 19: Screenshot of default Blender interface.

standardization and high customizability (see figure 19). These qualities set the terms by which Blender is positioned within, and in relation to, to epistemic cultures. I am here relying on the term *epistemic cultures*, as opposite laboratories or some other science-specific context, for a specific reason. *Epistemic cultures* is the term developed by Knorr Cetina to reflect science as contained within spatio-temporal regimes designated by practices that *recast* (and recreate) objects as oriented towards the positive production of knowledge.[223] Regarding the sciences as epistemic cultures and settings bypasses the more irrelevant specificities of individual disciplines and practice in favor of emphasizing the continuities in the production of knowledge, across many practices and, crucially, towards many forms of knowledge. This openness is useful for our approach here, trying to understand a software that traverses disciplines, uses, output, and practices, but which has been largely conceived of as having specific application. Blender was not created explicitly for use by scientists despite having been adapted in many contexts by them. However, it is

[223] Knorr Cetina, *Epistemic Cultures*.

the flexibility and modularity of Blender's software design that makes it both useful and anathema to institutionalized scientific practices. In some cases, Blender's openness means that it can only be used as a tool to assist scientists in their thinking (much like a brain map), and that these results must then be translated into more proper formats of scientific knowledge. This ambivalent relationship between Blender and its uses in the sciences and by scientists reflects less on the design of Blender and more on the state of institutional science and its discourses of knowledge production. Here again, Knorr Cetina's work is a constant touchstone.

In this chapter we will continue to explore how the conditions of visibility are transformed by digital technologies and how these conditions have the capacity to set agendas for epistemic cultures. We will explore how Blender's design, interface, and functions are adapted to the study of natural phenomena. At the same time that we do this we will also ask the parallel question of what it is, exactly, that is being made visible and how that *making visible* might inflect some unexamined influence on human perception.

Blender

Blender is a unique example of a 3D computer graphics and animation software, with a unique history containing a unique set of characters. At the same time, Blender comes out of a shared history of the development of computer graphics equpiment and software, out of the history of computers and their attendant links to politics, culture, and society. Founded in the early 1990's as an "in-house, proprietary tool" for the independent Dutch animation studio NeoGeo, Blender has neither been ahead of its time (at least, not by much) nor is it a rediscovered classic.[224] Blender is often referred to on online forums as the *swiss army*

[224] Julia Velkova and Peter Jakobsson, "At the Intersection of Commons and Market: Negotiations of Value in Open-Sourced Cultural Production," *International Journal of Cultural Studies* 20, no. 1 (January 2017): 18, https://doi.org/10.1177/1367877915598705.

knife of 3D animation and rendering programs. It's generally hailed as pretty good at everything. Yet, ranked against other competing programs such as Maya (as we will be looking at in greater detail here) and Z-Brush, users can easily provide a ranking: Maya is better for animation, Z-Brush for sculpting, for example.[225] Why, then, does Blender make for such an interesting case study here?

For one, Blender is *free.* If there was one quality that all users would agree sets Blender apart from the rest, it's that it is wonderfully powerful as compared to its cost of nothing. Blender is a popular choice for professionals working on film, 3D animation, and video games, but as a free, all-around powerful modeling software, it comes at very low risk to try out in other arenas. As of 2017 Blender's official site was advertising that "The official Blender release [had been] downloaded over 16K times per day, half a million times per month, for a total of 6.5 million times last year."[226] The software's accessibility makes it a popular resource for professionals and non-professionals alike. Increasingly as well, scientists are amongst the professionals that are using Blender. Blender can help researchers visualize events that are impossible to witness: events that either take place at the extremes of time (past or future), events that take place at remote or inhospitable locations (deep in space, the arctic), and events that take place at extreme scales (very small, cosmically large). We can see one such example of Blender's growing popularity in the sciences through an article published by Brian Kent, *Visualizing Astronomical Data with Blender*.[227] The article does not work to further any knowledge or

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[225] As an example, one might check out this quora thread: "How Does Blender Compare to Other 3D Animation and Rendering Tools? - Quora," accessed December 1, 2018, https://www.quora.com/How-does-Blender-compare-to-other-3D-animation-and-rendering-tools. The attitudes here are pretty indicative of what I have seen elsewhere in my browsing, on Blender's forums, on reddit's subreddit's dedicated to Blender and modeling, and elsewhere.

[226] Blender Foundation, "Statistics," *Blender.Org* (blog), accessed July 30, 2018, https://www.blender.org/about/website/statistics/.

[227] Brian R. Kent, "Visualizing Astronomical Data with Blender," *Publications of the Astronomical Society of the Pacific* 125, no. 928 (June 2013): 731–48, https://doi.org/10.1086/671412.

discovery in astronomy, but instead is a manual for how Blender can be managed and applied to the kinds of work that is done in astronomy.

Blender's cost-benefits garners it more goodwill than just a large user-base. There seems to be such a persistent gratitude that such a product could be made free that this gratitute has served as a social currency in itself. The initial idea for Blender, even before it was offered as a free software, was powerfully enticing to its prospective community. Julia Velkova notes that in the 1990s the computer industry underwent a restructuring that prompted the development of Blender. "Until the mid-1990s," she writes "software for computer graphics development was distributed as an add-on to very expensive hardware that media creators anyway needed to invest in."[228] Blender became free and opensource under a GNU/GPL license as a result of what Velkova and Peter Jakobsson have proposed as perhaps "one of the first examples of online crowdfunding" wherein NeoGeo raised €100,000 from its users "to resolve a debt issue with investors".[229] This early dynamic between Blender, its users, and its relationship to the market can be seen as fundamental to the Blender's success and functionality today.

Blender may be free and open source, but in certain regards Blender does not partake of the open-source culture. In an interview, Ton Roosendaal—Blender's original creator—cedes that "Open-source started with communities, Richard Stallman, the Linux and so on. This is not the way Blender started. […] the [...] other open-source projects do not look at the industry. Blender is […] not coming from this movement. It is the other way around."[230] In fact, as Velkova and Jakobsson note, it was the process of open-sourcing Blender that actually solidified

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228 Julia Velkova, "Free Software Beyond Radical Politics: Negotiations of Creative and Craft Autonomy in Digital Visual Media Production," *Media and Communication* 4, no. 4 (August 11, 2016): 46, https://doi.org/10.17645/mac.v4i4.693.

229 Velkova and Jakobsson, "At the Intersection of Commons and Market," 19.

230 Velkova, "Free Software Beyond Radical Politics," 21.

the centrality of Roosendaal. “While, in most free software projects, the community creates mechanisms for self-regulation, organization and decision-making,” Velkova and Jakobsson write, “in the case of Blender its initial founder set the framework of this relationship, navigating between his personal agenda and the wishes of the community.”[231] A key component of this agenda has been maintaining Blender as “between community and market,” according to Roosendaal.[232] This is structurally reflected in how Blender is organized. Blender is situated between three entities: the Blender Institute, the Blender Foundation, and the community of Blender users that includes its developers and artists. Blender is primarily developed by its developer community as well as with a limited number of employees employed by the Blender Foundation. Yet above all it is Roosendaal who sets the agenda and direction for Blender. Roosendaal is not simply the main developer of the software but also “recognized by the Blender user community as its ‘benevolent dictator’ for life.’”[233]

Blender’s origin story shows that it strikes two balances: one, between a centralized vision that is driven by Roosendaal and its community of developers, and two, between being “free and open source” while maintaining a relationship to markets. These balances work to Blender’s advantage. While Roosendaal’s may have the final word on Blender’s direction, for all intents and purposes Blender honors its commitments to community. To this end Blender offers a kind of radical openness through its “embedded Python application-programming interface (API)” which allows the software to be endlessly customized, rearranged, reorganized, and reappropriated to the explicit needs of individuals, sectors, and projects.[234] This kind of tailor-fit model also indirectly feeds into its second balancing strategy—

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[231] Velkova and Jakobsson, “At the Intersection of Commons and Market,” 19.

[232] Velkova and Jakobsson, 19.

[233] Velkova and Jakobsson, 19.

[234] Albina Asadulina et al., “Object-Based Representation and Analysis of Light and Electron Microscopic Volume Data Using Blender,” *BMC Bioinformatics* 16, no. 1 (December 2015): 2, https://doi.org/10.1186/s12859-015-0652-7.

maintaining a relationship to the market. Customizability promotes Blender's applicability to a range of disciplines and utility for a range of purposes. This quality, in combination with being free and open source, means that Blender is currently in use by an *astounding* number of people for an *astounding* number of different reasons, across multiple disciplines. Not only this, but a secondary result of Blender's specific social and commercial organization also enables users to be contact with a vast number of resources for tutorials, trouble shooting, and any other topic that might generally contribute to converting potential non-Blender users into fellow Blender devotees.

This customizability also means that Blender's internal standards and its standardization are highly variable. While this is something that the natural sciences have taken advantage of, for example, it also raises broader issues as to how results and experiments run in Blender might be accomodated by institutional science practices. For example, we can see parallel concerns raised in Stephen R.J. Sheppard and Petr Cizek's evaluation of virtual globe software systems such as Google Earth. The authors write, "just as the Internet is open to pornography and rampant commercialization, so Google Earth will attract spin, special interests, and amateurism."[235] The authors worry about about a level of "amateurism" that Google Earth invites with its free accessibility, and that threatens to taint the "setting" in which more valued, epistemic work is performed. Their response is a proposal for five solutions that would safeguard knowledge against the "misinformation" that could potentially arise out of a citizen science.[236] The researchers see themselves as outside of the "lay-users" who they worry threaten the purity of information

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[235] Stephen R.J. Sheppard and Petr Cizek, "The Ethics of Google Earth: Crossing Thresholds from Spatial Data to Landscape Visualisation," *Journal of Environmental Management* 90, no. 6 (May 2009): 2115, https://doi.org/10.1016/j.jenvman.2007.09.012.

[236] Sheppard and Cizek, 2116.

available via Google Earth. However, to their credit, they also concede that "a convergence of scientific/technical expertise, 3D computer modeling skills, and understanding of social responses to landscape imagery is needed". [237] This signals a crucial deficiency in technical skill and information that I would propose closes the gap between researcher and "lay-user." [238] While this is not explicitly addressed by the researchers it is nonetheless foregrounded; they write: "As lay-users increasingly enrich the information in virtual globe datasets, it is important to recognize that visualisation represents an entire language to be learned; knowing how the software works is only part of the issue."[239]

Cizek and Sheppard's debate on the ethics of using free and open source virtual globe systems highlights a breakdown that is unsurprising in how we think and treat forms of knowledge and the institutions that house them. The thin line between lay user and researcher rests on passing certain thresholds of accreditation. This threshold is rather more porous when researcher and lay-user are linked through their shared use of computational resources. Visualization, computation, and simulation/animation are all processes that the 3D computer graphics software wrests from the singular genius of the researcher. In each of these processes there inevitably comes a moment when expertise meets its limit; when user must either throw their hands up at a problem, or hand over control to an automated process into which one can only intervene, though never fully manage. I would propose that this limit is always accompanied by an encounter with the aesthetic; that when science calls on the aid of computation to assist in visual capture and/or processing, our familiar routines and protocols of epistemic practice have less effect or application. In other words, epistemic practice has fewer tools for doing epistemic work with images, and particularly with computer-aided imagery. This is a

[237] Sheppard and Cizek, 2115.

[238] Sheppard and Cizek, 2115.

[239] Sheppard and Cizek, 2115.

continuing theme of this thesis. In this chapter, we will specifically turn our focus on to how graphic software themselves produce a very specific mode of observation that is taken for granted by researchers through the particular constrictions software design and function places on perception. This work fits in with social constructivist critiques of modern scientific epistemologies, which as Mette Bryld and Nina Lykke have noted, "When pointing out that the technoscientific gaze in total control of its object is an imaginary construction [...] these critiques also emphasize that the controlling eye may indeed produce uncontrolled, unintended and subjective side-effects and excess meanings."[240] Never is this statement more true than when that technoscientific gaze offloads the work of its "controlling eye" onto software and algorithmic visibilities.

Notes on a History of Graphics Software & Hardware

It is tempting to consider the history of computer graphics through its disparate strands and communities: artists getting out-of-hours access to supercomputers, non-experts and experts logging long hours doing "blue sky" thinking. These are the most utopian facets of that prism, because as every history of computer graphics ultimately proves the connections between the military, the film industry, and digital culture are inextricable. Tom Sito writes, "At times the patronage of a government is as vital to the creation of new technology as the vision of a solitary genius." [241] A prefatory quote from Marc Andreessen reads, "I tease my libertarian friends who all think the Internet is the greatest thing. I'm like, yeah, thanks to government funding."[242] As Sito supports, most of the major breakthroughs of the 1960s and 70's such as "data storage, core memory, graphic

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[240] Bryld and Lykke, *Cosmodolphins: Feminist Cultural Studies of Technology, Animals and The Sacred*, 6.

[241] Tom Sito, *Moving Innovation: A History of Computer Animation* (Cambridge, Massachusetts: The MIT Press, 2013), 37.

[242] Sito, 37.

displays, networking, virtual reality, and more […] were accomplished due to ARPA funding."[243] I offer this as a small attempt to demonstrate how the history of computer graphics, while still in its infancy, is an elaborate tangle of polemical influences and influencers, people and institutions. From this perspective, what one might call an "indisputable" history of this complex set of characters remains to be written. I offer this as an anticipatory apology and simultaneous nod to the injustice I am exercising against this rich history by carving through it the way that I am about to do.

Blender is an outgrowth of the history of computer graphics that, in many ways began in the 1940's and 50's, but that really started to take the shape we know it today in the 1960s with the digital computer.[244] In one way, it is too challenging to begin the history of 3D computer graphics software without also going back to to the beginning of the hardware that subtends it. According to Lev Manovich, 3D computer graphics software take root in the development of the computer screen itself. In his telling, Manovich positions the cinema screen as a parallel point of understanding the history of computer screen. However, while the "origins of the cinema's screen are well known" he writes that the "origin of the computer screen is a different story... its history has not yet been written."[245] While the cinema screen explodes from the "popular spectacles and entertainment of the eighteenth and

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[243] Sito, 40.

[244] Sito's history of computer graphics is one good resource here, and he very justifiably does not provide a linear history of CG's development. However some of the events he cites from this time period as being influential for CG include the end WWII and the surplus of analogue computers that were then reappropriated for Project Whirlwind, or the conversion of the MIT lab into the Digital Computer Lab; Russell A Kirsch's development of pixel system, in coordination with the invention of the drum scanner, used to create the first digital picture of Kirsch's three-month-old son; and eastern philosophy. See: Sito, Tom. *Moving Innovation: A History of Computer Animation*. Cambridge, Massachusetts: The MIT Press, 2013.

[245] Lev Manovich, *The Language of New Media*, 1st MIT Press pbk. ed, Leonardo (Cambridge, Mass: MIT Press, 2002), 101.

nineteenth centuries: magic lantern shows, phantasmagoria, eidophusikon, panorama, diorama, zoopraxiscope shows", Manovich proposes that the history of the computer screen begins with radar.[246] With radar, Manovich writes, "we see for the first time the mass employment … of a fundamentally new type of screen, the screen which gradually comes to dominate modern visual culture — video monitor, computer screen, instrument display."[247]

In the 1950s, the U.S. was beset by a particular anixety about the threat of the Soviet Union attacking via "a large number of bombers simultaneously."[248] As a

Figure 20: SAGE radar monitors, circa 1957.

means of centralizing information so as to efficiently disperse a response attack, centers were established to receive all information from U.S. radar stations. Those who monitored from inside the centers did so from a personal computer display:

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[246] Manovich, 102.

[247] Manovich, 102.

[248] Manovich, 104.

Figure 21: Ivan Sutherland and Sketchpad.

"Whenever an officer noticed a dot indicating a moving plane, he would tell the computer to follow the plane. To do this the officer simply had to touch the dot with the special 'light pen.'"[249] This *light pen* would go on to play a crucial role in what is commonly agreed as the original computer graphics program: Ivan Sutherland's *Sketchpad* (figure 21). Ivan Sutherland's *Sketchpad* is regarded as the first "true animation program" and the first time that a computer "drew lines, and the lines formed recognizable images: a bridge, a leg moving, a face winking" rather than "a series of numbers"[250]—as well as *Softimage*, the first integration of all 3D

[249] Manovich, 104.

[250] Sito, *Moving Innovation*, 1. Sito highlights this note Sutherland as being on page 66, for reference.

processes (modeling, animation and rendering) into one software. Sutherland was a graduate student supervised by Claude Shannon. In his PhD thesis Sutherland notes, "Sketchpad need not be restricted to engineering drawings. Since motion can be put into Sketchpad drawings, it might be exciting to try making cartoons."[251]

Sutherland's work on Sketchpad popularized the idea of computer graphics at the same time that it also condensed certain strands of development in human-computer interaction. A key feature of radar that helped to make it a predecessor of computer graphics programs was its interface. Radar congregated a multiple and simultaneous amount of data onto one screen, and precipitated technology later developed for SAGE that included a range of "computer graphics programs that relied on the screen as a means to input and output information from a computer."[252] With Sketchpad Manovich emphasizes a feature that is illustrated in figure 21, that the circuit between user, data, and interface become compressed: a "human operator could create graphics directly on computer screen by touching the screen with a light pen." [253]

In this way, "Sketchpad exemplified a new paradigm of interacting with computers: by changing something on the screen, the operator changed something in the computer's memory. The real-time screen became interactive." [254] While Manovich emphasizes the temporality of this hardware shift, Paul Edwards's account of the history computer developments offers another way of understanding the overall historiography of computers. Real-time information processesing was not about an interactive interface but instead signaled a shift in infrastructures of information. "Computers linked other technologies to human beings by constituting

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[251] Sito, 1. Sito highlights this note Sutherland as being on page 66, for reference.

[252] Manovich, *The Language of New Media*, 104.

[253] Manovich, 104.

[254] Manovich, 104.

systems," Edwards writes, "constituting them conceptually, practically, and metaphorically—as information processors."[255]

A system constituted, however, is a system that can also be de-constituted, dispersed and distributed. In Ann Friedberg's history of the evolution of the interface through the metaphor of *windows*, she writes of the emergence of "multiple windows" as being a key moment wherein "modes of identity," time and place are "in a fractured post-Cartesian cyberspace, cybertime."[256] Friedberg does not distinguish, as Manovich does, between a cinematic or computer screen—instead they all form a *screen practice*. In this framing, the graphical user interface (GUI) is the historical break that separates out the computer screen from other forms. *Image projection*, that fundamental component of *screen practice*, shows that a constant of the history up until the GUI is that "viewers faced projected images on a screen, and most commonly, these images were projected sequentially rather than arrayed adjacently."[257]

Edwards, Friedberg, and Manovich each provide a different way into understanding the roots of Blender and 3D computer graphics & animation software. In Edwards's frame, we can see Blender as carrying with it the genes of that prominent genre of computer history that emphsizes the "engineering/economic history focusing on computers as devices for processing information."[258] Blender can satisfy the criteria to see computers and their evolution as more and more of a push towards developing the "digital calculating machines."[259]

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[255] Paul N. Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America*, Inside Technology (Cambridge, Mass: MIT Press, 1996), 125.

[256] Anne Friedberg, *The Virtual Window: From Alberti to Microsoft* (Cambridge, Mass: MIT Press, 2006), 235.

[257] Friedberg, 195.

[258] Edwards, *The Closed World*, xi.

[259] Edwards, xi.

These calculations, of course, take place at higher levels of integration and offer more complex procedures. The speed and efficiency with which Blender is able to calculate for shading behaviors, or objects in motion, is hidden by the simplicity of needing only press an option on one of the program's interface tool bars. Edwards also argues for understanding computer history as an integrated history that demonstrates that "ideas and devices are linked through politics and culture."[260] Here we can see how Edwards joins with Friedberg and Manovich's approach.

What can this history tell us about Blender? Digital tools have come to play unparalleled roles in the study of natural phenomena and in the production of scientific information. This supports the notion that sites of digital processing—code, hardware, screens, software GUI—can, and should, be read as laboratory settings. Understanding these sites of digital processing as a class of laboratory setting links into our understanding of digital tools as techniques of epistemology as well as a temporally-variable spatialization of *epistemic cultures,* to use the phrase established by Karin Knorr Cetina. For Knorr Cetina, epistemic cultures mark out "knowledge settings"—places where knowledge is created, produced and verified—and which also strongly emphasizes the notion of knowledge as "practiced-within structures, processes, and environments that make up specific epistemic settings."[261] The history of Blender and computer graphics picks up on the thread of computer history that distinguishes the visual culture of computation as somehow distinct from its broader lineage. As will be discussed at greater length in chapter six, this is a function of an inherent bias within the development of computation and the history of computation as a tool to be applied in the sciences that makes an arbitrary distinction between the nature and uses of images. Blender, as well as all 3D computer graphics softwares, share at least one commonality in Sutherland's

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[260] Edwards, xiii.

[261] Knorr Cetina, *Epistemic Cultures*.

Sketchpad which originated as an award-winning PhD project in Computer Science and Engineering, and which Sutherland himself explicitly proposed as "*not* be restricted to engineering drawings".[262] As we will explore further in the following section, while histories of computation and computer graphics may mark themselves as distinct from epistemic settings, their practices prove that nothing could be farther from the truth.

Friedberg and Manovich each emphasize the centrality of the interface and how it organizes domains of information in signally important developments in the history of the computer and computer graphics. From this perspective Blender signals a new and important era in computing. The externalization of computational logics onto the screen is an important feature seen in Blender's interface and the modes of engagement it elicits from users. Blender's application programming interface (API) is written in Python which allows for the program to be adapted to the specific needs and parameters of whoever is using it.[263] Repeat functions can be scripted to appear in the interface and be made to seem as though they are a natural part of the software experience. New computational maneuvers can be created and introduced as well, changing the character and significance of the software altogether. Software is formed and transformed through this medial layer that both connects and keeps human users separate from digital logics. In the next chapter we will further explore this dynamic in order to arrive an an understanding of the modeling-user relationship not as one with clearly marked out boundaries but instead as a continuum of perception, stimulus, and response; a cybernetic prescription of what is possible to be seen.

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262 Sito, *Moving Innovation*, 1. Emphasis mine.

263 This is a strong aspect of the research undertaken by Asadulinla et. al., who prove the usefulness of this feature across domains. They write, "The embedded Python API makes Blender extremely adaptable to specific problems. We used the Python API to develop scripts for importing volume data, querying annotations and connectivity, exploring gene colocalization and calculating network centrality measures." See: Asadulina et al., "Object-Based Representation and Analysis of Light and Electron Microscopic Volume Data Using Blender."

Blender, Misplaced Optics, and the Microworld

There is one way that Blender is understood and used: as a 3D computer graphics software, a software intended to produce animations, capable of performing modeling and producing stills. Yet in part because of Blender's openness, and in part because of the creative ways that scientists are engaging digital media, Blender's functionality far exceeds these preset modes. In particular, Blender's capacity and functioning as a site of optics is one that is relevant to our purposes here. In this section I will explore how Blender is a site of optics in its regular status as a 3D computer graphics software, and then expand this exploration to understand other unintended or misunderstood ways in which optics operates through the Blender program. These extended forms of optics syphoned through Blender's particular technical qualities and the ways the program gains users trust as a displaced site of *sight* is generative of specific modes of knowledge production. I will discuss three of these modes of knowledge production here: computational prediction, commonsense and embodied expert knowledge, and the technical production of sense. In addition to this, we can use Casey Alt's work on Alias|Wavefront's "premier computer graphics and modeling program known simply as *Maya*" as a comparative jumping off point for understanding the optical materialities present in Blender.[264] I will use this work to emphasize the argument that I am making in this chapter: that like Karin Knorr Cetina's understanding of

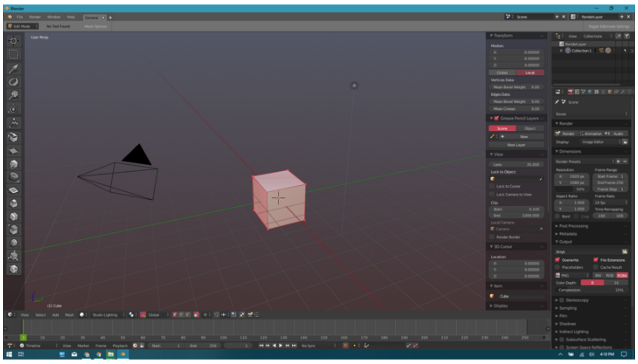

Figure 22: Screenshot of Blender's UI, version 2.8.

[264] Casey Alt, "The Materialities of Maya: Making Sense of Object-Orientation," *Configurations* 10, no. 3 (2002): 389, https://doi.org/10.1353/con.2004.0002.

the laboratory space,[265] software like Blender and Maya are not passive sites that make possible an objective observation of phenomena but create the phenomena in ways that are impressionable upon its observation and understanding.

Software like Maya and Blender, Alt argues, can erroneously give the impression that the objects contained within a software exist in a neutral vacuum. This error is not attributed to any function or command of the software itself but instead to a fundamental misunderstanding of the intersections of sense and software design. As Friedrich Kittler writes, and Alt references, "what we take for our sense perceptions has to be fabricated first."[266] Alt expands on Kittler's work here to foreground the importance of interfaces in this circuit of digital media, user, and sense perception. While for Kittler, graphical user interfaces (GUIs) merely hide the ways that older forms of media have been enfolded into computers, and thus block the user's view on to the "direct" functioning of media, Alt proposes that the design of interfaces in 3D computer graphics software are sophisticated to such a level as to not *hide* this vantage point but to instead continually inscribe human users and their sensory capacities into the design. From this continual inscription a paradox emerges wherein the human sensory engagement of 3D computer graphics software appears seamless, while on the backend being the product of a constant re-production. What's more, unlike the laboratory setting there are no clear markers that signal the detachment of phenomena from their naturally occurring environments. When 3D models are used in epistemic settings it is not only the phenomena that are

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[265] Knorr Cetina characterizes the laboratory as an "'enhanced' environment that 'improves upon' natural orders". Indeed, the fundamental presupposition of the laboratory setting is that phenomena need not be studied in their already-existing context but instead should be relocated into the laboratory to be viewed in their "purified" versions. A fundamental contradiction of this notion of the "purified" laboratory object is that what is brought into the laboratory are often the aesthetic traces of the phenomena: "one works with object images or with their visual, auditory, or electrical traces". This is not a matter of convenience, Knorr Cetina cautions, but instead an epistemic strategy. She notes, "it should be clear that not having to confront objects within their natural orders is epistemically advantageous for the pursuit of science". See: Knorr Cetina, *Epistemic Cultures*, 27.

[266] Alt, "The Materialities of Maya," 421.

reinvented by the senses themselves.

This quality is compounded in the absolute necessity of these technologies in contexts such as the study of phenomena that occurs on scales exceeding ordinary capacities of human perception. In these instances, there are no reasonable ways for scientists to study phenomena as they occur in their natural setting, so strategies of detachment, relocation, and temporal compression emerge as the only methods for observation. This is apparent, for example, in the study of climate change. When we discuss climate change in terms of its applications for science or governance strategies, we often refer to it as a singular object—the sum effect of changes to, and expressed by, climate over time. Yet climate change is not a holistic object whose only variable is time; it is instead a complex set of problems, each containing their own actors, effects, and temporalities. The misnaming of climate change as something singular also carries over to issues of climate more broadly, where it is common to see climate discussed as a single object that receives change, or foregrounds change in a measurable way so as to reveal certain other invisible, or partly visible, conditions. Three-dimensional modeling and animation software help to compress these actors, effects, and temporalities into that "single climate change object", enabling a more neatly observable phenomena for humans.

Modeling Speculation

We see then how three-dimensional computer graphics software like Blender or Maya can be understood as epistemic settings that act in the same way laboratories do by bringing phenomena into an observable arena, albeit while performing some degree of fabrication of the phenomena in the process. Yet it also worth looking at this situation one step prior—from where might 3D computer graphics software get their epistemic authority? A study proposing deduced effects of nuclear winter makes for an interesting case study. In a paper predating the debates on the Anthropocene entitled "The Atmosphere After a Nuclear War: Twilight at Noon," researchers Paul Crutzen and John Birks established the role of aerosols as a "risk to climate stability" as well as suggesting a range of effects should nuclear exchange take place.[267] Dan McQuillan writes that the researchers used "two-dimensional computer models … to predict what later became known as Nuclear Winter; a global darkening and cooling due to the smoke and particulates generated by firestorms following a nuclear exchange." [268] The goal of the study was to discuss "the state of the atmosphere following a nuclear exchange,"[269] published in the years following the cold war. [270] This timing, coupled with the persistent fear of a nuclear event in the decades prior, and the West's general heightened state of alarm, all lent plausibility to the events proposed by the study—an acute sense of the "real and immediate possibility" of this event.[271] Yet it cannot be ignored that what was being studied was, in part, a fictional, or invented, scenario. The tenuous connection between Crutzen and Birk's "object" and the present looms large in their results. Much of the study is written in almost entirely future perfect and future conditional tense; from the article's pull quote alone: "As a result of a nuclear war vast areas of forests *will* go up in smoke"; "tremendous fires … *will* burn for weeks in cities and industrial centers"; "it is likely that at least 1.5 billion tons of stored fossil fuels … *will* be destroyed"; "The fires *will* produce a thick smoke layer that *will* drastically reduce the amount of sunlight reaching the earth's surface" and "This darkness *would* persist for many weeks, rendering any agricultural activity in the Northern

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[267] McQuillan, "The Anthropocene, Resilience and Post-Colonial Computation," 2.

