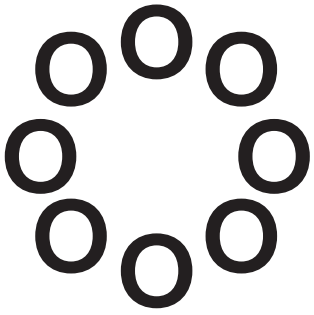
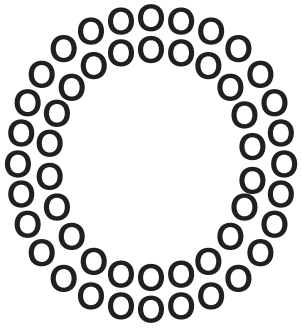
the cosmic Z



scale, knowledge, and mediation



zachary horton

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For those who call distant regions
of the scalar spectrum home

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1

scale theory

THE RABBIT HOLE

Curious Alice falls down a hole. Hurled into a radically unfamiliar world, she must quickly adapt to its alien logic. Ingesting certain substances, she discovers, causes her to change size. This revelation provides both a challenge and an opportunity. Each shift of scale alters her perspective on and relationship to Wonderland, complicating her quest to map its terrain and logics. Yet these very shifts in perspective expand her possibilities for apprehending and interacting with the environment's strange features.

The resourceful child passes briskly through three stages of scalar awareness. In the first, she finds herself inexplicably the wrong size for the task at hand. Her scale has become a handicap: "when she got to the door, she found she had forgotten the little golden key, and when she went back to the table for it, she found she could not possibly reach it."[1] The door is a threshold that admits only those who have mastered the antechamber's multiscalar mechanism. Frame, door, lock, table, key—each belongs to a different scale. How to unite them on a single plane?

In the second stage of scalar awareness, Alice learns through experi-

mentation that she can access other scales—eating cakes and drinking potions, she grows and shrinks, shifting her scalar relationship with her environment—but she cannot yet control her metamorphoses. In the third stage, after experimenting with the Caterpillar's mushroom, she learns to discipline her scale jumping, to contain it within narrow bounds, to tame the metamorphoses and deploy them strategically. It is in this third stage that Alice, pockets provisioned with fungi, finally unlocks the door to the garden and there encounters and nearly overcomes the pack of sentient playing cards that enforce Wonderland's laws. Through it all, Alice herself never alters more than her relative size. Her fundamental identity as an educated, upper-class Englishwoman-in-training remains invariant. She uses her abilities to master the logics of Wonderland but can't seem to understand why her anthropocentric assumptions continually upset her nonhuman interlocutors. "I wish the creatures wouldn't be so easily offended!" she thinks to herself, placing the blame squarely on their shoulders.[2] She has learned, that is, to *access* scalar alterity, but not to absorb its dynamics, to become herself other. *Alice in Wonderland* is a fable about scalar alterity, about how one scale comes to dominate another.

The Cosmic Zoom argues that as a species we are in a situation analogous to that of Alice. We have, like her, passed through three stages, from *awareness* of scalar alterity to blundering *encounter* to disciplined *access*. Like Alice, we injure the other beings we encounter through our anthropocentric attempts to force them to conform to our rules—rules developed by us, for us, at our native scale. We have extended the scales of our knowledge by disciplining it and are continually prying open new scales and forcing them to conform to the logics of our institutions and ideologies. As we unlock the doors of Wonderland, each leading to a new scalar milieu, we are apt to play out our story according to the well-worn narrative logics of colonization and extraction that Western culture has long rehearsed in its media, even knowing that on this path only environmental apocalypse awaits.

This is a book about scale. Its central purpose is to outline a genealogy of the concept and to build a critical transdisciplinary vocabulary and framework that will enable a larger dialogue. Such dialogue has until now progressed only in fits and starts, hampered by incommensurate theoretical frameworks and practical methodologies in different domains of knowledge. The most common way to approach scale in the humanities, for instance, is to assume a scalar axis, from the small to the large, and track how an artwork, text, technology, event, or discourse has engaged or produced a larger (or occasionally, smaller) scale than previously: a larger geographical milieu, a wider social scope, a greater word count, a national or imperial

or local sensibility, a greater audience, an interest in bacteriological and viral domains, and so on. This is a scholarship of scalar *access*. I want to differentiate that approach to scale from the central concerns of the book you are reading.

My goal in this volume is not to rehearse the scalar march of human cultural production to ever expanded scales along a small-large axis but to engage an entirely different axis: one of scalar alterity, which runs from the "pole" of *scalar difference* to that of *scalar collapse*, or the speculative conjoining of different scales within a single medium, eliding the qualitative differences between them. To investigate not individual scales but scalar dynamics themselves, I propose that we dig deeper in order to understand how and in what way our received size-domain axis emerges and what cultural work it performs.

While this study does engage questions of scalar access, its operative question is not *what* is accessed (a social group, a class, a city, a region, an empire, a nation, the planet, a genome, the cosmos) but rather *how* access is mediated in ways that engage or occlude scalar difference. The genealogy of scale that emerges is historically discontinuous and disarticulated from progressive expansions of access, focused rather on moments in which scalar mediation itself innovates techniques that frame our scalar access in new ways, stabilizing the protocols of such access either to enable the exploitation of other scales or to open up new forms of encounter. The central focus of this book is not, that is, the human experience of scale effects but, rather, the radically nonhuman dynamics and potentials of scale, as a concept and as a form of mediation. Engaging scalar alterity, we will see, implies a dismantling of the edifices of humanism itself, or at least the specialized mode that I call *pan-scalar humanism*.

Pan-scalar humanism is a tradition that tames the alterity of different scales by relativizing it, binding unfamiliar scales to the familiar ones of the human. It arose out of an Enlightenment notion of the absolute value, autonomy, and centrality of the human subject that, *a priori*, colors all potential trans-scalar encounters. Pan-scalar humanism frames all trans-scalar encounters as either extensions of the human into analogous scales (collapsing scalar difference) or as the beneficent extension of the human lifeworld into frontier scales. The human thus becomes a scalar technique of assimilation and colonization applicable in theory to all scales of reality. At the same time, pan-scalar humanism mobilizes radically disparate scales to buttress the human subject. *Alice in Wonderland* satirizes pan-scalar humanism without yet being able to articulate an alternative scalar economy or politics.

In order to examine the relationship between the human, mediation, and scale, I have chosen to focus on the "cosmic zoom," a self-consciously medial project that attempts to characterize the scalar articulations of the cosmos by visualizing, from a single perspective, a spectrum of scales from the largest to the smallest known.[3] The cosmic zoom has taken textual, imagistic, motion picture, and new media forms. The most famous instantiation is *Powers of Ten*, a 1977 film by designers Ray and Charles Eames that begins with two picnickers in a field, zooms out to encompass the entire universe, then zooms in again until the nucleus of a single carbon atom fills the frame. I discuss this film at length in chapter 4, but as we shall see in the antecedent chapters, significant examples of the cosmic zoom preceded it, beginning with the texts discussed in this chapter and emerging in fully modern form in the 1950s with *Cosmic View*, an influential book by a radical Dutch educator.

Using Michel Foucault's term for the unacknowledged framework that grounds the "conditions of possibility" of knowledge itself,[4] we might call the cosmic zoom the perfect encapsulation of a scalar *épistémè*, a set of scales that have been stabilized as legible environments and therefore objects of knowledge. The politics of the cosmic zoom are the politics of a culture's engagement with scale, dredged up from their subterranean depths and gilded for human consumption. Individual instantiations of the cosmic zoom can be imaginative or conservative, radical or reactionary. Developing a critical vocabulary and analytic framework for the cosmic zoom, then, is tantamount to developing a theory of scale itself.

The theory of scale that I develop in this book has, at its core, a simple premise: scale is a primary form of difference. It is primary in the sense that it is present on the scene and does its work before stable identities (subjects or objects) have formed along its spectrum. But it is also caught up in the operations of thought as entities begin to navigate their environments, stabilizing them into scaled milieus. Scale, as a series of relational dynamics, is thus a circuit: an irruption of the new on one side, and its ordering for others on the obverse. These dual scalar processes must be modulated in order to form a legible, navigable plane. Thus media, or rather mediation (as process), are fundamental to the operations of this scalar circuit. How scale mediates between an observing entity and the details of its environment is just as important, in what follows, as how conceptual, narrative, and technological mediation produce and stabilize individual scales.

While often conflated with size, scale has many facets and is difficult to define. It names a set of relations: external relations between two or more milieus, and internal relations between entities within a single milieu. Scale

is both a stabilizing process by which particular milieus (scales) emerge as defined domains of (inter)action and the differential potentials that arise between such stabilized milieus. Scale thus implies both a politics and an environment.

HUMANITY IN WONDERLAND

The world has changed. It may be difficult to pinpoint the exact moment we fell down the rabbit hole, but we know that we are now in Wonderland. Scales that we, as humans, had taken for granted are suddenly front and center, blocking the path both forward and back. And when we look around, everything seems different, as if the borders between things have slipped out of focus. We may adjust our glasses and wipe our screens, but it isn't entirely clear whether it is the "human" or the "environment" that has changed scale. There are moments, such as during the COVID-19 pandemic, that crystallize Wonderland's weirdly scrambled scales: global ligaments become viral infrastructure, while unmediated contact between human beings comes to seem grotesquely inhuman. These temporary crystallizations, so easily narrativized as anomalies, actually reveal long-term, profound scalar shifts in our technocultural milieus. The old-fashioned, comforting human scale has crumbled, and our species now stands poised between global climate change and big data. The latter has recomposed the human along new scalar fault lines, eliding the meso-scale individual as such while producing on-the-fly collectives from micro and macro attributes that humans can experience only through highly mediated means. Meanwhile, we are staring into the abyss of the most significant threat that the human and many nonhuman inhabitants of Earth have faced during our tenure as the planet's keystone species: global climate change.