[268] McQuillan, 2.

[269] Paul J. Crutzen and John W. Birks, "The Atmosphere After a Nuclear War: Twilight at Noon," in *Paul J. Crutzen: A Pioneer on Atmospheric Chemistry and Climate Change in the Anthropocene*, ed. Paul J. Crutzen and Hans Günter Brauch, vol. 50 (Cham: Springer International Publishing, 2016), 115, https://doi.org/10.1007/978-3-319-27460-7_5.

[270] McQuillan, "The Anthropocene, Resilience and Post-Colonial Computation," 2. The study McQuillan is referencing was published in 1983.

[271] McQuillan, 2.

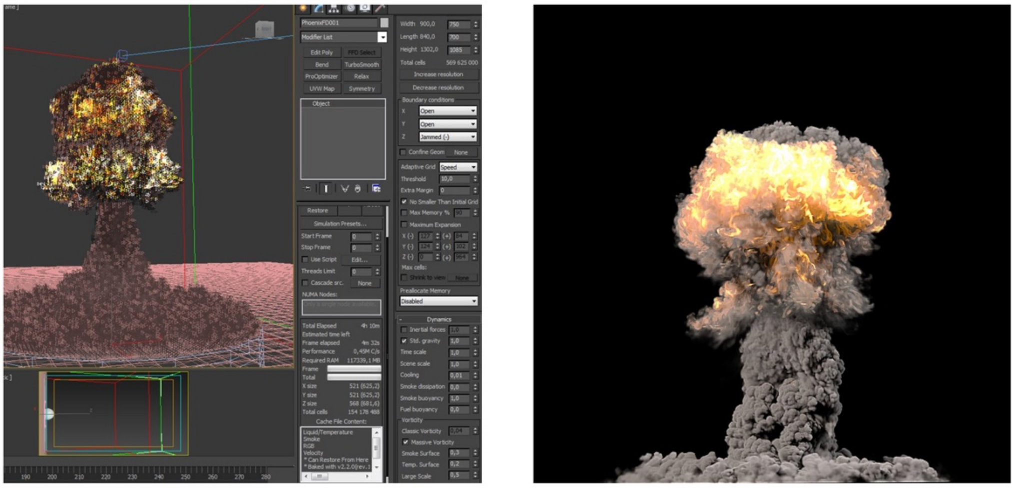

Figure 23: 3-D model for a nuclear explosion that was being sold on Turbosquid.com (at 40% off)

Hemisphere virtually impossible if the war takes place during the growing season."[272] In addition to this, the study also sets out a list of assumptions that made the conditions of creating this object of observation possible.[273]

At many levels Crutzen and Birks highlight the ways in which they were, in effect, inventing the conditions and object of their study. There was the fact that Crutzen and Birks's object of study was in itself conditional on their assumptions being true, and even prior to this, that their object and conditions were contingent on a hypothetical (though not improbable) event coming to pass. Despite this, Crutzen and Birks's published results still had various manifestations across sectors.

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[272] Crutzen and Birks, "The Atmosphere After a Nuclear War," 115.

[273] The researchers note: "We have modeled the atmospheric photochemistry following a Scenario I nu- clear war under the illustrative assumptions listed above. A description of the computer model used in this work is pro- vided in Appendix II . The mixing ratios of ozone in the present atmosphere as calculated by the unperturbed model for August I are provided in Figure 1, and these are in good agreement with the observations (35). The calculated ozone concentrations on August 1, 50 days after the start of the war, are shown in Figure 2. We notice the possibility of severe worldwide smog conditions resulting in high concentrations of ozone. With time, at midlatitudes in the Northern Hemisphere there may be large accumulations of ethane (50-100 ppbv) and PAN (1-10 ppbv)." See: Crutzen and Birks, 120.

Their findings "paved the way for subsequent public alarm about climate change," presumably in part because one of the researchers—Paul Crutzen—would go on to be the first to use the term *Anthropocene* in 2000 to "describe the influence of human behaviour on the Earth's atmosphere" and to subsequently become "one of the concept's most influential popularisers and advocates."[274] Yet we can see how software is made to enact a computational prediction about an object—atmospheric effects following a nuclear exchange—that was hypothetical from the start, and whose "naturally occurring environment" was entirely fabricated through the joint efforts of computer and user. That the knowledge produced, or proposed, under these conditions could have such impact—despite whatever degree of the study you accept as fictional—is evidence of power computation and computational prediction.

On this basis McQuillan makes a critical insight that computational culture has within it a "a boundary layer of over-reliance on calculative anticipation". [275] I would add to this that the over-reliance on calculative anticipation also points backwards. Anticipation is linked to events and objects; it is far harder a task to create anxiety around nothingness and non-events. This where modeling can excel: as a trusted form of prediction modeling gives literal shape and form to the kinds of things that computation tells us to worry about, but that are in essence events or objects not reducible to any present or accessible form. While McQuillan notes that "computational prediction is a powerful tool, but it produces neither 'truth' nor 'good'" it is still, remarkably powerful in animating the kinds of objects or events through visualization that can mobilize responses which would seek to claim "truth" or "good" for their grounding.[276]

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[274] McQuillan, "The Anthropocene, Resilience and Post-Colonial Computation," 2.

[275] McQuillan, 14.

[276] McQuillan, 14.

Sensing as Production

As we have just seen, computation and modeling can produce fictive objects that inspire real consequences in the form of affects and anticipatory action. How can we understand this power, to present invention as reality, or probably realistic? For this we turn to the form of modeling software themselves. Wendy Chun has warned against the way that software has become a shorthand for commonsense. Software builds consensus through the invisible ways it creates "systems of visibility" and perpetuates a certain idea of "seeing as knowing, of reading and readability that were supposed to have faded with the waning of indexicality."[277] In this formulation software already always comes to us as a form of validation. It legitimizes content simply as a matter of intake.

This is compounded in modeling software. As Alt proposes, modeling software like Maya and Blender are in constant negotiation of building these invisible systems of visibility. In fact, such constructions are fundamental to the success of the software. Maya's interface is an outward expression of this ultimate aim of building invisible systems of visibility. What looks to users as a piecemeal interface is actually "result of a very heterogeneous software design *process*". [278] Alt tells us that Maya was born from the merger of the products and practices of essentially three different graphics software companies (Alias, Wavefront, and TDI) and at least three different corporate structures (Alias, Wavefront, and Silicon Graphics)."[279] Maya's interface bears the compromises, mergers, and negotiations that take place at the intersections of corporatization, software, and design. To succeed it must come out of these intersections unifying the needs of its tripartite

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[277] Wendy Hui Kyong Chun, "On Software, or the Persistence of Visual Knowledge," *Grey Room*, no. 18 (2004): 27–28.

[278] Alt, "The Materialities of Maya," 389. Emphasis mine.

[279] Alt, 389.

inputs. Layered on top of this are the needs Maya must satisfy for its own reproduction and outward-facing use. This involves a far trickier task: a solution built on heterogeneity and compromise which must solve the counterintuitive problem of "modeling 3-D objects on the 2-D space of a computer screen."[280] The extent to which we can evaluate how Maya handles these effects Alt points out, is somewhat irrelevant because Maya is unconcerned with what some might charge as its "bad" interface design.[281] Maya is a program aimed at a highly skilled user and it invites them to perform complex technical operations. As opposed to expanding itself ever-outward in a mass market, Maya addresses itself to those users with extra-ordinary demands of the compute graphics experience. As Alt tells us, Maya continually develops "disparate but highly specialized tools … [that] encourage a

Figure 24: Three stills from Dr. Taylor's animation of the "nearby Universe," using Blender 2.49.

wide diversity of specialized techniques that can be *further customized* through MEL scripts for very precise design goals."[282]

From this perspective we can understand how modeling software actively draws in particular users by setting the barrier to access at a certain level of inaccessibility. In this way being able to use or work with Maya becomes in itself a form of epistemological validation. The notion of "commonsense" that is expected to be baked into software, as Chun alleges, is elevated to a *not-so-common* sense, and the barrier to using modeling software is an expert knowledge. This expert

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[280] Alt, 406.

[281] Alt, 408.

[282] Alt, 407. Emphasis mine.

knowledge becomes even more rarefied when we consider that the way one gets to know *how* to work with Maya is through the haptic experience of *using* Maya. "In order to successfully use Maya," Alt writes, "users must crawl inside, navigate, and inhabit the logic of the application's complex interactive space."[283] Crawling inside, navigating and inhabiting the logic of the application helps us to understand the expert knowledge of the software user as an *embodied* expert knowledge; what we have elsewhere seen, as in the work of Knorr Cetina, as the "black-boxed body of the scientists."[284] The ability to use Maya requires a continuous orientation that must be navigated not logically be *sensorially*, much in the same way that Knorr Cetina identifies scientists in the molecular biology lab as trusting "the body … to pick up and process what the mind cannot".[285]

The effect of Maya's "expert" design has the dual effect of not only confirming users as "experts" but also of *producing* expert users. Modeling softwares may draw in experts but these software also reform experts in their own image through their same grammars of accessibility that bar the layman from entry. The demand for the expert body to navigate haptically and sensorially Maya's counterintuitive "bad" interface—to inhabit and ingest this kind of "bad" design logic—also means that all users are disciplined into becoming the kind of "expert user" Maya wants them to be. As Alt confirms, to become successful users of Maya, users must "gradually adapt their usual habits of interaction to accommodate Maya's unconventional interface—a process that effectively reorganizes perception and cognition into a new field of relations."[286]

The way that Maya and modeling softwares entice, discipline and produce users is primarily through a cooption of the sensorial spectrum. Users must

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283 Alt, 408.

284 Knorr Cetina, *Epistemic Cultures*, 94.

285 Knorr Cetina, 98.

286 Alt, "The Materialities of Maya," 408.

overcome visually fractured and counterintuitive design in order to gain access; when they do, their perceptions become reordereed and reconfigured. The user is produced both as expert by virtue of their access to the software, and also as an expert in *Maya*, or modeling. On this point, Matthew Fuller's writing on surveillance as a mode of production can offer a useful parallel to how perception, too, functions as a mode of production. Fuller writes that surveillance can produce objects by means of its modes of subjectivation. This happens, one, through the discipline that creates homogenous bodies—"social organizations produce a homogeneous body, a machine, an army, a school"; and two, through control, in which "Life, activity, becomes a flowing force that is gated, transducted, filtered, recombined, rendered positive as if it were a stream of data."[287] In modeling software, the seamless movement of vision—user eyes scanning menu bars, searching icons—is returned back to users with a propriocentric knowledge: to execute *x*, move *y*. Look here, not there. Perception and its modes of conditioning are pried away from a unliateral seeing, a one-way commanding of software. Instead, modeling software disciplines expert users into a homogenous set of sensory commands that wait latent to be activated; sights directed here will drive clicks over there, scripts will run if you just know where to look. Disciplinary design produces users; user perception produces software when users meet their sensory limits and scripting for new functions; the sites of command and control become multiplied in the amplification of interfaces, feeding off perceptions and renewing the cycle again.

We can see this at play in the development of FRELLED, a series of Python scripts developed by Dr. Rhys Taylor and used to "to import 3-dimensional FITS files into Blender, where they can be viewed from any angle in realtime."[288] FITS stands for *flexible image transport system*, and it's the preferred file format for

[287] Fuller, *Media Ecologies*, 148.

[288] "FRELLED Wikia," accessed July 31, 2018, http://frelled.wikia.com/wiki/FRELLED_Wikia.

astronomers because it allows for images to be transported with extensive metadata about things such as spatial and photometric calibrations and origin data.[289] 3-dimensional FITS files are known as *data cubes*, and they are the formulations of events that stack the different spectrums into three dimensions, so that objects in motion are easier to conceptualize. Imagine a flipbook, but the book itself is clear, so all you see as you look through the multiple stacked images is the movement created in their animation.

FRELLED is a way of adapting technology to perform the kinds of observational work that is required of astronomers, but that is impossible to do directly, and difficult to do with existing software. Dr. Taylor tells me in an interview that because of the types of sensing technologies he's working with in radio astronomy, data comes to in a series of highly specific but undifferentiated formats. Sensors are trained onto one frequency, as opposed to a whole spectrum of frequencies, but provide no option to mark out data such as location coordinates. This creates a problem when astronomers are looking at five-hundred galaxies in a space of thousands of possible galaxies.[290] Sensors create stacks of impressions that are bundled into data cubes; but using traditional software such as SAOImage DS-9 and KVis are less adept at providing the three-dimensional viewing options that a 3D animation software like Blender is made to do. [291] Taylor explains that using

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[289] "FITS," in *Wikipedia*, June 15, 2018, https://en.wikipedia.org/w/index.php?title=FITS&oldid=845912404.

[290] Dr. Rhys Taylor, Practices of Blender in Astronomy, interview by Nicole Sansone, Skype, June 6, 2018.

[291] SAOImageDS9, or DS9 as Taylor referred to it, is "an astronomical imaging and data visualization application. It supports FITS images and binary tables, multiple frame buffers, region manipulation, and many scale algorithms and colormaps. DS9 provides for easy communication with external analysis tasks and is highly configurable and extensible." For more on this software, see: Smithsonian Astrophysical Observatory, "SAOIMAGEDS9," accessed November 22, 2018, http://ds9.si.edu/site/Home.html.

KVis is described as "a general-purpose image/movie viewer that can load multiple datasets, display multiple windows, overlay contours, annotations, show multiple overlaid profiles, and much more." I these software to handle data cubes means that "You simply only ever see a *slice* through your data. So, if you were looking at the sky you can see one image corresponding to one frequency tower at the time."[292] If you want to understand the three-dimensional structure of a galaxy, or a change over time, astronomers imagine events as three-dimensional, while they view data cube (in the old software) head on. This often involves looking for moments of light intensity and shadow. Alternatively, as Taylor confirms, for this kind of work Blender is a logical choice given "the far superior navigation interface of Blender" which "makes it possible to explore data sets in a completely different way to other 3D viewers" and "to do visual source finding and analysis much more rapidly and on a larger scale than was previously possible."[293] Blender is specifically designed to reimagine the space of the computer scene as a theater which imagines you, the user, as an omnipresent, polymorphously seeing being. On the viewer's side, your position is both fixed and enabled to be everywhere. Likewise, data cubes are so similar to mesh primitives they present no challenge to the normal functioning of the Blender program. No straining to visually extract the phantom of a three-dimensional event required in a program explicitly designed with the purpose of making viewing 3-D in 2-D possible.

If to use 3D computer graphics software users must absorb the movements dictated by the software's "unconventional interface" into their body, then FRELLED is an endorsement of the extent to which human users have embodied

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got this information off of the website for Karma, describes as "a **toolkit** for interprocess communications, authentication, encryption, graphics display, user interface and manipulating the Karma network data structure." While a lot of the functions attributed to KVis seem to overlap with the functionality Taylor sought in using, judging by the look of Karma, I would venture that these tools might have lapsed in their updates. See: Calabretta, Mark. "The Karma Homepage." The Karma Homepage, November 22, 2011. https://www.atnf.csiro.au/computing/software/karma/.

[292] Taylor, Practices of Blender in Astronomy.

[293] R. Taylor, "Frelled : A Realtime Volumetric Data Viewer for Astronomers," *Astronomy and Computing* 13 (November 2015): 15, https://doi.org/10.1016/j.ascom.2015.10.002.

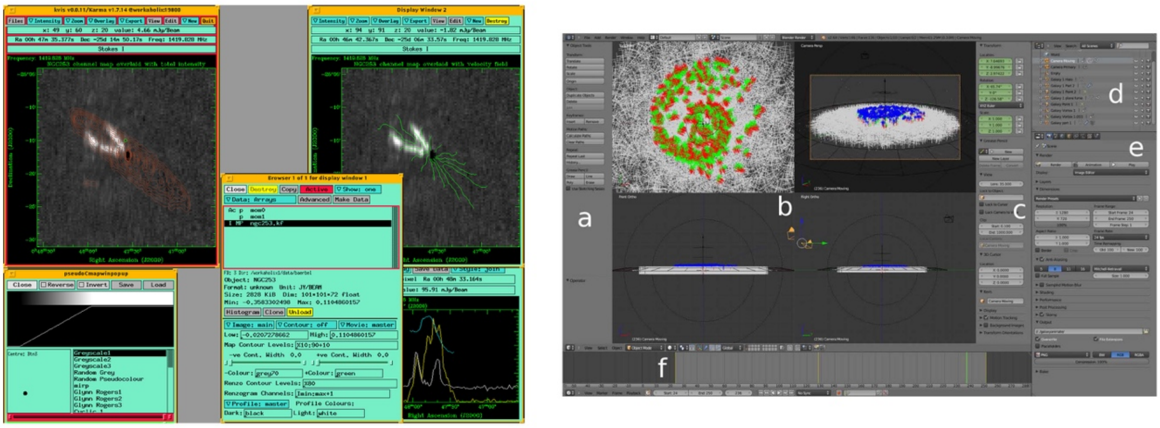

Figure 25: Left, screenshot of KVis interface. Right, screenshot of Blender interface handling data cube.

the logic of these interfaces. FRELLED is written as a series of python scripts that modify the interface of Blender, but that effectively recreate the program anew. For one, FRELLED reconstructs Blender's functionality from a modeling software into an interface for viewing files. In a second sense, it transforms Blender entirely from a 3D computer graphics and animation software into an astronomical imaging and data visualization application. Altering the software in these ways might be read as having an almost debilitating effect on the software. Blender goes from a powerful 3D computer graphics software with the capacity to produce and animate to solely an interface—a mere view onto data rather than a way to work in and around it. Counter to this reading, however, FRELLED demonstrates a hugely powerful aspect of Blender. Blender's openness and modularity endows it with a kind of endless shape-shifting: it can change itself, move through and speak to other machines, and it can also cannibalize other programs—such as it did with SAOImage DS-9 and Kvis—in ways not originally intended.

In all these readings, FRELLED demonstrates the interconnectedness of the user, software, perception triad. Perception is mediated and recreated in engagements with modeling software; we are as much software as software is us. What's more is that the power of these recreations far exceeds its constraints.

Human senses become malleable to technical demands, while programming must stretch itself to accommodate and inerpret the fleshy logics of human sensing. New grammars of interaction are invented at new intersections of perception. Given this dynamic, the use of modeling software in epistemic contexts—in astronomy, in climate science, in the natural sciences—fractures the grounds on which computational science stakes its authority. The extensive trust and validity that is afforded to computation is multiply relayed in the application of modeling towards science. At every click expertise is conjured, formed, and granted. And at every point a plurality of visibilities and knowledges created, contextualized, published

Modeling Software as the Site of Optic Entanglement

Blender is not an optical media, but an aestheticizing one. This does not derail our discussion of how Blender produces sense and visuality but instead can help to flesh out the textures of this novel dynamic. We can particularly see this when we apply our discussion of Blender to the framework proposed by Kittler on his lectures on optical media. In a commentary on the lectures, John Durham Peters notes that for Kittler optics are famously (if not reductively) a "subfield of physics" whereas aesthetics is to be "understood in its original sense as sensation."[294] Optics constitute the range of technical possibilities that vision can bring—"a subfield of physiology, psychology, and culture"—into materialization.[295] Kittler further notes "Aesthetic properties are always only dependent variables of technological feasibility."[296] Technology and physics produce sense which we can inhabit through aesthetics. At first reading, this might seem like a reduction ad absurdum. Yet it is

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[294] Durham Peters, John, "Introduction: Friedrich Kittler's Light Shows," in *Optical Media: Berlin Lectures 1999*, by Friedrich A. Kittler, trans. Anthony Enns, English (Cambridge, UK ; Malden, MA: Polity, 2010), 2.

[295] Durham Peters, John, 2.

[296] Durham Peters, John, 3.

worth staying with the absurdity. Durham Peters notes that, for Kittler, "the sense organs are signal processors, relatively weak ones at that" and, in true misanthropic Kittlerian fashion, "for [Kittler] we cannot know our bodies and senses until they have been externalized in media."[297] It is not without good reason that Kittler comes under criticism for what is seen as his reductive comments on technological objects and human capacities. Yet when we understand Blender and Maya as being in a continual conversation with both its inputs—both past (through the history of its founding) and present (through the user)—and outputs it becomes increasingly clear that the line between optics and vision, technology and human, is not a feasible one to draw.

Instead what I will propose here is that Blender gives the false illusion that it, like the telescope or the camera, coincides with optics. We can see this in a few specific examples. If Blender users aren't working the software to fit their own needs—by which I mean using the existing tools, options, and frameworks as metaphors, indices or symbols of some other realm of meaning—then they are likely working with one of the software's in-built *modifiers*. For example, under *lamp types,* Blender provides an entire panel dedicated to *Sky & Atmosphere*. On this panel users can find a range of effects that facilitate the simulation of "various properties of real sky and atmosphere" including changing the sky from blue when the sun is high to "dark blue/purple" when the sun is near.[298] In this mode of interaction, Blender is not massaged or coerced into "seeing" sky, or producing a visualization of sky and atmosphere from some physical world data set. Instead, Blender gently trains users how *they* will see sky, while Blender maintains its hold on mainstays, like the *lamp* (or light source, which for the purposes of the user's manual is referred to as "*Sun*

[297] Durham Peters, John, 3.

[298] "Sky & Atmosphere — Blender Manual," accessed May 29, 2018, https://docs.blender.org/manual/en/dev/render/blender_render/lighting/lamps/sun/sky_atmosphere.html.

light source") and *camera*.

Blender also sets out predetermined colors for the progression of the day. What we can learn from this assertion is that Blender's preprogrammed sky and atmosphere do not see weather, nor the effects of weather patterns on the outward appearance of the sky and horizon. Blender does not see a sun the way human users will see a sun—as a glowing orb in their vignette. Instead, Blender only sees a camera view, lamp/lighting source, the orientation of this lighting source, and the effect of this orientation on other objects within the scene.[299] Entering various values for turbidity presents users with their only options for effecting atmosphere, allowing for the following options: "In general, low values give a clear, deep blue sky, with 'little' sun; high values give a more reddish sky, with a big halo around the sun. Note that this parameter is one which can really modify the 'intensity' of the sun lighting."[300] Turbidity is a term which, outside of Blender, refers to a liquid made murky because of the presence of suspended particles. Yet what Blender sees as a turbidity value of two is what we would consider an Arctic-like atmosphere, and a turbidity value of ten as a hazy day.[301] A term that is intended to describe the crowding of particles in a liquid suspension is here used as a metaphoric bridge between user and software. Blender teaches us something about how it understands atmosphere: as a medium that contains, or can hold, a crowding of particles, behaving no differently than liquid. While human understandings of turbidity are organized around the understanding that liquid behaves differently than the gases

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[299] The manual states: "This way, in camera view (Numpad0, center area in the example picture), you will see where the "virtual" sun created by this effect will be. It is important to understand that the position of the sun has no importance for the effect: only its orientation is relevant. The position just might help you in your scene design." It is also worth noting that Blender does not see a "camera view" but instead a keyboard command, *numpad0*, referring to key 0 on a numberpad; however, even this command can be modified at the simplest level for laptop users without a number pad attachment, for example. See: "Sky & Atmosphere — Blender Manual."

[300] "Sky & Atmosphere — Blender Manual."

[301] "Sky Texture Node — Blender Manual," accessed May 29, 2018, https://docs.blender.org/manual/en/dev/render/cycles/nodes/types/textures/sky.html.

that constitute our atmosphere most of the time, Blender sees only impact and action. Visibility or non-visibility: the state of the algorithm is less important than its execution.

The false illusion that modeling softwares like Blender can *be* optical media, and don't just coincide with optics, is in part produced through the specific ways that epistemic cultures engage modeling software. Blender is a site of study, and the "observational" or "empirical" work that takes place in this site intensifies Blender itself as the material object and location. When this happens the material site of the actual event or object is critically undermined. This is from one perspective the logical consequence of an object that can only be observed by proxy. But such a reasoning can also forgive an excessive faith in software, algorithms and computation. Mastery over the tools stimulates the same part of epistemic actors that need to be in control of their study while control, as they would have it, silently slips away. Seen in this way Blender becomes what Paul Edwards has called a "microworld," a term he uses to point to the blindspots in simulated events. As Edwards tells us, "Every microworld has a unique ontological and epistemological structure, simpler than those of the world it represents."[302] As the main constituting force of this microworld, the Blender interface, and interfaces in general, work to give the impression of control which is foundational to epistemic practices, but this sense of control is both fleeting and misplaced. Interface design attempts to simplify the way it is made to bloat with all the possible permutations of user experiences; it is information management. When experiments are simulated and run in Blender, when data is brought into this interface in order to make information, it is a project that appeals to the most comforting parts of working with computers. "Computer

[302] Paul N. Edwards, "The Army and the Microworld: Computers and the Politics of Gender Identity," *Signs: Journal of Women in Culture and Society* 16, no. 1 (October 1990): 190, https://doi.org/10.1086/494647.

programs are […] intellectually useful and emotionally appealing for the same reason," Edwards writes, "they create worlds without irrelevant or unwanted complexity."[303]

In her essay on software and visual knowledge, Wendy Hui Kyong Chun writes:

> Software perpetuates certain notions of seeing as knowing, of reading and readability that were supposed to have faded with the waning of indexicality. It does so by mimicking both ideology and ideology critique, by conflating executable with execution, program with process, order with action.[304]

This quote succinctly emphasizes a key point of contention in the use of Blender in epistemic cultures and practices. When the notion of *seeing* is predominantly regarded as a mode of *knowing*, then it should be paramount to understand how *seeing* might function across registers and types of bodies. When these registers and types of bodies operate through a continuous sensorial spectrum that extends and flutuates between *human* and *technical*, Kittler's sense of the optical is at once negated, affirmed, and confused. We've seen how technical processes are shaped and informed *by* human expectations and limits, and how this process in turn presses back to *shape*, or *prime*, these same expectations and limits. In this constellation of bodies and forces, seeing needs to be calibrated across the different registers. What forms and types of gazes are activated beyond those that circuit through the human?

Chun offers that the answer to such a question might be in the ability of software to mimic ideology and ideology critique, but I want to also add to this that the answer might also include something beyond mimicry and the brute executions of code and concatenation. Whereas Chun mounts her critique from a position that understands the entire circuit of interaction as between humans and computers, I want to propose that given the relationships operable *between non-human actors* in the digital articulation of nature (between nature and computer; light and sensor;

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[303] Edwards, 190.

[304] Wendy Hui Kyong Chun, "On Software, or the Persistence of Visual Knowledge," 27.

etc.) there is an additional strain to understanding this conflation between seeing and knowing. To be clear, I understand the conflation that Chun speaks of as in-tact, but as a human contribution. Human actors cannot help but to overly rely on a visual paradigm to confirm that things are happening—that computers are working, that algorithms "make sense." And this is, in part, precisely the problem. As Hanneke Grootenboer argues for in her book on the relation between illusionism and realism, visual information is not just a unilateral transmission of information. Instead, visual information is always packaged in *the relation* of image *and* (and this part is critical) *modes of looking and interpretation.*[305] While humans can appraise *looking* and *seeing* only ever from one position outside the digital circuitry, the ways in which environmental data and technology speak to *each other* are in themselves particular modes of looking and interpretation that have yet to be properly dissected and understood.

On the Authority of Modes of Seeing

Getting inside of this particular mode of looking and interpretation is continual aim in this thesis. As we come to the end of this this chapter I want to propose some final thoughts on the generative overlaps of human and computational perceptions and interactions. In the background of this proposition I am asking that we think through how it is that Blender *as a software* "sees," and how this "seeing" might be distinct from, or give rise to, a mode of interpretation that marks realism out differently from that which can be understood by a human.

A first attempt. In her essay on software and visual knowledge, Chun writes:

> Software perpetuates certain notions of seeing as knowing, of reading and readability that were supposed to have faded with the waning of indexicality. It does so by mimicking both ideology and ideology critique, by conflating executable

[305] Grootenboer, *The Rhetoric of Perspective*.

with execution, program with process, order with action.[306]

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[306] Wendy Hui Kyong Chun, "On Software, or the Persistence of Visual Knowledge," 27.

trustworthy imagining of events that exceed human scales, whether in terms of time or distance? I propose there are two possible ways we can approach this question.

One way we can answer this question is by looking at visual techniques in the history of art that also encourage faith in a seemingly improbable or impossible image objects (painting). By recruiting from art history's debate on illusionism and representation we begin to flesh out one of the visual problematics expressed by Blender as a false optical media insofar as Blender contains both a "pictorial truth and optical deception".[307] I borrow this paradigm from Hanneke Grootenboer whose book on the relation between illusionism and realism in 17th century Dutch still lifes holds insightful parallels to our discussion here. We can observe how Grootenboer's paradigm plays out in the creative visualization of data vis-à-vis simulations and renderings of aerial and non-terrestrial phenomena. Simulations and renderings present as pictorial truths insofar as they appear as legible, probable events. The proposals for nuclear winter and the ways in which these elements were modeled did not involve the complete upending of how we expect the world to look and behave. It was familiar, but different, and all its contingencies explained by a series of assumptions and proposals. The computationally-generated image was, in this sense, a truth. Yet as we outlined earler, the event of nuclear winter was built on so many propositions, so many contingencies, that it would be reasonable to read this as a false event. In this way, the computationally-generated images are optical deceptions: they are optical because they exist as entities to be viewed, but deception to the extent that they participate in the pictorial truth, or the animating of an illusionism—not a realism. Understanding the delicate interpay between these orchestrations of aesthetics, representation, and knowledge transforms work with images from a binary presentation to instead a recalibration of a series of claims to truth that are different in degree, not in kind.

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307 Grootenboer, *The Rhetoric of Perspective*, 5.

This dynamic between pictorial truths and optical deceptions in the application of computer graphics towards epistemic practice also encourages a more deconstructive and expansive way of working with images. This method hinges on a continual negotiation of determining the relation be between images, meaning and "modes of looking and interpretation". [308] As Grootenboer argues, visual information is not just a unilateral transmission of information. Instead, visual information is always packaged in *the relation* of image *and* (and this part is critical) *modes of looking and interpretation.* While humans can appraise *looking* and *seeing* only ever from one position outside the digital circuitry, the ways in which environmental data and technology speak to *each other* are in themselves particular modes of looking and interpretation that have yet to be properly dissected and understood. These points are illustrative of the feminist modes of scientific engagement that Donna Haraway encourages. They inherently operate on the notion that science is a "rhetoric, a series of efforts to persuade relevant social actors that one's manufactured knowledge is a route to a desired form of very objective power." [309] Yet as Haraway also adds that "Such persuasions must take account of the structure of facts and artifacts, as well as of language-mediated actors in the knowledge game."[310]

On this point we can segue into a second way into understanding our trust in Blender. Another way of accounting for our trust in the authority of Blender might be cultivated through the discursive contexts in which Blender is situated, and which act to press belief and sensation together. What I am proposing here is that perhaps the belief that any computer graphics or rendering pipeline can pertain to reality, in any capacity, is due to the metaphors that are constructed to explain such interactions with Blender. This would include, for example, that notion that Blender

[308] Grootenboer, 5.

[309] Donna Haraway, "Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective," *Feminist Studies* 14, no. 3 (1988): 577, https://doi.org/10.2307/3178066.

[310] Haraway, 577.

can construct a simulation and does not, in fact, create events and phenomena anew. In addition to these metaphors, our belief might also be supported by the fundamental misunderstandings of Blender and computer graphics softwares that go uncorrected (but worked around) in our unchecked use of these softwares as an "optical" tool. For example, in astronomy work what Blender sees as changes to light and dark in texture mapping can help scientists simulate disturbances to surfaces; what Blender sees as a FITS[311] image can be an entire UV map that, when projected onto a cube, becomes a planetary nighttime view of Earth.[312] Thus, the combination of a misunderstood or misplaced optic/aesthetics tension, as well as the softwares' ability to contain a microworld within them and the fact such microworlds make possible the only view onto phenomena that exceed human scales, is a source of authority not to be discredited.

What is Represented, and What Remains

In this chapter we have studied the free and open source 3D computer grahpics software, Blender, as both a site and tool of epistemic practice. I have traced select trajectories and genealogies of the history of modeling software design and computer graphics hardware to contextualize our understanding of the sources of influence and investments that are embedded in both Blender's design and broader sociality. From these discussions we have highlighted a unique quality about Blender which is expressed through its "badly designed" interface. As Casey Alt argued, modeling softwares appear as intuitively "badly designed" because they are

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[311] One of the advantages of Blender for astronomy researchers is that it can import and work with FITS images. FITS is a file format predominantly used in astronomy that codes for a more robust system of presenting visual data and metadata by supplying an ASCII header with the image that is informative of the image's provenance. There is an interesting gap here, however, that what is being input, and what is coded for in the file format itself, is an expanded sense of image as well as an image that is specifically engineered out of and for an particular epistemic culture. What Blender sees, however, is a texture map, and it draws an equivalence between this

[312] Kent, "Visualizing Astronomical Data with Blender," 735.

tasked with the counterintuitive problem of attemping to create three-dimensionality in a two-dimensional space. Not only this, but modeling software is also unconcerned with lay users. Its aims are to perform complex and high-level tasks at the execution of increasingly expert users. It is in part for these reasons that modeling softwares lend themselves to the epistemic sensibility. We discussed how Blender has been inreasingly applied towards the study in the natural sciences in ways that include both the direct manipulation of data and variables, and also in the presentation of data to be observed.

I highlighted these examples as a way of problematizing what is often taken for granted with computation, and to a lesser extent, the use of computationally-generated images in epistemic practice. I proposed that computation and computationally-generated images have an overextended claim to authority in the presentation of data. This is an important point to make, or take under consideration, for two reasons. One, the method of working with computation and computationally-generated images that an acknowledgement of this overextension would necessarily require lends itself to a more feminist mode of doing science, or epistemic practice. Two, understanding the intersections of epistemic practice and the visual culture of computation holds strong potential for doing more expansive science. This "more expansive science" is not progressive in itself but rather continues, with some variation, a history of trying to parse the many facets of *representation* in scientific practice; weeding out that which is subjective from the objective, what is avoidable from what is unavoidable. Understanding the blindspots that are embedded in both human epistemic practice and our digital tools continues with the best parts of this self reflexivity, but with more of an eye towards the impossibilities (and inutility) of a "objective" or neutral science.

The theme of representation and objectivity/subjectivity is one we will be sticking with in the chapters to come. In the next section we will explore virtual Earth modeling as it currently takes place and form through four distinct aspects:

modeling communities, spaces of communing for modelers, software and online tools. These aspects allow us to observe the human and non-human sociality of making digital articulations of physical space—spaces that sometimes include realistic Earth vistas, fantasy spaces that seem an awful lot like Earth (but aren't), and supra-terrestrial spaces that leave Earth behind altogether. In creating these spaces, amateur earth modelers work in specific modes of collaboration with each other, with environment, and with digital tools. This collaboration, in combination with the decision making that takes place, points towards new forms of understanding the aesthetic's relationship to epistemology—of how we can represent what we know because we perceive it.

III.

Chapter Five: Modelers

Introduction

This is a chapter intimately connected with life online, and the methodology undertaken is precisely getting intimate with life online.[313] Both things take place in text and in text making; in typing and in talking. There is an irony in this, and it's one that anyone who has ever had a writing deadline can relate to. It's the distinct torture of being forced to sit down at the keyboard and made to stare into the pernicious blue light of your monitor (don't *they* know it's harmful for your circadian rhythms?), only to be relieved by finally meeting your deadline, at which point promptly celebrating by returning to your keyboard and staring at your screen (for Netflix, for YouTube, etc). While acts of being social online and laboring on a personal computer are very different, they mechanically share a lot. I have been talking to you, my reader, at some deferred moment from the moment I sit here and write this. I am also transmitting information to you. This is what is attempted in a doctoral thesis, and this is what is done on forums. Users communicate with each other textually on threads. What makes forums different from instant messages or chat rooms is not that responses on forums happen on a somewhat protracted timeframe. It's that forums are spaces where online chat is rarely superfluous, and almost always informative. They are distinct from most casual conversations in this way, but quite similar to pedagogical ones. In this sense, forums formally overlap with this thesis that connects you, to me. It's this formal overlap that has made forums such an extraordinary resource for my research.

This chapter is the first in a two-part thematic section of my research examining the logic of the landscape gaze in technology. To do this, I've undertaken an ethnography of the social world and work of virtual earth modelers not associated with Google Earth nor a scientific institution. Given this framing, I am referring to these modelers as *amateur earth modelers*, which is to emphasize their placement in

[313] I'm not so old that this was a huge leap or unfamiliar terrain.

relation to more formal bodies of knowledge and not at all a comment on skill or expertise. Some of this work was done by spending time on the software themselves, examining screenshots taken by users of notable moments that took place in the software, and generally getting a sense for how these programs are used. Where I spent most of my time, however, was on the forums attached to these software and interest-related communities. Conversations amongst modelers, users, coders, and a whole range of individuals are recorded and archived in the text of forums and subforums. Concerns about the functionality of the program, trouble shooting, plans for improvement, and so on, all get volleyed in these posts. While forum subscribers exchange with each other their tips and tricks, researchers can take a bird's eye view of these interactions, mapping a meta layer of meaning on top. That is what I have done here.

There are two main exercises carried out across the next two chapters. One produces close readings of the images the modeling software produce, and images associated with the modeling software. This includes user screenshots, screenshots I've taken while using the software, and marketing images. I pay careful attention not only to the images themselves but also, where possible, to the technical procedures that produce these images. The second produces textual engagements with the forums. While both of these exercises have been used to educate myself on a general feeling for the software and forums, what has been selected for purposes of theoretical engagement here are only the moments of trouble shooting and problem solving atmospheric related issues. The realism of clouds, the realistic functioning of weather, the existence of a moon and moon phases—as in the real world, these things all impact on the operational organization of virtual worlds and terrain visualization software. Their effects are impactful on not just on user experience—like for the user who needs realistic weather patterns to use the software for flight simulation—but also on the aesthetics of the software as a function of computer graphics. Successful 3D modeling always involves a successful manipulation of light;

staging and crafting environmental elements in a virtual world in the right way is an integral part of the formula for this success.

The purpose of this section, and the two chapters within it, is to draw out the criteria for ecological and landscape realism that is being built on the ground. Earth modeling provides a way to do this through the forums that make explicit their creative process and for the coding and rendering processes themselves. Troubleshooting on forums amongst earth modelers allow us to intervene in this pipeline between input and output. This is a crucial move because a legible landscape output or rendered nature scene does not always reflect good computation. At these moments, the rendered landscape can be a happy accident or a glitch imperceptible to the human eye. These are the moments when we can see the landscape gaze takes particular effect, bypassing the human to collaborate directly with other technical forms of perception.

More will be said on my method. Before that though it is important to map this area and some of its key players and values. Setting up the chapter this way also allows readers to dip in and out of areas they might already be more familiar with.

Earth Modeling & Terrain Visualization Platforms & Forums

In the process of earth modeling there are a few key components. I've zeroed in on four of these. One, the overarching project, the reason why it is done, its purpose, its uses. To this I look at Virtual Terrain Project. Second, the software itself—what is produced when the project aims are developed to an advanced enough state that a product is made. It is also the environment that is used, in use, and produced through earth modeling. Third is the forum. This is a social and technical hub for the software and/or project. It is where problem solving is carried out, it is where updates are evaluated. It is where new users are baptized into the ethos and uses of the project and software. For this I look at r/simulate, a subreddit on the popular social med and news-aggregate site Reddit, that was established to support a project that espoused a form of earth modeling but ultimately did not materialize. Fourth, and last, are the individual tools themselves that build the environmental modeling. This is something that will be looked at through Shadertoy.com, a community-based platform for sharing shaders, flexible tools for calculating rendering effects.

Project: Virtual Terrain Project (VTP)

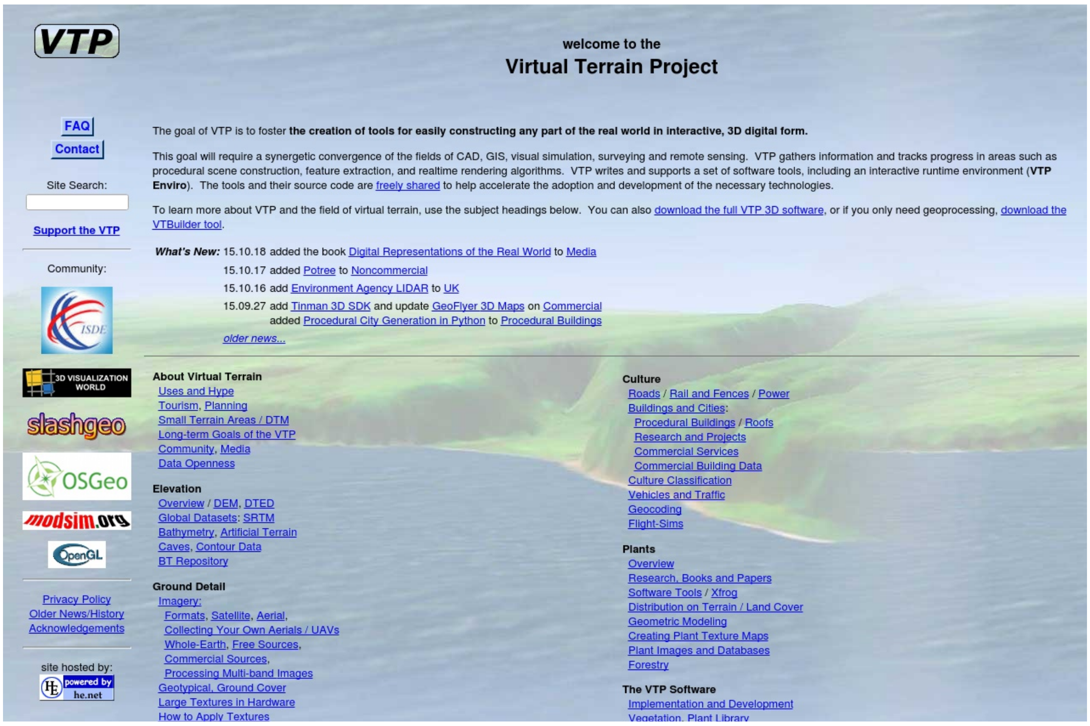

Figure 26: Screenshot of vterrain.org.

The Virtual Terrain Project (VTP) is as with all of the efforts examined here both an ideological project and a software project. VTP is a terrain visualization software but also has attached to a site that adds as a platform and news/tools aggregates explicitly aimed at "advanc[ing] the *entire field* of terrain visualization."[314] The software is indivisible from the site itself and the overarching project of VTP. This goal of advancing the entire field of terrain visualization conditions every part

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[314] "VTP FAQ," accessed March 31, 2018, http://vterrain.org/Site/faq.html#P1.

of their operations. As opposed to Outerra (discussed in the next section) which is modeled according to a goal inhered in the software itself, VTP instead structures an entire field comprised of theory and practice. As the site notes, "VTP gathers information and tracks progress in areas such as procedural scene construction, feature extraction, and real-time rendering algorithms. VTP writes and supports a set of software tools, including an interactive runtime environment (VTP Enviro)."[315] The goal of gathering and collating all available resources extends to recognizing the resource available in attracting as many people as users and developers as possible. Such a goal means that VTP has strategically enabled anyone to download the software by emailing the project administrators (to provide some user information, which is kept confidential) and following up by visiting the VTP download page. The VTP software is functional on a range of operating systems; the only requirement for functionality is good and fast internet connectivity.

As figure 26 makes clear, the VTP website immediately separates it from commercial or institutional projects. Its interface design is more akin to early geosites than the parallax scrolling and high-res imagery layouts that have come to be a box-standard in the age of Squarespace. The site has organized its design and information architecture around the goal of maximal usibility. It is like an arsenal of tools rather than a declaration of personal brand. The site's subheadings redirect visitors to specific pages and aggregates of information about the software itself, subcategories of information such as *About Virtual Terrain Project* and *FAQs* as well as some of its developer tools: *Rendering, Data Sources and Formats*, *The VTP Software*. It draws attention to specific areas of its development—*Ground Detail, Culture, Plants*—which provide case studies, how-to's, and libraries. Most significantly, it also directs its visitors *away* from the site and from the project, listing under *Other Terrain Software* links to a range of non-VTP projects

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[315] "VTP FAQ."

(commercial, non-commercial, government and academic, artificial and artistic) and resources. Clearly this has been a noteworthy detail for more than one visitor to the site because it is addressed in the site's FAQs. They write, in perhaps what should be considered a pithy mission statement, that "the goal of VTP is to foster the creation of tools for easily constructing any part of the real world in interactive, 3D digital form" and, further:

> This goal will require a synergetic convergence of the fields of CAD, GIS, visual simulation, surveying and remote sensing. … The tools and their source code are freely shared to help accelerate the adoption and development of the necessary technologies. … That's why the site tracks every related subject and software package. Producing and supporting the VTP's own software is only part of the larger goal. [316]

The extent to which VTP is aimed towards gathering resources, people and information in an effort to advance a certain ideological project almost makes the software itself secondary. For our purposes here it *will be* taken as secondary as we focus on the questions such a commitment to an ideological project of simulating physical environments raises.

Software: Outerra

Outerra bills itself as a "3D planetary engine for seamless planet rendering from space down to the surface."[317] The software is only available on Windows operating systems because of the significant driver issues that Linux and Mac OS would pose. Outerra is praised for its ability to synthesize real-world geospatial data into its renderings, and for posing a one-to-one relationship to the physical world.[318] This process is similar to what is performed in Google Earth, where real-life physical data from data archives are used to generate landscape images in a virtual

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[316] "VTP FAQ."

[317] "Outerra," accessed January 5, 2018, http://www.outerra.com/index.html.

[318] Mike Rose, "Outerra : A Seamless Planet Rendering Engine," Gamasutra, January 31, 2014, https://www.gamasutra.com/view/news/209538/Outerra_A_seamless_planet_rendering_engine.php.

Figure 27: Outerra landing page.

world. However one difference is that Outerra performs this function using procedural generation and fractal processing. Both of these processes save valuable computer resources and strain on users' graphics load. It is also a point of contention amongst users who see Outerra as a means to providing highly realistic, fictional worlds for personal use. Often this group of users want their simulated world to visualize a world very far into the future, far into the past, or a parallel, fantasy world.[319] Procedural generation puts constraints on the types of worlds that can be

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319 Here you could look at Star Citizen, which proudly announces on its webpage: "From the mind of Chris Roberts … comes STAR CITIZEN. 100% crowd funded, Star Citizen aims to create a living, breathing science fiction universe with unparalleled immersion… and you're invited to follow every step of development. More than a space combat sim, more than a first person [sic] shooter and more than an MMO: Star Citizen is the First Person Universe that will allow for unlimited gameplay." Another example of this kind of software is Elite Dangerous, which was started around the same time as Star Citizen. See: "About RSI: Next Generation of Space Flight," Roberts Space Industries, accessed April 3, 2018, https://robertsspaceindustries.com/about-the-game/spaceflight. See also: Nick Monroe, "6 Space Game Alternatives to Star Citizen," Gameranx (blog), July 29, 2016,

created from the moment of initial programming, which leads to complaints of "sameness" and "easily detectable algorithmic patterns".[320] The concern is then twofold: one, that procedurally generated game landscapes will not age well (as other games compete for market share by building on existing landscapes and producing new, more exciting ones); and two, that in a market of games that provide near-infinite possibilities, procedurally generated games will have limited lifetimes (read: get boring after enough plays).[321]

Outerra started as an individual project that was able to successfully (albeit slowly) grow. The founder, Brano Kemen, wrote to me in an email that "We initially worked on what would later become Outerra in our spare time for a couple of years, and after seeing the potential shaping up we decided to turn it into something that would also make us a living."[322] Similar as well is that Outerra was built not for a larger ideological goal, as with VTP, but as a personal exercise with an ultimate desire to "license the engine out to as many projects and developers as possible."[323] Kemen writes to me, "The very original goal I had was just to build me a world resembling Earth from ages before civilization, or a pristine contemporary

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http://gameranx.com/updates/id/66364/article/6-space-game-alternatives-to-star-citizen/.

[320] Raffi Khatchadourian, "World Without End," *The New Yorker*, May 18, 2015, http://www.newyorker.com/magazine/2015/05/18/world-without-end-raffi-khatchadourian.

[321] A counter example here, though, would be the 2016 release of the procedurally generated video game *No Man's Sky*. The creators of *No Man's Sky* boast that players will start at the edge of the galaxy with the possibility of visiting some 18 quintillion different planets. Procedural generation is actually a method of generating graphics that was popular in the 80's (such as in the 1984 game *Elite*) because does not require as much computer memory to power it. It is experiencing a bit of a renaissance now as developers revisit the idea of procedural generation as a way of extending the combinatorial possibilities for levels and world creation. What makes *No Man's Sky* interesting in this regard is that the originating seed number that powers their procedural generation is repeated at various points in the game. "The design allows for extraordinary economy in computer processing: the terrain for eighteen quintillion unique planets flows out of only fourteen hundred lines of code." See: Khatchadourian.

[322] Brano Kemen to Nicole Sansone, "Interview about Outerra?," February 6, 2018.

[323] Rose, "Outerra."

world without one, an open world playground for all kinds of personal experiments and experiences."[324] As more developers joined Kemen in this exercise, the uses and possibilities for Outerra expanded, with each individual (and the newly-forming collective) bringing with it modifications to the goals of the software. Kemen remembers it as, "Over time more devs [*developers*] hopped onboard and the project accumulated lots of possible uses such an environment can have for gaming, simulation and visualization, but we also got a considerable number of people just wandering and exploring, and imagining possible experiences, just like me at the beginning."[325] Though there are explicit proprietary goals with the development of Outerra and restrictions on users that would suggest that Outerra is more of a commercial enterprise than some of the grass-roots projects we've seen here, there are also key ways that Outerra remains connected to the open source spirit. For one, while Outtera had by 2014 already been licensed to a number of specialist simulation projects, this was done under the aegesis of building towards a "proof of engine"; following this Kemen publicly stated that fully intended to make Outerra "publically available" as well.[326]

There is a significant symmetry and overlap between those interested in modeling and those interested in modeling for gaming purposes. For this reason you'll often find that users will reference sources like *Grand Theft Auto V* (GVTA V) and *No Man's Sky* with the implication that they are all in the same field of work. Gaming might immediately remind one of popular video games like the GTA franchise, but gaming here also extends to other forms of recreational usage. For example, many users are interested in programs like Outerra for their use as flight simulators. Users using the game for flight simulation often have the most invested in the accurate portrayal of skies, clouds, and atmosphere because it so greatly

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[324] Kemen to Sansone, "Interview about Outerra?"

[325] Kemen to Sansone.

[326] Rose, "Outerra."

impacts the reality of their game scenario. Kemen has noticed that the kinds of users who engage with Outerra has changed overtime. He tells me that "early users of Outerra were and still are mainly various simulator fans, and then gamers dreaming about having a whole planet for their preferred game styles."[327] Not only have users of Outerra changed, but the possible uses for Outerra have changed as well. Most notably, the software now has commercial uses which include making use of the simulation features on the software for occupational training, as well as using the software to generate scenery for movies.[328] Despite these developments, Outerra's original, more fantastical goals remain in place. Kemen writes, "One of remote goals is also a world maker that would allow crafting arbitrarily detailed and believable worlds by people with a map-making and world-building interests. Whether some communities arise around these to fill and animate the worlds is a separate matter and frankly not something we'd want to control."[329]

Forum: r/Simulate

r/simulate, unlike the other platforms discussed here, didn't materialize into a software or grow out of troubleshooting a software. The r/simulate forum precedes a software like Outerra or Virtual Terrain Project. The forum was started by Tom Riecken as a meeting place and repository for thinking through what was then Riecken's personal project of (aspiring to) build a "universal API standard for engine-to-engine communication" that would support what Riecken imagined would be an "ecosphere of games".[330] Similar to how VTP was created as a place for people equally commited to the same project to meet and collaborate, Riecken envisioned that the r/simulate would facilitate discussions about how his imagined

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[327] Kemen to Sansone, "Interview about Outerra?"

[328] Kemen to Sansone.

[329] Kemen to Sansone.

[330] Tom Riecken to Nicole Sansone, "Re: Hello! From Subreddit," January 11, 2018.

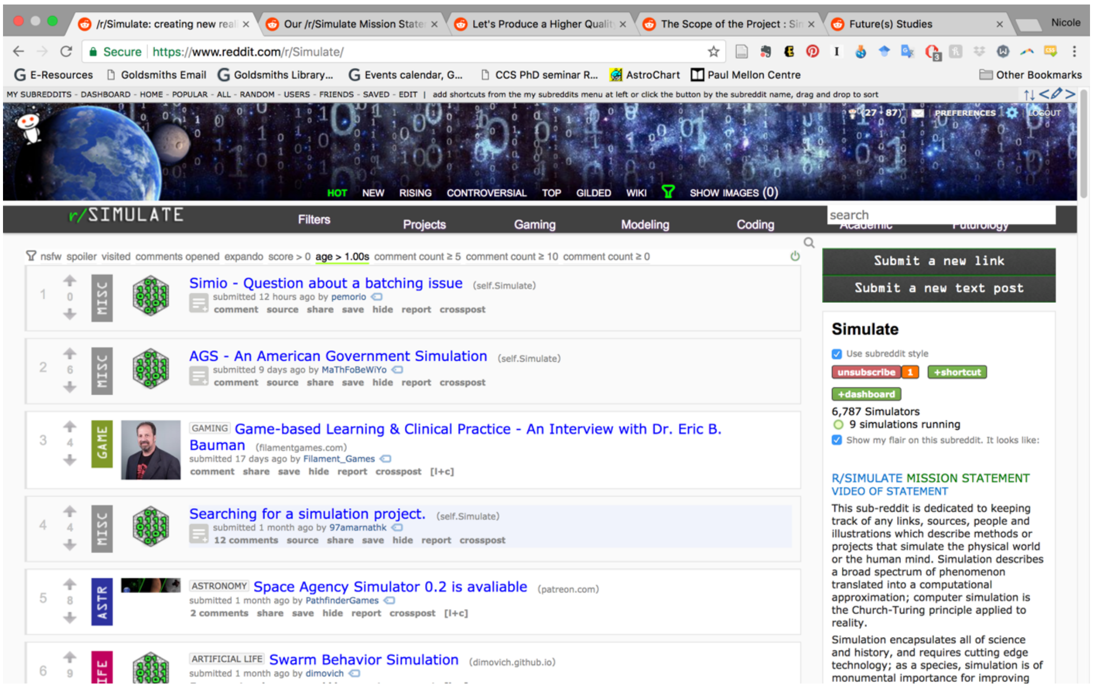

Figure 28: r/simulate landing page.

architecture could be built or assembled.

And, as is the case with VTP, the r/simulate has played a role in recruiting participants for "groups or open source challenges."[331] Riecken's vision for building the multiplatform API architecture began to erode under various pressures—most of them connected to money and resource constraints—so the collection of workers he built on r/simulate ended up, as he describes it, "devolv[ing] to – let's create an open source asteroid mining simulation game as proof of concept, then let's make it a Unreal Engine game".[332] Despite this, r/simulate still maintains some of its functionality as a troubleshooting community. In the absence of a communal project, posters still post links to personal projects for either celebration (validation?) or to ask for advice. Overwhelmingly the site provides a space for light discussion on a common interest in simulation. This often takes the form of sharing links to

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[331] Riecken to Sansone.

[332] Nicole Sansone to Tom Riecken, "Hello! From Subreddit," December 19, 2017.

relevant articles and the occasional collective praising of Elon Musk.

Without talking to Riecken at length, one might say that project that inspired r/simulate was the ambitious endgame of an intelligent and curious, though unstimulated, gamer who was looking to expand their own pleasure resources with the gamble that it might also pay off big in the end. Riecken has a background in physics and astronomy, and is a moderator on another subreddit called r/Futurology which is largely inspired by the work of Nick Bostrum.[333] You can see how these two interests perfectly come together in the foundations of r/simulate. However, what Riecken describes as the starting point for the r/simulate project is a philosophical prompt for thinking a universal system of equivalence the whole world over. He explains how he had spent time between 2012 and 2014 picking away at this project, trying think through if one would:

> …break down reality into all of its components structures in the way that would be best optimized to simulate at a computationally effective rate, how would you do that? Where would you break apart? You could have, like, agent-based modeling used for groups of people. You could have neural nets and machine learning for individual people. You could have statistical modeling for markets. What would be the intersectional points at which one model fed data to the other model, and if you could comprise enough of these models into like a single component architecture, could you simulate everything? […] Once you start to really think about the world map, you start thinking about the way that all of the sciences tie together. All science is is a set of models that describe phenomenon that are happening in the real world, and so if you can have accurate models of phenomenon, and can break that down into functions, operators ... The skies the limit. You just need to have models that can feed data into each other.[334]

Riecken goes on to explain how an early interest in high-level architecture and the ontology implicit in this coding framework served as the structure for his thought and creative inspiration. He expresses how he finds such a framework relevant for the way it describes thinking about "the bigger picture behind [that coding]" which

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[333] Nicole Sansone, Initial interview with Tom Riecken, founder of r/simulate, Skype, January 8, 2018.

[334] Sansone.

asks "how do you break apart phenomenon [sic] in such a way that you can have … different levels of abstraction, and have transitions between different levels of abstraction"?[335]

r/simulate is both a failed and ongoing project, and it is also none of these. Shortly after our interview Riecken had written to me to inform me that he was revisiting the subject of his dashed ambitions, at least in the sense that he was going to try to prepare an archive of the work and revisit (with fresh eyes) the more profitable parts of the endeavor. Riecken's ambitions here are relevant, but they are also parallel to the point. His project of wanting to transcode the natural world into a high level multi gaming API inspired the subreddit but was not ultimately carried out through the subreddit, and the majority of this work lives off of reddit. In these ways he almost constitutes an second scope of study.

However, as I set out earlier the value of these forums is in the material witness they attach to modes of creativity. Riecken's inspiration and his ambition are the same, both gesture towards a way of thinking of the physical world as interchangeable with layered strata of data—from game users, the Department of Defense, APIs and user interfaces, to the bare semiotics that can be made digital, communicable and therefore dispersible—that signals a significant new way of thinking ecological reality. Far from the historical divides between nature and culture, Riecken saw nature and technology as more than just coexistent or co-constitutive. He instead saw nature as subsumed in technology; that making nature more technological would reveal the ultimate techno underpinnings of our word-wide, subconscious simulation. That he shares this profound belief about the world around him with not just one but two subreddits demonstrates not just the one-off thinking of a few rogue gamers but instead a whole framework of thinking that has no problem in gathering converts.