Big data and anthropogenic climate change are the two sides of Wonderland, united through and as new scalar dynamics. Human actions that we conceive of as individual choices, governmental policies promoting national competitiveness and self-regulation, and trillions of economic exchanges predicated upon a rationalist, individualist logic no longer seem natural when viewed in the aggregate, at larger scales. The cumulative effect of billions of such "everyday" exchanges, climate change is a prime example of *scalar magic*: when the attention of any observer is fixed at one scale only, scaling phenomena will seem to vanish into thin air—when all they have really done is shift to other scales. This describes a scalar logic that is at once materially causal, ethically laden, and politically tactical.

What is scale? We could do worse than to begin with these three dimen-

sions: Scale is, first, an *ontological determinant* in that it dictates how certain physical states become other physical states. Growth, depletion, division, aggregation—these are shifts between scales, not merely metamorphoses of individual forms. Scale is, second, an *ethical ground* that binds individuals, groups, and territories into interconnected milieus of interdependence and responsibility. And scale is, third, a set of *political tactics* for aggregating and disaggregating assemblages. In this final capacity, contemporary scalar politics invests energy into singularities (individual heroes and villains, monuments, memes) and thus away from systems, while displacing undesirable consequences to nonvisible scales: the vast ocean, the atmosphere, the nano realm, the far future—comfortingly distant points on the scalar spectrum. But these scalar deferrals always return eventually. Rob Nixon refers to damaging processes that have been kept out of sight by assigning them to other scales as "slow violence." The damage is done to environments, humans, and communities, but it is "of indifferent interest to the sensation-driven technologies of our image-world," which require that events be concentrated in space and time to become visible as such.[5] Slow violence is not accidental; it is the result of weaponized scalar difference. How trans-scalar flows are managed and put to work, and what they produce for whom, are questions any contemporary analytic of power must ask.

A newfound scale mania has infected even those not professionally interested in questions of metamorphosis or power. Everyone seems to sense that they are in Wonderland, a new trans-scalar environment. Scale is on everyone's lips. Films that feature shrinking and expanding humans, such as Alexander Payne's *Downsizing* (2017) and Marvel's *Ant-Man* franchise, are enjoying a resurgence in popularity.[6] In the past decade, the long-standing preoccupation with scale in the natural sciences has diffused into many fields within the humanities and social sciences, concomitant with a surge of interest in the subject in popular science literature, including recent coffee-table volumes such as Hooft and Vandoren's *Time in Powers of Ten* and Caleb Scharf's *The Zoomable Universe*. We frequently speak of the scale of big data, of climate disasters, of drought, of pandemic, of rainforest destruction, of radioactive contamination, of airborne and waterborne pollution, of economic recession, of the mass displacements of refugees, of arctic and antarctic ice sheet depletion, of the sixth mass extinction. These otherwise disparate discourses share a common thread of scalar enthusiasm and scalar dread. Both are reflexive: their common narrative trope is the sounding of the scale of the human. Efforts to accomplish this have tended to posit a "species being," characterizing the human at a new temporal and spatial scale—the global, the planetary, or the geological. This

approach provides some critical distance from the human individual as the alpha and omega of meaning and value; it is nonetheless subject to the same panoply of essentialisms, apologetics, and homogenizations. As Derek Woods asks, "Is the concept of the human scalable? To answer this question, we need scale critique to grasp what 'human' means when it names the subject of the Anthropocene."[7] My approach in this book is to take the human as a multiscalar flux inextricably caught up in a flowing network of scales, sometimes as a fragment in larger bodies and sometimes as an environment for smaller ones. The human is scale-unstable, even as human media infrastructures and disciplinary knowledge practices seek to stabilize particular scales.

One of the consequences of taking up the question of "the human" from the perspective of scale is that it ceases to function as a boundary or membrane (conceptual or corporeal) between an inside and an outside. This is partly because the human is "trans-corporeal" in Stacy Alaimo's sense of uncontainably embodied and "always inter-meshed with the more-than-human world."[8] But further, human knowledge production has always, first and foremost, proceeded from a taming of scale. Containing scalar difference within stabilized domains and organizing those domains into a spatially and conceptually continuous plane anchored by the unmarked scale of the human is central to the project of humanism. Indeed, these mediations inaugurate the emergence of a scale-stable human subject in the first place. To reverse our analytical priority, to begin with scale itself rather than to enumerate it as an attribute of an already unified subject or object, profoundly disturbs this scalar pact of humanist thought. It may well be that humanism is ill-suited as a response to the challenges of Wonderland. At the very least we will need to change our default question: instead of asking which scales are occupied or accessed by a conceptually preconstituted human, we'll need to ask how the human emerges—along with many other objects and subjects—out of the dynamics of scale.

Welcome to Wonderland's feedback loop: the human emerges from fundamental scalar differentiation (explored in detail in chapter 5), stabilizes certain scales through discursive and medial infrastructures, and then harnesses them for further production. The result is a kind of "scalar accumulation," strata upon strata of produced objects and subjects organized and sorted according to their naturalized scales. Whether we analyze this in the form of capitalism, climate change, or big data, the result is the same: ever increasing scales of accumulation take the form of a widening milieu of the human, organized concentrically around our native scale—that is, the scale of our immediate sensory field. In economic terms, this means continually

expanding markets into new regions and temporalities, what David Harvey refers to as "spatio-temporal fixes" for capital's overaccumulation.[9] Now, however, this expansion is not merely geographical and cultural, but also trans-scalar: neoliberal capital is increasingly exploiting new scalar frontiers, from the solar system to future temporalities to the fabled "radical abundance" of the nanoscale.[10]

This dynamic is not, of course, sustainable: scalar alterity is not a matter of linear differentials (more or less of something, such as capital) but rather of radical discontinuities in the scalar spectrum. Any system predicated upon the continual appropriation and stabilization of new scales in the service of a single master scale (as a dominant and homogenizing logic) is bound to run up against its absolute limits relatively quickly, whether those limits take the form of a financial crash, a global pandemic, a massive loss of biodiversity, the tipping point of global climate dynamics, technological singularity, or the structural collapse of human civilization.

It may seem as though the very forays into other scales that brought us to Wonderland will necessarily prove our undoing. Yet this is not merely a question of having opened Pandora's box. Our encounters with other scales may be dangerous but also open up the possibility of our being remade *at* other scales. We believe we construct scale, but "our" scalar mediation confronts us with entities as terrifying and wondrous as supernovas and nuclear fission, sea-level rise and computer viruses, galactic spirals and quantum uncertainty. New forms of subjectivity are continually produced by these trans-scalar encounters. By "trans-scalar encounters" I mean the catalyzing events that take place when an observer adapted to a milieu defined by a particular scale of typical events encounters structures and processes at a different scale. The trans-scalar encounter is an encounter with difference and can therefore be either generative of further differentiation or a form of colonial capture, the imprinting of the dynamics of a socially engineered human scale onto another. Unfortunately, most of this occurs without any self-reflexive register in the realm of thought itself. Like Alice, we blunder into trans-scalar encounter without even knowing the local customs.

If the human is not the protagonist of the trans-scalar encounter, it becomes one subjectivizing effect among others. At issue here is how one region of the scalar spectrum comes to encounter another, discontinuous region. Understanding scale as a processual differentiation through encounter helps to challenge the unidirectional model of observer and observed. All of existence involves continuous trans-scalar encounter, but the discontinuity inherent in the process is reciprocal: each scale is stabilized only through

encounter, while encounters always begin from a particular scale. There is no difference between the observer and the observed—perspectives can emerge from any point on the scalar spectrum, along with subjectivities to inhabit them. Media theory furnishes us with important tools to help us theorize this destabilization of the relationship between observer and observed, which I address most directly in chapters 3 and 4 in relation to Ray and Charles Eames's cosmic-zoom films.

These, then, are the problems of Wonderland: How to think larger and smaller than the human scale? How to think with the nonhuman? How to incorporate a multiscalar form of thought without homogenizing detail and difference? My goal is to frame these problems and suggest the beginnings of solutions through an analysis of Wonderland's most scale-reflexive medial form: the cosmic zoom.

THE COSMIC ZOOM

This book develops a theory of scale as primary difference at the same time that it works to grow new connective tissues between our understandings of mediation, scale, and subjectivity. It is a necessarily experimental project, but it also tells a vital story. The story of the cosmic zoom is about the past seventy years of trans-scalar encounter, stretching from the systematizing and disciplining of scientific knowledge to the sublime encounter of ever-smaller and ever-larger forms of radical alterity. We have encountered new scales even as we have solidified our thinking about scale itself. We have encountered the earth as a pale blue dot and discovered that fundamental particles also behave as waves—and do not obey the "standard" laws of physics. We have explored deep space and produced silicon-based ultra-miniaturized gates that have enabled a computational revolution, in turn enabling us to study and characterize a global climate on the edge of a precipitous tipping point. We have experienced the emergence of social media and its datafied and surveilled digital environments. These twentieth- and twenty-first-century trans-scalar encounters constitute an opening up of the milieu of the human so disorienting and awe-inspiring that it might be considered a tear in the space-time continuum, now understood as a scalar spectrum. The cosmic zoom, as a heterogeneous set of medial compositions and as a conditioning of the scalar potentials of the cosmos, has served as a response to this unprecedented situation. It is not, however, entirely new as a conceptual or narrative framework.