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[335] Sansone.

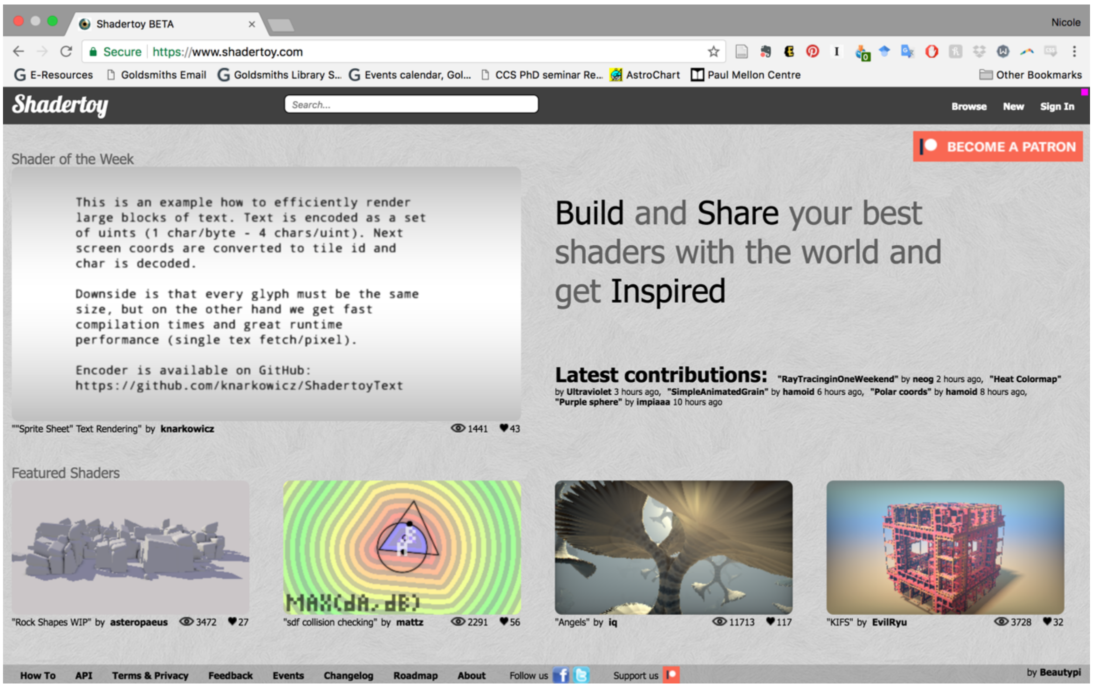

Figure 29: Shadertoy.com landing page.

Shadertoy.com isn't itself a program but instead a community for users to post their designs with relevant information. Shadertoy is the only instance where the service, or commodity, provided is the forum itself. That is to say, Shadertoy isn't attached to a shared project, software, or platform. It is precisely a place to discuss shaders that might then find their way into software like Outerra, or might be troubleshot in part on r/simulate as someone's personal project, or might find itself in a movie, etc.

A shader is a "user-defined program designed to run on some stage of a graphics processor. Its purpose is to execute one of the programmable stages of the rendering pipeline."[336] Shadertoy describes itself as a "web tool that allows

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[336] "Shader - OpenGL Wiki," accessed January 22, 2018, https://www.khronos.org/opengl/wiki/Shader.

developers all over the globe push pixels from code to screen using WebGL."[337] Shaders are part of the graphics pipeline[338] and are programs run on code meant for GPU. Shaders are exactly this: they are, and can only ever, turn pixels colors; they "return" the four color values *r,g,b,* and *a,* which becomes the color of a pixel.[339] Shaders are called as such because since they can determine the color of pixels, they are often used for lighting and shading. However, because shaders work so prescriptively with color and pixels, this counter-intuitively makes shaders *more* flexible in applying other visual effects. By operating on the most foundational components of graphics—pixels—shaders are sleeper agents for any computational process whose end goal is to be displayed.

From the public facing interface we can identify certain key aspects about Shadertoy and the community. Instead of just screen shots, videos are taken which allow for movements in and interaction with the video, as if offering a few seconds of a game experience. Users are also able to record these interactions which are immediately downloaded to your computer. As standard, comment sections are enabled. This is a fruitful area of debate, encouragement, troubleshooting and general exchange. To the right of these areas the shader coding is on display. Shaders are easily able to be directly linked and shared or embedded. The number of views is given and the number next to the [heart] indicating the number of times the shader has been "loved." The comments and work posted to Shadertoy are somewhat disjointed to r/simulate and Outerra in terms of the fact that their goals

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[337] Pol Jeremias and Íñigo Quílez, "Shadertoy: Learn to Create Everything in a Fragment Shader" (ACM Press, 2014), 1–15, https://doi.org/10.1145/2659467.2659474.

[338] Renderers form part of a rendering pipeline that moves a geometry of data points to the pixel rendering that appears on user's screens. Rendering pipelines are part of the graphics pipeline. It is important to conceptualize that these programs operate on the level of pixels and data points, not images, although their end goal is to produce images.

[339] "A Beginner's Guide to Coding Graphics Shaders," Game Development Envato Tuts+, accessed April 3, 2018, https://gamedevelopment.tutsplus.com/tutorials/a-beginners-guide-to-coding-graphics-shaders--cms-23313.

and purposes are different. Because there isn't a unified goal or purpose there is a lot more variability in what is displayed.

On the individual, private side, Shadertoy is set up very much like Adobe's Dreamweaver or any other program that allows for a pure code editing window and visualizer window. Both windows are designed to assist the coder in producing their shader. The code editor will call out syntax and compile errors, along with other releveant information; the visualizer window will display the compiled shader for troubleshooting, and contains "description and other relevant meta data of the shader."[340] Shadertoy does not allow for unlimited creativity: the creators Pol Jeremias and Íñigo Quílez freely admit that one restriction of Shadertoy is that contributors can "only write a fragment shader that is applied automatically to a quad", making the "creation process very minimalistic".[341] Jeremias and Quílez see Shadertoy as a "social platform" and one that is a place for "professionals and students alike to learn and teach about visuals, interactions, reactivity, procedural modeling, GPU internals and shading."[342] To this end Shadertoy provides a lot of assistance to users (though, as we've seen, this also puts certain restrictions on their

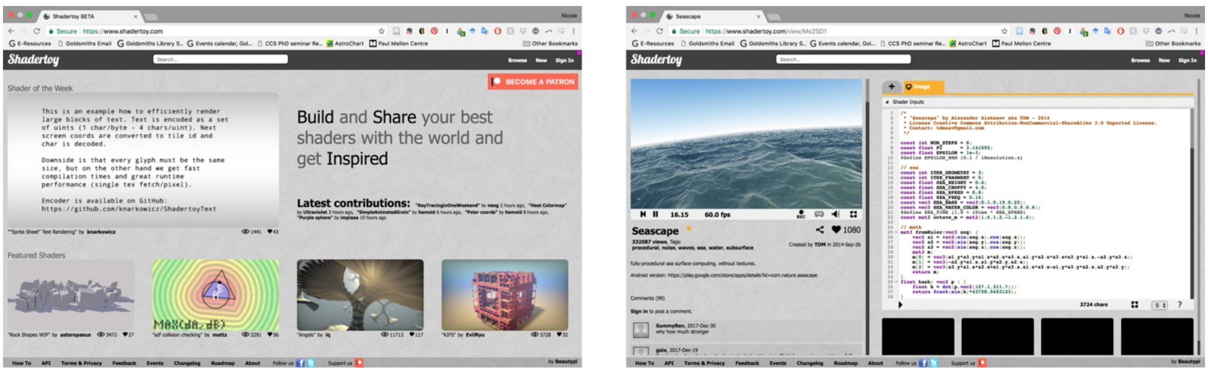

Figure 30: Screenshots of home page and shader page.

[340] Jeremias and Quílez, "Shadertoy."

[341] Jeremias and Quílez.

[342] Jeremias and Quílez.

builds) and options for preset textures, sounds, and videos.[343]

Shaders are a critical aspect of computer graphics but, despite this, are not as popular as they should be, particularly in the fields of computational arts and design. As one study explains, "One of the reasons for this situation is the need of advanced programming knowledge in shading languages. Although there are some online shader libraries, their usefulness as resources for beginners is limited".[344] To correct for this there are a number of processing APIs and, for the more intermediate coder, shader libraries (such as the NVIDIA, Geeks3D, GLSL sandbox, and VertexShaderArt, the latter which, like Shadertoy, is focused on webGL).[345] In the context of amateur earth modeling, this added layer of abstraction and the lack of clarity on the shader programming language presents a small but manageable obstacle to creating landscapes. However, it is clear from technical papers that very often the functions of shaders are made to act as direct metaphors for environmental conditions. In this regard color or audio controls, as one study showed, are reformatted as parameters to allow for the control of such elements as cloud cover, the measure of clouds over a view, density of cloud control, sunset, wind speed, and time of day, which we might assume to mean position of sun (lighting source) in the sky.[346] But again, in this example, what the sunset was actually a gradient of red applied to the clouds.[347]

Shaders are a fundamental tool for earth modelers, and the number of free libraries and APIs available to assist coders in building the best shader for their

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343 Jeremias and Quílez.

344 Andrés Felipe Gomez, Jean Pierre Charalambos, and Andrés Colubri, "ShaderBase: A Processing Tool for Shaders in Computational Arts and Design:" (SCITEPRESS - Science and and Technology Publications, 2016), 192, https://doi.org/10.5220/0005673201890194.

345 Gomez, Charalambos, and Colubri, "ShaderBase."

346 Timothy Roden and Ian Parberry, "Clouds and Stars: Efficient Real-Time Procedural Sky Rendering Using 3D Hardware" (ACM Press, 2005), 435, https://doi.org/10.1145/1178477.1178574.

347 Roden and Parberry, 435.

rendered environment is admirable. However, something is lost when constraints become dictums, and metaphors, rules. Shaders, and shadertoy, prove that what is input into computation and output may be legible to a human observer, but this does not guarantee a *true* or *accurate* result. Red gradients may be computable to be read as sunsets to a human observer, but to other code reading machines it will only ever read

```
void  mainImage( out vec4 fragColor, in vec2 fragCoord )
{
   vec2 xy = fragCoord.xy;
   xy.x = xy.x / iResolution.x;
   xy.y = xy.y / iResolution.y;
   vec4 solidRed = vec4(0,0.0,0.0,1.0);
    solidRed.r = xy.x;
   fragColor = solidRed;
}
```

Notes From A Lurker (Method & Reflections)

What has been done in this and the next chapter is not the result of ethnographic work in the sense that I want to understand *who,* and *why* people, interact with virtual globe software, whether for leisure or labor. That would be a somewhat trickier task because people participate in forums somewhat anonymously, in the sense that you may know a username and a posting history, but you might not know the person's birth name, day job, etc. The ethnographic method here instead comes to function as something akin to what the studio visit did for art criticism and review, providing insight into a creative process that happens at some displaced time from the moment of examination, over an extended period of time. And to be sure, the process of coding for virtual environments *is* an art, one that no less borrows from the traditions of art history than it does traffic in the procedures of computing. Forums allow a peek into the ebbs and flows of the extended moment of creating the imaged environments that furnish virtual globe and terrain visualization softwares. The inventiveness of these moments and this process can also tell us about the particular way that digital technologies force their unique branding onto the aesthetic formation of nature, as well as give documentation to the recalibrations that are taking place between humans and their physical environments *because* of digital technologies.

You might wonder what the advantage is to working with online forums only to import this conversation back into a discourse of art theory, and using art theory to reframe the work and purpose of online forums.[348] This question gets to the heart of what should now be plainly seen as my ever-present bedfellow, the continual challenge of trying to gain some critical purchase on a thing whose only access is through the same means of its manufacture.[349] To this challenge forums

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[348] Forums, and the particularly the ones addressed here, often function as a type of community question answering or CQA. Research on CQA's which look at ranging from the platforms mentioned here to Twitter, Foursquare, and Facebook—can fall into this project of viewing the big data made visible by these online communities as being the key to uncovering some meta-aspect of human culture. I'm not wholesale opposed to this research ethos, though I am highly skeptical of any method that looks at already-reduced abstractions for patterns, and then alleges that these patterns contain some mystical-level of information about who humans are and how they live and feel. However, this body of research is of somewhat more concern for the ways it ends up arbitrarily making cuts in its overwhelming data. Often the result entails resorting to sorting data and drawing conclusions on the basis of socially constructed ideas such as nationality, gender, race, etc. These concepts, left unchecked, reveal very little on their own and instead become creative fulcrums for reinforcing, or generating, harmful and overly reductive stereotypes.

[349] This thematic of my research study is transposed in a particular way that is worth noting in these two chapters. Commenting on the work of ethnographic authorship, Clifford Geertz cautions against "ethnographic ventriloquism: the claim to speak not just about another form of life but to speak from within it" (Geertz, 146). The work of ethnographic authorship, even in its dubious lapses into ethnographic ventriloquism, in sum participates in what Deleuze and Guattari have discussed as the plane of immanence on which concepts are inscribed. Contextualizing Geertz's concern in this way is useful for thinking through the links made later in this chapter about lurking as a conceptual persona. For more on the discursive and textual ethics of ethnographers, see: Clifford Geertz, *Works and Lives: The Anthropologist as Author* (Stanford, Calif: Stanford University Press, 1988).

provide—as skies do, as well—a case study that is, at first glance, one step removed from the aim of my study. The forums I work with are dedicated to the *wholesale creation* of images of nature but aim to do so with such a high degree of realism as to close the gap between model and copy. In other words, these images are text book examples of *trompe l'oeil*, and a classic staging for the art historical debate on realism versus illusionism.[350] Given the overall method of this thesis of moving back and forth between aesthetics and epistemology, I couldn't ask for a case study that more fully justifies such an approach than images that do not know what they are. It is clear on the forums that the collective horizon all members are pointed it at is in increasing realism; moving the images' representation further and further into indexical simulation. What goes unacknowledged is the fictional foundations of the very thing that constitutes their realism. If images of nature in landscape painting had to fight their way out of their presumed, overriding situatedness in the aesthetic, then it's clear that images of nature in these softwares must make the same move, but inverse: a reckoning with the subjective biases that no doubt inform their creation, regardless of how much an online world is made to mirror its physical counterpart. Shoving these images into conversation with illusionism—and worse, the oft marginalized, *almost* kitsch subsection of illusionism that is trompe l'oeil—catalyzes just such an operation.

Problem solving on the virtual globe and terrain visualization software offer key moments when programming is paused, rerouted, and the entire project is made to be redescribed to itself. Ideas and grand plans are hewn back into material constraints. The reality of what software and code will or will not allow, or confessions about how good something *really* looks (as opposed to the praise that might come with the relief of long-term persistence finally paying off, in whatever degree) are brought into relief. Problem solving as a relatively minor crisis mode

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[350] Grootenboer, *The Rhetoric of Perspective*.

opens up new modes of creation and investigation. Software problems or user experience problems reveal the upper limits of what a certain set of skills and functions can achieve. Desiring for more on the side of technicality—more functionality, better performance—means reaching beyond the strictly technical into the aesthetic; desiring for more on the side of the aesthetic—better imagery, greater realism—the technical. That the aesthetic becomes the instrumentalizable remainder of the technical—and vis versa—tells us something about the way these two things cooperate to begin with. Alternatively, if this presumption turns out to be wrong, then what we can also learn is the *how* and *why* humans—as the third party in this tripartite collaboration—have such firmly held expectations that this is, in fact, the case. In all cases, it's the reach for the polarity at the moment of break down that can help us write the discourse of the other.

Confessions of a Lurker

I have to confess (though it may come as no surprise) that I am a lurker in both my personal, and research, lives on the internet. The key characteristic of the lurker is their non-participatory participation on the subject/platform of their interest. As Olga Goriunova describes them:

> The lurker is a freeloader. Generally understood, it is a user that reads and follows, but never contributes. Lurking only happens in interactive environments: Watching television is not lurking, but reading all posts on an online forum without ever responding, posting, or starting one's own thread is lurking.[351]

This has been—*unwittingly!*—the guiding principle for the methodology of my research. In studying earth modeling I didn't try to become a modeler. I used software like Google Earth and Blender (where accessible) to familiarize myself with the programs' interface, with certain problems of use, vocabulary and actions. I also made accounts for the Outerra forum and subscribed to r/reddit with my existing

[351] Olga Goriunova, "The Lurker and the Politics of Knowledge in Data Culture," International Journal of Communication 11 (2017): 3918.

Reddit account, but I did not post, reply, or interact in any capacity on the forums. I looked at posts, at screenshots, I read linked papers, watched YouTube tutorials on how to create modeled natural elements, I watched YouTube tutorials of gamers who would film themselves walking through a world to highlight a particularly well-crafted quality. You could say that in a classical sense of ethnographic work, my work isn't an ethnography at all because of the level of my embeddedness and frequency and intimacy of contact with my "research subjects,"—which is also to say, not at all, or very little. Yet what counts as contact or has to be also readjusted here, because *contact* and *embeddedness* are ideas predicated on the ability of someone to put their physical body in the way of their research. For online research, contact and embeddedness are drawn out of the body and inscribed into a mode of interactivity facilitated by hardware. As Sarah N. Gatson writes, "lurking or reading online content *is* participant observation in a way that unobtrusive observation isn't in an offline ethnographic situation; if we're a reader of online spaces, we are already 'in,' in a real way because most online content is read (interpreted), and not necessarily interacted with by adding the reader's own post."[352]

That said, my physical body wasn't cut out of this process entirely. There is a certain challenge to assembling a story or narrative out of disparate forum posts, spanning an average of four or five years. In this respect, speaking to an informed user—a mod, in the case of r/simulate, or the owner of the business and main software engineer, as with Outerra—helped plug up holes in the timeline and clarified crucial aspects of the work. Interviews were conducted with video calling when possible (Skype, Facetime) and with audio only when necessary. Face-to-face interaction was important to me as a way of establishing trust and making sure that interviewees felt they had the space to share whatever might have needed to be shared. Interviewees were all made aware of my research. I made no secret of my

[352] Gatson, "The Methods, Politics, and Ethics of Representation in Online Ethnography," 516.

project and how this project was driving my interest in them and their work. Often this strategy of transparency led to a broadening of the conversation, with interviewees offering me new ways in to my project than I had anticipated. The interviews were recorded and transcribed, and now live as text documents that I have selectively quoted from here and use for personal reflection.

All of the interviews I did eventually trailed off the path of discussing a particular software or code into broader, passion topics like climate change, or digital culture. Conversation came to replace interview. Sometimes in the course of these conversations, details about personal situations involving health, money, career were revealed to me. With a giant as large as Silicon Valley looming over this entire conversation, this was an inevitability, and make no mistake—many, if not all, of these conversations touched on issues of competition and resources, as well as the Department of Defense (in the U.S.) and Silicon Valley. As frustrating and as exciting as these stories were to hear, and as much as their potency made me want to share them and expand my research, ultimately, they fell outside the remit of this study. The scope of my research has been trained on identifying how human and non-human actors work in concert to produce digital representations of the earth. Adding stories of human triumph and struggle that emerged out of producing these representations, while adding interesting and valuable context, tips the scales back in favor of understanding machines as solely human tools. What I have tried to do in this thesis, instead, is to maintain a balance between all three agents at play in the digital representations of earth—ecology, technology, and humans. Sometimes this has meant rhetorical strategies that seem to *over*-de-emphasize the human dimensions of my analyses. If this has been the case then it only further supports my reason for writing in this way: to *decentralize* (but never omit) human values and activities from the stories we tell about technology. Modeling softwares and computer graphics pipelines don't merely execute the bald desires of human users, and in the same ways consistently. As I have been arguing, these digital operators are as equally influenced by human users as they are influential *on* human users. Thus, for methodological balance, adding emotional drama to the human narrative of my research question required that I would also add an equally emotional drama fed through the technical narrative. How could one write that—what rhetoric would persuade human users to engage in a pathos-laden reading of technical operators? And furthermore, what would an emotional narrative of digital pipelines—texture mapping, modeling, rendering—be? I have not found an answer to either of those questions in this moment. All that said: my choice to not share personal, human stories doesn't mean that their potency doesn't still pulse through this text. One day I hope to have a chance to pick up where I have left off.

In more traditional ethnographies, such a mix of objective, distant observation and more intimate styles of investigation might invite some inconsistency in results or raise issues of ethics. However, participating with users and sharing information is foundational to the earth modeling communities; they are, at their base, efforts to collect and organize wide swathes of expertise, skill, and labor power for the shared common goal, which is also a shared reward. My aims might not have been to contribute to gaming environments or to produce an accessible program for flight simulation, but my enthusiasm for the projects mirrored that of the users and thus gained me access. Yet, I would be naïve to not entertain the idea that my access might have been more palatably granted because I brought a touch of hope (no matter how implicitly) by virtue of my position as a researcher and someone currently embedded in the structures of an academic institution. Perhaps my work would help to publicize, and thus revitalize, a project; perhaps a vital connection could be made via my network. Such hope is more palpably felt precisely in the shadows of giants like Silicon Valley, when just the act of individuals coming together can put even the most jaded into a kind of Marxist fever dream of uniting on the factory floor to overthrow the fat cats. Whether my access was granted on this basis, or to the former (and my personal opinion is that this is much more the case), or some mixture of the two, in the end is, I think, a negligible point. All of these feelings are wrapped up in any kind of grass-roots project organized on the internet, and it is only at their extremes that these individualized motivations make some kind of observable impact on the wellbeing of the whole.

Interviews with individuals in the earth modeling communities didn't just help to plug up holes in timelines, it also gave me access to rarefied information. There's a number of pressures that preclude information from freely circuiting—sometimes it's a proprietary issue, sometimes it's just as simple as no one thought to write it up.[353] This was my experience with, for example, Tom Riecken, the founder of the subreddit r/simulate. Once the project originally intended for the r/simulate proved too difficult to execute, the whole exercise was just sort of stopped in its tracks. Following our interview some years later, Tom expressed in an email to me that going through the events and all the efforts his team had gone through with r/simulate, seen with fresh eyes and the benefit of a few years distance, had inspired him to create an archive of their efforts and assemble a kind of CV for himself that would reflect his role in orchestrating this project.[354] The thrust of the project, what it was and what it had accomplished, even the story of its shortcomings, was simply lost because no one was going to archive it.

On the other hand, the subject of accessing privileged or rarefied

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[353] This could be seen as indicating a potential danger in my method by falling trap to exactly the poststructuralist critique of the impossibility of an "ethnographic authority" and "pointing to a discursive naïveté in ethnographic writing which is unconscious of the way it 'writes' and makes culture rather than discovering or reflecting on it." I would counter that what was performed here was in actuality an act of self-archiving, and while this is of course still susceptible to a rewriting of culture, it also seems outside the scope of my specific research concerns and of minimal impact (minus validating a project and a person that/who rightfully deserved credit!). See: Paul Willis and Mats Trondman, "Manifesto for Ethnography," *Ethnography* 1, no. 1 (July 2000): 6–7, https://doi.org/10.1177/14661380022230679.

[354] Riecken to Sansone, "Re: Hello! From Subreddit."

information also begs the question whether or not these online spaces aren't actually, by default, private spaces. An article by Samuel Wilson and Leighton C. Peterson reviewing the emerging intersections of anthropology and digital culture gives reason to pause. They note that information and communication-based technologies on the internet pose challenges to anthropological methods precisely on this fault line. Should "statements made publicly accessible discussion boards or other communication spaces" be considered in the public domain, and thus "freely used by researchers"?[355] Wilson and Peterson point out that, for some researchers, "this is a form of electronic eavesdropping that violates the speaker's expectation of privacy."[356] My original feeling in performing this research was that statements made on forums were, without question, part of a public domain. Yet in each of the forums I explored there was, in some form, a block to total and unfettered access. All four platforms required a login account for basic accessibility. They weren't password protected and they didn't cost money, but they did require you become a "participating" (or potentially participating) member of the group by identifying yourself (though, again, identification here is not understood as it would be in the physical world—it simply means attaching yourself to some kind of account, the veracity of which, or similitude to your offline life, being a moot point). If basic social access was partially limited, then one had to wonder why, or to what benefit, this restriction was connected to. On this point we might consider that these communities were either explicitly challenging a mainstream corporation and product (Google Earth), or striving to create something that could be monetized (as Tom Riecken and r/simulate were trying to do), or to troubleshoot and keep a software afloat (Brano Kemmen and Outerra), or to potentially get yourself known,

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[355] Samuel M. Wilson and Leighton C. Peterson, "The Anthropology of Online Communities," *Annual Review of Anthropology* 31, no. 1 (October 2002): 461, https://doi.org/10.1146/annurev.anthro.31.040402.085436.

[356] Wilson and Peterson, 461.

transforming a space of community and critique into, in part, an outsourced resumé available for viewing for employers (Shadertoy.com). In keeping with the code of ethics that Wilson and Peterson have suggested, I can only wager that my research is a sufficient level of remove from the aims or sensitivities of these communities so as to show "respect for people understudy, of protecting their dignity and best interests, of protecting anonymity or giving proper credit, and of obtaining informed consent-apply online as well as in face-to-face contexts." [357]

Looking Forward

In this chapter I have presented brief overviews of four parts of the earth modeling realm. We were introduced to earth modeling as an ideological project through Virtual Terrain Project; earth modeling as a software through Outerra; earth modeling as a forum through r/simulate; and earth modeling as a specific form of labor, in ShaderToy.com. I presented my methodology for the research in this chapter and as well as for what is produced in the next chapter. This chapter largely sets the stage for the following chapter.

The next chapter will address the aesthetics and epistemological parameters of the four platforms presented. Specifically, I will be looking at moments of trouble shooting and failure in VTP, Outerra, r/simulate, and Shadertoy when crafting sky or atmospheric elements. Skies, clouds, atmosphere and weather are all crucial parts to the functioning and consistency of the virtual world, yet they pose many unique and difficult challenges. That these elements could be so central to a program, and yet so awkwardly programmed, signals a breakdown of epistemology in the

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[357] The quote in full: "Our feeling, in keeping with the view that anthropology online is substantially the same as any other sort of anthropological research, is that although the AAA Code of Ethics does not address electronic communication directly, its ethical principles--of showing respect for people understudy, of protecting their dignity and best interests, of protecting anonymity or giving proper credit, and of obtaining informed consent-apply online as well as in face-to-face contexts." Wilson and Peterson, 461.

collaboration between humans, technology, and conventions of representing nature visually. While at first pass earth modeling may be seen as primarily an operation of the technological and the aesthetic, moments of breakdown introduce us to the ways in which the subjective is forced to bear out on critical points of decision. With this in mind, the next chapter sets itself to the task of unpacking the modeling process as always a site for the meeting of information and creativity—epistemology and aesthetics—and a technological process that is, significantly, always in deficit of what it is asked to do. The sum effect of this work therefore offers an initial mapping of landscape aesthetics that are not hewn to discipline or medium, but instead negotiated between cultural values and practices of representation.

Chapter Six: Modelers, Modeling

Introduction

In the previous chapter I introduced four distinct domains of amateur earth modeling through four platforms and software: Virtual Terrain Project, Outerra, r/simulate, and Shadertoy.com. As a form of ethnographic work performed online, I described my method of inconsistent but sustained contact with the forums attached to these software, and, in some cases, to the mods or lead programmers of programs.

This chapter builds on from the previous chapter. Its goal is to use earth modeling communities as a case study for understanding how aesthetics gets forcefully pushed into epistemology. Amateur earth modeling communities are not located in institutional labs or universities, nor do they receiving non-privatized funding (and, indeed, may not receive funding at all) and they typically do not produce scientific knowledge in the form of journal articles and conference proceedings, or do not do so with any regularity. Yet despite this, amateur earth modeling communities fit the definition of what Karin Knorr Cetina has called *an epistemic culture*, a term she uses to mark out "knowledge settings"—places where knowledge is created, produced and verified—and which also strongly emphasizes the notion of knowledge as "practiced-within structures, processes, and environments that make up specific epistemic settings."[358] This framing helps to draw out the significance of observing amateur earth modelers for understanding aesthetics and epistemology. Amateur earth modeling communities and software live an ambiguous life as both institutionally exiled and epistemically engaged. Freed from the conventional constraints, the choices that amateur earth modelers make in their work become stand-alone, freely-derived comments on the role of the visual in pragmatics, perception, and our attitudes toward natural phenomena. Inasmuch, these choices also present a contrast to the reified protocols of more institutionalized epistemic cultures. Using Knorr Cetina's sociological work on High Energy Physics (HEP) and molecular biology labs, we can compare the ways these different epistemic cultures foster beliefs and practices about how visual data, sensing bodies,

[358] Knorr Cetina, *Epistemic Cultures*.

and protocols for objectivity can (or cannot) be resolved.

It should come as no surprise to say that what we find in this comparison is that it is impossible for actors in epistemic cultures to reconcile objectivity with sensual data. This impossibility shifts the focus of the chapter away from the amateur earth modeling *actors* to earth modeling *practices*. These practices—manifest in the networked collaborations and projects—trouble the creation of knowledge through their unregulated reliance on vision, image, and affective sensibility. I argue that this troubling is the outcome of two histories of the antagonistic relationship of images to science, which also introduces the overarching theme of this chapter. The first of these histories is the history of computer graphics. Embedded in the foundation of computer graphics is an internal, institutionalized split between computer-generated images, and computer-aided data visualizations. At the center of this split is an ambivalence towards the *graphics* of computer graphic; or in other words, how the use of images might enhance, trouble, or discredit computationally derived knowledge.

The second history draws from the uses and disuses of images and the sensing body in epistemic practices. There is a long history of this troubled co-dependent relationship between science and sense which is best formulated in the history of scientific objectivity. Lorraine Daston and Peter Galison's study of the history of scientific objectivity here becomes a critical key for decoding the techniques that varyingly emphasize subjectivity and depersonalize results in the pursuit of "objective" knowledge. To the latter effect we find in the book's later treatments (spanning the periods of 1840 to 1900, and post-1900) that the scientific self is shipwrecked in the proliferation of image making machines like cameras and "changing ideals for fidelity to nature".[359] It is also in this confusion of depersonalization, science, technology and images that Daston and Galison outline

[359] D. Graham Burnett, "The Objective Case: A Review of 'Objectivity,'" *October* 13 (2010): 135.

the paradigm most applicable to understanding amateur earth modelers. This paradigm appears not in their concluding chapter on science and technology (the "fatally hip world of nanoscience", as one reviewer called it) but instead in their formulation of *structural objectivity*.[360] This form of objectivity, Daston and Galison argue, did not rely on images or representation for objectivity but instead looked for methods of suppressing subjectivity at a *special* register. What the scientists arrived at instead was a form of objectivity guaranteed by mathematics, philosophy, and the recognition of interlocking patterns across domains.[361] Structural objectivity understood in this way aptly describes the working methods of the amateur earth modelers. Yet a tension emerges when we consider that while the modelers adopt structural objectivity in some forms—distance from a scientific self, a reliance on communicable structures—they also distinctly rebuke those who adopt this objectivity in their work with images and visual data. Such a contradiction underscores yet another ambivalence about the status and role of images and visual forms of epistemology.

In Daston and Galison's account, structural objectivity notably eschews representation,[362] but I propose that in so doing, a great deal is revealed by omission about the relationship between pictures and thought. One might be inclined to think that the bulk of this insight is done at the end of their study, when Daston and Galison begin to look at the pursuit of nanotechnology as signaling a shift "from image-as-representation to image-as-process wrenched the image out of a long historical track".[363] Instead, I propose that this work has yet to be done. To conclude that structural objectivity was a built on a strict eschewal of the image as the form of

[360] Burnett, 143.

[361] Burnett, 143.

[362] As one reviewer put it: "These guys did not make a lot of pictures - indeed, that was sort of the point." See: Burnett, 143.

[363] Daston and Galison, *Objectivity*, 383.

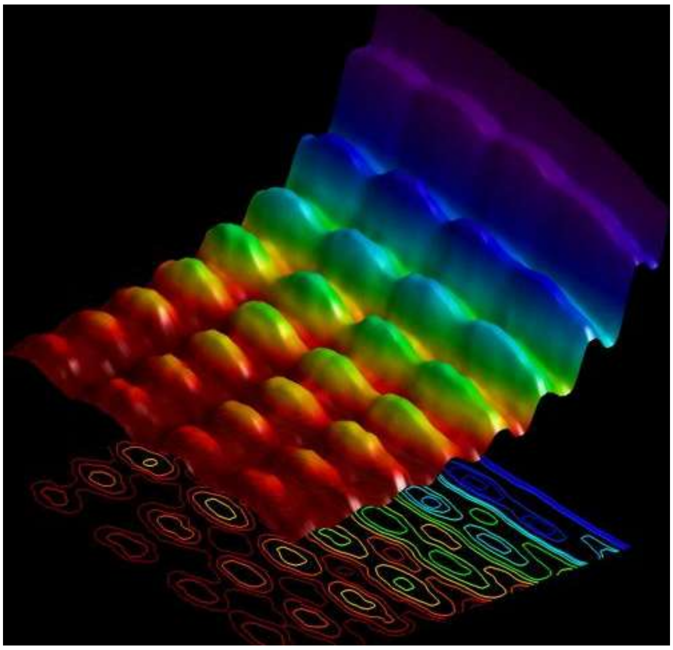
representation *par excellence* is to inadequately attend to the myriad formats we can understand an *image*. Discussion of the amateur earth modelers reinserts this debate into our study and highlights the way that disciplinary understandings of the knowledge-producing subjective most consistently collapse when confronting a visual world.

The confusing nexus of optic bodies and optical tools, image aesthetics and aesthetic tools, and the way in which this nexus is situated in an epistemic culture is thus the guiding inquiry of this chapter. Observing how each of these intersecting points is played out in the cultures and practices of the amateur earth modelers continuously invokes and invites a discussion of the political consequences of such confusions and intersections on a global, ecological scale.

Unlikely Labs

Karin Knorr Cetina's ethnography of the high energy physics (HEP) lab and a molecular biology lab is one of a number of texts that breaks down the social construction of scientific spaces. Knorr Cetina's focus on *the construction of the tools* that construct knowledge "deepens the split with traditional notions of knowledge", and in so doing emphasizes the fractiousness of the sciences. Such a task wreaks havoc on those guardians of the purity of science, which is to the advantage of everyone invested in opposing the racist, sexist, classist, or ableist discourses that have flowed from this monopoloy of the natural sciences throughout western history.[364] By arguing that laboratory settings are not passive spaces in which science

[364] These critiques can be found in the work postcolonial and feminist critiques of science. This sentence also reflects a fundamental attitude in cultural studies thinkers who follow Haraway in defining "science studies as cultural studies" and which fundamentally reorganizes the the dichotomies that pin these two domains—science and culture—into what Nina Lykke and Rosi Braidotti have described as a "a field that deals purely neither with 'nature', nor 'culture'—i.e. a monstrous construct that lurks subversively in between the humanities and the natural sciences in their classical sense." See: Haraway, Donna Jeanne. *Primate Visions: Gender, Race, and Nature in the*



This photo is an example of the kind of work that is performed in a high energy physics (HEP) lab. It is also shows the degree to which images in epistemic cultures—even as high-level, complex, and speculative as HEP—draw on aesthetic strategies to make data clear and enticing.

Figure 31: First-ever photo of light as both a wave and a particle.

is done but instead provide "enhanced environments" that serve as spatiotemporal mediums for the reconfiguration of phenomena, Knorr Cetina draws our focus to the fundamental ways that "Laboratories recast objects of investigation by inserting them into new temporal and territorial regimes."[365] Such a way of understanding laboratories proposes that scientific experiments and scientific actors do nothing short than actually to *create* the phenomena they wish to "passively" observe. That such a creative potential is built in to the very structures that hold scientific practices underscores their artifice, thereby necessitating the redefining of the actors and settings that comprise the scientific disciplines. Thus in place of a single science, a single knowledge, or a single episteme, it is more accurate to think in terms of

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World of Modern Science. New York: Routledge, 2006. See also: Lykke, Nina, and Rosi Braidotti, eds. *Between Monsters, Goddesses, and Cyborgs: Feminist Confrontations with Science, Medicine, and Cyberspace*. London; Atlantic Highlands, N.J., USA: Zed Books, 1996. See also: McKittrick, Katherine, ed. *Sylvia Wynter: On Being Human as Praxis*. Durham: Duke University Press, 2015.

[365] Knorr Cetina, *Epistemic Cultures*, 43.

epistemic cultures and epistemic settings, definitions which Knorr Cetina advocates for their emphasis on "knowledge as *practiced*-within structures, processes, and environments" (emphasis mine).[366] From this definition we can identify three core ways that define an epistemic culture or setting sets itself apart from its larger context: institutionalization, actors, and practices (methods).

Outsiders Within

With the exception of VTP to a large extent, Outerra, r/simulate, and shadertoy are not spaces that are knowingly trying to participate in a knowledge making process or community. Yet, what is being discussed is an approach that is firmly institutionalized and already participating in epistemic culture. Outerra is a software with plans of scaling up. It is also a business. The Virtual Terrain Project sees itself as a form of open source working and citizen science project to produce a highly modular, highly technical one-to-one representation of the globe and terrain that can then be applied towards Capitalist and civic applications (for example, flight simulators and educational purposes). Shadertoy.com is a free and open social platform that exists on the fringes of capitalist environmental modeling; its sociality is not institutional, but it is institutionalizing (as we saw in the last chapter). Shadertoy's premise works as a workaround for institutional barriers to participation; instead of having to learn the difficult work of programming shaders, preprogrammed shaders can be developed from the ground up, empowering more projects outside of the normal skilled circuits. And to this end, then, r/simulate had aspirations of forming a new kind of institution aimed exactly at attacking existing institutions: capitalist and venture capitalist institutions of tech world and silicon valley, institutions of labor and waged work that prevent the free and creative collaboration on projects without ends.

We saw in the previous chapter that all four projects are haunted by a

[366] Knorr Cetina, 8.

specter, in some form or another, of Capitalism. By this I mean to express the distinct ways in which earth modeling projects are variably conditioned by their access to resources, whether that comes in the form of money, time, personnel, equipment, etc. The clearest example of this was in Tom Riecken and r/simulate, whose project was corroded by the impossibilities of intensive work on a voluntary and distributed scale. This reality on the ground is in at least a partial contrast to, or even in conflict with, my own method of investigating how natural phenomena are modeled, in which I consulted textbooks, conference proceedings, and databases such as Web of Science. This information, in theory, represents the "best," most advanced, most developed information on their topics that is available. What we should know this to also mean is that independent of the unique skills, insights, and training of individual researchers, as well as the immense time and labor that they have all inevitably dedicated to their study, these "best of" achievements are also buoyed by institutional support. Tom Riecken, for example, was self-taught and *learning through* his attempt at building a simulation. While Knorr Cetina notes that in epistemic cultures technical objects and objects of study—shared projects—can join people together, whether to "confront or control [an] experiment" or work "together in a human endeavor", it is also undeniable that "'money' and 'manpower'" is a powerful tool for collectivizing.[367] For this reason we can the ways that r/simulate falters as an epistemic culture, yet VTP, Outerra, and Shadertoy continue to prove that such cultures need not be restricted to laboratories.

Knorr Cetina's study magnifies the frictions of the professionalization of epistemic cultures—a friction which extends to even to those seemingly out of such circles. Yet despite being structurally excluded from these domains, amateur earth modelers make claims to epistemic culture through a continual practice of

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[367] Knorr Cetina, 131.

epistemic-setting making; of making place that draws epistemic culture into it. This is achieved primarily through their online platforms. When the modelers take their efforts offline, as some do,[368] the coordination of these efforts is always originated in, or looped back through, the platform, which underscores the centrality of these networked spaces to the modelers' epistemic culture. We see this circuiting back into the platform again, for example in the way that institutionalized knowledge is brought into the platforms—whether by directing to links, problem solving on forums, circulating paywalled articles for free. This form of appropriation is most apparent in the organization of VTP's website.

While amateur earth modelers are dependent to a degree on institutionalized epistemic cultures for expert knowledge and best practice, the modelers' sources of knowledge are also largely of a rogue variety, springing from an internet-fed *hive mind*, or piece-mealed together through social networks, or collaboratively traded in a kind of informal economy of skills and good will.[369] For as much as we see these communities reach for the resources provided by institutionalized epistemic cultures, what we also can see emerging is a tactics of "making it work;" an imperfect pragmatism that arrives at conclusions or results through a kind of wild cat approach

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[368] Tom Riecken of r/simulate often met with people from his community. He notes that he had "met a couple of times" with the "guy who created [r/]Futurology"—a subreddit on which Tom is a *mod*, and is separate to r/simulate but not wholly unrelated. At the time of speaking Tom also told me he was "going to meet with one of my collaborators from the asteroid project in about a month." And not only Tom, but other members of the r/simulate project also had offline meetings that were not directly related to the project but shared enough common ground as to make the meeting generally beneficial to the act of making a knowledge community. Tom told me that his business partner from the r/simulate project "met with this other guy… who's actually working on a game called Eco". As Tom told me this, he was also quick to add that I should "look at [Eco] because it's kind of like Minecraft, but with ecology simulated directly in it. If you murder too many deer you're done. If you kill all the wolves you get sick. There's a lot of cool things like that out there." This kind of selfless promotion and generous sharing of information was something I frequently encountered with Tom personally and is a critical part of the platforms' structures. In this way, categorical knowledge sharing becomes another avenue by which epistemic settings are made (i.e. this is the place we go to learn about x) and individuals are anchored into an epistemic culture.

[369] This alone should signal how our epistemic cultures are ensconced in a under-criticized veil of other-worldliness and truth without copping to the fact that one need only purchase entry.

to problem solving. This wildcat approach is, of course, performed in collaboration with other humans-as-users, other humans as collaborators, and software itself. In this personalized engagement what we find is that aesthetics becomes both a tool *and* a standard of knowledge. Particularly in moments of problem solving or trouble shooting—breeches in the tightly enclosed epistemic world—aesthetics are called upon to plug up the holes. Aesthetics then both sets and invites conditions for a messy, grab-bag of techniques, intuition, and embodied knowledges.

A Motley Crew

Amateur earth modelers make epistemic cultures by making their platforms knowledge settings, and they also make themselves epistemic actors. We can see how they do this by comparing their practices with the physicists in HEP labs. Knorr Cetina describes a practice of high energy physics (HEP) labs, where the production of *negative knowledge* is linked to a rigorous form of a personalized, scientific *care of the self*. HEP produces knowledge about invisible matter, which makes the role of perception both central and problematic. This doubly extends to HEP's use of sensing and detection technologies, which are again, both central and laden with their own complications. "In many ways, [HEP] operates in a world of objects separated from the environment" Knorr Cetina writes, "or, better still, a world entirely reconstructed within the boundaries of a complicated multilevel technology of representation."[370] While technology can "provide the first level of these representations" for HEP scientists, it is well known that such a first level representation includes the sum effects and impressions of the experiment, the phenomena, and the technologies themselves. Such an overcrowding of undistinguished information, and little recourse for confident, external validation, necessitates the need for other resourceful methods for deriving some kind of truth (or self-consistency) out of the morass.

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[370] Knorr Cetina, *Epistemic Cultures*, 47.

To overcome this, HEP scientists "substitute a concern with their own internal production circuitry for a concern with real-time objects", or as Knorr Cetina puts it in Michel Foucault's words, "they substitute the care of objects with the care of the self."[371] Care of the self in this sense signifies a preoccupation of HEP "researchers with the experiment itself, with observing, controlling, improving, and understanding its components and processes."[372] This kind of concern with *observing, controlling, improving,* and *understanding* the components and processes of an epistemic project is the default mode of operation with the amateur earth modelers. As an epistemic culture supported primarily through online platforms, amateur earth modelers are always archived, observed, and made observable, at any point of engagement. As just one example (out of many) of such a practice, Outerra user *Avi* posts on the forum, "I have not seen this topic here so just a quick question to the developers if dynamic cloud shadows and scattering of light from clouds is on the to-do list or is this just too much detail to be considered working on?" Brano Kemen, one of the founders of Outerra, responds "It's on the todo list but it has some dependencies on the shadowing system and cloud rendering that have to be done first."[373] As you can see, contributing to the *todo* list is something open to all users on the forum; and, the *todo* list is often posted in fragments on the forum in the form of updates. Once these updates are released, threads often emerge for pointing out any bugs that arise out of new developments.

The basis of a laboratory care of the self is rooted not only in the understanding of the lab as a self-generating, self-contained world unto itself but also one that emerges from its own high-level sociality. In Knorr Cetina's account, there exists an interpersonality of subjectivity that is distributed out amongst all

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[371] Knorr Cetina, 56.

[372] Knorr Cetina, 56.

[373] Avi, "Cloud Shadows/Scattering.," Outerra Forum, February 17, 2016, https://forum.outerra.com/index.php?topic=3523.msg40109#msg40109.

elements in the cosmos of the laboratory. We find not only that detectors become individuals subject to moral behaviors (and reprimanded, if they transgress these benchmarks) but also that the detector-individuals operate in a collaborative society (that includes human actors), and not just a neutral society, but one in which alliances can be made, battles are fought, and unity is cemented against an imagined "enemy."[374]

The sociality of the amateur earth modeling communities is, in a certain sense, surprisingly less social and personal. While all of the four actors described in the previous chapter (r/simulate, Outerra, VTP, and Shadertoy.com) were invested in not only an earth modeling project but in a "multiplayer", "collaborative", "open source" project that emphasized the collaboration of more than one person at a time; a highly social society of people rooted in technology. Yet for all this sociality, the technology itself does not take on the same anthropomorphized sense of familiarity as in the HEP labs. There is no kinship between technology and programmer. There are problems, troubleshooting; objects break and create depersonalized problems;[375] their communities are comprised of "Organizations, Conferences, Community and News Sites".[376] The inclusion of project managing softwares like Trello can also point us to the utility of how these operators see their collaboration with technological counterparts—as tools for efficiency and problem solving, not collaborators.

In fact the question of distance and proximity between human and computer is a recurrent one, with the preference leaning towards distance, unfamiliarity; breaking that closeness that in Knorr Cetina's accounts makes for trust in a

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374 See: Knorr Cetina, *Epistemic Cultures*, 111–35.

375 fly77, "Bern Senery Graphics 'Clone/Smear' Problem," Outerra Forum, April 28, 2018, https://forum.outerra.com/index.php?topic=3820.0;topicseen.

376 "Virtual Terrain Community," Virtual Terrain Project, accessed April 30, 2018, http://vterrain.org/Community/.

laboratory in all its various taxonomies.[377] In one example of this distancing we can see a user comment on the workflow in Shadertoy that they would prefer to limit user autonomy on their platform; that rather than "allowing to save textures uploaded by users" removing this functionality optimizes tools: "it saves server space, and makes people think how to generate it all on the fly."[378] Not only does this move depersonalize the tools and processes of the software but we can also see how it demotes human actors in an imagined ranking by choosing for functionality that trains its users through punishment and restriction.

If in Knorr Cetina's account HEP physicists had aging detectors that had to be cared for against their senility, then amateur earth modelers have tools that are badly behaved, always on the brink of total revolt. At times we see the programmers make compromises in the private spheres of forum discussions and updates. At other times we sense there are hard won victories, but these are fleeting as programmers await notice of bugs and other knock-on problem effects. Modelers in effect do not fight against the difficulty of transforming natural phenomena into binary code and ordered mathematics; in effect, they fight against their tools disobeying them, rendering what should not be rendered, using too much hardware resource. At these moments it is most apparent how the strategy of engaging epistemic practice from outside of an institution can be of utility. In the Outerra forum on 7 December 2017, Brano Kemeni (user *cameni*) responded to a post by *josem75* requesting updates on terrain reflectance to avoid "overexposed situations. In snow and also terrain. Coz sometimes terrains are abnormally white in some mountains, and also get burn."[379] Kemeni explained that josem75's request would have to wait because

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[377] Taxonomies of truth Epistemically Cultures

[378] Vladimir Zh, "Shadertoy.Com Roadmap | Trello," Shadertoy.com Roadmap, September 23, 2016, https://trello.com/b/5hM0CjId/shadertoycom-roadmap.

[379] josem75, "Little Things of a Big Thing," *Outerra Forum*, December 2, 2017, https://forum.outerra.com/index.php?topic=3773.0. An image is considered "burnt", non-technically speaking, when the image shows "uniform blobs of color, black, or white where there should actually be detail."

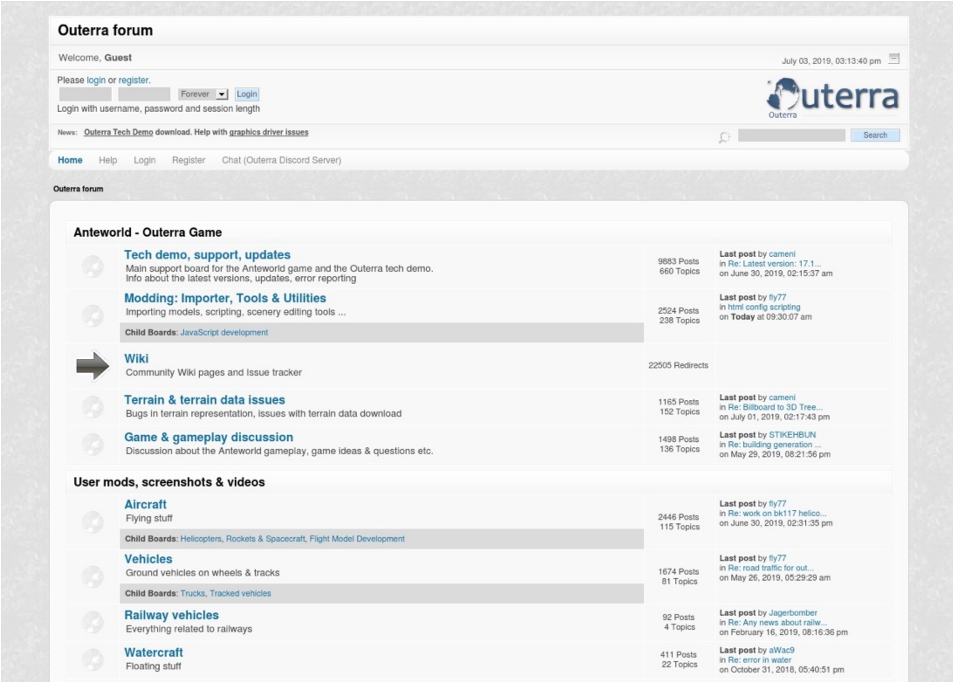

Figure 32: Screenshot of landing page for Outerra forum, the base of Outerra's sociality.

there was "going to be an update to terrain materials adding some PBR parameters (primarily adding the roughness) that will change the lighting quite a lot."[380] What is significant about this exchange is that josem75 raises an epistemic issue that presented aesthetically—an issue of light on terrain—and Kemeni responds that such an issue cannot be dealt with because there are other technical updates in the pipeline. Kemeni's response is not an either/or, nor does it dismiss the validity and urgency of a snag in the way Outtera looks. This expresses the extent to which the methods of working with visual data and technical data are blended in the amateur earth modeling procedures. This is something which, as we will see, is not always

[380] josem75, "Little Things of a Big Thing," *Outerra Forum*, December 7, 2017, https://forum.outerra.com/index.php?topic=3773.0. Cameni also adds that "Also the snow will eventually go away in its current form painted on the terrain." We can infer that this move to remove the "painted on" snow is part of the broader project to update and make more realistic Outerra through physical based rendering.

possible in more institutionalized epistemic cultures despite the fact that as sociologists of science and art historians often agree, "in terms of the attention scientists lavish on creating, manipulating, and presenting images, the 'two cultures' [of art and science] are virtually indistinguishable."[381]

Images That Trouble

It should come as no surprise to say that what we find in this comparison is that it is impossible for actors in epistemic cultures to reconcile objectivity with sensual data. This impossibility shifts the focus of the chapter away from the amateur earth modeling actors to earth modeling practices. These practices—manifest in the networked collaborations and projects—trouble the creation of knowledge through their unregulated reliance on vision, image, and affective sensibility. I argue that this troubling is the outcome of two histories of the antagonistic relationship of images to science, which also introduces the overarching theme of this chapter. The first of these histories is the history of computer graphics. Embedded in the foundation of computer graphics is an internal, institutionalized split between computer-generated images, and computer-aided data visualizations. At the center of this split is an ambivalence towards the *graphics* of computer graphic; or in other words, how the use of images might enhance, trouble, or discredit computationally derived knowledge.

Computer Graphics

Computer graphics in part is executed through images, which makes the ambivalent relationship of computation to visual data peculiar. As one text book notes:

> In the early years of the field, research in rendering focused on solving fundamental problems such as determining which objects are visible from a given viewpoint. As these problem have been solved and as richer and more realistic scene descriptions

[381] Elkins, "Art History and Images That Are Not Art," 559.

> have become available, modern rendering has grown to be built on ideas from a broad range of disciplines, including physics and astrophysics, astronomy, biology, psychology and the study of perception, and pure and applied mathematics. The interdisciplinary nature is one of the reasons rendering is such a fascinating area to study.[382]

Yet as we will see, despite a fascination with the application of other disciplines towards computing impediments persist in the output of these mixed methods, not least of which in their application and reception. One such example of this is the history of computation, and graphical computation, in the sciences.

While the history of computer graphics dates as far back at the 1940s and 50s, we can say that visualization in scientific computing (ViSC) became institutionally recognized at the 1987 SIGGRAPH conference with a presentation that later served a report funded by the National Science Foundation. The report, by McCormick et. al., acknowledges the growing field of ViSC as both a method of using technology for scientists and a technological pathway with promises of "radical improvements in the human/computer interface and [making] human-in-the-loop problems approachable."[383] In this document that sets the foundation of ViSC we find many of the same entanglements that orient the practices of amateur earth modelers today and the problems of digitally articulating natural phenomena. This happens along two concurrent lines of practice and thought. The first is the idea of making seen the unseen. McCormick et. al. note that "As a tool for applying computers to science, [ViSC] offers a way to see the unseen."[384] There is no question of whether or not the *unseen* could or would remain invisible. The issue is instead restated as a question of tools: provide scientists the right tools and they will find the way to make the unseen, seen. The second idea surrounds the idea ViSC as a study

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[382] Matt Pharr and Greg Humphreys, *Physically Based Rendering: From Theory to Implementation*, The Morgan Kaufmann Series in Interactive 3D Technology (Amsterdam ; Boston: Elsevier/Morgan Kaufmann, 2004), xi.

[383] Bruce H. McCormick, "Visualization in Scientific Computing," Computer Graphics, July 1987, vii.

[384] McCormick, vii.

in technology itself. Notice that this is distinct from the science presupposed in the first instance, and, as we will see, also requires that technology be treated with different deference—particularly with respect to the human body. McCormick et. al. note the powerful potential of ViSC as a technology to bring humans and computers into closer congress with one another. This hope foregrounds the importance of the aesthetic as a form, or pathway *to*, understanding that must be initiated when all other options fail.

This split in the history of computer graphics signifies an ongoing dissonance between how things look and their capacity to signal knowledge and limits. While the development of computer graphics as an expression of computing potential was initiated on one trajectory, ViSC was much later to the game. The hesitation of the sciences towards embracing visualization in computing is curious. As we saw in earlier chapters, visualization practices like drawing and painting have played important roles in the understanding and dissemination of natural knowledges. On top of this, the role of human optics has always been in the background of scientific knowledge practices, even while this relationship has been marked by discomfort and distrust. Even as image making was inhered in the schema that both confirmed the rationalization of human vision and was regarded as producing geometrical truths through the strategic use of perspective, the relationship between observation and knowledge has always existed as the soft underbelly of scientific practices.

One plausible explanation for the anxieties surrounding the use of computationally generated images in scientific research is precisely because the history of computer graphics shares so much with fine art. James Elkins notes that the discipline of fine arts has in recent years taken an interest in the whole range of nonart images for the ways in which they might inform art historical research. Of these nonart images, the two categories of images that have been of greatest interest are medical imaging and computer graphics, the former for its well-established influence on artistic practice from the fifteenth century onward as well as its ability to invoke pictorial conventions such as “gender, pleasure, and pain”.[385] The latter becomes is interesting for the ease with which one could “demonstrate an ongoing dependence of computer graphics on the older history of art.”[386] Not just an ongoing dependence, but software developers do nothing short of “recapitulate the history of art in various particulars”.[387]

Yet the idea of a realistic, high fidelity, or authentic computer simulation of natural phenomena is in itself a ridiculous notion. From the outset computer hardware is the wrong tool for the job. As Slater et. al. note in their work on computer graphics in virtual environments, display monitors themselves are one in a line of insufficiencies of computers to produce one-to-one simulations. They note that the RGB (red, green, blue) system for describing display colors cannot describe light energy in an environment.[388] In computer graphics broadly, this insufficiency is diminished by ordering the world and its aesthetic logics is ordered *around* the RGB system. They write:

> … the question ‘Is this set of displayed colors correct for this computer game/advertisement/logo physically correct?’ has no meaning, since there is no right answer in physical or human-visual-system terms. The real question is —does it look right for the effect that is to be conveyed? —does it make the game, or advertisement, or logo more or less ‘attractive’?”[389]

This is the practice we find in the sciences. As Elkins notes, “the strategies that

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[385] Elkins, “Art History and Images That Are Not Art,” 556.

[386] Elkins, 556.

[387] “…the history of three-dimensional rendering rehearses the early history of linear perspective, the current interest in translucent ‘mylar’ layering revives diaphanous Rococo effects of fresco and oil paint, and the routines for lighting gradients (such as Phong and Blinn rendering) recall seventeenth- and eighteenth-century interests in specular and diffuse reflections.” Elkins, 556.

[388] Mel Slater, Anthony Steed, and Yiorgos Chrysanthou, *Computer Graphics and Virtual Environments: From Realism to Real-Time* (Harlow, England; New York: Addison Wesley, 2002), 117.