In Cicero's "The Dream of Scipio" (*Somnium Scipionis*), the titular character is visited in a dream by his famous grandfather (by adoption), Scipio

Africanus, who takes him on a tour of the cosmos. He first finds himself floating far above the city of Carthage, then ascends higher, until the earth has shrunk to a small globe. His grandfather shows him nine successive spheres, each enclosing the last, which together make up the sum of the universe. Scipio is amazed: "In size the celestial bodies far surpassed the earth. Indeed, the latter was so insignificant by comparison that I was disgusted with our empire, which is but a speck on the surface of the globe."[11]

Despite his awakening sense of scale, the younger Scipio finds, as the cosmic tour continues, that he cannot tear his eyes away from his home planet. His grandfather notices and rebukes his monoscalar fixation: "You are still lost, I see, in the contemplation of that comfortable home of man. If the earth appears to you small, as it really is, keep your gaze riveted upon this Heaven, and care not a straw for earthly things."[12] Scipio Africanus's scalar lesson is simple: Carthage, Rome, and even the entire Roman empire are so diminutive when arrayed against the scale of the universe that nothing of significance has or can be achieved there. Still, however, his grandson experiences this scalar spectrum as radial, anchored, centered upon the earth—which even in this vision is located at the center of the universe. These are the basic ingredients of the cosmic zoom.

Cicero's text emphasizes alterity: the celestial spheres are fundamentally different from the earth, up to and including the "colossal revolutions" that produce "this music of the spheres," so overpowering that "no human ear can endure it."[13] The cosmos is fundamentally alien and incomprehensible to human senses and concepts, attuned as the latter are to a single conditioning scale. Exhorted by his guide to radically alter his scalar perspective, to look outward and experience difference, Scipio cannot abandon his fixation on the point of his departure. To remain fixed upon Earth is, as Scipio Africanus makes clear, to remain fixated upon the human, upon one's own subjectivity, however thickly contextualized spatially and temporally. Scipio's fate is to obtain a view from the cosmos, a view from everywhere, but to remain unchanged, to remain human, all too human. This didactic fable presents us with the roughest diagram of the cosmic zoom. The potential for difference, the trans-scalar encounter, and the reflexive mediation of scale are ultimately collapsed by human subjectivity that seems immune to alterity.

On its surface, the cosmic zoom is simple: it depicts a movement from the smallest known scale of potential experience to the largest (the universe as a whole). The examples analyzed in depth in this book begin with Kees Boeke's book *Cosmic View*, from 1957, and continue through the groundbreaking and extremely influential work of Ray and Charles Eames to cur-

rent cinematic and database-driven media. The cosmic zoom is so ubiquitous in media from the second half of the twentieth century to the present that it forms something of a master scalar trope. Cosmic-zoom media have, in large part, *taught us how to think about scale*. Incidentally, they have also taught us how to think about media, and even thinking itself. The cosmic zoom is a sandbox for scalar thinking, as will become clear when we view its constitutive instantiations through a media-archaeological lens. The cosmic zoom is a reflexive form, with mediation and scale as its entwined subjects. As I explore throughout this book, the cosmic zoom is more than a visual trope or narrative technique: it is a scalar ideology, a framework for ordering the world in relation to the human.

Throughout *The Cosmic Zoom* I treat individual instantiations of the cosmic zoom as both discursive and material objects. In most cases I explore the processes by which these zooms were constructed as jointly material and conceptual projects. This deconstruction demonstrates both how scales are stabilized in human knowledge production and how scale disrupts our knowledge practices. But which is true? Is scale a physical property independent of subjective experience, or is it entirely arbitrary, a set of conventions constructed by discursive practices? In my view, *both* of these propositions are correct in all but their logical exclusion of each other. Scale marks both ontological difference that is independent of experience and arbitrary domains generated by experiential accounts. I refer to this as the *scalar paradox*, and it will come up again and again in the pages of this book.

Rather than collapse the scalar paradox, I believe that scale theory demands we hold it open, in productive tension. It is vitally important to understand scale as a primary ontological determinant of form and function, especially in the face of persistent campaigns in nearly every discipline toward scalar collapse, or the elision of difference between two or more scales when they are placed in the same medial frame.[14] Scalar collapse is the result of epistemological and medial practices that unwittingly or deliberately normalize one scale to the dynamics, features, and cultural status of another. Collapsing one scale into another is a profitable and productive enterprise in many fields, and is at this point demanded by global capital as one of its primary engines of extraction and circulation. In the realm of thought, scalar collapse takes the form of a naivety or ignorance of scalar mediation, that is, of the ways in which scales are defined and stabilized out of manifold material existence, on one hand, and the ways in which matter differentiates itself into functionally unique entities at different scales, on the other.

While certain cosmic zooms have been analyzed in passing by many scholars, particularly the most famous and influential instantiation, the 1977 Eames film *Powers of Ten*, the cosmic zoom has never been properly studied as a transmedia project, and, surprisingly, no scholar seems ever to have publicly asked the question in every child's head after a first viewing: "How did they make that?" That the cosmic zoom has never been subjected to an analysis of its own construction, but only analyses of its reception and post facto critiques of its apparent ideology, is a symptom of the biases that hobble past attempts at scale theory in the social sciences and humanities. In this book, I employ a media-archaeological approach to the cosmic zoom in an attempt to uncover the methods, assumptions, and behind-the-scenes struggles that attended the construction of these iconic media works. The purpose is not simply historical curiosity or trivia but rather a far deeper engagement with the scalar paradox itself. As Siegfried Zielinski argues with respect to media archaeology, "The goal is to uncover dynamic moments in the media-archaeological record that abound and revel in heterogeneity and, in this way, to enter into a relationship of tension with various present-day moments, relativize them, and render them more decisive."[15] Every cosmic-zoom project is a battleground of conflicting knowledge practices, the strategic deployment of medial technologies, and an engagement with both sides of the scalar paradox. Excavating the ways that cosmic zooms have been made will therefore afford us the richest possible engagement with the fundamental dynamics of scale.

Before we embark on this fantastic voyage, however, we have to trace the multiple meanings of "scale."

DEFINING SCALE: FOUR DISCIPLINARY MODELS

When we talk about scale, we rely upon long discursive traditions and their attendant assumptions, which in most cases remain tacit. These keep us from fully recognizing Wonderland. Every discipline, academic or lay, has its own understanding of scale. Is scale a core feature of the universe or a way for thought to organize and *represent* the universe? This is the first demarcation line of disciplinary territoriality. Again, in this book I take the view that scale is both: the universe is scaled and scaling in a fundamental way that is independent of human interpretation, but is at the same time stabilized into discrete scales through human knowledge practices. This leads to the scalar paradox of knowledge production: disciplines divide the world into scales, carving up space and time into discrete, simplified compartments that can be studied and manipulated, yet the knowledge they

produce cannot help but shatter these scalar-disciplinary boxes. Knowledge produces discrete scales, but knowledge production itself relies upon the dynamics of scale to resolve features of the world. In 1898 Marie Curie discovers radium, an atomic element that appears almost magical in its scalar alterity; sixty-three years later radioactive elements are solidly in the realm of science when technicians at the US Army's SL-1 nuclear reactor, despite following strict protocols, accidentally trigger the first deadly nuclear meltdown. Every circumscription of scale is a foray into a world constantly creating and recreating itself through scalar difference. Every engagement with this radical alterity is an irruption into thought, a reordering of our milieus. To remain disciplined, human knowledge producers isolate and contain those irruptions, relegating them to their proper scales, and continue their work. The meltdowns, however, continue: scalar alterity can never remain fully contained.

Put another way, every discipline has its own way of taming scale. The result is that when we communicate *across* disciplines about scale, our dialogue is confused, piecemeal, and contradictory. When we deploy the concept of *scale*, are we referring to units of measurement, operations of shrinking and enlargement, relative ratios between representational surfaces, absolute size domains, or relationships of force? Do we really know what others, in their own situated knowledge practices, mean by the term? Or for that matter, what *we* mean? Each discipline has its tacit definitions, commitments, tools, and sacred scalar truths. The condition signaled by the concept of the Anthropocene is one in which we are confronted with the dire implications of scale effects at the historical moment of minimum discursive overlap between scale-mediating disciplines. The realization that we should be awakening to is that we lack a critical and shared vocabulary of scale.

This book sets out to rectify this problem. Rather than assuming an uncritical and disciplinary model of scale, rather than exploring scalar dynamics as an important but vague set of implications for some other object of study with which we are all more comfortable, these pages build a tentative transdisciplinary theory and vocabulary of scale itself. The broad scope of this introductory chapter is a response to the challenge implicit in this project: if we are not to rely upon received notions of scale, if we are truly to sound its depths, we must dispense with our preconceptions and problematize the concept itself.

Scale, like sex or identity, functions as an interfacial concept, acting as both an invitation to open-ended multiplicity of encounter and a ready-made, "obvious," even trivial, tool available in our everyday negotiations

with the world. This trivialization, this refinement and reduction of the tool of scale, is accomplished by disciplining knowledge production to obey precise boundaries and fit into carefully constructed categories. To problematize scale, to recover its multiplicitous meanings and potentials, we will need to defamiliarize it, to dig under and beyond its trivial definition and ask how it *works*. This requires an explicit engagement with the disciplinary structures that have cordoned off particular aspects of the concept, honing them for ready use in their own domains of knowledge production.[16]

In the remainder of this section I briefly trace four conceptualizations of scale that I feel have the greatest currency in our culture at large, as well as in academic discourse. Most deployments of the scale concept are either straight borrowings of one of these formations or a hybrid of two or more of them. The first is *scale as relational ratio*, derived from cartography. The second is *scale as absolute size domain*, derived from physics. The third is *scale as compositional structure of parts to whole*. This is the dominant understanding of scale in both engineering and biology. Finally, in mathematics scale is generally conceived of as a *homologous scaling operation* by which a figure or pattern is altered in magnitude while holding its internal relationships invariant. Let us explore these often contradictory conceptions of scale one at a time, noting both their critical affordances and their limitations for use outside of their progenitor disciplines.