[389] Slater, Steed, and Chrysanthou, 117.

scientists use to manipulate images *might well be called aesthetic* in the original sense of that word, since they are aimed at perfecting and *rationalizing transcriptions of nature*."[390] We see such aesthetic strategies at work when, in video games or other virtual environments where realism counts for appearances but not simulating phenomena, stars are fashioned through per-pixel color manipulations. It is surprising, but accurate, to write that the rationalization of burning balls of gas billion of light years away is most effectively (and often) represented by a shading language, which can not only color pixels to mimic the presence of a very far away, burning light source but can also encode for flickerings of stars as well through the individual color channels.[391]

The obstacles to the simulation of natural phenomena continue to beset graphics software. There are initial problems with what is seen as "the inadequacy" of the two-dimensional space of the computer screen being forced to act as a theater for the modeling of three-dimensional objects. Such an inadequacy is merely the task of painting and drawing, but for computer programmers with access to rich resources such as virtual reality, augmented reality, haptic technologies and immersion technologies the frustration must be more pronounced. And indeed we might say that the outpacing of hardware to the task of simulation is not only openly acknowledged by perhaps, to some degree, punished by the software engineers. For example, Casey Alt writes of Maya—a 3D computer animation software—that its interface is counterintuitive precisely because it must "[solve] a rather counterintuitive problem: modeling 3-D objects on the 2-D space of a computer screen" as well as being tasked with "enabl[ing] a 3-D interaction on a 2-D screen".[392] Alt concludes, in no uncertain terms, that Maya is "difficult to use"

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[390] Elkins, "Art History and Images That Are Not Art," 570. Emphasis mine.

[391] Roden and Parberry, "Clouds and Stars," 437.

[392] It is interesting to note here that Alt makes an explicit comparison with paint programs to

because using Maya requires no less than the wholesale revision of how users "perceive and interact with space". [393] Alt does reassure us, though that once you have completely reorganized your perception of, and modes of interacting, with space, then "navigating Maya becomes a very consistent and logical activity." Such a comment flags a contrarian relationship here between senses and the organization of software—in itself, a counterintuitive understanding of how these two things should ideally function together.

Yet this impulse to relentlessly discretize and rationalize, while arguably a utilitarian necessity for computation, also seems to needlessly make cuts and decisions about the phenomena it chooses to represent, and how it chooses to represent it. In an article critiquing computer-generated images, Elkins comments on the explosion of discussions and taxonomies of space that has come out of the 20th century—in "psychology, philosophy, physiology, art history, and art practice"—space that is both physical and metaphorical, but all Euclidean. He notes how "computer graphics has chosen to represent only two kinds of space: those determined by perspective and by parallel projection."[394] In both, perspective is dominant. The limits that such a choice in the realm of computer graphics stumps Elkins, though he does note that sometimes the boundary of a space is an inevitability as a given space falls outside the texture map range. Elkins writes:

> Contemporary computer artists and scientists make a point of emphasizing the infinite, homogenous and isotropic qualities of rational space that have been around since the beginning. Space itself appears in our pictures as an infinite volume, always potentially empty. Is it unfair to point out that the few 'photorealist' computer spaces that have a foreground, middle ground and background are reconstructions of existing paintings, and that more purely fictive scenes are

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illustrate their point, writing that "paint programs have such an intuitive interface" because "the space of the program mirrors the task at hand". Alt, "The Materialities of Maya," 406.

[393] Alt, 406.

[394] James Elkins, "Art History and the Criticism of Computer-Generated Images," *Leonardo* 27 (1994): 393.

typically unbalanced, unlimited, or oblique views?[395]

The poverty of space might well explain why so many earth modelers often abandon the task of just faithfully modeling the Earth. Modeling Middle Earth is a common project, and the one that is often most referenced is the Middle Earth DEM Project, which VTP points to as a way of applying what they have collected as pooled resources and tools "for rendering the Earth" and applying them to other projects.[396] The Middle Earth DEM Project (as seen in figure 33) released their first version of terrain data compiled for Outerra in early 2013, and the Kemeni was quick to install the dataset with "an option to select the planet to go to … on the Outerra login screen."[397]

Despite the fact that software design and computer graphics so heavily, and imperfectly, draw on art historical conventions of representation, a kind of double consciousness about images in computation persists. For one, scientific applications of computer graphics want to avoid the maneuvers that would reduce their output to the status mere "pretty picture"[398] ViSC is a perfect example of this. In its early coneptions, ViSC distinguished itself by determining that the "images" it would use

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[395] Elkins, 340.

[396] "Beyond Earth," accessed May 5, 2018, Art history and the criticism of computer-generated images.

[397] "Middle-Earth World for Outerra Released!," accessed May 5, 2018, https://forum.outerra.com/index.php?topic=1491.0.

[398] This is a near-categorical piece of nomenclature. In my interview with Matt Hancher (see: chapter two) he referred to the image of the cloud-free globe produced for Google as a "pretty picture" to signify that it was "not so much a scientific result" but instead merely an image that Google could use in their product; a visual object "that would be attractive and would accurately reflect the landscape." This kind of commentary erases the fact that such an image was derived from a scientific process of pixel sorting and a particular method of working with visual, geospatial data. James Elkins, drawing from the work of sociologist of science Michael Lynch and art historian Sam Edgerton, also comments on the use of "pretty picture" as establishing a category of "inexpressive," nonart images. Images in this category are typical in astronomy, typically have "strongly chromatic false colors", and are not intended to be "anything more than eye-catching or decorative." See: Elkins, "Art History and Images That Are Not Art," 558. See also: Michael Lynch and Samuel Y. Edgerton, "Aesthetics and Digital Image Processing: Representational Craft in Contemporary Astronomy," *The Sociological Review* 35, no. 1_suppl (May 1987): 184–220, https://doi.org/10.1111/j.1467-954X.1987.tb00087.x.

Figure 33: Screenshot of Middle Earth DEM project for Outerra.

wouldn't be images but rather *visualizations built from data*—transforming *image* into an "alternative to numbers" readable by all scientists.[399] In their bid to increase funding for visualization integration into research, ViSC proponents praised the use of images as a way of breaking down "fire hoses of information" originating from "high volume data sources" such as supercomputers, geospatial sensing technologies, medical scanners, and satellites.[400] Their proposal implies that properly harnessed computational power could manage this deluge of information appropriately, while images (visualizations) would support communication amongst scientists: "We speak – and for 5000 years have preserved our words. But, we cannot share vision."[401]

Significantly, McCormick et. al. suggest that the opportunity to be at the helm of how visualization happens, and thus be witness to creation in real time, is an

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[399] McCormick, "Visualization in Scientific Computing," 7.

[400] McCormick, 4.

[401] McCormick, 5.

opportunity for scientists to "steer calculations", and to do so "in close-to-real-time"; they expressly note that scientists "want to be able to change parameters, resolution or representation, and see effects. They want to drive the scientific discovery process; they want to *interact* with their data."[402] The desire of scientists to *steer*, *change*, and *interact* with data in visualization is, by definition, a desire to manipulate the aesthetics of their data; it is, as Elkins noted, a set of aesthetic strategies. This aesthetic dimension of the scientists research doesn't pull the scientists further into the realm of the aesthetic, and what's more, seems to go unnoticed. Later in the document, when giving recommendations for who should staff visualization interdisciplinary teams, visualization scientists and engineers appear *as well as* artists. Artists, they note, will "have a formal education in visual communication, including an understanding of color theory, composition, lighting, view angles, and related aesthetics" and will assist in "propos[ing] effective visual representations for analysis and communication"; while visualizations scientists and engineers are "developing tools and techniques that have broad applicability to advanced scientific and engineering research."[403]

Physically Based Rendering and Empirical Modeling[404]

ViSC came about after experiments in computer modeling had already been initiated, and much of what they were responding to were promises they saw in how modeling could be applied towards research. McCormick et. al. note that at the time

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[402] McCormick, 5.

[403] McCormick, 11.

[404] For this section I am indebted to the work (and minds) of Natalie Kane and Tobias Revell. Their collaborative curatorial and research project *Haunted Machines* has made insightful propositions about the place of rendering in the contemporary relationship between digital image production and notions of truth. See: Tobias Revell and Natalie Kane, "DEEP FAKES OR RENDERING THE TRUTH —," Haunted Machines, 2018, https://hauntedmachines.com/DEEP-FAKES-OR-RENDERING-THE-TRUTH-Third-event-run-by-the-Haunted.

of writing computation could generate two types of images: realistic (simulations) and 3D line drawings ("informative images that can be manipulated in real time").[405] Each of these kinds of images were, at the time of writing, produced by different hardware—vector and raster hardware. McCormick et. al. express their hope that with the evolution of computing vector and raster hardware could come to be fused in the same overall hardware unit. Some ten years later, with the sophistication and development of computational hardware and modeling software, such a feat is achieved but the same ontological questions about the use of images and aesthetic strategies persist. The division in techniques for modeling three-dimensional figures in computer graphics still exists, but such a division is expressed in whole paradigms of modeling, not just the technologies that engender certain kinds of imagery.

Particularly for the context of modeling natural phenomena and creating virtual environments, if programmers choose to code an object that prioritizes modeling on the basis of how we *think* natural phenomena behave, and deprioritize user experience, they are choosing to perform what is called *physically based rendering* (PBR), producing physically based models.[406] PBR takes as its basic foundations "the laws of physics and their mathematical expression", with "Efficiency [as] secondary to these […] goals."[407] PBR can put a great deal of stress on hardware resources, which in turn impacts on rendering speeds and creates lagtime. Not only this, but as a method PBR is challenging and tedious, requiring a high level of expert knowledge in areas like physics and the natural sciences, as well access to expensive sensing resources (if taking light samples for yourself, for example) and state-of-the art methods, which can often be blocked by academic journal paywalls, or

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405 McCormick, "Visualization in Scientific Computing," A-3.

406 Andrew S. Glassner, *Principles of Digital Image Synthesis*, vol. II, The Morgan Kaufmann Series in Computer Graphics and Geometric Modeling (San Francisco: Morgan Kaufmann, 1995), 722.

407 Pharr and Humphreys, *Physically Based Rendering*, xiv.

prohibitive costs for attending professional conferences such as SIGGRAPH.[408] In contrast, *empirical modeling* describes a method of modeling that more actively recruits programmers' *empirical* understanding of natural phenomena rather than how it is expressed through strict mathematical formulations. Empirical models often put less of a stress on hardware resources, can be quick routes for effective modeling, and are generally more accessible because they require that one have a knowledge of coding and powers of observation in order to complete the circuit.

PBR development began in the 1980's, with a significant amount of its work being performed in the Computer Graphics Lab at Cornell University. Papers from the Cornell lab from this time show the researcher's full confidence in being able to generate *simulations* of natural phenomena; where they falter is in their ability to control the production of these outcomes to such an extent so as to make them useful for the scientific process. In one such foundational text, Donald Greenberg et. al. write:

> If we could generate simulations that were guaranteed to be correct, where the

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[408] Even when one *does* have access to these resources, rendering phenomena according to their physical world behaviors is still not a straightforward enterprise. Donald Greenberg talks of these difficulties in measuring the behavior of light on physical substances, noting that complications for measurement experiments tend to fall into three categories: one, "Information on the calibration and precision of measurement equipment is scarce"; two, "Physical constraints sometimes make the measurement a complex task, particularly for systems involving dense data sets"; and three, "Certain phenomena play a large role in reflection models, and yet are extremely difficult to measure." Even when this knowledge is available, the cost of computing so many various, arbitrary, and intersecting elements can be a tax on an already over-stuffed GPU. This is, for example, the criticism raised of He's 1991 light reflectance model, which was based on "physical optics and incorporating the specular, directional diffuse, and uniform diffuse reflections by a surface", and which calculated for reflected light patterns dependent on "wavelength, incidence angle, two surface roughness parameters, and a surface refractive index." Greenberg et. al. note that while "The formulation is self-consistent in terms of polarization, surface roughness, masking/ shadowing, and energy", the "model is extremely cumbersome to compute, since it contains an infinite summation that converges very slowly." See: Donald P. Greenberg et al., "A Framework for Realistic Image Synthesis," *Communications of the ACM* 42, no. 8 (August 1, 1999): 44–53, https://doi.org/10.1145/310930.310970. Quotes here taken from: Greenberg et al. For original study, see: Xiao D He, "A Comprehensive Physical Model for Light Reflection," Computer Graphics 25, no. 4 (1991).

> algorithms and resulting pictures were accurate representations, then the simulations could be used in a predictive manner. This would be a major paradigm shift for the computer graphics industry, but would have much broader applicability than just picture making.[409]

Their aspirations of shifting the computer graphics industry suggests a still unresolved fissure in the use of computer graphics for the production of knowledge, but some things remain constant. First, the researchers' focus on *simulations*, as opposed to simulated stills, figures, visualizations, or images, tells us that static, graphical outputs somehow still belong to the realm of the arts (or "pretty pictures") and thus continue to be of no use for science. Greenberg et. al. go on to note, "in order to be predictive, we must prove that the simulations are correct. Fidelity is the key."[410] This raises a second issue, in which we learn that the simulations must be predictable—which would require that they be *wholly known,* that all parts could be accounted for—in order to prove their value. There is a punchline in this point, in spite of the authors' sincerity. What is stated here is that the key to realistic simulation is realism, and that realism of natural phenomena is based on little else besides homogeneity, order, and predictability. Since when has anything natural been any of these things, consistently?

Nevertheless, PBR remains the most appropriate choice for scientists or those looking to recreate the physical world in a computer simulation. Yet much to the chagrin of these researchers, technical documents often raise the concern that, despite being modeled on the physics of the natural world, virtual environments built with PBR can often *appear less* realistic than virtual environments crafted through empirical models. "Although they have a finer pedigree," Andrew Glassner writes in the seminal text on digital image synthesis, "physically based models can produce less realistic results than an empirical model carefully hand tuned for a

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[409] Greenberg et al.

[410] Greenberg et al.

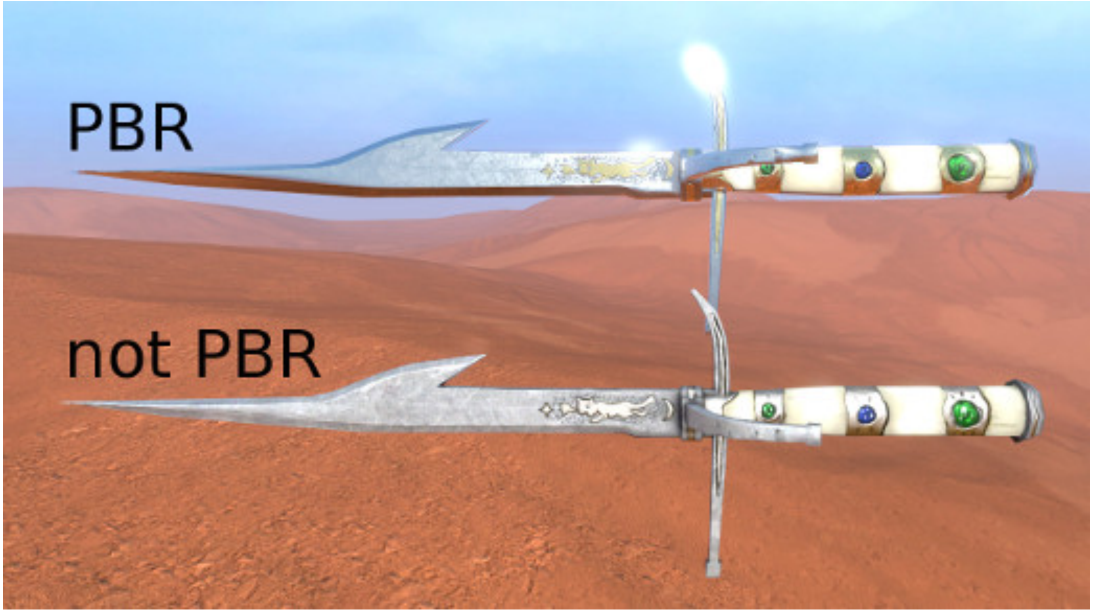

Figure 34: Image demonstrating the difference between physically based rendering and empirical modeling. The PBR example shows some qualities that are more "realistic," however we can see how the intense light glare at the top of the guard obscures the detail of the weapon. The lack of detail available for viewing could arguably be a detraction of realism, for some users.

particular type of material."[411] As a way of circumventing this shortcoming, PBR enact the performance of a similar *care of the self* that Knorr Cetina observed in the HEP labs. Computer graphics programmers understand that the parameters which they are using to model their phenomena, their *data,* "are contingent upon … apparatus and are representations of this apparatus (rather than of the world) reveals the detector as a mediating device".[412] Linked as they are to these devices, programmers displace a concern for their own bias or capacity for error onto the impersonal informational circuit that forms between phenomenon, programmer, and apparatus. They, in other words, "substitute a concern with their own internal production circuitry for a concern with real-time objects", by which is meant that

[411] Glassner, *Principles of Digital Image Synthesis*, II:722.

[412] Knorr Cetina, *Epistemic Cultures*, 55.

there arises a "preoccupation of the researchers with the experiment itself, with observing, controlling, improving, and understanding its components and processes."[413] Such a process is, by one textbook's account, the *definition* of PBR: "Those [models] that document all their assumptions carefully are typically called *physically based* models; those that just look good or are useful are called *empirical* models."[414] However, one might counter that PBR images are not "real" science, and empirical images are just the stuff of video games and MMORPGs. Glassner characterizes the distinction as one in degree, rather than kind, writing that while all models engage in some form of "[simplification] regarding the atomic and molecular structure of the material" that physically based modelers "document all their assumptions carefully", whereas empirical models "just look good or are useful".[415] Anyone who attempts to model a virtual environment, at any level of realism, is always knowingly performing an abstraction of their phenomena. However, it is the careful documentation of these abstractions, or assumptions, that lend credence (or "pedigree" to borrow a term used earlier) of PBR.

Knorr Cetina offers a commentary on the *care of the self* approaches of HEP scientists that while it is intended to construct a sense of the practice, here reads as a criticism of the perennial divide in computer graphics that we have been discussing. She writes, "Confronted with a lack of direct access to the objects they are interested in, caught within a universe of appearances, and unwilling to trespass the boundaries of their liminal approach … [the scientists] have chosen to switch, for large stretches of the experiment, from the analysis of objects to the analysis of the self."[416] From the point of view of someone observing these two models in their bid for knowledge, PBR and empirical modeling perform in curious, inverse proportions to each other.

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413 Knorr Cetina, 56.

414 Glassner, *Principles of Digital Image Synthesis*, II:722.

415 Glassner, II:722.

416 Knorr Cetina, *Epistemic Cultures*, 56.

PBR proposes that there is a truth of how light behaves in the world *and* can be represented in a one-to-one mathematically calculation that also serves as intelligible code for powering computation, and it is up to the modelers, in cooperation with technology, to obtain it. This cooperation extends far beyond, and prior to, the moment of computer simulation: it also requires a technical and precise cooperation between sensing technologies from other disciplines, such as environmental science, physics, and engineering. Empirical modelling bifurcates the reality of the virtual environment from its functioning in the physical world, presenting a reality that is—again, as in the world of molecular biology—*through* the aesthetic ("through sketches and pictures") "continuously referred to and … rendered present and called upon for assistance in decoding experimental signs."[417]

Earth Modelers

Given this history, the divide between what types of images, and how to work with them, it was impossible that the divide on images in computer graphics would also apply in the epistemic culture of the amateur earth modelers. However we can observe that the place of the modelers as both engaged with, and outside of, traditional epistemic cultures of sciences invested in the modeling of natural phenomena, reroutes the concerns of fidelity, control, and predictability in to new areas. In this sense, the modelers bring what Elkins had saw as a fundamental concern of image studies with the "narrow technical questions" of working with scientific images" into an epistemic arena, rather hearteningly transforming such a concern with a project of "fully develop[ing] alternate ways of working with images."[418] At the most general level, the choice between how simulations are developed is not one resolved by the question of communicating data, as McCormick et. al. had suggested it might be, regardless if such communication is

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[417] Knorr Cetina, 104.

[418] Elkins, "Art History and Images That Are Not Art," 570.

targeted at other scientists or, for example, communicating an urgent situation salient to policy makers. Instead, one way that this choice is resolved is on the basis of computational resource and simulation performance that bears in mind home computers rather than those whose cost or capacity might otherwise limit their sale to scientific institutions. In some cases this decision is not made by the programmers, and instead both options are put forward to users. For example, Outerra allows users to cycle through the resolution options they want for their terrain experience. This is such a well-liked feature that user *josem75* posted on the Outerra forum their desire for this cycling to be executed on command of keyboard shortcuts, writing:

> I love to play at 1080 terrain. And i can do in most of the places. But we know other like mountains are impossible. But the necesity of go into menus for change it, make you just play always at 720 or 600. And its a pity. The solution could be 'easy'.[419]

Josem75's strong preference for a certain mode of playing (with display at high resolution) underscores the effectiveness of this strategy as an exercise in speaking to the core of this community, as well as in experimenting with what a solution of *non-resolution*, or the simultaneity of *two* (if not conflicting) solutions, might look like in epistemic practice.

Such a broad directive of developing "alternate ways of working with images" also, in part, justifies the existence of projects like Shadertoy.com. Because the ability to code in shading languages is such a specific skill, but shaders' direct influence on the color and illumination of pixels is such a bedrock of computer graphics, the use of Shadertoy (and shaders in general) loosens programmers of the constraints that face more strident epistemic cultures. This dynamic is particularly apparent in the modeling of light. The successful modeling of light critical for the

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[419] josem75, "Little Things of a Big Thing," December 2, 2017.

successful modeling of a realistic virtual environments.[420] Accurately simulating light in a virtual world to behave and appear as it does in the physical world sets programmers up for success when modeling other elements. Modeling light requires setting up light sources which will determine the shadows and highlights of objects, producing volume. Modeling changes in light in the atmosphere gives a virtual world temporality, and the sense of a forward movement through day and night. Modeling light can also give sense of spring or summer. And, of course, we cannot forget that everything in a virtual world is built on light. A simple model for building a starry sky is done effectively by modulating the light pushed into individual pixels, orchestrating their fade ins/outs. A screen will illuminate nothing without itself first being a powered-on, illuminated monitor. A scene will display nothing if not commanded to do so.[421]

If your virtual environment is more of a gaming experience in a mythical world, there might be an upper limit on how "realistic" your light needs to be modeled. Maybe you don't need to have spontaneous rainbows appear from the back-refractions of light on water particles in the air. Maybe, instead, what you need

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[420] I can recommend the subreddit r/shittysimulated as a resource for simulations and general modeling practices that fail on this front, and many others. It should be noted before visiting r/shittysimulated that most of the simulations posted are done so for the ways they fail to accurately compute the laws of physics in motion (and spectacularly so), or completely pervert what we could only loosely call "human forms." Though perhaps not the star of the show, the lighting failures in these examples are still evident.

[421] There is a post on the subreddit r/shittysimulated titled *Simulation of a Universe without Light*. What is posted appears as a static black box. The highest rated comment in response to the post is "You could have at least made it a gif." Though likely an ironic riposte, the user's comment does still convey the sense that for a forum dedicated to simulation failures, this static, black box fails to meet criteria. What we can learn from this is that in modeling and computer graphics overall, light is *such* a basic and fundamental process that its failures are actually the limits to which programmers can turn programming failures into humorous and self-aware transgressions. This is significant because these moments of transgression are usually offered to communities/subforums for theorizing and trouble-shooting. In this case, then, we perhaps can see the lowest limit of the bar to entry in this specialized community. See: flam2006, "Simulation of a Universe without Light," */R/Shitty Simulated*, 2017, https://www.reddit.com/r/shittysimulated/comments/633kwe/simulation_of_a_universe_without_light/.

is a strong and well-developed sense of a light source that can be used to make sure characters and their coverings appear very naturalistic, and to imbue your world with narrativity by giving it a sense of day and night. In these instances, a lot of tax on computational resources is saved with empirical modeling and using library APIs for sky or illuminations. One way modelers empirically solve the modeling of light is to think of their environments as two pieces: sky and ground. This is also true for how the modeling of light is performed: there is atmospheric light and the light that shapes terrain. VTP guidelines suggest that lighting for terrain is "largely static" and therefore only needs to be calculated when "light moves or the terrain deforms."[422] Given what VTP estimate as the relative simplicity of terrain light model, they advise that "the most efficient way to render … is to combine the lighting with the texture map."[423]

Yet such shortcutting can limit a virtual environment that is already being used for a diversity of reasons. Light is important for modeling, and light is very difficult to model. In physics we consider that light can behave as both a particle *and* a wave. This is accounts for a range of behaviors emerging from the interplay of light and other matter, and for simulations, can make key differences in the behaviors of weather,[424] visibility at night,[425] and the appearance of clouds.[426] Such a detail often impacts most harshly on those users engaged with virtual environments

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422 "Terrain Lighting," Virtual Terrain Project, accessed April 10, 2018, http://vterrain.org/Performance/lighting.html.

423 "Terrain Lighting."

424 See:

425 See: Henrik Wann Jensen et al., "A Physically-Based Night Sky Model" (ACM Press, 2001), 399–408, https://doi.org/10.1145/383259.383306; and Tom Minor, Robert R. Poncelet, and Eike Falk Anderson, "Skyglow: Towards a Night-Time Illumination Model for Urban Environments" (The Eurographics Association, 2016), https://doi.org/10.2312/egp.20161055.

426 See, for example: Pawel Kobak and Witold Alda, "Modeling and Rendering of Convective Cumulus Clouds for Real-Time Graphics Purposes," *Computer Science* 18, no. 3 (2017): 241, https://doi.org/10.7494/csci.2017.18.3.1491.

who are using them for flight simulation. In these scenarios modeling the atmosphere so that light behaves exactly as we expect it to in the physical world is not only important to users for being able to see where they are flying but also for the building of add-on effects, such weather conditions. Even still, despite best efforts at calculating light for a close proximity to its behavior in the physical world, the greatest challenge to modeling light in virtual environments is that, as VTP notes, "the real world has much, much higher dynamic range than computers currently allow."[427]

Images and Objectivity

We have seen how the blended use of PBR and empirical models in the amateur earth modeling epistemic culture derives from a split within the history of computer graphics on the use of images versus visualizations, and simulation. However, this unsteady relationship with images, and particularly images and technology, also overlaps with another history. As has been alluded to already, the use of images in science is a distinct, if not contentious, mode of making knowledge. In part this contention seems to arise from a sense that imagery invites a certain amount of unregulated, unaccounted-for subjectivity that scientists are generally uncomfortable with. Subjectivity implies bias, which for conventions of the scientific method is equal to error. As a foil to subjectivity, objectivity in the sciences "filter[s] out the noise that undermines certainty"; it "aspire[s] to knowledge that bears no trace of the knower —knowledge un- marked by prejudice or skill, fantasy or judgment, wishing or striving"; it is "blind sight, seeing without inference, interpretation, or intelligence".[428] Yet, as Lorraine Daston and Peter Galison have

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[427] "Terrain Lighting: Dynamic Range," Virtual Terrain Project, accessed April 10, 2018, http://vterrain.org/Performance/dynamic_range.html.

[428] Daston and Galison, *Objectivity*, 17.

argued, objectivity in the sciences is not a given. Scientific objectivity "emerged as a new way of studying nature, and of being a scientist", Daston and Galison tell us, and it is a fitting description of our current study.[429] Scientific objectivity has been constructed over time, in different formats and to different ends, and what's perhaps more remarkable about this is that scientific objectivity is actually rather new: "Only in the mid-nineteenth century did scientists begin to yearn for this blind sight, the 'objective view' that embraces accidents and asymmetries".[430]

Despite its buffer to the subjective, the development of objectivity in the sciences did not arise as a strategy of, among other things, expelling the use of images in epistemic work. To the contrary, certain forms of objectivity were, and are, preserved through the use of images. Take, for example, as Daston and Galison do, work in nanotechnologies. Epistemic work performed at these scales signals a new paradigm of objectivity for Daston and Galison, one which is in fact predicated precisely on the transformation of how we use and think about images. Of this paradigm they write "No longer [are] images traced either by the mind's eye or by 'the pencil of nature.' Images … function at least as much as a tweezer, hammer, or anvil of nature: a tool to make and change things."[431] Significantly, this paradigm doesn't arise in tandem with new technologies, like nanotechnologies, because of technological novelty (though that does have some bearing on the dynamics, of course). The convening of objectivity and technology far predates nanotechnology—

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[429] The phrasing of this description of the origins of scientific objectivity is not, in my opinion, to be overlooked. The separate clauses *studying nature* and *being a scientist* can be read on two levels, one as a literal expression of the origin of objectivity, and a second, metaphoric level embodied in the syntax of the phrase. To the latter, this syntax—of studying nature *and* being a scientist; conjoined clauses expressing apparently different impulses—metaphorizes the way in which the pursuit of objectivity can equally be read as a battle of humanity contra itself: a quest to suppress the subjective qualities of the scientist while at the same time knowingly engaged in an endless praxis of refining those qualities because of their importance for engaging natural phenomena. Daston and Galison, 17.

[430] Daston and Galison, 17.