Scale as relational ratio. Mapping the spatial extension of one's environment is no doubt one of the most ancient human deployments of scale. In its two-dimensional, spatialized, disciplined form—cartography—scale functions as a guarantor of the relation between the map and its territory of interest. Contemporary cartographers refer to scale as the "denominator of representative fraction."[17] Let us parse out this terse definition. Scale is a ratio between distance on the map's plane and distance on the plane of the object of interest (the object being a physical area that has been surveyed in some fashion). The object is "full scale," so its scale is absolute, in whatever unit it is being measured—a numerator of 1. The map, generally smaller than the object, is only fractionally as large. If a map's scale is 4:1, the denominator is 4 and the map is one-quarter the size of its described object. In this case, the given distance between any two points on the map is four times smaller than the distance between the two points of the physical landscape represented by those points. As the above definition indicates, the map's function is assumed by cartographers to be representational; that is, the distances and features signified on the map's surface "represent" corresponding features on the surface of the landscape. The map's scale, along

with "contour interval" for topographic maps, determines (fixes) this representational relationship.[18]

Both scale and contour interval are measures of potential detail. Scale, as the ratio between two surfaces, determines how much space can be mapped onto the much smaller cartographic surface. The larger the ratio, the more detail is compressed into a given area of the map; in other words, the more area the map is said to represent. Cartographic scale thus determines both the resolution of the map (the fineness of detail that it can represent) and, in relation to the represented area, the size of the map itself. Contour interval, by contrast, is not expressed as a fraction but as a single value (the difference in elevation between adjacent contour lines). As such, contour interval directly expresses resolution, while scale corresponds to both resolution and map size. Because maps are fundamentally limited in the amount of detail they can reproduce, *scale expresses this tradeoff between size and resolving power*. "There is no map that will fulfill every need."[19] Cartographers, like ecologists, have to choose the "best scale" for their object of interest. While map users often forget about these tradeoffs, except when we can't find what we want,[20] we have nevertheless inherited something of the representational and fractional framework of cartography when we think of scale. In chapter 2, I argue that cartographic scale can be reconceived in nonrepresentational terms as a direct negotiation of ecological detail.

Scale as absolute size domain. Physicists tend to approach scale somewhat differently. In their discipline, scale is usually considered neither representational nor planar (projected onto a flat surface). Rather, it signifies a defined size domain. Planets occupy a certain scale, as do bacteria, electrons, and humans. As in cartography, physicists thus see scales as territories of a sort, only these are more often virtual, generic territories rather than singular ones. Each scale is a conventionally derived slice of reality. Such delineations make what I call a *resolving cut* in order to isolate features of the physical universe that can then be described empirically or theoretically. The concept borrows from Karen Barad's notion of the "agential cut" that, in quantum mechanics, differentiates one region of matter from another, making experience and knowledge possible.[21] To build on Barad's concept, a resolving cut, as a theoretical and as a practical matter, stabilizes a portion of the scalar spectrum, isolating a particular scale. It does so through a medial apparatus that determines what features become legible or readable for the assemblage making the cut. Like Barad's agential cut, a resolving cut is a differentiation of time and space from within; in this

case, it constructs a relationship between two distinct regions of the scalar spectrum. Any resolving cut is in one sense arbitrary, but in resolving the difference between the surface of observation and the surface upon which trans-scalar details appear, it enables fundamental ontological difference to emerge. The production of scales, for humans in particular, is thus inseparable from the differential functioning of disciplines, fields, and subfields. These knowledge domains come into focus through the resolving of specific material scales, whatever they may be. I explore these dynamics in further detail in chapters 4 and 5.

Scales cannot, of course, be usefully defined by specific Cartesian coordinates, as they must function *generically*. They are size domains, not determinate spaces. This is why the difference between size and scale—two concepts that are commonly conflated—is of great importance. The nanoscale can be as small as the head of a pin or as large as a galaxy; its spatial extension is arbitrary. What marks it as the nanoscale is the typical or characteristic size domain of its entities and dynamics. The nanoscale is the domain in which features measured in nanometers can be resolved as individual entities. Size is absolute and subject to direct measurement by the physicist. Scale, on the other hand, is relative: it requires that a relationship be stabilized between at least two entities. Scale already, then, smuggles in this process of stabilization itself. Scale is reflexive, size is not.

The physical notion of scale thus implicitly incorporates a notion of field of view, a perspectival phenomenon: what sort of entities are resolvable in a field of view only a few tens or hundreds of nanometers wide? In this sense, scale, unlike size, always exceeds the disciplinary apparatus that frames it; we stabilize scales, but we never know what we will find as a result of the encounters we thereby initiate. Scales are speculative: they define a field of view in which entities then become resolvable, often through technological mediation, as when the Dutch inventors of the microscope peered through it and began to describe the entities it made visible, giving birth to a new discipline and a new, stabilized scale. Of course, this scale existed in more fluid form prior to its disciplining in science, as a speculative milieu of germ cells, homunculi, and so on. As we shall see in chapters 2, 5, and 6, scales can be virtual ecologies even subsequent to their disciplinarization, when speculative media conjoin objects that occupy different spaces but similar scales.

In its production of new scales, physics proffers not only new entities, but also new insights into differentiation itself. Difference exists not only between an entity and its representation, or laterally between entities, but also along a scalar axis. To take a prosaic example, nonphysicists com-

monly assume that gold is straightforwardly yellow: no matter how tiny or how large the pile of gold, it will gleam with that hue. But at the nanoscale, gold can be orange, purple, red, or green.[22] Physics teaches us that yellow is a *macro* quality of gold, not a scale-invariant quality. The very same coordinates in space, resolved by an atomic force microscope, an electron microscope, an optical microscope, the naked human eye, and, at a distance of some light years, the Hubble Space Telescope, would be revealed to contain different entities, each unique in its characteristics, as well as the dynamics that form between them, the forces that affect them, and their capacities for structuration, deformation, complexification, and differentiation. These are scalar strata that occupy the same space but not the same scale, and can only be revealed through one or more forms of mediation. As I argue in chapter 5, such engagements necessitate a new understanding of the relation between scale and difference.

Despite the fecund results of physics' scalar differentiations, however, a countervailing tendency within the discipline has sought to contain such eruptions of difference through the positing of a homogeneous and holistic universal model governed by a single logic. The most notorious example of such an end run around scale within the discipline of physics is no doubt Isaac Newton's universal laws of motion and gravitation, commonly referred to collectively as "the clockwork universe." This conception of a deterministic universe requires and thus suggests—without evidence—that scalar difference is essentially illusory, that all entities at all scales behave in exactly the same way. This is the meaning of the likely apocryphal apple story: Newton sees an apple fall and "realizes" that apples and planets are fundamentally alike. While Newton's metaphysics (and thereby his physics) were determined by his particular theological predilections, as I briefly consider in chapter 5, many physicists have similarly labored to promote a model of the physical universe that would belie its apparent difference—as revealed through empirical observation—and repackage it as a kind of scalar layer cake in which each scale contains different entities, but all are unified and homogenized within the cake form.[23] This quest has consumed many physicists, from Albert Einstein, who defiantly declared in the face of quantum indeterminacy that "*He* [God] is not playing at dice," to David Bohm, who acknowledges the discontinuities of the quantum but posits a mysterious and metaphysical "implicate order" underlying them, to Stephen Hawking, whose mythical "complete unified theory" would homogenize the dynamics of all scales into "a complete description of the universe we live in."[24] These individual physicists, as well as many others, have embarked on quests to unveil scalar difference as an illusion or matter of

perspective rather than an ontological fact. Einstein's concept of relativity, for instance, seeks to remove time as an ontological determinant, collapsing it into space (technically "space-time"). As we shall explore in chapter 3, when the Eames Office set out to present a unified medial instantiation of a scale-free universe, they invoked Einstein to legitimate the frictionless space of perspectival mastery they were in the process of constructing. The projects of Newton, Einstein, Bohm, and Hawking, however influential, have all conspicuously failed to account for the totality of the scalar spectrum, each demonstrably breaking down at certain scales. The universe seems to be fundamentally scale-discontinuous.

Scale as compositional structure. In the biological sciences, as well as in engineering, the central scalar problem is that of function. How do organisms, bridges, and skyscrapers function differently as their size increases or decreases? Here, the effects of scale on an organism's or engineered structure's ability to sustain its form and successfully interact with its environment is one of the central objects of knowledge production. In biology, this problem is called "allometry," and describes the limitations imposed by scale on relations between an organism's whole (body) and its parts (organs). While these relations can be described by ratios between organs, skeletal structures, and so on, the ratios are not representational (as in cartography) and change as the absolute size of an organism changes. The central insight here is that organisms do not linearly scale: any change in size requires a redistribution of organs and their functions—in other words, a redesign of the organism. As biologist D'Arcy Thompson expresses it in his classic tome *On Growth and Form*, "There is an essential difference in kind between the phenomena of form in the larger and the smaller organisms."[25] This is due to the relative efficacy of forces at different scales (physics) as well as problematics of surface area versus volume, which affect how oxygen and nutrients are diffused through tissues. As biologist John Tyler Bonner notes, "Size is volume, yet life's activities require the appropriate surface to go with the volume and the result will be different shapes for different sizes."[26] Structures that work to distribute nutrients, gases, and waste within a tiny insect (such as direct tubules) will not work for larger mammals, which require increasingly complex circulatory systems utilizing blood as their medium and entail great increases in relative surface area and complexity as they scale up.