[431] Daston and Galison, 383.

to the mid-nineteenth century, according to Daston and Galison—and as an expression of the epistemic virtues of its time was more strongly was concerned with ethical issues "around witting and unwitting tampering with the visual 'facts'" than with technology itself.[432] This historical trajectory casts technology as a way to bestow, or safeguard, objectivity while remaining inclusive of the use of images in epistemic practice. As Daston and Galison show, even in its earliest history, while "epistemic virtues [were] inscribed in images, in the ways they [were] made, used, and defended against rivals" there still remained a need for mechanical objectivity "to protect images against subjective projections".[433] The savior of such mechanical objectivity was automatism, which signaled the prospect of generation "'untouched by human hands,' neither the artist's nor the scientist's."[434]

This conception of a mechanical objectivity, and even an objectivity that counters subjectivity, does not age well. Such a historical moment is in stark contrast to what Knorr Cetina has identified as the importance and centrality of "human hands," and particularly those of the scientists. In her study of molecular biology labs, Knorr Cetina notes that a necessary step towards knowledge production is that "one has to place oneself in the situation", signaling just how "The body is trusted to pick up and process what the mind cannot anticipate," in a maneuver that, however problematically demonstrates that "Those who feel this way respond to the Cartesian notion of the separation between body and mind" still find it necessary to give "priority to the body."[435] As images come to mean different things (*image-as-tool*, image that 'creates') and tools come to take on different qualities (tools that sense, tools that mediate, tools that age or disobey) we find that it is more logical to

[432] Daston and Galison, 122.

[433] Daston and Galison, 42–43.

[434] Daston and Galison, 43.

[435] Knorr Cetina, *Epistemic Cultures*, 98.

place these current practices in a historical outgrowth of what Daston and Galison term *structural objectivity*. Such a move deserves some remarks, seeing as Daston and Galison explicitly name this form of objectivity "objectivity without images."[436]

Structural objectivity presents an interesting lens through which to understand the amateur earth modelers because of the way it blends a contemporary epistemic virtue—that data should not be "biased" or transformed by some undue influence—with a recourse to a mixed method of procedures. The application of structural objectivity applies even to the way that its history is mimicked in amateur earth modelers. Structural objectivity arose with the post-1848 generation of physiologists and psychologists who drew on empirical methods to explore "The mind under laboratory conditions."[437] Daston and Galison characterize the format of objectivity precipitated by this group as a project of renouncing the self "that was in part the discovery of science itself".[438] By interrogating the mind the scientists toed a line between what had at the time been considered proper science and that which laid outside of it. Not only this, but as with Knorr Cetina's *care of the self*, the careful documentation of PBRs, and the compulsory archiving of earth modeler platforms, the scientists engaged in forming structural objectivity were also engaged in intense self-observation. Such practices gave reason to skeptics for criticism; as one critic confidently riposted: "there exist numerous sources of objective knowledge that promise better results than the inaccessible and deceptive [method of] self-observation, and that psychology runs no risk of running out of material, even if it restricts itself to the investigation of facts."[439]

Structural objectivity arose in a time that bridged two forms of working with

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[436] Daston and Galison, *Objectivity*, 253.

[437] Daston and Galison, 258.

[438] Daston and Galison, 258.

[439] Daston and Galison, 264.

sensual data. On the one hand was the assertion that the sensual worlds of individuals were closed off to one another, and so the goal of scientific work to build structures that could, in light of these shortcomings, make scientific knowledge communicable. Opposing this was radical empiricism which was to be claimed by "the phenomenological surface of things."[440] As a way of resolving these two different trajectories, *images* were abandoned as a means of transmitting information from one mind to another, and in its place, the significance of *relation* came to the fore. Sensual data might have exited in many different forms but so long as the relational structures were well developed, scientific progress could proceed. In Daston and Galison's account they speculate that such a paradigm must have been the source of much confusion and miscommunication. Yet with the age of computation and digital culture it is perhaps much simpler to conceive of how this structural objectivity can be ported into a rationality that actually clears a path for comprehension.

Not only this, but this form of working—searching for the communicable structures to make information multi-relational—not only guides a form of epistemic verification but we can see it as a goal unto itself in the work of the amateur earth modelers. Tom Riecken explained some of the earliest ambitions of r/simulate were rooted in thinking through high level architecture as a way of thinking "just how you encode your data," adding that "but the bigger picture behind that is how do you break apart phenomenon in such a way that you can have, at different levels of abstraction, and have transitions between different levels of abstraction?"[441] Riecken grappled with questions of how to model phenomena like human groups, individual behaviors, and markets; and not just how to model these elements but, as he put the question to me, "What would be the intersectional

[440] Daston and Galison, 284.

[441] Nicole Sansone, Initial interview with Tom Riecken, founder of r/simulate, Skype, January 11, 2018.

points at which one model fed data to the other model, and if you could comprise enough of these models into like a single component architecture, could you simulate everything?" Notably, Tom told me that as he was doing this research he wrote a number of blog articles (between 2012 and 2014, he estimates), and particularly that "I did some very interesting illustrations that … tried to portray the concepts that I was digging at".[442]

Tom's use of illustrations to grapple with the work of organizing a structural form pokes at a blind spot in how Daston and Galison's work *also* participates in a trajectory of misunderstanding between epistemology and aesthetics. Daston and Galison's *image-less* structural objectivity can proclaim itself as such because it considers the image in only one form. Yet as we have seen with computer graphics, the image as a static visualization is just one form of the scientific image—there also exists the series of images that make up a simulation, what some might see as exactly the relational images that subtended the development of structural objectivity. Not only this, Daston and Galison's image-less account of structural objectivity denies images the capacity for being structures themselves. Digital images provide a format for information that is useful for the ways it can prescribe an informational ordering *and* offer an architecture that makes data communicable.

Aesthetics in Non-Traditional Epistemic Practice

In this chapter we have taken a closer look at the amateur earth modeling communities introduced in chapter three. I have shown how amateur earth modelers prove themselves to be epistemic cultures through practices of placemaking the knowledge setting, practices of the self (through the care of the self) as well as more conventional forms of engaging their broader institutional fields while existing partly autonomously from them. Understood as sites of epistemology, the amateur earth

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[442] Sansone.

modelers, their platforms, and their practices present an interesting contrast to approaches modeling and self-organization when compared with more institutionalized epistemic cultures. This is specifically apparent in the modelers' use of, and attitudes towards, the role of aesthetics in epistemic practice.

Because amateur earth modeler communities are both epistemically engaged while institutionally exiled, we find that the modeling communities are much more lax in their views on how to use visual data. Amateur earth modelers engage in the practice of knowledge making through various means which often include unregulated combinations of PBR and empirical modeling, using images, and embodied or sensing knowledge. When compared to their scientific counterparts, we find that such strategies are a rebellion against at least two histories of the image in epistemic cultures: the history of computer graphics and ViSC, and the history of scientific objectivity. We also left off with the discussion of the possibility of a third history of the image in epistemology, which is a kind of metahistory: that of the writing of Daston and Galison's *structural objectivity* as in itself performing the same exclusion of images in thinking epistemology but without fully thinking through what we mean when we talk about "the image" or "images." Structural objectivity's preoccupation with shared sensual information and building structures to facilitate the transfer of that data precisely describes the work that is done with digital images in the area of the natural sciences. On the basis of this we can recommend that the history of the work of the psychophysiologists be revisited and reexamined for what it means when visual data are not seen as *images* but instead as communicable structures able to store and transmit data.

Conclusion

The Start to the End to a Another Start

I have set out to write a thesis about images of the sky, productions of these kinds of images. It's gotten messy. Somewhere in the mix, the sky was lost. We no longer talk about skies. We lose the thread of art history; contemporary art photographs come into view and recede again. We are introduced to a culture of modelers that we do not and cannot know; but we know well enough that they are males, we know well enough that we don't know enough about them. Where did the images go? There are screenshots, and then we are back to envisioning what early artist working on visualization in scientific computing might have looked like; we are envisioning what kind of community is writing to each other late night, debugging a virtual world so they can more accurately fly through a simulated world. We are imagining Chris Tanner, young and tired at 24—what must he be like now?

I concede to this mess. I openly admit and accept what might even be a criticism of this mess. But I need to argue the other side as well: how would *you* write about images today? How could you systematically write of ocularcentrism of the Western modernity and postmodernity that is a portmanteau of *ocular* and *centrism*—that is, ocular as in *human* eyes—and also balance the conceptual explosion of the human under the Anthropocenic revision of the humanities, under the dismantling of the humanism by way of Sylvia Wynter, amidst the highly affective spaces of a culture perhaps so bone-achingly tired it reserves its last strengths for the affects and emotions it still yearns to feel only now while on the couch, under a duvet, hot beverage in hand and the option to shut it all down at any moment? How do we write about a visual culture that orbits around culture, a notoriously difficult word to define, to be sure, but one that has profound loops through human sociality, even if I wouldn't attempt to define or declare where those loops might start and end?

This is what I have grappled with for the duration of the project and even still, as I reflect on my findings and how they will be found in the world. I have explored the social effects of images contained not solely or primarily within a human visual culture but instead within an epistemic visual culture populated by humans. We can't even say that humans are productive of this epistemic visual culture because, as was thematic throughout this thesis (and explicit in chapter four). The knowledge that produces images is a knowledge, at times, co-created equally between humans and nonhumans, though primarily through an un-parse-able, topologic relation between humans, machines, nonhuman organic life, nonhuman nonorganic life, and the chaos and complexity that encompasses all of these things at once.

In the introduction I noted that my thesis project began with wanting to understand how images of landscape that were highly mediated and steeped in the aesthetics of digital technologies could still be read as *landscape*. I had thought that this was a question about the visual essence of *what nature is*; about what the least amount of information needed to be represented for the idea of a natural world to be communicated. What my initial research showed was that answering such a question proved difficult, not solely because ideas of nature are many and varied but also because of the unstable and transient ontology of the image itself. Digital technologies only added another layer of complexity to this ontology by further dispersing the bounds of what might be contained within an image or reasonably called an image.

What came to pass, then, was that I was faced with two major instabilities—that of nature and images as aesthetic and ontological orders. These two instabilities hindered my ability to mark out the boundaries of a phenomenon, and so redirected my research in a different direction. Instead of trying to understand specifically how digital technologies—used as both tools for artistic creation and as tools infused in our everyday living environments—were influencing the practice of making landscape art, the thesis became much more broadly about the meeting point of aesthetics and epistemology. How does aesthetics work to teach us things—to show or make clear the boundaries of knowledge, and how we know that knowledge? And on the other side of that question, how does epistemology craft representation, in ways that are both obvious and imperceptible, but which always demonstrate clear impacts on our epistemological practices?

Against these ambiguities, I was persuaded that there was stability in the sky itself—as a real, organic entity—and it was this stability that was being misguidedly positioned as counter to a sliding spectrum of senses and perception. Each encounter, it seemed to me, created the sky in the image best formed to the senses that perceived it. Satellite images begot their own view of the sky as editable and interchangeable; as a display medium that could be perfected and manipulated to perform some other feat of visibility. Radio astronomy sensors could view through the sky altogether, into deep space to view far away galaxies, a capability that seemed to delegitimize the specificities of viewing so that visual data was only understood as a heuristic, transmutable into whatever form or vessel without consequence. This was not, as we've seen, to be exactly the case.

Not only this but the images that have inspired this thesis, I have argued, are always involved in the practice of creating *worlds*, and this act of creating worlds is always in part an epistemological act. Images of the sky and sky-related phenomena have helped to think this point through by closing the unconscious gaps in how we think and treat images in the arts, and images used for science. The sky is a useful framing in this sense because it embodies so many of the contradictions and challenges that are played out in the creation of ecological knowledge: it is an opaquely defined arena in the biosphere, it is always both near and far to those who seek to study it, and given these two things the sky has historically always required the assistance of technology to bring its phenomena into observation.

The existing literature did not quite seem to address the problem I was trying to solve. On the one hand, art historical literature with critical engagements of landscape art were damning of the social and cultural crimes that paintings committed. They showed how "realistic" depictions of the landscape art vignettes were often portrayed in inverse proportion to the social ills of the time. There was equally literature that was critical of the ways that landscape aesthetics could be annexed into projects of nation making, and crucially how these annexations erased the history of violence that often begot nation states. Images that fell under the umbrella of "art" were very rarely taken seriously on the level of their epistemological contributions. In some instances the study of the images in science did make an earnest attempt to unpack the contradictions that were revealed in the discursive and practical treatments of images.[443] Yet this literature still maintained the boundaries between images and nonart images. Their studies engaged with nonart images and commented on how art images could be used in publicity, or even commented on how artistic strategies were present in the scientific treatment of images, though the engagement did not extend beyond that. Laboratory studies in particular, such as Karin Knorr Cetina's and Klaus Amann, provided a surprisingly useful way of thinking about the socialities of digital technologies. Here the emphasis on the equal partnering of technologies—both in terms of machines and the ways that disembodied human parts such as hands and eyes could ambiguously be considered technologies—and human actors was a natural fit for thinking about the types of work that is carried out by programmers and the communities that form around troubleshooting. Yet laboratory studies, too, was not invested in the study of the image as perhaps both artistic and not, and so many of these strategies had to be translated towards my own project.

Not only this, but the study of display technologies and their connection to images was notably lacking. [444] This might be partly explained by the newness of 3D computer graphics software, and the ways they are applied in different sectors

[443] See, for example: Lynch and Edgerton, "Aesthetics and Digital Image Processing."

[444] One exception that might be raised here is Peter Galison and Caroline A. Jones's anthology, *Picturing Science, Producing Art*. While this is an extensive and far-reaching compendium on the intersections of science, art, and image, it does not directly deal with the complexities of computer display or rendering, which I would characterize as a durational format of the image. See: Caroline A. Jones and Peter Galison, eds., *Picturing Science, Producing Art* (New York, NY: Routledge, 1998).

unequally. Computer graphics and animation softwares, as we've seen, can be used in sectors as diverse as film, climate study, art and gaming. Each uptake of the software inspires new ways for it to be applied, imagined, and designed. Still, the patchy history of computer graphics and its overlaps with art history was a good way to begin to think about how history and theory could explain an aesthetic politics of data display. James Elkins has been among the art historians to show how the development of computer graphics has meant that its pedagogy has often missed continuities between art history, theory, visual culture, and the development of display strategies. However these early works, one, often quickly fall out of pace with the development of the technologies themselves, and so cannot be expected to fully address the full complexities of their findings; and two, do not also address the way aesthetic strategies and computer graphics are fused into meaningful effects on different sectors.[445]

An unanticipated point for consideration that emerged in the process of researching this thesis was how representation was being finely threaded through these discussions in coded ways. Representation was a blunt *either/or* question in art historical literature on landscape. Landscape showed what a society was not, or what it wanted to be: more nationalistic, more "natural"—though whose nature this *naturalness* reflected was a nomadic mark on a spectrum of possibilities. More recent scholarship between art history and visual cultures used representation as a deconstructive blueprint for understanding a model of vision and visuality.[446] Through images's unique ability to mimick and exploit theories of human vision,

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[445] See, for example: Elkins, "Art History and the Criticism of Computer-Generated Images."

[446] See, for examples: Grootenboer, *The Rhetoric of Perspective*; Martin Jay, *Downcast Eyes: The Denigration of Vision in Twentieth-Century French Thought*, 1. paperback print, A Centennial Book (Berkeley, Calif.: Univ. of California Press, 1994); Crary, *Techniques of the Observer*; Christine Buci-Glucksmann, *The Madness of Vision: On Baroque Aesthetics*, trans. Dorothy Zayatz Baker, Series in Continental Thought, no. 44 (Athens, Ohio: Ohio University Press, 2013).

these authors saw the unfolding of a type of logic which, for some, signaled a form of disembodied cognition, while for others, a tool of rhetoric or persuasion.[447] Within the approaches that were more deconstructive of the sciences and their uses of the image, representation was an equally a blunt instrument but it was often intertwined with the question of subjecitivty and objectivity. Lorraine Daston and Peter Galison's tome on the history of objectivity as an epistemic virtue came the closest to helping unpack and deconstruct this fraught figure of entangled representation. Their work highlighted the way that representation was never, at any point, purely subjective or able to be defanged of its subjectivity. Instead it was helpful to think of objectivity as a placeholder for the virtues of a particular culture's mode of epistemic work and engagement with the world. In this sense objecitivity had a distinctive aesthetic dint to it—it was about a macro- or meta-level ordering and an organization of a practice that manifested particular kinds of knowledge, linking in with a particular place, time, and set of characters.

Given these starting points, it was necessary for me to shape the thesis around a series of case studies. This was done not as a way to answer questions, but instead as a way of doing the critical preliminary work of *mapping the problem* I had originally faced. What can we observe from the encounter of the digital with the physical world that reflects on our current systems of aesthetics and epistemology? How does the digital offer particular formats of ecological knowledge? The thesis has thus explored in three sections how images of the physical world emerge through the joining up of different registers of perception and modes of computation.

Section I was designed to flesh out historical and present-day methods of

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[447] See, for examples: Erwin Panofsky, *Perspective as Symbolic Form*, 1st ed (New York : Cambridge, Mass: Zone Books ; Distributed by the MIT Press, 1991); Hito Steyerl, "In Free Fall: A Thought Experiment on Vertical Perspective," *E-Flux* (blog), accessed December 11, 2014, http://www.e-flux.com/journal/in-free-fall-a-thought-experiment-on-vertical-perspective/; Damisch, *A Theory of /Cloud/*.

aesthetically representing the sky. In these examples Maria Lugones's sense of *worlds* takes hold, showing how individual experiences, culture, phenomena, and modes of engagement open into multiple, laterally organized orders of the aesthetic, which also feed epistemologies of representation. In this way we understand representation as an aesthetic that is informed by, and informative of, what we know and how we know it. Framing representation not as difference in styles or knowledge but instead as *worlds* helps us to understand that we know and how we know it are not stylistic choices; they are among the many possible pluralities of meaning and meaning making. Significantly, then, such a broad approach to understanding the world can then be brought back down to detail and minutia—a darkened, mid 19th century cloud in London, a single white pixel in an RGB spectral band. These granular points in the broader aesthetic orderings that emerge through the movement of *worlds* show just how drastically and radically matter and meaning can pivot within a system. Was the darkened cloud in London a spectral commentary on the moral decay of society, or an early warning of the climate crisis to come? Such a question can be answered definitively *and* inconclusively. It is both, or one, or neither, given its appropriate *world*. While such a position might suggest that I'd leave knowledge vulnerable to a state of persistent relativism and inconclusivity, instead this section defines the aesthetic transformation of phenomena into knowledge as a system of constraints. Each of these systems of constraints is also alternately productive of their own particular kinds of knowledge; knowledges that can be amplified and dampened when placed into different relation with each other.

Section II explored these modes of representation/systems of constraints/*worlds* through two related technical systems: the computer graphics pipeline and the 3D computer graphics and animation software; for the former we explored the immediate context and history of texture mapping, inspired by the photography series *Postcards from Google Earth* by Clement Valla; for the latter, the free and open source software Blender, and its applications in the natural sciences.

While the previous section wrangled a multiplicity of aesthetic strategies for understanding the line between aesthetics and epistemology when engaging the sky, this section attempted to inhabit these systems individually. Through this inhabiting, I foregrounded a discussion of the asymmetric relationship between the perception of users and digital outputs. The aim of drawing out this asymmetry was to emphasize that visual information is always packaged in the *relation* of image to modes of looking and interpretation. The relation of image to modes of looking and interpretation was not something intended to simply import the insights of the art historical debate on representation into this discussion of images. It was also intended to inscribe Lugones's *worlds* and the plurality of meaning and meaning making into technical systems—to understand hardware and operators not as static agents that bump off each other but instead as each containing their own *medial drives*, and to suggest in this way that drives as well as perceptions are continuous across sentient and non-sentient bodies.

The third and final section drew from my virtual ethnographic work on amateur earth modeling communities and resources. I continued to stay with the theme of the relation of image to modes of looking and interpreting, but now contextualized these different images/modes within three distinct domains: the ecological, the human (optical) and the technological. This contextualization was supported in my discursive readings of earth modeling forums and the ways that the community collectively flagged issues, worked together to troubleshoot, as well as contributed to the seemingly immaterial—though revered—*to do* list. These practices required their own sets of contextualizations which directed us to the history of visualization in scientific computing and drew in a discuss of the available paradigms for 3D modeling. Through the history of visualization in scientific computing we saw the inherent bias in epistemic practice and computing cultures work against a preconceived notion of *the image*, often serving to make arbitrary cuts in how data was generated, used, and distributed. I questioned this bias by revisiting

Daston and Galison's notion of *structural objectivity*, which notably eschewed the use of images in search of universally communicable structures for the tranmission of knowledge. On the basis of this latter definition I saw no difference in the way visual phenomena was being crafted through imagery, modeling, and simulation on the basis of data that did not feel out of place in even the most institutionalized epistemic settings. Such an ambiguity throws up the question of whether or a rethinking of the ontology of the image is a necessary step for the continued, collaborative work of scientists and digital tools.

Throughout this thesis I have moved between, and inhabited, different orders of perception, from the technological (in the 3D computer graphics and animation software Blender and clipmapping in real-time rendering in virtual worlds), to the biological in the history of Western engagement with the clouds, to

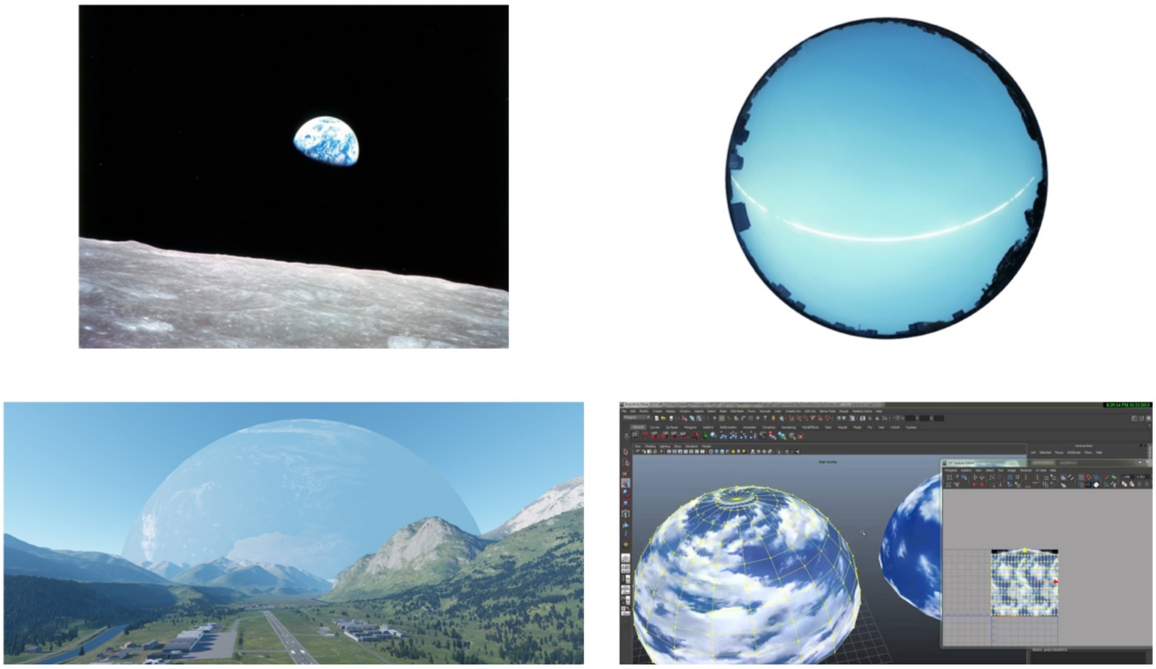

Figure 35: From top left, clockwise: Earthrise; Izima Kaoru, Koukyo, Japan; Still from YouTube tutorial on skydome techniques, done in Maya 3; Screenshot by user in Outerra, submitted to forum

what we might call a *cyborg* mode of perception,[448] as exhibited in the close collaborations of humans, machines, and the perception of nature in the virtual earth modeling communities. In all of these case studies, these perceptions became the primary pathways by which ecological knowledge was accessed and produced. How that ecological knowledge was validated and applied, however, changed across case studies, and in counterintuitive ways. Where we might have expected ecological knowledge in artistic contexts to be applied to creating better senses of realism in visual styles—like with *Postcards from Google Earth*—we saw a refinement of a technical world. Similarly, ecological knowledge in the sciences—as in the satellite

[448] Lev Manovich also adopts this framing but in perhaps a slightly more narrow sense of the term. Of the synthetic image—the kind that is produced by computer graphics but made to simulate reality—Manovich asks, "Whose vision is it? It is the vision of a computer, a cyborg, a automatic missile. … It is the vision of a digital grid." Such a sentiment is equally applicable to my work here, but I feel it is important to maintain the extended sense of how I am treating *image* and perceptions: as always socially contextualized, emergent through consensus practices, and continuous between bodies and machines. See: Manovich, *The Language of New Media*, 183.

images the Google Earth Engine team was working with—helped to stylize an image of the Earth's topography. These cross contaminations give proof to the necessity of working between aesthetics and epistemology differently; not to undoing these categories but understanding them as *worlds* that require consistent negotiation between registers of perception and culturally-constituted ideals.

What this thesis has done, then, has endeavored to make a critical intervention in the field of visual cultures by way of necessitating new visual research methods. What I have at times here referred to as the "messiness" of my method is also form following function. In making the case for understanding images as structures of data and information I have been faced with the challenge of doing visual cultures and art historical research while at the same time moving *away* from a concept of *the image.* How are visual debates reframed in terms of their data content—how is it possible to talk about the composition of an image entirely in terms of its informational capacities? In one way this question responds to classic themes in visual research methods, exploring what kinds of seeing images invite and what communities, cultures, and discourses they form in the process of their seeing. What has been necessary to add to this question, however, has been an acknowledgment of the indeterminacy of what this question, in its current state and framework, can properly address. Can visual culture stand apart from the human, and if so, can it still reflect, or provide insights, onto a human production?

These questions set the boundaries of my research, and made it necessary to look at boundary objects such as "the glitch" (that wasn't a glitch) in Google Earth, the inaccurate accuracy of a cloud-free planet Earth image, and the scientific eye-balling of amateur earth modeling. In each of these cases we saw the meeting point of aesthetics and epistemology, and crucially, where they fell short of each other. Couching this theoretical debate in contexts that are "executable"—the software that must run, the map that must way-find, the database that must hold its consistency—was a way of providing at least one means of accountability, if we stick to a traditional sense of knowledge, and if we think in terms of a more *situated knowledge,* then also provided comparative information about an image culture's values and degrees of "success" (for lack of a better term). The chapters on Blender and the early history of clouds provide counterweights to the other case studies by attempting to situate this new, messy research method in a phenomena far less human in degree, but without submitting to the illusion that me (a human) could ever produce something so distinctly inhuman. In particular, the history of clouds, rife with its bad science done by good scientists and historiography powered by hubristic notions of the primacy of a human do a great deal of heavy lifting to support the ways that visual cultures frameworks do not assertively enough find the seams of aesthetics and epistemology. In Crary's classic Techniques of the Observer we are given our first clue that this is where the work should go when he argues that realism *precedes* photography. In this argument we find early support for the idea of image as data and information, as Crary shows us how the aesthetic category of realism is in fact a computational ordering. Far from a visual presentation *or* an embodied sense of "realness," 19th century realism accounts for both, and is a concept deployed to standardize the informational capacities of the human eye by creating marginal or boundary phenomena out of idiosyncrasies such as retinal after images.[449] This historical work is important, but it doesn't tell us enough about the idiosyncrasies of a technological, ecological, or even cyborg "eye." In this statement, already, we can see the political stakes that working in this way poses even in its implications. The political process of standardizing the body, bringing it into order by creating norms and "margins", has a troubling history that persists today. In one reading, technology only amplifies this conceptual history; metaphors of how a standardized body work are transferred to frame how a properly functioning machine, code, or software works. Digital and networked technologies only amplify

[449] Crary, *Techniques of the Observer*.

the rate at which these maneuvers are made. There is less clarity, however, in accounting for the standardized/marginalized dichotomies of nonhuman and nonorganic bodies. Take, for example, the inabilities of the JPEG format to deal with a spectrum of deeper skin tones, and yet its inextricable impact on race through automated policing. By holding on to *realism* as a term and tool of aesthetic debates, are we complicit in the social effects of this history—even if from a remove? My thesis would suggest that yes, we are.

Expanded visual research methods and new concepts of the image require new frameworks of visuality and visual cultures. This thesis supports the position that aesthetics should be understood in its practical grammars as data and information, and also that this grammar extends out not solely to just the pictures and means by which they are "representative" but in ways in which *affects* here are too bundled into images, into images and information, and into the structures of images and aesthetics.[450] Images are a formatting of information, regardless of their disciplinary or utilitarian placement. In some respects, this is not a new or particularly bold statement, but it bears playing out when we consider the

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[450] But in case the idea of images realigned as a structure or format of data would call to mind a cold and unfeeling armature, images also show us the tenderness of information. Affect theory shows us already how this is at play; Massumi's first parable emphasizes that the primacy of affect comes through in the gap between content and effect, with the note that the images' content, how well it is done or the strength of its representation, bears no relation to its affective reception.[450] Affect, in Massumi's terms, is presented as a fourth-dimension form of cognizing; "virtual synesthetic perspectives anchored in (functionally limited by) the actually existing, particular things that embody them."[450] The autonomy of affect, its distance from emotion, is that while emotion is a qualified expressino at a certain intensity of the mode of cognizing an aesthetic phenomena or form, affect remains open to all potentialities. Affect is a cognition that is not *prior* but instead *open.* And though while this thesis doesn't deal with affect—it makes no contributions to affect theory nor does it make use of how affect theory might explain the aesthetic grammars of the images I treat—it is a useful precedent to mention here because it is a body of theory about a particular mode of aesthetic and perceptual logics. Now, while affect theory does not require human bodies, and for this already it has much to offer my thesis, it tells us less of the affections between nonanimal bodies—between machines, between light and sensors. I am not even clear that there is a possibility for affect between these two entities, but it seems worthwhile to point to the development of work here. If affect is an aesthetic cognition, and computation is an activity of cognizing, then it would seem we are behind the mark in this research.

overlooked ways in which images are installed into discourses as "banal" or "benign". The reading of images put forward in this thesis negates the possibility of just an image, or just a pretty picture.