For biology, then, scale describes the constitutive relationships between size, parts, and whole. These relationships, moreover, reconstitute themselves at multiple scales: the cell integrates its parts in a fashion particular to its scale, and functions in unison with many other cells to compose an

organism whose structure is keyed to *its* particular scale, and so on. Ultimately, the demands of scale on structure produce deep structural discontinuities within a physically (even organically) contiguous spectrum. As Thompson notes:

> In the end we begin to see that there are discontinuities in the scale, defining phases in which different forces predominate and different conditions prevail. . . . Man is ruled by gravitation, and rests on mother earth. A water-beetle finds the surface of a pool a matter of life and death, a perilous entanglement or an indispensable support. In a third world, where the bacillus lives, gravitation is forgotten, and the viscosity of the liquid . . . the molecular shocks of the Brownian movement, doubtless also the electric charges of the ionised medium, make up the physical environment and have their potent and immediate influence on the organism. The predominant factors are no longer those of our scale; we have come to the edge of a world of which we have no experience, and where all our preconceptions must be recast.[27]

Inevitably, then, a full consideration of scale in biology leads us to the problematics of topology and environment, or ecology. Here it is clear that structural scale in the world of the biologist or engineer is inseparable from the size domains of physics, even if it reveals different details and implications of scale through its divergent disciplinary problematics.

Scale as homologous transformation. Mathematics, on the other hand, when severed from empiricism, has tended to employ scale in a frictionless environment. Size domains do not apply to pure mathematics, nor do the constraints of changing parts-to-whole relations. Geometry's parts-to-whole relationships are scale-free: as a geometric shape is scaled up or down, its internal angles and ratios remain invariant. The universe of geometry, then, is wholly unlike that explored in cartography, physics, biology, or engineering. Here, *lack* of scale is its most salient feature, the master principle that ensures its consistency and thus its coherence. Mathematics, we might say, is without ecology—even if the reverse does not hold.

Frictionless scaling is not limited to geometry: all mathematical functions are, at their heart, abstract machines that exist in a frictionless environment of continuous correspondences between variables. This is to say that, in its essence, the function describes a continuous abstract space that generates, for any input, a corresponding output, the totality of which describes or at least implies an unbroken, graphable correspondence between homologous points, whether as a linear line, a sinusoid, an asymptote, or some other form. In its essence, mathematics describes continuities, despite its use of discrete digits. Of course, because the actual universe is chock-full of discontinuities, applied mathematics must attempt to model this, as in quantum mechanics and nonlinear dynamics. The point is not that mathematics is incapable of describing discontinuous relationships but rather

that it is at heart, before applying the constraints introduced by empirical description, the medium of a virtual, frictionless world of infinite capacity. As Gilbert Simondon argues, "Theoretical thought that makes use of numbers is essentially contemplative and of religious origin. It does not seek to count or measure beings, but to estimate what they are in their essence in relation to the totality of the world."[28] Mathematics transposes the physical into the realm of the metaphysical, where abstract forms rather than actual entities are compared without friction.

It is precisely this boundless flexibility, this capacity to surpass, subsume, and describe any bounded system (the real) that has thrilled mathematicians since antiquity. In the third century BCE, Archimedes wrote a treatise, "The Sand Reckoner," nominally addressed to the Syrian king Gelon, in which he gleefully calculates the upper bound for the number of grains of sand in the universe. Sand itself had been synonymous with the "uncountable," an incalculable quantity. In seeking to overcome this implicit trumping of number by matter, Archimedes first measures the number of grains of sand that fit within the diameter of a poppy seed, and from there begins to multiply the result by larger and larger units of measure until he reaches the size of the entire universe, as estimated by Aristarchus—where "universe" is understood to be the largest sphere of the cosmos that holds the invariant stars and contains the other heavenly bodies. To accomplish this, Archimedes invents a new system of numerical notation. Whereas the largest named number in the Greek system was the "myriad" (ten thousand), and thus the largest denotable number was a "myriad myriad" (one hundred million), Archimedes uses the myriad as a base, developing an exponential system, which allows him to add ordinal "places" rather than multiplying increasingly unwieldy sums. Using the volumetric upper bounds of such bodies as the earth, the sun, and the universe, as calculated by mathematicians of his day, he eventually concludes that the total number of grains of sand that *could* fit in the universe must be less than "10,000,000 units of *eighth order* of numbers" (10^{63} grains). Archimedes acknowledges that "these things . . . will appear incredible to the great majority of people who have not studied mathematics," but of course, for those who have, his argument will be recognized as a powerful proof.[29]

The key to this text, however, is not that it enables Archimedes to calculate the actual number of grains of sand in the universe—he is wholly uninterested in this empirical question—but rather that it allows him to establish the greatest *possible* number. Should physicists alter their model, making the universe larger, Archimedes's notation system enables the mathematician to simply increase the ordinal number (exponent), adding

one to effect an order of magnitude jump in size. Let's see sand keep up with that scalar technique! His proof, of course, concerns not sand but mathematics itself: number, it avers, is capable of trumping any actually existing quantity of anything. This reversal of priority between number and matter is the decisive ideological turning point for mathematics. Mathematics, using Archimedes's exponential system, can produce infinitely scaling forms: there is no limit to the magnitude it can signify or the system it can model. In one fell swoop, Archimedes has produced a system to derive arbitrarily large numbers and make them practically calculable, and has thus produced a way of mathematically "zooming" from one arbitrarily sized entity to any other arbitrarily sized entity. He thus lays into place the foundational mathematical, philosophical, and ideological tools for the twentieth century's cosmic zoom.

Archimedes's victory is a dangerous one. Freeing mathematics from empirical constraints is key to its functioning in theoretical domains, and certainly the source of much of its mystique and prestige, up to and including the contemporary era. However, we must take care not to backport its scale-free models to the world of difference, interdependence, and interaction that we actually inhabit. The history of mathematics and science is replete with such attempts. Already before Archimedes, Pythagoras had suggested that the cosmos was structured according to perfect ratios of whole numbers. Empirical observation to the contrary would not dissuade him. He even went so far as to suggest that, because ten was the perfect number, there must be exactly ten heavenly bodies in the universe. Only nine could be observed, so he invented a tenth: an anti-earth.[30] This is not to impugn theoretical cosmology or physics, but merely to suggest that it is all too easy to make oneself believe that just because something is possible mathematically it is possible physically. Such slides become even easier when we, like Pythagoras, subscribe to a form of aesthetics derived from mathematical proportion; this is the primary conduit by which mathematical forms come to seem more real than empirically observable reality, as Plato's theories of geometrical atomism (elaborated in his *Timaeus*) and that of the Forms (elaborated in book 7 of the *Republic*) attest.[31] This mathematically derived aesthetics is precisely an aesthetics of *freescaling*. Its most contemporary form is perhaps that of fractal geometry, which dispenses entirely with Pythagoras's whole number ratios, and recuperates a sense of the infinite and uncountable in natural forms (the contours of any coastline, to take a celebrated example), yet still seeks to reproduce a freescaling aesthetics. Benoit Mandelbrot informs us that "many of the irregular and fragmented patterns around us," which he names fractals, "tend to be *scaling*,

implying that the degree of their irregularity and/or fragmentation is identical at all scales."[32]

The very limited set of truly fractal patterns in the world is sometimes taken, in popular culture, to be a sort of general model of scale-invariance, incorrectly regarded as applicable to nearly any phenomenon. It is important to keep in mind that only certain phenomena exhibit fractal properties and that even for those, *not all of their properties* are scale-invariant, just their degree of boundary irregularity. Many structures *appear* similar at different scales, but we must temper our reflexive declaration of "self-similarity" by specifying a set of relevant dynamics: which relationships are actually self-similar across scales? It is all too easy to conflate visual similarity with actual mathematical homology, which requires a set of points in identical relationships at different scales or precise patterns that repeat at different scales. Computer-generated fractals, which scale infinitely, here seem to act as a kind of hypnotic trigger, giving us the same sense of infinite scaling imparted by Euclid's forms, which serve to bolster human fantasies of transcendence.[33] This impulse places the human in a privileged position of access with regard to the universe, which implies both a mastery and a self-centrality as a species—as privileged, rational, mathematical creatures. The first step toward the illusion of transcendence—another magic trick—is always to conquer or occlude scalar difference.

TRANSDISCIPLINARY KNOWLEDGE PRODUCTION IN THE ANTHROPOCENE

If we wish, as a culture and as a species, to increase our scale literacy, it will require a self-reflexive engagement with all four of the disciplinary formulations of scale explored in the previous section. Biology and engineering provision us with scale vis-à-vis the object, reminding us that scalar difference is irreducible: differently sized objects function differently. That is, the relation between parts and whole necessarily change along with an object's size. Godzilla and fractals aside, scale is not a secondary quality that can be applied to an object without changing its essence; rather, scale marks a spectrum of discontinuous constraints on the organizational possibilities of assemblages. Along with the size domains of physics, these restraints remind us that resolving cuts give us domains that have different rules. We have not imposed these rules upon them; they impose them upon us whenever we encounter them. This is, in some sense, the first step away from an anthropocentric orientation toward scale. The size domains of physics take us further, beyond the object as such to scale as relationality, as a set of dynamics and potentials that are once again singular to each scale, and

thus to each resolving cut we make. The scaling operations described by mathematics are equally important to confront, as they have been the most weaponized against our ecological milieus, principally in the form of petrocapitalism, when they could instead be applied to the virtual dimensions of scale: scalar transformations that potentiate new milieu dynamics. Cartographic scale provides the necessary emphasis upon the process by which resolving cuts are made in the first place. That is, cartographic ratio confronts us with our own medial systems and, when divested of its representational framework (as we shall see in chapter 2), also forces us to confront the relationship between resolution and perceivable detail. Cartography thereby brings us face to face with the fundamental process of negotiation by which scales are stabilized for observers.

An ecological view requires a partial integration of these disciplinarily divided forms of scale. Resolving cuts, the stabilization of scale domains, ontological scalar difference, and scale constraints on the composition of assemblages are all related and must be thought together. In this sense, we have much to gain by unthinking some of the boundaries and purifications that have honed these concepts for particular disciplinary purposes. We must see scale in its full light, as ontological difference, construct of knowledge, and speculative ecology—all at once.

Outside the disciplines of mathematics and the natural sciences, knowledge practitioners have picked up these various notions of scale and integrated them into their own strange brews according to their needs and predilections. In computer science, the increasing scale of data to be stored, manipulated, and searched has led to formulating scale as processing efficiency (algorithms) rather than raw processing power (hardware clock cycles). The corporation that most successfully formulated and tackled the problem of data scale on the early Web, Google, did so by developing the most efficient search algorithms and distributed computing infrastructure. The problem, however, remains a perennial one for the discipline as the scales of networked data proliferate and grow. As we will explore in chapter 6, the problem of big data has become a problem of subjectivity itself.

The social sciences, no less than computer science, have increasingly attempted to integrate scalar concepts into their practices throughout the twentieth century. Psychology, structural anthropology, linguistics, and sociology have all sought to discover patterns that hold across scales, and more importantly, explain the relations between phenomena observed in smaller and larger domains. In the field of historiography, the Annales School—and especially its superstar practitioner, Fernand Braudel—

developed a form of large-scale historiography (*longue durée*) that analyzed history as the product of environmental and socioeconomic processes that play out in patterns over millennia rather than in the short-term actions of individuals.[34] Manuel De Landa rekindled this torch in modified form, pushing further into nonhuman territory with his monumental *A Thousand Years of Nonlinear History*.[35] Human geography similarly attempts to expand the scale at which we resolve humans' interactions with their environment, analyzing them in spatial terms. After the late 1960s, however, intellectuals increasingly focused on the processes by which conceptions of space were *produced* by humans, and how these conceptions ordered actual spatial distributions. Michel Foucault's genealogies of power traced the connection between knowledge production and spatial distribution through exemplary studies in singular and circumscribed spaces of power that span scales as diagrammatic compositions. These diagrams of power order entire populaces via the topological and categorical structures they stabilize: the hospital in *The Birth of the Clinic*, the asylum in *Madness and Civilization*, and the prison in *Discipline and Punish*. Around the same time, Henri LeFebvre published his groundbreaking *The Production of Space*, which analyzed the history of spatial ordering as a dialectic between centers and peripheries leading to ever more abstract spaces determined by the exigencies of capitalism.[36] These works, which drove the "spatial turn" in the social sciences and humanities, employed the concept of scale not only as increasingly large size domains, but also as a form of large-scale or collective cartography that produced and reproduced the conditions of individual experience and identity. Society was not only a series of movements larger than its constituent actors but also the outcome of an emergent form of spatial production that functioned on multiple scales simultaneously. These discursive frames helped blur the lines between individual actors, larger-scale social dynamics, and infrastructural and environmental determinates, thus opening a conceptual space for interdisciplinary collaboration between the social sciences and humanities.

The traditional humanities have had a more difficult time shifting the resolution of their analyses to larger scales, though historiographical movements in the digital humanities have more recently advanced programs of "distant reading" or "macroanalysis" that do precisely this, shifting the analysis of cultural history toward the quantitative and large-scale, several decades after the initiation of the spatial turn.[37]

Another relatively recent approach paving the way for a (post)humanities theorization of scale relying on qualitative rather than quantitative analysis falls under the rather wide umbrella of the "material turn." Like

the spatial turn, this implicit repudiation of the linguistic turn that enamored the humanities in the 1970s through the 1990s purports to take matter and materiality seriously. We may roughly divide this movement into the object-oriented ontologists and the new materialists. The former have elaborated what Levi Bryant calls a "flat ontology" with only one class of matter: objects.[38] Timothy Morton's influential book *Hyperobjects* approaches the scalar concerns of the present as a "being-quake" heralded by the appearance of "hyperobjects" that massively outscale the human.[39] While I am sympathetic to this stringent appeal to objectness, *Cosmic Zoom* owes a much greater debt to the new materialists, who place less emphasis on objects and more on processes of becoming. Growing out of the materialist vitalism of Friedrich Nietzsche, Henri Bergson, and Gilles Deleuze, new materialists such as Jane Bennett and Karen Barad theorize matter itself as possessing active, compositional qualities. As we shall see in subsequent chapters, the lively (Bennett) and agential (Barad) qualities of matter help us make sense of the co-constitutive nature of observer and object in encounters across scalar difference, without recourse to human subjectivity.[40]

While the humanities may have come to the "scale table" fashionably (or just embarrassingly) late, their greatest disciplinary asset is perhaps their expertise in the self-reflexive analysis of knowledge production, including the intertwined processes of ideological reproduction, cultural narrative, and identity formation. While other disciplines have contributed enormously to knowledge of and about difference at disparate scales, and human processes as they are imbricated in large-scale processes, the humanities possess three unique potentials for scale theory. First, they are capable of problematizing scale itself as it is deployed in our culture—that is, rendering the specific toolset of scale visible, foregrounding it as a problem in itself. Second, their discursive analytics, accustomed to analyzing the ways knowledge is produced in many disciplines, could potentially integrate different discourses and disciplinary tools into a transdisciplinary form of inquiry and collaboration—but only if they can overcome their own disciplinary shortcomings. Finally, the humanities possess an accumulated expertise in the virtual dimensions of culture, and thus the capacity to shift the focus from an empirical study of entities and processes at different scales to the production of new forms of scalar thinking and engagement. Scale, in the hands of the humanities, could become more than a domain of analysis or critique; it could become a new horizon of thought, a collective project commensurate with the novel challenges of the Anthropocene.

We use scale to order our knowledge of the world even as the world uses scale to embarrass our orderings. These are the two sides of scalar mediation. Any proper study of scale must confront this aporia: we make scales; scale unmakes us. Despite attempts by humanist, capitalist, and industrialist apologists to contain the scalar problems of climate change, mass extinction, ocean acidification, and looming resource shortages within logics of market-based solutions, national regulation, and "clean" technology development, it has become increasingly clear that our regimes of knowledge production are deeply imbricated in the production and strategic occlusion of scalar relationships. The problem isn't that we don't talk about other scales (we do this constantly) or that we don't have medial access to them (we have unprecedented access in many media). The problem is that our access is mediated in such a way as to delimit our tactical responses, to frame and contain our conceptual engagement. The problem isn't that we lack effective scalar media, but that our scalar media are *too* effective—at predetermining the shape of our encounters. Any cultural scalar analysis must therefore begin by charting how scales are *stabilized* (speculatively, rationally, disciplinarily) both initially and over time in response to perturbations and challenges. Thus scalar problems like climate change and mass surveillance cannot be solved as long as they are framed as problems only within and by the forms of knowledge that have given rise to these dynamics. Rather, we must reconceptualize these problems from new, self-reflexive positions that take scale not as a given set of preexisting relationships but as a dynamic of mediation, and thus as a set of ongoing negotiations.

Access to scalar alterity requires resolving different scales, which in turn demands techniques by which one surface is put into contact with another. Media theory offers us vital tools in this analytic, not the least of which is that of the "affordance," or materially enabled potential contained within any medial form,[41] which allows us to evaluate the parameters of encounter with alterity in regimes of trans-scalar access. Ultimately—and here we return to the fundamental scalar paradox—all scalar mediations that frame access to other scales ultimately lead to encounters that, however circumscribed, push back against those frames. Thus scalar mediation can be viewed from two perspectives or stages (though neither of these stages is temporally prior to the other): first, the framing, through knowledge and technical affordances, of regimes of access to other scales and, second, the continual, primal differentiation and composition of elements into entities

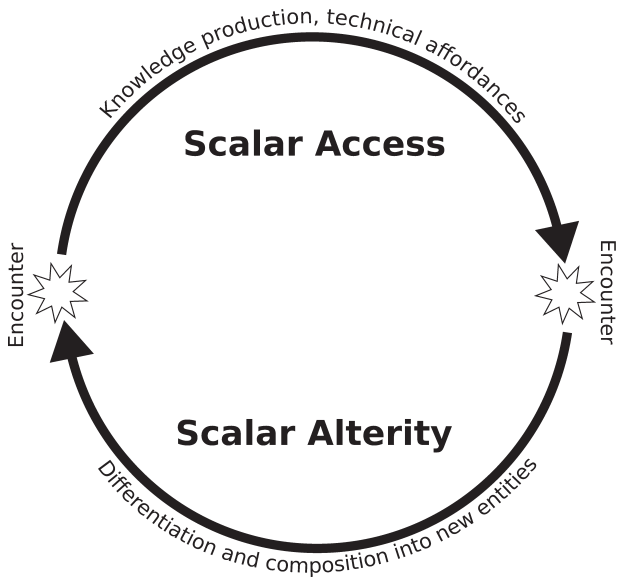

Figure 1 ▸ The circuit of scalar mediation.

at new scales. Together, these mediations form an uneasy, co-constitutive circuit (figure 1).