The Poetics of Worlds

There have been two guiding theoretical principles in this thesis. The first, which I will discuss now, has been the sense of *worlds* as it has been conceived and deployed by Maria Lugones. This thesis has, at times, covered brief and selective history of making images of the physical world from classical landscape art to satellite images and 3D computer graphics software. Through this history I have argued that you cannot represent a world without creating a world. Creating a world is intended to signify the way in which representation never is, nor can be, a neutral act. Creating a world means that a creator contributes to producing and/or perpetuating value systems and beliefs. *Worlds* in this sense also is double. *Worlds* manifest in the study of our phsyical environments, our physical *worlds*, like a set of nesting dolls encapsulating various scales of *oikos*: house, neighborhood, planet, galaxy, cosmos. *Worlds* also manifest as non-physical worlds. Virtual worlds become *worlds* held in relation to physical *worlds*. On the surface they seem to mimick physical environments, yet freed from the laws of physics and natural worlds, virtual worlds take flight. Non-physical *worlds* also emerge as in our knowledge fields. Discourses and practice rub upagainst each other until they orogenetically seems to spawn new worlds forced to share the same uncomfortably small horizon. "Plurality" might be another word for it, but "plurality" doesn't seem to quite capture the way *worlds* can interact with each other or pivot so radically on the same points. Poetically, as well, *worlds* has been a neat bridge between the various domains and concepts that I have dealt with. I am enthusiastic about the ways in which these poetic connections might come to form metaphoric linkages, productive of knowledges I cannot, at this moment, even foresee.

The research undertaken in this thesis emphasizes a key point of later scholarship on landscape art, which is what W.J.T. Mitchell has discussed as landscape's ability to simultaneously exert subtle power over people and be an invitation to "look at nothing--or more precisely, to look at looking itself—to engage in a kind of conscious apperception of space as it unfolds itself in a particular place."[451] This reemphasis is crucial work for a number of reasons. For one, it keeps alive a tradition of critically engaging with images of space and place which, as we have seen, have historically played important roles in projects of nation making that have sinister effects. Later studies in landscape aesthetics have also emphasized the asymmetries in social justice that use scenes of nature to displace, pathologize, and disadvantage people of color, LBTQIA+, and gender non-conforming. Secondly, given how much of our physical world is accessed and made knowable by digital means, there is a need for critique to be revisited on these terms. Digital technologies have a unique way of being able to distract from core issues. In this we risk reanimating old beliefs in the disembodiment of information and the neutrality of cyberspace. Nothing could be further from the truth, as this thesis has worked to show.

The case studies in this thesis contribute to existing work in the fields of sociology of science and science and technology studies that reveal the porous threshold between "hard" sciences and "soft" humanities. Clement Valla's *Postcards from Google Earth* series, the community of non-scientific earth modelers, and the cloud-free Google Earth project all show the intense entanglement of creativity and craft that is present in every act of epistemology. What these case studies uniquely contribute, though, speaks to the persistently unclear relations between the image, aesthetics, and epistemic cultures, or cultures of "hard" science. Astrophysics, astronomy, climate study, computing, software engineering—these are all fields

[451] W. J. T. Mitchell, ed., "Preface to the Second Edition of Landscape and Power: Space, Place, and Landscape," in *Landscape and Power*, 2nd ed (Chicago: University of Chicago Press, 2002), viii.

which see themselves as far removed from the arts, design, and visual culture. Their histories and current practices all reveal a deeply internalized mentality around practices of the image and work with aesthetics that, as was suggested in this thesis, actually requires more mental acrobatics to maintain than it does to dismantle. In this way Lorraine Daston and Peter Galison's work on the history of objectivity, which they mount through an inquiry into the history of atlas images, finds another life.

When all of these parts converge, the thesis overall textures the field of ecology. It troubles the knowledge that *is* admitted to this field by means of things like satellite images and climate models and validates the knowledge that *is not* admitted to this field like paintings, photography, and new media artworks. Creating this critical tension is important work now more than ever when climate instability threatens every aspect of our lived experience on Earth. Tension brings to the fore questions of form and content: of their inextricability with one another as well as the ways they individually, and in combination, multiply the sites and formats of what we can do and can know about our changing environment.

Ecology and environment were a good context for this discussion because of the way that issues inherent in both could be staged in terms of both aesthetics and epistemology. There were claims one could make about how the physical world was represented that had a push and pull with what we knew about the physical world, and vice versa. The history of the computer and computer graphics also provided a good context for this discussion because of the way this history and its discursive evolution showed a persistent and arbitrary treatment of images in the scientific computing. Technical documents from the early history of visualization in scientific computing even through to today's manuals on 3D modeling software like Blender and physically based rendering show that epistemic cultures have long been conflicted about their own thresholds and determining criteria between when something is an image or data, creative or objective.

The method of my study holds important implication for how histories of new media art should be approached and written. Much of my insights from this thesis are derived from digging deep into the technical specificities of software and the discursive ways these technical specificities are presented. These explorations have had significant impact on understanding image, digital structures of the image, and content. The debate between "pretty picture" and "database" are a clear example of this. The thresholds of what separates one from another are unclear, and while epistemic cultures retreat to their usual corners on the issue the case studies in this thesis have shown how this is a missed opportunity to understand not only the knowledge contained in picture/databases but also in performing the care of the self that Knorr Cetina identified as so central to new practices of working in tandem with machines to make knowledge.

The antipathy between art/science and image/data is also persistently replicated across domains. We can see this in the multidisciplinary works that use landscape paintings as ways of accessing environmental and meteorological knowledge by other means, such as in Stanley Gedzelman's work on weather forecasting in art; the reinterpretation of Turner's paintings by Michel Serres and climate researchers; the re-reading of Ruskin's environmentalism, and even the origins of geography.[452] These works tend to circulate on the fringes of art history and their target fields, representing more niche interests or novel approaches to classic questions.

As we've seen here, digital images demonstrate how aesthetics have the

[452] Gedzelman, "Weather Forecasts in Art"; Gedzelman, "The Meteorological Odyssey of Vincent van Gogh"; Maev Kennedy, arts, and Heritage Correspondent, "Spectacles a Clue to Turner's Style," the Guardian, accessed May 15, 2015, http://www.theguardian.com/uk/2003/nov/18/arts.artsnews; Serres, "Science and the Humanities"; Brian J. Day, "The Moral Intuition of Ruskin's 'Storm-Cloud,'" SEL Studies in English Literature 1500-1900 45, no. 4 (2005): 917–933; John D. Rosenberg, The Darkening Glass: A Portrait of Ruskin's Genius (New York: Columbia University Press, 1986); Jay Appleton, The Experience of Landscape, Rev. ed (Chichester ; New York: Wiley, 1996).

capacity to impact physical space: to concentrate or dilute; to produce or represent; to clarify or reorganize. Given its evident impact, geospatial digital images and the technologies that subtend them would be served by their importation into fields oriented towards guardianship of the image: art history, aesthetics, and visual studies. As W.J.T. Mitchell has pointed out, it is precisely iconology as a study of images "which opens the border to the image, the fundamental unit of affect and meaning in art history" and media aesthetics which "opens the border on the relation of the arts to mass media, avant-garde to kitsch, polite to popular arts, art to the everyday."[453] These are two useful touchstones in the study of our image-saturated environments. And, as Johanna Drucker has pointed out in her discussion of art historical formalism, the acceptance of these cultural aesthetic nodes—while perhaps for some risking the maintenance of normative conventions better left destabilized and disordered—still offer "much to gain from recognizing the ways in which contemporary art practices are circumscribed" by outside domains. This thesis has worked towards these ends, offering a method of how to engage with digital images and suggesting that the boundaries of these images far surpasses their visual outputs. Not only this, but digital images of environment also demonstrate how many modes of perception are present in any given image, and how these modes of perception are often irreconcilable with each other, resulting in images that are either improperly read or wrongly classified as faulty or glitched. This paper seizes on these moments of breakdown to use as examples for unpacking and mapping how digital images of environment are never just technological or stylistic, but instead always imaging some form of excess that only makes itself known when we start to understand perception as the negotiation between cultural values and practices of representation.

[453] W. J. T. Mitchell, *Image Science: Iconology, Visual Culture, and Media Aesthetics* (Chicago ; London: University of Chicago Press, 2015), 28.

Of Tears and Pixels (and the Limits of this Thesis)

There still remains ways in which the image and what it proposes about visuality are incomplete in themselves. Representation is difficult to untangle from the many inputs that construct it. Theories of perceptions by authors such as Jakob von Uexküll,[454] Humberto Maturana and Francisco Varela,[455] and James Gibson[456] all prove the valid and considerable weight that the perception of environment has measurable impact on the order of how we see the world. This sense of *biosemiotics* is not just applicable to the sciences or to cybernetics but must also can be read more broadly as an aesthetic theory: an ordering of how things can look and be perceived as the thing they are, and also as an epistemological theory in itself: that things are perceived as themselves because there are fundamental modes of representation that constitute the knowledge of that thing. Trying to then use modes of representation, as Grootenboer does, as a method for dialing into known and unknown modes of seeing and perceiving becomes a challenge. Add to this the instability and polymorphousness of the image in the digital age and it would appear that some of our go-to tools and techniques inevitably fall short.

I should also here address the concern that the articulation of an ever-emerging, dynamic production of knowledge from the culturally-mediated negotiation of perception and representation legitimizes the formation of a relativist cul-de-sac. This is not my intention at all. Rather, I would suggest that my conclusions fall in line with what many feminist scholars of science have already proposed: that knowledge be acknowledged as, at least partly, constructed, and that

[454] Jakob von Uexküll, *A Foray into the Worlds of Animals and Humans: With A Theory of Meaning*, 1st University of Minnesota Press ed, Posthumanities 12 (Minneapolis: University of Minnesota Press, 2010).

[455] Humberto R Maturana and Francisco J Varela, *Autopoiesis and Cognition: The Realization of the Living* (Dordrecht: Springer Netherlands, 1980).

[456] James J. Gibson, *The Ecological Approach to Visual Perception* (Hoboken: Taylor & Francis, 2014).

we incorporate this knowledge *of* the limits of thought into the formalization of knowledge. Science that insists on its own autonomy and insularity of rationalization serves no one. Such claims to absolute mastery are, as Haraway might characterize it, a "Coyote or Trickster," suggestive of a situation "when we give up mastery but keep searching for fidelity, knowing all the while we will be hoodwinked."[457] My thesis is not, at this stage, precisely a proposal for how science should be done or how the image should be considered. It is instead a mapping out of *existing* practices of science, art, and the image in ecological contexts intended to shed light on the complexities of these histories and practices, and to draw out the many ways which these mappings might provide guidance towards another way of working.

In this thesis I have staked the grounds of my investigation into images on the question of claims to epistemological authority—who has it, where it might come from, how it is produced. In hindsight, this is a straightforward and logical way to think about the study I've done and the questions I had. Coming to the end of the project, however, I find myself wanting to push this framing further. Keguro Macharia writes of their interest in representation as "a major *scene of encounter* and a *pedagogy of feeling*."[458] Perhaps I have undertreated or taken for granted the interactions contained in this thesis for the major scenes of encounter that they are. In my critique of the use of images in the sciences, have I myself also failed to account for the forms of knowledge attendant to the image that science marginalizes? In trying to drill down to the fundamental components of texture mapping pipelines and pixel bases in images, have I been neglectful in my treatment of each of these sites as scenes of encounter—and more importantly, as having such a power so as to *teach* its viewers how to feel? In this statement I don't mean to

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[457] Haraway, "Situated Knowledges," 199.

[458] Keguro Macharia, "Black (beyond Negation)," *The New Inquiry* (blog), May 26, 2018, https://thenewinquiry.com/blog/black-beyond-negation/.

conjure up the highly programmatic way that value systems are constructed as the semiotics of feeling. I do not wish to return sights and scenes of "nature," to an index of moral cultural codes, no matter how progressive they might be. And in another way, saying that a visual scene or representation can only ever function as an iconography seems to suggest that the thing itself, the *site of encounter* between agents, is not enough–it is merely a catalyst to trigger (perhaps in our most sinister reading) the overemotional brain of some onlooker. Having come out on the other end of this research, I know this to not be true. Feelings, experiences, and perceptions are far more cutting and influential than this. They are transformative—possibly beyond for what we are able to currently measure.

Consider for a moment James Elkin's study of people who cry in front of paintings. The inspiration for Elkin's study came, he says (and quite fittingly for us here) from an episode with his student, Tamara, crying freely at a painting by Caspar David Friedrich in a 1990 exhibition by the Art institute of Chicago called *The Romantic Vision of Caspar David Friedrich*. To begin, the exhibition was an "unusual experiment:"

> …the light was so low that when you first stepped in, it was hard to be sure how many people were in the room. A half-dozen paintings were hung at wide intervals, each carefully picked out by a hidden spotlight. The curators had fitted an audio system, which was playing Schubert impromptus. The music rose and fell, sometimes loud, other times nearly inaudible. The rooms were dreamy and hypnotic. When people stood close to the pictures, a glow spread around them like the corona of an eclipse.[459]

Tamara looked at the painting of the high mountains, out into the mountain chasm, and felt herself openly weep for two minutes before leaving the exhibition. All of this she reported to the class in their following session. Elkins admits feeling judgmental of Tamara's crying. The "unusual" show had, to his mind, felt like

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[459] James Elkins, *Pictures and Tears: A History of People Who Have Cried in Front of Paintings* (London: Routledge, 2004), 148.

Figure 36: "Mountain Peak with Drifting Clouds" (circa 1835) by Caspar David Friedrich. This is one of the paintings from the exhibition, though it is uncertain which one made Tamara emotional.

emotional deception. Tamara was training to be an art historian (under his instruction, no less!), and as the many art historian friends that Elkins polled about the situation agreed, she should have known better than to allow emotion cloud her critical gaze. At the least, if she couldn't help *but* to cry, then she should have interrogated the way the exhibition itself was resposible for this, manipulating and creating emotional experiences with artifice rather than engagement. But then Elkins starts to regret his judgments. *Why shouldn't she have cried*?[460] Crying is what Friedrich would have wanted: "Viewers were meant to be over-whelmed by his

[460] Elkins, 151.

panorama of vast mountains, snow, and fog; they were supposed to be overcome by a nearly unbearable sense of solitude and loneliness."[461] Elkins reproaches Tamara in his mind for "refusing to play the game", for refusing to perform a historical analysis that is devoid of tears, only to have to pivot on the same sentiment and ask, "Could I really fault Tamara for responding in a way that Friedrich himself might well have wanted? Wasn't her reaction more historical than that of the other students?"[462]

In so many ways I see this moment as encapsulating what has been expansively mapped out over the course of this thesis. There is a scene, a site of encounter, a physical world experience, and then there are the tools we come to that experience with in order to dissect it. The experience is reproached for being an experience—*don't play music! don't dim the lights!* But the experience is information our tools cannot accommodate. The experience remains an experience even as it overhelms our tools. It is free-flowing data. Tears become method. The method frustrates those who themselves too might have once dared to cry in front of a painting and were rigorously trained out of such techniques. When did crying get itself expelled from the historical method? When did crying become exclusive of data? For as much as I reflect on whether I too have been guilty of parsing out the kinds data and knowledge I admitted into this study (should I have kept a log of my tears? my frustrations?) I also know that I included John Constable's cloud studies for this reason: for those terrificly detailed, scientific data sketches that I picture being done with Constable's sickly wife by his side, bundled to keep out the cold and also taking long, hopeful breaths to draw Brighton's seaside air into her lungs, bringing its special magic to her organs, wringing out the ailments and toxicity from her fascia before exiting in small, slow sighs.

I read once that tears are a vehicle for getting excess hormones out of the

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[461] Elkins, 151.

[462] Elkins, 151.

body.[463] When I read this I felt myself physically travel through *worlds*; I left the *world* in which crying was what little kids and over-emotional women did and came up for air in a *world* where tears had calculations and marks of a body refined to persist over thousands of generations. Writing this now I think about tears in the same way that Matt Hancher thought about satellite images: as containers for data, a million tiny granular components opening up onto their own *worlds* of aesthetically ordered information. I'm also thinking of tears as images: images of a body in an experience, an experience of imbalance, disruption, or un-ordinariness that might just be at a mechanical level (*is the endocrine system out of whack? are you chopping an onion? is your lover wearing perfume?*) or it might not. Is this tear-image showing me a body in pain? In distress? In excitement? The tear-image remains the same: a recombinant mixture of water, saline, protein-based hormones but it opens up multiple modes of understanding and avenues of information.

Central to my study has been an expanded sense of the image. Understanding the image as more than what can be contained in the mind or in a picture format, identifying its locations in the digital pipelines that propel and create the animated images and pixels on our screen, has been a critical methodological step in my thought process. Freed from the traditional constraints of understanding an image even in the diverse forms that W.J.T. Mitchell outlined has allowed me to

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463 See, for example: C. Claiborne Ray, "Hormones and Women's Tears," *The New York Times*, January 3, 2011, sec. Science, https://www.nytimes.com/2011/01/04/science/04qna.html. An early seminal study is: William H. Frey and Muriel Langseth, *Crying: The Mystery of Tears* (Minneapolis, Minn: Winston Press, 1985). I make this issue of tears in the service of a larger point I'm trying to make, so I've not adeqately reviewed the literature on tears and hormones enough to make any kinds of claims. However from even just these initial glances, the gender bias that is present in the study of tears seems remarkable, and frustratingly so. That the study of such small phenomena—water, saline, hormones, peptides, proteins—could be gendered feels like a real forced effort. In popular culture I believe this is what is called a "hot cis take." I assume that the disdavantage of such insistent gendering is self-evident, even at this level of the mechanical dissection of tears. If tears are mechanisms to return bodies to homeostasis, then why bother signaling the dog whistle on a cultural judgment as to who is, or is not, allowed to live in a balanced body?

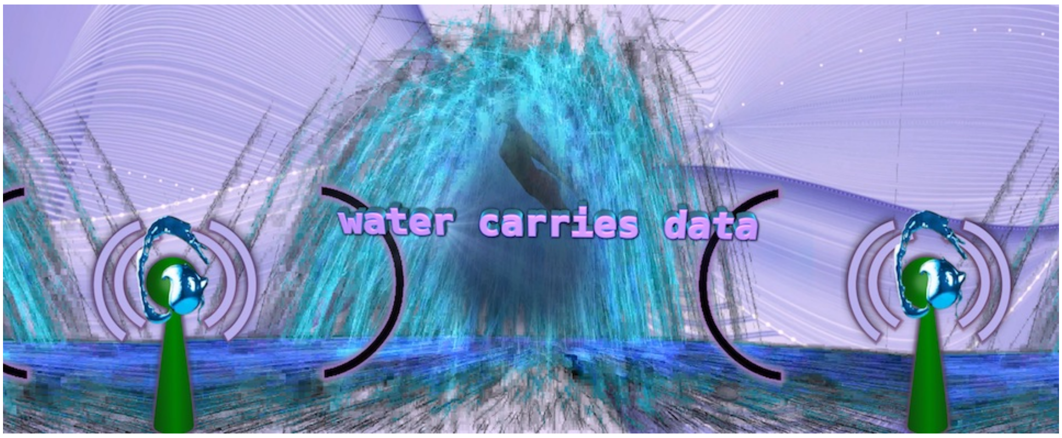

Figure 37: Still from "Deep Down Tidal" (2017) by Tabita Rezaire.
Rezaire's video essay explores the way relation, politics, spirituality and communication are all intersected by bodies of water. She explores these themes through the material (deep-sea fiber optic cables) as well as the immaterial, as in the stories of what is buried in the oceans such as the lives of drowned sailors and complex histories of colonialism.

see epistemology as its own scene of encounter with aesthetics, and vis versa. Through this I also feel emboldened to say that very little changes based solely on the tools and medium in which this circuit is completed. Is this a function of the frame of the image, or is it more metaphysical than that? Nicholas Mirzoeff has argued that a key feature of the human life today is that "The body can no longer make sense of what is presented to it" and here, of particular relevance to this thesis, he clarifies by adding, "We cannot articulate what we perceive, namely, that the climate is wrong—too hot, too dry, too wet, or all of the above."[464] Yet what we believe and know teaches us how to *how* to feel; what we see and feel teaches us what we believe and know. This is a critical point for consideration in assessing aesthetics, and one that Mirzoeff assigns as an antiaesthetics, following what Rancière calls, "an 'aesthetics' at the core of politics . . . as the system of a priori

[464] N. Mirzoeff, "Visualizing the Anthropocene," Public Culture 26, no. 2 73 (April 1, 2014): 214, doi:10.1215/08992363-2392039.

forms determining what presents itself to sense experience."[465] In what Mirzoeff addresses, and what I have been building in these various approaches to software, image, and skies, it becomes necessary to rethink the orders of aesthetic criteria that have traditionally been in place, and to put forward new ones. Mirzoeff encourages us to "to recognize how deeply embedded in our very sensorium and modern ways of seeing the Anthropocene-aesthetic-capitalist complex of modern visuality has become" and to also "recognize that this interface is neither singular nor self-contained: it moves in nonlinear and networked form."[466] Expanding what we count as the image also asks us to develop different modes of engaging visual information, to cultivate different our sensoriums and modern ways of seeing in new directions. Developing different modes of engagement means uncovering more knowledge we do not, or cannot, know. Working with different different knowledge resources holds a promise of doing science differerently. Doing science differently can shift the base of cultures.

Some Concluding Thoughts

This thesis makes at least two concrete contributions to knowledge. For one, this thesis contains within it two oral histories that have not yet been documented. These include the history of clipmapping that was directly told to me by Chris Tanner, and the story of the cloud-free Google Earth image. So much of the early development in computing and the commercial history of digital cultures have a relatively shallow history that has yet to be written. The histories that have been written of certain technologies and/or commercial cultures come with their own framings, and do not always extend to incorporate the personal experiences of

[465] Ibid.

[466] Mirzoeff, "Visualizing the Anthropocene," 214.

individual programmers.[467] There is part of me that regrets not making more space in the thesis to explore the links Chris Tanner's personal experiences at SGI—tired, overworked, the fact that he would eventually marry his co worker, as many of the young SGI employees did—and how these elements factor into process constructing the asynchronous multilevel texture mapping pipeline. I'm equally not sure that such a process would have been fruitful, either. However, in the spirit of the method that I am proposing here—of incorporating multiple and diverse entry points to a single problematic, of allowing it to pivot and open up or shut down various *worlds* of meaning—it seems an important activity to both document Tanner's oral history as well as do the work of linking this history up with my own visions, in the contemporaneous space of writing, the nauseating smells of sick and ashen faced fighter pilots that also play their role in the development of clipmapping. Similarly, the story of the cloud-free Google Earth image has not yet been published outside of this thesis work. While the process by which the cloud-free Google Earth image was generated is based on a procedure that was used in deforestation mapping and *these* results were published, the Google Earth Engine team never published any work from their cloud extraction project. This is a topic I have engaged, briefly, in recent conference papers and talks. In these talks I have suggested that one reason for why the Google Earth Engine team would publish their work on the deforestation maps, and not their cloud-extracted map, has clear overlap with the themes explored in this thesis—an inherent institutional and individual disbelief in

[467] Examples to the contrary might include Gabriella Coleman's anthropology of hackers and Matthew Fuller's recent work on geek culture. However it is worth nothing that these are accounts with a particular focus on contemporary and decentralized cultures organized around computing, which again, is distinct from the history I've provided here. There is also the work of Paul N. Edwards, for example, which is foundational to understanding the broader geopolitical context in which computational culture has been developed. Yet again, such a bird's-eye view onto this history doesn't do the same things as a history written through the perspectives of individuals, individual companies, etc. See: E. Gabriella Coleman, *Coding Freedom: The Ethics and Aesthetics of Hacking* (Princeton: Princeton University Press, 2013); Matthew Fuller, ed., *How to Be a Geek: Essays on the Culture of Software* (Cambridge, UK ; Malden, MA, USA: Polity, 2017); Edwards, *The Closed World.*

the capacities of aesthetics as data, a bias against the image. This is a potential area for further exploration.

A second contribution that this thesis puts forward is performed through the virtual ethnography of virtual modeling communities. Contextualizing the work of this distributed community of individuals, software, and techniques as epistemic work is a signficant step in doing the kinds of work with knowledge-making that I have here been advocating. It promotes an understanding of work with images as not exclusive of the capacity to be generative of data and evidence *while* also performing a stylistic function. Observing the way that the modeling communities have worked with images and considering these methods with respect to the broader histories of the image in the history of visualization in scientific computing has foregrounded how much aesthetics demands that labor be organized around it. This is particularly true for cultures that have a heavy computational component, though I can see it also being neatly extrapolated out as a paradigm for any kind of communal work that must consider material constraints. Above all, the modeling communities, understood as epistemic cultures puts a heavy underline on how pragmatics, negotiation, sociality, and perception intersect to promote important negotiations that begin with the capture of physical phenomena and are ushered through digital and social technologies used to produce evidence and, ultimately, knowledge.

Beyond this, this thesis has worked to make a case for understanding images and their uses in more expansive ways. Through the process of mapping the points of friction in working with aesthetics in epistemic cultures, it has become evident that there is a persistent misunderstanding of images. I have proposed that images are not contained to the static, formal, or constrained formats that they have been previously thought. Digital culture only further pushes this notion forward. The boundaries that mark *an* image, *the* image, or *any* image are fluid, contingent, and steeped in continual negotiation with the contexts of their creation and use. Digital procedures and software protocol mirror the ethical praxes of epistemic cultures throughout history in their pursuit of a particular kind of knowledge, at the same time that they lay bare the contradictions in working in this way. To this point, this thesis further contends that while the domains of the sciences and computational culture have central and defining codes of conduct and principles of engagement, what is overlooked are the codes and principles that so, too, are formative to the ontology of the image.

Art historians perhaps have a better grip on this in their steadfast commitment to reading images according to certain axioms: color, composition, format, historical context. Yet even these engagements with the image can fail to fully embrace the way such aesthetic axioms are also a form of logics, and logics that do not remain in tight constraint to the image and its exegesis in art history. In this the risk is that one does not see how such logics open up into the world, into *worlds*, in ways that have lasting and material impact. One might contend that what I am proposing is precisely the task assigned to visual cultures. I wouldn't oppose such a contention, but I would add to it this: Nicholas Mirzoeff has written of visual culture (in a work that is perhaps slightly outdated, but still telling) that the contemporary moment of visual culture is not debating what future it has but instead parsing the present in which it is performed. He writes, "There is a good agreement on these goals now, making it possible to at least envision the goal of a 'mutual and reciprocal relativization,' offering the chance of 'coming not only to "see" other groups, but also through a salutary estrangement, to see how [each] is itself seen.'"[468] While this certainly has relevance to my project and the conclusion I am putting forth here, I am also careful to note that my work is not solely about swinging about and around different perspectives. It is also about admitting that there are perspectives that do not fit within either side of any polarity; perspectives

[468] Nicholas Mirzoeff, ed., *The Visual Culture Reader*, 2. ed, repr (London: Routledge, 2010), 19.

that are new, unfamiliar, and, likely, inaccesible. I see this as taking place in the medial space between human, technical and aesthetic work, or alternatively as the loop between human and technical modes of perception become so in tuned with each other they abstract out further and further from their origin points.

Put succinctly, this thesis has mapped some ways in which the sciences are using images without understanding that aesthetics is a code in itself. In these practices scientists are attempting to make knowledge with images without understanding the fundamental ways that images represent themselves and how they have, more pressingly, been constructed to persuade us of what is true and false. Such an insight does not only bare upon the knowledges we have and hope to produce generally, but also impacts on specific disciplines in unique ways. For example, I recognize parts of my own work in that of Jennifer Gabrys when she writes of the *becoming environmental* of computation not as a moral trigger but as an invitation to more fully collide the chaos of the organic world into the rigidity of computation.[469] She and I are aligned in the belief that the invitation of new modes of working—and of these kinds of working—are born out of necessity. They acknowledge that very often images and computers are indistinguishable from each other, and both individually and in their compounding relation, they are susceptible to their contexts and conditions. They are, in short, more than the sum of their parts. It is the limits of computation in capturing and understanding natural phenomena that Gabrys rightly uses to call for new modes of planetary computation, and ones that require the absence of human intervention not in the service of some value of objectivity but so that we might remove ourselves as an obstacle in the way of "understanding … the real-time ecological relations that unfold."[470] While I may not be prepared to call for the absence of human intervention full stop at this

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[469] Jennifer Gabrys, *Program Earth: Environmental Sensing Technology and the Making of a Computational Planet*, Electronic Mediations 49 (Minneapolis: University of Minnesota Press, 2016).
[470] Gabrys, 268.

moment, I would certainly entertain it as an interim technique in doing what I see as the more urgent and long-term work of decentering the human from understanding, and the full spectrum of practices that facilitate this and *new*, potential forms of knowledge production. On this note, this thesis closes with a call for the recognition of what new *worlds* we dare to enter when we allow for more organic modes of relating to emerge between aesthetics, epistemology, and a diversity of practices.

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