We experience both sides or vectors in this cycle. The first we experience as our own stabilizing knowledge practices, which order and narrativize our conditions of experience into defined (if implicit) milieus. The second we experience as the impingement or perturbation of other assemblages upon us, which constantly modifies our milieus. This push-back of scalar alterity exceeds our framing narratives and stabilized scalar boundaries, but it is experienced by us only as a result of those regimes of access. Disturbingly, they haunt and harass us as destabilizing, non-human agency. Whether as climate change, a viral infection, a declined credit card, quantum entanglement, or bioaccumulated toxic particles, these "strange strangers" jolt us into the realization that others mediate scale just as we do.[42]

Media, as particular conceptual assemblages, provide us with many of the tools needed to theorize this cycle of trans-scalar encounter. Media theory is useful in part due to its historical focus on materiality (the substrata or mediums in which communication is embedded), embodiment (how meaning is generated through interfacial structures and protocols), environment (the navigation and alteration of terrain), and technics (the protocols and affordances of particular technological assemblages). It allows us to understand how thought and matter are connected, and to

trace the formation of assemblages that transduce matter and meaning between them. This was implicit in Marshall McLuhan's original formulation of the media concept: "The personal and social consequences of any medium—that is, of any extension of ourselves—result from the new scale that is introduced into our affairs by each extension of ourselves, or by any new technology."[43] Media articulate new scales, which in turn usher in new constraints and potential becomings. As should be clear by now, however, McLuhan's anthropocentric containment of the media concept is too limited. Nonhumans produce media as well, from buckyball molecules to orca pods to the dark matter that pervades the universe. A media theory that answers what I call the "trans-scalar challenge of ecology" must work at all scales without collapsing their difference, and must extend itself not only to nonhuman animals but to nonorganic entities.[44] It must go all the way around the circuit of scalar mediation.

While media theory has plenty to teach us about scale, scale also has a lot to teach us about media. One of the central arguments of this text is that scalar differentiation *is* mediation. That is, we can understand scale as a form of mediation that paradoxically engages fundamental scalar alterity as negotiated surface differentials but also produces certain milieus based upon scalar stabilizations. Media link ecology to subjectivity: a milieu (medium) is "made up" of scalar difference, which stabilizes the subject that narrativizes it. James Gibson's environmental affordances are revealed and activated by what I have been calling *resolving cuts*, or stabilized slices of an environment that produce a scale and thus determine what level of differential detail can be revealed upon its surfaces. This process takes place as a negotiation between a primary and a secondary (medial) surface, and is thus simultaneously technologically and conceptually mediated. This theorization of scalar mediation, developed more fully in the next chapter, reveals, from one angle, scale as a product of milieus and, from another, milieus as products of scale. A milieu is a signifying environment constrained by resolving cuts that nevertheless reveals itself continually to be a *shared* space simultaneously resolved by scalar others.

These considerations push us to expand our notion of media beyond the terms by which it is understood colloquially, as well as its most common academic forms. Media cannot be reduced to communication channels for information transfer or to a certain class of technologies. Neither should media be understood only as an established regime for the dissemination of mass communication (the "mass media" or "news media") or as platforms for the organization of semiotic content. Media are all of these things, but they are much more besides: they constitute a system within which we are

already enmeshed, not as consumers, and not even as producers, but as nodes in an environment. This medial environment exceeds the anthropogenic: it is machinically heterogenic, in Félix Guattari's sense of self-generating and -differentiating, and forms operationally closed but constantly evolving assemblages, in the sense captured by Matthew Fuller's concept of "media ecologies."[45] My emphasis throughout this book is, in addition, on the affordances of both human and nonhuman medial systems for interaction with actual (not represented) environments that co-determine the forms of its assemblages.

My focus is not only on the description of medial forms—an empirical practice—but on medial futures: the virtual dimension of media assemblages. This is to consider how media produce new relations that exist outside of themselves and their protocols. Sarah Kember and Joanna Zylinska have figured this conceptual shift from media as objects to media as processes of becoming as a conceptual move from "media" to "mediation." More than simply media in action, "*mediation can also serve as a name for the dynamic essence of media*, which is always that of becoming, of bringing-forth and creation."[46] While I do not insist on a hard and fast distinction between "media" and "mediation" as signifiers, the distinction Kember and Zylinska develop between "representationalist aspirations aimed at closing the gap between the viewer and the screen" and a mode of medial "lifeness" is a key component of medial scale theory. Scalar collapse is, at the medial level, driven by the received (and actively promoted) view that media are fundamentally representational, that they stand in for something else. Because all media mediate scale—that is, they stand in the middle of at least two scales, producing effects across a scalar boundary—a representationalist view of media reduces this mediation to a mere scale model: the television shrinks a recorded image of something else to the size of the screen, a map represents a larger territory, and so on. We are already quite aware of the inadequacy of this conception—we know that the television does far more than passively echo an event elsewhere, and that a map produces or stabilizes a territory rather than passively denoting it. We simply haven't fully applied these insights to the scalar dynamics of mediation. An adequate theory of scalar mediation must therefore be nonrepresentational. That is, it must be able to capture how assemblages come to be different, not merely how one system represents another.

Scale, as a form of mediation, is both spatial and temporal. Human media tend to stabilize spatial scales easier than temporal ones, leading many of us to visualize or conceive of scale as primarily spatial. Yet the cosmic zoom, as a form of media and form of thought, always marshals

differential timescales as well as spatial scales. As we shall see, particularly in chapters 3 and 4, timescales and spatial scales are co-constitutive, an ontological fact that has proved convenient to cosmic-zoom designers who have wished to exchange time for space in order to more effectively suture their real-time human viewers to an implied, often universal, observer. A focus on scale as mediation helps to remind us that even in medial systems that explicitly evoke only spatial scaling, temporal scaling is always taking place, even if only "behind the scenes." Chapter 6 considers the linkage of spatial and temporal scale in the context of database-driven media as what I call the "generic scalar event."

The often tragic interlinking of temporal and spatial scale is familiar to anyone concerned with the problematics of the Anthropocene, the era in which we chart not only the spatial scale of damage wrought by our species, but also its temporal reach. As a geological epoch (official or unofficial), the Anthropocene marks a self-reflexive awareness, the moment when the human enters deep time and makes its unflattering mark. Jussi Parikka has suggested that the concept of media is particularly suited to geological thinking and analytics. In his view we ought to extend our concept of mediation to include the forces of the earth at expanded temporal and spatial scales. We must not continue to discount the geological and ecological substances and processes that underlie our contemporary media ecologies. "Nature affords and bears the weight of media culture, from metals and minerals to its waste load." Thus, tracing "the affordances that enable digital media to exist as a materially complex and politically . . . mediated realm of production and process" must become part of our medial narrative.[47] Yet, even as media theory extends the notion of media to geological processes, geology suggests a trajectory for media studies that radically decenters it from the axis of the human. Geological processes produce media before and beyond the human, at radically different temporal and spatial scales. "Geology becomes a way to investigate materiality of the technological media world. It becomes a conceptual trajectory, a creative intervention to the cultural history of the contemporary."[48]

Similarly, John Durham Peters's *The Marvelous Clouds* calls for a renewed engagement of media theory with nature, "the background to all possible meaning." Media, as "ensembles of natural elements and human craft," provide the infrastructural ground for being.[49] Air, earth, fire, and water are natural mediums within which we devise means of surviving and communicating. Each has its affordances and has given rise to different infrastructural formations at the intersection of environment (ground) and techné. Peters urges media scholars to contextualize digital communica-

tion technologies in relation to the larger infrastructural assemblages that they exist within, depend upon, and modify. In the same vein, nonhumans possess rich media, extending far into areas that, in the human context, we consider technology: "Technology to humans is nature to many animals."[50] These calls to think technique beside technology, the nonhuman beside the human, and elemental mediums beside the digital, point toward a media studies that ventures far beyond the scales of the human and the humanness of scale. Peters's meditation on elemental media reengages both vibrant matter (in Bennett's sense) and medial alterity, opening an inquiry into grounds and potentials. "In the grandest view," he reminds us, "media studies is a general meditation on conditions."[51] Perhaps not coincidentally, this echoes Ernst Haeckel's founding definition of ecology: "the whole science of the relations of the organism to the environment including, in the broad sense, all the 'conditions of existence.'"[52] We may wish to say that media make up part of ecology just as much as ecology is a form of mediation. Scalar mediation articulates these into the same conceptual circuit and material network.

Alexander Galloway and Eugene Thacker argue that "networks are a matter of scaling, but a scaling for which both the 'nothing' of the network and the 'universe' of the network are impossible to depict. One is never simply inside or outside a network; one is never simply 'at the level of' a network."[53] Digital networks are not networks *of* things, they are networks as processes, as consequential mediations. One of their primary effects is asynchronous scaling, even as networks evade scalar coordinates themselves. The network form, precisely because it enables rapid scaling without itself possessing a determinate scale, becomes the key infrastructure of neoliberal capital, and thus the chief conjurer of what I above referred to as "scalar magic." In this book I engage the network form not only as an object of analysis, in chapters 5 and 6, but as a mode of visualization, in chapters 4 through 6. Here I utilize network graphs to visualize the interrelations between scalar milieus produced by cosmic-zoom films. The network graph serves in this capacity to explore trans-scalar ecology and reveal scalar biases that are occluded by the mesmeric aesthetics and temporal manipulations of the films themselves. The network graph thereby acts as a simultaneous defamiliarization and demystification of time-based cosmic-zoom media.

Beyond the scaling affordances of digital media and their consequent efficacy in contemporary control regimes, I also wish to consider a second axis of digitality that arises as a process, not of computational transformation (scaling), but of scalar stabilization. This axis of digitality marks not

the division between continuous contour (the analog) and discrete code (the digital) but rather that between scalar contiguity and discrete resolving cuts. We might call this *scalar digitality* in order to distinguish it from computational digitality, on one hand, and scalar continuity/contiguity, on the other. N. Katherine Hayles's concept of "intermediality" is a useful tool for thinking through the "complex transactions between bodies and texts as well as between different forms of media. Technological functions (making, storing, transmitting) understood as media effects."[54] In this book I consider scale as a primary axis of intermediality. Scale is, in this sense, both an intermedial effect and a primary site of intermediation. While traditional differentiations between analog and digital media rely upon the distinction between discrete and continuous communication channels or mediums, when we consider scalar media *effects*, the medial construction of continuous scalar gradients (in "analog" media) actually works to occlude difference and negate the resolving cuts made by mediation. At the same time, intermedial negotiations generate resolving cuts with profound implications. In both modes or directions of intermediality, the site of translation between the digital and the analog is a key site of scalar mediation: it is here, where one assemblage is encoded or decoded in negotiation with another, that the trans-scalar encounter most often takes place.

While all forms of media bring two or more surfaces into interfacial relation, and the process of mediation that establishes their relationship must always grapple with the differential position of those surfaces along the scalar spectrum, that encountered alterity can be resolved for an observer as either discrete detail or contiguous scalar analogy. I refer to the first case as "scalar digitality" and the second as "scalar continuity," a form of analog scale. As we shall see, what we think of as analog media is capable of mediating scale digitally, and digital media often mediate scale as analog. This study, then, seeks to complicate our common notions of analog and digital media as well as to trouble our received notions of scale.

PROGRESSION OF THE BOOK

The modern form of the cosmic zoom begins with a little book written by radical Dutch headmaster Kees Boeke in 1957. Following the theoretical considerations of the scale concept covered in this introduction, chapter 2 explores the conceptual and material apparatuses of Boeke's remarkable work, *Cosmic View: The Universe in Forty Jumps*, tracing the political, historical, and technological forces that converged in its construction. I will flesh out the concept of scalar mediation by exploring the work's self-

reflexive materiality, which it deploys to establish and then stabilize a series of relationships between surfaces—for instance, a page of the book and the courtyard of Boeke's school. This discussion leads to a tentative definition of scale as a processual (medial) negotiation of difference between surfaces. I discuss the mediating relations between surface and milieu, on one hand, and mediation and resolution, on the other. Along with a robust account of scalar mediation as a material practice, one of my central concerns in chapter 2 is an exploration of the concept of *resolution* as it relates to scale and media. Reading *Cosmic View* as a "drama of resolution," I argue that the discursive framework of scale and the medial practice of resolution render scalar mediation a simultaneously ecological, narrative, and ontogenetic process. Here I characterize the trans-scalar encounter as a narrative excursion into resolved ecological difference between discontinuous points on the scalar spectrum, necessitating an accretive scalar memory. Each trans-scalar encounter, however, is also an encounter with mediation itself—a theme that develops throughout this book, with differential implications in analog and digital media.

Chapters 3 and 4 go behind the scenes to excavate the genealogies that ultimately produced the most influential of cosmic zooms, *Powers of Ten*, a short film by Ray and Charles Eames. Chapter 3 treats a selection of the Eameses' earlier "toy" and "computer" films as explorations of scalar dynamics, material encounter, and information theory. These projects culminate in 1968's *Rough Sketch*, their first full-scalar-spectrum cosmic zoom.[55] As with the earlier book *Cosmic View* and the later film *Powers of Ten*, I treat this project not as a post facto media object but as a process of mediation with two phases: its fraught construction and its later intermedial compositions. From aesthetics to the history of science and optical technology to questions of interface and temporality, I examine many of its influences, as well as the intense disagreements and agonizing decisions that marked the construction of the film by its core development team. As in other chapters, I employ archival research that challenges received views about Boeke's and the Eameses' projects. Chapter 3 focuses on the aesthetics of the zoom as a medial process and trope, as well as the attendant politics of animating trans-scalar encounter. Building on the scalar stabilizations enacted by Boeke's book, I argue that the animation process primarily engages its own techniques of mediation in order to obscure the seams between distinct scalar milieus. Central to this process is the manipulation of temporal scale to fix scalar coordinates for the viewer. What emerges is a particular form of anthropocentric, nonlinear access to an underlying linearity—what I refer to as "equidistant optics," a new topology of knowledge

production in which all scales are medially equidistant from the human knowledge producer. This mediated experience invokes Einsteinian relativity in order to exchange time for space, a scalar shell game that I analyze as a form of scalar collapse particular to cinema.

Chapter 4 continues my reconsideration of the filmic work and design philosophy of the Eameses, detailing the tortuous process of revising and remaking *Rough Sketch* into 1977's *Powers of Ten*. My focus in this chapter is on the relation between disciplined knowledge production and scalar mediation. In remaking their film, the Eameses altered its aesthetic and ideological framework in significant ways, producing a view of the cosmos in which underlying contiguity is broken up into distinct knowledge domains—physics, biology, geology, astrophysics, and so on, each a form of containment as well as a framework for discovery. Disciplinary access then produces intensifications within its constructed continuity, authorizing human access and mastery as normalized medial encounter. This arrangement perpetuates itself: because knowledge is scale-disciplined, it only ever concerns itself with a small slice of the scalar spectrum, and thus the illusion of scalar contiguity is maintained. Nonetheless, despite the mesmeric qualities of the final version of *Powers of Ten*, it still bears traces of the contradictory impulses that determined its construction. I trace some of these, including debates between Phylis and Philip Morrison, scale-obsessed science popularizers who became principal collaborators on the film, and the Eames team. I close this chapter by considering the political and aesthetic reversal that took place when the Morrisons, along with Ray Eames, remediated the 1977 film into a 1982 book for Scientific American. My underlying argument is that any instantiation of the cosmic zoom is essentially a form of ecology, an act of knowledge production that constructs a particular "shape" for the cosmos, as a networked constellation of scales. The cosmic zoom, then, is not merely a medial form but a framework for precharacterizing the scalar spectrum's differential potentials for encounter.

Chapter 5 constitutes the philosophical heart of this book. Here I fully develop the concept of *scalar difference* that has remained implicit up to this point. What kind of difference do we encounter across scales? Following early philosophical work on identity and difference by Gilles Deleuze, I distinguish between *primary scalar difference* and *secondary scalar difference*, arguing that this distinction is crucial for developing a non-anthropocentric understanding of scale. Primary scalar difference is an immanent form of intensity, enacted by matter-energy itself. This leads to the conclusion that scale is, ontologically, difference itself. Secondary scalar difference emerges

comparatively after we have stabilized not only particular scalar milieus but objects within them. Secondary scalar difference is being across difference; primary scalar difference is becoming. Such a conception of scale, in turn, provides a framework for theorizing the interface between digital media and analog environments. I use the example of 1999's *Powers of Ten Interactive* to explore the affordances of applying a posthuman conception of scale to human-made medial systems, arguing that such systems have the potential not only to stabilize scales in new and more generative ways, but also to enable trans-scalar encounter as an embodied form of multiscalar ecology.

Chapter 6 extends this discussion of scale, mediation, and ecology to the multiscalar milieu of database-driven culture. In the age of big data and social media, scale and scaling operations are widely understood to constitute key dynamics and affordances of the digital. This chapter harnesses the long genealogy of the cosmic zoom and the theory of scalar difference developed throughout the book to recontextualize digital mediation as a trans-scalar force of composition rather than one of analog-to-digital mimesis. Beginning with digital cosmic zooms (including 1996's *Cosmic Voyage* and an interactive Flash applet) that harness the pixel and the database as twin affordances, and leading to recent cinematic examples that offer a counter-aesthetics of the cosmic zoom, I trace a shift in scalar mediation from an aesthetics of contiguity to one of multiscalar aggregation. Historicizing the functional affordances and constraints of the database, I trace its technical evolution from hierarchical and network organizational models to that of the contemporary relational model. I argue that this shift inaugurates a scale-instability at the heart of the database form, leading to a concomitant medial shift from trans-scalar *access* to multiscalar *address*. At stake in this chapter is the status of the subject within the milieu of database-driven media. I explore the subject jointly produced by neoliberal capital and urban banality as defined by a scalar constellation of switching nodes, recursively traversing the same terrain from variously interior and exterior modes. From the scalar flattening of neoliberal capital to mass profiling and surveillance, identity is distributed differently in our database milieu than it has been in the past, largely due to the relational database's recursive mediation of scale. As database-driven media produce and store information at scales radically at odds with subjects' own self-narratives, and then address subjects using newly stabilized scalar coordinates, the classical subject faces a desperate crisis.

While there are many possible tactical responses to the subjugation inherent in database culture, I suggest the possibility of a cautiously affirma-

tive, creative one. Chapter 6 therefore develops the notion of the *recursive self* to describe such a hypothetical subject, one that would embrace the ontogenetic, creative affordances of the database to enable a recursive encounter with oneself across scalar alterity. In this way, contemporary media can enable a potentially radical shift in scalar subjectivity, a new medial mutation in identity capable of following—as contour and as critique—the oppressive scaling operations of our contemporary sociopolitical order. The continued existence of many beings, including our own species, may depend upon the innovation, at the heart of our cultural practices, of a scale-fluid subjectivity that fully engages—rather than foreclosing and controlling—the radical potential of the trans-scalar encounter.

The cosmic zoom is, in one sense, a way to shore up the fragments of the human against our (scalar) ruins.[56] As I explore throughout this book, however, it also contains the basic provisions for an approach to identity and alterity that holds out the promise of saving, not "us," but the radically transformative potentials of the trans-scalar encounter.

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